Spring and Summer 1988 Drought over the Contiguous United States—Causes and Prediction*

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(Manuscript received 17 January 1989, in final form 27 August 1990)

ABSTRACT

This paper deals primarily with the 1988 summer drought over much of the contiguous United States and its generation from conditions during the preceding spring. Both the spring and summer environment are described in terms of hemispheric flow patterns in midtroposphere, temperature and precipitation anomalies, and sea surface temperature anomalies. Conditions in March were especially indicative of the ensuing drought, since a model routinely employed in long-range forecasting showed that the March circulation would most likely be followed by a hot dry April, May, and June over much of the nation—a pattern which persisted into early summer. This result suggests that the initiation of the drought was rooted in extratropical climate variations, an alternative hypothesis to one which attributes the persistent drought-producing circulation to oceanic and atmospheric conditions in the tropics.

In many respects the summer drought of 1988 was similar to earlier great droughts of the Great Plains, although it was spatially more extensive. Attempts by three forecast groups to predict the summer conditions from spring's were moderately successful, though none of these anticipated the drought's severity and extent. The underlying reasons for the summer forecast made by the author are verified using objective tools. Premonitory signs showed up in antecedent seasons when deficient precipitation occurred, when climatological contingencies provided alerts, and when extratropical sea surface temperature patterns evolved in a conducive manner. A new modified barotropic model iterating from the May midtropospheric height pattern using a mean summer estimate of seasonal forcing produces a reasonably successful estimate of the summer circulation and, in retrospect, even more so when initialized from the March height pattern for the April, May, and June period of inception.

1. Introduction

The great drought of the spring and summer of 1988 once more brought home to the public the socioeconomic impact of short period climatic fluctuations. It also incited warnings of global warming by greenhouse gases, with scenarios that such droughts might become more frequent in years to come (Kerr 1989). The result of a numerical model simulation also prompted the suggestion by Trenberth et al. (1988) that, in this case, the drought-producing circulation was generated by the northward-displaced intertropical convergence zone associated with tropical Pacific sea surface temperature (SST) anomalies. Because of these interests and concerns, it is important to analyze the 1988 drought and relate it to similar events of the past. This paper attempts to do this by employing the present knowledge of droughts resulting from a number of studies carried on over much of the 20th century.

Foremost among considerations is that drought, like all major short-term climatic fluctuations, is usually not attributable to a single cause, but rather to multiple factors that are often synergistic. The factors involve atmospheric teleconnections to and from the Great Plains, interactions between large scale SST anomalies and the atmosphere, and equally important, air–land interactions in the domain of the drought.

The inception of the drought is first examined in late spring 1988 and then its persistence into much of summer is described. This work emphasizes the role of conditions in the middle latitudes, as opposed to those in the tropics, in creating the drought-producing circulation.

2. Developments during spring 1988

As pointed out by NOAA (1988), the months of April and May had hot dry weather over much of the central United States—a condition which set the stage for continued drought in subsequent months, particularly June and July. As in previous cases (Namias 1983) the characteristic signature of this drought was an upper-level anticyclone over the central United States flanked by troughs off either coast. These conditions are clearly shown by the average 700 mb height

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* *Delivered in part as the Jule Charney Lecture at the 1988 Fall Meeting of the American Geophysical Union, San Francisco, CA*

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pattern and its anomalies for April through June in Fig. 1.

It will now be demonstrated that this pattern was the outgrowth of abnormal extratropical conditions observed as early as March. To bolster this suggested evolution, techniques are employed, which have been routinely used and tested in previous seasonal forecast cases (Namias 1988). One such procedure first approximates the 700 mb pattern (called a hypothetical chart) which applies to the three-month period following March by assuming that the March *standardized* 700 mb height anomalies persist. Such a chart estimating the average April, May, and June 700 mb height anomalies is shown in Fig. 2, where solid lines represent contours and broken lines represent anomalies. Essentially, this method is an attempt to capture the net effects of seasonal forcing together with appropriate seasonal inflation or deflation of the anomalies, but it assumes that boundary abnormalities due to SST and land surfaces will tend to produce similar forcing as they did in March. This first approximation (or hypothetical chart) may not be dynamically stable, however, and must be adjusted so that its component parts (ridges, troughs, and anomalies) will be compatible and stable. To do this, two methods are employed: 1) teleconnections and 2) application of a modified mean barotropic model to the hypothetical chart.

As for item 1, the strong (−53 m) negative center in the central North Pacific (at 50°N, 160°W from the strong negative anomaly center in Fig. 2) is the key center in the 700 mb pattern projected from March; Fig. 3 shows that the downstream responsive positive anomaly is apt to lie in the interior of the West Coast, not along or off the coast as indicated in Fig. 2. In other words, a deep trough in the central Pacific in March, April, and May is most likely to command an eastward movement of any ridge and its anomaly from a position along the West Coast in March. Method (2) applies a mean modified barotropic model (to be detailed in section 5) to the hypothetical chart of Fig. 2, resulting in Fig. 4, which reinforces the teleconnections by suggesting that the West Coast anomalous ridge and positive anomaly in March are apt to be found farther east in the subsequent three-month period. Specifications (Klein 1985; Klein and Boom 1987) of temperature and precipitation anomalies from the predicted 700

AVERAGE APR., MAY, JUNE 1988 700mb HT & DM (m)

