EXPERIMENTAL INDICES FOR MONITORING GLOBAL DROUGHT CONDITIONS

K.H. Bergman*, P. Sabol, and D. Miskus
Climate Analysis Center, NWS/NOAA
W/NMC5, Washington, DC 20233

1. Description of the Indices:

Two related moisture, or drought, indices have been developed:

1. Cumulative Moisture Anomaly Index (CMAI). This index reflects the amount of excess runoff that has accumulated in time compared to the amount of unsatisfied moisture demand imposed by cumulative excess potential evapotranspiration, compared to normal conditions. It is intended to be a measure of moisture conditions as they affect reservoirs, large streams, deep well water, etc.

2. Soil Moisture Anomaly Index (SMAI). This index reflects the degree of saturation or dryness of the soil, compared to normal conditions, and is intended to be a measure that is useful in evaluating the effect of recent moisture conditions on agricultural crops.

Both of these indices are based on the precipitation vs. potential evapotranspiration moisture accounting approach of C.W. Thornthwaite (1948 and later years). The indices are both cumulative in the sense that a set of moisture parameters for the preceding week (or month) is updated to reflect precipitation vs. evapotranspiration conditions for the current week (month). The computations and the resulting indices evaluate <u>anomalous</u> moisture conditions, that is, the normal precipitation and potential evapotranspiration are subtracted from the currently observed or computed values of these quantities in doing the calculations.

For precipitation, normal weekly (monthly) values are subtracted from reported values for the current week (month). Potential evapotranspiration (PET) is computed from a formula that is a function of mean weekly (monthly) temperature, latitude, and calendar day of the year. This formula closely approximates Thornthwaite's more complicated formulae. Since anomalous values of PET are computed, approximations in the PET formulation tend to cancel out. However, the approximation used here, like the Thornthwaite formulation, neglects the effects of varying cloudiness, humidity, and wind speed on evapotranspiration. (An alternate, more comprehensive expression for PET could be

* (Current affiliation: Board on Atmospheric Sciences and Climate, National Research Council/National Academy of Sciences, 2101 Constitution Ave. (HA 594), Washington, DC 20418.)

substituted provided current and normal measurements of these additional variables are available.)

Another factor that enters into the computations is the soil moisture capacity. Following W.C. Palmer (1965) and K.J. Johnstone and P.Y.T. Louie (1984), a soil reservoir for moisture consisting of two layers, "topsoil" and "deepsoil", is assumed to exist at each station. In the experimental version, the soil is assumed to be capable of holding a total of 180 mm of moisture (the average value for the US that is used in the Palmer Drought Severity Index) at every station, but individual values could be assigned on the basis of soil type. Since Johnstone and Louie have extensively studied the relative roles of topsoil and deepsoil in soil moisture capacity, their ratio of two parts of topsoil to three parts of deepsoil is used here, i.e, topsoil moisture capacity = 72mm and deepsoil moisture capacity = 108mm.

In doing the soil moisture computations, when precipitation exceeds PET, the excess moisture is added first to the topsoil, until it is saturated, and any additional excess is treated in the following way: The amount of moisture already present in the deepsoil is noted, the difference between that and full deepsoil capacity is determined, and the percent saturation of the deepsoil is computed. Subtracting this from 100 percent gives the percent of the total deepsoil that is not saturated. Only this percentage of the excess left over after the topsoil is filled is added to the moisture already present in the deepsoil. This procedure is similar to that of Johnstone and Louie, and its purpose is to reflect the increasing difficulty of adding additional moisture to deepsoil that is approaching saturation. The excess precipitation that is not added to the soil is denoted as "runoff."

When PET exceeds precipitation, the process works as follows: Moisture is first withdrawn from the topsoil layer to satisfy the PET demands until it is completely dry. Then, moisture is withdrawn from the deepsoil to partially satisfy any additional PET demand, but only in proportion to the percentage of moisture, compared to saturation, that remains in the deepsoil. Once again, the purpose is to reflect the increasing difficulty of removing moisture from the deepsoil as it becomes increasingly dry.

The above soil moisture calculations are done for both the current week (month) and the "normal" week (month), and anomalies computed. These anomalies form the basis for the calculation of the CMAI and SMAI. After the soil moisture needs and changes have been computed, the anomalous precipitation excess (anomalous runoff), or the anomalous precipitation deficiency (anomalous unsatified water need), represents the week´s (month´s) contribution to the CMAI. The weekly (monthly) anomaly is added to (excess) or subtracted from (deficiency) the CMAI for the preceding week (month) to get the new CMAI value. For interstation comparison purposes, the CMAI is normalized by the annual precipitation of the station. The SMAI is obtained from the amount of moisture present in both layers of soil, compared to normal conditions. All of the indicated computations are done each week (or month) in order to obtain continuing updates of the CMAI and SMAI.

