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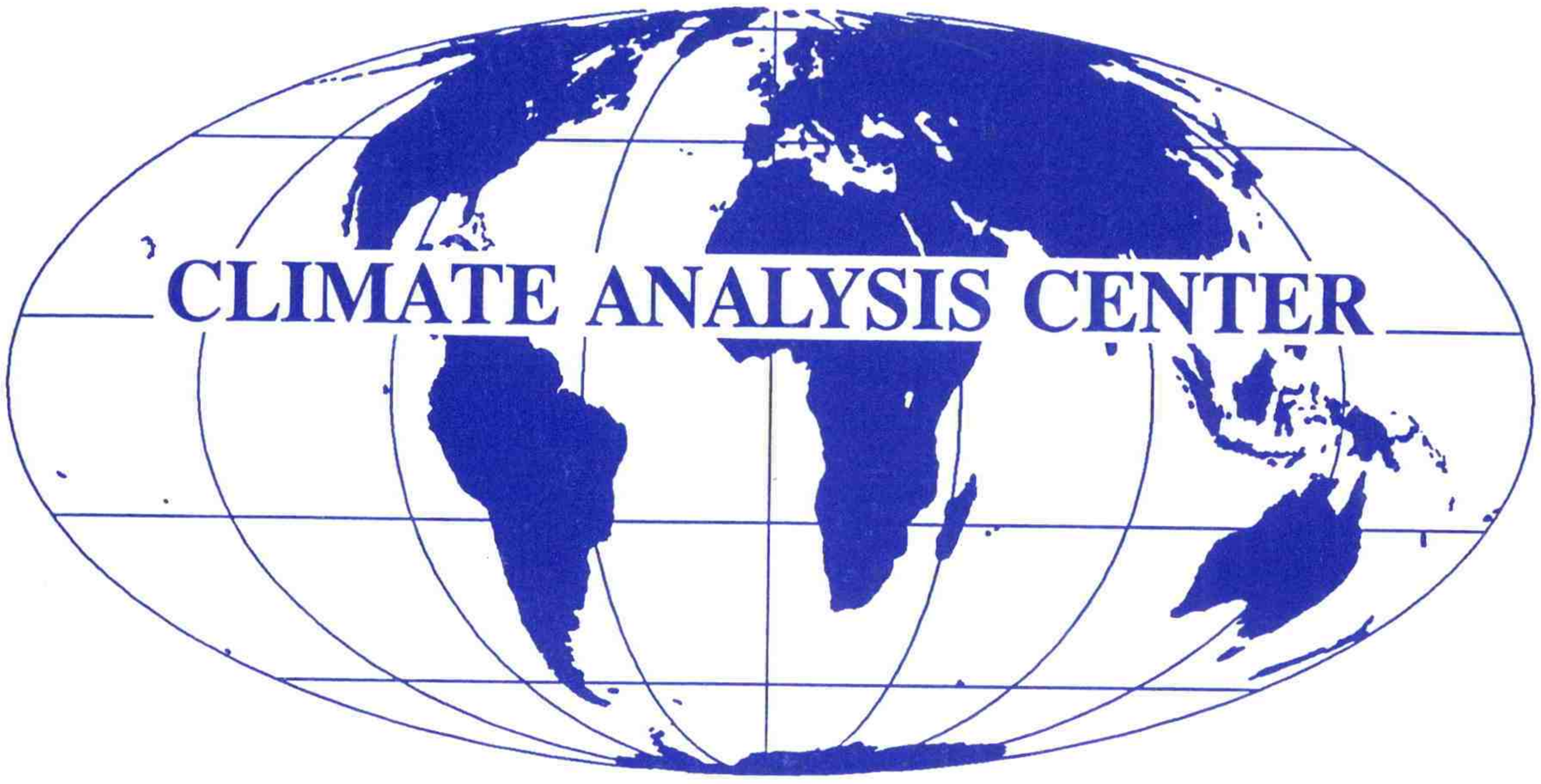

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CLIMATE ANALYSIS CENTER

FY 1991

ANNUAL REPORT

TECHNICAL EDITOR: LUKE MANNELLO

January 1992

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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EXECUTIVE SUMMARY

INTRODUCTION

After another year in a "growth industry" of climate-related issues, the variety of projects and interests at the Climate Analysis Center (CAC) defies a concise summary. Within a growing and changing environment, the mission of the CAC should be emphasized, that is, "to maintain a continuous watch on current climate fluctuations and diagnose and predict them." These efforts are designed to assist in coping with climate-related applications to food supply, water resources, and energy allocation.

This year we can present a record of progress in the monitoring of climate anomalies, in the development of diagnostic tools, and in the improvement of forecasting methods for a unified suite of four climate outlook products: 6-10 days, monthly, seasonal, and ENSO. In addition, we have taken on a new program (Regional Climate Centers) which is focused on regional climate services and applications. Through this program, we hope to continue to improve our ability to apply research results to practical problems which will benefit the national economy.

I. NEAR REAL-TIME CLIMATE PRODUCTS

Monthly Climate Diagnostics Bulletin - Improvements include the expansion of the Bulletin to include "Discussion and Outlook" of global ENSO-related climate anomalies in the Forecast Forum, a significant expansion of the discussions of extra-tropical climate, and augmentation of figures used in ocean diagnostics. Data sets from the Climate Diagnostics Bulletin were, for the first time, made available on the CAC Climate Dial-Up Service; thus, allowing other NOAA Offices, Government Agencies and University scientists easy access to these data.

ENSO Advisories - The current ENSO event stimulated a new set of Advisories to provide real-time assessments of the evolving warm episode. These advisories served as the scientific basis of ENSO monitoring for the governments of several South American countries as well as the domestic and foreign media.

Climate Diagnostics Data Base (CDDB) - A comprehensive plan was formulated to improve and enhance the CDDB. Elements of this plan addressed the relationship of the CDDB to the Climate Data Assimilation System (CDAS) and the Reanalysis Project and expanded current data base activities to include satellite data (the Satellite Climate Diagnostic Data Base), coupled model assimilated data, and input from the ETA model.

Decadal Review - CAC produced, coordinated, and distributed the publication: "Climate Assessment - A Decadal Review 1981-1990". This review represented a syntheses of NOAA's understanding of the state of the global climate over the past decade. This is the second year of this publication which we plan to establish as standard for end-of-the-year climate assessment.

Graphics - Improvements in the quality of graphical climate products have been made in a number of steps. For example, machine-independent applications, use of optimum interpolation, and incorporating scanning and desk-top-publishing techniques. As a result, quality has improved and automation of products has permitted meteorologists more time for their primary tasks.

CAC Routine Products - A complete list of CAC routine products under climate services, climate diagnostics, and climate prediction follows this Summary.

II. REGIONAL CLIMATE CENTERS PROGRAM

Project Office - A Project Office was established at the CAC (November 1990), for regional climate applications and services. The program of six Regional Climate Centers (RCCs) was organized with a plan which recognizes the importance of consensus decisions, prompt funding of the Centers, development of regional services and research programs, peer review at the regional and national levels, and the flexible application of these principles to the needs of each center. Also, a comprehensive RCC Budget Initiative for FY 1993 was written for an expanded RCC program to include a solar radiation network, climate impacts research, and applications of research results from the Global Change Research Program.

A Climate User Community - A national user community for climate products and services drawn from private industry, state and local governments, and academia is being developed. To support this effort, CAC has developed a real-time national data backup capability for the RCCs and is developing an NWS product delivery system for them. Selected RCC products (e.g. impact assessments) are being distributed to NWS Regional Offices. The RCCs maintain unique data sets which are not available at national centers and can identify and educate potential users on the availability and means to obtain climate data and products.

III. CLIMATE DIAGNOSTICS RESEARCH

CDAS and Reanalysis Projects - The CAC has maintained an active supportive role in the development of the Climate Data Assimilation System (CDAS) and the planning of the Reanalysis Project. In particular, CAC scientists planned and executed an extremely difficult and complex series of diagnostics analyses of NMC model output for the CDAS project. These analyses (comparisons among the T40, T60, and T80 models) served as the basis for further development of both the CDAS and Reanalysis Projects.

Diagnostics of Tropical Precipitation - As part of the international Global Precipitation Climatology Project, the CAC was designated as an "Algorithm Intercomparison Center." This Center worked effectively with other U. S. Government Agencies, as well as with representatives from other nations (Germany, Japan, United Kingdom) to conduct a successful cooperative precipitation intercomparison study.

Improved Empirical ENSO Prediction - The operational statistical ENSO prediction method based on correlation analysis was improved in content and presentation. These ENSO predictions appear regularly in the Monthly Climate Diagnostics Bulletin and "official" CAC ENSO forecast. These empirical forecasts will be a standard for judging improvements in model prediction.

ASOS Intercomparison A special session on ASOS-Climate issues was organized and held at the 15th Climate Diagnostics Workshop followed by a working meeting of the ASOS Climate Working Group in October 1990. This meeting provided a basis for the development of a comprehensive ASOS temperature intercomparison study in cooperation with the NESDIS/ National Climatic Data Center and the University of Colorado. Management of these studies was turned over to the NWS/Office of Meteorology and funded by the new NOAA/ESDIM Activity.

Improved Ocean Diagnostics- New diagnostics analyses techniques were initiated which utilize assimilated data from oceanic, atmospheric, and coupled models . These techniques are designed to improve the operational monitoring of ENSO variability and related research. This new activity is being carried out in cooperation with NOAA/ERL and the university community under EPOCS funding.

IV. CLIMATE PREDICTION

Climate Outlooks - Record skill scores for the 6-10 day forecasts were achieved on final U. S. surface temperature and precipitation forecasts for several months during FY 1991. This was due to: 1) continuous improvements of raw forecasts by models, 2) the high level of predictability of persistent flow observed during Spring 1991, and 3) increased experience with numerical products. Monthly and seasonal skill scores were variable. Some forecasts were highly successful; but, some had large discrepancies. As usual, CAC forecasters had frequent interactions with the public and the media during the year.

Verification Summary - Forecast verification summaries that highlight the temporal history of skill for both monthly mean NH heights and U.S. surface temperature have been published nationally (Proceedings of the 15th Annual Climate Diagnostics Workshop) and internationally (ITCP/WMO Report on the Technical Conference on Long-Range Weather Forecasting Research). These reports highlight positive trends in skill, including the achievement of a clear advantage over persistence in the 1980's.

DERF Program - The operational, bi-weekly lagged forecast experiment was restructured to consist of 9 members at 6 hour spacing. Continuous adjustment took place in response to ever-changing computer resources. An improved version of lagged forecasting was developed that appears to be successful. Following the recommendations of a DERF Workshop (Boulder, CO, June 1990), about 20 cases were selected that would provide the best tests for models to investigate Monte Carlo forecasts, sensitivity to resolution, and the impact of observed SST.

10-YEAR RUN - The same model used to generate 128 90-day forecasts (DERF90 Experiment) was also used for a successful 10-year run. The amplitude and phase of the annual cycle were better than expected. One issue, the inclusion of mass sinks and sources due to water, was found to be important in the annual cycle. As a result, the CAC recommended that a change be made in the continuity equation of the MRF. It appears that this change has a positive impact on the 1-10 day forecast as well.

In addition to the above activities, CAC scientists participated in many National and International Programs (see Section 6). Scientific articles have been published and a number of formal presentations were made (see Section 7). It is appropriate, therefore, to conclude this Summary with an acknowledgment to the entire CAC staff for all of the above accomplishments.

David R Rodenhuis
Director, CAC

NOAA/NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER
CLIMATE ANALYSIS CENTER

MISSION

The mission of the Climate Analysis Center is to maintain a continuous watch on short-term climate fluctuations and to diagnose and predict them. These efforts are designed to assist agencies both inside and outside the federal government in coping with such climate-related problems as food supply, energy allocation, and water resources.

PRODUCTS

- Weekly Climate Bulletin
- Special Climate bulletins
- Drought Advisories
- Climate Dial-Up Service
- Daily Weather Maps
- Weather and Climate Update
- Precipitation Summary & Temperature Observations (PRESTO)
- Weekly Weather and Crop Bulletin
- Special Agricultural Bulletins
- Weekly Agricultural Assessment Briefings

- Global Stratospheric Analyses
- Global Ozone Analyses and Trends

- Monthly Climate Diagnostics Bulletin [real-time & delayed]
- Monthly Global Atmospheric Analyses
- Monthly Global Oceanic Analyses
- ENSO Advisories
- Seasonal Climate Review Article (J. of Climate)

- Medium-Range (6-10 day) Outlook [3 times weekly]
- Monthly Outlook [semi-monthly]
- Seasonal Outlook [monthly]

- Annual Climate Diagnostics Workshop

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1. CLIMATE DIAGNOSTICS

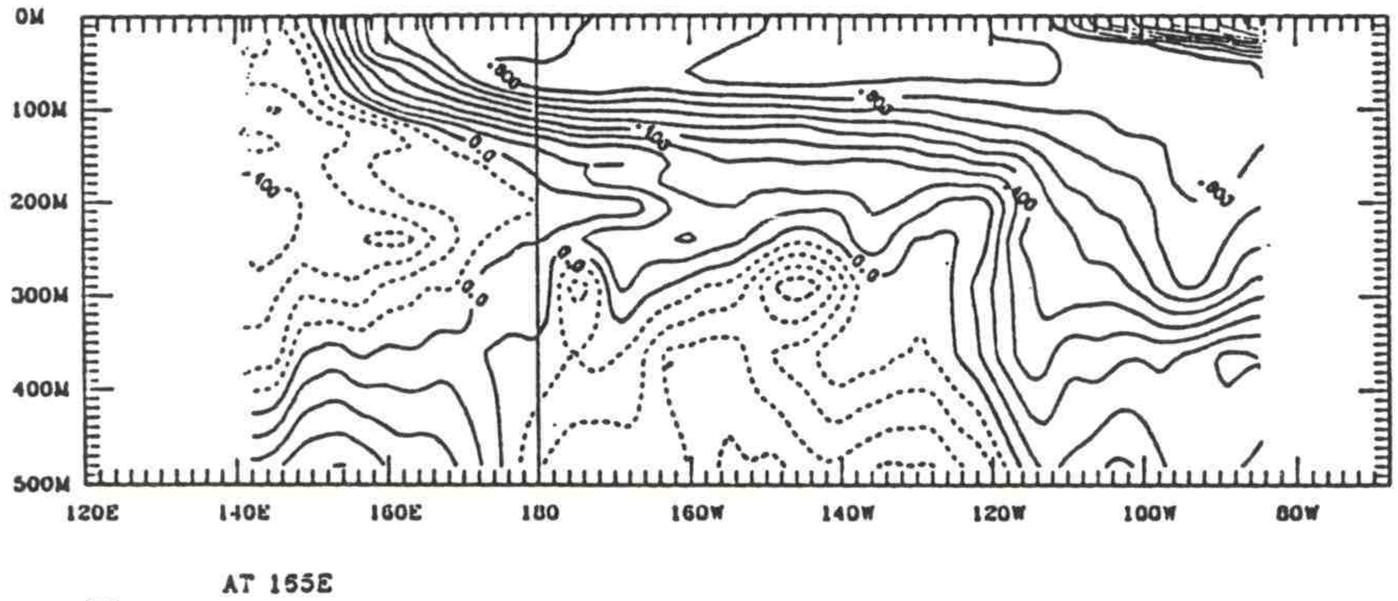
1.1 Tropical Ocean - Atmosphere Interaction

1.1.1 Ocean-Atmosphere Coupling (Kousky, Ropelewski, Smith, Chelliah)

The goal of this collaborative project (with NMC/Coupled Model Group) is to develop an understanding of the evolution of the Southern Oscillation in the ocean-atmosphere coupled system. A system is being designed that will enable detailed diagnostics to be performed on the coupled ocean-atmosphere model runs. Thus far, efforts have focused on joint principal component analysis of blended monthly SST anomalies and cross sections of ocean temperature anomalies. Figure 1 shows the first mode of analysis of north-south cross section temperature anomalies at 165°E, and 110°W with an east-west section along the equator (1985 -1991). This mode clearly shows the dominance of the warm ENSO event in 1986-1987, and the cold event in 1988. Loadings along the equator show the near surface temperature variations over the period, extending deepest in the east due to deepening or shoaling of the thermocline. The 110°W section's loadings suggest variability in the strength of the North Equatorial Current, as well as equatorial temperature variation associated with the warm and cold event. At 165°E, most of the temperatures are out of phase with the dominant equatorial surface event.

In another joint study (with R. Reynolds, NMC), tests for optimal averaging (OA) of SST were completed for 10°x10^{o} areas. The OA is a statistical averaging technique which minimizes least-squared error and uses the same statistics as those needed for optimal interpolation (OI). The principle advantage of OA is that it improves the accuracy of area averages in regions where data are unevenly distributed. The statistics used in OA and OI have been computed directly from SST data, which improves their accuracy over earlier estimates. A year of SST increments were assembled from day and nighttime satellite observations as well as ship and buoy data. To date, statistics have been computed within non-overlapping 20°x20^{o} ocean areas. Table 1 shows globally-averaged statistics for the various data types, as well as the values currently used by the OI. The analysis error standard deviation, in theory, should be the same for each data type, and the relative closeness of the different estimates is encouraging. A test of the OI using the new globally constant statistics was computed and compared to the operational version. The results (figure 2) show that the computed statistics yield a smoother SST field than the operational statistics do. The major reason is the increase in size of the correlation scale, which tends to smooth out smaller-scale features. The overall pattern and the magnitude of highs and lows is the same in both versions.

(a)



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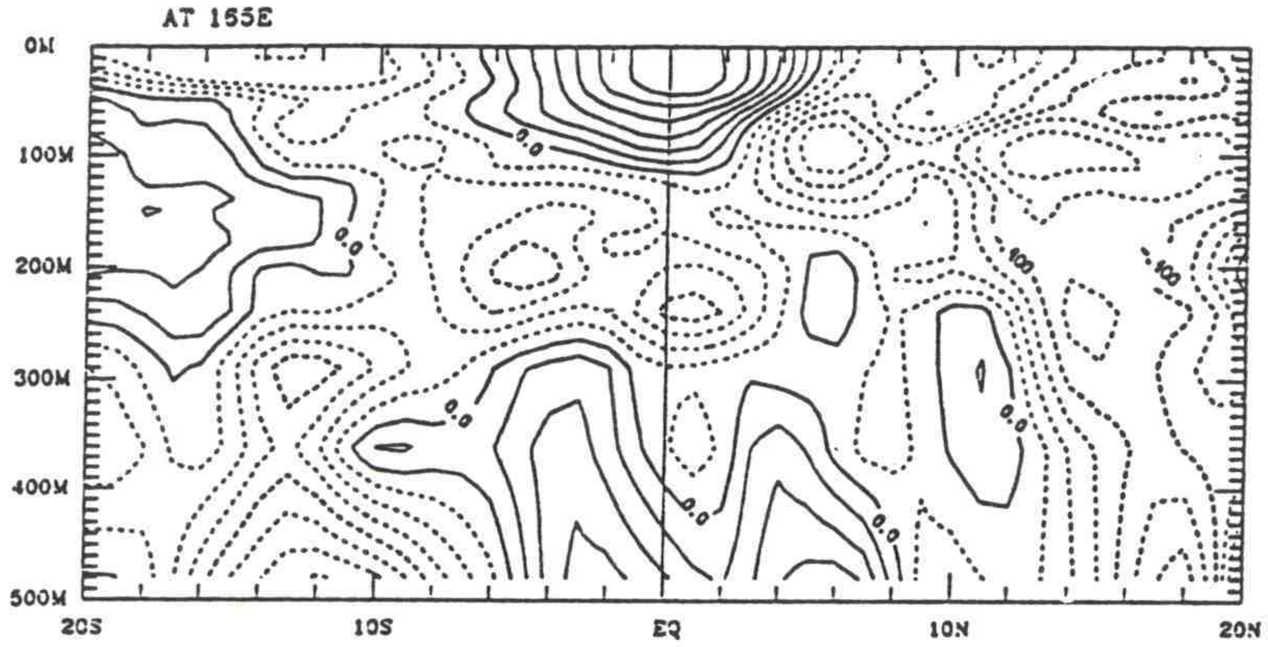

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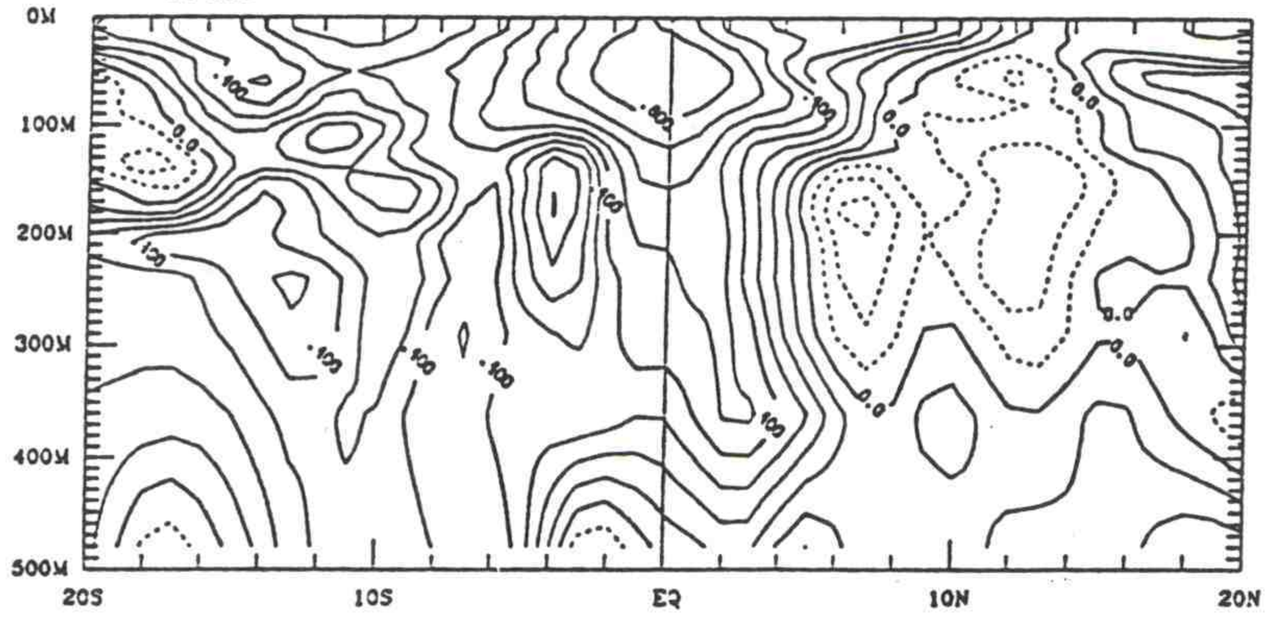


(d)

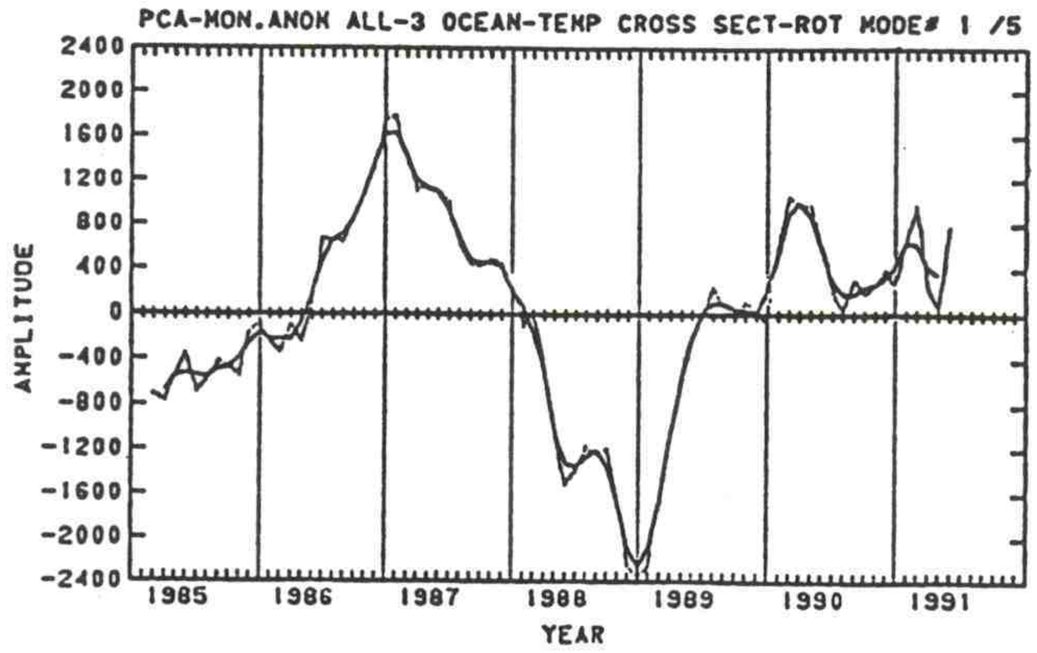
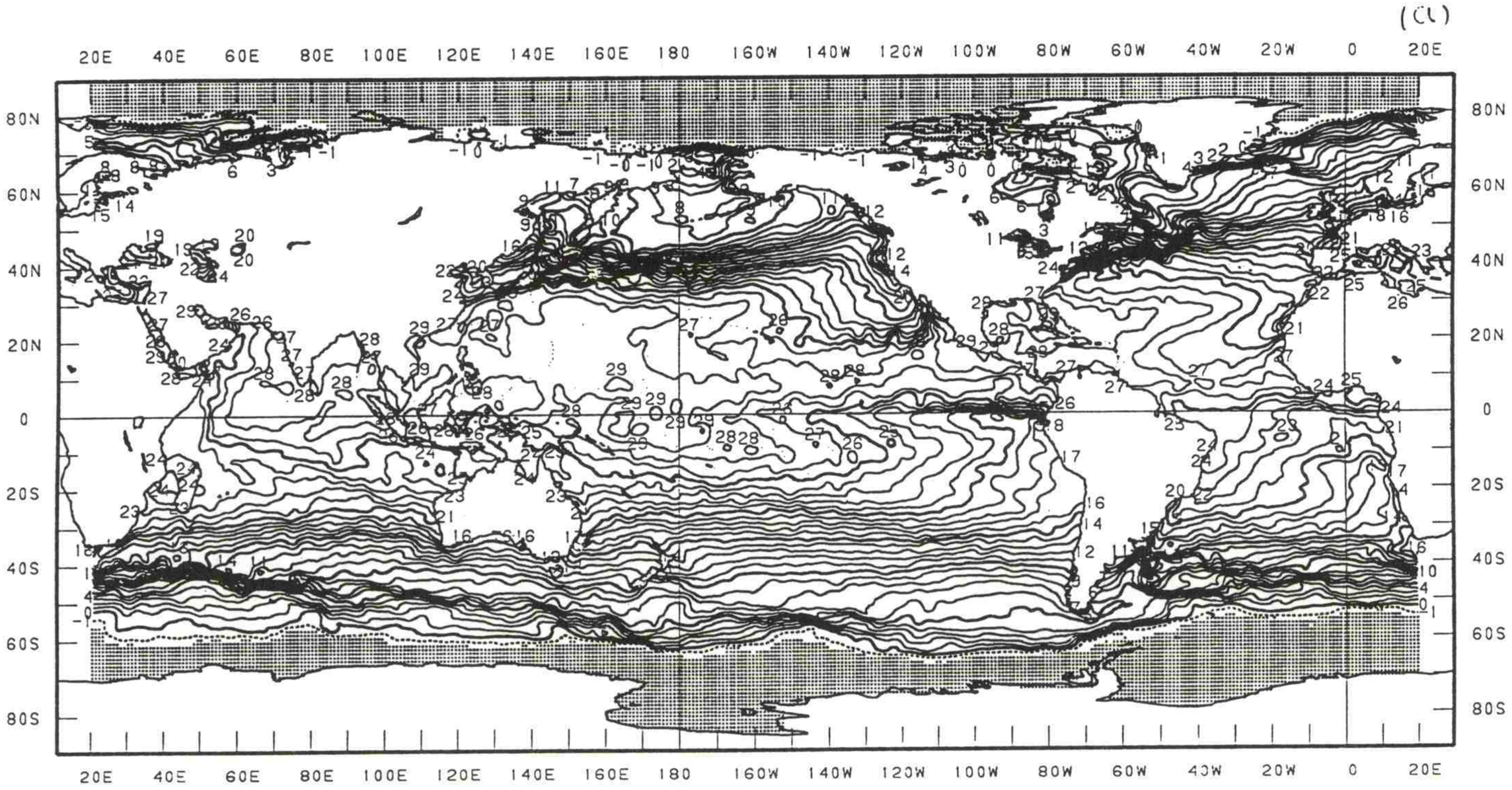


Figure 1: Rotated joint principal component analysis of ocean temperature anomalies on cross-sections: east-west along the equator (a), north-south at 165E (b), north-south at 110W (c). The first mode loadings and associated time series is shown in (d).

Table 1: Computed global averages of the correlation scale (D), standard deviation of the data error (S_d), standard deviation of the analysis error (S_a), and ratio of the standard deviation of the data error to analysis error (S_d/S_a). Data types are day satellite (DSAT), night satellite (NSAT), ship data (SHIP), buoy data (BUOY), and the combined satellite data (DS+NS). For comparison, the estimates currently used in the operational OI for satellites, ships, and buoys are also given.

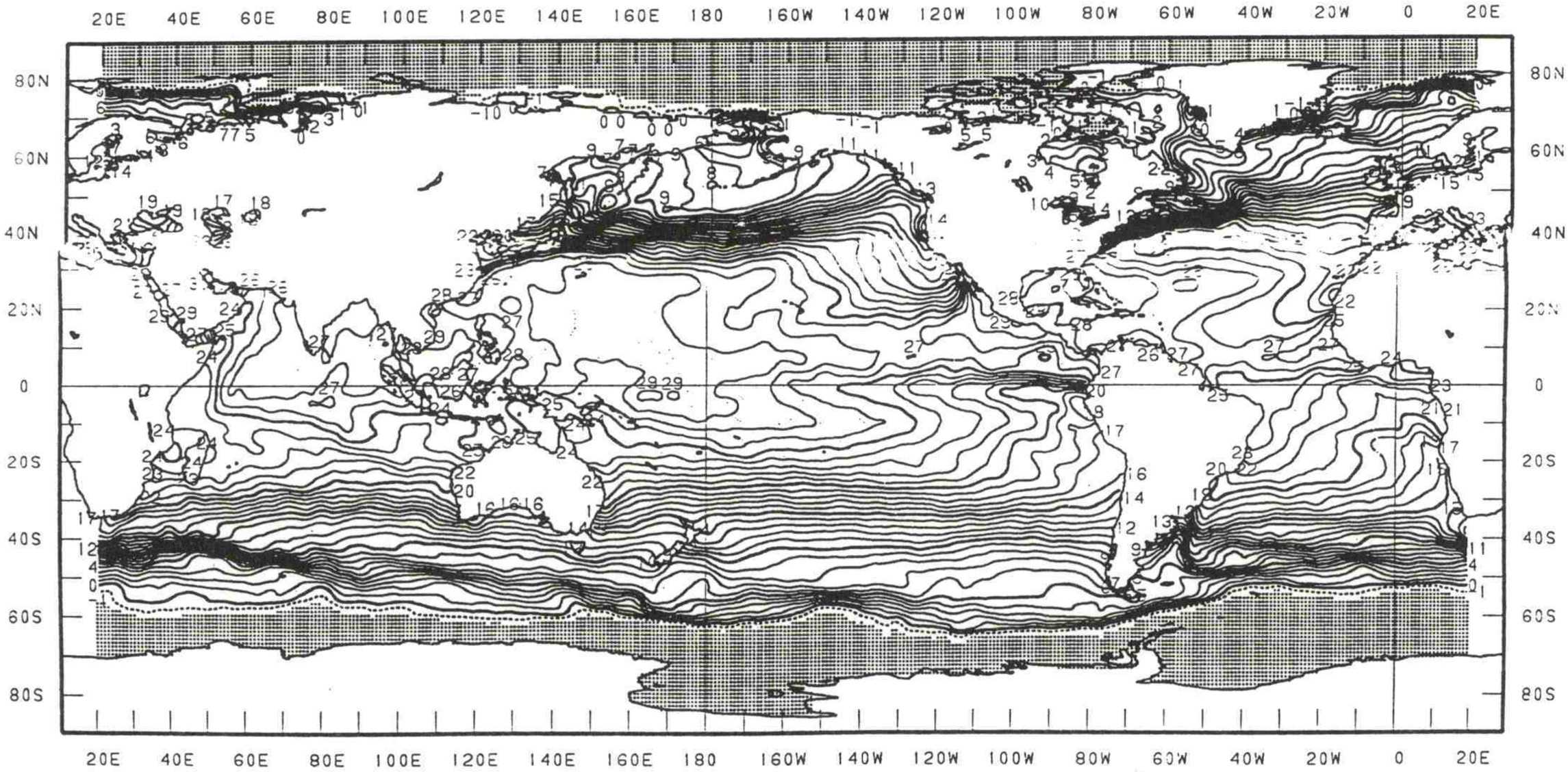
	D (Km)	S_d	S_a	S_d/S_a
Computed:				
DSAT	686	0.41	0.48	0.85
NSAT	740	0.31	0.36	0.86
DS+NS	705	0.37	0.43	0.86
SHIP	947	1.31	0.50	2.94
BUOY	901	0.75	0.51	1.34
Operational:				
DSAT	222	0.50	0.50	1.00
NSAT	222	0.50	0.50	1.00
SHIP	222	0.90	0.50	1.80
BUOY	222	0.50	0.50	1.00

(a)



OI (NO BIAS COR: 1-2-1) SST ANALYSIS 22 SEP 91 TO 28 SEP 91

(b)



OI (NO BIAS: TEST) SST ANALYSIS, D=700 KM 22 SEP 91 TO 28 SEP 91

Figure 2: The OI of SST with no bias correction for the week of September 22, 1991 using (a) the operational statistics and (b) the computed statistics.

1.2. Circulation Diagnostics

1.2.1 Large Scale Tropical Circulations (Mo, Rasmusson)

In this study, an examination was made of tropical extratropical linkages during the 1987-1989 ENSO cycle. Figure 3 shows the 200 mb streamfunction and divergence differences between the warm and cold seasons during the Northern Hemisphere winter. The linkages between the equatorial Pacific convection anomalies and the extratropical circulation are viewed in terms of regional Hadley component anomalies and the tropical extratropical divergence anomaly zones. The primary ingredients of the coupling are: the subsiding branch of the anomalous Hadley cell in the North Pacific (figure 3a), enhanced downstream subtropical westerlies across the Gulf of Mexico into the Atlantic, and an equatorward enhancement of 200 mb synoptic scale variability associated with the enhanced westerlies (figure 3b). The northeastward extension of the anomalous equatorial convection across Mexico into the Gulf of Mexico and Atlantic gives rise to the anomalous divergent circulation. The upward branch of this circulation coincides with the region of enhanced convection and the subsiding branch extends from the Amazon Basin eastward to the Atlantic.

1.2.2 Australian Monsoon (Wang, Mo)

A study was completed that examined relationships among the Australian monsoon, equatorial intraseasonal oscillation, and Asian cold surges during the past five Northern Hemisphere winters. The data included twice daily wind, temperature, and humidity from the NMC/Global Data Assimilation System. The results indicate that the monsoon activities are modulated by the Madden Julian oscillation and can be classified into two categories. The first is when equatorial intraseasonal oscillations are strong and regular (e.g., during the 1988-1989 winter); the monsoon is strong and has clear breaks and few episodes (figure 4). The second is during an ENSO winter or when the SSTs are above normal in the western Pacific (e.g., during the 1990-91 winter); intraseasonal oscillations are weaker, there is one monsoon onset, and the breaks are weak and brief (figure 5).

Results also showed that Asian cold surges have an impact on the onset of the monsoon, only when the major events are in phase with the Madden Julian oscillation. The major cold surge events are, in general, accompanied by an increase of moisture convergence and convection upstream over the Singapore-Borneo region. The convection moves downstream as a part of the intraseasonal oscillation and strengthens the local Hadley cell. As a result, the Australian subtropical jet grows stronger and shifts poleward. Then, baroclinic eddies increase and the upper level equatorial easterlies extend to Australia. This activity is usually followed by intense monsoon rainfall.

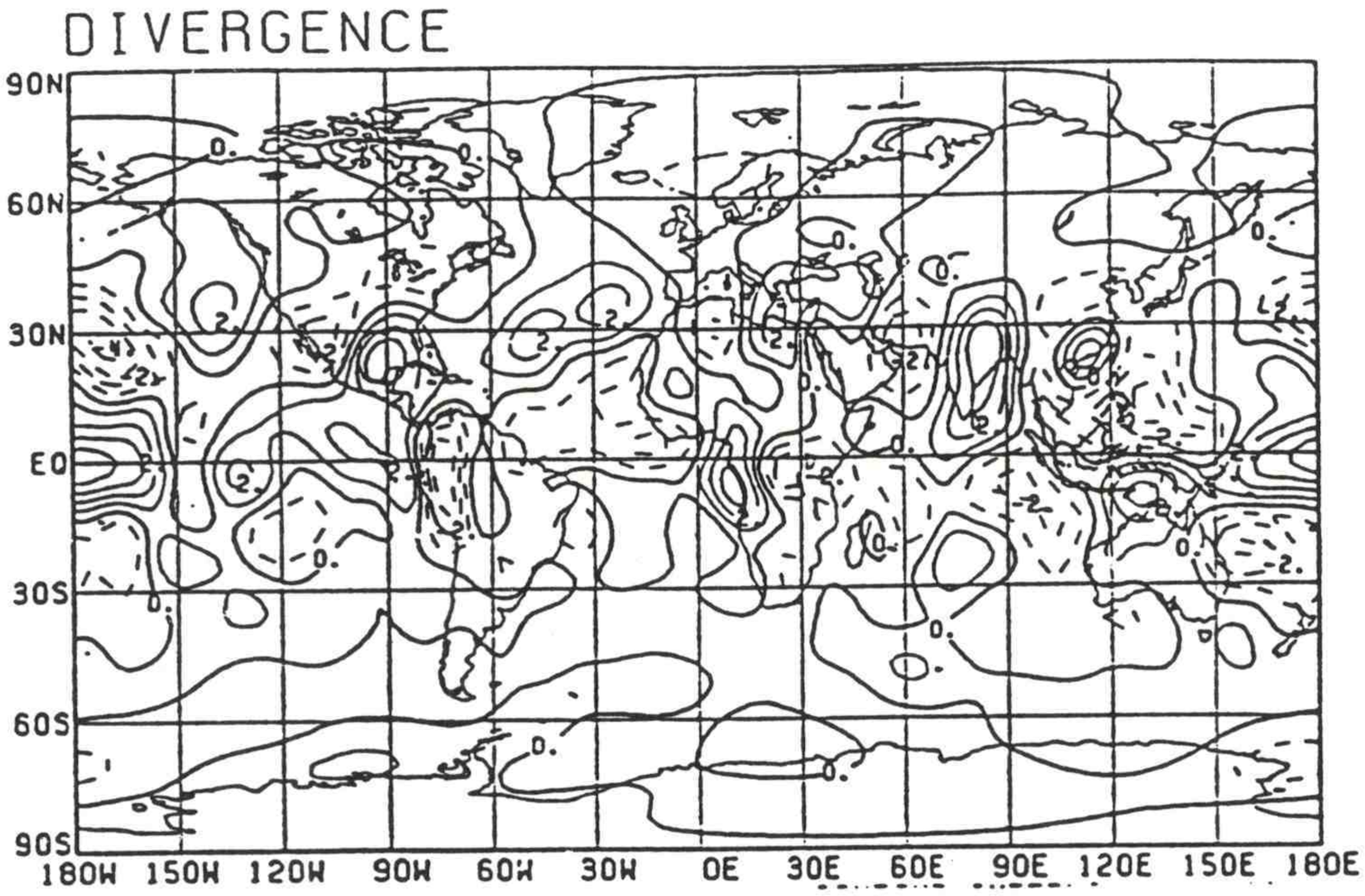


Figure 3a: Warm minus cold phase 200 mb divergence difference from analyses for JFM. Contour interval 1.E-06/sec.

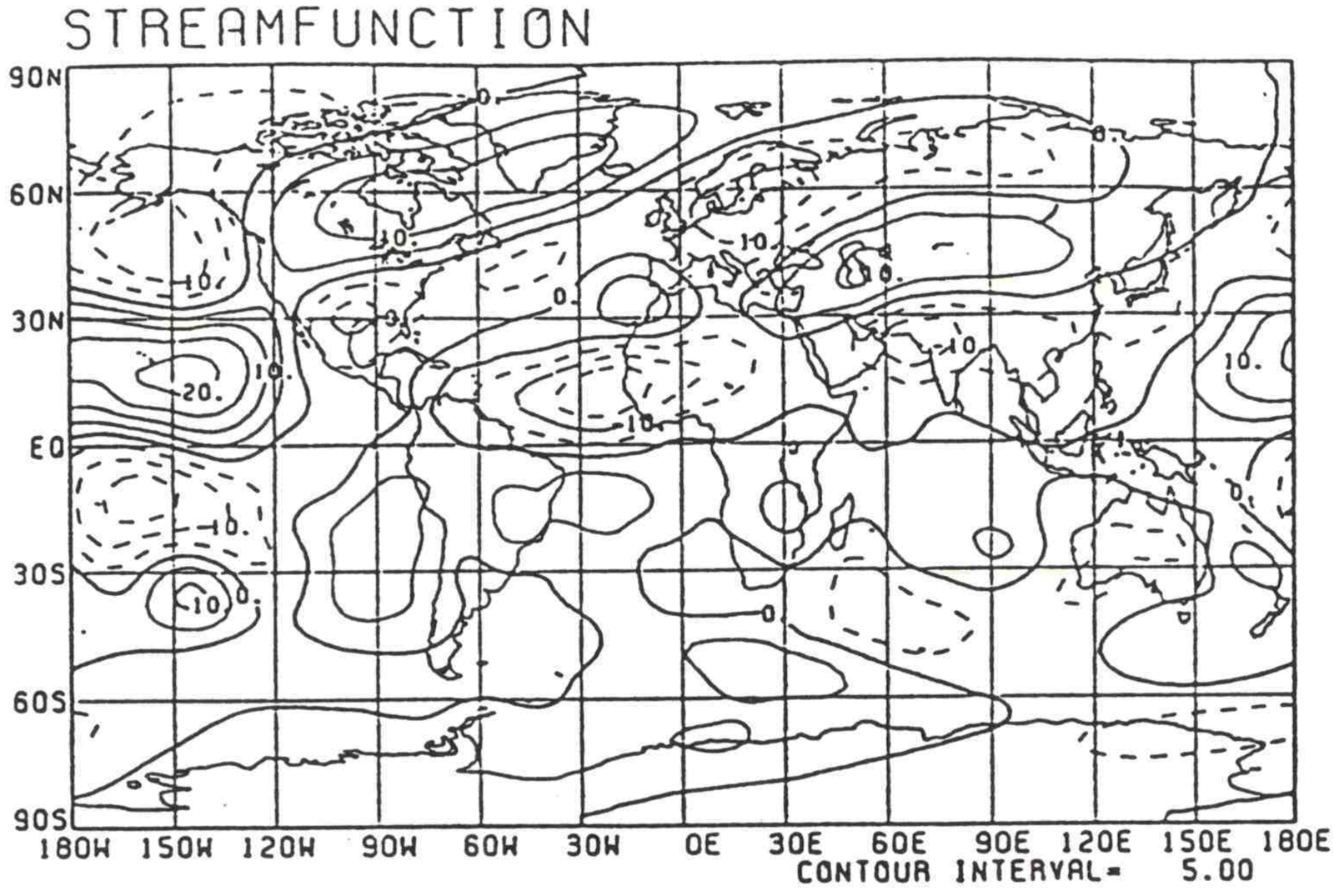


Figure 3b: Warm minus cold phase 200 mb asymmetric stream-function difference for JFM. Contour interval is 1.E+07m*m/sec.

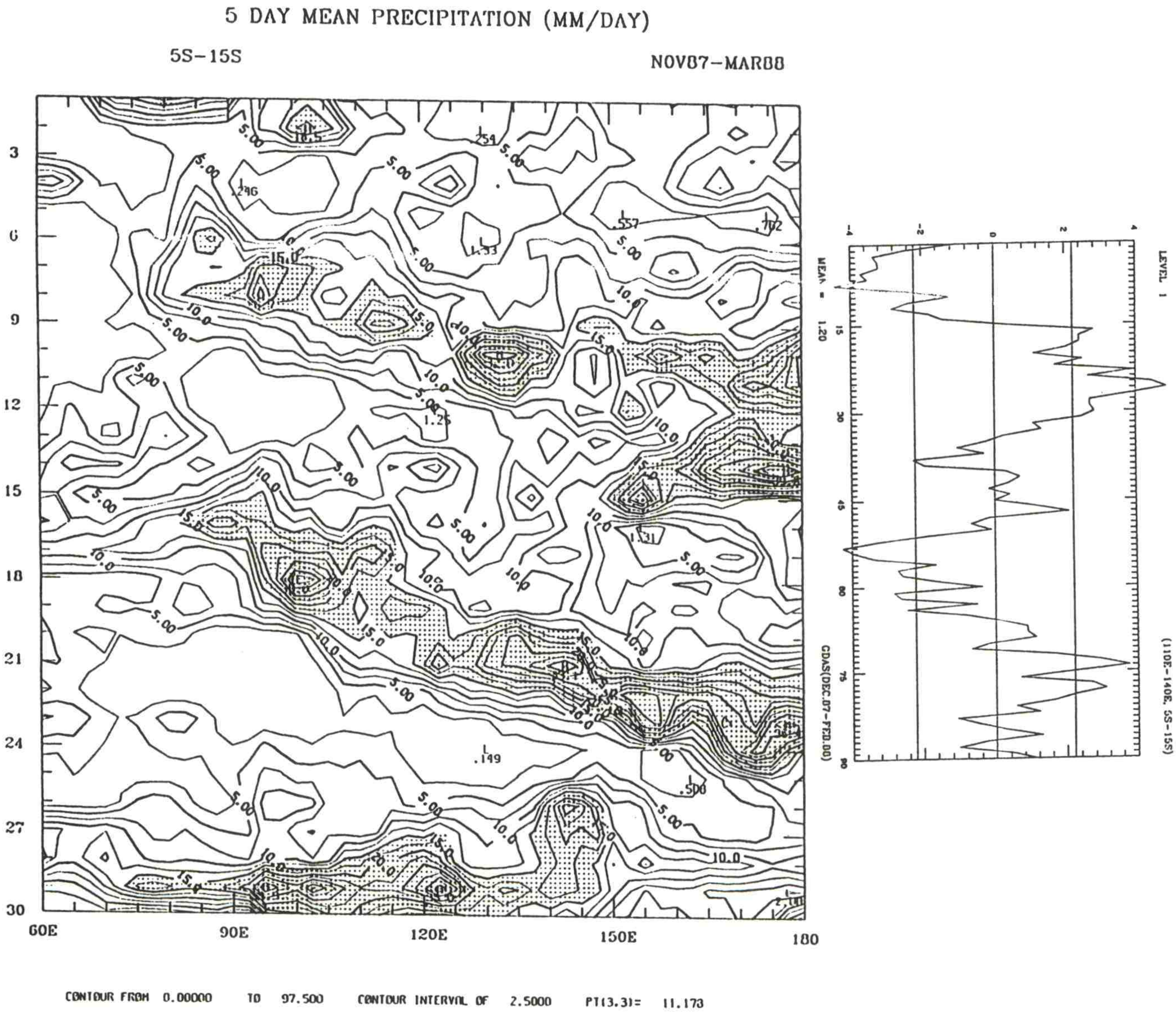


Figure 4: Hovmoller diagram for pentad mean precipitation averaged over 5S-15S (Nov. 1, 1987 to March 31, 1988) from GPCP. Also shown is the zonal wind at sigma level 1, averaged over the box (110E-140E, 5S- 15S).

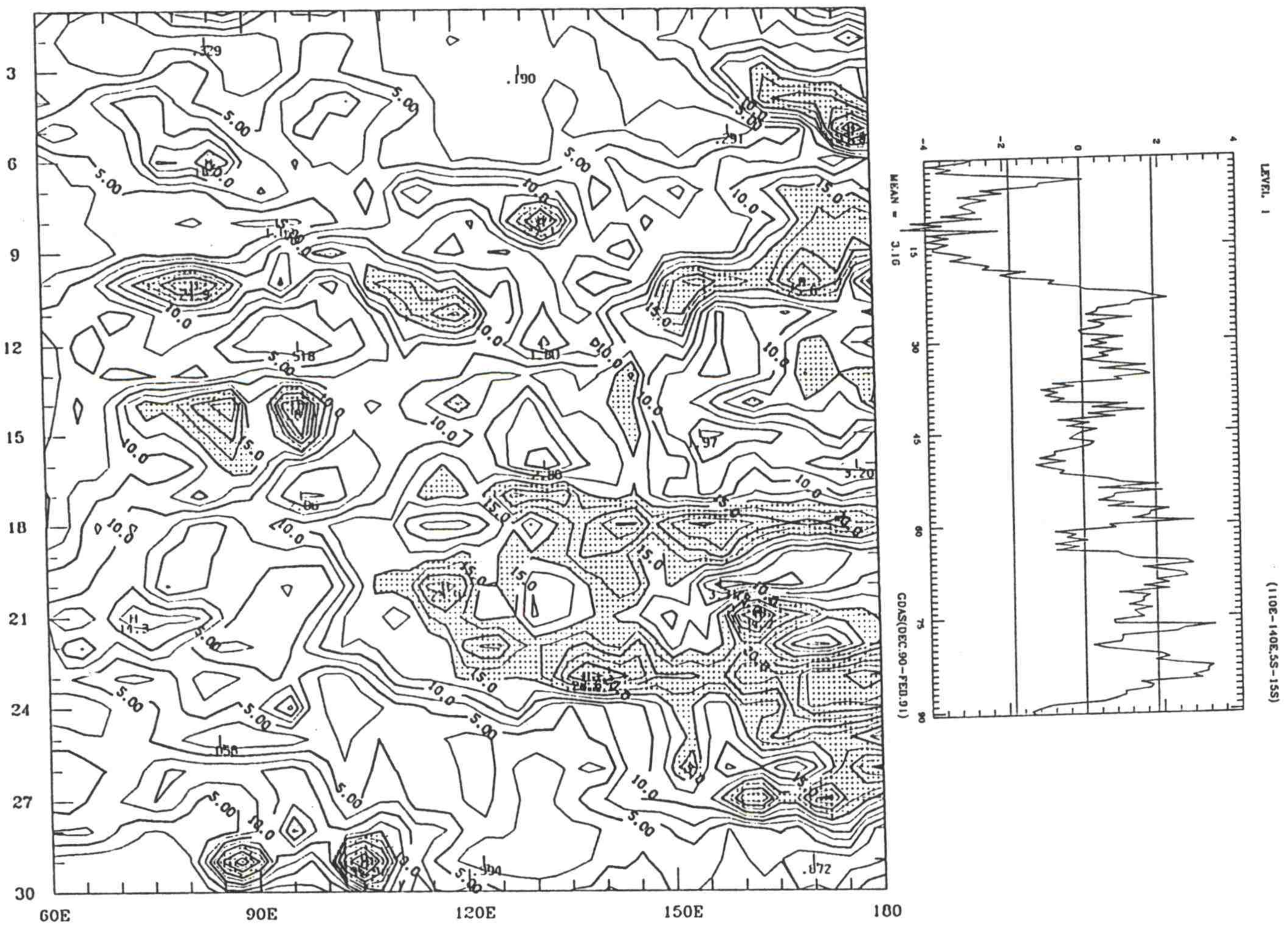


Figure 5: Same as figure 4, but for the winter of 1990-91.

1.2.3 Climate Model Diagnostics

1.2.3.1 Global Data Assimilation System (Mo, Wang)

A diagnostics study was performed (July 1991 case) to assess the impact of horizontal resolution on the Global Data Assimilation System (GDAS). Two assimilation processes were run using identical observed data. The first set was obtained from the current operational GDAS, with a horizontal resolution of T126. The second set was obtained using the same model, but with a horizontal resolution of T62. A comparison was then made between the 2 data sets. Results showed that for the rotational part of the flow (e.g., 500 mb height or 200 mb streamfunction), the differences in both patterns and magnitudes in the Northern Hemisphere are small (figure 6). However, larger differences occur over the tropics and the southern Indian Ocean, where the T62 model underestimates ITCZ-associated divergent circulation by at least 25% and produces a weaker Hadley circulation.

1.2.3.2 MONEG Experiments Using the NMC MRF Model (Mo)

Two sets of experiments were performed in this study. The first set consisted of 90 day forecasts with sea surface temperature anomalies (SSTA) updated daily during the entire integration. For the summer of 1987 and 1988, SSTA experiments were made using different initial conditions centered on June 1, separated by one day. The second set of experiments used the same initial conditions; however, the integrations were performed using SST from climatology (CSST). The results showed the SSTA experiments to be more skillful. A comparison was then made between simulated monthly ensemble mean rainfall from the SSTA experiments and satellite estimates of precipitation (from the Global Precipitation Climatology Project).

The results from this comparison showed good overall agreement (figure 7a-d). Two centers of maximum rainfall, over the Arabian sea and the Bay of Bengal, are well simulated; however, the model failed to capture the movement of the rainfall associated with the Indian monsoon. The model did simulate the interannual variability of rain over India and the Sahel; although, the simulated convection in the central Pacific associated with the 1987 warm episode is not realistic. The results also indicate that when the model is able to simulate the convection associated with the SSTA's, then the updated SSTs have a large positive impact on tropical seasonal forecasts. The impact on the extratropical forecasts is, in general, small.

