WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR AGRICULTURAL METEOROLOGY

CAgM Report No. 73

EXTREME AGROMETEOROLOGICAL EVENTS

Prepared by

CAgM-X Working Group Members: G.J. Benson, D. Dambe (Chairman), T. Darnhofer, R. Gommes, G.N. Mwongela, D.E. Pedgley, V. Pérarnaud

WMO/TD-No. 836

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SUMMARY

The Working Group on Extreme Agrometeorological Events was composed of the following rapporteurs:

(a) Rapporteur on measures to monitor and predict the effects of agricultural drought;

(b) Rapporteur on agrometeorological inputs to measures to alleviate the effects of drought and to combat desertification;

© Rapporteur on agrometeorological information for locust control;

(d) Rapporteur on agrometeorological information for the monitoring of the spread of animal diseases;

(e) Rapporteur on the specific aspects of natural disaster which affect agricultural production and forecasts, particularly wildfires, hurricanes and severe local storms.

This summary gives an overview of the reports from the five rapporteurs, and from the additional papers that are found essential to provide more information. Due to the nature of the overall theme of the Working Group (Extreme of Agrometeorological Events), a report produced by Dr R. Gommes (FAO) was adopted as part of the introduction to the working groups' theme. The paper generally addressed world wide extreme agrometeorological events, giving statistics of both human and agricultural losses, and examples of episodes that occurred in several countries.

The rapporteur on measures to monitor and predict the effects of agricultural drought, starts her report by describing drought severity, as not only dependent on the duration, intensity, and geographical extent of a specific drought episode, but also on the demands made by human activities and by vegetation on a region's water supplies. The rapporteur goes on to define and describe the meteorological, agricultural and hydrological drought. The report identifies the most important meteorological indices that characterize drought as precipitation, potential evapotranspiration, and precipitation minus potential evapotranspiration. These determine the available soil-moisture in the soil; which is one of the most important tool to monitor drought. The report then describes the drought monitoring system in France, which uses the soil water balance model. Soil water balance is monitored every ten days in all synoptic stations, with the aim of providing early warning to the relevant authorities, once significant soil water deficits are detected. Finally, the report concluded by pointing out the most important tools used to fight against agricultural droughts:

- irrigation in area that have adequate water supply;
- growing of drought resistant plants that are adapted to the prevailing climate and soils;
- planting during the bet planting period;
- the amelioration of the maximum available water content.

The rapporteur on agrometeorological inputs to measures for alleviating the effects of drought and combatting desertification, adopted definitions agreed upon the International Convention to Combat Desertification (INCD). The method of collecting information from member countries by means of questionnaires is unsuccessful because there are very few responses received. The rapporteur has to rely on the available literature, and inputs from available experts on specific topics, to produce the report. The report reviews and summarises the available literature on drought and desertification. The drought monitoring system in Botswana is given as a an example; emphasising the role of agrometeorology in drought monitoring, and its effectiveness as an advice to policy makers, the implementors and the farming community.

Professor Williams and Professor Bolling produced a summary report providing additional information on the interactions of desertification and climate. Their report provides supplementary information on the agrometeorological inputs and measures to combat desertification. Botswana's experience on desertification are also outlined and a summary of the INCD case study is included in the appendices. Finally, recommendations are made to the CAgM.

A rapporteur on agrometeorological information for locust control reports on ten representative of locust species, their breeding and movement. The report describes how rainfall, temperature and wind affects locusts and discussed the potential of meteorology for improving the monitoring, forecasting and control of locust populations. The operational preparation and use agrometeorological information for lost control was also discussed in the report.

Questionnaires are sent to countries that are at risk of locust infestation, but also about a fourth of the countries that are sent the questionnaires responded. The information received from the countries at risk of infestation use agrometeorological advice to monitor and control locust. Lastly, the report recommends that an improved co-operation between national meteorological and locust control services, and the provision of information that is, or can be, produced routinely and therefore requires little or no additional resources, would contribute most to the improved monitoring and control of locust. Rapporteur on agrometeorological information for monitoring the spread of annual diseases reports on the epidemiological study of Lumpy skin disease (LSD) in Kenya, and its possible correlation on its spread to weather factors. The report concentrates on a period when there is a massive outbreak of LSD (between 1989-91). The result of the study is not conclusive as far as the massive spread of LSD in Kenya when correlated with weather factors. However, rainfall and wind flow pattern are possible contributing factors in the spread of insect vectors that are responsible for the spread of LSD. The rapporteur finally recommends that a further investigation on the weather aspect of the disease on infestation should continue.

The rapporteur on the specific aspects of natural disasters which affect agricultural production and forests, reports extensively on the review of methodologies for assessing economic and social inputs of extreme events as well as an overview of the categories of natural disasters including meteorological, geological and epidemiological events. However, the main thrust of his report is on wild land fires, severe local storms and hurricanes. Other mentioned are hailstorms, tornadoes, thunderstorms and heavy rainflash flooding (associated with severe local storms); storm surges, heavy rains/flood associated with hurricanes. Though river flooding is mentioned, it is not a major focus of the report of the rapporteur.

In an effort to report accurately an assessment of impacts of extreme events, the rapporteur enumerated two major constraints viz lack of any systematic methodology, acceptable to meteorologists, economists and planners and more importantly, there are inadequate information within member countries on impacts of specific phenomenon or events. The rapporteur then recommends that the CAgM Working Group on Extreme Meteorological Events should undertake a survey of accepted method of assessing economic and social benefits of such events with a view to select and implement the preferred approach on the part of WMO Members. It is also recommended that CAgM Working Group on Extreme Events jointly develop a standard approach to case studies which are useful for investigating the economic and social impacts of extreme events.

CHAPTER 1

AN OVERVIEW (EXTREME AGROMETEOROLOGICAL EVENTS) ([1]) by R. Gommes

1.1 INTRODUCTION

In the same way as a disaster is defined as "the interface between an extreme physical event and a vulnerable human population" (Susman *et al.*, 1983), extreme agrometeorological events are at the interface between a vulnerable agricultural system and extreme weather conditions. However, the definition of extreme agrometeorological events is broader, as they include as well weather conditions conducive to the development of agents (like pests and diseases) that negatively affect agriculture (the term, according to the FAO definition, includes crop agriculture, livestock and pastures, forests and fisheries, both ocean and inland fisheries).

It is a characteristic of the type of farming practised in developing countries, that they are very vulnerable to extreme agrometeorological events, in terms of impact on the global economy. Traditional food production systems tend to be well adapted and rather resilient to local weather. However, due to population pressure, more marginal land has to be put under cultivation([2]) and the fallow period tends to grow shorter. This entails an increased variability of food production, even under relatively stable weather conditions.

It is also worth mentioning that modern farming practices (high yielding varieties - HYVs-, use of fertilizer and other inputs) can turn out to be negative factors if they are not backed by improved infrastructure, in particular transport and storage of agricultural produce. There are many examples from semi-arid areas where, due to their higher water requirements fertilized HYVs have suffered more from dry spells than traditional crops (Gommes, 1993).

Another vulnerability factor is the predominant role of agriculture in the economy of many developing countries. In the five countries of the Central American Common Market (MCCA), according to a study by the Economic Commission for Central America (ECLA) for the period 1960-74, disaster-related damages represented an average loss of 2.3% of the Gross National Product (GNP) every year, while the annual GNP increase reached 5.6% (population growth rate averaged 3%, World Bank, 1976, 1960-70 data).

1.2 SOME CHARACTERISTICS OF EXTREME AGROMETEOROLOGICAL EVENTS

1.2.1 Importance of the agricultural background

In order to assess the impact of a weather disaster on crop production, one must link two fundamental aspects: first, the disaster proper, i.e the destructive power of the event; secondly, the characteristics of the agricultural system which has been hit. This is illustrated below in the example of Bangladesh, based on FAO statistics and Rahman, 1985. Good examples are also provided by Xiang and Griffiths for China (Xiang and Griffiths, 1988).

Between 1970 and 1984, three major weather-disasters struck the country. In mid-November 1970, one of the worst cyclones in history caused between 200,000 and 400,000 deaths in Bangladesh only; in 1978-79 a most severe drought befell the country, followed, in 1984, by extended heavy floods which lasted unusually long, from May to September. The result was, for each of the three events, a sharp decrease of the total rice production.

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[1] This section is largely based on the N. 2 of FAO Agrometeorology Working Papers Series by R. Gommes and T. Nègre (22 pp., FAO 1992).

[2] *E.g.* land lower natural fertility, low water storage capacity and prone to erosion.

In 1970, the cyclone struck the country in November. This coincides with the start of the Aman rice harvest ([3]), of which a sizeable fraction could not be harvested. This led to a drop in production of 1 million tons as compared with the previous year.

However, November is also the planting period for the Boro rice crop. Following the cyclone, the disruption of economic activity, the destruction of infra-structure and floods (including a tidal wave), the area cultivated with Boro rice was less and planting or transplanting was delayed. This accounts for the sharp decrease in Boro production the following year (1971).

The Aus rice crop was not directly hit, but it suffered as a result of the problems listed above, compounded by a war in 1971.

This quick overview shows that weather-disaster interactions with agriculture are complex and that they are very likely to involve non-agricultural factors.

1.2.2 Distribution of the losses within the agricultural sector ([4])

For most developing countries, deaths, hunger, injured people and crop losses represent the bigger part of the damage caused by a climatic disaster. Damages to mostly little developed infrastructures are usually lower than agricultural production losses.

In monetary terms, the losses incurred by livestock raising, forestry and fisheries mostly remain below those suffered by crop agriculture. In this respect, Madagascar is quite representative. Following several cyclone occurrences in 1983-84, the FAO Office for Special Relief Operations estimated that crop losses represented 85% of the total damage to the agricultural sector, whereas the damage to infrastructure and equipment (drainage and irrigation channels, fishing gear...) barely reached 15%. Livestock losses were negligible (OSRO, 1984).

The traditional, small-scale fisheries were also hit by the cyclone but, if human losses were to be deplored (5 fishermen), the damage to fishing gear and boats represented only 0.6%.

A rather different impact pattern occurs in small islands like Antigua and Barbuda where fisheries constitute the backbone of the economy. After hurricane "Hugo" in 1989, 47% of the losses occurred in fisheries, but crop losses still represented almost 40% of the total damage (OSRO, 1989b).

Finally, it is worth mentioning the losses affecting cash crops, which constitute a major source of export earnings in a number of developing countries.

In Nicaragua, the Ministry of Agricultural Development and Agrarian Reform reported that direct losses of export crops due to hurricane "Juana" ("Joan") in late 1988 to amounted to 21% of the total losses in the agricultural sector (MIDINRA, 1988). Coffee and bananas suffered a direct loss of their fruits and mechanical damage to their plants. Nonetheless, food crop losses were estimated to be higher (35%), while the livestock sector was less affected (8%, of which one fifth was poultry).

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[3] Bangladesh has three main rice seasons: Aus, Aman and Boro. Aus and Aman are planted or transplanted at the beginning of the monsoon between March and June and harvested between July (Aus, at the peak of the monsoon) and November-December (Aman, at the end of the rainy season). Boro is planted at the end of the rainy season in November-December, irrigated during the dry season (December-February) and harvested at the beginning of the monsoon (April-June).

[4] The figures given in the following text refer only to direct losses in the agriculture sector.

1.2.3 Direct and indirect effects

Whatever the economic sector concerned, two broad categories of effects can be identified: direct and indirect effects.

Direct effects regard the property and the income of the people, the enterprises and the public sector. For a central-american farmer, victim of a cyclone, direct effects could be, for example, the loss of his current crop and damages to his irrigation facilities.

Indirect effects appear progressively, as a result of low income, decrease of production, environmental degradation and other factors related to the disaster. The farmer may well have to pay high prices for seeds because of increased demand and the disruption of the transportation system. He might also lose a portion of future harvests because of a tidal wave-related salinization of soils or the destruction of perennial plantation crops which sometimes take 5 to 10 years to establish again.

For an annual crop, the Office of the United Nations Disaster Relief Co-Ordinator (UNDRO, 1979) estimated the global loss (direct and indirect) at 1.5 to 2 times the direct loss (the lost harvest value). For a perennial crop, the global loss was evaluated at 5 to 7 times the value of the lost harvest.

Indirect effects are difficult to quantify and therefore, they are often termed "invisible" effects. Plants weakened by adverse weather are much more susceptible to cryptogamic diseases or pest attacks, like the explosion of "coconut black beetle" (*Oryctes rhinoceros* L.) populations on wind damaged coconut trees.

Particularly for perennial crops, a number of years may be required before the normal situation is restored. The following values are given as examples: 30 years for certain timber varieties after hurricane Allen (6/8/1980) hit Jamaica (FAO, 1982), but more frequently from 6 months (frost defoliation in tea, wind defoliation) or one year (banana) to 4 to 5 years (coffee, sugar cane).

Even for crops that regenerate easily after partial damage, harvesting (and in particular mechanical harvesting), is usually made difficult by the "abnormal" morphology, thus further reducing yield expectations.

Conditions conducive to the development of pests and diseases are to be regarded as indirect effects. In fact, the conditions which trigger pest and disease development are rarely directly harmful *per se*. They are usually a combination of moisture or temperature conditions which do not directly affect crops. Typical examples are desert locust outbreaks or increased disease incidence on sugar cane after hurricanes.

1.2.4 An example of indirect effects: fires

Fires, more specifically forest fires, are mentioned in this context as they constitute an important cause of forest produce losses in many countries, next to wind, hail, etc. In addition, the origin of a forest fire is often natural (lightning) and the weather conditions (low rainfall, low air moisture, wind) rank highest among the factors which favour the spreading of forest fires.

The relative importance of fires and some other factors is illustrated below, based on South African plantations data during 1984-85 (Environmental Affairs, 1986).

Out of approximately 250,000 ha of plantations, 8,510 ha were affected by adverse factors of which fires, wind, snow and hail account for half. Drought turned out to be a negligible factor while pests and diseases make up the other half.

If the same results are presented by value, a completely different picture emerges: about 83% of the losses is to be ascribed to fire only, followed by rodents (12.7%) and by winds (1.9%). In this particular instance, insects and other weather factors play a negligible part.

The spectacular difference between the losses as expressed by area or by value is explained by the rather severe damage inflicted by fires. In the current example, the loss varies from about US$ 300/ha (fires, fungi) to US$ 6/ha (insects). Weather factors occupy intermediate values from US$ 12/ha (snow, hail) and wind (US$ 35/ha) to drought (US$ 132/ha). The figures above apply only to the affected areas.

1.2.5 An example of predominantly direct effects: food production in Bangladesh

In disaster-prone areas, the pressure of disaster risk on crop production is rather heavy. As indicated above, in countries like Bangladesh, "exceptional" weather events such as floods, drought and cyclones occur almost every year.

The inter-annual variation of a risky crop production (like the Aman rice) may well reach 20 to 25%. This is more or less equal to the increase in Aman rice production over the last 30 years. (The improvement was achieved through technology development and the improvement of farming practices).

Similar data for the Sahelian countries would show the extreme dependence of food production in many tropical countries on the weather vagaries.

1.3. A TENTATIVE LIST OF EXTREME AGROMETEOROLOGICAL EVENTS

Below is a table showing some weather factors which may negatively affect agriculture. It is very difficult to provide specific values for the extreme weather factors listed, as such values would be crop and phenology specific. In addition, each organism reacts according to specific combinations of intensity and duration of climatic factors. Finally, extreme factors are usually combined, for instance high temperatures and low rainfall during drought, or strong wind and intense rainfall during cyclones.

The table also includes some events which belong to geophysics *s.l.* rather than to meteorology, for instance volcanic eruptions, avalanches and earthquakes. Dam failures, which may be due to a number of reasons, including extreme weather, could be added as a factor which completely disrupts the general and agricultural infrastructure in addition to causing a direct loss of crops, fish ponds and farm animals.

There are numerous examples for each of the disasters above. Some disasters occur with extremely low absolute frequencies (approx. once in a century), like impacts of sizeable meteorites. However, when they occur, like the Tunguska impact in Siberia of June 1908, which levelled about 2000 km^2 of forest, the damage may be huge.

Finally, it should be noted that extreme or unseasonable conditions frequently interfere with farm operations, thereby resulting in sub-optimal practices and loss of production.

Weather factor	Negative effects on agriculture of extreme values (both direct and indirect)
Rainfall	Direct damage to fragile plant organs, like flowers; soil erosion; water logging; drought and floods; land slides; impeded drying of produce; conditions favourable to crop and livestock pest development; negative effect on pollination and pollinators
Wind	Physical damage to plant organs or whole plants (e.g. defoliation, particularly of shrubs and trees); soil erosion; excessive evaporation. Wind is an aggravating factor in the event of bush or forest fires
Air moisture	High values create conditions favourable to pest development; low values associated with high evaporation and often one of the most determinant factors in fire outbreaks
High temperatures	Increased evapotranspiration; induced sterility in certain crops; poor vernalization; survival of pests during winter. High temperatures at night are associated with increased respiration loss. "Heat waves", lengthy spells of abnormally high temperatures are particularly harmful
Low temperatures	Destruction of cell structure (frost); desiccation; slow growth, particularly during cold waves; cold dews
High cloudiness	Increased incidence of diseases; poor growth
Hail	Hail impact is usually rather localized, but the damage to crops - particularly at critical phenological stages- and infrastructure may be significant. Even light hail tends to be followed by pest and disease attacks
Lightning	Lightning causes damage to buildings and the loss of farm animals. It is also one of the causes of wildfire
Snow	Heavy snowfall damages woody plants. Unseasonable occurrence particularly affects reproductive organs of plants
Volcanic eruptions, avalanches and earthquakes	The events listed may disrupt infrastructure and cause the loss of crops and farmland, sometimes permanently. A recent example of carbon dioxide and hydrogen sulphide emissions from a volcanic lake in Cameroon (lake Nyos, 1986) caused significant loss of human life and farm animals
Air and water pollution	Air pollutants affect life in the immediate surrounding of point sources. Some pollutants, like ozone, are however known to have significant effects on crop yields over wide areas. In combination with fog, some pollutants have a more marked effect on plants and animals. Occurrences of irrigation water pollution have been reported

1.4 METHODOLOGICAL ASPECTS OF EXTREME AGROMETEOROLOGICAL IMPACT ASSESSMENT

The paragraph below presents a more systematic treatment of the factors to take into account when assessing vulnerability to, or risks associated with extreme agrometeorological events.

Problems are particularly difficult when dealing with factors which mechanically damage crops. There is little work done on this subject and it is sometimes difficult to separate the effects of classical (physiological) factors and mechanical effects. Typical examples are root asphyxiation following flood-like runoff, high-intensity rains or water logging, or frost.

1.4.1 Weather factors

(a) **Mechanical** versus **non-mechanical.** Mechanical factors are those which directly and physically damage plants. Continuous rains and drought fall into the category of non-mechanical disasters. The energies involved in non-mechanical disasters are usually of the same order of magnitude as the normal factors; non-mechanical disasters are more often due to abnormal **duration, distribution** or **simultaneous occurrence** rather than to unusual intensity;

(b) As mentioned above, the **energies** or **intensities** of the weather factors linked with disasters may be vastly different from their normal range. High intensities are mostly linked with relatively short durations (hours or days). The wind speeds which accompany tornadoes/hurricanes are about one order of magnitude greater than their averages. In addition, the kinetic energy (and destructive power) of winds vary with the square of wind velocity. Similar considerations apply to the size of hailstones and frost intensity;

(c) **Presence/absence** characterizes such factors as hail, which occur with very low absolute frequencies;

(d) **Cumulative/non cumulative** effects. Trees uprooted by violent wind gusts are unlikely to suffer further damage from the same factor. However, heavy rains typically have a cumulative effect on soil erosion, where both the duration and the intensity play an important part (WMO 1983). A practical consequence is that for rainfall damage assessment a number of data is required , while for wind a single value (maximum windspeed) is usually sufficient;

(e) **Timing** and succession of events: some extreme events build up gradually, as is the case with droughts or water logging, quite independently of their intensity. In many instances, it not possible to assign a precise point in time for the beginning (or the end) of the extreme agrometeorological event. This is the main justification behind monitoring and warning systems. The **rate of change** plays also an important role for such factors as temperatures. Organisms can adapt more easily to slow changes.

1.4.2 Crop factors

(a) **Thresholds** and qualitative effects characterize a number of plants and animals with regard to their response to weather factors. Very well known examples are the effect of high temperatures on rice sterility and the breaking of the stems and branches of certain rubber cultivars by wind. Another interesting example of this is given by Foong (1980, based on various authors) according to which abnormal sunshine duration leads to abnormal frequency of male inflorescence in oil palm.

The existence of thresholds are a major cause of non-linear response of crop yields to adverse weather factors.

(b) **Specific differences.** There are numerous examples of certain crops suffering very different losses under comparable adverse conditions. According to OSRO (1988), hurricane "Juana" (21-23 October 1988) almost completely destroyed coconut palms (more than 70% were broken or uprooted) in the worst-hit areas of the western coast of Nicaragua, while the most badly affected cocoa plantations lost less than half their trees. It is also a common observation that plantations suffer more direct and apparent damage than natural forest, to such that the latter constitute efficient protective barriers. However, it should be noted that the complex natural ecosystems may take a long time to rebuild their diversity, sometimes even centuries.

To quote an extreme example, it is also a common observation that root and tuber crops and creeping plants suffer very little from hurricanes while tree crops and cereals may be badly hit.

Similarly, floating rice varieties (like the B-Aman in Bangladesh) are characterized by very fast stem elongations which can keep pace with rapidly rising waters during floods.

(c) **Phenology and size.** Crop development stages are a very important qualitative factor. While still in their early stages grasses and cereals suffer little wind damage (Sturrock, 1975); rice appears to be very sensitive to hail at the time of transplanting and harvest. Wind will affect rice most at the time of heading and reaping (Daigo, 1957) and the damage to adult trees may vary from defoliation to uprooting.

One of the major causes of crop losses after hurricane "Juana" hit Nicaragua in 1988 was the germination of maize still drying on the cobs in the fields (OSRO, 1989).

Flowering appears to be the most sensitive stage, as any factors preventing fertilization or flower-set will result in very poor yield, independently of the crop's standing biomass.

1.4.3 Other environmental factors and complex interactions, including long-term effects

A typical complex interaction is the one observed during heavy rains and floods. Waters have during these events several combined destructive effects on crops. Erosion and re-sedimentation are physical effects caused by running water, while water logging and root asphyxiation involve crop physiology. But floods may have positive effects as well like silt deposition, water reserves repletion and soil desalinisation. Of particular notice in this context are river-bed changes and major land-slides which may completely modify the agricultural landscape.

Another example of this is the combined effect of the tidal wave, strong winds and floods, and the "ocean spray" of sea water blown inland during storms or cyclones. Salt may take years to be washed out, thus reducing crop yields.

Topography (slope, aspect) obviously plays a major role in most extreme weather factors.

1.5 CONCLUSIONS

(a) Damage caused by extreme agrometeorological events to the agricultural sector may be significant, sometimes of the order of magnitude of the GNP growth. For many disaster-prone countries, agricultural losses due to exceptional weather events are a real constraint on their global economy;

(b) Agrometeorological disasters result from the interaction of a meteorological factor, or a combination of meteorological factors, with an agricultural system. The extent of the damage depends as much on the characteristics of the agricultural system as on the physical event which causes it;

(c) Indirect effects may continue to affect agriculture negatively long after the extreme event took place. The time needed to recover from some extreme agrometeorological events ranges from months to decades.

1.6 REFERENCES

Daigo, Y. (1957). A study of the agroclimate of Japan. Geophys. Mag., 28(2):149-236.

Environmental Affairs (1986). Report of the Director-General: Environmental Affairs for the period 1 April 1984 to 31 March 1985. Environmental Affairs Authority, Republic of South Africa, Pretoria, 100 pp.

FAO (1982). Salvage and rehabilitation in the forestry sector of the hurricane affected areas of the eastern region, Jamaica. FAO, Rome, 16 pp.

Foong, Sang Foo. (1980). Weather-based model for estimating oil palm fruit yield. MSc thesis, University of Guelph, Canada. 171 pp.

Gommes, R. (1993). Current climate and population constraints on world agriculture. In: Agricultural dimension of climate Change, H.M. Kaiser and T.E. Drennen, Eds, St Lucie Press, Delrey Beach, Florida. 67-86.

MIDINRA (1988). Daños en el sector agropecuario provocados por el huracán "Juana". Evaluación preliminar. Managua, Nov. 1988. 39 pp. Anexo 1: Reporte agrometeorológico, Dirección de Agrometeorología, 21 pp. Anexo 2: Impacto del huracán "Juana" y programa de emergencia y rehabilitación del campesino de las regiones V, VI, y las zonas especiales II y III, Dirección General de Reforma Agraria y Fomento Campesino, 39 pp.

OSRO (1984). Madagascar, Evaluation de la situation agricole à la suite des cyclones. OSRO TCP/MAG/4404, FAO, Rome, 43 pp.

OSRO (1988). República de Nicaragua, Evaluación de la situación alimentaria, agrícola, ganadera, pesquera y silvícola después del huracán "Juana". OSRO 05-88-S, FAO, Rome, 103 pp.

OSRO (1989). Republic of Costa Rica. Evaluation of the agriculture Situation in the areas affected by hurricane "Joan". OSRO 02-89-E, FAO, Rome, 33 pp.

OSRO (1989b). Evaluation of the agriculture situation in eastern Caribbean countries affected by hurricane "Hugo". OSRO 03-89-E, FAO, Rome, 63 pp.

Rahman, S.M. (1985). Agroclimatic methods for Bangladesh. Bangladesh Meteorol. Department, Dhaka, 41 pp.

Sturrock, J.W. (1975). Wind effects and their amelioration in crop production. In: Physiological aspects of dry-land farming, edited by U.S. Gupta. Oxford and IH Publishing Co., New Delhi, 283-313.

Susman, P., O'Keefe, P., Ben Wisner (1983). Global disasters, a radical interpretation. In: Interpretations of calamity, 263-280. The Risks & Hazards Series: 1. Edited by K. Hewitt. Allen & Unwin Inc. Boston, London, Sydney. 304 pp.

UNDRO (1979). Prévention et atténuation des catastrophes. Vol. 7: Aspects Economiques. OMM UNDRO UNEP, UNDRO/22/76, Geneva, 78 pp.

WMO (1983). Meteorological aspects of certain processes affecting soil degradation, especially erosion. Technical note No 178. WMO No 591, Geneva. 149 pp.

World Bank (1976). World Tables 1976, World Bank and John Hopkins Univ. Press, London and Baltimore, 552 pp.

Xiang, S., and J.F. Griffiths, (1988). A survey of agrometeorological disasters in south China. Agric. For. Meteorol., 43(3-4): 261-276.

CHAPTER 2

MEASURES TO MONITOR AND PREDICT THE EFFECTS OF AGRICULTURAL DROUGHT

by V. Pérarnaud

2.1 INTRODUCTION

In laymans terms, the word drought signifies water shortage conditions. In addition to the identification of water shortages in a given setting or region, however, any analysis of the causes and effects of drought must be undertaken in terms of **meteorological drought, agricultural drought** or **hydrological drought.**

Anomalies in the general atmospheric circulation occur upstream from all types of drought (Choisnel, 1993). Studies of this phenomenon have revealed highly complex mechanism and interactions that affect the atmospheric water cycle, the energy balance in the atmosphere, air mass circulation and vertical atmospheric movements. One of the meteorological causes of drought in temperate zones is the persistence of high-pressure zones over the territory concerned, since this type of situation causes descending atmospheric movements that dry the air and distance it from saturation. Another cause is linked to the absence of a water vapour supply, owing to evaporation at ground level or by lateral replenishment of moist air.

A drought situation cannot be forecast without at least a 15-day forecast of atmospheric circulation conditions. Yet any deterministic weather forecast is curtailed by the turbulent and chaotic nature of atmospheric movements, which limits the range of this type of weather forecast to about 10 days at most, and current weather forecasting abilities are limited to a 5-day range. Therefore drought forecasts should not be focused on the atmospheric aspect of the drought alone, but should also include analyses of soil parameters, whether they be measured (e.g. precipitation amount) or estimated (e.g. potential evapotranspiration or soil moisture content).

Once the drought has been clearly defined as being meteorological, agricultural or hydrological, and investigation is undertaken of the drought's impact on agricultural output in France in terms of the duration of the drought.

Drought can be analysed using meteorological indices, or by using indices derived from water balance model. While the latter method is used in France due to its temperate climate, the model can be adapted to climatic conditions typical to any given country.

Once the spatial-temporal variability of the drought is factored into the equation, the extreme event can be placed within its climatic context, the drought can be geographically plotted, and its dynamic development can be tracked.

On-going monitoring of the water balance in soils at the national level will provide an early diagnosis of the risk of drought, and public authorities can thus be notified in a timely manner. Consequently, measures can be taken to alleviate drought-caused damage to agriculture.

2.2 METEOROLOGICAL, AGRICULTURAL AND HYDROLOGICAL DROUGHT

Meteorological drought

There are numerous definitions of meteorological rought. Yet while one definition may be applicable to a given region, it cannot be extrapolated to other regions having different climatic features. Hence, in the USA (Blumenstock, 1942) drought conditions are said to occur when less than 2.5 mm of rainfall is recorded over 48 hours, whereas in Libya (Hudson, 1964) they occur when cumulative annual rainfall is less than 180 mm.

Other definitions of drought compare the degree of drought with an average obtained over a long period of time, which is referred to as "normal". For example, McGuire and Palmer (1957) define drought as a period during which monthly or annual rainfall is a certain percentage below normal. Thus, each country may have its own definition of drought.

Agricultural drought

A plant's water requirements depend on the current weather conditions, the biological features of the crop concerned, its stage of development, and the physical and biological properties of the soil. An operational definition of agricultural drought must take into account the variable sensitivity of crops at different stages of development. Consequently, attention must be paid to soil moisture content, which varies with water replenishment (rainfall, irrigation) and water loss (real evapotranspiration).

Hydrological drought

Hydrological drought is defined in terms of the effects of dry spells on surface or groundwater hydrology, as opposed to a meteorological description of the phenomenon. For example, Linsley *et al*, (1975) define hydrological drought as a period during which flow fails to meet the usage needs of a given water management system. Definitions of the frequency and severity of hydrological drought are often based on its effect on catchments.

The start of a drought episode is difficult to determine. Subsequently, however, a time discrepance emerges between the onset of the rainfall deficit and the first signs of the drought's effects on agricultural production. In practice, therefore, as a result of this time discrepancy the dates of the beginning and end of these two types of drought do not coincide.

The years 1988-91 in France (Choisnel. 1992) are an example. For instance, at the conclusion of the 1988-89 winter, there was no potential agricultural drought in the northern half of France in that, despite a considerable rainfall shortage during the autumn-winter period, the soil reverted to "field capacity" throughout the region. Thus there was only a hydrological drought, since the rainfall shortage led to vastly reduced or non-existent runoff to water tables. In the southern half of France, on the other hand, in addition to rainfall shortages amounting to about 50% below average, there was abnormal soil moisture content, particularly in the Garonne Valley. Thus, hydrological and agricultural drought occurred simultaneously.

The fundamental difference between the drought of 1989 and 1976 is that in April 1989 rainfall exceeded two or three times the average and, unlike June 1976, despite rainfall shortages June 1989 was not an exceptionally dry month.

The most unusual aspect of this unprecedented drought scenario was the delayed effect of the winter drought, which reduced the amount of water available for irrigation. Analyses of the 1976 situation led to predictions as early as February 1989 of a critical agricultural situation developing in the summer of 1989.

2.3 DIFFERENT DROUGHT SCENARIOS IN FRANCE

The effects of drought on agricultural yield vary enormously, depending on the time of year the drought occurs. Drought occurring during the susceptible stages of a plant will have a severe impact on its final yield.

2.3.1 Summer drought

The effects of summer drought on agriculture are self-evident. There is always considerable damage to non-irrigated crops because the absence of rainfall coincides with the susceptible stage of crops, i.e. just before or just after flowering. For obvious reasons, summer drought is the most widely studied and best known scenario in France in terms of its impact on agriculture. The summer drought of 1986 had important repercussions on agricultural production in France, and 98% of the money disbursed by the "Fonds National de Garantie des Calamités Agricoles" that year was paid as a result of the drought.

2.3.2 Spring-summer drought

This scenario may be considered more damaging than the preceding scenario, since all spring-summer crops are affected. When spring-summer drought occurred in 1976, the paucity of grazing forced farmers to buy high-priced animal fodder on the international market. And owing to tardy sowing, maize was unable to take shoot at all because root development was hampered by topsoil desiccation.

2.3.3 April drought

On average, April is one of the rainiest months of the year through France. Rainfall shortages during this month can adversely affect spring shoots due to the lack of moisture in topsoils. This scenario occurred in April 1982, particularly in central France where less than 10 mm rain fell in three weeks, whereas the average cumulative rainfall for April in this region is in the order of 50 mm.

2.3.4 Autumn drought

Autumn droughts are characterized in particular by delayed replenishment of soil water reserves in the first metre of depth, which does not occur until winter. The date at which groundwater runoff resumes its flow to the water table is likewise delayed.

In Autumn 1978 a considerable hydrological drought lasted until about mid-December, yet no agricultural drought occurred at that time. Conversely, the rainfall shortages that began in early August 1985 and the absence of any significant rainfall in September that year resulted in no new grass growth and caused hardship for livestock farmers.

2.3.5 Autumn-winter drought

From the hydrological standpoint, these droughts are extremely serious since coil conditions at this time should revert to field capacity and the runoff that replenishes the water tables should resume. Indirectly, autumn-winter droughts can have very serious consequences on the yield of irrigated spring-summer crops in cases where irrigation water is rationed. The drought years 1988-89 and 1989-90 are noteworthy in that rainfall in both September-January periods, particularly in the south of France, was only 40% of the average.

2.4 DROUGHT ANALYSIS

A number of indices relating to the climatic features of a country may be used in drought analyses. These indices are described in WMO Technical Note No. 138 "Drought and Agriculture". A description of the indices used in France is provided below.

2.4.1 Meteorological indices

As a first step, consideration should be given to meteorological variables such as **depth of precipitation, potential evapotranspiration, potential water balance (rain-potential evapotranspiration)**. The advantage of these indices is that they refer to meteorological parameters only, and in no way take the soil or crop type into account.

Meteorological variables can either be considered chronologically, or cumulatively after a given date (that supposedly corresponds to the onset of the drought). In order to highlight the exceptional nature of the variables, they may be:

- positioned in relation to a relevant statistical parameter so that, for example, values below the first quintile correspond to a 20% risk of drought; or
- relate them to normal values calculated over a long period of time.

Hence, **Figure 2.1** relates cumulative rainfall in July-October 1985 to normal July-October rainfall (1951-80) expressed in percentage terms (%). The Massif Central (in central France), Provence (in south-eastern France), and Burgundy (central-eastern France) are all severely affected with a ration of less than 30% and even 20%.

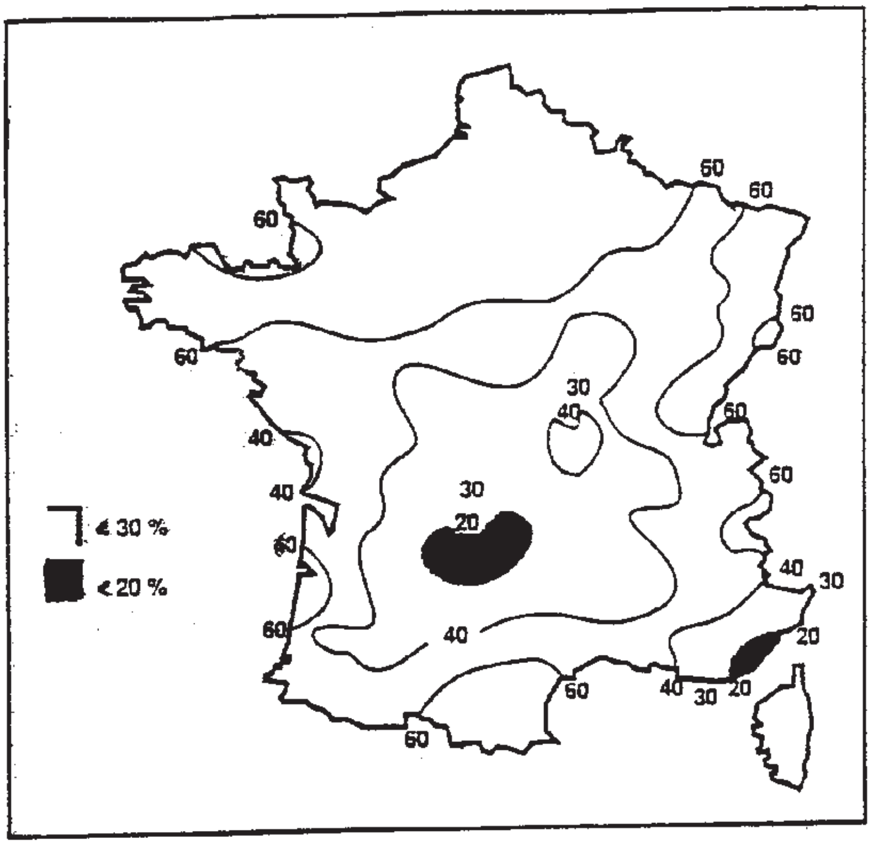


Figure 2.1 - Ratio of cumulative rainfall July-October 1985 compared with normal July-October rainfall (1951-80), expressed in per cent.

2.4.2 Indices obtained from a water balance model

Agricultural drought is defined as the presence of abnormal hydrological conditions in the soil throughout the area under consideration, normally to a depth of 1 metre. Such conditions have a direct impact on the crop's evapotranspiration and impede the physiological functions of the plant. The process, then, consists of plotting hydrological conditions in the soil over time and as a function of certain meteorological parameters (rain, potential evapotranspiration calculated either from global radiation or, alternatively, from sunshine duration, temperature, air humidity, wind speed). A suitable tool for this process is a soil water balance model which, in addition to meteorological conditions, takes pedological and crop factors into account. The following functions are involved in calculating the soil water balance:

(a) **Calculating the evolvement of soil moisture reserves as a function of time.** This step entails the monitoring of one or several underground reservoirs which, combined, constitute the Total Reserve R(t);

(b) **Calculating the decrease in real evapotranspiration in relation to maximum evapotranspiration.** This process is a regulator function.

Another advantage of a water balance model is that it is possible to take into account the effect of the pluviometry lag on soil moisture content, particularly since the lag increases with rises in Available Reserves (AR).

2.4.3 Establishing a water balance model

In a local setting, variations in water content depend on weather conditions (rain, potential evapotranspiration), crop type and crop development (crop coefficient), and soil type (available reserve).

An essential first step consists of determining the hydrological conditions in soils nationwide. Then, so as to avoid influence by crop type, the water balance is determined in soil with a specific vegetation cover - grassland - which is representative of vegetation cover with year-round evapotranspiration and under natural conditions (i.e. without irrigation).

A standard soil depth of 1 metre is established for each simulation point. Available reserves may then be modulated according to soil type from 100 mm (sandy soil), to 150 mm (clay soil), and even 200 mm (clay-mud soil).

2.4.4 Monitoring the water balance

In order to calculate the water balance, a starting date must first be selected and the soil water content must be initialized on a specific date. In temperate climates such as in France, the most suitable date for this is the end of winter (i.e. 1 March), when soils are assumed to be at field capacity. In tropical regions, on the other hand, calculations should commence at the end of the dry season, and reserves should be initialized to zero on that date.

In all cases, it seems preferable to undertake a multi-annual soil water balance simulation whether a drought occurs or not. Initialization of soil moisture reserves (at the Available Reserves value) is only undertaken once, on 1 January of the first simulation year. Calculation of the water balance is undertaken continuously year-round, the advantage of on-going monitoring being that possible delayed effects of a drought from one year to the next can be identified. Thus, if a drought has occurred the preceding year, it will be possible to determine whether or not the drought has had a delayed effect on the hydrological conditions in the following year; i.e. based on calculations from the soil water balance, whether the soil has reverted to "field capacity" in a given region. 10-day intervals seem to be suitable for the purpose of monitoring hydrological conditions. From an operational standpoint, therefore, moisture content is determined on the 10th, 20th or last day of the month. **Thus, without the ability to forecast drought occurrence, efforts can nonetheless be made to monitor drought evolution through regular, station-by-station surveillance of the water balance in soils throughout the nation.**

2.4.5 Results derived from the model

At 10-day intervals, an inventory can be compiled of the water balance model's output data so that useful data can be identified, data that might be combined can be selected, and the data's informativeness level determined.

- **The status of reserves R(t) at the conclusion of the 10-day interval** is the sum of the remaining water reserves, in the superficial reservoir on the one hand (providing it is not empty) and in the deep reservoir on the other (assuming the selected water balance model is based on a system of two reservoirs). This variable is related to the Available Reserves and is then expressed as a percentage. It corresponds to a given instant;

- **The difference (AR - R(t))** indicates the level of depletion within the reservoir;
- **Real evapotranspiration (RET)** calculated by the model can be used to evaluate how much rainfall has undergone effective evapotranspiration by the crop concerned;
- **The RET/PET ratio** thus provides an index showing the degree to which the plant's water requirements are satisfied. The index may be cumulated over a variable time period ("ΣRET/ΣPET") so as to provide a global index relative to the period concerned. For example, in certain regions where rainfall is scarce or non-existent in July and August, the RET/PET index is far more relevant than the near-zero R/AR.

The numerous index variations used to characterize drought are synthesized in **Table 2.1** below:

Description	Symbol	Unit
Potential water balance	Rain - PET	mm
Ration of remaining reserves to available reserves (at end of 10-day period	R(t)/AR	%
Depletion in soil	AR - R(t)	mm
Water requirements satisfaction rate (for grassland)	RET/PET	%
Estimated irrigation requirements	(MET - RET)	mm

Table 2.1 - Various drought indices

2. 5 DROUGHT MONITORING

2.5.1 Temporal and spatial variabilities in the water balance

The quantification of any anomaly must take into account the fact that the water balance is linked to a well-defined seasonal cycle. Hence it is essential that at any given time the value derived from the water balance is related to its statistical variability. In practice, specific distribution values are used as markers, namely, the first quintile, the median, and the 4th quintile (calculated over a 30-year period if possible). If drought occurs, the value at the 1st quintile (representing a 20% risk, or one year in five) becomes the most significant. **If an extreme drought occurs, the value at the 1st decile, or even the minimum, may be used as the marker.**

Figure 2.2 provides a graphic representation at 10-day intervals of the Reserves/Available (R/AR) at the Toulouse station in south-western France, showing the first quintile (broken line) and the year 1976 (solid line). It show how, starting in early 1976 (although this scenario actually began in winter 1975), the R/AR is below the first quintile, and only exceeded the first quintile again during the 22nd 10-day period, i.e. in mid-July.

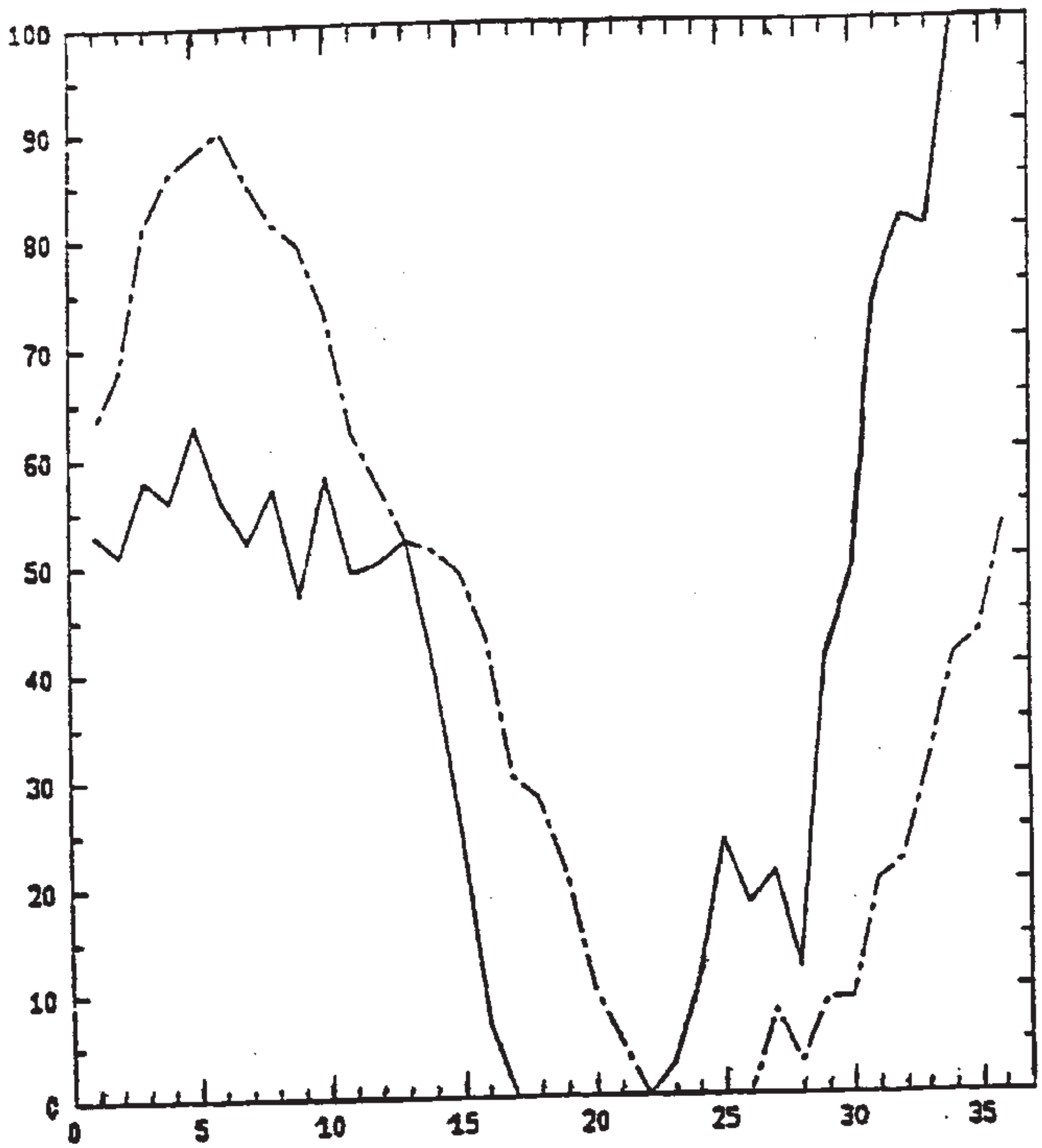


Figure 2.2 Position of the R/AR ratio in 1976 compared with the 1st quintile in Toulouse.

________ 1976 _._._._ 1st quintile

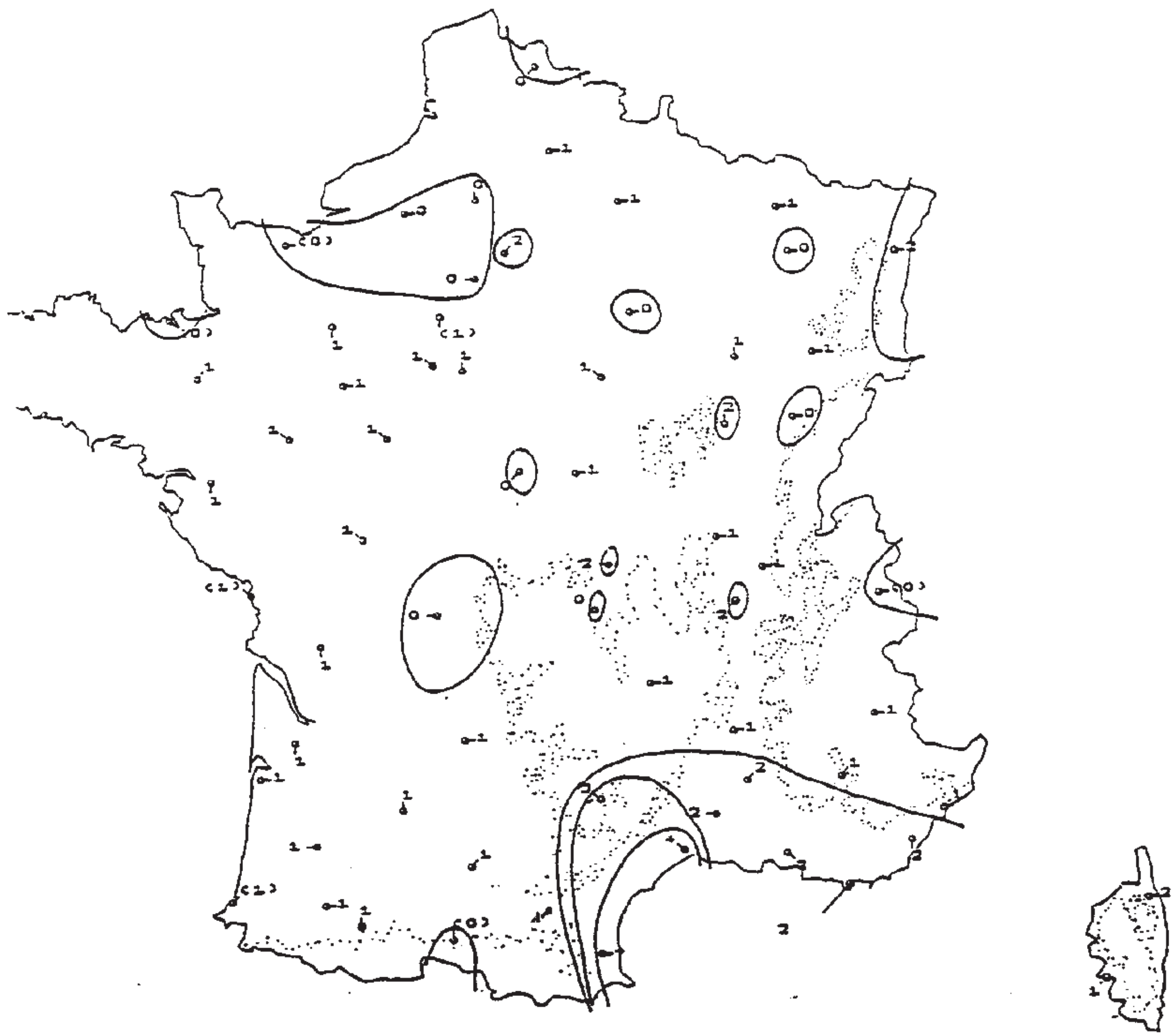


Figure 2.3 - A comparison of R/AR with the statistical elements on 30 November 1989.

An analysis of the spatial extent of the drought is essential, since drought is always heterogenous in space and in time. Its spatial heterogeneity can be identified by plotting values, such as R/AR derived from the model, at a number of stations on a given date during the drought episode. However, an R/AR value may be considered "normal" in one station and "abnormal" in another. The R/AR value should therefore be placed in its climatic context at each station on a given date, by comparing it with the statistical parameters established for the same date over a long period of time. The following index may be used for this purpose:

Value	Description	Significance
I=0	R/AR < Minimum	Record drought
I=1	Minimum < R/AR < 1st quintile	Drought anomaly
I=2	1st quintile < R/AR < Median	Slight water deficit
I=3	Median < R/AR <4th quintile	Normal soil conditions
I=4	4th quintile < R/AR < Maximum	Excess soil conditions
I=5	R/AR > Maximum	(Record) excess soil conditions

The Territory is then divided into zones according to synoptic stations with the same index. This type of analysis serves a dual purpose in that it provides an early warning system for anomalies and defines the spatial extent of such anomalies.

Figure 2.3 compares the R/AR. of the statistical parameters (for the period 1951-80) with the date 30 November 1989. As shown, the whole of France falls within the I=1 index (i.e. the R/AR values are below the 1st quintile) or even the I=0 index (i.e. the R/AR. values are below the minimum recorded over the period 1951-80). Only the Montpellier and Perpignan stations (in the south of France) show an I=4 index, which represents an excess.

Dynamic zoning of the drought may also be undertaken during the course of the year. In this way, at different times during the drought those parts of the territory where the R/AR parameter falls below the 1st quintile (on the same date) can be identified.

Figure 2.4 shows zones with drought anomalies (corresponding to the I=1 index) on four dates spaced one month apart (20 June, 20 July, 20 August, 20 September) in the summer of 1986. Thefigure shows the early onset of drought on 20 June over an area covering the mid- and lower Garonne Valley, as well as in Eure-et-Loir.

2.5.2 Early warning of drought

Thus, early warnings of hydrological anomalies and an accurate representation of their spatial coverage on a regional scale can be obtained by calculating the soil water balance, based on meteorological data from preceding months. There is always a time lag between the emergence of negative rainfall anomalies and the onset of drought in terms of its effects on agriculture. Due to the hydrological lag time in soil, this discrepance is usually in the order of 3 weeks - a time that can be used to alert users of the anomaly. So although droughts cannot be "forecast" *per se*, it is nonetheless possible to sound the alarm and give a timely warning (in the event that rainfall shortages continue).

Hence, soil moisture content anomalies in France in late February would warrant early warnings because, as of March, evapotranspiration normally exceeds rainfall and this situation would be very likely to continue.

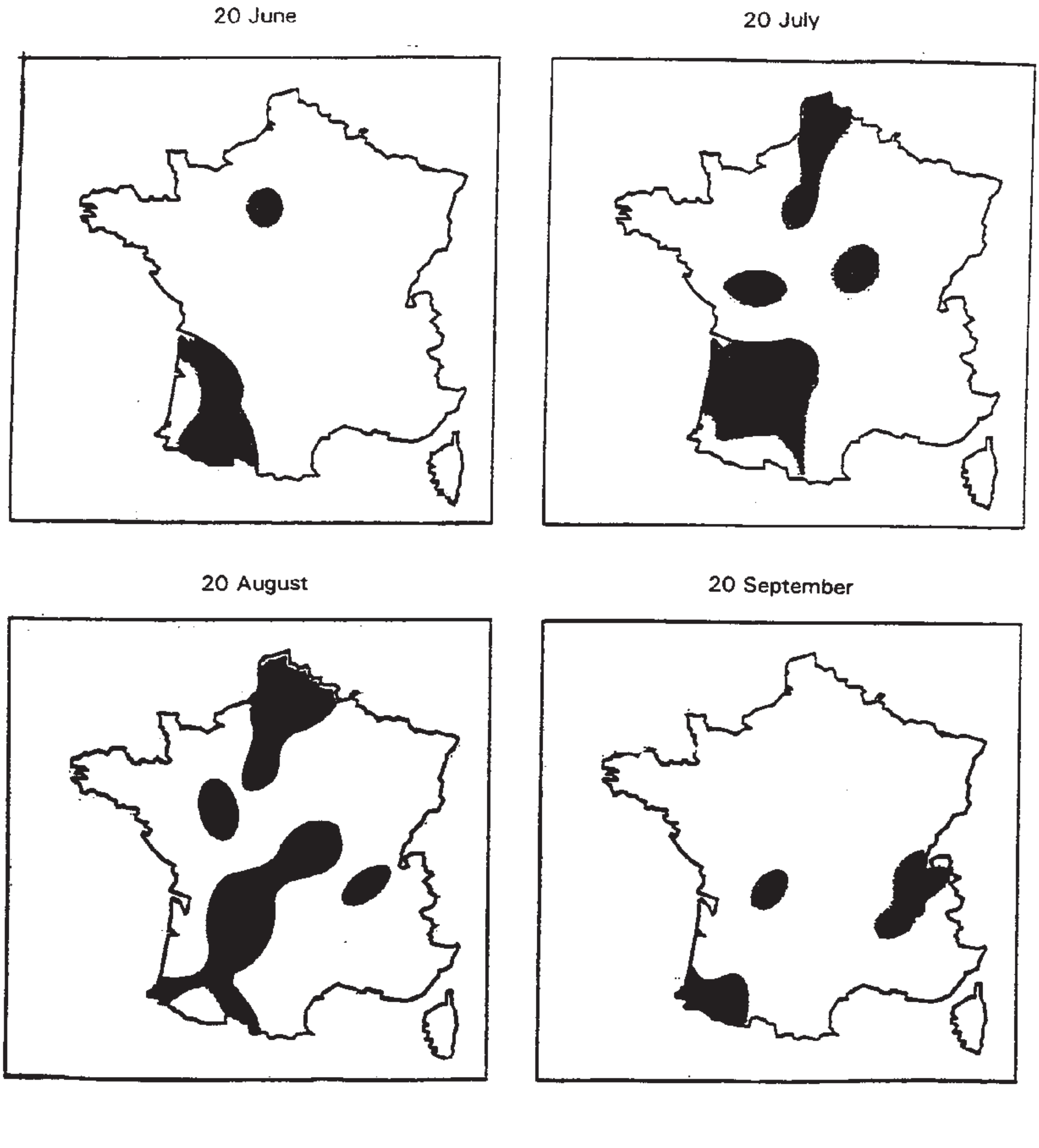


Figure 2.4 - Zones with abnormal soil hydrological conditions during the 1986 drought.

In such a case the government would be alerted.(In France, the Ministry of Agriculture and the Ministry of the Environment would be contacted). The government would then be in a position to take water conservation measures during the ensuing months if need be, either for irrigation purposes or for drinking water supplies. Such measures are especially applicable and effective if the affected zones have been accurately plotted.

2.6 HOW TO ALLEVIATE THE EFFECTS OF AGRICULTURAL DROUGHT

2.6.1 Drought and agronomy

Water is essential to plant life in that it ensures both its turgidity and its food supply. Mineral elements from the soil pass into the soil solution, the source of plant nourishment. Water shortages, substantial evaporation, sensitive plants and soil with poor moisture content are all factors that will allow a drought to manifest itself on crops. The concurrence of drought during the sensitive stages of a plant's life will have a very great impact on its yield. Based on analyses of these elements, the most effective means of combatting drought appear to be the following:

Irrigation: Where water supplies exist or are available, irrigation serves to supply the plant with its hydrological needs. Undertaken correctly, plant development can be controlled more effectively by irrigation in that crops are less vulnerable to vicissitudes in the weather. Fertilizers can also be used more effectively, and residue is less likely to be solubilized by rain and washed down to the water table.

Use of plant species adapted to the climate and the soil, plants with fewer water requirements, or hardier species: Drought will have less impact on the yield of such plants. J.C. Remy (1990) briefly classified cultivated plant species according to their growth requirements, as follows:

- drought-sensitive requiring water (maize, soya);
- moderately;
- moderately drought-resistant plant (sunflower);
- drought-tolerant plants (sorghum, millet).

Improving the water holding capacity of soils through cultivation techniques, adding organic matter, drainage, improved soil structure, etc.

Where water is a limiting factor, a choice must be made as to which system is best suited to the available water resources (J. Puech, 1990). On the one hand strategic decisions must be made concerning production, and on the other tactical choices must be made as to the extent of irrigation.

From the strategic standpoint: when selecting the best options during an economic drought, several scenarios should be investigated in terms of **agrometeorological conditions** (such as soil type, climate, and the probability of water shortages) and **socio-economic factors** (such as marketing prices, revenue dependability, manpower and equipment).

From the tactical standpoint: In order to optimize limited water resources, **crops must be monitored** in **real time** using various methods to evaluate the water balance.

2.6.2 Impact on the 1989-91 drought on French agriculture

Although the water shortages that occurred in summer 1989 had been predicted as early as February 1989, the French agricultural sector did little to modify its cultivation techniques and suffered the full force of the drought because of subsequent water restrictions. In all, 50 "départements" fell victim to the disaster. By 1990, however, agriculturalists had learned their lesson from the previous year's drought and had taken appropriate action:

(a) Agriculturalists turned to crops and cultivation techniques better suited to drought conditions, selecting crops with fewer water requirements such as sunflower and sorghum;

(b) New cultivation techniques for working the soil also had to be adopted, such as subsoiling and greater tilling depth in order to increase rooting depth;

(c) Some agriculturalists chose to alter the sowing period so that plants would complete highly drought-sensitive stages before the decrease in summer rainfall. In some cases, this resulted in the choice of different plant varieties;

(d) A dialogue began. In 1989 a "drought cell" was established by the Water Administration of the Ministry of the Environment, and still meets today. At the regional and departmental levels, drought cells comprising representatives from the Chambers of Agriculture, METEO FRANCE, the Ministry of Agriculture, the plant protection service, and produce associations, have met regularly since January 1990. Their objectives were, *inter alia*, to monitor reserves and the effects of rotation cropping over time and to apply irrigation water restrictions as required.

The Chambers of Agriculture took a number of steps to aid agriculturalists affected by the drought, namely:

- compiling detailed inventories of available water supplies and fodder;
- establishing agronomy and livestock councils and assigning them the responsibility of monitoring livestock food and water shortages and providing solutions;
- building water tours in some regions;
- providing agricultural advisory services concerning;
- optional water usage during severe economic conditions, based on studies of crop potentiality and production systems;
- the choice of appropriate spring crops in terms of available water resources;
- fertilization techniques and how to avoid pollution;
- communicating with the government and all water users concerning the establishment and administration of services designed to optimize water usage;
- compiling dossiers on disasters and emergency situations.