2. Some Preliminary Results

Experimental runs for both the CMAI and the SMAI have been made, using both weekly and monthly updates. The runs were started from January 1987 data, with the assumption that both layers of soil were saturated at the beginning of January and that this was the normal climatological condition (near-saturation is to be expected at most humid temperate stations in midwinter). The expectation was that, after a year had elapsed, the system would be "spun up" enough to reflect actual moisture conditions. These experimental runs continue at this writing (January 1989).

Space does not permit listing the relatively straightforward moisture budget bookkeeping equations upon which the index values are based. For easy recognition on maps, categories of dryness or wetness were defined (see lower left-hand corners of Figs. 1 and 2). These categories were arbitrarily chosen but appear to be useful in delineating areas with significant moisture anomaly.

Figs. 1 and 2 show the categorical distribution of the CMAI and the SMAI respectively for the U.S. at the end of June 1988. Note that stations indicated by commas have an annual precipitation of less than 250 mm; most of these are located in the West. Computations were not done for these relatively dry stations.

Figs. 3 and 4 show analyzed categorical maps for the PDSI and CMI as of July 2, 1988 (from the Weekly Weather and Crop Bulletin) for comparison. The severe drought conditions that developed over large parts of the nation during the spring and early summer were near their worst at this time. It should be noted that the PDSI and CMI maps are based on climate division data, whereas the experimental CMAI and SMAI maps show individual station values.

Both the CMAI and the SMAI maps show widespread anomalous dryness over large parts of the nation, consistent in general with the PDSI and CMI and with the widespread reports of severe drought conditions. The most noteworthy differences between the CMAI and SMAI depiction are in the zone from the western Great Lakes region eastward to northern New England, where the CMAI reflects the unusually wet conditions of 1987, and along parts of the West Coast, where 1987 was unusually dry. Because the CMAI continues to "remember" past moisture anomalies until they have been countered by equal anomalies of the opposite sign, the CMAI has in effect a very long memory. This feature is appropriate for an index that is intended to be a measure of slowly changing factors such as reservoir levels and major streamflow.

The SMAI tends to change more rapidly with changing soil moisture conditions, but the pattern of dryness is, perhaps fortuitously, similar to that of the CMAI on June 30. The differences can be traced to comparatively recent anomalous events that have not lasted long enough to significantly change the cumulative index. In general, the SMAI chart shows moderate to severe anomalous soil dryness extending from the northern Great Plains eastward into the Great Lakes and Ohio Valley and southward into parts of the Southeast. These are all areas that reported severe agricultural drought conditions by the end of June 1988. By way of contrast, the western Texas - eastern New Mexico area, which has seen well above normal rainfall during most of the last three years, shows up as an unusually wet region according to both the CMAI and SMAI.

The general agreement of the CMAI and SMAI with the indications of the PDSI and CMI is heartening, although, as mentioned above, a direct comparison cannot be made. Furthermore, the new indices are not attempts to duplicate the PDSI and CMI exactly; see the next section for more discussion of this point. In many respects, the SMAI map looks more like the PDSI map than the rapidly changing CMI map. Although more test runs are needed, our results to date suggest that the SMAI changes somewhat more rapidly in time than the PDSI but not as rapidly as the CMI.

At present, the CMAI and SMAI are being computed and updated every week as well as once a month for over 1000 stations worldwide. The indications of severe anomalous dryness lingering in parts of the Great Plains and prevailing in northern Argentina and adjacent areas of South America, in southwestern Europe, and in much of eastern China in late December 1988 (Fig. 5) accords well with other information about drought conditions in these areas.

3. <u>Discussion</u>

One may ask the question: Why develop another set of indices when we already have the Palmer Drought Severity Index (PDSI) and the Crop Moisture Index (CMI)? Three responses to this question are:

1. The PDSI and CMI, although based on considerations of precipitation <u>vs</u>. evapotranspiration similar to those used for the CMAI and SMAI, involve more complex reasoning and more calculations than the relatively straightforward "bookkeeping" procedure described above. As a result, the PDSI and CMI are indices that may have utility in describing moisture conditions but that are not easily related to the physical processes involved.

2. The PDSI and CMI contain several arbitray assumptions that condition the resulting index values. The CMAI and SMAI also contain arbitrary assumptions, at least in the experimental versions described here, but generally it is easier to see how modifications to the CMAI and SMAI methodologies might be made to remove the arbitrary features than it is for the PDSI and the CMI.

3. The PDSI and CMI were developed originally for a restricted region, namely the central United States; as a result, these indices were "tuned" in order to be meaningful in that region. Their applicability to other regions is therefore questionable; even in the rest of the United States their use has been criticised. The CMAI and SMAI, on the other hand, have been designed for global climate monitoring purposes, and the more basic and (hopefully) less arbitrary nature of their calculation should befit them better for global use.