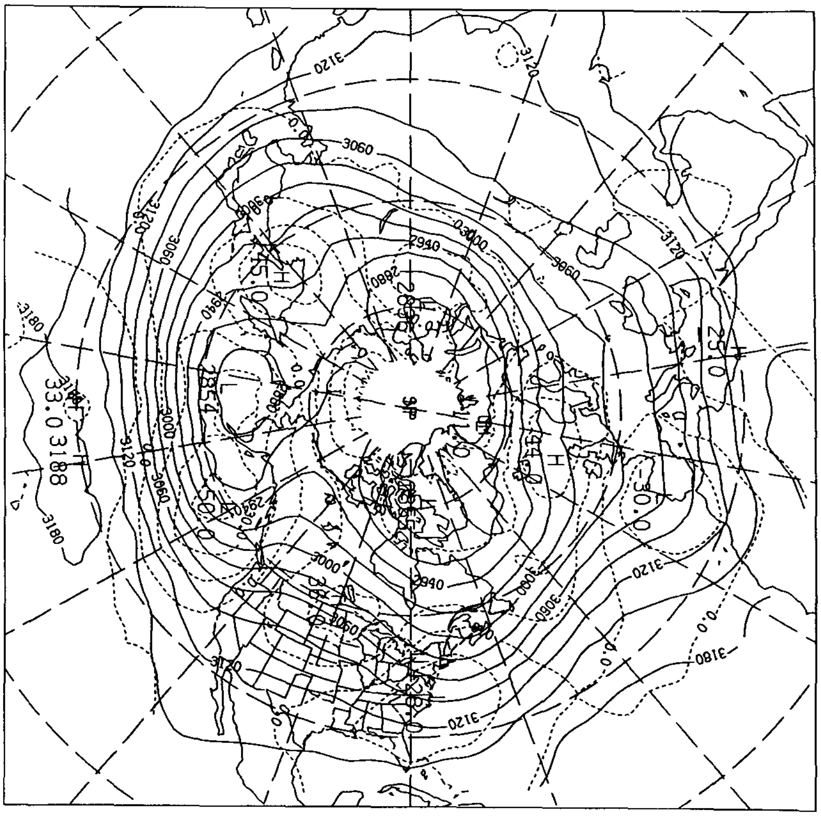


FIG. 1. Average 700 mb height (in *m*, solid) and anomalies (*m*, broken) for the three-month period April, May, and June, 1988. Contours are drawn at intervals of 30 m and anomalies at 15 m.

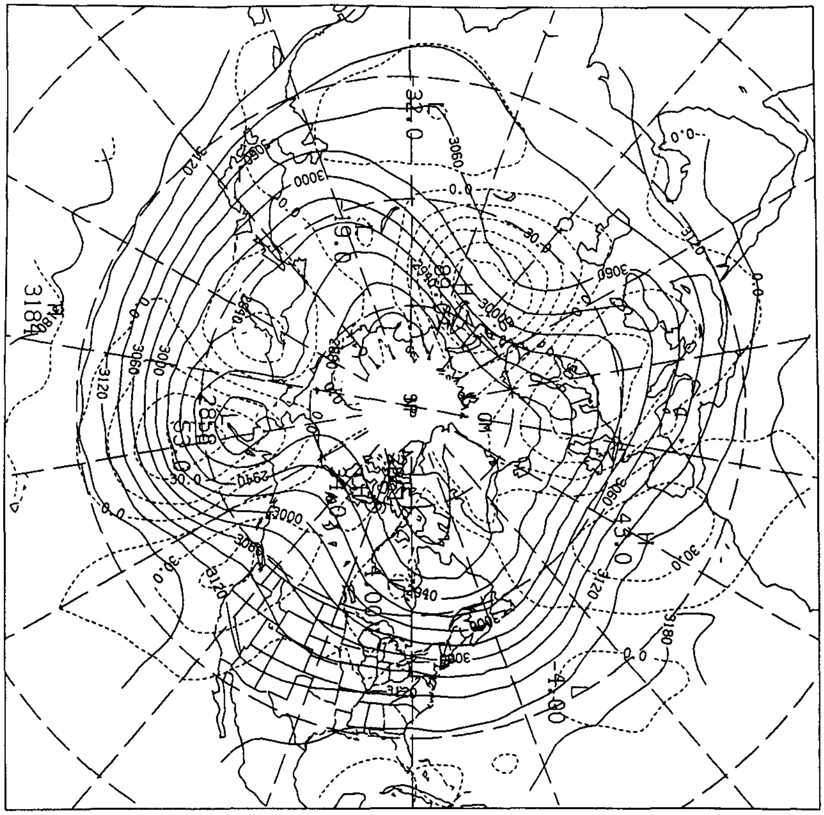


FIG. 2. Hypothetical 700 mb and anomaly chart for the average April, May, and June period assuming that the standardized anomalies for March 1988 are conserved. Intervals and units are the same as in Fig. 1.

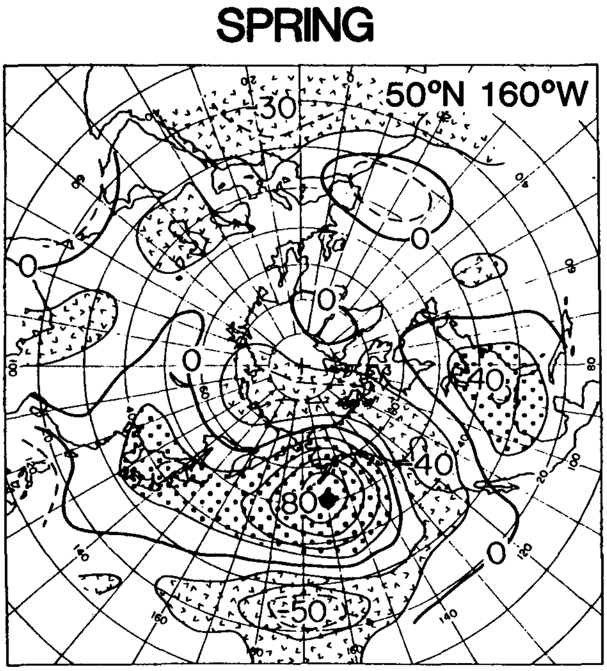


FIG. 3. The 700 mb height anomaly teleconnections for spring keying on 50°N, 160°W—the strong negative center in Fig. 2.

mb anomalies of Fig. 4 are remarkably similar to the observed temperature and precipitation for March, April, and May.

There is a striking similarity of the modeled heights in Fig. 4 to the observed pattern in Fig. 1; the pattern correlation between the model and observed anomalies is 0.84 (area bounded by 30°–60°N, 50°–160°W). The strong precursory signals seen in March suggest that the seeds of the spring–summer drought of 1988 were already present in the midlatitude Northern Hemisphere atmospheric circulation. This point of view is an alternative to the thesis that conditions in lower latitudes instigated the drought pattern (Trenberth et al. 1988), although both of these explanations hinge upon the importance of the anomalous circulation over the western hemisphere which actually produced the drought. A major feature in the tropics during the drought was the la Niña (cool SST) along the eastern tropical Pacific. (Note that the Trenberth et al. hypothesis does not attribute the drought to the cool tropical Pacific waters alone, but rather to the pattern of SST and associated atmospheric heating). If, for example, the cool tropical Pacific SSTs played a role in reinforcing the drought, this influence must have come later—the anomalies of SST in the equatorial Pacific