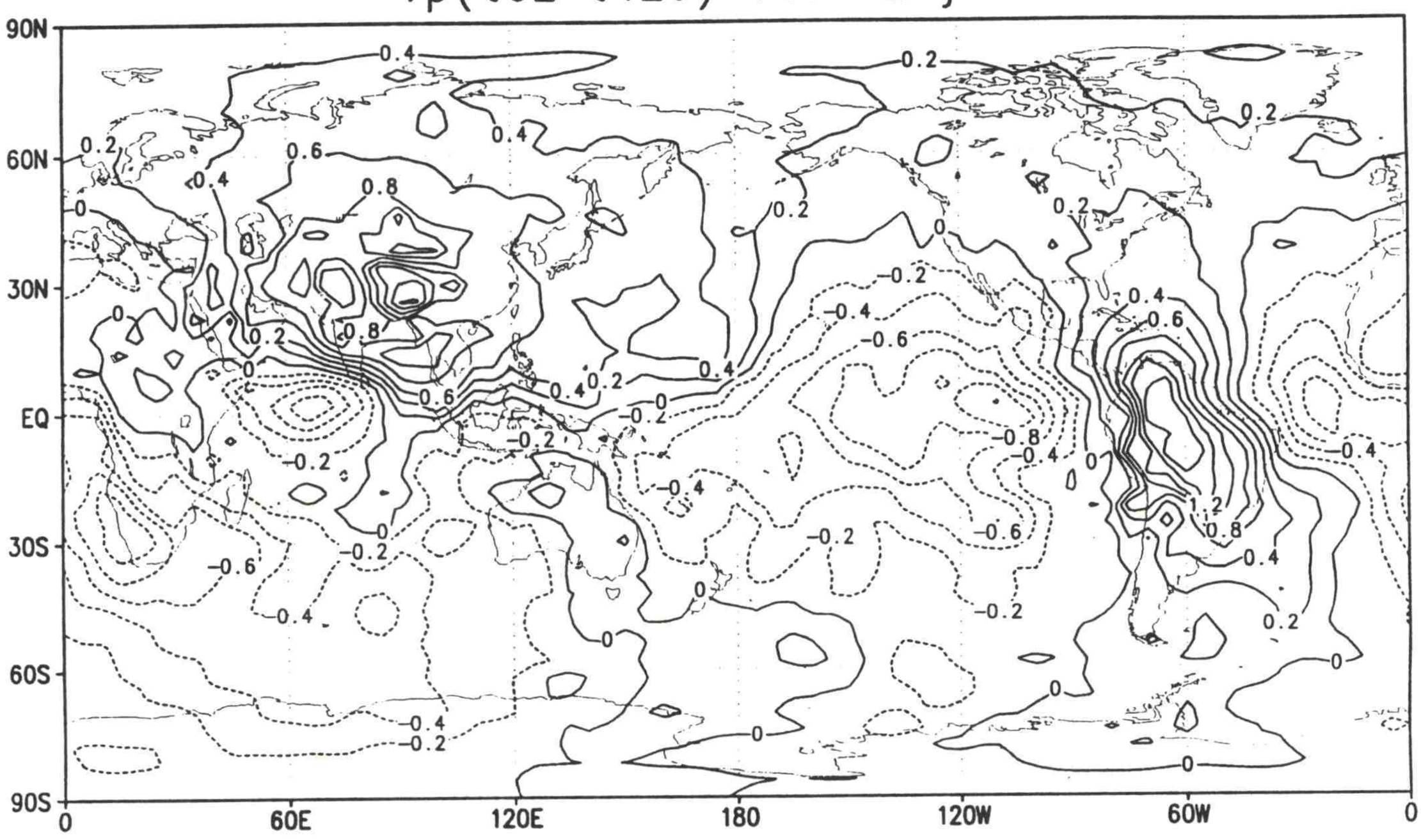


Figure 6: Difference of analyzed velocity potential difference at the sigma level 12 for July 1991 between T62 and T126 model. Contour interval is 0.2E+06m*m/sec.

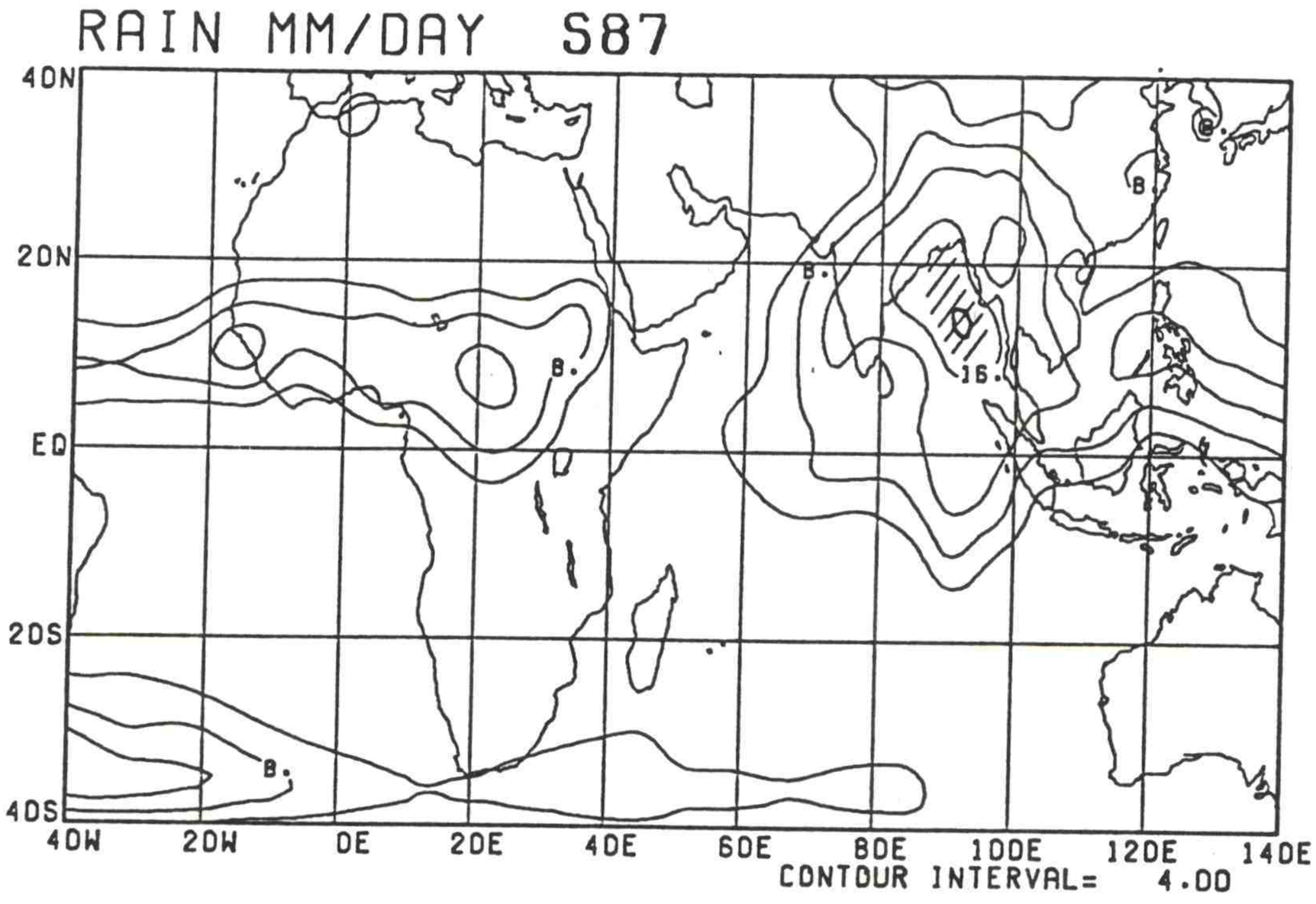


Figure 7a: Seasonal mean rainfall for JJA 1987 from GPCP.

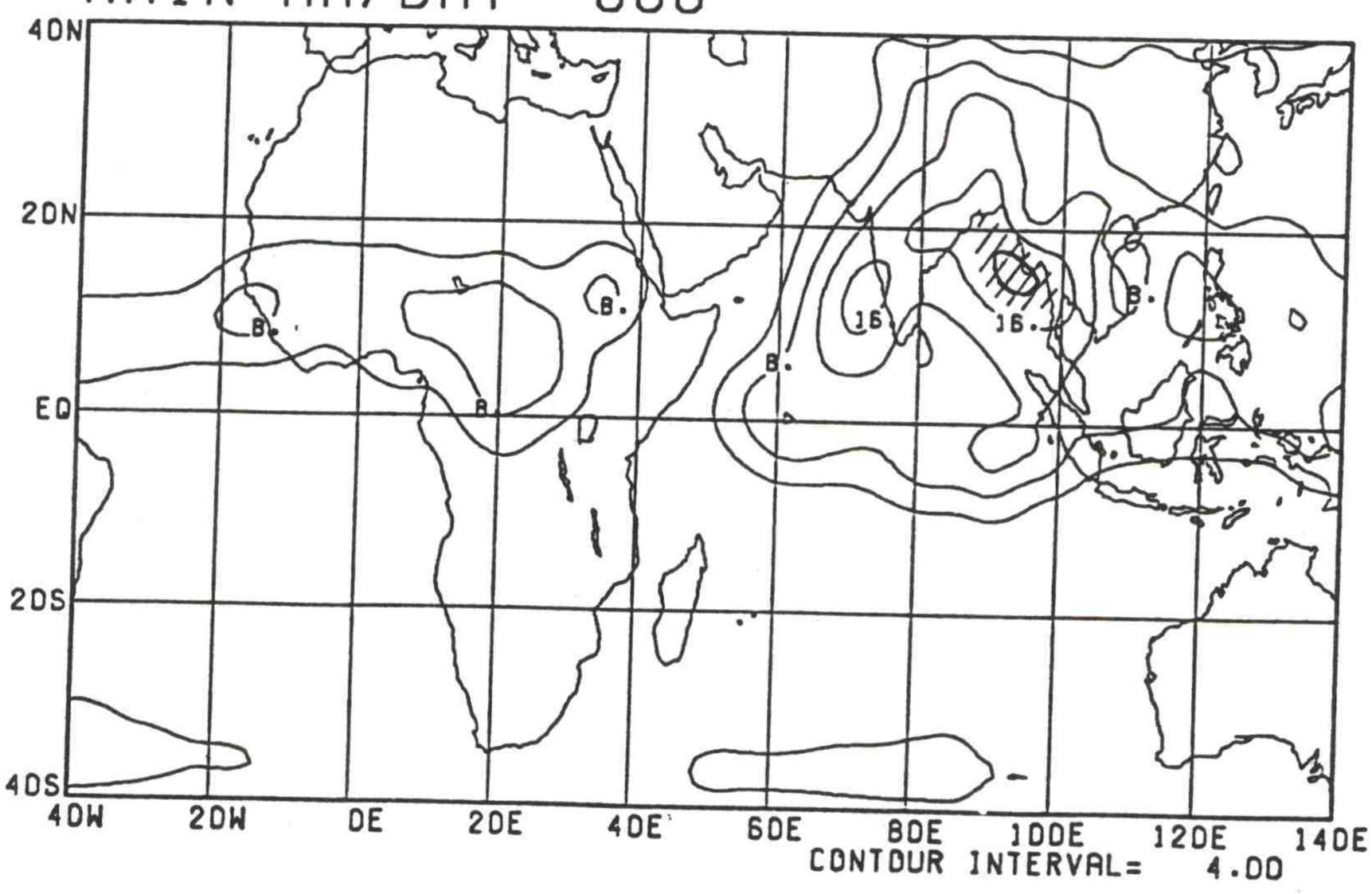


Figure 7b: Seasonal mean rainfall for JJA 1988 from GPCP.

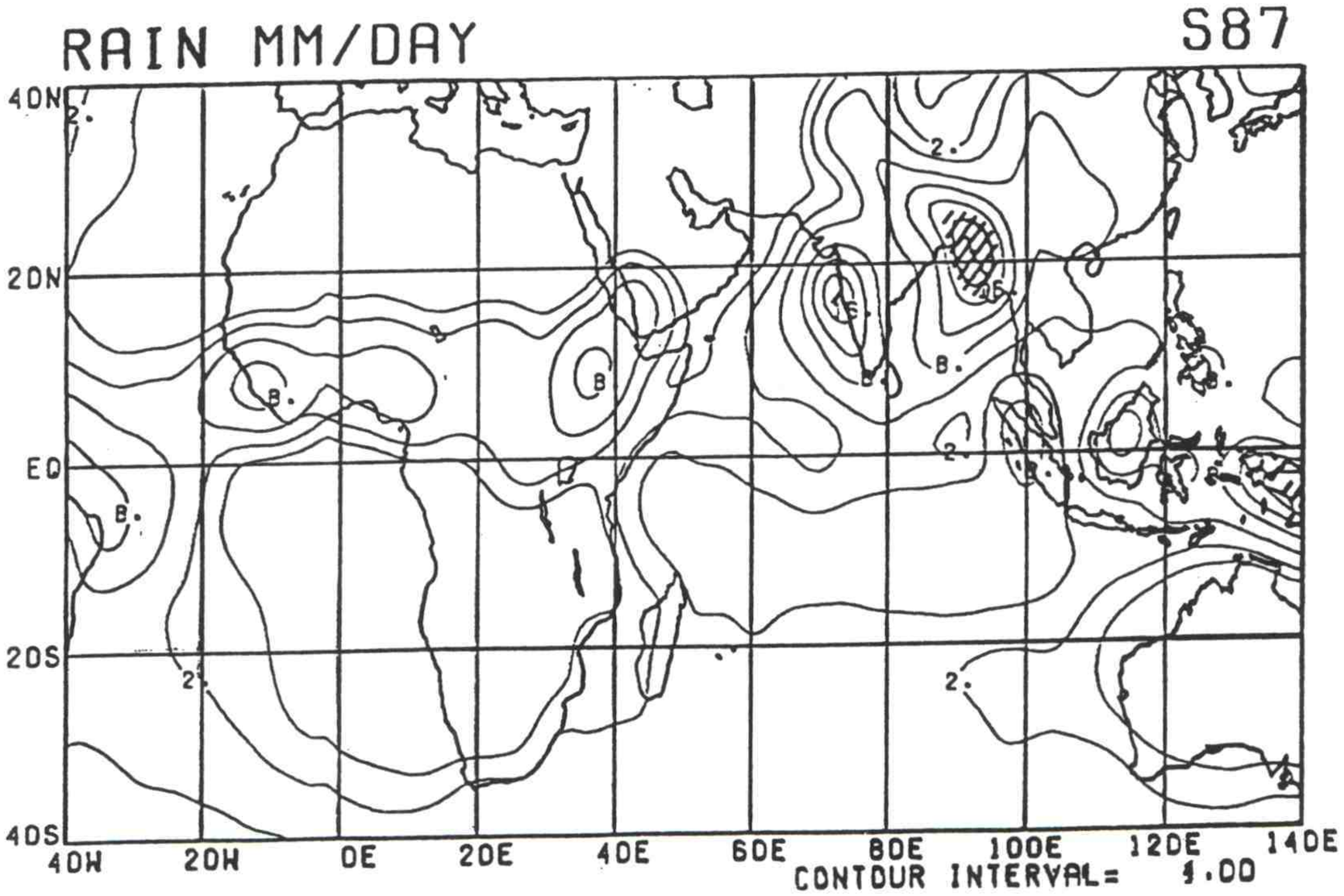


Figure 7c: Seasonal ensemble mean rainfall for SSTA 87 experiments.

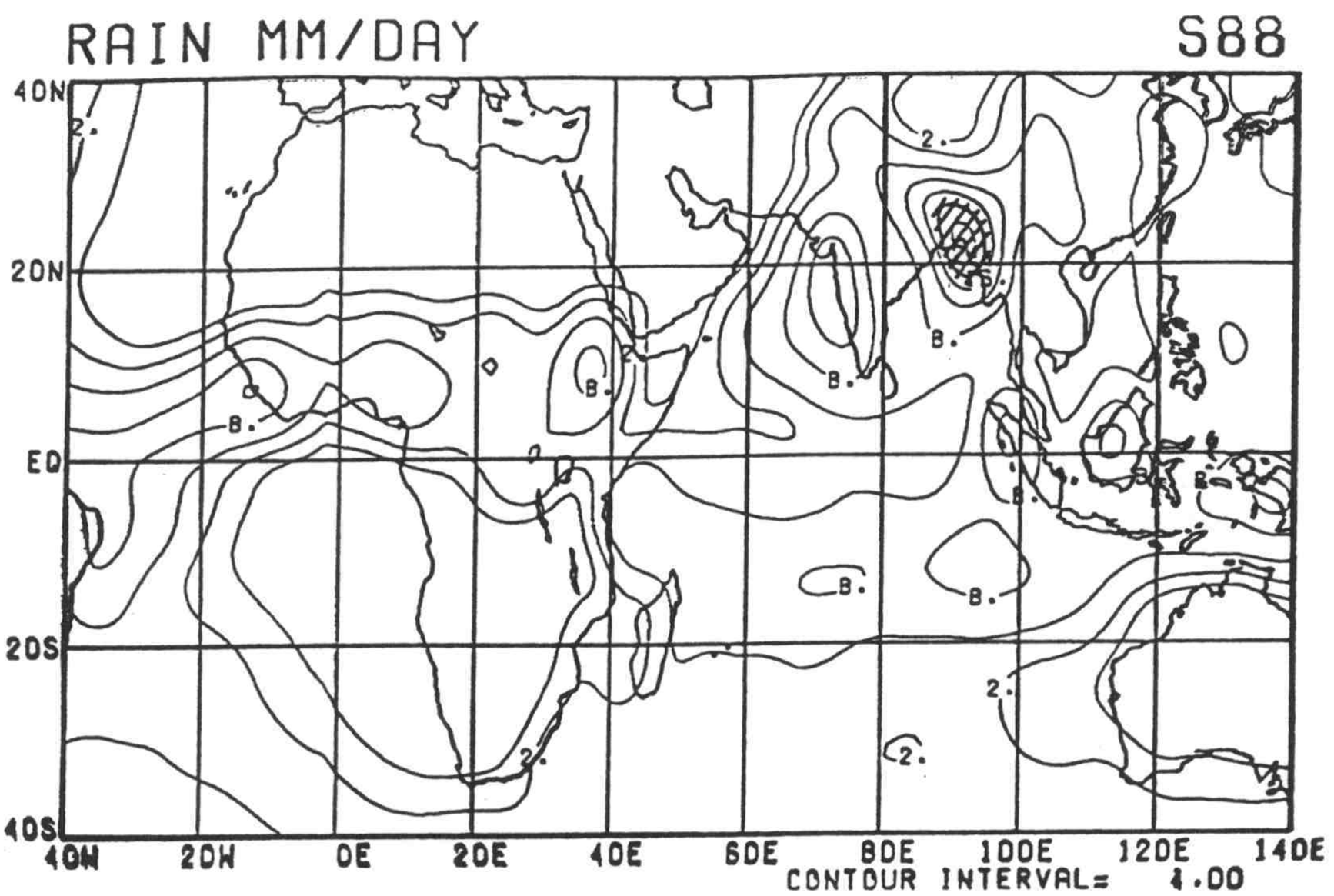


Figure 7d: Seasonal ensemble mean rainfall for SSTA 88 experiments.

1.2.4 Tropical Convection/Atmospheric Circulation (Kousky)

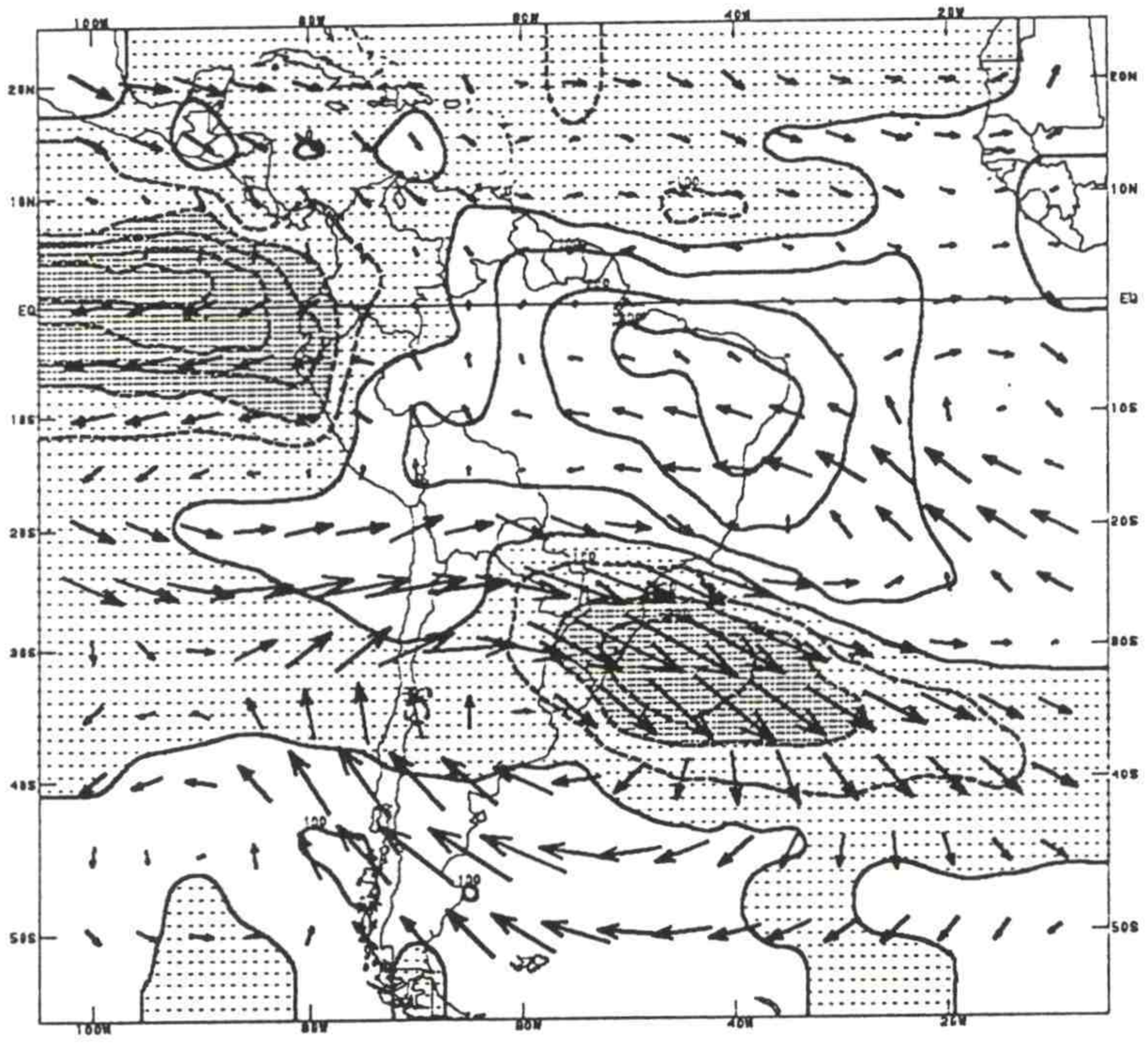
A collaborative study (with visiting scientist M. Kayano, INPE) was initiated to determine the principal atmospheric circulation (250 mb) and related deep convection (OLR) modes in the South American sector. These modes were computed using rotated combined principal component analysis, which enables computations based on more than one variable. The time series was filtered to isolate variability on intraseasonal and inter-annual time scales. The resulting modes show physically consistent relationships between the selected variables. As one would expect, the lowest order modes (as shown in figure 8) are closely related to the Southern Oscillation and intraseasonal (30-60 day) oscillations. The analysis was performed using all seasons together and cool and warm seasons separately.

The resulting patterns display certain seasonal aspects of the Southern Oscillation. The first mode (figure 8a), for the low-pass filtered case in which intraseasonal oscillations have been removed, describes variability associated with the Southern Oscillation. The major OLR anomalies, for positive amplitudes of this mode, agree with the precipitation anomaly pattern over South America for warm episodes. This mode shows very little seasonality (figure 9a). The second mode (see figure 8b), also related to extremes in the Southern Oscillation, shows strong seasonality with the largest positive and negative amplitudes occurring during March - May (figures 9b and 9c). This mode focuses on a regional feature of the effects of Pacific warm and cold episodes; i.e., circulation and rainfall over northern and northeastern South America.

1.2.5 Oscillatory Modes Flow Regimes (Mo)

In a joint study (with M. Ghil, UCLA), oscillatory modes in the interannual frequency band for the Northern Hemisphere were examined, based on monthly mean 700 mb height data from 1949-1990. Singular spectrum analysis of the leading principal components of these data revealed two dominant modes. One is a quasi-biennial (QBO) mode with a period near 32 months; the other is a low frequency (LF) mode with a period of about four years. Weaker oscillations with periods of 22, 10 and 6 months were also found. The time series associated with the QBO mode shows a long interval of strong activity from 1954 to 1966 (figure 10a). After that, the oscillation became irregular in amplitude. The LF mode (figure 10b), which is closely linked to ENSO variability, does not appear to be phase-locked with the annual cycle. During strong warm ENSO events, the extratropical QBO and LF modes are both amplified and in phase with each other.

(a)



(b)

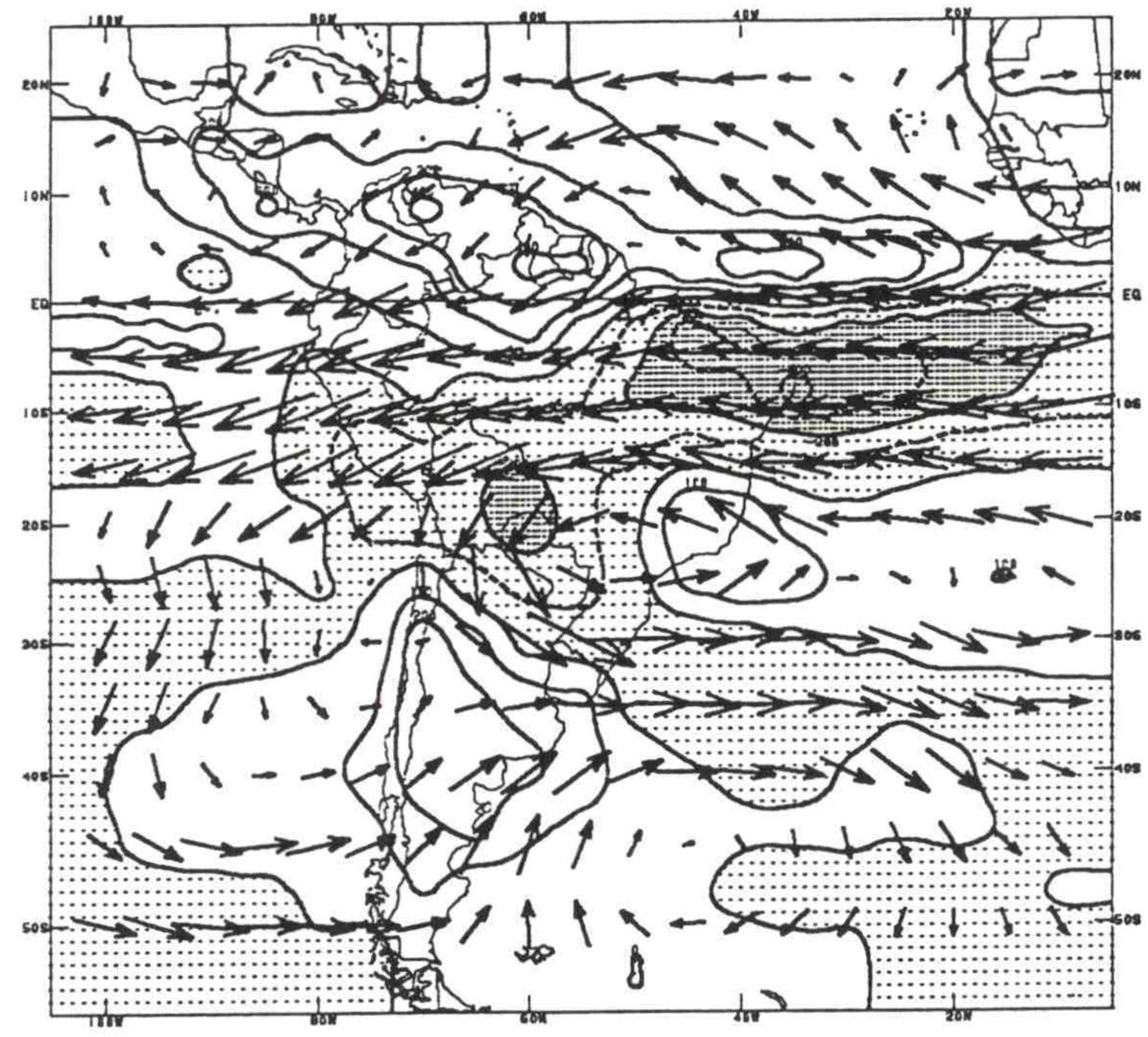
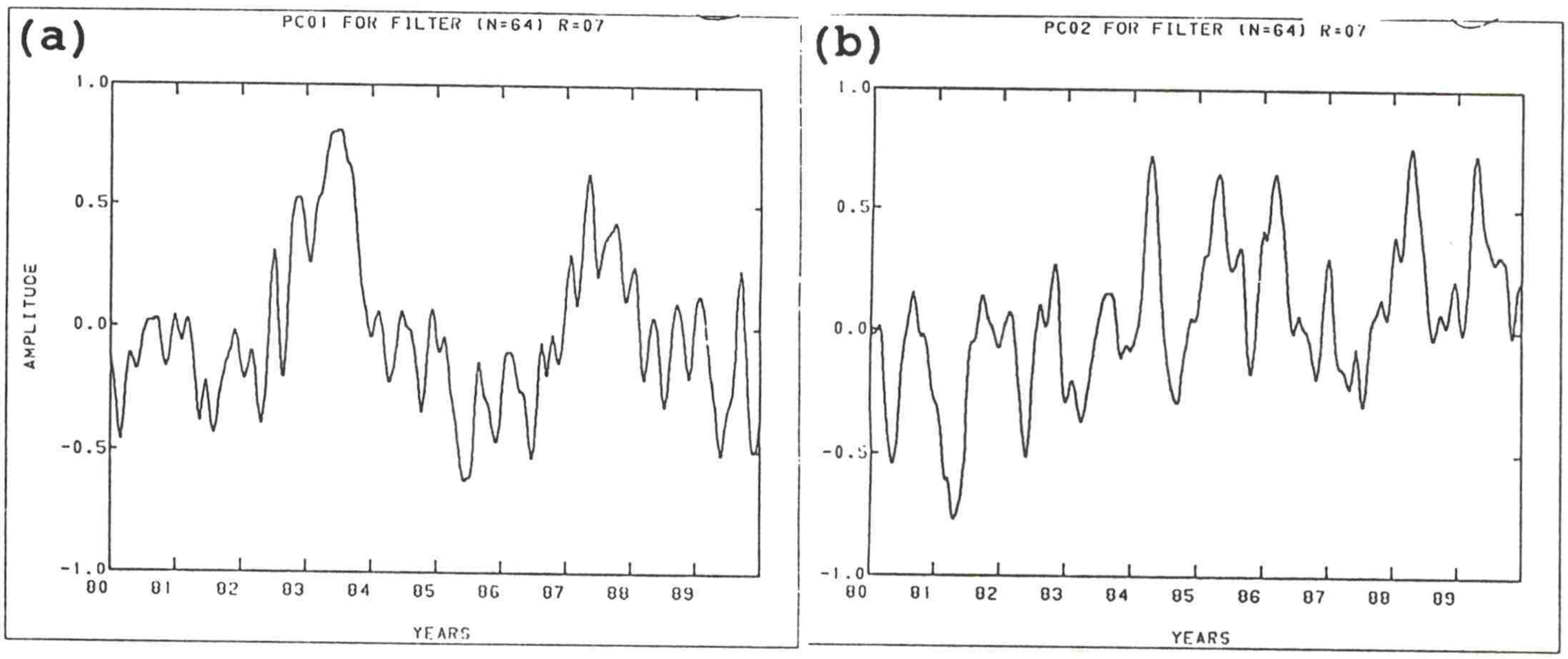


Figure 8: Combined rotated outgoing longwave radiation and 250 mb vector wind patterns, using the entire calendar year, for a) EOF-1, and b) EOF-2. OLR loadings are contoured with negative values shaded.



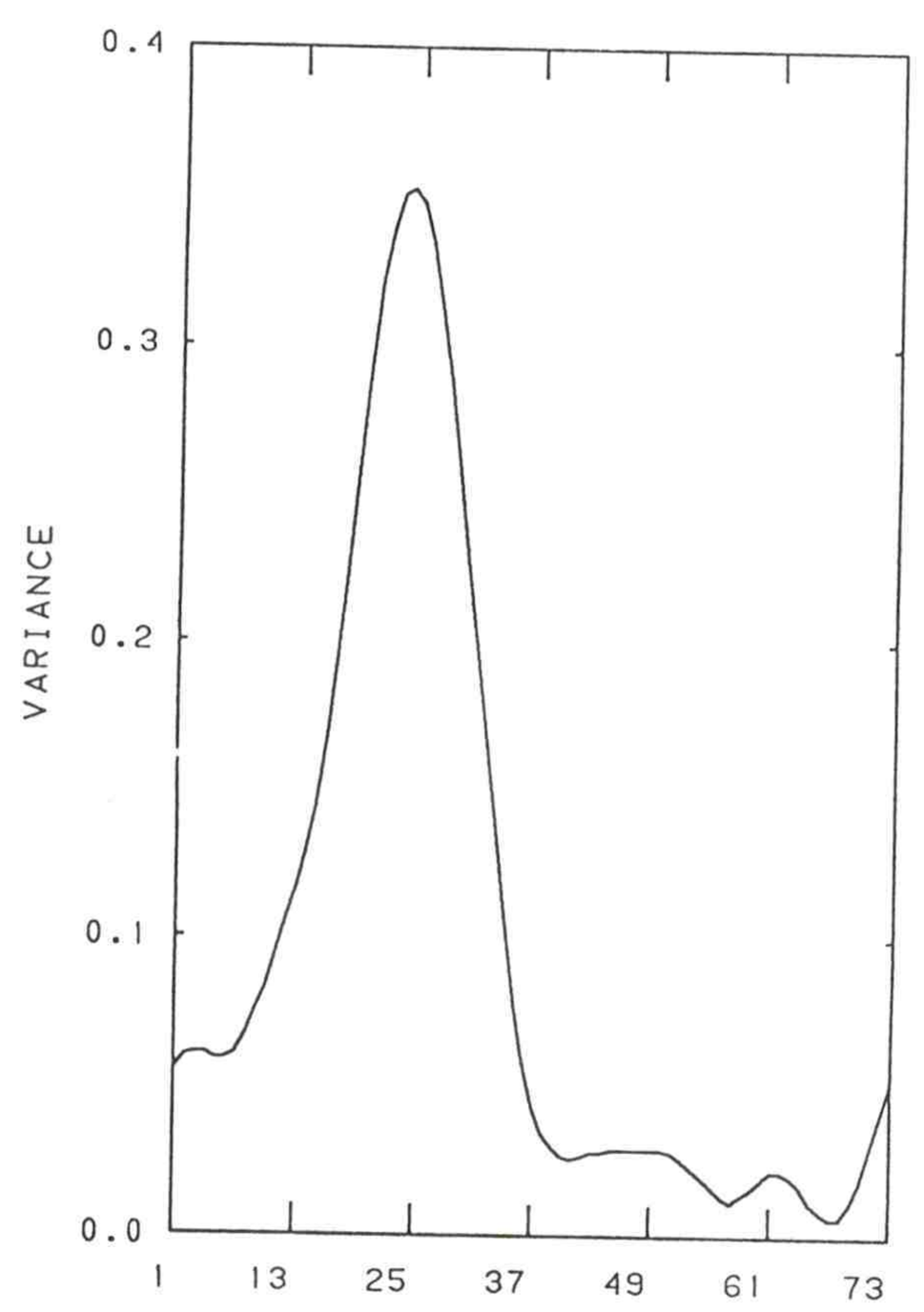


Figure 9: Amplitude time series (a) and (b) for the first two combined rotated modes shown in figure 8. Variance of the principal component time series for EOF-2, as a function of pentad (c).

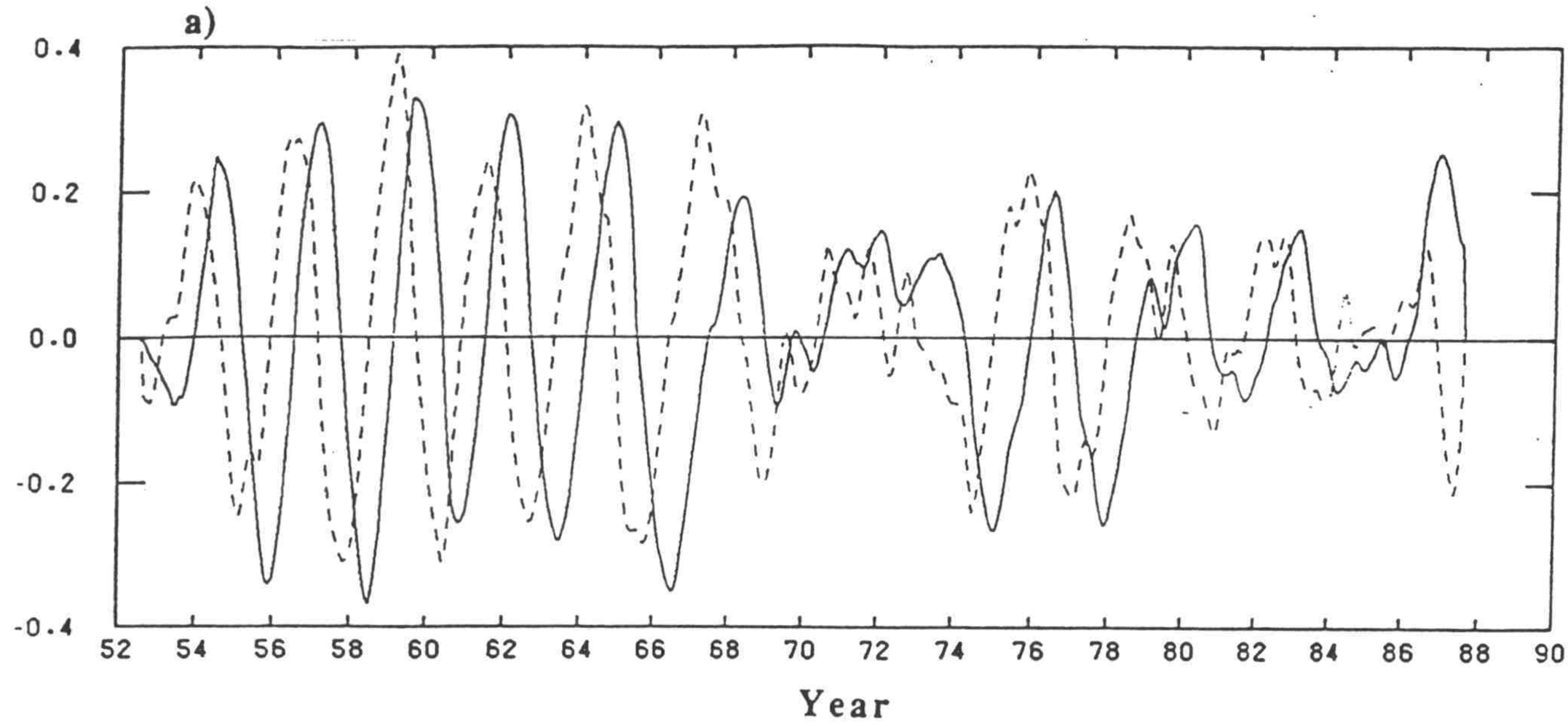


Figure 10a: Standardized temporal principal components 1 and 2 associated with the QBO mode.

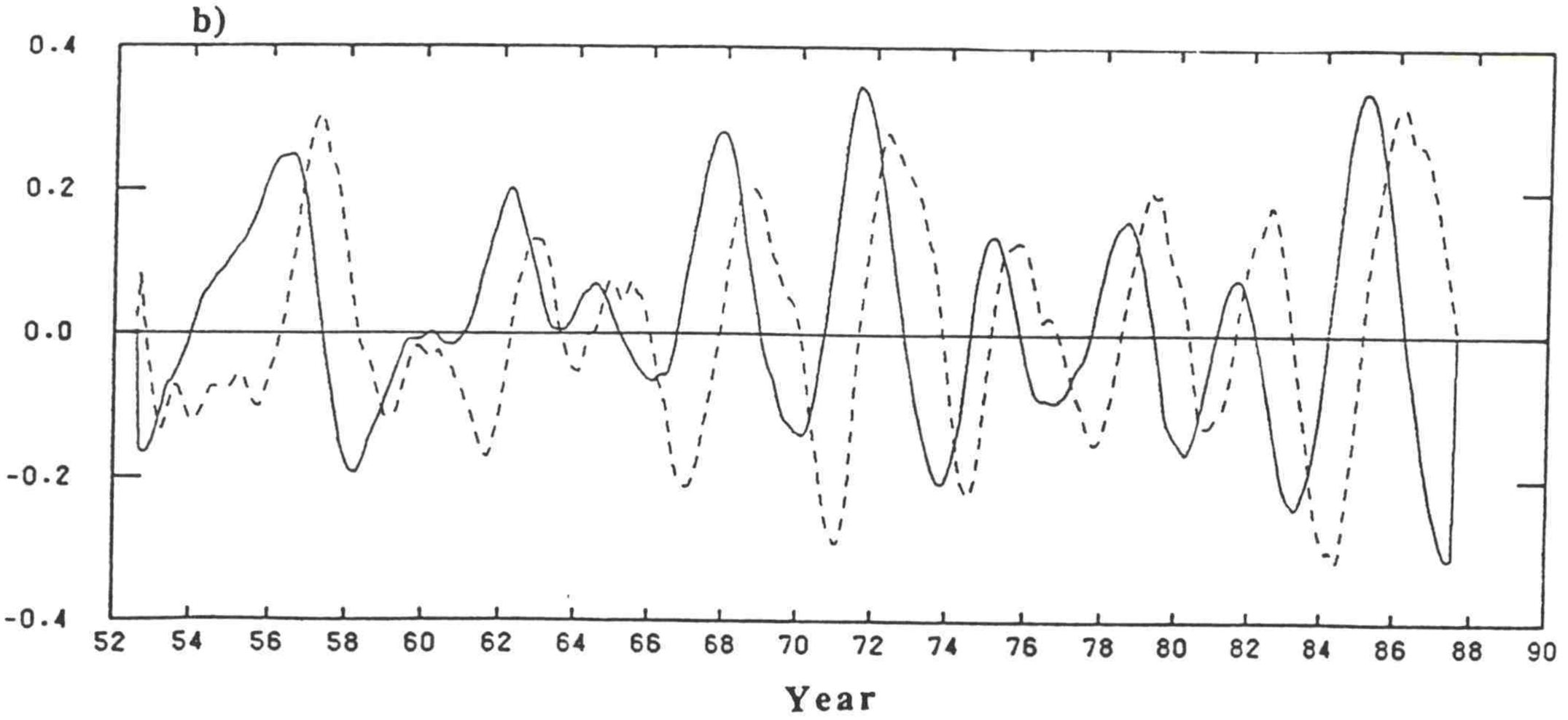


Figure 10b: Same as figure 10a, but for LF mode.

1.2.6 Extratropical Circulation (Bell)

A study was initiated to document the structural evolution of low frequency (periods greater than 30 days) and medium frequency (periods of 10-25 days) fluctuations during the evolution of blocking episodes. A major blocking episode, which persisted from March-June 1991 over the South Pacific Ocean, was examined. Preliminary results suggest that height field variability in the vicinity of the mean block position, centered near $60^{o}S,120^{o}W$ (figure 11c), is dominated by low frequency fluctuations (figure 11a, b, d). These low-frequency fluctuations account for a significant portion of the total height anomaly in the vicinity of the block during May and June, the time of maximum block intensity (figure 12a, b). The height field variability, both upstream and equatorward of the mean block position, is dominated by medium-frequency fluctuations (figure 11e); whereas, high-frequency fluctuations (periods of 2-6 days) contribute little to the observed height field variability in vicinity of the block (figure 11f).

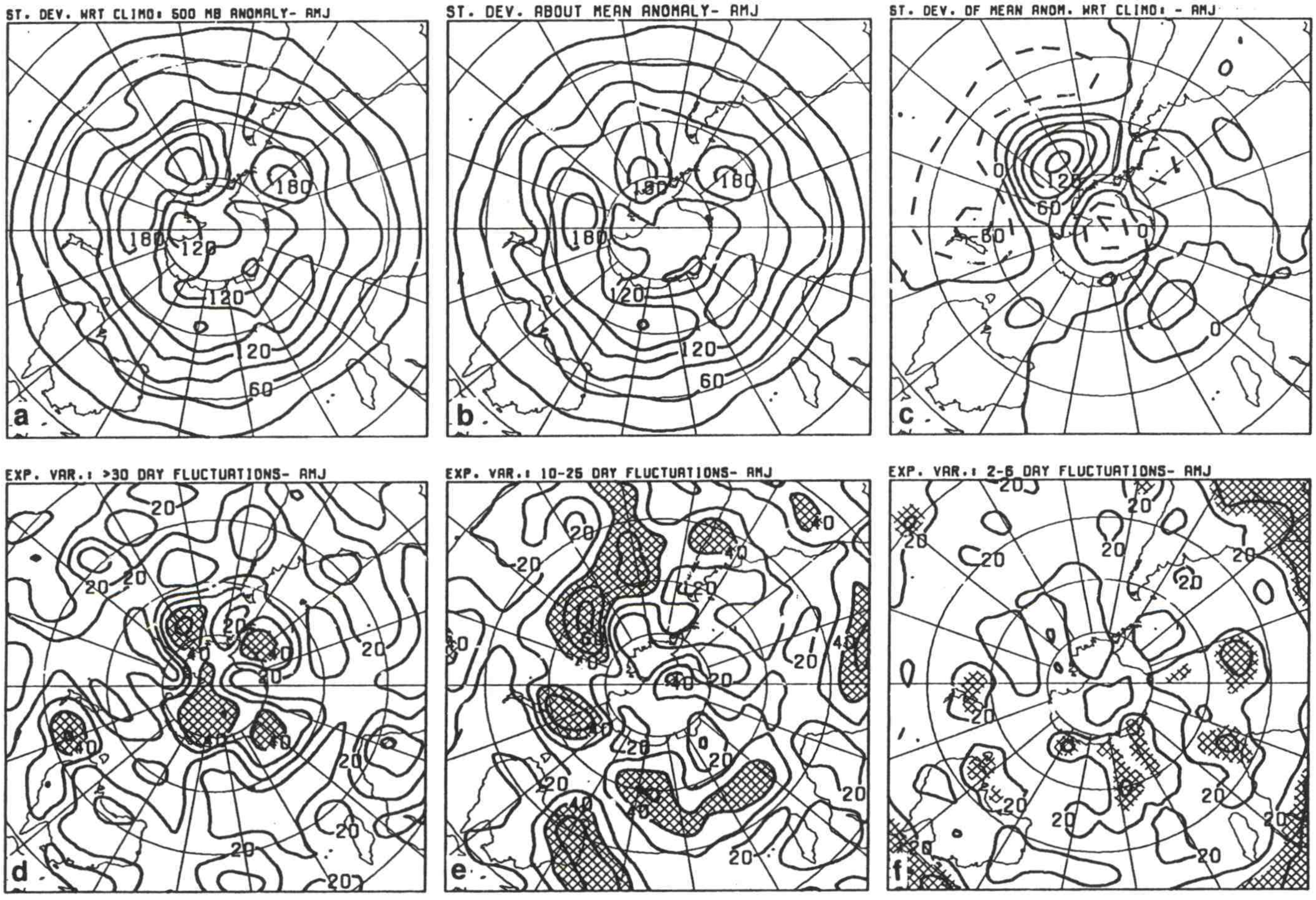


Figure 11: Southern Hemisphere - (a) Standard deviation from climatology (interval is 30 m) of the 500 mb height anomaly field during AMJ 1991; (b) standard deviation (interval is 30 m) of the 500 mb height field from the AMJ mean height anomaly field; (c) mean AMJ height anomaly field (absolute values reflect the standard deviation of the mean AMJ height anomaly from climatology). Percent of variance (interval is 10%) in (b) explained by fluctuations having periods (d) greater than 30 days, (e) between 10-25 days, and (f) between 2-6 days. Shading identifies regions in which explained variance exceeds (d,e) 40% and (f) 25% (shaded values identify regions in which explained standard deviation exceeds 63% and 50%, respectively). Anomalies are computed from the 1979-1988 base period.

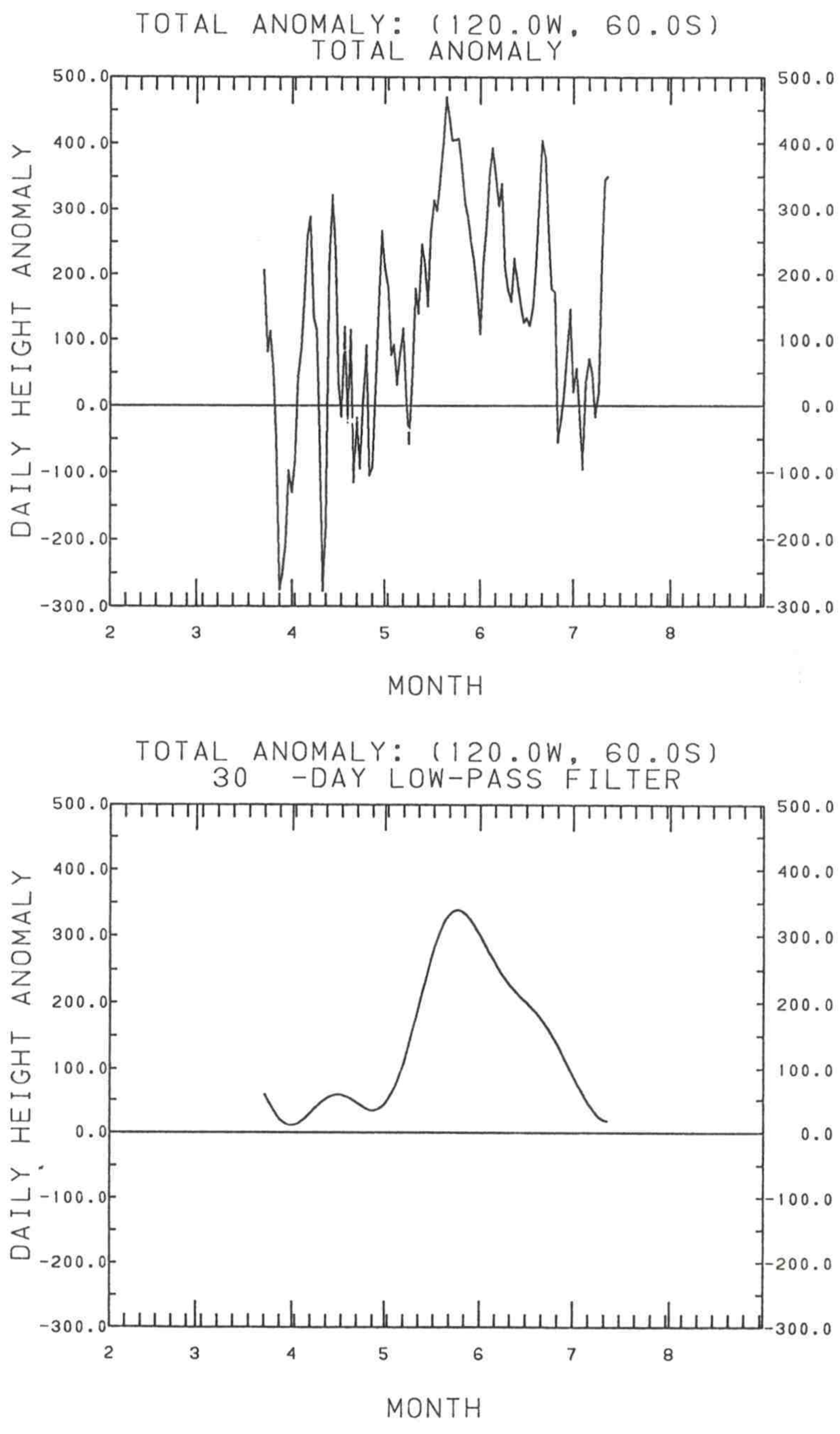


Figure 12: Time series of (a) 500 mb height anomaly (meters) and (b) the contribution to the 500 mb height anomaly field by fluctuations having periods >30 days (meters) for the period April-July 1991 over the mean block position (120°W, 60°S). Analyses are based on daily 0000 UTC height data and anomalies are computed with respect to the 1979-1988 base period.

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2. CLIMATE MONITORING

2.1 Surface Climate

2.1.1 Surface Climate Anomalies (Halpert, Ropelewski, Garrett)

New global temperature and precipitation normals were computed for the 1961-1990 base period. Comparisons were made between the new mean temperatures and those from the 1951-1980 period. Preliminary results reveal that the 1961 - 1990 base period mean temperatures are generally higher than the 1951-1980 mean temperatures (figure 13). However, large differences do occur between regions and even between seasons.