There are several ways in which the CMAI and SMAI formulations might be improved. Probably the most severe limitation of the current formulations is the use of a universal value of 180mm for the total soil moisture capacity. Studies by Johnstone and Louie (1984) for Canadian stations show that soil moisture capacities for individual locations range from around 100 mm to more than 300 mm, depending on the type of soil. For the PDSI calculations in the U.S., each climate division is assigned a soil moisture capacity. These average about 180 mm but also show a wide range. Clearly, the first priority in improving the system should be to estimate the soil moisture capacity for each location or region using a global soil map or similar information.

Other items that might be included if the data are available in real time are inclusion of clouds, wind, relative humidity, and sunshine in the potential evapotranspiration computations; inclusion of the delayed moisture effects of snowcover (see Johnstone and Louie for a scheme to do this) in the moisture budget computations; and improved partitioning of the amount of moisture added to the soil _vs._ amount of runoff, based on streamflow measurements.

In summary, two new related indices for monitoring moisture conditions on a global basis have been described and some early experimental results shown. We have argued that their relative simplicity of computation from basic moisture budget considerations may make them more universally useful and interpretable than the well known PDSI and CMI, but acknowledge that much work still needs to be done, especially with regard to variable soil moisture capacity, in order to make the new indices truly useful for the monitoring of global drought conditions.

References

Johnstone, K.J., and P.Y.T. Louie, 1984: _An Operational Water Budget for Climate Monitoring_. Canadian Climate Centre, Report No. 84-3, Atmospheric Environment Service, Downsview, Ont., 45pp.

Palmer, W.C., 1965: _Meteorological Drought_. U.S. Dept. of Commerce, Weather Bureau Research Paper No. 45, Washington, DC, 58pp.

Thornthwaite, C.W., 1948: An Approach Toward a Rational Classification of Climate, _Geographical Review_, v. 38, pp 55-94.

72268 ROSWELL, NM UNITED STATES 3330 10453 270.9 0.5000

DATE	P	PN	E	EN	M	MN	M+	M+N	S1B	S1BN	S2B	S2BN	Q	I	J	ND	CHARS
870131	6.4	10.1	7.0	6.3	-0.6	3.8	0.0	0.0	71.4	72.0	108.0	108.0	0.0	0.0	-0.01	31.0	. *** . ***
870228	51.3	11.8	16.9	14.4	34.4	-2.6	0.0	0.0	72.0	69.4	108.0	108.0	0.0	0.0	0.04	28.0	. *** . ***
870331	5.2	10.1	28.3	32.7	-23.1	-22.6	0.0	0.0	48.9	46.8	108.0	108.0	0.0	0.0	0.04	31.0	. *** . ***
870430	5.8	10.3	57.3	66.4	-51.5	-56.1	0.0	0.0	0.0	0.0	105.4	98.7	0.0	0.0	0.19	30.0	. *** . ***
870531	39.1	18.0	102.7	109.6	-63.6	-91.6	-10.9	-62.3	0.0	0.0	52.7	49.3	31.4	11.6	0.19	31.0	+ +++ . ***
870630	93.8	24.9	146.0	157.6	-52.2	-132.7	-26.7	-108.0	0.0	0.0	27.2	24.7	112.6	41.6	0.29	30.0	W WET . ***
870731	10.2	43.2	165.8	168.3	-155.6	-125.1	-142.0	-112.8	0.0	0.0	13.6	12.3	83.5	30.8	0.29	31.0	W WET . ***
870831	121.5	53.2	148.4	146.6	-26.9	-93.4	-23.5	-87.2	0.0	0.0	10.2	6.2	147.1	54.3	1.46	31.0	W WET + +++
870930	19.9	44.2	101.1	102.7	-81.2	-58.5	-76.1	-55.5	0.0	0.0	5.1	3.1	126.5	46.7	1.46	30.0	W WET + +++
871031	7.2	26.6	67.1	54.8	-59.9	-28.2	-57.3	-27.4	0.0	0.0	2.6	2.3	96.5	38.6	0.33	31.0	W WET . ***
871130	10.9	8.7	23.8	19.6	-12.9	-10.9	-12.5	-10.7	0.0	0.0	2.3	2.0	94.6	34.9	0.27	30.0	W WET . ***
871231	35.2	9.8	6.0	7.5	29.2	2.3	0.0	0.0	29.2	2.3	2.3	2.0	94.6	34.9	5.73	31.0	W WET W WET
880131	5.6	10.1	4.6	6.3	1.0	3.8	0.0	0.0	30.2	6.1	2.3	2.0	94.6	34.9	3.99	31.0	W WET W WET
880229	37.5	11.8	15.6	14.5	21.9	-2.7	0.0	0.0	52.1	3.4	2.3	2.0	94.6	34.9	6.62	29.0	W WET W WET
880331	0.7	10.1	33.5	32.8	-32.8	-22.7	0.0	-18.9	19.4	0.0	2.3	1.7	113.6	41.9	7.37	31.0	W WET W WET
880430	9.9	10.3	65.5	66.6	-55.6	-56.3	-38.5	-55.4	0.0	0.0	1.4	0.8	130.6	48.2	1.56	30.0	W WET M MST
880531	86.8	18.0	106.2	109.8	-19.4	-91.8	-19.1	-91.4	0.0	0.0	1.2	0.4	202.9	74.9	2.97	31.0	W WET M MST
880630	32.2	24.9	154.5	157.6	-122.3	-132.7	-121.7	-132.5	0.0	0.0	0.6	0.2	213.7	78.9	2.97	30.0	W WET M MST