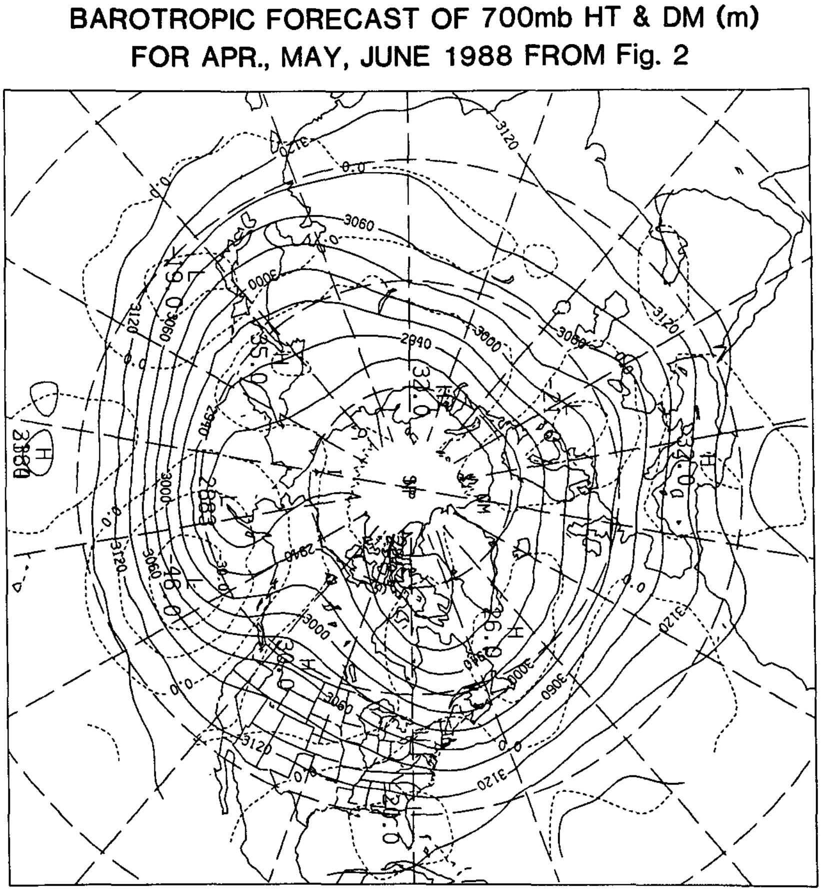


FIG. 4. Prediction for the average of April, May, and June using a modified-mean barotropic model initialized from the hypothetical chart shown in Fig. 2. Units and line spacing like in Fig. 1.

(see Fig. 5) show that la Niña was not yet present in March (anomaly of 0.5°C above normal) and did not drop to very low values until May.

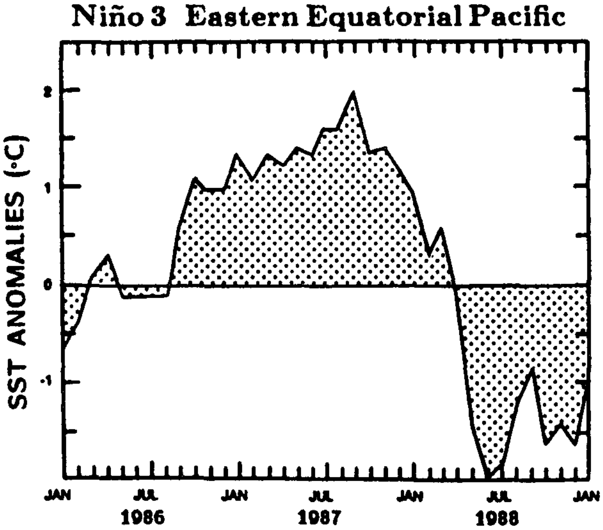


FIG. 5. Average SST anomalies for the equatorial region from 5°N–5°S, 90°–150°W from January 1986–September 1988 (from Trenberth et al. 1988). This sequence shows the development of the el Niño of 1986/87 and the rapid onset of la Niña in late spring 1988.

3. Predictions for summer 1988

A comprehensive discussion of the 1988 drought has been written by the NOAA Climate Program Office (1988). Undoubtedly, the 1988 drought will be described and studied by scores of meteorologists and others, just as have other severe episodes like the Dust Bowl droughts of the 1930s, the southwest droughts of 1952–54, and the summer drought of 1980. Information on the 1988 drought has been presented by Janowiak (1988) and Ropelewski (1988). Detailed statistics have been routinely published in the Weekly Climate Bulletin and the Weekly Weather and Crop Bulletin, both put out by NOAA in collaboration with the United States Department of Agriculture.

Observed and forecast temperature anomalies for summer 1988 over the contiguous United States by three forecast groups are displayed in Fig. 6, where

