THE GLOBAL CLIMATE SYSTEM

CLIMATE SYSTEM MONITORING

JUNE 1986 - NOVEMBER 1988

UNITED NATIONS
ENVIRONMENT
PROGRAMME

RLD METEOROLOGICAL
ORGANIZATION
WORLD CLIMATE
DATA PROGRAMME

CSM R 84/86

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Front cover

The image of the 1987 Annual Normalized Difference (ND) days was prepared as part of a research effort to examine the use of remotely sensed data to monitor global vegetation as a potential tool for monitoring global climatic conditions. The annual Normalized Difference (ND) days represent the seasonal duration of green vegetation for a given location. Regions of the world with long growing seasons (e.g., Equatorial rain forests) display the greatest annual number of ND days. The annual number of ND days generally decreases, as the length of the growing season decreases, with increased latitude north or south of the Equator. Fluctuations in this general trend are primarily due to terrain of the land (mountains) or major climatic features (deserts). Research continues on the use of vegetation indices, including the annual ND days, as potential indicators of climatic conditions. If relationships can be established, then vegetation indices might be utilized as one of the many tools to monitor global climatic change.

FOREWORD

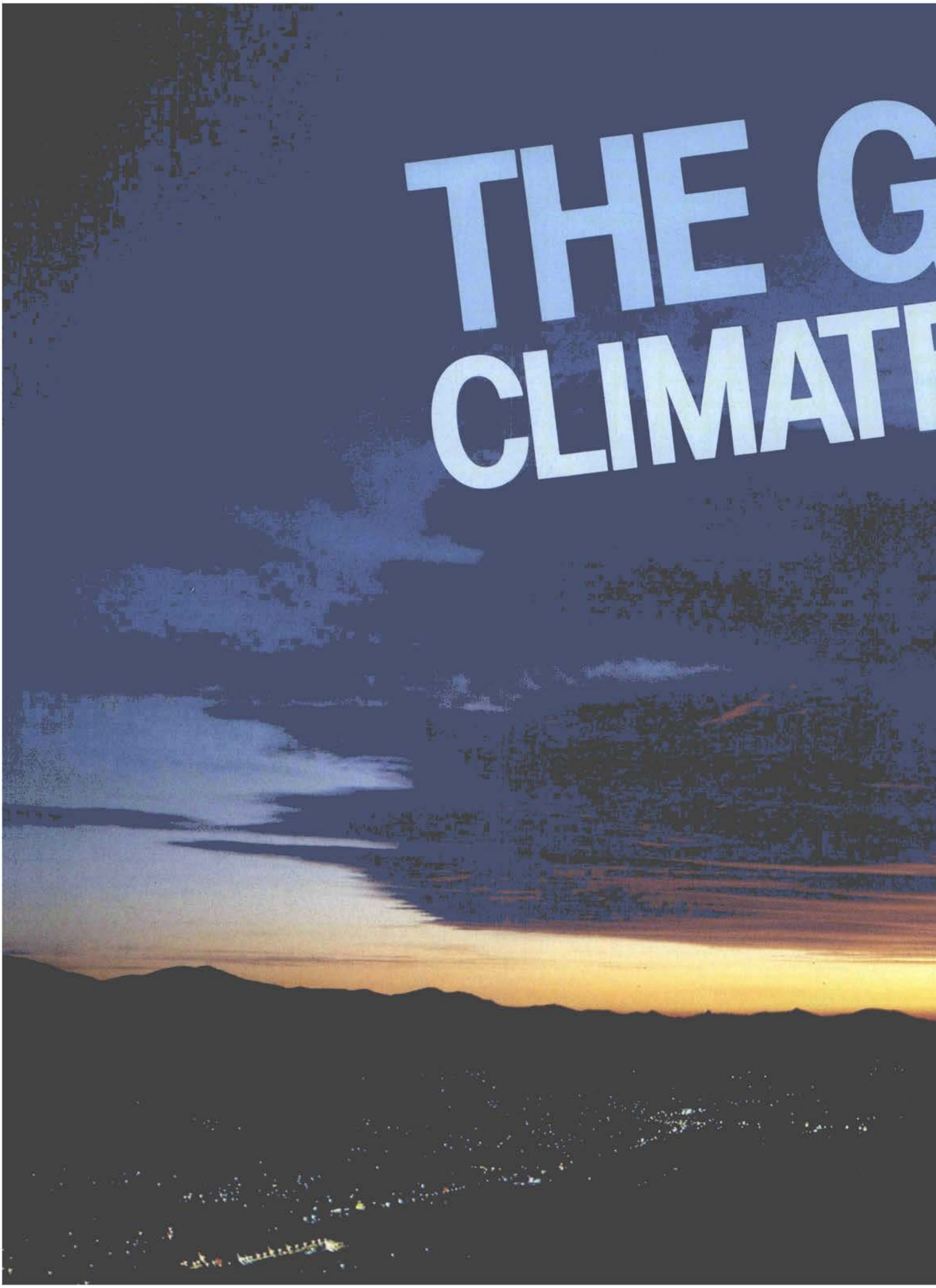
The Climate System Monitoring (CSM) project of the World Climate Data Programme (WCDP) was initiated in 1984 following a recommendation of the Ninth Congress of the World Meteorological Organization (WMO) in response to the occurrence of significant climate system anomalies over the last few years associated with adverse impacts on the social and economic activities of many countries. CSM is designed to provide Meteorological Services and other national and international organizations with synthesized information on the state of the climate system and diagnostic insights into significant large-scale anomalies of regional and global consequence. A CSM Monthly Bulletin has been issued since July 1984.

This report, the third biennial review of THE GLOBAL CLIMATE SYSTEM, is based on the current scientific understanding of the climate system and provides a basis for the monitoring of global change. Due to deficiencies in the global observing system, the diagnostic analyses of cause-effect relationships are preliminary for some regions and some climatic events or processes. It is hoped that the review will promote further research and better observing systems that would lead to improved models of the complex interactive processes occurring within the climate system. Much of this report was compiled from the input of a diverse group of experts from various regions around the world, who are acknowledged at the end of the report. Use was also made of readily available scientific literature: an extensive bibliography is provided at the end of the report for further reading.

The co-sponsorship of the CSM project by the Global Environmental Monitoring System (GEMS) programme of the United Nations Environment Programme is gratefully acknowledged.

V. Boldirev

Director, World Climate Programme Department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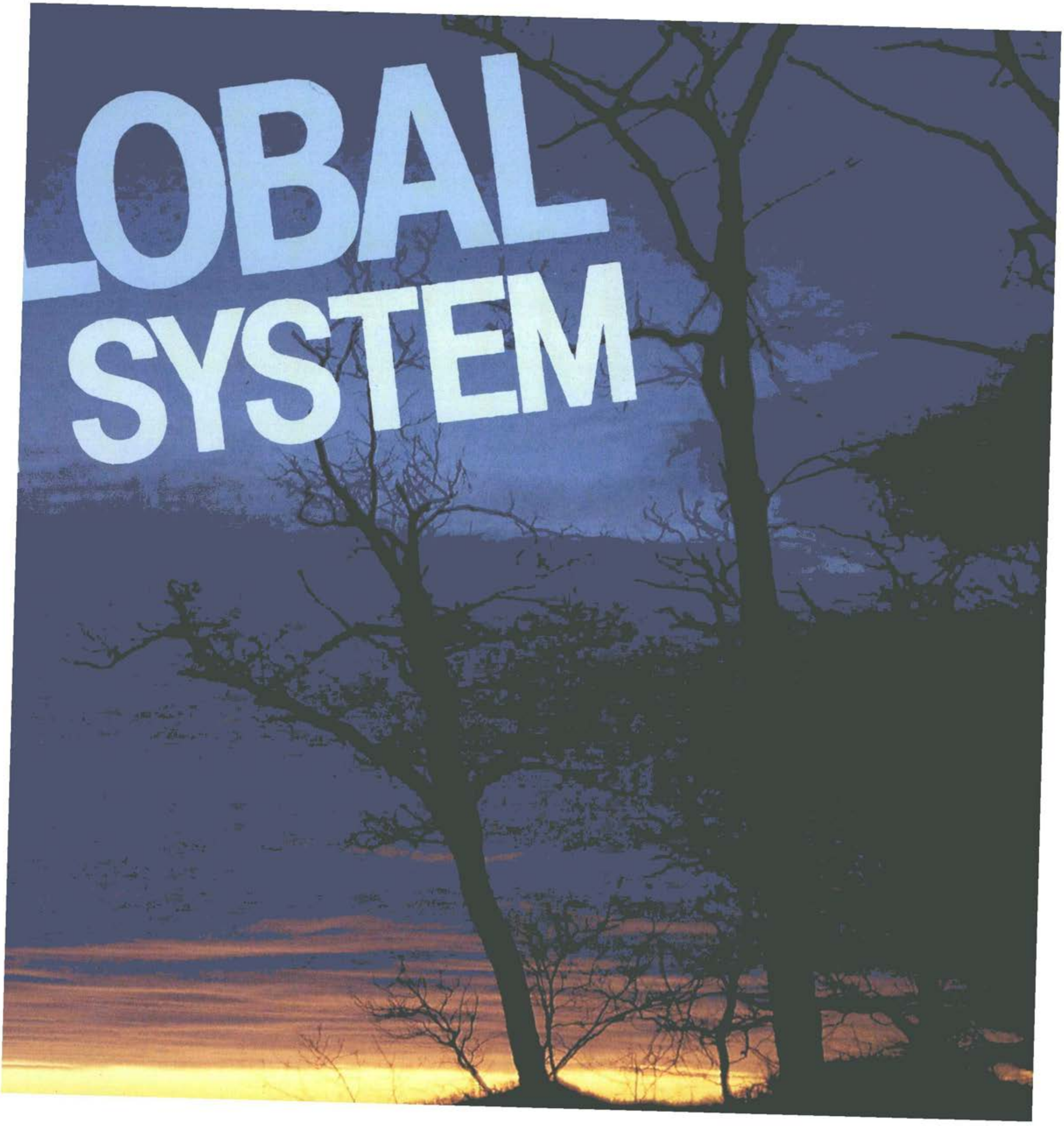
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CONTENTS

1 INTRODUCTION

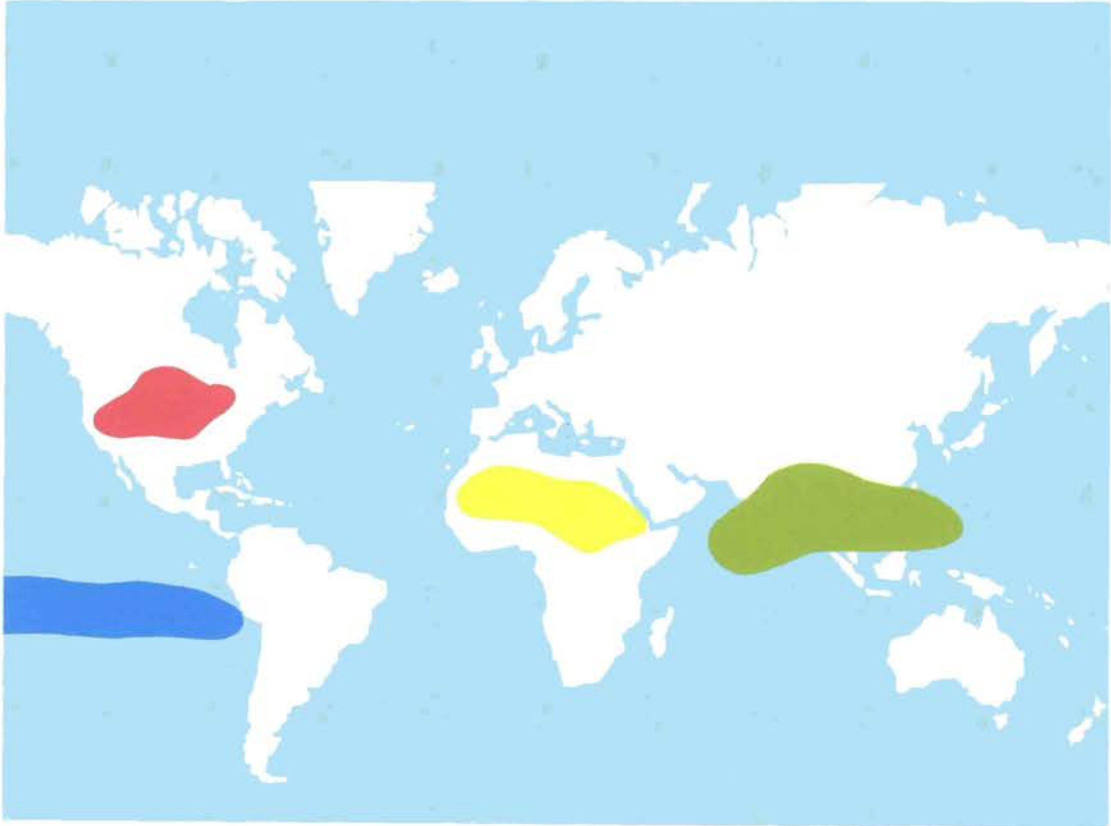
Over the past decade, climatology has moved from providing statistical based information to near real-time analysis of meteorological anomalies. This vitalization of climatology has, in part, been brought about by the worldwide concern about climate change. The meteorological anomalies reviewed in this issue of THE GLOBAL CLIMATE SYSTEM REVIEW, 1986-1988 are often regional in extent but should be viewed as manifestations of the global climate system. The system involves the atmosphere, oceans, land surface and cryosphere, all of which interact in a complex way over vast time scales. These anomalies may in some cases be associated with complex climate-control mechanisms or may just be isolated anomalies that deserve investigation and review.

Over the past few years, dramatic climatic events such as the warm and cold episodes of the Southern Oscillation have been reported over much of the globe. There have also been droughts in North America, Australia, parts of China, Europe, and South America, excessive warm spells, floods and unusually cold outbreaks throughout the world. These events have brought considerable loss of life, much suffering and economic losses. However, there have also been benefits from some anomalies such as mild winter conditions.

Some anomalies may be associated with climate change, but it is difficult to prove at this time due to a lack of sufficient evidence and a better understanding of the complex climate system. It is widely believed, however, that climatic changes could result from the continuing increase of atmospheric concentrations of carbon dioxide, nitrous oxide, methane, ozone and man-made chlorofluorocarbons. The impact of increased concentrations of these gases on climate has been studied by global climate models which indicate that an increase in the earth's surface temperature could occur, as well as a lowering of stratospheric temperatures, reduced sea ice, rising sea levels and changes in glacier mass balance and in patterns of precipitation and atmospheric pressure. However, understanding the magnitude and pattern of changes in these variables as a result of climatic change is still limited. Thus, care must be taken in attempting to relate the anomalies and extent of the anomalies presented in this review to climate change. The purpose of this Review is to provide a scientific summary of significant climate events over the period from June 1986 through November 1988 and where possible, relate recent events to historical information through the use of data time series. The significance of climate anomalies is defined by departures of various components of the climate system from their long-term "normal" values and not necessarily by their impacts. Thus, short-period events with temporal scales of less than one season, which have had significant socio-economic impacts, may not be specifically addressed. This report is a synthesis of published material and readily available data. Source material is not always referenced in the text but a bibliography is provided.

Figure 1

Approximate locations of some of the major anomalies and events described below are shown on this map.



2 HIGHLIGHTS

* **LARGE SWINGS FROM THE WARM TO COLD PHASE OF THE SOUTHERN OSCILLATION** were associated with significant anomalies in the global climate system.

* Generally **POOR 1987 RAINFALL IN MOST MONSOON AREAS** was replaced by abundant precipitation and flooding in 1988.

* **NORMAL RAINS RETURNED TO MOST OF THE SAHEL REGIONS** in 1988 after 20 years of below-normal rainfall.

* **SEVERE DROUGHT REDUCED CROP YIELDS** in many of the food producing regions of the world. The near-record drought of 1988 was especially harsh in North America.

* **WIDESPREAD TEMPERATURE VARIABILITY OCCURRED OVER THE CONTINENTS** of the northern hemisphere which featured some record to near-record warm and cold spells. This was particularly notable in 1988 when meridional atmospheric flow patterns predominated along with some prolonged periods of blocking.

* **GLOBAL MEAN TEMPERATURES REACHED A RECORD-HIGH LEVEL IN 1987 AND AGAIN IN 1988**, due primarily to unusual warmth in the tropics and some extremely warm regional temperature anomalies.

3 A MODERATE WARM EPISODE OF THE SOUTHERN OSCILLATION IN 1986/87 FOLLOWED BY A PRONOUNCED COLD PHASE IN 1988

The 1986 through 1988 period was characterized by dramatic and profound swings in the phase of the Southern Oscillation. The 1986 to 1987 period was marked by evolution of a moderate warm El Niño/Southern Oscillation (ENSO) episode followed, in 1988, by the dramatic appearance and development of a cold, or high Southern Oscillation Index (SOI) index, episode. These extremes of the Southern Oscillation dominated the global climate system for the entire period 1986 to 1988. While the 1986/87 warm episode was the second ENSO of this decade, the 1988 cold episode was the first to occur since 1975 and demonstrated that both extremes of the Southern Oscillation are important components of the global climate system.

3.1 Evolution of the Southern Oscillation

Early in 1986 there were signs that a warm, ENSO episode was about to start. This was evidenced primarily through the appearance of positive sea-surface temperature (SST) anomalies in the eastern Pacific. These eastern Pacific SST anomalies soon lost their character and the episode appeared to languish until the establishment of westerly wind anomalies in the central equatorial Pacific in the September through November period. These wind anomalies signaled the collapse of the central Pacific trade winds and the appearance of positive SST anomalies in this region (see *Figures 2 and 3*). During this warm episode, initiation-period convective activity moved east of the date line (*Figure 4*) and the Tahiti - Darwin SOI became strongly negative (*Figure 5*). By late 1986, it was clear that a significant warm episode was underway. Eastern Pacific SSTs anomalies, in the traditional El Niño areas, also returned to positive values (*see Figure 29*). These positive

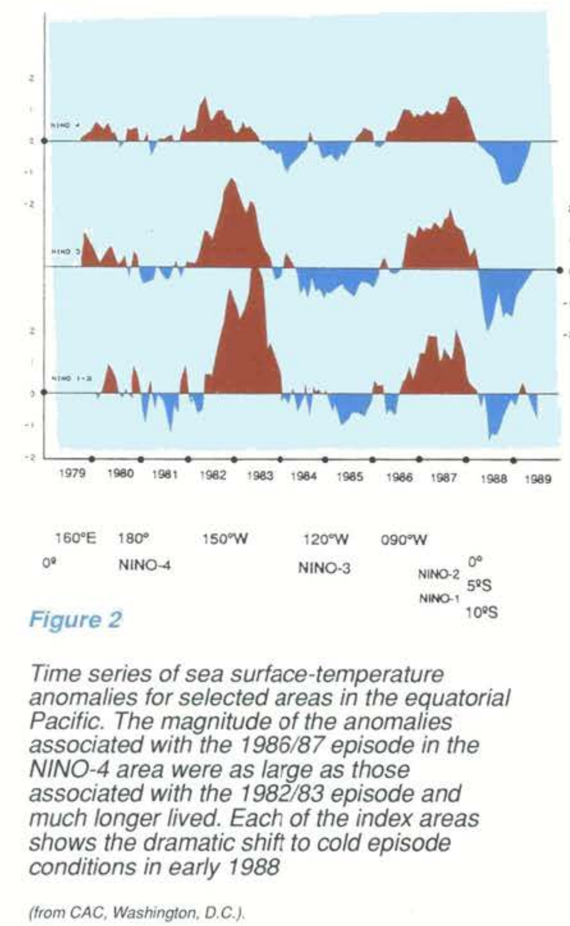


Figure 2

Time series of sea surface-temperature anomalies for selected areas in the equatorial Pacific. The magnitude of the anomalies associated with the 1986/87 episode in the NINO-4 area were as large as those associated with the 1982/83 episode and much longer lived. Each of the index areas shows the dramatic shift to cold episode conditions in early 1988

(from CAC, Washington, D.C.).

SST anomalies continued through the remainder of 1986 and throughout 1987.

While the magnitudes of the SST anomalies were not as large as those associated with the 1982/83 warm episode in the eastern portions of the Pacific basin, the central equatorial Pacific SST anomalies equalled those of the 1982/83 episode and persisted at these high levels through 1987. This relatively large pool of warmer than normal SSTs and the corresponding teleconnection to higher latitudes covered a large portion of the globe and undoubtedly contributed significantly to the large positive global temperature anomaly reported for 1987.

The warm phase of the Southern Oscillation gave way to a rapidly developing cold episode early in 1988. The initiation of the cold, or high index, episode was signalled by the appearance of extremely vigorous easterly trade winds in the Pacific Basin. These were accompanied by the retreat of equatorial convective activity to west of the

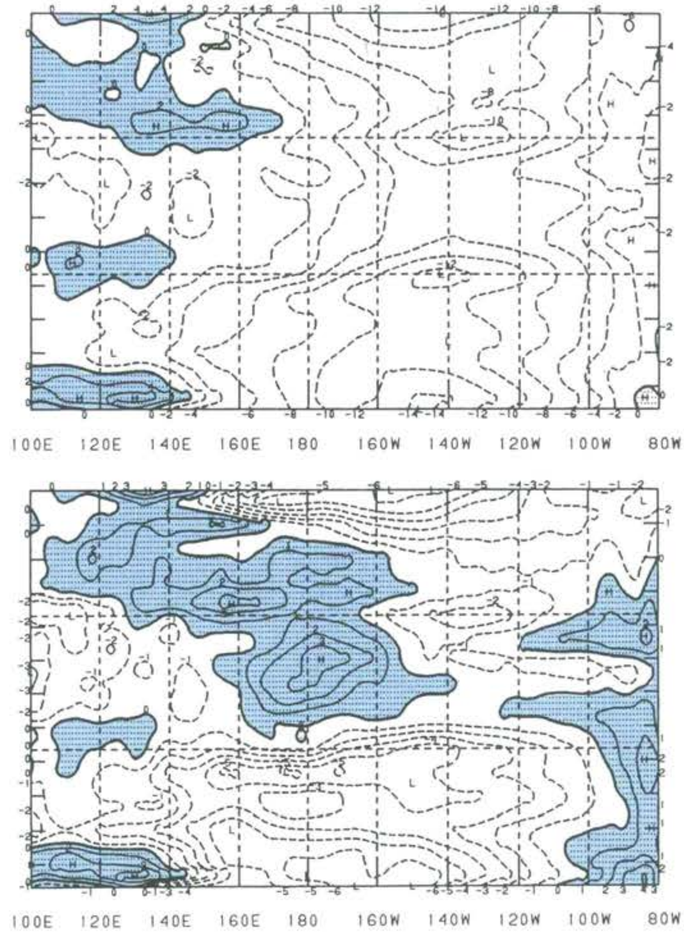


Figure 3

Time-longitude cross section of the monthly 850-hPa zonal wind for a 10 degree-latitude band centered on the equator. A) The mean is plotted with a contour interval of 2m/sec. B) Zonal wind anomalies with a contour interval of 1m/sec. Anomalies are departures from the 3/80 to 2/84 base-period means

(from CAC, Washington, D.C.).

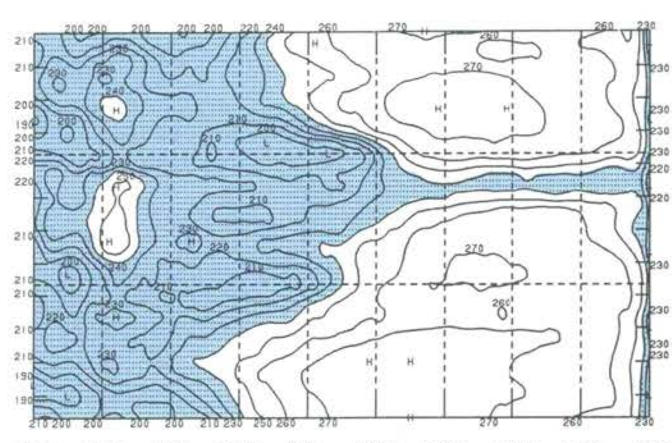


Figure 4

Time-longitude section of monthly outgoing long-wave radiation for a 10 degree-latitude band centered on the equator. Contour interval is 10 watts/sq m. OLR values less than 240 W m^{-2} indicate convective activity and values greater than 250 W m^{-2} dry conditions

(from CAC, Washington, D.C.).

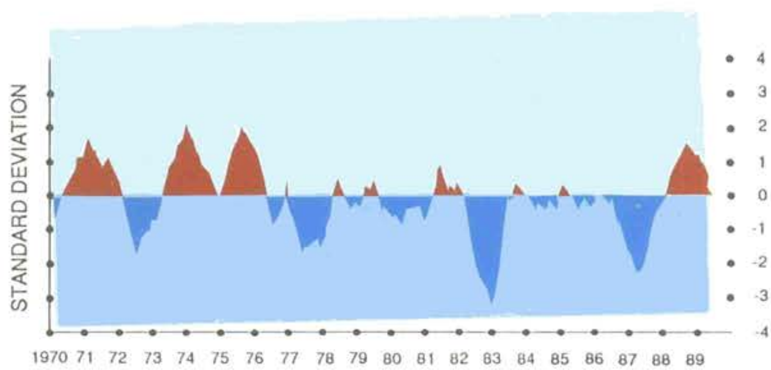


Figure 5

Time series of the difference between the standardized sea-level pressure anomalies of Tahiti and Dawin (Tahiti-Darwin). Values are standardized by the standard deviation of the appropriate monthly mean. The solid line represents a five-month running mean. Crosses indicate individual monthly values

(from CAC, Washington, D.C.).

dateline and a rapid rise of the Tahiti - Darwin SOI to values not experienced since the last cold episode in 1975.

The SSTs throughout the equatorial Pacific fell rapidly to produce negative anomalies early in 1988. By the June through August period of 1988, negative SST anomalies dominated the Pacific Basin in a striking contrast to the positive SST anomalies associated with the previous year's warm episode (*Figure 30*). The cold episode continued to influence the global climate system through the remainder of 1988. These influences were manifest in the clear and large differences in global-scale atmospheric circulation as well as in the contrast between precipitation patterns from 1987 to 1988.

3.2 ENSO - Associated Precipitation Patterns

The Southern Oscillation is associated with modulation of the monsoons on a global scale. While the precipitation patterns associated with the Southern Oscillation are very complex, research has demonstrated that the warm phase of the Southern Oscillation is generally associated with decreased precipitation in the major monsoon areas of the world, while the cold phase of the Southern Oscillation is generally associated with enhanced precipitation in these areas (*Figure 6*). These precipitation patterns represent the mean Southern-Oscillation-related precipitation patterns and thus we might expect some variations to occur in conjunction with individual episodes. In general, however, the major precipitation anomalies over the 1986 to 1988 period tended to follow these typical patterns.

In particular, the poor summer monsoons of 1987 in India and the 1987/88 dryness in Australia, the relatively light rainfall in southern Africa, the Philippines, northeastern South America, the relatively enhanced October to March precipitation in the southeastern United States and November to February precipitation in southeastern South America, and the shift in convection from the western Pacific eastward to the central Pacific are all consistent with patterns generally associated with the warm phase of the Southern Oscillation. Only the rather complex precipitation patterns of eastern equatorial Africa failed to exhibit typical warm-episode precipitation.