2.7 CONCLUSION

An evaluation of the probability of agricultural drought is a two-pronged process: the first involves a statistical evaluation, based on knowledge of climatic variability region by region, and the second entails evaluation during the course of the drought itself. Drought monitoring must be undertaken continuously, at 10-day intervals, throughout the year and over the entire territory. In this way early warnings can be made of anomalies in the hydrological conditions of the soil, the spatial extent of such anomalies can be plotted, and the government alerted. Agriculturalists are thus in a position to take steps to alleviate the effects of the drought by selecting crops with fewer water requirements, altering sowing crop monitoring (i.e. identifying the most critical period of the drought), and monitoring the water balance. French agriculture was seriously affected by the four consecutive drought years of 1989-92. The exceptional nature of this drought lay in the fact that it occurred during the autumn-winter periods rather than the summer, but its impact on the ensuing summers was all the more serious since the extent of agricultural irrigation has increased considerably over the last 20 years. Indeed, this was an "unprecedented" drought scenario in terms of weather conditions did occur during the period 1945-49. Unfortunately, it is difficult to compare the effect of these two drought periods on agricultural production since major advances have been made in the food and agricultural market during the 40 years separating these two events.

2.8 REFERENCES

Choisnel, E. (1993). Le risque de sécheresse en agriculture. Chambres d'agriculture, supplément au No. 807, January.

Choisnel, E. L'analyse spatiale du bilan hydrique en agrométéorologie.

Choisnel, E., and Jacquart, C. (1991). Les sécheresses et leurs diagnostics: qualité et rapidité d'information. Compte rendu de l'Académie d'Agriculture, France.

Choisnel, E., and Barbini, F. (1992). Suivi de la sécheresse en France, le cas des années 1989-90. Communication de la 16ème conférence régionale de l'Europe et de la CIID, Budapest.

Puech, J. (1990). Les progrès possibles pour une utilisation plus rationnelle de l'eau à l'échelle de l'exploitation. Proceedings of the symposium: "Eau et agriculture: leçons d'une sécheresse, Cemagref, Ed., Paris.

Remy, J.C. (1990). Résistance des plantes à la sécheresse - choix des cultures et variétés. Proceeding of the symposium: "Eau et agriculture: leçons d'une sécheresse". Cemagred, Ed. Paris.

WMO. (1975). Drought and agriculture. Technical Note No. 138, WMO-No. 392.

CHAPTER 3

AGROMETEOROLOGICAL INPUTS IN MEASURES TO ALLEVIATE THE EFFECTS OF DROUGHT AND TO COMBAT DESERTIFICATION

by D.D. Dambe

3.1 DEFINITIONS OF DROUGHT AND DESERTIFICATION

Both definitions that are used in this document are as adopted by the Convention to combat desertification in countries that are experiencing serious drought and/or desertification.

DROUGHT, as defined during the Intergovernmental Negotiating Committee of the Convention to Combat Desertification (INCD), is the naturally occurring phenomenon that exist when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems. However there are many numerous definitions of drought that exist, depending on the measures used to determine its causes, severity and its impact.

DESERTIFICATION as defined in the Agenda 21, at the Earth Summit in Rio, is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

3.2 SUMMARIES FROM QUESTIONNAIRES FROM SOME MEMBER COUNTRIES

The response to the questionnaires sent out through the CAgM secretariat was not encouraging. Only seventeen replies were received from all the six WMO regions. The information received was not even a representative of a single WMO region. Most responses were from Region I, presumably because drought and desertification have been more prevalent in this region, during the recent past decades, and their impacts were devastating.

To summarise the little information received, five of the six WMO regions reported that their countries have experienced drought, although at different magnitudes. The same countries reported that they used agrometeorological inputs to determine drought years and also to alleviate the effects of drought. Most countries that replied, used the existing methods/models, such as Palmer's Severity index, FAO Water Satisfaction Index, remote sensing methods etc., to monitor drought. Australia is one of the countries that reported to be extensively using information on the El Niño Southern Oscillation (ENSO) phenomena, in an attempt to predict drought occurrences in their region. Half of the countries that are affected by drought reported to have national drought policies.

Half of the countries that replied, reported the existence of desertification. Half of those countries that reported the existence of desertification have national policies on desertification. Some countries in Region I and V described agroclimatic models used to determine the encroachment of the desert, and methods used to stop or slow down the process of desertification.

The poor response to the questionnaires forced me to rely on the available literature, rather than what was received from CAgM members. The summary of the responses to the questionnaires can only give an indication the countries that are affected by desertification particularly in Region I, and whether or not they have in place methods/models to combat desertification.

3.3 LITERATURE REVIEW

Drought and desertification have been given a lot of attention by several authors from different scientific organizations. The Commission for Climatology and Commission for Agricultural Meteorology have given special attention to these topics and several technical reports have been published under WMO. A CAgM-IX Working Group on Monitoring, assessment and combat of Drought and desertification produced a report that covered the practical agrometeorological aspects in the combat of drought and desertification, the onset and cessation of drought, and a survey of methods and indices for monitoring and assessment of drought. Report of the CCl-X on Drought and Desertification in Warm Climates by Ogallo (1989), summarized information on drought and desertification from WMO questionnaire, for each WMO region. The report also covered the required meteorological network density and its design to effectively assist efforts to combat desertification. The rapporteur went on to produce drought probability indices a model for drought response plans. Examples of drought probability and aridity indices produced by this report are attached in the appendices.

A report of the CAgM Working Group on the Assessment of Drought was prepared by C.E. Hounam, J.J. Burgos, M.S. Kalik, W.C. Palmer and J. Rodda. Amongst other topics the group review meteorological indices of agricultural drought, and different methods of analysis, to detect and assess drought conditions. The technical note also summarised different drought definitions and/or associated concepts.

Sakamoto and Steyaert (1989), presented a paper on the international drought early warning programme of NOAA/NESDIS/AISC, which concentrated on the use of the remote sensing technology to provide information that mitigates the effects of drought and reveal the extent of desertification. The paper summarized the NOAA Drought Early Warning System, which is based on three subsystems, notably, agroclimatic indices, satellite assessment models, and crop yield forecast models. The concept of Geographic Information System was used in the Early Warning System by using different data sources and integrating the data to provide relevant information. The agroclimatic indices mainly required a reliable and timely rainfall data base, which is normally received daily through the WMO Global Telecommunications System (GTS). The satellite assessment models use data from the European Space Agency's Geostationary Meteorological Satellite (METEOSAT) and the NOAA Polar Orbiting Satellite. The METEOSAT imagery is mainly used to estimate rainfall amount according to the cloud types and coverage, based on the processes of cloud indexing. The NOAA satellite provides daily data from the Advanced Very High Resolution Radiometer (AVHRR).

The Department of Theoretical Production Ecology (TPE) and the Centre of Agrobiological Research (CABO) in Wageningen, Netherlands have been engaged in the development of a series of simulation monographs. WMO asked the CABO and TPE to give short courses in various developing countries, on simulation of primary production of crops and natural pastures and the resulting carrying capacity, using crop-, soil-, and agrometeorological data. Botswana was fortunate to be one of the countries that benefitted from the roving seminars that took place, under the sponsorship of WMO.

A Crop Yield Simulation and Land Assessment Model for Botswana (CYSLAMB) has been developed to serve the needs of land evaluation in a semi-arid environment. By modelling the interaction of environmental variables, physiological responses, inputs and management, CYSLAMB predicts the yield of a particular crop production system on a specified land unit. The use of rainfall data for individual years enables evaluation of inter-annual yield variability and the quantification of risk in the specifications of the production system, the impact of such changes in yield can be evaluated, and extension recommendations can be closely targeted. The model was produced by De Wit, Tersteeg and Radcliffe (1993), but it has not yet been put into operation.

A workshop on the prediction, detection, monitoring, early warning, impact assessment, adaption and adjustment, planning and response was held in Pretoria, South Africa, by the Southern African Regional Commission for the Conservation and Utilization of Soil (SARCCUS). Papers were presented by several experts from within and outside the Southern African region. Different agrometeorological techniques on the above mentioned aspects of drought were discussed and at the end, the proceedings of the workshop were published under SARCCUS (1989).

Due to severe drought conditions that engulfed many parts of Region I during the past two decades, Drought Monitoring Centres (DMCs) have been established in Nairobi, Kenya and in Harare, Zimbabwe. DMCs are sub-regional climate diagnostic centres where all the information relating to drought in the sub-region is made available to all users. The centres are located in Nairobi, Kenya (main one), and in Harare, Zimbabwe. These centres resulted from a WMO/UNDP project for Eastern and Southern African countries, initiated by 21 countries from the two sub-regions. The main objective of these centres is to monitor drought and provide prognostic advice to member countries. Meteorological data bank in the centres is provided by National Meteorological Services in the sub-regions. The centres closely collaborates with other weather and climate analysis centres, to capture global weather phenomena that have been found to be responsible for anomalous climatic variations in the sub-region. Currently the centres publish the following:

(a) Monthly Drought Monitoring Bulletin, which contained:

- (i) monthly and three monthly climatological summary and drought severity indices of the sub-region;
- (ii) dominant synoptic systems and three months weather outlook for the sub-region;
- (iii) agrometeorological conditions and its impacts on the sub-region.

(b) Ten day advisory bulletin, which contains:

- (i) dekadal climatological summary and drought severity indices;
- (ii) dekadal agrometeorological conditions and its impacts;
- (iii) dekadal synoptic review and weather outlook for the sub-region.

(c) Dekadal, monthly and three monthly actual meteorological data for the region.

3.4 EXAMPLES OF OPERATIONAL USE OF AGROMETEOROLOGICAL INPUTS

3.4.1 Drought monitoring system (Botswana Experience)

Drought monitoring system in Botswana is done at two levels, the technical level and the policy level. The Early Warning Technical Committee (EWTC) operates at the technical level while the Inter-ministerial Drought Committee (IMDC) is at a policy making level and advisory to the government. The EWTC is multi-disciplinary and its members are:

- Ministry of Agriculture (Division of Crop production, Animal production, Division of Agricultural Planning and Statistics);
- Food Resources Department (assessment of food stocks, planning of food imports, distribution of food in the country, etc.);
- Botswana Agricultural Marking Board (buys, sells and stores grain produced inside the country and from neighbouring countries);
- Central Transport Organization (controls the government fleet);
- Ministry of Health (Division of Nutrition) to assess the nutritional status of the vulnerable groups;
- Department of Meteorological Services (Agrometeorological Section) to assess drought conditions throughout the country, produce crop yield forecasts, produce agrometeorological bulletin.

The committee is chaired by Rural Development Division in the Ministry of Finance and Development Planning. Reports from this meeting are then sent to the (IMDC) for further discussions before recommendations are made to the Minister of Finance, and Cabinet.

The Inter Ministerial Drought Committee is composed of a larger number of members, representing the ministries of Finance and Development planning, Health, Agriculture, Local Government and Lands, Works Transport and Communications, Mineral Resources and Water Affairs. The IMDC is less involved with the technical aspects of drought monitoring but more with the socio-economic effects of drought, the planning and the supervision of the relief activities, identification and removal of bottle necks, co-ordination with multi and bilateral organizations, and donor community.

3.4.2 The role of agrometeorological services in drought monitoring systems

The Department of Meteorological Services is responsible for the monitoring the impact of weather on crops and grazing during the growing season. It also provides an estimate of the annual crop yield to the Ministry of Agriculture before the end of the growing season, using weather and climate information. Meteorological information, as the primary conditions of drought, are the earliest indicators of a good or a bad season. The department provides ten day and monthly agrometeorological bulletins, which contain rainfall amounts and its distribution, presented in tables, maps and graphical formats. As rainfall alone is not sufficient to monitor drought, the bulletins are based on the following analysis:

- total rainfall since the start of the rainfall season, calculated percentage departures from normal rainfall, to give an indication if and where there are deficiencies. Applies available statistical software (Instat),to produce graphs, maps and tables that would better interpret the meteorological data at hand;
- daily rainfall distribution on ten day basis to determine the length of dry spells;
- monitors the soil moisture reserves before and after the assumed planting period, in some selected agrometeorological stations, using neutron probe method. Estimates the soil moisture reserves, throughout the country using of water balance models;
- calculation of rainfall probabilities for major rainfall stations in Botswana;
- calculation of crop yield forecasts, using the FAO water satisfaction index model;
- collects agricultural information from Ministry of Agriculture, needed to produce crop yield forecasts. (planting dates, crop calendars, type of crops grown etc.);
- the Department has a Primary Data User System (PDUS) which receives data from the Meteosat. The Cold Cloud Duration method is used to eventually estimate the amount and distribution of rainfall in an area based on the threshold temperatures that correlate with a certain amount of rainfall. Presently this facility only allows us to follow rain-bearing clouds, not to estimate the amount of rainfall that has fallen, as the ground truthing exercise has not been completed;
- the Department also periodically receives NDVI images from FAO Rome, which are further processed using available software (IDA) to provide locally useful products, that are able to periodically monitor vegetation status on the ground. However this technique has not yet been fully developed.

3.4.3 Effectiveness of agrometeorological advice to policy makers and the farming community

Dissemination of agrometeorological information has been a difficult task in Botswana, particularly to farmers at subsistence level. The agrometeorological advice on drought events has been welcomed by most policy makers but further training needs to be done, so that they can fully understand and interpret its meaning. A National Committee for Agricultural Meteorology was formed in 1984 with the aim of involving as many scientists as possible so that they take part in the formulation of the advice provided. The terms of reference of the committee are as follows:

(a) To improve meteorological information and advice to agricultural policy makers, research and extension workers and farmers for the benefit of increasing food production;

(b) To identify the types of decisions in agricultural activities that should draw on weather information and assess the future requirements;

(c) To keep an inventory of the existing research projects and other projects that could have results useful in the field of agrometeorology, to prepare an inventory of research results available in Botswana relating to agricultural problems as affected by weather and climate;

(d) To discuss the "Monthly Agrometeorological Bulletin" on its adequacy and relevance to the users, and make proposals for improvement;

(e) To arrange presentation of research results to agrometeorology in the country and promote exchange of technical bulletins or notes with other countries and review new publications of interest;

(f) To promote training of weather/climate information for agricultural activities.

Agricultural Demonstrators are the closest agricultural officers to farmers. They are responsible for the dissemination of all technical information to farmers. In Botswana this is an area where a lot more work still needs to be done, so that farmers can fully benefit from the technical information that is provided by institutions that develop them. More seminars and workshops need to conducted for both the ADs and the farmers to improve the flow of data.

3.5 DESERTIFICATION

3.5.1 Literature review

In May 1974, the UN General Assembly's resolution 3202 (iv) was recommended that the international community should undertake concrete and speedy measures to arrest desertification and assist the economic development of affected countries. Later on, on the 17th of December the same year, the General Assembly decided by resolution 3337 (xxix) to initiate concerted international action to combat desertification. The UN Conference on Desertification (UNCOD) followed (29 August to 9 September 1977 in Nairobi, Kenya), where an effective and comprehensive programme was drawn to study ways and means to combat desertification. United Nation Environment Programme (UNEP) among other organizations played a leading role in this exercise.

UNEP has produced a "World Atlas of Desertification" (1992). The atlas is partitioned into three sections, the global situation, the continental situation (Africa), and case studies from different countries around the world.

The Executive Director of UNEP produced a report "Status of Desertification and Implementation of the United Nations Plan of Action to Combat Desertification", for a Governing Council Third Special Session, Nairobi, February 1992. The report discusses the world status of desertification, the United Nations Plan of Action to Combat Desertification (PACD), the policy guidelines and course of action for combating desertification, and the financing of the PACD.

UNEP also produces Desertification Control Bulletins that cover the World Events in the Control of Desertification, Restoration of Degraded Lands and Reforestation. The bulletins publish papers, reports, research findings on desertification from all over the world.

A UNEP project contracted to the Office of Arid Lands Studies (OAS) under The University of Arizona produced a World Desertification Bibliography in August 1991, which was a revision and update of the previous volumes. The aim of the project was to increase the availability of relevant information on desertification control for decision makers, planners, and researchers/scientists, to increase the size of Desertification Control Programme Activity Center (DC/PAC's) database, and to produce a hard copy for general distribution.

There are papers presented to the Ad-Hoc Consultative Meeting on Assessment of Global Desertification; Status and Methodologies (15-17 February 1990, UNEP, Nairobi, Kenya). The proceedings were edited by R.S. Odingo. The papers discussed the definition of desertification, different methods of assessment of desertification, and development of new methods of assessment and monitoring of desertification.

The eleventh session of the Commission for Climatology produced a report on Drought and Desertification, by rapporteur Kerang Li and A. Makarau. Among other topics, the report discussed monitoring, causes, prediction and management of drought, including response plans and preparedness.

Climate Application Referral System-Desertification (CARS-DESERTIFICATION) is a project of the World Climate Application Programme (WCAP) to provide WMO Members with information on proven (tried and tested) methods of the application of meteorology, climatology and hydrology to combat and control desertification. The CARS also covers fields such as: food, energy, urbanization, building, transportation, human biometeorology, tourism and recreation and economic planning. The field of desertification was later added during the ninth session of CAgM in 1986. One of the terms of reference for this report is to make contributions towards CARS-FOOD, and CARS-DESERTIFICATION. Unfortunately there are no new application methods developed on drought and desertification that can be added to both fields.

3.5.2 Botswana Experience

Desertification exists in Botswana. Its major causes have been found to be anthropogenic, although due to recent prolonged episodes of droughts in the region, natural causes may also be responsible. It is however difficult to separate causes of desertification, since they are inter-dependent. At times it is amazing how ecosystems in semi-arid zones, such as in Botswana recover from devastating droughts, if there is no human interference. According to Hare (1987) "natural ecosystems out live prolong drought with little or no change. Individual plants and animals die, but the population to which they belong survive, even flourish, since drought eliminates aggression from less hardy species. Xerophylic ecosystem are among the world's most patient and stable systems". The anthropogenic causes of desertification, especially near large settlements or in areas that is overstocked, are quiet evident in Botswana.

Botswana falls under the desert margin and the semi-arid zones, because of its high population of livestock and wildlif, coupled with poor farm m anagement practices. However the new agricultural policy has made plans to fence all communal grazing areas in an attempt to control carrying capacity and restrict unwarranted movement of livestock.

Population growth in peri-urban areas and large settlements (villages), results in more and more demand for fuel wood. The outskirts of these areas end up being denuded of the marginal vegetation that existed. The government is introducing alternative fuel such as coal and use of gas to replace wood.

Land use planning is conceived as a tool for sustainable use of land and therefore every land use plan, should be accompanied by environment impact assessment analysis. Agricultural long-term plans are now advised to incorporate the environment assessment analysis. The CYSLAMB model was developed to serve the need of land evaluation in Botswana, and determine the potential of an area before it is allocated for use.

Botswana has mainly sandy and shallow soils which are vulnerable to erosion once its structure is disturbed by over-stocking, or exposure to high intensity rainfall or direct sunlight, after the removal of natural vegetation. The onset of rains in Botswana are characterized by high intensity showers, that find most of the top soil unprotected (end of dry period), hence it is easily washed away.

Combat of desertification in Botswana is still in its infancy stages. There is a National Tree Planting Day, when the whole nation is encouraged to plant trees. This has not succeeded because a very small percentage of the trees that were planted survived, due to drought that engulfed that persistent over Southern Africa for the past decade. Since the major causes of desertification are due to human activities, the first step to stop or slow down the process would be to educate people and make them aware of the consequences of land degradation. This activity has already started in parts of the country, where desertification has been identified.

The African Ministerial Conference on Environment (AMCEN) held in 1985, approved a Cairo Plan of Action to have the UNEP's Desertification Control Programme Activity Centre (DC/PAC) to formulate a project for the development of a regional plan of action for rangelands monitoring, protection and rehabilitation in the Kalahari-Namibia affected areas. Under the assistance of UNEP, Southern African Development Commission (SADC) a fully fledged project document. The Kalahari-Namibia region includes most of Botswana, the Northeastern and eastern areas of Namibia, Southeastern region of Angola, the western and southwestern part of Zambia, the western part of Zimbabwe, and the Northern part of Republic of South Africa. The objectives of the project is:

- to achieve sustainable exploitation of natural resources in the Kalahari-Namibia region;
- to stop man-induced land degradation and desertification processes;
- to improve the welfare of population in the area and thus contribute to break the circle of poverty--> land degradation - --> increased poverty.

Preparation for the implementation of this project is underway, as soon as all the necessary funds are obtained.

A Summary of a Botswana Case Study for the United Nations Convention to Combat Desertification is included in the appendix. The case study was conducted by The Department of Environmental Science in the University of Botswana.

3.6 PROBLEMS AND RECOMMENDATIONS RELATING TO DROUGHT AND DESERTIFICATION

A substantial amount of work has already been done on drought assessment and monitoring. Most of the methods/models developed are already being successfully applied in many countries affected by drought. However prediction of drought has proved to be difficult despite the concerted efforts by several weather/climate analysis centres to produce drought predicting regional and global models. There are Drought Monitoring Centres in most drought prone regions of the world. These centres need to be strengthened so as to have the capacity and capability to give warnings and long term drought predictions, to areas of their responsibilities. This calls for adequate data banks and computing power, trained personnel, fully equipped reference libraries and good communication with the rest of the world, particularly with other weather/climate analysis centres. Regional observation network, especially in Region I, needs to be improved so that it provides all the necessary data to the regional centres.

Most countries that are affected by desertification have at least identified the problem, and are aware of the causes, particularly those that are anthropogenic. Methods have been developed to assess the rate of desertification. However most countries are unable to successfully slow down, stop, or reverse the processes of desertification. The United Nations Convention to Combat Desertification has now been signed and affected countries are now awaiting policy guidelines, the course of action and the means of financing National Action Plans.

Agrometeorology techniques, in most developing countries, particularly those seriously affected by desertification, have not been fully applied to combat desertification. Agrometeorological practices, such as agro-ecological, land and crop suitability maps, methods of soil moisture conservation etc., when fully applied would contribute to the combat of desertification. National desertification policies are important tools that governments can use to guide their nations on what needs to be done to combat desertification. Education at all levels, to make all communities aware of the consequences of desertification should be seriously considered because ignorance also plays its part.

There are far reaching causes of desertification that are of a social and economic nature. INCD have identified poverty to be one of the catalysts of desertification. Many poor nations in the third world are forced into acts of land degradation for survival. Alternative inexpensive and sustainable means of survival, have to be introduced to such communities, to avoid practices that lead to desertification. For instance a very high percentage of the population in Botswana depend on wood for fuel. The country has an abundance of coal which should be used basic fuel cooking. Coal costs money, therefore poor households may not be able to afford it, when compared to cutting trees for wood. The government of Botswana has embarked on a project to produce wood and coal efficient simple stoves to cook basic food, so that less wood is used.

3.7 REFERENCES

CAgM-IX Working Group on Monitoring, Assessment and Combat of Drought and Desertification.

De Wit, Tersteeg W. and Radcliffe D. (1993). Crop Yield Simulation and Land Assessment model for Botswana.

Hounam C.E, Burgos J.J, Kalik M.S, Palmer W.C, Rodda J. (1975). Drought and Agriculture. WMO Technical Note No.138 WMO No.392.

Kerang LI. and Makarau A. (1993). Drought and Desertification. Reports to the Eleventh Session of the Commission for Climatology (Havana, February 1993).

Odingo R.S. (1990). Desertification Revisited. Proceedings of an Ad Hoc Consultative Meeting on the Assessment of Desertification. UNEP-DC/PAC, Nairobi. Kenya.

Ogallo (1989). Drought and Desertification in Warm Climates. Report of the CCL-X Rapporteur on Drought and Desertification in Warm Climates.

Sakamoto C. M. and Steyaert I.T. (1989). International Drought Early Warning Program of NOAA/NESDIS/AISC. Paper presented on Drought Planning Workshop. pp 247.

Sarcuss. (1989). Proceedings of a Workshop on Drought. Drought Detection, Monitoring and Early Warning.

UNEP (1992). Executive Director's report for a special session in Nairobi. Status of Desertification and implementation of the United Nation Plan of Action to Combat Desertification.

UNEP (1992). World Atlas of Desertification.

3.8 APPENDIX - BACKGROUND ON CASE STUDY OF DESERTIFICATION CARRIED OUT IN THE MID-BOTETI, BOTSWANA

This case study of desertification was carried out in the Mid-Boteti area in Botswana for the Ministry of Agriculture, As Botswana's contribution toward the preparation for an Inter-governmental Convention on Desertification. The specific objectives of the study were:

(a) To determine the extent and the elements of desertification;

(b) To assess local perceptions about desertification and its consequences;

(c) To involve the local population in assessing the desirability of abatement measures and the options for alternative sources of income.

The study used the United Nations Conference on Environment and Development (UNCED) definition for desertification: "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities". The study was conducted by a multidisciplinary team from the Department of Environmental Science, University of Botswana. Research was carried out between July and October 1993.

The Ministry of Agriculture and the consultants agreed to conduct an in-depth study in only one of the worst affected areas in the country, i.e. the Mid-Boteti region in Northwestern Botswana.

Mid-Boteti is representative of the more remote parts of the country, but has the unique feature of the Boteti river which flows during the dry season, fed by water originating from Angola (via the Okavango). The area is also located in the country's sandveld region which has low natural productivity due to low rainfall and poor sandy soils. Nevertheless, human pressure is relatively high as people have since historical times been attracted to the area because of the availability of surface water and the absence of the tsetse fly. In recent decades,. human pressure has rapidly increased and has caused increasing resource problems, particularly during droughts and in years when the river does not flow, as has been the case during most of the last decade.

3.8.1 The extent of desertification

Desertification was found to occur at a significant scale in the study area. Symptoms which occurred or increased since the 1970's include: large areas of bare soil, recently formed sand dunes, the removal of up to 2-3 cm of the topsoil through wind-erosion, changes in the composition of vegetation, a high proportion of dead trees, a declining groundwater table and increasing salinity of wells, and a substantial reduction in wildlife numbers.

As regards the main agents of desertification, no evidence was found of desiccation (the long term process of aridification). Alternating drought/wet climatic cycles and human factors were found to be largely responsible for land degradation. Within the scope of the study, it was impossible to verify in detail the contribution of each agent, but it is likely that the drought impacts are growing more serious due to increasing human pressure. The impacts of the next drought may yet be more severe, if nothing is done to curb the increasing human pressure. Similarly, it has not been possible to measure the impact of desertification on resource productivity, but it can be reasonably inferred that due to degradation the productivity of the area's soils, flora and fauna is declining, leading to increasing resource scarcity - view confirmed by the local population.

It must be noted, however, that desertification may take many different forms, and that it does not occur everywhere throughout the study area. Particularly affected areas include the zone along the river, areas around villages and around boreholes, where pressure tends to be relatively high. Particularly important aspects of desertification in the mid-Boteti area include:

(a) The frequent flood failures of the Boteti river, which seriously affect flood recession cultivation as well as watering of livestock and wildlife;

(b) Vegetation changes on rangelands, affecting the regrowth potential of trees and veld-products (including veld-floods);

(c) A decrease in the groundwater table, mostly affecting livestock and trees;

(d) Wind-erosion, which blows away the topsoil, exposing the underlying calcrete layer, and reducing the soil fertility.

In order to survive in a harsh environment with recurrent droughts, people have traditionally developed several adaptations such as:

(a) The practice of flood recession (or "molapo") cultivation, which makes use of the seasonal rive flow in an otherwise semi-arid environment;

(b) Combining molapo and dry-land cultivation to reduce the risk of outright crop failure; with the same objective, farmers practise mixed cropping techniques;

(c) Mobile livestock management strategies, largely determined by available water sources;

(d) Replacement of cattle by goats during droughts;

(e) Engagement in a combination of agricultural and non-agricultural activities to reduce vulnerability to the large agricultural risks.

In recent decades, however, many of these adaptations are becoming less feasible due to population increase and changing conditions. Extra molapo land is no longer available, while livestock mobility has been reduced by the demarcation of wildlife reserves.

3.8.2 The analysis of desertification

It is clearly showed the importance of both (inter)national and area-specific factors in understanding, on the one hand, the processes behind desertification and, on the other hand, the possible solutions. The analysis also showed that different forms of desertification are linked. For example, some people, in order to compensate for agricultural income losses due to desertification, resort to the selling of wood and veld-products, thereby contributing to deforestation. In addition, rangeland degradation was found to adversely affect the availability of veld-products such as thatching grass and edible berries.

The analysis first focused on the causes and impacts of desertification. Subsequently, solutions adopted by the local population were analysed, and additional solutions were considered. The study revealed eight common causes of desertification:

(a) An increase in human population with the associated increase in subsistence needs, leading to increased numbers of cattle and goats, the expansion of cultivated land and the increased collection of wood and veld-products;

(b) The low income of the majority of the population which perpetuates their reliance on "free" natural resources, because substitutes for fuelwood cannot be afforded and extra inputs toward the improvement of resource management cannot be purchased;

(c) Government programmes and policies which emphasize production increases without due consideration of the local environmental conditions (e.g. agricultural programmes) or are implemented without consultations with the local population (such as Wildlife policies; which have alienated the local population in the study area);

(d) Lack of resource management due to the fact that traditional authorities have lost most of their responsibilities in this regard, while modern institutions are not yet effectively involved in the management of local resources;

(e) Resource-use and land-use conflicts (e.g.: for the poor veld-products are an important source of flood, but over-grazing tends to destroy veld-foods);

(f) Limited employment opportunities outside agriculture;

(g) Increasing commercialisation of resource use, contributing especially to the depletion of rangelands and wildlife resources;

(h) Drought or short-term climatic changes, considered by the people as the most important cause of desertification, although they do accept the influence of the above mentioned human factors.

The impacts of desertification are substantial in both socio-economic and physical terms. People are most concerned with the fomer as desertification reduces their income and depresses their living conditions. Some people manage to make up for the losses incurred through formal employment, the sale of cattle or veld-products. However, the poor, who mostly depend on dry-land cultivation, hunting wildlife and the collection of veld-products, have little to fall back on and are hardest hit. Physical impacts include wind-erosion and loss of biodiversity. There are two interrelated cycles that affect the long-term sustainability of the environment. Firstly, over utilisation of the resources - as occurs today - adversely affects the productive potential of the environment. This became evident from reports about declining wildlife numbers and reduced availability of veld-products. Continued over exploitation will negatively affect the regenerative capacity of the environment. Secondly, the position of the poor is crucial Poor people rely most heavily on "free" natural resources in the vicinity of the place of domicile - where depletion is usually most serious - as they cannot afford boreholes in remoter locations where rangelands are still in good condition. The poor are thus disproportionately affected by the decline in productivity of the environment, and suffer most income losses. As a result, they are often compelled to further increase resource pressure, for example by collecting wood or veld-products for sale, potentially leading to a downward spiral of increasing resource degradation.

The combination of both the physical and the socio-economic cyclical processes is at the core of the desertification model presented in the main report. Current conditions of increasing resource demand, a dwindling resource supply and absence of resource management, suggest that the study area is experiencing these cyclical processes. Continuation of the trend will result in more serious desertification and increased impoverishment of the population. Unless people adapt extremely will and resource management drastically improves, the people in the study area, in particular the poor, would find themselves trapped in the downward spiral.

3.8.3 Toward solution for desertification

In order to have workable solutions, it is imperative to know the views and secure the active participation of the local population. Most local inhabitants blamed "drought" for much of the resource degradation. However, they admitted that human factors contributed towards degradation. However, they admitted that human factors contributed towards degradation, mostly as secondary factors. The perception of the desertification process focuses very much on the direct causes and impacts; underlying processes are more rarely identified.

Whilst most people felt that the primary causes of desertification were of a physical nature, the primary impacts were thought to be of a socio-economic nature, including: loss of income opportunities and lowering of living standards. The higher educated have a better eye for the complexity of desertification and mention more causes and impacts. Interestingly too, perceptions are influenced by a person's socio-economic position. For example with regard to the possibility for expansion of cultivation and livestock holdings, the poor were quite pessimistic, probably because they have a limited radius of access to resources. The rich were also fairly pessimistic, possibly in defence of their control over the remoter areas, while the middle-income group was most optimistic, possibly reflecting their desire to expand cultivation and livestock holdings. A final striking feature of the perception is people's apathy towards the problems and possible solutions and their dependence on government assistance. On the one hand, this reflects the fact that people "wait for the return of the rains". On the other hand, it reflects the fact that people have become accustomed to relying on government assistance rather than trying to **jointly** solve the problems themselves. It must b noted, however, that local consultations yielded a wide variety of suggestions for solutions, which deserve further follow-up.

In the study area, measures to solve desertification must be aimed mainly at correction and prevention. It is believed that most of the environment still possesses sufficient reliance to recover once the main causes of desertification have been removed. However, it will take time before solutions will be implemented and yield results. Therefore, they must take into account expected future development, both general and area specific factors. General future developments with an impact on desertification are likely to be:

(a) Continued high population growth with increasing subsistence resources;

(b) Increasing commercial pressure on natural resources;

(c) Stagnation in the growth of non-agricultural employment, putting more pressure on rural resources;

(d) Rapid urbanisation and population concentration into large villages, putting more pressure on resources around large settlements;

(e) Increasing influence of government policies, and pressure to improve natural resource management through the National Conservation Strategy and the relevant sectoral policies such as those in agriculture.

Area-specific issues include:

(a) Increasing accessibility through improvements in infrastructure, opening up new development opportunities;

(b) A decline of natural capital, especially wildlife and groundwater and possibly surface water, depending on possible upstream water-works development;

(c) The future role of Orape which is currently a closed town, in the integration into the region's economy.

Suggested solutions must also take into account the coping strategies, already locally employed. Recent technological and economic development have opened various new coping strategies in addition to existing ones. Some of the more important are:

(a) Borehole-dependent expansion of cattle ranching away from the river (only feasible for the rich);

(b) Expansion of arable farming, mainly on dry-land;

(c) Improved income opportunities outside the agricultural sector, which led to large scale out-migration (and remittances) and reduced the population growth in the area to 1.6% in the 1980's which is well below the rural average;

(d) An apparently permanent switch from cattle to goats by the poor and middle-income groups;

(e) Increased commercial harvesting and sale of veld-products and wood;

(f) Some intensification of resource use (e.g. supplementary feeding of animals, disease control, small-scale irrigation along the river).

One major coping strategy which was important in the past no longer works today, i.e. expansion of the resource base (viz.(a) and (b) above). The study area is now virtually fully used: livestock production has reached the boundaries of the Game Reserves.

3.8.4 Suggestions and recommendations

(a) There is a need for government policies (especially those dealing with agriculture wildlife) to be made more relevant to the local environmental and socio-economic conditions; they should be flexible enough to be relevant both to sandveld and hardveld conditions, and provide support for molapo farming, while in addition, livestock policies should provide more support for goat rearing;

(b) There is an urgent need to fill the resource management vacuum with respect to all natural resources, but particularly with respect to veld-products and wood; pressing management questions include:

(i) what is the best type of resource use (in terms of comparative advantages) for the local communities?
(ii) how can the increasing number of resource conflicts be resolved; is zoning an alternative?
(iii) how can multiple resource use be encouraged?

(c) Strengthening of resource management must involve the local authorities and communities; organisational issues to be addressed include:

(i) the decentralisation of certain resource management responsibilities to the local level; the suggestion is made to involve the population regularly in monitoring of resource issues and to discuss solutions;
(ii) the mobilisation of people's involvement in resource management; this implies that they should perceive and reap some benefits, for example in the following ways:

- a return of environmental revenues such as those from the Wildlife Reserves to the local level to be spent on local resource management and development projects;
- the establishment of a locally managed revolving fund for local resource management projects;
- provide employment and income opportunities for local people: this could be employment of local game wardens, but also employment resulting from the establishment of a natural resource based industry or service sector (for example in ecotourism);

(d) There is a need to raise environmental awareness among the local population, particularly regarding locally implementable solutions; local environmental issues should be integrated intc the school curriculum and local schools could be involved in the monitoring of local resource changes, while existing or expanded community literacy programmes could incorporate environmental education;

(e) There is an urgent need to systematically monitor resource and environmental trends, especially because Botswana relies heavily on renewable and non-renewable natural resources.

Since poverty is both a cause and an impact of desertification, poverty alleviation must remain a major priority in efforts to combat desertification and to sustain the local resource base. To succeed in this it is necessary that the local population, especially the poor, have adequate access to and control over local resources (including land, water and wildlife) and that they participate in policy making for resource management. One important recommendation is therefore that a revolving fund be established for the funding of small scale local, environmentally friendly, development projects, to be administered by a local institution subject to community control.

Poverty is still widespread in rural areas despite the rapid economic growth in Botswana. Poverty greatly restricts people's coping strategies against drought and desertification. An important role in poverty eradication must be played by the promotion of employment opportunities, both formal and informal.

Specific programmes for the combatting of desertification and poverty which might be considered (pending detailed investigation) for the study area and other similar areas in Botswana, include:

(a) Non-agricultural employment creation, e.g. through:

- (i) community based ecotourism projects;
- (ii) small scale mining projects for industrial minerals;
- (iii) fish farming projects;
- (iv) community based wildlife management schemes;

(b) Agricultural income improvement, e.g. through:

- (i) forestry and agro-forestry projects;
- (ii) small scale irrigation and horticulture projects;
- (iii) game farming projects;
- (iv) bee-keeping projects;
- (v) projects for harvesting and marketing river and veld-projects;
- (vi) pasture grass farming projects;
- (vii) dry-land crop farming projects;

(c) Land conservation programmes, including e.g.:

- (i) small scale sand dune stabilisation projects;
- (ii) planting of wind-breaks around villages.

Institutional arrangements are of crucial importance for a coordinated approach to the desertification problem. It is recommended that on the government side the coordinating institution would be the NCS agency. It is further recommended that the activities of the various line ministries be integrated into a land-use zoning plan. As emphasized before, it is further critical that the local population and local institutions are involved in preparing and implementing projects. In addition, some aspects of monitoring can also be effected at the local level.

CHAPTER 4

INTERACTIONS OF DESERTIFICATION AND CLIMATE: AN OVERVIEW
by T. Darnhofer

4.1 INTRODUCTION

Desertification is now a direct threat to over 250 million people around the world, and an indirect threat to a further 750 million people. In the last 25 years, desertification has become increasingly apparent in the dry sub-humid regions of the world, where mean annual rainfall ranges from 750 to 1500 mm, and where the majority of the human inhabitants of the drylands now live.

Current best estimates suggest the roughly 70% of all agricultural used drylands are to some degree degraded, especially in terms of their soils and plant cover (UNEP 1992 a.b.). The total area concerned is 3.5 billion hectares, and over a hundred countries are now suffering from the adverse social and economic impact of dryland degradation (**Table 4.1**).

Table 4.1 - Extent and severity of dryland soil degradation, grouped by continent, (millions of hectares) (adapted from UNEP 1992 b.)

Region	Aridity zone	Light and moderate	Strong and extreme	Total	% Total dryland area
Africa	Dry sub-humid Semi-arid Arid	25.2 69.9 150.2	12.1 39.6 22.3	37.3 109.5 172.5	0.7 2.1 3.3
Asia	Dry sub-humid Semi-arid Arid	70.6 124.2 131.9	7.7 17.2 18.8	78.3 141.4 150.7	1.5 2.7 2.9
Australia	Dry sub-humid Semi-arid Arid	4.2 32.9 48.9	0.6 1.0 0.0	4.8 33.9 48.9	0.1 0.7 0.9
Europe	Dry sub-humid Semi-arid Arid	59.0 30.8 4.8	2.3 2.6 0.0	61.3 33.4 4.8	1.2 0.6 0.1
North America	Dry sub-humid Semi-arid Arid	15.0 50.9 6.3	3.2 2.3 1.6	18.2 53.2 7.9	0.4 1.0 0.2
South America	Dry sub-humid Semi-arid Arid	21.4 43.9 7.5	2.3 4.0 0.0	23.7 47.9 7.5	0.5 0.9 0.1
Total (5,200) Total dryland area (5.2 billion hectares)		897.6 17.3	133.7 2.6	1035.2 19.9	

In the 1992 UN Conference on Environment and Development held in Rio de Janeiro, desertification was formally defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities". The term "drylands" as used in this report includes the arid, semi-arid and dry sub-humid regions of the world, but excludes the hyper-arid regions such as the Atacama and Sahara Deserts, where very low rainfall and very high rates of potential evaporation restrict plant growth to a minimum and preclude other than transient or extremely sparse and localised occupation.

Manifestations of desertification include accelerated soil erosion by wind and water, increasing salinisation of soils and near-surface groundwater supplies, a reduction in soil moisture retention, an increase in surface runoff and streamflow variability, a reduction in species diversity and plant biomass, and a reduction in the overall productivity in dryland ecosystems. Additional impacts include an increase in particulate and trace gas emissions from biomass burning in drylands and an increase in atmospheric dust loads. A combination of climatic stress and dryland degradation can lead in turn to extreme social disruption, migrations and famine.

This paper is a very brief summary of a much longer report on interactions of desertification and climate prepared for WMO and the United Nations Environment Programme (UNEP) (Williams and Balling, 1994). The aim of this report is to evaluate the interactions of desertification and climate. In seeking to understand and quantify the interaction between desertification and climate, the single biggest impediment is the dearth of accurate data on the current extent, status and trends of desertification. There is an urgent need to improve and expand existing efforts to establish accurate baseline data relating to dryland degradation using consistent and uniform methods and criteria.

Despite the variable quality of much of the data relating to the severity and distribution of desertification, sufficient semi-quantitative information now exists to allow us to identify the impact of human actions on the surface characteristics and atmospheric composition of various dryland regions.

These human-induced changes in the dryland areas have a significant influence on the energy balance of both the surface and atmosphere of the earth. For example, any change in surface albedo will affect the amount of solar radiation absorbed by the surface. Similarly, changes in soil moisture levels will determine the portion of energy that is used in evaporation and transpiration processes, which in turn affects the amount of energy used to heat the ground or air. Changes in surface roughness alter near-surface wind speeds and turbulence levels, and thereby influence evapotranspiration rates. Similarly, changes in atmospheric composition directly affect the earth-atmosphere exchanges of shortwave and longwave radiant energy which influences the atmosphere's temperature structure, vertical stability and propensity to precipitate.

Both climate and desertification interact at a variety of scales through a complex and still only partially understood series of feedback loops (**Figure 4.1**) For clarity and simplicity, we first consider how climate influences some of the processes leading to desertification. We then consider how desertification processes may in turn influence local and regional climate, before turning to the much more imponderable question of the role of desertification in global climatic change. We conclude with a few key recommendations.

4.2 IMPACT OF CLIMATE ON DESERTIFICATION

Climate has an important but often subtle influence on desertification processes through its impact on dryland soils and vegetation, on the hydrological cycle in dryland, and, ultimately, on human land use in that 40% of the land area of the globe classified as "drylands" (UNDP 1992 a.b.).

Unlike the organically rich soils of more humid regions, dryland soils often have a low organic matter content and are frequently saline an/or alkaline. As such, they are often highly susceptible to accelerate erosion by wind and water (**Table 4.2**).

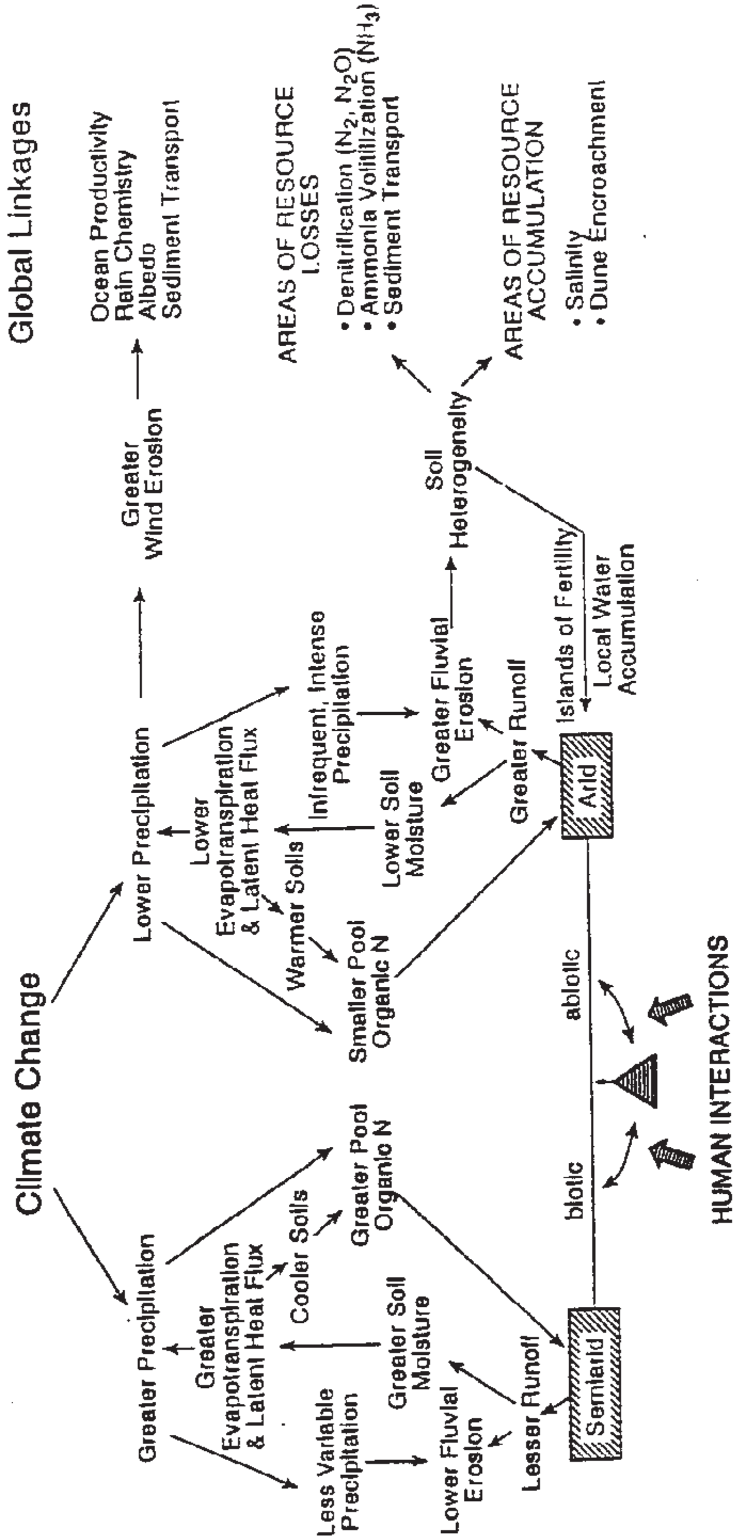


Figure 4.1 - Linkages between global change and human activities during desertification in drylands (Source: Schlesinger *et al.* 1990).

Table 4.2 - Dryland soil groups (FAO, 1991) and desertification status (compiled by M.A.J. William based on the author's field observations in Africa, Asia and Australia).

Parent material	**Soil group**	**Natural erosion status**	**Desertification hazards**
Fresh or weathered Rock	Cambisols Leptosols Regosols	A1 A1 A1	A2, B1 A2 A2
Weathered Rock	Ferrasols	A1, B1	A2
Limestone	Calcisols	A1	A2
Sand Sheets	Arenosols	C1	A1, B1, C3
Alluvium	Fluvisols Luvisols	A1, B1 A1, B1	A2, B1, D3 A2, B2, C2, D3
Clays	Vertisols	A1, B1	B2, D2
Sands over Clays	Planosols	A1, B1	A2, B3, C1, D2
Clays, Silts, Sands	Solonchaks Solonetz	A2, B1, D1 A2, B1	A2. B2, D3 A3, B3, D3

A: sheet erosion, B: gully erosion, C: wind erosion, D: salinisation
1: minor, 2: moderate, 3: severe

This table is an attempt to summarize a plethora of field observations relating to the actual and potential vulnerability of the various dryland soils to water erosion, deflation and salinisation. It does not take into account current management practices and is no more than a qualitative and tentative guide to potential desertification hazards.

With the increasing use of Geographical Information Systems (GIS) and satellite imagery, there is now a better appreciation of seasonal changes in dryland plant cover in response to rainfall variability and biomass burning. Although climate exerts a strong influence over dryland vegetation type, biomass and diversity (Le Houérou and Hoske 1977; Nicholson *et al.* 1990; Tucker *et al.* 1991), this may be moderated by local or regional factors such as soil type, lithology, relief and aspect (Shmida 1985).

Long seen as having an adverse impact on ecosystem functioning and resilience, environmental disturbances is now considered to play an important role in maintaining the diversity and adaptability of many tropical and dryland ecosystems. However, the magnitude and frequency of the disturbance, and the temporal and spatial scale at which it is operating, need to be clearly identified (Delcourt and Delcourt 1992). Much of the confusion over the ability of dryland ecosystems to cope with climate variability and periodic droughts and floods arises from an initial failure to specify the appropriate scale in both time and space at which the ecosystems in question are being considered.

Dryland ecosystems have a variety of strategies for coping with low erratic rainfall, high temperatures, poor and sometimes saline soils, and periodic or seasonal climatic extremes (Crawford 1989). There is a higher degree of resilience in dryland ecosystems to periodic floods and droughts than is sometimes appreciated, and this is true on both plants and animals (Stafford-Smith and Morton 1990). Interannual variations in biomass are a natural response to rainfall variability. These should not be confused with the impact of human-induced desertification processes.

Both field observations and remote sensing data have confirmed very large spatial variations in dryland plant density and biomass, as well as equally important temporal fluctuations in biomass in response to seasonal and interannual fluctuations in rainfall (Tucker *et al.* 1985,1991; Nicholson *et al.* 1990). This variations in time and space of dryland plant cover is well known to pastoralists in these regions, and is one dryland plant response to the limiting factors of water and soil nutrients (Noy-Meir 1973; Westoby 1980; Kassas and Batanouny 1984; Noor 1989; Rao *et al.* 1989; Stafford-Smith and Morton 1990; Lange and Fatched 1990).

A preliminary study by Dregne and Tucker (1988) used satellite NOAA AVHRR satellite imagery to monitor changes in vegetation along the semi-arid margins of the Sahara in relation to variations in annual rainfall. Later work by Tucker *et al.* (1991) confirmed the earlier findings and demonstrated the highly elastic response of vegetation cover to growing-season rainfall, with the desert margin vegetation cover expanding or contracting from year to year depending on the annual variations in rainfall.

Between 1980 and 1990, the southern limit of the 200 mm annual rainfall boundary (arbitrarily taken to define the southern limit of the Sahara) fluctuated considerably (**Figure 4.2**), and showed significant differences between different regions on a longitudinal basis, some areas showing a high degree of variability and others very little. The rainfall boundary was based on average vegetation index values which were inferred from satellite spectral data in the red and near-infrared wavelength bands, that together provide a measure of total primary production when averaged over the growing season.

In 1984, which was the driest year this century in the Sahel, this "Normalised Difference Vegetation Index" (NDVI), which shows a statistically significant linear relation to mean annual rainfall, had the lowest value of the decade, and the Sahel/Sahara boundary was even further south than in previous years. During the dry years 1980 to 1984, the inferred 200 mm isohyet moved 240 km to the south, averaging a 60 km southward shift per year. During the next two years (1984 to 1986) the desert retreated north, 110 km on average from 1984 to 1985, and a further 33 km from 1983 to 1986. The overall conclusion of Tucker *et al.* (1991) was that a study extending over decades would be required to determine whether there was any long-term expansion or contraction of the Sahara.

4.3 IMPACT OF DESERTIFICATION ON CLIMATE

After this brief overview of the ways in which climate may influence desertification hazards through its impact on dryland hydrology, soils and plant cover, we now consider how desertification processes may in turn have an influence on climate.

Human activities are known to have substantial impacts on the surface characteristics and atmospheric composition in dryland regions. These human-induced changes in dryland areas have a significant influence on the energy balance of both the surface and atmosphere. Changes in albedo, surface roughness, soil moisture and particulate load in the atmosphere perturb the background surface-atmospheric energy and moisture exchanges. Following the publication of work by Charney *et al.* (1975), building on more local work by Otterman (1974), atmospheric scientists intensified their efforts to understand the impacts of these changes on local and regional climate conditions. Despite the construction of complex numerical models to investigate the underlying processes that drive the climate response to human activities in dryland and measurements made in numerous field experiments, many fundamental questions remain (**Table 4.3**). In some areas, desertification seems to lead to atmospheric cooling while in other areas, desertification leads to atmospheric warming and increased potential evapotranspiration. Linkages to rainfall changes are even more complex, and the impact of human activities on rainfall amounts remains a topic of considerable debate.

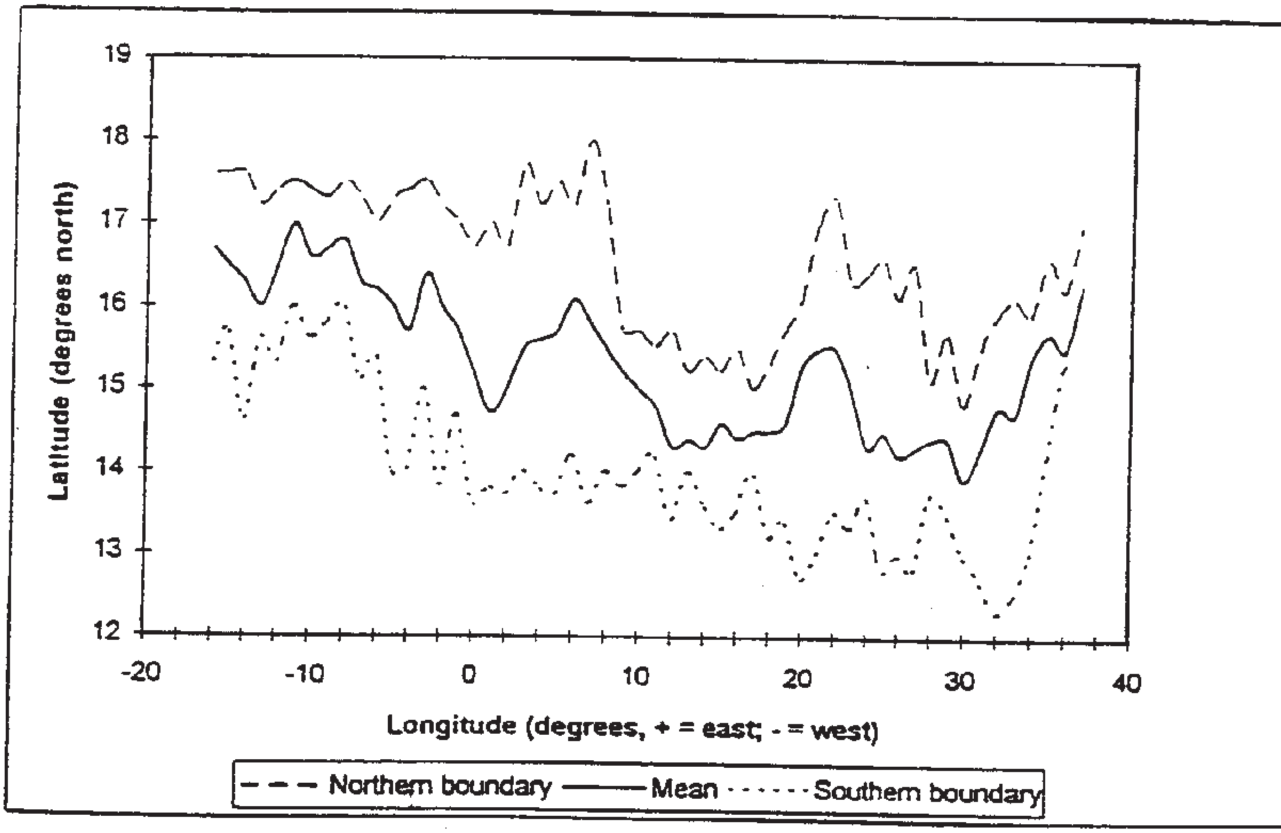


Figure 4.2 - Summary of the mean (middle line), most northern (top line) and most southern (bottom line) portions of the 200 mm/yr boundary location from 1980 to 1990 at every half degree of longitude from °W and 38.5°E. The error is estimated to be ±15 km (±0.14°) (Source: Tucker *et al.* 1991).

Biomass burning is common practice in the tropics and sub-tropics, and dryland fires are significant sources of atmospheric aerosols and tract gas emissions. Savannah burning contributes significantly to global emissions of soot, as well as nitrogen, carbon and ozone. It is difficult to distinguish the net contribution of dryland fires to atmospheric particulate and trace gases. Total smoke emissions from tropical biomass burning are estimated to range between 25 to nearly 80 x 10^{12}g/yr, which is comparable to estimated smoke emissions produced by fossil fuel burning (22.5 to 24 x 10^{12}g/yr). Ozone from global biomass burning furnishes 38% of all tropospheric ozone. During burning, nearly half of all nitrogen in the biomass is released as N_2 causing a major loss of fixed nitrogen in tropical ecosystems amounting to 10 to 20 x 10^{12}g/yr.

While few figures exist for the contribution of emissions from burning of dryland specifically, estimates of carbon and nitrogen emitted from Savannah burning are that this source contributes 30% and 20%, respectively (Crutzen and Andreae,1990). Given that total biomass burning contributes about 40% of gross emissions from all sources (Crutzen and Andreae,1990; Cachier, 1992), the contribution from dryland burning is conservatively estimated to be around 10%.

Arid and semi-arid regions are widely recognised as sources for crustal-derived aerosols (dust) that are transported by the atmosphere. The impact of atmospheric dust on the surface and atmospheric energy balance is complex, and is related to its size distribution, source strength, deposition rate, extinction, scattering, absorption, single scattering albedo, asymmetry factor and optical depth of the dust (Carlson and Benjamin, 1980; d'Almeida, 1989). Warming generally occurs in the dust layer and cooling generally occurs beneath them near the surface (atmospheric heating rates can be 2°C per day while the surface cooling rates can be 10 to 15+C per day). The major change to the surface energy balance is a substantial decrease in incoming shortwave solar radiation in the presence of an absorbing dust layer. An important secondary change is the stabilisation of the atmosphere that occurs when dust differentially warms a layer of the atmosphere at the expense of near-surface cooling.

Table 4.3 - Schematic presentation of the underlying assumptions, testable conclusions and model results in the various biogeophysical feedback models of the Sahel drought proposed by Charney (1975) and Charney *et al.* (1975, 1977).

1	Overgrazing reduces vegetation cover
2	Reduced plant cover increased albedo
3	Increased albedo decreases net radiation
4	Decreased surface net radiation results in surface cooling
5	Surface cooling promotes subsidence of air aloft
6	Subsidence decreases convection and cloud formation
7	Reduced convectional instability leads to less precipitation
8	Additional drying in the Sahel region leads to regional climatic desertification which positively feeds back to 1
9	Atmospheric general circulation models show that an albedo increase from 14% to 35% north of the Intertropical Convergence Zone (ITCZ) results in a southward shift of a few degrees in the ITCZ
10	Rainfall in the Sahel region is thus decreased in the model by 40% during the rainy season

Many investigators have found that the overwhelming effect of desertification on the surface and atmospheric energy balance comes from disruptions to the hydrological cycle. In many cases, removal of vegetation leads to increased runoff and potential evapotranspiration rates due to higher surface and near-surface temperatures, higher near-surface wind speeds and lower near-surface atmospheric moisture levels. The increased in runoff and evapotranspiration rates then leads directly to a decrease in soil moisture and a rapid decrease in amount of energy used to evaporate or transpire water into the atmosphere. When less energy is consumed in the latent heat term, LE, of the energy balance equation, more energy is available for heating the ground, G, or heating the air, H. The Bowen ratio, defined as H/LE, typically increases in areas where desertification is occurring (see Bryant *et al.*, 1990). These changes to the energy balance associated with modifications to the hydrological cycle, in many cases dwarf the effects associated with albedo, surface roughness and dust in the atmosphere. Phillips (1993) summarised this by suggesting that soil moisture levels in drylands are directly related to vegetation cover, precipitation and water erosion, and negatively related to albedo, temperature and aeolian erosion.

Human-induced changes in dryland surface conditions and atmospheric composition can certainly have an impact on local and regional climate conditions in that they directly affect the energy budget of the surface and the atmospheric column. These changes to the energy balance have been simulated in many numerical modelling studies and they have been directly measured in a variety of empirical experiments.

Given the many complexities involved (e.g., hydrological considerations, background climate and surface conditions), perturbations to the energy balance may affect near-surface and surface temperatures in many different ways. Numerical modelling studies and empirical measurements have shown both warming and cooling in areas that have been undergoing desertification. Hydrological considerations are critically important in determining the magnitude and sign of the temperature response.

These somewhat conflicting results point to significant gaps in our understanding of the physical processes involved in climate-desertification interactions, and only limited accuracy can be obtained in translating perturbations in the energy balance of dryland regions directly into local or regional temperature or precipitation consequences at this time. Numerical models are improving each year, but they remain relatively unrealistic on their abilities to simulate the perturbations occurring in drylands and to simulate regional climate in general.