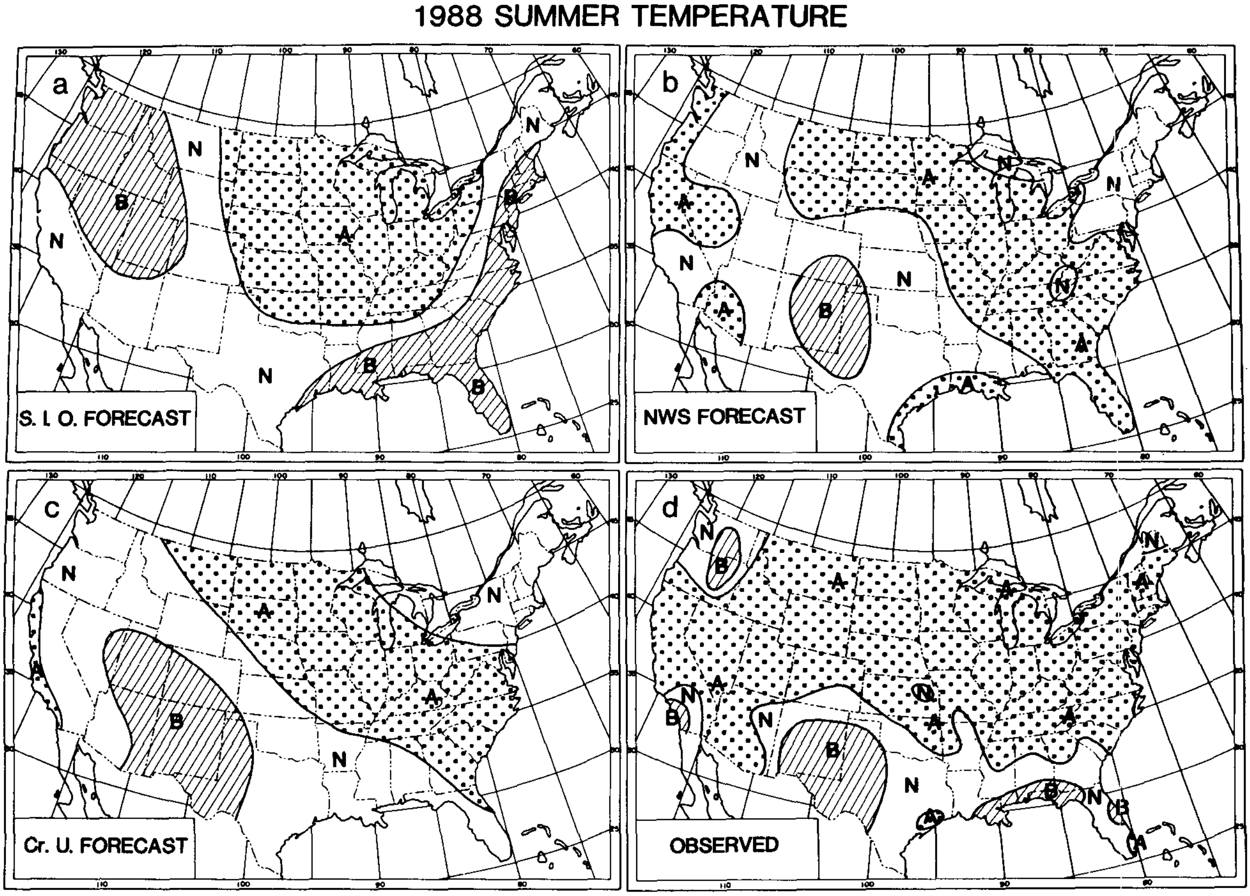


FIG. 6. Observed temperature anomalies for summer 1988 (d), and forecasts made by (a) J. Namias of the Climate Research Division, Scripps Institution of Oceanography (S.I.O.), (b) by the Long Range Prediction Group of the National Weather Service (NWS), and (c) by Arthur Douglas of Creighton University (Cr.U.). Classes shown are terciles computed from about 30 summers. The symbol A stands for above normal, B for below normal, and N for near normal.

three classes (terciles) have been employed. Corresponding observed and forecast precipitation in the classes light, moderate, and heavy are also shown in Fig. 7. The temperature and precipitation forecasts for one season in advance were made at the end of May by the National Weather Service of NOAA, by Arthur Douglas at Creighton University, and by this author at the Scripps Institution of Oceanography. The latter two forecasts are part of ongoing research designed to improve methods of seasonal prediction. While these predictions do not express the precise degree of abnormality, it is obvious that they portray the signature of drought over most of the contiguous United States, especially in the Great Plains. The low frequency of occurrence of the observed anomalies is detailed in the publications cited above. The observed patterns of anomaly are shown in panel (d) of each figure. Although none of the three forecasts foresaw the great extent and severity of the drought—particularly the large area of deficient precipitation—it was evident to at least two of the forecasters by May that summer drought in the Great Plains had emerged as a probability rather than a possibility. A composite of the three forecasts would have been better than any one of them, especially in the southeast. However, each of these forecasts display positive skill. Using a verification at 99 grid points over the nation, the number of points forecast in the right category of three were: for Scripps Institution of Oceanography, 44 for temperature and 48 for precipitation; Creighton University, 55 for temperature and 41 for precipitation; and for the National Weather Service, 57 for temperature and 45 for precipitation. (Thirty-three points would be expected correct by climatological probability using a tercile forecast.) These predictions are displayed to emphasize that precursory signs of drought were evident at least by late spring, and probably by March, as indicated in section 2.

While in this short article it is not possible or is it desirable to spell out all prognostic indications, a number of the primary ones employed by the present author are next explained.

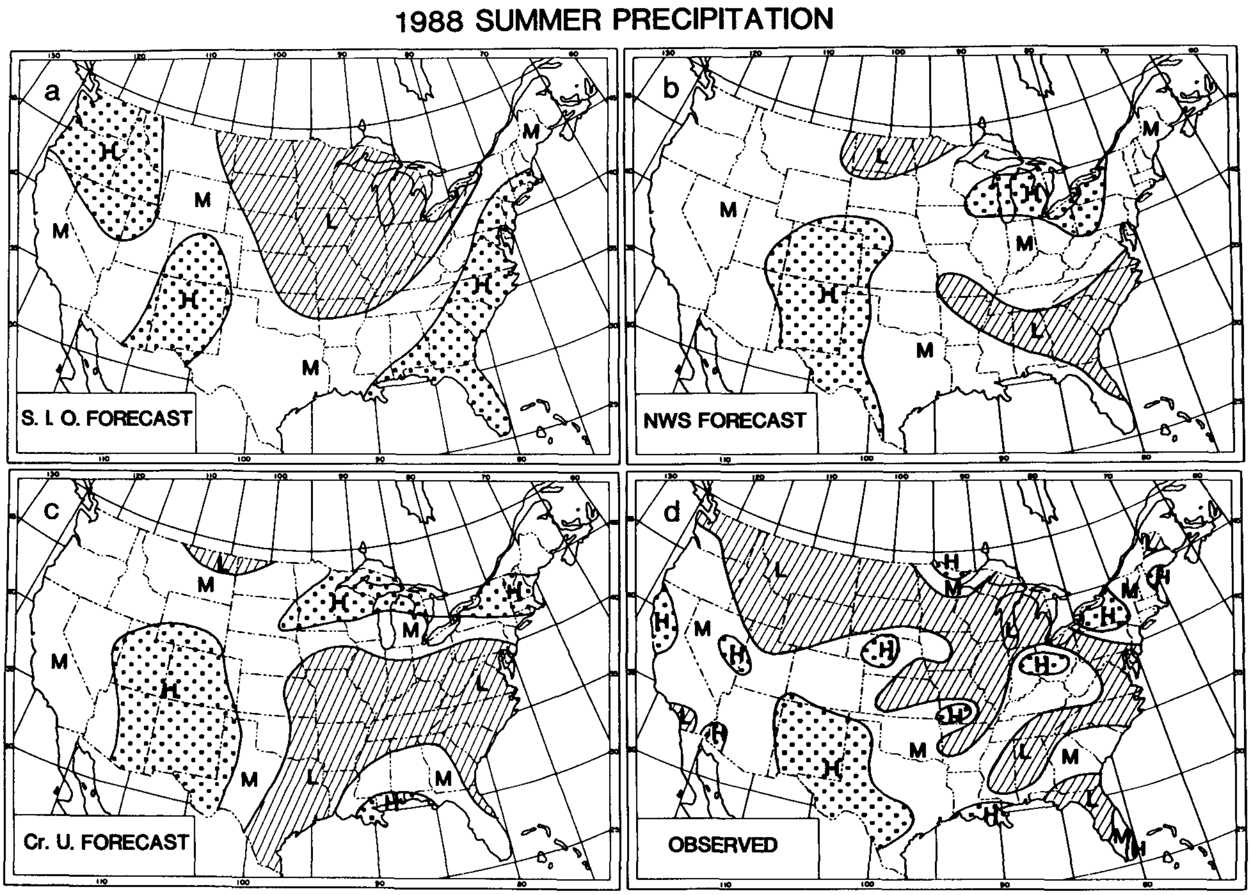
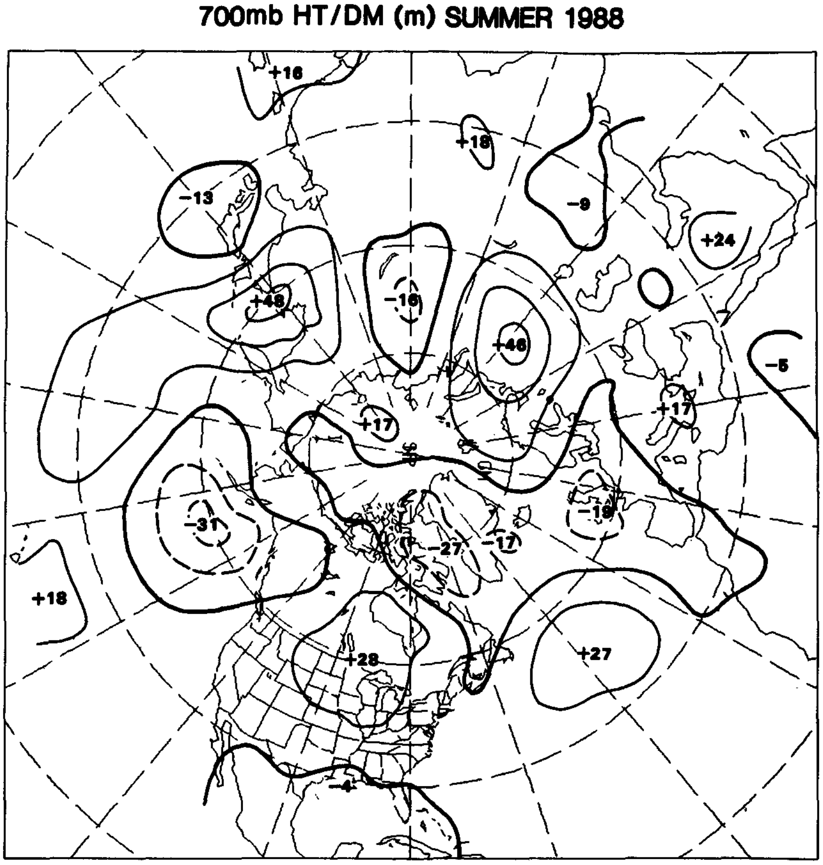