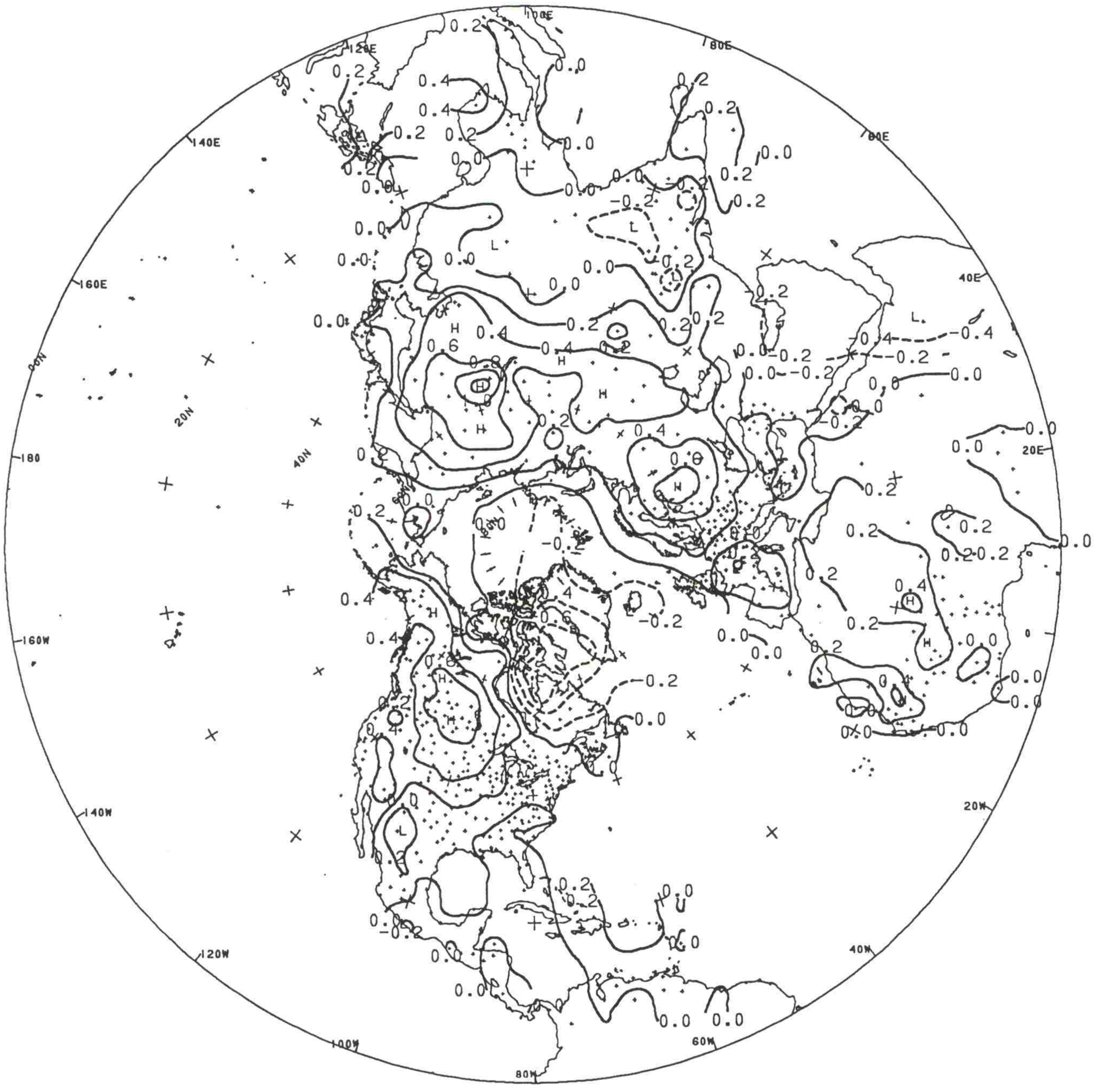
In another task, comparisons were made between CLIMAT data and monthly summary values (computed by CAC). Results, so far, show that the monthly temperature values are 0.5 - 1.0^{o}C greater than the CLIMAT values, with the largest differences in Africa and Southeast Asia. This task will continue in an effort to determine the cause of these differences.

CAC staff participated (with other NOAA scientists) in meetings to help develop the Global Climate Perspectives System. This system will enable NOAA to place local-to-global scale temperature and precipitation anomalies in century-scale perspective. Also, plans were established for a global drought monitoring system and for the coordinated development and implementation of an integrated software and hardware system.

2.1.2 Normalized Difference Vegetation Index (Halpert, Schultz)

The satellite-derived Normalized Difference Vegetation Index (NDVI) continues to be used as a climate monitoring tool. Normalization techniques were tested to try to eliminate the bias in the NDVI, which is caused by sensor degradation and orbital drift. Figure 14 shows a time series of the NDVI for 1986 - 1989 in a 3° latitude by 6° longitude area in Iowa. Although a severe drought affected this area during 1988, the peak values (week 30) for the index during 1988 and 1989 appear similar (figure 14a). However, after the NDVI values were normalized by the mean of the first 12 weeks of the year, the 1988 peak values appear significantly lower than in 1989 (see figure 14b).

In a related task, a diagnostic study is being performed on six years of historical NDVI data. The first harmonic has been fit to vegetation data for the United States during 1986 - 1988. Difference maps between the years indicate that the annual cycle of vegetation during 1986 and 1987 was about 10-20% greater than during 1988 in the drought-stricken Midwest.



MAM 9999 TEMP DIFFERENCES (1961-1990) - (1951-1980)

Figure 13: Northern Hemisphere temperature differences between the 1961-1990 and the 1951-1980 base periods for the MAM season. Contour interval is 0.2°C with negative contours dashed. Positive differences indicate that 1961-1990 base period means are greater than the 1951-1980 means.

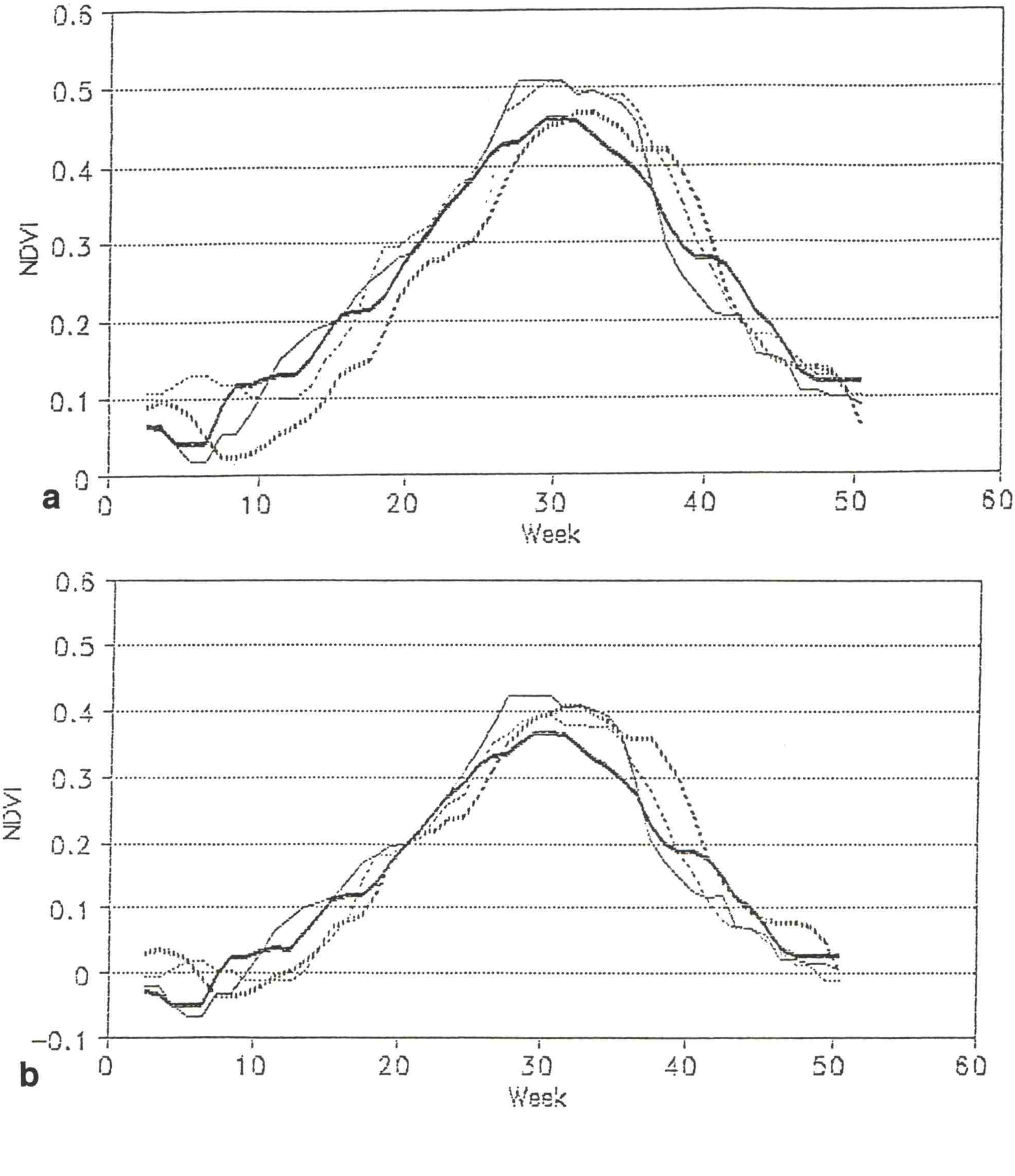


Figure 14: (a) Time series of the NDVI for the years 1986 - 1989 and (b) normalized by the mean of the first 12 weeks of data for each year. Data are spatially-averaged over an area from 41°N-43°N and 92°W-97°W and are smoothed with a four point median filter.

2.1.3 Snow/Ice Monitoring (Ropelewski, Garrett)

Weekly snow cover data (from NESDIS) were reprocessed for the 1973-1990 period to provide a temporally consistent set of weekly and monthly data. A study was then initiated to investigate the relationships of large - scale seasonal temperature anomalies and snow cover. Preliminary analysis (see figure 15) indicates that for the last half of the 1980's, Northern Hemisphere positive temperature anomalies were associated with snow cover deficiency at the southerly boundaries of the largest temperature anomalies.

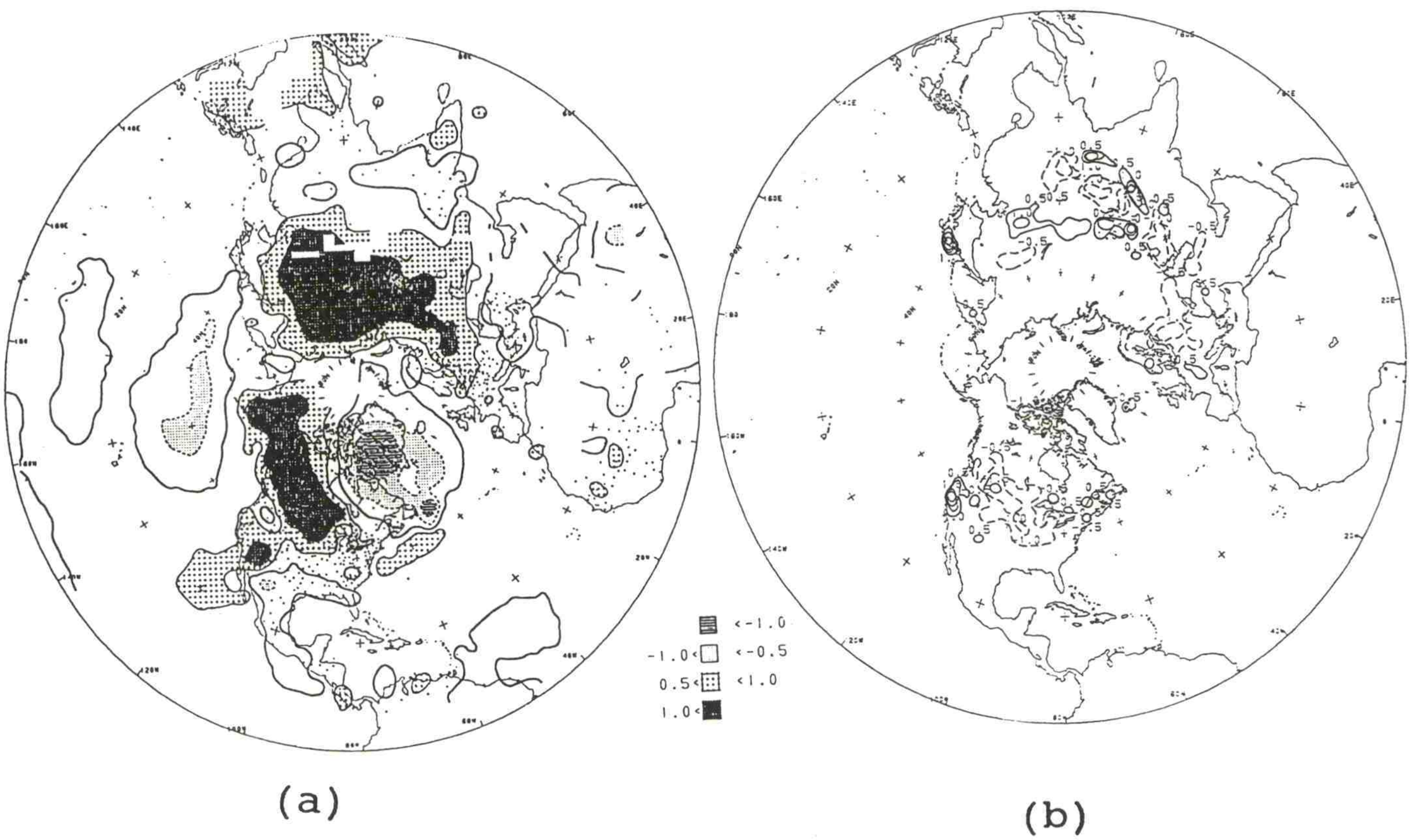
2.1.4 Climate Assessment (Halpert, Ropelewski)

A comprehensive decadal review was produced and published, which contains numerous surface and atmospheric circulation parameters for the 1981 - 1990 period. These parameters include decadal summaries of surface temperature, precipitation, snow and ice, tropospheric temperatures, teleconnections, and ozone. In addition, there were summaries of significant meteorological events, such as the Southern Oscillation and extreme temperature and precipitation events. Figure 16 is an example of the type of figure contained in the review. In this analysis, surface temperature anomalies for the 10-year period were computed for both warm and cold seasons in each hemisphere. One can see, from this figure, that the majority of the above normal temperatures occurred in the December-May season in the Northern Hemisphere.

2.1.5 Diagnostic Studies of the Coupled Ocean-Atmosphere System (Chelliah, Smith, Ropelewski)

A diagnostic study was initiated to compare sea surface temperature (SST) data from the COADS data set and CAC's database. The main purpose is to show how these 2 datasets compare over the data-rich and data-poor regions of the tropical Pacific. The CAC blended SST (from 1982 to the present) is based on ship reports, drifting buoys and satellite data, while the COADS based SST (historical record) is based only on existing ship reports. The analysis period is from 1982 to 1987 and the domain is the tropical Pacific (20°N - 20°S, 120°E - 80°W). For both data sets, monthly anomalies were computed using the same monthly COADS based climatology. Rotated principal component analysis was performed on both data sets.

Figure 17 shows the time series and the spatial loading patterns for the leading two principal components of the COADS based SST analysis. Figure 18 is same as figure 17, except for the blended SST analysis. The explained variances of each of these modes is given at the top right hand corner of the corresponding loading functions. Overall, it appears that the



(a) (b)

Figure 15: Northern Hemisphere, December to May surface temperature anomaly for the period 1981 to 1990 (a). Schematic of Northern Hemisphere snow cover anomaly for the same period (b).

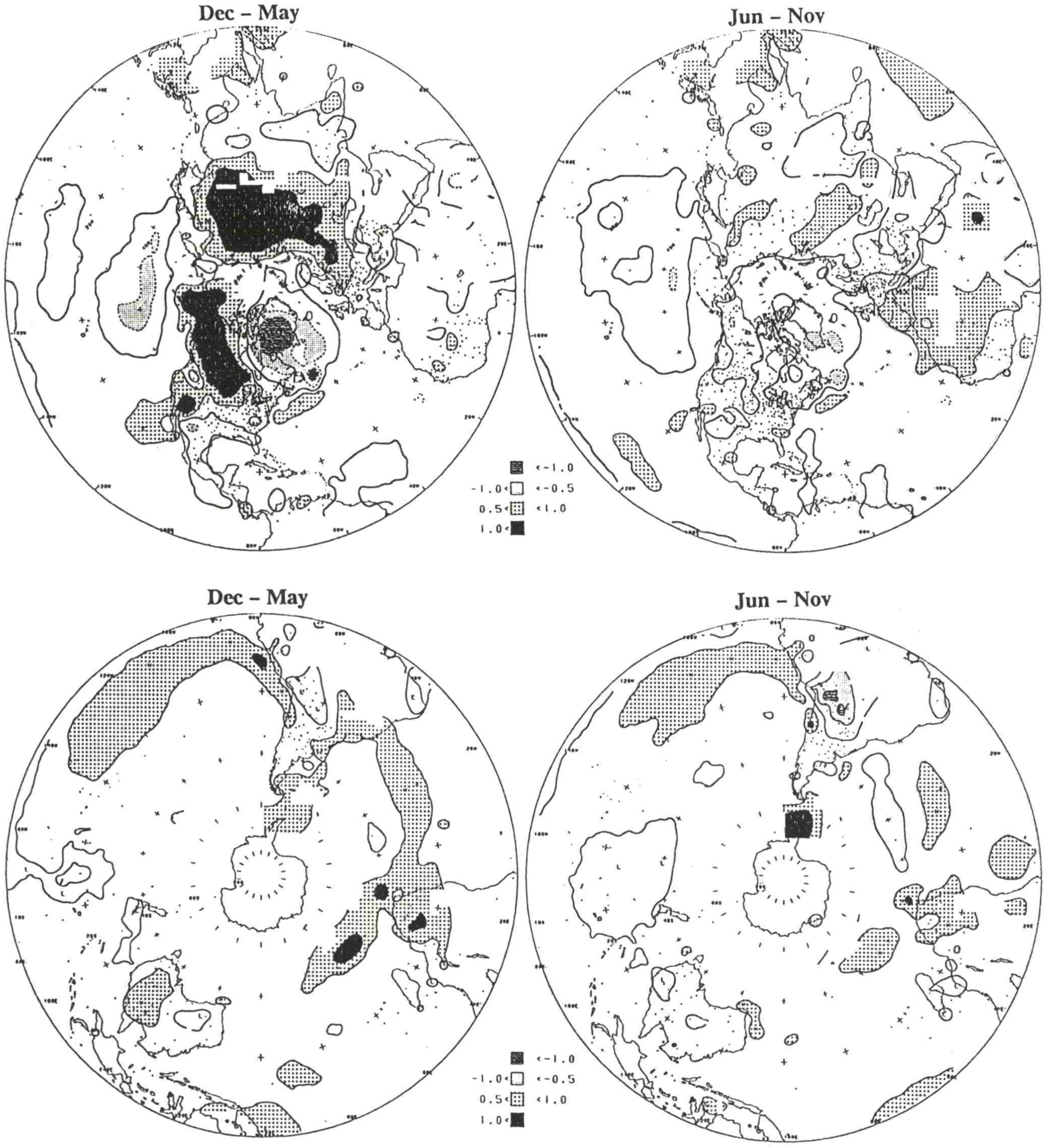
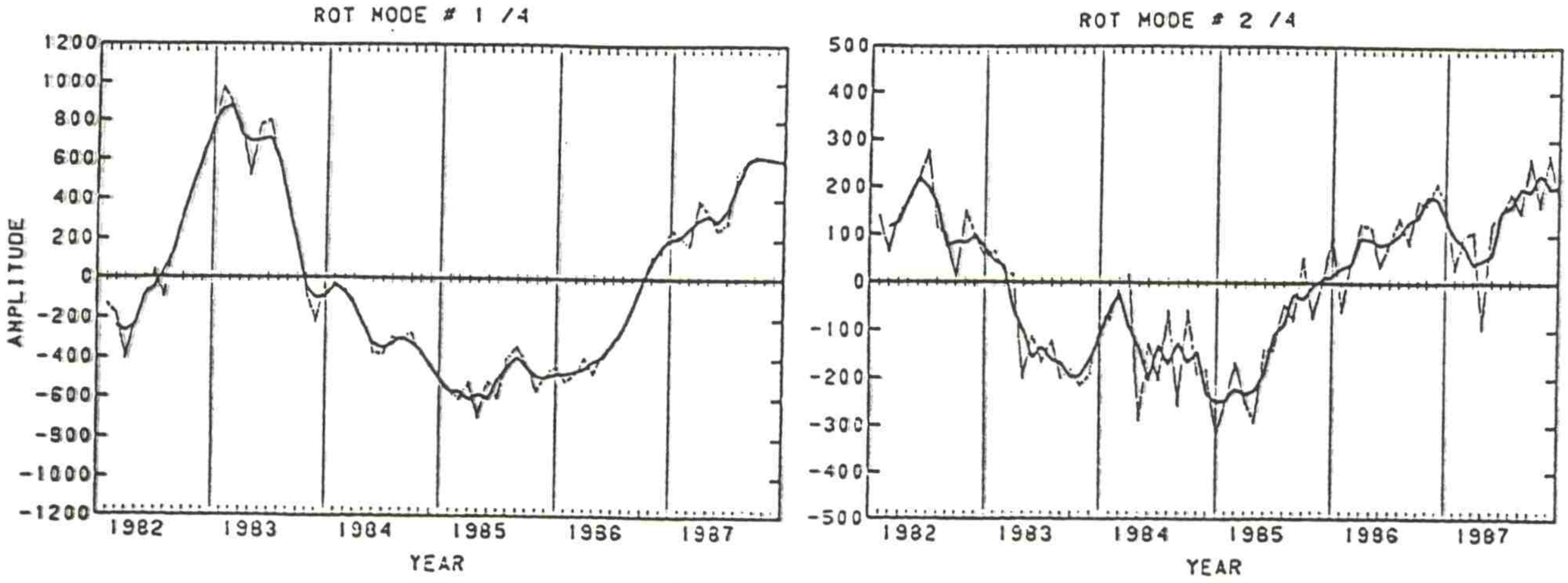


Figure 16: Decadal (1981-1990) mean surface temperature anomaly patterns for the December through May season (left) and June - November season (right). The analysis is based on station data over land and sea surface temperature over water. Anomalies for station data are from the 1951-1980 base period, and from the COADS/ICE climatology over water. Small plus signs indicate data locations over land. The contour interval is 0.5°C with negative anomalies dashed.

PCA - COADS SST MON.ANOM.TIME SERIES-



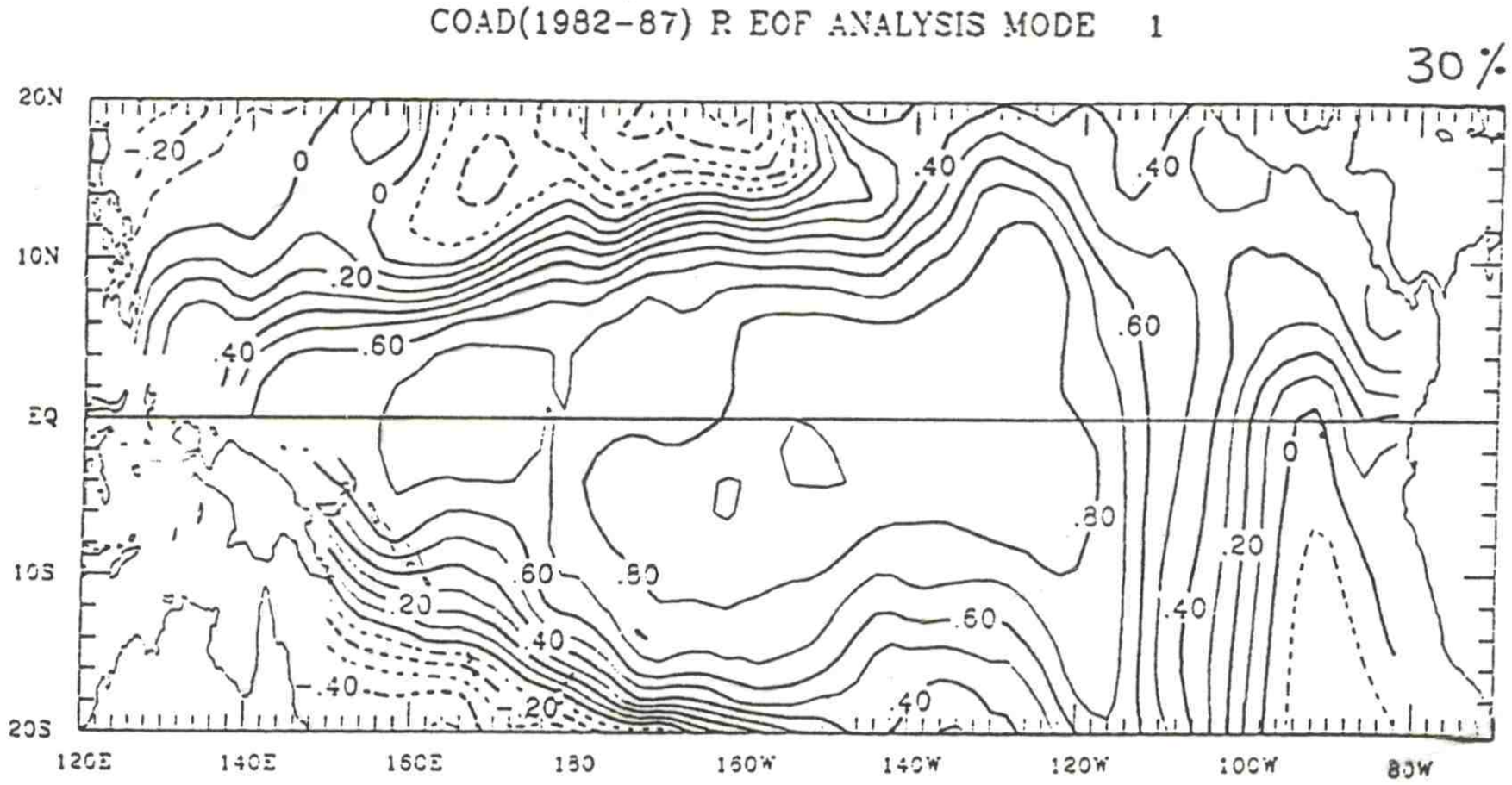
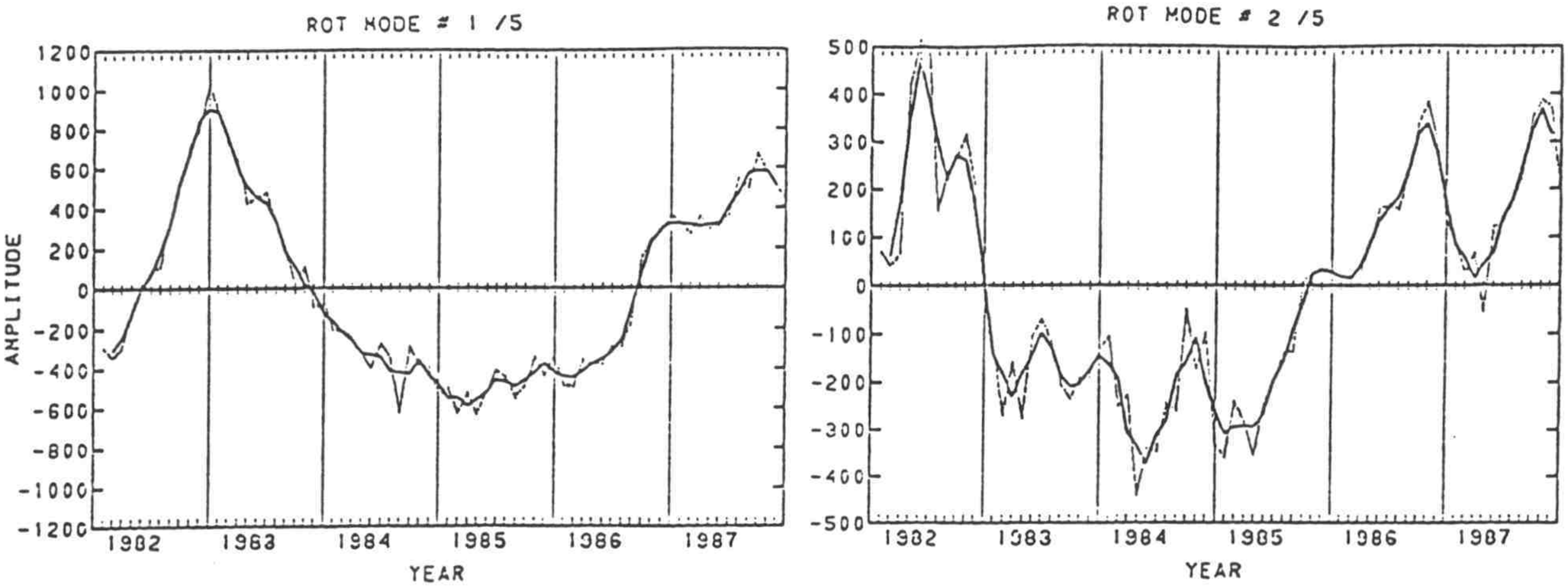


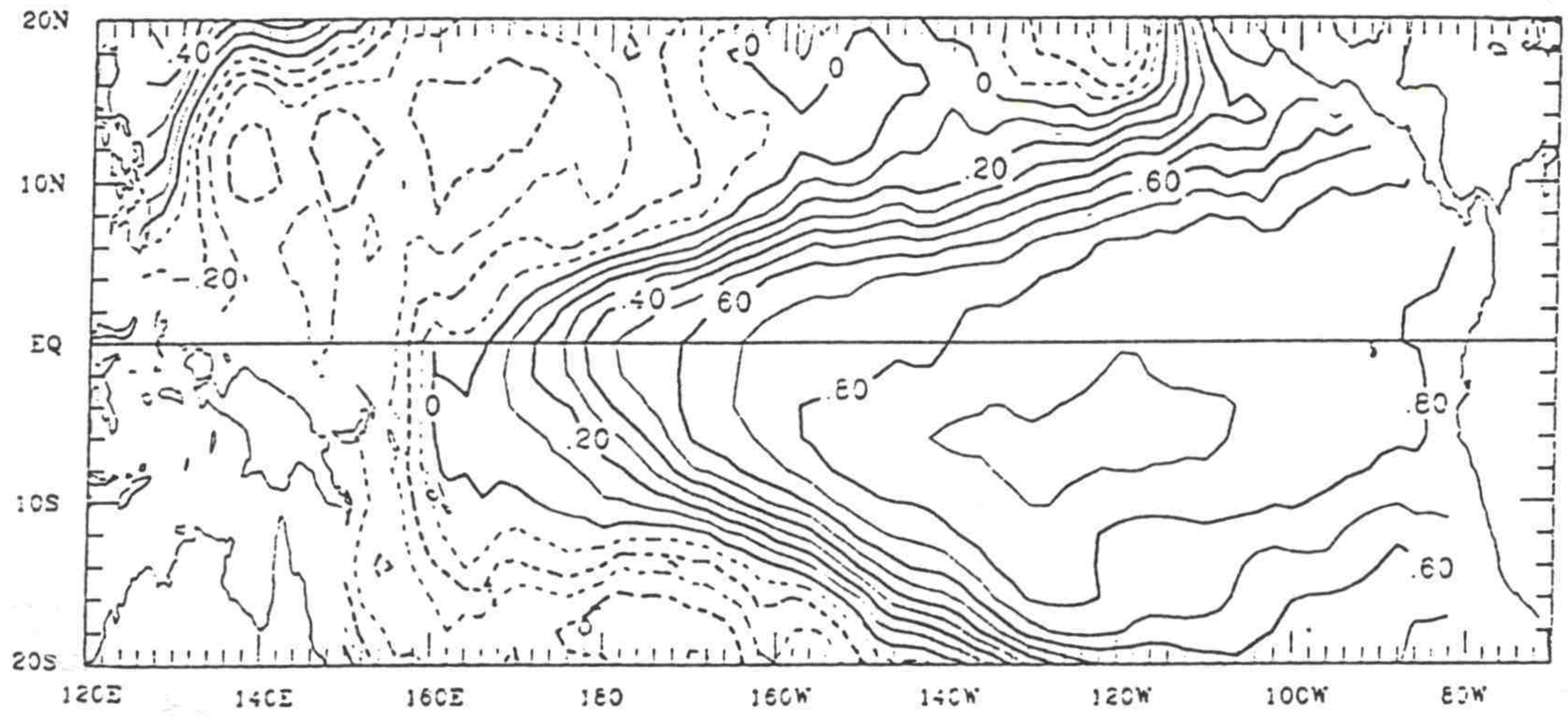
Figure 17: The time series and the spatial loading patterns for the two leading principal components of the COADS based monthly SST anomalies from 1982 to 1987.

PCA -BLENDED SST MON.ANOM.TIME SERIES-



SST-(1982-87) R EOF ANALYSIS MODE 1

29%



SST-(1982-87) R EOF ANALYSIS MODE 2

15%

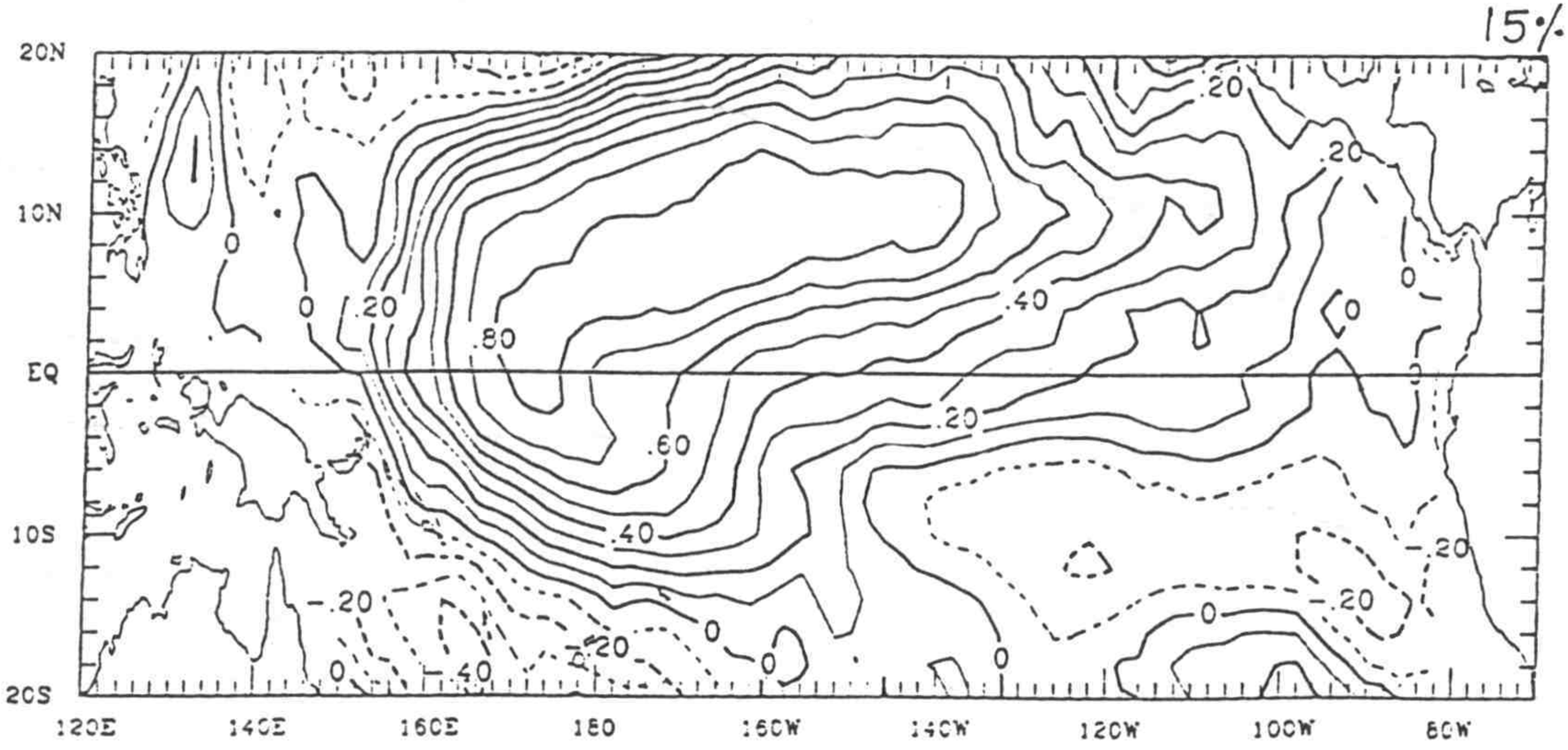


Figure 18: The time series and the spatial loading patterns for the two leading principal components of the CAC blended monthly SST anomalies from 1982 to 1987.

leading two eigenmodes, which are associated with the two warm ENSO events in the tropical Pacific, correspond respectively to each other. However, it is striking to see that there are very large differences between the two SST's (especially over the data-sparse eastern Pacific) in even the leading eigenmodes. An examination of the time series and the spatial loading patterns beyond the second mode (not shown) indicates that there is very little agreement between the two SST's. A preliminary conclusion is that the SST variability in COADS data set is only good enough to analyze the low-frequency ENSO time and space scales over the data-rich regions.

2.2 Clouds and Precipitation

2.2.1 Global Precipitation Climatology Project (GPCP)

2.2.1.1 Geostationary Satellite Precipitation Data Center (Janowiak)

The NMC/Climate Analysis Center was designated as the Algorithm Intercomparison Center for an experiment that was designed to determine the accuracy of satellite-based rainfall estimation techniques. This study was conducted over Japan during June - August 1989. High-resolution infrared and visible data from the GMS geostationary satellite (hourly) and microwave data from the U.S. Defense Meteorological Satellite Program (DMSP) spacecraft (twice daily) were sent to each algorithm development group. All of the groups were required to submit estimates of monthly rainfall accumulation for specified 1.25° latitude-longitude squares. A validation data set (composite of radar estimates and 1300 automated raingauges) was then assembled by the Japanese Meteorological Agency. This data set was not sent to any group until their rainfall estimates were received by the validation center.

A statistical plot, used to evaluate the remotely sensed precipitation estimates against the validating observations (June 1-30 1989), is shown in figure 19. The figure shows estimates of error, correlation (time and space mixed), and "percent correct"; that is, the percentage of correct estimates as computed from a 4 category contingency table. Figure 20 shows the intercorrelation among estimation methods for both observing periods and is useful in determining the similarities and differences among the techniques. Initial results indicate that the majority of the infrared-based techniques yield similar results. There is some evidence that techniques which use visible data in conjunction with infrared data yield more accurate estimates. Microwave-based algorithms seem to yield promising results for "instantaneous" cases; but, for daily or monthly estimates, they suffer from temporal sampling problems due to the polar orbit of the satellite.

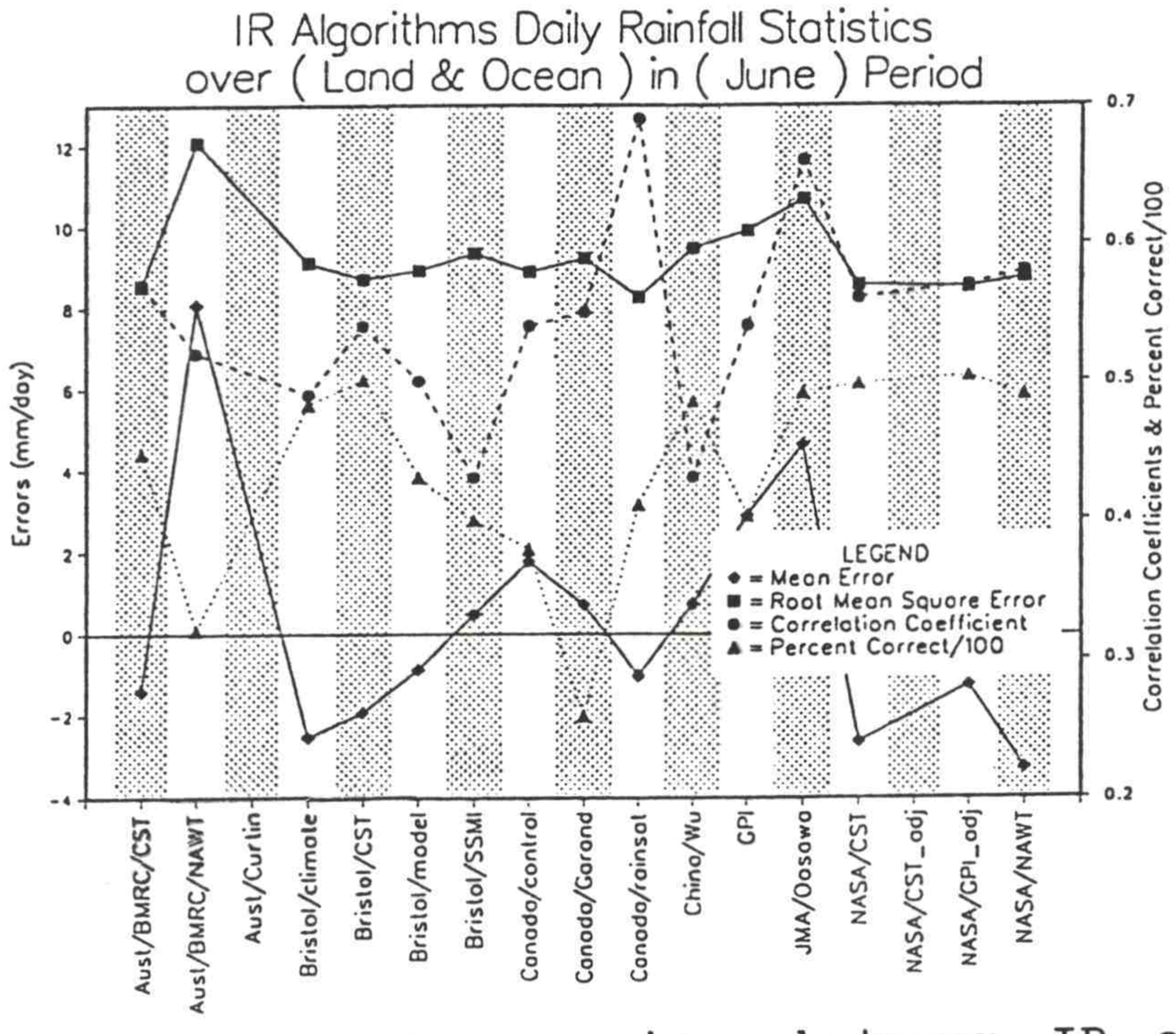


Figure 19: Statistics of comparison between IR and IR/VIS algorithm estimates and validation data for June 1-30, 1989.

Figure 20: Inter-correlation among infrared and infrared/visible algorithm estimates for both observing periods.

2.2.2 Tropical Rainfall (Janowiak)

A comparison was made between 5-day accumulations of satellite-derived tropical rainfall estimates (GPI) and precipitation forecasts from the NMC Medium Range Forecast (MRF) and ECMWF models. Comparisons of mean rainfall from March - November 1989 show that the satellite estimates and the model forecasts agree reasonably well, except in the northern Indian Ocean and the Pacific ITCZ regions (figure 21). Zonal-mean rainfall for land only, ocean only, and combined (figure 22) indicates reasonable agreement among the data sets, except over land from 10N-10S where all 3 data sets substantially disagree.

Temporal correlations (from 54 five-day periods) indicate no statistically significant association between the model forecasts and the satellite estimates in much of the tropical belt as depicted in figure 23. These low correlations apparently reflect the inability of the models to characterize 30-60 day bursts of convection that are often seen in the tropics. To demonstrate this, figure 24 shows the time series of spatially-averaged rainfall forecasts and estimates for a location where there is a low correlation between the model forecasts and satellite estimates.

2.3 Atmospheric Circulation

2.3.1 Tropospheric Variability (Kousky, Mo)

A study was initiated to investigate the principal global modes of anomalous upper tropospheric stream function. A pentad archive (from NMC analyses) served as the basis for this study, which enables the examination of variability on intraseasonal to interannual time scales. Preliminary results indicate that the lowest modes describe the spatial and temporal variability associated with extremes in the Southern Oscillation. Research is continuing concerning the interpretation of higher modes of variability in both hemispheres.

2.3.2 Tropospheric Anomalies (Janowiak, Kousky, Mo)

An archive of zonally-averaged temperature (monthly averaged in time) for each discrete pressure level in the Climate Diagnostics Data Base (CDDB) was produced to monitor possible temperature fluctuations associated with the volcanic eruption of Mt. Pinatubo, Philippines. Although the time series begins in October 1978, it contains several discontinuities that coincide with changes in NMC's Global Data Assimilation System. However, this information may still be useful to detect possible temperature trends by comparing current values with past ones.

NOAA Coral Gables Library Center
1320 South Dixie Highway, Room 520
Coral Gables, Florida 33146

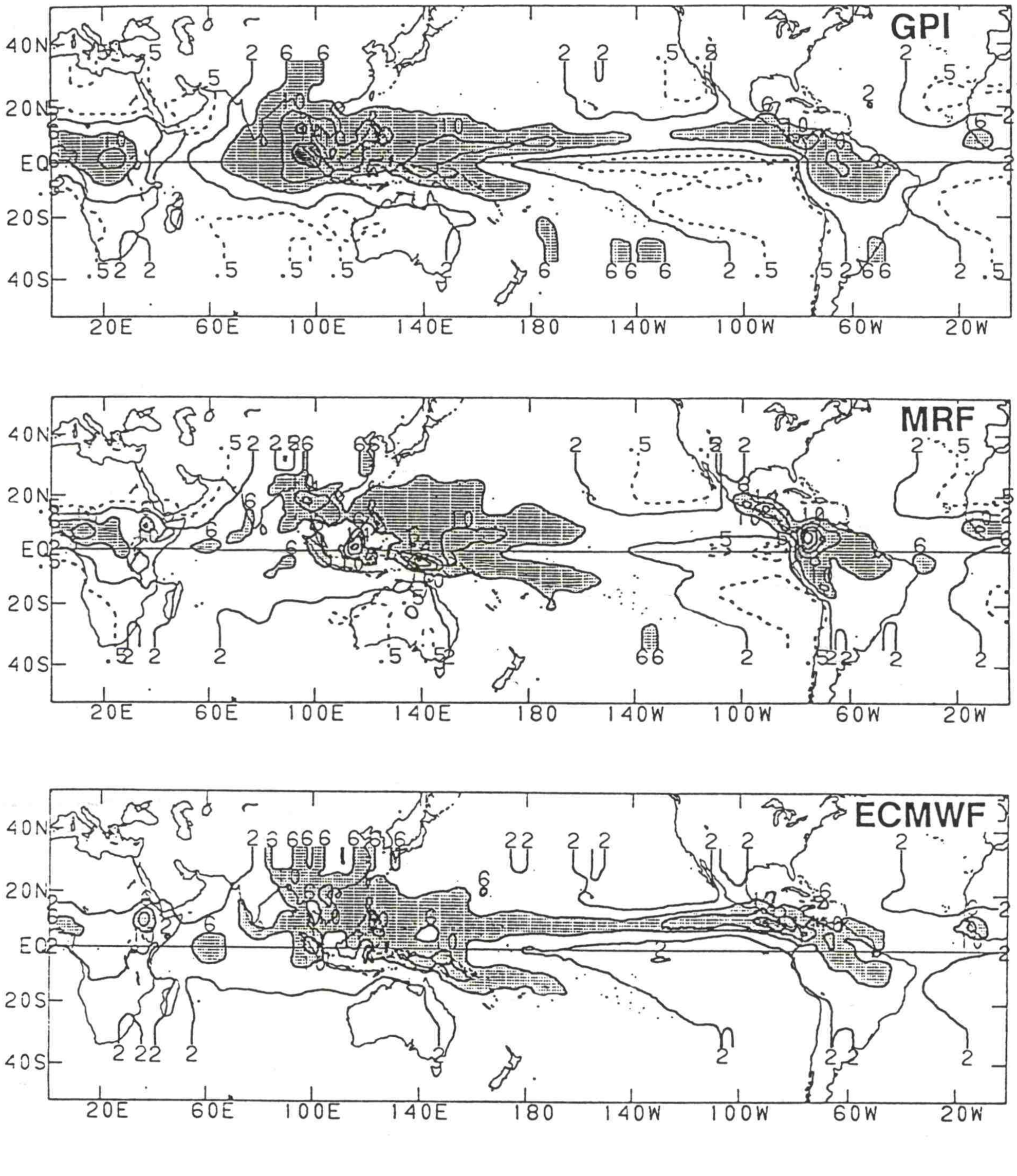


Figure 21: Mean rainfall (mm/day) for the March 7 - December 1, 1989 period from the satellite - based estimates (GPI), the NMC (MRF) model, and ECMWF model precipitation forecasts.

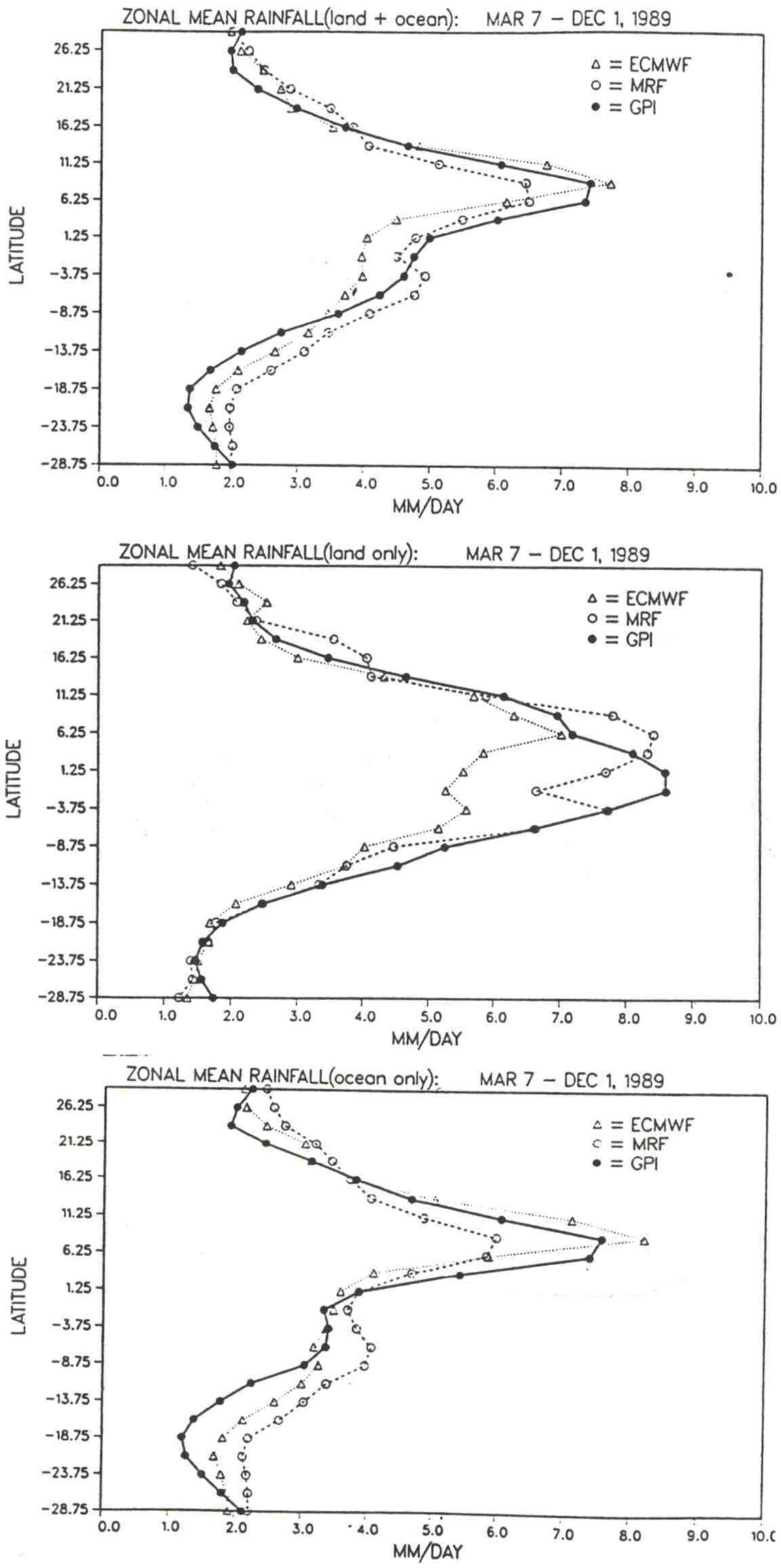


Figure 22: Latitudinal profile of zonal mean rainfall for GPI (solid), MRF (dashed), and ECMWF (dotted) over the period March 7-December 1, 1989 for each 2.5^{o} latitude band from 30°N-30°S (centered in the middle of each band) for all locations, land only, and ocean only. Units are "mm/day".