The influence of human activities on surface and near-surface air temperatures in drylands has been clearly identified in a variety of experiments. However, human influence on local and regional precipitation levels has been more difficult to identify. The large variability in dryland precipitation in time and space complicates the search for a clear signal that could be related to surface changes. Circumstantial evidence suggests that increasing vegetation can enhance precipitation in drylands, while decreasing vegetative cover can reduce local precipitation levels.

4.4 DESERTIFICATION AND GLOBAL CLIMATIC CHANGE

First, recent warming has dominated the dryland areas. The western of the USA, American, southern African and Australian dryland regions all show pronounced warming in this century. Warming has also occurred in the eastern portions of the Middle East and western sections of the Asia Desert region described earlier. However, a region of cooling this century is centred in the Asian deserts.

Most drylands show no statistically significant changes in precipitation levels. There is a tendency for wetter conditions both in the southwestern deserts of North America and the western deserts of Australia. However, by far the most pronounced change in precipitation levels in any of the dryland areas is seen in the Sahelian region. Here, precipitation levels have dropped sharply since the mid 1950s and the decrease in precipitation has contributed to enormous human and economic loss in the region (Glantz, 1987; Le Houérou, 1989). Recognising the need to understand the causes of the observed decline in Sahelian rainfall, climatologists have proposed many causal mechanism that may be associated with the downward trend in rainfall. Interrelated changes in sea-surface temperatures (including linkages to El Niño/Southern Oscillation events), land-surface conditions, general atmospheric circulation pattern and atmospheric concentrations of various greenhouse gases have all been proposed to explain at least some of the variance in the observed regional precipitation levels (Ayoade, 1977; Druyan, 1989; Nicholson, 1989; Lam and Peppler, 1991). Nonetheless, models with elevated atmospheric concentrations of various greenhouse gases predict less precipitation in this area, and the observational record is broadly consistent with prediction. However, just as the connection between temperature patterns and greenhouse gas buildup was complicated by many factors, the connection with regional precipitation patterns is equally difficult to establish.

Many factors influence global and regional climates. However, when considering likely climate changes over the next century, many climatologists believe that the climate forcing associated with the buildup of greenhouse gases will become detectable and substantial. Proposed increases in greenhouse gas concentrations are expected to force global temperatures to rise between 1 °C and 5 °C over the next century.

The role of drylands in contributing to buildup of greenhouse gases is difficult to assess, but drylands will probably contribute between 5 to 10% of the overall greenhouse gas buildup. Degradation of drylands contributes a small (probably $<5\%$), but not inconsequential, amount to this greenhouse gas forcing. While these values may seem small at the global scale, they are significant at the regional or national scale. Many dryland countries have relatively small anthropogenic emissions of carbon dioxide. In these cases, their net contribution to the global flux of carbon dioxide could be stabilised by rehabilitating the vegetation of their drylands.

The significance of future global warming for dryland climates is difficult to assess with confidence at the present time. Predictions based on many general circulation model experiments suggest that temperatures will rise in all dryland regions in all seasons. There is some evidence that the warming will be more rapid in the middle to higher latitudes. Predictions of future precipitation changes, including the impact of rainfall variability, vary widely from model to model and region to region, and consequently, the confidence limits on the predictions of precipitation changes in dryland areas are lower than those for temperature.

The predicted increase in temperature would most probably have the effect of increasing potential evapotranspiration rates in the drylands, and in the absence of any large increases in precipitation, many drylands are accordingly predicted to become more arid in the next century.

During the past century, the equivalent carbon dioxide of the global atmosphere has increased by approximately 40%. The observed temperature and aridity trends in many dryland areas are consistent with numerical simulations of climate responses to increasing atmospheric concentrations of greenhouse gases.

4.5 CONCLUSIONS AND RECOMMENDATIONS

In our report we have attempted a preliminary evaluation of the interactions between desertification and climate on a global and regional scale, taking dur account of local factors and influences. In our view, the single biggest impediment to quantifying the interactions between desertification and climate stems from the variable quality of the data relating to the extent, severity and trends of the various forms of dryland degradation collectively contained within the general term desertification. There is a particular and increasingly urgent need for uniform and objective methods of data collection relating to the characteristics and status of dryland ecosystems, soils, water resources, salinity and micro-climates, and for the evaluation and dissemination of such data on an integrated basis.

Although there are some excellent monitoring networks already in existence in different dryland regions, there is a very real need for the strengthening of existing centres and for the establishment of a more extensive international monitoring network with personnel equipped and trained to collect base-line data relevant to all aspects of desertification. This infrastructure would support regional analyses and the consequent detection of any long-trends and their causes.

Notwithstanding the variable and the often poor quality of much of the primary observational data relating to the extent and severity of desertification processes, a range of well-defined human impacts on the surface characteristics and atmospheric composition of various dryland regions can now be clearly identified.

The more visible manifestation of desertification include:

(a) Accelerated soil erosion by wind and water;

(b) Salt accumulation in the surface horizons of dryland soils;

(c) A decline in soil structural stability with an attendant increase in surface crusting and surface runoff and a concomitant reduction in soil infiltration capacity and soil moisture storage;

(d) Replacement of forest or woodland by secondary savannah grassland or scrub;

(e) An increase in the flow variability of dryland rivers and streams;

(f) An increase in the salt content of previously freshwater lakes, wetlands and rivers; and

(g) An overall reduction in species diversity and plant biomass in dryland ecosystems.

Not all of these processes are caused solely by human activities; short-term climatic variability, longer term climatic desiccation, and occasional very severe floods and droughts all play an important role. Furthermore, the diverse processes of dryland degradation are not all active at the same time and in the same place. For that reason, when attempting to quantify the causes and consequences of desertification it is crucial to specify which process is operating, over what area, and over what timespan. As yet, our knowledge of the magnitude and frequency of such ubiquitous processes as wind and water erosion in drylands is still very patchy and, for some regions, is altogether deficient.

Dryland ecosystems are highly responsive to climatic variability. Plant biomass and ecosystem complexity are a function of precipitation, temperature, soil physical and chemical properties and cumulative solar radiation. The sparser the plant cover, the more vulnerable the topsoil to detachment and removal by raindrop impact, surface runoff and wind.

Dryland precipitation is innately variable, as is the consequent dryland runoff. The coefficient of surface runoff or overland flow is often higher in drylands than in more humid regions owing to the tendency of dryland sils to form impermeable surfa ce crusts under the impact of locally intense rainstorms and in the absence of significant surface plant litter and protective vegetation cover. In these circumstances, soil movement may be an order of magnitude greater per unit momentum of falling raindrops than when the soil surface is well vegetated. This effect is particularly evident in the seasonally wet tropical drylands and at onset of the rainy season, and may be aggravated by human disturbance or removal of the protective vegetation cover during the wet season, or by the planting or row crops onto bare soil.

Dryland rivers have extremely variable flow regimes, and both river discharge and sediment yield are highly sensitive to fluctuations in precipitation as well as to any changes in the vegetation cover in their catchment headwaters. Deforestation of the headwaters of dryland rivers can increase sediment load, and may lead to a sometimes dramatic change from a sinuous suspension load river carrying a dominant load of clay and silt to a less stable, more seasonal, much coarser bedload river characterised by a rapidly shifting set of braided channels in its downstream and aggrading reaches.

Relatively slight interannual variations in sea-surface temperature leading to periodic floods and droughts reflected in ENSO events tend to be amplified in dryland rivers. As a result of the innately more variable flow regime of dryland rivers, management practices appropriate in more humid catchments may be inapplicable in the drylands. Attempts to manage dryland rivers as if they were fully comparable to their humid temperature counterparts may have an adverse impact on arid, semi-arid and sub-humid freshwater ecosystems. The aquatic biota in dryland steams and wetlands show a wide range of behavioural and physiological adaptations to the "floods and droughts" flow regime characteristic of dryland drainage systems. Artificial modification of the flow regime may negate the survival value of such adaptations.

Human land use in drylands, whether involving rangeland pastures, rainfed agriculture or irrigation agriculture, reflects a variety of adaptive strategies designed to cope with large temporal and spatial fluctuations in precipitation, soil moisture and plant productivity. Large interannual variations in dryland biomass are an integral effect of dryland climatic variability as exemplified in the West African Sahel.

The resilience of dryland ecosystems to innate climatic variability is becoming better understood, but we still lack an adequate understanding of the thresholds of different ecosystems to regional deficits in soil moisture and to temperature extremes and salinity. We also lack adequate information about the role of disturbance in the maintenance of long-term ecosystem viability, and the environmental thresholds above which dryland ecosystems can no longer retain their ability to cope with external stress. It is for these reasons that desertification is best defined as dryland degradation caused by both climatic variability and human activities. In practice, there will be many instances when the relative role of climate and humans in bringing about desertification remains equivocal, especially in rangelands and the more arid regions of the world. In the cas of salinisation caused by faulty irrigation practices, the role of human activities for outweighs that of climatic variability.

Successful ecological restoration of degraded drylands is already in progress in certain parts of the world, and the lessons learnt from these examples of successful dryland management could be usefully applied elsewhere. Any measures designed to prevent or mitigate dryland degradation mus be both short and long term. The first prerequisite for any successful amelioration project is an accurate diagnosis of the problem, followed by careful identification of the physical and human causes of degradation.

Short-term remedial programmes for dealing with immediate problems such as soil erosion, salinisation or famine are designed to alleviate their more immediate manifestations. Of far greater ultimate value are longer term strategies which aim to attack the root causes underlying dryland degradation. Such long-term strategies must fulfil four main requirements:

(a) Any community action must be suited to the ability of the people directly affected by the degradation to finance and carry out appropriate conservation and restoration programmes, which often presupposes the use of relatively inexpensive, simple and appropriate local technologies;

(b) The nature of the degradation processes concerned must be thoroughly understood, the problems clearly diagnosed, and careful initial assessment made of the most suitable options for prevention and rehabilitation. It is no solution to resolve one degradation problem by crating new problems, such as widespread salinisation caused by irrigated shelter belts designed to stabilise sand movement;

(c) Long-term ecological sustainability must be paramount. Short-term considerations based solely on narrowly defined economic criteria will seldom be useful in treating the ultimate causes of dryland degradation in that they only treat the symptoms;

(d) The maintenance of soil quality is essential. If the soils becomes degraded so too will the dryland ecosystems. The ultimate viability of all dryland human communities depends ultimately on the quality of the soils water resources which sustain the plants and animals upon which they depend.

4.6 REFERENCES

Ayoade, J.O. (1977). Perspective on the recent drought in the Sudano-Sahelian region of West Africa, with particular reference to Nigeria. *Archiv für Meteorologie, Geophysik und Bioclimatologie (Series B)* 25, 67-77.

Bryant, N.A., Johnson, L.F., Brazel, A.J., Balling, R.L., Hutchinson, C.F. and Beck, L.R. (1990). Measuring the effect of overgrazing in the Sonoran Desert. Climatic Change 17, 243-264.

Cachier, H. (1992). Biomass burning sources. In: W.A. Nierenberg (ed). Encyclopedia of Earth Science Systems. San Diego: Academic Press.

Charney, J.G. (1975). Dynamics of deserts and drought in the Sahel. Quarterly Journal of the Royal Meteorological Society 101, 193-202.

Charney, J., Quik, W.L., Chow, S and Kornfield, J. (1977). A comparative study of the effects of albedo change on drought in semi-arid regions. Journal of Atmospheric Sciences 34, 1366-1385.

Charney, J.G., Stone, P.H. and Quirk, W. (1975). Drought in the Sahara: A biogeophysical feedback mechanism. Science 187, 434-435.

Crawford, R.M.M. (1989). Studies in Plant Survival Ecological case histories of plant adaptation to adversity. Oxford: Blackwell Scientific Publications.

Crutzen, P.J. and Andreae, M.O. (1990). Biomass burning in the tropics: impact on Atmospheric chemistry and biogeochemical cycles. Science 250, 1669-1677.

d'Almeida, G.A. (1987). On the variability of desert aerosol radiative characteristics. Journal of Geophysical Research 93, 3017-3026.

d'Almeida, G.A. (1989). Desert aerosol: Characteristics and effects on climate. In: M. Leinen and M.Sarnthein (eds), Paleoclimatology and Paleometeorology: Modern and Past Patterns of Global Atmospheric Transport. Dordrecht. Holland: Kluver Academic Publishers, 311-338.

Delcourt, P.A. and Delcourt, H.R. (1992). Ecotone dynamics in space and time. In: A.J. Hansen and F. di Castri (eds), Landscape Boundaries; consequences for Biotic Diversity and Ecological Flows. Ecological Studies 92, New York: Springer Verlag, 19-54.

Dregne, H.E. and Tucker, C.J. (1988). Desert encroachment. Desertification Control Bulletin 16, 16-19.

Druyan, L.M. (1989). Advances in the study of sub-Saharan drought. International Journal of Climatology 9, 77-90.

FAO (1991). World Soil Resources: An Explanatory Note on the FAO World Soil Resources Map at 1: 25 000 000 scale. World Soil Resources Reports 66. Rome: FAO.

Fournier, F. (1960). Climat et Erosion: la Relation entre l'érosion du Sol par l'eau et les Précipitations Atmosphériques. Presses Universitaires de France.

Glantz, M.H. (ed) (1987). Drought and Hunger in Africa: Denying Famine a Future. Cambridge, Cambridge University Press.

Hulme, M. and Kelly, M. (1993). Exploring the links between desertification and climate change. Environment 35(6), 4-11 and 39-45.

Kassas, M. and Batanouny, K.H. (1984). Plant ecology. In: J.L. Cloudsley-Thompson (ed), Sahara Desert. Oxford: Pergamot, 77-90.

Lamb, P.J. and Peppler, R.A. (1991). West Africa. In: M. Glantz, R.W. Katz and N. Nicholls (eds), Teleconnections Linking Worldwide Climate Anomalies. Cambridge: Cambridge University Press, 121-189.

Lange, R.T. and Fatchen, T.J. (1990). Vegetation. In: M.J. Tyler, C.R. Twidale, M. Davies and C.B. Walls (eds), Natural History of the North East Deserts, Adelaide: Royal Society of South Australia, 133-147.

Le Houérou, H.N. (1989). The Grazing Land Ecosystems of the African Sahel. Berlin, Springer-Verlag.

Le Houérou, H.N. and Hoske, C.H. (1977). Rangeland production and annual rainfall relations in the Mediterranean Basin and the African Sahelo-Sudanian zone. Journal of Range Management 30(3), 181-189.

Middleton, N.J. (1985). Effect of drought on dust production in the Sahel. Nature 316, 431-434.

Nicholson, S.E. (1989). Long-term changes in African rainfall. Weather 44, 46-56.

Nicholson, S.E., Davenport, M.L. and Malo, A.R. (1990). A Comparison of the vegetation response to rainfall in the Sahel and East Africa, using Normalized Difference Vegetation Index from NOAA AVHRR. Climatic Change 17, 209-241.

Noor, M. (1989). Rangeland Management in Pakistan. International Centre for Integrated Mountain Development. ICIMOD Senior Fellowship Series No. 1. Kathmandu, Nepal, ICIMOD, 193 pp.

Noy-Meir, I. (1973). Desert ecosystems: environment and producers. Annual Review of Ecology and Systematics 4, 25-51.

Otterman, J. (1974). Barin high-albedo soils by overgrazing: A hypothesized desertification mechanism. Science 186. 531-533.

Phillips, J.D. (199). Biophysical feedbacks and the risks of desertification. Annals of the Association of American Geographers 83, 630-640.

Rao, A.-u.-R., Arshad, M. and Shafiq, M. (1990) Perennial Grass Germplasm of Cholistan Desert and its Phytosociology. Bahawalpur, Cholistan Institute of Desert Studies, Islamia University, 85 pp.

Stafford-Smith, D.M. and Morton, S.R. (1990). A framework for the ecology of arid Australia. Journal of Arid Environments 18, 255-278.

Tucker, C.J., Dregne, H.E. and Newcomb, W.W. (1991). Expansion and contraction of the Sahara Desert from 1980 to 1990. Science 253, 299-301.

Tucker, C.J.,. Townshend, J.R.G. and Goff, T.E. (1985). African land-cover classification using satellite data. Science 227, 369-375.

UNCED (1992). Earth Summit Agenda 21: Programme of Action for sustainable development. New York; United Nations Department of Public Information.

UNEP (1992a). Status of desertification and implementation of the United Nations Plan of Action to Combat Desertification. Report of the Executive Director. Nairobi: United Nations Environment Programme.

UNEP (1992b). World Atlas of Desertification. Editorial commentary by N. Middleton and D.S.G. Thomas, London: Edward Arnold.

Westtoby, M. (1980). Elements of a theory of vegetation dynamics in arid rangelands. Israel Journal of Botany 28, 169-194.

Whetton, P., Adamson, D. and William, M.A.J. (1990). Rainfall and river flow variability in Africa, Australia and East Asia linked to El Niño-Southern Oscillation events. In: P. Bishop (ed), Lessons for Human Survival: Nature's Record from the Quaternary. Geological Society of Australia Symposium Proceedings, 1, Sydney: Geological Society of Australia, 71-82.

Williams, Martin. A.J. and Balling Robert C.Jr. (1994). Interactions of Desertification and Climate. WMO/UNEP. Geneva and Nairobi.

CHAPTER 5

AGROMETEOROLOGICAL INFORMATION FOR LOCUST CONTROL
by D.E. Pedgley

5.1 SUMMARY

The dependence on weather for breeding, development and movement of ten representative locust species is summarised in paragraph 5.3.

The potential of meteorology for improving the monitoring, forecasting and control of locust populations is outlined in paragraph 5.4.

The operational preparation and use of agrometeorological information for locust control is discussed in paragraph 5.5.

Recommendations to improve the application of meteorology for locust control are made in paragraph 5.6. These are based largely on improved cooperation between meteorological and locust control services, and the provision of information that is, or can be, produced routinely and therefore requires little or no additional resources.

5.2 INTRODUCTION

Locusts are various kinds of grasshoppers having the ability to change their behaviour from scattered individuals to dense, cohesive swarms that can travel hundreds or thousands of kilometres. Sudden arrival of swarms in crops can threaten severe damage and loss of yield. Because their formation and movement are greatly affected by the weather, the occurrence of swarms constitute and extreme agrometeorological event.

Swarms result from crowding but their method of cohesion is not understood. Frequent contact between individuals can lead rapidly to gregarious behaviour - usually at an early stage in the life cycle, before wings develop. Crowding results from breeding, from shrinking of the habitat, or both. Breading needs to be widespread, over thousands of square kilometres, if many swarms are to form, for swarm densities are typically tens of millions of locusts in a square kilometre.

Many species of grasshoppers sometimes produce swarms. Those that do so most frequently and over large areas are the greatest threat to agriculture. The following have been selected to illustrate:

(a) Their wide geographical occurrence;

(b) Differences of behaviour between species;

(c) Variations in weather influences on behaviour.

The Desert Locust (*shistocerca gregaria*) is perhaps the most widely known. Swarms of this species have repeatedly invaded some 60 countries in northern, western and eastern Africa and in southwestern Asia. Several other species affect parts of Africa, notably the Migratory Locust (*Locusta migratoria*), the Red Locusts (*Nomadacris septemfasciata*) and the Brown Locust (*Locustana pardalina*). The Migratory Locust also occurs in MadagascarEurope and Asia, and in Australia, where the Australian Plague Locust (*Chortoicetes terminifera*) is a major pest. A relative of the Desert Locust, the South American Locust (*Schistocerca cancellata*) can invade six countries in that continent. There are other species with more restricted distributions or that rarely give species with more restricted distributions or that rarely give rise to swarms, e.g., the Moroccan Locust

(*Dochiostaurus maroccanus*), the Bombay Locust (*Nomadacris succincta*), the Sahelian Tree Locust (*Anacridium melanorhodon*) and the Senegalese Grasshopper (*Oedaleus senegalensis*).

Swarm incidence varies greatly from year to year. When there are many swarms of a given species, perhaps in many countries, there is a **plague**, but when there are few or no swarms there is a **recession**. Plagues take several generations to develop but then may last from one to many years; they are separated by recessions lasting from years to decades. During a recession, locusts are still present but they are far fewer and widely scatted, doing little or no harm. Individual locusts then behave like the many species of non-swarming grasshoppers to be found in crops and grassland. However, locusts in large numbers, even in the absence of swarms, can still cause considerable damage to crops and grazing. During a plague, swarms spread widely, invading areas of major agricultural production within, but more particularly around, the areas of origin.

Locusts live mostly in arid or semi-arid areas; they have adapted to the erratic seasonal rains typical of such areas to produce the vegetation on which they need to feed and shelter for survival. Their rate of development increases at higher temperatures, and swarms in flight are carried downwind in all but light winds. This profound dependence on the weather for breeding, development and movement has been well studied for a few locust species. Our understanding is summarised in the next paragraph for the ten above-mentioned species; more detail can be found in the publications listed in the references. The potential of meteorology as a contribution to controlling locust populations, based on this understanding, was discussed in depth at a workshop held in Tunis in 1988, prompted by invasion of northwest Africa by Desert Locust swarms in the previous year. This potential is outlined in paragraph 5.4, followed in paragraph 5.5 by a discussion of the operational preparation and use of meteorological information. From the results, some recommendations are made in paragaph 5.6 to improve the application of meteorology to locust control.

5.3 WEATHER AND LOCUSTS

Weather effects on the breeding, development and movement of the Desert Locust have been studied for decades and the results have long been applied to forecasting and control of the species in many countries. These effects are described first, followed by the other species mentioned.

5.3.1 Desert Locust (*Schistocerca gregagria*)

Females lay clusters (pods) of about 100 eggs in moist soil at depths between about 5 to 15 cm. Moisture at these depths is essential for full development of eggs, otherwise they desiccate; moisture in the top 5 cm does not affect development. About 25-30 mm of rain, or the equivalent in run-off, is usually sufficient for full egg development. Heavier falls may be needed if soil is to remain sufficiently moist for egg laying up to several weeks later. However, too much rain can kill locust eggs by exposing them on the soil surface, by washing them out of the ground, or by causing them to rot.

Flying locusts that reach an area of moist soil will usually mature sexually in about one week and egg laying starts soon after. Widespread rain leads to widespread synchronous egg laying and subsequent hatching. Because rains are seasonal in the Desert Locust invasion area, so breeding is seasonal. In the north (from northern Africa to the Middle East), breeding takes place on the winter and spring rains accompanying eastward-moving atmospheric disturbances of temperature latitudes. In the south (from western to eastern Africa) it is on the summer (monsoon) rains associated with westward-moving disturbances. In the east, over parts of the Indian sub-continent, breeding can occur in both seasons, and the same is true around the southern Red Sea, which has the most complex seasonal rainfall and breeding in all the invasion area.

Swarms can form widely within the recession area if rains are adequate. There are no restricted outbreak areas but plagues start more often in the borders of highlands where there can be substantial run-off in many outward-radiating valleys (the central Sahara and around the southern Red Sea, Gulf of Aden and Gulf of Oman). A succession of seasonal rains, falling in different regions but linked by flight of successive generations of locusts, can lead to a plague. Breaks in the succession can weaken or end a plague upsurge. Swarms reaching the outer parts of the invasion area, where rains are more reliable, may breed successfully and produce more swarms. In this sense a plague is self-perpetuating.

Temperature affects locusts development rate and locust flight. Duration of egg development (from laying to hatching) decreases at higher temperatures (of soil at egg depth, but his is will related to air temperature at screen level). It varies from about 11 days at mean air temperature 30-35°C to about 45 days at 25°C. Winter temperatures may be low enough to inhibit development. Immature stages (hoppers) develop in 30-40 days, again faster at higher temperatures, and flight becomes possible in a further 10 days. A rainy season is usually long enough for one generation, sometimes two, but rarely three.

Swarms usually start flying during the morning and settle towards sunset. The night is spent roosting, usually on vegetation, although flight can continue in very hot weather. In cloudy weather, the threshold temperature for take-off is about 20°C, but about 25°C if flight is to be sustained. Locusts bask in the morning sun to raise their body temperature; hence take-off and flight in sunshine can occur with air temperatures as low as 15°C.

Winds affect locust take-off and flight across country. Mean speeds greater than about 5 m/s (about 15 km/h) inhibit take-off, which ten occurs in the lulls between gusts. Because the flight speed of an individual, about 3 m/s, is often less than the wind speed, flying locusts are usually taken downwind. Because swarms often roll across country, with part settled at any one time, their speeds are never greater than, and usually only a small fraction of, the mean wind speed in the layer from the ground to swarm top. During sunny weather, when swarms tend to be cumuliform owing to atmospheric convection, tops reach one or two kilometres above the ground, but seldom higher because the air there is too cool for flight. Towards sunset, or in cloudy weather, swarms tend to be stratiform and close to the ground.

Daily flight durations are often 5-10 hours in warm weather, leading to daily displacements of 100-200 kilometres in a week occur. Downwind displacements of several thousand kilometres between seasonal breeding areas are common - e.g., Sudan to Morocco, or India to Yemen. In the presence of moving atmospheric disturbances, however, displacement trajectories are more complex. They can be markedly different from that expected from the average wind flow for the time of year; and loops can result in zero displacement after several days flying. In the cooler months, northward movements are particularly extensive on spells of warm southerly winds ahead of eastward-moving disturbances.

Where wind direction has a regular diurnal variation, as near coasts and mountains, trajectories can be saw-toothed. Sea breezes usually prevent day-flying swarms from moving out to sea, but strong off-shore winds can take swarms to distant islands (e.g. Cape Verde Islands and Canary Islands), although many individuals may drown on the way. Persistently convergent winds bring swarms closer together and may lead to merging, but such winds do not seem able to form swarms out of scattered populations - density changes are too great. Spreading downdraughts from rainstorms can temporarily trap moving swarms; moreover, swarms do not always move when winds and temperatures allow - hence there may be other, as yet unknown, environmental controls.

Solitary (non-gregarious) locusts fly at night, but flight duration, and therefore displacement distances, are poorly understood. Surface winds at night can be light and unrepresentative of winds at flying heights. If there is a night-time wind acceleration near the top of the temperature inversion (a so-called low-level jet) then downwind displacement may be several hundred kilometres in a night, leading to surprise infestations in areas previously clear.

In any one year, only part of a seasonal breeding area becomes infested because not all winds may be favourable for bringing locusts there from their sources; moreover, subsequent rains may be inadequate. The sequence of events during build-up has been different in each of the few plagues that have ben examined in detail. Plague decline occurs naturally through failure of rains or windborne movement out to sea, but there are probably other reasons, as yet unstudied, e.g., predation, parasitism, and reduced fecundity after many gregarious generations. Whether control has been more than just a contributory factor in Desert Locust plague decline is still matter of debate.

5.3.2 Migratory Locust (*Locusta migratoria*)

This species occurs widely over the plains of Africa, Europe, central and souther Asia, and Australia, but plagues have originated from limited and well-defined areas of flood plains, the deltas of some major rivers and some areas of impeded inland drainage. The last plague in Africa (1928-41) started in the flood plains of the central Niger River, in Mali, subsequently spreading all over sub-saharian countries.

Seasonal rains generally allow two generations, but more often only one near the cool northern limits of its range, where the winter is spent as dormant eggs in the soil. The retreating floods of the central Niger River provide a large habitat for two further generations during the dry season. It is this particular geographical occurrence of out-of-phase seasonality of rains and flooding that probably determines the source of African plagues. In other parts of the distribution area, drought years lead to crowding on the flood plains as water levels fall, and hence an association with swarm formation and even plague initiation.

Locust movements within the flood plains are not always related to winds, perhaps because solitary (non-gregarious) locusts fly at night and they may avoid spells of strong winds. During plagues, however, judged by studies of the last plague in West Africa, swarms fly by day and are taken downwind in the same way as the Desert Locust, travelling over 100 kilometres in a day. As a result, movements are generally northeastwards during the monsoon and southwestwards during the harmattan (trade wind) season, leading to an ever-wider distribution. The greater latitudinal range of movement than around the flood plain sometimes allows three generations in a rainy season. In Australia, swarms have appeared in Queensland following scrub clearance. Similarly in Philippines, plagues have started in Mindanao where grasslands have followed forest clearance. Swarms from there have spread across the archipelago, even crossing the sea to reach Taiwan.

Considerable reduction of flood plain habitats, resulting from agricultural development, has greatly reduced the risk of plagues in some outbreak areas, e.g., the central Niger River and the Yellow River flood plain of eastern China.

5.3.3 Red Locust (*Nomadacris septemfasciata*)

This species is confined to Africa. As with the Migratory Locust, swarms develop in flood plain grasslands with impeded drainage. Plagues originate only from limited outbreak areas in eastern Africa. During the last plague (1930-44), swarms spread from there to reach most countries south of the Sahara.

Development is slower than in the previous two species, so there is only one generation a year. Adults remain sexually immature during the dry season, followed by a long maturation period with onset of the next rainy season. Egg laying and hatching are therefore not synchronised. Swarms fly by day but near the ground. They are taken downwind, but flight duration seems to be only a few hours so daily movements are only a few tens of kilometres. This flight behaviour, contrasting with the two previous species, may be related to an apparently higher flight threshold temperature.

Attempts to control the Red Locust by reducing the size of its flood plan habitats in eastern Africa have been unsuccessful.

5.3.4 Brown Locust (*Locustana pardalina*)

This species is confined to southern Africa. As with the Desert Locust, there are no outbreak areas but, unlike that species, its eggs are drought resistant, and indeed some eggs laid by solitary Brown Locusts remain dormant for up to a year or more. In this way it takes advantage of the erratic rains of the Karroo, in southwestern Africa, where it thrives. However, adequate rains can lead to as many as three generations in a season. When swarms form they are day-flying, travelling downwind over 100 kilometres in a day, and spreading as far as 16°N. Because of control measures, swarms are now rarely encountered, although large and damaging non-swarming populations still occur.

5.3.5 Moroccan Locust (*Dochiostaurus maroccanus*)

This species occurs widely in the semi-arid areas of the Mediterranean basin, and eastwards to Afghanistan. There is one generation a year, developing on the abundant vegetation following winter and spring rains, and the new generation appears in early summer. Swarms fly by day but movements are local and long-distance flights are rare. Drought-resistant eggs are laid during the summer and lie dormant until hatching in the following spring. Its economic importance as a pest has declined because expansion of agriculture has generally reduced the availability of egg-laying sites.

5.3.6 Bombay Locust (*Nomadacris succincta*)

This is a species of southern and southeastern Asia. Sometimes it occurs in large numbers, particularly in areas of forest cleared for cultivation, but it has been seen to swarm only in India, and even there not since 1927. Like the Moroccan Locust, it has one generation a year, but overwintering is in the immature adult stage, with egg laying at the beginning of the rains.

5.3.7 Australian Plague Locust (*Chortoicetes terminifera*)

This species is confined to Australia. Outbreak areas occur in the semi-arid interiors of Queensland, New South Wales and Western Australia. Widespread spring rains there cause overwintering eggs to hatch. Plagues develop rapidly (in 2-3 generations) and frequently (almost every other year, on average) but they are short-lived.

Swarms fly by day in light winds and near the ground; with flight speeds similar to the Desert Locust, such winds lead to small daily movements (10-20 kilometres) in comparison with other species. Long-distance movements, in contrast, take place at night, when non-swarming populations fly at heights up to a kilometre above the ground. Those moving on spells of warm north winds ahead of eastward-moving disturbances can travel several hundred kilometres in a night and rapidly reach the crop-growing areas of the southeast, where they may reach swarms and nature quickly on the rains accompanying the disturbances. Sometimes they cross the sea to Tasmania. Movements westward are also possible but they have been poorly recorded.

5.3.8 South American Locust (*Schistocerca cancellata*)

This species is confined to South America east of the Andes between about 17°S and 43°S. Like the Desert Locust, it requires moist soil for egg laying. Because there is a single, but long, season of erratic rains over most of the invasion area, breeding is seasonal, with usually two generations in a year. Winter, the dry season, is passed as sexually immature adults. Plague outbreak areas are in the drier, western part of the invasion area, but breeding can occur anywhere over vast plains as well as in the inter-montane basins of the west.

Swarms fly by day, when air temperatures exceed 20°C, but less in sunny weather. In hot weather, swarms are cumuliform and tops can extend to more than one kilometre above the ground. In all but light winds, swarms are taken downwind. During the winter, low temperatures greatly restrict movement, but in spring longer flights become more frequent, particularly in spells of warm north winds ahead of eastward-moving disturbances. Maturation can be delayed for many months but egg laying starts where locusts meet soils wetted by early rains. Locusts of the new generation spread widely and breed again. By the time the second generation is flying wind directions are less variable. A semi-permanent summertime heat low is present them, centred over northwestern Argentina, and swarms tend to be taken towards it, not only from Argentina but also from any neighbouring countries that may have been invaded, but some may not reach there before lower temperatures again restrict flight. Although there is a considerable redistribution of locusts during the year, there is a region of northwestern Argentina where the species is always present.

Plagues have been frequent in the past but control of swarms in recent years has prevented their development.

5.3.9 Sahelian Tree Locust (*Anacridium melanorhodon*)

This species is confined to the open woodland of the Sahel, as well as eastern Africa and the Arabian peninsula. As with the Bombay Locust, there is one generation a year, with the dry season being passed in the immature adult stage. Eggs are laid in moist soil at the beginning of the rains. Hoppers and adults feed on trees, and at night. Swarms fly by night, but little is known about distances flown although individuals have been caught more than 100 kilometres out to sea.

5.3.10 Senegalese Grasshopper (*Oedaleus senegalensis*)

This species, which can occur over an area as vast as that of the Desert Locust, seldom produces swarms, but severe damage is threatened in years when large numbers appear. It has been studied extensively in West Africa, where three generations develop on the monsoon rains, each in a different latitude zone between 10°N and 18°N, and each taking about two months. The first generation appears in the south following early rains. It develops from eggs that have lain dormant in the soil during the dry season. Resulting adults are taken at night on the southwest monsoon winds and breed further north. The resulting second generation is also taken downwind, to breed in the northern parts of the invasion area. When the third generation is ready to fly winds have reversed to the northeast harmattan (trade wind) and the habitat is drying out. Adults are therefore taken south (sometimes out to sea) and females are triggered by shortened day length to lay eggs that stay dormant through the dry season, some of them up to several seasons.

5.4 METEOROLOGY FOR LOCUST CONTROL

The aim of locust control is to prevent the appearance of numbers large enough to cause serious damage to crops and grazing. Preventing a plague, or at least reducing the size of a plague that has started, is particularly important because of the huge numbers involved and their great mobility. Although the effects of weather on locusts vary somewhat between species, as the previous paragaph has shown, the main effects are clear. **Rainfall** largely determines the extent and intensity of breeding. **Temperature** affects the rate of development of all stages in the life cycle - eggs, hoppers and adults - as well as the duration of flight. **Wind** affects the direction and speed of locust flight and the tactics of spray application from an aircraft or a ground vehicle.

It follows that locust control services can plan monitoring, forecasting and control more effectively by making use of meteorological information for estimating:

(a) Where breeding is likely to occur;

(b) When the next generation is likely to be flying;

(c) Where and when that generation is likely to reach areas at risk of invasion;

(d) Effects of weather on logistics of control - the moving of staff and materials as well as the application of insecticide sprays against hoppers and swarms, both on the ground and from the air.

The following meteorological information can be used for making these estimates.

5.4.1 Rainfall

Daily and weekly (or 10-daily) totals from gauges within areas where locusts are known or are likely to be present. If these areas are unknown, gauges from the whole locust are within the nation may be needed. Daily totals are more valuable than weekly ones because they increase the precision of estimates of timing of breeding. Records are needed promptly because the locust life cycle can be as short as to months. Evenso, late reports are still valuable for subsequent reassessment of events. So, too, are monthly totals, which may not be available from some gauges until breeding has finished.

Satellite-derived estimates of rainfall (usually 10-daily). Although their reliability varies geographically, they are valuable because from the gauge network. In areas of few or no gauges, they may be the only source of quantitative information.

Warnings of the occurrence of widespread heavy rains and run-off that might contribute to a plague upsurge. Such rains are often associated with readily recognisable synoptic weather systems, on either surface or upper charts. The warnings may add considerable to field reports from the control service's own staff. (Areas and quantities that are critical can be agreed in advance with locust control services).

Warnings of the occurrence of a sequence of widespread and heavy rains spaced about one generation apart. They can be particularly useful is assessing the likely number of generations in a rainy season, and hence the rapidity of plague development.

Warning of continuing poor rains in drought years. They can help in the assessment of risk of a plague developing in those species that breed on contracting flood plains.

Forecasts of widespread and heavy rain likely in the coming few days. They can provide valuable preparation time for control teams in the field.

5.4.2 Temperature

Daily mean temperature, for calculating development rate and the date when flight of the new generation is likely. Soil temperature at egg depth is preferable for egg development calculations, but an alternative is screen-level temperature, where its relationship with development (both eggs and hoppers) is known. Again, prompt delivery is essential if the calculations are to be made in time for the results to be useful. But late reports can be used in any subsequent reassessment of events.

Daily maximum temperature, for calculating flight duration of swarms.

Daily temperature at sunset (or the nearest synoptic hour), for estimating the possibility of take-off by non-swarming locusts before long-distance night flights.

Warnings of the occurrence of spells of temperatures markedly different from the seasonal mean - they may indicate an increase or decrease of either development rate or flight duration.

Warnings of the occurrence of temperature persistently too low for development - they are useful for estimating prolonged development, particularly by overwintering eggs or adults, with implications, for example, in timing the deployment of control teams in the field.

5.4.3 Wind

Daily maps of the windfield, for estimating the direction and (in combination with estimates of flight duration) distance of daily swarm movements. A representative time would be the nearest synoptic hour to 1200 or 1500 local time. The surface map would be suitable on most occasions, but the 850 mb map would be needed when high daytime temperatures encourage flight within a deep layer of the lower atmosphere, or when swarms are in mountainous country (where the 700 mb map may be more appropriate).

Daily maps of the windfield at 500 m above the ground at night for estimating direction and distance of night fight. A representative time would be the balloon-sounding time nearest to midnight. In its absence, daily maps of the windfield at sunset would be a substitute, particularly if some guidance can be given on the likely diurnal variation up to dawn at flying heights. A less reliable substitute would be a daytime map.

Warnings of the occurrence of persistent and strong coastal winds blowing from land to sea - they may carry large numbers of locusts to islands or to mass drowning.

Warnings of the occurrence of spells of winds markedly different in direction and/or temperature from the seasonal mean - they may indicate the occurrence of unusual or unprecedented locust movements to areas not usually at risk or at risk earlier than normal.

Forecasts of disturbances accompanied by such winds, particularly spells of warm poleward-blowing low-level jets (south in the northern hemisphere, north in the southern hemisphere) ahead of cold fronts, known for their associated long-distance and rapid movement of swarms by day and of non-swarming locusts at night.

Forecasts of winds for spraying. The aim of **air-to-air** spaying of a flying swarm is to release a cloud of droplets just unwind. Because the swarm moves slower than the wind, the cloud passes through it, from rear to front. Early and late in the dat are the best times, when swarms are densest. The aim of **air-to-ground** spraying (ob both adults and hoppers) is to place the minimum necessary insecticide on the vegetation and locusts, not on the ground where it would be wasted. Spray is applied across wind but avoiding turbulence, so again early and late in the day are usually the best times. **Ground-to-ground** spraying for hopper control is in the form of strips on the vegetation laid across wind, again avoiding turbulence.

This list includes advice (warnings and forecasts) as well as data. Most, if not all, should be available routinely within national meteorological services or through international exchange, not just from agrometeorological sections but also from aeronautical sections. Hence, additional resources are not needed to provide this information to locust control services. Indeed, a locust control service is an example of a user of meteorological information whose requirements can be met largely with standard products. The type, amount and frequency of information can be agreed in advance between the two services. How far such information is currently provided is assessed in paragraph 5.5, based on replies to a questionnaire.

5.5 CURRENT USE OF METEOROLOGICAL INFORMATION FOR LOCUST CONTROL

In an attempt to survey the current use of agrometeorological information in countries at risk of locust infestations, a questionnaire was sent to 119 Members of the WMO Commission for Agricultural Meteorology. These Members were selected on the grounds that there had been infestations of locusts at some time in the past. Of the 27 replies, 13 stated that either there were no locusts and therefore no meteorological input to control, or outbreaks were so rare as not to warrant any input. In one country a forecasting service is currently being built up. An analysis of the remaining 14 replies follows. Further valuable accounts of the operational provision of information by 8 Members has already been published by WMO - CAgM Reports 36 (1991) and 53 (1992).

5.5.1 Reports and guidance material used in the preparation of agrometeorological information for locust control

Nine Members use locust situation bulletins prepared nationally, regionally or internationally (FAO), but five not use such bulletins. There was no mention of any guidance obtained from publications describing either the effects of weather on locusts or the use of meteorological information in locust control.

5.5.2 Information provided by locust control

All 14 Members provided information, usually at 10-day, 15-day or monthly intervals, or when requested. In one of them, synoptic reports and charts, and satellite imagery were provided 3-hourly. Members providing information were:

climatological normal	13
current synoptic reports	11
climatological charts	9
synoptic charts	9
forecast charts	9
satellite imagery	8

5.5.3 Organizations receiving information

The principal recipients were:

national plant (crop) protection (production) departments (services/divisions/organizations)	12
regional locust control organizations	4
other regional organizations	3
FAO	2

Information was sent mostly by fax (6) or mail (6), and rarely by messenger (2), radio (1), telephone (1), telegram (1), or e-mail (1). It was used to assist in monitoring, forecasting and controlling locusts, usually more than one species in a given country.

5.5.4 Arrangements for the preparation of information

Several members listed particular arrangements that had been made for the preparation of information. They included:

(a) Reception by fax of forecast winds and trajectories from global numerical models;

(b) Reception by PC-based station of satellite images;

(c) Comparison of 10-day rainfalls with normal and dry years;

(d) Temporary installations of observing stations in areas of swarm movement.

5.5.5 Training in the use of information

Six Members provided training of locust control staff in the use of agrometeorological information, but 8 did not. Of the 6 members, 5 provided lecturers from the meteorological services who spoke about the use of regular bulletins or of satellite imagery. One relied on seminars or workshops organized internationally.

5.5.6 Operational use of information

Members were asked to provide examples; 10 out of the 15 did so. They included:

(a) Climatological charts for specific months;

(b) Location of breeding areas in specific months;

(c) Modelling of locust phenology;

(d) Advice on specific invasions.

Concerning the value of the information provided, 4 said or implied that operational locust control would be impossible in the absence of the information. Others did not state the value, although 1 admitted to being "not sure". It is for users to judge the value.

Seven Members responded to a request for recommendations to improve the information provided. They included:

(a) Greater coverage of observing stations, including automatic stations;

(b) More frequent interactions between meteorological and locust control services, through training;

(c) Use of expert systems;

(d) Improved electronic access to data;

(e) Improved weather forecasts;

(f) Improved interpretation of satellite imagery.

These recommendations were made despite only 1 Member reporting difficulties encountered when arranging the preparation of information.

5.5.7 Research in locust monitoring, forecasting and control

Of the 14 Members replying, only 6 reported any research projects. They included:

(a) Case studies of breeding and swarm movement;

(b) Improvement of locust development models.

Three Members did not specify projects.

5.5.8 Other information of use for locust control

In response to a request for additional information, 8 Members responded. Their comments included:

(a) Publications giving results of studies by other Members or by WMO and FAO were needed;

(b) Data bases of locust outbreaks and corresponding meteorological situations would be valuable;

(c) Better understanding of drought is needed;

(d) Better satellite monitoring of breeding areas is needed.

5.5.9 Users views on the information provided

In an attempt assess the value users place on the agrometeorological information provided to them, users in the 14 Member countries responding to the questionnaire were asked for their views on that value and on any recommendations for improvements. Of the 14, 6 replied. They agreed that the information was essential to the planning and execution of locust field monitoring, forecasting and control, but various deficiencies were recognised and the following improvements suggested (not in any order of priority):

(a) Closer working relations between national meteorological services and locust control services;

(b) Provision of information in user's language;

(c) Provision of additional meteorological observing stations in remote locust breeding areas to complement the existing network, which is based mainly on urban centres;

(d) Better distribution of existing satellite-derived products (including Early Warning bulletins) from neighbouring countries and regional agencies;

(e) Provision of PC-based satellite receivers for high-resolution cloud and vegetation maps;

(f) Assistance in the preparation of high-resolution rainfall maps;

(g) Improvement of existing trajectory models.

5.5.10 Discussion of current use of meteorological information for locust control

Some Members have been providing information to locust control services for a decade or more. They have evolved collaborative and effective systems to reduce the threat resulting from swarm invasion. Accounts of these systems are given in CAgM Report No. 36. But replies to the questionnaire revealed deficiencies elsewhere. Five of the 14 Members replying did not use locust situation bulletins in the preparation of agrometeorological information for locust control. Although they provided some routine agrometeorological products, the implication hee is that there is some lack of appreciation of the types of information needed. This implication is supported by:

(a) The almost complete absence of use of publications as guidance to the information needed;

(b) The few comments made on the value of the information to users.

Climatological normals and charts are widely provided. They are certainly useful for understanding the long-term seasonal dynamics of locust populations and for long-term planning of deployment of funds, staff, equipment and other resources. However, as made clear in paragraph 5.4, 3 **daily** synoptic data and charts, supplemented by satellite imagery and forecast charts, are essential for understanding the day-to-day developments of locusts populations, particularly breeding and movement. Whereas 11 Members provided synoptic reports and 9 provided charts, they were almost always at 10-day, 15-day or monthly intervals. Only 1 Member reported provision daily. (However, the value of daily meteorological information during the invasion of Maghreb countries in 1987 and 1988 was graphically emphasised in accounts included in CAgM Report No. 53).

There seems to be a serious lack of appreciation of the fundamental importance of the daily availability of the information that is essential for maximum precision when estimating onset of breeding, duration of development to flight, and direction and distance of movement by flight. Such estimates are essential for tactical deployment of control measures based on effective monitoring of locust development and on timely forecasting of movements. It has already been said that most, if not all, of the information should be available routinely.

These implications, concerning apparent lack of appreciation by some Members of:

(a) The kinds of information needed by locust control services;

(b) The critical importance of daily information;

highlight an urgent need for improved interaction between meteorological and locust control services of some Members - a point emphasised by 1 Member and 1 user. Such interaction should include training of locust control staff, as is already undertaken by meteorological staff of 6 Members.

Despite an almost complete absence of reported difficulties encountered when preparing information for locust control, it is clear that there were serious constraints on the quality of information that could be provided. These constraints arose from:

(a) Lack of sufficient meteorological data from critical areas, either from lack of observing stations or intermittent failure of communications, nationally or internationally;

(b) Inadequacies of weather forecasts and of interpretation of satellite imagery;

(c) Lack of access to electronic data bases and expertise.

Removing these constraints is probably outside the capacity of some meteorological services. However, improvements are possible through regional and international assistance, particularly by provision of:

(a) Additional meteorological observing stations, preferably automatic with transmission via satellite;

(b) Improvements in communication links, both within and between countries;

(c) Forecasts and trajectories from global numerical models by fax;

(d) PC-based satellite receivers, geographical information systems and expert systems.

Meteorological services have recently started to assist in the reporting the presence of Locusts at synoptic stations through the introduction of coded messages added to routine synoptic reports.

5.6 RECOMMENDATIONS FOR IMPROVING THE USE OF METEOROLOGICAL INFORMATION IN LOCUST CONTROL

Some Members have provided agrometeorological information to locust control services for a decade or more, with fruitful collaboration to identify both the information needed and how it is best used. However, the survey shows that other Members could improve the information they provide. The following recommendations are intended to show how improvements can be made. They support the recommendations made by the Tunis workshop of 1988.

Where national collaboration does not exist, formal arrangements should be made to make clear what agrometeorological information is needed by the national locust control service, how it can be provided to users in the fields, and how operational decisions based on it are made to undertake not only field monitoring and forecasting but also the planning and implementation of control. The kinds of information needed will vary between countries, depending principally upon locust species and resources available to both meteorological and locust control services. Paragraph 5.4 outlined the usefulness of various kinds of information almost all of which is, or can be, produced routinely, either by agrometeorological or aeronautical sections, but there is a need to improve means of sending the information to users in the field in a format they can act upon.

Staff training - of meteorologists in the use of locust reports, and of locust staff in the use of meteorological information - should be undertaken in all countries prone to locusts so as to improve awareness of the need for collaboration. It would also clarify and overcome difficulties in the provision and use of information - e.g., insufficient data, poor communications, late delivery, wrong format. Traning could be by brief detachment of meteorologists to locust forecasting and control centres for informal in-service collaboration. Practice could be arranged through exercises during recession periods using records from a previous plague. Such training has been undertaken internationally in the past; its effectiveness needs to be assessed.

Some Members have published their experience in the operational application of meteorological information to locust control. This includes, e.g., outlines of operational procedures and how they changed in the light of experience, as well as methods to assess the relevance of information. Other Members should be encouraged to publish their experiences, in collaboration with national locust control services. In this way a body of guidance materials can be built up and all Members can benefit through discussion of how operational difficulties were identified and overcome.

Published accounts of the use of meteorological information in locust control need to be available to both meteorological and locust control services in all Member countries threatened by locusts. Some of these have been distributed widely in the past but there is little evidence of their use.

Some potentially useful routine synoptic observations are not being made available regularly, either nationally or internationally. Communications failures, resulting in missing synoptic data, sometimes at critical places, need to be reduced.

Further consideration needs to be given to installation of automatic weather stations reporting by satellite from remote locust breeding areas.

The distribution of existing satellite-derived products could be improved, both internally and from neighbouring countries and regional agencies. These include imagery of clouds, estimated rainfall and vegetation, as well as Early Warnings. Meteosat is used internationally for cloud imagery of Africa and western Arabia but Insat is not available for the remaining, eastern part of the Desert Locust area. 1 km vegetation imagery from NOAA satellites should be made available directly using PC-based receivers to aid location of the sparse vegetation upon which locusts live.

Further research needs to be undertaken and published to improve:

(a) Understanding of the effects of various kinds of weather systems on locust breeding and movement;

(b) Estimation of rainfall amount by satellite remote sensing over locust breeding areas;

(c) Use of PC-based electronic data bases for locust and weather information, with expert systems to assist forecasting locust development and movement;

(d) Application of trajectory models to forecasting swarm movements.

Much of this research requires international cooperation, but case studies of particular locust events can be undertaken nationally. Existing unfinished case studies need to be completed. Research methods are described in already published case studies for the Desert Locust but they need to be applied to other species.

5.7 REFERENCES

Centre for Overseas Pest Research (1981). Desert Locust Forecasting Manual, vols. I and II. London.

Natural Resources Institute. (1988). Locust Handbook, 2nd edition. Chatham, UK.

WMO/IESCO (1993). Reference manual of WMO Codes for Transmission of Pest Locust Data.

FAO (1994). The Desert Locust guidelines: 1. Biology and behaviour.

Centre for Overseas Pest Research. (1982). The locust and grasshopper agricultural manual. London.

WMO (1991). Meteorology and Locust Control Contributions by National Meteorological Services. CAgM Report No. 36.

WMO (1992). La météorologie au service de la lutte anti-acridienne. Contribution d'un Service météorologique national. CAgM Report No. 53.

WMO (1963). Meteorology and the migration of Desert Locusts. Technical Note No. 54.

WMO (1965). Meteorology and the Desert Locusts. Technical Note No. 69.

WMO (1988). Workshop on meteorological contributions to locust control. Tunis. (unpublished report).

CHAPTER 6

AGROMETEOROLOGICAL INFORMATION FOR MONITORING THE SPREAD OF ANIMAL DISEASES

by G.N. Mwongela

6.1 INTRODUCTION

The livestock industry in Kenya is one of the major sources of income in the Agricultural sector and also a major source of foreign exchange for the country. The livestock sub-sector contributes about 10% of the total GDP. The success of the livestock industry very much depends on an effective monitoring of animal disease outbreaks and subsequent control measures.

This case report has carried out an epidemiological study of Lumpy Skin Diseases (LSD) in Kenya and examined for possible correlation on its spread to weather based factors. An investigation has been carried in this report on the possible causes of a massive outbreak of LSD in Kenya that occurred between 1989-91 and was reported in 30 of the 41 administrative districts. This outbreak caused an element of panic among farmers as the disease appeared in the virulent form with a high morbidity and consequent major losses in productivity. Similar outbreaks of LSD had earlier been reported in Tanzania, Zimbabwe and later in Uganda.

The period under study in this LSD case report (1989-91) was quite a wet year for Kenya and hence the need to look for possible weather based factors that can be of use in predicting possible future outbreaks of this disease. FAO has categorized LSD in "Emerging Diseases" group (Weiss, 1963), in recognition of its importance in Livestock Industry.

6.2 LUMPY SKIN DISEASE (LSD)

(Ngamiland cattle Disease, Knopvelsie-Kte, Maladie nodulaire cutine's, Pseudo urticaria)

Lumpy Skin Disease is a disease of cattle caused by Pox virus characterized by development of cutaneous nodules and general lymphadenopathy (Burdin and Prydie, 1959; Weiss, 1968; Davies, 1986). The disease is of low prevalence and occurs almost exclusively in Africa. LSD may present itself in acute, subacute or asymptomatic forms involving the skin, the subcutis, the respiratory and digestive systems. Skeletal systems may also be involved. All breeds of cattle are equally susceptible. Heavy economic loss results from loss of body condition, fall in milk yield, infertility and damage to hides.

The virus is closely related to the sheep and goat pox virus (Weiss, 1968; Nawate, 1978; Davies, 1982). "Neethling type" specifically refers to the severe type of LSD and distinguishes it from the Pseudolumpy skin disease which is caused by "Allerton", a herpes virus. Neethling was the form where LSD virus was first isolated in South Africa.

6.2.1 History

Lumpy Skin Disease was unknown until its first appearance in Norther Rhodesia (Zambia) towards the end of 1929. The disease appeared after the onset of rains and had not been seen before then by the Colonial Veterinary Department nor by the native cattle owners. Since then LSD has spread to Southern Africa and northwards to involve the whole of East Africa, the Sudan, Egypt and most of Western Africa. After its first appearance in Zambia the disease was next reported in Botswana (Bechuanaland, 1943), South Africa (1944), Zimbabwe (Southern Rhodesia, 1945), Swaziland (1946), Mozambique (1946), Lesotho (Basutoland, 1947), Madagascar (1954), Tanzania (1954), Zaire (Belgium Congo, 1955), Kenya (1959), Malawi (1965), Sudan (1971), (Ali and Obeid, 1977); Chad (1973) (Provost, 1974); Niger and Nigeria (1974) (Woods, 1974); Ivory Coast (1976) (Pierre, 1978).

The disease has also been reported in Somalia (Mohammed *et al.*, 1984), Ethiopia (Mabratu *et al.*, 1984), Egypt 1988 (FAO, 1989). Lumpy Skin Disease was first reported in Kenya in December 1957. The outbreak occurred in Nakuru district within the Great Rift Valley. Between 1957-59 the district reported over 80 sporadic outbreaks. By 1958 the disease had spilled over to the neighbouring districts of Kericho, Trans-Nzoia and Uasin Gishu (**Map 6.1**). The focus of infection were scattered all over those areas and did not seem to follow any specif pattern. However, the disease was confined to those areas for sometimes probably due to the Livestock Movement restrictions and quarantines imposed by the Veterinary Department.

6.2.2 Etiology

The causative agent of LSD is a Poxvirus of the *Genus Capripoxvirus*.

Natural Epizootiology and transmission. It is not entirely known how the virus is transmitted from one animal to another. However since the disease is most prevalent during warm wet weather and in low lying marshy areas, it is strongly suspected that insect vectors play a major role in its dissemination. Epizootics seem to occur during long rains (Nawathe *et al.*, 1978; Davies, 1982; Davies, 1986). Authors personal observations during the LSD outbreak in Machakos district of Kenya (1989-90). Outbreaks in South Africa were frequently restricted to water courses in dry weather but rapidly spread during heavy rains (Woods, 1988).

In Kenya it was observed that outbreaks occurred in hards several miles apart with intervening or neighbouring farms remaining clear. The farm where the first outbreaks occurred in Kenya was heavily infected with mosquitoes *Culer mirificus and Aedes natronius.* Burdin and Prydie, (1959); Martin, (1981); Woods, (1988) reported the presence of many biting flies of the genus *Lyperosis* in the outbreaks of LSD in Chad. LSD virus has been isolated from *Biomyia fasciata* and *Stomoxys Calcitrans* caught feeding in cattle (Weiss, 1963).

Epizootics of LSD in some areas seem to follow a cycle of 5 years as has been observed in South Africa in 1942, 1947, 1953, 1962 and 1967 and Nigeria in 1974 and 1979 (Woods, 1990). In Kenya the outbreaks do not seem to follow any pattern.

6.2.3 Clinical manifestation

The incubation period in natural infection is not knows due to lack of knowledge on the exact mode of transmission. However, Diesel (1949) states an incubation period of 14 days from observation he made in accidental inoculation of cattle with Lumpy Skin Disease virus (LSDV) contaminated anaplasmosis vaccine in South Africa. In experimental infection, incubation varies from 4 to 14 days (Martin, 1981; Prozesky *et al.*, 1982). The disease is commonly observed 2 to 4 weeks after exposure to infection. The characteristic skin swelling on one or more legs. Sick animals are often reluctant to move and walk with stiff gait. There may also be lachrymation, photophobia, increased salivation and mucoid nasal discharge. The skin lesions are usually intracutaneous, round well circumscribed nodules, slightly elevated above the general skin surface and usually flattened. They vary in diameter from a few millimetres to about 2 centimetres across. Their frequency ranges from a few nodules which are widely scattered to very large numbers spread all over the body. They are often numerous on the lower parts of the body, perineum and the legs. Lesions in the respiratory tract may cause dyspnoea. There may also be nodules on the teats with a more or less painful swelling of the udder. In bulls the scrotum is often severely affected.

The majority of superficial lymphnodes are often enlarged and firm. Many animals show oedematous swelling of the external genitalia or of one of more limbs, extending in some cases to the shoulder, brisket, dewlaps, and lower aspects of the head and neck.

The lameness may be accompanied by swelling of the coronet,e xtensive necrosis of the skin, sloughing, secondary bacterial infection and suppuration follow in a few cases. The characteristics skin nodules may resolve rapidly and completely but a proportion become indurated and persist for long periods. Superficial necrosis may occur in which case healing is accompanied by formation of superficial scab; with temporary loss of hair. In most cases the necrosis is deep seated and a central disc of dead skin eventually sloughs out like a plug, leaving a deep sore which heals by granulation. Secondary bacterial infection may lead to abscessation and delay in healing.

In severe cases, death occurs in about 10 days but these are unusual. Loss of body condition and long convalescence are of great economic importance. Pregnant animals may abort. Recovered female animals may show anoestrus for 4 to 5 months duration; similarly bulls may become temporarily sterile.

Generally morbidity rate varies from 10 to 100% whereas mortality rate is very low hardly exceeding 10%. The mortality rate in calves due to LSD seems higher than in adults. This is due to starvation as a result of oral lesions and lack of milk as a result of mastitis in the dam.

6.2.4 Diagnosis

Clinical signs are usually typical and unmistakable. Confirmation can be made by excising early skin nodules and fixing in formal saline for histological examination and the other fresh half for viral isolation.

6.2.5 Treatment

Good nursing and feeding. Treat skin sores with antiseptics or sulfonamide.

6.2.6 Immunity

The exact nature of immunity is not well understood. Recovered and asymptomatic acquire life-long immunity. Protecting neutralising antibodies can be demonstrated in these recovered cattle for up to 5 years after infection (Weiss, 1968).

Successful immunization of cattle in Kenya has been carried out using a sheep pox attenuated Live Vaccine produced in Kenya since 1959. This vaccine causes a local reaction at the site of injection in 10% of animals. The second type of vaccine is the Neethling strain type attenuated by serial passage in lambtertis cells. It is safe with no local reaction and fully protects cattle against LSDV. Calves that are born of immune dams acquire colostral immunity that lasts up to six months (Woods, 1990).