FIG. 7. Observed precipitation classes for summer 1988 (d), and forecasts made by (a) J. Namias of the Climate Research Division, Scripps Institution of Oceanography (S.I.O.), (b) by the Long Range Prediction Group of the National Weather Service (NWS), and (c) by Arthur Douglas of Creighton University (Cr.U.). Classes are terciles determined from about 30 summers.

4. Indications used in preparing the summer 1988 Scripps forecast

First, the midtropospheric 700 mb height anomalies observed for the summer as a whole are examined. These are reproduced in Fig. 8, which exhibits the anomalously strong high over the plains, concomitant weak or negative anomalies (troughs) off either coast, and stronger than normal upper-level highs in the central North Atlantic and, to a lesser degree, in the central North Pacific. This three-cell pattern has been found in several previous cases (e.g., Namias 1982, 1983) to be characteristic of summer drought over the plains. Subsidence in and below the continental high encourages dryness and helps steer cyclonic systems away from the anticyclonic domain. If one knew in advance that this pattern would prevail into the summer of 1988, he could make a reasonably good prediction of the drought, because objective specifications from the monthly or seasonal 700 mb height anomalies (developed by Klein 1985; Klein and Boom 1987, not shown) provide a good picture of the observed temperature and precipitation patterns.

Teleconnections between the high cell over the core of the drought area and other remote areas in the Northern Hemisphere can be shown in a number of ways. Perhaps the best and most up-to-date method is to employ the work of J. Wagner and N. Maisel of the Prediction Branch of the Climate Analysis Center, National Weather Service (1988, personal communication). They selected key centers for large positive and negative anomaly centers from a 40-year series of 15 day mean 700 mb gridded data with a 2 month-wide window centered on the reference month, and extracted 30 cases of largest positive and largest negative anomalies at these key points. They then calculated the probability of sign of the 700 mb height anomaly at each grid point over the hemisphere when the key center was strongly positive or strongly negative. The teleconnection chart for July, the midmonth of summer, for large positive anomalies over the Great Plains is reproduced in Fig. 9. Note the strong indications of



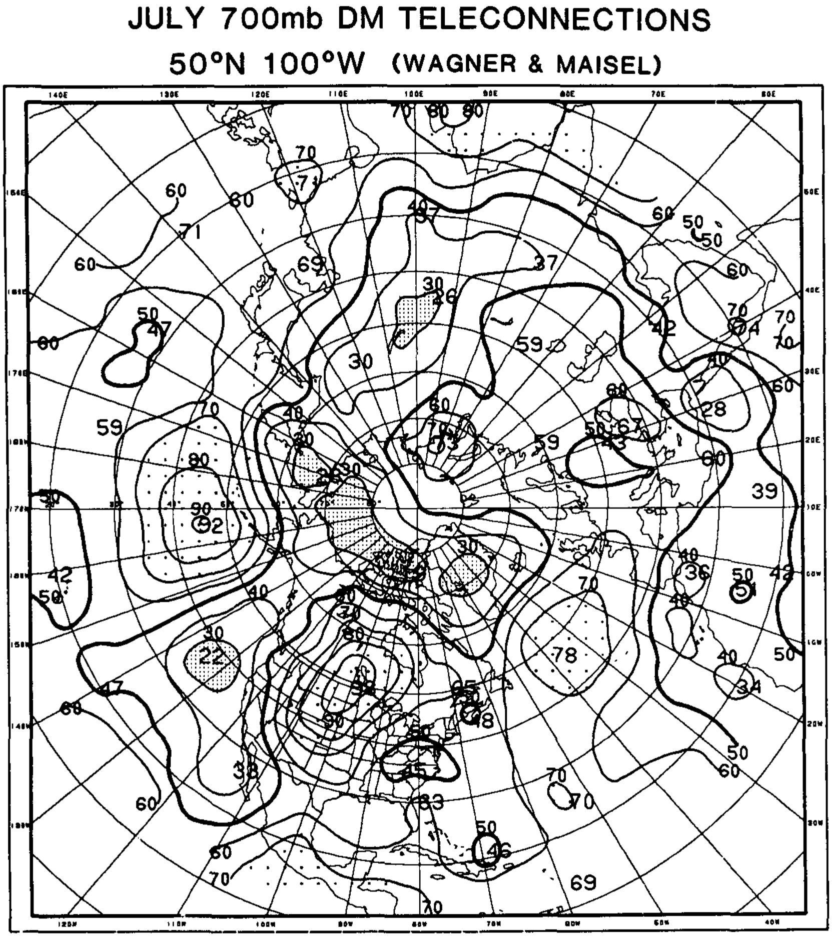
700mb HT/DM (m) SUMMER 1988

FIG. 8. The 700 mb height departures for summer, 1988 from the long term (40-year) summer mean. Centers labeled in *m*, and isopleths drawn for every 15 m.