72312 GREENVILLE, SC UNITED STATES 3490 8222 1293.9 0.5000

DATE	P	PN	E	EN	M	MN	M+	M+N	S1B	S1BN	S2B	S2BN	Q	I	J	ND	CHARS
870131	117.1	103.8	5.6	8.9	111.5	94.9	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	31.0	. *** . ***
870228	186.0	111.1	12.7	13.7	173.3	97.4	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	28.0	. *** . ***
870331	127.5	152.4	31.7	33.1	95.8	119.3	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	31.0	. *** . ***
870430	58.1	109.9	60.4	64.2	-2.3	60.7	0.0	0.0	69.7	72.0	108.0	108.0	0.0	0.0	-0.04	30.0	. *** . ***
870531	33.7	99.0	119.3	108.7	-85.6	-9.7	0.0	0.0	0.0	62.3	92.1	108.0	0.0	0.0	-1.77	31.0	. *** D DRY
870630	167.8	110.4	150.6	144.1	17.2	-33.3	0.0	0.0	19.2	28.9	92.1	108.0	0.0	0.0	-0.60	30.0	. *** - ---
870731	91.0	114.2	168.6	154.3	-77.6	-40.1	-12.4	0.0	0.0	0.0	66.0	91.8	-12.4	-1.0	-1.99	31.0	. *** D DRY
870831	70.9	132.0	154.2	144.7	-83.3	-12.7	-60.3	-6.6	0.0	0.0	23.0	55.5	-66.3	-5.1	-2.54	31.0	- --- D DRY
870930	92.0	117.9	113.6	106.4	-21.6	11.5	-17.0	0.0	0.0	11.5	18.4	55.5	-83.3	-6.4	-3.72	30.0	- --- S SVR
871031	9.4	86.8	41.4	57.7	-32.0	29.1	-26.5	0.0	0.0	40.5	13.0	55.5	-109.8	-8.5	-5.78	31.0	- --- S SVR
871130	71.4	79.3	31.6	28.0	39.8	51.3	0.0	10.2	39.8	72.0	13.0	65.2	-120.0	-9.3	-2.75	30.0	- --- D DRY
871231	117.3	102.7	14.8	12.2	102.5	90.5	22.8	69.1	72.0	72.0	60.5	86.6	-166.3	-12.9	-0.52	31.0	- --- - ---
880131	99.3	107.8	2.5	8.9	96.8	98.9	73.0	88.2	72.0	72.0	84.2	97.3	-181.5	-14.0	-0.23	31.0	- --- . ***
880229	45.5	111.1	11.2	13.7	34.3	97.4	26.7	32.0	72.0	72.0	91.8	102.6	-246.8	-19.1	-0.19	29.0	D DRY . ***
880331	93.2	152.4	34.2	33.3	59.0	119.1	50.9	116.6	72.0	72.0	99.9	105.3	-312.3	-24.1	-0.09	31.0	D DRY . ***
880430	86.6	125.1	64.3	64.6	22.3	60.5	20.7	39.5	72.0	72.0	101.6	106.3	-331.2	-25.6	-0.08	30.0	D DRY . ***
880531	49.8	99.0	102.6	109.0	-52.8	-10.0	0.0	0.0	19.2	82.0	101.6	106.3	-331.2	-25.6	-0.96	31.0	D DRY - ---
880630	83.0	110.8	145.1	144.2	-62.1	-33.4	-2.6	0.0	0.0	28.7	61.2	106.3	-333.7	-25.8	-2.28	30.0	D DRY D DRY