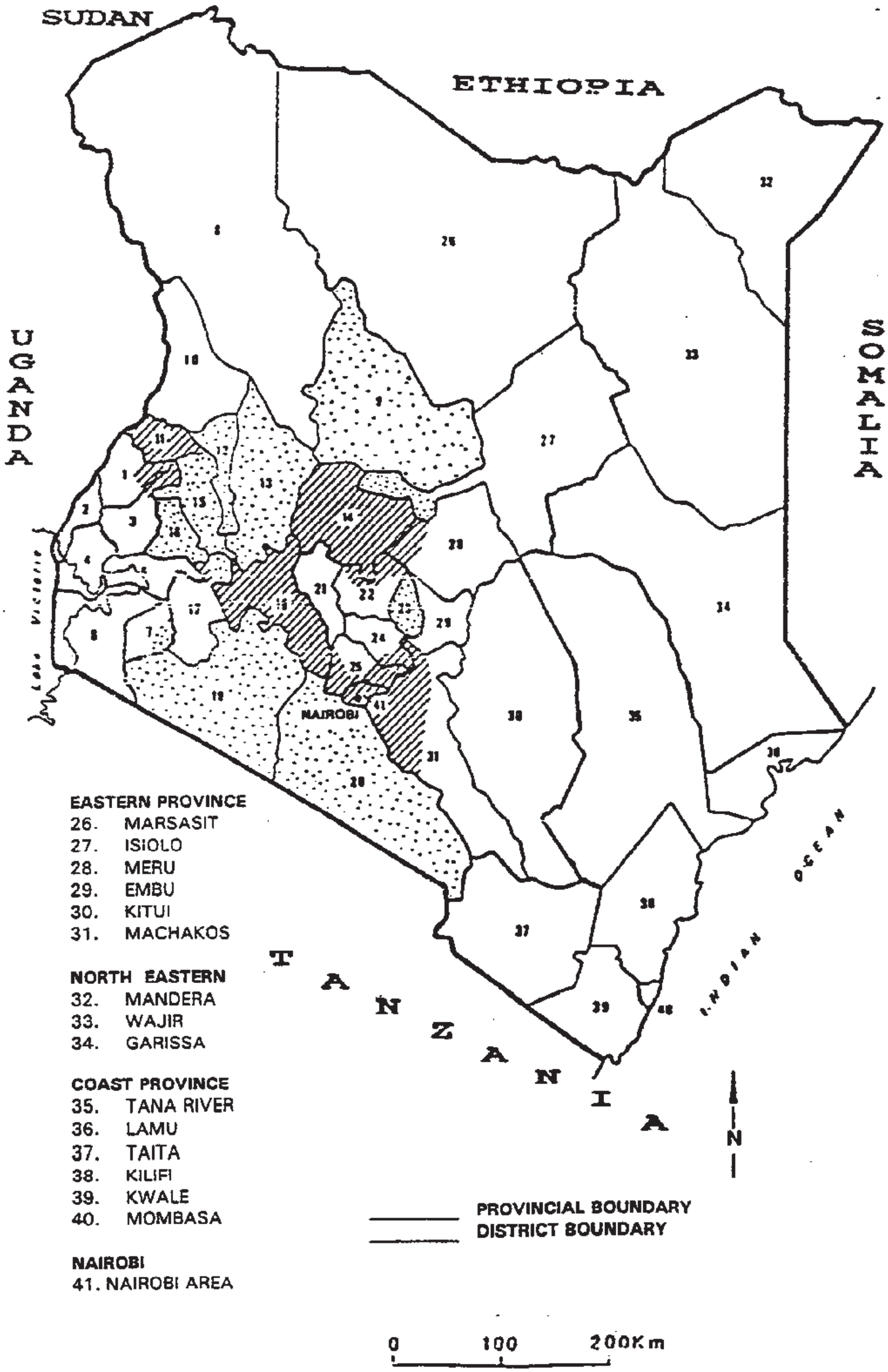
6.2.7 Control

Quarantine measures alone may not prevent the spread of LSD. Movement of hides have also to be restricted in addition to measures like insect control.

Public awareness of these facts is important to dispel many myths and fears about the disease.

6.3 CASE REPORT

An outbreak of Lumpy Skin Disease of enormous proportions in Kenya between 1989-91 has been studied in this report. The possible weather based epidemiological factors that may have contributed to the spread of the disease from Zimbabwe then to Tanzania and finally to Kenya in early 1990 have also been looked into.



WESTERN PROVINCE
1. BUNGOMA
2. BUSIA
3. KAKAMEGA

NYANZA PROVINCE
4. SIAYA
5. KUSUMU
6. SOUTH NYANZA
7. KISII

RIFT VALLEY
8. TURKANA
9. SAMBURU
10. WEST POKOT
11. TRANS NZOIA
12. ELGEYO MARAKWET
13. BARINGO
14. LAIKIPIA
15. UASIN-GISHU
16. NANDI
17. KERICHO
18. NAKURU
19. NAROK
20. KAJIADO

CENTRAL PROVINCE
21. NYANDARUA
22. NYERI
23. KIRINYAGA
24. MURANG'A
25. KIAMBU

EASTERN PROVINCE
26. MARSASIT
27. ISIOLO
28. MERU
29. EMBU
30. KITUI
31. MACHAKOS

NORTH EASTERN
32. MANDERA
33. WAJIR
34. GARISSA

COAST PROVINCE
35. TANA RIVER
36. LAMU
37. TAITA
38. KILIFI
39. KWALE
40. MOMBASA

NAIROBI
41. NAIROBI AREA

Map 6.1 - MAP OF KENYA

Kenya has an estimated area of 582,670 km^2 and lies between 5°N and 5°S Latitude and 34°E and 41° Longitudes. Latitude 0° Equator divides the country into two almost equal parts. Kenya borders Tanzania to the South, Indian Ocean to the South East, Somalia to the East, Ethiopia and Sudan to the North and Uganda to the West, (**Map 6.1**). Lake Victoria, a fresh water lake is shared by the East African Countries, Tanzania, Kenya and Uganda.

The LSD outbreaks in this report started in a massive form in the Coastal districts of Kenya: namely Lamu, Kilifi and Tana River and then the Southern districts: Machakos and Kajiado, with the latter sharing a common border with Tanzania (**Map 6.1**). The LSD presented itself with a high morbidity and virulence. This caused a lot of concern to the farmers and the Veterinary Department personnel. The Veterinary Department in Kenya responded quite fast with vaccination of cattle with the issue of LSD vaccine doses from the Headquarters to the field stations rising from a figure of 26,418 in 1988 and 156,900 in 1989 to a figure of 1,752,300 in 1990. This represents a Ill6% increase in vaccine issues, and hence a reflection on the seriousness of the disease. By the end of 1991, the disease had spread to 30 of the 41 administrative districts - a figure representing 73% spread int he country within a period of 3 years.

Three districts, namely Machakos, Nyandarua and Bungoma where outbreaks occurred within this period were selected for epidemiological study. The three districts are over 200 kilometres apart and have no known inter-district livestock movement into each other. This was one way of eliminating the possible spread of the disease through contact as a result of livestock movement from infected areas to clean ones.

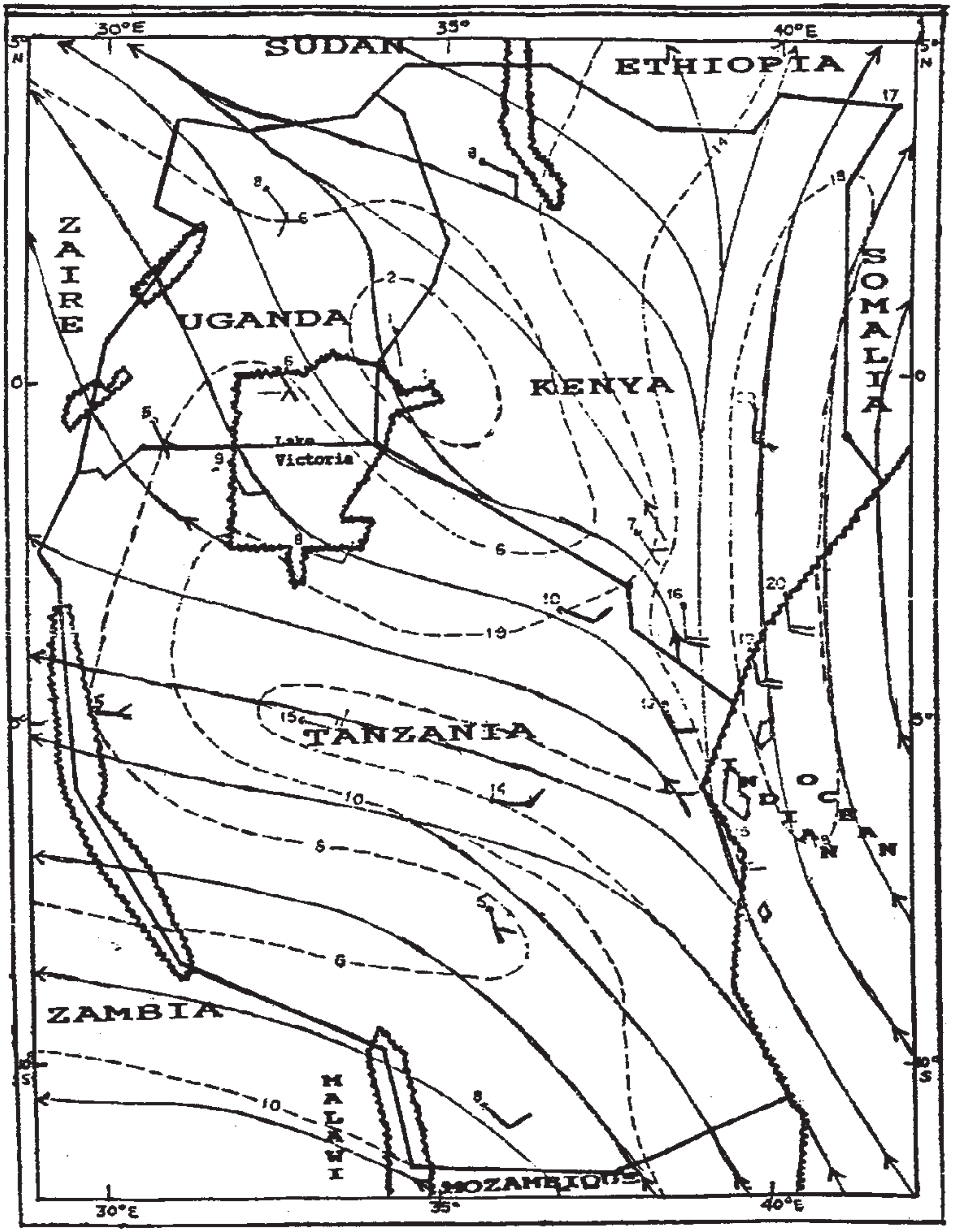
The first district, Machakos (No. 31 on **Map 6.1**) is at the southern part of Kenya and close to Kenya/Tanzania border. The second district, Nyandarua (No. 2 on **Map 6.1**) is located in the central part of Kenya and is traversed by the Equator. The third district Bungoma (No. 1 of **Map 6.1**) is located in the western part of Kenya and shares a common border with Uganda. An analysis of the monthly rainfall recorded during the period of the disease occurrence and the long term rainfall average for the period 1962-92 for each district have been plotted in **Figures 6.1** to **6.3**. In **Figure 6.4**, the total of all LSD outbreaks in Kenya on monthly basis for the period of ten years: 1981-91 have been plotted in a graph. This is an attempt to look for possible correlation between the monthly rainfall regime and the months over the ten year period that most LSD outbreaks occurred.

This report has also examined the wind systems and rainfall regimes of East Africa. East Africa is mainly dominated by the two monsoonal wind systems. The north easterlies occur during the southern summer (November to January) season, while the South easterlies occur during the northern summer (June to August) season. On rainfall pattern, this region experiences both bimodal and monomodal rainfall regimes, (Johnson, 1962; Tomsett, 1969; and Potts, 1971). Kenya mostly experiences the bimodal regime in most areas. The maximum precipitation occurs from the months of March to May and September to November. The long term mean streamlines of wind at 1.5 km above mean sea level over East Africa for the months of May and December (**Maps 6.2 and 6.3**) have also been examined.

6.3.1 Discussion

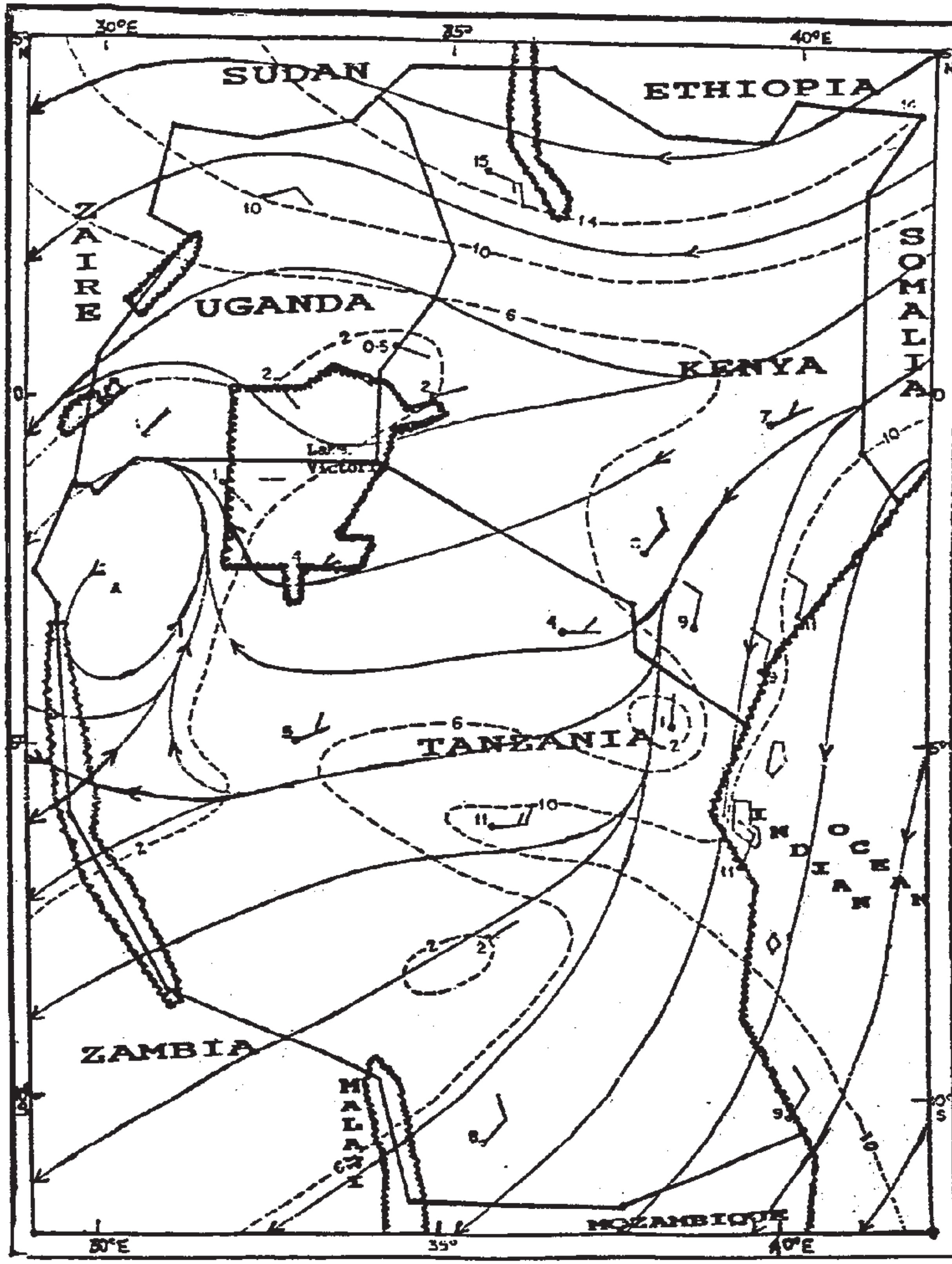
The notification in the gazette of livestock disease outbreaks in Kenya is normally done after laboratory confirmation of the disease. A time lag normally occurs from the incubation stage of the disease through to the manifestations of clinical signs and then laboratory confirmation of the disease. The notification in the gazette of a disease outbreak in an animal population thus clearly indicates that the disease has been present for some time.

In this report and the accompanying graphs, I have referred to each disease quarantine so gazetted as an outbreak. An outbreak in administrative area does not include the number of cattle affected by LSD during the period the disease is present in the particular area. At any one time, more than one administrative area in a district may be declared infected with the disease, depending on its geographical size. The records on the number of animal infected with a particular disease within an area under quarantine has not been easy to maintain in Kenya due to the diverse farming systems in the country.

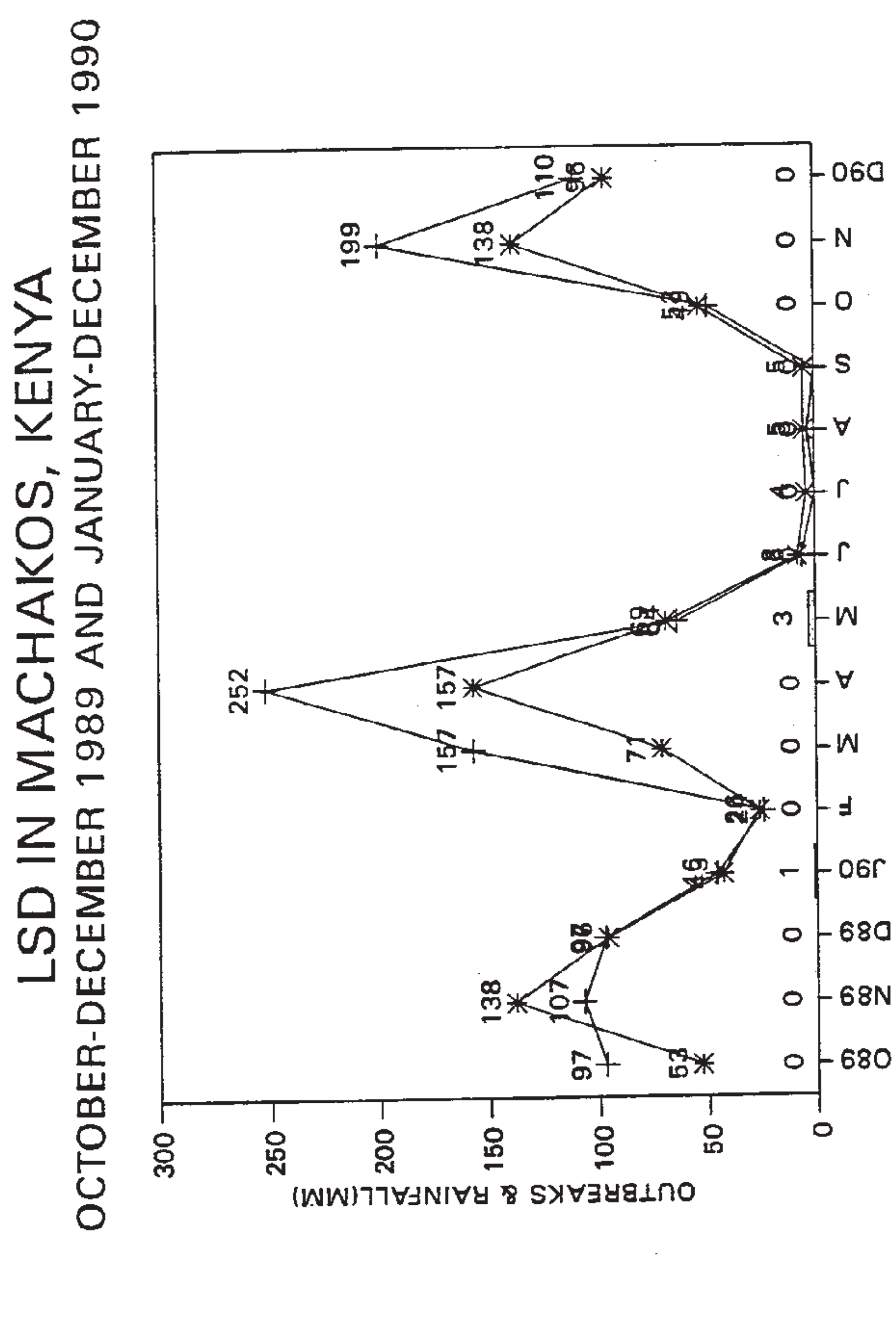


Map 6.2 - **MAP OF EAST KENYA**

Mean wind Field at 1525 Metres Above mean sea level over East Africa in May.

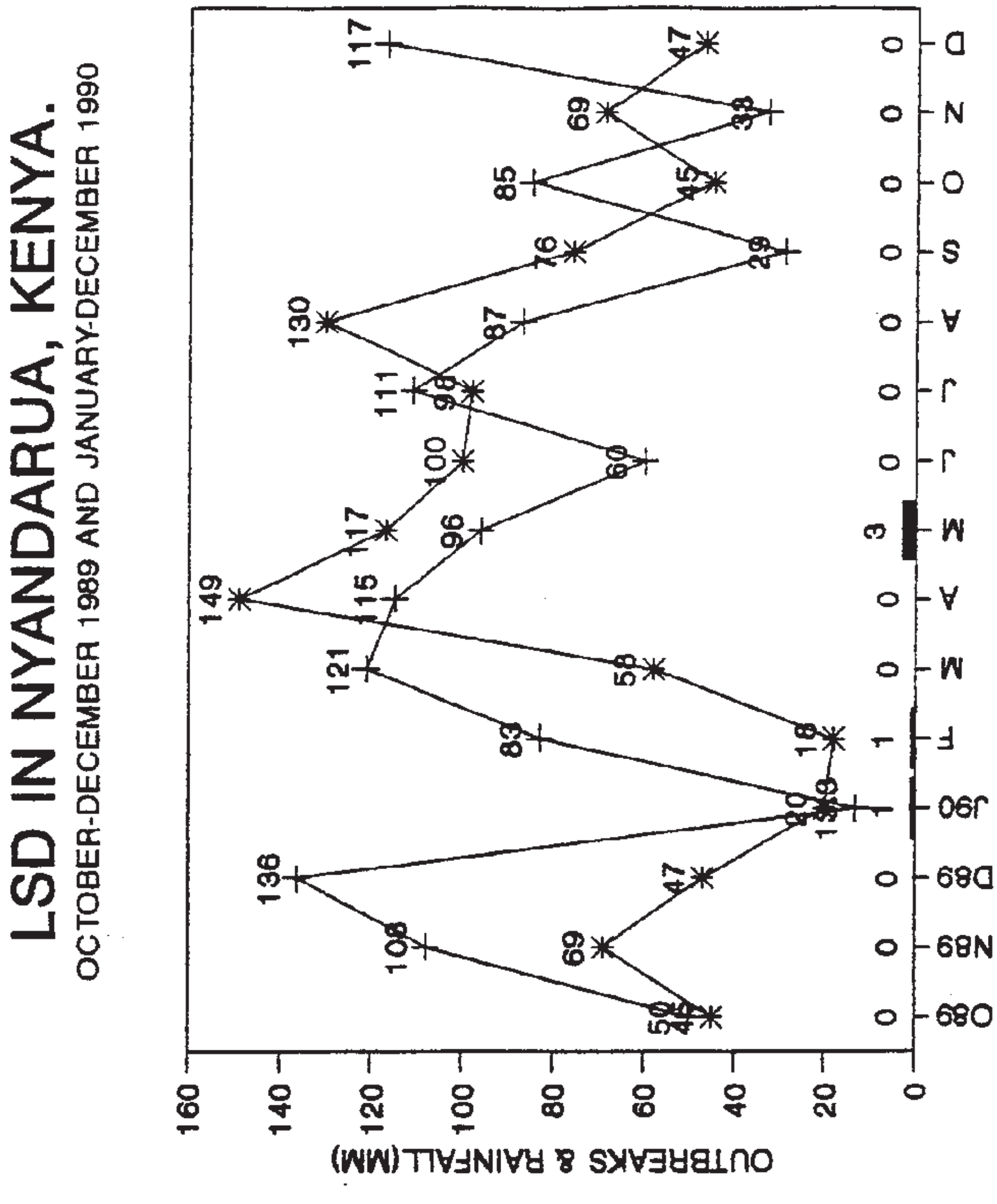


Map 6.3 - **MAP OF EAST AFRICA**
Mean wind Field at 1525 Metres Above mean sea level over East Africa in December.



	O89	N89	D89	J90	F	M	A	M	J	J	A	S	O	N	D90
Outbreaks	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0
+ Monthly rainfall	97	107	97	46	24	157	252	64	6	0	3	0	49	199	110
* Long-term average	53	138	96	43	26	71	157	69	8	4	5	5	53	138	96

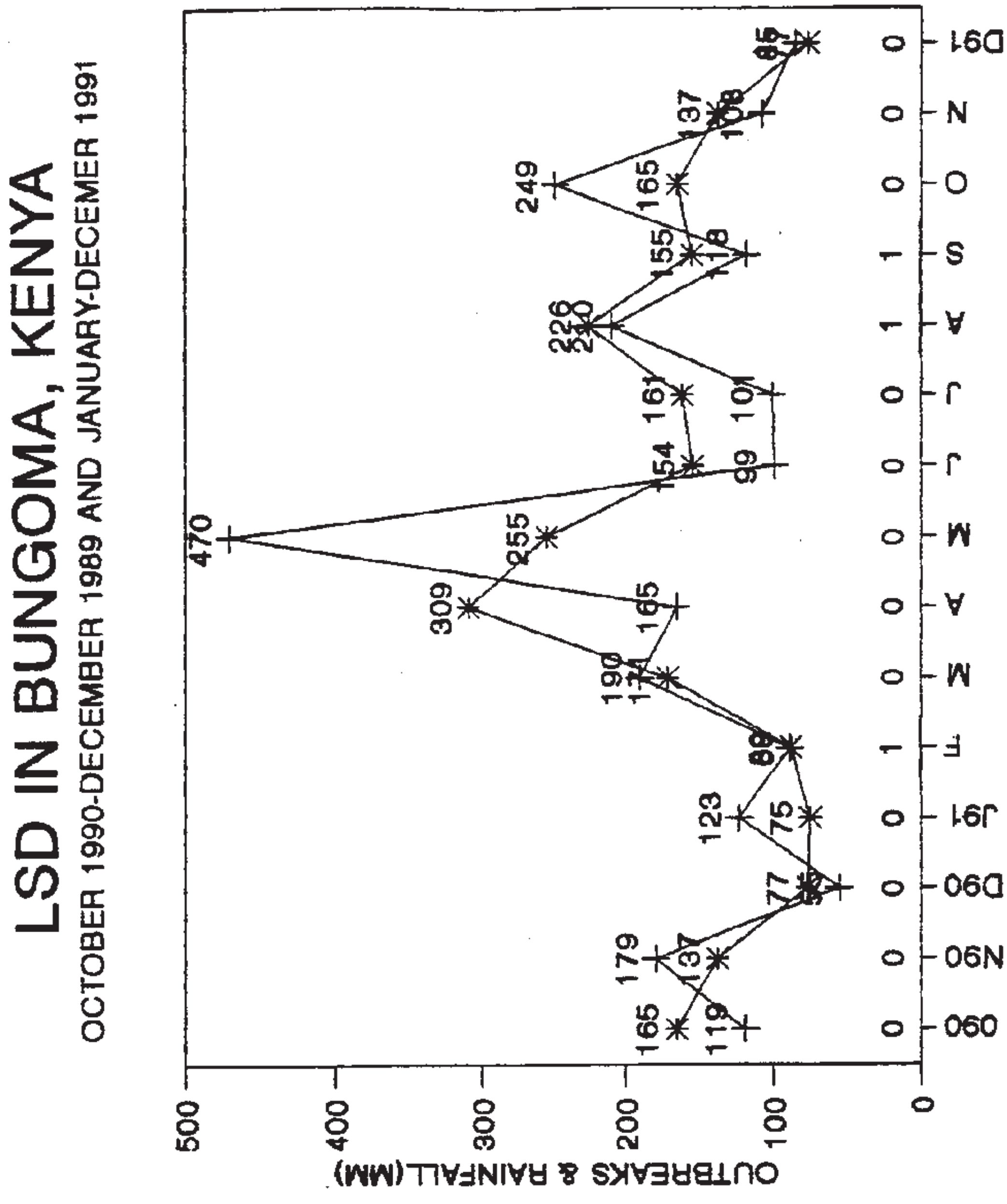
Figure 6.1 - Long-term average rainfall = 1962-92.
Outbreaks = Gazetted LSD outbreaks in the District.



	O89	N89	D89	J90	F	M	A	M	J	J	A	S	O	N	D
■ Outbreaks	0	0	0	1	1	0	0	3	0	0	0	0	0	0	0
+ Monthly rainfall	50	108	136	13.3	83	121	115	96	60	111	87	29	85	33	117
* Long-term average	45	69	47	20	18	58	149	117	100	98	130	76	45	69	47

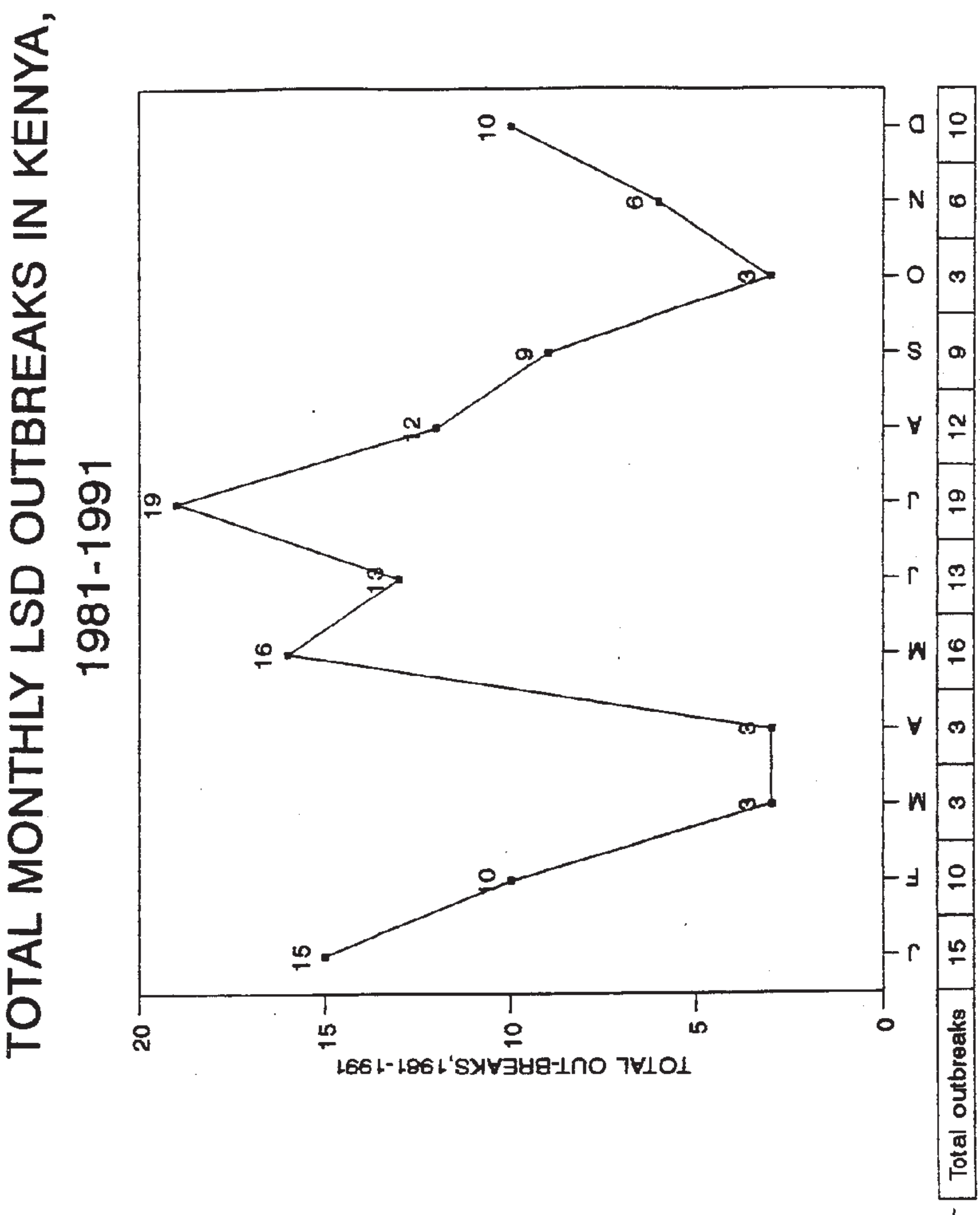
MONTHS

Figure 6.2 - Long-term average rainfall = 1962-92.
Outbreaks = Gazetted LSD outbreaks in the District.



	O90	N90	D90	J91	F	M	A	M	J	J	A	S	O	N	D91
■ Outbreaks	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
+ Monthly rainfall	119	179	55	123	89	190	165	470	99	101	210	118	249	108	85
✳ Long-term average	165	137	77	75	88	171	309	255	154	161	226	155	165	137	77

Figure 6.3 - Long-term average rainfall = 1962-92.
Outbreaks = Gazetted LSD outbreaks in the District.



	J	F	M	A	M	J	J	A	S	O	N	D
Total outbreaks	15	10	3	3	16	13	19	12	9	3	6	10

Figure 6.4

The analysis on the outbreaks of LSD in the three districts of Kenya, namely Machakos, Nyandarua and Bungoma in relation to the respective regimes (**Figures 6.1 to 6.3**) indicates that the outbreaks occurred during months with rainfall above average or immediately after the wet months. **Figure 6.1** of Machakos district where the first outbreak occurred in January 1990 had been preceded by a high rainfall peak of 138 mm in the month of November 1989. The other three outbreaks recorded in May of 1990 has also been preceded by a very high rainfall peak of 252 mm in the month of April of the same year. It is worth noting that new outbreaks did not occur in the dry months of June to September 1990 when the rainfall was very minimal.

The case for Nuandarua district (**Figure 6.2**) shows a situation quite similar to that of Machakos. The first outbreak in January 1990 occurred immediately after a high rainfall of 108 mm and 136 mm in the months of November and December 1989 respectively. A similar situation can be said of the simple outbreak in February 1990 and the three others in May 1990. In Bungoma district case (**Figure 6.3**), the three outbreaks occurred during or immediately after rainfall season.

An analysis of the total monthly LSD outbreaks in Kenya over a ten year period, 1981-91 (**Figure 6.4**) clearly shows that most disease outbreaks occurred during the months of the year when the rainfall peaks were high, and have a relevance tot he bimodal rainfall pattern in Kenya. This is effect supports the epidemiological data on the disease that implicates biting insects in the transmission of the disease. The wave like spread of the disease from the southern districts of Kenya to other parts of the country can possibly be attributed to the wind flow pattern over East Africa. The long term mean streamlines of wind at 1.5 kilometres above mean sea level for the months of May and December over east Africa (**Maps 6.1 and 6.2**) were examined by Anyamba (1983). The wind flow in the month of May (**Map 6.1**) shows that the south easterly winds move from the Coastal and Southern parts of Kenya and Tanzania to their respective western borders. This pattern of wind flow may possibly be said to explain the spread of LSD vector from the coastal and southern districts of Kenya to other inland districts of the country. The disease was finally reported in Turkana district (No. 8 on **Map 6.1**) in North Western Kenya bordering Sudan and Ethiopia.

Similarly it can that the LSD outbreaks reported in early 1989 in Zimbabwe by the Veterinary Department in their Animal Health Status No. 3 of 1989 and which spread northwards to Tanzania and then to Kenya can possibly be said to have been influenced to some extent by wind flow. A similar observation can be made on the wind flow patterns in the months of December (**Map 6.3**). The wind flow is mainly North easterly from Northern hemisphere. They originate from India through the coastline and through northern Kenya to Uganda and further south.

6.3.2 Conclusion

The weather based factors discussed above are not conclusive as far as an attempt to explain the massive spread of LSD in Kenya in the period under discussion is concerned. However, on the basis of the discussion, it can be said that rainfall regimes and wind flow patterns are possible contributing factors in the spread of the insect vectors that are responsible for the spread of Lumpy Skin Disease. It is also possible that years that can be predicted by the Meteorological Department to receive rainfall above average can be used to forewarn the respective veterinary departments of their respective countries of a possible increase in biting fly population.

It is my recommendation that a further investigation into other weather based factors can be explored in an attempt to conclusively enable the relevant department predict future outbreaks of Lumpy Skin Disease.

6.4 REFERENCES

Ali, B.H. and Obeid, H.M. (1977). Investigation of the First Outbreak of Lumpy Skin Disease in the Sudan. British Veterinary Journal 133, 184-1986.

Anyamba, E.K. (1983). Monthly mean lower tropospheric circulation and the anomolous circulation during 1961-62 floods of east Africa. MSc Thesis, University of Nairobi.

Burdin, M.L. and Prydie (1959). Observation of the First Lumpy Skin Disease in Kenya. Bull. Epix. Dis. Afr. 7, 21-26.

Burdin, M.L. (1959). The use of Histopathological Examinations of Skin Material for the Diagnosis of Lumpy Skin Disease in Kenya. Bull. Epiz. Dis. Afr. 7, 27-36.

Davies, F.G. (1982). Observations on the Epidemiology of Lumpy Skin Disease in Kenya. J. Hyg. Camb. 88, 95-102.

Davies, F.G. (1986). Infectious Tropical Diseases of Domestic Animals. (Lossos, J.G.E. Lumpy Sking Disease, 527-737.

Diesel, A.M. (1949). The Epizootiology of Lumpy Skin Disease in South Africa. Proceedings of the 14th International Veterinary Congress, London, 2, 492-500.

Fao-Who-Oie (1984). Disease Information, 2 (38), 137.

Fao-Who-Oie (1989). Animal Health Year Book A.070, pp. 201.

Johnson, D.H. and Murth, H.T. (1962). Rain in East Africa. Quart. J. Roy. Met. Soc., 88, 1-19.

McOwan, K.D.S. (1959). Observations on the Epizootiology of Lumpy Skin Disease during the first occurrence in Kenya. Bull. Epizote. Dis. Afr. 7, 7-20.

Martin, W.B. (1981). Disease of cattle in the tropics. (Ristic, M. and McIntyre, i.e. Lumpy Skin Disease and Pseudo Lumpy Skin Disease, 167-169.

Mebratu, G.Y., Kassa, B., Firke, Y., Berhanu, B. (1984). Observations in the Outbreak of Lumpy Skin Disease in Ethiopia (Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux 37 (4), 395-399. En. es. Fr. 9 ref. J. Nat. Inst. Debre Ze Ethiopia).

Mohammed-Abdi-Arushi, Hussein, H.A., Abdijabar, H.D., Salim, H.A. (1984) (Lumpy Skin in Somalia). Bollettino Scientifico della Facoltà di Zootecnica e Veterinaria. (Publ. 1985) 5, 75-79.

Nawathe, D.R., Gibbs, E.P.J., Asagba, M.O., and Lawman, M.J.D. (1978). Lumpy Sking Disease in Nigeria. Tropical Animal Health Production 10, 49-54.

Pierre, F. (1978). (Lumpy Skin Disease in the Ivory Coast). Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux 31 (3), 281-286.

Potts, A.S. (1971). Application of harmonics analysis to the study of East African rainfall data. J. of Tropical. Geog., 33, 31-44.

Prozesky, L. and Barnard, B.J.H. (1982). A study of the pathology of Lumpy Skin Disease in cattle. Ondersterpoort J. of Vet. Res. 49, 167-175.

Tomsett, J.E. (1969). Average monthly and annual rainfall maps of East Africa. EAMD Tech. Memo, No. 14.

Weiss, K.E. (1963). Lumpy Skin Disease. "Emerging Diseases of Animals". FAO Agricultural Studies, 61. FAO, Rome, 179-201.

Weiss, K.E. (1968). Lumpy Skin Disease Virus. Virology Monographs 3, 111-131.

Woods, J.A. (1974). A skin condition on cattle. Veterinary Record 95, 326.

Woods, J.A. (1988). Lumpy Skin Disease Review. Tropical animal production 20.

Woods, J.A. (1990). Lumpy Skin Disease Review. Virus infections of Ruminants in Viral Infections of Vertebrates, 3. (Dinter and Marein, ed.), 53-69.

CHAPTER 7

SPECIFIC ASPECTS OF NATURAL DISASTERS WHICH AFFECT AGRICULTURAL PRODUCTION AND FORESTS, PARTICULARLY WILDLAND FIRES, SEVERE LOCAL STORMS AND HURRICANES

by G. Bedson

7.1. SUMMARY

7.1.1 Opening comments

This report was prepared in my capacity as Rapporteur on Specific Aspects of Natural Disasters which Affect Agricultural Production and Forests, particularly wildland fires, hurricanes and severe local storms. Preparation of the report entailed an extensive literature survey, and the preparation and analysis of a three part questionnaire designed to obtain information on the incidence and impact of these natural disasters. Although having attempted to use examples from as many countries and Regions as possible, I have inevitably drawn heavily upon experiences and practices in my own country, Australia and have, in fact, devoted a chapter to an Australian focus. Despite some disadvantages of such an approach, I believe that the Australian experience will provide useful information to readers, since that country suffers major impacts from all of the extreme events covered in this report and, despite its relatively small population, has advanced infrastructure and reporting systems. At the outset I would like to acknowledge the significant contribution made by colleagues in the Australian Bureau of Meteorology , members of the WMO Secretariat and also other members of the CAgM Working Group on Extreme Agrometeorological Events. Without that support, preparation of this report would not have been possible. I would also like to acknowledge the generous permission of a number of authors to quote extensively from reports and papers, particularly Dr.'s Rene Gommes (FAO) and Kwabena Anaman (Macquarie University, Sydney Australia).

7.1.2 Overview

A useful definition of a disaster is provided by Gommes (1992) as being "*the interface between an extreme physical event and a vulnerable human population.*" A key observation was that the lower the level of development, the greater the relative loss of human life against material damage. Developed countries characteristically experience higher absolute material damage because of a greater level economic activity and a better developed infrastructure. As well as greater loss of life and human injury in developing countries from natural disasters, losses to agricultural produce, particularly crops, generally represent proportionally greater material losses. In addition to direct losses, there are indirect effects which are likely to be at least 1.5 to 2 times the latter in economic terms. Some examples will be given in the report, mainly from the work of Gommes, R. and Negre, Th ., (1992).

Although operational agrometeorological models have assumed an increasing importance in agriculture over the ast 10 to 20 years and for the most part operat e effectively within the normal range of environmental factors, they don't cope particularly well with exceptional weather events such as the major floods which affected southern China in June 1994 with a reported loss of more than 400 lives, about 6,500 injured, 20 million affected, 482,000 houses destroyed, and 3 million hectares of cultivated land inundated. The cost of damage was estimated at 16.86 billion yuan ($2.7 billion) (*AFP Reuters*). This report indicates that there is a major requirement for complementary databases and methodologies which may facilitate the development of preparedness measures in both pre and post disaster phases.

Although categories of natural disasters include meteorological, geological and epidemiological events, most of the report will concentrate on meteorological events, with perhaps minor comments on geological events with a meteorological component likely to result in losses to forestry or agricultural operations eg. landslides. The main thrust will be on wildland fires, severe local storms and hurricanes. Subcategories of these which will be mentioned are hailstorms, tornadoes, thunderstorms and heavy rains/flash flooding (associated with severe local storms); storm surges, heavy rains/ floods associated with hurricanes. Although river flooding will be mentioned, it will not be a major focus of this report, unless associated with tropical cyclone activity. Some attention will be focussed on frost and heatwaves.

The report will examine and evaluate the status quo particularly in relation to pre and post disaster infrastructure in as many countries as possible, explore emerging tools and methodologies and suggest potentially viable ways of minimising (predominantly economic) damage caused by meteorologically related natural disasters, to agriculture and forestry, mainly by highlighting areas where research and development effort is warranted.

Summaries of methodologies, results and conclusions from applied scientific and operational literature are interspersed throughout this report under appropriate chapter headings. Although the electronic library accession system of the Australian Bureau of Meteorology was used, many of the publications and papers identified originated from a relatively small number of countries or agencies, particularly USA, China, Australia, New Zealand, WMO and FAO. Clearly there is much more material which has a strong bearing on scientific aspects of decision support and warning systems, but because much of the scientific bases of operational systems is given in bibliographies of individual papers, most has judiciously been omitted from the list of references given in paragraph 7.13.

Hazard reduction measures are in place in a significant number of the nations surveyed, and ongoing research and development to improve and expand these measures are also a features of many national strategies to minimise adverse effects.

In a general way, knowledge of weather and its evolution constitutes a resource whose implications are at the same time economic and social: economic, since this information is a factor in the management of activities and resources, and social, since meteorology is closely tied to measures to ensure the security of people and property. Thus it influences both individual and collective behaviour. (Extract from the *Report of the Economic and Social Council of France* - January, 1985). Various studies have been undertaken to attempt to assess socio-economic benefits of meteorological data. The studies described in this report are intended to provide examples of more or less in depth social and/or economic investigations which may be used as models when similar decisions need to be taken or information extracted. Questions addressed include:

- should a particular innovation be embraced in a specific situation; and
- what are, as accurately as can be ascertained, the real costs to various communities, of specific natural hazards.

7.1.3 Approaches to assessing economico impacts

A survey is undertaken of methods for assessing economic impacts, but the literature is far from abundant, and the survey of Members did not provide a great deal of information. An Australian study being undertaken by the Macquarie University (Sydney, Australia) in collaboration with the Australian Bureau of Meteorology offers considerable promise, combining as it does expert economic input with specific examples of events and services. The study methodology has been reported by Anaman *et al.* (1995). Anaman, as an economist brings a rigorous methodology to bear, this being of particular value in assessing economic impacts of meteorological events and services. The study was financed by the Australian Research Council, and an earlier version of the paper was presented at the World Meteorological Organisation Conference on the Economic Benefits of Meteorological and Hydrological Services held in Geneva, Switzerland from 19-23 September 1994.

The discussion on impacts of extreme events on agriculture is based upon work reported by Gommes and Negre (1992) in FAO Agrometeorology Series Working Paper No 2. They referred to Susman's 1983 definition of a disaster as *"the interface between an extreme physical event and* *a vulnerable human population.*" Various studies have highlighted the link between the level of economic development and the material damage caused by natural disasters. Two broad categories of effects were identified:

(a) Direct effects on property and income of people and enterprises in the private or public sectors;

(b) Indirect effects caused by reduced income arising from such factors as a decrease of production, environmental degradation and other factors related to a natural disaster.

For most developing countries, most impact and damage from natural disasters are caused by deaths and injuries, and by crop losses. The Gommes-Negre study provides examples of impacts within the agricultural sector, for several less developed countries.

7.1.4 Warning systems

A major function of National Meteorological Services is the provision of public warning of weather conditions expected to be hazardous to life or property. There has been considerable analysis of the key components of warning systems, for example in the context of the WMO Tropical Cyclone Programme as well as major progress in the development of warning systems during the past 25 years, but implementation varies significantly between WMO Regions. For example North America (Region IV), Europe (Region VI) and parts of Asia (Region II) have sophisticated observations, communications, data processing and dissemination systems with well developed counter disaster and public response components. Many other Members are at an intermediate level of development, but large areas of Africa (Region I) have underdeveloped national infrastructures.

The importance of installing and maintaining observational networks cannot be overstressed, and with related appropriate infrastructure they are likely to recoup costs of training staff, installation and maintenance several times over in the longer term. National and international aid agencies are regularly providing the kind of assistance needed to establish and improve national meteorological facilities in less developed countries via advice on instrumentation, networks, observational practices, computer based equipment for manipulation of data, charts, decision support, archiving data etc. from visiting teams of experts; arranging for training and upgrading of competencies of local staff at appropriate training centres in the Region etc.

There are at least two aspects of forecasting and warning systems for natural disasters relevant to this report, the communications infrastructure by which the warning office obtains information on which to base its forecasts and warnings; and the dissemination system for the warnings about the impending hazardous event. Failure of any component means that critical information does not reach communities at risk. A robust and reliable communications network is a key component for, among a host of other functions, the dissemination of warnings to vulnerable agricultural sectors.

The most important aspect of the dissemination component, particularly in the event of a significant meteorological hazard is its robustness. Timeliness is paramount in disseminating and acting upon warnings of extreme events. Above ground telephone lines for the delivery of tropical cyclone warnings, for example, are likely to be the 'least robust' component in the warnings dissemination system. Of almost parallel importance is, where possible, having a range of warning outlets or methods - radio (break-ins to the normal program, inclusion in news reports, repetition at frequent agreed intervals etc), television (crawlers, news coverage, etc), audible alarms in threatened areas, pre-arranged signals at agreed locations, weather radio with the capacity to transmit warning beeps or alarms with the issue of a warning, VHF radio and many others. Inmarsat communications have proved invaluable in establishing communications links in many post disaster situations and international agreements are in place to allow such usage. This method of communication has great potential for the issuance of important warnings and will no doubt soon begin to bridge gaps in communications systems in developing countries, in particular isolated island nations or those developing nations where distance and isolation are major considerations.

An intrinsic part of the forecasting and warning process is the verification component. The degree of sophistication of the verification process will vary for event categories and according to the resources of the National Meteorological Services. However, if there is no verification process or the role of the verification process is not given adequate weight or resources, it is most unlikely that forecasters will learn by their mistakes or that the Service will be motivated to implement measures to improve overall performance in the issuance, accuracy or timeliness of warnings. Any push for improved methodology or new technology will not be as strong and the impact of new or improved forecast methodologies will not be quantifiable.

The role of geostationary meteorological satellites, such as METEOSAT for Europe and Africa and GOES-E and GOES-W for the USA and Canada, and the Japanese GMS satellite series for western Pacific nations including Japan, China, Philippines, Indonesia and Australia, in the provision of warnings for the principal natural hazards of this report continues to expand. This expansion is the result of technological progress which has meant:

(a) Improved access to satellite data, especially by less affluent nations, by virtue of reductions in the cost of receiving equipment, computer hardware and software for processing, viewing, looping and otherwise manipulating the satellite imagery;

(b) Expansion, diversification and cost reductions related to modes of dissemination of imagery, including facsimile and radio facsimile, computer to computer transference through high speed data lines, communications satellites, and more innovative packaging of the imagery in television weather presentations;

(c) Expansion in satellite applications, many of which have a direct bearing on warning formulation and accuracy.

7.1.5 Databases for extreme events

A major difficulty in obtaining a coherent overall picture of the qualitative and quantitative hazards posed to agriculture by extreme meteorological events has been the lack of a systematic data base. Establishment of such a data base is the first and most basic requirement in hazard assessment for extreme events. Such data bases should record:

- as many parameters as possible;
- their scale;
- their spatial extent;
- start and finish times; and
- measures of event severity, using such concepts as: number of deaths (human and animal), damage to buildings, communications, level of imported food aid, people's response eg. migration. Fujita's F scale for tornado intensity is a well known example, which has become widely accepted.

7.1.6 Results from questionnaire

A Questionnaire was devised to identify the nature of the threat posed to, and services provided by Members of WMO. The questionnaire was divided into three parts, devoted respectively to wildland fires, tropical cyclones and severe local storms. In analysing the questionnaires, responses were grouped by Region, to attempt an intercomparison. Much valuable information was obtained, but particular difficulty was experienced in obtaining specific information on economic impacts. It is also difficult to (a) devise and (b) systematically apply a methodology for assessing economic impacts of extreme meteorological events. The summary provided in paragraph 7.4 may provide a beginning.

Part 1 of the questionnaire covered wildland fires. Responses, 40 in total, to Part 1 of the suite of questionnaires were received from the following countries:

Region I - Benin, Botswana, Guinea, Malawi, Mali, Sudan, Tunisia
Region II - China, Iran, Mongolia, Thailand
Region III - Argentina, Peru, Uruguay
Region IV - Belize, Canada, Cuba, Dominican Republic, USA
Region V - Philippines, Malaysia (Australia is treated in detail in *Focus on Australia*)
Region VI - Austria, Bulgaria, Germany, Hungary, Ireland, Israel, Netherlands, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Turkey, Ukraine, United Kingdom, Yugoslavia.

Much valuable information was received on the method used by national meteorological and hydrological services to monitor fire danger. Many respondents indicated that there is a need for improved modelling and for systematic application of remotely sensed data. In several countries, there is growing use of Geographic Information Systems.

Information provided on impact of wildland fires on agriculture and forests was very sketchy, and for the most part subjective. Nevertheless, it is clear that globally, hundreds of lives are lost annually, as well as several billion dollars (US) and the destruction of many thousands of hectares of cropland and forest.

Part 2 of the questionnaire related to local severe storms. There were 40 responses as follows:

Region I - Benin, Botswana, Gabon, Guinea, Malawi, Mali, Sudan
Region II - China, India, Iran, Republic of Korea, Mongolia, Thailand
Region III - Argentina, Peru, Uruguay
Region IV - Belize, Canada, Cuba, Trinidad & Tobago, USA
Region IV - Malaysia, Philippines, Vanuatu (Australia is treated in detail in *Focus on Australia*)
Region VI - Austria, Bulgaria, Denmark, Germany, Israel, Netherlands, Poland, Portugal, Romania, Russian Federation, Spain, Switzerland, Turkey, Ukraine, United Kingdom, Yugoslavia.

Although local severe storms were considered a significant hazard to either or both agriculture and forests in all but one (Gabon) of nations in Region I, there were two other nations, viz. Benin and Guinea, who did not provide a warning service for local severe storms. Mali indicated that floods were also a problem for that nation. Agriculture in all countries in Region II was affected by local severe storms and forests in the Republic of Korea and India were also affected. Of the American nations responding to questionnaires, all but two (Peru and Belize) provided a warning service for local severe storms. Belize, however provides some unofficial advice. All these countries considered local serve storms a significant hazard for agriculture and most (exceptions Uruguay and Trinidad and Tobago), a significant hazard for their forests. In Region V, Vanuatu did not consider severe local storms to be a significant hazard to agriculture or forests and hence had no warning service. Philippines, although afflicted by all manifestations of severe local storms had not implemented a warning service. Malaysia, though only agriculture was affected, and flash flooding the only class of storm outcome, had implemented a local severe storm warning service. Information for Australia, also in Region V is given in *Focus on Australia*. In the main, Region VI respondents answered in the affirmative to providing a local severe storm warning service. Denmark did not, as severe local storms were not considered a hazard to primary industry in that country; Poland though subject to severe hail and wind gusts did not provide a service, nor did the Turkey, although subject to severe hail.

As with wildland fires, there was not a great deal of information on economic and social losses. Extrapolating those responses which were received, it is clear that each year there is the loss of dozens of human lives, thousands of stock and thousands of hectares of crops. Hail and flash flooding are major factors. The Canadian response comments that if major cities are hit by hail, damage (mainly to homes, buildings, and vehicles) can be several hundred million dollars (US) e.g. Calgary 1991 hailstorm damage was between $300 and $400 million, similarly for tornadoes: e.g. the Edmonton 31 July 1987 tornado claimed 27 lives and caused $250 million in damages.

Part 3 of the questionnaire related to tropical cyclones. In all, 16 responses were received. The respondents were Gabon, Malawi, China, India, Republic of Korea, Thailand, Belize, Canada, Cuba, Dominican Republic, USA, Malaysia, Philippines, Vanuatu, Israel and the United Kingdom. This total, however, included three countries, Gabon (Region I) and Israel and the United Kingdom (Region VI) which do not experience this natural hazard. (Responses from Australia are examined in the chapter *Focus on Australia).*

Tropical Cyclones were considered a significant natural hazard to both agriculture and forests by all respondents who experience tropical cyclones, with the exception of Malaysia who responded in the negative with respect to both agriculture and forestry. In response to Q2., China replied that the agricultural regions along the coastline in southeast China were affected by tropical cyclones in summer; Canada's response was that its Atlantic provinces were affected by decaying or dying remnants of tropical cyclones; Dominican Republic attested to their influence in the Caribbean Sea and the Gulf of Mexico. USA restricted their influence in its area of responsibility to the States on the eastern seaboard from Texas to Maine, to Puerto Rico and the Hawaiian Islands; Philippines cited their Regions I and II as the primary areas affected; Malaysia's answer restricted significant effects to Sabah.

As with the other extreme events, it was difficult to obtain a coherent picture of annual losses from tropical cyclones. Many nations provided no information at all on this question. Malawi listed livestock affected to be cattle and goats; crops to be tobacco, maize, tea, sugar and cotton; and timber varieties to be pine, bluegum and ameliora. No monetary values of (annual) losses were given. The Republic of Korea listed only "rice plant" as a crop affected by tropical cyclones; Thailand's response was (for crops) rice, upland crops and fruit and annual (areal) losses of 160,000 ha of these commodities; and (for timber variety) rain forest, monetary value $30 - 450 million and annual (areal) losses of 4,800 to 76,000 ha. The response from USA was $50 million annually from crop losses; Philippines reported livestock losses of about $4 million (for 1991) and crop losses of about $5 million (for 1992); for Vanuatu crops affected were coconuts ($165,000 to $826,000 losses) with an area damaged of 50,000 - 100,000 ha; cocoa ($41,000 to $226,000) with an area damaged of 10,000 to 20,000 ha and garden crops ($816,000 to $4,110,000) with an area damaged of 500 to 1000 ha. Thus, extrapolating from those responses received that annually there are billions of dollars (US) lost annually, including the destruction of thousands of hectares of crops. Losses are particularly severe in some small island countries which are affected occasionally, but devastatingly.

Arising from the report, I have made three significant recommendations for follow up action by the Commission for Agricultural Meteorology. They are relatively specific and, if implemented, could make a useful contribution to further planning and development of strategies to mitigate impacts of natural disasters and associated improvements in monitoring and warning systems as well as assessment of economic impacts. These issues are particularly significant in the context of the objectives of the International Decade for Natural Disaster Reduction.

7.2 INTRODUCTION

Most definitions of natural disasters, sometimes referred to as extreme events or natural hazards, include at least two components.

Gommes provides a useful definition of a disaster as "*the interface between an extreme physical event and a vulnerable human population.*" Their observation that the lower the level of development, the greater the relative loss of human life against material damage, is not unexpected.

Developed countries characteristically experience higher absolute material damage because of a greater level economic activity and a better developed infrastructure. Not-withstanding, in addition to greater loss of life and human injury from a climatic disaster in developing countries, losses to agricultural produce, particularly crops, generally represent proportionally greater material losses. In addition to direct losses, there are indirect effects which are likely to be at least 1.5 to 2 times the latter in economic terms. Some examples will be given in the report, mainly from the work of Gommes and Negre, (1992).

It is acknowledged here that, over the last 10 to 20 years, operational agro-meteorological models have assumed an increasing importance in agriculture and are now widely used, particularly in developed countries, for forecasting and assessing yields of both cash export crops and major food crops. In common with all models they are developed, for the most part to operate within the normal range of environmental factors and mostly don't cope with exceptional weather events such as the major floods which affected southern China in June 1994 reported (*Herald-Sun* newspaper, Melbourne, Australia of 20 June, 1994) a loss of more than 400 lives, 6470 injured, 20 million affected, 482,000 houses destroyed, 3 million hectares of cultivated land inundated, putting the cost of damage at 16.86 billion yuan ($2.7 billion) (*AFP Reuters*). This report indicates complementary databases and methodologies which may facilitate the development of preparedness measures in both pre and post disaster phases.

Although categories of natural disasters include meteorological, geological and epidemiological events, most of the report will concentrate on meteorological events, with perhaps minor comments on geological events with a meteorological component likely to result in losses to forestry or agricultural operations e.g. landslides. The main thrust will be on wildland fires, severe local storms and hurricanes. Subcategories of these which will be mentioned are hailstorms, tornadoes, thunderstorms and heavy rains/flash flooding (associated with severe local storms); storm surges, heavy rains/floods associated with hurricanes. Although river flooding will not be a major focus of this report unless associated with tropical cyclone activity. Some attention will be focussed on frost and heatwaves.

The report will examine and evaluate the status quo particularly in relation to pre and post disaster infrastructure in as many countries as possible, explore emerging tools and methodologies and suggest potentially viable ways of minimising (predominantly economic) damage caused by meteorologically related natural disasters, to agriculture and forestry, mainly by highlighting areas where research and development effort is warranted.

7.3 LITERATURE SURVEY, INCLUDING SOME EXAMPLES OF RECENT NATURAL DISASTERS

Summaries of methodologies, results and conclusions from applied scientific and operational literature are interspersed throughout this report under appropriate chapter headings. Although the electronic library accession system of the Australian Bureau of Meteorology was used, many of the publications and papers identified originated from a relatively small number of countries or agencies, particularly USA, China, Australia, New Zealand, WMO and FAO.

Clearly there is much more material which has a strong bearing on scientific aspects of decision support and warning systems, but because much of the scientific bases of operational systems is given in bibliographies of individual papers, most has judiciously been omitted from the list of references given in paragraph 7.13. Hazard reduction measures are in place in a significant number of the nations surveyed and ongoing research and development to improve and expand these measures are also a features of many national strategies to minimise adverse effects. Interpreting the scope of the report in a broad sense, all references cited contain material with some relevance to the topic. Detailed descriptions of established systems such as those quoted in paagraph 7.10, e.g. USA *BEHAVE* fire weather system are not given as it is assumed such are readily available in the literature.

7.3.1 Examples of recent disasters, some appreciation of their effects on the country's populace, economy and infrastructure and other pertinent remarks.