remote positive cells over the central North Pacific and central North Atlantic separated by lesser or negative anomalies along or off the West and East coasts. The positive center located north of Hawaii in Fig. 9 is noteworthy inasmuch as Trenberth et al. (1988) have suggested that in 1988 such a cell in the late spring and summer was associated with the distribution of SST anomalies in the low latitudes of the Pacific: cool SST along the eastern tropical Pacific and warm SST to the north between 10° and 20°N.

By themselves, teleconnections do not prove cause-and-effect—they merely express linkages of abnormalities between parts of the general circulation. In addition to the North Pacific strengthened anticyclone, events in the North Atlantic, the seat of one of the positive 700 mb height anomalies (Fig. 8), also may have helped to stabilize this circulation. The positive heights in the North Atlantic might have been produced partly by the anomalously warm SST observed there in summer 1988 (not shown). Also, in the area of the Great Plains, regional influences could have favored the incidence and maintenance of the drought, aside from the dynamics associated with teleconnections.

Both empirical and theoretical evidence (Namias 1960; Shukla and Mintz 1982; Oglesby and Erickson 1989) indicate that the character of the soil in the plains, whether wet or dry, exerts a strong influence on overlying wind and weather patterns. It does this through latent and sensible heat alterations. When the soil is unusually dry, as in spring 1988 (see Fig. 10), the increasing insolation with the advance into summer is used to directly heat the soil and the overlying air, instead of evaporating the soil moisture. In the Great Plains, this process encourages the growth of an upper-level high, decreases relative humidities, and inhibits cloud formation. These effects are implied by the probabilities of summer temperatures and summer precipitation following temperature and precipitation conditions in spring over the Great Plains, as shown in Tables 1 and 2 (Namias 1960). These contingency tables show that warm dry springs in the western plains states (nine states for springs and summers of 66 years) are much more apt to be followed by warm and dry summers than are wet and cool or normal springs. It seems likely that these mechanisms will reinforce the plains' high pressure cell, which is also favored by the



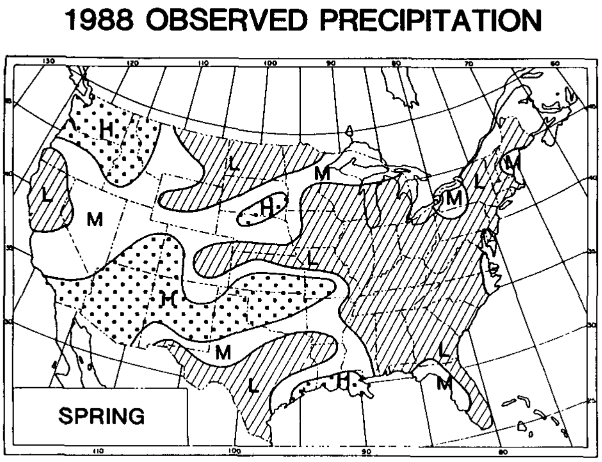
JULY 700mb DM TELECONNECTIONS

50°N 100°W (WAGNER & MAISEL)

FIG. 9. Teleconnections of 700 mb height anomalies keyed on 40°N, 90°W (near the core of the drought upper-level high pressure cell) for positive key centers in the Julys since 1947. Isopleths of probability of sign of anomaly are drawn for every 0.10. Shaded areas indicate values less than 30 percent and dotted areas positive values greater than 70 percent. (From Wagner and Maisel of the National Weather Service).

teleconnection mechanisms suggested. Thus, it could be argued that the positive anomaly observed over the Great Plains in the summer of 1988 may have been both cause and result of the positive anomaly north of Hawaii.

Before closing this section on the summer of 1988 forecast, it is germane to point out that once in place, summer drought over the plains may forebode a tendency for above normal temperature during the following summer (Namias 1978). In Table 3, some contingencies are displayed like those shown in Tables 1 and 2 but for the summer temperature anomalies in the Great Plains following drought during the *preceding* summer. Apparently, there are interseasonal and interannual spells of persistence which cannot be ascribed to linear trend. Unless this circumstance is due to long-period solar influences, it could indicate some conservative characteristics of the soil of the plains, or of the



1988 OBSERVED PRECIPITATION

FIG. 10. Observed precipitation pattern for spring 1988, expressed in terciles.

TABLE 1. Summer temperature classes (terciles) over 9 western Great Plains states as functions of combinations of antecedent spring temperature and precipitation. For example, as highlighted by the bold row of figures, of the 86 cases when spring was warm and dry (light precipitation), 9 were followed by cold summers, 27 by normal, and 50 by warm summers. Data involve seasons of the years 1900–1965. Totals for particular classes given in italics.

Spring temperature	Precipitation	Following summer temperature: Cold	Normal	Warm	Total
Cold		*101*	*70*	*40*	
	Light	29	21	10	*60*
	Moderate	31	18	19	*67*
	Heavy	41	31	11	*83*
Normal		*53*	*74*	*81*	
	Light	12	18	34	*64*
	Moderate	18	33	27	*78*
	Heavy	23	23	19	*65*
Warm		*57*	*65*	*87*	
	Light	**9**	**27**	**50**	**86**
	Moderate	18	22	22	*62*
	Heavy	30	16	16	*62*

sea underlying the oceanic high pressure cells, or both, which survive changes of intervening seasons between summers.

The above evidence and material supports the point of view that severe droughts, such as that in 1988, are manifestations of multiple effects in many branches of the general circulation and are not likely to be caused and maintained by a single factor.

5. Objective estimates of the 700 mb height pattern for summer 1988

In preparing the forecast for summer 1988 at the end of May 1988 (shown above), several indicators were employed. The influence of dry soil appears in contingencies for individual states (Fig. 11) which show probable summer temperature anomalies based on about 70 years of spring and summer data. The numbers indicate the excess over chance (33 percent) that the summer would be A (above normal), B (below normal), or C (near normal), based on the antecedent spring anomalies of temperature (solid numbers) and precipitation (italicized numbers). Only values exceeding 10 percent above the 33 percent expected by chance are shown. Inasmuch as spring over the plains was exceptionally dry in large areas (Fig. 10), contingencies between spring precipitation and summer temperature were employed as well as spring temperature and summer temperature contingencies.