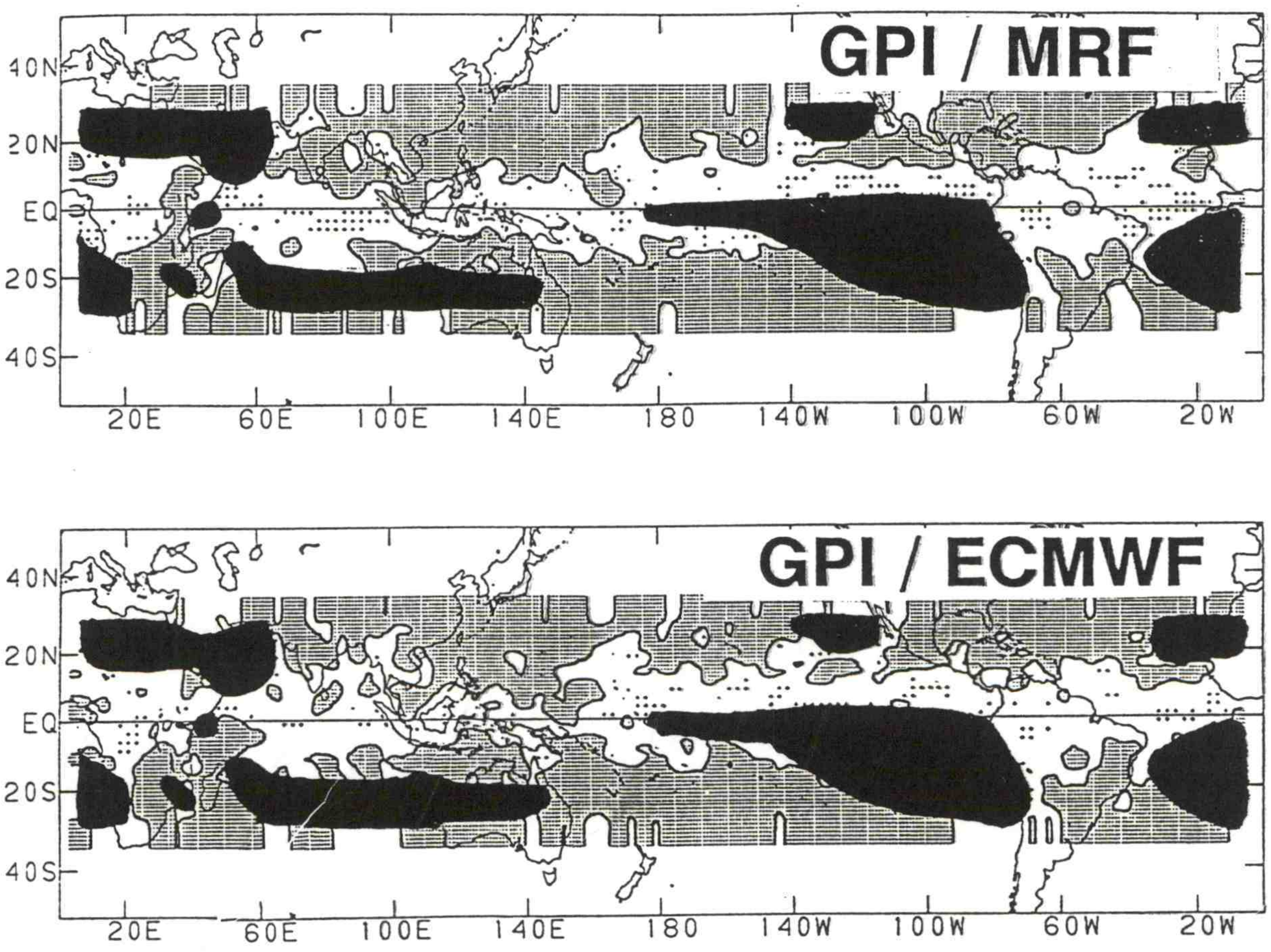


Figure 23: Temporal correlation at each 2.5° location between 30°N-30°S on rainfall differences between adjacent pentads between GPI vs. MRF and GPI vs. ECMWF for the period March 7-December 1, 1989. Black regions are where mean rainfall for the period (as determined from the GPI) was < 1 mm/day and correlations were not computed. The lightly shaded regions indicate where the correlations are significant at the 95% level. Areas with no shading indicate no significant correlation between the GPI estimates and model forecasts, and symbols inside these areas are where the correlations are negative.

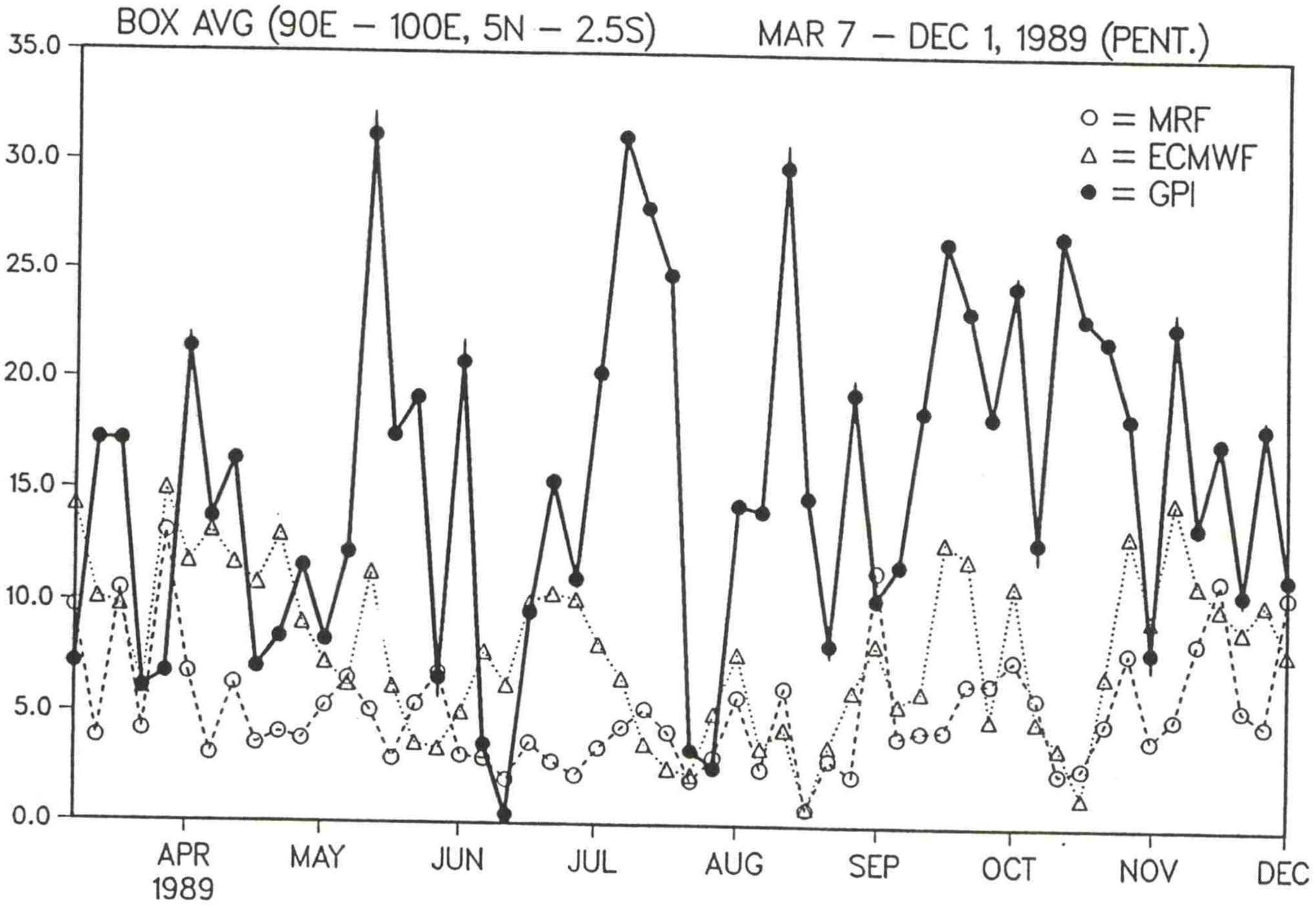


Figure 24: Time series of rainfall in grid box defined by 90° - 100°E and 5°N-2.5°S for the period March 7-December 1, 1989 (mm/day) for GPI (solid), MRF (dashed), and ECMWF (dotted).

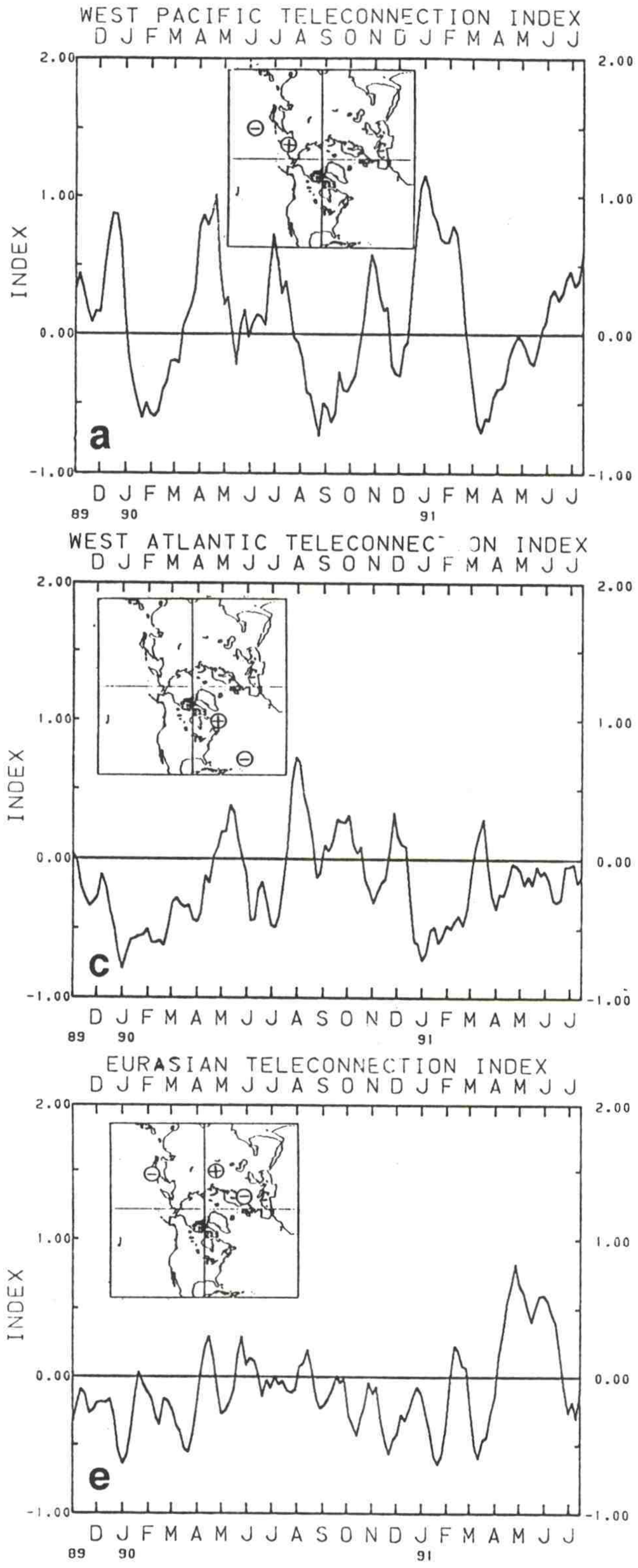
Software was developed and implemented that enhances user access to the CDDB and its products. All CDDB fields that appear in CAC's Monthly Climate Diagnostics Bulletin are now routinely uploaded to the CAC Dial-Up Data Service. The method by which streamfunction, velocity potential and divergence values are computed for the Bulletin has been changed from grid point calculations to a spherical harmonic approach. Data, necessary for the production of time-longitude plots and index time series, are now routinely transferred to a workstation for the automation of many graphical products.

2.3.3 Mid-latitude Monitoring Program (Bell)

The goal of this project is to monitor and diagnose mid-latitude circulation variability occurring on the intra-monthly through inter-seasonal time scales. The first step was to develop a set of prototype indices and diagnostics. Some of the diagnostic tools include: (1) a time series of teleconnection indices to monitor the phases of 5 primary Northern Hemisphere teleconnection patterns (figure 25); (2) an analyses of monthly 500-mb height variability to identify persistent positive and negative anomalies in each hemisphere (figure 26); and (3) an analyses of spectrally-decomposed 500-mb height anomalies to monitor planetary and sub-planetary scale contributions to intra-monthly circulation variability in each hemisphere (figures 27 and 28). These diagnostics depicted the spatial and temporal evolution of two features (described below) which exhibited remarkable persistence during April - June 1991.

In the Northern Hemisphere, the 500-mb circulation was dominated by a stationary wave-train of large amplitude height anomalies extending eastward from North America to north-central USSR (figure 26a, b). A time series of the total anomaly field (figures 27a, d), the planetary scale (figure 27b, e) and sub-planetary scale (figure 27c, f) height anomaly fields suggest that the anomalous wave pattern reflected persistent positive sub-planetary scale height anomalies that were reinforced by a planetary scale pattern. The analysis also shows that the stationary wave pattern represented a major disruption of transient wave activity emanating from the eastern and central North Pacific (figure 27d). Finally, the positive height anomalies over the USSR reflected the persistent positive phase of the Eurasian teleconnection pattern (figure 25e).

In the Southern Hemisphere, a major blocking episode began in late March and persisted through June. During this event, persistent 500-mb height anomalies were concentrated over the south-central and south-eastern South Pacific and a pronounced lack of persistence was noted elsewhere (figures 26c, d). In contrast to the Northern Hemisphere analysis, persistent planetary scale height anomalies dominated the region of the block (figures 28a, b). This block became particularly enhanced during May when positive sub-planetary scale height anomalies became concentrated over the region (figure 28c).



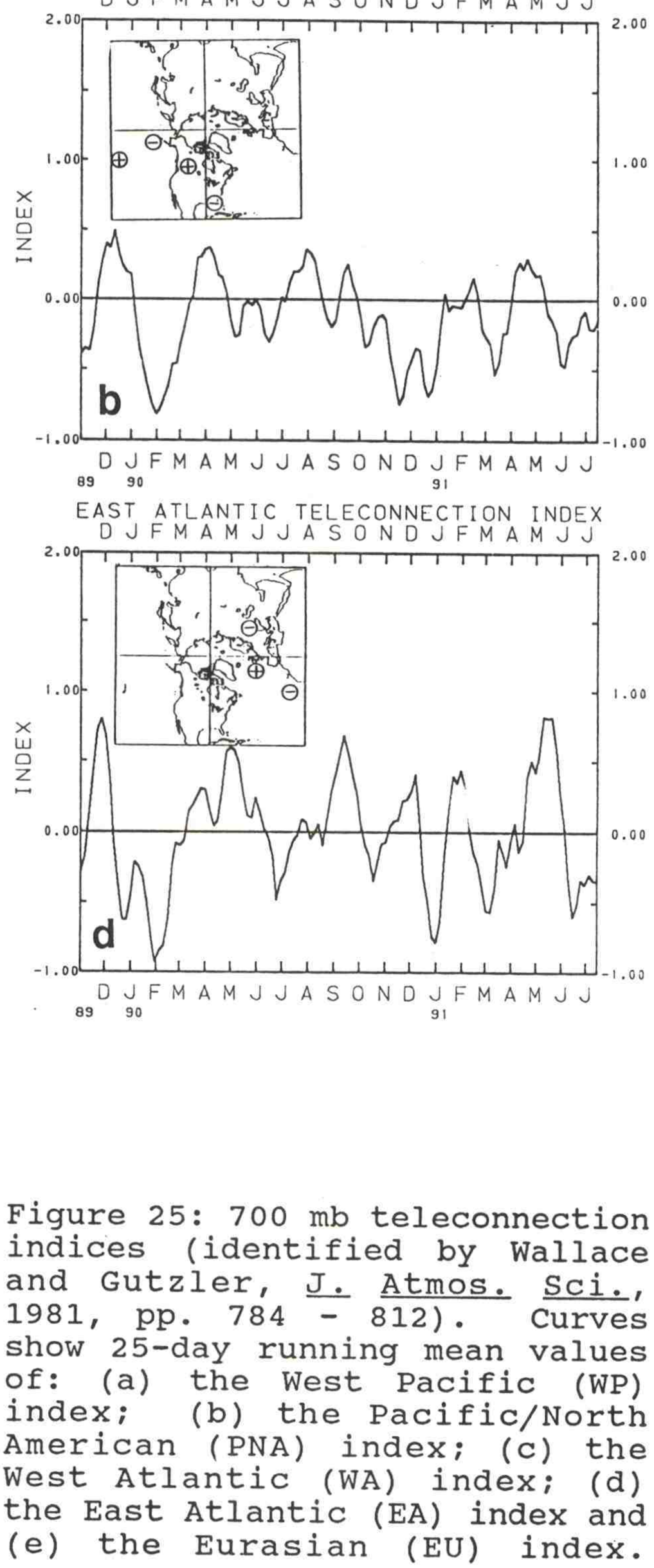


Figure 25: 700 mb teleconnection indices (identified by Wallace and Gutzler, J. Atmos. Sci., 1981, pp. 784 - 812). Curves show 25-day running mean values of: (a) the West Pacific (WP) index; (b) the Pacific/North American (PNA) index; (c) the West Atlantic (WA) index; (d) the East Atlantic (EA) index and (e) the Eurasian (EU) index. The running mean is applied to non-overlapping 5-day averaged index values determined from daily normalized 700 mb height data for the period December 1989 through July 1991. Daily height anomalies are normalized using 27-year (1964-1990) daily means and standard deviations. Tick marks along horizontal axes are placed at the beginning of each month. Inset illustrates positive phase of the teleconnection pattern index, with height anomalies over action centers indicated by (+) and (-) signs.

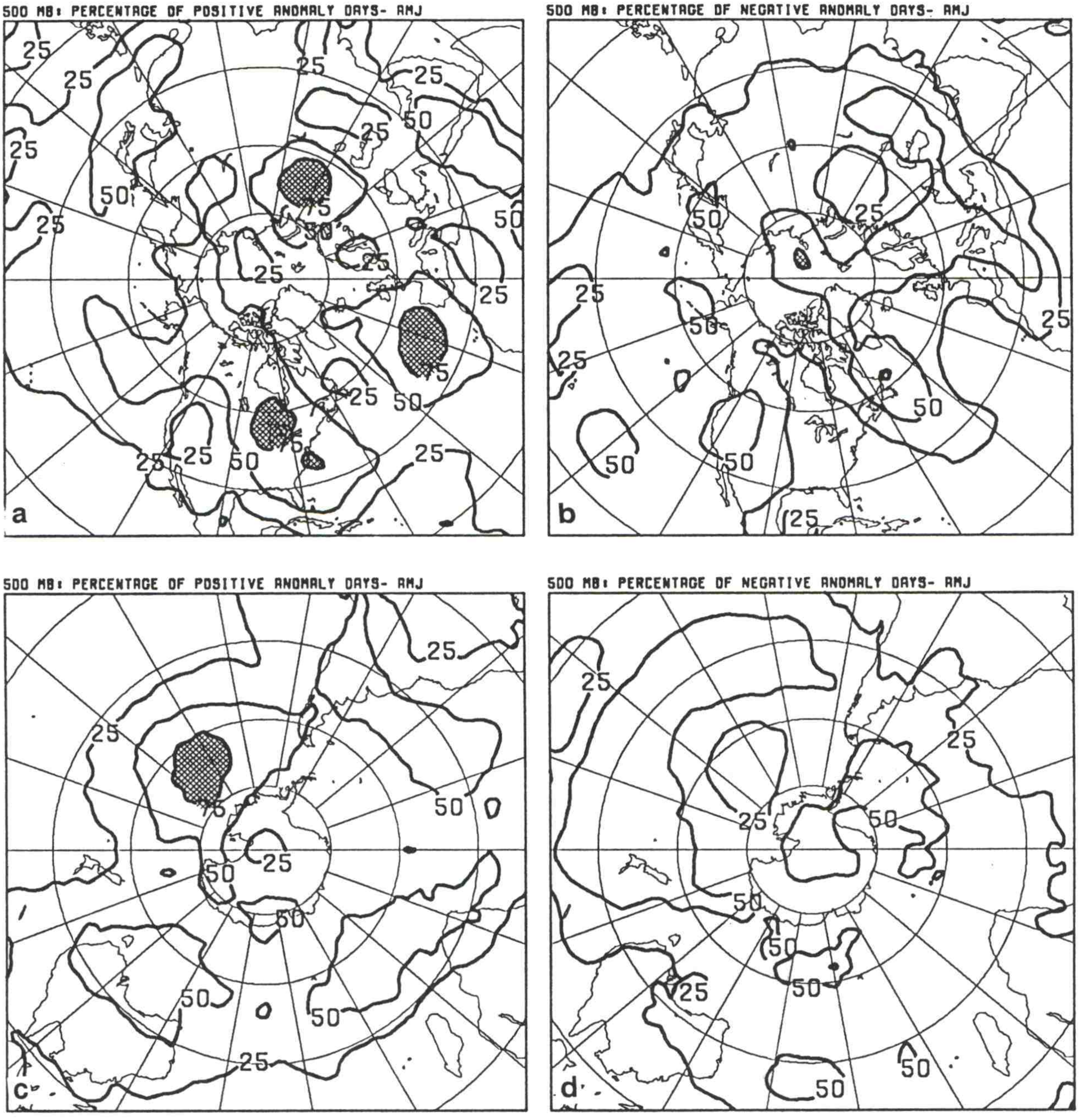


Figure 26: Percentage of days during April-June 1991 in which 500 mb height anomalies (a,c) greater than 15m were observed in the Northern and Southern Hemisphere, respectively; and (b,d) less than -15 m were observed in the Northern and Southern Hemisphere, respectively. Values greater than 75% are shaded.

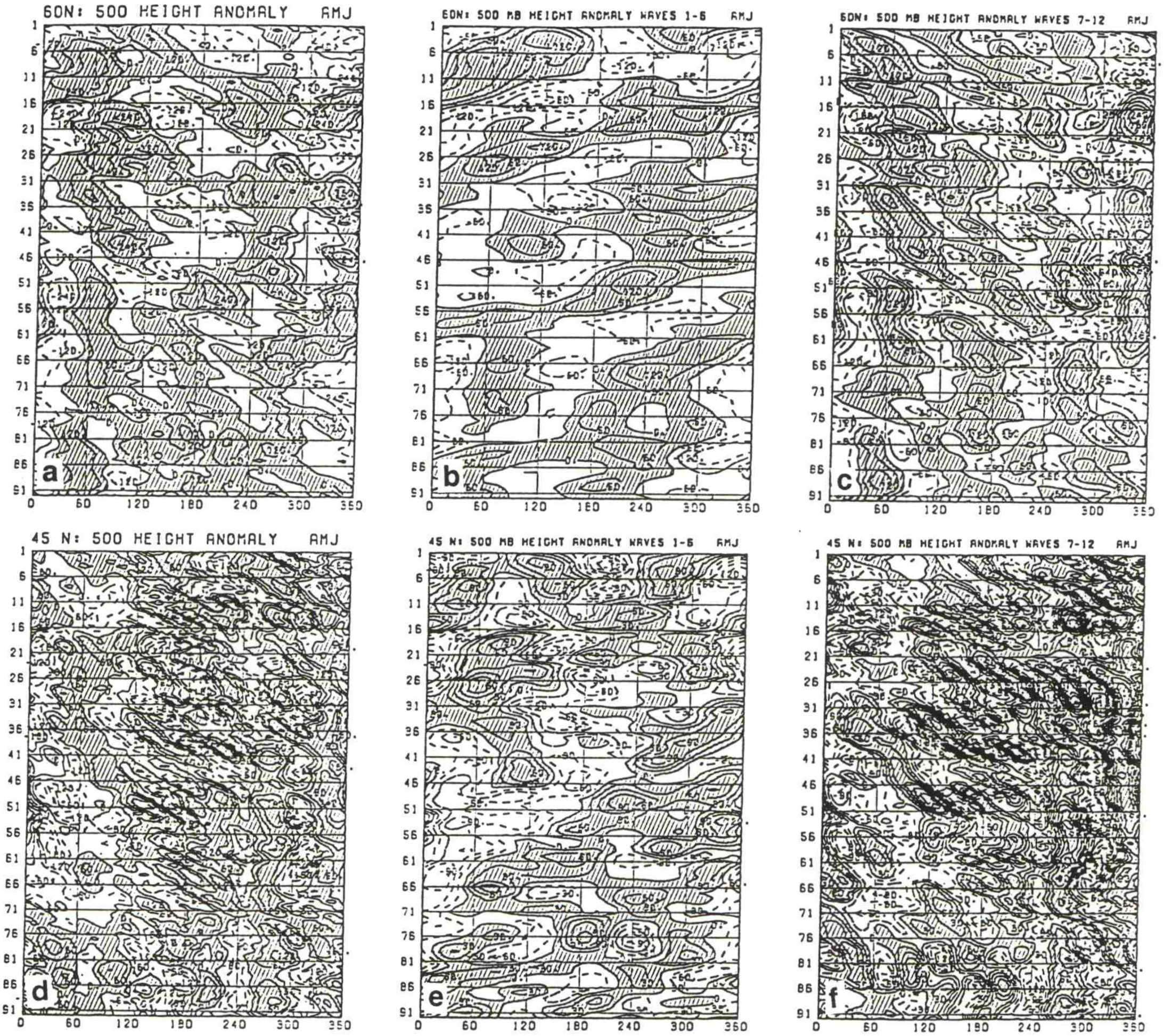


Figure 27: Northern Hemisphere - Daily 500 mb height anomalies for AMJ 1991 averaged over 10° latitude bands centered at (a)-(c) 60°N and at (d)-(f) 45°N. Panels (a) and (d) show the full 500 mb height field anomalies (interval is 120 m); Panels (b) and (e) show the planetary scale (two-dimensional wavenumbers 1-6, zonal mean removed; interval is 60 m) height anomalies; Panels (c) and (f) show the sub-planetary scale (two-dimensional wavenumbers 7-12; interval is 60 m) height anomalies. Positive height anomalies are shaded. Anomalies are computed with respect to the 1979-1988 base period.

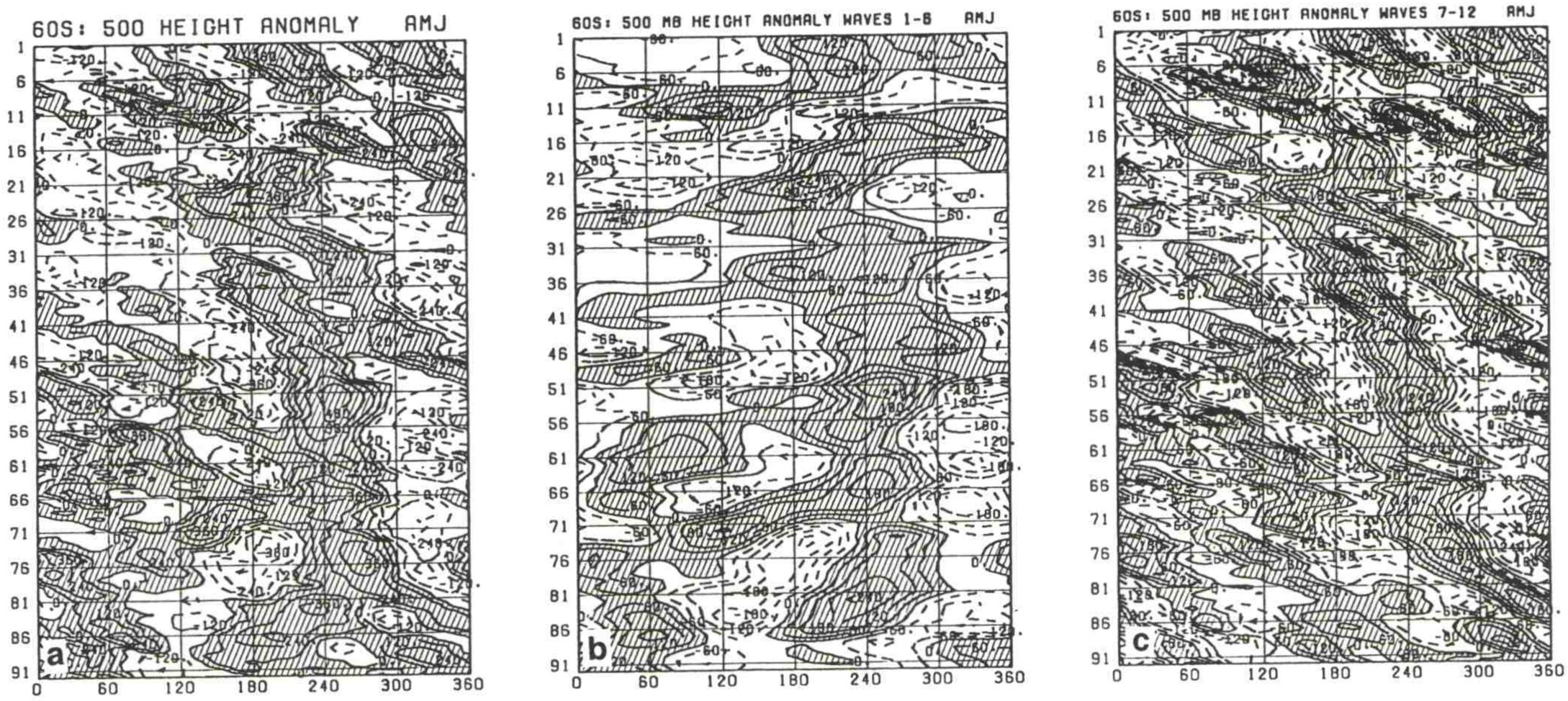


Figure 28: Southern Hemisphere - Daily 500 mb height anomalies for AMJ 1991 averaged over 10° latitude bands centered at 60°S. Panel (a) shows the full 500 mb height field anomalies (interval is 120 m); Panel(b) shows the planetary scale (two-dimensional wavenumbers 1-6, zonal mean removed; interval is 60 m) height anomalies; Panel (c) shows the sub-planetary scale (two-dimensional wavenumbers 7-12; interval is 60 m) height anomalies. Positive height anomalies are shaded in all panels. Anomalies are computed with respect to the 1979-1988 base period.

2.4. Operational Products

2.4.1 Climate Diagnostics Bulletin (Kousky)

The Monthly Climate Diagnostics Bulletin (CDB) was enhanced by several new diagnostic products, which depicted features of the extratropical Northern and Southern Hemisphere circulation patterns. These additions offer users a more comprehensive and balanced analysis of global anomaly patterns. Diagnostic plots of subsurface temperature anomalies and upper layer heat content have also been added to further improve real-time monitoring of oceanic variability in the tropical Pacific. The CDB has also highlighted and will continue to feature the effects of the eruption of Mt. Pinatubo in the Philippines, namely the stratospheric aerosol cloud and its dispersal.

Several ENSO Advisories were issued during 1991 as oceanic and atmospheric anomaly patterns in the tropical Pacific continued a slow trend toward a warm episode (figure 29a, b). Low-level easterlies weakened throughout the equatorial Pacific and positive sea surface temperature anomalies of greater than $1^{o}C$ continued in the central equatorial Pacific near the date line. During the northern spring of 1991, the Southern Oscillation Index became strongly negative (figure 30) and SST anomalies increased throughout the equatorial Pacific. However, persistent enhanced convection failed to develop in the central equatorial Pacific. There was no further evolution toward a warm episode in June or July; however, August and September 1991 data did show some indication.

2.4.2 Seasonal Climate Review (Diagnostics Branch staff)

2.4.2.1 September - November 1990 (Mo)

Conditions during the September-November (SON) season evolved toward a warm episode in the tropical Western Pacific. Sea surface temperature (SST) anomalies greater than $+1^{o}C$ were found and the oceanic thermocline along the equator continued to deepen. However, the pool of warmest water remained west of the date line. Tropical convection for the season was normal and did not show any characteristics of a warm episode. Also, most atmospheric conditions were near normal; although, anomalous westerlies at the 850 mb level were observed over the western Pacific during November.

In the Northern Hemisphere, a Pacific blocking event occurred in September and a strong Western Pacific Oscillation (WPO) pattern persisted through November. The WPO pattern is noted for the strength of the negative correlation between the two teleconnection centers located at $60^{o}N/155^{o}E$ and $30^{o}N/155^{o}E$ and for its broad longitudinal extension at low latitudes. Diagnostics suggest that this event may be related to anomalous convection in the Pacific. Above normal temperatures continued to occur over much of the land areas.

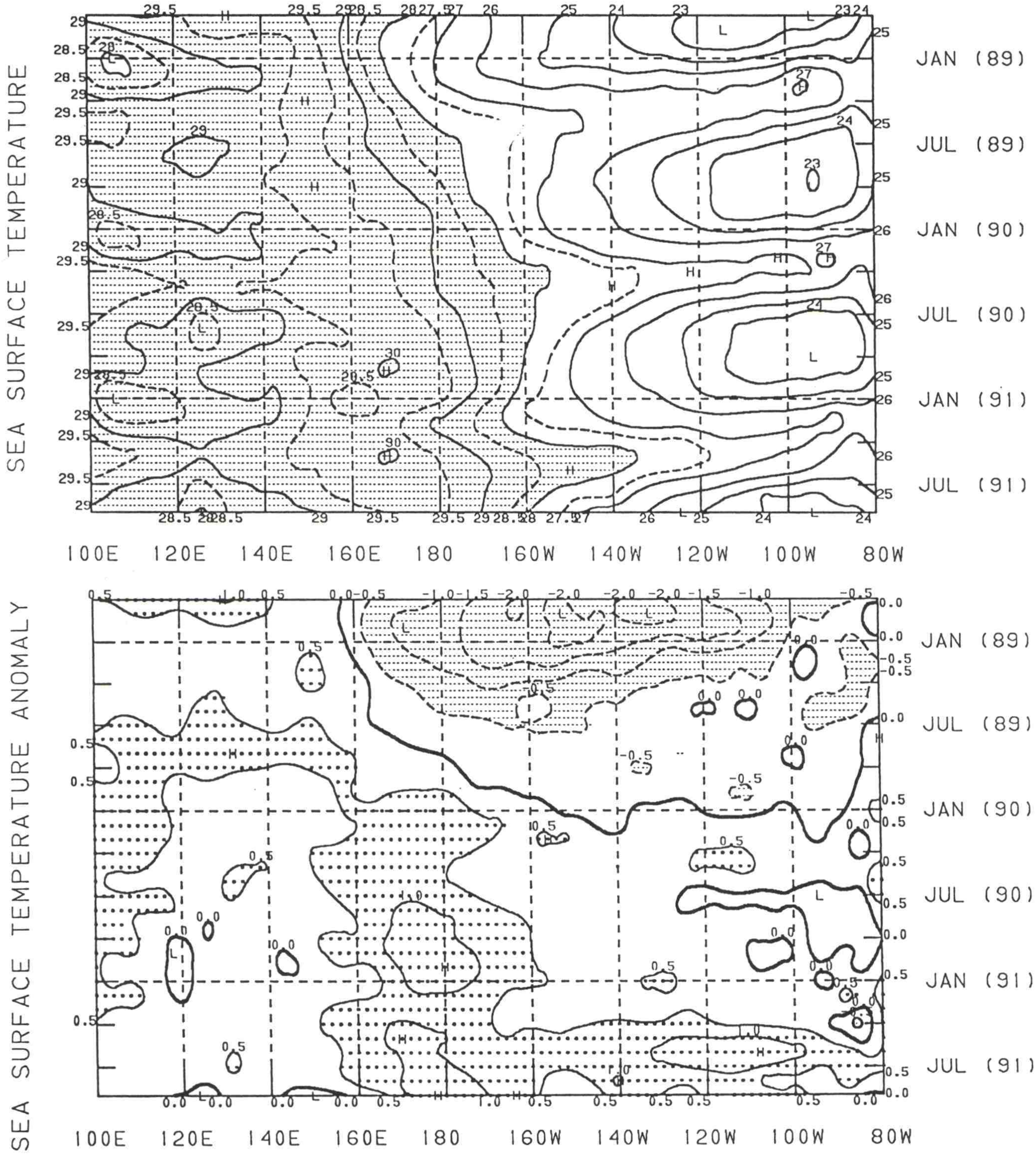


Figure 29: Time-longitude section of a) mean and b) anomalous sea surface temperature for the latitude band of 5°N-5°S. Contour interval is 1°C and 0.5°C, respectively. SST values greater than 28°C and anomalies less than -0.5°C are shaded. Stippled areas indicate anomaly values greater than 0.5°C.

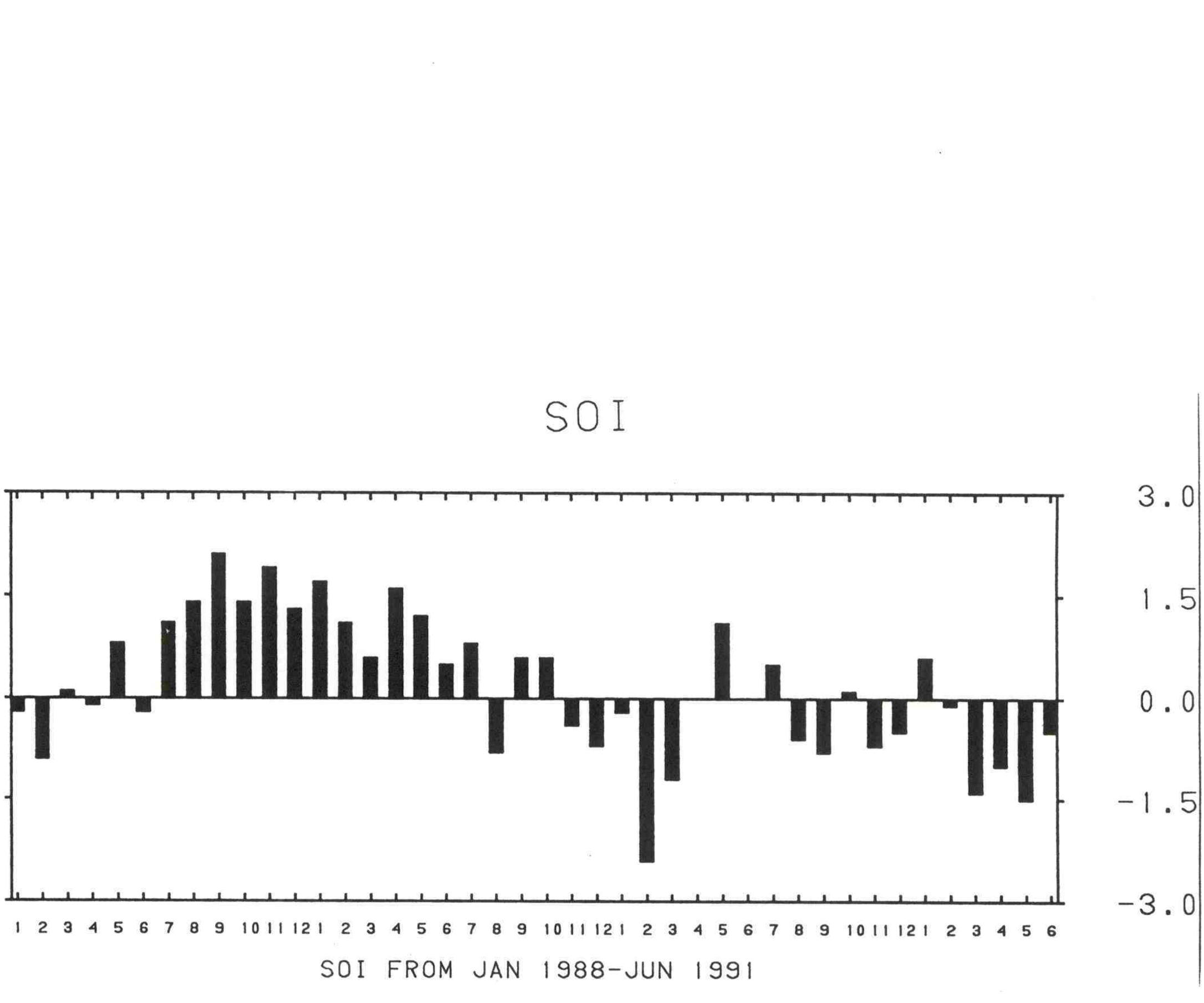


Figure 30: Monthly values of the Southern Oscillation Index for the period January 1988 - June 1991.

2.4.2.2 December 1990 - February 1991 (Chelliah)

There was no significant change in the seasonal mean areal extent of sea surface temperature (SST) in the equatorial Pacific. This was the case for the 29°C and 30°C isotherm and the 1°C SST anomaly over the western and central sections. However, along the South American coast, negative SST anomalies were replaced by positive values. On a month-to-month basis, the area occupied by the +1°C SST anomaly (centered on the equator and the date line) and its eastward extent started to decrease steadily in January and February from their peak December values. These changes at the surface are consistent with changes in the upper layer heat content in the Pacific basin and the depth of the 20°C isotherm along the equator. The thermocline showed steady signs of deepening in the eastern Pacific and shallowing in the western equatorial Pacific since December 1990. Consistent with these SST changes, 850 mb easterly anomalies returned to all three index regions in the Pacific during January and February, for the first time since October 1989. Also, both the Southern Oscillation Index and the 200 mb zonal wind index approached near zero values in February.

For the season as a whole, much of the Northern Hemisphere continued to experience above normal temperatures. However, normal to below normal temperatures occurred over the western two thirds of the continental United States and Canada. Drought conditions continued in the western U. S., particularly in California. In contrast, the Gulf Coast states had above normal precipitation. In Europe, both the temperature and precipitation were below their seasonal means.

In the Southern Hemisphere, pockets of above normal temperatures were observed in southeastern Africa, coastal South America, southern Australia, and for most of Indonesia. Winter monsoon rainfall was deficient, except over northern Australia.

2.4.2.3 March - May 1991 (Bell)

Most tropical oceanic and atmospheric indices during March-May (MAM) 1991 indicated the initial stages of a developing warm episode. Positive SST anomalies spread throughout the central and eastern equatorial Pacific during April and May, resulting in the largest SST anomalies in the east-central equatorial Pacific since the 1986-87 ENSO event. These increased SST anomalies were combined with sharp decreases in the SOI. Atmospheric wind indices suggested a reduced strength of both the easterly trades and subtropical jet speeds over the east-central equatorial Pacific, implying a reduced strength of the Walker circulation. One key feature, generally associated with ENSO events (enhanced convection in the central equatorial Pacific), was not observed during MAM. Instead, convective activity (as indicated by OLR anomalies) has been near normal along the equator near the date line.

In the Northern Hemisphere, the primary mid-latitude 500-mb circulation anomaly shifted from the central North Pacific (in March) to the entire Atlantic sector (in April). The mean 500-mb circulation was then dominated by a wave-train of large amplitude height anomalies extending eastward from North America to north-central USSR. In May, the mean 500-mb height anomaly field reflected primarily an intensification of the April pattern throughout this region.

For the season as a whole, the contiguous United States experienced its third warmest MAM since 1931; while the north-eastern states had their warmest MAM. Similarly, mean MAM temperatures were the second highest on record for the south-eastern and Gulf Coast states and the upper midwest. Above normal precipitation was observed in the western United States, particularly during March. Above normal precipitation also occurred in the Northern and Central Plains states (April and May). Rainfall along the Gulf Coast was very heavy, with totals exceeding the 90th percentile throughout much of the region.

In the Southern Hemisphere, a pattern of persistent positive height anomalies over Australia was associated with above normal temperatures in southern and eastern portions of the continent. This pattern was also associated with large precipitation deficits throughout Australia, which is consistent with precipitation patterns often observed during warm episodes.

2.4.2.4 June - August 1991 (Halpert)

Tropical Pacific atmospheric/oceanic indices continued to indicate the early stages of an El Niño/Southern Oscillation (ENSO) episode. One year ago, sea surface temperatures (SST) in the central Pacific increased to about 1.0^{o}C above normal and have remained anomalously warm. During this season, however, positive SST anomalies decreased to near normal in the eastern Pacific, but remained above normal in the west. Also, weak westerly low-level wind anomalies occurred over the central Pacific throughout the season. In addition, outgoing longwave radiation anomalies over the tropical Pacific were strongly negative (greater than normal convection) during August for the first time in over a year. This increase in convection may indicate that conditions, which prevailed in the Pacific for the past year, are now evolving into a significant warm episode.

Over the Northern Hemisphere, a major blocking pattern that became established over north-central USSR in April dissipated in July. Negative height anomalies then prevailed throughout the region for the remainder of the season. Persistent positive height anomalies were found over eastern Siberia and also over central Canada during JJA. These two anticyclonic circulation anomalies were associated with above normal surface temperatures and below normal precipitation. Elsewhere, positive temperature anomalies were observed over much of the hemisphere.

In the Southern Hemisphere, the primary circulation anomaly for the past several months has been a blocking episode centered over high latitudes in the central and eastern South Pacific. This feature dissipated during July in association with a major circulation change throughout the South Pacific basin. Positive height anomalies over the south-central South Pacific during August reflected the retrogression of a planetary scale ridge axis, whose evolution appears to be independent of the previous blocking episode.

3. STRATOSPHERE AND TRACE GASES

3.1 Field Analysis

3.1.1 Stratospheric Winds (Long)

One of the goals of this project is to derive an accurate wind field from CAC's analyzed stratospheric height fields. A "balanced" wind field has been computed from the height field and compares favorably with MRF-analyzed winds at overlapping pressure levels of 70 and 50hPa. One deficiency found in the "balanced" wind field is the lack of resolution which prevents the discernment of small scale eddies. However, wind fields produced by the above method are being used to track the ash cloud and the movement of stratospheric aerosols from the Mt. Pinatubo volcanic eruption. Another use of the balanced wind fields will be to assess the validity of winds derived by the High Resolution Doppler Imager (HRDI) instrument on board the Upper Air Research Satellite (launched in September 1991).

3.1.2 ERBE (Yang)

An evaluation was made of the new (S-4G) products, as part of the NASA/Earth Radiation Budget Experiment (ERBE). The data and documentation were evaluated and suggestions were made that resulted in changes to accommodate computer systems. The availability of these S-4G data have proved useful in a joint study (with D. Kann) on atmospheric energy transport. The seasonal energy transport (computed from net atmospheric radiation) was compared with the energy transport (calculated from dynamic fields). Some deficiencies were found over the tropics that may be due to procedures in the initialization.

In another study, several forecast runs with NMC's global model have been conducted to investigate the roles of clouds. This work supports the NASA "First April 1989 Surface Radiation Budget Experiment." The results were compared with the other radiative transfer calculations and substantial differences occurred over the tropics. The differences can be attributed to the different treatment of the surface temperature and specification of the optical properties of the low level clouds.

A new algorithm was developed (with S. Zhou, NRC visiting scientist and L. McMillin, NESDIS) to improve the cloud product from NOAA/TOVS algorithm. An intercomparison between TOVS-derived cloud products and cloud datasets has shown that the TOVS products substantially underestimate the lowest and highest level cloud. The new algorithm uses two pilot channels to determine the approximate cloud levels and then selects the proper channels for cloud retrievals. The results have shown improvements and the new algorithm will be tested further with the goal of replacing the current algorithm.

In a joint project (with NMC/Development Division, NESDIS and the University of Maryland), the bulk atmospheric longwave cooling rates were calculated utilizing NMC archived data for the mid-December 1990 to mid-January 1991 period. The results were compared with those derived from satellite measurements and better agreement was found for upper layers (250 mb and above).

3.1.3 Upper Air Intercomparisons (Gelman)

A number of tests were conducted on radiosonde instruments that are used for NWS operations. An evaluation (with NWS personnel at Sterling VA) was made and technical reports have been completed. These reports describe the precision and compatibility of the new radiosondes manufactured by VIZ Corporation relative to the older model. Results showed good temperature compatibility, but there were differences between humidity values. Reports are also in preparation describing test results of Space Data Corporation radiosonde precision and compatibility versus the present VIZ radiosonde. Results from this test showed differences in both temperature and humidity. Also, a first draft of the Federal Handbook No. 3, Rawinsonde Observations was reviewed by M. Gelman, as Chairman of the Ad Hoc Group.

CAC staff continued to provide technical support and information to NASA/Houston in connection with Space Shuttle landings. Data from rawinsondes, rocketsondes and NMC analyses are used to derive detailed estimates of atmospheric parameters from 400,000 feet to the surface along the re-entry path of each flight. Support was provided for 8 landings during the year.

3.2 Ozone/Temperature Trends

3.2.1 Trend Analysis (Nagatani)

The joint trend analysis project continues with personnel from the University of Chicago, University of Wisconsin, and Lawrence Livermore Laboratories (LLL). Ozone and temperature trends were calculated from monthly-averaged ozonesondes and radiosonde temperatures. With the use of an autoregressive time series model, calculated trends from radiosonde temperatures were compared with computed model results from the LLL radiative transfer model. The observed temperature trends indicate a significant cooling in the upper troposphere and lower stratosphere that is in substantive agreement to that projected from the observed ozone decrease when the ozone decrease is put into the LLL model. Together, the results confirm the existence of the lower stratospheric changes which were not anticipated from traditional gas-phase chemical models. Figure 31a shows the ozone trends, figure 31b shows the calculated temperature trends, and figure 31c shows the computed LLL model trends.

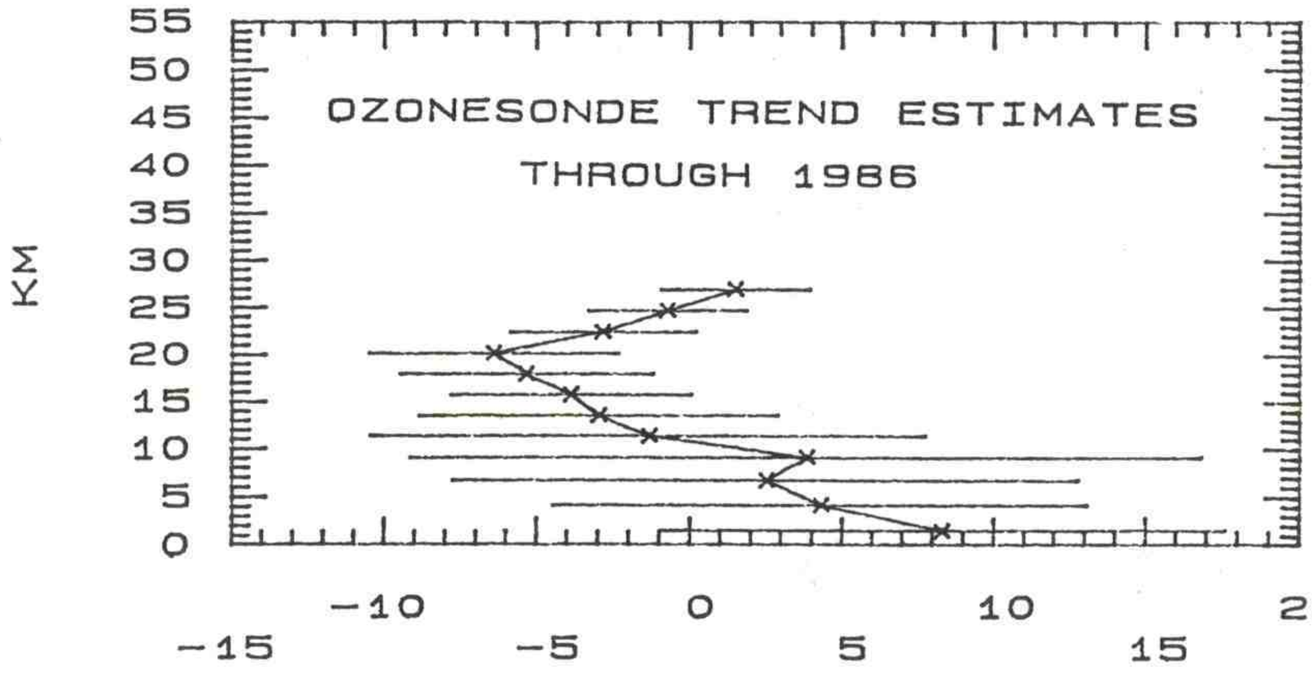


Figure 31a: Decadal ozonesonde trend estimates as a function of height. Horizontal lines represent 95% confidence limits. (Units are percent per decade.)

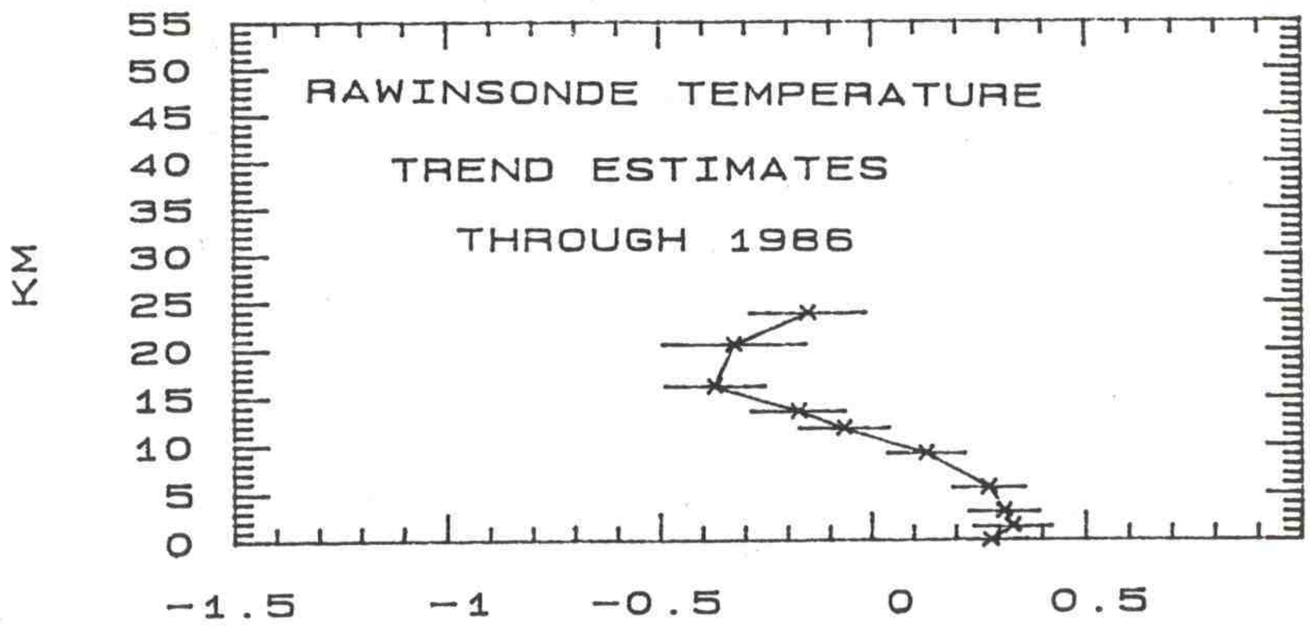


Figure 31b: Decadal rawinsonde temperature trend estimates as a function of height. Horizontal lines represent 95% confidence limits. (Units are degree per decade.)