Restoration of Agricultural Production of Areas of Venezuela Affected by the Tropical Storm, "Bret". (FAO, 1994)

On 7-8 August, 1993, tropical storm Bret affected a considerable area of Venezuela, caused significant loss of life in metropolitan Caracas, had major economic and social impact on several regions, and was very severe in the rural sector, particularly in the states of Barinas and Portuguesa, due to the prolonged heavy rains which accompanied the storm. The magnitude of the disaster can be appreciated by noting that, according to Civil Defence records, 20,000 people were directly affected by flooding, 5000 needing external assistance.

The agricultural losses from the disaster affected areas were, according to official sources, 14,000 ha. of maize (22% of the area under cultivtion), 1,500 ha. of rice, 750 ha. of cassava, 150 ha. of bananas, 150 ha. of horticulture/fruit trees, as well as 2000 head of cattle, large numbers of pigs, poultry and other animals. The magnitude of the losses were so great that emergency relief was sought via the Program of Technical Cooperation from FAO, who were able to implement a 12 month project to help in the recovery phase. The project included activities aimed at disaster mitigation and prevention. The project is comprehensively discussed in FAO, 1994.

Following its involvement in the recovery phase of this event, FAO made a number of recommendations aimed at prevention and mitigation of damage to, inter alia, the agricultural sector from a similar future storm. These included:

(a) To unify the system of providing meteorological warnings, and by doing this, identifying and overcoming the shortcomings evidenced within the system operating when Bret occurred;

(b) To continue and increase studies of the kind which assist agriculturalists with their management and planning activities and to establish an infrastructure by which the results of this focussed research is passed to enterprises interested in agricultural production, particularly to the poor and those most in need of this help;

(c) To strengthen the structures and functionality of Civil Defence, incorporating new and varied protection measures for the population and their economic and social concerns. In addition there was a need to improve contingency planning for disasters to include a better and broader definition of goals to be achieved for each of the factors operating in natural disaster situations, and by means of mass media dissemination, talks, seminars, conferences and other means, reach and instruct the citizenry;

(d) To instigate projects for the areas affected with multiple objectives which include: protection of river basins, sanitisation of affected lands, improvements to river drainage, improvements in agriculture and grazing practices taking into account the agricultural lifestyles of the regions concerned, improvement of income levels and living standards of rural communities. Towards the last objective the FAO recommended financial support for the identification, preparation and implementation of agricultural development projects and environmental improvement.

Reported Damages to the Economy of Jordan Resulting from Heavy Rainfall and Snow Storms in Winter, 1992.

At the time when the Government of Jordan was actively working to prepare and implement a recovery and economic adjustment program to deal with the aftermath and devastating consequences of the Gulf Crisis on the economy of Jordan, the country witnessed a persistence of unusually severe weather conditions as heavy rains and snow storms hit the country and caused significant damage to the economy. Such rare weather conditions had been witnessed previously only in 1922 and 1951. In normal weather conditions, the heavy rainfall and snow which started in late December, 1991 would indicate a good return to the agricultural sector. However this expectation was soon shattered by frosts and freezing temperatures which began in the second half of January, 1992.

Agriculture sustained the worst losses, followed by losses to roads and highways, Government infrastructures including telecommunications and school buildings, drinking and waste water networks, private property and power grids. Total losses in 1992 $US were $115.6 M of which $70.8 M was sustained by agriculture.

In the Jordan Valley, which accounts for the bulk of Jordan's agricultural production, hundreds of dunums of land cultivated with seasonal fruits and vegetables were completely destroyed, vegetable and fruit crops were lost to frost damage, gales destroyed plastic and glass greenhouses, and tunnels, and uprooted trees in orchards and windbreaks. In the north of the country, damage to trees, mainly olive, was estimated at, at least 75 %, crushed by the weight of snow. The river Jordan was converted from a tiny rivulet to a torrent more than a kilometre wide, flooding and destroying irrigated fields and orchards. Water storage were overtopped, contributing to the flood calamity of the Jordan Valley. In the Highlands, heavy snow and storms destroyed plastic housing, allowing frosts to destroy the intensive crops. The weight of snow badly damaged olive and fruit trees. The latter were also affected by deep frost. Large losses of sheep and goats occurred in eastern and southern parts of the country. Relief operations were hampered by the adverse weather conditions which lasted for several weeks. By early February a large number of farming families had already been deprived of their livelihood, with irreparable damage to intensive crop installations, irrigation infrastructure and great stock and crop losses with the worst storm (24 of February) to bring further damage and destruction.

Impact on Mozambique from Cyclone "Nadya"

Another example of a natural disaster was that of cyclone *Nadya* which affected 13 of the 22 districts in Nampula, Mozambique in early April, 1994. Heaviest damages were sustained in coastal districts of Nacala Porto, Ilha de Mocambicue and Angoche. About 1.5 million people of the Nampula province were affected. Food crops such as maize, cashew, maxdeira, mapira and cassava were badly affected about two weeks before harvest. In the worst affected districts 80% of these crops were lost and about 870,000 people are considered the worst affected. In addition to its affect on agriculture, the cyclone caused outbreaks of diarrhoea and cholera associated with unsanitary conditions, destroyed 170 km of mains electricity lines, as well as 95% of the energy supply network and many other equally disruptive effects on the populace. International assistance was requested and provided with restoration of agriculture for the 1994-95 harvest being the greatest priority. Some early estimates of damage and restoration costs for some of the effects of the cyclone were all that was available at the time of writing this report. (DHA,1994).

Impact of Heavy Rains of 22, 23, and 24 November, 1993 on Guantánamo, Cuba

The information sources for this event are somewhat fragmentary (UNDP, 1993; Guantánamo Provincial Assembly, 1993; Cuban Representative of FAO, (CRF) 1993). However they point to a torrential rain event, occurring between 22 and 25 November, which affected the Cuban provinces of Guantanamo, Santiago de Cuba and Holguin, with the first of these being the most severely affected. Reported rainfall totals at stations in Guantánamo to the morning of 24 November were:

- Niceto Pérez - 300 mm;
- Felicidad de Yateras - 230 mm;
- Ciudad Guantánamo - 226 mm;

- Songo-la Maya - 223 mm (Possibly erroneous);
- Valle Caujerí - 200 mm.

These totals were greatly in excess of November rainfall totals for the decade 1980-89 for the province. (These ranged from 44 mm to 121 mm) Some of the resultant disruption to this province is conveyed by reference to a table on page 5 of CRF, 1993: viz.

Close to 24,000 people were evacuated from their homes between 25 and 30 November; 4,618 dwellings were damaged (618) or destroyed (4000); there were 27 deaths and 3 people missing by the end of the event; agricultural losses included 4,020 ha of various crops; 697 ha of cassava, 429 ha of garden vegetables, 2,734 ha of sugar cane, 200 head of cattle, 3000 domestic birds, and significant production losses of milk, eggs and salt (from desalinisation plant). Another table in CRF, 1993 titled "Evaluation of Damage in Guantánamo" for the FAO Assistance Project, formatted the available losses in terms of:

- Tonnage of tuber, root and banana crop production lost: 10, 580;
- Tonnage of garden vegetables lost: 3,673;
- Tonnage of grains lost: 1,061.

Available documentation does not give any reduction and/or mitigation recommendations from the FAO project team in relation to this event.

Disaster in the South Pacific: Impact of Tropical Cyclone "Namu" on the Solomon Islands, 18-20 May 1986.

Tropical Cyclone Namu caused 150 deaths and nearly one third of the population (total = 267,000) to leave their homes. The worst of the devastation was on the coast exposed to the southeast winds. Three days of torrential rain caused massive downstream flooding with rivers depositing debris and mud over the country's prime agricultural basin. Floodwaters brought down huge highland rain-forest trees (an estimated 20,000 tonnes of trees washed down), which contributed to secondary hazards such as landslides and severe structural damage to buildings, roads and bridges. Entire villages were smothered in mud and were abandoned. It has been suggested that indiscriminate logging may have aggravated conditions.

Agricultural losses, especially timber, cocoa, coconuts, and palm oil were particularly heavy. It was estimated that 10-15% oil palm, 15-20% copra and 10-25% cocoa production would be lost over the following 3 years.

Because the Solomon Islands economy is heavily dependent on the export of a few primary commodities, all of which were adversely affected by the cyclone, the Ministry of Economic Planning expected that it would take seven years for the economy to recover. In mid-July 1986, the economic loss due to the cyclone was about 13% GDP and about 26% of total export earnings.

7.3.2 Example of human fire management activities contributing to degradation of forest environment in the Amazon basin

Although not strictly in keeping with the specific thrust of this report, the following summary of the affects of adverse fire "management" is included.

Kauffman *et al.*, (1993) state that unprecedented rates of deforestation and biomass burning in tropical dry forests are dramatically influencing biogeochemical cycles, resulting in resource depletion, declines in biodiversity, and atmospheric pollution. The effects of deforestation and varying levels of slash-fire severity on nutrient losses and redistribution in a second growth tropical dry forest ("Catinga") near Serra Talhada, Pernambuco, Brazil were quantified in this study. Three experimental fires were conducted during the 1989 burning season. As much as 96% of the prefire aboveground nitrogen and carbon pools and 56% of the prefire aboveground phosphorous pool was lost during combustion processes. With increasing fire severity, the concentrations of nitrogen and phosphorus in ash decreased while the concentration of calcium increased. This indicates greater amounts of these nutrients were volatilised (i.e., greater ecosystem losses occurred) with increasing fire severity. Following fire, up to 47% of the residual above ground nitrogen and 84% of the residual above ground phosphorus were in the form of ash, which was quickly lost from the site via wind erosion. Based upon the measured losses of nutrients from these single slash burning events, it would likely require a century or more of fallow for reaccumulation to occur. However, current fallow periods in this region are 15 years or less.

7.4 REVIEW OF METHODOLOGIES FOR ASSESSING ECONOMIC AND SOCIAL BENEFITS

7.4.1 Introduction

In a general way, knowledge of weather and its evolution constitutes a resource whose implications are at the same time economic and social: economic, since this information is a factor in the management of activities and resources, and soial, since meteorology is closely tied to measures to ensure the security of people and property. Thus it influences both individual and collective behaviour. (Extract from the *Report of the Economic and Social Council of France - January, 1985).*

Various studies have been undertaken to attempt to assess socio-economic benefits of meteorological data. The studies described in this chapter are intended to provide examples of more or less in depth social and/or economic investigations which may be used as models when similar decisions need to be taken or information extracted; questions such as:

- should a particular innovation be embraced in a specific situation; and
- what are as accurately as can be ascertained, the real costs to various communities of specific natural hazards.

7.4.2 Methods for assessing economic benefits based on an australian study

Introductory Comments

This section is based on a paper by Andaman *et al.*, (1995), which reported a major study being undertaken by the Macquarie University (Sydney, Australia) in collaboration with the Australian Bureau of Meteorology. Andaman, as an economist brings a rigorous methodology to bear, this being of particular value in assessing economic impacts of meteorological events and services. The study was financed by the Australian Research Council and an earlier version of this paper was presented at the World Meteorological Organisation Conference on the Economic Benefits of Meteorological and Hydrological Services held in Geneva, Switzerland from 19-23 September 1994.

Methods for valuing the economic benefits of services include the direct economic benefits derived from the use of meteorological services for producers and consumers based on the producer and consumer surplus concepts, simulation modelling incorporating economic optimisation based on the cost-loss ratio technique and cost function analysis to establish the effect of the quality of weather information on the operating costs of a business fim. The average cost of climate-related natural disasters is high and of necessity, this section will refer in some detail to Australian experience. This is not necessarily a disadvantage, since Australia whilst possessing an advanced economy experiences a representative range of extreme events, ranging from tropical cyclones, through severe storms to major fires. Direct economic losses of least one billion Australian dollars (A$) are experienced annually by individuals and the general public (Blong, 1992). It can reach as much as A$10 billion in some years (Australian Bureau of Meteorology, 1993). Joy (1991), for example, reports that the total insurance payouts provided by the Insurance Council of Australia for the five main insurable natural disasters (i.e. bushfires, cyclones, severe storms, floods and earthquakes) over the 20-year period from 1970 to 1989 was about A$4.6 billion with tropical cyclone payouts accounting for about 33% of the total payments. He also indicates that insurance payouts do not cover the total damage caused by severe weather events with insurance costs, for example, representing just about 25% of the total damage due to severe storms. Severe storms (thunderstorms) are the second most costly weather phenomenon in Australia after tropical cyclones. A severe hailstorm in Sydney on the 18th of March 1990 caused damage to insured property worth a total of A$313.5 million (Mitchell and Griffiths, 1993).

However as noted by Ryan (1993), significant benefits can also arise from severe weather events. For example, tropical cyclones can result in increased inland rainfall, benefiting agriculture. Blong (1992) also indicates several benefits of severe weather hazards. These include the fixing of atmospheric nitrogen by thunderstorms, the germination of many native plant species resulting from bushfires, the maintenance of the fertility of floodplain soils due to flooding and the reduction of the background human death rates due to the occurrence of severe storms forcing fatigued and sleepy drivers from using the roads.

Important sectors of the economy such as aviation, agriculture, mining and tourism which are major export earners, are very sensitive to adverse weather and climate. The major policy challenge resulting from the extreme variability of the climate and the frequent occurrences of weather-induced natural disasters such as bushfires, heatwaves, cyclones, severe thunder-storms and tropical cyclones is for the establishment of measures to manage the economy, to respond effectively to these events and allow for quick recovery of local areas that suffer from natural hazards. Reduction of weather-induced disasters through disaster avoidance measures offers important economic and social gains, for example, through the reduction in injuries and loss of life and through increased benefits that accrue to major weather-sensitive industries.

Major decisions at all levels of government are increasingly being subjected to approval based on benefit-cost analysis in an era of widening and extensive application of meteorological services made possible by advanced technology and growing customer demand for specialist services. The study by Andaman et al reviews several methods for the estimation of the economic and social benefits of meteorological services with particular emphasis on Australia. The meteorological services considered are the basic public weather service generally classified as a public good and a host of user-pay specialist services produced by the Bureau of Meteorology for business firms in selected sectors of the Australian economy. The contingent valuation technique commonly used for the measurement of the economic value of public goods is discussed including its usefulness and limitations for measuring the benefits of the basic public weather service. The social benefits of meteorological services are also considered important, but with the acknowledgment of the difficulty in placing monetary values on these benefits.

Public weather services account for about 60% of the total expenditures on meteorological services in New Zealand, about 84% in Australia and close to 100% in many countries. These services have been directly financed by Government in all countries over the last 150 years. The political process by and large determines the level, extent and the mechanism of collection of charges if *any* to be levied on individuals using public goods with particular attention paid in practice to the effect of user' charges on income distribution and the taking of disaster avoidance and protective measures to reduce the effects of natural hazards. The economic value is an important factor but non-economic and social values held by the public at large are also important in the choice of policy strategies for the supply of public goods.

Economic theoretical framework

Basic public weather forecasts and warnings display two important "public good" characteristics i.e. *they are indivisible and generally non-exclusive.* The consumption of public weather services is *non-rival* because the consumption by one individual does not reduce the availability of the forecasts and warnings to others and hence they are classified as *indivisible.* In addition, in virtually all countries, the political process ensures that the basic public weather forecasts and warnings are provided freely to the general public through the mass media and hence they are *non-exclusive.* Because individuals are not excluded from using these weather services once the information is available through the mass media, the marginal cost of using that information is zero. However the *production* of these services is not free even though they are provided at no direct charge to the public. Therefore it will be improper to use the market price to establish the economic value of these services. The theoretical framework for determining the economic value of public goods and services using contingent valuation techniques can be explained either using (a) algebraic analysis or (b) graphical analysis.

Discussion of the contingent valuation method

Contingent valuation techniques involve the researcher creating a hypothetical or artificial market for a public good. A group of actual or potential users are requested through surveys to indicate their *stated preferences* in terms of the amounts of money they are willing to pay for different levels of quality or quantity of the public good. The most popular contingent valuation techniques used to estimate the economic value of public goods are direct questioning of respondents and iterative bidding techniques (Randall, 1981). Direct questioning involves asking respondents directly how much they are willing or prepared to pay for a particular type of public or non-market good based on surveys. This approach is widely used especially with mail-in and telephone surveys because it is relatively inexpensive. However the good in question must be well defined and comprehensible to the respondents. Iterative bidding technique also involves surveys. However the researcher varies the amount of money that the respondent is prepared to pay until the highest amount is ascertained. This highest amount then becomes the individual's willingness-to-pay (WTP) for the public good.

Usefulness of the contingent valuation technique

The usefulness of the WTP approach is that it allows for the establishment of economic valuation and desirability of the public good based on the real income and price situations faced by individuals and the sacrifice that individuals are prepared to undertake in terms of them giving up the consumption of some of the market goods and services available to them for the public good in question. Approaches that value public goods by asking individuals to indicate the "social" values that they attach to these goods are often inappropriate for economic policy decisions because they ignore the income constraints of the individuals and the existing prices of market goods and services. This it could be possible for individuals to express their values for public goods beyond the levels of income earned by them. This may give exaggerated values of the public good in question and distort the allocation of Government or taxpayers' monies for the maintenance or supply of the good *vis à vis* other public goods in the economy.

The major limitation of the contingent valuation approach lies in the potential measurement problems involved in estimating WTP of public goods through surveys. Other limitations include the fact that the approach does not measure non-economic values such as the religious and moral conviction of individuals for having access to a public good and community values like natural justice.

The use of enhanced information about the natural world by, for example agricultural producers, may lead to an increase in the supply of weather and climate-sensitive commodities. In economic terms, improved information may lead to a downward shift of the supply curve of the commodity. The shift in the supply curve of a commodity as a result of the use of improved information lead to changes in the economic welfare of producers and consumers. On the other hand, the use of the improved information about the natural world by producers may sometimes have negligible effect on the market price of the commodity even though production may have increased. This may imply that there is no change in the consumer surplus **because the market price of the commodity with the unimproved information service is the same as the market price with the improved information service**. The change in producer surplus can be estimated by the incremental net returns of producers from using the improved information service, for example, through surveys.

Lave (1963) was one of the first economists to investigate the impacts of improved weather information on the market prices of commodities and concluded that a modest increase in supply due to the use of improved weather forecasts for the production of raisins would reduce the total profits of the raisins industry because of the inelastic demand of the commodity. Babcock (1990) has suggested that improved weather and climate information may reduce the level of producer surplus (net returns) given an inelastic demand of the commodity not only because of the increase in expected supply but also due to a possible reduction of supply by producers (using the improved weather information) being aware that it may lead to a reduction in total industry profits.

Cost function analysis

Costs are incurred by any business firm to produce a commodity or service. Some of the costs of production include wages and salaries paid for hired workers and prices of raw materials. A *cost function is* defined by economists as a relationship between the costs incurred by the business firm and the level of output of the commodity and the prices of inputs used by the firm in the production process. A *production function is* defined as the schedule that gives the maximum quantity of output that can be produced from a given set of inputs and technology. Based on a simple assumption that the manager of a firm attempts to minimise the costs of producing any given level of output, economic theory.

A flexible form of cost function can allow the establishment of the effect of the quality of meteorological information on the total cost of a business firm such as an airline company. Meteorological services also provide social benefits in terms of the provision of data and information to assist national, state and local authorities to monitor and control rural and urban pollution, energy and coastal development policies and improved national defence from weather services supplied to the military.

7.4.3 Evaluation of an enhanced weather service for cotton growers

Part of the series of studies described by Andaman is a sample survey of 152 out of a total of 326 members of the Namoi Cotton Cooperative in New South Wales, Australia. This Cooperative is a subscriber of a specialised user-pay enhanced weather service produced by the Bureau of Meteorology Regional Office in Sydney targeting cotton producers. The survey is being undertaken to determine the effectiveness of information these users receive from the Bureau.

7.4.4 Estimation of the economic benefits of tropical cyclone warning services

Tropical cyclones have significant economic impact in many regions, including the northern part of Australia, especially in terms of property damage and human casualties. Tropical Cyclone Warning Services (TCWS) have improved the conditions of people living in cyclone-prone areas through the reduction of human deaths and property damage. The first component of this sub-project involves the use of a contingent valuation technique to estimate the benefits people in cyclone-prone areas derive from TCWS. A sample of residents in cyclone-prone areas of Queensland, Australia are asked to indicate the *maximum amount of extra tax* that they are prepared to pay (WTP) to finance the TCWS. The WTP values are elicited based on information on the actual probability of being hit by a tropical cyclone and the average impact in terms of property damage, the number of human deaths and related casualties. The aggregate WOP values are compared with (a) historical tropical cyclone payouts and (b) the estimates of the societal economic value of lost human lives from tropical cyclones based on the concept of the economic value of a "statistical" life.

The second part of the sub-project considers the effect of overwarning about tropical cyclones on the revenues of tourist operators. The costs of overwarning due to inaccurate forecasts is an important part of the costs of TCWS. Much of the benefits resulting from the upgrade of the TCWS are likely to come from reduced overwarning. An important industry cost caused by overwarning is hotel cancellations (Sofield, 1993). There are indications that the relationship between hotel cancellations and cyclone warnings could be of economic importance to the tourism industry in Queensland. However a significant statistical relationship is yet to be established. The impact of TCWS on tourism industry revenues is being investigated through multiple regression analysis involving time-series and cross-sectional data.

In addition WTP values for public weather services will tend to depend directly on the levels of income of individuals as implied by economic theory of demand. The contribution of individuals to general Government tax revenues also depends on earned income with higher income earners paying relatively more taxes. Therefore in real life, the production of public weather services in all countries has been achieved through Government financing based on taxpayers' monies through contributions by all taxpayers. This financing approach has been used in order to assure a basic minimum level of warnings to all individuals for public safety and to minimise Government disaster relief payments and related social welfare payments in the event of severe weather events as people are expected to use the public weather information to protect themselves and their property. Government disaster relief and other related social welfare payments could be very high for areas where people are not warned in advance of impending severe weather events.

7.4.5 A Study of the economic effect of the bushfires in South Australia on 16 February 1983

Healey, Jarrett and McKay (1985), have produced a study of the economic effect of the bushfires in South Australia on the 16 February 1983. An examination of the study would show that the costs are large and ill defined. It was demonstrated that the difficulties in estimating the costs of such a disaster were so great that accurate estimates will probably never be made.

Some of the major points were that the costs were not equally borne by all the members of the community and considerable costs were born by Governments at local, regional and national level. Costs of prevention and the costs of volunteer firefighting were estimated.

An attempt was made to estimate the effect of the fires on the input-output aspects of the South Australian economy. Healy concluded "This study has attempted to provide estimates of the economic impacts of the Ash Wednesday bushfires in terms of the consequences for output and income in the State economy of South Australia. Direct production losses in agriculture and forestry were modelled, with significant flow-on effects to other sectors being found. In particular, the manufacturing and finance sectors were found to be significantly affected, the former via direct production linkages and reduced household consumption spending, the later via reduced household consumption. Estimation of the results classified by thirty-six sectors showed that the most affected of the manufacturing sectors were those making machinery, appliances and equipment. The motor vehicles sector was also significantly affected. Other tertiary sectors such as trade and community services were also affected by the lost economic production.

Reparation activity in the aftermath of the fires was modelled in terms of asset replacement (other than livestock) and forestry stockpiling operations. The manufacturing and finance sectors were again found to be the major recipients of the flow-on effects, with some impacts also being felt in community services, trade and transport and communication.

In conclusion, it is clear that a natural disaster, such as a bushfire, has widespread economic effects in parts of the economy other than those directly affected by the disaster. Any proper assessment of bushfire damage, and a study of the benefits of bushfire prevention, would do well to take these conclusions into account".

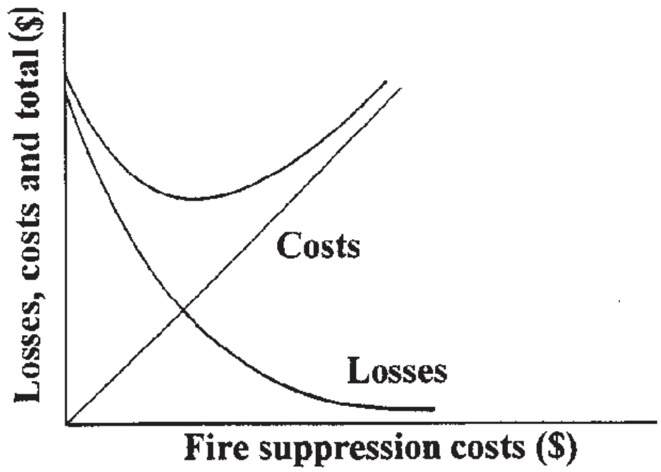


Figure 7.1 - Cost-plus-loss fire suppression.

7.4.6 A cost-benefit study from France of forest fire protection measures with a particular focus on meteorological information

Roux (1992) attempted to assess the cost benefit ratio related to the supply of operational meteorological information to forest fire fighting units in the southeast of France. Assessments comparing the cost of supplying meteorological information to the community at large with benefits provided by its availability give benefits of between 10 and 30 times costs. The author sought to detail known costs and probable benefits by considering losses avoided through the prevention of a major forest fire. His arguments are summarised here.

The author chose the south east of France since he was familiar with the enhanced meteorological services provided during the forest fire danger period there of about 100 days duration and was able to ascertain in some detail the (daily) cost of the various components of forest fire fighting initiatives. Costs of these various components are tabled below:

Cost of meteorological information

For 100 days of campaign each summer, the costs are the following:

Personnel	about	600,000 FF
Materials (amortised annually over five years)	about	60,000 FF
Infrastructure	about	300,000 FF
Total		960,000 FF
	or about	1,000,000 FF
	This is about	10,000 FF/da

Comparisons

Daily cost of meteorological information	10,000 FF
Cost of preventative land based personnel and infrastructure	250,000 to 750,000/day
Hourly cost of a water-bombing aircraft	20,000 FF
Cost of ground based fire fighting	1,000,000 FF/1000ha
Global cost estimate of a fire	7,000,000 to 12,000,000 FF/1000 ha

The author stressed that it is always difficult to evaluate the economic impact of meteorological information and this pertains equally when related to the operations and infrastructure assembled to minimise the occurrence, areal extent and frequency and hence socio-economic impact of forest fires on a given community.

Two broad scenarios were postulated for the use of meteorological data, viz:

(a) The domain of decision support, concerned with putting in place preventative measures by means of reference to meteorological data. This use often achieves large savings; and

(b) Specific and regular use of meteorological information by industry and agriculture. Incremental savings are achieved.

The severity of a forest fire weather season is strongly related to past, present and future meteorological conditions and is considered to best reflect the first scenario elucidated above. Meteorological information helps to decide the nature and extent of preventative measures and also is of overriding importance in fighting going fires. Outcomes of timely, accurate and well formatted meteorological information, given an adequate response infrastructure, are reflected by (often greatly) reduced social and economic impacts. Four stages in the management of this problem are postulated:

(a) Basic preventative action before the active fire season. This involves management of the forest environment (reviewing and constructing fire breaks, delineating watering points used for aerial attack, clearing forest litter and undergrowth, prescribed burns) and distributing general information to communities and activity sectors in the region. Meteorological forecasts are provided for fuel reduction burns, otherwise the effect of meteorological information in this domain is indirect though useful. The cost-benefit relationship of public information is difficult to evaluate but if thoughtfully produced with concrete suggestions and practical information, it is part of the investment that should be made;

(b) Just before and during the season. The emphasis now turns to the system's readiness within the framework of a global strategy. Meteorological information includes daily weather bulletins; longer term forecasts (several days ahead) of essential parameters, particularly rain, temperature and wind; detailed forecasts on a small scale and in the short term. Tailored quality information, used efficiently will permit optimal management of the risk situation. If on the other hand, the meteorological information is absent, deficient or badly formulated, the consequences can be grave;

(c) While a fire is occurring. The problem now is fighting and management of the fire, whether it be the original or a back burn to counter its progress. Timely, tailored and accurate meteorological information is of key importance provided those at the fire front are well trained in its use and are equipped to choose the fire fighting tactics best suited to limiting the area burnt. The type of meteorological information at this juncture is real time and short to very short term forecasts. Although not mentioned in this paper, fire authorities in Australia and USA have found that outposting of trained meteorological staff with portable automatic weather stations and access to selected charts, satellite data and other resources has led to better interpretation of conditions and guidance material than staff in the central office are able to provide. It is in this situation that deficiencies in meteorological information and forecast advice can be catastrophic, both in loss of human life and proportionately greater property losses and environmental damage;

(d) After the fire this is the time for rehabilitation of the environment, including replanting and re-stocking with animal varieties, attention to soil erosion problems etc. In this phase meteorological information plays only a minor role but the cost of these operations and other consequences of a major conflagration is always very high and probably impossible to evaluate fully. Such costs are in fact the cost of failure of the preventative strategies, including, on occasions, shortcomings in the meteorological service provided to the fire fighting organisations.

The other aspect to consider is that of evaluation of damage avoided by preventive measures, effective fire fighting techniques and good logistical planning. Unfortunately, as in other areas, this evaluation is almost impossible. However if one admits that in certain conditions, quick and accurate response to fire outbreaks. (The service in the southeast of France is geared to rapid detection of fires and extinguishing each fire within 10 minutes of detection) avoids at least one large fire (a notion which varies from one country to another) has been avoided, then one can have some measure of damage avoided. A key aspect is avoidance of environmental damage, which is extremely difficult to determine but nevertheless a key element in the cost-benefit equation.

7.4.7 Costs and benefits of tropical cyclones, severe thunderstorms and bushfires in Australia - Two Studies

The first study of Ryan did not address the issue of the value of warning services, but confined itself to historical costs and, to a much lesser degree, benefits of the three hazards. The primary source of cost data for the study was insurance payout summaries provided by the Insurance Council of Australia (ICA), combined with records of deaths. Little information on the magnitude of benefits was found to be available.

It was found that the insurance payouts for damage caused by the three hazards over the 25 year period from 1967-91 throughout Australia, at 1989 values, were:

- tropical cyclones, $A 1,715 million;
- severe storms $A 1,808 million; and
- bushfires - $A 488 million.

The relatively low figure for bushfires reflects the fact that forest areas are usually not insured.

Some of the benefits of these natural hazards were identified as rainfall, natural fertiliser (from the effect of lightning on atmospheric nitrogen) and germination of native plants. However, no estimates were made of the magnitude of these effects. The study concluded that the available data on costs and benefits are inadequate to identify any trends which may exist and that predictions of changes in severe weather costs and benefits, based on climate change scenarios, should be approached with extreme caution.

The second study of Joy was confined to estimates of the cost of natural disasters in Australia, but examined a wider range of hazards. As well as analysing cost data for cyclones, storms and fires, Joy also presented figures for floods, droughts, bushfires, earthquakes, storm surge and coastal erosion.

The "manageability" of the hazards was also considered and assessed. Joy identifies three ways in which disasters can be managed to reduce their adverse impacts:

- by modifying the behaviour of the disaster itself;
- by modifying physical infrastructure to reduce risk of damage; and
- by modifying the social infrastructure of communities at risk, i.e. the population response to the disaster.

The availability of mitigation measures such as levees and dams, and the predictability of the location of the threat make floods the most manageable of the hazards considered.

Insurance claim data again formed the basis of the analysis, but an attempt was made to include the public costs incurred by government in response and relief operations and the extra private costs not covered by insurance. The annual component costs and their totals for each hazard are shown in **Table 7.1**.

Table 7.1

Resource type	Number of home bases	Optimal number of aircraft at each base	Area savings (ha)	Gross savings ($'000)	Fixed costs ($'000)	Net savings ($'000)
Airtrankers						
DC6	1	1	6907	660	524	138
Bell 212	1	2	4544	306	228	78
Thrust Commander	3	2	3445	237	160	77
Bell 206	2	2	3269	232	204	28
DC4	1	1	4109	344	336	8
Tracker	1	1	3149	227	301	-74
CL-215	1	1	2579	233	511	-278
Hercules	1	1	5317	415	788	-373
Ground crew	No. of districts					
Machine	45		8947	713	598	115
Hand	45		3531	372	309	63

NOTES: The results are based (unless otherwise specified) on:

- the number of available aircraft indicated above;
- utilisation on any fire of the number of aircraft providing the best savings, up to a maximum of the number available at nearest base;

- fixed costs for the number at each base times the number of bases;
- exclusive use of each model in turn, ie. no combinations of different models;
- use of whichever retardant type provided the best savings on each fire;
- costs and losses are on a common level, June 1983, using C.P.I. for Melbourne.

7.5 REVIEW OF METHODOLOGIES FOR DAMAGE ASSESSMENT OF NATURAL DISASTERS

7.5.1 Introduction

This Chapter is based upon work reported by Gommes and Negre (1992). They referred to Susman's (1983) definition of a disaster as "the interface between an extreme physical event and a vulnerable human population." Various studies have highlighted the link between the level of economic development and the material damage caused by natural disasters. The effects in various counties have been assessed by post event surveys **Figure 7.2** taken from the Gommes and Negre report and based on UNDRO data illustrates the general schematic relationship.

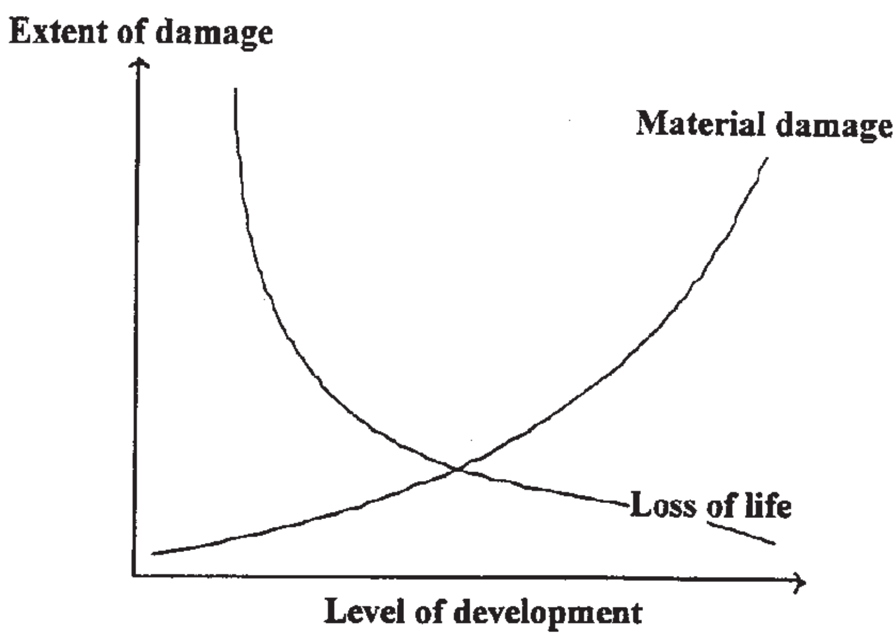


Figure 7.2 - Relative importance of disaster-caused material damage and loss of life according to the level of development (after UNDRO 1979).

Two broad categories of effects were identified:

(a) Direct effects on property and income of people and enterprises in the private or public sectors; and

(b) Indirect effects caused by reduced income arising from such factors as decrease of production, environmental degradation and other factors related to a natural disaster.

For most developing countries, most impact and damage from natural disasters is caused by deaths and injuries and by crop losses. In many developing countries, cash crops represent a major source of export revenue. The Gommes Negre study provides representative examples of impacts within the agricultural sector, for several less developed countries.

The first example is an analysis of damage to the agricultural sector in Madagascar in 1983-84 due to a series of tropical cyclones. The Food and Agriculture Organization (FAO) Office for Special Relief Operations estimated that crop losses represented 85% of total damage to the agricultural sector, whereas damage to infrastructure and equipment (drainage and irrigation channels, fishing gear) barely reached 15%. Five fishermen were lost. Another example given was the effect of Hurricane Juana on Nicaragua in late 1988. Direct losses of export crops amounted to 21% of total losses, 35% of the coffee and banana crop was damaged and livestock losses were 8%.

Forest fires represent an important source of forest produce losses, particularly in many sub tropical and temperate countries. Parts of this report focus directly upon the Australian experience; therefore a further example from Gommes and Negre will be cited. In examining the causes of damageto forest plantations in South Africa, about 83% of financial losses were due to fire, 12.7% to rodents and less than 2% to wind. Thus, because of the severe damage caused by fires, the relatively smaller percentage area burnt accounted for most of the economic losses. Damage figures were analysed to vary from US$300/ha for fires and fungi to US$6/ha for insects. Weather factors occupied intermediate values varying from US$12/ha for snow and hail, US$35/ha for wind to US$132/ha for drought.

In many areas, e.g. Bangladesh and in the Sahelian zone of Africa, there is a particularly high risk of damage to agricultural production from natural disasters. An analysis of rice production in Aman, Bangladesh over a 34 year period to 1984 undertaken by Rahman shows that the inter annual variation of rice production due to floods and cyclones may be as much as 20 to 25%.

7.5.2 Agricultural strategies adopted in areas with high weather risk

Strategies vary widely according to the level of development, the type of disaster and the desired outcome which can vary between maximising monetary benefits and stabilising food supply. Key features of the two extreme options are as follows:

(a) To maximise monetary benefits, there may be high infrastructure costs such as construction of embankments or dams, irrigation schemes in drought prone countries, advanced processing and storage systems and high yield plant varieties. Often, disaster warning and monitoring systems, and insurance can reduce losses and damage, spread risk and reduce it to acceptable levels; and

(b) Stabilisation of food supply may involve minimisation of risk through crop diversification, mixed cropping, preference for traditional disease resistant crop varieties over more fragile high yielding ones.

7.5.3 Important factors for disaster assessment in agrometeorology

The Gommes-Negre study lists three factors to be taken into account:

(a) Weather factors, such as drought or abnormal distribution, duration or intensity of rain;

(b) Crop factors such as characteristics which may render them more or less susceptible to damage under certain adverse weather regimes. These may include differing damage thresholds for differing plant varieties, specific differences between species which account for different levels of damage in adverse weather situations and differing effects at various stages of crop development; and

(c) Environmental and other complex longer term effects which may include the effects of salt from inshore winds during tropical cyclones, erosion and re-sedimentation and "abnormal" morphology which may persist for many years after a major event such as a tropical cyclone.

There are still major problems in assessing impacts on agriculture of natural events and Gommes and Negre state the first step in disaster assessment should always be a clear description of the situation to allow unambiguous interpretation. Other problems are mentioned, for example the practice of confining reports of crop yields to harvested areas may distort the effect of adverse weather in the case of drought when only part of the planted crop may be harvested. Although Gommes and Negre advocate the use of post disaster ground surveys as the major source of information for production loss assessment, they also indicate their belief that agrometeorological models and remote sensing imagery analysis will become more and more important.

7.5.4 The use of models

Yield forecasting models are usually subdivided into two broad categories, analytic and statistical.

Analytic Models

Analytic models simulate physical, chemical and physiological plant process and are very sensitive to drastic departures from normal conditions. Although it is particularly difficult to assess the impact of mechanical weather damage with analytic models, they may be used to simulate recovery and regrowth after mechanical damage has occurred.

Statistical Models

Statistical models relate crop response to measured variables such as rainfall intensity through such procedures as multivariate statistical analysis. Gommes and Negre point to the need for agrometeorological services in tropical cyclone affected countries to develop wind and rainfall based indices which could be related directly and quantitatively with tropical cyclone damage. If properly calibrated, it would be possible for such indices to provide a more general approach to tropical cyclone damage and allow inter country and inter event comparisons

7.5.5 The use of remotely sensed data

Remote sensing data are being used increasingly to assess post event damage or for monitoring environmental parameters. For example Australian Fire Authorities are increasingly utilising NOAA AVHRR data to monitor overall fire risk. Gommes and Negre also indicate that remote sensing techniques are particularly promising for post event assessment where changes in underlying surface have occurred due to damage. The following phenomena have been investigated:

(a) Extent of flooding utilising visible, near infra red or infra red channels;

(b) Identification of forest fires in remote areas; and

(c) Monitoring seasonal drying of vegetation.

7.6 Review of warning systems

A major function of National Meteorological Services is the provision of public warning of weather conditions expected to be hazardous to life or property. There has been considerable analysis of the key components of warning systems, for example in the context of the WMO Tropical Cyclone Programme and the International Decade for Natural Disaster Reduction (IDNDR). **Figure 7.3** shows the essential components of a meteorological surveillance and warning system, based on WMO Report No. TCP-26 (1990). The components of this warning system and their interconnectedness are applicable to the various types of severe weather systems being considered in this chapter.

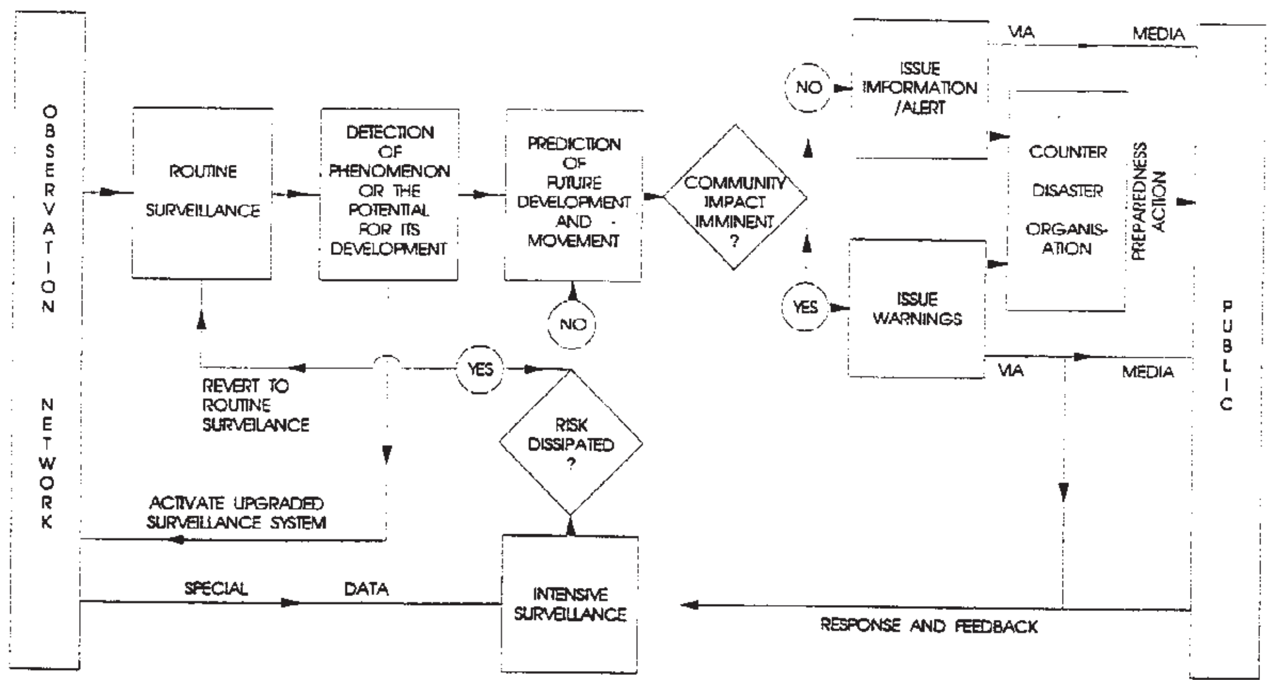


Figure 7.3 - The essential components of a meteorological surveillance and warning system.

There has been considerable progress in the development of warning systems during the past 25 years, but implementation varies significantly between WMO Regions. For example North America (Region IV), Europe (Region VI) and parts of Asia (Region II) have sophisticated communications, data processing and dissemination systems with well developed counter disaster and public response components. Many other Members are at an intermediate level of development, but large areas of Africa (Region I) have underdeveloped national infrastructures.

7.6.1 The key components and their evolution

Observational networks

Observational networks play a key role in any warning system and their improvement and expansion is one of the options to consider when a warning system is to be implemented or improved. Of course the range of component networks and sophistication of any national observational network varies in accordance with national resources, government policies, region of the globe, size or perceived benefits to the country's economy from a well resourced National Meteorological Service. Some of these are linked to the threat from meteorological hazards of the kind this report addresses.

As an example, Australia, a developed island-continent nation of 7,682,300km^2, with a population of 18 million people, most of whom live close to the coast on the eastern and south eastern seaboard, supports extensive surface and space based observations networks as well as atmosphere watch observations networks. The components of this system are detailed in **Table 7.2.**

Table 7.2 - The main components of the Bureau's surface and space based observation networks (30 June, 1994) were:

Bureau staffed stations (includes Regional Offices, subregional offices, local offices and a research station)	61
Weather watch radars	38
Automatic weather stations (AWS)	176
Cooperative Observers (Synoptic and climate)	564
Total of synoptic stations	629
Rainfall stations (All types)	7,104
Drifting buoys (between 0-90S, 50-180E)	52
Floodwarn river height	637
Voluntary observing ships recruited by Bureau	108
Aircraft with AMDAR (Aircraft meteorological Data relay) system	38
Ground stations for geostationary satellites	3
Ground stations for polar-orbiting satellites	7
Geostationary satellite control stations	2

A component radar network which is most significant for monitoring and detection of particular natural hazards, (tropical cyclones, local severe storms) is given in **Figure 7.4.** Doppler radar are proving to be an extremely useful tool in the detection and definition of severe local storms, including tornadoes and hurricanes in the USA and elsewhere. A unit is under evaluation in Darwin, Australia. Australia's observational resources are maintained and upgraded as resources and staffing allow, but the principal aim is that both real time and climate data is of the highest quality that can be achieved so that Bureau data can meet a host of needs from Greenhouse investigations to hazard reduction activities (through warnings, mitigation activities, hazard mapping etc).

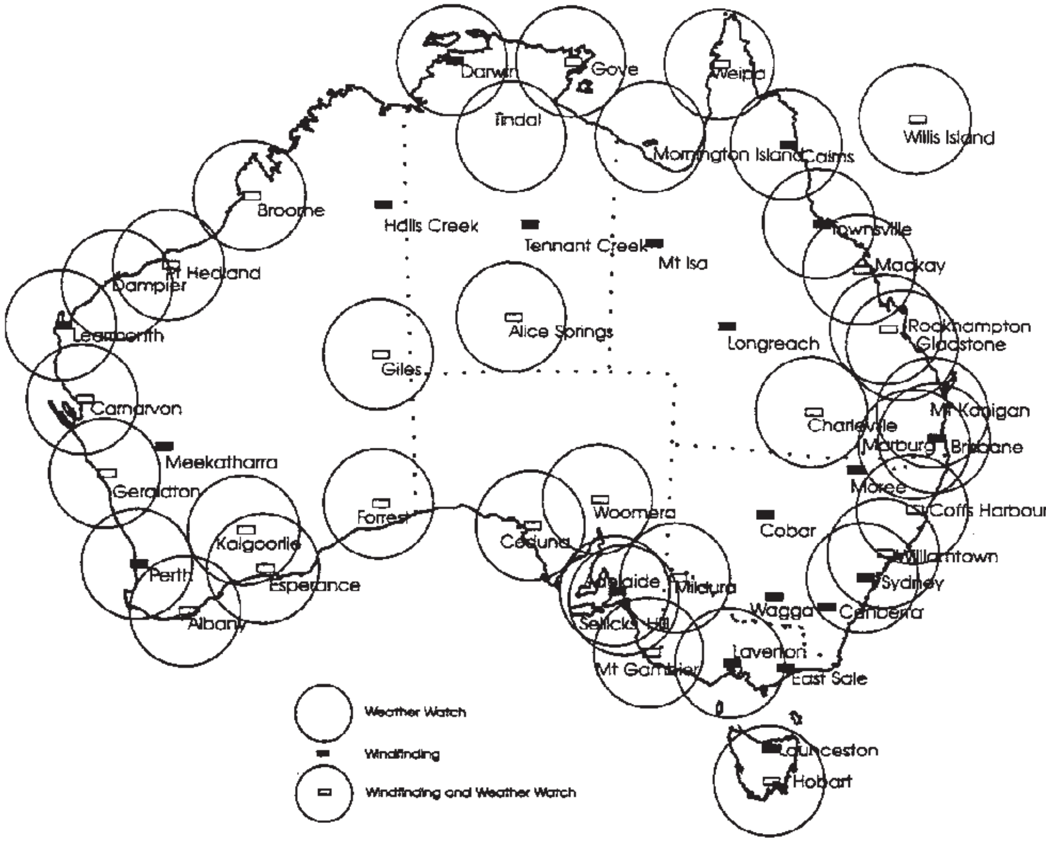


Figure 7.4 - The Bureau's radar network as at 30 June 1994.
Windfinding radars are also installed at Norfolk and Lord Howe Islands.

As part of an upgrade to Severe Weather Warning Services, a network of severe thunderstorm spotters was begun in Australia during the early 1990's to report on the local occurrence of weather phenomena likely to cause damage such as tornadoes, severe local winds, large hail and flash flooding. The network consists of volunteers from the Australian Bureau of Meteorology, State Emergency Services, Police, Fire Control Authorities, University and Scholl groups, as well as interested members of the community. Information provided by the network allows better warnings to be prepared for threatened communities. It also adds considerably to our knowledge of the frequency and effects of storms which, due to their relatively small size, might otherwise escape detection by the established synoptic scale reporting network. In addition by involving the Australian community in the Severe Weather Service, the network serves an important role in public education on the severe thunderstorm threat.

Less developed areas and the difficulty of maintaining conventional surface based networks

For developing nations, island nations often of less than a million people, and others whose infrastructures have been severely affected by political instability and conflicts, meteorological networks will be much simpler, if they exist at all. The importance of installing and maintaining observational networks cannot be overstressed and with related appropriate infrastructure, they are likely to recoup costs of training staff, installation and maintenance several times over in the longer term. National and international aid agencies are regularly providing the kind of assistance needed to establish and improve national meteorological facilities, via advice on instrumentation, networks, observational practices, computer based equipment for manipulation of data, charts, decision support, archiving data etc. from visiting teams of experts; arranging for training and upgrading of competencies of local staff at appropriate training centres in the Region etc. In Crane, (1991), a description is given of this process as it applied to a number of Pacific Island nations. A robust and reliable communications network is another key component for, among a host of other functions, the dissemination of warnings to vulnerable agricultural sectors.

Communications networks

There are at least two aspects of relevance to this report, viz.:

(a) The communications infrastructure by which the warning office obtains information on which to base its forecasts and warnings; and

(b) The dissemination system for the warnings about the impending hazardous event, failure of any component of which will mean that the critical information advising action of some kind does not reach communities at risk.

It is not within the scope of this report to address the former in any depth but as background, the following overview of the communications system, primarily concerned with data and information exchange for the formulation of the National Weather Service products is provided. (It seems superfluous to comment that any major failure of this primary system would be likely to result in a degradation of accuracy or timeliness of National Weather Service's products to its clients). Of course external lines of communication toclients can be regarded in the widest sense as part of the National Weather Service's communications network.

Over recent years, communications systems have diversified and as a general rule become more cost effective. The Australian Bureau of Meteorology has been using a national pictorial product distribution system, Difacs to meet its national requirements and the system now supports the exchange of meteorological charts to the neighbouring nations of New Zealand and New Caledonia. A wide range of charts and satellite pictures can be accessed through a hierarchical menu system at a computer terminal. There is the facility to run a selection of satellite loops as well. The system is increasingly being used by external clients as well as the other National Meteorological Services to address a wide range of applications, including warning applications.

Industry users and the general public are also able to obtain a selection of weather charts, satellite images and textual information through any facsimile machine set to polling mode, as part of the Infofax System of the national telecommunications service. This service has proved a very popular adjunct to the standard radio and television warning outlets when tropical cyclones threaten. *Metfax* is a voice menu, number selection system that delivers its output to the recipient's facsimile machine, where a telephone system is inbuilt or attached, and is designed to meet the needs of the media and a limited number of other specialised users requiring access to products held on a regional basis. The rapidly decreasing cost of facsimile machines over the last five years or so have made them a viable outlet for Bureau products, though polled fax has understandable limitations for unexpected warnings.

A very important aspect of the dissemination component, particularly in the event of a significant meteorological hazard is its robustness. Above ground telephone lines for the delivery of tropical cyclone warnings, for example, are likely to be the 'least robust' component in the warnings dissemination system. Of parallel importance is, where possible, having a range of warning outlets or methods - radio (break-ins to the normal program, inclusion in news reports, repetition at frequent agreed intervals etc), television (crawlers, news coverage, etc), audible alarms in threatened areas, prearranged signals at agreed locations, weather radio with the capacity to transmit warning beeps or alarms with the issue of a warning, VHF radio and many others. Such a diversity of methods contributes to the timeliness of the advice, another important consideration. Inmarsat communications have proved invaluable in establishing communications links in many post disaster situations and international agreements are in place to allow such usage. This method of communication has great potential for the issuance of important warnings and will no doubt soon begin to bridge gaps in communications systems in developing countries, in particular isolated island nations or those developing nations where distance and isolation are major considerations.

Verification

An intrinsic part of the forecasting and warning process is the verification component. The degree of sophistication of the verification process will vary for event categories and according to the resources of the National Meteorological Services. However, if there is no verification process or the role of the verification process is not given adequate weight or resources, it is most unlikely that forecasters will learn by their mistakes or that the Service will be motivated to implement measures to improve overall performance in the issuance, accuracy or timeliness of warnings. Any push for improved methodology or new technology will not be as strong and the impact of new or improved forecast methodologies will not be quantifiable.

Hales, (1988) investigates the number of severe storm reports versus the number of severe storm warnings issued by USA Weather Services Offices (WSOs) before and after a verification plan was put in place. The goal was to see just what effect the verification requirement had on the data. Listings were generated to show how many reports per thousand population and per thousand square miles occurred. One of the most interesting findings was that the total number of severe thunderstorm reports from the After Verification (AV) period (1980-83) was 83% greater than the number reported in the BV period (1976-79). This was equivalent to a total of about 10,000 severe thunderstorm events.

Another was that the issuance of warnings, particularly BV, showed a strong bias toward population centres, the number of warnings being inversely related to the distance from the warning site. For Missouri, for example, some outlying counties were warned of severe thunderstorms one quarter as frequently as the urban counties in the BV period. The conclusion reached was that the decision to issue the warning took into account two other factors other than the radar signatures. They were: whether a severe report had been received from the storm, and the likelihood of receiving a report of the storm from the county being warned (conclusions were substantiated by on-site meteorologists).

The AV period for Missouri showed some dramatic changes, the most notable being for the Columbia WSO, whose warning changed from a bulls eye shape to one covering the forecast area more uniformly. There was also a large increase in warning frequency in the latter period. These changes were related to: post storm searches undertaken by civil defence agencies, local police and others, for severe weather reports; a new radar; a more extensively trained spotter network and a change of station manager in 1979. It is considered that the Columbia WSO is now providing a much more reliable warning service.

Even with the normalisation of reports, severe events from sparsely populated areas were generally lower than expected on the basis of urban statistics. A suggested improvement was to categorise the most severe events which were capable of causing millions of dollars damage or loss of life as *significant* severe storms. Nominated threshold values were 2 inch diameter hail, wind gusts of 65 kts or greater, tornadoes of F2 or greater on the Fujita-Pearson (FPP) scale and all events resulting in a fatality, three injuries or damage in excess of $50,000 (1988 US dollars). Although the number of severe thunderstorm events as defined by the lower threshold values continue to increase in populous areas, the annual incidence of these *significant* severe storms has levelled out. A similar set of statistics has emerged for *killer* tornadoes (those resulting in loss of life) versus all tornadoes in the US.

There were several more insights and the warning service was considerably improved as a result of this study of into aspects of verification.

Fundamental importance of geostationary meteorological satellite monitoring

The role of geostationary meteorological satellites, such as METEOSAT for Europe and Africa and GOES-E and GOES-W for the USA and Canada, and the Japanese GMS satellite series for western Pacific nations including Japan, China, Philippines, Indonesia and Australia, in the provision of warnings for the principal natural hazards of this report continues to expand. This expansion is the result of technological progress which has meant:

(a) Improved access to satellite data, especially by less affluent nations, by virtue of reductions in the cost of receiving equipment, computer hardware and software for processing, viewing, looping and otherwise manipulating the satellite imagery;

(b) Expansion, diversification and cost reductions related to modes of dissemination of imagery, including facsimile and radio facsimile, computer to computer transference through high speed data lines, communications satellites, and more innovative packaging of the imagery in television weather presentations;

(c) Expansion in satellite applications, many of which have a direct bearing on warning formulation and accuracy.

7.6.2 Some Satellite Applications in Warnings Situations

Tropical Cyclone Monitoring Technology having Warning Applications

Chapter 9 of WMO/TD-No. 394, (1990) informs that 'geostationary satellites (in addition to the orbiting satellites program) now monitor a large area of the global tropics and are capable of providing updated images, at least three hourly, but hourly and even half-hourly during special periods (Indosat imagery is not disseminated). Satellites provide the capability of detecting developing and existing tropical cyclones, and tracking and estimating intensities with fair accuracy. As intimated above, hardware for the reception and interactive display of meteorological satellite data can be obtained relatively cheaply, and is regarded as a basic requirement in all tropical cyclone warning centres (TCWCs).

Interpretation of visual and infra red satellite images following empirical rules is widely used in TCWCs for estimating tropical cyclone intensities. The method may be used on a single satellite picture or on a sequence of pictures and has the advantage of providing intensity estimates under practically all conditions. A weakness in the scheme is some subjectivity, particularly for weaker systems. A modified version of the technique provides completely objective intensity estimates, as yet not very reliable, for certain classes of severe tropical cyclones using a computer graphics device (Man-computer Interactive Data Access System - McIDAS).

McIDAS has undergone progressive development since the early 1970s and the system is currently in use in a number of countries including the USA where it originated, China, Australia and Japan. This system facilitates the application of research findings which integrate high resolution soundings derived around a tropical cyclone, satellite derived (cloud drift) winds, upper air warm anomalies in the temperature field etc. to refine the analysis in the area around it and subsequently forecast its new position and sometimes its intensity or maturity. McIDAS clearly extends the information base pertaining to the system in real time by analysing large volumes of satellite digital image data. In India, the geostationary VHRR images are being used to estimate real time rainfall, using instantaneous rainfall measurements as validation.

7.6.3 Examples of warning systems of significance to agriculture and forestry focussed upon individual hazards *which have occurred*

To better serve those communities affected by tropical cyclones in Bangladesh, the use of small radios for timely reception of warnings and advice has been strongly promoted, concrete shelters have been built above average storm height, use of INMARSAT has been important as a means of communication, mainly post-event, there has been refinement of warning content and structure for optimal response to the threat and international advice and expertise have been employed to minimise loss of life and economic loss.

Fire Weather Warning Service

Southeastern Australia is recognised as one of the most fire prone areas in the world. As a consequence fire weather warning services provided by the Bureau of Meteorology are comprehensive and address the strategic and tactical needs of the fire control agencies. Fire control is primarily a responsibility of individual Australian states and hence the service delivered by the Bureau in each state, although fundamentally similar, is tailored to meet local requirements. What follows is an outline of the services provided by the Office of the Bureau in the state of Victoria.

The control of fires outside of the Melbourne metropolitan (urban) area is generally undertaken by two principal agencies - the Country Fire Authority whose responsibilities are mainly for fire protection strategies and control on private property, and the Department of Conservation and Natural Resources whose responsibilities are mostly for public lands.

A specialised forecasting service is provided for approximately 6 months of the year between November and April. The service comprises three sets of routine estimates for 25 representative locations throughout the state issued at 0630, 1130 and 1700 hours each day, a fire weather briefing statement issued at 1030 hours and "spot" forecasts issued on request for local fire areas. Provision is also made for dispatching an "outposted" forecasting team to the forward control centre of potentially devastating fires and for a weather liaison officer to be located at the central control centres of these agencies on days of extreme danger.

The routine estimates provide forecasts of maximum daily temperature and the humidity, wind conditions and fire danger from the McArthur fire danger metres at this time. They also include timing of significant wind changes, the likelihood of significant rainfall (defined as greater than 5 mm), the expected frequency of lightning, upper winds at 1000 m above ground level and the height of low level atmospheric mixing. Routine estimates may be amended at any time when required. "Spot" requests for fires that have started contain all the above parameters at 2 hourly intervals for the first 6 hours with an outlook for a further twelve hours.

Fire weather warnings are issued for all or part of the state when fire danger predicted by the McArthur metres becomes extreme. On these days the fire control authorities, in close consultation with the Bureau, may issue a Total Fire Ban which severely restricts the lighting of fires and operating of machinery in outdoor locations.

The fire weather briefing statement issued mid-morning elaborates in plain language the days forecast and highlights areas where fire danger may differ from the "representative" stations. The statement also attributes a level of confidence to the forecast and when appropriate details alternative scenarios which may develop.

Forecasters at the regional office have access the to several innovative data displays. One of these, MDMS, displays surface wind data from automatic and synoptic weather stations on a map of Victoria, refreshing data every ten minutes and alerting significant changes with various colours. This assists in monitoring changes crossing the state. By selecting individual stations a time series of temperature, dewpoint, humidity and wind is displayed. Another system under development, "Weather for Windows" retrieves upper air and surface data for mapping to a PC screen and calculates parameters such as real-time forest and grass fire danger indices and surface lifted index, a measure of atmospheric instability.