TABLE 2. As in Table 1, except for precipitation as a function of antecedent spring temperature and precipitation classes. For example, dry summers tend to follow warm and dry springs.

Spring temperature	Precipitation	Following summer precipitation: Light	Moderate	Heavy
Cold		*53*	*73*	*85*
	Light	12	18	30
	Moderate	19	24	25
	Heavy	22	31	30
Normal		*70*	*73*	*65*
	Light	28	17	20
	Moderate	27	26	26
	Heavy	15	30	19
Warm		*87*	*63*	*58*
	Light	**49**	**22**	**14**
	Moderate	24	16	22
	Heavy	14	25	22

TABLE 3. As in Tables 1 and 2, except for summer temperature related to the preceding summer's temperature and precipitation. Note that warm summers tend to be preceded by warm dry summers in the preceding year.

Summer: Temperature	Precipitation	Following summer temperature: Cold	Normal	Warm	Total
Cold		*86*	*79*	*46*	*211*
	Light	11	13	7	31
	Moderate	30	17	22	69
	Heavy	45	49	17	111
Normal		*73*	*69*	*62*	*204*
	Light	16	18	23	57
	Moderate	30	30	18	78
	Heavy	27	21	21	69
Warm		*42*	*58*	*91*	*191*
	Light	**18**	**33**	**59**	**110**
	Moderate	16	19	23	58
	Heavy	8	6	9	23

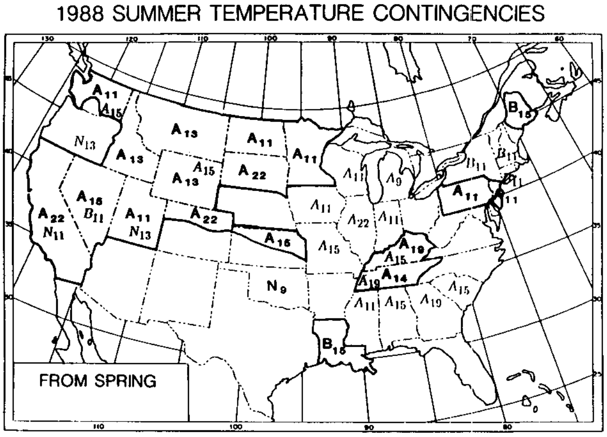
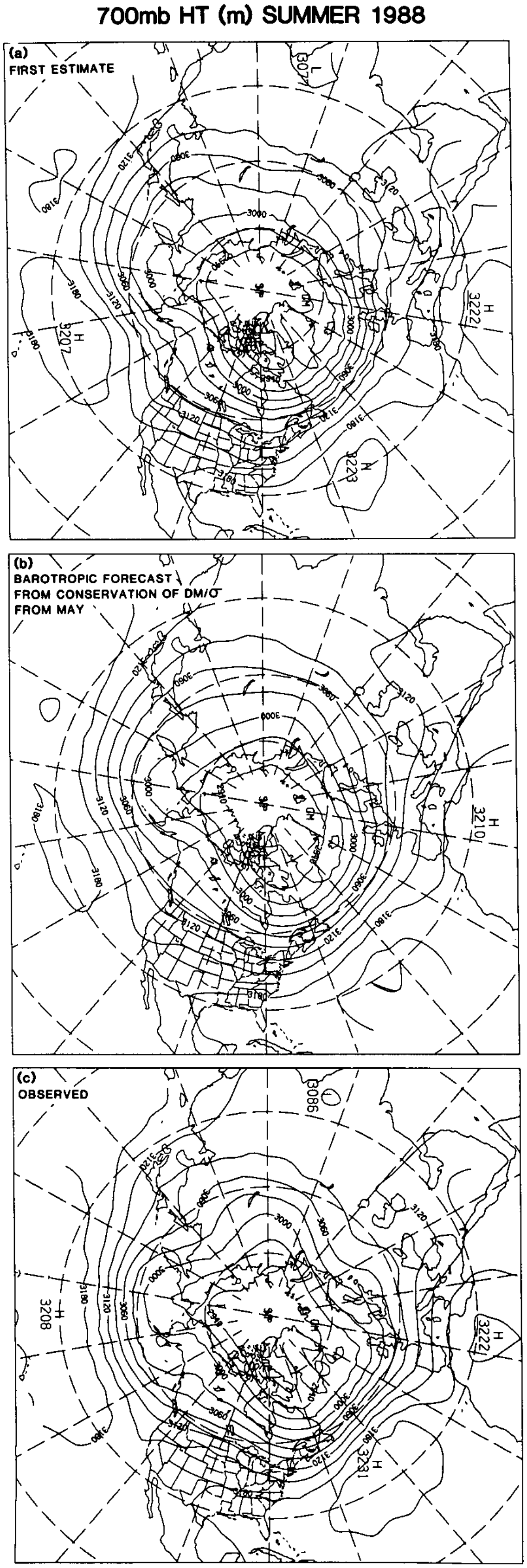


FIG. 11. Contingencies of summer temperature based on spring temperature anomalies (solid numbers and letters) and on spring precipitation (italics). Numbers beside classes indicate excess over 33 percent, the value expected by chance. Only those excesses above 10 percent are shown.



Several considerations promoted the idea that the summer would contain an anomalously strong continental anticyclone and its companion cells over adjacent oceans. Foremost among these prognostic indications is the concept that the final observed state of the flow pattern resulted from: 1) a tendency of the existing 700 mb anomaly pattern of spring to persist into summer, 2) anomalous boundary conditions, generated largely by spring air–sea–land interactions, operating in summer, and 3) normal seasonal changes in the strength of anomalies from spring to summer. Item 3 was taken into account by letting standardized anomalies persist from spring to summer, rather than the anomalies themselves. Because a strong circulation pattern had firmly taken hold in May, it was decided to use May for initial data in this calculation. Thus, Fig. 12a shows the pattern of 700 mb height that would characterize summer if the standardized anomalies of May persisted. The arrangement of anomalies in Fig. 12a, while stable for May, was unlikely to be stable for summer, which has a different mean state than the spring circulation. Thus, the anomalies should be shifted. While there is no simple method to adjust the monthly/seasonal anomalies, some experiments have suggested the use of a modified barotropic model to apply to the hypothetical chart (Fig. 12a), which assumes conservation of standardized height anomalies from May to summer (Namias 1988). The modified-mean barotropic model (supplied by John Roads of the Scripps Institution of Oceanography) increases the velocities in the initial hypothetical chart by an arbitrary factor of two, so as to offset the retrogression of long waves that might otherwise occur, and then proceeds iteratively to predict patterns out to about a week. The choice of the length of the prediction period is arbitrary, but it is assumed that because the low frequency component of this spring circulation is used as initial conditions, the predicted pattern will recur throughout summer. This recurrence is frequently observed in nature. The outcome of this procedure (Fig. 12b) is a pattern similar to the observed chart for summer (Fig. 12c), even in areas remote from North America. Anomalies of this forecast are not in such good agreement as they were in the case of April, May, and June (section 2, Figs. 1 and 2), although the wave patterns are fairly congruent. It must be emphasized that all above procedures were employed in making the summer 1988 forecast.