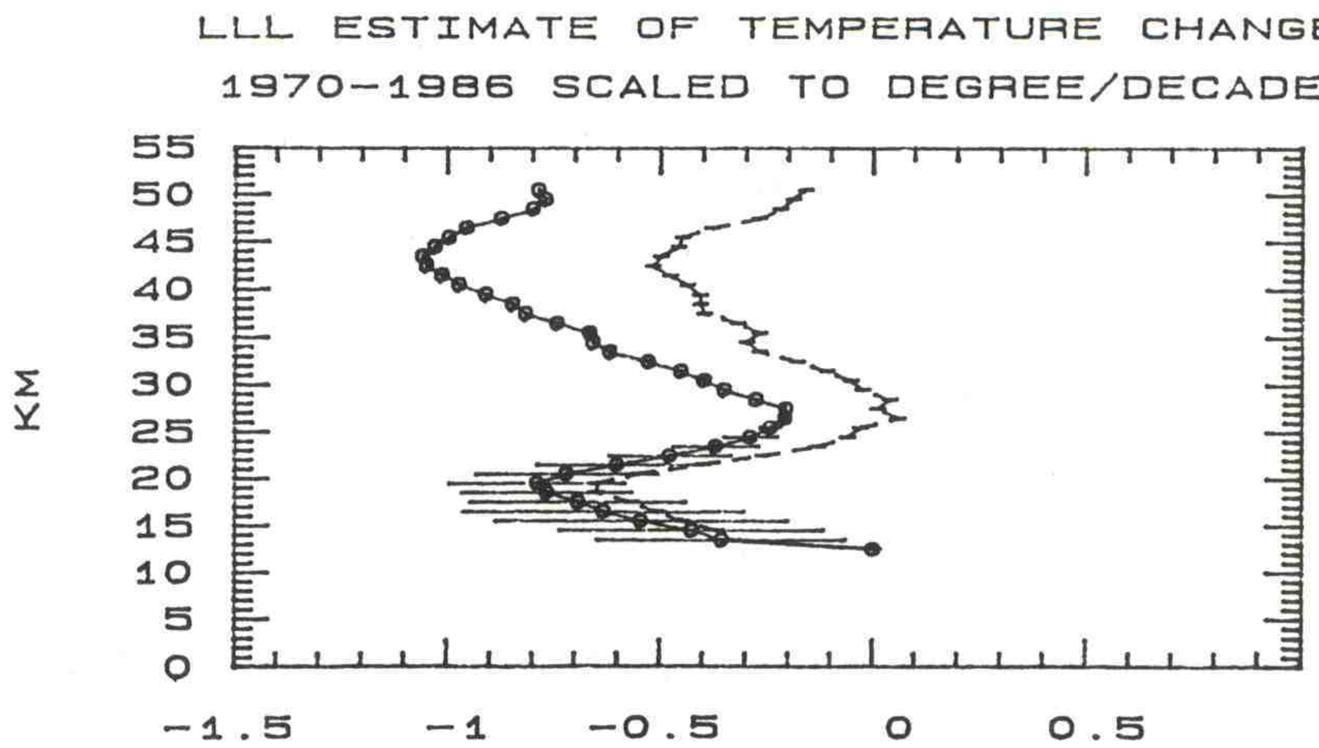


Figure 31c: Decadal temperature trend estimate derived from LLL radiative transfer model. The circles represent estimates with CO2 changing through the period and the horizontal lines represent 95% confidence limits. The x's represent the calculation with CO2 fixed at the 1970 value. (Units are degree per decade.)

In addition to trends computed from profiles, a combined Nimbus 7 SBUV, NOAA-9 SBUV/2, and NOAA-11 SBUV/2 total ozone dataset was compiled and adjusted to Dobson data. Integrated data from 60N to 60S were used to compute an overall trend using the autoregressive time series model for the period November 1978-August 1990. The computed decadal trend was a decrease in ozone of 3.25% (± 0.27%) at the 95% confidence level. This compares well with trends computed from TOMS and Dobson data.

3.2.2 Temperature Trends (Gelman)

Lower stratospheric temperature conditions are being monitored closely using CAC's daily global analyses, especially after the eruptions of Mount Pinatubo, Philippines (June 1991). The magnitude of the eruptions suggests that significant stratospheric temperature increases may be anticipated. Figure 32 shows the progression of zonally-averaged 30 mb (24 km) temperature for 1991 relative to the long-term (1978-91) average at 10S. From January to June 1991, the tropical 30 mb temperatures were approximately 2C below the long-term average. After the Mt. Pinatubo eruption, temperatures have increased dramatically, reaching approximately 2C above average by the end of September.

A presentation on the detection of stratospheric change was made before the TOVS Pathfinder Science Working Group. The emphasis was on the important use of TOVS data in monitoring the stratosphere and the need for careful intercalibration of measurements from the successive satellite instruments. The Working Group completed a Report that recommended an approach to reprocessing TOVS data for detecting climate change.

A comparison was made between CAC analyzed stratospheric temperature and geopotential height fields with radiosonde, rocketsonde, and lidar data. Preliminary results showed some problems with lidar data during several summer seasons. These comparisons are especially important because of the drastic reduction of the rocketsonde program. Ground-based temperature information are essential for interpreting long-term changes of CAC's upper stratospheric temperatures, which are based on satellite data from successive operational TOVS instruments.

3.2.3 Stratospheric Climatology (Nagatani)

Global monthly mean rawinsonde data and CAC stratospheric gridded analyzed data are being used to compile a climatological dataset for NASA's High Speed Research Program. The purpose is to use the same initial input into various models (employed by researchers around the world) for evaluating the impact of thousands of high-speed aircraft that are expected to be flying in the stratosphere in the 21st century. This dataset will be made available at a central computer facility (NASA/Langley Research Center) from which an international group of modellers will be able to access data for initial input into their models.

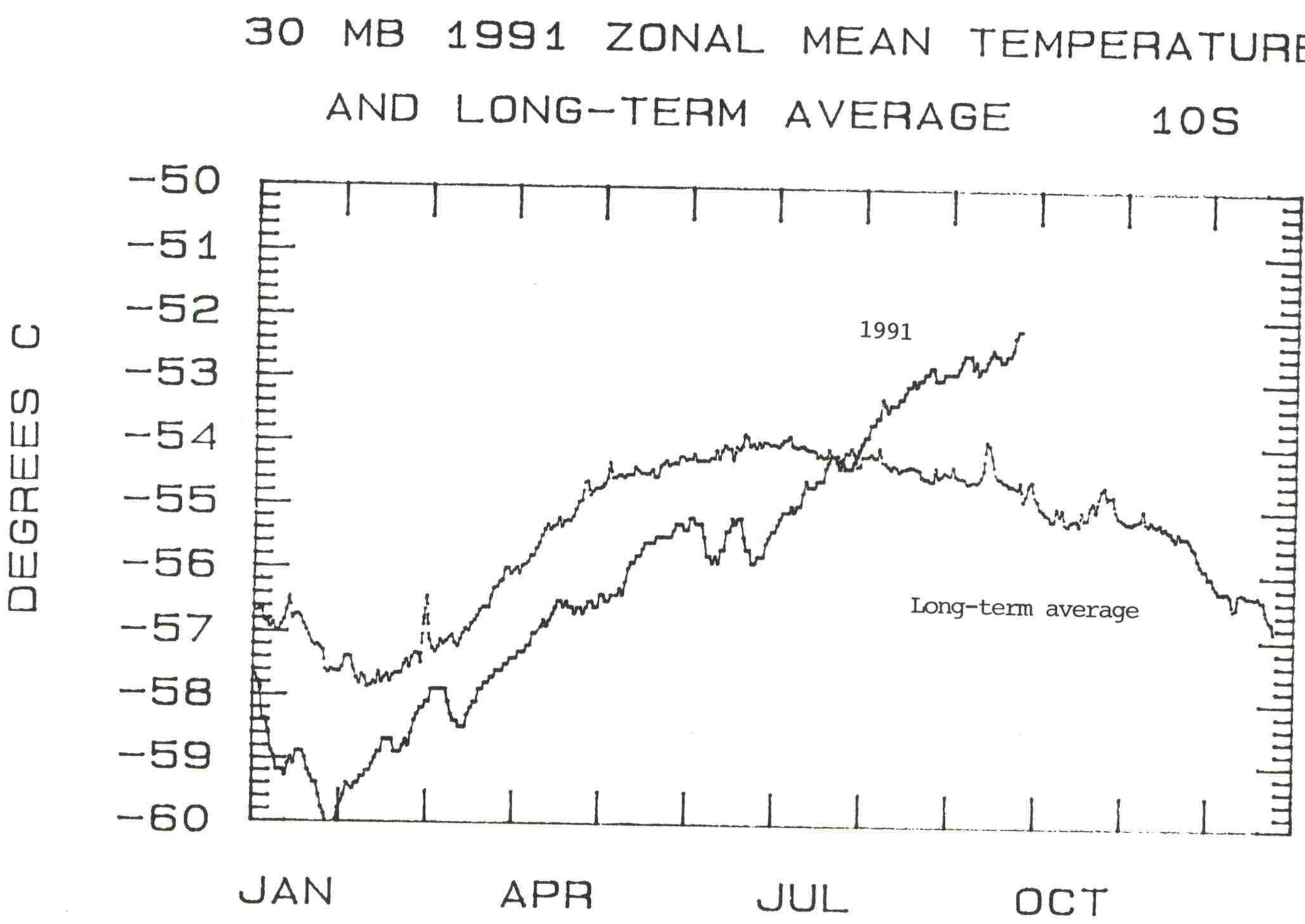


Figure 32: Daily zonal average 30 mb (24 km) temperatures for 1991 (solid line) at 10S, relative to the 1978-1991 average (dashed line).

3.3 Operational Products

3.3.1 Circulation/Temperature Analysis (Gelman, Nagatani)

During the Northern Hemisphere 1990-91 winter, a stratospheric warming took place (mid-January to mid-February), which was accompanied by strong anticyclonic easterlies over northern latitudes. Although the circulation never met the criterion for a major stratospheric warming (10-mb westerly circulation was not completely replaced by easterlies poleward of 60N), the circulation was quite active. Stratospheric temperatures were below their long-term average from mid-February to March 31.

The CAC is disseminating daily Southern Hemisphere 70 and 30 mb charts to researchers in Antarctica, where lower stratospheric temperature conditions are of special interest in regard to the "ozone hole." Figure 33 shows that 50 mb zonal temperatures, during 1991 at 80S, are near their long-term average. This is consistent with reported near record low ozone values.

CAC's stratospheric analyses are also being used in support of other scientific projects. One use is for data processing algorithms of several instruments on board the Upper Atmosphere Research Satellite (launched in September 1991). Another use is for the upcoming NASA/Arctic Airborne Stratospheric Experiment (October 1991 - February 1992) to support aircraft routing and data interpretation.

3.3.2 Atmospheric Angular Momentum (Kann, Long)

The major activity this year was the program review that was conducted as part of the Chapman Conference on Geodetic Very Long Baseline Investigation: Monitoring Global Change in April 1991. As a result of this review, it was recommended that the two-year commitment by the NMC/CAC to support the International Sub-Bureau for Angular Momentum be continued. Further activities included coordination with the European Center for Medium - Range Weather Forecasts and the Japan Meteorological Agency. One purpose is to have these two important Groups expand their efforts within this program. The responses of the agencies has been positive and the CAC is working closely with them to ensure that all information is inserted into the Sub-Bureau data base.

3.3.3 Ozone Analysis (Nagatani)

Although the algorithm for all SBUV and SBUV/2 retrievals is undergoing change and the entire dataset will be reprocessed, day to day changes in the ozone values can still be monitored. For example, ozone profile and total ozone values have measured the effects of the Mt. Pinatubo eruption and the Antarctic ozone hole. Ground-based Dobson and Umkehr measurements are also undergoing reprocessing. Comparisons will then be made with reprocessed satellite and ground-based data.

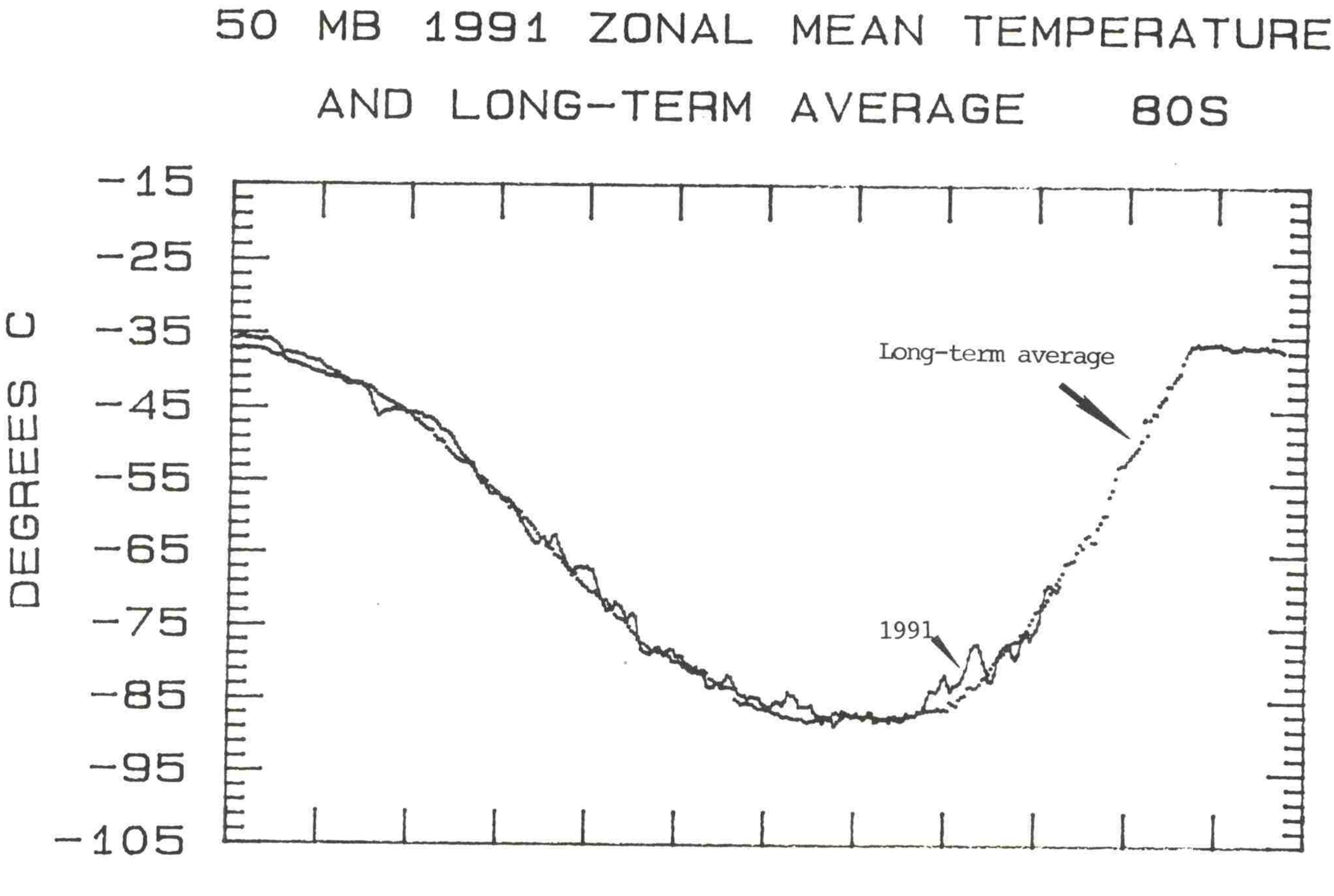


Figure 33: Daily zonal average 50 mb (20 km) temperatures for 1991 (solid line) at 80S, relative to the 1978-1991 average (dashed line).

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4. APPLIED CLIMATOLOGY

4.1 Surface Data

4.1.1 Surface Climate Assessment (Miskus)

Much of the Northern Hemisphere recorded widespread and prolonged above normal temperatures during late 1990 and most of 1991. However, there were also significant periods of subnormal temperatures covering portions of the hemisphere. Bitterly cold Arctic air enveloped eastern Alaska and western Canada during November; the western U.S. experienced its coldest December on record; frigid conditions persisted across eastern Canada during January; most of Europe endured a cold February; and the western U.S. and Europe had unusually cool weather during late spring and early summer. Similarly, precipitation anomalies varied greatly during October 1990-September 1991, as depicted in figure 34.

In the contiguous United States, conditions varied greatly. While heavy winter rains inundated the Gulf Coast, long-term drought continued across most of the far West, particularly in southern California, as the area recorded its fifth consecutive below normal rainy season. However, at the end of February and continuing into March, a series of strong Pacific storm systems produced copious precipitation over much of California. Heavy spring rains soaked the Mississippi Valley, but abnormal late spring and summer warmth and dryness afflicted the Ohio Valley and mid-Atlantic. Although the 1991 Atlantic hurricane season was rather tranquil, Hurricane Bob slammed into New England (in August), producing wind gusts of 115 mph, 7 inches of rain, and causing an estimated $1.5 billion damage.

In Europe, a stormy and wet November and December, was followed by extremely dry weather during the first five months of 1991. Then, in late July and early August, torrential rains fell on central and southeastern Europe, especially Moldavia, the western Ukraine, northeastern Rumania, and Austria, with the latter reporting its worst flooding in 30 years.

In Asia, many areas had ample precipitation during late 1990 and most of 1991. Parts of China, Korea, Japan, Siberia, the Philippines, and South-east Asia endured several episodes of torrential rains that caused extensive destruction and loss of life. In July, some of the worst flooding on record battered eastern China's Yangtze River Valley; while in August, copious rainfall caused Burma's worst flooding in 50 years south of Rangoon. Also, intense August monsoonal rains produced devastating floods in southwestern Cambodia. An extremely active western Pacific Ocean produced 24 tropical storms, most of which became typhoons. In contrast, below normal rainfall in southeastern China, Taiwan, and the Philippines adversely affected hydrological and agricultural interests.

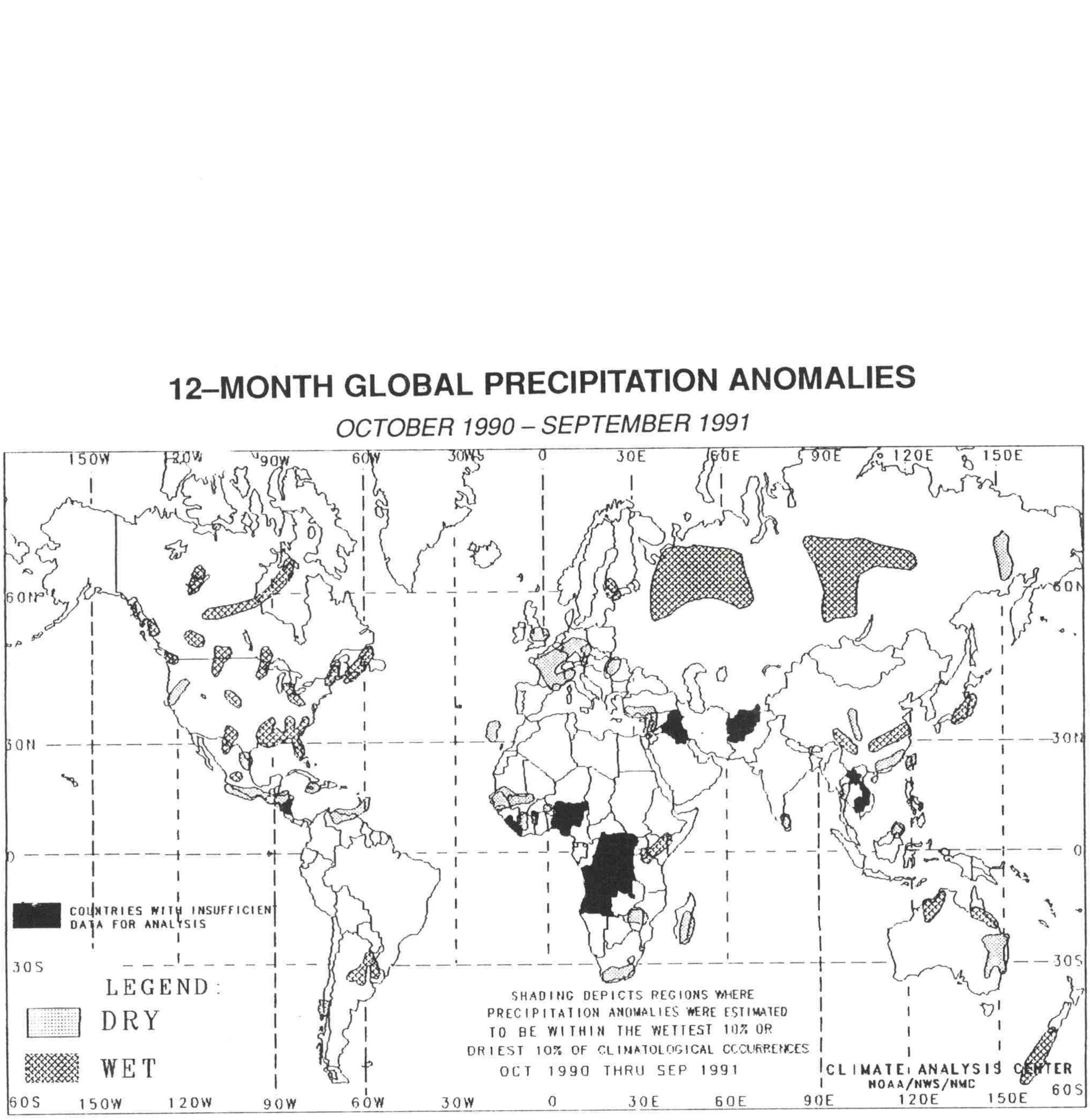


Figure 34: Significant global precipitation anomalies for October 1990 - September 1991. Shading depicts regions where anomalies were estimated to be within the wettest (double hatched) or driest (dotted) 10% of 1951-1980 climatological occurrences.

Just before the Indian monsoon season began, an intense tropical cyclone (with estimated winds of 160 mph and 20-foot waves at landfall) devastated coastal Bangladesh and its low-lying offshore islands. This storm left over 10 million homeless and took more than 139,000 lives. The remainder of the 1991 monsoon season (June-September) was fairly typical, with ample rains occurring over southern and eastern India. Although Pakistan and central and western India experienced generally dry conditions, timely rains kept crop production high.

The African Sahel experienced above normal rainfall in April and May and near normal rainfall during the summer. In Senegal, early summer dryness was eased by late season rains. Farther east, however, rainfall was infrequent in northern Sudan and Ethiopia and this prompted concerns of additional famine.

In the Southern Hemisphere, widespread inundating rains drenched northern Australia in early 1991, after an extremely dry November and December. The wet spell began with rains from Cyclone Joy in late December and continued into early March. In contrast, drought has afflicted much of Indonesia since mid-year. In east-central South America, surplus spring rainfall was offset by subnormal summer precipitation. After an extremely slow start to the rainy season in southern Africa, generous rains fell during late December to early March 1991.

4.1.2 CLICOM (Katz)

Software support for CLICOM's international program continues to be funded jointly by the NWS/Office of Meteorology and CAC. Work has concentrated on corrections and revisions to graphic applications, based upon test results from WMO regional CLICOM experts. Additional efforts have focused on verification of non-graphic printer codes, user manual updates, installation procedures, and instructions for the upcoming CLICOM version 3.0. The release date of CLICOM 3.0 is scheduled for late 1991.

4.1.3 SOLRAD (Yang)

The Solar Radiation Monitoring Network (SOLRAD) has performed at about the same level as the previous year, even without funding. Five stations showed significant improvement in the data reporting rate, while six stations showed signs of degrading. Due to the phasing in of ASOS, Dodge City, KS has had to cease operation. The data communication system stayed the same, with twenty-two stations reporting via AFOS and the rest submitting diskettes. In other related activities, data distribution from CAC's Climate Dial-Up System has been normal and processed data (submitted to World Radiation Data Center Leningrad, USSR) are being quality controlled more stringently.

4.2 Agricultural Applications

4.2.1 Climate/Agricultural Assessments (LeComte)

Climatic fluctuations during the past year resulted in crop losses for many important agricultural areas. A wet spring followed by a dry, hot summer reduced wheat, corn, and soybean yields in the United States. Summer drought in the Soviet Newlands hurt the wheat crop, while devastating floods during May through July reduced rice production in China's Yangtze River Basin. Severe dryness occurred over sections of Indonesia and Australia during July-September 1991, drastically reducing crop output. In addition, the southwest monsoon was weak over northern India which affected crop output.

A WMO-sponsored visit was made (by D. LeComte) to Drought Monitoring Centers in Zimbabwe and Kenya (May 13-22, 1991). The main purpose was to discuss the development of improved drought-monitoring products. Various Climate Analysis Center maps and publications were distributed as examples of useful products.

4.2.2 Africa FEWS (LeComte)

CAC's Agricultural Weather Section began providing automated color rainfall maps (developed by A. Herman, Ellsworth) to the Agency for International Development. The maps, in support of the Famine Early Warning System (FEWS), incorporate Meteosat rainfall estimates with reported ground observations. Also, Inter-Tropical Convergence Zone location data and written weather summaries were provided to FEWS.

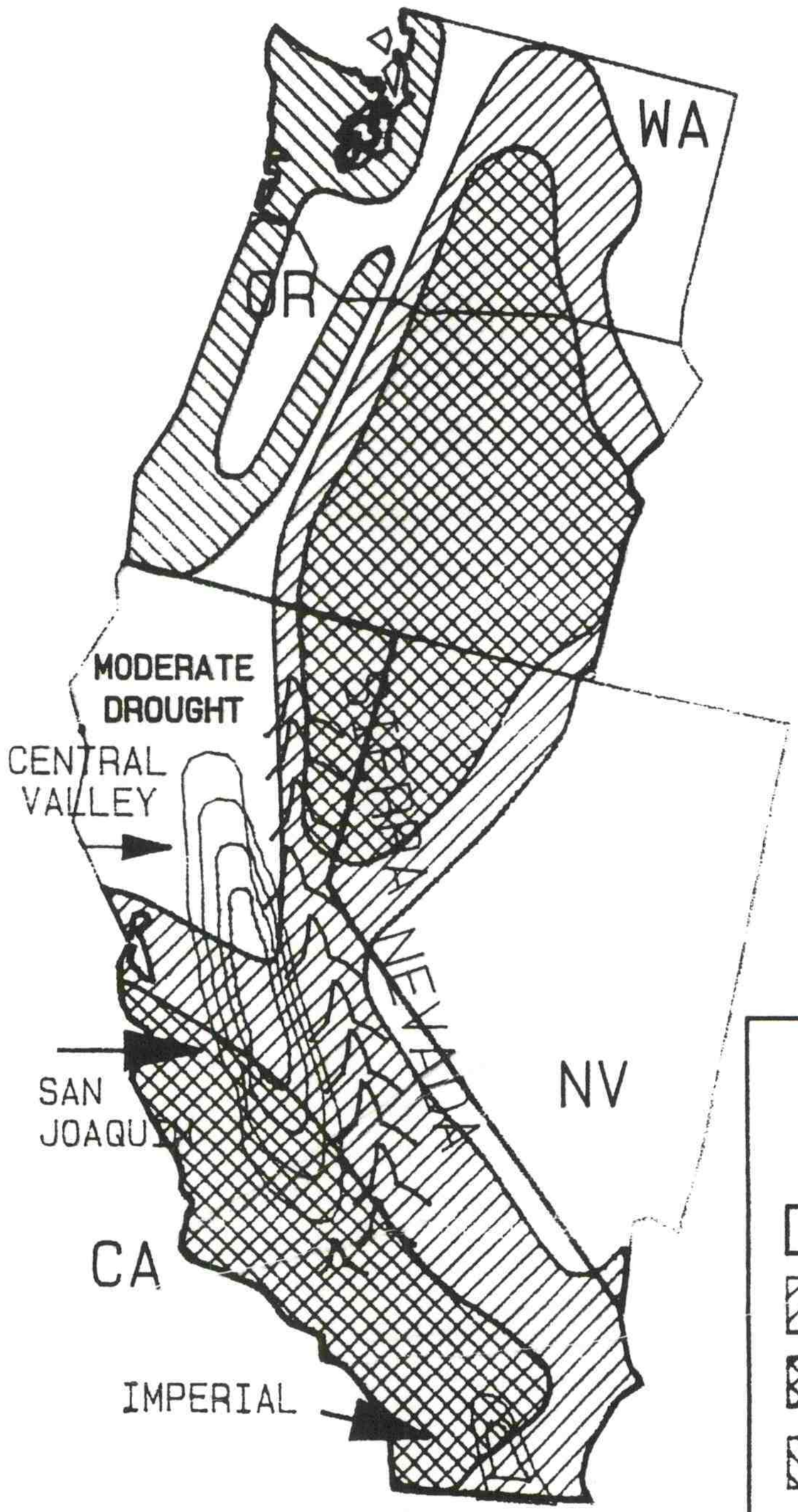
In the Sahel region, the 1991 growing season was generally favorable and better than in 1990. Rainfall totals were mostly near long-term averages, except for below normal values in Senegal, Mauritania, and western Mali.

4.3 Climate Impacts: Monitoring

4.3.1 Products for Impact Evaluation (Laver)

CAC products were incorporated into several color graphic packages on special topics. These included a ten-page package on California Drought Conditions (see figure 35), and a seven-page package on Nevada Drought Impacts for the honorable Senator Reed of Nevada (presented by the Director/NMC). Also, a special "Executive Climate Summary" was developed to depict current and historical climate information for top-level NOAA executives. This four-page package (figure 36) contains geography, recent conditions, climatology, and a long-range (one-month) outlook for requested areas of the world.

WEST COAST DROUGHT UPDATE
March 20, 1991



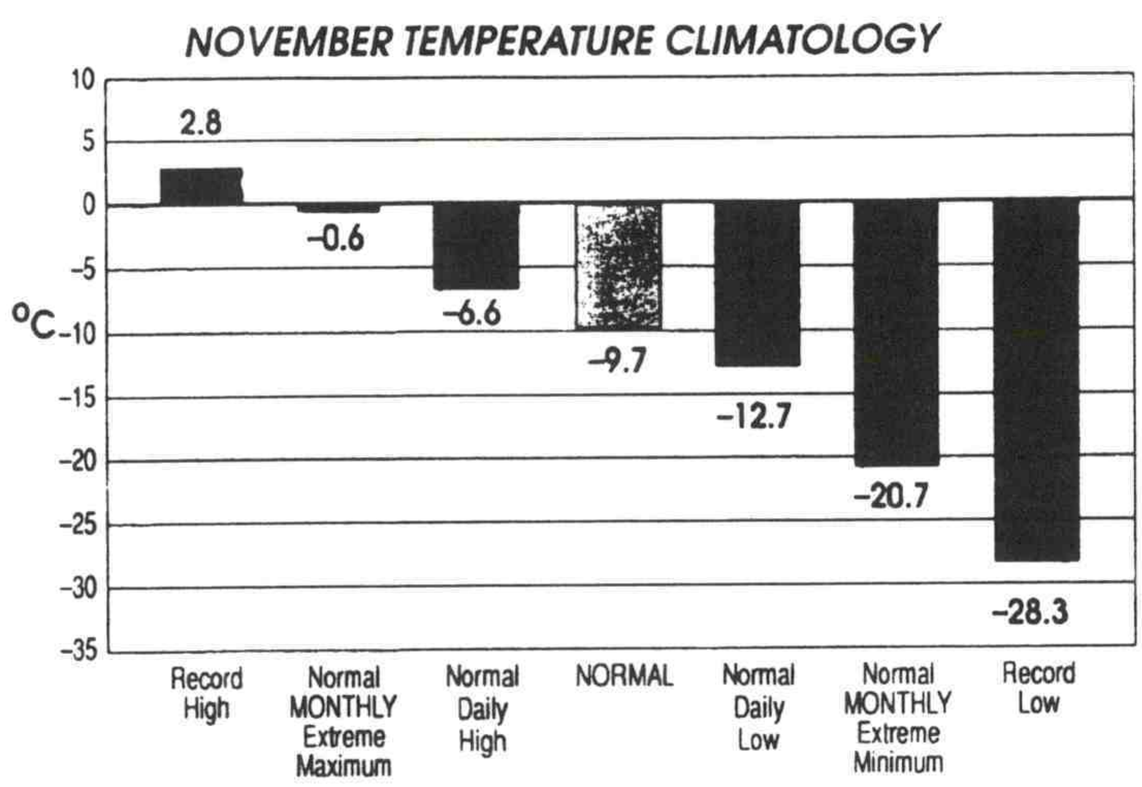
- Drought - 5th Consecutive Year
- Wet Season: Oct - Apr
- Moisture deficit reduced to moderate-severe in Central Valley and San Joaquin Valley
- As of Mar 18, 1991, total rainfall was 65% of normal in California this season
- Reservoir storage estimate: California - 70%
- Snowpack in CA Sierra Nevada Mountains increased from 16% on Mar 1 to 65% of normal on Mar 18
- Streamflow on Mar 1 forecast at 15 - 25% of normal, increased to 45 - 60% on Mar 18, 1991
- Widespread precipitation (1 - 3 inches) since Mar 13

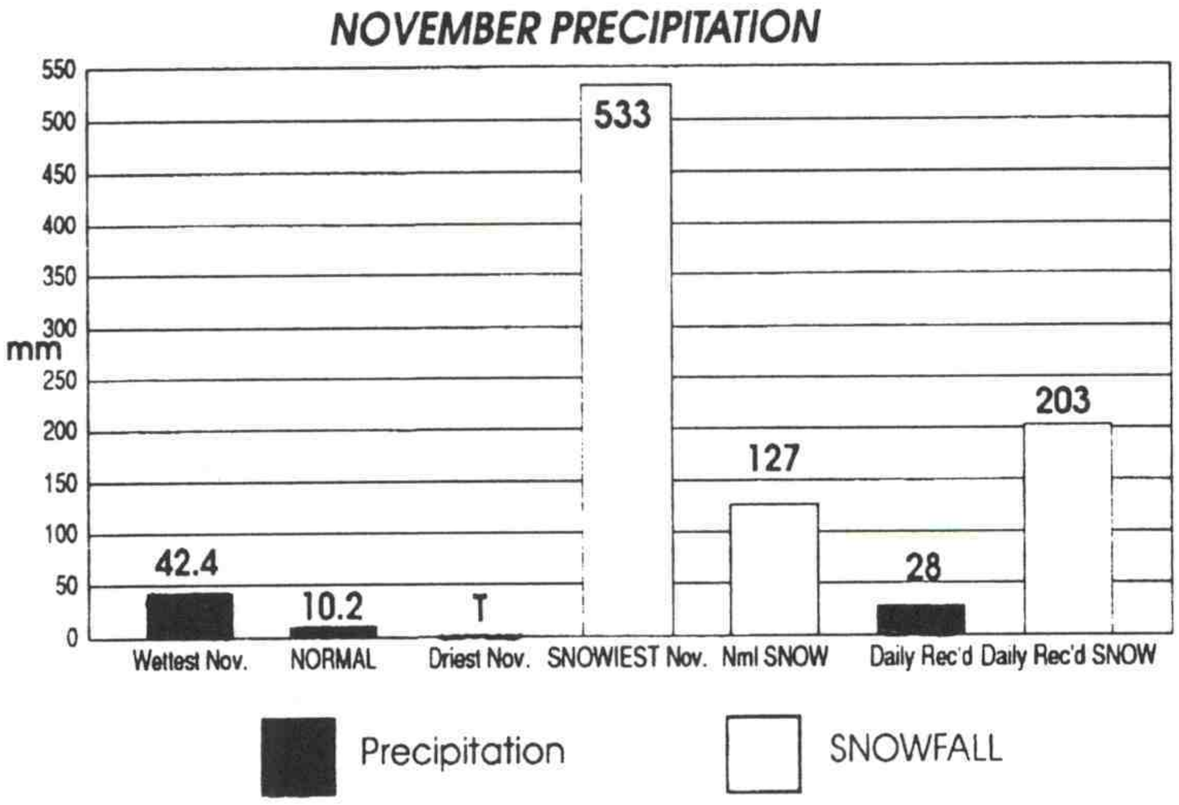
DROUGHT SEVERITY
PALMER DROUGHT INDEX
measures prolonged moisture deficit relative to normal

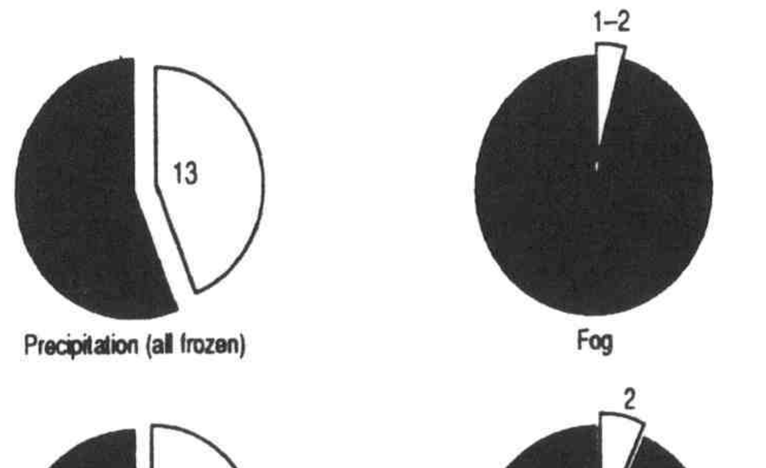
- MODERATE -2 to -3
- SEVERE -3 to -4
- EXTREME below -4
- MOIST above +2

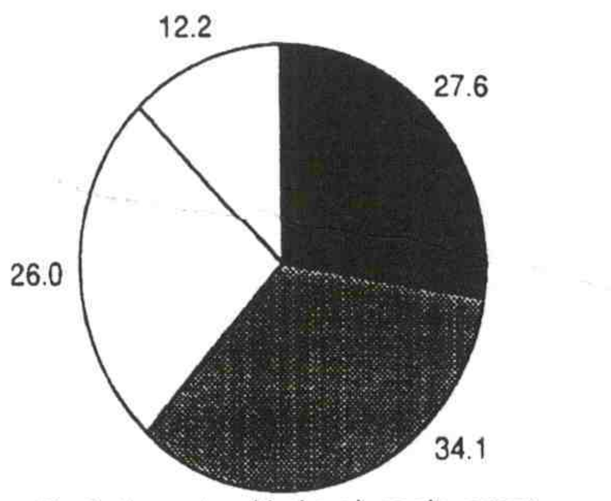
Data as of March 18, 1991
(Based on preliminary data)

Figure 35: Summary page of the ten-page (normally in color) California Drought Conditions briefing package prepared for the USDA/JAWF.









MISCELLANY (NOVEMBER)

Thunder is observed 1 day in 6000
Temperatures have never reached 0°C during Oct 31–Nov 11
The prevailing wind is from the East at 12 knots
The normal monthly wind chill is –21°C
A peak gust of 77 knots was reported in 1976
The normal November peak gust (each year) is 48 knots

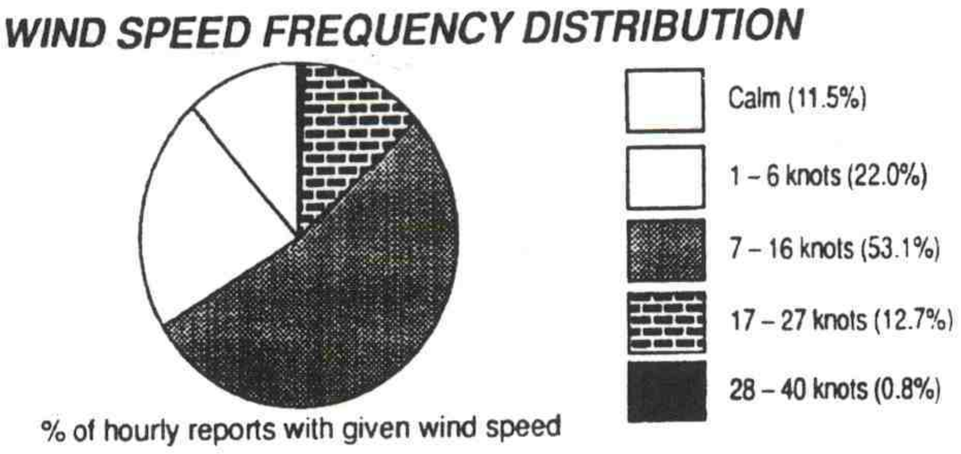


Figure 36: Page from the Executive Climate Summary (ECS) color package for November at McMurdo, Antarctica. This product was developed to depict current and historic climate information for top-level NOAA executives.

In addition, diskettes containing files of snow cover and snow water equivalent (produced by the NWS's National Hydrologic Remote Sensing Center, Minneapolis, MN) were converted into images and then color hardcopied. An experimental color version using a special analysis scheme on these files is depicted in figure 37. Also, test versions of "detailed" monthly Regional Climate Centers weather and climate impact reports have been produced for downloading on the CAC's Climate Dial-Up System. A "condensed" test version from the Northeast RCC (NERCC) has been evaluated by the NWS/Eastern Region and their suggestions are being incorporated by the NERCC for potential AFOS transmission.

4.3.2 Socioeconomic Impacts (Lehman)

A number of interactive PC software products were developed to model climate data sets used to assess departures from normal and the likelihood and impacts of extreme events. These products were distributed to Regional Climate Centers, government agencies and private groups. One software product accepts data file or keyboard input of monthly averages and creates an output file of daily normals, with on-screen verification that the output is summed and/or averaged accurately. Another product accepts data file input, calculates the maximum likelihood estimates of the alpha and beta parameters in the gamma function model of the data, and gives the modeled probabilities of a range of outcomes including extremes. Other software accepts keyboard input of the skewness parameter specifying a gamma model and calculates the probabilities for a range of standardized outcomes for the model.

4.3.3 Regional Climate Centers (Bermowitz)

A NOAA Project Office for regional climate applications, based on the program of six Regional Climate Centers (figure 38), was established at the NMC/Climate Analysis Center in November 1990. At that time, responsibility for the management of the Regional Climate Center's (RCC) Program was transferred to the Climate Analysis Center from the NOAA National Climate Program Office. There have been a number of activities since the transfer took place. A RCC Management Plan was developed which recognizes the importance of consensus decisions, funding of the centers, development of regional services and research programs, peer review of operational services and applied research at the regional and national levels, and the flexible application of these principles to the needs of each Center. A strategy document, detailing desirable activities of a RCC as a key link in a national climate services system, was also written and approved by each RCC. This document will provide a basis for consistency and a means for judging performance.

During the year, proposals from each RCC for operations, services, and applied research were submitted to the Climate Analysis Center for funding. Support was also provided to a

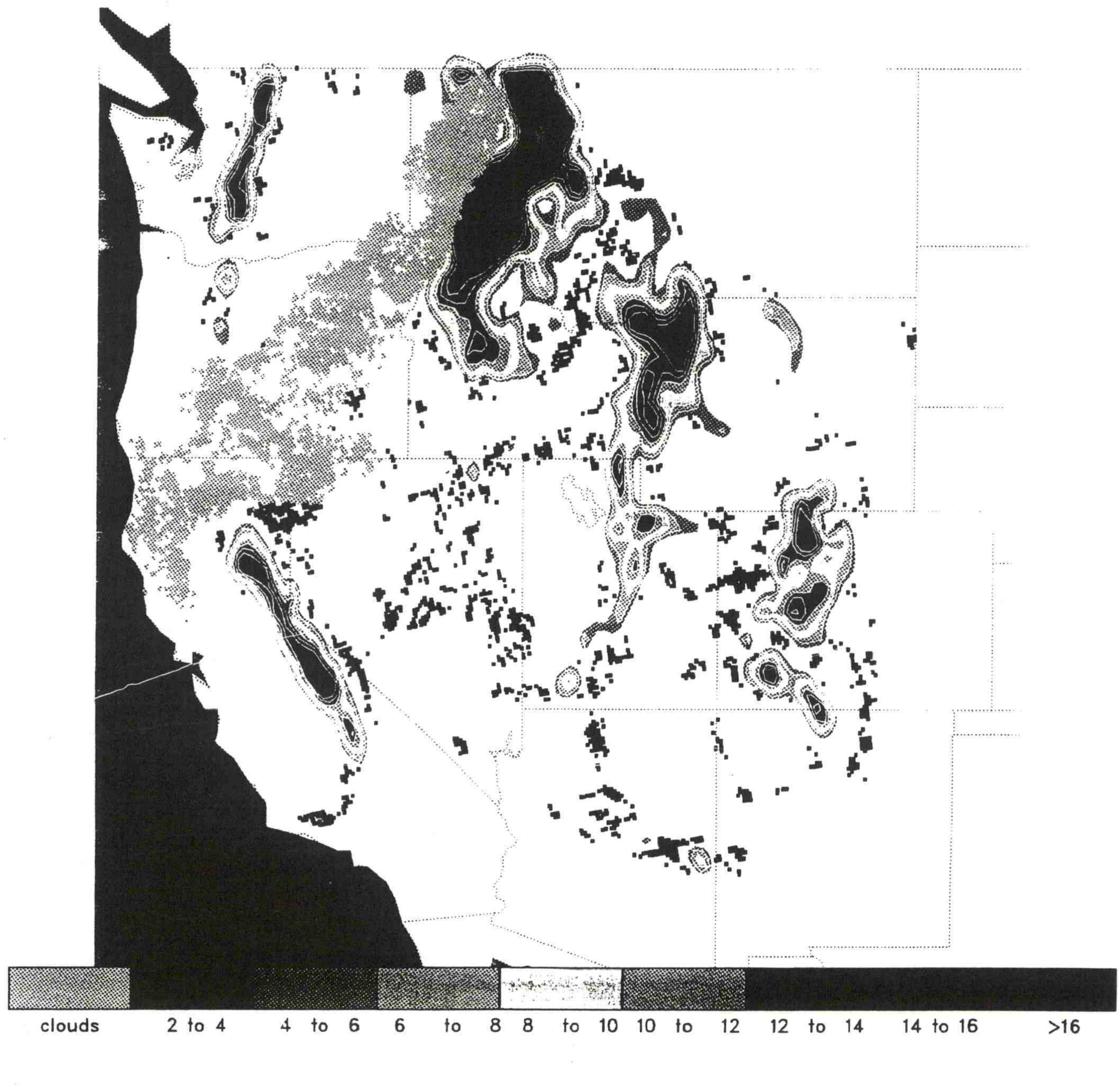


Figure 37: An experimental enhanced analysis of snow water equivalent in the western U.S. (normally in color). The data and image were originally collected, produced, and distributed by the NWS National Operational Hydrologic Remote Sensing Center in Minneapolis, MN.

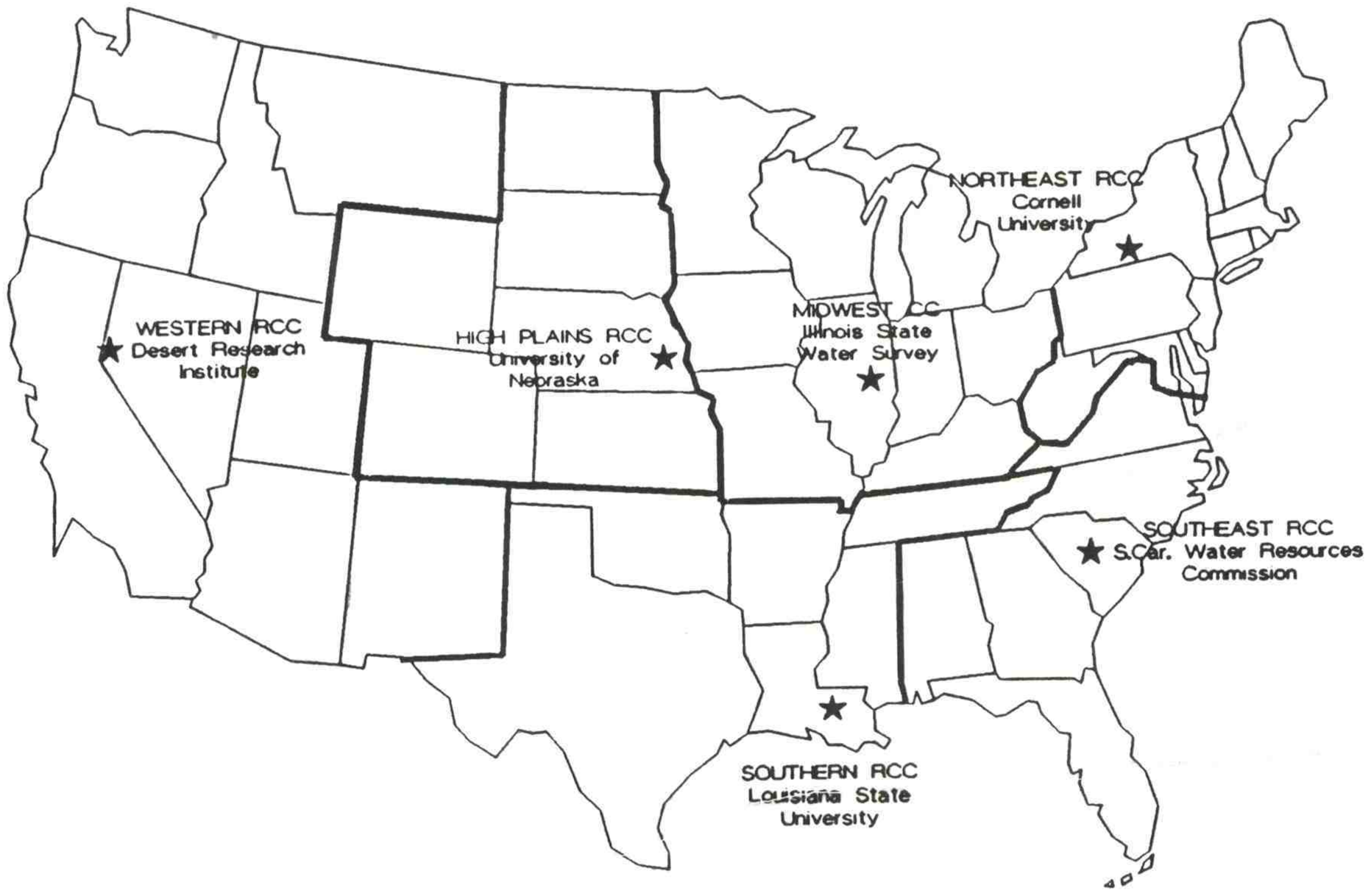


Figure 38: Locations of the six Regional Climate Centers.

U.S./Canadian climate change impacts effort for the Great Lakes (involving four of the RCC's) and a Southern Weather Data Management Workshop (involving the other two RCC's). In addition, a RCC Budget Initiative for FY 1993 was written to enhance the development of the RCC's as an important element of a NOAA Climate Services Program. This initiative also proposed an additional level of activities consisting of database development, improvements to the NOAA SOLRAD Network, impact assessments of climate anomalies and potential climate change, and the transfer of current global change research results into operational climate services.

4.4 Operational Products

4.4.1 Climate Dial-Up Service (Fulwood)

The first full year of Microvax operations of CAC's Climate Dial-Up Service (CDUS) went well; although, as with any new system, modifications were needed. One feature requiring substantial effort was modem operation refinement to disconnect any modem from the CDUS if no signal was detected during a specified time period. Also, many of the CDUS automated data retrieval routines and their NAS9000 counterparts were modified to operate properly under this new environment. In addition, CDUS software was modified and a new forecast release time was established to accomodate security requirements and update procedures for CAC/Prediction Branch's 6-10 day forecasts.

Interest in the CDUS continues to increase with many requests for new accounts and renewals of existing accounts for the NWS/Family of Services. The total number of monthly users is about 400. The network capabilities of the CDUS are being utilized by routine transmission of CLIMAT data to NCDC eliminating the need for computer tapes. In addition, accounts were established for the Regional Climate Centers that have enhanced information exchanges between the Centers and CAC.

4.4.2 Daily Weather Maps (Dionne)

A number of activities were conducted to enhance the production of the Daily Weather Maps. A new contract/printer was selected, which has resulted in greater attention to the proper registration of base maps and overlays. Most of the artwork is now produced on an interactive workstation (by NMC/Meteorological Operations Division), which eliminates the need for manual shading of the maps. This action has also improved the quality of the final product and reduced the time needed in data preparation. Finally, the processing of subscriptions, and free-list maintenance continues in a timely fashion.

4.4.3 Weekly Climate Bulletin (Heddinghaus)

The production of the Weekly Climate Bulletin (WCB) continued to improve, with the number of recipients now up to 1500. All maps are now automatically analyzed which enables quicker and easier publication, utilizes fewer people, and maintains quality standards. Also, most of the pages are routinely produced on an workstation (using desk-top publishing software).

A Global Climate Highlight page was added as a regular feature (see figure 39), replacing the weekly degree-day maps. The WCB also featured articles on climate-related impacts that were received from Regional Climate Centers (RCCs). These included: drought in California and subsequent beneficial March rains, heavy rain and flooding in the lower Mississippi Valley, and low soil moisture conditions in the Corn Belt, Northeast, and mid-Atlantic states.

Other special articles included: typhoons in the Far East, Tropical Cyclone (2B) which devastated Bangladesh, and Hurricane Bob which struck New England. In addition, monthly and seasonal historical data from the National Climate Data Center and eight El Niño Southern Oscillation (ENSO) advisories from CAC's Diagnostics Branch were included during the year.