The global-scale shifts of the atmospheric circulation patterns and Pacific Ocean basin SST into the cold, high-index, phase of the Southern Oscillation were accompanied by corresponding adjustments in the large-scale precipitation patterns early in 1988. These precipitation anomalies included the extremely heavy Indian monsoon rainfall and related flooding in Bangladesh and enhanced precipitation in southern Africa, Indonesia, northern South America and eastern Australia. The cold episode was associated with precipitation deficiencies in northern Argentina, Uruguay, and extreme southern Brazil. The 1988 cold phase of the Southern Oscillation was also clearly associated with large-scale shifts in the equatorial tropical convective patterns. Drier-than-normal conditions prevailed in the equatorial central Pacific while the western Pacific received abundant rains. The 1986 to 1988 period witnessed the first large-scale swing from one extreme

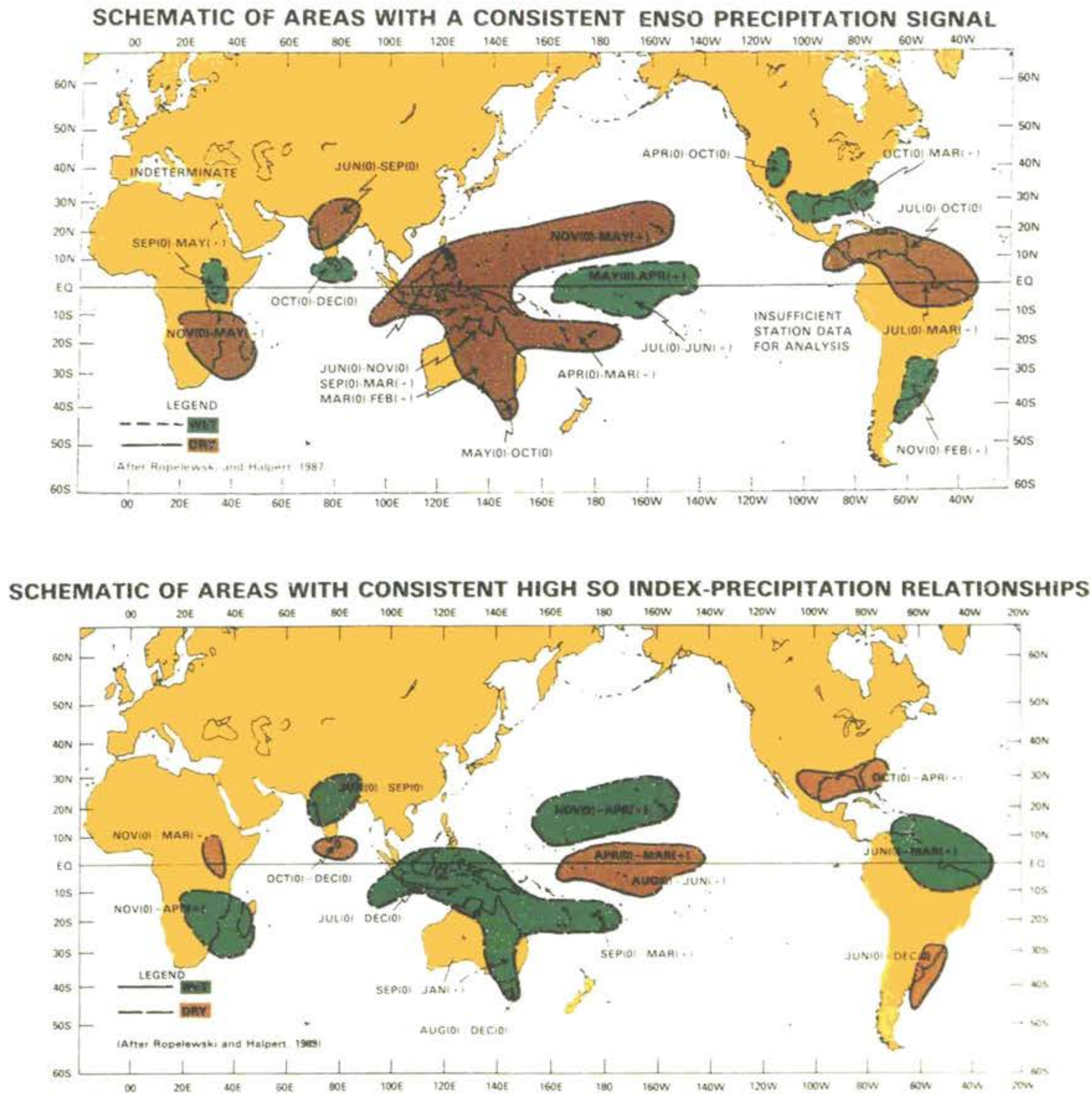


Figure 6

Schematic of precipitation patterns associated with the extremes of the Southern Oscillation. Top for the Warm (ENSO) Phase and bottom for the Cold (High Index) Phase. Areas shaded in green indicate enhanced precipitation while those shaded in brown indicate precipitation deficiencies. The "0" in parentheses after the month indicates the month of the same year as the Southern Oscillation extreme: a "+" indicates the following year

(after Ropelewski and Halpert, 1987 and 1989).

of the Southern Oscillation to another in over a decade. The profound changes in the state of the global climate system were associated with a host of precipitation anomalies. While not all of the large scale climate anomalies during the period can be ascribed to the Southern Oscillation, most of the typical Southern Oscillation-related precipitation patterns were observed.

Large-scale temperature patterns associated with the extremes of the Southern Oscillation have not been as well documented. Since the influence of the Southern Oscillation tends to span calendar years, the influence of the oscillation on calendar-year global temperature estimates is difficult to assess. Nonetheless, it is clear that the 1986/87 warm episode contributed significantly to the near-record global temperature estimates of 1987 and 1988.

4 GLOBAL MEAN TEMPERATURES RISE DESPITE SOME COLD ANOMALIES AT HIGHER LATITUDES

The surprising global mean warmth of 1987 and 1988 combined with some other abnormally warm years this decade has fuelled contentions that we are now witnessing the predicted warming effect of increasing atmospheric concentrations of trace greenhouse gases. The global warmth of the past two years has been due to some strong positive regional anomalies, particularly in the tropics. Other regions though, experienced pronounced cold temperature anomalies which in some cases led to below-normal temperatures over the past two years.

4.1 Global mean temperatures continue to rise in the 1980s

Time series analyses of a comprehensive, global, land and marine temperature data set from the Climatic Research Unit at East Anglia University, Norwich, U.K. (*Figure 7*) show a warming of about 0.5°C in both hemispheres since the second half of the nineteenth century. Globally, the warmest two years of the record were 1987 and 1988, with 1988 being the warmer by 0.01°C. The six warmest years globally have all occurred during the 1980s. In descending order these are 1988, 1987, 1983, 1981, 1980 and 1986.

Although the overall warming is similar in both hemispheres, the rate and degree of warming has varied considerably during the present century. Most of the warming in the northern hemisphere took place between the late 1910s and 1940 with little change between 1940 and the present. At present, decadally-averaged temperatures in the northern hemisphere for the 1980s are only marginally higher than those prevailing during the 1940s. In contrast, the southern hemisphere has experienced a more nearly monotonic

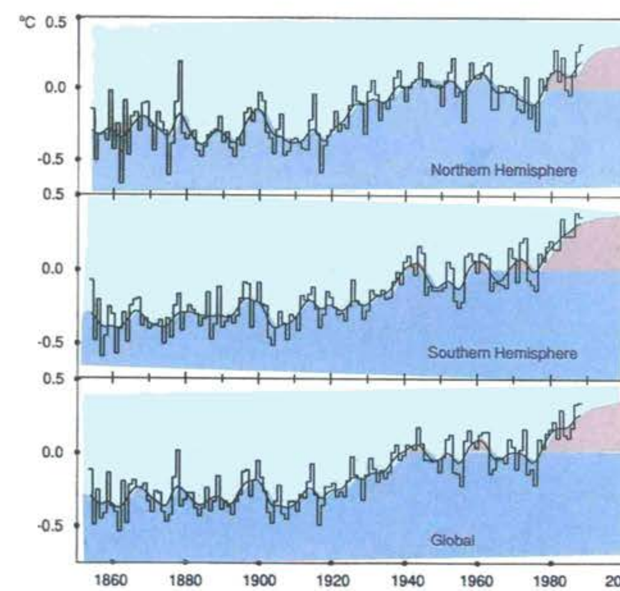


Figure 7

Annual hemispheric and global temperature departures from normal (reference period 1950-79) for the period 1854-1988. The smooth line depicts variations on the decadal time scale

(Climate Research Unit, Norwich, UK).

rise in temperature since late last century. Temperatures prevailing here in the 1980s are clearly warmer than any previous decade. This interhemispheric

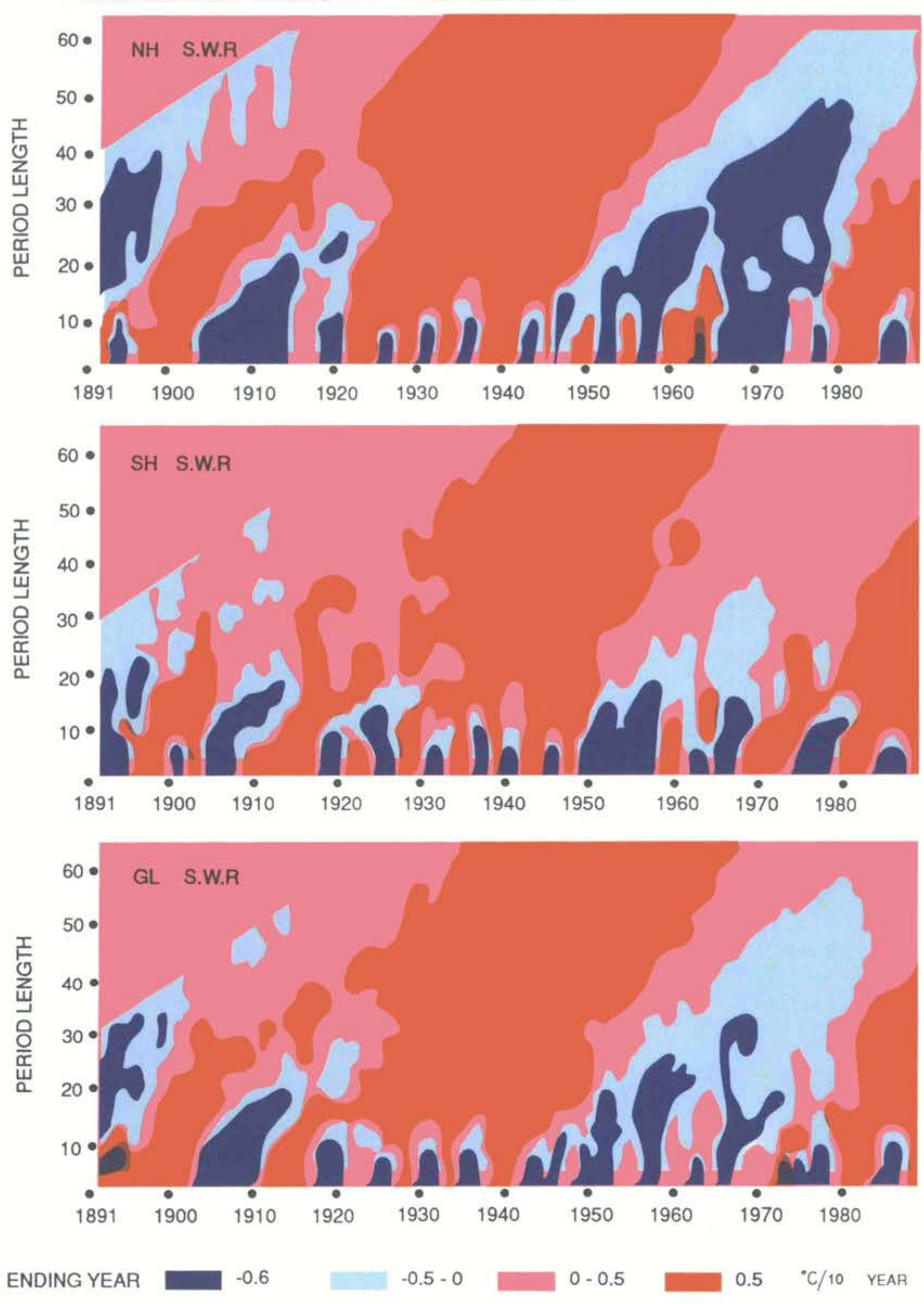


Figure 8

Regionally-averaged surface air temperature linear-trend coefficients (°C/10 years) for the northern and southern hemispheres and the globe as function of the length of the period (vertical axis) and ending-year (horizontal axis).

contrast has meant the prevailing level of temperature over the southern hemisphere is currently about 0.3˚C above that of the northern hemisphere compared to the value during the 1940s.

The hemispheric values are averages of grid-point data on a 5˚ x 5˚ grid encompassing the land and marine areas of the world. The land data come from the Jones et al. (1986a, b) compilation while the marine data are sea-surface temperatures from the COADS compilation (Woodruff et al. 1987). Although coverage is poorer in earlier years, annual estimates are reliable back to about 1890. Earlier estimates are less reliable, but they indicate the course of events on a decadal scale.

The quality of the land data is assessed by Jones et al. (1986a, b) and references therein. The maximum degree of urban influence over the twentieth century in the land data set has been assessed to be 0.1˚C by comparison of the gridded land data with independent rural series (see Karl and Jones, 1989 and Jones et al. 1989 for details). However, a thorough analysis of USA data showing an urban bias comparable to the overall temperature trend this century underscores the need for a thorough global study of the complex urbanization effect.

The marine data quality has been assessed by Jones et al. (1986c and 1990). The marine data used here differ from Jones et al. (1986c) by a correction to the SST data according to the techniques outlined by Folland and Parker (1989). These techniques assume that, between 1905 and 1940, all SST data were taken using canvas buckets. Folland and Parker (1989) have developed a model that simulates the amount of cooling (or possible slight warming in some areas and seasons) that takes place while the bucket is being hauled onto the deck and the reading taken. Hemispherically, this amounts to an additive correction of about 0.35˚C to SST data over this period. The use of the model enables different corrections to be applied to each region of the world for each month, the corrections depending on the SST, air temperature, wind speed, ship speed and humidity. Between 1854 and 1905, corrections are applied assuming a gradual transition from wooden to canvas buckets. Wooden buckets, being better insulators require less of a correction.

It is interesting to compare the current global rising temperature trend in the 1980s with previous temperature trends in the recorded history dating back to the late 19th century. The extent and magnitude of hemispheric and global trends are effectively revealed in *Figure 8* which shows regionally-averaged trend coefficients in degrees Celsius per ten-year period. Of particular interest is the pronounced cooling trend in the northern hemisphere which began in the early 1940s and extended into the late 1970s. For example, in 1973, the negative temperature trend was greater than 0.5˚C/10 years for the previous 10, 20, 30 and 40-year periods. This cooling trend was not as pronounced in the southern hemisphere.

The predominant feature on these time-series graphs (figure 8) is the warming trend which began near the turn of the century and terminated in the early 1940s. At and just prior to 1940, the linear trend coefficients exceeded +0.5˚C per 10 years. The current warming period is not yet as extensive but its magnitude is comparable.

4.2 No pronounced temperature trends in the USA or USSR

The dramatic rising trend of globally-averaged surface temperatures during this decade is not quite as evident or pronounced when one examines the individual time series of areally-averaged temperatures over

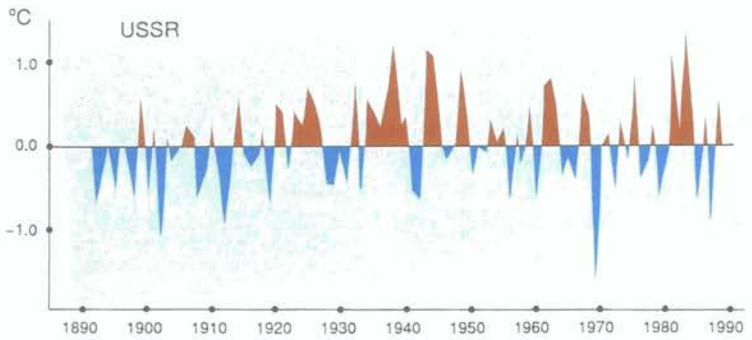


Figure 9

Regionally-averaged annual (December-November) surface-air-temperature anomalies over the Soviet Union. Anomalies were computed relative to the period 1951-1989.

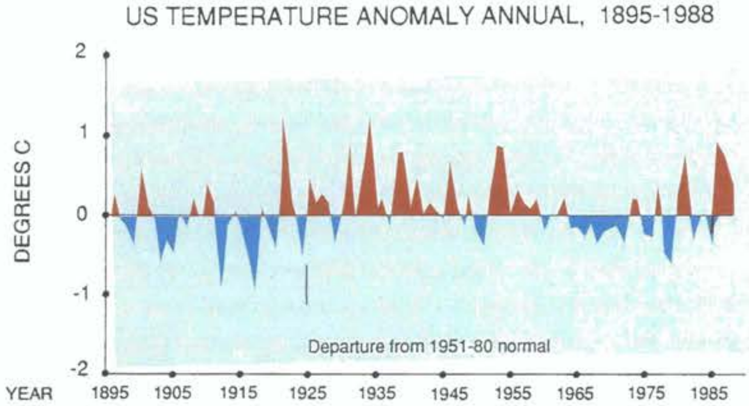


Figure 10

Regionally-averaged annual (January-December) surface-air-temperature anomalies over the contiguous United States. Anomalies were computed relative to the period 1951-1980

(from NCDC Asheville, NC, USA).

the USSR and the contiguous USA (*Figures 9 and 10*) respectively. Globally, the six warmest years have occurred in the 1980s. The six warmest years in the USA were, in descending order: 1934, 1921, 1931, 1986, 1953 and 1954 and for the USSR: 1983, 1943, 1981, 1938, 1944 and 1948. Not only is the warming trend of the 1980s subdued in these regional graphs but so is the warming trend in the early part of this century. The global cooling trend from the mid 1950s to the late 1970s was very evident in the USA but hardly discernible in the USSR except for the extremely cold year which occurred in 1969. In summary, it can be concluded that, up to 1988, the presence of any long or short-term warming trend is not at all obvious in either the regionally-averaged data from the USA or USSR.

4.3 Regional temperature anomalies in the northern hemisphere

It is important to note that the globally-averaged rising trend of temperatures in this decade, which reached record-high values in both 1987 and again in 1988, was not a result of a uniform rise in temperatures around the earth, rather it was an average of regional warm and cold temperature anomalies in which the warm anomalies predominated.

Figure 11

Annual (December-November) anomalies (relative to the 1951-80) of air temperature over the northern hemisphere (units - °C) in a) 1986, b);1987, and c) 1988.

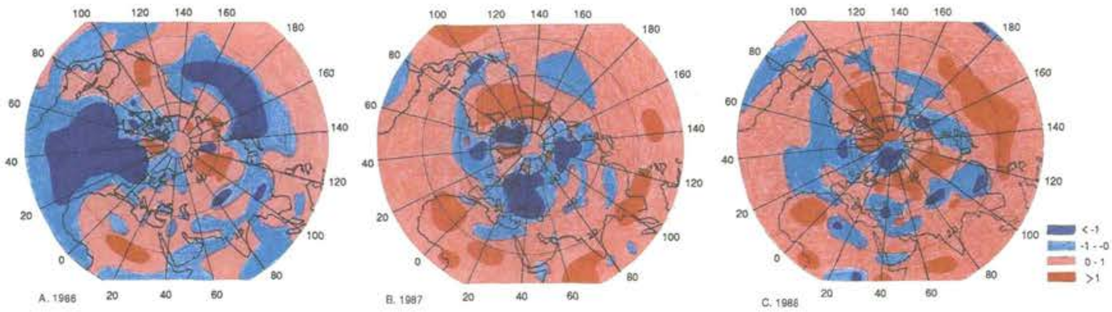


Figure 12

Latitude versus time diagram of zonal temperature over the northern hemisphere 85-5°N. Left: normals (°2C)over the 1951-80 period; right: anomalies relative to the 1951-80 for June 1986 to March 1989.

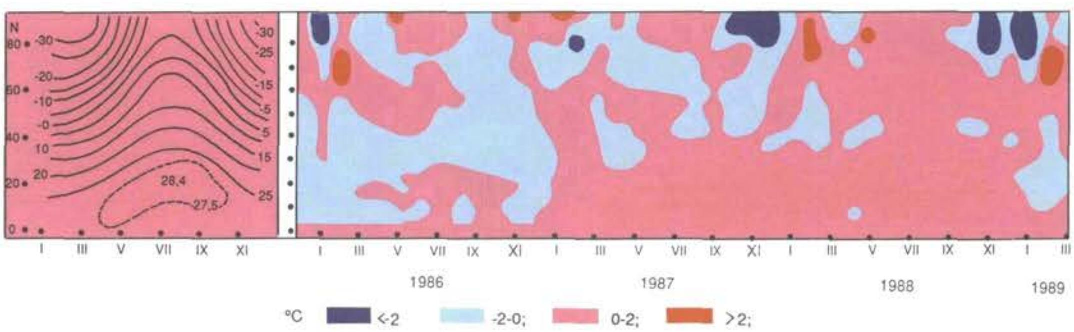


Figure 11 shows the distribution of annual temperature anomalies around the northern hemisphere in 1986, 1987 and 1988 with the following significant features:

-the predominance of warm anomalies over latitudes south of 35°N in 1987 and 1988 and a corresponding concentration of cold anomalies in northern latitudes (*see also Figure 12*);

-cold-temperature anomalies over the North Atlantic, North Pacific and eastern Arctic Oceans (*see also Figure 13*) during all three years with particularly strong ones in 1986;

-extremely warm anomalies over North America in both 1987 and 1988 which, in 1987, led to the highest annual temperatures ever recorded at many locations in central and northwestern Canada; and

-despite the fact that, globally, 1987 was the warmest year ever recorded up to that year, a pronounced cold-temperature anomaly covered a vast expanse of northern Asia and extended into western Europe (*see also Figure 13*).

On a seasonal basis, regional anomalies can become very intense as is illustrated by the two successively mild winters in China in 1987 and 1988. The winter of 1986/87 was the mildest in China since 1947. Three-month (December-March) seasonal temperature anomalies exceeded 3°C in the northwest, north and south of the country. The mercury climbed to 25.8°C at Nanjing on February 10, 1987 which was the highest temperature for this time of the year since 1905. During the following winter of 1987/88, the warmth affected just the northern half of the country where, in the southern part of the northeast provinces and Inner Mongolia, the maximum three-month temperature anomaly reached +3.6°C. These two mild winters appear to be part of a recent 27-year trend to warmer winters in northern China as shown in *Figure 14*.

These regional temperature variations can be directly related to the upper tropospheric flow patterns which control the global distribution of warm air from tropics northward and the movement of polar air masses southward. *Figure 15* shows the 1987 mean annual flow pattern at the 500-hectopascal level of the atmosphere and the associated geopotential height anomalies. Compare *Figure 11b* with *Figure 15b* and note the correspondence between anomalies of surface temperature and those of geopotential height of the same sign, particularly over North America and northern Asia where pronounced warm and cold temperature anomalies prevailed respectively.

4.4 Relating the greenhouse gas effect and ENSO to recent temperature trends

In trying to determine what climatic control mechanisms might be related to this pronounced global warming during 1987 and 1988, one naturally thinks of a possible greenhouse gas warming effect. In fact, many climatologists would say that the build-up of greenhouse gases in the atmosphere is the most likely cause of the long-term warming trend, although the evidence is even now equivocal. A contrary view held by some climatologists is that the recent warm years are simply a manifestation of

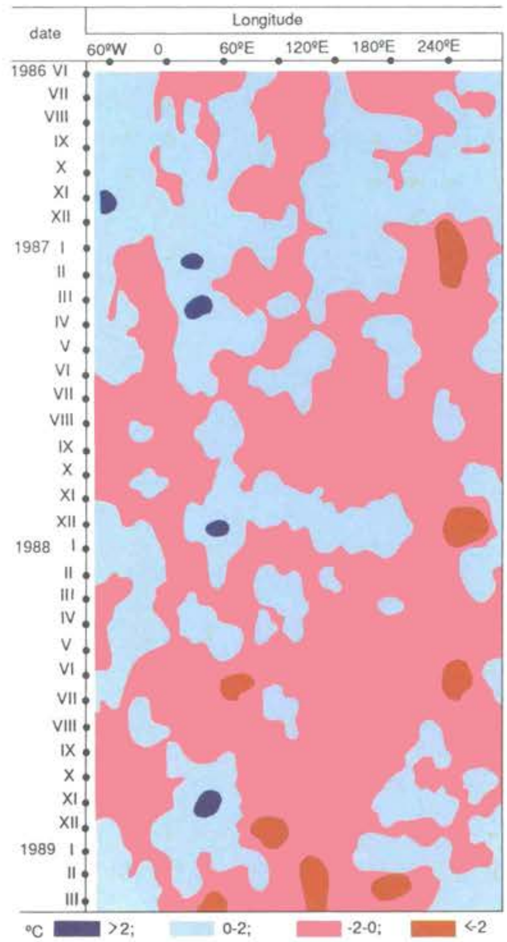


Figure 13

Time-longitude section of monthly-mean air temperature anomaly (relative to the 1951-80) for 85-5°N for the period June 1986 to March 1989.

a greater frequency of ENSO events in the Pacific.

From the global perspective, the events of 1987 and 1988 are very consistent with global climate model (GCM) projections of a trace-greenhouse-gas-induced warming trend. The fact that the more pronounced warming occurred in the tropical latitudes does not, however, fit GCM projections of relatively greater warmth at higher latitudes. Another possible inconsistency is the significant global cooling that occurred just prior to the 1980s warming event which does not correspond to the steady increase in greenhouse gas concentrations that occurred throughout and prior to this period.

The moderate 1987/88 ENSO event was obviously a contributing factor to the anomalous warmth experienced in the tropics. The established relationship between ENSO events and abnormally warm winters in northwestern North

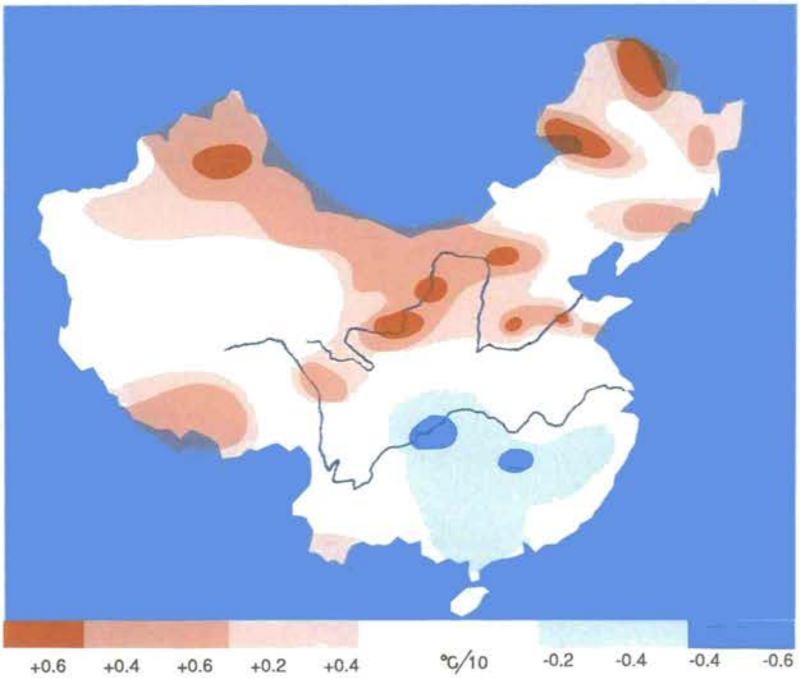


Figure 14

The areal distribution of winter temperature trends (°C/10 Yr.) in China through recent 27 years (1960 - 1986)

(Xu, data from Central Meteorological Observatory).

America (Ropelewski and Halpert, 1987) was observed in two successive winters, thereby contributing to the strong annual positive temperature anomalies over North America in 1987 and 1988. These same ENSO relationships were also prominent during the strong 1982/83 event which leads one to believe that these two ENSO events have significantly contributed to the observed global warming trend of this decade.

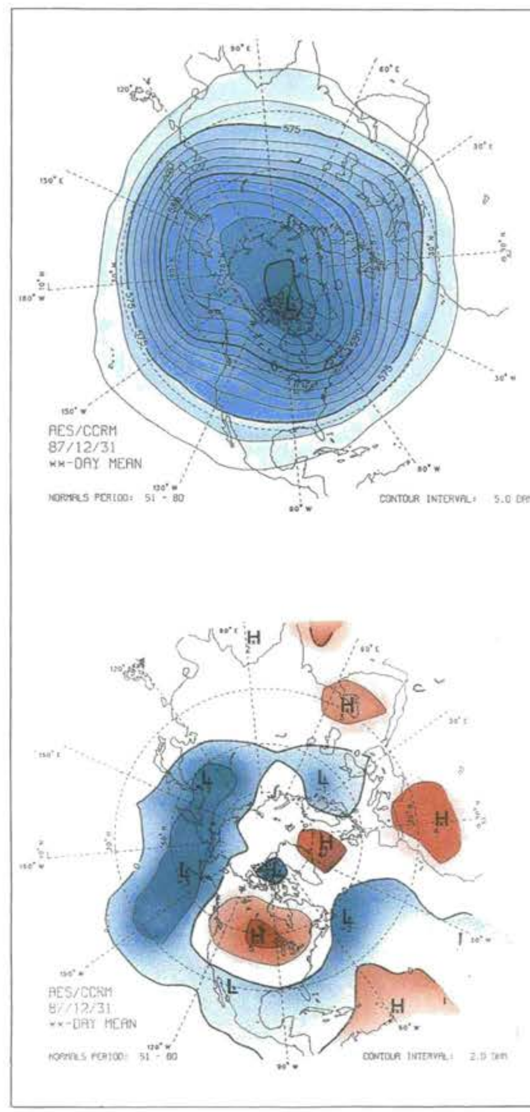


Figure 15

a) Top: 500-hPa geopotential height field, 365-day mean for 1987 contour interval is 5.0 decametres. b) Bottom: 500-hPa geopotential height anomaly field. Base period is 1951-80. Contour interval is 2.0 decametres

(from the Canadian Climate Centre, Toronto, Ontario).

5 MAJOR DROUGHTS PLAGUE FOOD-PRODUCING AREAS

Drought is an abstract phenomenon - a non event in sharp contrast to a distinct recognisable event like a flood. Different disciplines have different notions as to what constitutes a drought, be it agricultural, hydrological or meteorological. Though drought is a physical phenomenon, it is very difficult to define or quantify. No wonder attempts made in this direction (Mooley and Parthasarthy, 1983, Chowdhury et al. 1989 etc.) have met with little success.

Severe drought afflicted several parts of the world's agricultural areas during the 1986 to 1988 period. The droughts were largely regional in nature and had different characteristics and histories. In early 1988, rapidly deteriorating climatic conditions in North America merged several regional drought areas to form a near-record continental-scale drought that stretched from the southeastern United States, across southern Canada, to the west coast of North America.