Outposted forecasting services may be dispatched on request by the fire control authorities to fires which pose significant threat to life, property and the economy of a region if not quickly brought under control. Locating forecasters at the forward control centre near the fire site allows detailed weather input into strategic planning and tactical fire operations and improves the safety and efficiency of fire control activities. Forecasters carry portable computers which access all the information available at regional forecast offices including global and local model output, hourly weather observations, satellite and radar imagery. In addition outposted forecasters erect a portable automatic weather station at a critical location near the fire which automatically relays 10 minute data via VHF radio, and establish an hourly weather reporting network from local fire towers and fire control offices.

Weather forecasters are sent on request to the headquarters of the fire control authorities on days of extreme fire danger serve a strategic role in staging weather briefings and interpreting weather changes during the day.

7.6.4 Some examples of warning systems of significance to agriculture and forestry focussing upon individual hazards *which could be implemented with available technology*

Section 7.11 contains analyses of data on warning systems for hurricanes (tropical cyclones), wild land fires and local severe storms in WMO Member Countries.

7.6.5 Guidelines for effective warning

A workshop (AEMI, 1993) involving 150 contributors and an IDNDR Conference concerned with protecting vulnerable communities (Merriman and Browitt, 1993) provide the basis for the comments and advice which follow. The context of the workshop was to further improve the effectiveness of severe weather and flood warnings in Australia.

Although both meetings were concerned with a wider range of recipients than agricultural communities alone, for most severe weather and flood warnings, agricultural interests are a sub-group of those likely to suffer from the ravages of such events.

A key premise is that warnings need to get the message across and stimulate those at risk to take action that will reduce the risk of death and injury, property loss and damage.

For the achievement of desired goals four key areas of activity are postulated, viz.:

(a) Identifying "stakeholders" (delineation of roles, coordination mechanisms, establishing boundaries);

(b) Involving people at risk;

(c) Disseminating the warning; and

(d) Designing the warning message.

Identifying "stakeholders"

An important task of major "stakeholders" e.g. the national meteorological organisation, emergency managers, other specific interest groups such as retailers and vulnerable industries, of which an important sub-group is agricultural enterprises is to develop a coordinated action plan ensuring the necessary interaction and feedback. Such activities may include:

(a) Establishing working relationships and procedures;

(b) Identifying hazard(s), quantifying risk to establish warning requirements and planning responsibilities;

(c) Developing a resilient system with alternative backups to compensate for failure of any components in the total system;

(d) Training and warning system exercises involving at least key "stakeholders"; and

(e) Establishing mechanisms to ensure adequate review and quality control.

Involving people at risk

These people need to be involved in the design, development and operation of *their* warning system. These goals may be achieved by:

(a) Developing an understanding of the specific needs and characteristics of the intended recipients (in the agricultural context, this involves a knowledge of precisely what measures need to be taken to minimise potential damage, for inclusion in the warning if practicable); and

(b) Design an effective public education campaign through schools, local groups, media, targeting especially high risk groups based on their exposure and response pattern.

For developed countries who are *information rich* but *attention poor* a public education campaign can be a particular challenge. Presentation of information through story lines in serial dramas (soap operas) can be quite effective. Identifying those at risk may depend on physical proximity to the hazard, but further refinement may be possible through socio-economic and spatial maps of vulnerability e.g. targeting angora goat enterprises for detailed information on "Graziers Alerts" in Victoria (issued when cold, wet, windy conditions are expected to develop).

Disseminating the warning

Key factors to be considered here are:

(a) Choosing the right channels to ensure timeliness, reliability, effectiveness;

(b) An authoritative originator and messenger (if possible use multiple channels for message dissemination, selecting as many as feasible from options available including informal disseminating networks);

(c) Deciding on warning frequency by referral to the intensity and duration of the threat, community needs and expectations, available communication modes; and

(d) Following up to ensure that the message was dispatched as planned, received by the target audience and that its content and format allowed optimal response to the threat.

Designing the warning message (its form, content and structure)

An effective warning will tell each member of the community at risk what is happening, what it means to them and what they can do. While adhering to the KISS (Keep it short and simple) maxim, three components of a warning should be present and identifiable. These are:

(a) Non-technical information for public safety;

(b) Technical information with supporting detail;

(c) An action statement recommending protective behaviour.

Given the occasional media shortening, a sound approach is to place the most important information first in the warning message. The use of simple, plain (but arresting) language makes it easy for announcers to read and all sections of the community to understand and take notice. An effective warning message should include the following where applicable:

- **header/title** - threat description
- **sequencing** when appropriate
- **date/time** of issue
- **issuing source/authority**
- **validity period**, where appropriate
- **target audiences**, if not obvious in heading
- **synopsis** (summary) - must quote how big it is
- **forecast** of probable development and consequences (must quote source)
- **location** of phenomenon and probable impact areas
- **stage in development** of event with action statements sourced from and attributed to the appropriate authority
- **graphics** (for visual media)
- **source** of further information
- **time** when next warning will be **available**

Illustrative example (after input from issuing authority, user group and journalists):

Severe Storm Warning Example

- A severe storm warning has just been issued by the Weather Bureau;
- People in the Bellarine Peninsula, Geelong, Port Phillip, Mornington Peninsula and Melbourne areas are warned of the approach of severe thunderstorms from the west;
- Large hail and damaging winds are predicted for the western suburbs of Melbourne, Geelongand the Bellarine Peninsula in the next hour;
- The storm may extend to eastern areas by early evening;
- Hail large enough to damage house roofs and cars have been reported at Ballarat;
- The State Emergency Service says that people should secure outside items, move cars undercover then seek shelter;
- This thunderstorm warning will be updated in half en hour at 5:30;
- For more information call 12345.

7.7 REVIEW OF OTHER STRATEGIES FOR MITIGATION OF ADVERSE EFFECTS

7.7.1 Models used in conjunction with forecasting, warning and evaluation of tropical cyclones

The use of objective cyclone model forecasting methodologies as guidance is routine in most ocean basins. The objective guidance provides a control on the quality of the forecast. It supports the forecaster in making critical decisions about cyclone movements and provides information about the likely errors in his prediction.

There are two broad and overlapping categories of objective tropical cyclone forecasts. The simpler forecasts are based on the cyclone track data (i.e. current and past date-time, position, intensity, etc) and the more complex forecasts based on analysed and/or predicted environmental grid-point data (usually output from a numerical model). Statistical methods are widely used to optimise predictions from both categories of forecasts.

Forecasts based on track data include: - persistence - a simple linear extrapolation of the cyclone's motion over the last 6 or 12 hour period; climatology - based on an analysis of historically analogous cyclones in the area and CLIPER which is derived from a statistical regression using a combination of track CLImatology and PERsistence. CLIPER has been recommended as the best no-skill bench mark against which other forecasts should be compared.

On average, track forecasts with lead times less than 40 hours are more accurate than forecasts guidance from numerical models. The main exception to this occurs in the North Atlantic basin where (a) the use of aircraft reconnaissance provides sufficient high quality data for model usage and (b) CLIPER forecasts are combined with other guidance forecasts.

There are many types of numerical model predictions of environmental grid point data from which explicit cyclone track data can be derived. These include global, regional and small area baroclinic models and nested barotropic models. Mostly they provide the best guidance beyond 40 hours but there is some regional variation. In general the weakness in predicting cyclone motion is the lack of data rather than an inability to model the atmosphere.

The dynamical concept of tropical cyclone "steering" by the environmental flow combined with the so-called beta drift, is generally held to be valid. This movement is determined by interactions in an envelope at an effective radius some 100 to 300 km from the cyclone centre, and is sensitive to changes in cyclone size and outer wind strength, while changes in core intensity have little effect.

Broad scale environmental winds in the middle troposphere play the largest role in steering tropical cyclones. However pressure weighted deep-layer average winds show higher correlations with cyclone translational speed and direction than any individual layer wind.

Analysis and forecasting of tropical cyclone wind fields in TCWCs is second only to the importance of position and forecasting of motion. Interpretation of visual and enhanced infra-red satellite photographs following the empirical rules devised by Dvorak is the most widely used method of assessing tropical cyclone intensities over the ocean and also provides a 24 hour forecast of central intensity. Improvements to intensity estimates using sounding data from orbiting and geostationary satellites, in combination with dynamical reasoning, statistical and expert systems are being developed in several countries.

7.7.2 Models used in conjunction with forecasting, warning and evaluation of wild land fires

Fire Behaviour Models

The aim of all fire danger models is to quantify fire danger, to define parameters that determine it and predict fire properties from it, especially the rate of spread, flame height and fire intensity, (Packham, 1989). A World Meteorological Organisation report on "Systems for evaluating and predicting the effects of weather and climate on wild land fires" by Reifsnyder and Albers provides a concise summary of the fire models available around the world to assist in fire hazard management.

Many fire models have been generated; the earliest appears to date from 1926 when it was noticed that severe fires first occurred in the north east of the USA, only when the atmospheric relative humidity fell below 30%.

Types of models

Fire behaviour models can be divided into several classes which include the following, as described by Packham, (1989) and Powell, (1992).

Empirical: In these models some estimate of the fire hazard is related to fuel moisture content and then to observed fire behaviour, in either field experiments, or post mortem studies of wildfires. The major empirical models in Australia are the well known McArthur models, the last version of each being the Mark 5 models for forests and for grasslands. Sets of equations for computerised operation of the McArthur Forest and Grassland models are provided by Loane and Gould, (1986).

There is also a West Australian Forests Department model (The Red Book model of G. B. Peet). This latter provides reliable estimates for fuel moisture content and head fire rates of spread for six standard structure fuel types common to the southwest of West Australia. The red book model has a rigorous and published base that gives confidence in the model and provides easy transportation of fuels other than the forests of Jarrah (*Eucalyptus marginata*) and Kauri (*Eucalyptus diversicolour*) for which it was devised. The model has not been tested for the very intense fires of the type that can occur in the higher fuel areas southeast Australia. The McArthur model is used to predict fire danger ratings (FDRs). These FDRs are based on a fuel load of 12 tonnes per ha of dry eucalypt forest with little or no understory, situated in the drier regions of Australia. The major problem with extending the use of the McArthur model to other area is that it not supported by adequate documentation or experimentation. For Australian grassland conditions, the McArthur model has been judged by Packham "the best of a bad lot". In fact, he is uncertain as to whether the Peet model can be adapted to (Australian) grasslands, but thinks it quite likely.

Quasi-Physical: These are based upon the quasi-physical relationships between fuel consumption rate and the rate of fire spread. This type of model is supported with calibration factors from extensive wind tunnel experiments and some limited field experiments. The Rothermel model (1972 and 1983) also called BEHAVE used by the USA Forest Service, is the major model in this class. It depends on fuel models which are predominantly for American fuels.

Theoretical: This type is based on heat transfer equations which are used to develop relationships with the rate of spread of fires. Sometimes field measurements are used to calibrate such models. Theoretical models should be promoted but subjected to the usual exhaustive tests before being adopted for fire weather forecasting. The list of fuel variables affecting fire behaviour include fuel spacing, surface area-to-volume ratio of fuel particles, specific heat, bulk density and temperatures. These parameters are considered too difficult to measure in the field for operational use.

Climatological: These models are the result of studies of fire occurrence and meteorological parameters. Such models are useful for strategic planning, public awareness, and effective deployment of fire-fighting units.

7.7.3 An Example of the use of satellite data and techniques as aids to the mitigation of adverse effects from the specified natural hazards

Forest Fires

Kasischke, *et al.*, (1993): Normalised difference vegetation index (NDVI) composite image data, produced from AVHRR data collected in 1990, were evaluated for locating and mapping the areal extent of wildfires in the boreal forests of Alaska during that year. A technique was developed to map forest fire boundaries by subtracting a late-summer AVHRR NDVI image from an early summer scene. The locations and boundaries of wildfires within the interior region of Alaska were obtained from the Alaska Fire Service, and compared to the AVHRR-derived fire boundary map. It was found that AVHRR detected 89.5% of all fires with sizes greater than 2000 ha with no false alarms and that, for most cases, the general shape of the fire boundary detected by AVHRR matched those mapped by field observers. However, the total area contained within the fire boundaries mapped by AVHRR were only 61% of those mapped by the field observers. The AVHRR data used in this study did not span the entire time period during which fires occurred, and it is believed the areal estimates could be improved significantly if an expanded AVHRR data set were used.

Severe Storms

Visible, Infrared and Water Vapour Imagery

Cloud imagery in the visible and infrared has become a vital part of weather monitoring prediction on the synoptic scale since the 1960s. More recently water vapour imagery hasand become available to some weather services. The identification and tracking of synoptic-scale systems such as fronts, cyclones and jetstreams is a basic part of the process of predicting severe thunderstorms and windstorms, both in manual analysis and in NWP. Particular attention has been paid to the problem of data-void areas over the southern hemisphere oceans, with the early work of Guymer (1969), Martin (1968), Zillman and Price (1972) and Streten and Troup (1973), leading to the current derivation of pseudo-observations of mean sea level pressure and 1000-500 hPa thickness for input to regional and global NWP models.

Because of the impact of cloud imagery on synoptic-scale analysis and NWP, this tool is of prime importance to the prediction of synoptic-scale windstorms. Where severe thunderstorms are part of larger systems such as Mesoscale Convective Complexes (Maddox, 1980) warning services have benefited from the ability to identify characteristic cloud patterns, but the short lifetimes of most thunderstorms and their small horizontal scale have limited imagery's main role to the identification of "triggers". These are atmospheric disturbances which cause potential instability to be released, initiating convection and enhancing it. The importance of trigger is illustrated in the short-range thunderstorm prediction technique of compositing, which relies on the identification of many different types of atmospheric discontinuities (in pressure, temperature, moisture, wind veloicity, etc.). In simple terms severe thunderstorms are most likely to be triggered at the intersection of these boundaries.

In the US, where water vapour imagery is available every 30 minutes from the GOES geostationary satellite it has been found to be effective in distinguishing triggers such as jet streaks, vorticity maxima and diffluent regions. Ellrod (1990) shows how water vapour imagery can be used to identify dry slots, which, being indicators of layers which are potentially unstable, can be used in conjunction with knowledge of triggers to identify high risk areas.

The nowcasting phase of severe thunderstorm prediction requires particularly high resolution cloud imagery. The high, cold cirrus clouds of the thunderstorm anvil are readily distinguished on current images, but the forecaster must generally rely on ground-based radar to identify the signatures of single-cell, multicell or supercell storms. Horizontal resolution of 1 km or better and image frequency of 30 minutes or less are required, but when storms are viewed from above, anvil cirrus shields much of the structure which identifies a dangerous supercell storm on radar.

Temperature and Humidity Soundings

The US TIROS Operational Vertical Sounder (TOVS) data, which have been available for more than a decade, have had a positive impact on forecasting, particularly on global NWP models over the data sparse southern hemisphere (Menzel 1992). TOVS soundings of temperature provide reasonable accuracy of 1.5°K to 3°K compared with radiosondes (Le Marshall, 1988), and the temporal (6 hourly) and horizontal (60 km) resolution of the TOVS soundings are significant improvements upon the radiosonde networks in all parts of the world. However, these data are still not adequate for true mesoscale monitoring and prediction.

Inaccuracies in humidity measurements and generally poor vertical resolution (2 km), in particular, lessen the value of the soundings for thunderstorm forecasting. Cloud cover is also a problem for the sounding retrievals, but better horizontal resolution would help to overcome this in broken cloud areas.

High accuracy is required when observing temperature and humidity profiles for thunderstorm forecasting. **Figure 7.5** uses the conventional parcel theory of convection to show that small differences in the observed environmental profile can lead to widely differing predictions of instability, as measured by Convective Available Potential Energy (CAPE). The theoretical path of a rising convective parcel is marked by the Lifted Condensation Level (LCL), Level of Free Convection (LFC) and the Equilibrium Level (EL). The temperature and humidity of the lowest layers of the atmosphere, below about 850 hPa, are particular crucial and must be measured accurately, but it is this layer which generally exhibits the most rapid changes in the hours preceding thunderstorms.

The VISSR Atmospheric Sounder (VAS) also provides temperature and humidity profiles. The use of a geostationary platform theoretically allows VAS profiles to be retrieved as frequently as every 20 minutes, but in practice soundings are provided approximately hourly to US forecasters. This frequency increases the potential for true mesoscale monitoring but the averaging techniques required for accurate retrievals yield a horizontal resolution of 20 to 75 km and vertical resolution which, at about 2 km is similar to TOVS. Biases of 1 to 4 C in temperature and 2° to 6°C in dewpoint temperature have been found in comparisons with radiosonde data (Jedlovec, 1985), suggesting that gradient and tendency information is of more operational value than the absolute values. Olsen and Fuelberg (1990) have also described discrepancies between radiosonde and VAS soundings, particularly in the crucial thunderstorm predictor, CAPE.

Rainfall Rate

Radar is the primary nowcasting tool for thunderstorms, because it provides continuous, high-resolution information about rainfall rate over a domain large enough to encompass entire storm systems, in both horizontal and vertical cross-section. The radar reflectivity signatures of severe storms are well-known and allow precise warnings to be prepared for downstream communities. However, individual ground-based radars are limited in effective range to 200 km or less, so the concept of spaceborne radar is an attractive one. Although such an instrument has been planned for the Tropical Rainfall Measuring Mission (TRMM) (TRMM, 1988) and Bilan Energétique du Système Tropical (BEST) (BEST, 1988), considerable development is till required. Numerical simulations by Testud *et. al.* (1992) favour the choice of a dual-beam system operating at 24 GHz to overcome the problems of attenuation from high altitude and the large dynamical range of 1 to 50 mm/h. The addition of Doppler capability to such an instrument would have the considerable benefit of providing three-dimensional wind field observations wherever precipitation occurs.

Passive microwave instruments such as the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I) can also provide rainfall rate data. Techniques to retrieve climatic-scale rain rate have been developed (Arkin and Ardanuy, 1989, and Wilheit *et. al.*, 1991) have been developed, but research continues to refine methods for real-time, mesoscale retrievals.

Wind Profiles

Vertical profiles of the wind are essential to the prediction of severe thunderstorms and windstorms. High-resolution measurements of the three-dimensional wind field are necessary for the initialisation of NWP models. Southern hemisphere forecasts benefit more from satellite-derived data than do those in the north.

Satellite wind data are derived as Cloud Motion Vectors (CMV) using visible and infrared imagery to track cloud features, or indirectly from temperature profiles through the thermal wind relation between temperature gradient and vertical wind shear. The accuracy of CMVs depends upon the frequency with which the cloud features are observed (half-hourly using Meteosat and GOES, hourly with GMS) and the identification of the cloud top height. Problems associated with CMVs are the lack of data in cloud-free areas, clouds which do not move with the ambient flow (lenticular clouds and large cumulonimbus), and height assignment for thin clouds such as cirrus. The use of water vapour channels as well as infrared can assist with the first and third of these, but the second requires manual analysis before CMVs can be used in model initialisation. European experience with winds retrieved by Meteosat sgg est errors, compared with radiosonde and aircraft observations, of about 1.5 m/s (Saunders and Seguin, 1992), but VAS-derived CMVs have been estimated by Menzel (1992) to have errors at high levels of about 6 m/s.

It is low to mid-level winds which are of most importance for severe thunderstorm prediction, principally with regard to storm longevity and form. A recently developed forecasting tool is storm-relative helicity, which is a function of the ambient wind profile in the lowest 3 km and the storm motion, and is proportional to the shaded area in the figure. Davies-Jones *et. al.* (1990) and others have demonstrated the value of this parameter in predicting tornado development and intensity. It must be noted that since this technique requires knowledge of the storm motion it can only be used for nowcasting. Satellite-mounted Doppler lidar has been proposed as a means of measuring CMVs more accurately, since height assignment can be made with an accuracy, in theory, of 2 hPa (Boers *et al.*, 1988), compared with 50 hPa for the infra-red brightness-temperature technique (Menzel *et al.*, 1983). However, lidar retrievals would also be mainly confined to cloud tops and so to high levels.

Surface Pressure

Atmospheric pressure at the surface is a basic part of meteorological analysis on the synoptic scale. Similarly at the mesoscale the surface pressure pattern gives clues to the presence of unstable areas or triggers. The desirable horizontal resolution of 10 km cannot be achieved over large areas using ground-based instruments. It appears that a form of lidar flown on a polar-orbiting satellite could provide such data in the future.

Lightning

Lightning is common to all thunderstorms, and growing experience with ground-based radio-frequency sensors is showing that significant information about storm intensity and evolution can be deduced in real-time. Mosher and Lewis (1990) have shown that lightning data contribute unique knowledge to the severe storm forecasting process in USA in more than 50% of storms. Studies in the tropics (Williams *et al.*, 1990) and in mid-latitudes (Buechler *et al.*, 1990) have established that cloud-to-ground flash rate is related to measures of storm intensity such as CAPE and total precipitation, while Holle *et al.*, (1990) have shown that lightning data can be used for identification and diagnosis of the stage of life cycle of Mesoscale Convective Systems.

Ground-based lightning detection networks have proliferated in recent years, but large areas remain unmonitored, so the broad coverage afforded by a satellite-borne instrument, such as the planned Lightning Imaging Sensor (LIS) within the TRMM payload is attractive. It should be noted, however, that research indicates that lightning characteristics such as polarity and cloud-to-ground flash rates (as opposed to intra-cloud rates) are important clues to storm structure and behaviour. Radio frequency sensors can provide these data but the LIS will not.

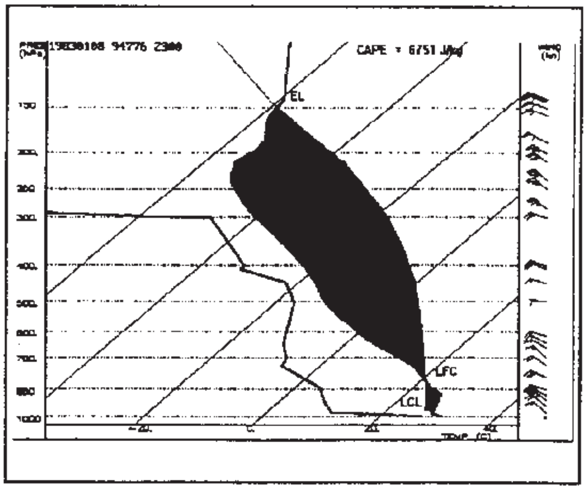


Figure 7.5(a) - Aerological diagram showing temperature and humidity profiles. The large shaded area represents the energy available to a convective parcel.

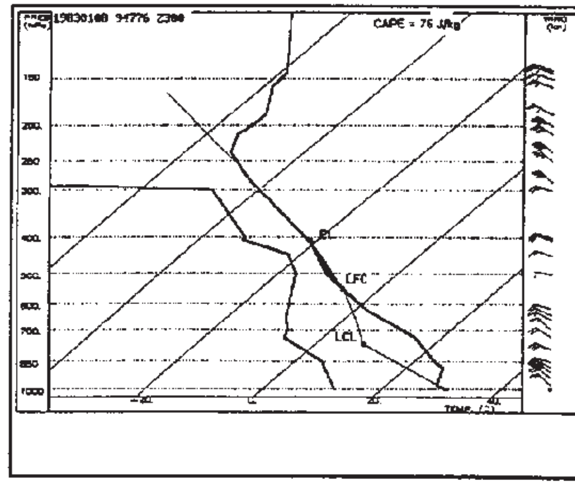


Figure 7.5(b) - As 7.5(a) but replacing the surface dew-point temperature with the mean value in the ground to 850 hPa layer. Note the Convective Available Potential Energy change from 6751 to 76 J/kg.

7.8 HAZARD ASSESSMENT METHODOLOGY AND HAZARD REPRESENTATION

The first and most basic requirement in hazard assessment for extreme events is an adequate database. For example, an IGBP Workshop Report (1990) judged that databases of extreme event information in Australia at the time were generally badly structured and difficult to use. The key problem precipitating this situation was the lack of personnel to reorganise, improve or even maintain existing databases and archives.

7.8.1 Contents of extreme event databases

Recommendations for improvement of extreme event databases were to record:

(a) As many parameters as possible;

(b) Their scale;

(c) Their spatial extent;

(d) Start and finish times; and

(e) Measures of event severity, using such concepts as: number of deaths (human and animal), damage to buildings, communications, level of imported food aid, people's response eg. migration. Fujita's F scale for tornado intensity is a well known example, which has become widely accepted. (Fujita and Pearson, 1973). The Australian Bureau of Meteorology had defined minimum criteria for local severe storm categories; (**Table 7.3**) and hurricane/tropical cyclone severity categories are widely recognised (**Table 7.4**).

Australian threshold criteria for local severe storms

Table 7.3

hail exceeds 2 cm in diameter;
wind gusts exceed 90 km/h;
tornadoes occur; or
associated heavy rainfall causes flash flooding.

Table 7.4 - Tropical Cyclones - Category definitions

Category	Strongest wind gust (km/h)	Typical effects
1	less than 125	Negligible house damage; damage to some crops, trees and caravans; craft may drag at moorings
2	125-170	Minor house damage; significant damage to signs, trees and caravans; heavy damage to some crops; risk of power failure; small craft may break moorings
3	170-225	Some roof and structural damage; some caravans destroyed; power failure likely
4	225-280	Significant roofing loss and structural damage; many caravans destroyed and blown away; dangerous airborne debris; widespread power failures
5	more than 280	Extremely dangerous with widespread destruction

The rainfall required to produce flash flooding varies greatly from location to location. The Australian Bureau of Meteorology states as a general guide that flash flooding is likely if the rainfall total from a thunderstorm exceeds the one hour fall with a return period of between five and ten years. It also notes that flash flooding can occur in conjunction with mechanisms other than severe thunderstorms, eg periods of intense rainfall in a general rain situation. Lightning is present with all thunderstorms but there are no techniques to predict which lightning strikes will cause damage. Lightning is therefore not included in the Australian definition of severe thunderstorms.

Further debate and collaboration are indicated, in some cases, to, where possible, agree on measures of event severity which will be widely, if not universally accepted.

7.8.2 Networking of database components

Recommendations to improve the usefulness of extreme event data archives were for the various components contributing to the archive(s) to be networked to the best standards that current technology will allow. These networks should ideally:

(a) Include high density surface data;

(b) Include radar and satellite data, other remote sensing information and GIS techniques;

(c) Record the magnitude, frequency and probabilities of extreme events (useful for inclusion into extreme event forecasting models);

(d) Include data gathered in as many different spatial and temporal scale as possible;

(e) Be comprehensive; and

(f) Universally accessible.

7.8.3 Problems with automation of data collection

Concerns were expressed at the workshop that the automation of data collection was jeopardising the collection of future extreme event data in some categories. These included:

(a) By replacing human observers by AWS, hail and thunderstorm observations, for example, were not collected;

(b) With AWS, diversity and utility of databases were reduced; and

(c) A perceived need to maintain integrity between past and current databases.

7.8.4 Role of remotely sensed data

Ideally, remotely sensed data would be incorporated into an extreme events database, in addition to its availability in (near) real time. Adequate coverage of some larger developed countries as well as a majority of developing countries by radar facilities is unlikely in the foreseeable future (Australia would need about 100 radar installations to cover the whole country). Nevertheless, what data there is, should be retained in a format which extreme event researchers can easily access and radar coverage should be extended to relevant areas as funding permits. A regional/national lightning detection network does, to a degree, make up for AWS limitations, and this data too should be readily available for researchers.

Another initiative which can lessen the disadvantages of decreasing numbers of cooperative observers and more AWS (listed above) is a Storm Spotter Network. At this point, a note of caution is expressed about the use of remotely sensed data. It is not a panacea, as in many cases, data can only be inferred by indirect means. Its primary use should be to "fill in" for conventional data in remote or inaccessible areas.

7.8.5 Investigation of natural disasters

Services are encouraged to set up a national initiative similar to the American National Science Foundation approach.. When there is a natural disaster, a team of scientists, engineers and other relevant personnel collect data, including on-site information/ deductions, do accurate research on the disaster and its consequences and so detect weaknesses in established emergency procedures and make recommendations on measures for improvement.

7.8.6 Recognition of the Importance of basic data collection and storage

While measures to optimise an extreme events database should be avidly pursued, it needs to be recognised that basic data collection and storage remains the foundation stone of research on extreme events and these are receiving decreasing attention/resources in many places e.g. South Pacific nations (IGBP Workshop Report No. 7, 1990). The importance of the routine activities of:

(a) Taking basic meteorological observations;

(b) The proper management of data;

(c) Basic and upgraded training of personnel responsible for observations and data management; as well as

(d) Rescue or archival data, not forgetting data collected on the nature and consequences of extreme events (some of which is being lost due to a lack of appreciation of its value);

needs recognition and ongoing commitment, perhaps with oversight/monitoring and encouragement by an international Program such as the IGBP.

7.8.7 Some further thoughts on data and data archives

A number of valuable suggestions resulted from the *Expert Consultation on the Coordination and Harmonisation of Databases and Software for Agroclimatic Applications* (FAO, 1993). Those of relevance to this report are listed and discussed below.

The observation was made that data was often under-utilised, even though methods exist to increase their "graduality" and optimise their use; for example by the use of statistical techniques, the integration of data sources (e.g. remote sensing data in combination with traditional surface observation stations) and the use of physical models.

It was acknowledged that often the weakness lay in the tools or interface between the data and the user. This suggested the need for partnership and the strengthening of interactions between t-2Hhe datanagers, "tool" producers and the users or receivers of the (agrometeorological) advice. This need was applicable at all levels; from WMO and national meteorological centres to local weather services offices; national and international disaster organisations to local disaster combat teams; and international food and agriculture organisations to national departments of agriculture and agricultural extension services.

A call was made for the establishment of meta-databases which will contain: sources of data, simple and standard tools (so called procedures) and models. These initiatives would require the establishment of expert steering committees on: the establishment of these databases; standard data exchange formats (definition/dissemination of exchange formats for all data types used in agrometeorological and agroclimatic applications); agrometeorological procedures (inventory/ collection, standardisation and dissemination procedures) as well as guidelines in their usage. The steering committee would pay permanent attention to training, including the need to prepare training material including software training and training data sets.

The working group also addressed issues of data availability which included: timely accessibility; spatial and temporal adequacy; format (the comment was made that non digital data must often be regarded as non available e.g., printed maps); new licensing and costing policies of data providers. Resolves of the working group were: to affirm that data be regarded as an essential common resource for cooperative research and development; to encourage adequate funding for further data collection, archival and dissemination; and that mechanisms should be developed to ensure these measures are pursued. An important ingredient in achieving the stated aims was for data users to recognise meteorological services as collaborative partners in data management and use.

7.8.8 The Australian Bureau of Meteorology's severe local storms archive (July, 1994)

Since 1988 a project to collect all existing records of severe thunderstorm events into a single database has been carried on by the Head Office Severe Weather Program Office and the Regional Severe Weather Sections, located in each of the six Australian States and the Northern Territory. Initially all of the existing Regional data sets were collected and entered into a dBASE III database and each of the Regional Severe Weather Sections was then given the responsibility for adding new events as they occur and, when possible, seeking out old records. As a result, the Regional versions of the database have diverged to a considerable extent in their structure and completeness.

A new, national database is about to be implemented using the Microsoft Access relational database software. All of the existing Regional databases are to be translated into the new structure which will allow SQL (Standard Query Language) to be used.

The national database will contain about 3000 records of severe thunderstorm events, beginning in 1795. The official definition of a severe thunderstorm (hail exceeds 2 cm in diameter; wind gusts exceeds 90 km/h; tornadoes occur; associated heavy rainfall causes flash flooding) is the basis of the database, but many records do not include reliable measurements of these characteristics. Instead, most events in the database have been included because the associated damage or injury suggests that the weather phenomena reached the severity threshold. This is taken into account by including a severity confidence index. This ranges from 1 for phenomena measured on Bureau equipment or observed by Bureau qualified staff, to 4 for severity deduced by damage assessment.

For each event the database records location and time and details about the severity of the phenomena, such as maximum wind gust strength, hail size, rainfall rate. The extent of damage or injury caused by each phenomenon is also recorded, usually as descriptive text but sometimes also as insurance pay out cost.

Environmental conditions such as stability, wind and temperature fields may also be stored in the database as well as details of thunderstorm warnings so that, in future, the accuracy of the warning service will be able to be calculated automatically by a database query.

7.9 FACILITATING ACCESSIBILITY OF DATABASE INFORMATION TO SERVICES CONCERNED WITH HAZARD PREPAREDNESS, MITIGATION AND REDUCTION

The Natural Hazards Map Working Group (NHMWG), alternatively known as The Circum Pacific Map Project (CPMP)

In 1992, an application was made to IDNDR by the Australian Bureau of Meteorology and funding received to produce a natural hazards map of SE Asia and the SW Pacific Region. The proposal was to produce:

(a) 1:10 million maps of an agreed set of natural hazards in the Australasian Region; and

(b) An accompanying well illustrated and easy to read pamphlets containing a series of descriptions of each hazard for the non specialist.

As a result of the successful application, the NHMWG was formed and brought together experts on a suite of natural hazards.

Some results of the NHMWG are pertinent to this report and these are provided below.

Tropical Cyclone Hazard Map (Refer to **Table 7.4** *for definitions of category 1 to 5 cyclones)*

The contours were plotted using frequency data which was calculated for each point on a grid of latitude and longitude lines separated by 1°. Frequency was derived by counting the number of times within the data set that each grid point lay on the tracks of tropical cyclones of each of the five intensity categories. The track data are held as three hourly positions and intensities. Note that a stationary or slow moving cyclone would not be counted more than once at one grid point even if it maintained its position for more than three hours.

The data set contains cyclone positions and intensities for the period 1959-88, ie. from the beginning of the period when satellite imagery became available for tropical cyclone tracking.

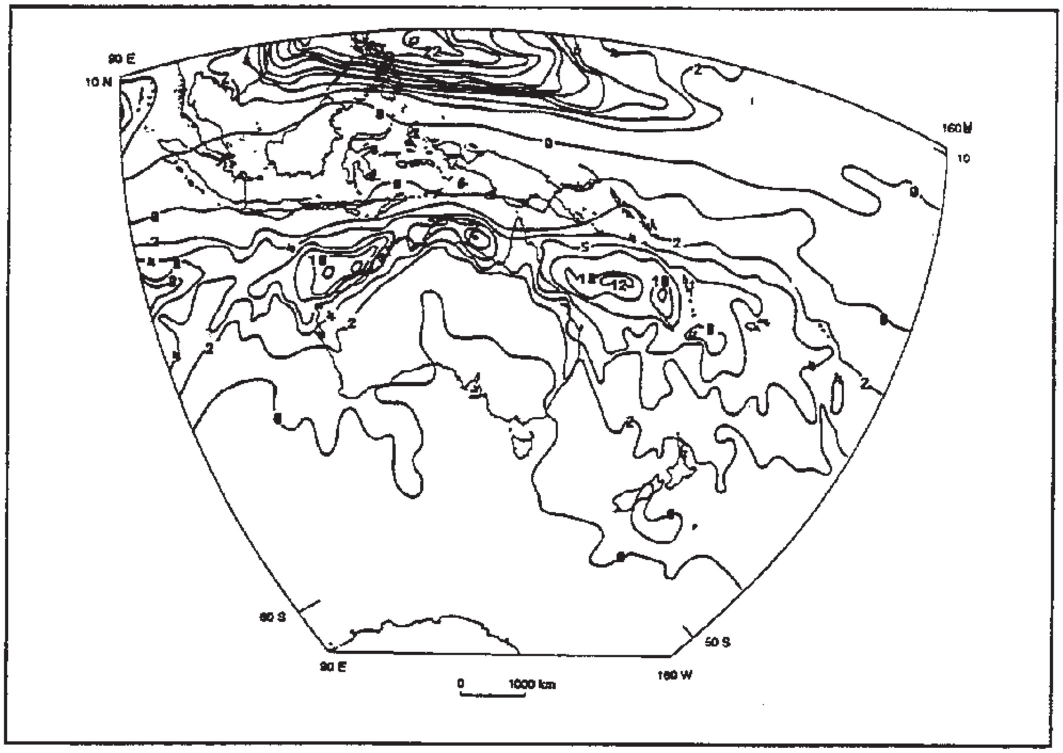


Figure 7.6 - Countours of total number of tropical cyclones n the southwest Pacific (Category 1 to 5), from 1959 to 1988 (Note that contour maps of cyclones for Category 2, 3, etc. and above to Category 5 were also produced for the project, but are not reproduced here.

Definition of phenomena - No universal definition of severe thunderstorms exist, so it was not possible to carry out a consistent analysis over the entire southwest Pacific region. In addition, most countries do not maintain a compiled database of severe storm events, particularly in the tropics where tornadoes and large hail are very rare, even though thunderstorms are common. For the purpose of the study severe thunderstorms included those which produced large hail, strong and locally damaging wind gusts and tornadoes. Note that thunderstorms can also produce severe weather such as flash flooding and lightning, but that these phenomena have not been considered here.

Description of method - For Australia, severe wind producing storms were identified from data collected at 39 Bureau of Meteorology observing stations scattered around the country, using anemograph records of thunderstorms. Tornadic and severe hail producing storm frequencies at the same 39 locations were extracted form the Bureau of Meteorology's severe Thunderstorm Archive, using records from the period 1972-91. These frequencies were then normalised to represent an area of 100 km^2, using the known built-up area of each town or city (the smallest "towns" were assigned the minimum area of 100 km^2). The normalised frequency of tornadic and hail storms wad then added to the frequency of wind storms to give the total decadal frequency of severe thunderstorms.

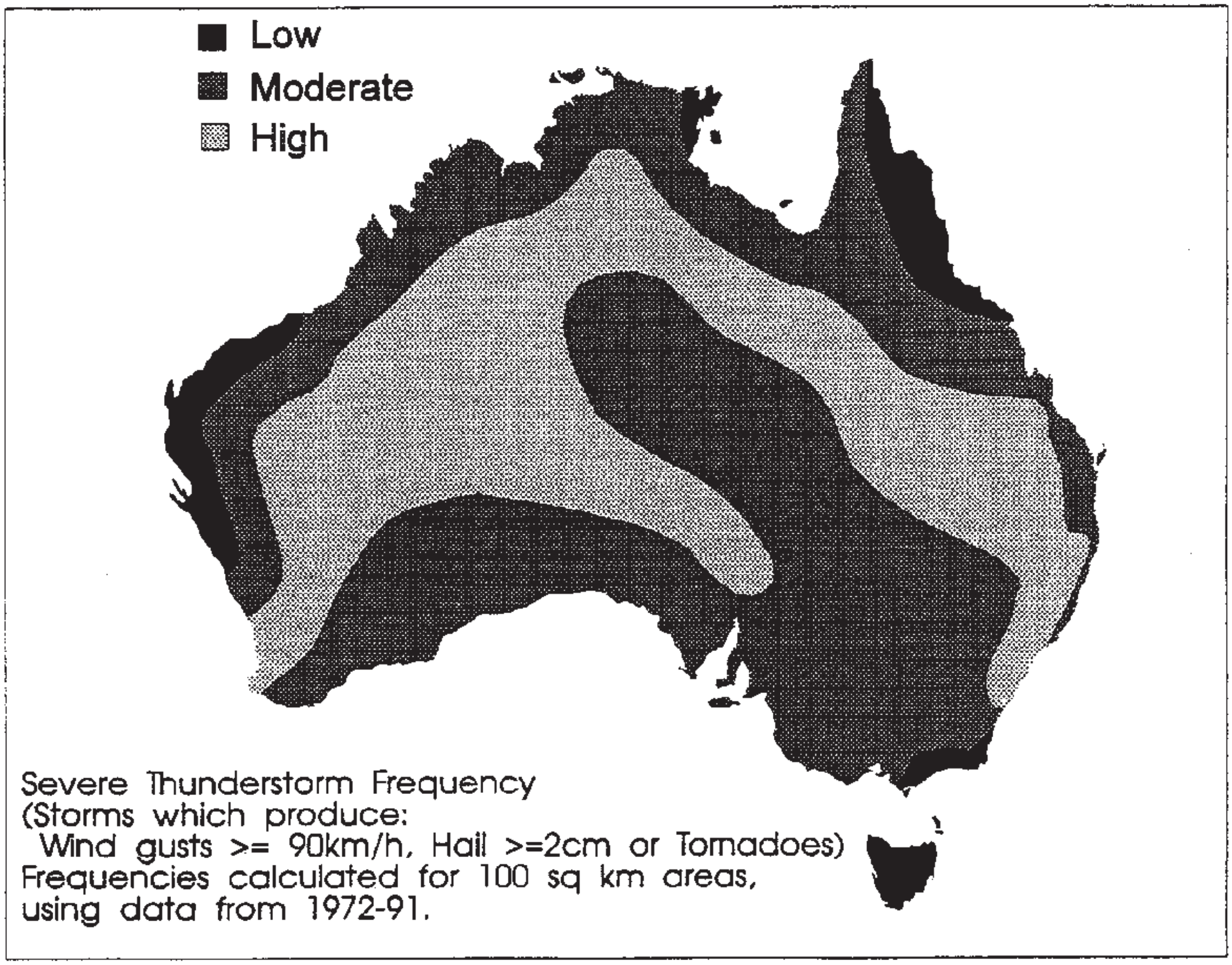


Figure 7.7 - Severe thunderstorm frequency.

The contour intervals (storms per 100 km^2 per decade) chosen to represent low, moderate and high relative frequencies were:

- Low - Less than 4;
- Moderate - 4 to 7.9; and
- High - Greater than or equal to 8.

Other choices of threshold values would produce different contour patterns. Because of the small number of data points used as the basis for contouring, the pattern which results should be seen as giving a broad view rather than being accurate at very high resolution.

The highest severe thunderstorm frequency calculated by this process was 12.9 storms per decade per 100 km^2 at Sydney, New South Wales.

The information on the following pages, which is to be included in the pamphlet accompanying the Australian Severe Thunderstorm Hazard Map for Australia pertains to the incidence of severe storms in remaining, (mainly island) nations of the CPMP region. It is reproduced as an example of the type of information currently available from small (island) nations of the Western Pacific. It will hopefully act as an incentive for improving and perhaps standardising databases of severe storm information for use in hazard mitigation and evaluation.

Brunei

Hail is not a significant hazard in Brunei and thunderstorm wind gusts in excess of 90 km/h are rare. Thunderstorms with heavy rain occur at Brunei's International Airport on average 12 times each year, and the highest wind gust observed there between 1979 and 1992 was 86 km/h (two occasions).

Caroline, Mariana and Marshall Islands

These island groups experience the same basic weather, including moderate to heavy rainfall with the wettest period on average between June and November. The major natural hazard is typhoons (tropical cyclones), although thunderstorms occasionally also cause flooding. Tornadoes are very rare, with the only recorded instances being at Guam (two events in the period 1953-90).

Malaysia

Hail is rare and generally less than 2 cm in diameter, although the annual number of thunderstorm days is generally high, ranging from 70 (Kudat) to 224 (Subang). Thunderstorms do produce severe wind gusts on occasions, although serious damage is rare. Records at 25 Principal Synoptic Stations show maximum wind speeds which range from 72 km/h (Pulau Langkawi) to 140.4 km/h at Ipoh.

New Zealand

Using a definition of severe hail which includes hailstones of 0.5 cm or more in diameter, it has been calculated that on average 9 severe hailstorms occur each year, although there is a large year to year variation. Sixteen percent of those storms produced stones of diameter greater than 3.0 cm and in three percent the diameter was greater than 6.0 cm. The incidence of severe hailstorms was found to be most frequent in the coastal strip, the plains and the adjacent hill country extending from Oamaru to Ranfiora (North Otago to central Canterbury); in central Hawke's Bay from about Waipukurau to Napier, and in an area of the Waimea plains to the south and west from Nelson.

Severe wind gusts in New Zealand are most commonly associated with depressions of tropical origin or intense troughs moving from the west. Tornadoes and extreme wind gusts from thunderstorms are rare.

Niue

Thunderstorms occur on an average of 11 days each year, but hail is extremely rare (NZ Met. Service (A), 1986).

Northern Cook Islands

Hail was observed only once from 1937 to 1982, but thunderstorms are common, particularly in the wet season (October to March). The average number of days with lightning peaks at 4.5 in November at Rakahanga. (NZ Met. Service (B), 1986).

Philippines

A short period of records (1985-87) shows that tornadic thunderstorms are relatively frequent in Philippines, with an average of 4 tornadoes per year. This sample suggests that tornadoes occur primarily on the island of Luzon, but population and reporting biases must be taken into account when assessing the representativeness of this distribution.

Singapore

Hail falls on average once each year, but is generally less than 1.5 cm in diameter and causes no damage. Thunderstorm wind gusts of 50 to 90 km/h occur on average twice per year, but no gusts in excess of 90 km/h have been observed between 1972 and 1991.

Southern Cook Islands

Hail is very rare (one or two days every 10 years) but thunderstorms are common, particularly in the wet season (October to March). Up to 16 days with lightning per month have been observed (NZ Met. Service (C), 1986).

Thailand

Hail is an occasional occurrence, reaching a diameter of 2.5 cm in extreme events. Severe wind gusts from thunderstorms are more common, with an extreme speed of 140 km/h having been recorded (Mukdahan). From 1980 to 1991 the average number of severe thunderstorm events recorded has been 21 per year, generally occurring between February and May.

Tokelau

Thunderstorm occurrence is spread fairly evenly throughout the year. For the period 1948-69 the highest observed frequency of thunder was 15 days per year at Nukunonu (NZ Met. Service (D), 1986).

Tuvalu

Thunderstorms are spread fairly evenly through the year with the highest frequency being 31 days per year at Funafuti (NZ Met. Service (E), 1987).

Western Kiribati

Thunderstorms are spread evenly through the year and have a maximum frequency of 10 per year at Tarawa (NZ Met. Service (F), 1987).

Western Samoa

Thunderstorms are twice as common in the wet season (October to March) as at other times of the year. On average there are 60 thunderstorm days each year. Only one report of a waterspout has been made (NZ Met. Service (G), 1987).

Data sources - The relative severe thunderstorm frequency plotted on the main map was derived from the Australian Severe Thunderstorm Archive, maintained by the Australian Bureau of Meteorology. This Archive has been compiled from newspaper reports, Bureau of Meteorology Observing Station reports and reports from volunteer storm spotters. The Archive includes the data on tornado climatology described by Allen (1980).

General information on thunderstorm frequency and intensity outside Australia was provided by the Malaysian Meteorological Service, the Meteorological Department of Thailand, the

Department of Civil Aviation in the Ministry of Communications of Brunei, the Meteorological Service of Singapore, the National Institute of Water and Atmospheric Research Ltd of New Zealand, the Philippine Atmospheric Geophysical and Astronomical Services Administration and the National Oceanic and Atmospheric Administration of the USA.

7.10 ANALYSIS OF QUESTIONNAIRES

7.10.1 Introduction

A Questionnaire was devised to identify the nature of the threat posed to, and services provided by, Members of WMO. The questionnaire was divided into three parts, devoted respectively to wild land fires, tropical cyclones and severe local storms. In analysing the questionnaires, responses were grouped by Region, to attempt an intercomparison. Much valuable information was obtained, but particular difficulty was experienced in obtaining specific information on economic impacts. It is also difficult to (a) devise and (b) systematically apply a methodology for assessing economic impacts of extreme meteorological events. The summary provided in paragraph 7.4 may provide a beginning.

7.10.2 Wild land fires

Responses, 40 in total, to Part 1 of the suite of questionnaires were received from the following countries:

Region I - Benin, Botswana, Guinea, Malawi, Mali, Sudan, Tunisia
Region II - China, Iran, Mongolia, Thailand
Region III - Argentina, Peru, Uruguay
Region IV - Belize, Canada, Cuba, Dominican Republic, USA
Region V - Philippines, Malaysia (Australia is treated in detail in *Focus on Australia*)
Region VI - Austria, Bulgaria, Germany, Hungary, Ireland, Israel, Netherlands, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Turkey, Ukraine, United Kingdom, Yugoslavia.

Questions 1, 2 and 3 are listed below and the responses are summarised in accompanying text, figures and tables.

Q1 *Are wild land fires considered to be a significant hazard to agriculture or forests in your area of responsibility?*

Q2 *What sort of wildfires occur in your area of responsibility? - Forest (Dry forest/ rain forest), grass, heathland or other (to be named).*

Q3 *Do you provide a fire weather service?*

The results, summarised briefly below indicate that wildfires pose a significant hazard, but in a number of countries fire weather services are not well developed.

Region I Responses indicate that although wild land fires are a significant hazard to forests in five of these African nations and to agriculture in three, Tunisia (who does not consider fire to be a hazard to agriculture or forestry) is the only African respondent providing a fire weather service. Botswana listed 'woodland' fires as significant in that country.

Region II All the Asian respondents reported wild land fires as a significant hazard to forests and Thailand and Mongolia as a significant hazard to agriculture. Three of the four nations had implemented a fire weather service.

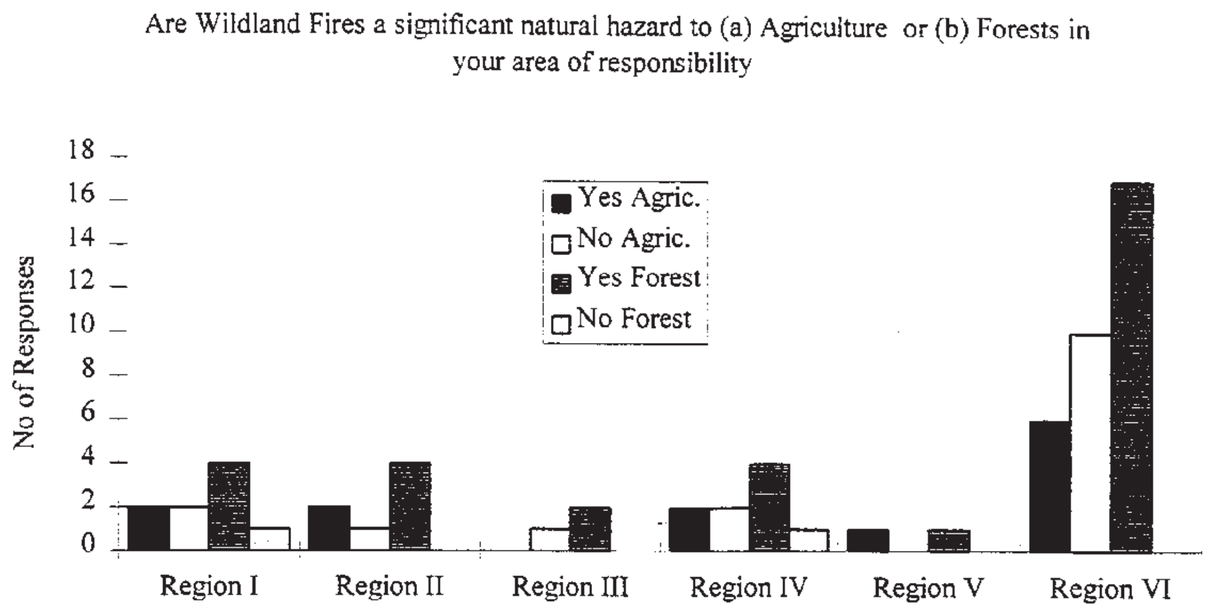


Figure 7.8 - Significance of wildland fires to agriculture and forestry in WMO Regions.

Region III All three South American nations who responded reported wild land fires as a significant hazard to forests. Argentina reported that fire poses a significant hazard to agriculture. Peru had no fire weather service.

Region IV Of the five Central and North American nations, three stated that wild land fires were a significant hazard to agriculture and all for forests. All of these nations supported a fire weather service. "Peat muskeg" fires were of significance in Canada.

Region V In addition to Australia, two countries responded. Neither maintains a fire weather service but Philippines indicated that wild land fires are a hazard both to its agriculture and forests.

Region VI Six of the seventeen European nations responding admitted to wild land fires being a significant hazard to agriculture and all but Austria for forests. Eleven countries answered in the affirmative to having a fire weather service, four responses were no, and Austria and Israel did not mark either box.

Questions 4 and 5 are listed below and responses are summarised in accompanying text, figures and tables.

Q4 *Whom do you provide the fire weather service to?*

Q5(a) *What means are used to provide the information to farmers and foresters?*

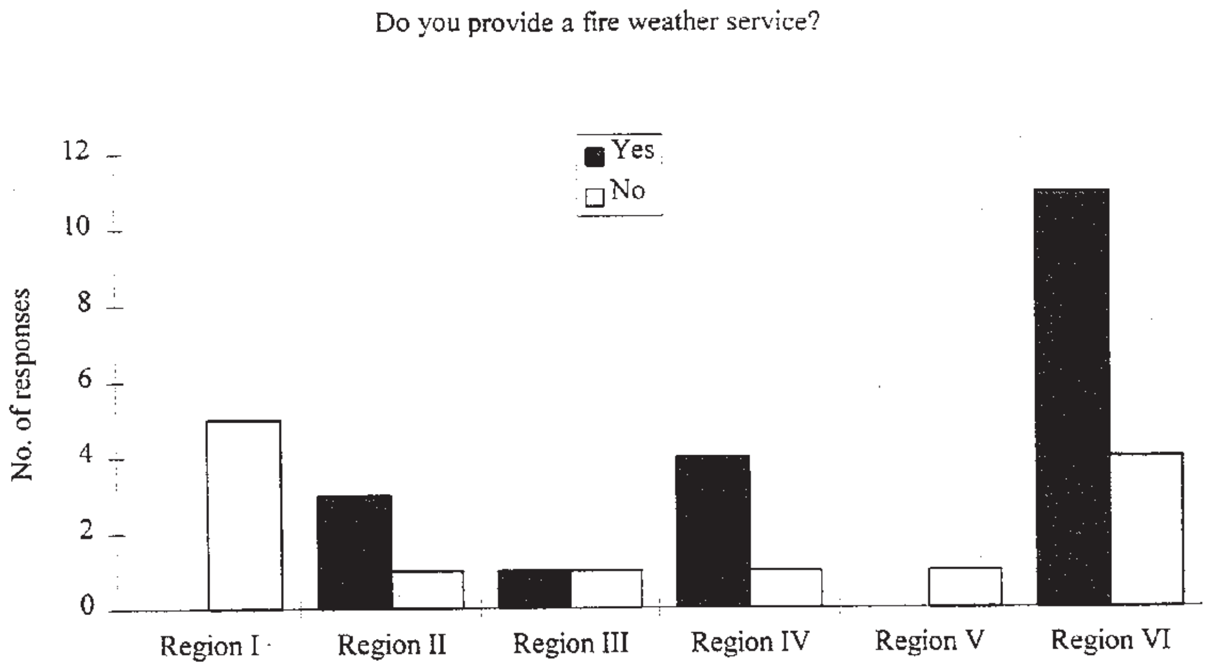


Figure 7.9 - Provision of a fire weather service in WMO Regions.

	Country	Recipients of Fire Weather Service	Means of Provision
Region I			
	Tunisia	Forestry Department, Department of Civil Protection	Fax, telephone, telex
Region II			
	China	Government Departments	TV, radio
	Iran	Interior Ministry, Ministry of Agriculture, etc.	Circular letter
	Mongolia	Public farmers, foresters	Public relations, press
	Thailand	Public, farmers, foresters	Radio, TV
Region III			
	Argentina	National Forest Institute (IFONA) (Not a regular service)	Radio, TV
	Uruguay	Press, media, Forest Service	Press and media advices

Region IV			
	Belize	The Forestry Department (from the US NWS)	Fax, telephone, radio
	Canada	Provincial and territorial fire control agencies and fire management staff	Radio, fax, electronic computer networks
	Cuba	Forest and Fauna Protection Department, Ministry of Agriculture and Civil Defence	Met. bulletin (prepared every 10 days)
	Dominican Republic	Own service and special users	Word of mouth, radio, press
	USA	All federal and state land management and fire control agencies	Primarily-via telecommunications system
Region V			
	Neither respondent (Malaysia, Philippines) has a Fire Weather Service		
Region VI			
	Austria	No service	
	Bulgaria	Ministry of the Interior (Antifire Protection Service), Civil Defence Commission.	Radio, TV, press
	Germany	Ministries and the general public	Forwarded by the Ministries
	Hungary	Territorial authorities, police, fire stations	No answer
	Ireland	State Forestry Service (Coillte)	To forecasters through the Central Forestry Services
	Israel	Forest authorities and the fire service	Fax
	Netherlands	No service	
	Poland	No service	
	Portugal	National protection civil service, Operational centres	No information provided directly to these users
	Romania	Fire Fighting Organisations	Telephone, Telex, fax
	Russian Federation	Aeroservice for Forests and Areal Forestry Protection Corporation	Not given
	Spain	Institute for Nature Conservation, Forest Services, Civil Defence, Government delegates	Fax

	Sweden	National Rescue Service Board who operationally delivers it to surveying authorities in each country	Fax
	Turkey	No service	
	Ukraine	The Ministry of Timber Industries	Telegraph
	United Kingdom	Forestry Authorities	Radio, TV
	Yugoslavia	No service	

The responses to **Question 5(b)**: *What problems do you have in providing warnings to them quickly?* are summarised below.

Region I The only fire weather service provider, Tunisia, mentioned no problems.

Region II Although not supporting a warning service, Mongolia reported problems with the network when providing information; Thailand stated that people ignored the warning message and there was a limited budget.

Region III Argentina stated that the worst problems were with communications. Uruguay had no problems.

Region IV Canada had occasional communications problems in remote areas; Cuba had problems with the communications infrastructure and the USA found it difficult to verify the receipt of forecasts and warnings to users.

Region V No service provided by respondents (Malaysia and Philippines).

Region VI Ireland reported no major problems. The Russian Federation noted that although in general there were few problems, there was a need for more modern forecast and dissemination methods. Remote areas were not well served.

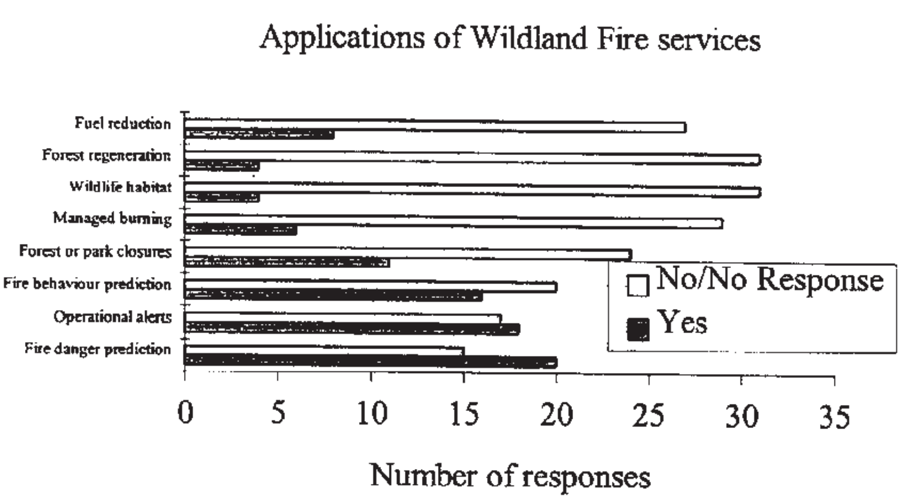


Figure 9.3 Applications of Wild land Fire services

The responses to **Question 5(c)**: *What is the fire weather information used for? Fire danger prediction?, Operational Alerts?, Fire behaviour prediction?, Forest or park closure or other related purposes?, Scheduled burning according to a management program?, Wildlife habitat?, Forest regeneration?, Fuel reduction?* summarised in the following Tables and Figure.

The responses to **Question 6**: *What are the parameters (weather elements etc.) used in the fire forecast?* are summarised below:

Region I

Tunisia
Soil moisture
Wind-speed
Max air temperature
Amount of latest rain
Number of rain since last rain

These parameters give a daily rating which is used to determine a frequency table for each forested region.

Region II

China	**Iran**	**Thailand**
Temperature	Wind speed	Temperature - high temperature
Humidity	Wind direction	Humidity - low humidity
Wind-speed	Dry bulb temp	Precipitation - antecedent rainfall
Precipitation	Synoptic pattern	Fuel Moisture Content - low fuel moisture content
	Dew point	Wind speed - high wind speed
	Moisture Deficit	
	Relative humidity	

Region III

Argentina	**Uruguay**
Maximum temperature	Dry bulb temperature
Humidity	Wet bulb temperature
Wind speed and direction	Rain at local 13:00 (Local hour)
Loss of soil moisture	
Electrical storms	

Region IV

Belize	Canada	Cuba	Dominican Republic	USA
Max temperature	Temperature	Rain	Rain	Wind - 200 ft
Relative humidity-3 pm	Relative humidity	Relative Humidity	Temperature	Temperature - max and min -night time recovery and rate of change
Wind	Wind speed/direction direction/wind shifts	Wind	Wind direction	Humidity - as above
Cloud and precipitation	Lightning potential or probability		Wind velocity	Sky condition and weather
Min temperature	Barometric pressure		Topography	Lightning activity (6 classes)
Risk of thunderstorms	Upper air soundings data			Stability/ smoke dispersion
Heavy rain and high wind warnings	Precipitation probability and amount			Precipitation - amount, duration and areal extention

Region V

A full range of fire weather services is provided in Australia, but the two other respondents to the questionnaire do not currently provide such services.