4.4.4 Weekly Weather and Crop Bulletin (LeComte)

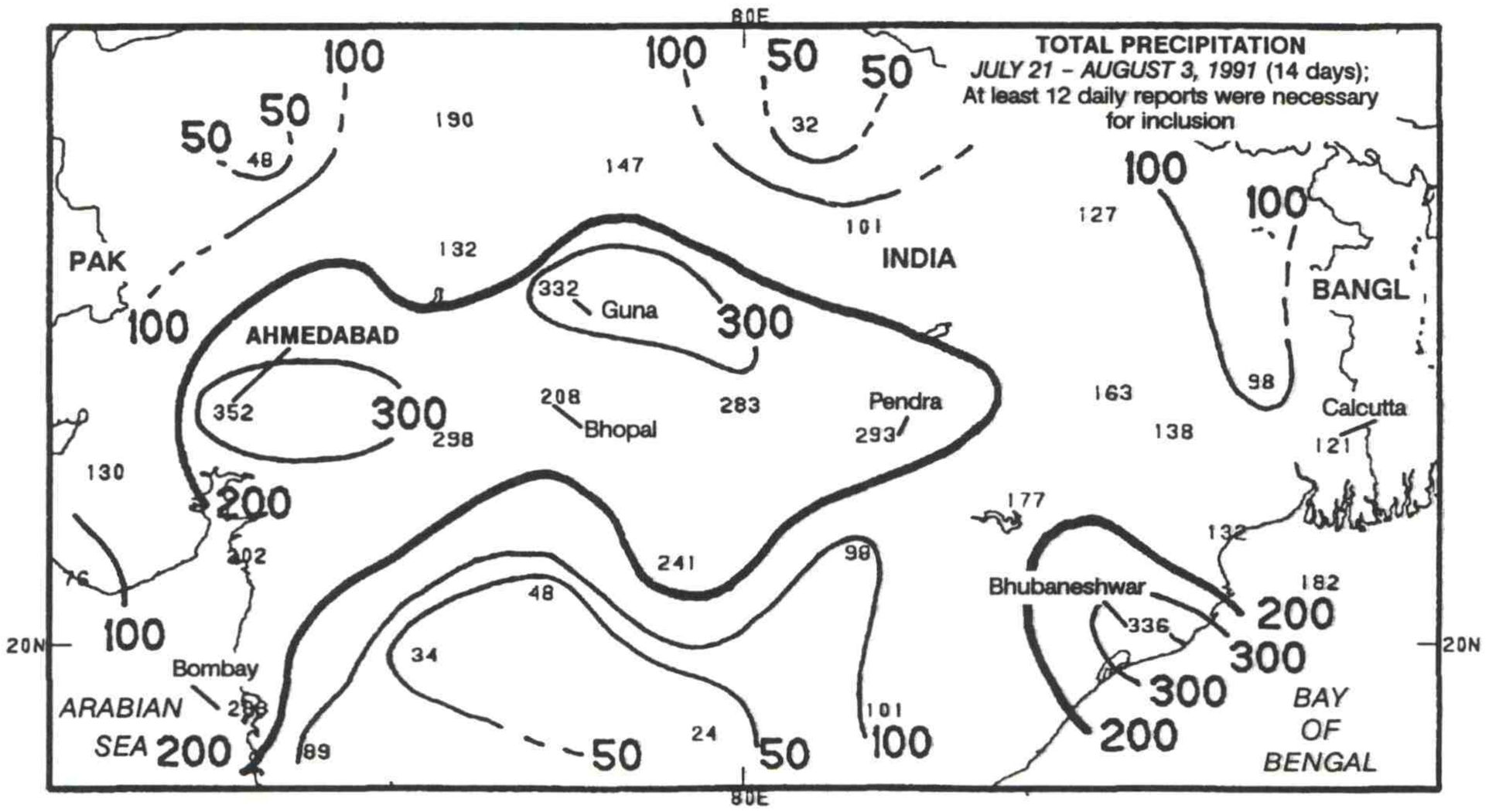
The production of the Weekly Weather and Crop Bulletin continued, as well as changes to enhance its appearance. More pages are now being produced on a PC, using desktop publishing software. The international temperature and precipitation tables and U.S. heating degree day tables were converted to this method which decreases the need to photographically reduce pages and will be economical in the long run.

Special articles were published in the Bulletin including one on the devastating cyclone which struck Bangladesh (April 1991). A historical list of storms (included in the article) indicated that this storm was one of the deadliest of all time. Other articles dealt with the heavy March rains in California, the December freeze in the western U. S., the record rainfall in the lower Mississippi Valley, and the South African drought.

4.4.5 Weekly Climate and Weather Update (Sabol)

A number of changes have been made to the Weekly Climate and Weather Update. The orientation of the page was changed and the size of text type reduced (figure 40), which allowed more space for maps and/or graphics. Then, values were added to the maps to give the reader an indication of the highest precipitation total or the strongest temperature anomaly. A lead story was added and highlighted in color and the maps were converted to a full-color, fully-automated analysis.

GLOBAL CLIMATE HIGHLIGHTS FEATURE



After a slow start to the 1991 monsoon across central and western India, torrential downpours have inundated much of central India from the northwestern Bay of Bengal coast westward into Eastern Gujarat during the last two weeks. According to press reports, more than 10,000 individuals were left homeless and several hundred people lost their lives as a number of rivers, including the Wardha River in Maharashtra's Nagpur region, swept out of their banks and engulfed numerous villages.

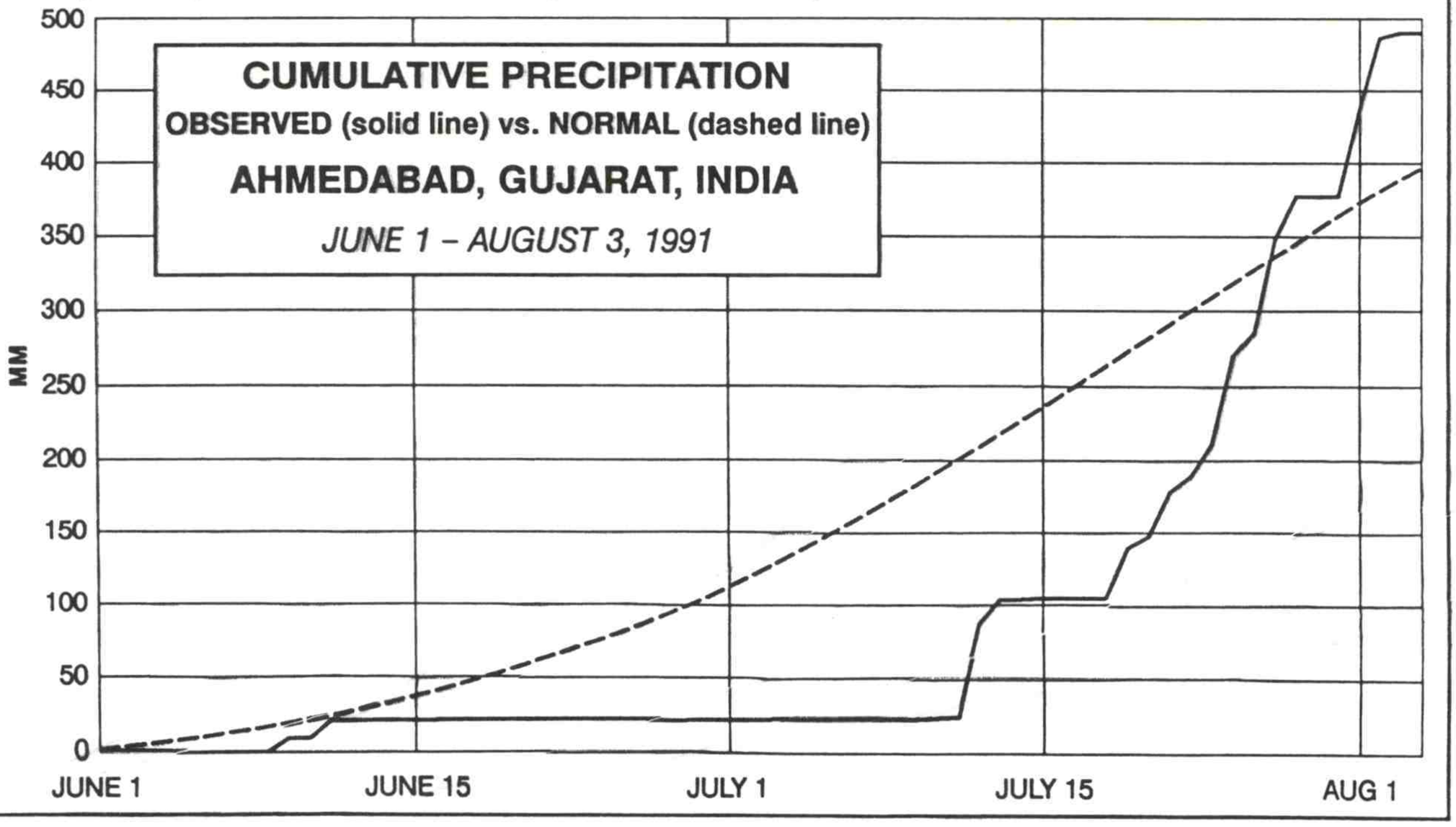


Figure 39: Global Climate Highlight Feature page from the Aug. 3, 1991 issue of the Weekly Climate Bulletin, depicting the heavy late July monsoonal rains across west-central India.

CLIMATE AND WEATHER UPDATE

Monday, September 30, 1991

HEAVY RAINS DRENCH DEEP SOUTH, ATLANTIC COAST: Severe thunderstorms brought torrential downpours, high winds, and hail to the deep South as cold air plunged through the nation's midsection. Almost six inches of rain deluged portions of Texas while totals exceeded three inches across large sections of the South (top right). The leading edge of the same cold air mass also brought heavy rains and severe thunderstorms to New England and the Atlantic coast. Winds gusted to 110 MPH at Boston's Logan International Airport, and up to four inches of rain inundated the Atlantic coast

RECENT WEEK (September 22 - 28, 1991): Rare thunderstorms rumbled across the San Francisco Bay area while unusually wet weather persisted across central and southern California. The western states experienced unseasonably warm weather as temperatures averaged up to 11°F above normal (bottom right). In sharp contrast, subnormal temperatures dominated the central and eastern states. Departures reached -13°F in Michigan as temperatures dipped to record lows by the end of the week. Hawaii reported near normal temperatures while Alaska was unseasonably warm, with temperatures as much as 7°F above normal.

CURRENT SITUATION (September 29 - 30, 1991): Summer-like conditions returned to portions of the central and southern United States, with highs exceeding 90°F in the central Plains. Strong thunderstorms dumped almost eight inches of rain near Jacksonville, FL and brought showers to much of the south Atlantic and central Gulf coasts. In sharp contrast, wintry weather affected the upper Great Lakes and New England. Snow and sleet fell in parts of Vermont and northern Maine while record cold gripped Michigan as temperatures dipped into the twenties.

HYDROLOGIC CONDITIONS: Major flooding developed along the Rio Grande River in southwestern Texas. Water was released from several reservoirs as they reached record levels. Significant damage occurred at Big Bend National Park, and many roads and bridges in the area were washed out. Levees broke about sixteen miles southeast of Presidio, flooding large tracts of farm land and closing roads. Some minor to moderate river flooding was also reported during the week in parts of south-central Texas while beneficial rains helped ease abnormally dry conditions in parts of the middle Atlantic region.

OUTLOOK (October 1 - 5, 1991): Above normal temperatures will persist across the western quarter of the nation and are expected to develop in the Northeast by the end of the week. A surge of tropical moisture may bring soaking rains from the Carolinas northward by midweek. Chilly Canadian air is expected to push southward through the Plains by the weekend, generating shower activity over the eastern quarter of the nation.

LONG RANGE OUTLOOKS: October Monthly Outlook and October through December Outlook for the United States are attached.

Contacts: P. Sabol, J. Harrison: 301-763-8071

S. Kroczynski; 301-427-7630

Climate Analysis Center, NMC, NWS

Hydrometeorological Information Center, OH, NWS

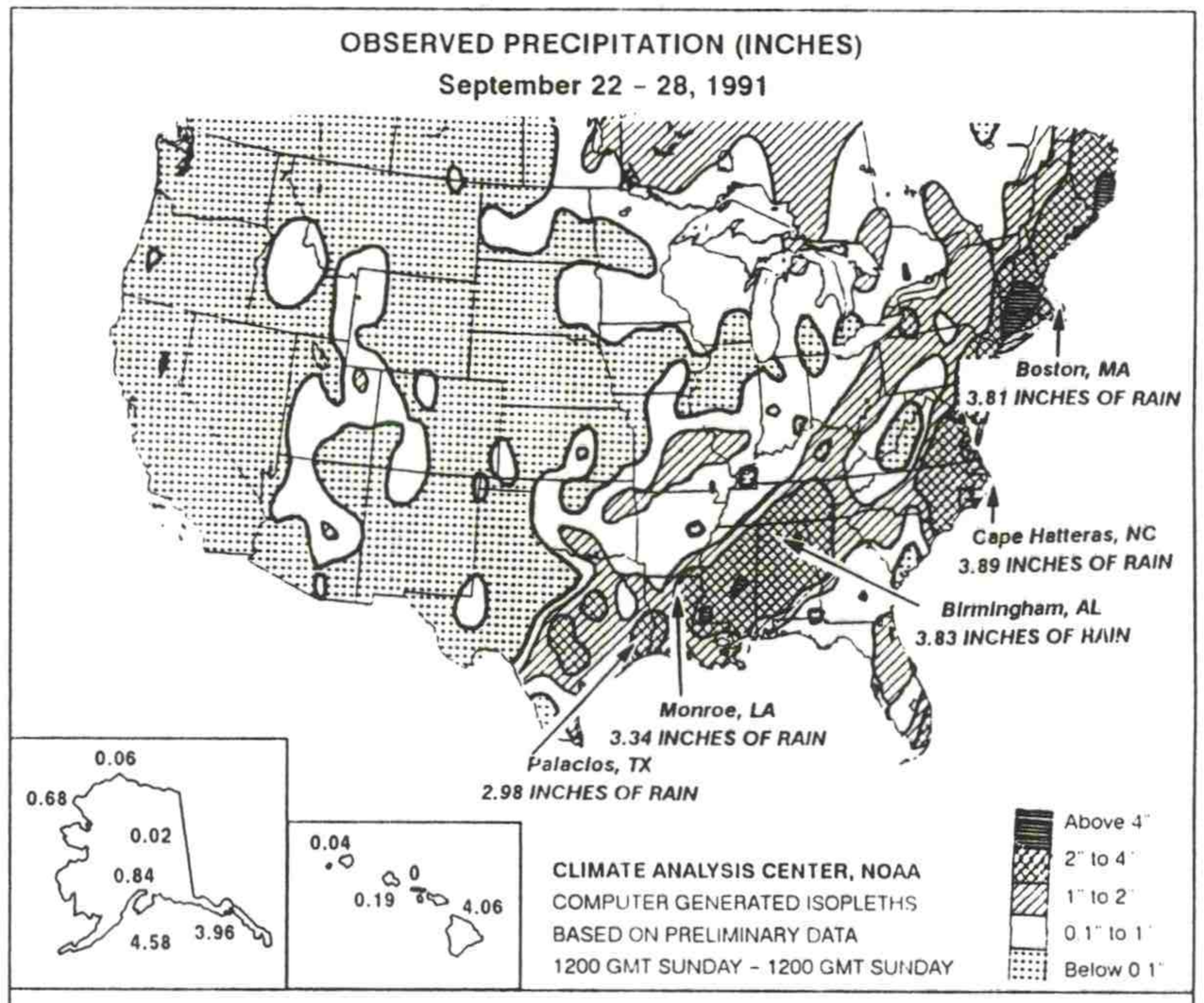


Figure 40: The new format of the cover page of the Weekly Climate and Weather Update.

As a result of the above efforts, more information is now provided, improvements in readability and attractiveness were made, and the production time was reduced. Also, frequent use has been made of monthly precipitation and/or temperature quantile analyses to give the reader some perspective on how an anomaly compares to climatology. In addition, full-color maps of one- and three-month temperature and precipitation outlooks were published on a second page. This product is now included in the Secretary of Commerce's Weekly Briefing Book.

4.4.6 PRESTO - National Capital Summary (Harrison)

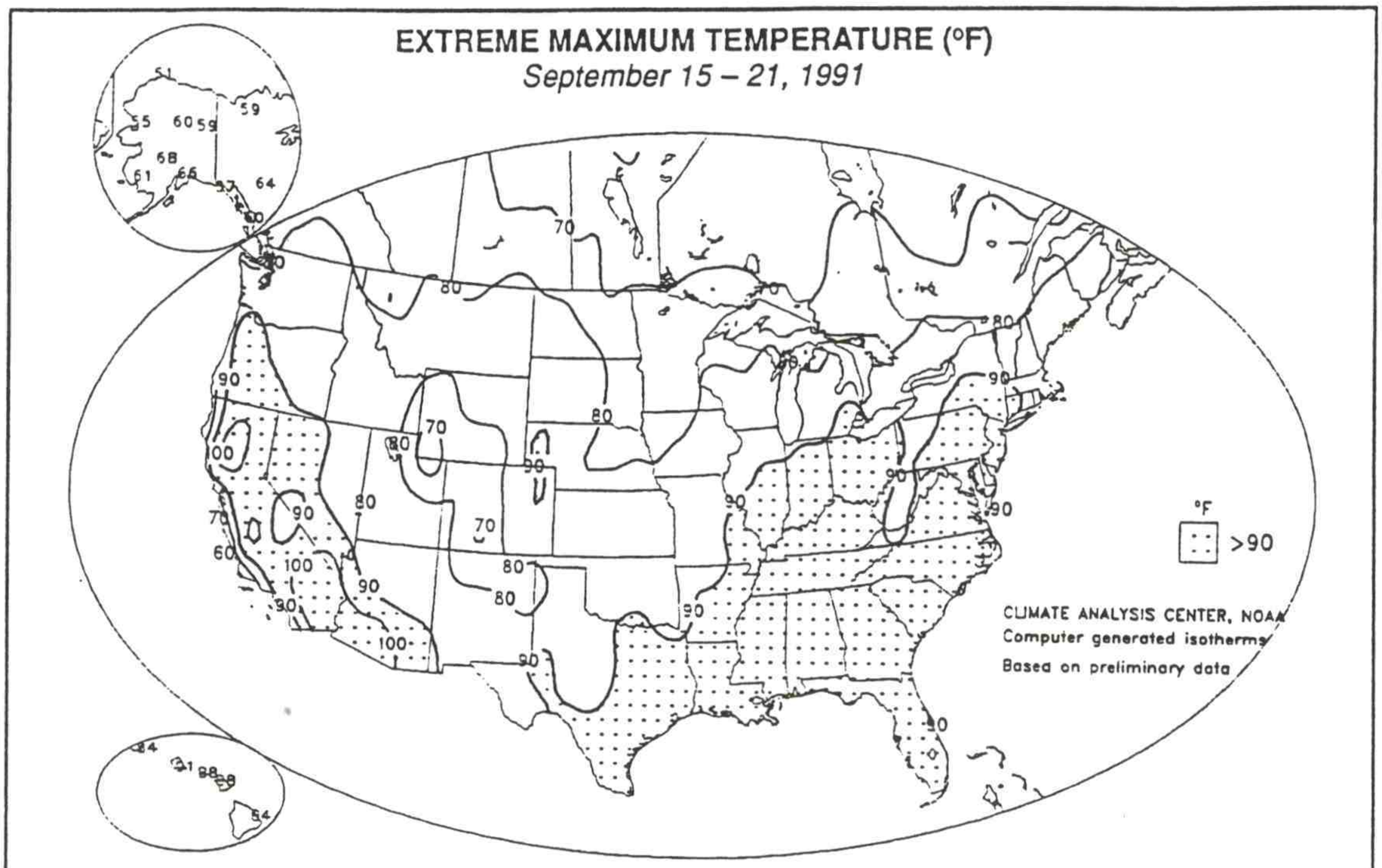
The production of PRESTO continues with improvements and modifications made, as required. For example, the January 1991 issue featured a "special decadal edition." The archival of monthly temperature and precipitation data for National, Baltimore, and Dulles Airports has been installed into Lotus software and has been beneficial for statistical computations. Currently, the archival of daily data (January 1949 - present) for National Airport is almost completed and interactive software is being developed to manipulate the archived daily data. Also, microvax software was developed to extract the daily local temperature and precipitation data to automatically produce statistics tables. In addition, PRESTO is now distributed to all Washington D.C. television stations, after a visit by local TV weathercasters. Lastly, the number of recipients is now 280.

4.5 Supporting Projects

4.5.1 Graphics Applications (Miskus, Herman)

A major milestone in the operational graphics production was reached this year. The capability now exists to produce operational maps automatically at either the World Weather Building or USDA/JAWF, send them in various formats across the network, and print publication-quality monochrome versions (see figure 41) at both locations. The technique includes a modified NCAR graphics software package, a specialized set of analysis programs and options, automated Cray and Apollo batch jobs, and optional workstation capabilities for data modification. Color screen and hardcopy output was developed for the above maps, for the Palmer Drought Index, and Northern Hemisphere ozone.

Also, Microvax software was developed that automatically collects half-hourly METEOSAT satellite-derived cloud temperatures over the African Sahel, converts them to 10-day rainfall estimates, compares them with ground-truth rainfall, and then color hardcopies the analysis. Improved mathematical models for the METEOSAT estimates have now reduced the mean square errors in semi-arid (dry) areas from 15mm to 8mm, and from 35mm to 20mm in tropical (wet) regions. In addition, software development is underway that will plot and/or contour data for any area with several types of geographic projections.



Abnormally warm weather affected a large portion of the East and Far West as highs exceeded 90°F (top). Oppressive heat and humidity produced apparent temperatures over 100°F in the deep South, mid-Atlantic, and parts of the Southwest (bottom).

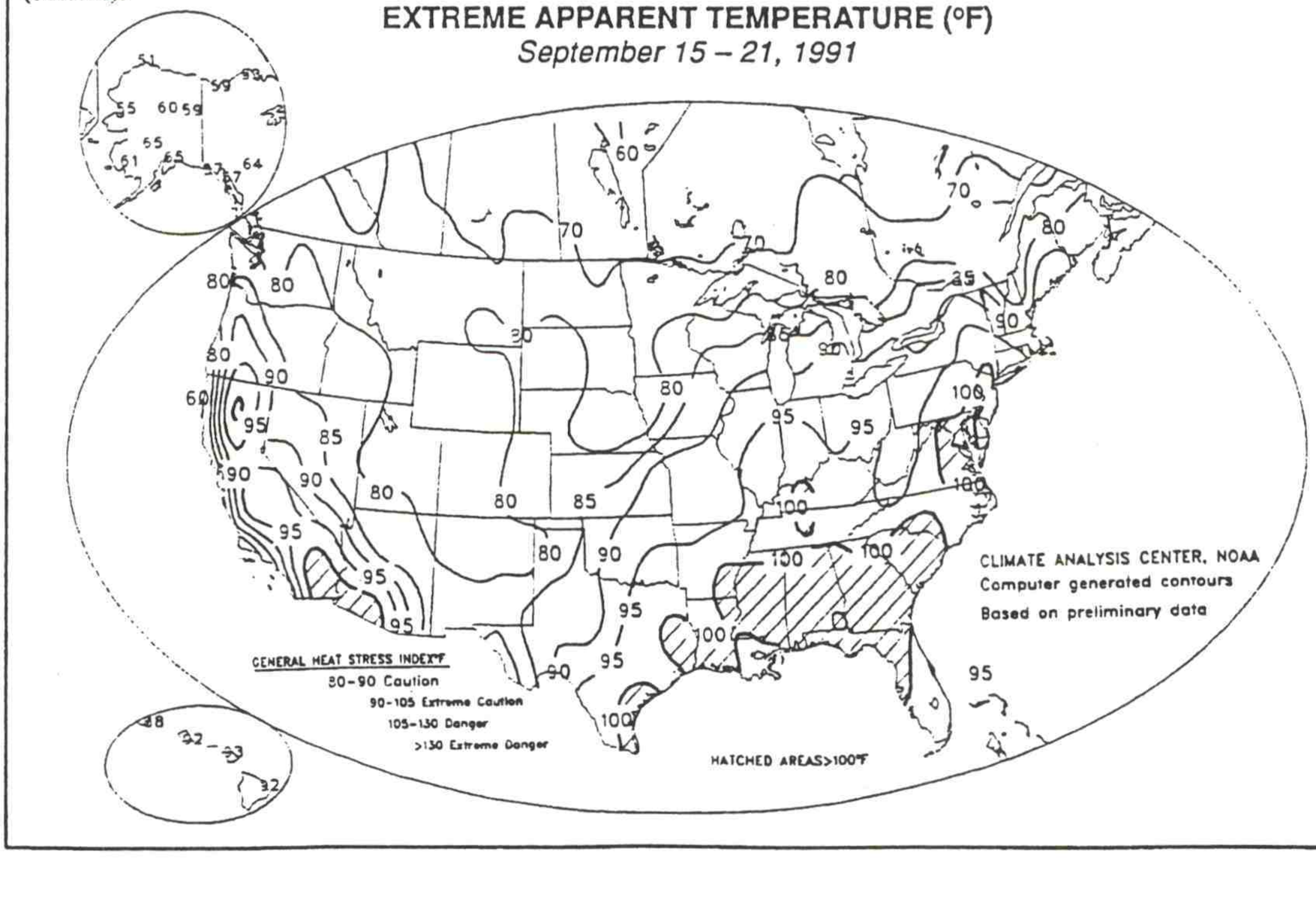


Figure 41: Examples of the publication-quality U.S. analyses automatically produced twice a week for use in CAC publications. Weekly data are analyzed by a pseudo-optimal interpolation analysis scheme (on the Cray computer) and sent to a workstation. Graphics software then produce a monochrome or color version of several parameters.

4.5.2 Systems and Communications (Thomas)

Hardware systems used by the CAC have been enhanced in a number of ways. Seven new PC systems (25 MHz-386) were added to enhance the office automation and publication capabilities. A new Digital Equipment Corporation VAX 4000 series 300 system was added to the VAX cluster to support the Data Host Facility of the Network for Detection of Stratospheric Change. Also, Ethernet was expanded to include most PC's operated by the CAC's Analysis and Information Branch and the Director's Office. Figure 42 illustrates the extent of the current network for CAC's Analysis and Information Branch and the Director's staff.

In addition, a 6250 reel to reel tape drive has replaced an older one; a thinwire IEEE 802.3 Ethernet multiport repeater was obtained; DEC Pathworks, a software product that allows networking of PC's was installed on the VAX cluster; and NCAR graphics were installed on the VAX cluster to make it compatible with the NCAR package that was installed on the Cray and Unix workstations. The use of the VAX systems has greatly increased due to the launch of the UARS satellite, the addition of the Regional Climate Centers, and the Arctic Airborne Stratospheric Experiment. Operations had an uptime exceeding 98% for the year.

4.5.3 Satellite Monitoring Products (Tinker, LeComte)

Ten-day and monthly maps and gridfields, depicting estimated rainfall and percent of normal rainfall across the African Sahel, were routinely generated on workstations, printed on color devices, and provided to the AID-Famine Early Warning System. These color maps combined any available surface rainfall reports with 30-minute METEOSAT satellite data to create a "first guess" analysis. A monochrome version (normally in color) of 10-day rainfall estimates is depicted in figure 43.

In addition, the lower resolution colorized cloud-top counts were generated on both a 10-day and monthly basis as an aid to the rainfall analyses. These charts are created on the VDUC terminal and printed on a color device. Both the spatial and temporal resolution of the product were increased to improve accuracy and to create a product that samples the same data as color maps. Thus, the previous 4-km resolution METEOSAT images were replaced with 2-km resolution images, and the frequency was increased from once every 3 hours to once every 30 minutes.

4.5.4 Climate Assessment Data Base (Miskus)

In maintaining an operational Climate Assessment Data Base (CADB), all problems were resolved without any major delay or data loss. One task involved the transfer of several CADB data files from one disk pack to another on the NAS mainframe. This required extensive and complex software development, since the two types of disk packs were incompatible. Another problem

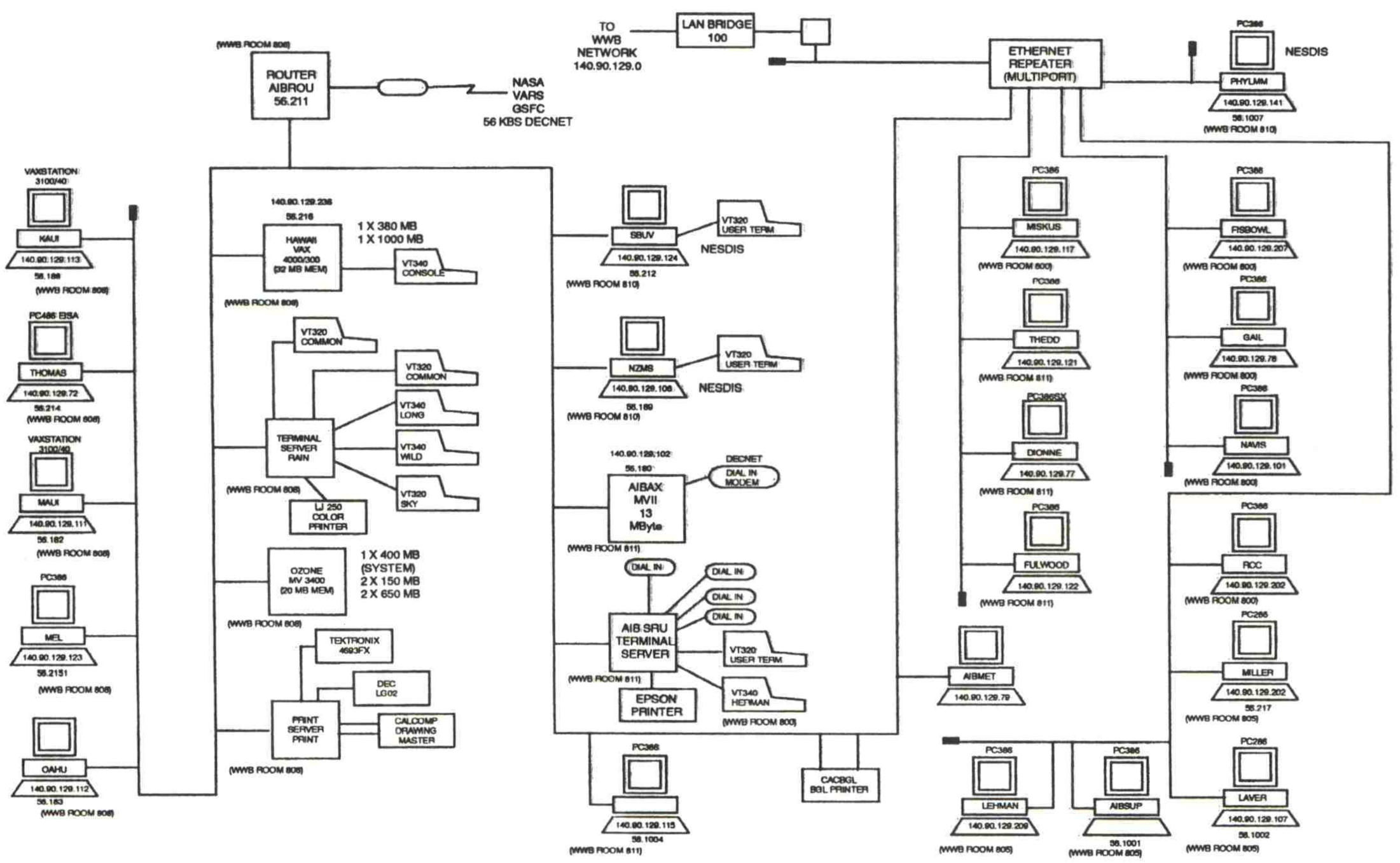


Figure 42: CAC's ethernet network for one of its Branches and the Director's Office, located in the World Weather Building.

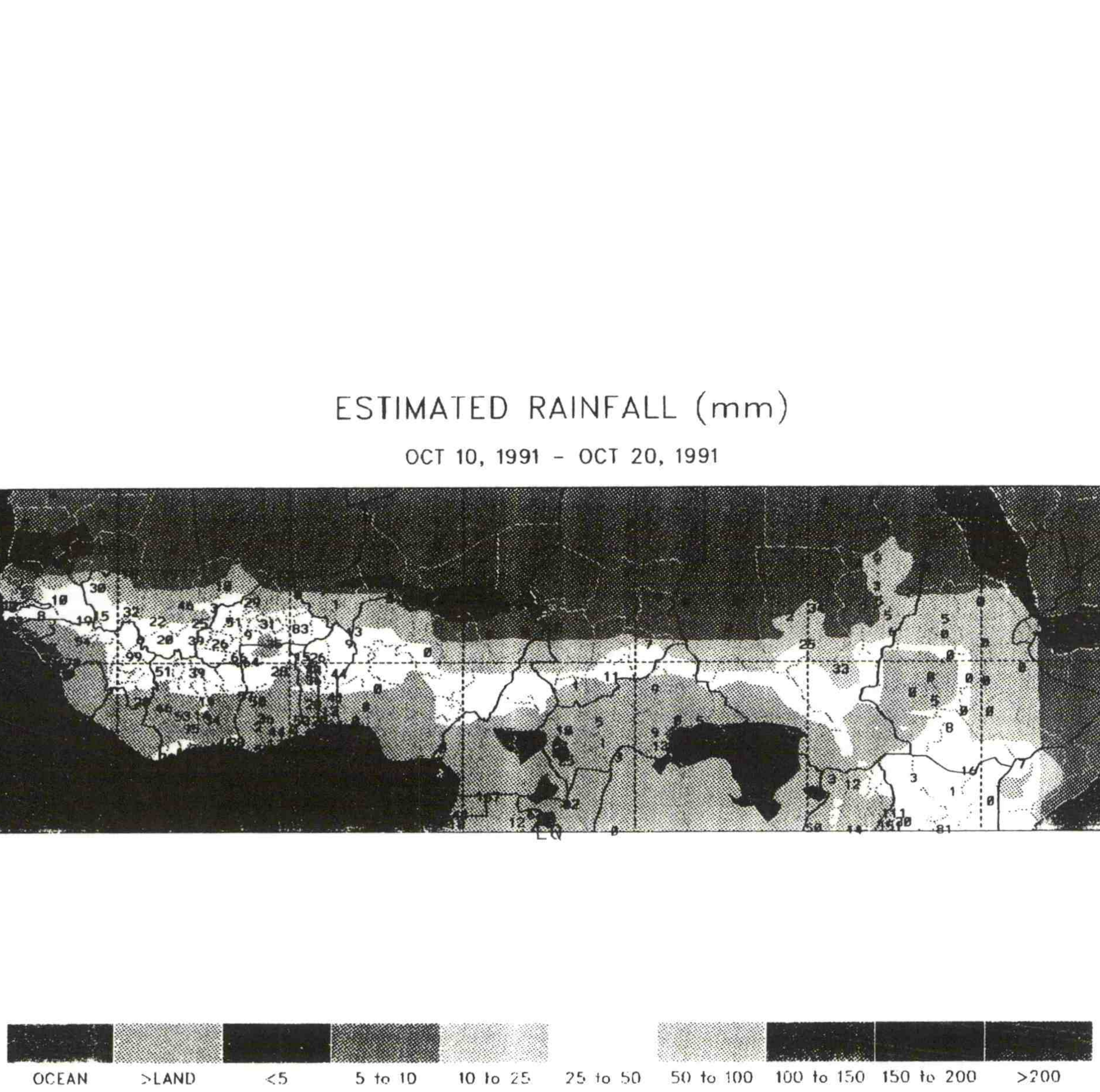


Figure 43: Analyzed decadal rainfall estimates of the African Sahel (normally in color), with synoptic rainfall totals plotted. The technique combines ten-day METEOSAT satellite rainfall estimates with decadal ground station rainfall totals, producing a "first-guess" analysis that can be manually adjusted to remove biases between the station and satellite data.

was the slow turn-around time of the NAS, which created errors in the sequential data and data files. This problem was not only solved, but any future delays of this magnitude are now anticipated by the program. Also, special software was modified that corrects underestimated precipitation totals caused by new or changed synoptic reporting practices.

An extensive update of the entire CADB station library and its associated software was completed, which resulted in acquiring dozens of new synoptic stations. Major modifications involved updating the station's quality flag, country and region numbers, city and country names, and any incorrect latitudes, longitudes, and elevations. In addition, modifications to the monthly CLIMAT data collection and transmission programs have improved data quality and increased data quantity. Newly generated statistics allow quick detection of problems, and new software enables the manual input of missing CLIMAT into the CADB. Also, the electronic transmission of the daily/monthly CADB and monthly CLIMAT data (via Microvax computer) has rapidly increased the turn-around time of sending data from CAC to NESDIS/NCDC and eventually to their users.

4.5.5 JAWF Briefings (LeComte)

CAC meteorologists at the Joint Agricultural Weather Facility (JAWF) continued to keep USDA meteorologists and crop analysts informed of world weather events by means of daily and weekly briefings. Highlights of the weekly briefings included the drought in the Soviet Newlands, floods in China, the cyclone in Bangladesh, and the drought in eastern Australia. USDA crop analysts were kept up to date on the progress of the El Niño/ Southern Oscillation event and its potential impact on crops.

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5. CLIMATE PREDICTION

5.1 Empirical Studies

5.1.1 Medium-Range (6-10 day) Forecast Development (Epstein)

Efforts have focused on reprogramming the imperfect prog temperature forecast system to ensure its predictability factors, predictand selection procedures and regression coefficients. Numerical 5-day mean temperature predictions, based on the original set of predictability factors, are available to 6-10 day forecasters and apparently have reasonable skill although this has not been quantified.

A study was also made of the influence of ENSO conditions, in a climatological sense, on 5-day precipitation frequencies and amounts conditioned on the frequencies. The results confirmed the strong influence of ENSO on precipitation and identified regions in which the effect was primarily one of frequency, primarily one of amount with little influence on frequency, or due to a combination of frequency and conditional amount. The ENSO effects, while not necessarily large everywhere, did prove to be more widespread than previously thought.

5.1.2 Seasonal Empirical Prediction (Livezey, Barnston)

Experiments to compare the analog prediction technologies of the CAC and the USSR Hydrometeorological Center culminated in the completion of several experiments in early 1991. This was achieved during the visit of Professors G. V. Gruza and E. Ya. Rankova, under a U.S.-Soviet Bilateral Agreement. Of primary interest to CAC was the viability of Gruza's "optimization" concept for *a priori* selection of U.S. seasonal analog forecast predictors. Validation of this procedure would lead to a more efficient design of analog prediction models and the elimination of some subjectivity in the process that inevitably resulted in over statements in realizable skill. The procedure's effectiveness was tested using CAC predictor and predictand data sets and cross-validation methods. Skills of different models were assessed on the basis of 40 seasonal forecasts at 100 stations.

Tests of the Soviet GRAN ("Group Analog") method were first run without optimization, using the *a posteriori* selected predictors employed in the CAC system. A version of the CAC system which excludes antianalogs (similar to GRAN without optimization), was run for comparison. The results shown in table 2 reveal that these systems perform in a practically identical manner when predictor and predicted data sets are the same. GRAN forecasts were then made using *all* available predictors and then using *only* predictors selected by optimization. Also, values in the last row of the table show that objective *a priori* predictor selection by optimization is just as effective as subjective *a posteriori* selection.

	Winter	Spring	Summer	Fall
CAC Model (no antianalogs, a posteriori selected predictors)	0.11	0.05	0.09	0.08
GRAN Model (no optimization, a posteriori selected predictors)	0.11	0.04	0.09	0.05
GRAN Model (no optimization, all predictors)	0.04	0.08	0.06	0.04
GRAN Model (optimized predictors)	0.11	0.04	0.13	0.07

Table 2: U.S. seasonal forecast skill, (Heidke), 1950 - 1989.

5.1.3 Soil Moisture and Temperature Forecasts (van den Dool, Huang)

The purpose of this project is to calculate daily soil moisture for the United States and to improve long-range temperature forecasts with the knowledge of antecedent soil moisture. As a pioneer study, the relationship between monthly mean precipitation (MMP) and temperature (MMAT) was examined by using MMP as a first order proxy for the soil moisture anomaly. The study was based on both climate division and station data during the 1931-87 period. Preliminary results showed that the P-T correlation is generally negative, with the maxima in summer and for the interior U.S. continent.

Results also showed, on the whole, that the inclusion of MMP as a second predictor only slightly improved the MMAT forecasts. This is due to the fact that the first predictor (temperature persistence) has accounted for the MMP's predictive variance. However, in wet months, the inclusion of MMP as a second predictor can make a better MMAT forecast than using temperature persistence only (see figure 44). The higher skill in wet months suggests that for the monthly or longer range MMAT forecasts, the P-T and T-T correlations can be used with more confidence in these months. Moreover, the predictability of the empirical forecasts can be determined when making the forecasts according to the current MMP.

5.1.4 Long - Range Forecasting of U.S. Surface Temperature at Non - Zero Lead Times (Barnston)

An exploratory study of long-range forecasting of U.S. surface temperature, at non-zero lead time using canonical correlation analysis (CCA), has produced evidence of useful skill at certain times of the year - particularly late summer and late winter. This feature is shared to varying degrees by forecasts with leads of one-half month to three months and averaging periods of one to three months. The components of the predictor fields for several periods preceding forecast time that give rise to skill in the forecasts are identified as a standard part of the CCA prediction procedure, making possible some understanding of the origin of the skill.

For example, figure 45a shows the regional distribution of cross-validated predictive skill for forecasts of mean August U.S. temperature made in mid-July (half month lead time). Figure 45b shows the main anomaly centers of the mid-June to mid-July sea surface temperature (SST) pattern associated with the strongest of the several modes leading to the forecast skill reflected in figure 45a. In this case, anomalously warm SST in the northern equatorial Atlantic Ocean in the latter half of June through the first half of July tends to be followed by hot August weather in much of the eastern half of the U.S. The SST pattern (figure 45b) has sometimes been noted in the summer following the completion of a warm ENSO episode.

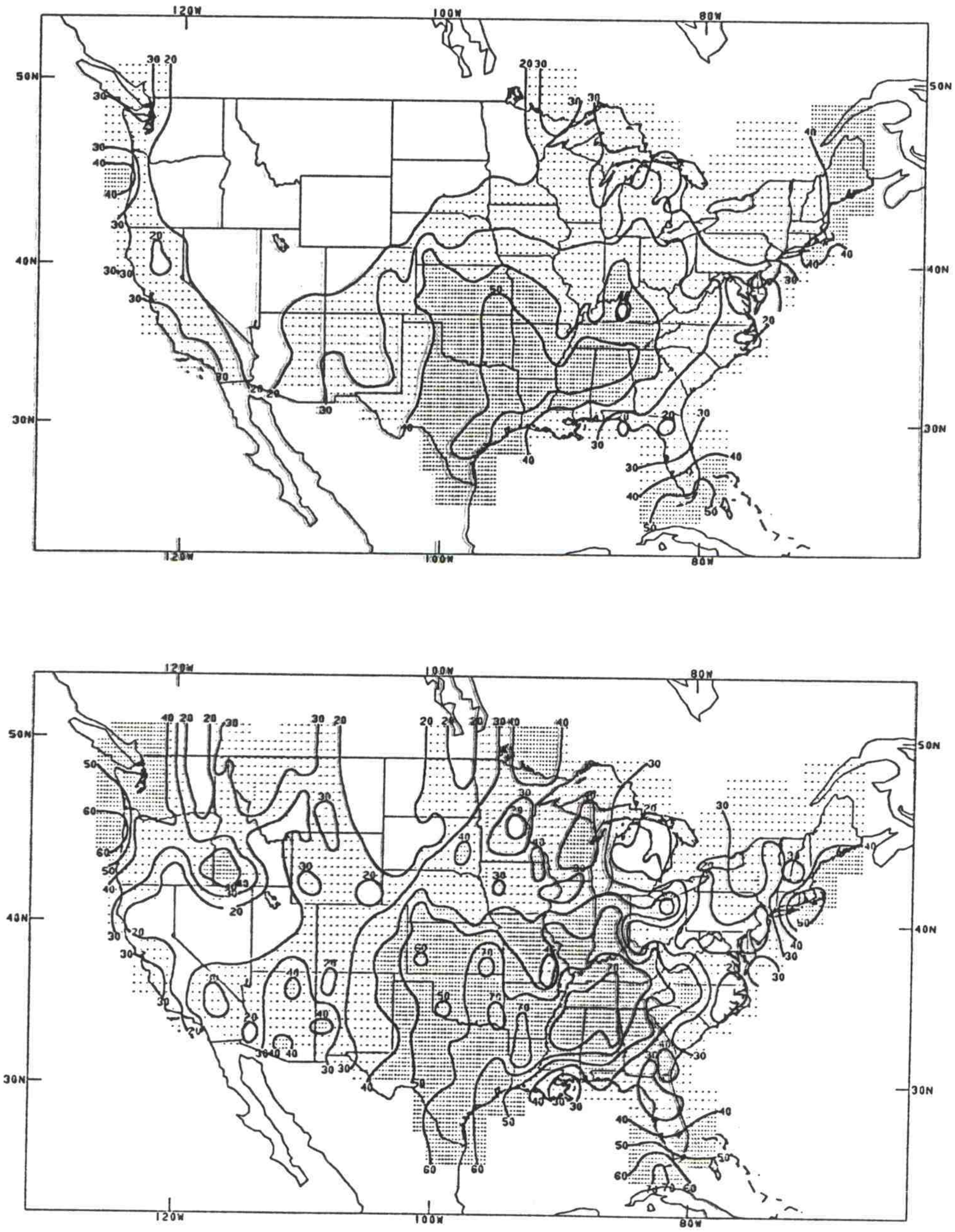
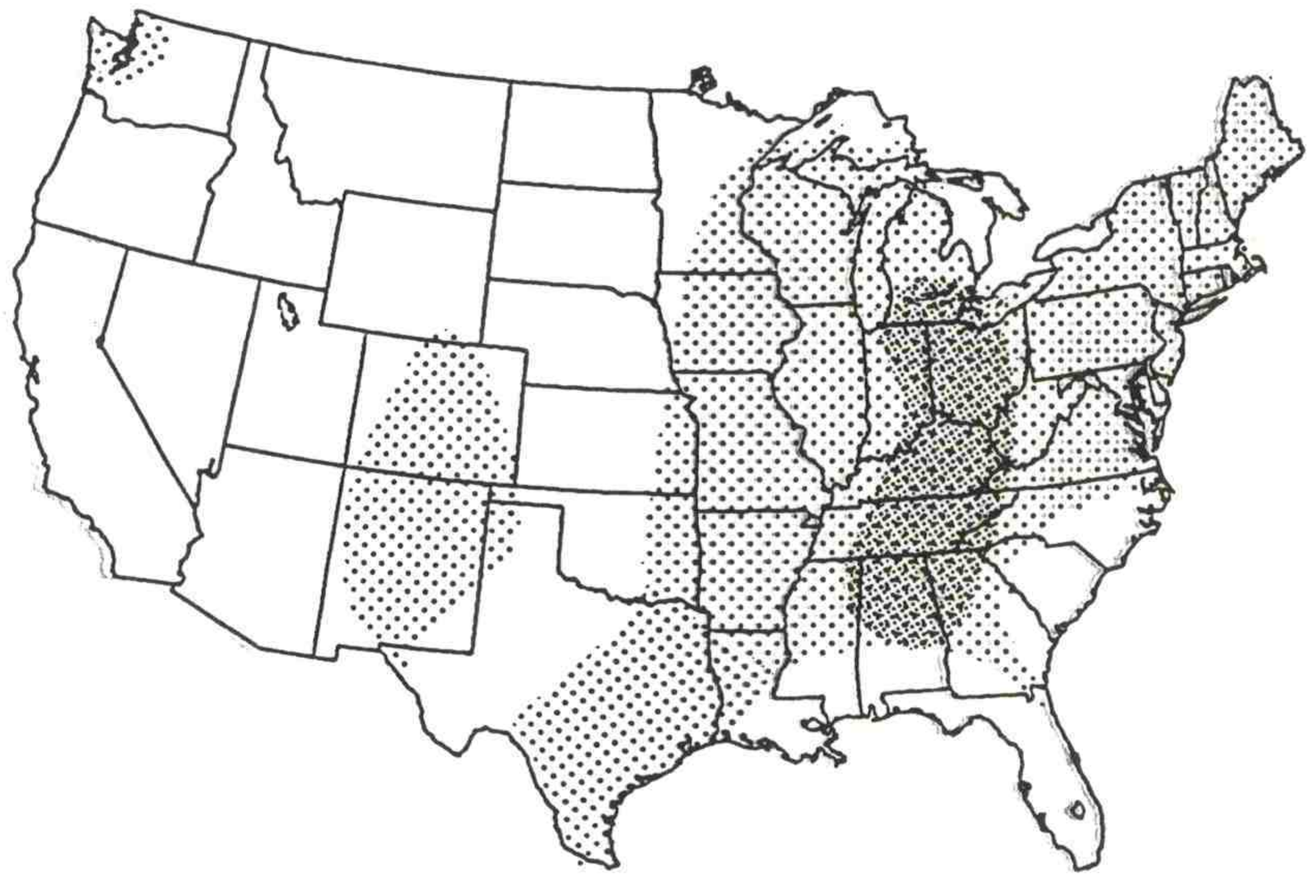


Figure 44: Temporal correlation between observed August temperature and predicted by regression models. In the upper panel, the predictor is July temperature. In the lower panel, the predictors are July temperature and precipitation and the verification shown is for wet initial Julys only. Development of regression and verification are based on 1931-1987, i.e., dependent data.

a



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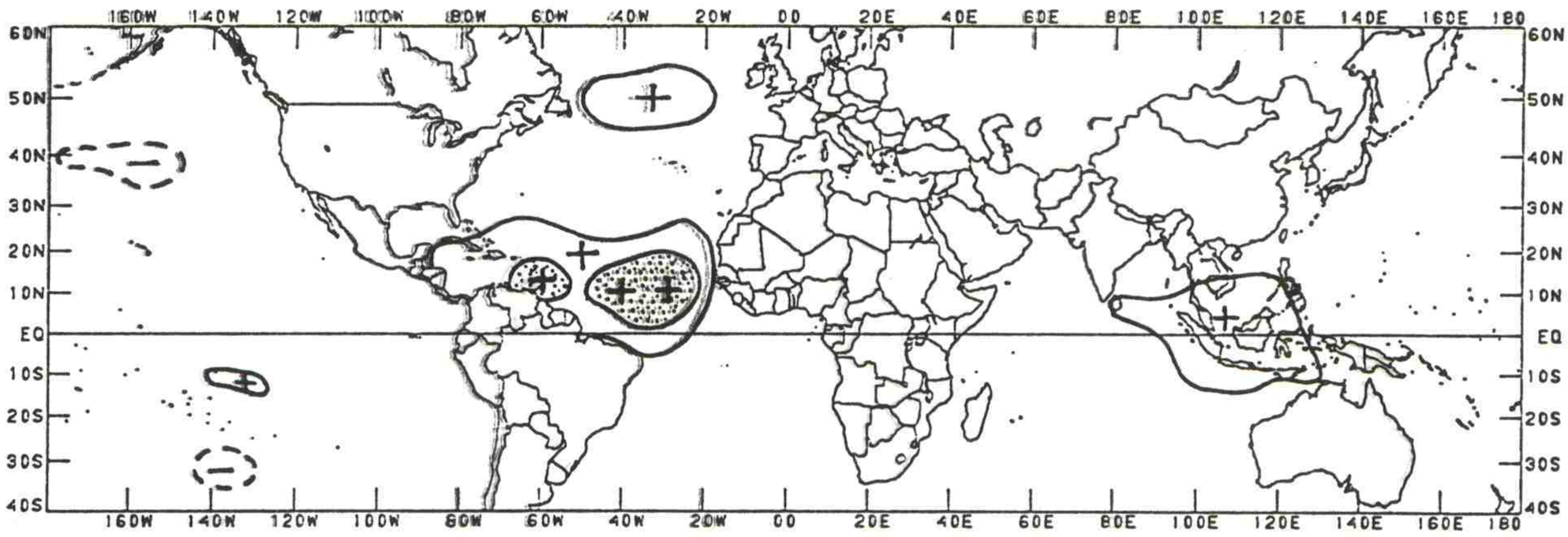


Figure 45: Diagnosis of CCA forecasts of United States August mean surface temperature made at mid-June (one-half month lead time) on the basis of near-global SST, Northern Hemisphere 700mb height, and U.S. surface temperature itself during four previous 1-month periods. Part (a) shows the spatial distribution of forecast skill cross-validated over a 35-year period (expressed as a correlation between forecasts and observations), where the light stippling denotes a skill of 0.3 or higher and dense stippling 0.5 or higher. Part (b) illustrates the portions of the SST field for the mid-June to mid-July predictor period that contribute most strongly to the skill pattern shown in part (a). In this example, positive SST anomalies in the north equatorial Pacific, near Indonesia, etc. and negative SST anomalies south of the Aleutians tend to be followed by anomalously warm surface temperatures in the eastern U.S. and the southern Rockies.

5.2 Dynamical Methods

5.2.1 DERF - Operational Feasibility Assessment (Ebisuzaki)

The purpose of this study is to use an ensemble of forecasts to produce a single forecast. One such effort is focused on testing a modified lagged average forecast (LAF)-ensemble which is theoretically better for finding spread-skill relationships. The LAF ensemble being tested in the DERF probability forecasts consists of 9 MRF forecasts run from analyses every 6 hours over a 48-hour span. Here, the perturbations consist of the forecast errors from earlier forecasts. A study is being conducted on an ensemble whose perturbations are still generated by forecast errors; however, the amplitudes of the perturbations are scaled by the age of the forecast. In addition, both positive and negative normalized forecast errors are used. Using a six hour spacing over the span of two days, the ensemble consists of 17 members including the control run.

Results show that this modified LAF produces better forecasts than the control forecast even at short forecast times (figure 46). This is an improvement over the simpler LAF which generally produces a worse forecast at shorter forecast times (figure 47). In addition, this modified LAF should show a stronger spread-skill relation because the spread is no longer dominated by the older members of the LAF ensemble which would skew the results. A stronger spread-skill relationship is necessary for making predictions of the forecast skill useful. So far, 5 modified LAF ensembles were run at T40 resolution. The results have been encouraging enough that for the second phase, the T62 version of the MRF is being used and two ensembles were completed. Some of the forecast dates will coincide with either those from DERF Probability Tests and case study experiments or with those from external ensemble runs.

5.2.2 DERF - Regime Dependent Predictability (Tracton)

A detailed evaluation and diagnosis of forecasts for selected case studies are being used to assess the dependence of forecast skill upon circulation regime and, especially, regime transitions. Each case involves generating a 9 member LAF ensemble with a 6 hour spacing between initial conditions (T80 model). To date, in this extremely computer-intensive exercise, 9 of 20 ensembles have been run. Extensive time and effort have been expended in generating appropriate charts, diagnostic output, and verification quantities. Also, to assess alternative methodologies for generating ensembles, some cases have been partially rerun with the modified LAF procedure described in Section 5.2.1.