5.1 North America

The southeastern United States was plagued by persistent drought throughout most of the review period. The dry conditions began locally as early as late 1984 but reached a region-wide peak of severity during the summer of 1986. Large parts of Georgia, Tennessee, and the Carolinas had less than half of their normal precipitation from mid-spring to mid-summer 1986. This was due to the frontal systems of spring and convective activity of summer being weaker than normal, with an upper-level anticyclone predominating over the region. Agricultural and other losses were estimated by several U.S. federal agencies to be several hundreds of millions of dollars. Historical rainfall for this area indicates that the 1986 drought was probably the worst southeast drought in at least 109 years (*see Figure 16*). Rains beginning in August 1986 eased the drought but did not end it.

Another drought-affected area was the west coast of North America. Rainfall along the west coast is highly seasonal, with most of the annual precipitation occurring during the October through April period. The rainy seasons of 1985-86 through 1987-88 were consistently dry in this area (*Figure 17*) due to persistent upper-level ridging. Massive forest fires and acute water shortages developed in 1987. Nearly 51,000 fires burned about two million acres by mid-September in Idaho, Washington, Oregon, and California. The longest dry period since at least 1909 occurred in Yakima, Washington, with 103 consecutive days without measureable precipitation. The September mean flow of the Columbia River in Oregon was the lowest in 108 years of record.

Drought was intensifying in several parts of North America near the end of 1987. British Columbia and the western Canadian provinces reported dry conditions beginning in September. Conditions worsened again in the southeastern United States in the autumn, causing the region's most destructive autumn forest fires since 1964. The winter of 1987-88 was dry in the northern Plains of the United States and southern plains of Canada in addition

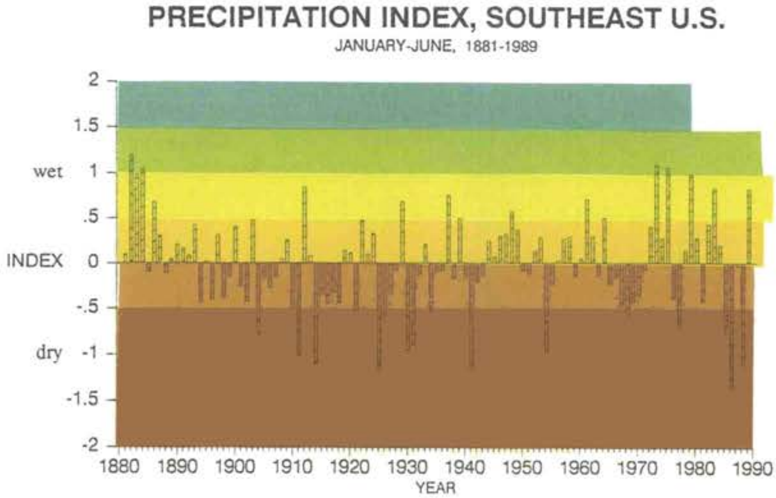


Figure 16

Total precipitation for the January through June period for the southeastern United States (30 to 40 degrees north latitude, 73 to 92 degrees west longitude), from 1881 to 1989. The precipitation for a total of 46 climate stations was standardized for comparison, then the standardized values were averaged to determine the regional precipitation. Bars that extend above the zero line indicate wetter-than-average years, whereas bars that extend below indicate relatively dry years. Record drought occurred in 1986

(from NCDC, Asheville,NC, USA).

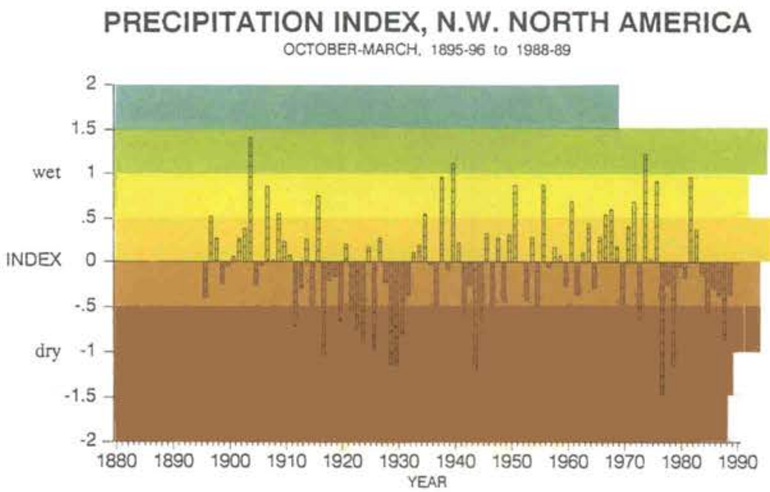


Figure 17

Total precipitation for the October through March period for the west coast of North America (40 to 55 degrees north latitude, 120 to 130 degrees west longitude), from 1895-96 to 1988-89. The precipitation for a total of 24 climate stations was standardized and averaged. The 1986-87 and 1987-88 droughts were major back-to-back droughts, but they were not as severe as the 1976-77 to 1978-79 dry episode

(from NCDC, Asheville, NC,

to the west coast of North America. The stage was set for a drought disaster as 1988 began.

Record dry conditions occurred during April to June in 1988, rapidly expanding the regional dry areas and merging them into a continental drought that rivaled the Great Droughts of the 1930's and 1950's in terms of size and intensity. Large areas in the United States and Canada had less than half of their normal rainfall during this period (*Figure 18*). April through June 1988 was the driest such period in at least 103 years for central North America (*Figure 19*). Many dug-outs, sloughs, and shallow lakes in the southern Canadian Prairies dried up completely. The dry area expanded into southern Ontario, causing water restriction and conservation measures to be imposed in June. Toronto, Ontario observed the second driest May-June period in 148 years of record.

Major agricultural problems were caused by the dryness during the first half of the growing season (April-June). The growth of crops, especially corn, in Ontario was notably stunted. The Ontario drought caused a 30 percent reduction in corn, soybean, and spring wheat yields when compared to 1987 yields. Wheat yields on the Canadian prairies dropped to 64% of normal. In the United States, coarse grain yields were about 36 percent lower than in 1987, and wheat yields some 14 percent lower.

The 1988 drought conditions contributed to major forest fires in northwestern Ontario and central Alberta. Ontario experienced one of the worst forest fire years since 1917. Wind erosion ravaged many Canadian farms, particularly in southern Alberta, and a large number of small communities and farms had to make arrangements to transport water to meet their normal needs.

The Mississippi River, which is the primary river system in the United States, had the lowest river levels since the 1930's. At Memphis, Tennessee, the river level was the lowest (3.1 m below normal) since records began in 1872. Barge and towboat traffic was restricted along the lower Mississippi and hydroelectric power generating companies experienced difficulty due to the low river levels.

Several researchers have related the 1988 North American drought to anomalous sea surface temperature (SST) conditions in the tropical Pacific Ocean. Below average SST's along the equator in the northern spring of 1988, combined with warmer than normal water from 10 to 20 degrees north (*see Figure 30*), led to a northward displaced but still active intertropical convergence zone (ITCZ) southeast of Hawaii. Their study (Trenberth, et. al., 1988) indicates that this displaced ITCZ and its associated heating anomalies forced a planetary wavetrain across North America, consisting of strong anticyclonic conditions and a northward displaced jet stream.

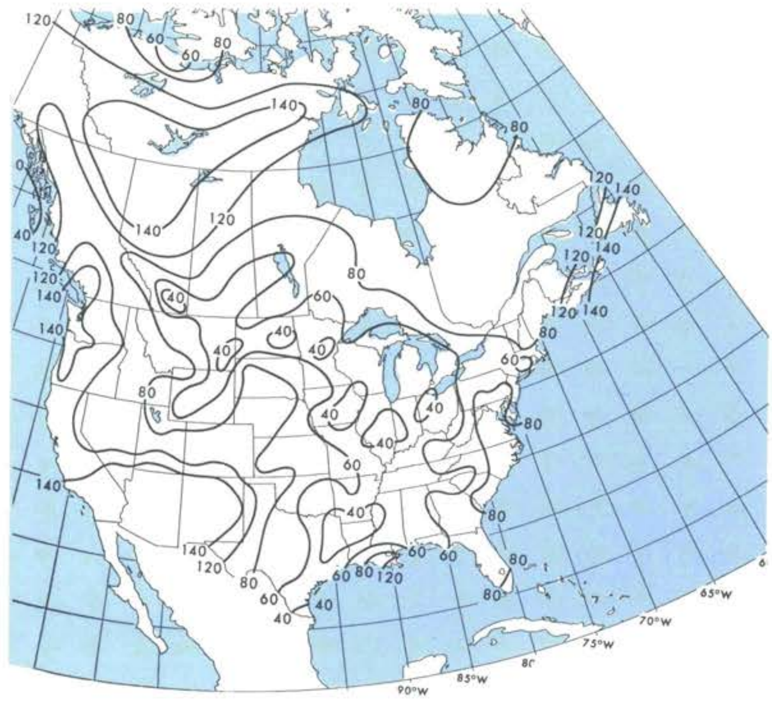


Figure 18

Large areas in Canada and the United States received less than 60% of their normal (1951-80) rainfall during April to June 1988. Extremely wet regions are indicated in green and extremely dry in yellow and brown

(from NCDC, Asheville, NC, USA).

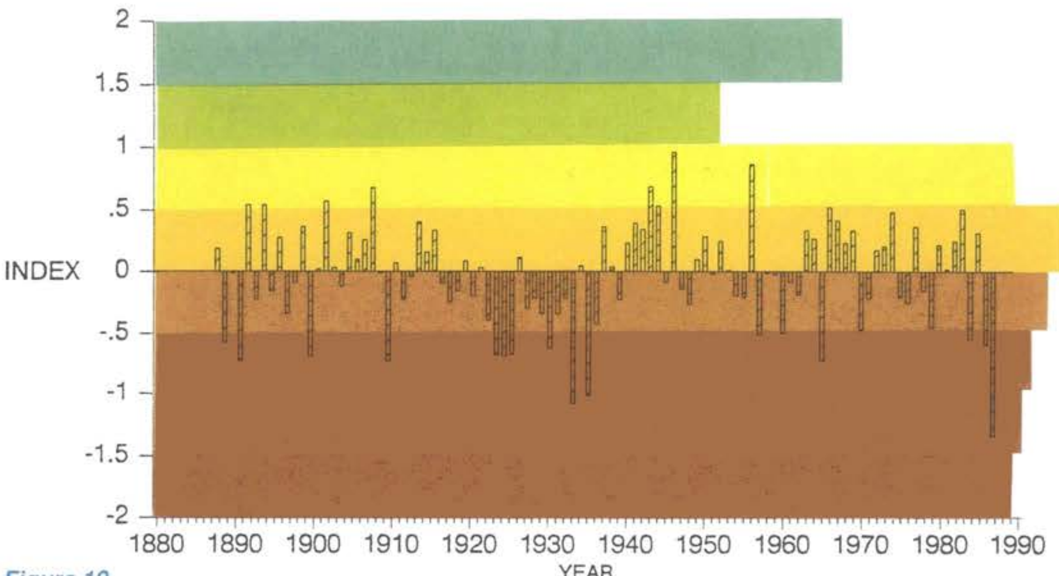


Figure 19

Total precipitation for the April through June period for the northern Plains of the United States, southern Canadian prairies, and Great Lakes region (central North America, 40 to 55 degrees north latitude, 80 to 115 degrees west longitude), from 1886 to 1988. The precipitation for a total of 63 climate stations was standardized and averaged, as before. The 1988 drought produced the driest April-June period in the last 103 years in this region

(from NCDC, Asheville, NC, USA).

The drought conditions in the northern United States and the Canadian prairies were aggravated by a scorching heat wave. Many all-time record high temperatures were set during the summer of 1988. Several locations in the southern prairies of Canada and northern plains of the United States experienced their warmest summer on record.

The drought peaked in mid-summer. About 40 percent of the contiguous United States reached the severe drought category, making 1988 comparable to the extensive 1976-77 drought, but not as big as the droughts of the 1930's (the worst drought decade) and 1950's (second worst drought decade). The drought in the Canadian prairies was comparable to, but not worse than, the previous major drought years of 1936, 1937, 1961, and 1984.

Rainfall, starting in mid-July, brought relief to most of Canada and much of the eastern United States. However, drought conditions continued in parts of the central and western United States, with wildfires plaguing much of the northern Rockies in August. Rainfall in October along much of the west coast was below normal, threatening to bring yet another dry rainy season to that area.

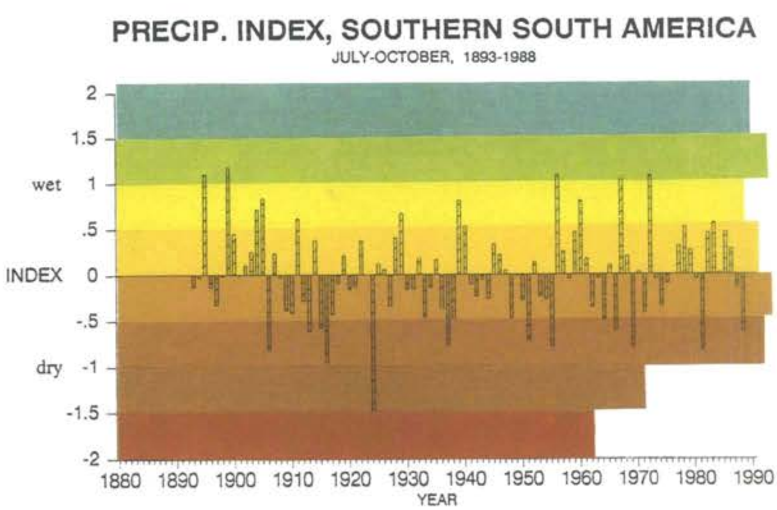


Figure 21

Total rainfall for the July through October period for southeastern South America (18 to 35 degrees south latitude, 38 to 65 degrees west longitude), from 1893 to 1988. The precipitation for a total of 46 climate stations was standardized and averaged, as before. Although severe, the 1988 drought was not as extreme as several droughts in the past

(from NCDC, Asheville, NC, USA)

5.2 South America

Autumn (March-May) 1986 began with long-term moisture conditions well-below normal in large areas of southern Brazil, Paraguay, and extreme northeastern Argentina. The widespread drought conditions had generally ended by winter.

Anomalously dry conditions returned to the region in mid-1988. Large areas in northern Argentina, Uruguay, Paraguay,

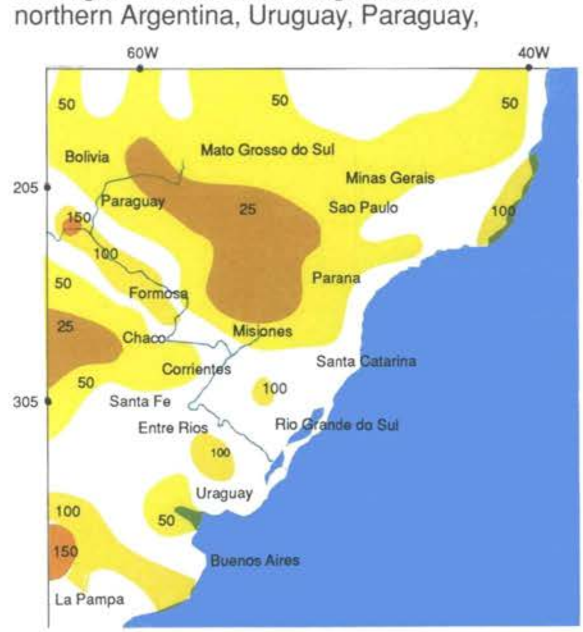


Figure 20

Drought affected large areas in South America in 1988. Parts of northern Argentina, Uruguay, Paraguay, southeastern Bolivia, and southern Brazil received less than 50% of their normal rainfall during July to October

(from CAC, Washington, D.C.).

southeastern Bolivia, and southern Brazil received less than half of their normal rainfall during July-October (*Figure 20*). Winter drought in Argentina cut the country's wheat output by roughly 18 percent. Although severe, the drought conditions in southeastern South America were not the driest that have occurred (*Figure 21*).

5.3 Australia

The period, June 1986 to December 1988, included the 1986-87 El Niño episode. In contrast with the 1982-83 El Niño, the 1986-87 episode was not associated with major widespread drought in eastern Australia. Rainfall in 1987 over inland eastern Australia was characterised by more frequent dry spells than in 1986 and 1988, but a few relatively short wet periods (notably in March, June, August and December of 1987) were generally sufficient to overcome deficiencies (*see Figure 22*).

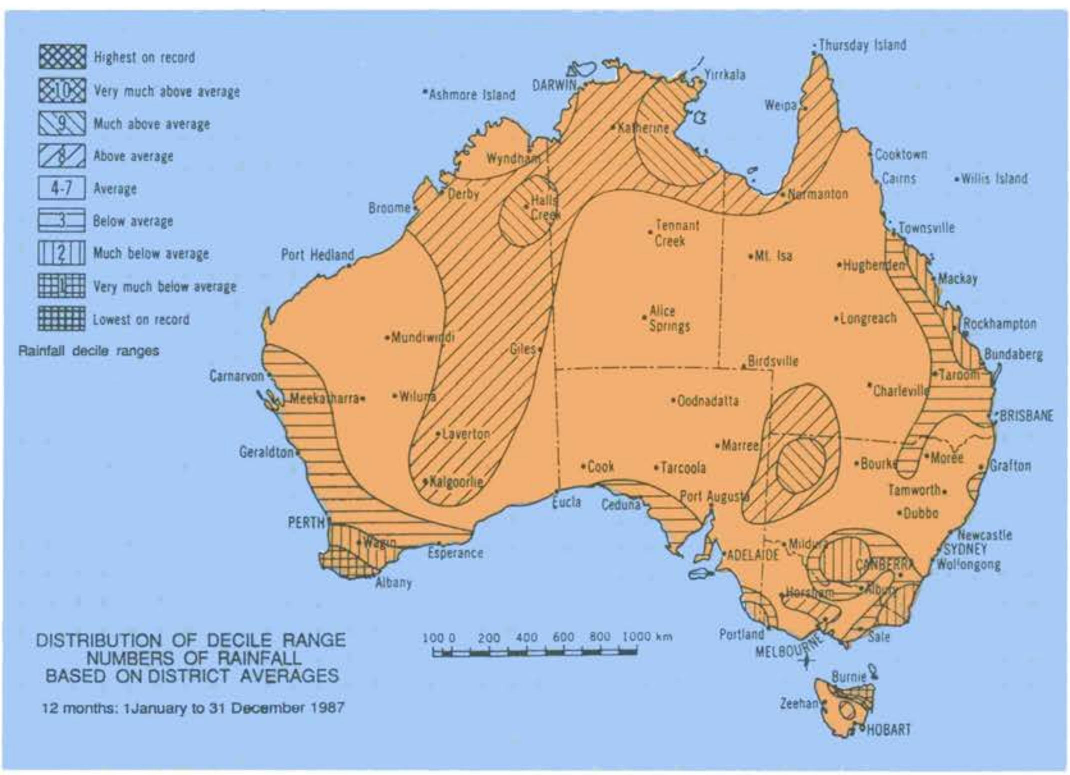


Figure 22

Distribution of decile range numbers of rainfall based on district averages over the 12-month period 1 January to 31 December 1987

(National Climate Centre, Melbourne, Australia).

Droughts in Australia during the 1986-87 El Niño based on pastoral rainfall deficiency were relatively small and scattered. The two main drought-affected areas during June 1986 to December 1988 were Tasmania and parts of South Australia as indicated in *Figure 22*.

In Tasmania, severe regional drought occurred over most of that state, with some areas registering lowest rainfall on record for the 15 months February 1987 to April 1988 inclusive. The drought was virtually broken with rains in May 1988.

In South Australia there was regional drought in the south of the state with record low rainfall for the 14 months August 1987 to September 1988. In localized areas, deficiencies continued into 1989, persisting for over two years.

5.4 Mediterranean Basin

Normally, most of southern Europe and the northern coast of Africa receives the majority of their annual precipitation during the autumn and winter months. During the September to November periods in 1986 and 1988, rainfall was significantly below-normal in some areas, resulting in serious drought conditions in the southern European Mediterranean Basin by the end of 1988. Drought conditions in Italy were considered extremely serious. The time series graph shown in *Figure 23* uses the Standardized Anomaly Index (SAI) for a group of Italian stations dating back to 1813. The value of the SAI less than -.85 was used as the determination of drought. As can be seen from the graph, the current drought is one of the 14 that have occurred since 1813. The intensity of this drought can be compared with the others.

Figure 23

Standardized Anomaly Index (SAI) for precipitation at a consistent group of Italian Station

(Climate Unit of the Italian Meteorological Service)

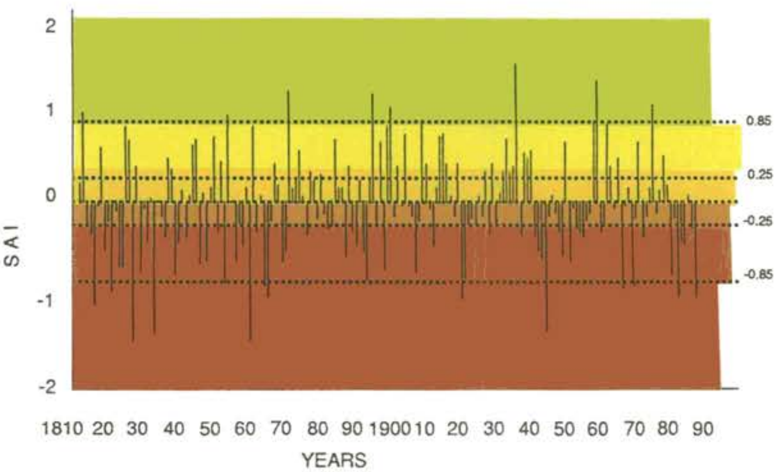
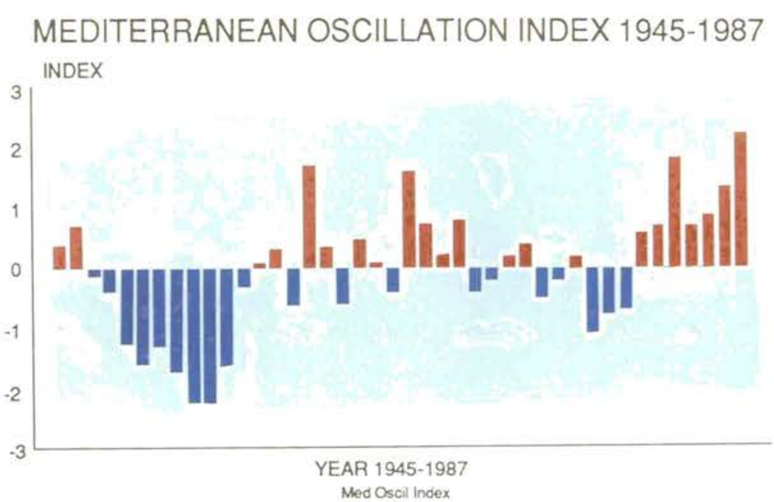


Figure 24

The Mediterranean Oscillation Index is defined as the Alger minus Cairo 500 hPa geopotential height difference anomaly. Values have been standardized by dividing the annual anomalies by their long-term standard deviation

(M. Conte - Italian Meteorological Service).



This drought could be related to a recent trend towards higher upper atmospheric heights and surface pressure in the western Mediterannean. The Italian Meteorological Service has defined the Mediterranean Oscillation Index (MOI) as being the difference between the 500 hPa height anomalies at Algers and Cairo. The time series graph in *Figure 24* depicts the oscillation in this index since 1946 which shows an apparent cycle of about 22 years. Taking into account the oscillation and the positive trend at Algers gives an indication that a cell of the subtropical anticyclone is slowly invading the western and central Mediterranean.

5.5 India

According to Bhatia (1967) some of the worst drought and famines occurred in ancient India. Systematic rainfall records are available from a large number of observatories in India since 1875. Figure 25 depicts droughts which have occurred over India since 1875. With reference to rainfall deficiency, the five worst droughts were 1877 (-51%), 1897 (-27%), 1918 (-26%), 1972 (-25%) and 1987 (-19%). But with respect to the area of the country receiving deficient rainfall, the worst droughts in decreasing order of intensity were 1918, 1899, 1877, 1987 and 1972, the area affected being respectively 69%, 51%, 32%, 29% and 28%.

Thus in recent years, the monsoon failure during 1987 is one of the worst on record in India. Rains failed on a vast scale in India, particularly in the northwest.

Important features of the rainfall anomalies observed during 1987 were:

* 20% or more rainfall in a few sub-divisions in NE India

* 20% or less rainfall in most of thezones

* 20% or less in nearly the whole of NW India.

The following factors, either individually or in combination probably caused the large-scale drought in 1987.

* positive pressure anomalies over most parts of India

* weak surface heat low-over Baluchistan (Pakistan)

* weak cross equatorial flow in the lower troposhpere

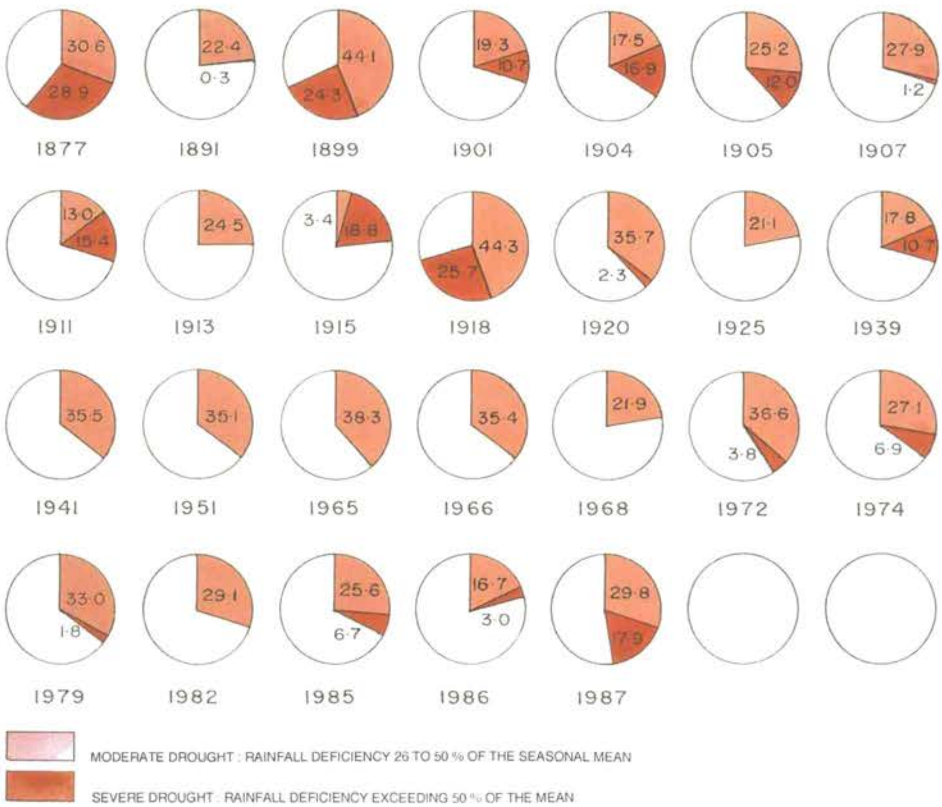


Figure 25

Pie diagram showing area under drought in India since 1875. Sections with the coloured portions indicate the percentage of India affected by drought. Note: there was no significant areas of drought during the 1988 monsoon season

(India Meteorological Department).

* non-formation of storms over south China during June-July and their abnormal tracks over NW Pacific

* a "blocking high" type situation in mid-latitude region west of India with a pronounced ridge along 40-60˚E and

* persistence of ENSO phenomenon which reached its peak in June-July 1987.

5.6 China

The interannual variability of the monsoon of east China led to serious drought conditions, particularly in 1986 and 1987 when the monsoon was weaker than normal. In 1986, there were significant deficiencies of rain over large areas, including Inner Mongolia, the mid - south part of north China, the upper reaches of the Huaihe River Valley and in the southern provinces of Zhejiang, Jiangsi and Fujian. In 1987, drought conditions persisted over most portions of north China and the southeast provinces (*see Figure 26*). In north China, 9.47 million hectares of farmland were damaged by the drought. In 1988, there were again significant deficiencies of summer rains in the southeast provinces while the previously dry areas of north - central China received above-normal rainfall.

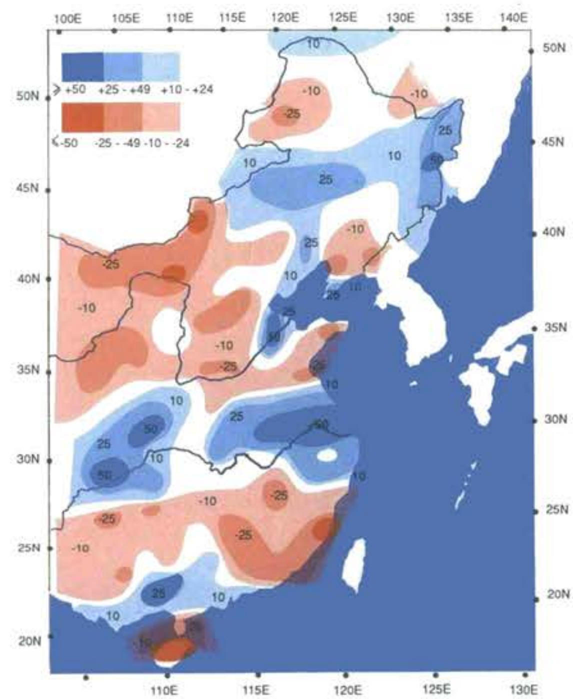


Figure 26

Percent of normal (1951-80) precipitation anomalies for the 1987 summer rainfall in east China

(Xu from the Meteorological Monthly, 1987).