72405 WASHINGTON/NATIONAL, D UNITED STATES 3885 7703 984.9 0.5000

DATE	P	PN	E	EN	M	MN	M+	M+N	S1B	S1BN	S2B	S2BN	Q	I	J	ND	CHARS
870131	124.4	69.7	1.2	1.8	123.2	67.9	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	31.0	. *** . ***
870228	57.2	68.1	3.9	6.5	53.3	61.6	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	28.0	. *** . ***
870331	38.7	87.4	25.0	20.5	13.7	66.9	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	31.0	. *** . ***
870430	57.8	74.9	48.5	55.2	9.3	19.7	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	30.0	. *** . ***
870531	64.5	83.8	103.1	94.5	-38.6	-10.7	0.0	0.0	33.4	61.3	108.0	108.0	0.0	0.0	-0.52	31.0	. *** - ---
870630	99.9	86.5	152.3	143.2	-52.4	-56.7	0.0	0.0	0.0	2.7	88.6	108.0	0.0	0.0	-0.64	30.0	. *** - ---
870731	66.2	98.3	183.2	163.0	-117.0	-64.7	-72.7	-8.1	0.0	0.0	64.3	54.0	-64.6	-6.6	-0.57	31.0	- --- - ---
870831	52.7	111.3	150.6	145.6	-97.9	-34.3	-75.8	-17.2	0.0	0.0	22.2	36.8	-123.2	-12.5	-1.67	31.0	- --- - ---
870930	124.7	81.1	102.7	103.1	22.0	-22.0	0.0	-14.5	22.0	0.0	22.2	29.3	-108.7	-11.0	1.18	30.0	- --- + +++
871031	64.3	73.3	38.6	52.4	25.7	20.9	0.0	0.0	67.7	20.9	22.2	29.3	-108.7	-11.0	0.95	31.0	- --- + +++
871130	114.0	71.2	26.3	22.1	87.7	49.1	22.4	0.0	72.0	70.0	65.1	29.3	-86.3	-8.8	0.93	30.0	- --- + +++
871231	65.5	80.3	9.9	5.6	55.6	74.7	34.9	33.3	72.0	72.0	86.5	68.7	-84.7	-8.6	0.35	31.0	- --- . ***
880131	79.8	69.7	0.3	1.8	79.5	67.9	69.1	68.2	72.0	72.0	97.3	88.3	-63.8	-6.5	0.16	31.0	- --- . ***
880229	64.1	66.1	4.1	4.6	60.0	61.5	54.6	51.7	72.0	72.0	102.6	98.2	-63.9	-6.2	0.07	29.0	- --- . ***
880331	57.7	89.4	23.4	23.6	34.3	65.8	32.6	61.9	72.0	72.0	104.3	103.1	-90.3	-9.2	0.02	31.0	- --- . ***
880430	50.8	73.7	47.5	55.3	3.3	18.4	2.4	17.8	72.0	72.0	104.4	103.9	-104.9	-10.7	0.01	30.0	- --- . ***
880531	114.3	87.8	97.9	98.7	16.4	-10.9	15.4	0.0	72.0	61.1	105.0	103.9	-89.1	-9.0	0.20	31.0	- --- . ***
880630	24.0	84.5	143.2	143.2	-119.2	-58.7	-1.3	0.0	0.0	2.4	59.1	103.9	-90.4	-9.2	-1.70	30.0	- --- D DRY

72530 CHICAGO/O'HARE, IL UNITED STATES 4198 8790 867.0 0.5000

DATE	P	PN	E	EN	M	MN	M+	M+N	S1B	S1BN	S2B	S2BN	Q	I	J	ND	CHARS
870131	42.7	41.0	0.0	0.0	42.7	41.0	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	31.0	. *** . ***
870228	25.1	24.9	0.7	0.0	24.4	24.9	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	28.0	. *** . ***
870331	39.9	68.8	12.7	4.0	27.2	64.8	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	31.0	. *** . ***
870430	59.6	47.8	34.9	39.6	24.7	8.2	0.0	0.0	72.0	72.0	108.0	108.0	0.0	0.0	0.00	30.0	. *** . ***
870531	55.6	79.8	88.3	70.6	-32.7	9.2	0.0	0.0	39.1	72.0	108.0	108.0	0.0	0.0	-0.58	31.0	. *** - ---
870630	55.6	109.9	134.3	116.7	-78.7	-6.8	0.0	0.0	0.0	66.0	68.6	108.0	0.0	0.0	-2.69	30.0	. *** D DRY
870731	107.6	83.8	153.8	134.7	-46.2	-50.9	-17.0	0.0	0.0	15.1	39.1	108.0	-17.0	-2.0	-3.31	31.0	. *** S SVR
870831	434.4	96.1	123.2	119.1	311.2	-23.0	207.7	0.0	72.0	0.0	73.5	94.0	190.8	22.0	1.26	31.0	M MST + +++
870930	23.9	104.0	80.0	78.1	-56.1	25.9	0.0	0.0	15.9	25.9	73.5	94.0	190.8	22.0	-0.85	30.0	M MST - ---
871031	60.0	50.3	40.7	36.0	19.3	14.3	0.0	0.0	34.1	40.2	73.5	94.0	190.8	22.0	-0.64	31.0	M MST - ---
871130	70.4	54.2	13.3	7.6	57.1	46.6	13.3	12.9	72.0	72.0	79.8	96.0	191.2	22.0	-0.29	30.0	M MST . ***
871231	95.3	59.6	0.0	0.0	95.3	59.6	81.7	53.6	72.0	72.0	93.9	102.0	219.2	25.3	-0.14	31.0	M MST . ***
880131	47.8	41.0	0.0	0.0	47.8	41.0	41.8	38.7	72.0	72.0	100.1	104.3	222.1	25.6	-0.07	31.0	M MST . ***
880229	32.4	28.4	0.0	0.0	32.4	28.4	33.4	27.4	72.0	72.0	102.5	105.3	226.6	25.9	-0.04	29.0	M MST . ***
880331	56.1	68.8	6.3	4.0	49.8	64.8	46.1	63.4	72.0	72.0	105.0	106.6	207.3	23.9	-0.03	31.0	M MST . ***
880430	52.8	47.8	29.7	30.7	23.1	17.1	22.4	66.4	72.0	72.0	105.6	107.3	163.3	18.8	-0.03	30.0	M MST . ***
880531	33.3	79.6	78.5	70.6	-45.2	9.0	0.0	9.0	23.9	72.0	105.6	107.4	154.4	17.8	-0.94	31.0	M MST - ---
880630	27.0	109.2	131.6	115.3	-104.6	-6.1	-27.4	0.0	0.0	65.9	52.8	107.4	126.4	14.6	-3.43	30.0	+ +++ S SVR