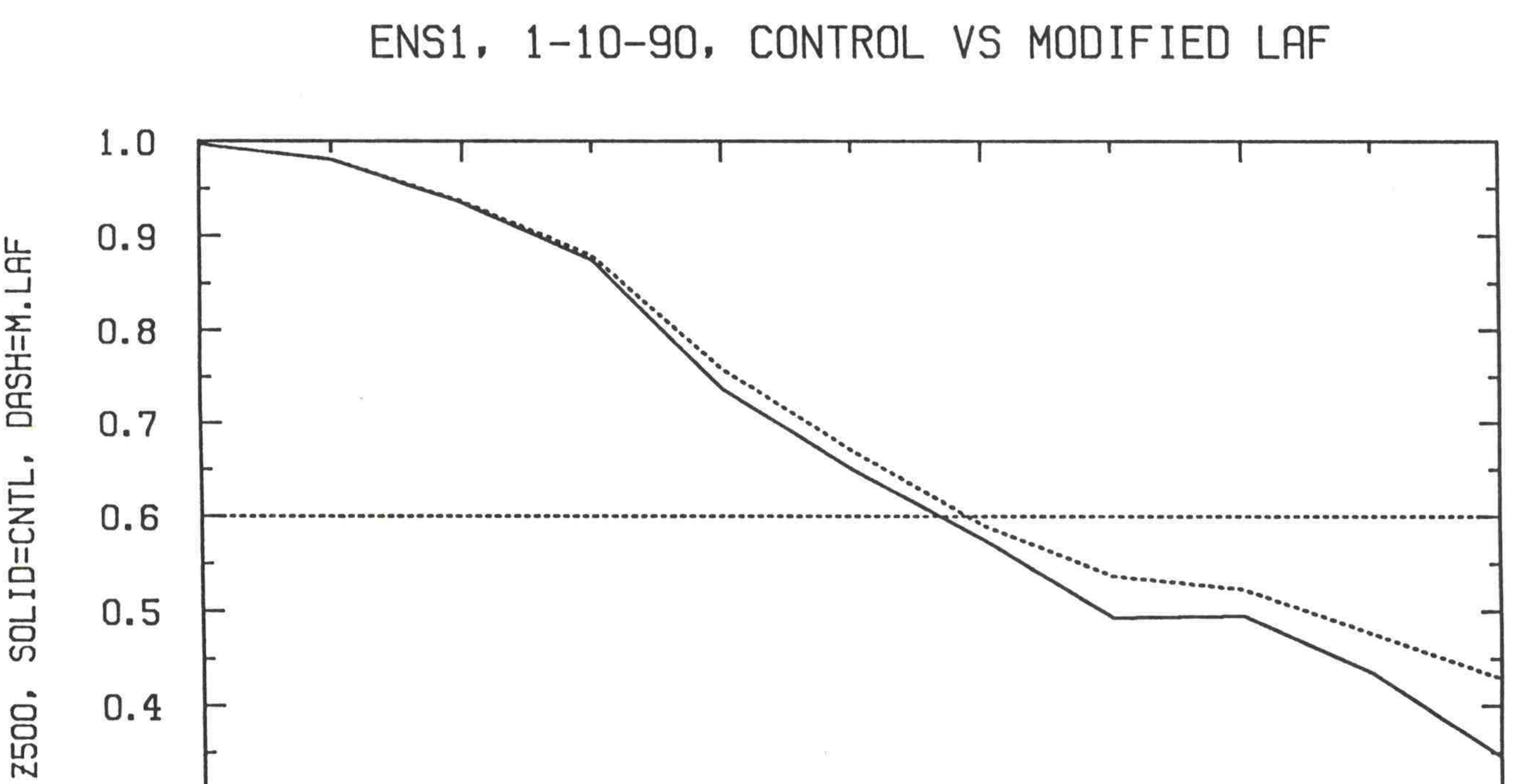


Figure 46: The forecast skill of the control run (solid) and a modified LAF (dash) for a typical ensemble. Both the control run and the ensemble are T40.

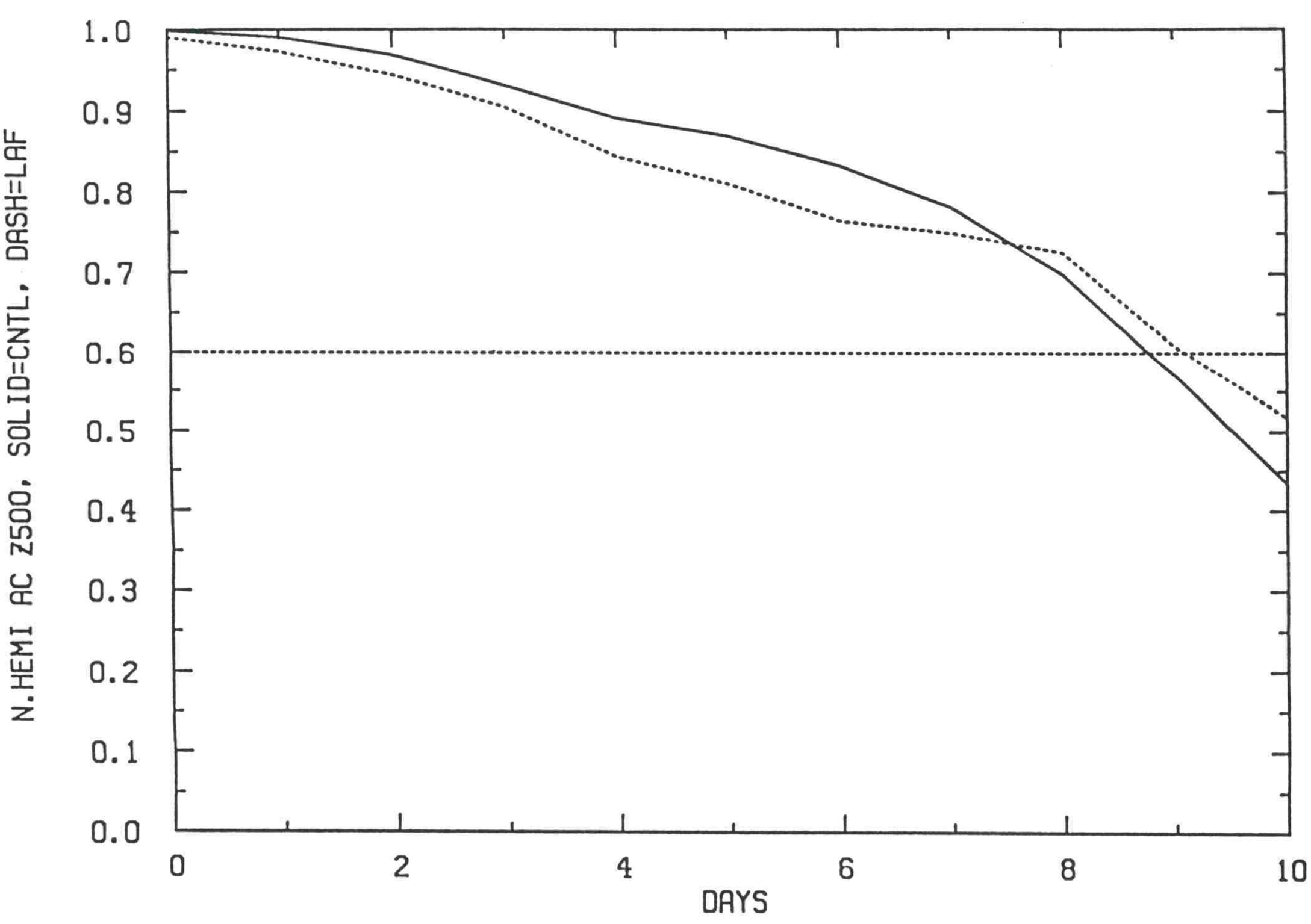


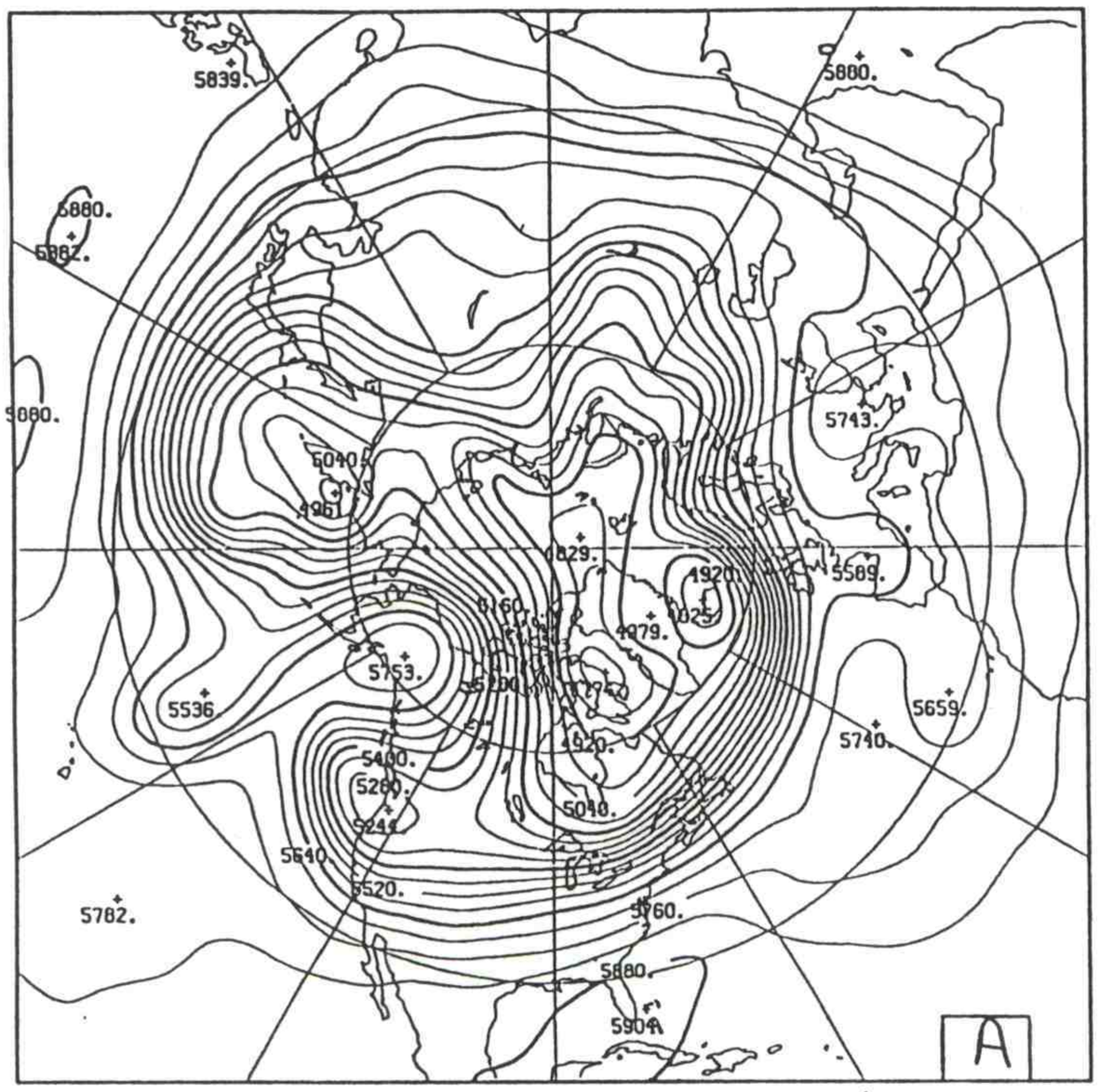
Figure 47: The forecast skill of the control run (solid) and the (unmodified) LAF (dash). Both the control and LAF are T80, and the LAF has 9 members with 6 hour spacing, (9 members, 6 hour spacing). Note that the skill of the LAF is worse than the control at shorter forecast times.

The evaluation, so far, has focused on predictability as it relates to scale interaction processes, particularly in blocking and associated cyclogenesis. Diagnoses reveal that evolution of the planetary and sub-planetary scale circulations can be, but is not always, dependent upon their interaction with one another. The degree of this dependence has clear implications on the predictability of the phenomenon in question. In one case (January 1989), scale interactions appeared crucial to the development of a block in the Pacific. In all but one ensemble member, forecasts did not capture this development. In this exception, the phasing and subsequent interaction of planetary and sub-planetary systems (comparable to events in the verifying analyses), resulted in an extra-ordinarily good prediction at the 15-20 day range (figure 48).

5.2.3 Probability Forecast Experiment (Tracton)

The name of this project (formerly the "spin-off" test) has been changed because the medium and extended-range predictions are intrinsically probabilistic in nature, and forecast ensembles are necessary to provide estimates of the uncertainties. Beginning in February 1991, the lagged average forecast (LAF) ensembles were upgraded from 5 forecasts at 24-hr. intervals to 9 members with 6-hr. spacing. In addition, the target period of the LAF ensembles was extended from D+8 to D+13. This configuration was implemented on the Cyber computer using the T80 version of the MRF. However, due to the loss of the Cyber in March and time constraints on the new Cray super computer, the probability forecast extensions were truncated to T62 in April. Limited experiments suggested that the T62 model is less satisfactory, at least in some cases (e.g. blocking).

Attempts were made, but were unsuccessful, for modifications to NMC's operational suite which would have permitted a return to the T80 model. Although less than optimum, the probability experiment is realistic in the sense of reflecting the most that can be done in the context of NMC's operational environment. Also, this experiment can be viewed as the benchmark for judging possible improved versions pursued outside the operational block. Evaluation of the upgraded experiment awaits a longer, more stable sample of cases, e.g., during the cold season. A comprehensive evaluation of the probability experiment through March 1991 was completed and a paper was written for journal publication. The results did not demonstrate any positive influence of the extended runs on CAC's Monthly Outlooks of surface temperature anomalies. This was attributable, at least in part, to the limited number of members and coarseness of spacing within LAF ensembles.



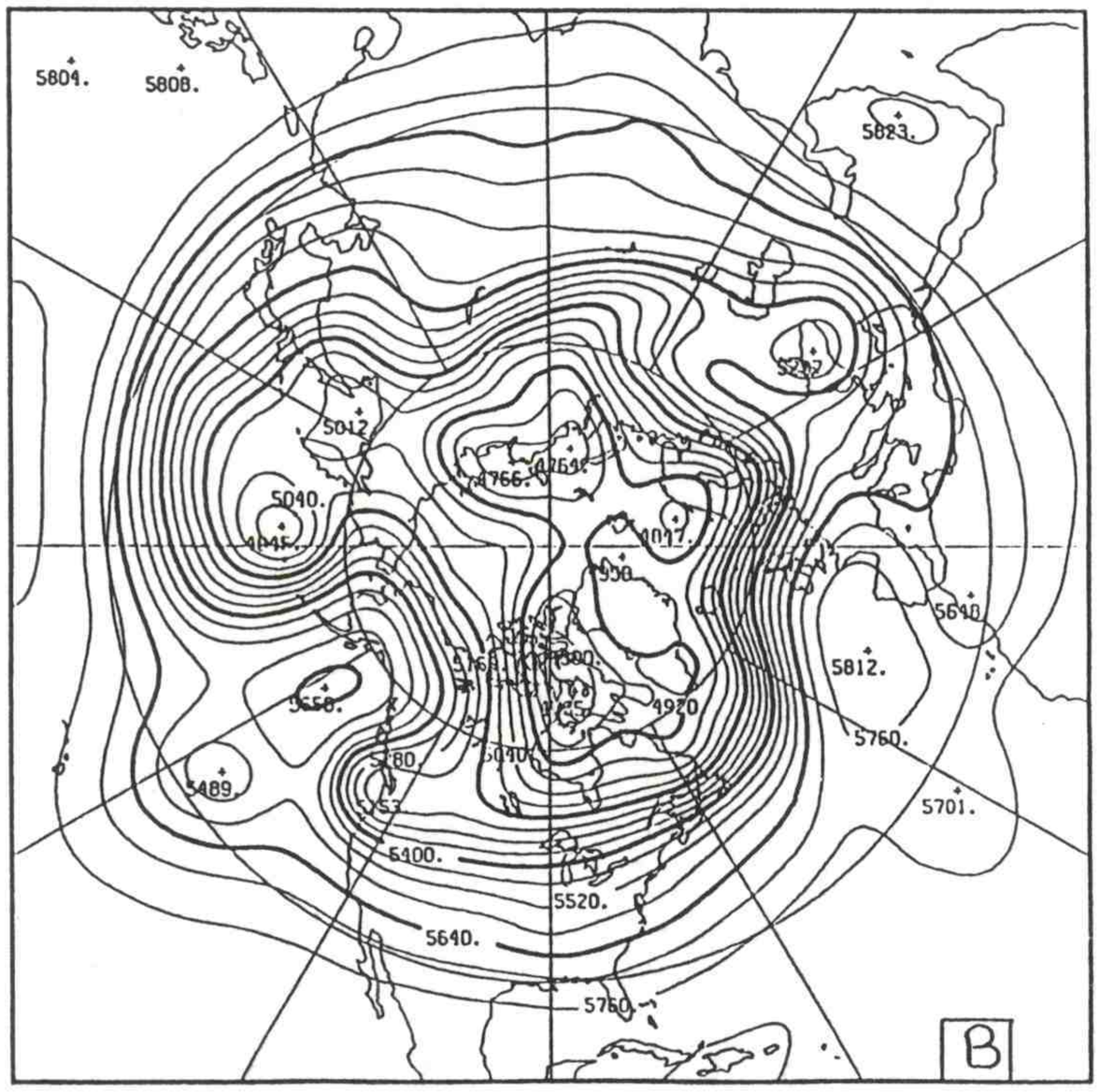


Figure 48: DERF day-18 500mb height from 00Z, 17 January 1989 (A), and corresponding verification (B).

5.2.4 MRF Model Skill Prediction (Chen)

In an effort to increase the capability of predicting forecast skill, an examination is being made of Dynamical Extended Range Forecast Experiments. The goal is to determine if there is any relationship between the skill of medium/extended range forecasts over the Pacific/North America (PNA) region and the fluctuations of the PNA mode of low frequency variability. The relationship between the extent of the PNA mode and predictability of the prediction model was also investigated. The PNA circulation regime in the initial conditions as a predictor of forecast skill is contrasted in detail with that in the forecasts. Statistical significance of the relationships was also examined. The results indicate that the PNA mode extent in the forecasts has a much better capability to sort out in *a priori* the higher-skill forecasts from the lower-skill forecasts, as shown in figure 49.

Furthermore, the performance of forecasts for the North Pacific and North Atlantic sectors were evaluated separately, to isolate the effects of El Niño/Southern Oscillation anomalies. A number of distinct features were found. Both dynamical and persistence forecasts had higher skill for the Pacific sector than for the Atlantic sector. In addition, a systematic bias towards a positive PNA circulation pattern was found in forecasts at extended ranges. This explains the fact that the average forecast skill over the Pacific sector at extended ranges appears significantly above zero.

5.2.5 MRF Model Behavior and Predictability (Chen)

In order to increase the understanding of atmospheric predictability, a case study was examined for November 1989. During November 1-11, a strong zonal flow occurred over the North Atlantic, followed by a prominent 30-day long blocked flow. As shown in figure 50, the flow was still zonal on November 9; but with only 3 days of transition, a well established blocking pattern can be seen on November 13. The breakdown of this block was as rapid as its establishment. Figure 51a shows a block over the North Atlantic on December 5-7; then, on December 11-13, this is replaced by strong zonal flow (figure 51b).

The mechanisms of regime transition and maintenance of blocking were diagnosed, using a daily sequence of isentropic potential vorticity (IPV) maps. Prior to block development, the ambient flow field was found to be diffluent and it stretched the embedded disturbances meridionally and compressed them longitudinally. This resulted in a large amount of vorticity and temperature exchanges between low and high latitudes, overturning the normal north-south IPV gradient and establishing the blocking configuration. Prior to any breakdown

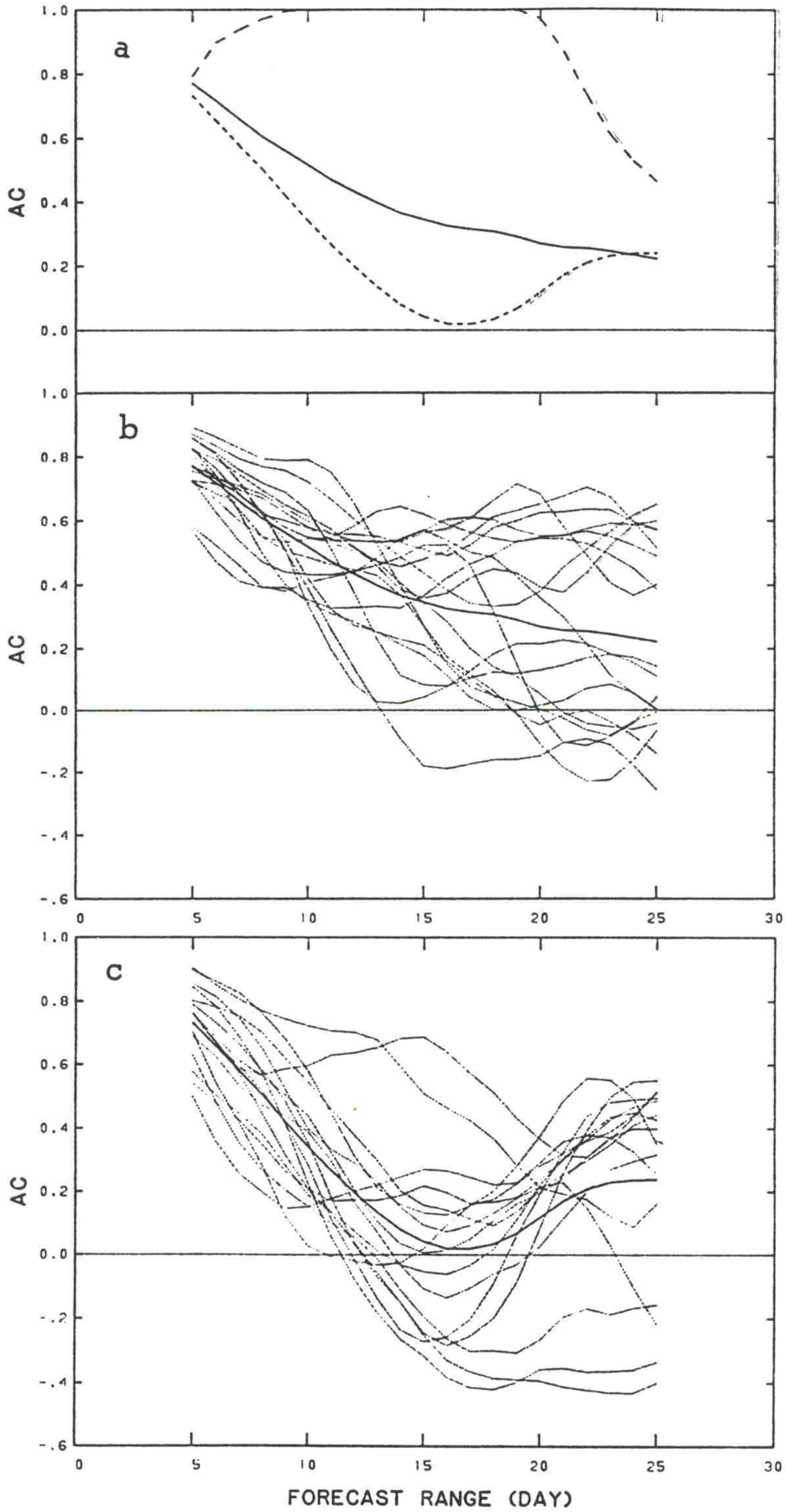


Figure 49: The anomaly correlation skill scores of those forecasts being selected by large 15-day-forecast PNA mode extent (panel b); by small 15-day-forecast PNA mode extent (panel c). Solid curve is the mean of each group. Panel a contrasts those two mean values, where the solid curve is from panel b and the dashed curve from panel c; the broken curve indicates the confidence level of the difference between those two means.

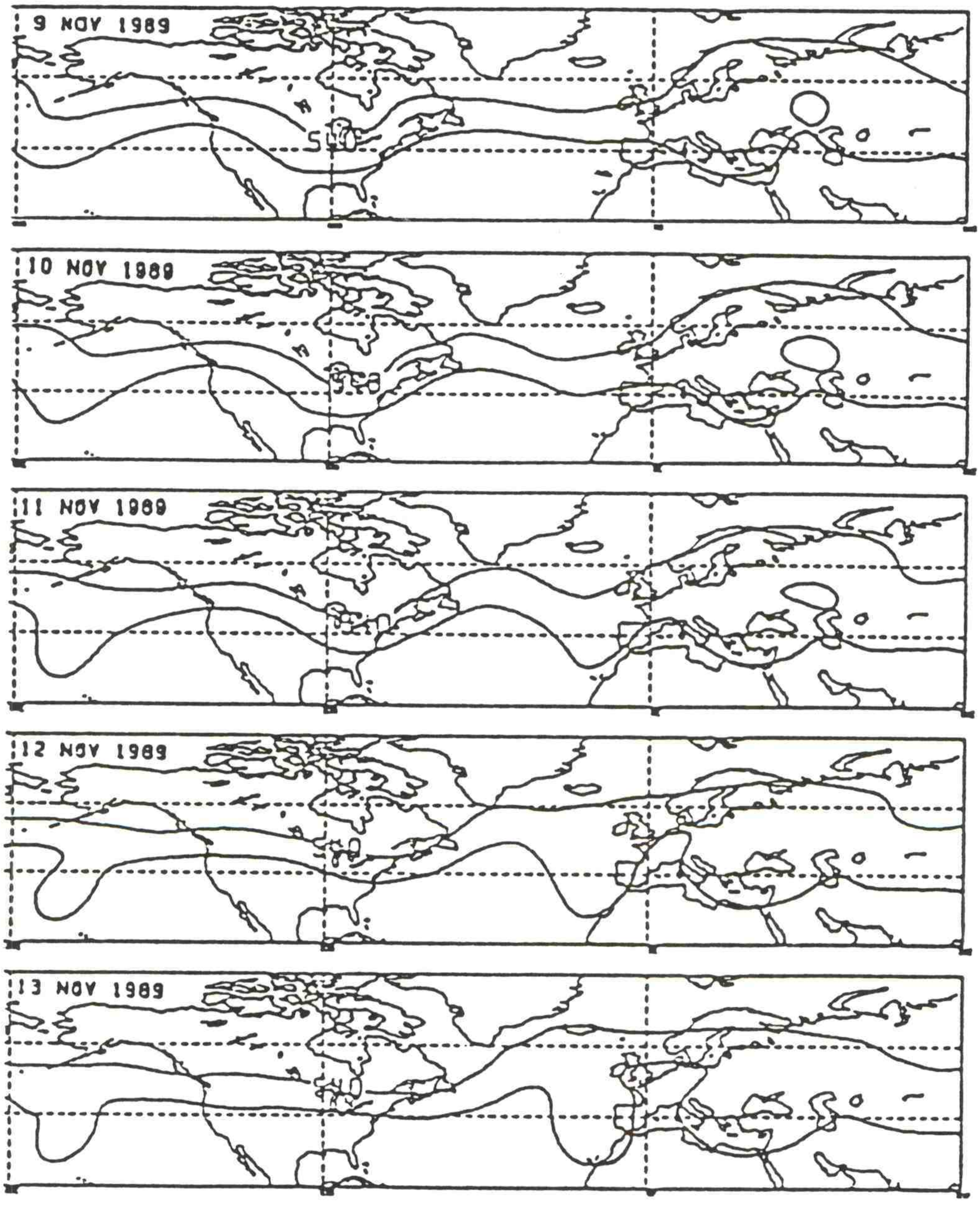


Figure 50: Diagram showing rapid transition from a zonal flow to a blocking flow regime for Nov. 9-13, 1989. The contours are 540 and 570 dam Z at 500mb. A three-day running mean filter has been applied to each contour.

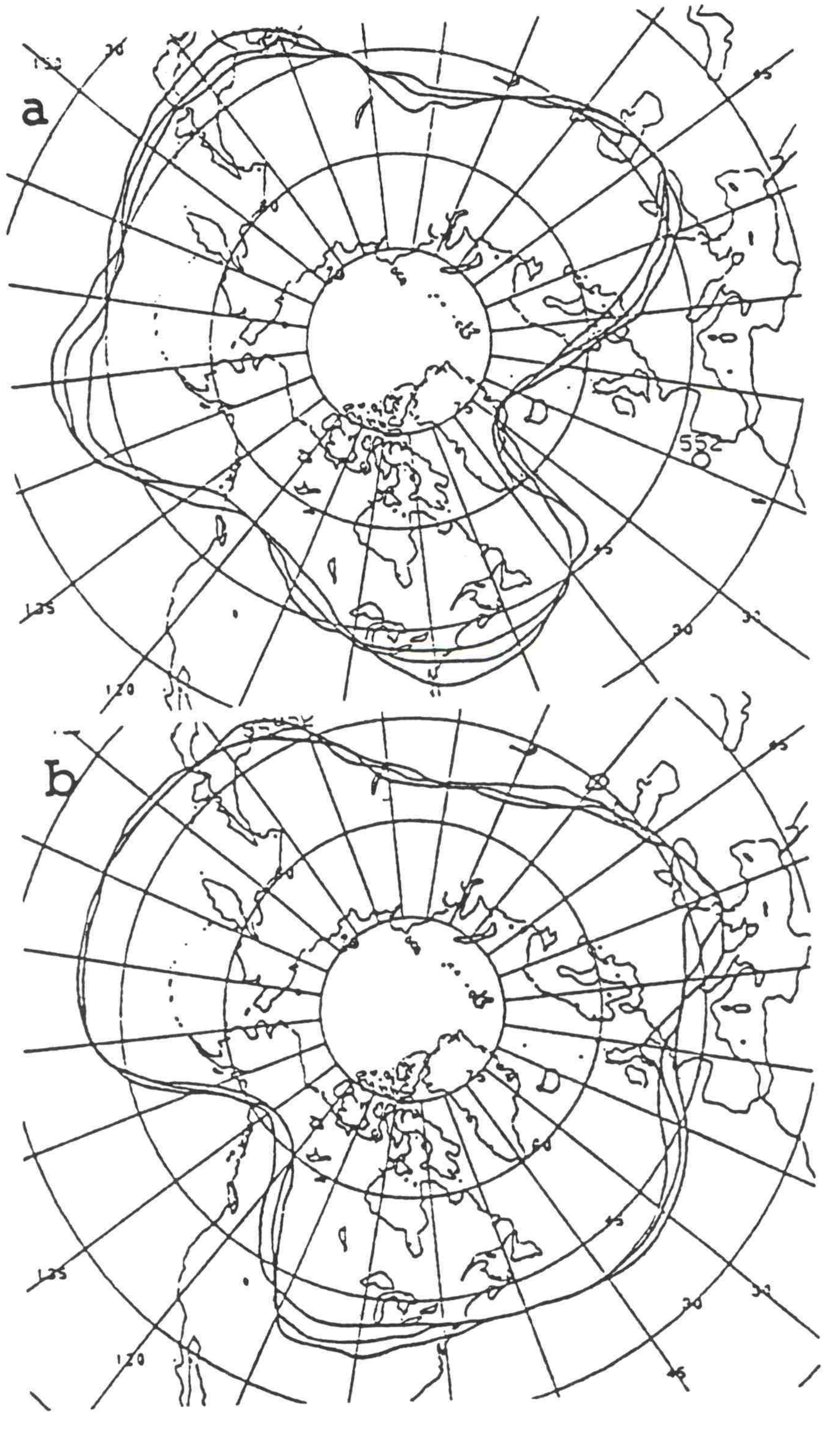


Figure 51: Diagram showing rapid transition from a blocking flow to a strong zonal flow regime over the North Atlantic. Daily 500mb 552 dam Z contours are for Dec. 5-7, 1989 (a) and Dec. 11-13, 1989 (b). A three-day running mean filter has been applied to each contour.

of the block, the diffluence in the ambient flow field diminished dramatically. A depression became longitudinally elongated and pierced through the blocked region with high IPV air, which prevented low IPV air from being swept to the blocked area. Without replenishment of new low IPV air, the previous low IPV air in the blocked area gradually dissipated and subsequently the block disappeared.

5.2.6 Prediction of Persistent Atmospheric States (Anderson)

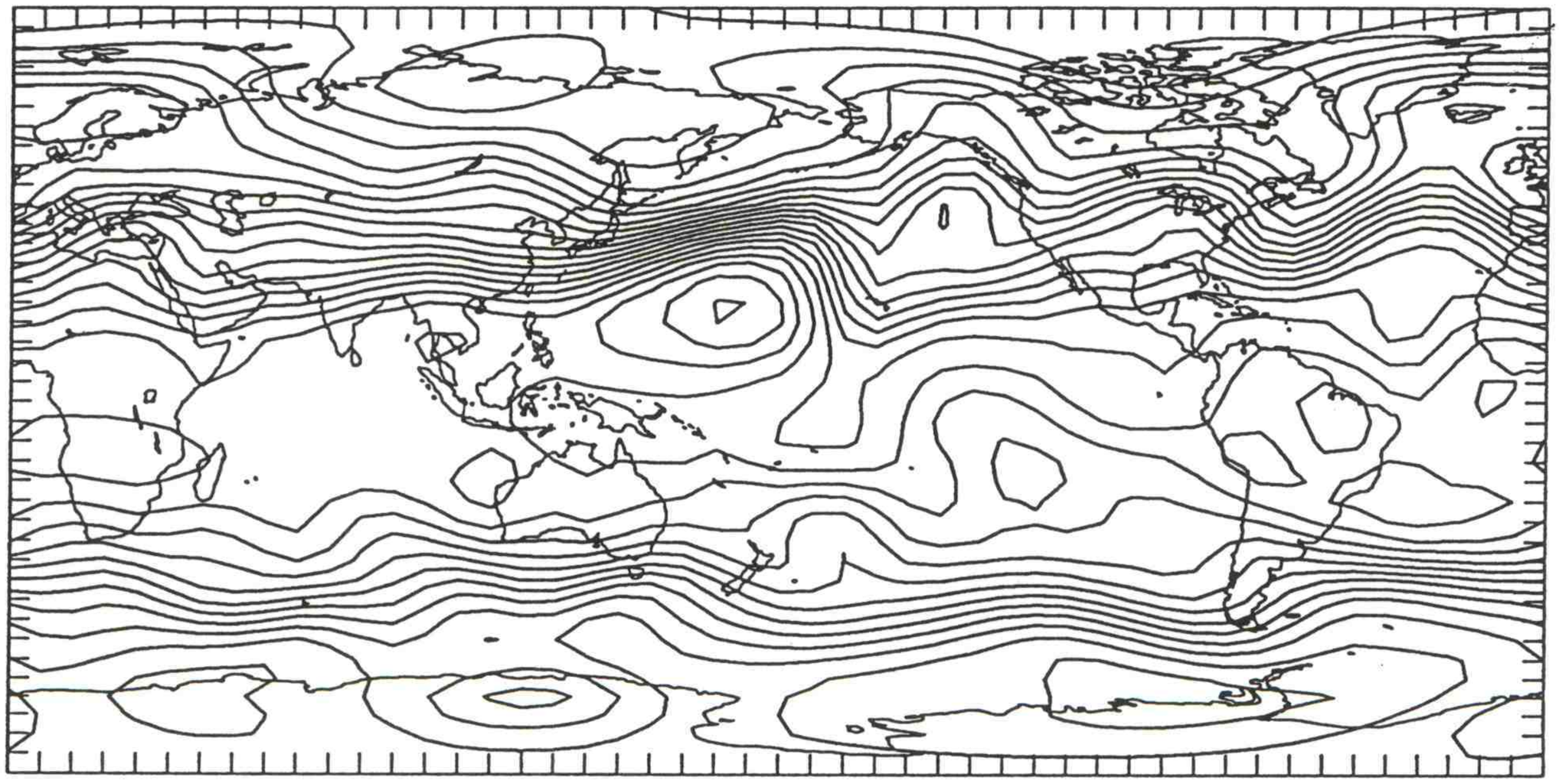
The objective of this study is to develop a dynamical explanation and conduct a diagnostic test for unusual persistent atmospheric patterns. First, a robust algorithm was developed that calculates nearly stationary states of the unforced barotropic vorticity equation that are "close" to an observed global atmospheric stream function distribution. The algorithm was then applied to a number of 300mb Northern Hemisphere winter instantaneous and time averaged flows. In all cases studied, the method is able to converge to a nearly stationary state, one for which a measure of the time tendency has been reduced by several orders of magnitude. When applied to instantaneous flows, the algorithm converges to either relatively zonal or strongly blocked flows, depending on the initial conditions. In almost all cases, observations that have even slight hints of blocking converge to strongly blocked nearly stationary flows.

Figure 52 shows the observed 300mb stream function (for January 14, 1987) and the resulting blocked nearly stationary state. When applied to monthly mean flows, and to apparently unblocked instantaneous flows, the algorithm converges to unblocked, but still wavy, flows. Only the long wave components of the observed state need be retained in the initial condition in order to converge to nearly stationary blocking states. Results of normal mode instability, using the nearly stationary states as basic states, show that even some weakly blocked observed states are in the "attractor basins" of strongly blocked nearly stationary states. This suggests that these stationary states may play some indirect role in the occurrence and persistence of blocking states in the real atmosphere.

5.2.7 Long Series of Extended Range (90-day) Forecasts (van den Dool)

A joint project (with Saha, Kalnay, Kanamitsu/NMC, Development Division) was initiated to study seasonal forecasts/ simulations using a state-of-the-art general circulation model. The model integrated was a T40 version of the global spectral Medium-Range Forecast model that is used operationally (at T80 resolution) at the National Meteorological Center. The model has 18 vertical levels in the sigma coordinate system and all integrations were carried out on the CRAY-YMP8 supercomputer.

a



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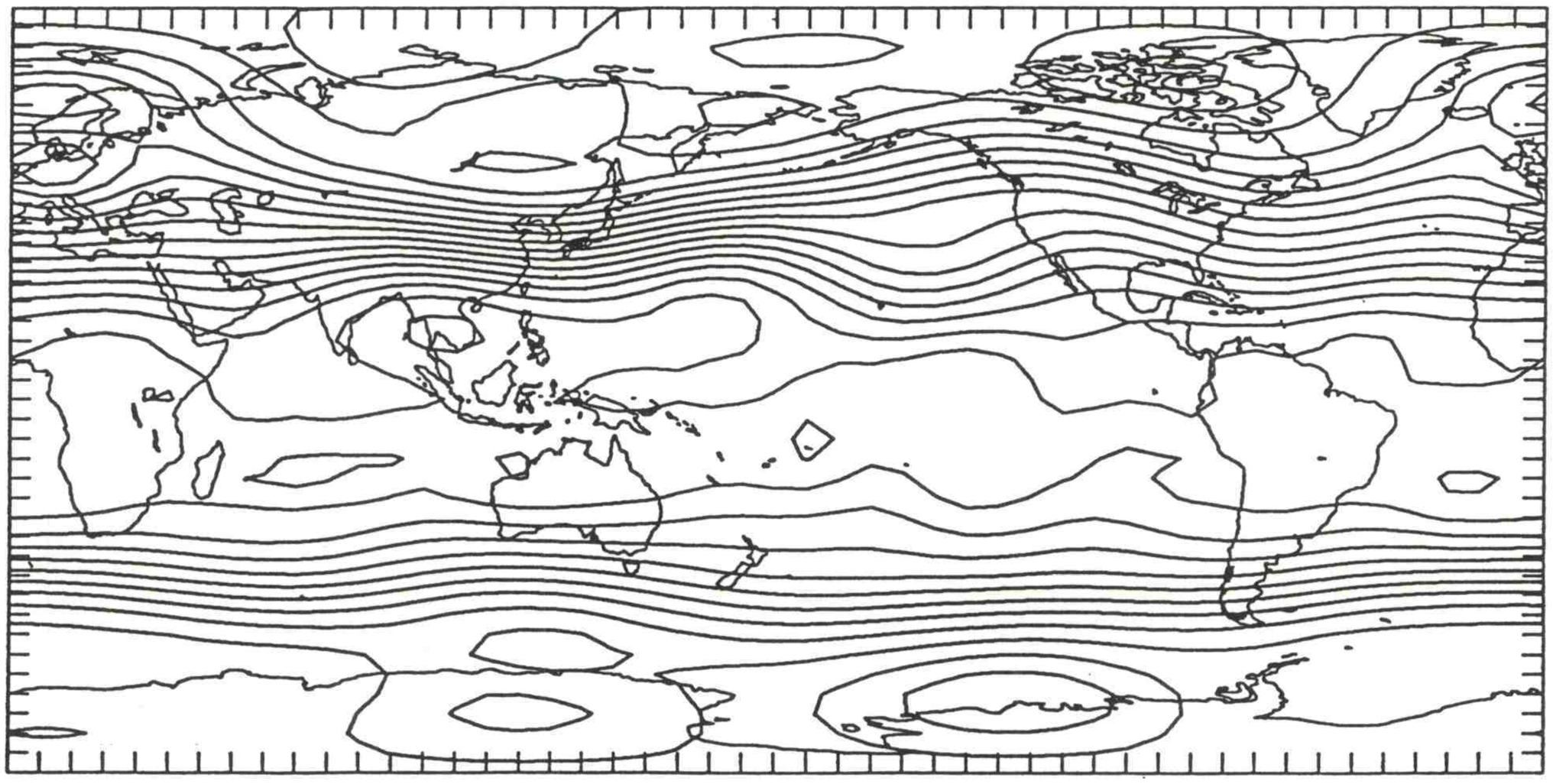

Figure 52: Observed (a) and corresponding nearly stationary (b) streamfunctions for January 14, 1987.

The model was integrated out to 90-days from 128 successive initial states (from May 3, 1990 - October 6, 1990). The first 90-day integration started on May 3 and its 90th day forecast verified on August 1, 1990. Similarly, the last 90-day integration started on October 6 and its 90th day forecast verified on December 6, 1990. In order to complete a Lorenzian data block, forecasts were also run from initial conditions, but with decreasing forecast lead time. For example, the integration from October 7 was run out to 89 days, and that from the October 8 was run out to 88 days, and so on.

The complete output of diagnostic data (reduced form at T21 resolution) for each 90-day integration has been archived. The following fields are now available: A) Surface gridded fields (2.5 x 2.5 latitude/longitude grid) of total rainfall, convective rainfall, surface temperature, soil wetness, snow depth, sensible heating flux, latent heating flux, and U-and V stress flux. B) Spectral files (T21 resolution) of geopotential height, vorticity, divergence virtual temperature (1000-50mb) relative humidity (1000-300 mb) vertical velocity (1000-100 mb) and a surface pressure log. Time series of each of the 74 fields will be archived separately to facilitate fast access from magnetic tape or optical disk. Figure 53 shows the skill of the models for forecast day 1 to 90 averaged over all cases. The anomaly correlation is negligible at day 10 (in the mean), and truly zero at day 20.

5.2.8 Transient Wave Structures in the Atmosphere and In Models (Johansson)

In this study, the DERF/90 data set (90-day forecasts from 128 contiguous daily analyses) was used to analyze: 1) the structure of transient baroclinic waves, and 2) the drift of these quantities from those observed for the atmosphere to those of the model. It was found that the structure of the baroclinic waves undergo rapid changes during the first 5 to 10 days of integration, as shown in figure 54. Thereafter, the structures seem to have reached its statistical equilibrium. The main interest here is that the climate drift in many of the mean quantities occur on a much longer time scale. Thus, it is hypothesized that fundamental problems exists with the model which causes the transient waves to obtain erroneous structures rapidly. These erroneous structures imply erroneous feedbacks to the mean flow and a subsequent equilibration between mean flow and transients that is different from what is observed. Consequently, the transients are seen as a cause of the climate drift in the mean flow quantities.

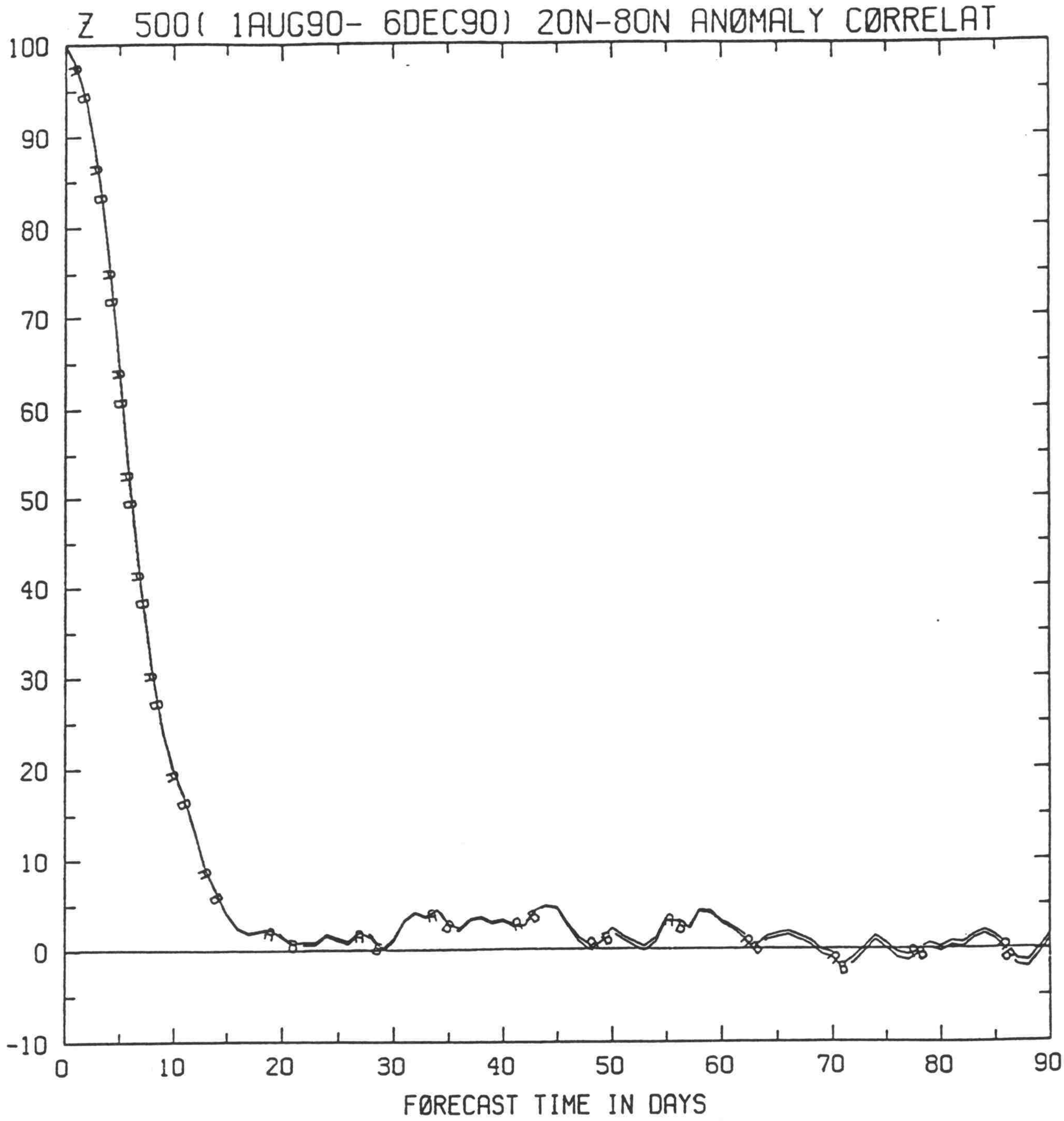

Figure 53: 128 (Aug. 1 -Dec. 6, 1990) ninety-day forecasts. Skill for forecast day 1 to 90 averaged over all cases. (Classic verification!)

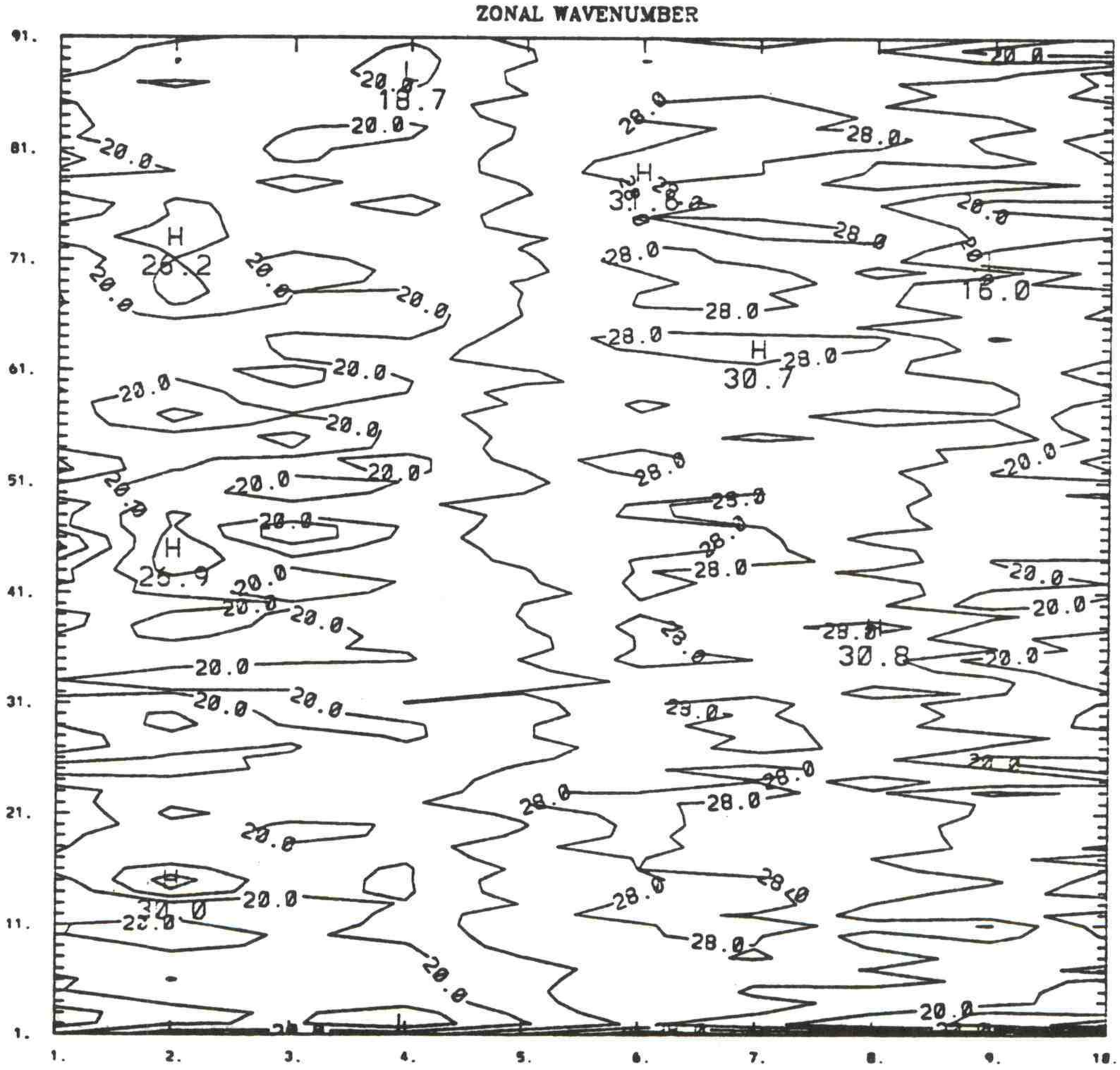

Figure 54: The phase difference between the geopotential height and temperature fields for transient baroclinic waves at 500 hPa in the area between 40S and 63S. The zonal wave number is on the abscissa and forecast lead time in days is on the ordinate. The contour interval is 4.

5.2.9 The Climate in a Multi-Year NMC Model Run (van den Dool)

The purpose of this joint study (Saha, NMC/Development Division) is to establish the climate properties of a state-of-the-art general circulation model. The model integrated was a T40 version of the global spectral Medium-Range Forecast model used operationally (at higher resolution) at NMC. The model has 18 vertical levels in the sigma coordinate system and was integrated for 10 years (3653 days) on the CRAY-YMP8 super computer from initial conditions on July 31, 1991. The lower boundary conditions were as follows: solar radiation, snow depth, soil moisture, sea-ice and sea-surface temperature were updated daily. As far as external conditions were concerned, 10 identical annual cycles were processed; thus, year-to-year variability can be attributed to the model's internal dynamics. Mass was generally well conserved with an increase of only 3 mb in global mean surface pressure over 10 years.

A time series of the global mean surface temperature (00Z) at all 3653 days is shown in figure 55a. One can see 10 annual cycles, the highest values occurring in Northern Hemisphere summer. One can also see a certain amount of interannual variability (note the cold in year 5). In addition, the initial drift is evident, as a drift towards colder values sets in from the initial condition. The climatological annual cycle was studied in the model, based on 10-year mean monthly fields. Figure 55b shows the annual variation of hemispherically averaged 500mb height, i.e., the total heat content below that level. Apart from the cold bias that helps offset the curves, the similarity of the annual variation in both hemispheres is remarkably good.

5.2.10 Systematic Errors in the MRF Model Five-Day Mean 500mb Height Anomaly Predictions (Schechter)

This purpose of this study is to determine the nature of systematic errors in the MRF forecasts of five-day mean 500mb height anomaly centers. The spatial distribution of these anomaly centers is a key tool used to prepare the 6 to 10 and 30-day forecasts. So far, forecasts from the MRF model have been examined for December 1986 - April 1987 and positive and negative anomaly centers were treated separately. Individual anomaly centers that met specified criteria were tracked during each available MRF model forecast cycle on an interactive computer system. Verification of anomaly tracks was achieved using 5-day mean 500 mb height analyses, with statistics on the anomaly track errors stratified by month and season. Efforts are now underway to relate the observed systematic track forecast errors to several indices that reflect characteristics of the 500mb flow regime present in the initial conditions. An effort will also be made to detect any systematic error behavior during blocking episodes.