5.7 Philippines

Much of the Philippine archipelago experienced persistently below-normal precipitation over the approximate period November 1986 through March 1987 which led to the development of moderate to severe drought conditions in several areas. The drought was most severe in those areas that normally receive heavy rainfall during the northeast monsoon, which prevails from November through March. The rainfall deficiency in the Philippines was believed to be related to the presence of ENSO conditions in the Pacific basin and the consequent disturbance of normal atmospheric circulation patterns (see Figure 27).

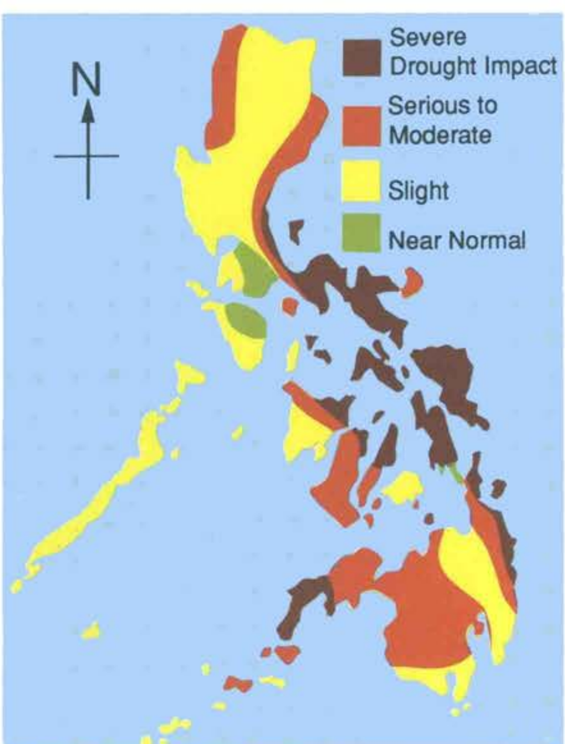


Figure 27

Map showing the extent of the drought conditions of 1987 in the Philippines

(Philippine Atmospheric, Geophysical and Astronomical Services Administration).

6 NEAR-NORMAL RAINFALL FINALLY RETURNS TO THE SAHEL IN 1988

6.1 Sahel rains in 1987 and 1988

The severe drought affecting the Sahel and surrounding zones intensified slightly in 1987, which was among the driest years in the Sahel this century (*Figure 28*), ranking close to 1972-3 and 1982 though not as extreme as 1983 and 1984. Rainfall in June 1987 was patchy, with some stations recording over twice the normal and others less than half. July, however, brought less than half the normal rainfall over virtually the entire Sahel, with more severe drought in the east. In August, which is climatologically the wettest month, rainfall was very sparse throughout the Sahel, with many central areas receiving under 25% of normal, and only isolated localities in Ethiopia and Senegal having substantial relief from the drought. September 1987 followed much the same pattern as August, but with somewhat higher percentages of normal rainfall especially in parts of Senegal and Mauritania.

1988 saw a substantial relaxation of the Sahel drought. For the Sahel as a whole, the rainy season was the wettest since 1969 (*Figure 28*) but the rainfall still averaged slightly below the long-term normal. As in 1987, June saw sporadic rains. July was generally drier than normal, but August brought widespread, plentiful rains throughout most of the Sahel. The severe flooding in Khartoum in early August was caused by local heavy rainfall combined with heavy falls in the Ethiopian highlands, which are outside the Sahel. September 1988 was also moist in many, but not all, parts of the Sahel.

The contrast in Sahel rainfall between 1987 and 1988 was associated with:

* a fall of surface temperature from about 2°C above normal to near normal, probably because of reduced insolation and increased evaporation;

* a change from generally positive to generally negative anomalies of outgoing longwave radiation, as a result of increased cover of convective cloud;

* a weakening of the west African mid-tropospheric easterly jet stream over and to the south of the Sahel, possibly as a result of the above-mentioned changes of surface heating in the region; and

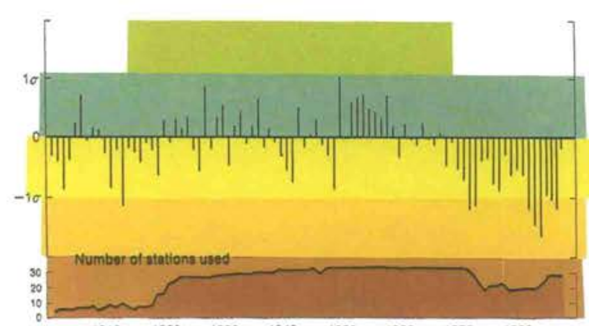


Figure 28

Standardized annual rainfall anomalies for the Sahel, 1901-88. Values up to 1984 are after Nicholson (1985); 1985-88 are estimates from CLIMAT reports and national publications.

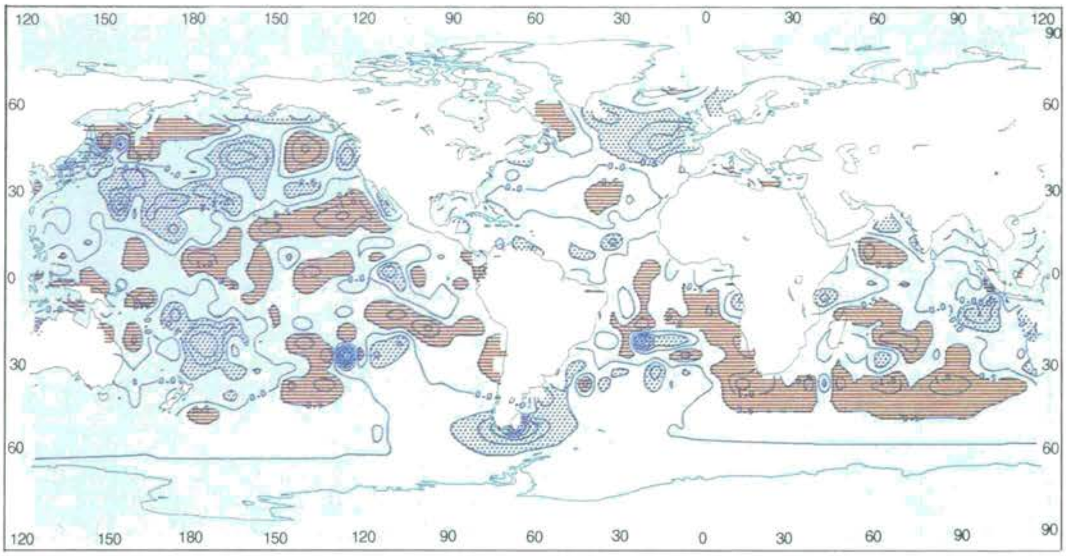


Figure 29

Sea-surface temperature anomalies for August 1986. Contours are at 0, ±0.5, 1.0 and 2.0°C. Values to the south of 45°S should be ignored since there are no data in this region

(Meteorological Office, Bracknell, UK).

* replacement of westerly or southwesterly anomalies of 200-hPa winds by mainly southeasterly anomalies.

These atmospheric circulation changes are in agreement with previous observational and numerical modelling studies (e.g. Newell and Kidson, 1984; Owen and Folland, 1988).

6.2 Relating the Sahelian drought conditions to changing sea-surface temperature anomalies, 1986-88

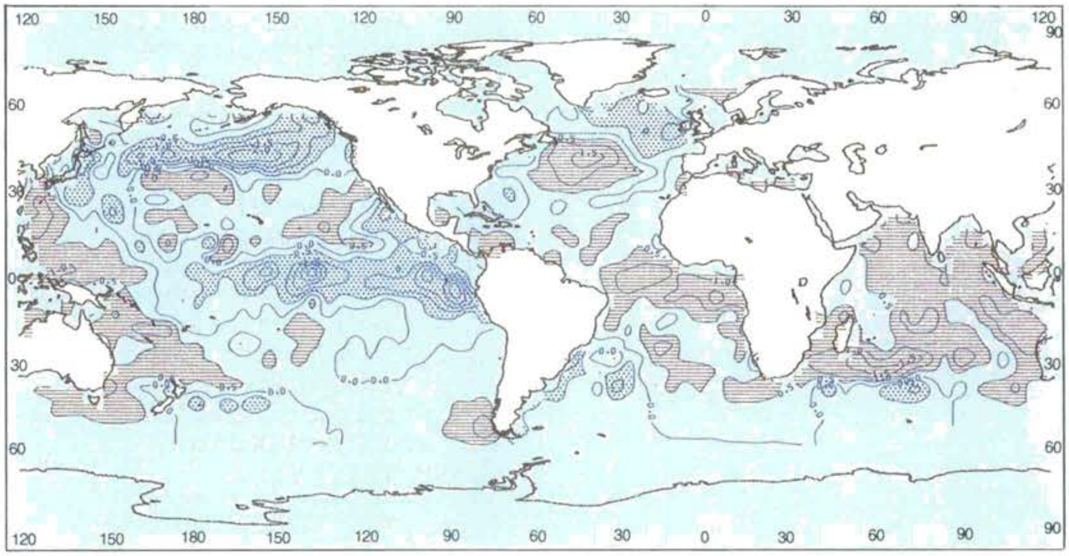
As has already been discussed in Section 3, the period 1986-88 brought the second major El Niño-Southern Oscillation event of the 1980's. Sea- surface temperature (SST) anomalies for August 1986 (*Figure 29*), at an early stage of this event, show warmth in much but not all of the central and eastern tropical Pacific. The combination of warmth in the Indian Ocean and the south Atlantic, and coldness in the north Atlantic and north Pacific, apparent in *Figure 29*, has been associated with drought in sub-Saharan Africa in both empirical and numerical-modelling studies (Folland et. al, 1986; Owen and Folland, 1988). 1986 was a severe drought year in the Sahel (*Figure 28*). The slight intensification of the Sahel drought in 1987 was accompanied by persistence of this pattern of SST anomalies, the major difference being the greater warmth in the eastern tropical Pacific as the El Niño reached maturity. There is a slight tendency for El Niño to be accompanied by reduced Sahel rainfall (Palmer, 1986; Parker et al, 1988).

Around June 1988, cold 'La Niña' conditions developed rapidly in the eastern tropical Pacific (*Figure 30*). At the same time, there was warming in much of the sub-tropical north Atlantic, and cooling in the sub-tropical south Atlantic, relative to climatology. The former warming was associated with a combination of anti-cyclonic conditions and southerly flow in the overlying atmosphere. The development of La Niña and the weakening of the south Atlantic-north Atlantic contrast of SST anomalies is likely to have resulted in the relaxation of the drought in sub-Saharan Africa (Parker et. al, 1988).

Figure 30

Sea-surface temperature anomalies for July/August 1988. Contours are at 0, ±0.5, 1.0 and 2.0°C. Values to the south of 45°S should be ignored since there are no data in this region

(Meteorological Office, Bracknell, UK).



7 DRAMATIC FAILURE OF THE INDIAN MONSOON IN 1987, BUT AMPLE RAINS RETURN IN 1988 WHILE VARIABLE CONDITIONS OCCUR IN OTHER MONSOON AREAS

The name 'monsoon' has traditionally been used to describe both the phenomenon of rains and the southwesterly surface winds which prevail during summer over India and neighbouring regions. However, monsoon like conditions also occur over eastern China and east Africa. In the meteorological jargon, monsoon has come to mean the seasonal reversal of wind defined by Ramage (1971) as follows:

* the prevailing wind direction shifts by at least 120° between January and July;

* the average frequency of prevailing wind direction in January and July exceeds 40%; and

* the mean resultant winds in at least one of the months exceed $3ms^{-1}$.

7.1 India

The summer monsoon (June-September) of south Asia is a unique phenomenon in itself. After the torrid heat of April and May, it brings welcome relief to the people, with temperatures dropping from 40-45°C to 25-30°C. The monsoon rains constitute the greatest climatic resource of India and is also an important source for hydro-power generation. Any large anomaly from long-term climatic normal monsoon conditions upsets the economies of the south Asian countries.

Some of the principal factors controlling the monsoon circulation are the "heat-low" over the Baluchistan region of Pakistan, the pressure gradient over the Indian peninsula, the low level flow pattern, the location of the monsoon trough, monsoon depressions, the strength of cross-equatorial flow and the sea-surface temperature over surrounding sea areas.

Figure 31

Delay in Monsoon Advance (in days) during 1987

(India Meteorological Department).

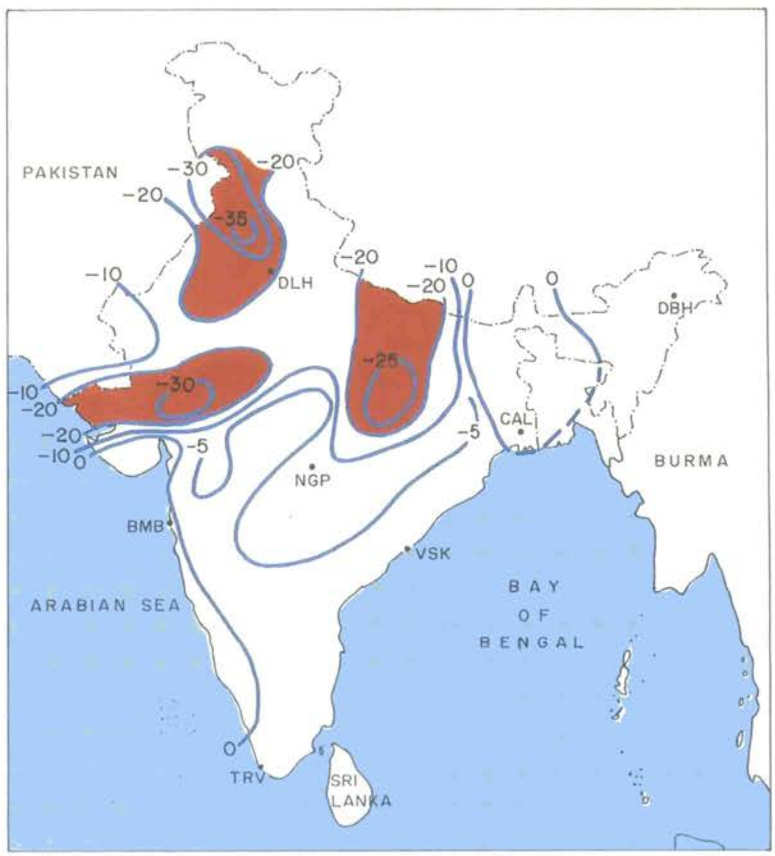


FIG. 1. DELAY IN MONSOON ADVANCE (IN DAYS) DURING 1987.

DELAY OF 20 DAYS OR MORE

The three monsoon seasons in the period under review (1986-88) witnessed some spectacular swings from a markedly dry to excessively moist monsoon regimes particularly over India.

In 1986, most parts of India experienced a delay in the onset of the monsoon by 4-5 days while it withdrew generally around the normal date. During the summer of 1987, the advance of the monsoon was, by and large, as per climatic average over southern parts of India, but its northward march was abnormally arrested. In some parts of northwest India, it was as much as 30-35 days behind schedule (Figure 31). In contrast, the monsoon retreated approximately by the normal date, thus restricting the total length of the monsoon season. The number of meteorological sub-divisions receiving sub-normal rainfall was 30 out of 35. In 1986, there were 31 climatic divisions that received below-normal monsoon rains, but the deficiencies in 1987 were more intense with many parts, particularly in northwestern India, receiving just a third of the normal precipitation. Also, whereas in 1986, the average rainfall for India as a whole was 768 mm (against a 1871-1978 climatic normal of 853 mm), it plummeted to 707 mm in 1987. In recent years, the monsoon failure during 1987 was one of the worst on record in India.

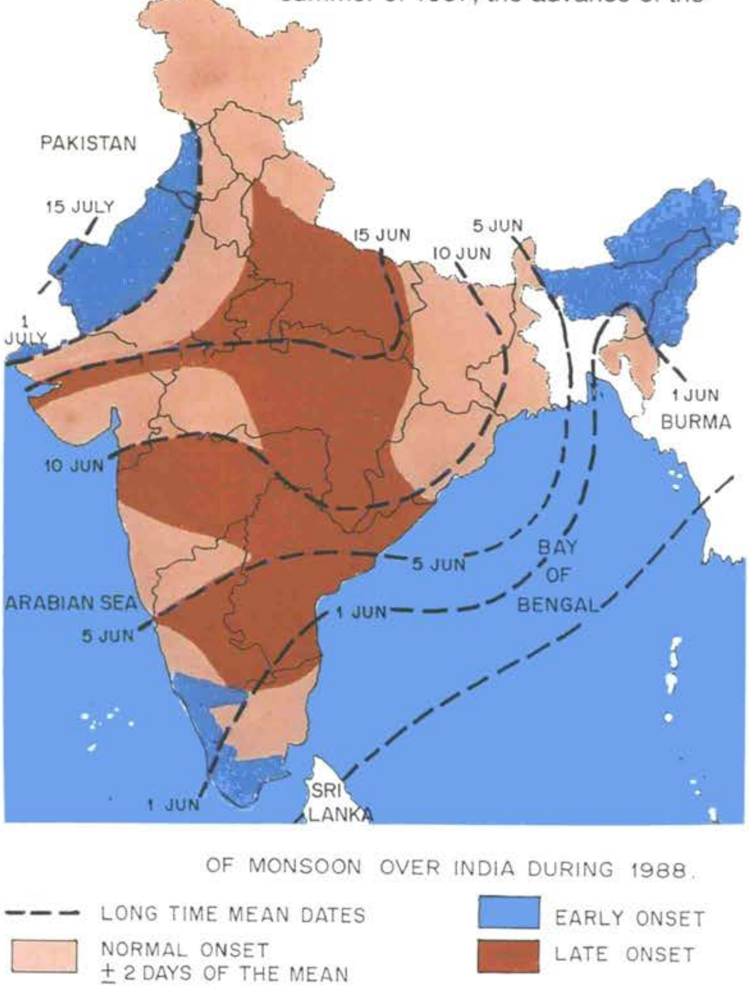


Figure 32

Composite chart showing progress of the monsoon over India during 1988

(India Meteorological Department).

In sharp contrast to the extreme dryness experienced by northwest and peninsular India, NE India and adjoining areas of Bangladesh witnessed extreme wetness. In India, some such areas received 125-140% of the June-September normal.

In contrast to the poor monsoon rains in 1986 and 1987, most of India experienced above-normal monsoon

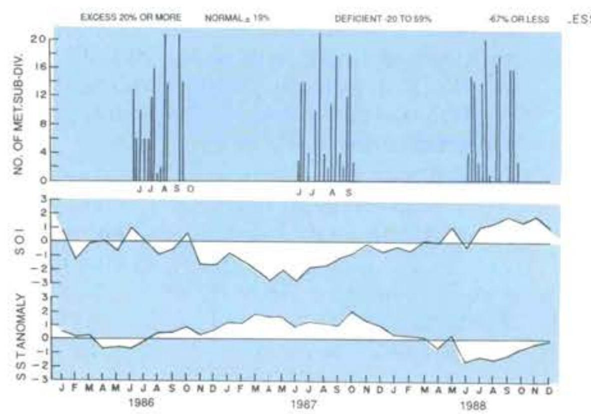


Figure 33

Monthly progress of the SST anomaly the central Pacific Ocean, the SOI and seasonal anomalies of rainfall in India indicated by the number of subdivisions receiving different amounts

(India Meteorological Department).

rains in 1988. The first surge of the monsoon arrived appreciably early over the southern tip of India but subsequently, over central India, the northward march was slightly delayed. However, over the Thar desert and adjoining areas it arrived earlier than normal (Figure 32). The withdrawal was near normal over central and northwest India and early over peninsular and northeast India. Thus, in spite of the somewhat shorter duration of the monsoon over some parts, the overall average rainfall for India was quite large at 1018 mm. Only some parts in northwest India received below-normal rainfall.

Sir Gilbert Walker (1923) was the first to hypothesize that the abnormalities in monsoon over India may be associated with the anomalous circulation in the Pacific, now known as El Niño/Southern Oscillation (ENSO) phenomenon. Sarker (1988) found that intense El Niño episodes have concurrent relationship with deficient monsoon rainfall over India on 60% occasions. Figure 33 depicts the association of rainfall with SST anomalies over the equatorial Pacific and the Southern Oscillation Index (SOI). Though the association appears weak in 1986, there is a stronger relationship between the low ENSO index and poor rainfall in 1987. There also seems to be a relationship between the high SOI index and the abundant monsoon rainfall in 1988.

7.2 East China

The summer "monsoon" of east China (east of 110°E) is generally characterized by a seasonal northward movement of a monsoon like rainy belt from May to August. It has some resemblance to the progress of the Indian monsoon in that they are both moving gradually northward from May to July. Climatologically, the northward progression takes place in three stages.

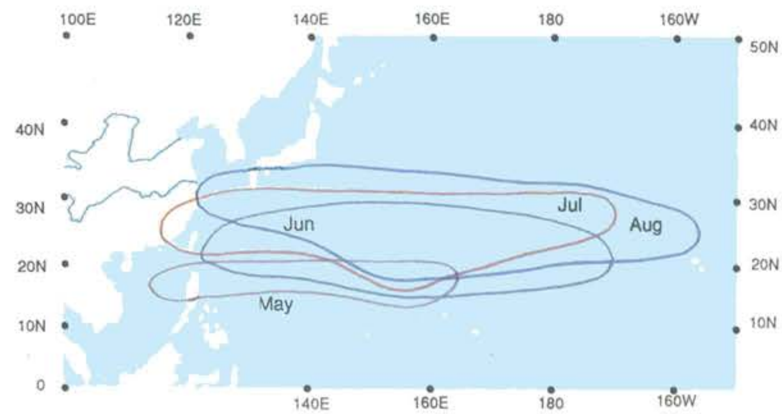


Figure 34

Mean monthly positions of the west Pacific High based on the averaged position of the 5880 geopotential-metre contour from 1951-80

(Xu Qun, data from the Central Meteorological Observatory of China).

First, the axis of rainy belt is located in south China (23 - 26°N) from May to early June. In about mid-June, it moves northward and stays in the mid - lower Changjiang and Huaihe valley. This is the so-called "plum rain (Meiyu)". By mid-July, it reaches its most northerly extent (36-41°N) where it remains until mid-August. The rainy season thus appears once a year in the north and the northeast of China. After mid-August or early September, the rainy belt rapidly retreats southward.

This seasonal meridional movement of the east China monsoon is directly influenced by the seasonal displacement of the west Pacific High (at the 500-hpa level) which generally moves northward from spring to mid summer (Figure 34). Actually, there are two branches of the rainy belt located on the north and south sides of the west Pacific High. The north branch is caused by the convergence of southwest warm moist air from the Bay of Bengal and the cold air from the westerlies. The southern branch is located on the southern side of the High with precipitation being caused by the Inter-Tropical Convergence Zone or tropical waves in the easterlies.

During the summer portion of the year, the northern branch plays a more important and active role both in seasonal and interannual change. This is the principle difference between the summer

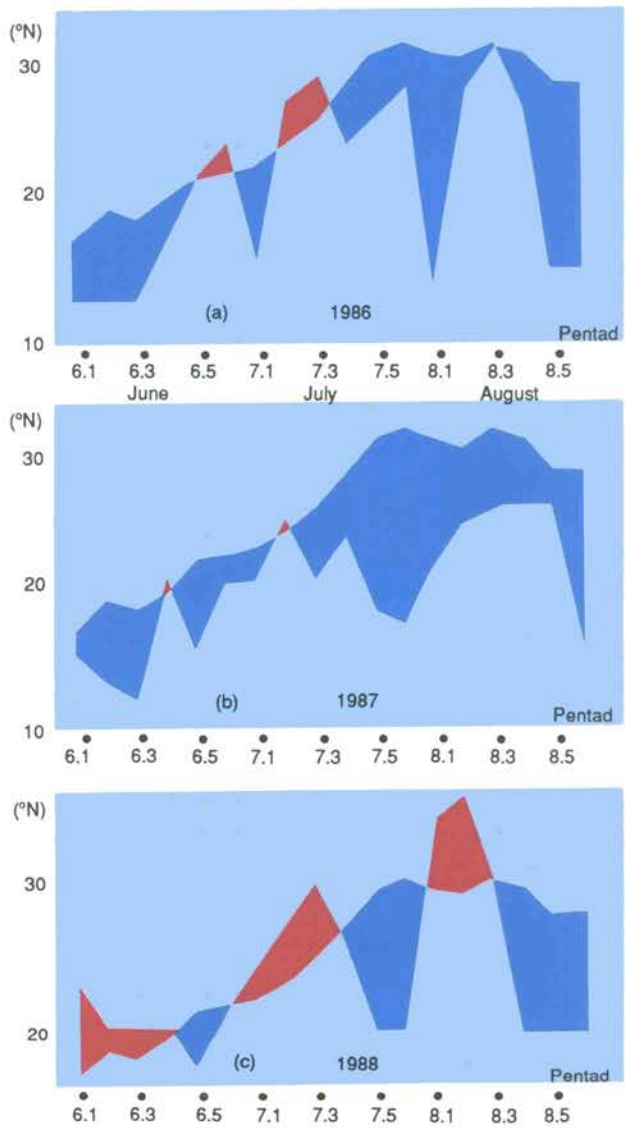


Figure 35

Latitudinal variation of the summer position mean of the central ridge line of the west Pacific High (at 500-hpa level) in a section between 110-130°E during summer 1986(a), 1987(b) and 1988(c). The broken line is the normal position based on averages from 1965-1982

(Xu Qun, data from the Central Meteorological Observatory of China).

monsoon of China and India. The latter, like the southern branch in China, normally occurs at the southern side of the subtropical High (Tibetan).

Owing to the large interannual variation of the west Pacific High, the main (northern) branch of east-China monsoon changes greatly from year to year. The maximum difference between the ending dates of the plum rains has been as great as 1.5 months (Xu, 1965). The earliest was in 1961 and latest in 1954.

The summer monsoon of 1986 in east China was weaker than normal, due to the fact that the west Pacific High was further south than normal during most weeks of summer (Figure 35a) and its strength was also significantly weaker during one third of the weeks of this summer. The result was a large area of summer drought in the central areas (between 33° and 40°N) in which rains in many places were less than 50% of normal. However, just to the south, the plum rains were not deficient in contrast with the larger area of drought to the north.

The monsoon of the 1987 summer in east China was also weaker than normal as the ridge line of the west Pacific High remained in a more southerly location than normal during most weeks of the summer (Figure 35b). This anomalous subtropical circulation resulted in less monsoon rains in the whole of southeast China during June and a delayed onset (1 July) of the plum rains in mid - lower Changjiang. However, the plum rains lasted until the end of July, resulting in large areas of the Huaihe valley (32 - 34°N, east of 113°E) and mid - lower Changjiang becoming waterlogged. In contrast, persistent drought occurred over most portions of north China and the southeast provinces.

In 1988, a strong monsoon prevailed over east China during the summer in contrast with the same season of 1986 and 1987. The location of the west Pacific High was more northward during most weeks of this summer (Figure 35c). After the end of plum rain on June 23rd (earlier than normal by about half a month), the monsoon rain belt seasonally shifted to the north of China in early July (earlier than normal by half a month, where it persisted.) So, for the first time since 1979, north China received abundant rain in the high summer, while severe flooding also occurred in the center of the northeast China and Guangxi province.

The strong summer monsoon of 1988 was also manifested in the strength of the west Pacific High, which resulted in abnormally high temperatures in middle and south China. In some areas, temperatures reached 41 - 42°C with more than 20 counties recording new daily high temperature records.

7.3 East Africa

Within the period 1986-1988, most of East Africa received near and above-normal rainfall during the major rainfall seasons (March-May and September-November). The only exceptional period was September-November 1987 when some parts of the central and northeastern regions, together with the coastal areas, were quite dry. The dry conditions were associated with the late onset of the northeast monsoonal wind systems.

One of the physical factors which can be used to explain the observed anomalies in the characteristics of the monsoonal wind systems include the positive SST anomalies which dominated part of the Arabian Sea region during this period (*see Figures 29 and 30*). Positive SST anomalies over this region reduce the intensity of the Arabian sub-tropical anticyclone and interfere with the normal flow of the East African monsoonal wind systems.

Although June-July is generally dry over many parts of East Africa, the western parts come under the influence of moisture incursions from the large lakes nearby and the Atlantic Ocean. Above and near-normal rainfall was recorded at most of these locations during 1986-1988. In fact, the most extreme rainfall events in the June-July period were the extreme wet conditions which extended over most of the western areas in 1988 (*see Figure 62*). The resulting flooding conditions extended north into Sudan and Ethiopia. It has been found (Ogallo, 1988) that the correlation between June-August rainfall over western Kenya and the Southern Oscillation Indices (SOI) is about 0.5.