Table 1

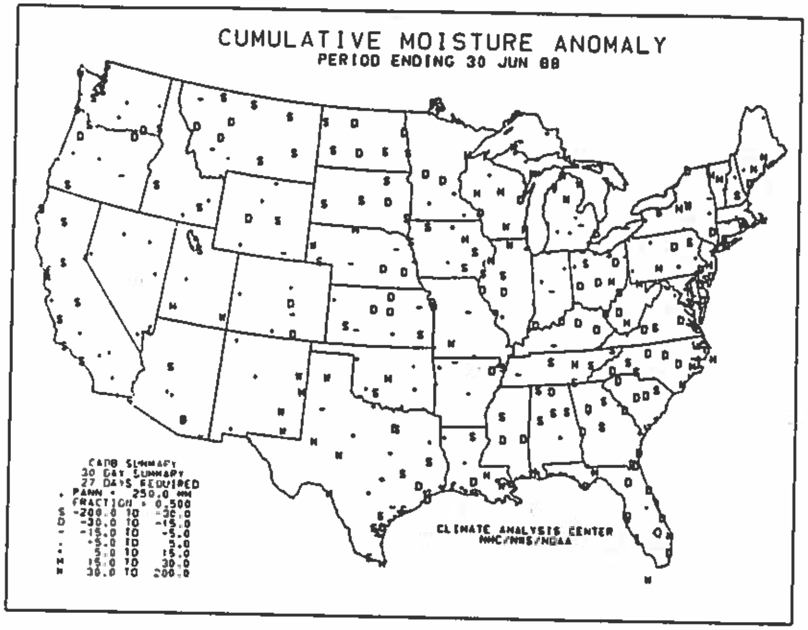


Fig. 1

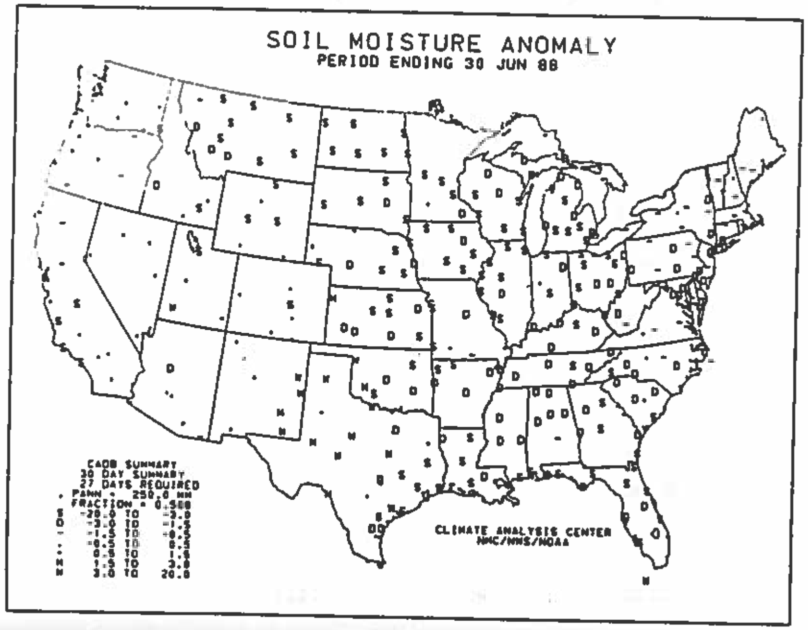
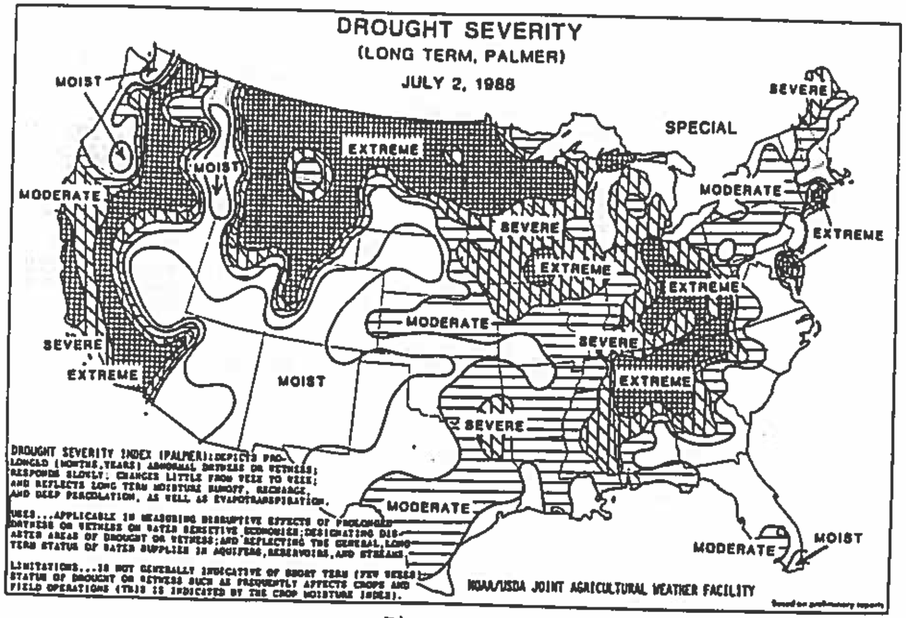