Region VI

Bulgaria	Germany	Ireland	Israel	Sweden
Air temperature	Daily rain amount	Rainfall in past 30 hrs.	Pure climate parameters	Past rain (weighted)
Air humidity	Relative Humidity	Relative humidity at 2 pm on day of issue	Temperature	Forecast rain
Precipitation	Temperature	Both of above - >fire probable index	Relative humidity	Wind
Wind speed and direction	Calculation of potential evaporation and daily water balance ->fire factor (1 to 5)		Rainfall	Humidity
	Forecast risk factor for 2 days		Wind intensity and direction	Sunshine
			Indices	Type of vegetation
			Ignition coefficient and burning index	

Portugal	Romania	Russia	Spain	United Kingdom
Air temperature	Temperature (max> 33-35°C)	Temperature -max	Temperature	Rain - probability and amount
Relative humidity	R.H. < 30%	R.H. - direct measurement or temperature and due point temperature	Relative humidity	Max temperature
Wind speed	Wind-speed > 8-0 m/s	Amount of growth	Wind	(Min) R.H.
No of days without rain	Soil moisture (0-20 cm reaches high level of dryness)		Storm probability (in particular without precipitation)	Wind-speed and direction
	Atmos. pressure (> 1015 hPa for several days)			Sunshine
	High temperatures			

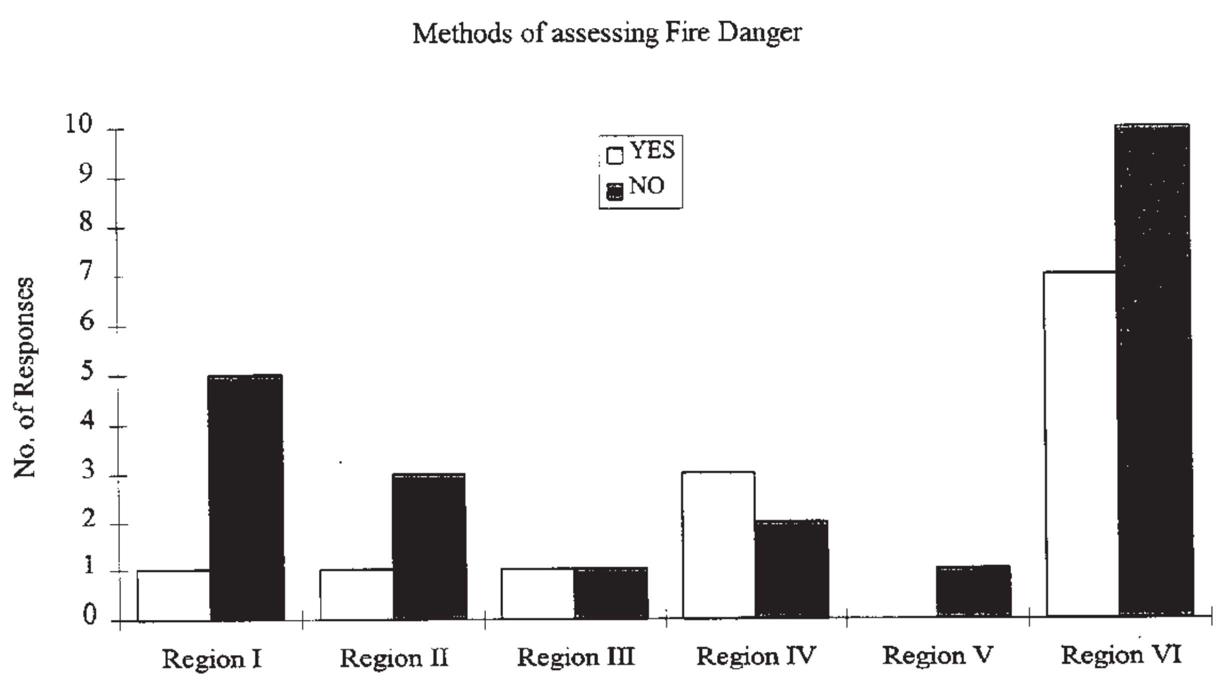


Figure 9.4 Methods used to assess Fire Danger: Fire behaviour model, metre, tables or forms

Questions 7 and 8 were:

Q7 *Do you use a fire behaviour model, or a metre or tables of any form to assess fire danger?*

Q8 *If so, which ones?*

Those countries answering in the affirmative are tabled below.

Region	Country	Model or Method Description
I	Tunisia	A statistical model which determines the regional disposition. Index is called DMRIF and is used to calculate FDMRIF for each forested region
II	Iran	Fransis Lows index, Nesterov index, Angstrom Risk Factor, Foehn effect
III	Argentina	We work on the meteorological situation and if the parameters to hand, indicate the approach of a critical situation, an alert of fire probability is given
III	Uruguay	Masterov
IV	Canada	Canadian forest fire danger rating system: a) Fire weather index; b) Fire behaviour prediction system; Northwest Territories (NWT) Fire preparedness system; Lightning Analysis preparedness planning system; 3-D fire growth model (under development NWT)
IV	Cuba	Methods of other countries - Russia, Poland
IV	Dominican Republic	Period of dryness; wind velocity; type of combustible material and area covered
IV	USA	National Fire Danger rating System; BEHAVE
VI	Bulgaria, Germany	Statistical models for fire danger
VI	Ireland	Separate weekly probability tables, historically derived
VI	Israel	Fire Danger Rating System, USA version 1988
VI	Romania	Angstrom; Nesterov; J C Drouet
VI	Russian Federation	Model relating temperature and relative humidity to give a forecast (c.f. fire danger rating) Tables to give likelihood of dangerous fires. Metal tool
VI	Spain	Tables to calculate index

The responses to **Question 9**:

(a) *Is there a demand for better models?*

(b) *Is there a demand for more fire weather services?*,

The following responses were provided:

Region	Country	Better models?	More fire weather services?	Region	Country	Better models?	More fire weather services?
II	China	Y		VI	Ireland	Y	N
II	Thailand	Y	Y	VI	Israel	Y	Y
III	Uruguay	Y	Y	VI	Portugal	Y	
IV	Belize	Y	Y	VI	Russian Federation	Y	N
IV	Canada	Y	Y	VI	Spain	Y	
IV	Dominican Republic	Y	Y	VI	Sweden	Y	
IV	USA	Y	Y	VI	Germany	Y	
IV	Cuba	Y	Y				

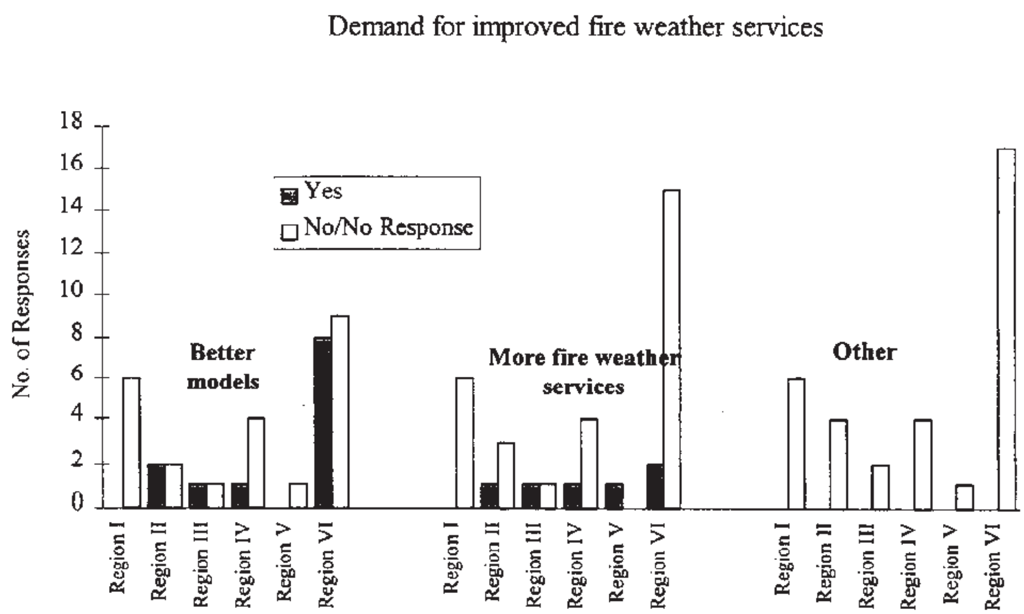


Figure 9.5 Type of demand for improved fire weather services

Some countries provided further comments. These were:

Belize (R IV)	-	Fire behaviour models need to be developed for Belize.
Canada (R IV)	-	Improved extended range (3-5 day) forecast are desired, improved models and radar derived precipitation.
Cuba (R IV)	-	Methods from other countries are being studied.
USA (R IV)	-	Major needs include improved medium & long-range fire weather forecasts; improved lighting forecasts; incorporating geographic information systems into fire behaviour systems.
Germany (R VI)	-	Our model fails from time to time because of its statistical emphasis.
Ireland (R VI)	-	The model described above was intended for April/May period. There continues to be a demand to extend the warning service both into March and June/July.
Israel (R VI)	-	The Israel Met. service is trying to adapt the American model to mediterranean type conditions. We need more training for the forecasters and the people at the receiving end.
Portugal (R VI)	-	They are developing a micro-scale model.
United Kingdom (R VI)	-	In general no pressure for new or extended services. However, one or two private forestry organisations have expressed interest in the use of soil moisture deficits as a prediction tool.

The responses to **Question 10**:

(a) *Is any fire weather research being done in your area of responsibility?*

(b) Describe briefly. were as follows.

Country	**Research?**	**Comments**
Tunisia	Y	Verification of the results of the model used in Tunisia (the local Tunisian model) with the aim of improving the model
China	Y	The research includes: a) The relationship between fire and weather factors b) The relationship between weather system and fire c) The relationship between microclimate and fire d) Theoretical research
Iran	Y	The MSc thesis has been carried out under the supervision of Mr Taghizadeh. The above mentioned model had been adopted in the north of Iran
Argentina	Y	Recently investigations on fire weather have begun, as a result of recent requests
Canada	Y	Wind field modelling; lightning occurrence prediction; fuel moisture modelling; spectral interpretation of fire weather info.;smoke dispersal; test burns; wildfire monitoring and correlation to fire weather indices; impacts of forest fire severity and index of Canadian forests; upgrading of forest fire training manual; electronic bulletin board system for hourly fire indices

Country	Research?	Comments
Dominican Republic	Y	Frequency of fires by area; industries affected; economic losses
USA	Y	Research into the Haines Index (Measure of stability/dryness of atmosphere to assess fire growth potential)
Bulgaria	Y	A method to access temperature-humidity complex and crop and forest inflammability was developed
Germany	N	Due to statistical inaccuracies the fire danger index has to be improved by deterministic methods
Israel	Y	Verification of fire forecast; Improvement of forecasts; Controlled fires as a tool in forest management; Impact of fire on ecological conditions
Portugal	Y	Use of remote sensing data to archive another forest fire risk index
Romania	Y	As Romania has experienced a period of 10 to 12 years of dry conditions and the period 1990-92 has been extremely dry (in 1992 the months of July and August, temperatures above 32-33°C) in some places in the south of the country, fires have occurred and the biomass is very dry. This had meant the necessity of taking into consideration these phenomena. Although research in this area is only beginning it is hoped that in the next two years, information helping to prevent fires will be generated as part of the daily routine
Russian Federation	Y	Research into forecasting temperature and R.H
Spain	Y	Evaluation of special indices for forest fire danger. Specific predictions related to the indices
Sweden	Y	Proposed projects are: 1. Automated fire detection by satellite (NOAA/AVHRR). 2. A sophisticated fire behaviour model based on meso-scale numerical models

The responses to **Question 11:**

(a) *Do you use radar for forecasting/ warning for fires? If your answer is "yes" then:*

(b) What is the wavelength of the radar? are summarised below.

Respondents answering in the affirmative to Q11(a) (with wavelength of radar and how effective they found the radar in brackets) were:

China, answer to 11(a) was "no" but radar wavelength (3 cm, 5 cm, 10 cm - "very effective")
Belize answered 11(a) with a "?" and gave radar wavelength as 10 cm. - Radar "not very effective"
Canada, only in Quebec (5 cm - "very effective")
The USA (10.3 cm and 5.4 cm - "excellent")
Bulgaria (3 cm and 10 cm - "very effective")

Hungary (3 cm and 10 cm)
Ireland (10 cm)
Romania, the answer to answer to 11(b) is given in detail viz. The configuration of the radar network in the country is 7 operational radars:

- 3MRL 5s, built in Russia with 2 wavelengths
- 3MRL 2s built in Russia with wavelength 2.3 cm
- one Plessey 42x, English radar with wavelength 3.2 cm
- Note - the MRL radars operate automatically.

Radar wave length summarised as (3.2 cm and 10 cm). A comment is as follows: It is considered that radar, functioning at $\lambda = 3.2$ as the most appropriate, as it is able to detect echoes coming from columns of smoke emanating from a fire. The fundamental problem that must be resolved is that of recognising the radar echo as coming from a column of smoke emitted by the fire as against cloud echoes, precipitation, topography.

Answer to **Question 12**:

(a) *Do you use satellite data?*

(b) *Do you use Geographic Information System (GIS) information?*

(c) *Information on how either/ both used in relation to wildfire operations.* are tabulated below:

Country	**Q12(a)**	**Q12(b)**	**Comments**
Tunisia	Y	N	Only the supplied satellite data (Meteosat 4) are used for general meteorological forecasting
China	Y	Y	Monitoring occurrence of forest fires
Belize	Y	N	During the fire season 15 March - 31 May satellite imagery are used to track deep convective activity over Yucatan, Guatemala and Belize which are potential fire initiating electrical storms
Canada	Y	Y	In Quebec satellite data are merged with radar data to estimate probability of rain over areas not covered by radar. Satellite imagery is used as a standard tool for determining cloud cover and weather system location. IN the NWT GIS (ARC/INFO) has just been installed and is in the "Beta" stage, it may be used to support fire management activities in the 1994 season. Use of GIS - Impact analysis projects and trend analysis
USA	Y	N	Satellite - Fire Weather forecasting; limited use on fire detection
Hungary	Y	N	As part of standard meteorological forecast activity
Ireland	Y	N	For qualitative evaluation of approaching weather systems
Israel	Y	N	It is used for general forecast which is later applied for fire
Portugal	Y	N	NOAA - AVHRR data

Country	Q12(a)	Q12(b)	Comments
Romania	N	N	There is the prospect of using satellite imagery (NOAA) for surveillance and warning of fires over large areas. The problem to be resolved is that the reception of satellite imagery is in numerical format
Russian Federation	Y	N	
Spain	Y	N	As an aid to the prediction of the meteorological parameters employed

The countries with Doppler Radar were: China, Canada, the USA and Ireland.

Question 13 asked *Do you use aircraft for gathering data for operational fire weather forecasting?*

Listed are countries that either replied in the affirmative or, if in the negative, provided a comment.

Country	Q13 answer	Comment
Dominican Republic	Y	Locating fires Evaluating personnel requirements to achieve control
USA	Y	On-site temperature profiles using helicopters
Israel	N	The meteorological service would welcome a specialised short term training prog. for the Mediterranean regions
Portugal	Y	Aircraft are used to survey and fight the fires
Romania		We do not have aircraft but occasionally we utilise aerial photogrammetry within certain contractual arrangements
Russian Federation	Y	
United Kingdom	N	The Met office does not use aircraft to collect information but it is probable that the Forestry Commission makes limited use of aircraft data

With respect to **Question 14**: *Please provide an estimate of the annual losses from wildfires:*

(a) *For livestock;*

(b) *For crops;*

(c) *For forests (timber varieties)*, a very small number of respondents were able to provide reasonably specific data for parts (a) and (b) of this question. More specific information was provided by more respondents to part (c).

Livestock

Country	Livestock Type	Monetary Value*	Lives Lost
Mongolia		$93,698 US	7346
Philippines		millions	hundreds
Ireland		none	
Netherlands	cattle		only incidental
Argentina	range of cattle, wild animals	not valued	not available

* Responses are expressed in relevant national currency, except when stated explicitly in USD.

Crops

Country	Crop	Monetary value*	Area damaged (ha)
Thailand	fruits		
Philippines		millions	thousands
Netherlands	fruit and vegetables	DFL 200,000,000	not available
Turkey	grain		11,000 ha

Timber

Country	Timber Variety	Monetary Value*	Area Damaged (ha)
Botswana	Burkiaea plurijuga, Burkea africana	not given	not given
Malawi	Pine	not given	500 ha pa
Mali	Karite, Nere, Combretacees, Kaya, Bombax (French)	not given	2,000 ha pa
Mongolia	not given	about $260,000 M US (sic)	
Thailand	Teak, Dipterocap species	$400 M	2 M ha pa
Argentina	Depends on fire region	not valued	not available
Peru	not given		60 ha pa
Uruguay	general forest vars.	$1 M US	not given
Belize	Pinus coribaea	not given	620 acres ('92), 675 acres ('93)
Canada	All types - soft and hardwoods	Hundreds of millions of dollars	approx 700,000 pa

Country	Timber Variety	Monetary Value*	Area Damaged (ha)
Cuba	not specified	$1,533,320	3263 ha
USA	not given	not given	1,094,354 ha (average wildfire acreage nationwide)
Philippines	not given	millions	thousands
Germany	wood	570 - 19700 ECU/yr	289-8768 ha/yr (1975-84 data)
Ireland	Sitka, Norway spruce, Douglas fir, Lodgepole pine	IR £2,500)/ (3,000 ECU) per ha	502 ha
Poland	not given	not given	3000-6000 pa
Portugal	Pine, eucalyptus	~ 6, 210,000 ECU	49,848 ha (1987), 46,015 ha (1992)
Russian Federation	Forest	not given	not given
Turkey	Pine, alder, beech, hornbeam	$11,800,000	12,000 ha
Yugoslavia		15,000 m^3	2,000 ha

7.10.3 Local severe storms

Responses, 40 in total, to Part 2 of the suite of questionnaires were as follows:

Region I - Benin, Botswana, Gabon, Guinea, Malawi, Mali, Sudan
Region II - China, India, Iran, Republic of Korea, Mongolia, Thailand
Region III - Argentina, Peru, Uruguay
Region IV - Belize, Canada, Cuba, Trinidad and Tobago, USA
Region V - Malaysia, Philippines, Vanuatu (Australia is treated in detail in *Focus on Australia*)
Region VI - Austria, Bulgaria, Denmark, Germany, Israel, Netherlands, Poland, Portugal, Romania, Russian Federation, Spain, Switzerland, Turkey, Ukraine, United Kingdom, Yugoslavia

The responses to **Questions 1, 2 and 3**

Q1 *Are severe local storms (including hail, wind, tornadoes and flash floods) considered to be a significant natural hazard to agriculture and forests in your area of responsibility?*

Q2 *What sort of severe local storms occur in your area of responsibility? (Severe hail, wind gusts, tornadoes, flash floods, other (to be named))*

Q3 *Do you provide a warning service for severe local storms?*

are summarised below.

Region I Although local severe storms were considered a significant hazard to either or both agriculture and forests in all but one (Gabon) of these African nations, there were two other nations, viz. Benin and Guinea, who did not provide a warning service for local severe storms. Mali indicated that floods were also a problem for that nation.

Region II Agriculture in all countries in Region II was affected by local severe storms and forests in the Republic of Korea and India were also affected.

Regions III & IV Of the American nations responding to questionnaires, all but two (Peru and Belize) provided a warning service for local severe storms. Belize, however provides some unofficial advice. All these countries considered local serve storms a significant hazard for agriculture and most (exceptions Uruguay and Trinidad and Tobago), a significant hazard for their forests.

Region V Vanuatu did not consider severe local storms to be a significant hazard to agriculture or forests and hence had no warning service. Philippines, although afflicted by all manifestations of severe local storms had not implemented a warning service. Malaysia, though only agriculture was affected, and flash flooding the only class of storm outcome, had implemented a local severe storm warning service. Information for Australia, also in Region 5 is given in *Focus on Australia*.

Region VI In the main, Region VI respondents answered in the affirmative to providing a local severe storm warning service. Denmark did not, as severe local storms were not considered a hazard to her primary industry; Poland though subject to severe hail and wind gusts did not provide a service, nor did the Turkey although subject to severe hail.

The responses to **Questions 4 and 5,**

Q4: To whom do you provide it?

Q5(a): What means are used to provide the information to farmers and foresters?

are summarised below.

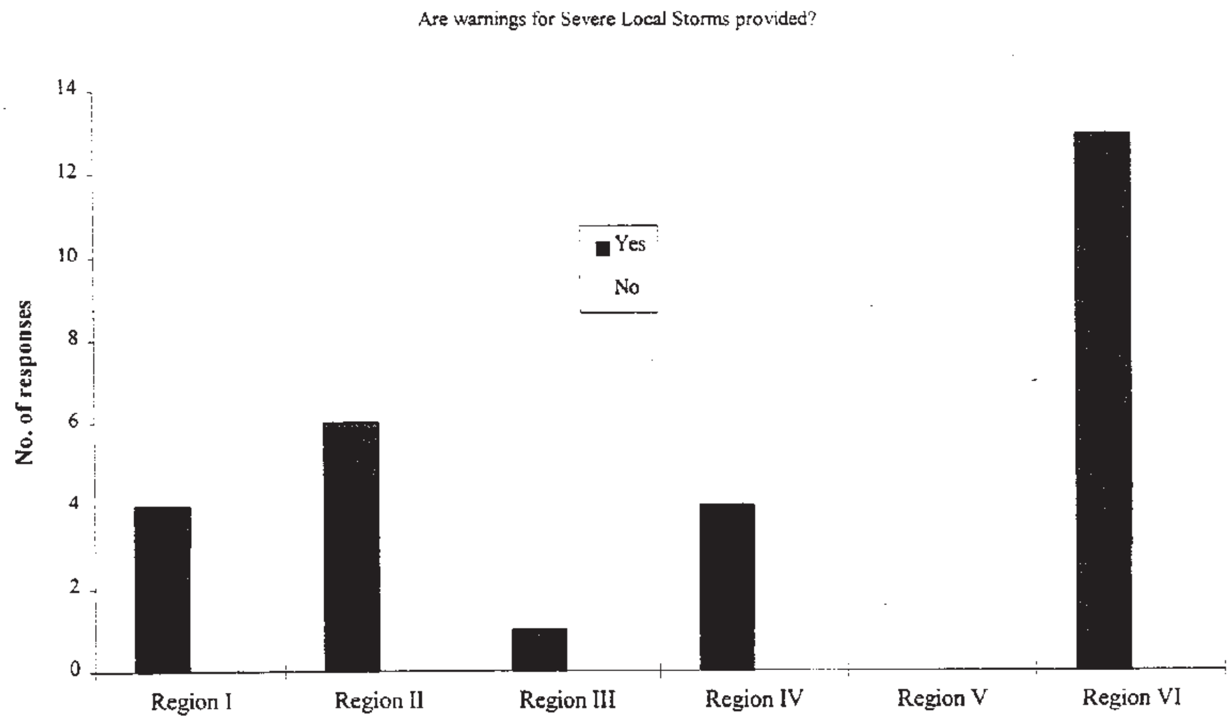


Figure 7.13 - Provision of warning services for severe local storms.

	Country	Recipients of Fire Weather Service	Means of Provision
Region I			
	Botswana	Public; aviation; farmers	Radio
	Malawi	Aviation; farmers; flood forecasters	Telephone, radio
	Mali	General public (peasants, foresters, etc.)	Not given
	Sudan	Public; decision-makers	Agrometeorological bulletin, TV

Region II			
	China	Public; Government Departments	
	Republic of Korea	Ministry of Home Affairs, National Anti-calamity Headquarters, Forestry, Police, Rural Development Office, etc.	Radio, TV
	India	Predesignated authorities; aviation	Radio, TV, telegrams, telephone, agro. advisory service
	Iran	Ministries of Interior and Agriculture and other authorities	Circular letters
	Mongolia	Hydrometeorological Research Institute	Radio, TV, newspaper
	Thailand	Prime Minister's Office, Ministry of Interior Local Administration and Public Welfare Departments, Public	Radio, TV, Public Relations Department
Region III			
	Argentina	Civil Defence who distribute to fire, fighting organizations, police, etc.	Mass communications via telex, fax
	Uruguay	General public, lifeguard organizations	Press media
Region IV			
	Canada	To general public, civic, municipal and country authorities via all broadcast media, with hard copy backup on Newswire service. On auto answering "farm-weather line" telephone service, to emergency response agencies via fax with phone backup, on continuous broadcast "weatheradio"	
	Cuba	All concerned organizations and personalities via Ministries of Agriculture and Sugar Industry and Civil Defence	Radio, TV
	Trinidad and Tobago	General public, Commercial and Industrial sectors. National Meteorological Emergency Agency	Electronic media
	USA	Local and federal Government agencies, Public	Radio, TV
Region V			
	Malaysia	Aviation, city halls, Public	Radio, TV
Region VI			
	Austria	Not given	Braodcasting, custormers
	Bulgaria	Permanent Government Committee for Civil Defence against Accidents and Disasters at the Council of Ministries	Radio, TV

	Germany	Public and private consumers	Radio, TV, telephone, vidiotex
	Israel	Agricultural Sector, forest and fire authorities	Fax, telex, telephone, radio, TV
	Netherlands	Shipping, aviation, agriculture, Public	Telephone, computer
	Portugal	National Protection Civil Service, Floods Forecast Service, Public	Not given
	Romania	Interested Government Ministries	Local decision parameters are provided through Regional Forecast Centres, fax, telephone, info bulletins, radio, TV, agromet. bulletins
	Russian Federation	Government Ministry of Agricuture, local agricultural bodies	Not given
	Spain	Civil Defence Agriculture Organizaions, Public	Fax
	Switzerland	Shipping on lakes, aviation	Not given
	Ukraine	Ministry of Agriculture and Food	Telegraph
	United Kingdom	Local authorities, emergency services, general public	Fax, radio, TV
	Yugoslavia	Electrical and water power industries, Agriculture, traffic and forestry institutions, public	Radio, TV, telephone

Question 5(b) asked *What problems do you have in providing warnings to recipients quickly?*

The responses are summarised below.

Region 1 Benin, although only warning "unofficially" suffered from lack of communications. Malawi noted that not every farmer has access to radio or tv. Sudan noted poor coverage of its warnings.

Region II China and the Republic of Korea reported no problems. India had communications problems and local power failures. IRIMO (Iran) could not be abreast of all potential warnings due to lack of weather radar and polar orbiting satellite imagery. Mongolia stated that the "network situation" was a problem. Thailand did not have the authority to broadcast messages to the public as soon as possible.

Region III Argentina gave "communications" as their significant problem. Uruguay did not have adequate resources to provide warnings quickly enough.

Region IV Belize said that there was not much coordination between forecasting office and hydrological unit. Canada's primary problem was ensuring timely delivery of the complete warning to the customer by overcome delays and distortions at broadcast media outlets. In Trinidad and Tobago warnings are broadcast to the public but no feedback mechanism exists to determine effectiveness of delivery. The USA did not have any significant problems.

Region V Malaysia reported the need for more frequent broadcasts of its warnings. Philippines wanted to provide electrical power and communication training to forecasters.

Region VI Israel said the absence of receiving partner during non office hours was a problem for them. Romania stated that the lack of appropriate technical equipment was their main problem. Russian Federation gave insufficient modern equipment and a poor surface observations network as the key problems. In the Ukraine the absence of a computer system for data processing was causing difficulties. Yugoslavia had insufficient telecommunication lines especially computer ones.

Question 5(c) sought to find out *What is the severe local storm information used for?*

Lightning strike precautions? - A
Operational alerts of dangerous phenomena? - B
Other (Describe)

Nations providing responses to these questions and the answers given are tabulated below.

Country	A	B	Other
Botswana (R I)		Y	
Malawi (R I)	Y	Y	
China (R II)		Y	Aviation
Republic of Korea (R II)	Y	Y	Low visibility warning
India (R II)	Y	Y	Warning the people to save lives and property
Iran (R II)	Y	Y	
Mongolia (R II)	N	Y	
Thailand (R II)	Y	Y	
Belize (R IV)	Y	Y	Flash flooding alert
Canada (R IV)	Y	Y	Sheltering moveable equipment, monitoring livestock, damage control, emergency operations and repair, verifying insurance claims
Cuba (R IV)	N	Y	
Trinidad and Tobago(R IV)	N	Y	
Philippines (R V)	Y	Y	
Austria (R VI)	Y	Y	Weather radar network
Bulgaria (R VI)	Y	Y	

Country	A	B	Other
Germany (R VI)			To allow precautions for shipping, building sites, traffic circulation, aircraft to be taken
Israel (R VI)	Y	Y	Floods, hail, strong winds
Netherlands (R VI)	Y	Y	
Portugal (R VI)	Y		
Romania (R VI)		Y	
Russian Federation (R VI)	Y		
Spain (R VI)	Y	Y	
Switzerland (R VI)	N	Y	
Ukraine (R VI)	Y	Y	
United Kingdom (R VI)		Y	
Yugoslavia (RA VI)	Y	Y	Preparation for anti-hail protection system operation

The responses to **Question 6** *What are the parameters (weather elements, derived indices etc.) used in the local severe storm warning?* are tabulated below.

Region I

Botswana	Malawi	Sudan
Showalter Index	Pressure	Clouds - general cloud cover and rainfall estimates
	Wind	Wind - the expected wind strength and direction
	Temperature	

Region II

China	Republic of Korea	India
Wind speed	Wind speed, Wind direction	Instability conditions
Rainfall	Temperature, Dew point	Strong convergence
	Showalter stability index	Abundant supply of moisture
	K-index	
	Pressure	

Iran	Mongolia	Thailand
SI, K, TT, CT,VI - temperatures - Radar,	Temperature	Temperature- high temperature during the day
Thunderstorm detection,	Rainfall	Gust - high wind speed
Weather, NOAA images,	Humidity	Convectional Cloud - convectional cloud formation
Dew point at Surface and upper layer	Wind speed/direction	Precipitation - heavy rain

Region III

Argentina
High Temperatures
Convective activity
Pressure variation
Wind, changes in speed and direction
Low Temperature
Wind squalls

Region IV

Belize	Canada	Cuba	Trinidad and Tobago	USA
Wind speed and direction	Wind - gusts over 90 km/h	Wind gusts	Rainfall - flash flooding	Wind Speed - threshold 50 knots (58 mph)
Severity of Weather	hail - stones over 20 mm diameter	Hail	Rainfall - riverine flooding	Hail size - threshold 3/4" (or larger)
Dangerous lightning - lightning risks	heavy rain - rates >30 mm/h	Heavy rain and related flash floods	Wind - Damage to physical structures, agriculture	
Hail	Tornadoes	Tornadoes		
		Lightning		

Region V

Philippines
Atmospheric pressure
Temperature and Humidity
Wind Speed
Precipitation
Clouds

Region VI

Austria	**Bulgaria**	**Germany**	**Israel**	**Netherlands**
Echo intensities - weather radar	Wind speed	Wind gusts - max wind speed	Hail	Wind - means and gusts
Wind gusts	Wind direction		Strong winds	Lightning - risk of occurrence
	Precipitation intensity		Synoptic forecast	

Portugal	**Romania**	**Russian Federation**	**Spain**
Wind speed	Radar parameters - echo intensity and height, speed of movement, evolution tendencies	Wind - m/s	CAPE - hydrological soundings plus numerical models
Hail	Conceptual parameters, danger criteria	Precip - mm/ 12h	Conceptual models of severe storms seen by satellite and radar
Heavy rainfall	Satellite information	Relative humidity - %	
	Temperature, wind gusts, pressure, humidity	Temp - max and min	
	Indices - Showalter, Whiting etc. (when these pass specified limits)	Stage - in rivers	
	Barometric tendency, pressure and thermal gradients, precipitable water	Hail - in mm	

Switzerland	Ukraine	United Kingdom*	Yugoslavia
Wind	Wind speed - 25 m/sec	Severe gales - wind speeds in excess of 70 km/h over inhabited areas	Area - which will be covered
Pressure	Hail, diameter- 20 mm	Heavy and prolonged rainfall - lasting at least 2 hours and giving a fall of 15 mm or more within a 3 hour period	Starting time
Temperature and humidity	Air temp 35° C	Snowfall blizzards and drifting snow - likely to reach a depth of 1 post or about a metre	Duration
Lightning/thunder	Air temp 30° C		Intensity
Precipitation			Direction

* The United Kingdom made this comment -"The criteria for the issue of warnings is that there is a strong likelihood of severe weather which may cause considerable inconvenience to a large number of people and/or present danger to life".

Questions 7 and 8 asked: *Do you maintain a database of severe local storm events and impacts? If your answer to Q7 is 'Yes', please describe your database/ databases. (i.e. name and description of fields/ products contained in the database).*

Those countries answering in the affirmative to Q7 are tabled below.

Region	Country	Database description
Region I	Sudan	Maintained in the usual meteorological system for data archiving
Region IV	Canada	These vary by region (area) of the country. *Databases of events*:time, location, track, damage, subjective severity of weather elements that caused the damage; *databases of volunteer weather watchers* by name, address, phone no.. county, lat/ long, organisation; *small database of values* of various predictions during severe events
Region IV	Cuba	Not given
Region IV	USA	Storm data (NCDC publication) database includes narrative description of each reported event within 50 states and of number of facilities, injuries, tornado path - length/width, hail size, max wind speed & total crop damage
Region VI	Bulgaria	Work for creating database including information from 38 synoptic stations has begun since 1992. The database consists of two fields a) wind b) precipitation. Product - expert system for intensive precipitation prediction
Region VI	Romania	There is a collection of satellite imagery but if it is not organised or systematically stored in time order. It is used for meteorological and hydrological case studies

Region VI	Russian Federation	Monthly & annual reviews, tables
Region VI	Ukraine	Annual book, climatic reference book temperature regime, rain regime, humidity humidification of soil, humidity deficit and so on

Question 9 asked; *Is there a demand from outside organisations for:*

Access to radar displays? - A
Access to lightning data displays? - B
More local severe storm warning services? - C

Countries answering at least one of the above questions in the affirmative are given below.

Country	**A**	**B**	**C**	**Country**	**A**	**B**	**C**
Botswana (R I)	Y		Y	Cuba (R IV)	N	N	Y
Gabon (R I)			Y	Austria (R VI)	Y	Y	Y
Malawi (R I)	Y		Y	Germany (R VI)	Y	Y	Y
Mali (R I)		Y	Y	Netherlands (R VI)	Y	Y	
China (R II)	Y	Y	Y	Portugal (R VI)	Y		
Republic of Korea (R II)	Y	Y	Y	Romania (R VI)	Y	Y	Y
Thailand (R II)	Y	N	Y	Russian Federation (R VI)	Y	Y	Y
Uruguay (R III)	Y	N	Y	Spain (R VI)	Y	Y	Y
Belize (R IV)	Y	Y	Y	Switzerland (R VI)	Y	Y	Y
Canada (R IV)	Y	Y	Y	Yugoslavia (R VI)	Y	N	Y
Trinidad and Tobago (R IV)	Y	N	N	Philippines (R V)	Y	Y	Y
USA (R IV)	Y	Y	Y				

Further comments or clarification are given below:

Canada states a media requirement for both on-site coverage and by telephone during warning situations. **Trinidad and Tobago** reports that during the hurricane season, RSMC Miami requests radar display information in situations that are pertinent. **The USA** comments that multiple levels of government and private organisations utilise NWS data (precipitation reports, observations (surface/ upper air, satellite) and watch/ warning/ advisory texts). **Netherlands** informs that radar and lightning data displays are available on-line to subscribers. **Romania** reports that there is a system in place for monitoring and warning of dangerous meteorological phenomena, comprising all varieties of severe local storm. This system is well organised and structured with key specifics and rapid, appropriate international distribution.

Question 10 asked; *Is there any severe local storm research being done in your area of responsibility?*

Below is a list of countries replying in the affirmative to this question and/ or commenting about it.

Country	A	Comments/ Description of Research
China (R II)	Y	China has conducted a series of research projects on severe local storms. Please contact the Chinese Academy of Meteorological Science for more information. The address is: Beishiqiao Lu 46, Beijing, China. Post code: 100081
Republic of Korea (R II)	Y	a) Meteorological Survey of heavy rain areas (1978); b) Numerical experiments of the heavy rainfall event which occurred over the Republic of Korea during 1-3 September 1984 (1989); c) Initialisation experiments on a mesoscale numerical model for heavy rainfall simulation (1991)
India (R II)	Y	There is a local severe storm research unit at Calcutta under RMC Calcutta which undertakes research projects on topics related to local severe storms
Iran (R II)	Y	Storm research has been done by MSc students in class 11 courses. Some individual studies have been carried out by Mr. Taghizdel in the Persian language. These papers have focussed on instability indices like SD, K, TT, CT, VT and adapted them for all areas of the country
Canada (R IV)	Y	Continuous work to improve skill in forecasting severe weather development through the use of severe weather predictors; an index based on correlation of predictors; annual and cumulative storm climatology; regional case studies of individual severe storms
USA (R IV)	Y	NWS research is actively involved in research associated with severe local storms, especially National Severe Storms Laboratory (NSSL) in Norman, OK and the National Severe Storms Forecast Centre (NSSFC). Innumerable technical studies as documented in reports from field forecasters many of which are available through NWS Regional Headquarters
Austria (R VI)	Y	Hail formulation and possibilities if suppression
Bulgaria (R VI)	Y	Synoptic situations of hazard events causing intensive precipitation have been studied
Portugal (R VI)	Y	Analysis of rainfall intensity in short periods
Romania (R VI)		Most are case studies - analyses of storms in each province in terms of favourable areas but also there are general studies which result in conceptual models which have a certain usefulness in operational activities
Russian Federation (R VI)	Y	
Spain (R VI)		Studies on developmental conditions, trajectories etc. have been completed
Ukraine (R VI)	Y	
Yugoslavia (R VI)	Y	Catalogues of historical data on storm and hail hazards; development of a very short range forecast and early warning system; a radar network and data base; a satellite data reception system; cloud modification studies and operational hail suppression (hail protection has been functioning for >20 yrs.)

Question 11 asked;

Q11(a) Do you use radar for forecasting/ warning of severe local storms? - AIf your answer is "yes" then:

Q11(b) What is the wavelength of the radar? -

Q11(c) Do you use Doppler radar? - C

Q11(d) How effective do you find radar? - D

Responses of nations answering in the affirmative to Q11(a) are tabulated below:

Regions I and II

Country	B	C	D	Country	B	C	D
Botswana(R I)	5 cm	Y	new	Republic of Korea	5 cm	Y	see below
Malawi (R I)	10 and 5.4 cm	N	very good	India (R II)	3 cm	N	very good
China (R II)	3.5 and 10 cm	Y	very good	Thailand (R II)	5 and 10 cm	Y	very good

The Republic of Korea comments that when unexpected severe local storms have occurred, radar is effective for obtaining critical information for forecasting them and giving timely warnings.

Regions III, IV and V

Country	B	C	D	Country	B	C	D
Argentina (R III)	10 and 3 cm	N	70%	USA (R IV)	8.5 and 10 cm	Y	see below
Belize (R IV)	10 cm		see below	Malaysia (RV)	10 cm		
Cuba (R IV)	3 and 10 cm	N	very good	Philippines (R V)	10 cm	Y	
Canada (R IV)	5 cm	Y	see below				

Belize comments that their radar (a 30 year old 10 cm Mitsubishi) is no longer 100% efficient but it does indicate areas of convection. There is only very limited coverage by Doppler radar in **Canada.** Radar is found to be very effective within its range; there the radar information is the primary source for making a decision to issue warnings. **The USA** comments that the WSR 57 has served effectively for 32 years. The WSR 74C85 have been effective as local warning radar. The WSR-88D (Doppler) is a revolution and is state-of-the-science.

Region VI

Country	B	C	D	Country	B	C	D
Austria	5 cm	N		Spain	5 and 10 cm	Y	see below
Bulgaria	3 and 10 cm	N	very good	Switzerland	5 cm	N	very useful
Germany	5 cm			Ukraine	Not provided		
Israel	Not provided			United Kingdom	Not provided		
Netherlands	5 cm	N	very	Yugoslavia	2.5 and 10 cm		satisfactory
Portugal	5.5 cm		good	Romania	3.2 and 10 cm	N	

Spain reveals that the radar is the principal means for very short term prediction.

Question 12 asked:

Q12(a) *Do you use satellite data? - A*

Q12(b) *Do you use Geographic Information Systems (GIS) Information? - B*

Q12(c) *If your answer is "Yes" to either or both questions, please provideinformation on how they are used in relation to local severe storm warning operations.*

Affirmative answers to 12(a) and/ or 12(b) are tabulated below.

Regions I to VI

Country	A	B	Comments
Botswana	Y	N	Meteosat images - track down severe storms by looking at cloud bands and estimating the temperatures of the cloud tops
Malawi	Y		Cloud movement and vertical development
Sudan	Y		We use rainfall estimates and cold cloud information provided by METEOSAT through a ground receiver
China	Y	Y	The satellite data is processed into images which are very helpful in the forecasting of severe local storms
Republic of Korea	Y	N	Analysing the movement, tendency, intensity and location from radar and comparing with synoptic weather charts and satellite data; radar is used to determine the area likely to be affected, precipitation for severe storm warning operations
India	Y	N	Cloud pictures, type of cloud and its location
Thailand	Y	N	Intensity, movement and covering area of storm

Country	A	B	Comments
Argentina	Y	Y	These are only used to make a sequence for the verification of alert forecasts and not operationally
Belize	Y	N	Satellite imagery are used to track pre-frontal squall lines that move ahead of approaching fronts over GIF Mex and Yucatan. Severe local storms develop from these squall lines
Canada	Y	Y	Hourly GOES imagery outside radar coverage is used to identify and track thunderstorms; data can be limited and false-colour enhanced
Cuba	Y	N	The satellite data are used for identifying the cloud systems related to severe weather events, their evolution and movement
USA	Y	N	Satellite photo imagery is used in National Centres (NMC & NSSFC) for severe storm forecasting and heavy precipitation identification. Local offices use satellite imagery to identify potentially severe storms and areas of suspected severe weather
Philippines	Y		
Vanuatu	Y		

Region VI

Country	A	B	Comments
Austria	Y		
Germany	Y		Observation of cumulonimbus (height, temperature of cloud top, dimensions)
Israel	Y		
Netherlands	Y		Satellite data are very helpful in assessing the evolution of weather systems in which severe local storms can develop
Portugal	Y		By watching the clouds with strong vertical movements
Russian Federation	Y		
Spain	Y	N	
Switzerland	Y	N	To locate cumulonimbus. To observe the development and movement of cumulonimbus
Ukraine	Y	N	
United Kingdom	Y	N	
Yugoslavia	Y	N	Satellite data are additional data to that from 12 radar centres and the observational stations network which are the basis of the operational system

Question 13 asked:

Q13(a) Do you use lightning location networks for gathering data for operational local severe storm forecasting?

Q13(b) If your answer is "Yes", please provide information on their usefulness and problems encountered.

Below are listed all respondents who answered Q13(a) in the affirmative, or if in the negative provided a response to Q13(b).

Country	**Q13(a)**	**Information on usefulness and problems encountered**
Sudan (R I)	Y	We use the obs to locate and then predict how severe
China (R II)	Y	
Canada (R IV)	Y	Very useful in out range data-sparse areas to locate and track cells real time
USA (R IV)	Y	NWS use of lightning data is limited because no operational federal lighting detection system exists, NWS has access to some lightning data through academic institutions and cooperative agreements. *NWS contracts for national lightning data*: NWS now contracts to private firms. Information transmitted to all warning offices
Austria (R VI)	Y	"ALDIS" system (- Austrian lightning detection and information system) newly installed
Netherlands	Y	(A 24 page report *Experimental evaluation of an arrival time difference lightning positioning system.* Scientific reports WR-92-01)accompanied the questionnaire)
Spain	Y	The network is useful for forest services, electrical companies and for the predictors themselves
Switzerland	Y	To locate cumulonimbus. To observe the development and movement of cumulonimbus
United Kingdom	Y	
Yugoslavia	Y	These data from the meteorological stations network are used for research - they are not included into operational monitoring system

The responses to **Question 14:**

Q14 Please provide an estimate of the annual losses from severe storms. it would help if you could give an estimate for specific types of livestock/ crops/ timber varieties.

are summarised below.

Livestock

Country	Livestock Type	Monetary Value	Lives Lost
Republic of Korea (R II)	Livestock	USD 7, 500	293
Mongolia (R II)			150,000
Uruguay (R III)*	Sheep (adult and lambs)	$3,230,000 US	(not readable)
Canada (R IV)	All	minimal	<100 (in Alberta)
USA (R IV)	Attachment referred	to but missing from	returned questionaire
Philippines (R V)		millions	hundreds
Austria (R VI)	Mostly cows	10 - 20 Mio ATS	10 - 20 minimum

* **Uruguay**'s data suspect due almost illegible typeface. It was stated that there was no data for cattle.

Argentina commented that the Agrometeorological Centre has no information of this kind. and do not know of other organisations who keep it.

Canada made the comment that if major cities are hit by hail, damage (mainly to homes, buildings, and vehicles) can be several hundred million eg Calgary '91 hailstorm damage was between $300 and $400 million. Similarly for tornadoes: eg Edmonton July 31/87 tornado - claimed 27 lives caused $250 million in damages.

Crops

Country	Crop	Monetary Val.	Area (ha) Damaged
Malawi (RI)	Tobacco		
Republic of Korea (RII)	Dry field crops rice plants	No statistics No statistics	9.60 (sic) 39.00 (sic)
Mongolia (RII)	Not given	Not given	60,000
Thailand (RII)	Rice, upland crops, fruit	Not given	50,000
Uruguay (RIII)*	Potato	$ 700,000	
Canada (RIV)	All field crops	$15 M(Hail only-Alberta)	
USA (RIV)	Attachment	Missing	
Malaysia (RV)	Tobacco	RM 26.5 M	2,500
Philippines (RV)	Not given	Millions	Thousands
Austria (RVI)	Not given	100 - 500 Mio ATS	1,000 - 5,000
Bulgaria (RVI)	Not given	119,945,000 BGL (1992)	206,537
Germany (RVI)**	See comment		
Yugoslavia (RA VI)***	All crops	Not given	300,000

* **Uruguay** states that this data relates to a particular severe storm in February, 1993. There is no averaged annual data for crops.

** **Germany** states "Average of losses: 1976-90 500 Mio bis 1,2 Mrd DM" (It is not clear whether this comment refers to livestock and crops, or to either one.)

*** **Yugoslavia** states that arable lands cover around 3,900,000 ha of cultivated lands which total 6,300,000 ha. Maize (1,500,000 ha) and winter wheat (1,000,000 ha) are the most common arable crops. Annual areal damage to theses crops caused by hail, wind heavy showers and torrential floods are 300,000 ha on average per year. This data refers to the total territory, irrespective of the degree of damage.

Argentina commented that the Agrometeorological Centre has no information of this kind. and do not know of other organisations who keep it.

Country	**Timber Variety**	**Monetary Value***	**Area (ha) Damaged**
Malawi (R I)	Pine, Bluegum, Gmelina	Not Available	Not Available
USA (R IV)	Attachment	missing.	
Philippines (R V)		Millions	Thousands
Austria (R VI)	Not given	100-300 Mio ATS	100 - 300 ha
Netherlands (R VI)	Fir, pine	DFL 200,000	600
Spain (R VI)	Not given	Not given	10,000
Switzerland (R VI)	Not given	50 M Swiss Francs	Not given
Yugoslavia (R VI)	All varieties		20,000 m^3 (sic)

7.10.4 Hurricanes; Tropical Cyclones and Typhoons

In all, 16 responses were received to Part 3 of questionnaires distributed to member countries on tropical cyclones. The respondents were: Gabon, Malawi, China, India, the Republic of Korea, Thailand, Belize, Canada, Cuba, the Dominican Republic, USA, Malaysia, Philippines, Vanuatu, Israel and the United Kingdom.

This total, however, included three countries, Gabon (Region I) and Israel and the United Kingdom (Region VI) which do not experience this natural hazard. (Responses from Australia are examined in the chapter *Focus on Australia).*

The approach which will be taken in this analysis is to take one question or a group of related questions and examine responses to this question or group of questions on a Region by Region basis. In this way similarities/differences between regions will be the primary focus, however there will still be scope to compare responses by countries in the same region. The tables and graphs at the end of this part will provide an alternative presentation of the responses.

The responses to **Questions 1 and 2**

Q1 *Are tropical cyclones considered to be a significant natural hazard to agriculture or forests in your area?*

Q2 *Which agricultural or forest regions are affected by tropical cyclones in your area of responsibility?*

are summarised. Tropical Cyclones were considered a significant natural hazard to both agriculture and forests by all respondents who experience tropical cyclones, with the exception of **Malaysia** who responded in the negative with respect to both agriculture and forestry. In response to Q2., **China** (R II) replied that the agricultural regions along the coastline in southeast China were affected by tropical cyclones in summer; **Canada's** (R IV) response was that its Atlantic provinces were affected by decaying or dying remnants of tropical cyclones; the **Dominican Republic** (R IV), attested to their influence in the Caribbean Sea and the Gulf of Mexico. **The USA** (R IV) restricted their influence in its area of responsibility to the States on the eastern seaboard from Texas to Maine, to Puerto Rico and the Hawaiian Islands; **Philippines** (R V) cited their regions I and II as the primary areas affected; **Malaysia's** answer restricted significant effects to the region of Sabah.

Questions 3 and 4 asked:

Q3 Do you provide cyclone warnings?

Q4 To whom do you provide them?

All countries, answering in the affirmative to Q1, provided tropical cyclone warnings. Malaysia did not.

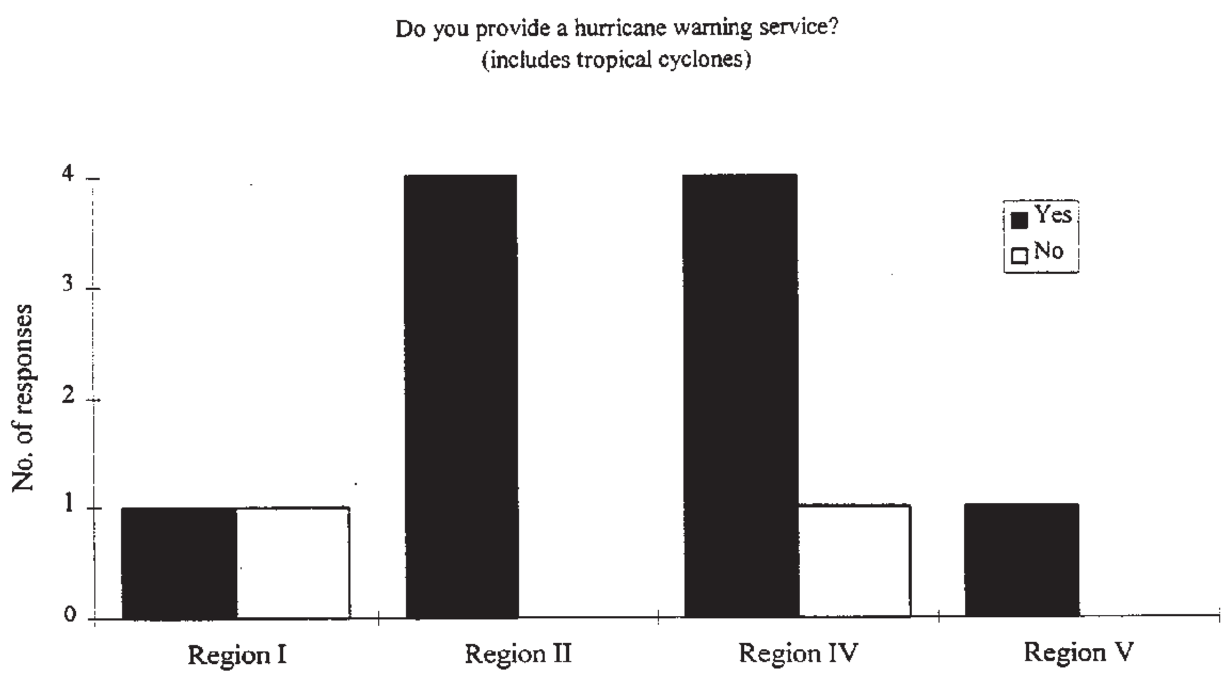


Figure 7.14 - Provision of hurricane/tropical warning services.

Malawi (R I) serviced aviation personnel, marine services and the general public. **India** (R II) listed many recipients in the marine sector; the aviation industry; press, radio and TV; State Government officials including defence and railways; farmers and the general public. **The Republic of Korea** (R II) serviced the broadcasting companies; government agencies including Ministry of Home Affairs, National Anticalamity Headquarters, the Office of Forestry, the Office of Police, the Office of Rural Development etc. **Thailand's** (R II) distribution list included government departments, radio, TV and press; farmers and the general public. **Belize** (R IV) warned the general public. (The Hurricane Central Emergency Committee was responsible for evacuation and relief). **Canada** (R IV) provided warnings to commercial radio and TV, weather radio and ATADS (Automatic Telephone Answering Devices). **The Dominican Republic** (R IV) advised civil and military authorities. **USA** (R IV), as the Regional Special Meteorological Centre (RSMC) for the western hemisphere co-ordinates warnings for all countries in the region and directly issues warnings for high seas, aviation interests throughout the region as well as the USA mainland and islands. **Philippines** (R V) serviced the media, local government, agencies, public and private companies and the general public and **Vanuatu** (R V) warned all organisations and the general public.

Question 5 asked:

Q5(a) *What means are used to provide the information to farmers and foresters?*

Q5(b) *What problems do you have in providing the warnings to them quickly?*
Q5(c) *What is the tropical cyclone information used for?*

All replies to Q5(a) included radio. For **Malawi** (R I), and **Vanuatu** (R V), no other method of distribution was given. For **China** (R II), the only additional means listed was telegram. All other responses included TV. The press was named or implied for **Canada** (R IV), **Dominican Republic** (R IV), **USA** (R IV) and **Philippines** (R V). An additional distribution mode for Canada and the USA was weather radio.

Problems in providing warnings quickly were flagged from **India** (R II) - During bad weather there is total communication disruption due to strong winds; **Thailand** (R II) - who do not have the authority to broadcast to the public as soon as (otherwise) possible; **Belize** (R IV) has the problem of breaks in communications lines; **Cuba** (R IV) attests that the communications infrastructure is not suitable enough; while **Philippines** (R V) complain of communications system failure.

All countries involved in tropical cyclone warnings replied in the affirmative to the listed usages for the warnings viz.: - for wind prediction, rain prediction, flooding prediction, safety of stock, safety of people, counter disaster preparations. **India** (R II) also listed prediction of storm surges as another use and **Philippines** (R V) added relief operations and insurance.

Question 6 asked:

Q6 *What are the parameters (weather elements, derived indices etc.) used in the tropical cyclone forecast?*

This question may have been misinterpreted in isolated cases, where it was taken to mean the content of the warning, rather that the parameters used in warning preparation.

Malawi (R I) cites wind and pressure; **China** (R II) wind and rain; **India** (R II) - synoptic charts, cloud imagery, 10 cm radar, ships' data; **the Republic of Korea** (R II) - central pressure, pressure 6 hours ago, present position and the radius of winds greater than 15 m/s; **Thailand** (RA II) - wind strength, direction of movement of the storm, storm stage (intensifying or decaying), affected area, heavy rain/ flash flooding possibilities; **Belize** (R IV) - maximum strength of sustained winds, extent of winds above gale force, central pressure, speed and direction of movement; **Canada** (R IV) - wind and rain; **USA** (R IV) - wind, temperature, pressure, moisture in the system and its environment; **Philippines** (R V) - pressure (barotropic, baroclinic and climatological), temperature (maximum, minimum, dry bulb and wet bulb), cloud cover and direction, humidity, water temperature (related to evaporation), sea (swell height etc.); **Vanuatu** (R V) - wind direction and speed (DVORAK technique), rainfall (subjective); storm surge (semi-objective/ objective), seas (semi objective/ objective).

Questions 7 and 8 were:

Q7 Do you use numerical models of any form?

Q8 If so which ones?

Countries responding in the negative to Q7 were: Malawi, China, Thailand, Belize and Vanuatu. Positive responses were given by: India, the Republic of Korea, Canada, Dominican Republic, USA and Philippines.

India (R II) used numerical weather prediction models on an experimental basis; **the Republic of Korea** (R II) uses a spectral model called the Korea Typhoon Model (KTM). Its prediction period is 48 hours, its resolution 50 km and coverage 5400*5400 km^2; **Canada** (R IV) employs numerical weather prediction models, both of Canadian and USA origin; **Cuba** (R IV) reported the use of (Cuban) barotropic models, analogue track models, climatological persistence models, statistical-synoptic models and global numerical models; **Dominican Republic** (R IV) reported its use of Cliper; the USA employed global models (NMC, UKMO, BCMWP), track prediction models, intensity prediction models and statistical models; **Philippines** (R V) used a global spectral model.

It is not within the scope of this paper to describe models or techniques used in tropical cyclone forecasting in depth and those wishing more information on this subject are referred to WMO/TD-No.72, Cyclone Prediction Techniques. A brief overview on tropical cyclone prediction models, summarised from (WMO/TCP-26, 1990) is given in *Review of Other Strategies for Mitigation of Adverse Effects*.

Question 9 asked: *Is there a demand for:*

(a) Better models?;

(b) More detailed forecasts?;

(c) More accurate forecasts?;

(d) Other?

Most of the respondents replied in the affirmative to parts (a), (b) and (c) with only one response to (d) from the United States who answered "better data for models".

No response was given by **Malawi** (R I) and **Vanuatu** (R V) to (a), while **Dominican Republic** (R IV) responded in the negative to (a). **The Republic of Korea** (R II) provided the only other negative answer to this suite of questions, i.e. to (b).

Question 10 asked:

Is there any tropical cyclone research being done in your area of responsibility? Describe briefly or attach copies of any reports.

Nations giving positive replies and summaries of research are provided in the table below:

China Contact NMC, Beishigiao Lu 44 Beijing, China.

India At Cyclone Warning Research Centre (CWRC), Madras, and many other centres.

Republic of Korea

a) Characteristics of the Typhoon approaching and the performance of the WPCLPR model (1990);

b) Forecasts of Typhoon using the Quasi-Lagrangian Typhoon model Part I: Model survey and Test runs (1992);

c) Typhoon development in a two dimensional axis-symmetric model (1992);

d) Numerical Experiment of cloud parameterisation in Typhoon model (1993).

Canada Transition from tropical to extra-tropical.

Dominican Republic Provided a case study on cyclone Cindy (August, 1993) with a strong plea that the plethora of information and advice from many sources in the event of tropical cyclones, be unified in order that the general populace is not bewildered by the range and complexity of it.

USA Improved tropical analysis; better use of model guidance, quantitative evaluations of accuracy of forecasts; in probability form for use in cost/loss analyses; properties at risk.

Philippines TOPE; typhoon moderation; typhoon path; typhoon damage; typhoon forecasting (refer ESCAP/ WMO Typhoon Committee Review).

In response to **Question 11**

Q11 Do you use radar for forecasting/ warning of tropical cyclones?

If your answer is "Yes" then:

Q11(a) What is the wavelength of the radar?;

Q11(b) Do you use Doppler radar?;

Q11(c) How effective do you find radar?.

radar was used by all respondents apart from Vanuatu.

10 cm radar was employed by Malawi, China, India, Thailand, Belize, USA and Philippines; 5 cm radar was used in Malawi, China, the Republic of Korea, Thailand, Canada; 4 cm radar in Malawi and 3 cm radar in China. Doppler radar was used in India, China, Thailand, USA and Philippines.

Comments of very (effective) were registered by China, Thailand, Belize, Canada, USA and Philippines. India commented that cyclones within 450 km from the coast can be detected, the centre of the system can be fixed and characteristics of the eye and the eye wall can be studied (using radar). The Republic of Korea noted that because of the limitation of covering the area, radar is found to be less effective than satellite for forecasting/ warning of tropical cyclones. Belize used radar to get an eye-fix when the storm was in range - 300 km radius.

Question 12 asked:

Q12(a) Do you use satellite data?;

Q12(b) Do you use Geographic Information Systems (GIS)?;

Q12(c) If your answer is "Yes" to either or both questions, please provide information on how they are used in tropical cyclone operations.

All respondents used satellite data in their operations. All nations responded in the negative to Q12(b) except China (yes) and USA (partially).