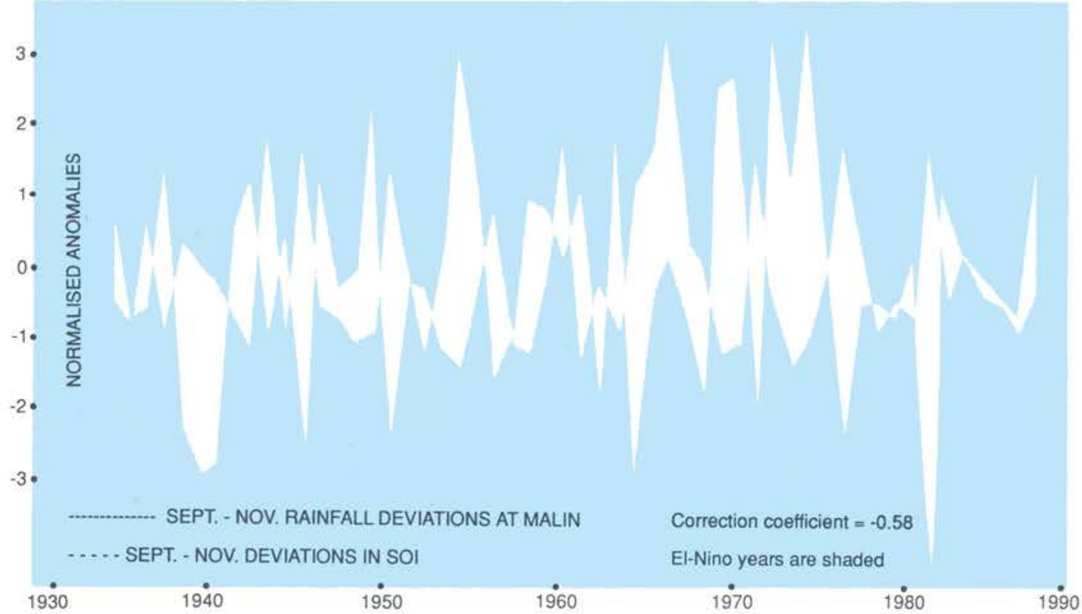


Figure 36

Time series of the Southern Oscillation Indices (SOI) and Kenya coastal rainfall (Malindi) during the short rainfall (September - November) season

(Ogallo, 1988)

The extreme wet conditions in 1988 could therefore be partly associated with the large positive anomalies which were observed in the Southern Oscillation Indices (SOI) during this period.

Maximum correlations between the SOI and East African rainfall are concentrated over the coastal regions during the September-November season when values in the range of -0.6 are common at many locations. Based on this negative correlation, one would have anticipated below-normal rainfall over these areas in 1988 when SOI values were positively large. *Figure 36* indicates an increase in rainfall to near-normal conditions along the coastal areas during September-November 1988. *Figure 36* also shows that there have been similar episodes observed in the past when this ENSO-related response was not observed.

Nonetheless, some of the observed dry and wet conditions within 1986-1988 indicate that the SST anomaly patterns over the western Indian and eastern Atlantic oceans play some significant role in the determination of the characteristics of the African sub-tropical anticyclones which often control the patterns of the monsoonal wind systems over eastern Africa.

8 CONTINUED INCREASES IN TRACE GASES IN THE ATMOSPHERE

The concentrations of many trace gases (carbon dioxide, methane, tropospheric ozone, chlorofluorocarbons) in the atmosphere are continuing to increase. Without exception, the cause of the increases, at least in part, is anthropogenic. Some gases like carbon dioxide continued an increase that began with the industrial revolution of the last century. Others, like chlorofluorocarbon (CFC-113), which is used primarily in the micro-electronics industry, is relatively new and regular measurements of its atmospheric concentration exist for less than ten years. The two main consequences for mankind of these trace gas increases (as firmly indicated by theoretical models but not conclusively proven from empirical evidence) are a global-scale warming of the planet and depletion of ozone in the stratosphere.

8.1 Carbon Dioxide

Atmospheric measurements of carbon dioxide are now continuously made at 22 Background Air Pollution Monitoring Network stations and flask samples are weekly taken at another 2 dozen locations. The long-term change (see Figure 37) since routine monitoring began at Mauna Loa Observatory in 1957, when the CO_2 concentration was 215 ppm, has generally followed the release of carbon dioxide to the atmosphere from the burning of fossil fuels. During 1986 - 1988, the global mean value increased by about 2.0 parts per million (ppm)/year. In 1988, the milestone of 350 ppm was crossed, representing an increase of 25% from the pre-industrial value of about 280 ppm (WCP-53, 1983).

Inspection of the measured carbon dioxide record (*Figure 37*) shows three scales of variation: the long-term increasing trend, an annual cycle primarily driven by the northern hemisphere vegetative growing season, and a smaller signal usually associated with the El Niño/Southern Oscillation. This latter feature was distinctly present in 1987-1988. Although there is scientific disagreement about the specific physical processes responsible, the net effect was a greater than normal year-to-year carbon dioxide increase during the ENSO. In fact, from mid-1987 to mid-1988, the carbon dioxide growth rate averaged 2.5 ppm/year, which is about

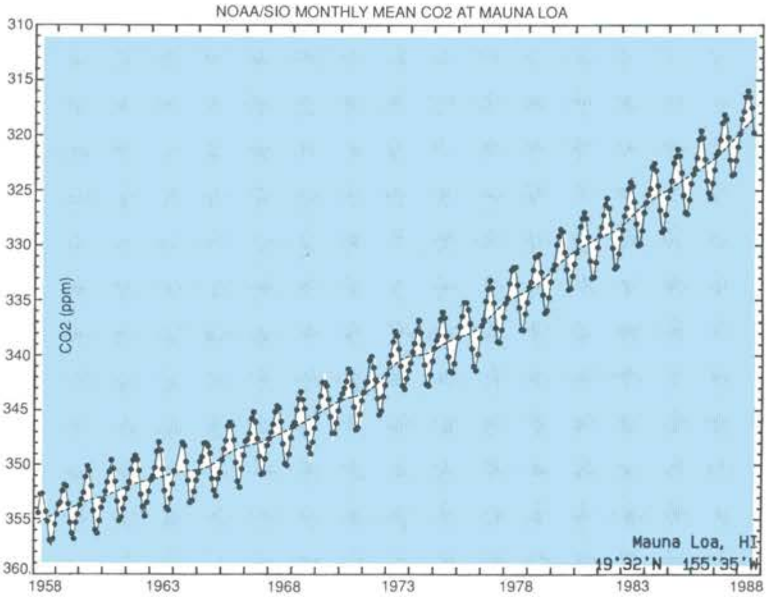


Figure 37

Monthly mean values of carbon dioxide measured at Mauna Loa Observatory 1958 - 1988 by Scripps Institution of Oceanography

(C.D. Keeling) and NOAA.

1.0 ppm/year more than the proceeding two years. By late 1988, as the ENSO was weakening, the carbon dioxide growth rate was returning to more normal values.

8.2 Methane

The second most important greenhouse gas is methane. Its recent rate of growth in the atmosphere is about 13 parts per billion (ppb)/year, or about 0.8%/year. Four

Figure 38

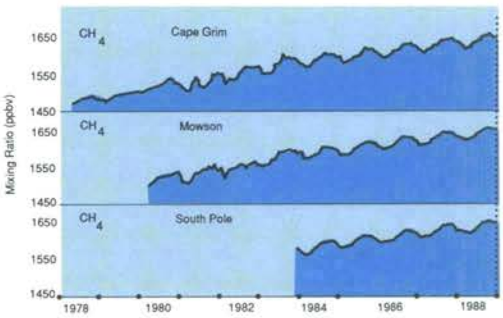
Long-term trends of methane (CH_4) concentrations. Results from four long-term, methane measurement programs:

the Commonwealth Scientific and Industrial Research Organization of Australia (CSIRO);

the National Oceanic and Atmospheric Administration of USA (NOAA);

the Oregon Graduate Center of USA (OGC);

and the University of California at Irvine of USA (UC).



extensive data sets from different institutions now exist; their results are summarized in *Figure 38*. Clearly, the methane increase is a global phenomenon and is fairly consistent from year to year. There is general agreement that the primary sources responsible for the methane rise include rice production, domestication of ruminant animals, burning vegetation and fossil fuels, and landfills of organic waste. There is still disagreement, however, on the magnitude of each source.

8.3 Precursor Gases for Stratospheric Ozone Depletion

There are many gases which, when broken down, introduce halogen, nitrogen, and hydrogen compounds into the stratosphere that play important roles in ozone destruction. Most of these species also have greenhouse radiative properties and thus play a dual role in anthropogenic modification of the atmosphere. Current information on the global trends and tropospheric concentrations of these source gases and those discussed above are listed in Table 1 (from the WMO/NASA Ozone Trends Panel Report, 1988). The primary ozone-depleting species, CFC-11 and CFC-12, continued their significant rate of increase at about 4%/year (*Figure 39*). Other species like CFC-113 (used as solvents for electronics micro-circuits) and Halons-1211 and -1301 (used as fire extinguishing agents), have found expanding industrial use and their atmospheric concentrations are growing at more than 10%/year.

One of the most significant events of the period with respect to atmospheric trace gases was adoption of the "Montreal Protocol on Substances that Deplete the Ozone Layer," by many states of the world in 1987. This represented the first international agreement to limit the production and use of several species with significant ozone-depleting potential. Once in effect, the Protocol should reduce the growth rates of several important species, including CFC-11, and CFC-12. However, because their atmospheric lifetime is very long (usually exceeding 100 years), it will be many decades before atmospheric concentrations are actually lowered. The recent WMO/UNEP scientific assessment of the ozone layer (1989) has suggested that it would require a complete phase out of all fully-halogenated CFCs, halons, carbon tetrachloride and methyl chloroform, as well as careful considerations of the HCFC substitutes, to return the Antarctic ozone layer to levels approaching its natural state, by the middle of next century. Otherwise, the Antarctic ozone "hole" is expected to remain, provided that the present meteorological conditions continue.

Table 1 Concentrations and global trends of tropospheric gases for 1987. Lifetimes are given, where available (adapted from Ehhalt et al., 1989).

8.4 Others

Other gases involved in greenhouse climate warming include carbon monoxide and ozone. Carbon monoxide does not have greenhouse radiative properties itself, but has an important indirect influence via its role in the atmospheric oxidation of methane to carbon monoxide to carbon dioxide. Because the species has large spatial and seasonal variation and is short lived, determination of any secular trend is difficult and available data are not conclusive. In contrast, there is evidence that, globally, ozone in the troposphere is increasing by at least 1% per year, whereas ozone in the stratosphere is decreasing by about 1% per decade. The tropospheric ozone has a measurable surface heating effect; the stratospheric ozone decline will cause a decrease of the middle stratospheric temperatures by as much as 6 to 8°C by the middle of the next century with still not clearly understood effects on the weather. These offsetting trends lead to a relatively small combined greenhouse impact.

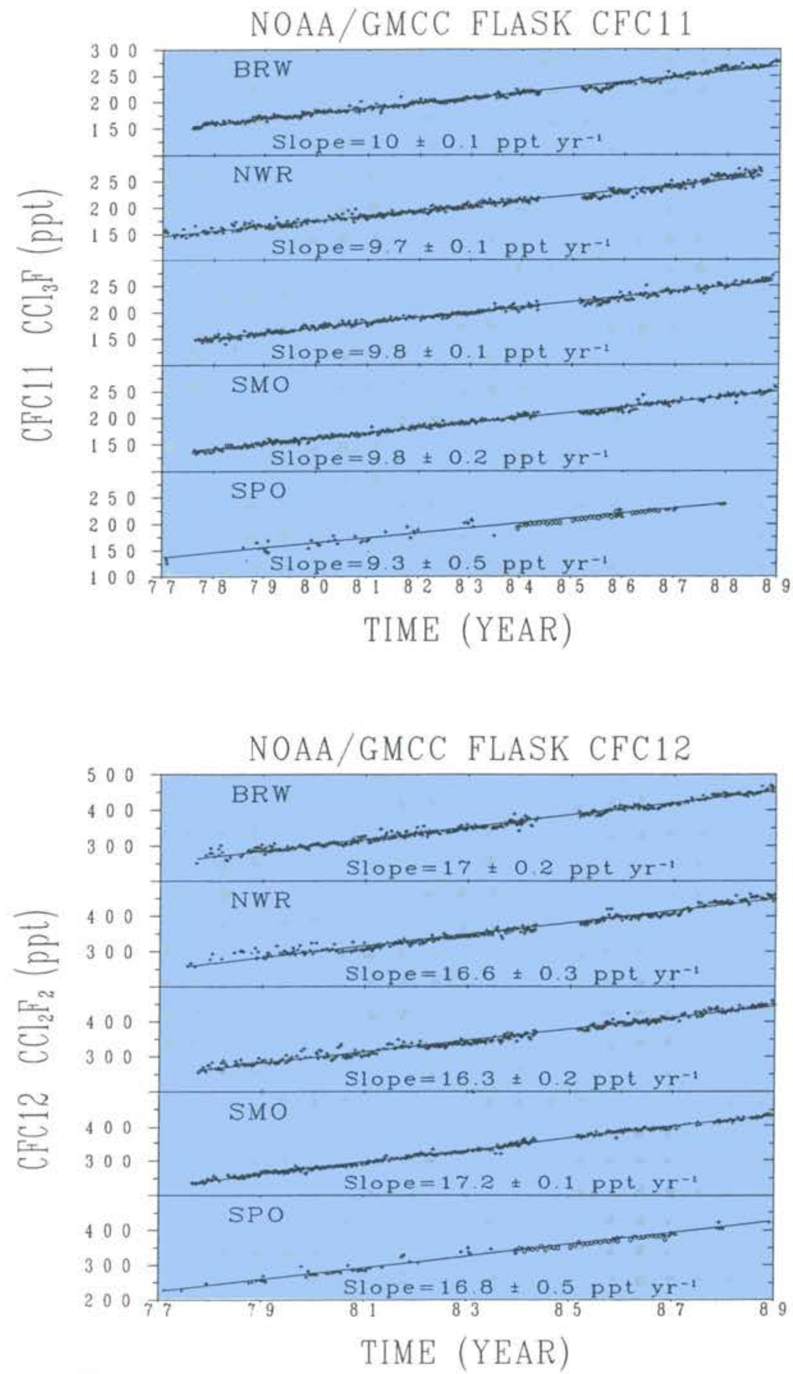


Figure 39

Record of CFC-11 and CFC-12 measured (parts per trillion) at Mauna Loa Observatory by the Geophysical Monitoring for Climatic Change Division of NOAA, 1977-1988. The rates of growth from linear estimates with time are also shown.

Source gas	Mixing ratio pptv*	Rate of increase pptv*/yr	%/yr	Lifetime yr
CCl_3F (CFC-11)	240	9.5	4.0	110
CCl_2F_2 (CFC-12)	415	16.5	4.0	75
CH_3CCl_3	150	6.0	4.0	7
CCl_4	140	2.0	1.5	40
CCl_2FCClF_2 (CFC-113)	45	4-5	10	90
$CHClF_2$ (CFC-22)	100	7	7	20
CH_3Cl	600			1.5
$CHCl_3$	30			0.7
CH_2Cl_2	35			0.6
CCl_2CCl_2	30			0.6
CH_2ClCH_2Cl	35			0.6
$CClF_2CClF_2$	15			180
$CHClCCl_2$	10			0.1
$CClF_2CF_3$	5			380
$CClF_3$	5			400
$CBrClF_2$	1.7	0.2	12	25
$CBrF_3$	2.0	0.3	15	110
CH_3Br	10-15			1.5
$CHBr_3$	2-3			0.4
CH_3Br_3	2-3			0.5
CH_3CH_3Br	2-3			
CH_3BrCl	1-2			
$CHBr_3Cl$	1			0.6
CH_3BrCH_3Br	1			0.6
$CHBrCl_3$	1			0.6
N_2O	307 ppbv	0.6-0.7	0.2	150
CH_4	1680 ppbv	12	0.7	10
	1680	16	1.0	
CO	90 ppbv		N0 (NH)	0.2
			N0 (SH)	
CO_2	348 ppmv	1.6-1.9	0.45-0.55	
O_3	N20 ppbv		N1 (NH)	
			N0 (SH)	

* parts per trillion per volume unless otherwise specified

ppmv - parts per million per volume
ppbv - parts per billion per volume

Table 1 Concentrations and global trends of tropospheric gases for 1987. Lifetimes are given where avaiable (adapted from Ehhalt et al., 1989).

9 STRATOSPHERIC OZONE DEPLETION

A major assessment of global ozone trends over the past two decades was completed in 1988 by the WMO/NASA "Ozone Trends Panel" (WMO Ozone Report No. 18, Ehhalt et al, 1988). Two of its key findings were:

-There is undisputed observational evidence that the atmospheric concentrations of source gases important in controlling stratospheric ozone levels (chlorofluorocarbons, halons, methane, nitrous oxide, and carbon dioxide) continue to increase on a global scale because of human activities; and

-Analysis of data from ground-based Dobson instruments, after allowing for the effects of natural geophysical variability (solar cycle and the quasi-biennial oscillation), shows measurable decreases from 1969 to 1986 in the annual average of total-column ozone ranging from 1.7% to 3.0%, at latitudes between 30 and 64 degrees in the Northern Hemisphere. The decreases are most pronounced, and ranged from 2.3 to 6.2%, during the winter months, averaged for December through March, inclusive. Dobson data are not currently adequate to determine total-column ozone changes in the tropics, subtropics, or Southern Hemisphere outside Antarctica.
The findings by this prestigious international group of some 100 scientists represent the most thorough assessment ever undertaken of the magnitude and causes of stratospheric ozone change. They also indicated that future ozone changes will be even larger unless significant reductions are made in the use of the critical source gases.

Perhaps the most dramatic evidence of man-made alteration of the atmosphere during 1986-1988 was further confirmation of the existence of an Antarctic ozone hole. The "hole," or substantial reduction of ozone below that naturally occurring over Antarctica during the first 4 to 6 weeks of the austral springtime, was first reported in June 1985 by Farman et al. (1985). In 1987, the spring decline was spatially broader and the total ozone amount was the lowest than at any time since measurements began in the early 1950's (*Figure 40 and 41*). The polar stratospheric vortex was extremely cold and strong during that year. Thus the low values persisted until the destruction of the vortex which occurred later in the summer season than usual. Several scientific expeditions to Antarctica in 1987 produced data that provided a basis for theoretical explanations of the reactions that destroy the ozone thereby implicating

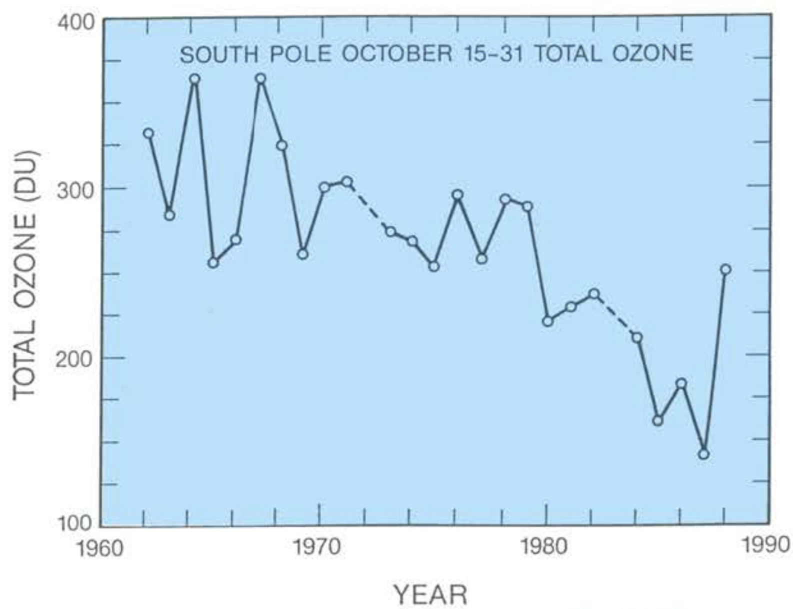


Figure 40

Total ozone (in Dobson units) over South Pole for Oct 15-30 for the last 25 years

(Peterson, NOAA Environmental Research Laboratories, Boulder, CO, USA).

man-made chlorofluorocarbons as a cause. In 1988, the ozone depletion was far less severe because the meteorological conditions were not as favourable. The Southern Hemisphere polar vortex was not as zonally intense as usual and, thus, did not as effectively

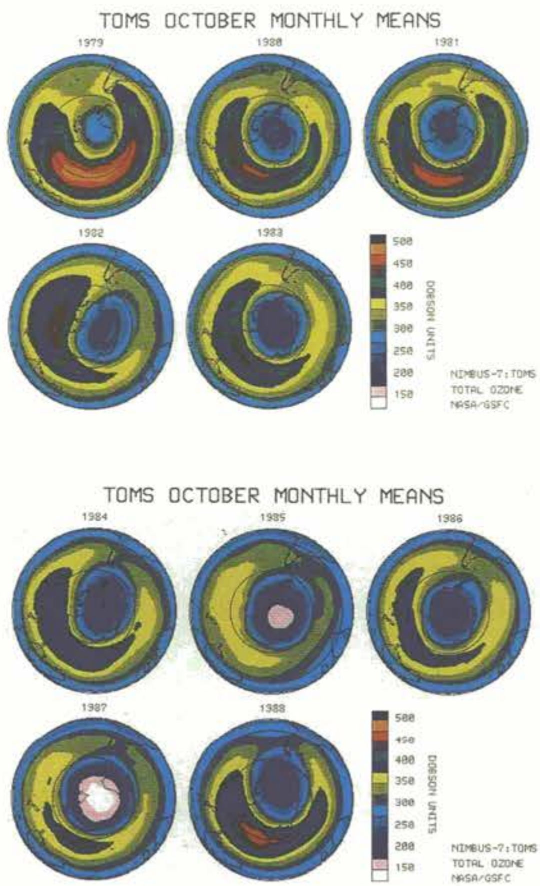
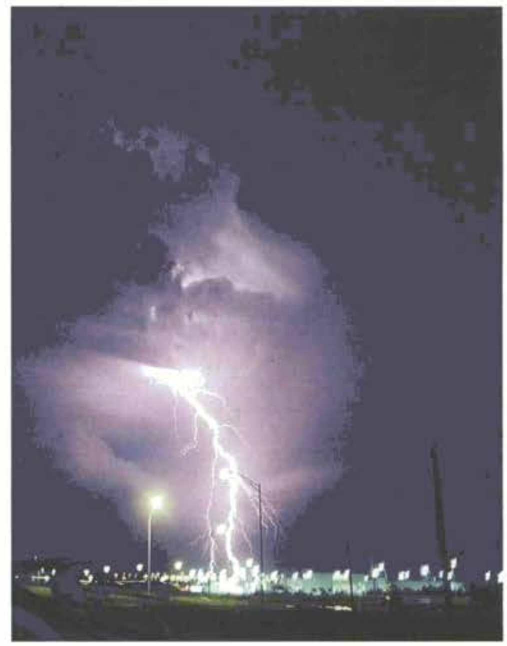


Figure 41

isolate a cold air mass over Antarctica. The greater north-south exchange inhibited lowering the temperatures below -80°C, the level associated with the formation of polar stratospheric clouds and ice crystals which facilitate the heterogeneous chemical reactions leading to ozone depletion.

Over the North Pole, the frequent exchange of air between the Pole and the middle latitudes make the formation of a strong circumpolar vortex much less frequent. Therefore, the conditions for extremely cold stratospheric temperatures rarely exist. Aircraft observations and occasional balloon ozone soundings in the winter of 1988-89 indicate a perturbed state of the chemical



composition in the lower stratosphere, and ozone depletion for short time periods over some areas in the Arctic, similar to the disturbed chemical processes observed in the Antarctic spring, however with less intensity.

10
ATMOSPHERIC AEROSOL CONCENTRATIONS STABILIZE

10.1 Stratosphere

There were no major volcanic eruptions during the period and only a few minor ones. The stratospheric aerosol record was marked by a slow, but continuing, decrease since the El Chichon eruption of 1983. The record of atmospheric transparency from Mauna Loa Observatory (*Figure 42*), obtained from measurements of direct solar radiation, shows that values had nearly returned to background levels by the end of 1988.

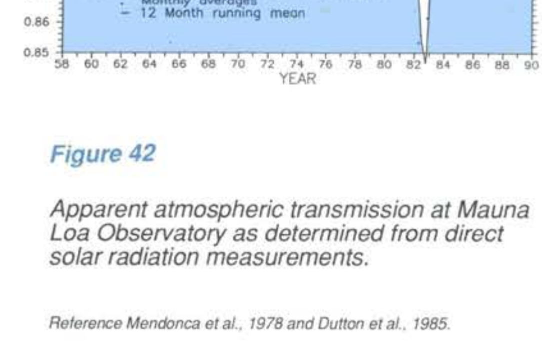


Figure 42

Apparent atmospheric transmission at Mauna Loa Observatory as determined from direct solar radiation measurements.

Reference Mendonca et al., 1978 and Dutton et al., 1985.

10.2 Troposphere

Industrialization and urbanization in many parts of the world lead to higher than background concentrations of atmospheric particulates. The effect of changing particulate amounts on incident direct solar radiation is illustrated in

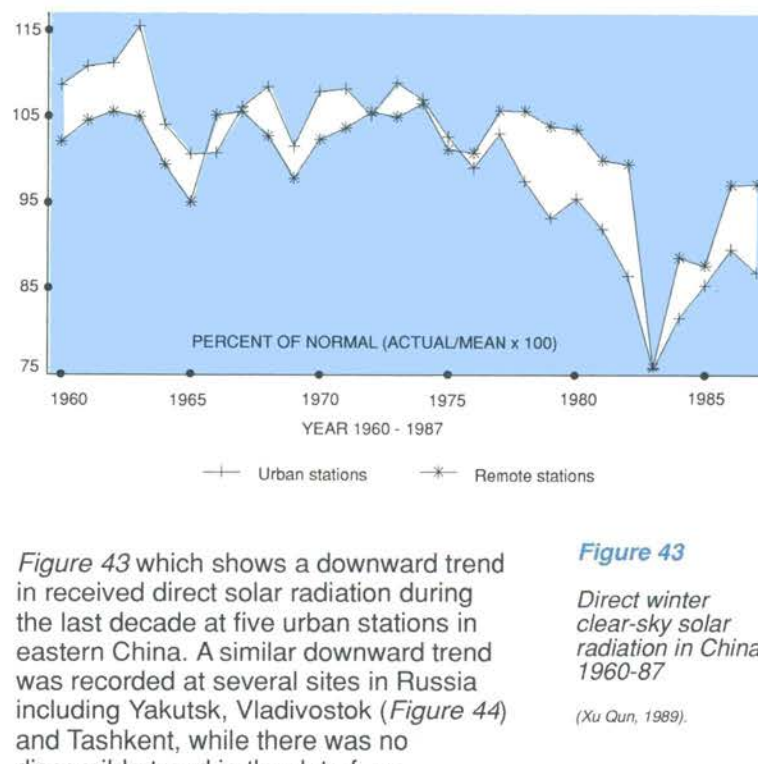


Figure 43 which shows a downward trend in received direct solar radiation during the last decade at five urban stations in eastern China. A similar downward trend was recorded at several sites in Russia including Yakutsk, Vladivostok (*Figure 44*) and Tashkent, while there was no discernible trend in the data from Lenningrad and Omsk. From *Figure 43*, it can be seen that Chinese urban areas have experienced a gradual increase in particulate pollution with time, while the rural areas have not. Note that the

Figure 43

Direct winter clear-sky solar radiation in China 1960-87

(Xu Qun, 1989).

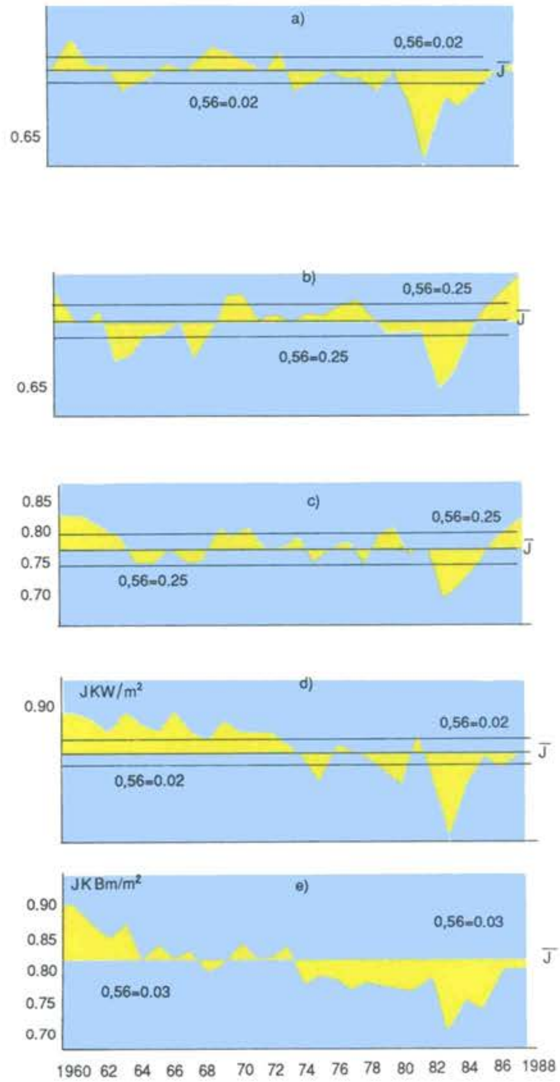
volcanic effects of Agung (1963+) and El Chichon (1982+) are clearly indicated in the Russian and Chinese data. In 1987, values of direct solar radiation at all stations in the USSR were higher than in 1986, and at some stations values for the first time since 1963, approached those recorded before that eruption.