Fig. 2

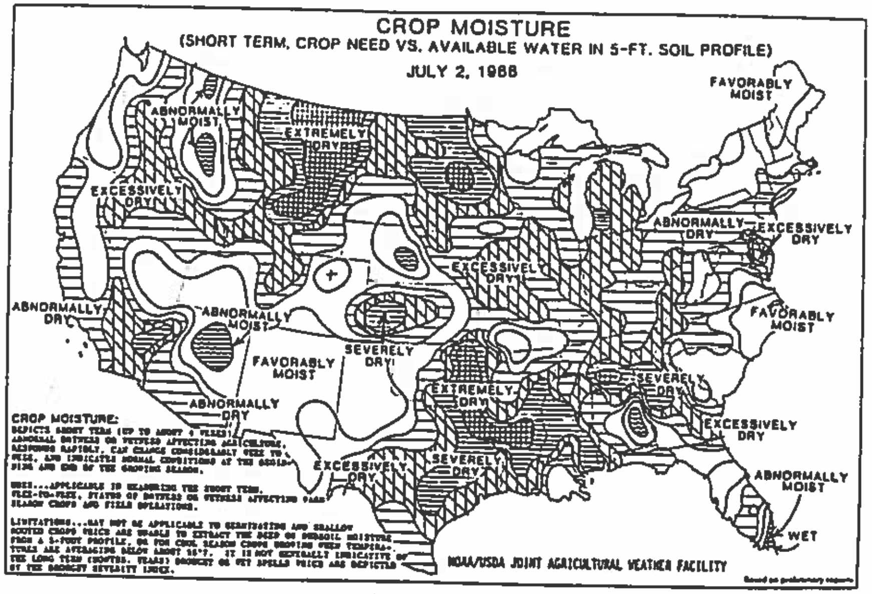


DROUGHT SEVERITY INDEX (PALMER): DEPICTS PROLONGED (MONTHS, YEARS) ABNORMAL DRYNESS OR WETNESS; RESPONDS SLOWLY; CHANGES LITTLE FROM WEEK TO WEEK; AND REFLECTS LONG TERM MOISTURE RUNOFF, RECHARGE, AND DEEP PERCOLATION, AS WELL AS EVAPOTRANSPIRATION.

USES...APPLICABLE IN MEASURING DISRUPTIVE EFFECTS OF PROLONGED DRYNESS OR WETNESS ON WATER SENSITIVE ECONOMIES; DESIGNATING DISASTER AREAS OF DROUGHT OR WETNESS; AND REFLECTING THE GENERAL, LONG TERM STATUS OF WATER SUPPLIES IN AQUIFERS, RESERVOIRS, AND STREAMS.

LIMITATIONS...IS NOT GENERALLY INDICATIVE OF SHORT TERM (FEW WEEKS) STATUS OF DROUGHT OR WETNESS SUCH AS FREQUENTLY AFFECTS CROPS AND FIELD OPERATIONS (THIS IS INDICATED BY THE CROP MOISTURE INDEX).