6. Test of the role of cool equatorial SST

Does la Niña cause drought in North America? Although the Trenberth et al. (1988) hypothesis for the

FIG. 12. The 700 mb forecasts for summer 1988, together with observed: (a) made by conserving the standardized 700 mb anomalies from May to summer, (b) using a modified barotropic model initialized on chart (a) for 5 days in advance and averaging, and (c) the observed 700 mb pattern for summer 1988.

origin of the related 1988 drought hinges on the *pattern* of SST and convection in the tropical Pacific, a consideration is whether an anomalously cool tropical Pacific in and of itself might cause summer drought in the Great Plains. To shed further light on the generation of North American summer drought by equatorial phenomenon, especially la Niña, seven summers during which cold equatorial water occurred (1949, 1955, 1967, 1970, 1971, 1973, and 1975) were selected and a composite 700 mb height pattern and its anomalies were computed. The standardized anomaly chart for this composite, shown in Fig. 13, bears little resemblance to the 1988 case shown in Fig. 8. Furthermore, there is little similarity to North American summer drought circulation in general, and translation of this composite 700 mb pattern into surface temperature anomalies (not shown) using Klein's equations (1985) does *not* yield a drought pattern. It is emphasized that these selected cases did not generally show the extreme equatorial SST pattern that occurred in 1988, and it is possible that the Trenberth et al. hypothesis applies only to the pattern of this particular case.

7. Summary

The drought of late spring and summer of 1988, involving a large portion of the contiguous United States, has been described in the context of a historical analysis of earlier droughts. The 1988 drought was a symptom of the classical three upper-level anticyclonic anomalies over the North Pacific, North Atlantic, and continental United States in early summer. The crucial question is: What caused this circulation pattern to develop and persist? Interactions with dry soil which developed in the plains during April and May probably played a role in strengthening the anticyclone over the United States and in anchoring this teleconnection pattern. Teleconnections among these areas appear to describe the main characteristics of the observed patterns. The influence of cool tropical eastern Pacific sea surface temperature was also examined. While the la Niña and other tropical anomalies may have contributed to the drought pattern, objective predictions made from March show that a dry April, May, and June were already indicated, and this condition persisted into

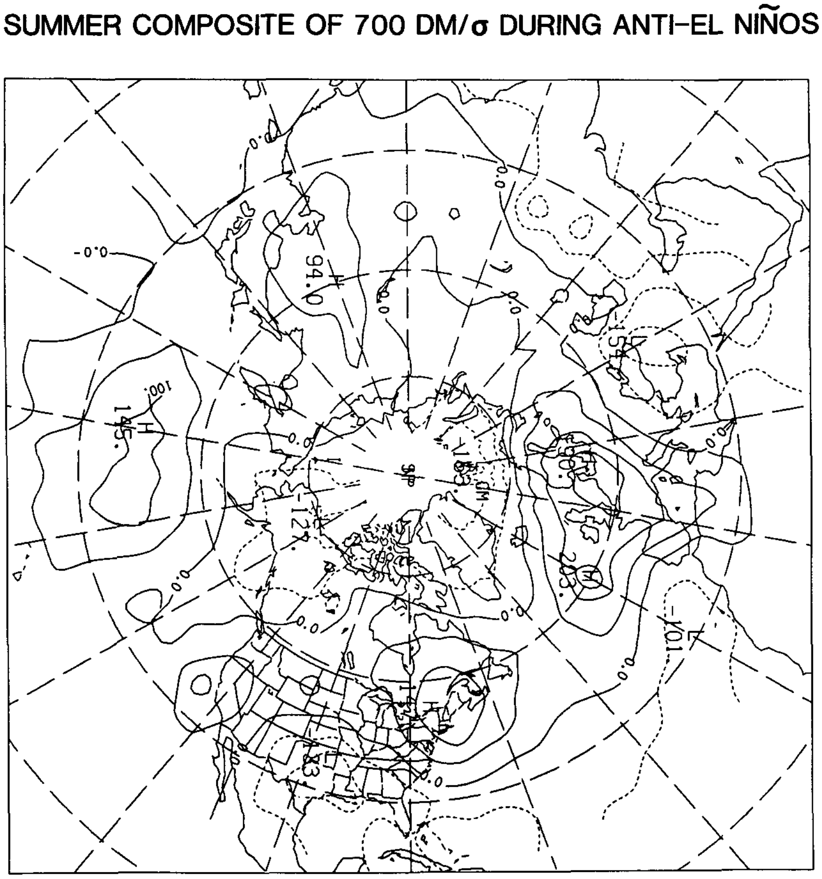


FIG. 13. Composite standardized 700 mb height anomalies for those summers when cold water (la Niña) was observed along the equator. Lines drawn for 1 and 2 standard deviations; solid for positive and dotted for negative values. Contrast with Fig. 8.

the first half of summer. La Niña and its attendant equatorial SST pattern was not in place until May, however, and cold events are not generally associated with drought. The above conclusions are reinforced by moderately successful predictions from extratropical conditions made in late spring of 1988 and a "hindcast" of the April through June atmospheric circulation using March data. The observed midtropospheric flow patterns in spring and summer of 1988 were quite well simulated by applying a modified barotropic model to reasonable statistical estimates of seasonal forcing from initial conditions a month before.

Acknowledgments. I thank Daniel Cayan for discussions and editorial assistance, Emelia Bainto for programming, Marguerette Schultz for illustrations, and Peggy Whan and Hector Jhong for word processing. Suggestions by Art Douglas, Richard Rosen, and an anonymous reviewer were especially helpful. This work was supported by the National Science Foundation under Grant ATM 84-07891, by the USGS under Grant 14-08-0001-G1483, and by the National Climate Program Office under Grant NA81AA-D-0054.

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