Aerosols are relatively short-lived in the atmosphere because they are readily removed by precipitation processes. Thus, there does not appear to be a global-scale buildup of particles at this time. The condensation nuclei record from the South Pole (*Figure 45*), for example, indicates rather consistent values since 1973.

Figure 44

Annual means of direct solar radiation intensity at Vladivostok USSR

(World Radiation Data Centre, Leningrad, USSR).



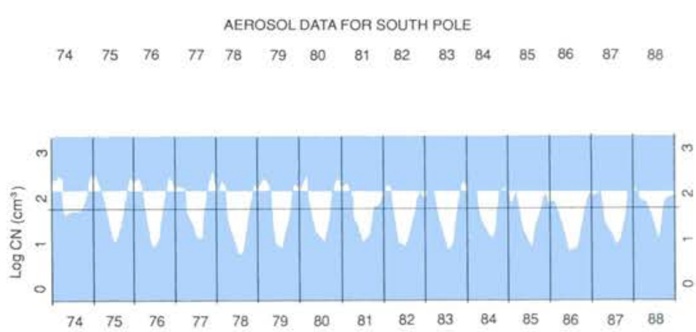


Figure 45 *Plot of monthly mean values of condensation nuclei at South Pole from NOAA/GMCC network, 1973-1988*

(Bodhaine et al., 1987).

11

INCREASED TROPICAL STORM ACTIVITY IN THE EASTERN ATLANTIC DURING 1988.

Both 1986 and 1987 were characterized by below-average hurricane and tropical-storm activity in the North Atlantic Ocean. Only six tropical cyclones developed in 1986. Since 1930, there have been just nine seasons when less than seven tropical storms and hurricanes have developed (*see Figure 46*). The seven tropical cyclones that developed in 1987 were also weaker than usual. Emily, the strongest hurricane of the season, had a minimum pressure of 958 millibars, which contributed to ranking the 1987 season as the fourth weakest in the past 20 years (Case, 1988). The number of tropical storms and hurricanes that developed in 1988, by comparison, was slightly above the long-term mean.

The 1988 season will most likely be remembered as the season of Hurricane Gilbert. This storm, which achieved tropical storm status on September 9 and strengthened into a hurricane the following day, developed a maximum sustained wind speed of 160 knots and lowest pressure of 888 millibars, making it the most powerful hurricane on record in the Western Hemisphere. Gilbert caused 318 deaths and about 5 billion dollars (U.S.) in damage, wrecking havoc across the central and northwest Caribbean and southwest Gulf of Mexico. Gilbert reached category 5 on the Saffir/Simpson Scale, while subsequent hurricanes Helene and Joan reached category 4. This is the first time in 27 years that three hurricanes achieved that high a rating in a single season (Gross and Lawrence, 1989).

In the eastern North Pacific, 17 tropical storms and hurricanes developed in

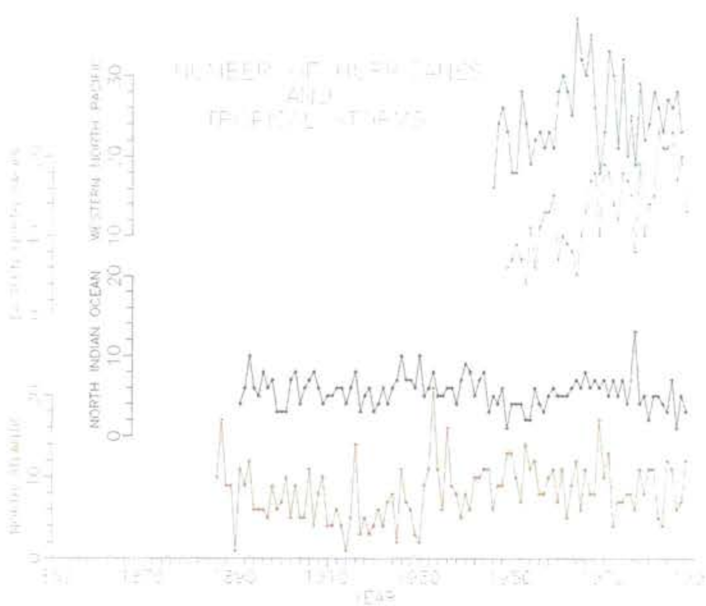


Figure 46

Annual number of hurricanes and tropical storms in four ocean basins, through 1988. Source: North Atlantic, eastern North Pacific, and western North Pacific (National Climatic Data Center, NOAA, tape dataset TC-9697); north Indian Ocean (A. Chowdhury, Indian Meteorological Department). Major improvements in the observation of tropical cyclones were made in the mid-20th century (Jarvinen, Neumann, and Davis, 1984). Consequently, some storms in the early part of the Atlantic and Pacific records probably went undetected.

1986, 18 in 1987, and 13 in 1988. These are near the 22-year mean of about 16 tropical storms and hurricanes per year.

The western North Pacific saw 27 tropical storms and typhoons in 1986, 24 in 1987, and 26 in 1988. These are near the 29-year mean of about 27 tropical storms and typhoons per year. Lynn, one of six super typhoons of the 1987 season, hit Taiwan with excessive rainfall (over 1.7 meters in Taipei) and severe flooding. Super Typhoon Nina was the most intense and destructive storm of 1987. It devastated Truk and killed over 600 people on southern Luzon, making it the most destructive typhoon to hit the Philippines in 20 years.

Tropical cyclone activity in the North Indian Ocean was near or below the long-term mean (*see Figure 46*). This is consistent with the dry conditions which occurred over India during 1986 and 1987.

12

PRONOUNCED UPPER ATMOSPHERIC BLOCKING DURING THE FALL AND WINTER OF 1987/88 IN THE NORTHERN HEMISPHERE.

Blocking processes are one of the principal reasons for large weather anomalies that last from a week to a season, and they are of special interest for climate monitoring (Korovkina, 1989). The blocking indices, presented in *Figure 47* characterize duration (TD) and intensity (TI) of blocking ridges for the season.

The major feature of development of blocking ridges in the northern hemisphere in 1987 was their high intensity and duration in middle latitudes in autumn (September-November) 1987 and in winter (December-February) 1987/88. In autumn 1987, a moderate blocking event was observed over North America and, a stronger one over Europe (*Figure 47a*). Over Europe, the blocking ridge, which had begun in late September in the West Atlantic, shifted eastwards towards the Urals until mid-October and then, by beginning of November it returned to its initial position where it persisted until mid-November. This strong block accounted for the warm, dry weather of October-November in the north of Europe, heavy precipitation on the west European coast and the cold, wet autumn in Asia.

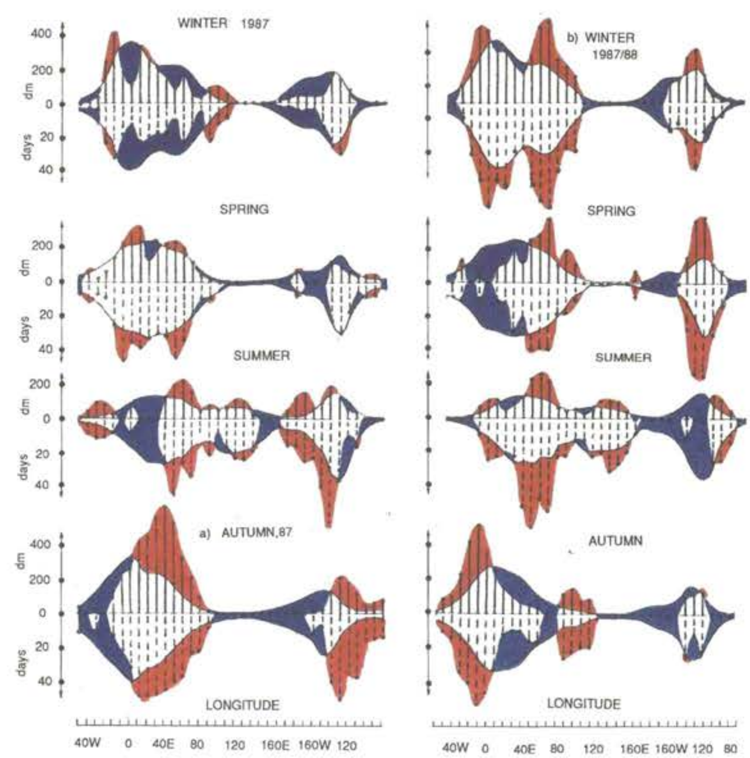
A similar development of a blocking event, except with a month's time lag, was observed on the North American continent. Here, a blocking ridge, which had begun in August, migrated in the autumn from the northwest Pacific to the eastern parts of North America and back again. This blocking situation accounted for the prevalence of warm and dry weather in the USA and Canada and for heavy precipitation in the northern regions (70-75°N) of North America in September.

The highest values of blocking indices (TD and TI) reached were 38 days (50°N, 20°E) and 430 decameters (60°N, 40°E) over Europe and 63 days (55°N, 120°W) and 370 decameters (50°N, 110°W) over North America.

In the winter of 1987/88, maximum blocking index anomalies were observed over 3 areas: the northeast Atlantic

Figure 47

Northern hemisphere blocking indices: total seasonal duration in days (TD) and total seasonal intensity in decametres (TI) of blocking at 60°N as function of the longitude. Blocking at a point is defined as a period of existence of a high (j) 500 hectopascal geopotential height deviation from the zonal mean value in 7 or more days (Climate Monitoring-87, 1989). TD values are shown by a downward dashed line, TI (decametres) by an upward solid line across every 10° of longitude.



Ocean, the Urals and the northeast Pacific Ocean (*Figure 47b*).
In the Atlantic - western Siberia sector, which includes the first of the 2 areas of maximum blocking indices, blocking ridges were observed during practically all winter months, migrating from the first area to the second and back. Such a blocking situation accounted for heavy precipitation along the northwest coast of Scandinavia, the Pyrenees, and Transcaucasis in December and in the north and south of Asia in December-February. There was also anomalous warmth in Europe in January and a large negative air-temperature anomaly in central Asia, which usually occurs once every 50 years.

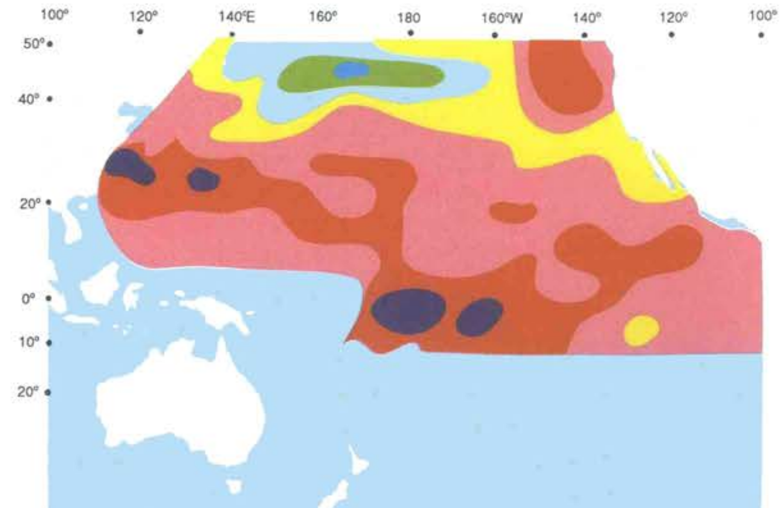
The blocking in the eastern Pacific and western parts of North America resulted in one of the warmest Decembers ever in Canada. There was also a lack of precipitation in the latitudinal zone 50-55°N and an increased amount of precipitation to the north and south of this zone in December-February.

The greatest values of blocking indices anomalies TD and TI were, correspondingly 23 days (60°N, 10°W) and 250 decameters (50°N, 30°W) in the first area; 39 days (70°N, 50°E) and 290 decameters (60°, 60°E) in the second and 15 days (60°N, 130°W) and 110 decameters (60°N, 130°W) in the third.

13

NOTABLE RISING TREND IN THE SEA-SURFACE TEMPERATURES OF THE NORTHWEST PART OF THE TROPICAL PACIFIC OCEAN

A notable rising trend in sea-surface temperatures (SST) has been detected in the north Pacific Ocean during the past 7 years (1982-1988), especially in the northwest subtropical Pacific and central equatorial Pacific. January SSTs in these places have been rising at a rate of +0.4 to +0.6°C per year (Figure 48). If we observe the long time series of monthly mean SST in January averaged over the area of the subtropical western Pacific (20 - 30°N, 120 - 160°E), the upward trend through the 7 years is indeed very significant (*Figure 49*), rising to +3.4°C from 1982 to 1988. Much of the rising trend in the tropical latitudes can be attributed to the two ENSO events during the 1980s. In the subtropical latitudes, the rise could be due to natural oscillations of ocean currents, but one can't exclude a greenhouse gas warming effect.



The distribution of significant rising trend of North Pacific SST in January from 1982 to 1988 (Maximum +0.5 - +0.6°/yr.)

Figure 48

The distribution of significant rising trend (^0C/Yr.) of north Pacific in January through 1982 - 1988

(Xu Qun, data from the Central Meteorological Observatory of China).

This significant warming has taken place off the east coast of China at the westernmost side of subtropical north Pacific which includes a large portion of the Kurishio current. A relationship has been found between the winter temperature of the Kurishio current and the monsoon rain of mid - lower Yangtze River Valley during early summer (plum rains). When the former is warmer, then the onset of plum rains is earlier and the rainfall amounts larger (Xu, 1986).

This trend to earlier onsets and greater intensity of rains in the mid-lower Yangtze (plum rains) demonstrates a need to closely monitor changes in SST in the subtropical westernmost portions of the north Pacific Ocean.

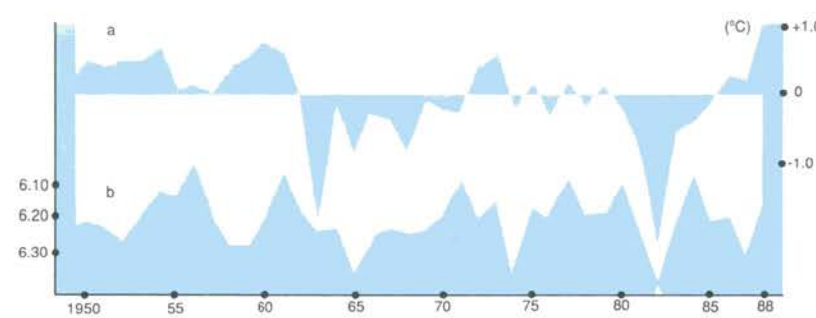


Figure 49

The variation of January monthly mean SST anomaly averaged over the area of 20 - 30°N, 120 - 160°E relative to the mean of 1949 - 1988

(Central Meteorological Observatory of China).

14

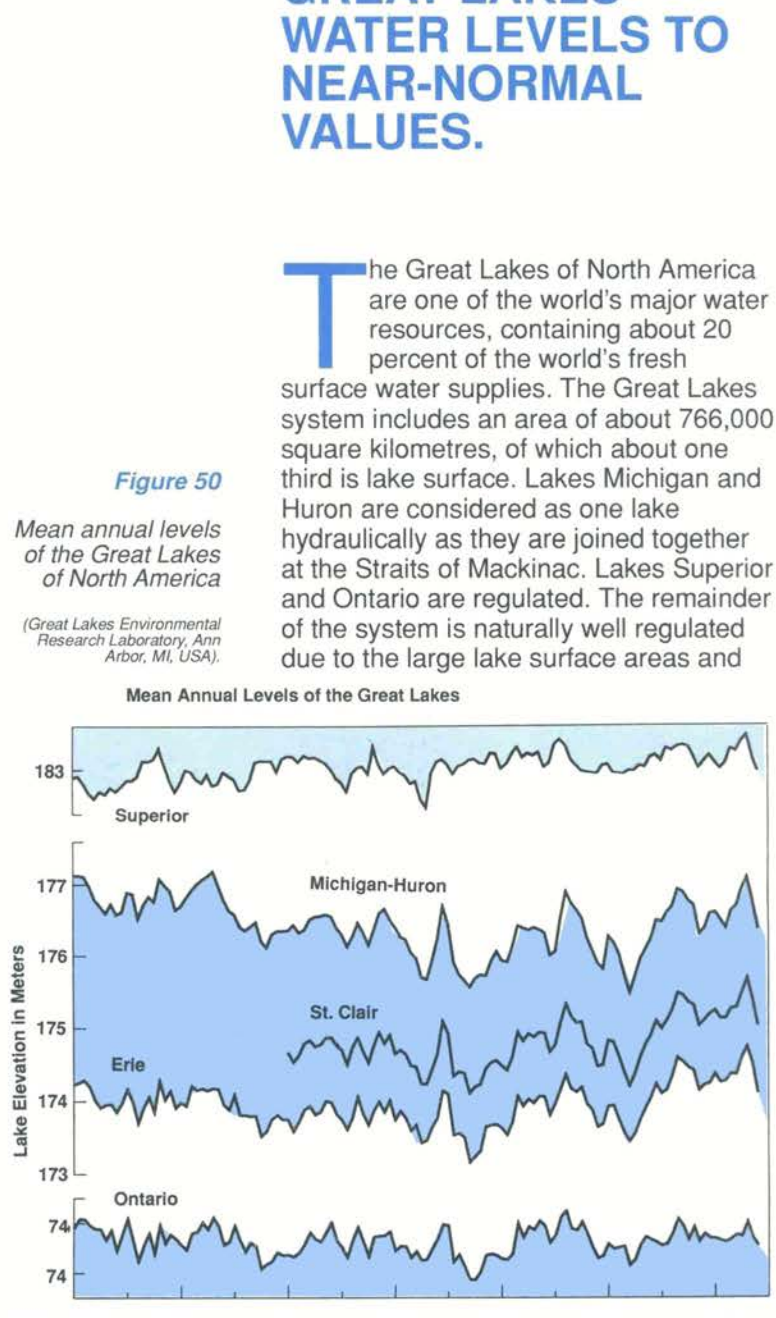
RAPID DROP IN GREAT LAKES WATER LEVELS TO NEAR-NORMAL VALUES.

The Great Lakes of North America are one of the world's major water resources, containing about 20 percent of the world's fresh surface water supplies. The Great Lakes system includes an area of about 766,000 square kilometres, of which about one third is lake surface. Lakes Michigan and Huron are considered as one lake hydraulically as they are joined together at the Straits of Mackinac. Lakes Superior and Ontario are regulated. The remainder of the system is naturally well regulated due to the large lake surface areas and constricted outlet channels. This has resulted in the lakes historically fluctuating through a very small range in levels, about 1.8m. The past 20 years have been notable due to the establishment and continuation of a high lake level regime which began about 1970. This regime ended in early 1987 due to an extensive drought. By the end of 1988, the lake levels were approaching their long-term means.

Figure 50

Mean annual levels of the Great Lakes of North America

(Great Lakes Environmental Research Laboratory, Ann Arbor, MI, USA).



The Great Lakes water levels have been continuously gauged since 1860 providing one of the longest time series of continuously measured hydrologic data in North America. The lake levels serve as integrators of water supply variations and climatic change, yielding both a well-defined seasonal cycle and longer-period fluctuations. The annual lake levels as shown in *Figure 50* represent the longer-term variability of the system. Of particular interest is the drop in the levels of Lake Michigan-Huron in the mid-1880s from which the lakes have never recovered. This was the probable result of a major decrease in the precipitation over the upper Great Lakes coupled with dredging in the connecting channels.

There have been three distinct lake-level regimes over the past 120 years; a relatively high regime ending in the 1880s, a low regime lasting from the 1880s to about 1940, and a high regime lasting from 1940 through present. From 1970 through 1986, the lakes were in a very high-level regime reaching record to near-record levels in 1985/86. The high precipitation regime which led to the high lake levels ended in November 1986. Drought conditions, including the severe spring and summer drought of 1988, greatly reduced the water supplies and brought rapidly falling levels through the end of 1988. The drop in lake levels between October 1986 and December 1988 were the third and second highest 26-month drops in their respective records.

Great Lakes water levels have varied significantly over the past several thousand years and can be expected to vary considerably in the future. The current normals, as usually represented by the records from 1900-1969 may not be indicative of longer-period normals. The wet and cool climatic conditions that led to the recent record lake levels may be more indicative of longer-term normals than conditions occurring earlier this century. The high water supplies of the 1970s and early 1980s could be offset in the future, however, by global warming, which could result in major decreases in both water supplies and lake levels.

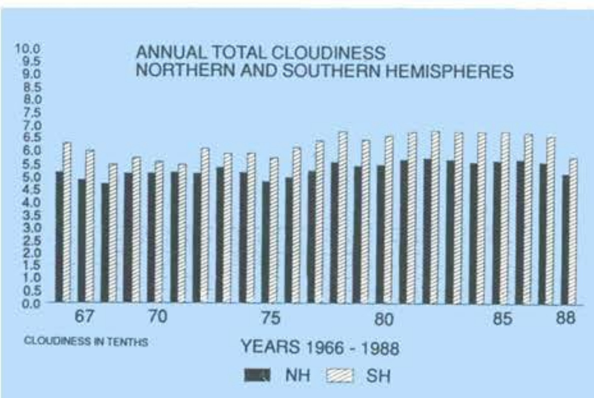


Figure 51

Time series of annual mean values of total cloudiness in the northern and southern hemispheres

(from Gruza, USSR).

15

A DECREASE IN GLOBAL CLOUDINESS IN 1987 AND 1988.

Information received from the USSR indicates a decrease in global cloud cover in 1987 and again in 1988 from the high cloudiness levels reported in the early part of this decade. *Figure 51* shows the average annual amounts of cloud cover over the northern and southern hemispheres from 1966 through 1988.

The data is based on the analysis of visual and infrared images from the "Meteor" satellite system (Matveev, 1986). The data set is comprised of daily data on a 5° x 10° grid covering the northern and southern hemispheres (Aristova, Gruza 1987). Spatial averaging is done for 62 regions including the globe, the northern and southern hemispheres, continents and oceans, the largest countries and 10-degree latitudinal circles and latitudinal zones. Mean monthly cloudiness values are obtained by averaging daily data. The daily values of global cloudiness are stored at the Russian Hydrometeorological Centre (World Data Centre B) where they have assembled an historical data base back to 1966.

Annual mean cloudiness over the globe was 5.6 tenths in 1988, which was 0.2 less than normal, and 0.6 and 0.4 less than the values in 1986 and 1987 respectively. In the northern hemisphere, annual mean cloudiness was 0.7 tenths less than in the southern hemisphere. Positive anomalies of global cloudiness were observed in January-March 1988. However, beginning in April 1988, the mean cloudiness over the globe declined to below normal with the lowest values being reported in August.

Despite decreased cloud cover in 1987 and 1988, there has generally been a positive trend in cloudiness in both hemispheres since 1966, with the increase being somewhat greater in the southern hemisphere. Not every region has experienced increased cloudiness. A decreasing trend in cloudiness has been observed over polar regions.

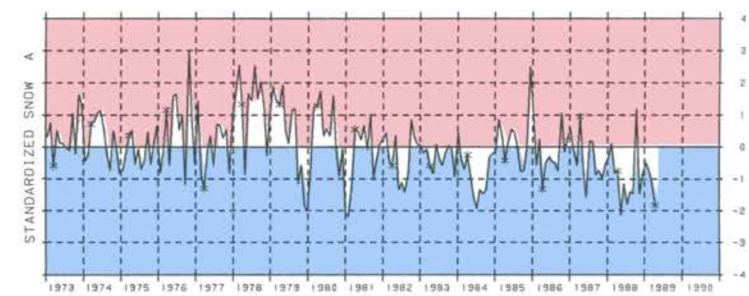


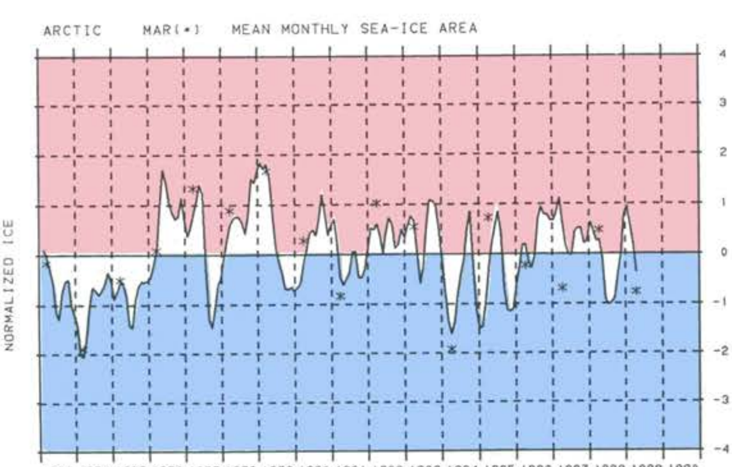
Figure 52: *Time series of standardized northern hemisphere snow cover area through March 1989. The "*" represents March of each year. The snow cover anomalies for each month are normalized by the appropriate monthly standard deviation.*

16

LITTLE CHANGE IN GLOBAL ICE COVER BUT REDUCED SNOW COVER IN 1988

Northern hemisphere snow cover area fluctuated about its base-period mean during most of 1986 and 1987 with few large variations in either direction. During 1988, however, snow cover tended to remain below its mean for most months of the year (*Figure 52*).

Both Arctic and Antarctic sea-ice area also fluctuated about their mean values for the 1986 to 1988 period with no large fluctuations in either direction. Sea ice areas anomalies tended to remain in phase in both polar regions (*Figure 53*). This behaviour contrasts to a previous slight tendency for sea ice anomalies in each hemisphere to vary somewhat out of phase.



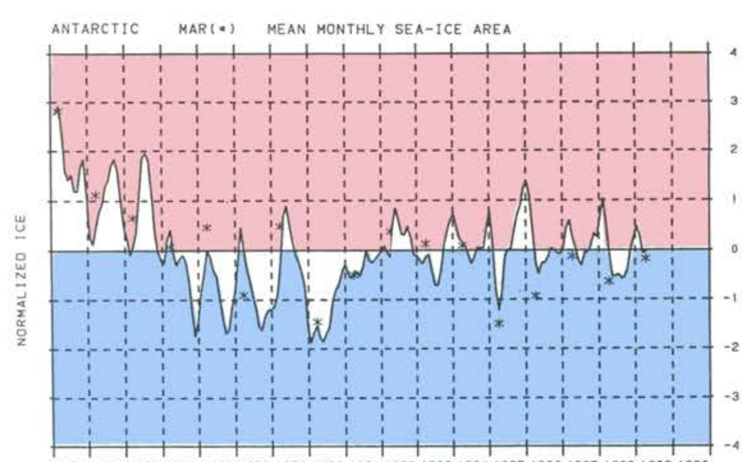


Figure 53: *Time series of standardized Arctic (a) and Antarctic (b) sea-ice area through March of 1989. The "*" represents March of each year. Sea-ice area anomalies for each month are normalized by the appropriate monthly standard deviation.*

17

SIGNIFICANT RISE IN GLOBAL SEA LEVEL

Observations of rising sea level have been taken as an indication of the global climate warming caused by the buildup of CO_2 and other greenhouse gases in the earth's atmosphere. The problem of detecting climate-induced, sea-level change is complicated by the large number of physical factors which can affect sea level. Short-term changes in sea level (within the last 100-150 years) are determined from tide-gauge records. These records are geographically biased toward the northern hemisphere, and the time series are often too short or too broken to be useful. Furthermore, the records contain variations caused by tides (diurnal to longer-period tides, such as the 18.6-year cycle), ocean-atmosphere effects such as the El Niño Southern Oscillation (ENSO), and land movements (including effects of glacial rebound, neotectonism, sedimentation and compaction, and groundwater fluid withdrawal). Thus, changes in sea level, as recorded by tide gauges, may reflect real changes in the volume of the oceans (the eustatic change), as well as changes in land elevation on local to regional scales, or shifts in ocean currents. Because of the growing awareness of the complex array of variables that can affect relative sea-level curves, and the high variability in the data, some scientists have questioned whether a meaningful eustatic trend can be determined by simply averaging tide-gauge measurements (Pirazzoli, 1986; Bryant, 1988).