Malawi uses satellite imagery to estimate intensity using Dvorak T-numbers; China processes the satellite data to produce a 'trace' and to determine the landfall location of the storm; In India, satellite derived winds are used for analysis of weather charts, INSAT pictures are taken every half hour during the cyclone period, Satellite Bulletins indicating T.No./Centre of cyclone etc. are issued to all concerned warning offices. RSMC New Delhi issues advisories/ outlooks to panel countries on the basis of these bulletins, cloud top temperature and S.S.T. based on satellite data are also used to study the cyclones; the Republic of Korea analyses the movement, tendency and central position of tropical cyclones from consecutive satellite pictures and compares derived information with synoptic weather charts. Satellite data are used to determine the most likely area to be affected and the storm trajectory. Satellite imagery is used in Thailand to locate the storm centre, determine intensification characteristics, the direction of movement and the extent of the storm; Belize's uses of the satellite data are to track storm motion and check on intensity, and also to check the extent of the central dense overcast (CDO) and eye wall convection; Canada's response was the imagery is used for analysis and monitoring - track and development; the Dominican Republic's response was that the data was used for analysis, historical considerations and prognoses; the USA stressed the absolute necessity of geosynchronous satellites, for forecasting and warning purposes as they are the primary means of observing the tropical cyclone and its environment. Vanuatu uses GMS and NOAA APT data to estimate position and intensity of tropical systems.

In response to **Question 13:**

Q13 Do you use aircraft for gathering data for operational tropical cyclone forecasting, and if so please provide information on their usefulness and problems encountered?

USA, Dominican Republic and Philippines were the only nations responding in the affirmative. The data gathered by aircraft is used for research purposes by the Dominican Republic; USA finds their use absolutely necessary for precise warning formulation for vulnerable areas; Philippines uses aircraft data to assess wind speed, movement and intensification and to support logistical planning.

Question 14 asked:

Q Please provide an estimate of the annual losses from tropical cyclones. It would help if you could give an estimate for specific types of crops/ livestock/ timber varieties.

Many nations provided no information at all on this question.

Malawi listed livestock affected to be cattle and goats; crops to be tobacco, maize, tea, sugar and cotton; and timber varieties to be pine, bluegum and ameliora. No monetary values of (annual) losses were given. The Republic of Korea listed only "rice plant" as a crop affected by tropical cyclones; Thailand's response was (for crops) rice, upland crops and fruit and annual (areal) losses of 160,000 ha of these commodities; and (for timber variety) rain forest, monetary value $30 - 450 million and annual (areal) losses of 4,800 to 76,000 ha. The response from the USA was $50 million annually from crop losses; Philippines reported livestock losses of about $4 million (for 1991) and crop losses of about $5 million (for 1992); for Vanuatu crops affected were coconuts ($165,000 to $826,000 losses) with an area damaged of 50,000 - 100,000 ha; cocoa ($41,000 to $226,000) with an area damaged of 10,000 to 20,000 ha and garden crops ($816,000 to $4,110,000 with an area damaged of 500 to 1000 ha.

7.11 FOCUS UPON AUSTRALIA

This chapter focuses upon Australia for two reasons, first that the country is prone to many types of natural disaster, second that it is a large country with a diverse range of climates from desert to rain forest, and third that despite the relatively small population there is a well developed infra structure and warning system. Most of the natural disasters are meteorological in origin or contain weather-related elements and all have the potential to impact adversely on agriculture and/ or forests. Tropical cyclones are probably the most well-recognised of the meteorological hazards, but the list also includes severe storms, floods and drought. Yet more hazards are a combination of weather with other factors such as geology, vegetation or technology. Some of these combination hazards with some degree of relevance to the agricultural focus of this report are landslides (triggered by rain), bushfires (intensified by wind, low humidity and high temperature) and crop and animal disease (spread by the wind). Several of the hazards listed are the subject of separate investigations by other members of the Working Group on Extreme Agrometeorological Events.

The Australian Bureau of Meteorology provides services for all four phases of the disaster management cycle: prevention/ mitigation, preparedness, response and recovery. The main thrust of this chapter will relate to **preparedness**, with a lesser focus on meteorological support in the **response** phase. It will give an overview of tailored meteorological forecast and warning services for tropical cyclones, local severe storms, bushfires and will touch on those for river flooding.

It is difficult to estimate the cost to the community of disasters, and even more difficult in a country like Australia to partition costs, so that losses suffered by particular sectors (agriculture and forests in this case) can be calculated. Some further discussion on this is contained in paragraph 7.5. **Prevention/mitigation** initiatives by the Australian Bureau of Meteorology are examined to some extent in the present chapter, and also, together with those of other nations and international organisations, in paragraphs 7.7 and 7.8.

The Australian Bureau of Meteorology's services are most focussed upon the **preparedness** phase of disaster management and weather warnings are a vital part of the complex disaster preparedness plans which exist in all States and Territories of Australia. There is a large and rapidly growing demand for forecast information which allows efficient preparation for disasters. The Bureau delivers a multitude of specialised services such as tropical cyclone warnings, severe thunderstorm warnings, flood warnings, fire weather warnings, and others not relevant to this study, to allow the public and authorities such as the Police and Emergency Services to take action which minimises the impact.

Weather forecasts and observations are required in the disaster **response** phase, and these services again form an integral part of disaster plans of the Australian States and Territories. Once a major bushfire or significant river flooding has begun, for example, the managing authorities need weather forecasts and observations to execute their response. In many cases, early preparation triggered by warnings makes the response more effective. For example, early warning of dry electrical storms when fire danger ratings are extreme, allows Fire Fighting Organisations to deploy resources optimally to provide a quick response when fires are initiated.

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During the **recovery** phase, there is great disruption to normal life - whether due to injury, homelessness, loss of power, water supplies, personal belongings or means of obtaining a livelihood - that people are most vulnerable. Rebuilding and recovery tasks also are subject to the weather. The routine forecasts of weather therefore increase in importance to many sectors of the community during this phase of a disaster. In the sections which follow, the role of the Bureau of Meteorology in disaster and emergency management is discussed in more detail and divided into two major categories:

(a) Warning services which assist real-time preparedness and response to disasters; and

(b) Services which assist planning or routine activities and help to prevent or mitigate disasters.

7.11.1 Hurricanes, tropical cyclones and typhoons

Because of the regular occurrence of cyclones in the northern parts of Australia, and their potential to inflict loss of life and widespread destruction, the Tropical Cyclone Warning Service is of the highest priority. The vulnerability of cyclone prone areas is increasing Because of paid growth of population and investment. The threat is recognised by State and

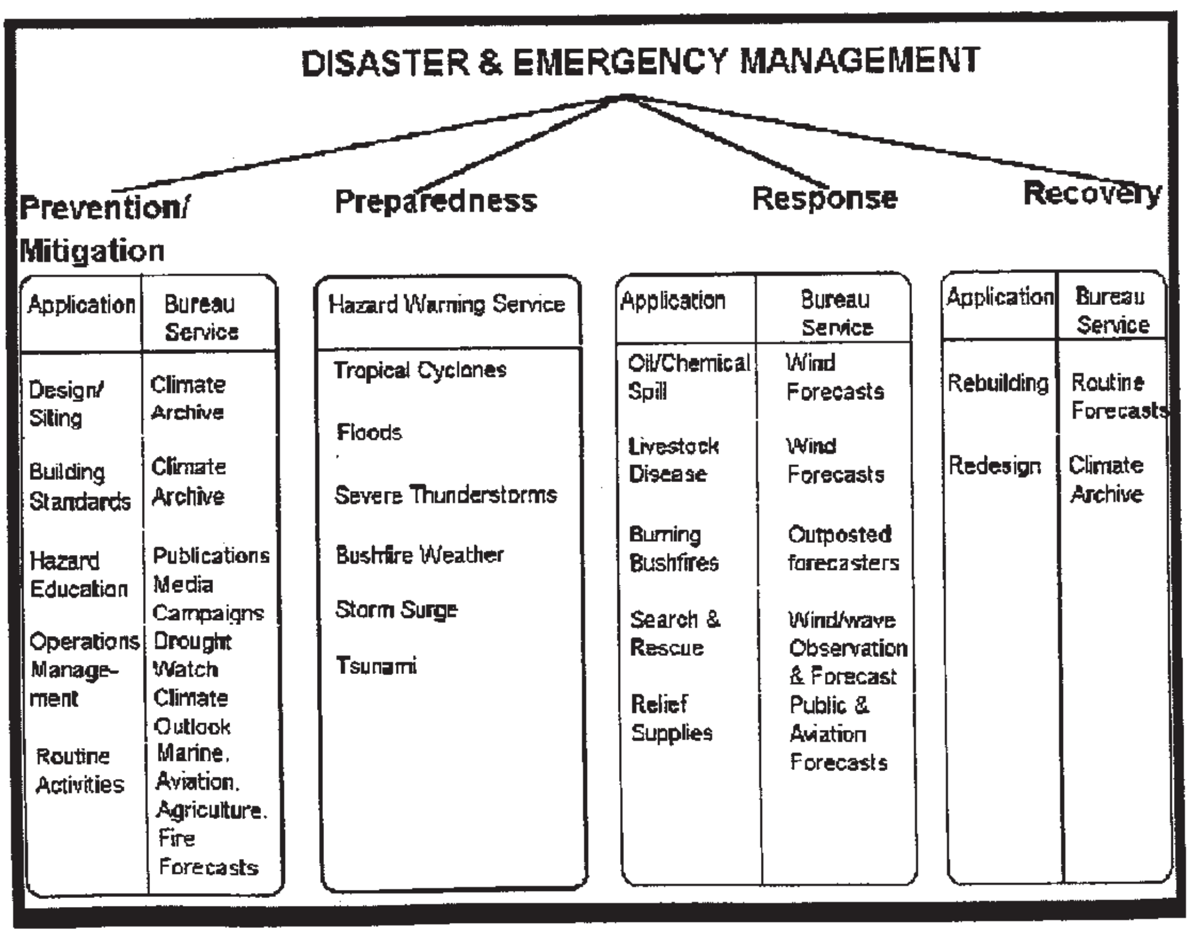

Figure 7.15 - The role of the Bureau of Meteorology in disaster and emergency management.

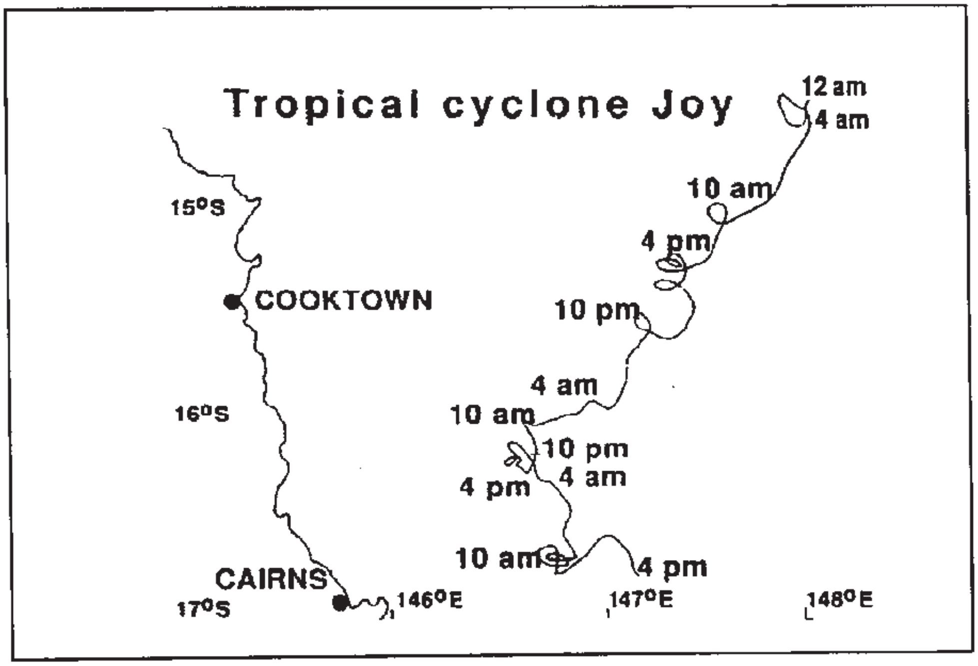

Figure 7.16 - Track of cyclone Joy (21-25 December 1990)

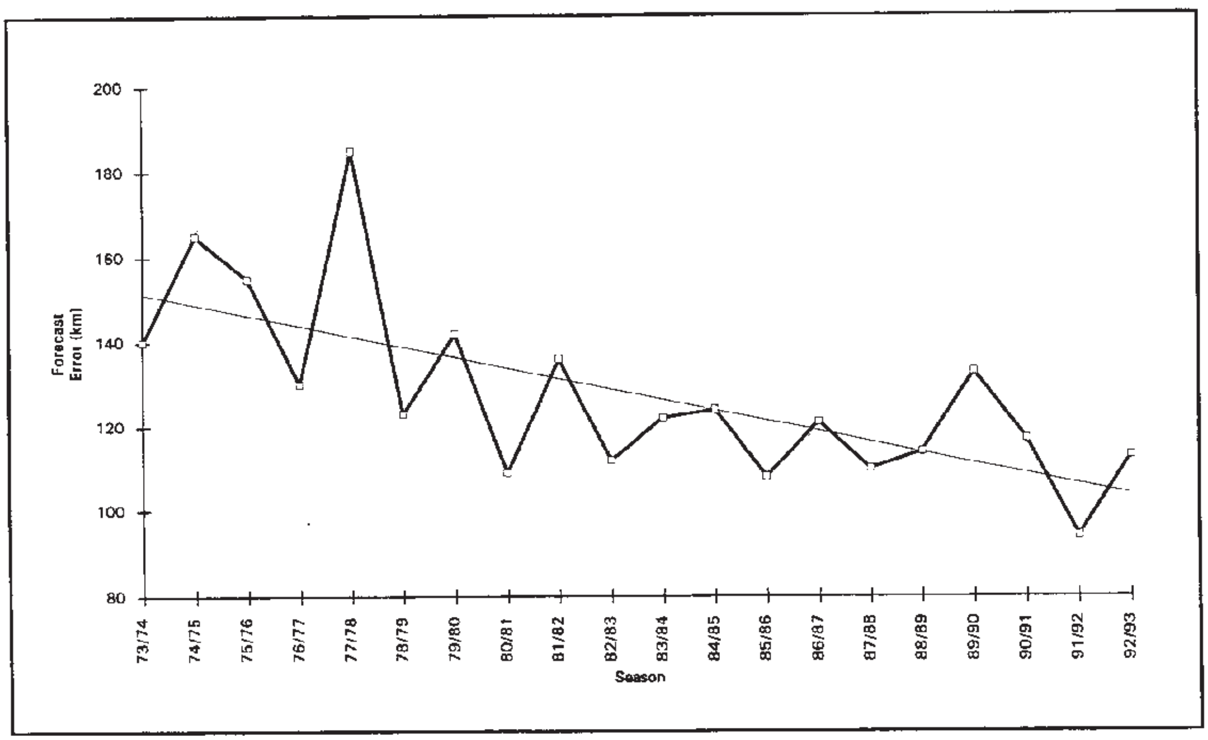

Figure 7.17 - Annual average errors in tropical cyclone position forecasts

local government authorities, and comprehensive preparation and response plans are well-established. These plans rely on frequent, accurate information from the Meteorology, which has developed a well structured, nationally coordinated warning service which operates from centres in Brisbane, Perth and Darwin and relies heavily on satellite and radar data during the most active phases. Each of the warning centres maintains a detailed Tropical Cyclone Directive which is regularly updated and describes warning procedures, address lists, duties and priorities. There are eight main phases of operation of the warning service, outlined below.

The Pre-season System Check Phase consists of a thorough check of all aspects of the system to ensure that equipment is in good working order, and that plans, schedules and procedures (including emergency contingency procedures) are up to date and still feasible. A publicity campaign is also conducted during this phase, in conjunction with emergency services authorities, to raise the level of public awareness of the coming seasonal cyclone threat and to publicise any changes to the warning system. This phase is completed by 1 November.

The Routine Monitoring Phase which opeates between 1 November and 30 April consists of special daily checks for signs of potential tropical cyclone activity within the regions of responsibility. Scientifically-based procedural check sheets are developed for this purpose.

The Cyclone Information Phase is entered when a tropical cyclone or a tropical low expected to develop into a cyclone has formed in or is approaching the area of warning responsibility but is not expected to cause gales on the coast within 48 hours. Specific warnings are issued for shipping, aviation and defence users within the affected area. Relevant information is given to the news media and emergency services organisations.

The Cyclone Watch Phase is entered where an existing or potential tropical cyclone poses a threat of gales in some coastal sector within 48 hours but not within 24 hours. This phase activates public counter-disaster plans and has a significant community preparedness cost impact. Cyclone Watch messages are not issued to shipping and aviation.

The Cyclone Warning Phase is the highest level of operation of the warning system and has a very large cost impact for both Bureau operations and community in preparedness. This phase is entered as soon as a tropical cyclone is expected to cause gales on the coast within 24 hours. Warnings for shipping and aviation are issued using formats and update frequency as designed to suit those user groups.

The Impact Assessment Phase is entered as soon as the cyclone has dissipated. This is an information-gathering, performance-review and public-relations phase intended to apply primarily to major cyclone strikes on the coast. Bureau officers visit the affected area as soon as possible after the cyclone has ended, and personally collect relevant observational data and discuss the Bureau's warning system performance with people and authorities in the area.

The Documentation Phase is entered as soon as a cyclone has been named but most of the activity in this phase commences as soon as the cyclone threat has passed. All relevant information about the cyclone (including forecasts and warnings and other output products) are collected and assembled in a case history file for archival. Selected data are extracted for storage in computer compatible form in the Bureau's National Climate Centre. A summary of each season's tropical cyclone activity is prepared annually for publication in the Australian Meteorological Magazine and special reports on major disaster impact cyclones are prepared for extensive public distribution (e.g. see **Figure 7.16**).

The System Review Phase occurs mainly in the off-season. A review conference is held every second year (alternating with workshops for tropical cyclone forecasters). The system operation is also kept under constant review during the cyclone season and necessary remedial action is implemented immediately, whenever possible or practical to do so.

The effect of improving technologies on the tropical cyclone warning service has been to increase the accuracy of forecasts of the position of cyclone centres. This improvement minimises the area which is warned unnecessarily and so decreases the costs associated with disaster preparation. One of the most important contributors to this improvement has been imagery from the Japanese Geostationary Meteorological Satellite (GMS), whose orbital position, above Papua New Guinea, is ideal for coverage of Australia and the surrounding waters. Improvements in resolution and frequency of images with each successive satellite in the GMS series have been of particular benefit to the tropical cyclone warning service, since cyclones spend most of their lives well out to sea, away from conventional land-based observing networks. The introduction of routine hourly images has led to improvements in both cyclone track prediction and in the speed with which warnings can be updated. **Figure 7.17** shows the twenty-year trend towards greater warning accuracy.

The Regional Offices of the Bureau of Meteorology go to considerable effort to tailor the cyclone warning service to the needs of the community, including those industries which are most affected. Consultative meetings are held with government authorities (State and local levels) and with industry representatives prior to each season and after major events. The aim is to achieve a balance between the requirement for adequate warning and the need to avoid over-warning, with its consequent costs in lost production and tourism revenue.

7.11.2 Severe local storms/ severe thunderstorms

Severe thunderstorms are defined by the Bureau of Meteorology as those thunderstorms which produce:

- hail of diameter 2 cm or greater;
- wind gusts of 90 km/h or greater;
- very heavy rain or flash flooding; or
- tornadoes.

Because thunderstorms generally affect small areas for short periods of time, their status as a hazard is often underestimated and their average annual damage bill (as measured by insurance payouts) is greater than that due to tropical cyclones, floods, earthquakes or bushfires. The small size and short lifetimes of these systems create difficulties in providing the public and disaster response authorities with adequate warnings.

In 1990 the Australian Bureau of Meteorology introduced the first phase of an upgraded two tiered warning service for severe thunderstorms. The two tiers are designed to allow detailed short-range warnings where observing resources allow it, and broader longer-term advice in other areas. Because radar is the most effective means of monitoring thunderstorms available at present, the short-term warning service (up to 3 hours ahead) is as yet confined to the capital cities. The longer.term advice service (up to 6 hours ahead) is provided to the capitals and to provincial areas. As forecasting techniques and observing systems are developed it is planned to extend the advice service throughout Australia.

Forecasters make use of weather watch radar, volunteer storm spotter networks, satellite imagery and, most recently, lightning detection networks to recognise dangerous situations, monitor existing storms and predict the storm movement and intensity before these relatively short-lived systems strike major population centres.

Figure 7.18 compares the quality of severe thunderstorm warnings during the period 1983-87 with that for the thunderstorm season (1992-93). The service quality is measured in terms of Probability of Detection (POD), which is the percentage of all storms for which warnings are issued; False Alarm Ratio (FAR), which is the percentage of all warnings which were not required; and Leadtime, which is the average time between the issue of a warning and the onset

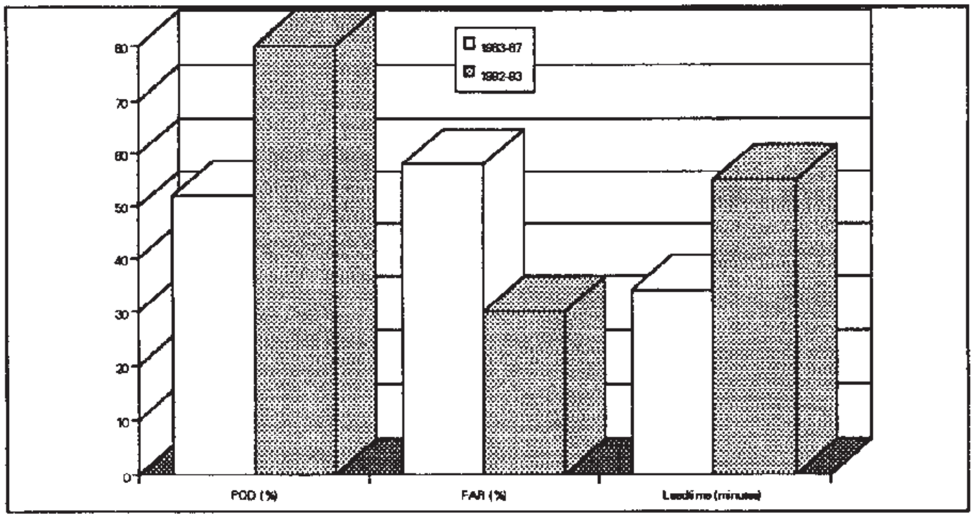

Figure 7.18 - Probability of Detection (POD), False Alarm Ratio (FAR) and Average Leadtime for severe thunderstorm warnings before and after upgrading.

of a storm. Perfect warnings would have a POD of 100%, FAR of 0% and leadtime of more than 30 minutes. It can be seen that the new service has improved considerably upon the old, as gauged by all three measures.

7.11.3 Wildland fires/ bushfires

Bushfires are a serious natural hazard in Australia whose costs have never been effectively evaluated. The loss of life since 1901 has been some 467 people of whom about 340 have been in the State of Victoria. Tasmania and South Australia have been the next two most dangerous States. Most of these fatalities have ocurred in a small number of disastrous events such as the Black Friday (1939) fires, in Tasmania in 1967 and the Ash Wesdnesday fires in Victoria and South Australia in 1983.

The Australian Bureau of Meteorology, as a result of a particular clause of the Meteorology Act, "issues warnings of ... weather conditions likely to give rise to ... bushfires". These warnings are for specific occasions when the fire danger becomes extreme and are supplemented with a service that provides forecasts of fire danger daily throughout the fire danger period. The warnings are promulgated through the media to the public and sent direct to rural fire services, forest and national park authorities and many other clients. The accuracy and effectiveness of the warnings have been improving steadily over the last three decades and have reached a proficiency such that it is unlikely that a major bushfire emergency could arise without prior weather warning. As well as warning of extreme situations, there is also an increasing demand for the Bureau to provide routine forecasts and other support services to fire authorities.

Of special importance are the services for fuel reduction burning which enables fire authorities to safely reduce fuel litter which, in turn, reduces the risk of major wildfires in the following seasons. The Bureau interacts closely with the State fire authorities and the national coordinating body, the Australian Fire Authorities Council (AFAC), and conducts workshops and research projects to improve the service.

7.11.4 Floods

Flooding is the most expensive natural disaster in Australia, costing the nation almost $400 million per year. It is also the most manageable of the weather-related disasters with a range of structural and non-structural mitigation measures available. To assist in reducing the economic and social impact of flooding, as well as improving public safety, the Australian Bureau of Meteorology provides a flood warning service, coordinated nationally and provided by Regional Offices. This service involves the provision of timely forecasts of flooding to emergency management agencies, local authorities and the general public for key flood-prone locations. The aim of these forecasts is to provide time for action to be taken to minimise damage and reduce the risk to public safety and loss of life, including evacuation of people from threatened areas, raising and/or removal of property and personal belongings, planning for loss of infrastructure and removal of stock to high ground.

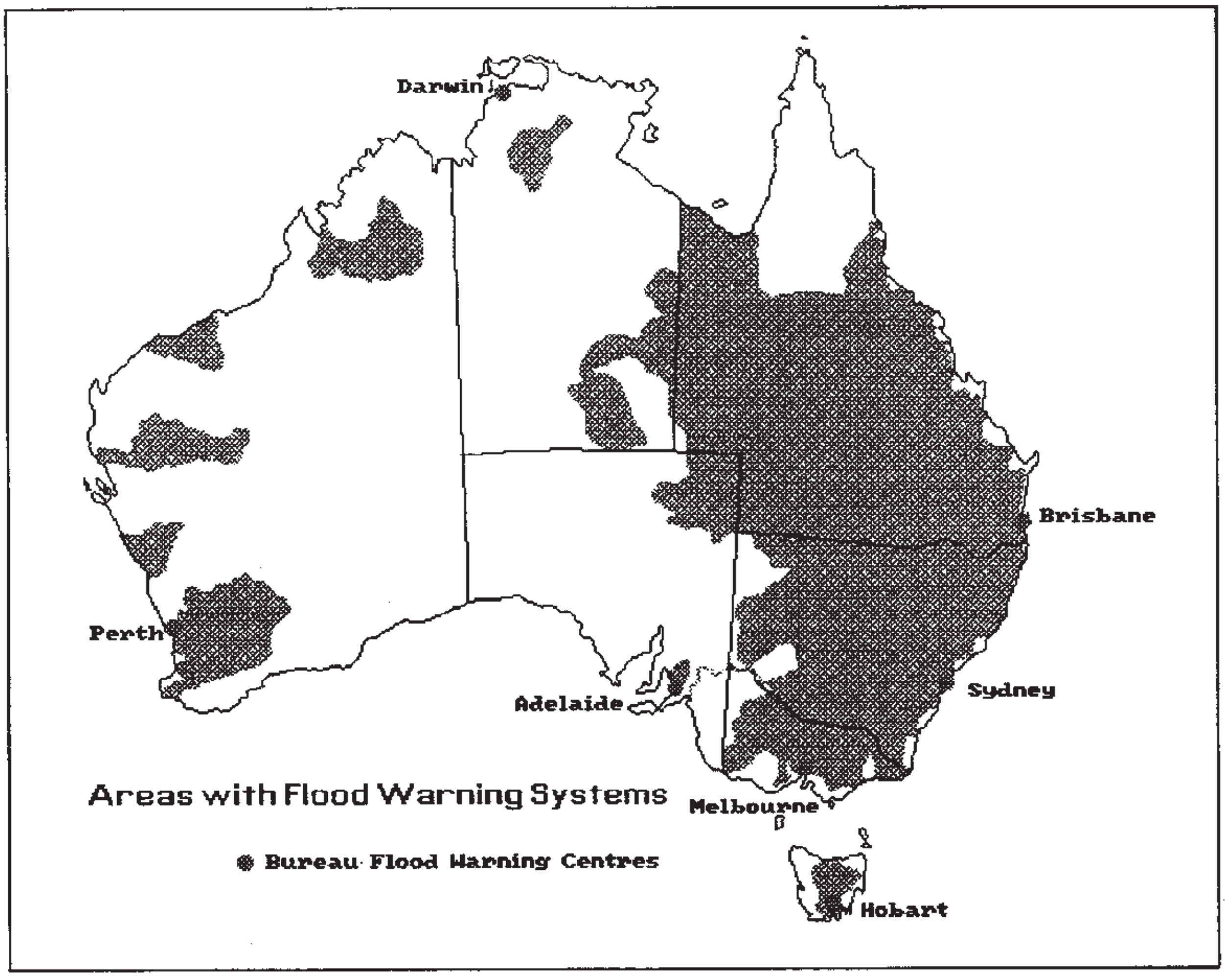

Figure 7.19 - The extent of flood warning systems throughout Australia

Different levels of service are provided in accordance with the need and the available resources, varying from specific predictions of flood height at key locations for most river basins in the more flood-prone eastern states of Queensland, New South Wales, Victoria, Tasmania and South Australia, to more generalised warnings for the less populated areas of Western Australia and the Northern Territory (**Figure 7.19**). The importance of an integrated nationwide service is highlighted during flooding episodes such as April 1990 when a significant proportion

(**Figure 7.10**) of the continent experienced major flooding. Twenty seven river basins were affected, 9 experiencing record major flooding, with over 12,000 warnings disseminated to more than 700 individual addresses from Flood Warning Centres in 4 States.

The service is provided in close cooperation with State and Local Government agencies who share in the capital costs and maintenance of the data collection networks used, as well as co-ordinate flood warning with other flood mitigation strategies. Integration with floodplain management programs at State and Commonwealth level is assisted through Bureau involvement in bodies such as the Agriculture and Resource Management Council of Australia and New Zealand. The flood warning service is integrated into flood emergency management plans prepared at the State and local level to ensure that Bureau forecasts are used effectively.

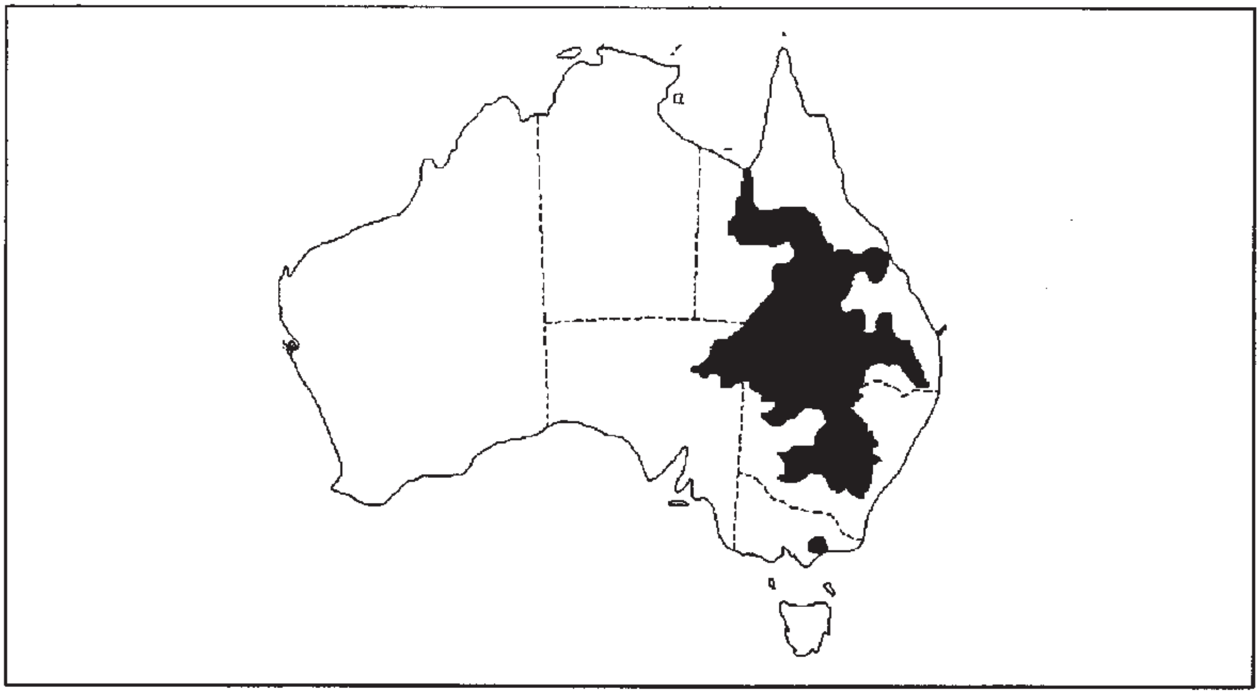

Figure 7.20 - Areas affected by major flooding during April 1990.

Priorities for new and improved services are determined in close consultation with relevant state and local agencies through State and Territttory Flood Warning Consultative Committees, ensuring that the most important needs are met and that costs are shared equitably. This cooperative approach has led to significant growth in the coverage as well as a gradual improvement in the quality of services. Accurancy is one indicator of quality; for example, in New South Wales the percentage of flood height errors greater than 0.6 metres has decresed from 38% to 27% over the period 1988 to 1992, with a corresponding increase in the number of forecasts within 0.3 metres.

The benefits of the flood warning service to agriculture can be demonstrated using major flooding in the Fitzroy River (Queensland) in 1991 as an example. Surveys after the event indicated that $5.5 M of the potential damage to stock and equipment was avoided. While not all of this saving can be directly attributed to the warning system, it does indicate the potential benefit of the service.

Because of their relatively low cost compared to other measures, flood warning systems are generally quite cost-effective. For example the benefit-cost ratio of the Brisbane River Flood warning service has been estimated as 6.6. Effectiveness is enhanced by close co-operation in the design and operation of the warning system between the Bureau and emergency management and other response groups.

7.12 CONCLUSION/ RECOMMENDATIONS FOR FURTHER STUDY

Despite a number of difficulties experienced during the preparation of this report, and the inevitable pressures which occur, the exercise has enabled a valuable start to be made in obtaining a global view of the impacts of extreme events such as wildland fires, local severestorms and tropical cyclones. One somewhat unexpected benefit has been the access gained to a number of valuable sources of information such as the UN Food and Agriculture Organization. There is, however, the need to establish a generally accessible data base of extreme events and their impacts. Such a data base will need to be carefully designed and of a format which will enable easy and universal access. There will also need to have threshhold definitions and severity classes for extreme events with a view to standardisation. *It is therefore* ***recommended*** *that the CAgM Working Group on Exreme Meteorological Events be given the task of designing and co-ordinating the establishment of a data base of extreme meteorological events and their economic and social impacts, with emphasis on agriculture and forestry.*

In attempting to assess the economic and social impacts of extreme events, two major problems were encountered, (a) the lack of any systematic methodology, acceptable to meteorologists, economists and planners and (b) the lack of information within Member countries on impacts of specific phenomena or events. Generally, but with some exceptions, when information was provided it was subjective and generalised. Nevertheless, extrapolation of responses to specific questions in each of the three parts of the questionnaire showed that hundreds of human lives, thousands of animal livestock and billions of US dollars are lost annually throughout the world. Nothwithstanding, the data need to be presented comprehensively and convincingly to government planners to demonstrate the tangible savings that accrue from effective monitoring and warning systems. *It is therefore* ***recommended*** *that the CAgM Working Group on Extreme Meteorological Events undertakes a survey of accepted methods of assessing economic impacts of such events with a view to achieving implementation of a a preferred approach on the part of WMO Members.*

Case studies are a very useful way of investigating and drawing attention to the economic and social impacts of extreme events and should be promoted. *It is therefore* ***recommended*** *that the CAgM Working Group on Extreme Events develops a standard approach to case studies and collaborates with appropriate representatives of individual Members to obtain or undertake such studies after events which meet agreed threshold criteria.*

BIBLIOGRAPHY

Ackermman, J.A., 1994. The economic and environmental benefits of weather forecasts for salting operations in Devon. J. Meteor. Applns, 1(2), 112.

Allen, S.C., 1980. A Preliminary Australian Tornado Climatology. Tech. Rep. 39, Aust. Bureau of Met., 14 pp.

Amman Ministry of Planning 1992. Reported Damages to the Economy of Jordan Resulting from Heavy Rainfall and Snow Storms in Winter, 1992 (Paper - courtesy of R. Gommes, FAO).

Anaman, K., Thampapillai, D., Henderson-Sellers, A., Noar, P. and Sullivan, P., 1995. Methods for assessing the Benefits of Meteorological Servicces in Australia, J. Meteor. Applns, 2.

Anderson, L.G. and Burnham, J.M., 1973. Application of economic analysis to hurricane warnings to residential and retail activites in the U.S. Gulf of Mexico coastal region. Monthly Weather Review, 101, 126-131.

Anon, 1994. Airborne Remote Sensing Aids Bushfire Battle. CSIRO Space Industry News, Aust., No. 56, February, 1994.

Abderrazak Arif, 1993. The Meteorology and the Forest Fires. Art., Met. Nat. Inst., Tunisia, July, 1993.

Advisory Committee on IDNHR, 1987. Confronting Natural Disasters. An International Decade for Natural Hazard Reduction. Nat. Academy Press, Washington, D.C., 1987.

AIIMS Publications Group, 1991. Incident Control System, the Operating System of AIIMS. Australia Assn. of Rural Fire Authorities, 1991.

Arkin, P.A. and Ardanuy, P.E. 1989. Estimating climatic-scale precipitation from space: a review., J. Climate, 2, 1229-38.

Aust. Assn. of Rural Fire Authorities Conf., 199.: Proc. of Tenth National Conference of Australian Association of Rural Fire Authorities. (various papers). 10-13 May, 1993. Twin Waters Resort, Mudjimba Beach, Qld.

Aust. Bureau of Met., 1992. Preprints from the Third Severe Thunderstorm Workshop. (various papers) 31 May - 5 June, 1992. Gympie, Qld.

Aust. Bureau of Met., 1993. Fire Weather Workshop. 3-7 May, 1993. Bowral, NSW.

Aust. Bureau of Met., 1993. Annual report 1992-93. Australian Government Publishing Service, Canberra, Australia, 125 pp.

Aust. Bureau of Met., 1993. The Role of the Bureau of Meteorology in Disaster and Emergency Management, pp 24. Submission to Senate Standing Committee on Transport, Communications and Infrastructure Inquiry into Major Disasters and Emergencies.

Aust. Bureau of Met., 1994. Annual report 1993-94. Australian Governmnet Publishing Service, Canberra, Australia, 141 pp.

Aust. Bu410Xreau of Statistics, 1994. Australian Demographics and Labour Force Statistics: Catalogs 3101.0 and 6202.0. Canberra, Australia.

Aust. Emergency Mgt. Inst., 1993. Towards Improved Severe Weather and Flood Warning Effectiveness. A Workshop, 4 pp. 12-15 July,1993, Mt Macedon. Vic.

Babcock, A. B., 1990. The value of weather information in market equilibrium. American Journal of Agricultural Economics, 72(1), 63-72.

Baker, E. J., and Carter, M., 1984. The Role of Information in Public Response to Hurricane Threats. Paper JT21.2, 15th Conf. on Hurricanes and Tropical Meteorology, January 9-13, 1984. Miami, Florida. AMS.

Bally, J., 1993. Study Tour to the United States, 21 February 1993 to 20 March 1993. O'seas Visit Rep. No. 30/1545, Aust. Bueau of Met.

Bartha, I., 1994. Development of a decision procedure for forecasting maximum wind gusts associated with thunderstorms. J. Meteor. Applns, 1(2), 103-107.

BEST (Tropical System Energy Budget), 1988. Scientific objectives a preliminary definition of a satellite mission dedicated to GEWEX and GLOBAL CHANGE. Centre National d'Etudes Spatiales, 58 pp.

Blong, R., and Power, C. (coordinators), 1990. 19-20 July 1990, Macquarie Uni, NSW.

Blong, R., 1992. Impact of Climate Change on Severe Weather Hazards-Australia. Department of the Arts, Sport, the Environment and the Territories, Australian Government Publishing House, Canberra, Australia, 35 pp.

Boers, R., Spinhirne, J.D. and Hart, W.D. 1988. Lidar observations of the fine-scale variability of marine stratocumulus clouds. J. Appl. Meteor., 27, 797-810.

Bosch, D. J. and Eidman, V.R. 1987. Valuing information when risk preferences are nonneutral:an application to irrigation sceduling. Amer. J. of Agric. Eco.

Buechler, D.E., Wright, P.D. and Goodman, S.J. 1990. Lightning/rainfall relationships during COHMEX. Preprints 16th Conf. on Severe Local Storms, Kananaskis, Canada. Amer. Meteor. Soc., 710-4.

Button, K. 1993. Transport, the Environment and Economic Policy. Edward Elgar Publishing Limited, Hants, Great Britain.

Chapman, R.E. 1992. Benefit-Cost Analysis for the Modernisation and Associated Restructuring of the National Weather Service. National Institute of Standards and Technology, United States Department of Commerce, Washington, 105 pp.

Chen Duansheng, Wu Ping, *et.al.*, 1993. A Decision-Making System for Preventing the LowTemperature Chilling Injury to Rice in Ningxia. 261-267, Proc. of Int. Symp. on Climate Change, Natural Disasters and Agricultural Strategies. May 26-29, 1993. Bejing. China Met. Press.

Chen Zhenghong, Yang Hongqing, Ni Guoyu, 1993. Freezing and Hot Damage to Citrus in the Three Gorge Area of the Yangtze River Valley. 339, Proc. of Int. Symp. on Climate Change, Natural Disasters and Agricultural Strategies. May 26-29, 1993. Bejing. China Met. Press.

Christensen, L.R., Jorgenson, D.W. and Lau L.R. 1973. Transcendental logarithmic production frontiers. Review of Economics and Statistics, 55, 28-45.

Compton, A. J., and Sanders, J., 1984. Is It Time to Modernise the Hurricane Warning System? Paper JT21.3, 15th Conf. on Hurricanes and Tropical Meteorology, January 9-13, 1984. Miami, Florida. AMS.

Crane, G. D., 1991. Reduction of Natural Disasters Related to Tropical Cyclones in the Pacific Region. WMO Sub. to UNDP. January 1991. Bureau of Met. Qld.

Cuban Representative of FAO, 1993. Informe Resumen sobre los Efectos de las Lluvias de Finales de Noviembre 1993, en las Provincias Orientales (de Cuba). 14 December 1993. (Paper courtesy of R. Gommes, FAO).

Cummings, R.G., Brookshire, D.S. and Schulze, W.D. (1986). Valuing Environmental Goods: A State of the Art Assessment of the Contingent Valuation Method. Rowtrand and Allanheid, Boulder, Colorado, U.S.A.

Davies-Jones, R.P., Burgess, D. and Foster, M. 1990. Test of helicity as a tornado forecast parameter. Preprints 16th Conf. on Severe Local Storms, Kananaskis, Canada, Amer. Meteor. Soc., 588-92.

DHA - Geneva, 1994. Mozambique, Cyclone "Nadya" Situation Report, No. 5, 8 April, 1994. (Information courtesy of R. Gommes - FAO)

Drake, L. 1994. Relations Among Environmental Effects and Their Implications for Efficiency of Policy Instruments, Second Revised Edition. Department of Economics, Swedish University of Agricultural Sciences. Uppsala, Sweden.

Ellrod, G.P. 1990. Applications of GOES water vapour imagery to severe storms analysis. Preprints 16th Conf. on Severe Local Storms, Kananaskis, Canada. Amer. Meteor. Soc., 154-9.

Feng Yuxiang, He Weixun, *et.al.*, 1993. The Relationship within Frost Injury, Low Temperature and Different Population of Ice Nucleation Active Bacteria. 225-229, Proc. of Int. Symp. on Climate Change, Natural Disasters and Agricultural Strategies. May 26-29, 1993. Bejing. China Met. Press.

Fletcher, D., 1984. Hazard Assessment and Preparedness Planning - The Role of the Private Meteorologist. Paper JT21.4, 15th Conf. on Hurricanes and Tropical Meteorology, January 9-13, 1984. Miami, Florida. AMS.

Food and Agriculture Organisation of the United Nations, 1994. Summary of Expert Consultation on the Co-ordination and Harmonisation of Databases and Software for Agroclimatic Applications, November 29 - December 3, 1993, Rome, Italy.

Food and Agriculture Organisation of the United Nations, 1994. Rehabilitación de la Producción Agrícola Afectada por la Tormenta Tropical, "Bret". Proj. TCP/VEN/2351 (E) (International Consultant - Marcos I. Nieto Lara) Informe Técnico do Consultoría. Caracas, Venezuela. June, 1994.

Foley, G. R., 1992. Overseas Visit Report No. 1992/93-35(30/2663) on ICSU/WMO Int. Symp. on Tropical Cyclone Disasters. Bejing. 12-16 October, 1992.

Frank, N. L., Meteorologists in the Decade of the 90s. Meteorological and Hydrological Risk Assessment and Disaster Reduction, Lectures presented at the 41st session of the WMO Exec. Cnc., WMO-No. 738.

Freebairn, J.W. 1979. Estimating the benefits of meteorological services: Some methodological questions. Proceedings of the Value of Meteorologcal Services Conference, Bureau of Meteorology, Melbourne, Australia, 117-123.

Fujita, T.T. and Pearson, A.D., 1973. Results of FPP classification of 1971 and 1972 tornadoes. Preprints, Eighth Conference on Severe Local Storms, October 15-17, American Met. Soc. , Boston, pp. 142-45.

Gommes, R. and Negre, Th., 1992. The Role of Agrometeorology in the Alleviation of Natural Disasters, Agmet. Working Pap. (2), February, 1992, FAO, Rome, Italy.

Gould, J.P. and Ferguson, C.E. 1980. Microeconomic Theory Fifth Edition. Richard Irwin Inc., Homewood, Illinois, U.S.A.

Griffith, D.A., 1984. The Issuance of Hurricane Probabilities as Effectuating Local Evacuation Management: Will They Help or Hurt? Paper JT21.1, 15th Conf. on Hurricanes and Tropical Meteorology, January 9-13, 1984. Miami, Florida. AMS.

Griffiths, D.J., Colquhoun J.R., Batt, K.L. and Casinader, T.R. 1993. Severe thunderstorms in New South Wales: climatology and means of assessing the impact of climate change. Climate Change, 25, 369-388.

Guantanamo Provincial Assembly, 1993: Informe Cuantitavo de las Afectaciones Causadas por las Lluvias del 22 al 25 de Noviembre de 1993. (Paper courtesy of R. Gommes, FAO).

Guymer, L.B. 1969. Estimation of 1000-500 mb thickness patterns from satellite pictures of convective areas. Proc. Inter-Regional Seminar on Interpretation of Meteorological Satellite Data, Melbourne, 1968, Aust. Bureau of Met., Australia, 51-6.

Hales Jr., John E., 1988. An Examination of the National Weather Service Severe Local Storm Warning Program and Proposed Improvements. National Severe Storms Forecasting Centre, pp 34.

Healey, D.T., Jarrett, F.G. and McKay, J.M., 1985. The Economics of Bushfires: The South Australian Experience, Oxford University Press, Melbourne, 153 pp.

Heyne, P. 1991. The Economic Way of Thinking, Sixth Edition. Maxwell Macmillan International, Sydney, Australia, 587 pp.

Hicks, J.R., 1937. Value and Capital First Edition. Oxford University Press, London.

Hillier, F.S. and Lieberman, G.J. 1980. Introduction to Operations Research, Third Edition. Holden-Day Inc., San Fransisco, U.S.A.

Holland, G.J., 1981. On the quality of the Australian Tropical Cyclone Database. Aust. Meteor. Mag., 29, 169-81.

Holle, R.L., Watson, A.I., Ortiz, R. and Lopez, R.E. 1990. Spatial patterns of lightning, radar echoes and severe weather in mesoscale convective systems. Preprints 16th Conf. on Severe Local Storms, Kananaskis, Canada. Amer. Meteor. Soc., 721-6.

IGBP Workshop Report No.7. on Extreme Events and Global Change.

Institution of Engineers Australia The, 1988. Bushfires and Technology, A Victorian Perspective for the 1990s and beyond. Nat. Lib. of Aust., Taskforce on Advanced Technology for Bushfire Prevention, Detection and Combat.

Jedlovec, G.J. 1985. An evaluation and comparison of vertical profile data from the VISSR Atmospheric Sounder (VAS). J. of Atmospheric and Oceanic Technology, 2, 559-81.

Johnston, J. 1994. Econometric Methods, Third Edition. McGraw-Hill Book Company, New York.

Joy, C.S., 1991. The Cost of Natural Disasters in Australia. Climate Change Impacts and Adaption Workshop, Climatic Impacts Centre, Macquarie University, 13 - 15 May, 1991, 9 pp.

Kasischke, Eric S., French, Nancy H. F., Harrell, Peter, Christensen, Norman L., Jr., Ustin, Susan L., Barry, Donald, 1993. Monitoring of Wildfires in Boreal Forests Using Large Area AVHRR NDVI Composite Image Data. Remote Sensing of Environment, New York, NY, 45(1), 61-71, July 1993.

Kauffman, J.Boone, Sanford, Robert L. Jr., Cummings, Dian L., Salcedo, I. H., Sampaio, E. V. S. B., 1993. Biomass and Nutrient Dynamics associated with Slash Fires in Neotropical Dry Forests. Ecology, Tempe, AZ, 74(1), 140-151, January 1993.

Kirby, M.G. 1986. Airline economies of scale and Australian domestic air transport policy, Journal of Transport Economics and Policy, (September), 339-352.

Lave, L.B. 1963. The value of better weather information to the raisin industry. Econometrica, 31, 151-164.

LeMarshall, J.F. 1988. An intercomparison of temperature and moisture fields derived from TOVS data by different techniques. Part I: Basic statistics. J. Appl. Meteor., 27, 1011-30.

Littlejohn, R. N., 1984. Extreme winds and forest devastation resulting from cyclone "Bernie". Weather and Climate, Wellington, N.Z., 4(2), 47-52, August, 1984. Refs., tables.

Loane, I. T. and Gould, J.S., 1986. Aerial Suppression of Bushfires; Cost Benefit Study for Victoria. Project Aquarius. Nat. Bushfire Res. Unit. CSIRO Div. of Forest Res. Canberra, April 1986.

Maddox, R.A. 1980. Mesoscale convective complexes. Bull. Amer. Meteor. Soc., 61, 1374-87.

Martin, D.W. 1968. Satellite studies of cyclonic developments over the Southern Ocean. Technical report No. 9, Bureau of Meteorology, Melbourne, Australia.

Matson, M. and Stephens, G., 1987. Fire Detection Using Data from the NOAA-N Satellites. 961-970, Int. J. Remote Sensing, 1987, Vol. 8, No. 7.

Maunder, W. J., 1986. The Uncertainty Business - Risks and Opportunities in Weather and Climate. Methuen, 1986.

Menzel, P. 1992. Monitoring the earth and atmosphere with the NOAA operational satellites. Instruments and Observing Methods Report No. 49, World Meteorological Organization, 8-13.

Menzel, W.P., Smith, W.L. and Stewart, T.R. 1983. Improved cloud motion wind vector and altitude assignment using VAS. J. Climate Appl. Meteor., 22, 377-84.

Merriman, P. A. and Browitt, C. W. A. (editors), 1993. Natural Disasters: Protectin Vulnerable Communities. Proc. of IDNDR Conf., 119-129, 13-15 October, 1993, London.

Miller, G.Y., Rosenblatt, J.M. and Hushak, L.J. 1988. The effects of supply shifts on producers' surplus, American Journal of Agricultural Economics, 70(4), 886-891.

Mishan, E.J. 1988. Cost-benefit analysis, 4th edition. Unwin Hyman Limited, London, 461 pp.

Mitchell, E. and Griffiths, D.J. 1993. The Sydney Hailstorm of 18 March 1993. Special Report, Bureau of Meteorology, Melbourne, Australia.

Mitchell, R.C., and Carson, R.T. 1989. Using Surveys to Value Public Goods: The Contingent Valuation Method. Resources for the Future, Washington. D.C., U.S.A.

Mjelde, J.W., Peel, D.S., Sonka, S.T. and Lamb, P.J. 1993. Characteristics of climate forecast quality: implications for economic value to Mid-Western corn producers. Journal of Climate, 6, 2175-2187.

Mosher, F.R. and Lewis, J.S. 1990. Use of lightning location data in severe storm forecasting. Preprints 16th Conf. on Severe Local Storms. Kananaskis, Canada. Amer. Meteor. Soc., 692-7.

Mueller, W., 1993. Methods of Hail Defence. 304-310, Proc. of Int. Symp. on Climate Change, Natural Disasters and Agricultural Strategies. May 26-29, 1993. Bejing. China Met. Press.

Murphy, A.H. 1985. Decision making and the value of forecasts in a generalised model of the cost-loss situation. Monthly Weather Review, 113, 362-369.

Murphy, A.H. and Ehrendorfer, M. (1987). On the relationship between the accuracy and value of forecasts in the cost-loss ratio situation. Weather and Forecasting, 2, 243-251.

Pearce, D.W. and Turner, R.K. (1990). Economics of Natural Resources and the Environment. Harvester Wheatsheaf, London.

New Zealand Met. Service, (A) to (G), 1986-1987.

Oliver, J., 1989. Tropical Cyclone Warning System, A Survey of Public Interpretation and Opinions in Queensland on the Present Tropical Cyclone Warning System. Ochnas. Pap. Se., Occasional Paper: 2. Disaster Management Studies Centre, Cumberland College of Health Sciences.

Olsen, S.R. and Fuelberg, H.E. 1990. An evaluation of VAS-derived severe storm parameters. Preprints 16th Conf. on Severe Local Storms, Kananaskis, Canada, Amer. Meteor. Soc., 150-3.

Pack+2HHam,1989. Background to Fire behaviour Models. Proceedings of the Third Australian Fire Weather Conference. 18-20 May, 1989 Hobart, Tas.

Paltridge, G. W. and Barber, J., 1988. Monitoring Grassland Dryness and Fire Potential in Australia with NOAA/AVHRR Data. 381-394. Remote Sensing of Environment, No.25.

Panel Disc., 1984. Session JT1: On the Role of the Private Sector in Disseminating Hurricane Forecasts and Warnings. Chairperson Joseph Golden (ERL)/NOAA, Boulder, Colo. J1-J64. 15th Conf. on Hurricanes and Tropical Meteorology, January 9-13, 1984. Miami, Florida. AMS.

Pearce, D.W. and Turner, R.K. 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf, London, Great Britain.

Powell, F. A., 1992. A Review of the Application of Remote Sensing Together with Other Considerations in Combating Bushfires in Australia. 79-95 Météorologie et Incendies de Forêts (documents divers) organisée par l'OMM et la Météorologie du Maroc, en collaboration technique avec la Division des Ressources Forestières de la FAO. Genève, 1992.

Randall, A. 1981. Resource Economics. Grid Publishing Inc., Columbus, Ohio, U.S.A., 415 pp.

Rasmussen, J. L., 1990. Uncertainties in the Development of Predictions of Large Scale Atmospheric Phenomena, Droughts, Tornadoes and Hurricanes. Prediction and Perception of Natural Hazards, Proc. Symp., 22-26 October, 1990, Perugia, Italy. IDNDR. Kluwer Acad. Pubs. Dordrect/ Boston/Lond.

Reifsnyder, W.E., and Albers, B., 1994. Special Environmental Report no. 11 Systems for evaluating and predicting the effects of weather and climate on wildland fires (Revised with additional material on the use of remote sensing techniques in forest fire management. WMO No.496, Geneva.

Rijks, D. and Ciesla, W. M. (editors), 1992. Météorologie et Incendies de Forêts. (documents divers) organisée par l'OMM et la Météorologie du Maroc, en collaboration technique avec la Division des Ressources Forestières de la FAO. Genève, 1992.

Rothermel, R.C., 1972. A mathematical model for predicting fire spread in wildland fuels. Research Paper INT-115. Ogden, Utah: U.S. Dept. of Agriculture, Forest Service, International Forest and Range Experiment Station, 1972, 40p.

Rothermel, R.C., 1983. How to predict the spread and intensity of forest and range fires. General Technical Report INT-143. Ogden, Utah: U.S. Dept. of Agriculture, Forest Service, International Forest and Range Experiment Station; 162p.

Roux, D., 1992. Impact Economique de L'Information Météorologique dans le Domaine de la Prévention et de la Lutte contre les Incendies de Forêts (Une approche des enjeux opérationnels en France). Météorologie national, France. 423-431 Météorologie et Incendies de Forêts (documents divers) organisée par l'OMM et la Météorologie du Maroc, en collaboration technique avec la Division des Ressources Forestières de la FAO. Genève, 1992.

Ryan, C.J., 1993. Costs and Benefits of Tropical Cyclones, Severe Thunderstorms and Bushfires in Australia. Climatic Change 25, 353-367, 1993.

Saunders, R.W. and Seguin, B. 1992. Meteorology and Climatology. Int. J. Remote Sensing, 13, 1231-59.

Session JT25, 1984. The Role of Private Meteorologists in Warning and Disaster Prevention. Papers JT25.1-JT25.4, 15th Conf. on Hurricanes and Tropical Meteorology, January 9-13, 1984, Miami, Florida. AMS.

Severe Weather Program Office, 1990. Second Severe Thunderstorm Workshop, 7-9 March, 1990. Melbourne. Proc. and Recomnds. (various papers) Aust. Bureau. of Met. SWPO.

Silberberg, E. 1978. The Structure of Economics: A Mathematical Analysis. McGraw-Hill Book Company, New York.

Smith, D. K., 1989. Natural Disaster Reduction: How Meteorological and Hydrological Services Can Help. WMO-No. 722.

Sofield, T.H.B. 1993. Cyclones and Tourism: The Economic Impact of Visitor Cancellations to Affected Areas and Attitudes Towards Media Treatment of Cyclones. Department of Tourism, James Cook University, Townsville, Queensland, Australia, 30 pp.

Sonka, S.T., Mjelde, J.W., Lamb, P.J., Hollinger, S.E. and Dixon, B.L. 1987. Valuing climate forecast information. Journal of Climate and Applied Meteorology, 2,: 1080-1091.

Streten, N.A. and Troup, A.J. 1973. A synoptic climatology of satellite observed vortices over the southern hemisphere. J. Roy. Meteor. Soc. 12, 23-37.

Swinton, S.M. and King, R.P. 1994. The value of pest information in a dynamic setting: The case of weed control. American Journal of Agricultural Economics, 76(1), 36-46.

Tang Zhicheng, Sun Han, *et.al.*, 1993. Applications of Weather Satellite Remote Sensing Techniques in Monitoring Meteorological Disasters and Environment. 311-314, Proc. of Int. Symp. on Climate Change, Natural Disasters and Agricultural Strategies. May 26-29, 1993. Bejing. China Met. Press.

Teske, S. and Robinson, P. 1994. The benefit of the United Kingdom meteorological office to the national economy. Proceedings of the Conference on the Economic Benefits of Meteorological and Hydrological Services, World Meteorological Organisation, Geneva, Switzerland (19-23 September), 21-24.

Testud, J., Amayenc, P. and Marzoug, M. 1992. Rainfall-rate retrieval from a spaceborne radar: comparison between single-frequency, dual-frequency, and dual-beam techniques. J. of Atmospheric and Oceanic Technology, 9, 599-623.

Tharnpapillai, D.J. 1991. Environmental Economics. Oxford University Press, Melbourne, Australia, 89 pp.

Tice, T.F. and Clouser, R.L. 1982. Deterrnination of the value of weather information to individual corn producers. Journal of Applied Meteorology, 21(4), 447-452.

TRMM, 1988. A satellite mission to measure tropical rainfall. Report of the Science Steering Group, GSFC/NASA, 94 pp.

UNDP, 1993. Informe del Representante Adjunto Visita a la Provincia de Guantanamo. (Paper courtesy of R. Gommes, FAO)

United Nations Manual, 1991. Mitigating Natural Disasters; Phenomena, Effects and Options. A Manual for Policy Makers and Planners. (various pages) UNDRO, United Nations. NY, 1991.

Wadge, G., 1993. Remote Sensing for Natural Hazard Assessment and Mitigation. STOP Disasters, IDNDR. 9-10, No.16, November-December 1993.

Wilheit, T.T., Chang, A.T.C., and Chiu, L.S. 1991. Retrieval of monthly rainfall indices from microwave radiometric measurements using probability distribution functions. J. Atmospheric and Oceanic Technology, 8, 118-36.

Williams, E.R., Geotis, S.G., Renno, N., Rutledge, S.A., Rasmussen, E., Rickenback, T. 1990. "Hot towers" in the tropics. Preprints 16th Conf. on Severe Local Storms, Kananaskis, Canada. Amer. Meteor. Soc., 698-703.

WMO Annual Review, 1991. ESCAP/WMO Typhoon Committee Annual Review, 1991. (various pages) WMO.

WMO, TD-No.394, 1990. Tropical Cyclone Warning Systems, Tropical Cyclone Programme, Report No. TCP-26, WMO/TD-No.394, 1990.

WMO, No.773, 1990. Economic and Social Benefits of Meteorological Services. (various papers) Proc. of Tech. Conf. Geneva, 26-30 March, 1990. WMO-No.733.

Zillman, J.W. and Price, P.G. 1972. On the thermal structure of mature Southern Ocean cyclones. Australian Meteorological Magazine, 20, 34-48.