Fig. 3

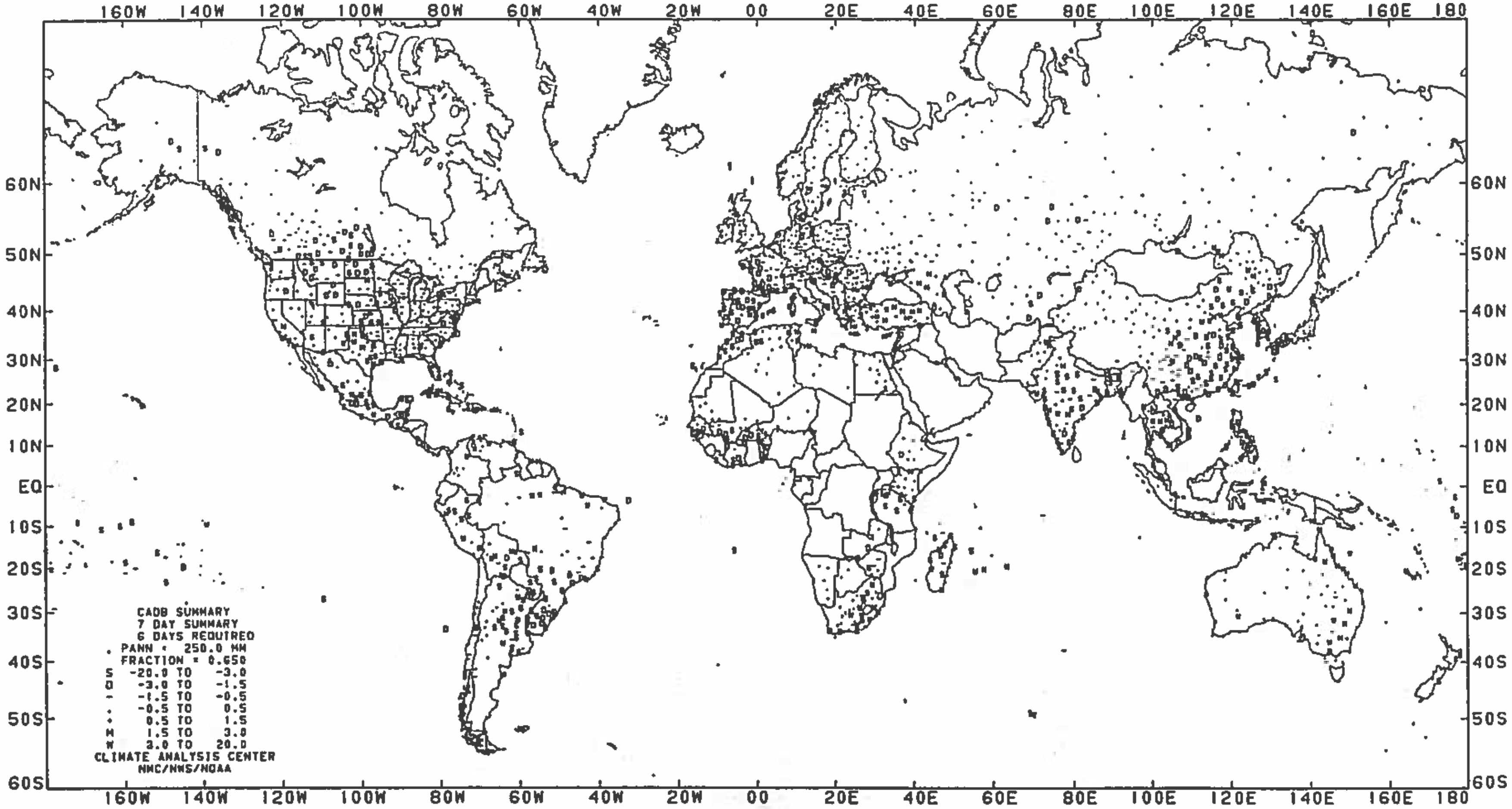


CROP MOISTURE: DEPICTS SHORT TERM (UP TO ABOUT 4 WEEKS) ABNORMAL DRYNESS OR WETNESS AFFECTING AGRICULTURE. RESPONDS RAPIDLY, CAN CHANGE CONSIDERABLY WEEK TO WEEK, AND INDICATES NORMAL CONDITIONS AT THE BEGINNING AND END OF THE GROWING SEASON.

USES...APPLICABLE IN MEASURING THE SHORT TERM, WEEK-TO-WEEK, STATUS OF DRYNESS OR WETNESS AFFECTING WARM SEASON CROPS AND FIELD OPERATIONS.

LIMITATIONS...MAY NOT BE APPLICABLE TO GERMINATING AND SHALLOW ROOTED CROPS WHICH ARE UNABLE TO EXTRACT THE DEEP OR SUBSOIL MOISTURE FROM A 5-FOOT PROFILE, OR FOR COOL SEASON CROPS GROWING WHEN TEMPERATURES ARE AVERAGING BELOW ABOUT 55°F. IT IS NOT GENERALLY INDICATIVE OF THE LONG TERM (MONTHS, YEARS) DROUGHT OR WET SPELLS WHICH ARE DEPICTED BY THE DROUGHT SEVERITY INDEX.

Fig. 4



SOIL MOISTURE ANOMALY

PERIOD ENDING 24 DEC 88

Fig. 5