Nevertheless, numerous studies of global-mean sea-level changes based upon tide-gauge records of the last 100 years or less, yield increasing rates between 0.5 and 3 mm/yr., with most reported values ranging between 1-2 mm/yr. In spite of the noisy data, spatially and temporally coherent rises in sea level can be recognized, especially for better-documented regions with large station populations. Furthermore, the results fall into a relatively narrow range of values, irrespective of sampling or averaging methods. More significantly, rates of sea level rise over the last 100 years, in general, exceed those of the late Holocene (last 6000 years) and especially those of the last 2000-3000 years. It is more likely that these differences represent a recent increase in the rate of sea-level rise than an acceleration of land subsidence or sediment compaction. Recent results obtained by removal of the glacial isostatic component using viscoelastic models reinforce the hypothesis that the

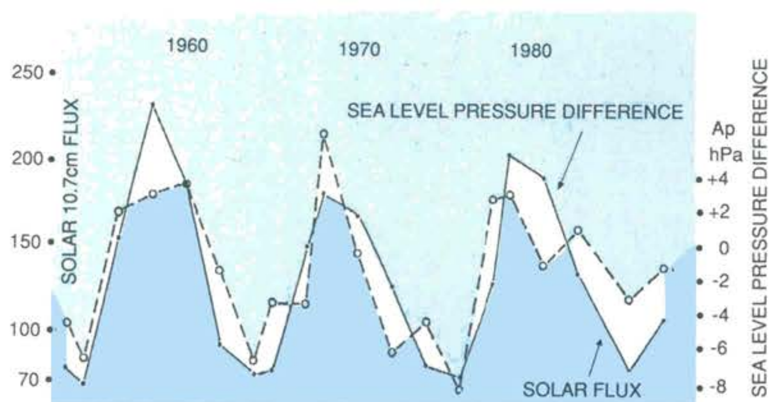


Figure 54

Mean-global, sea-level curve over the last hundred years. The scale is in cm, and baseline is obtained by setting the average for the period 1951-1970 equal to zero. Line represents the annual mean; the blue line is the 5-year running mean

(slightly modified from Gornitz and Lebedeff, 1987).

observed sea-level rise represents a true eustatic change.

The global-mean, sea-level rise, corrected for long-term crustal movements, is shown in *Figure 54*. The slope on this curve, as determined by least-square linear regression, is 1.0 mm/yr., for the period 1880 to 1983. Short-wavelength neotectonic and anthropogenic-induced land movements, and oceanographic components still contaminate the sea-level record. In the near future, independent methods of isolating vertical and land motions, using Very-Long Baseline Interferometry (VLBI) and the Global Positioning System (GPS) will provide a measure of absolute sea level rise.

18 INCREASING DESERTIFICATION IN CHINA

The desertification process in China is significant. China is the country having the largest area of desert in the world. It extends like an arc across the northwest, the north and northeast provinces with the total area amounting to 7.1×10^5 km^2. The grassland zones south of these deserts are the places being severely desertified and these areas of north China occupy up to 1.76×10^5 km^2. In addition, there also exists 9.7×10^3 km^2 covered by eolian sand in the humid and semi-humid zones (Zhang and Yin, 1986). The desertification has seriously affected the middle reaches of Yellow River where the sand content of this river is the highest in the world (Jing, 1988).

Chinese geographers have analyzed and found the following main causes of desertification: cutting forests and woods, overgrazing, and increasing farmlands and cultivation. All these factors are associated with the increase of population in the arid and semi-arid zones (Dong, 1987).

Based on a comparative analysis of aerial photography from the late 1950's and late 1970's, the desertified area of China has expanded by about 3.9×10^4 km^2 in the past 25 years, which means an increase of 1560 km^2/yr. Unless countermeasures are taken, the desertified land will further increase to about 7.53×10^4 km^2 by the year 2000 (Zhang and Yin, 1986). This approximates the area of Ningxia province.

19

NEW EVIDENCE RELATING THE SOLAR CYCLE TO VARIATIONS IN THE ATMOSPHERE.

An intriguing relationship has been discovered between the strength of the polar vortex and the 11-year solar cycle when data are stratified according to the east and west phases of the equatorial Quasi-Biennial Oscillation (QBO). Labitzke (1987) found a correlation of 0.77 when plotting stratospheric (30-hectopascal level) winter temperatures at the north pole in the West Years of the QBO as a function of the 11-year solar cycle. This suggests that the polar vortex can warm and break down in the westerly phase of the QBO when the solar cycle is at a peak.

In the northern winter, the apparent solar influence is as clear in the troposphere as in the stratosphere (van Loon and Labitzke, 1988). In the east phase of the QBO, it emerges in the sea-level pressure anomalies as the North Pacific Oscillation, and in the west phase as the North Atlantic Oscillation. *Figure 55* shows the strong correlation (0.77) between sea-level pressure differences in the western North Atlantic and the solar maxima and minima in West Years which indicates that the meridional pressure contrast is smaller in solar maxima than in minima. This means that the westerlies are considerably weaker during the solar maxima. Since the difference between solar maxima and minima is coherent through the troposphere, the polar-front jet stream and the frequency and movement of low-pressure systems are also affected by the solar cycle. For instance, at 60W the frequency of lows between 40N and 50N is half in solar maxima of that in solar minima in the West Years (Labitzke and van Loon, 1989).

Despite the limited length of the data base (1956-1988), rigorous statistical significance tests suggest that the results are unlikely to have occurred by chance. Nevertheless, one cannot be certain that we are dealing with an influence of the 11-year cycle on the atmosphere unless a mechanism is found that can translate the observed small changes in solar irradiation between peak and valley of the cycle into the large effects suggested by the results of van Loon and Labitzke.

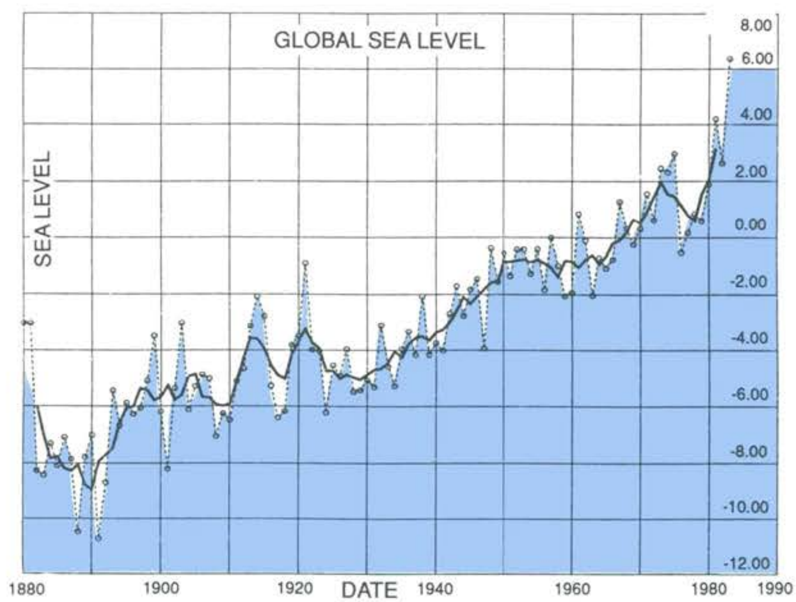


Figure 55

Time series of sea-level pressure anomalies (difference 70N, 100W - 20N, 60W) and the 10.7 cm solar flux (Note that the strength of the solar flux varies as the sunspot number.) in January-February during West Years of the QBO

(van Loon and Labitzke, 1988).

20

CHRONOLOGICAL SUMMARY OF CLIMATE ANOMALIES 1986-1988

20.1 June-July-August 1986

Equatorial Pacific oceanic and atmospheric indices began to show a mid-Pacific warming. The highest central equatorial Pacific temperatures (30°C) shifted to near the dateline. Strong convection throughout this area was associated with the low Outgoing Longwave Radiation. The southwest monsoon was progressing normally throughout the Asian basin and India. The period saw an abundance of tropical storms, hurricanes, and typhoons, several causing local damage and destruction. Precipitation deficiencies were noted in North America, central South America and China. The drought in Southern Brazil, N.E. Argentina and Paraguay continued to intensify. The western Sahel region also experienced abnormally dry conditions.

20.2 September-October-November 1986

All Pacific indices indicated that a moderate El Niño was forming. Indicative of this event was the sharp rise in the pier temperature at Paita, Peru (*Figure 56*). Warm conditions prevailed throughout the period in Europe and northwestern Soviet Union, with the anomaly being as large as 10°C above normal. While this was occurring abnormally cold conditions prevailed over Canada and the northeastern United States. Extremely wet conditions were prevalent in eastern Brazil, with some areas receiving over 1000% of normal precipitation. Wet conditions also were experienced over Taiwan and southeastern China with reporting stations having between 250 and 1000% of normal precipitation. Much of this precipitation resulted from typhoons and tropical storms. During this period southeastern Europe reported less than 50% of normal precipitation. Early withdrawal of the southwest monsoon left parts of India and Southeast Asia in an extremely dry situation.

Figure 56

Time series of sea-surface temperature at Paita Peru 1956

(F.;Chavez, Duke University, Marine Biological Laboratory, Beaufort, NC, USA).

20.3 December 1986-January-February 1987

Atmospheric convection, as inferred from the satellite-derived outgoing long-wave radiation data, was enhanced along the equator in the ENSO area. The OLR anomaly field contained features associated with the mature phase of an ENSO event. Many global anomalies began that may have been related to this event. Abnormally warm conditions prevailed throughout north-central North America, in many areas as high as 10°C above the long-term normal. South-central Soviet Union and China (*see Figure 57*) also experienced abnormally high temperatures throughout the period. Drought-like conditions were observed in the northeastern United States and the maritime Provinces of Canada. In addition, very dry conditions extended throughout the period in Japan, Malaysia and Sumatra. Heavy precipitation occurred in Ecuador and northwestern Peru, with some areas experiencing up to 950% of normal precipitation. Extremely wet conditions occurred in central Australia, partially a result of typhoon Elsie. In southern Africa, near or above-normal precipitation occurred during the rainy season. Large parts of southern Asia were unusually dry with only small areas receiving normal or above-normal precipitation during the rainy season.

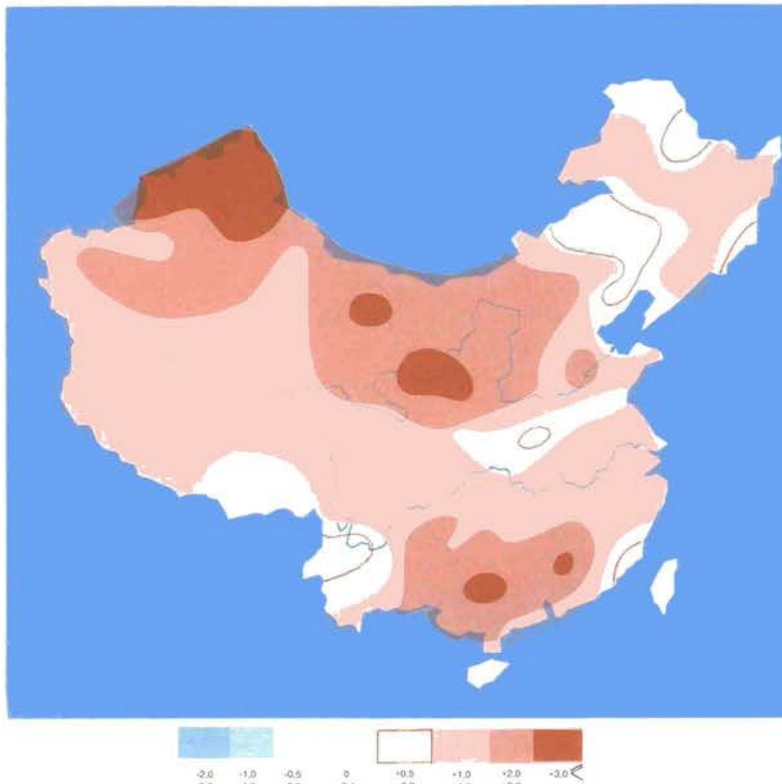


Figure 57

Seasonal mean winter (December 1986-February 1987) temperature anomalies over China relative to the period 1951-80

(Xu Qun, data from the Central Meteorological Observatory of China).

20.4 March-April-May 1987

Anomalously strong atmospheric convection occurred throughout the central and eastern equatorial Pacific during the period, while weaker-than- normal convection was observed in the area of the Philippines and Indonesia. ENSO-related events were reported globally. Extremely warm conditions prevailed throughout the northern United States and southern Canada, while slightly warmer than normal conditions prevailed in the Philippines. Cold conditions occurred in southern Europe and parts of northern Africa. The dry and warm weather reported in the Philippines resulted in drought conditions. Similar conditions were reported throughout the Australasian basin and Southeast Asian area. Dry conditions also occurred throughout the Caribbean and Central American countries. In Africa, the Sahel area also continued to be abnormally dry (*see Figure 58*).

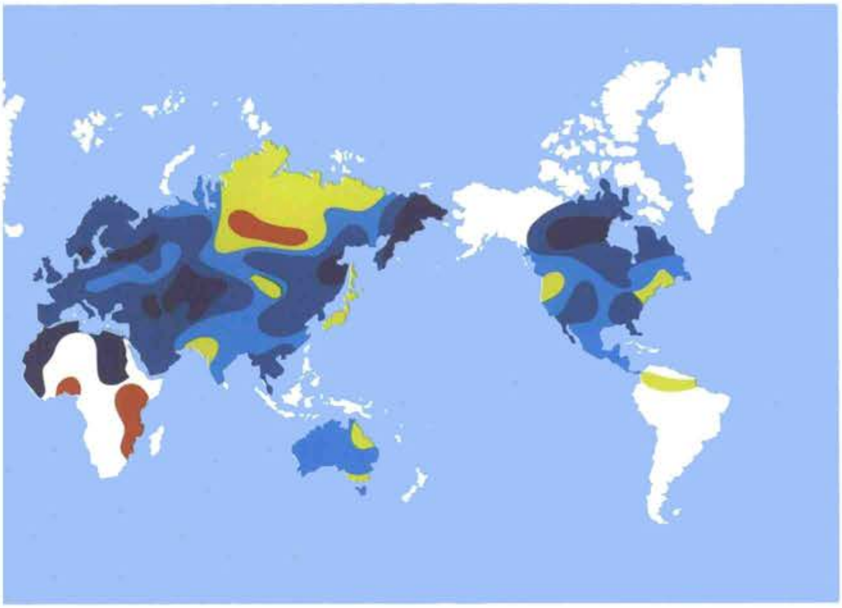


Figure 58

Anomalies of mean annual global solar radiation in 1987. Data are from the World Radiation Data Centre at Leningrad, USSR with anomalies being derived from data over the period extending as far back as 1964. Due to the lack of data, anomalies have not been presented over the oceans and some continental areas. In 1986 as well as 1987, areas with negative anomalies were more extensive than those with positive anomalies which means less solar radiation reaching the earth's surface. Analysis of seasonal variations showed that the negative annual anomalies resulted from a decrease in radiation (due to an increase in the amount or density of cloud) in the June-September period, while positive anomalies appeared due to a decrease in the amount or density of cloud in the October-January period.

20.5 June-July-August 1987

The ENSO event continued with positive sea-surface temperature anomalies, weaker than normal low-level atmospheric easterlies and enhanced atmospheric convection continuing to dominate the central equatorial Pacific. This pattern was consistent with an eastward displacement from normal of the position of the South Pacific Convergence Zone, which resulted in drier than normal conditions in the region of New Guinea southeastward through the Solomon Islands to New Caledonia and Fiji. Abnormally warm conditions prevailed through Eastern Europe with temperatures averaging 9°C above normal. As discussed above, Fiji and French Polynesia were very dry throughout the period, recording less than 50% of normal precipitation. The Sahel region also reported below-normal precipitation. The major warm anomalies were in the African Sahel and northwestern India which exacerbated drought conditions in those regions. Unusually dry conditions continued in the Caribbean islands and Central America. In Canada, a devastating tornado struck Edmonton, Alberta (*see Figure 59*).

Figure 59

A tornado devasted parts of Edmonton, Alberta Canada on July 31, 1987 causing the death of 26 people. This was the second worst tornado disaster ever in Canada.

20.6 September-October-November 1987

The ENSO event continued with many areas of the globe experiencing effects correlated to the event. However, many of the indices indicated a trend toward normal. The Southern Oscillation Index finally returned to 0 and the 850-hPa winds showed a trend toward decreasing westerlies and increasing easterly anomalies. Near the end of the period, a noticeable decrease in convective activity returned the eastern Pacific to normal. This obviously was the signal that the event was ending. Warm conditions prevailed in central North America and the Pacific coastal areas. Central Australia experienced temperatures of 4°C above normal throughout the period. The Sahel area of Africa continued to report well-above-normal temperatures while in the central Soviet Union, temperatures remained 10 to 13°C below normal. Fiji and other Pacific islands remained significantly dry. The Philippines and Central America continued to experience drought-like conditions. These were all anticipated results related to the ENSO event. Signals of the upcoming North American drought were evident in significantly dry conditions in central Canada and the United States. A weak and late Indian monsoon left many parts of India with below normal precipitation. Parts of Taiwan experienced excessive rainfall and severe flooding in association with typhoon Lynn (*see Figure 60*).

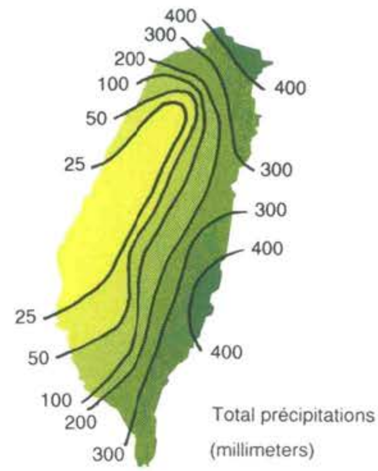


Figure 60 Parts of Taiwan experienced excessive rainfall and severe flooding in association with Typhoon Lynn. Most of the precipitation occurred on 24th and 25th of October, in association with Typhoon Lynn to the south and a slow-moving front to the north. Satellite pictures indicated that the "front" did most of the damage in northern Taiwan. This map features total precipitation from 22-27 October

(Climate Analysis Center, WMC-Washington, D.C., USA).

20.7 December 1987-January-February 1988

ENSO trends continued their progression toward normal. Positive sea-surface temperature anomalies decreased sharply along the equator throughout the index regions. However, greater-than-normal convective activity was evident from the OLR anomaly pattern. This was a result of residual positive SST anomalies which supported enhanced cloudiness and precipitation. Temperatures throughout the Philippines continued above normal. Warm conditions also prevailed throughout India, with temperatures averaging more than 4°C above normal. Extremely mild conditions prevailed across northeastern China, Korea and parts of Japan. Departures up to 10°C above normal were recorded in some areas. Due to the warm temperatures, there was no snow cover in the northern parts of this area as late as the end of January. Both western and eastern Canada and the United States experienced extremely dry conditions with many areas recording no precipitation during the period. Parts of Australia were extremely dry with several areas reporting less than half their normal rainfall. Much of the coastal and mountainous regions near Rio de Janeiro were inundated with torrential rainfall in February (*see Figure 61*). The floods and

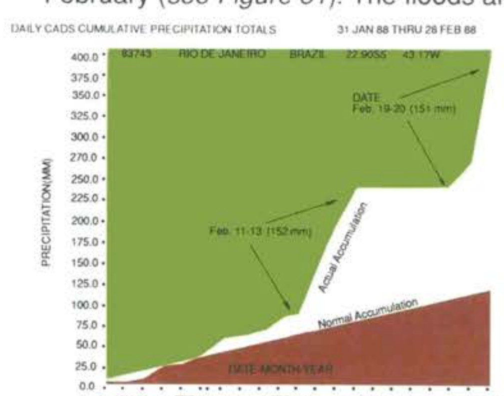


Figure 61 Heavy precipitation falls in Rio de Janeiro during February 1987. The majority of the precipitation occurred during February 11-13 and February 19-20. The first episode dropped 152 mm, while over 151 mm fell during the latter dates. During the second occurrence, 127 mm was measured on February 20 alone, the majority of which fell during a four-hour downpour

(from CAC/WMC - Washington D.C.).

mudslides that followed were most likely enhanced by saturated soils from previously heavy rains. In Africa, heavy precipitation inundated portions of southern Africa. Totals in some areas exceeded 200 mm over a two-week period.

20.8 March-April-May 1988

The ENSO event of 1987-1988 finally ended as the Southern Oscillation Index exhibited a major change in April. The OLR returned to its normal pattern. Convection throughout the central Pacific area also returned to normal conditions. Above-normal temperatures prevailed along the United States and Canada border. Southern South America experienced cold conditions, averaging 5-6^{0}C below normal. Conditions in Central Europe averaged 4-5°C above normal. Above-normal temperatures and extremely dry weather led to drought conditions in central and eastern Canada and the United States. Central Europe also reported well-below-normal precipitation throughout the period, that lead to near-drought conditions. Central America continued with warm temperatures and dry conditions that had persisted for the previous 26 weeks.

20.9 June-July-August 1988

The El Niño phase of the ENSO finally came to an end. However, a high-index phase of the Southern Oscillation demonstrated signs of beginning by the end of the period. Central and southern Europe and northwestern Africa experienced a very warm anomaly in the later part of the period. Very warm and dry weather prevailed in the central and eastern United States and adjacent areas of Canada which led to one of the worst droughts this century. An extreme cold wave with below-freezing temperatures hit the Brazilian coffee region, causing widespread damage to the crop. Dry conditions were also reported throughout southern Europe. Heavy precipitation was experienced in western Africa causing some local flooding and damage. Above-normal rainfall was reported in the central Sahel region of Africa, breaking a prolonged period of below-normal rainfall which had persisted for nearly 20 years (*Figure 62*).

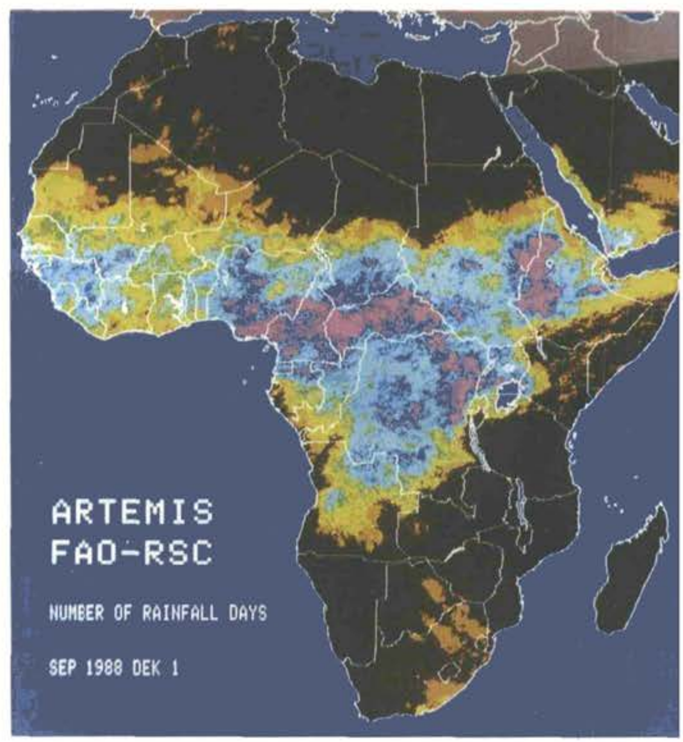


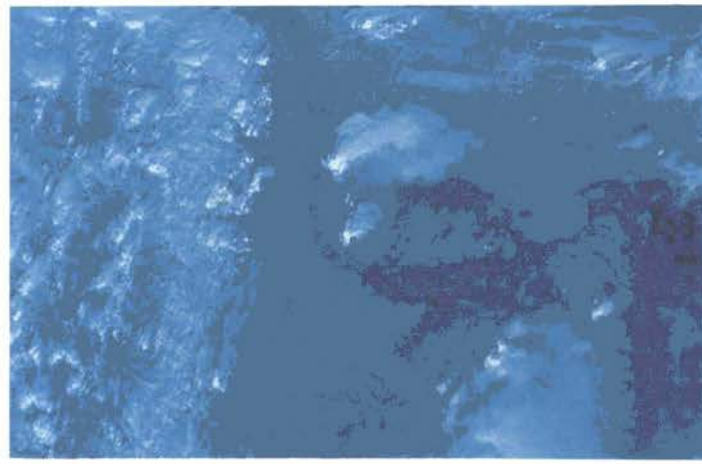
Figure 62

Number of rainfall days in Africa - September 1988. This image is from the operational satellite environmental monitoring system, ARTEMIS, implemented by the Food and Agriculture Organization of the UN in 1988, in cooperation with NASA Goddard Space Flight Center, the National Aerospace Laboratory of the Netherlands and the Universities of Reading, Bristol, for real/near realtime precipitation and vegetation assessment in Africa, the Near East and southwest Asia, based on the integrated use of high-frequency Meteosat and NOAA AVHRR data.

20.10 September-October-November 1988

The high-index phase of the Southern Oscillation continued to increase during this period. Negative anomalies appeared in the OLR anomaly charts indicating a decrease in convective activity in the central Pacific area. This is the opposite of the El Niño phase. Alaska and northern Canada experienced extremely cold conditions as did eastern Europe, while most of Siberia reported temperatures 7-11°C above normal. Dry conditions persisted throughout Central America and in central South America. However, Tropical Storm Miriam passed through Central America with heavy precipitation which alleviated the dry conditions somewhat. The Sahel region returned to dry conditions following a period of near-normal precipitation. Many rivers in Bangladesh rose to unprecedented levels in September (*Figure 63*), inundating almost three-quarters of the country. More than 1500 people were drowned and almost 300,000 head of cattle lost. Over ten million houses were completely destroyed and 1.5 million ha of crops ruined. The country was still reeling from the effects of these floods when it was struck by a severe cyclonic storm on 29 November (*Figure 64*). Typhoon Ruby brought heavy rains to the Philippines with some areas reporting over 331 mm of rain in a two-day period.

The image was derived from methodology which uses a manual image analysis procedure, combined with computerized data processing and enduser product generation for obtaining ten-day and monthly estimated rainfall images for Africa on a one-degree grid (approx. 100 x 100 km) as well as monthly rainfall anomaly maps, obtained by computerized comparison of the actual estimated monthly rainfall with the long-term mean monthly rainfall, stored as digital reference maps in the computer system, in terms of percentage departures from normal.



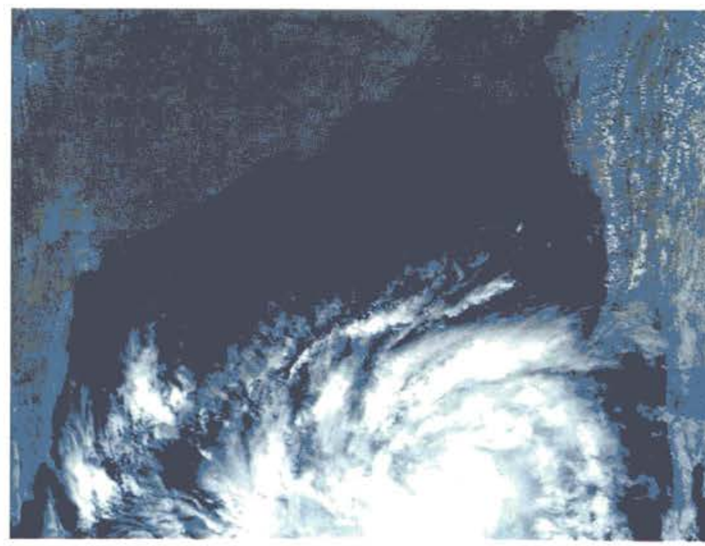


Figure 63

Bangladesh floods from NOAA-9, September 19, 1988, AVHRR LAC Channel 2. An estimated 75 to 80% of the country was flooded, thousands missing

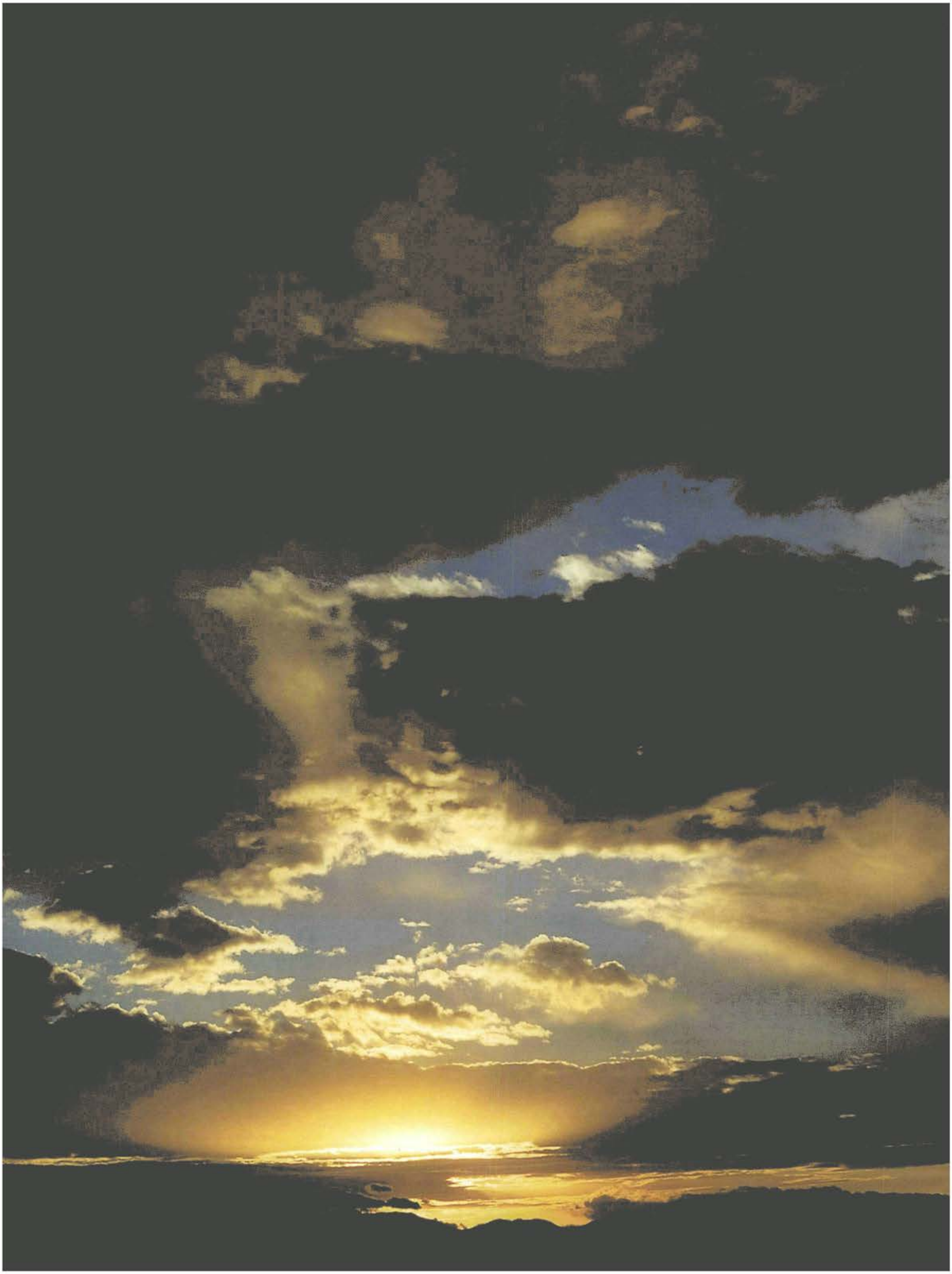
(photo provided by R. M. Carey, Satellite Research Laboratory NOAA/NESDIS).

Figure 64

Bay of Bengal typhoon approaching Bangladesh, November 25, 1988. AVHRR LAC Channel 2 with colour enhancement. 500 people reported killed, 1,000 missing from tidal wave forced up the Ganges delta

(photo provided by R.;M. Carey, Satellite Research Laboratory NOAA/NESDIS).

This imagery-based analysis agrees well with the observations of dryness in Gabon, the continuation of a prolonged wet spell in western Kenya and the return to near-normal precipitation in the Sahel.



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REFERENCES

Alley, W. M., 1984: The Palmer Drought Severity Index: Limitations and Assumptions. Journal of Climate and Applied Meteorology, Vol. 23, pp. 1001-1009.

Barnston, A. G. and R. E. Livezey, 1989: An Evaluation of an Association between the 11-Year Solar Cycle, the QBO, and the Atmosphere. Proc. 13th Clim. Diagnost. Workshop, 1988, Cambridge, Mass., pp. 102-108. An extended version has been submitted to J. Clim.

Bergman, K. H., 1987: The Global Climate of September-November 1986: A Moderate ENSO Warming Develops in the Tropical Pacific., Mon. Wea. Rev., 115, pp. 2524-2541.

Bergman, K. H., D. F. Ropelewski and M. S. Halpert, 1986: The Record Southeast Drought of 1986. Weatherwise, Vol. 39, pp. 262-266.

Bhatia, B. M., 1967: Famines in India, Asia Publishing House, Bombay, pp. 1-2.

Bjerknes, J., 1969: Atmospheric Teleconnections from the Equatorial Pacific. Mon. Wea. Rev., 97, pp. 163-172.

Bodhaine, B. A., J. J. DeLuisi, J. M. Harris, P. Houmere and S. Bauman, 1986: Aerosol Measurements at the South Pole. Tellus, Vol. 38B, pp. 223-235-

Bradley, R. S., 1988: The Explosive Volcanic Eruption Signal in Northern Hemisphere Continental Temperature Records. Climatic Change, Vol. 12, pp. 221-244.

Bryant, E., 1988: Sea-level Variability and Its Impact within the Greenhouse Scenario, in Pearman, G. I., Ed., Greenhouse: Planning for Global Change, CSIRO, Melbourne, Australia, pp. 135-146

Case, R. A., 1988b: Atlantic Hurricanes - A Subdued Season. Weatherwise Vol. 41. pp. 25-29.

Chang, F. C. and J. M. Wallace, 1987: Meterological Conditions during Heat Waves and Droughts in the United States Great Plains. Monthly Weather Review, Vol. 115. pp. 1253-1269.

Changnon, Jr., S. A., 1987: Climate Fluctuations and Record-high Levels of Lake Michigan. Bulletin of the American Meteorological Societz, Vol. 68, pp. 1394-1402.

Chowdhury, A., M. M. Dandekar and P. S. Raut, 1989: Variabili ty in Drought Incidence over India - A Statistical Approach, Mausan, 40, 2, pp. 207-214.

Clark, G. and M. Lawrence, 1987: North Atlantic Tropical Cyclones, 1986. Mariners Weather Log, Vol. 31, No. 1, pp. 18-24.

Climatic Perspectives, Vol. 8-9, January 1986-December 1988: Canadian Climate Center, AES, Downsview, Ontario.

Conte M. and A. Giuffrida, 1988: The Mediterranean Oscillation: General and Specivic Climatic Aspect. Submitted to Rivista Met. Aeron.

Conte M. and S. Palmieri, 1988: Tendenze evolutive del clima d'Italia. Proceedings of "Giornata Ambiente-Atmosfera", Acc. Naz. Lincei, Rome, June 1988 (in press).

Cross, R., 1987: Eastern North Pacific Tropical Cyclones - Another Near-record Year. Weatherwise, Vol. 40, pp. 25-26.

Cross, R., 1988a: Eastern North Pacific Tropical Cyclones - Another Active Year. Weatherwise, Vol. 41, pp. 30-31.

D'Agostino, A., 1987: Il problema delle variazioni climatiche; analisi critica delle Metodologie, Indagini su serie storiche ita liane. Thesis, Universit! degli Studi "La Sapienza", Roma.

de la Lanza, G. and Galindo, I., 1989:ENSO 1986-87 at Mexican Subtropical Pacific Offshore Waters. Atm;sfera, 2, pp. 17-30.

Diaz, H. F., 1986: An Analysis of Twentieth Century Climate Fluctuations in Northern North America. Journal of Climate and Applied Meteorology, Vol. 25 pp. 1625-1657.

Dong, Yuxiang, 1987: The Role of Population in Desertification, in "Population of the Northwest" (in Chinese), No. 1.

Drought Network News, Vol. 1, January 1989-May 1989. Intern ational Drought Information Center, University of Nebraska, Lincoln, NE.

Druyan, L. M., 1989: Advances in the Study of Sub-Saharan Drought. Journal of Climatology, Vol, 9, pp. 77-90.
Dutton, E. G., J. J. DeLuisi and A. P. Austring, 1985: Interpretation of Mauna Loa Atmospheric Transmission Relative to Aerosols, Using Photometric Precipitable Water Amounts. J. Atm. Chem., Vol. 3, pp. 53-68.
Eder, V. K., J. M. Davis and J. F. Monahan, 1987: Spatial and Temporal Analysis of the Palmer Drought Severity Index over the South-eastern United States. Journal of Climatology, Vol. 7, pp. 31-56.
Ehhalt, D. J., P. J. Fraser, D. Albritton, Y. Makide, R. J. Cicerone, F. S. Rowland, M. A. K. Khalil, L. P. Steele, M. Legrand and R. Zander, 1988: Trends in Source Gases, Chapter 8 in: Report of the International Ozone Trends Panel, WMO Ozone Report No. 18, 1988.
Ellsaessesr, H. W., M. C. MacCracken, J. J. Walton and S. L. Grotch, 1986: Global Climatic Trends as Revealed by the Recorded Data. Rev. Geophys., Vol. 24, 745-792.
Evans, W. F. J., 1989: Chemical Depletion of Ozone at Alert in February 1989, Geophys. Res. Lett.
Evans, W. F. J., 1989:A Hole in the Ozone Layer in the Arctic in March, 1986, Can. J. Phys.
Farman, J. C., B. G. Gardiner and J. D. Shanklin, 1985: Large Losses of Total Ozone in Antarctica Reveal Seasonal C10x/NOx Interation. Nature, Vol. 315, pp. 207-210.
Folland, C. K., T. N. Palmer and D. E. Parker, 1986: Sahel Rainfall and Worldwide Sea Temperatures, 1901-85. Nature, Vol. 320, No. 6063, pp. 602-607.
Folland, C. K. and D. E. parker, 1989: Observed Variations of Sea Surface Temperature. In (M. F. Schlesinger, Ed.). Climate-Ocean Interation Kluwer Academic Publishers (in press).
Folland, C. K. and D. E. Parker, 1985: Workd-wide and Regional Variations of Surface Marine Temperature 1856-1985. Proc. of the Joint Royal Meteoro. Soc./Hellenic Meteoro. Soc. Meeting (Athens, April 1985).
Fraser, P. J., R. J. Francey, J. Mansbridge and I. E. Enting, 1989: The CSIRO Global Methane Program, submitted to J. Atmos. Chem. Presented at the Second Conference on the Scientific Application of Baseline Observations of Atmospheric Composition (SABOAC II), CSIRO, Aspendale, Victoria, Australia, November 14-17, 1988.
Galindo , I., 1987: El Niño/Oscilación Suriana en las costas del Pacifico mexicano. Mem. IIa. Reunión indicativa Act. Regionales Rel. con la Oceanogr., Com. Intersec. Inv. Oceanog. (in press).
Gao, Youxi and Xu Shu-Ying, 1962: Some Problems about Monsoon of East Asia, pp. 78-87, Science Press (Beijing).
Gornitz, V., 1989: Mean Sea-level Changes in the Recent Past, in Proc. of Int. Workshop on Climatic Change, Sea Level, Severe Tropical Storms, and Assoc. Impacts, Norwich, England, UNEP, CEC, U.S. EPA, and U. K. Water Res. Cen. (in press).
Gornitz, V. and S. Lebedeff, 1987: Global Sea-level Changes during the Past Century, In Nummedal, D., Pilkey, O. H., and Howard, J. D., Eds., Sea-level Fluctuation and Coastal Evolution, SEPM Special Publication No. 41, pp. 3-16.
Halpert, M. S., 1988: The Global Climate for December 1987-February 1988: A Return to Normal in the Tropical Pacific. J. Climate, 1, pp. 627-652.
Heim, Jr., R. R., 1988: About that Drought. Weatherwise, Vol. 41, pp. 266-271.
Heim, Jr., R. R. 1989a: Drought in the U.S. 1988: Severity and Historical Perspective. Drought Network News, Vol. 1, No. 1, pp. 7-8.
Heim, Jr. R. R., 1989b: Historical Perspective: Drought in the U.S. Drought Network News, Vol. 1, No. 2, pp. 14-15.
Henry, J. A. and S. E. Dicks, 1988: On Drought in South-eastern United States. Journal of Climatology, Vol. 8, pp. 529-531.
Hoffman, D. S. and P. Amideau, 1989: Ozone Depletion at Kiruna in January, 1989, Nature, July 19.
Holton, J. R., and H.-Ch. Tan, 1980: The Influence of the Equatorial Quasi-Biennial Oscillation on the Global Circulation at 50 mb., J. Atmos. Sci., 37, pp. 2200-2208.
Janowiak, J. E., 1988: The Global Climate of March-May 1988: The end of the 1986-1987 Pacific Warm Episode and the Onset of Wide-spread Drought in the United States. J. Climate, 1, pp. 1019-1040.
Jarvinen, B. R., C. J. Neumann and M. A. S. Davis, 1984:A Tropical Cyclone Data Tape for the North Atlantic Basin, 1886-1983: Contents, Limitations, and Uses. NOAA Technical Memorandum NWS NHC 22, National Hurricane Center, Miami, 21 pp.
Jiang Youxu, 1988: Forest and Environment, in "Forest and Mankind" (in Chinese), No. 3, pp. 9-12.
Jones, P. D., 1988: The Influence of ENSO on Global Temperatures. Climate Monitor, Vol. 17, No. 3.
Jones, P. D., P. M. Kelly, C. M. Goodess and T. R. Karl, 1989: The Effect of Warming on the Northern Hemisphere Temperature Average. Journal of Climate 2, pp. 285-290.
Jones, P. D., S. C. B. Raper, R. S. Bradley, H. F. Diaz, P. M. Kelly and T. M. L. Wigley, 1986a: Northern Hemisphere Surface Air Temperatures: 1851-1984. Journal of Climate and Applied Meteorology 25, pp. 161-179.
Jones, P. D., S. C. B. Raper, R. S. Bradley, J. F. Diaz, P. M. Kelley and T. M. L. Wigley, 1986: Northern Hemisphere Surface Air Temperature Variations, 1851-1984. Journal of Climate and Applied Meteorology, Vol. 25, pp. 161-179.
Jones, P. D., S. C. B. Raper and T. M. L. Wigley, 1986b: Southern Hemisphere Surface Air Temperatures: 1851-1984. Journal of Climate and Applied Meteorology 25, pp. 1213-1230.
Jones, P. D., T. M. L. Wigley and G. Farmer, 1990: Marine and Land Temperature Data Sets: A Comparison and a Look at Recent Trends. In M. E. Schlesinger Ed., Greenhouse Gas Induced Climate Change. Kluwer Academic Publishers (in press).
Jones, P. D., T. M. L. Wigley and P. B. Wright, 1986c: Global Temperature Variations between 1861-1984. Nature 322, pp. 430-434.
Kalnichy, R. A., 1987: Seasons, Singularities, and Climatic Changes over the Midlatitudes of the Northern Hemisphere during 1899-1969. Journal of Climate and Applied Meteorology, Vol. 26, pp. 1496-1510.
Kane, R. P. and N. B. Trivedi, 1986: Are Droughts Predictable? Climatic Change Vol. 8, pp. 209-224.
Karl, T. R., 1988: Multi-year Fluctuations of Temperature and Precipitation: The Gray Area of Climate Change. Climatic Change, Vol. 12, pp. 179-198.
Karl, T. R. and P. J. Young, 1987: The 1986 Southeast Drought in Historical Perspective. Bulletin of the American Meteorological Society, Vol. 68, pp. 773-778.
Karl, T. R., G. Kukla and J. Gavin, 1987: Recent Temperature Changes during Overcast and Clear Skies in the United States. Journal of Climate and Applied Meteorology, Vol, 27, pp. 698-711.
Karl, T. R. and Jones, P. D., 1989: Urban Bias in Area-averaged Surface Air Temperature Trends. Bulletin of the American Meteorological Society, 70, pp. 265-270.
Kousky, V. E., 1988: Evolution of the 1986-87 Pacific Warm Episode. WCP Newsletter, 10, pp. 10-11. World Climate Programme, WMO.
Kousky, V. E., 1987: The Global Climate for December 1986-February 1987: El Niño Returns to the Tropical Pacific. Mon. Wea. Rev., 115, pp. 2822-2838.
Kousky, V. E., 1987: The Global Climate for September-November 1988: High Southern Oscillation Index and Cold Episode Characteristics Continued. J. Climate, 2, pp. 173-192.
Kousky, V. E. and A. Leetmaa, 1988: The 1986-87 Pacific Warm Episode: Evolution of Oceanic and Atmospheric Anomaly Fields. Subm. to J. Dyn. Climate.
Krepper, C. M., B. V. Scian and J. O. Pierini, 1989: Time and Space Variability of Rainfall in Central-east Argentina. Journal of Climate, Vol. 2, pp. 39-47.

Krishnamurti, T. N., H. S. Bedi and M. Subramaniam, 1989: The Summer Monsoon of 1987. Journal of Climate, Vol. 2, pp. 321-340.
Kukla, G. and J. Gavin, 1981: Cool Autumns in the 1970's. Monthly Weather Review, Vol. 109, pp. 903-908.
Kumar, K. R. and L. S. Kingane, 1988: Long-term Variations of Surface Air Temperature at Major Industrial Cities of India. Climatic Change, Vol. 13, pp. 287-308.
Labitzke, K., 1987: Sunspots, the QBO, and the Stratoospheric Temperature in the North Polar Region. Geophys. Res. Lett., 14, pp. 535-537.
Labitzke, K. and H. van Loon, 1989: Association between the 11-year Solar Cycle, the QBO, and the Atmosphere. Part III: Aspects of the Association. Journal of Climate, Vol. 2, pp. 554-565.
Landscheidt, T., 1988: Solar Rotation, impulses of the Torque in the Sun's Motion, and Climatic Variation. Climatic Change, Vol. 12, pp. 265-296.
Lawrence, M., 1987: Atlantic Hurricane Season - Mild, Not Wild. Weatherwise, Vol. 40, pp. 21-24.
Lawrence, M. B., 1989: Return of the Hurricanes. Weatherwise, Vol. 42, pp. 22-27.
LeComte, D., 1989a: The Rains Return to the Tropics. Weatherwise, Vol. 42. pp. 8-12-
LeComte, D., l989b:A Sun-baked Summier in the U.S. Weatherwise, Vol. 42, pp. 13-16.
Maheras, P., 1988: Changes in Precipitation Conditions in the Western Mediterranean over the Last Century. Journal of Climatology, Vol. 8, pp. 179-190.
Mariners Weather Log, Vol, 30-33. Winter 1986-Winter 1989: National Oceanographic Data Center, NOAA, Washington, D.C.
Mass, C. F. and D. A. Portman, 1989: Major Volcanic Eruptions and Climate: A Critical Evaluation. Journal of Climate, Vol. 2, pp. 566-593.
Mendonca, B. G., K. J. Hanson and J. J. DeLuisi, 1978: Volcanically Related Secular Trends in Atmospheric Transmission at Mauna Loa Observatorx, Hawaii. Science, Vol. 202, pp. 513-515.
Meteorological Monthly, 1986, 1987 and 1988: Climatic Data Office of State Meteorological Administration (Beijing).
Monthlx Climatic Data for the World, Vol. 39-41, January 1986-December 1988: National Climatic Data Center, NOAA, Asheville, NC.
Mooley, D. A. and B. Parthasarathy, 1983: Variability of Indian Summer Monsoon and Tropical Circulation Feature. Mon. Weath. Rev., 111, pp. 967-978.
Neumann, C. J., B. R. Jarvinen, A. C. Pike and J. D. Elms, 1987: Historical Climatology Series 6-2: Tropical Cyclones of the North Atlantic Ocean, 1871-1986. National Climatic Data Center, NOAA, Asheville, NC, 186 pp.
Newell, R. E. and J. W. Kidson, 1984: African Mean Wind Changes between Sahelian Wet and Dry Periods. J. Climatology Vol. 4, pp. 27-33.
Nicholson, S. E., 1985: Sub-Saharan Rainfall 1981-1984. J. Clim. and Appl. Meteor., Vol. 24, pp. 1388-1391.
Nicholson, S. E., 1986: The Nature of Rainfall Variability in Africa South of the Equator. Journal of Climatology, Vol. 6 pp. 515-530.
Ogallo, L. J., 1988: Relationship between Seasonal Raiunfall over East Africa and the Southern Oscillation. J. Climatology, 8, pp. 31-43.
Ogallo, L. J., T. E. Janowiak and M. S. Halpert, 1988: Teleconnections between East African Rainfall and Global Sea Surface Temperature Anamolies. J. Met. Soc. Japan, 66, 6, pp. 807-822.
Olaniran, O. J. and G. N. Sumner, 1989:A Study of Climatic Variability in Nigeria Based on the Onset, Retreat, and Length of the Rainy Season. Journal of Climatology, Vol. 9, pp. 253-270.
Olapido, E. O., 1987b: Some Features of the Growing Season Precipitation Fluctuations in the Interior Plains of North America. Journal of Climatology, Vol. 7, pp. 531-540.
O'Lenic, E. A., 1988: The Global Climate for September-November 1987: Mature Phase of Tropical Warm Event Continues Amid Global Warmth and Dryness. J. Climate, 1, pp. 548-568.
Owen, J. A. and C. K. Folland 1988: Modelling the Influence of Sea-surface Temperatures on Tropical Rainfall. 'Recent Climatic Change' (Ed. S. Gregory), Belhaven Press, London, pp. 141-153.
Palmer, W. C., 1965: Meteorological Drought. Research Paper No. 45, U.S. Weather Bureau, 58 pp. [NOAA Library and Information Services Division, Washington, D.C. 20852].
Palmer, T. N., 1986: Influence of the Atlantic, Pacific and Indian Oceans on Sahel Rainfall. Nature, Vol. 322, pp. 251-253.
Parker, D. E., C. K. Folland, and M. N. Ward, 1988: Sea-surface Temperature Anomaly Patterns and Prediction of Seasonal Rainfall in the Sahel Region of Africa. 'Recent Climatic Change' (Ed. S. Gregory), Belhaven Press, London, pp. 166-178.
Peltier, W. R. and Tushingham, A. M., 1989: Gloval Sea Level Rise and the Greenhouse Effect: Might They Be Connected? Science, Vol. 244, pp. 806-810.
Pirazzoli, P. A., 1986: Secular Trends of Relative Sea-level Changes (RSL) Indicated bz Tide-gauge Records. J. Coastal Res., Sepc. Issue 1, pp. 1-26.
Posmentier, E. S., M. A. Cane, and S. E. Zebiak, 1989: Tropical Pacific Climate Trends since 1960. Journal of Climate, Vol. 2, pp. 731-736.
Ramage, C. S., 1971: Monsoon Meteorology, Academic Press, New York p. 6.
Rasmusson, E. M. and T. H. Carpenter, 1982: Variations in Tropical Sea Surface Temperature and Surface Wind Fields Associated with the Souther Olscillation/El Niño, Mon. Wea. Rev., 110, pp. 354-383.
Rasmusson, E. M. and J. M. Wallace, 1983. Meteorological Aspects of the El Niño/Southern Oscillation. Science, 222, pp. 1195-1202.
Reynolds, R. W., 1988:A Real-time Global Sea Surface Temperature Analysis. J. Climate, 1, pp. 75-86.
Rind, D., R. Goldberg and R. Ruedy, 1989: Change in Climate Variability in the 21st Century. Climatic Change, Vol. 14, pp. 5-38.
Ropelewski, C. F., 1988: The Global Climate System for June-August 1988: A Swing to the Positive Phase of the Southern Oscillation: Drought in the United States and Abundant Rains in Monsoon Areas. J. Climate, 1, pp. 1153-1174.
Ropelewski, D. F. and M. S. Halpert, 1987: Global and Regional Scale Patterns Associated with the El Niño/Southern Oscillation. Mon. Wea. Rev., 115, pp. 1606-1626.
Ropelewski, C. F. and M. S. Halpert, 1989: Precipitation Patterns Associated with the High Index Phase of the Southern Oscillation. J. Climate, 2, pp. 268-284.
Ropelewski, C. F. and M. S. Halpert, 1989: The Southern Oscillation and Northern Hemisphere Temperature Variability. Proceedings of the DOE Workshop on Greenhouse Gas-Induced Climate Change, 8-12 May, 1989, Univ. of Massachusetts.
Rosen, J. R., S. A. Oltmanns and W. F. J. Evans, 1989: Observations of Polar Stratospheric Clouds, Nitric Acid and Ozone Alert, 1989, Geophys. Res. Lett.
Sadler, J. D., M. A. Lander, A. M. Hori and L. K. Oda, 1987: Tropical Marine Climatic Atlas, Vol. II. Pacific Ocean, University of Hawaii, UHMET 87-02.
Sarker, R. P., 1988: Drought in 1987: Causes and Remedies. Proc. Int. Conf. on Tropical Micro-meteorology and Air Pollution, New Delhi, pp. 1-2.
Schickedaz, P. T. and E. G. Bowen, 1977: The Computation of Climatological Power Spectra. J. Appl. Meteorol., 16, pp. 359-367.
Shea, D. J., 1989: Some Applications of Statistics to Solar-atmospheric Relationships. Proc. 4th Internat. Mtg. on Stat. Clim., Rotorua, 1989 (in press).
Storm Data, Vol. 28-30, January 1986-December 1988: National Climatic Data Center, NOAA, Asheville, NC.

Thomson, R. E. and S. Tabata, 1989: Steric Sea Level Trends in the Northeast Pacific Ocean: Possible Evidence of Global Sea Level Rise. Journal of Climate, Vol. 2, pp. 542-553.
Trenberth, K. E., G. W. Branstator and P. A. Arkin, 1988: Origin s of the 1988 North American Drought. Science, Vol. 242, pp. 1640-1645.
Tucker, C. J., I. Y. Fung, C. D. Keeling and R. H. Gammon, 1986: Relationship between Atmospheric CO2 Variations and a Satellite-derived Vegetation Index. Nature 319, p. 195.
U.S. Climate Analysis Center, 1986a: Climatic Diagnostics Bulletin. July, 1986. National Weather Service, Washington, D.C.
U.S. Climate Analysis Center, 1986b: Climate Diagnostics Bulletin. August, 1986. National Weather Service, Washington, D.C.
U.S. Dept. of Commerce, National Climate Program Office, 1987: Annual Report.
van Loon, J., R. A. Madden and R. L. Jenne, 1976: Oscillations in the Winter Stratosphere. Part 1. Description. Mon. Wea. Rev., 103, pp. 154-162.
van Loon and K. Labitzke, 1988: Association between the 11-year Solar Cycle, the QBO, and the Atmosphere. Part II: Surface and 700 mb in the Northern Hemisphere in Winter. J. Climate, 1, pp. 905-920.
Wagner, A. J., 1987: The Global Climate for March-May 1987: Moderately Strong Mature Phase of ENSO with Highly Persistent Monthly and Seasonal Temperature Anomalies over the United States. Mon. Wea. Rev., 115, pp. 3166-3187.
Walker, G. T., 1923: Correlation in Seasonal Variations of Weather, VIII: A Preliminary of World Weather (World Weather II). Memoirs India Meteorol. Dept., 24, pp. 75-131.
Watson, R. T., M. J. Prather and M. J. Kurylo, 1988: Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report NASA Reference Publication No. 1208. National Aeronautics and Space Administration. Washington, D.C.
WCP - 53, Report of the WMO (CAS) Meeting of Experts on the CO2 Concentrations from Pre-industrial Times to I.G.Y. (Boulder, USA, 22-25 June 1983).
Weekly Climate Bulletin, No. 86/1-88/12, January 1986-December 1988: Climate Analysis Center, NOAA, Washington, D.c.
Wolf, R., 1987: Agricultrual Drought in the Midsouth, 1986: National Weather Digest, Vol. 12, pp. 11-19.
Wolter, K., 1989: Modes of Tropical Circulation, Southern Oscillation, and Sahel Rainfall Anomalies. Journal of Climate, Vol. 2, pp. 149-172.
WMO, 1984: The Global Climate System - A Critical Review of the Climate System during 1982-1984. WMO.
WMO, 1986/87:WCDP Climate System Monitoring Bulletin Nos. 1, 2, 3, 7, 10 (1986) and No. 1 (1987).
WMO, 1987:WCDP Global Climate System Review (September 1984 to May 1986).
Woodruff, S. D., R. J. Slutz, R. L. Jenne and P. M. Steurer:A Comprehensive Ocean-atmosphere Data Set. Bulletin of the American Meteorological Society, Vol. 68, pp. 1239-1250.
Woodworth, P. L., 1987: Trends in U.K. Mean Sea Level, Mar. Geodesy, Vol. 11, pp. 57-87.
Wright, P. B., 1989: Homogenized Long-period Southern Oscillation Indices, Journal of Climatology, Vol. 9, pp. 33-54.
Wyrtki, K. and W. G. Leslie, 1980: The Mean Annual Variation of Sea Level in the Pacific Ocean. Hawaii Inst. of Geophys., University of Hawaii, 159 pp.
Wyrtki, K., 1986: Fluctuations in Upper-layer Volume or Near-surface Upper Oceanic Heat Content. In: Climate System Monitoring Bulletin No. 3, WMO.
Xu Qun, 1965: The Plum Rains (Meiyu) of the Middle and Lower Yangtze Valley for Recent 80 Years. Acta Meteorologica Sinica, 35(4), pp. 507-518.
Xu Qun and Hu Xianbain, 1986: The Influence of Zonal Thermal Difference over North Pacific on Meiyu in the Middle and lower Changjiang Valley. Scientia Atmospherica Sinica, 10(1), pp. 96-106.
Xu Qun, 1989: The Significant Change of Solar Radiation of China (in clear skies) through the Recent 28 Winters. To be published in Scientia Atmospherica Sinica.
Zhang Jijia and Yin Xianxi, 1986: Climatic Change, Drought and Desertification, in "Meteorology of China", No. 6, pp. 2-6.

ABBREVIATIONS

AVHRR Advanced Very High Resolution Radiometre
CAC Climate Analysis Centre (of the World Meteorological Centre, Washington, USA)
CSM Climate System Monitoring
ENSO El Niño/Southern Oscillation
FAO Food and Agriculture Organization
GCM Global Climate Model
GEMS Global Environmental Monitoring System
hPa hectopascals
NCDC National Climatic Data Center, Asheville, NC, USA
NESDIS National Environmental Satellite, Data, and Information Service
NOAA National Oceanic and Atmospheric Administration
ITCZ Inter-Tropical Convergence Zone
OLR Outgoing Long-wave Radiation
QBO Quasi-biennial Oscillation
SOI Southern Oscillation Index
SST Sea-surface Temperature
UNEP United Nations Environment Programme
WCDP World Climate Data Programme
WCP World Climate Programme
WMO World Meteorological Organization

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WORLD CLIMATE PROGAMME

UNITED NATIONS ENVIRONMENT PROGRAMME
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