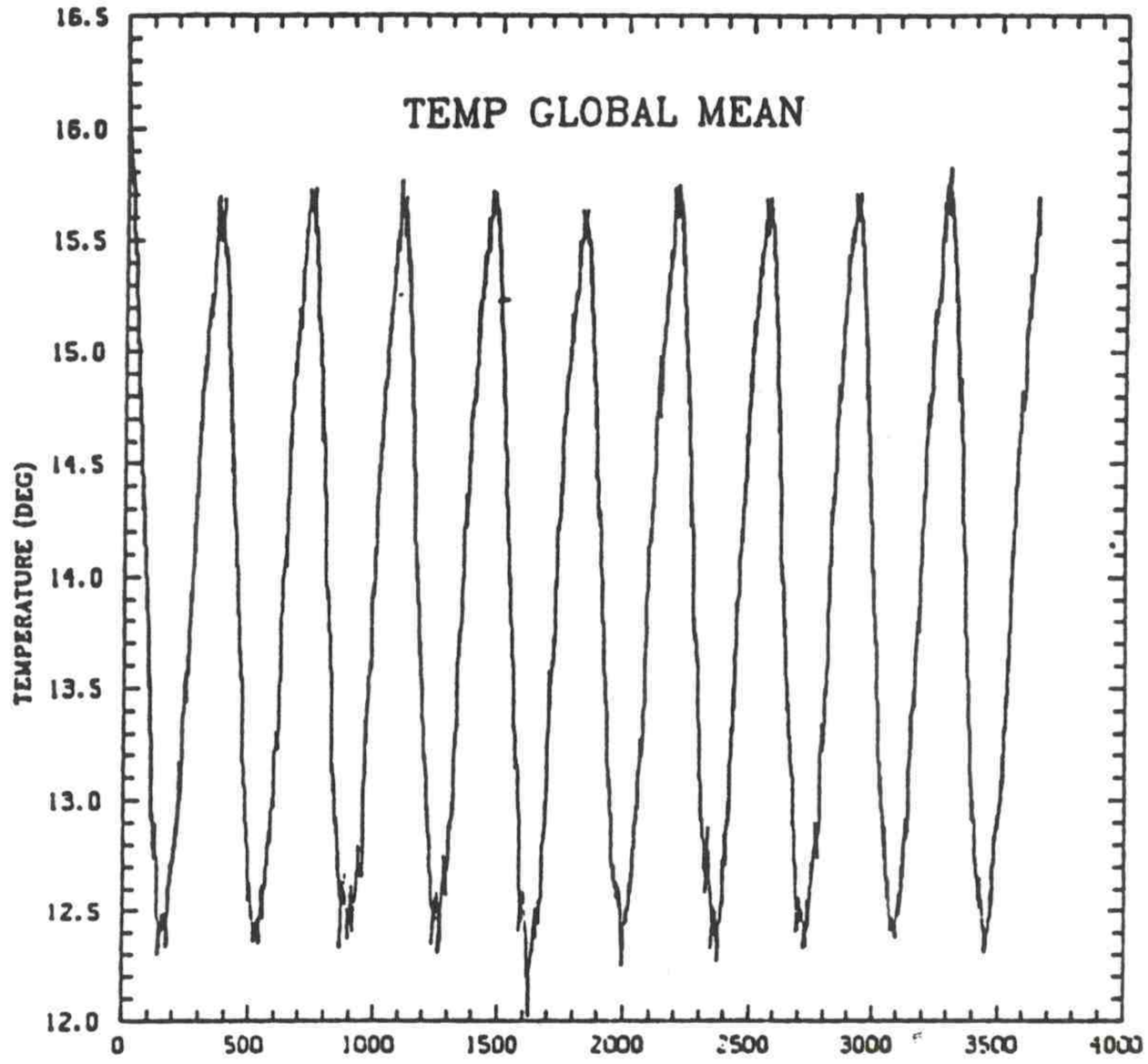

Figure 55a: Time series of global mean surface temperature (00Z) for 3653 days.

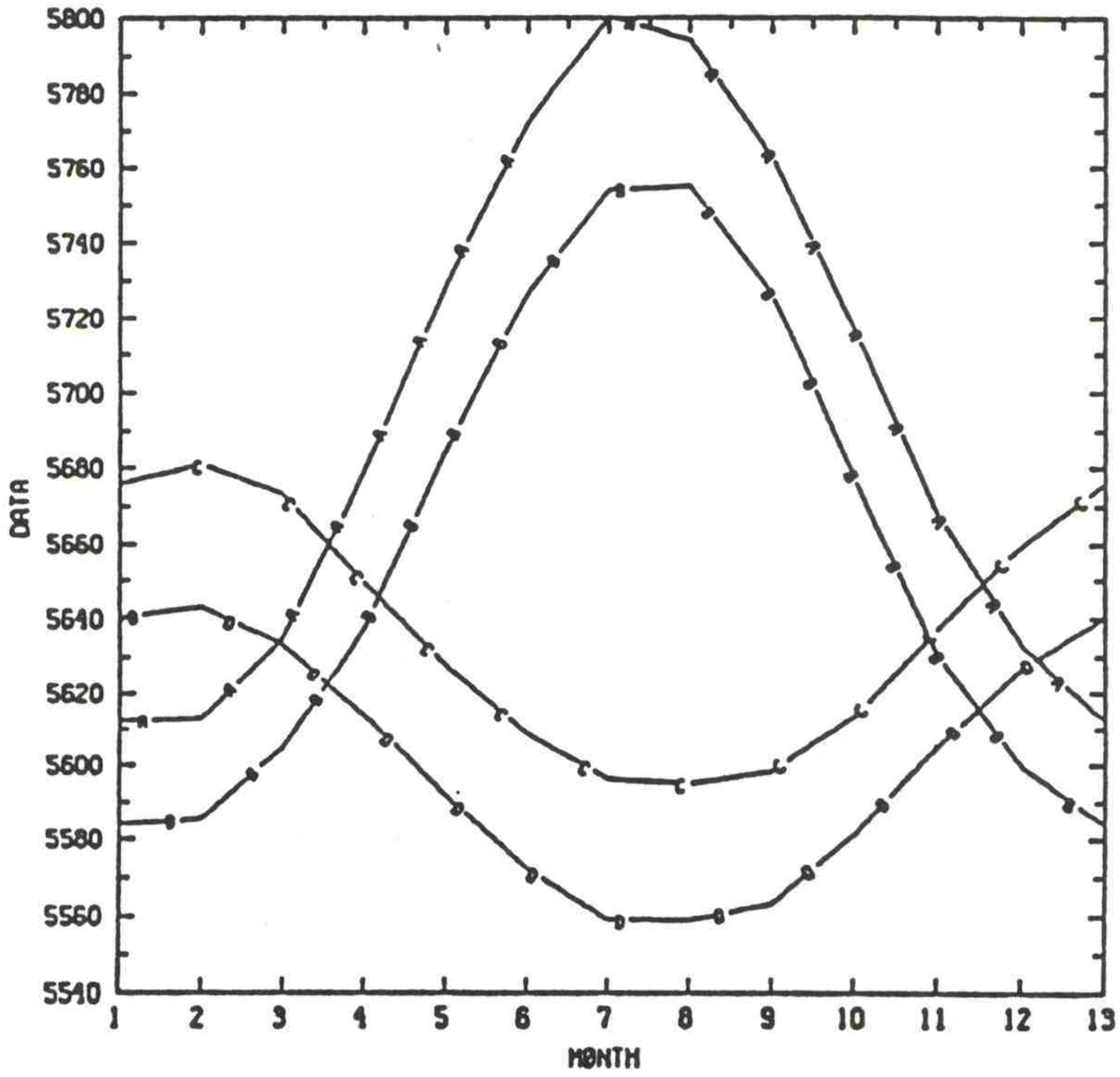

Figure 55b: The annual cycle in hemispherically -averaged height based on a 10 year climatology. Units are gpm. Observed NH (A), Model NH (B), Observed SH (C), and Model SH (D).

5.3 Evaluation

5.3.1 Operational Outlooks (Livezey, Hoopingarner)

A program of modernization and automation of forecast operations has led to the creation of accessible digital files of monthly and seasonal forecasts. These include: forecasts of monthly U.S. temperature and precipitation categories (in three classes); hemispheric 700mb height anomalies (produced 24 times a year since 1974); seasonal U.S. temperature and precipitation categories (produced 4 times a year from 1958-1981, and 12 times a year thereafter). Probability forecasts for Alaska/Canada and mid- and high-latitude Eurasia are available since 1987. These data form the basis for a detailed documentation of the variability over time, and by season, location, parameter, and class of the skill of U.S. monthly and seasonal prediction practices. Ideally the information generated will not only prove useful for management of forecast operations and for the forecasters themselves, but also to potential users as part of their particular decision-making process.

For categorical forecasts a skill score that measures the percent of hits above that expected from random forecasts is most heavily employed, while for probability forecasts the rank probability score is used. Time series of map skills, including dependency of skill on season, maps of local skills, and summary contingency tables have been produced for all surface forecasts and have been examined for meaningful variability. An example of such variability is depicted in figure 56, which shows the difference in skill between official U.S. monthly mean temperature forecasts and forecasts of persistence. The large change in this difference between the 1970's and 1980's can be partially attributed to improvements in global numerical weather prediction and has been completely a consequence of cold season forecasts.

In the case of 700mb height forecasts, skill was examined by the use of a score based on the percent of reduction in mean square error compared to climatology forecasts and a decomposition of this score into terms representing phase, amplitude, bias, and climatology errors. The results of such an analysis, so far, have exhibited a variety of interesting features. They include: a trend in increasing skills from a reduction in phase errors (mainly from cold season forecasts); initially weak amplitude errors as a result of extremely conservative forecasts, with a recent upsurge in these errors because of overly bold forecasts; and a moderately high level of bias error without a break over the last several years (mostly in the Spring and Fall), because of a trend toward a warmer lower troposphere. These analyses are being augmented by several approaches for examining the regional variability of the various sources of error.

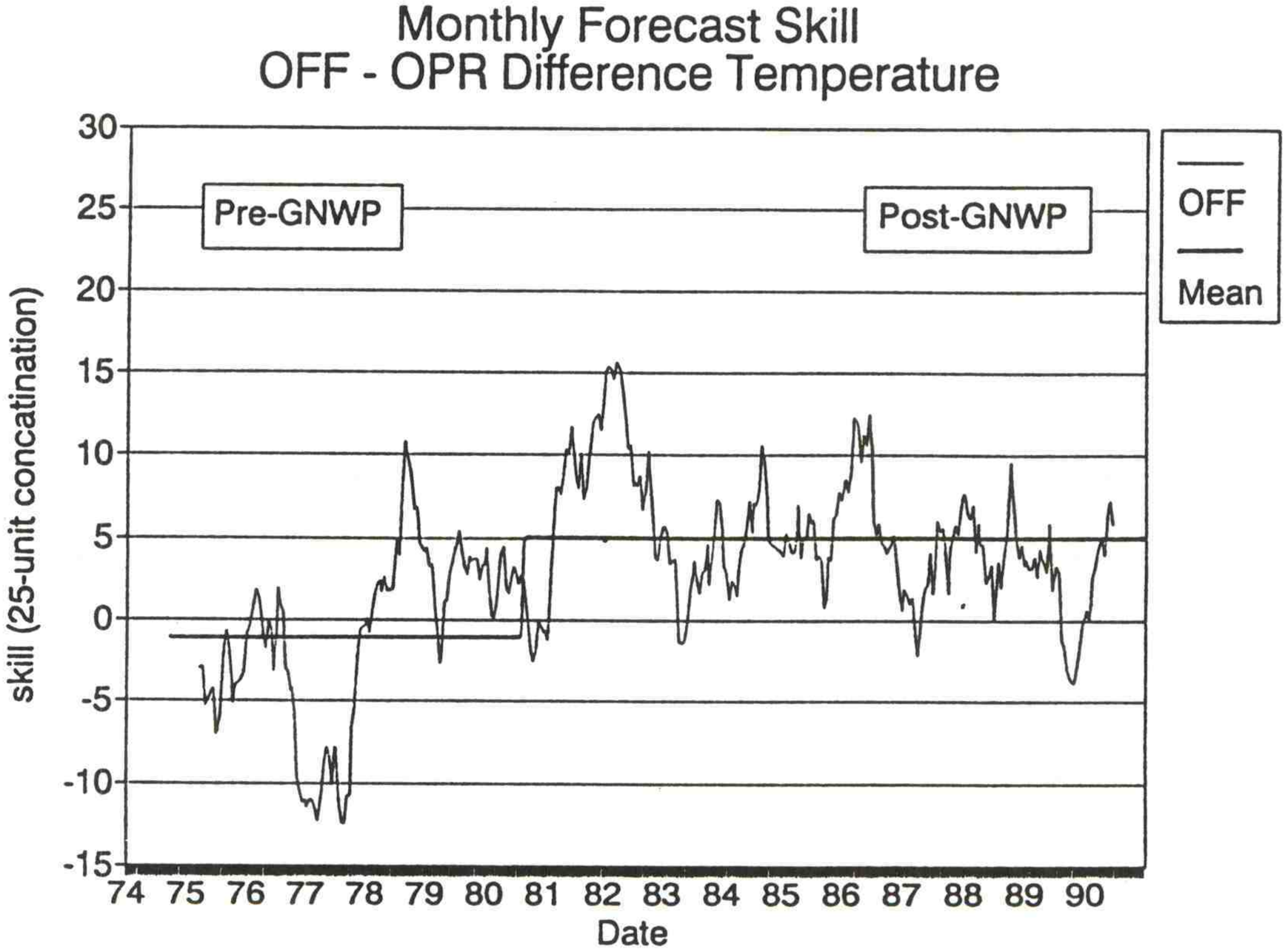

Figure 56: Skill differences for monthly mean U.S. surface temperature forecasts.

5.4 Operational Products

5.4.1 Six-to-Ten Day Forecasts (Hughes)

The skill of the operational 6-10 day U.S. temperature and precipitation forecasts (as measured by the Heidke Skill score) were above the long-term average (1979/80 - 1989/90) for each season, except Winter for the former (figure 57), and Fall for the latter (figure 58). Also, the skill of the 500mb prog for North America (as measured by the normalized correlation score) was above the long term average for each season (see figure 59).

5.4.2 Monthly Outlook (O'Lenic)

The monthly temperature forecasts were most skillful during the spring and summer of 1991. Unlike the seasonal forecasts, the monthly forecasts captured, fairly well, the unusual warmth that characterized both seasons. One outstanding forecast (by S. Tracton), had a skill score of 78, a new record for monthly forecasts. (Most of the other forecasts during that period had skills in the 15-20 range.) This forecast is particularly interesting, since it strongly opposed persistence. Forecast skill for the months of April, May, and June 1991 were in the 20-30 range.

5.4.3 Seasonal Outlook (O'Lenic)

The seasonal temperature forecasts for the U.S. had their highest skill during Fall 1990 and Summer 1991. Skill was also higher, in almost all seasons, for the eastern third of the country than for the central and western portions. This was likely due to an unusually persistent warm period which spanned virtually the entire year. This persistent pattern resulted in a preponderance of above normal observed seasonal temperatures at stations where seasonal forecasts are verified. In the long run, of course, there is a more equitable distribution of observed temperature categories at a given station.

Under the conditions observed during the last year, a statistically-based forecast technique suffers, since it will tend to generate an equitable distribution of above and below normal categories. The upswing in skill scores during Summer 1991 indicates that the forecasters had caught on to the trend in temperature and were relying more on persistence.

5.4.4 Modernization of Forecast Operations (O'Lenic)

A number of tasks were performed in regard to the modernization and security of CAC's 6-10 day forecast operation. The first step was to install an Intergraph workstation, which was achieved with teamwork between CAC and NMC/Automation

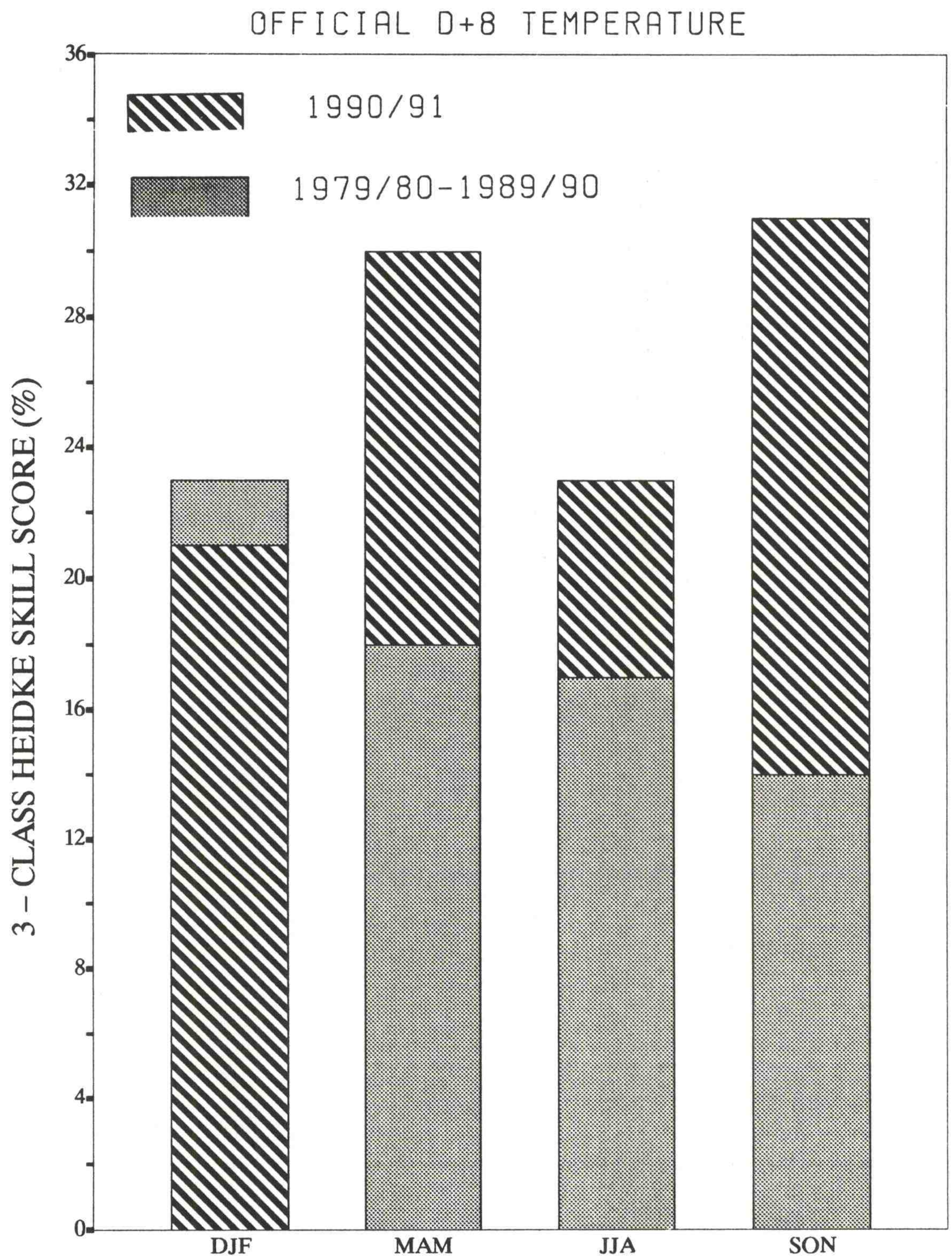

Figure 57: Average Heidke skill score for 63 U.S. stations from CAC's 6-10 day temperature forecasts. The hatched bar graph shows the skill for each season for the latest year. The solid bar graph shows the average skill for the years 1979/80 - 1989/90.

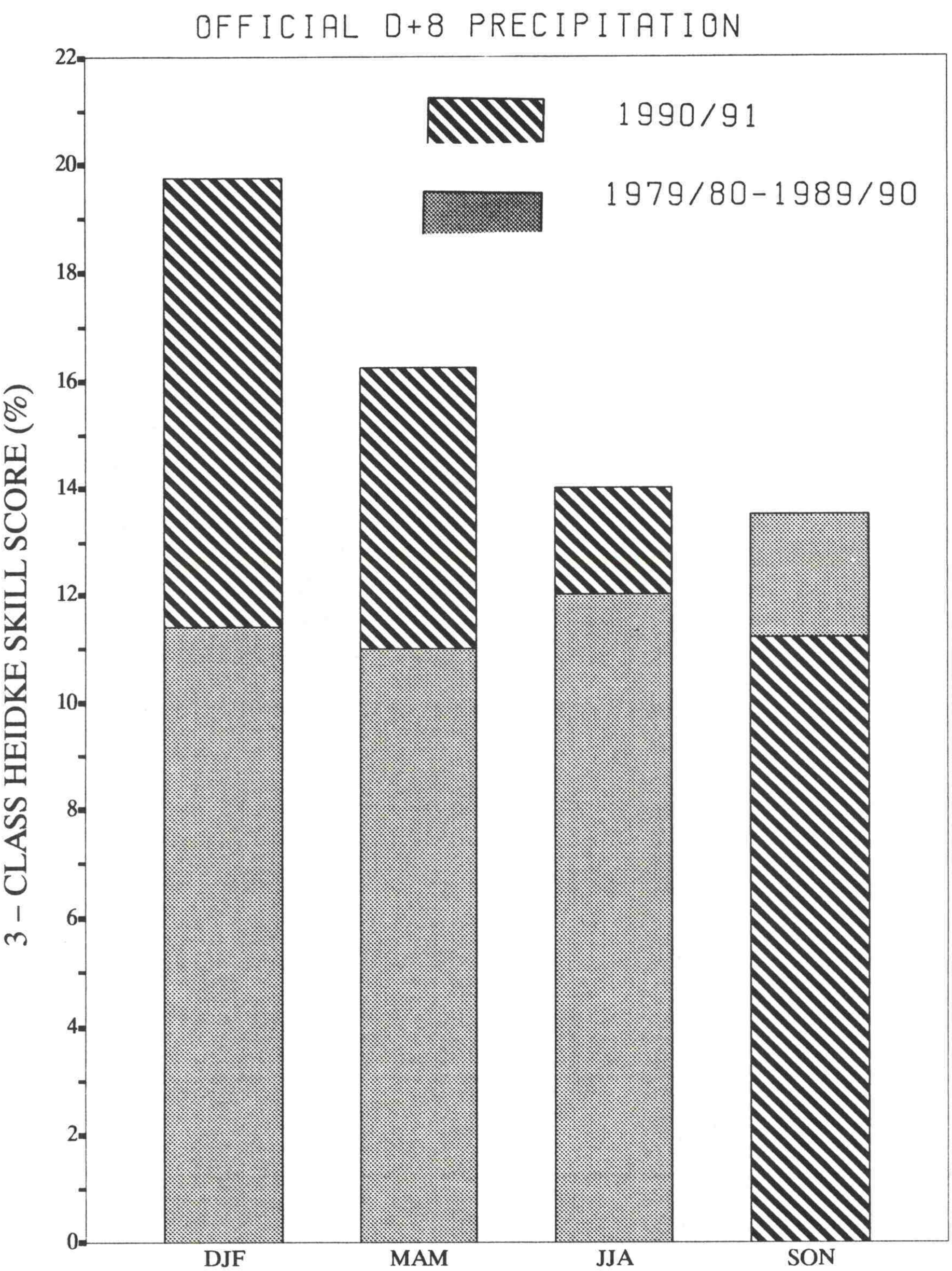

Figure 58: Average Heidke skill score for 100 U.S. stations from CAC's 6-10 day precipitation forecasts. The hatched bar graph shows the skill for each season for the latest year. The solid bar graph shows the average skill for the years 1979/80 - 1989/90.

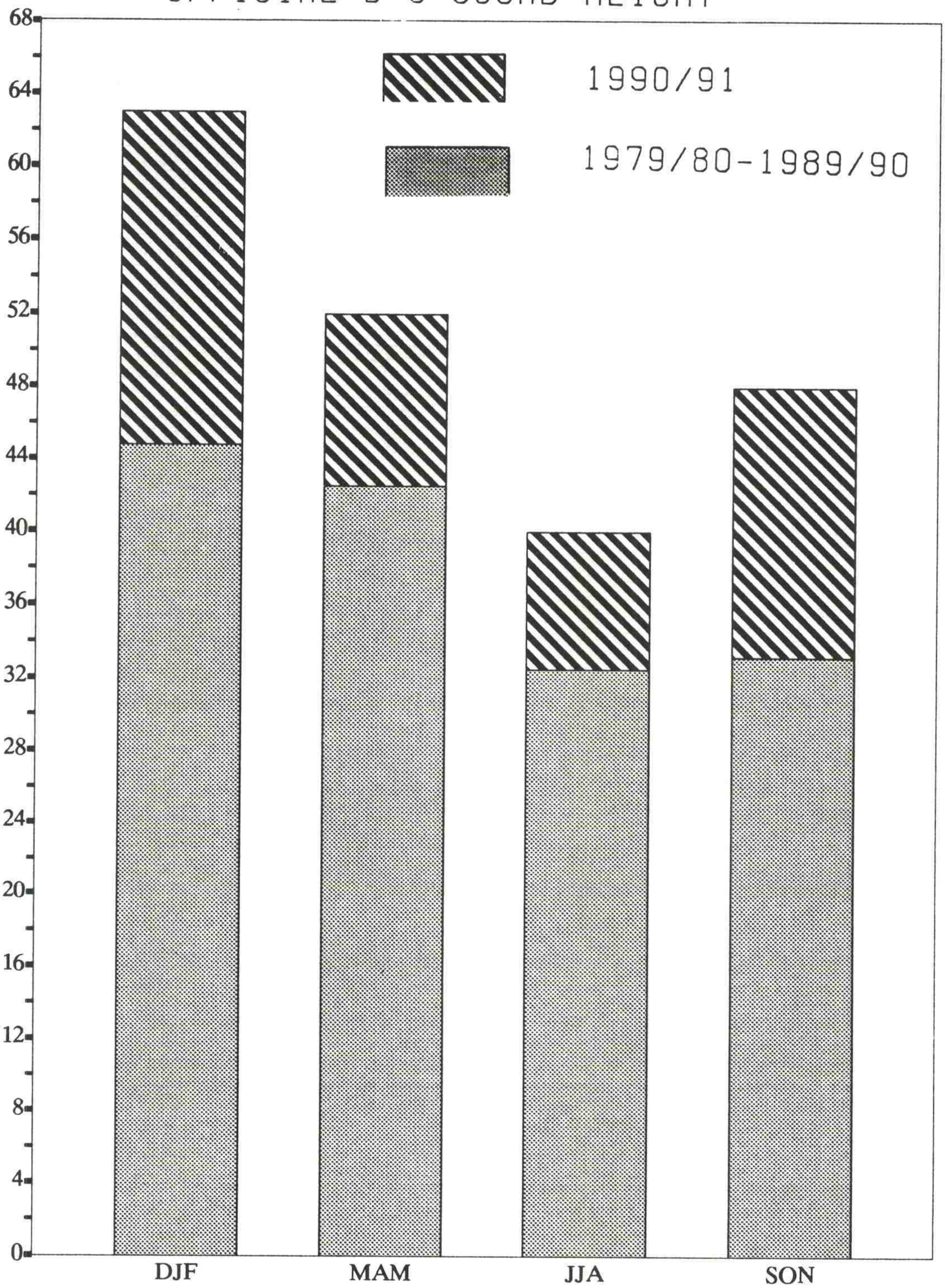

Figure 59: Average normalized correlation score for 130 NMC grid points over NOAM and vicinity from CAC's 6-10 day 500 mb height progs. The hatched bar graph shows the skill for each season for the latest year. The solid bar graph shows the average skill for the years 1979/80 - 1989/90.

Division. Techniques had to be developed and implemented which incorporated the workstation into the heart of the forecast process. The workstation is not only used in the development and dissemination of 6-10 forecast products, but is the key to their secure storage during an embargo prior to dissemination.

Also, physical and automated controls were developed and implemented in a short time span to protect sensitive forecast products and tools from being accessed by unauthorized persons. The physical controls include actions to be employed by forecasters and modifications to workspaces. The automated controls run the gamut of NMC hardware and software. In addition, a paradigm for forecast security was developed which should facilitate the evaluation of security requirements in a wide array of settings. Finally, a plan has been developed that will gradually shift forecast operations from one which is heavily dependent upon printed maps, to one in which forecast materials are created, stored, and viewed on a workstation.

5.4.5 A Circulation-Based Check on U.S. Temperature Trends
(van den Dool, O'Lenic)

A perfect prog technique for computing surface temperatures from observed monthly mean 700mb height anomalies (developed by W. Klein/University of Maryland) has been used as a 30-day forecast tool for many years. For several years now, this product has produced temperatures with quite a noticeable cold bias over much of the United States (figure 60). If some, as yet unspecified, process were progressively warming the climate, it would, given a stable vertical temperature stratification, manifest itself first in warmer surface temperatures. Under unstable temperatures stratification, this initial warm temperature anomaly would be rapidly dispersed throughout the troposphere, through the actions of convection and large-scale atmospheric motions. If indeed the warming is confined to the lower troposphere, it would have little effect upon large-scale, middle-tropospheric circulation regimes for some time. If this is true, then a given circulation regime will tend to be associated with warmer surface temperatures during the later, warmer period than in earlier years.

The above scenario is just what the cold-bias of the perfect prog surface temperatures seems to indicate. To investigate this hypothesis, a time series of perfect prog surface temperatures over the U.S. was computed for 1951-91 and compared with observed temperatures during the same period. Since the perfect prog equations were developed from 1948-81 data, the temperature residuals (perfect prog minus observed) are expected to be fairly small during the 1950-81 period. However, if the later years of the 1980's have experienced a warming, a cold bias, growing as the 1980's progress, should characterize the time series of the residuals. As shown in figure 61, this is exactly what appears to be happening. This time series will now be extended in time and expanded in area.

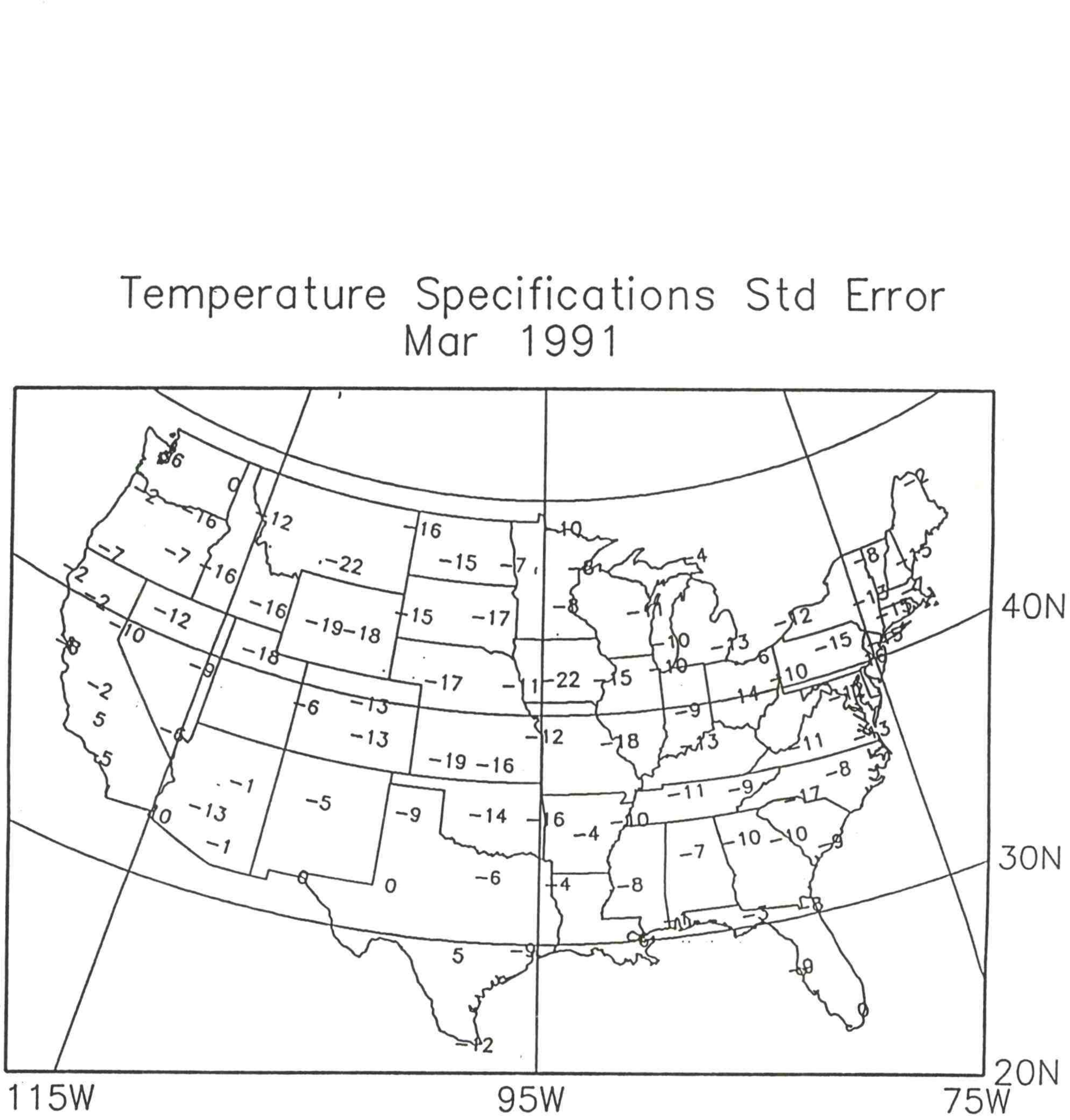

Figure 60: Standard error of surface temperature specifications from perfect prog technique for March 1991.

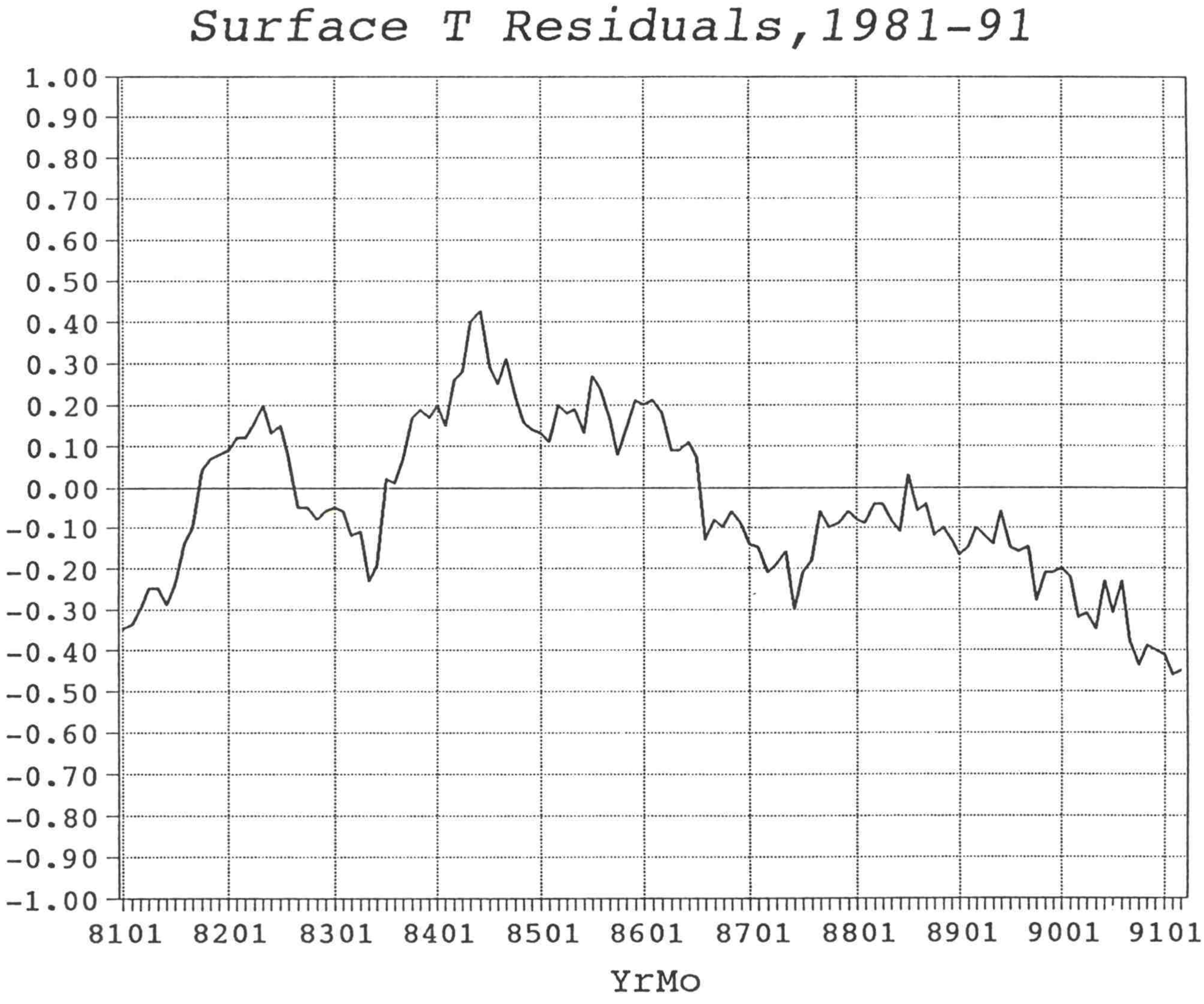

Figure 61: Surface temperature residuals (perfect prog minus observed) for 1981-1991 period. Temperature is ^{o}C. (Data are plotted at monthly intervals.)

5.5 Supporting Projects

5.5.1 Anomaly History and Teleconnections (Wagner)

Maps of monthly and seasonal U. S. temperature and precipitation anomalies were produced from the CAMS data set, for years prior to 1947 when 700mb data were either unavailable or unreliable. Even without accompanying 700mb height and anomaly maps, the temperature and precipitation patterns are useful for selecting specification analogs for monthly and seasonal precipitation forecasts based on the predicted temperature pattern. Thus far, maps have been completed for the months May through November back to 1915, and for the seasons May-July through October-December back to 1901.

Maps from the CAMS data set display large-scale patterns that are basically similar to older analyses during the 1930's and 1940's. However, noticeable differences occur when the patterns are relatively flat with extensive areas in the near normal or moderate category. Differences also show up in the southwestern U.S. where recent climate trends, due to urban warming at several fast-growing cities, have induced an artificial cold bias in the earlier part of the temperature record. This is due to the fact that the values are referenced to 1951-80 normals used in the CAMS data set.

5.5.2 Long-Lead Seasonal Forecasts (Wagner)

Ten years of quasi-real-time, experimental, long-lead forecasts of U.S. temperature were completed and verified for the four meteorological seasons. The three-class Heidke skill scores (table 3) show that there is useful forecast information available at long lead times, particularly for the spring and summer seasons. The columns labeled "Forecast" give scores for subjectively made forecasts, using both lag correlations of 700 mb height and persistence of surface temperature anomaly for all seasons up to and including that lead time. The columns labeled "Persistence" used only the surface temperature anomaly pattern for that particular season.

The skill significance was determined by use of a Monte Carlo distribution of skill scores obtained by cross-matching the available seasonal forecasts with all observed temperature patterns through 1983. The upper skill significance indicator includes artificial skill due to biases and climate trends at certain stations, particularly in the southwestern U.S., whereas the lower indicator estimates the true significance without the artificial skill. It is evident that most of the skill is robust enough to hold up even without the help of artificial skill.

10-YEAR AVERAGE THREE-CLASS HEIDKE SKILL SCORES OF EXPERIMENTAL LONG-LEAD SEASONAL TEMPERATURE FORECASTS									
SEASON	10-YEAR CLIMATOLOGY	2-YEAR PERSISTENCE	2-YEAR LEAD FORECAST	1-YEAR PERSISTENCE	1-YEAR LEAD FORECAST	3-SEASON PERSISTENCE	3-SEAS LEAD FORECAST	2-SEASON PERSISTENCE	2-SEAS LEAD FORECAST
SUMMER	13.6 *	3.7	10.2	16.9 **	12.5	10.3	14.6 *	18.7 **	18.6 **
FALL	7.0	5.9	8.6	11.7	16.4 **	12.6 *	12.9 *	7.2	6.1
WINTER	3.5	11.1	5.6	4.8	17.1	7.4	8.5	3.3	8.6
SPRING	19.1 ***	6.1	7.7	24.8 ***	12.6 *	11.8 *	17.2 **	7.9	14.0 *

* Skill significant at 95% level ** Skill significant at 99% level *** Skill significant at 99.9% level

Table 3: Ten - year average three-class Heidke skill scores of experimental long-lead seasonal temperature forecasts.

6. SUMMARIES

6.1 Climate and Global Change Program (Rodenhuis, Ropelewski, van den Dool, Livezey, Mo, Janowiak, Miller)

The primary focus of Climate and Global Change activities at the CAC is on climate diagnostics, climate monitoring, and climate trends. The accomplishments for related tasks are described in preceding sections of this report. They include: Sections 1.2.3; 2.1.1, 2.1.2, 2.1.3, 2.1.4, 2.2.1, 2.2.2; 3.2.1, 3.2.2; and 4.5.2.

CAC is a participant in a number of FY 1991 Tier I Projects under the NOAA Climate and Global Change Program. These include: Stratospheric Monitoring and Data Management (with ERL), Vegetation Index (with NESDIS), Climate Data Assimilation System (with NMC), Global Climate Perspectives (with NESDIS), Global Precipitation Climatology Project (with WMO/WCRP), and DERF (with ERL, GFDL, and NMC).

In addition to the above Projects, CAC staff have either originated or collaborated in a number of new proposals that were submitted to the Office of Climate and Global Change for FY 1992 funding. These include: Empirical Prediction of ENSO Fluctuations, North American Land Surface/Atmospheric Hydrologic Cycle, Development, Soil Moisture and Temperature Predictions Over the U.S., Operational Climate Satellite Data Base, Objective Extratropical Empirical Prediction on Seasonal Time Scales, and CD-ROM Center for Climate Applications.

6.2 TOGA Activities (Diagnostics Branch staff)

The primary focus of TOGA activities at the CAC is on operational monitoring of the ENSO and oceanic-atmospheric fluctuations. The accomplishments for related tasks are described in preceding sections of this report. They include: Sections 1.1.1, 1.2.4.1; 2.1.5, 2.3.1, 2.3.2, 2.3.3; and 2.4.1.

CAC staff (Ropelewski) attended and participated in a TOGA ENSO Prediction Workshop, Silver Spring MD, Dec. 12-13, 1990. Also, Ropelewski attended a TOGA Panel Meeting (Jan. 23, 1991) and presented a briefing on the current state of the Southern Oscillation.

6.3 EPOCS Activities (Diagnostics Branch staff)

The primary focus of EPOCS activities at the CAC is on diagnostic studies of the tropical oceanic-atmospheric circulation. The accomplishments for related tasks are described in preceding sections of this report. They include: Sections 1.2.1, 1.2.2; and 2.1.5.

Proposals that were approved by the EPOCS Program Office for support in FY 1991 included: Associated Global Circulation Changes" (Ropelewski and Chelliah, P.I.'s); and "Atmospheric Teleconnection Dynamics During the 1986-90 ENSO Cycle" (Mo and Rasmusson, P.I's). An EPOCS proposal, entitled "Diagnostics Studies of the Coupled Ocean-Atmosphere System," (Ropelewski, Chelliah, and Smith, P.I.'s) was submitted for FY 92 funding.

An EPOCS Panel Meeting (held in Miami, FL, January 21-24, 1991) was attended by Ropelewski, who accepted an invitation to join the EPOCS Advisory Council.

6.4 Bilateral Activities

6.4.1 U.S.-Brazil Bilateral Agreement (Kousky)

Under the auspices of the U.S. - Brazil Bilateral Agreement for Science and Technology, Ms. C. Ferreira, from the Ceara Foundation of Meteorology and Water Resources, completed her 4-month stay at NMC's South American Desk in June; Dr. M. Kayano, from the Brazilian National Institute of Space research, visited the CAC from January - May; J. C. Figueiredo, from the Institute of Meteorological Research in Brazil, began a three month visit to the South American Desk in August 1991. These visiting scientists participate in the preparation of numerical forecast discussions, which are disseminated on the Global Telecommunications System (GTS) to all South American countries, and in forecast evaluation studies.

At the beginning of each month a description is prepared (by Kousky) concerning the current climate anomalies in the tropical Pacific and disseminated via the GTS to South American countries.

Under the bilateral agreement, Kousky participated, as rapporteur, in a Workshop on the Relationship of the Atlantic to Regional and Global Climate Variations. This Workshop was held in Fortaleza, Brazil, October 1-5, 1990.

6.4.2 U.S. - Soviet Bilateral Agreement (Rodenhuis, Barnston, Livezey, Ropelewski)

Under the activities of Working Group 8 of the U.S. - Soviet bilateral agreement, there was a successful outcome of a joint project/exchange between the USSR Hydrometeorological Center and the CAC. Preparatory work (A. Barnston) took place in Moscow in 1990 to conduct experiments that would compare analog prediction technologies developed at the respective centers. This work culminated in the completion of several of these experiments at CAC (R. Livezey) during the working visit of Professors G. V. Gruza and E. Ya. Rankova (Institute for Global Climate and Ecology, Moscow, USSR) during early 1991.

Three Soviet scientists attended the 15th Annual Climate Diagnostics Workshop, held in Asheville, NC, October 28 - November 1, 1990.

The annual planning meeting for Working Group 8 was held (Leningrad, USSR in January 1991) to prepare a plan for scientific exchange in the following year. D. Rodenhuis participated as leader of Project 8.11, Climate Change. Also, preparations were made for the upcoming Workshop on Hydrology and Climate Monitoring (Leningrad, USSR) in October 1991. A presentation is planned (by D. Rodenhuis) on regional climate monitoring and revised plans for the project in the coming year.

Also, efforts were made (C. Ropelewski) to exchange climate anomaly data in near-real-time with the World Data Center B at Obninsk, USSR using the San Francisco/Moscow teleport link.

6.5 World Climate Program Activities

6.5.1 Climate System Monitoring (Kousky, Rodenhuis, Ropelewski)

The CAC provided data, graphics and analysis support for the WMO's third Climate System Monitoring biennial review. Analyses of the significant global surface temperature and precipitation anomalies were also provided by CAC's Analysis and Information Branch. In addition, the CSM Monthly Bulletin (published by the World Climate Program) contains a large amount of CAC products. The CSM/Working Group Meeting (held in Helsinki, Finland, August 1991) was attended by V. Kousky.

CAC staff (Rodenhuis and Ropelewski) participated in planning activities of the WMO Climate Change Detection Project.

6.5.2 Global Precipitation Climatology Project (Janowiak)

There were several activities associated with the Global Precipitation Climatology Project (GPCP), which is supported by the NOAA/Climate and Global Change Initiative. Among these activities were: participation in the GPCP Working Group for Data Management (Laurel, MD , May 1991); participation in, coordination of, and the production and dissemination of results from the GPCP/Algorithm Intercomparison Project I; and a presentation of a comparison between NMC and ECMWF model precipitation forecasts with GPCP rainfall estimates at the "NMC Re-analysis Workshop" (Camp Springs, MD, April 1991).

6.5.3 Global Energy Water Cycle Experiment (GEWEX) (Janowiak, Ropelewski)

A workstation and data have been received at the CAC for "Wetnet" - related studies. J. Janowiak agreed to be a steering committee co-chairperson for the "Precipitation Intercomparison Program". This Program is a WETNET activity that will compare precipitation estimates derived from microwave (SSM/I) data.

A proposal for a joint study (with E. Rasmusson, Univ. of Maryland/CICS) was submitted to the NOAA Office of Climate and Global Change for funding. The purpose of the study is to provide an improved diagnosis of continental-scale atmospheric/surface hydrologic balances over the U.S. and southern Canada, derived from routinely acquired data. This project is designed to fold into the GEWEX/Continental International Program.

6.5.4 Intergovernmental Panel for Climate Change (IPCC) (Ropelewski, Chelliah)

CAC provided a number of parameters as input to the IPCC update report. These include: Outgoing Longwave Radiation data, uncertainties in global estimates of sea surface temperature, and sea ice and snow cover totals.

6.5.5 Commission on Climatology (CCl) (Rodenhuis, Ropelewski)

Although no meetings of the Commission or its Advisory Committee were held, there were ad hoc working group meetings on the Early Detection of Climate Change. As a result of these meetings, recommendations were considered by the WMO Executive Committee. Subsequently, an international Working Group Meeting is planned for October 1991, in Geneva Switzerland. Preparations are being made for the meeting (by Ropelewski).

6.6 National Weather Service Programs

6.6.1 Data Management (Rodenhuis)

CAC staff (Ropelewski) participated on the NMC Committee for Data Base Management. Also, a cooperative effort was initiated (with C. Mass, Univ. of Washington) to create and distribute NMC climate-related data on CD-ROM optical disks.

6.6.2 ASOS Climate Working Group (Rodenhuis, Ropelewski)

A special session on ASOS was held at the 15th Annual Climate Diagnostics Workshop (Asheville, NC, November 1990). The ASOS/CWG met to discuss the use of supplemental observations and the impact of ASOS on climate observations. A draft "ASOS Climate Plan" was circulated for comment.

Two projects were initiated to intercompare ASOS with "conventional" data in the central United States. The first one is under the direction of the Dr. T. McKee (Colorado State University) and the second one by Dr. T. Karl (NESDIS/NCDC). Both are funded by the NOAA/Earth System Data and Information Management Project

6.7 Annual Climate Diagnostics Workshops

6.7.1 Fifteenth Annual Climate Diagnostics Workshop (Rodenhuis, Ropelewski)

The NMC/Climate Analysis Center and NESDIS/National Climatic Data Center were co-sponsors of the Fifteenth Annual Climate Diagnostics Workshop, held in Asheville, NC (October 29-November 2, 1990). These Workshops provide a forum for researchers to present recent results and to exchange ideas on a variety of climate topics. This meeting focused on: Recent Climate Anomalies; ENSO; Interannual, Intraseasonal, and Low-Frequency Variability; Climate Data Sets; Ocean-Atmosphere Interactions; Climate Impacts and Studies; and Climate Prediction. There were 95 presentations; a Proceedings was published and distributed in March 1991.

6.7.2 Sixteenth Annual Climate Diagnostics Workshop (Rodenhuis, Mo)

Arrangements were completed to hold the Sixteenth Annual Climate Diagnostics Workshop in Lake Arrowhead, CA. The UCLA/ Dept. of Meteorology has agreed to co-host the Workshop which is scheduled for October 28 - November 1, 1991. Preparations included: invitations to the Workshop and a Workshop announcement published in the Bulletin of the AMS (June 1991).

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Reale, A. L., H. E. Fleming, D. Q. Wark, C. S. Novak, F. S. Zbar, J. R. Neilon, M. E. Gelman and H. J. Bloom, "Baseline Upper Air Network (BUAN) Final Report", NOAA Technical Report NESDIS 52, October 1990, 57 pp.

Reynolds, R. W., "Sea surface temperature analyses from in situ and satellite data," Palaeogeography, Palaeoclimatology, Palaeoecology, (Global and Planetary Change Section), Elsevier Science Publishers B. V., Amsterdam. 90, 1991, pp. 183-187.

Reynolds, R. W. and A. Leetmaa, "Data assimilation - tropical oceans," Proceedings of the International TOGA Scientific Conference - WCRP 43, Honolulu, HI, July 1990, pp. 9-18.

Ropelewski, C. F., "Real-time monitoring of global snow cover," Palaeogeography, Palaeoclimatology, Palaeoecology, (Global and Planetary Change Section), Elsevier Science Publishers B. V., Amsterdam. 90, 1991, pp. 225-229.

Ropelewski, C. F., "Building a satellite climate diagnostics data base for real-time climate monitoring," Proceedings of the Second Symposium on Global Change Studies, New Orleans, LA, January 13-18, 1991, pp. J13-J18.

Ropelewski, C. F. and A. G. Barnston, "Why predict ENSO?," Proceedings of the 15th Annual Climate Diagnostics Workshop, Asheville, NC, October 29-November 2, 1990, pp. 26-29.

Ropelewski, C. F. and M. S. Halpert, "The Southern Oscillation and Northern Hemisphere temperature variability,"Greenhouse Gas-Induced Climatic Change: A Critical Appraisal of Simulations and Observations, (M. E. Schlesinger, Editor), Elsevier Science Publishers , Amsterdam, 1991, pp. 369-376.

Salstein, D. A. and D. M. Kann, "The Sub-Bureau for Atmospheric Angular Momentum at CAC: Earth rotation-related data from Meteorological Centers," Proceedings of the 15th Climate Diagnostics Workshop, Asheville, NC, October 29-November 2, 1990, pp. 231-236

Shea, D. J., K. E. Trenberth and R. W. Reynolds: "A global monthly sea surface temperature climatology," NCAR Technical Note, NCAR/TN-345 STR, Boulder, CO, 1991, 167 pp.

Smith, T. M., "Interannual changes in the tropical Pacific Ocean from 1985-1989: Heat storage variability,: Proceedings of the 15th Climate Diagnostics Workshop, Asheville, NC, October 29-November 2, 1990, pp. 60-64.

van den Dool, H. M. and C. J. Schuurmans, "Uitzonderlyk warm," Zenit, June 1991, pp. 214-216.

van den Dool, H. M., J. Feng and T. Murphree, "Dynamic calculation of teleconnections," Proceedings of the 15th Climate Diagnostics Workshop, Asheville, NC, October 29-November 2, 1990, pp. 520-527.

Wang, X-L. and E. M. Rasmusson, "The dominant planetary-scale modes of ENSO cycle variability," Proceedings of the 15th Annual Climate Diagnostics Workshop, Asheville, NC, October 29-November 2, 1990, pp. 76-80.

7.3 Presentations at Formal Scientific Meetings*

Bell, G.D., "Mid - tropospheric cutoff cyclogenesis," presented at the AMS/First International Winter Storms Conference, New Orleans, LA, January 14-18, 1991.

Bell, G. D., "Shear and curvature potential vorticity interchanges during cutoff cyclone formation," presented at the AMS/First International Winter Storms Conference, New Orleans, LA, January 14-18, 1991.

Bermowitz, R. J. "Climate services, development and research activities at the NOAA/NWS Climate Centers," presented at the Southern Data Management Workshop, Atlanta, GA, June 10-13, 1991.

Gelman, M. E., "Detection of stratospheric change," presented at the TOVS Pathfinder Science Working Group Meeting, University of Maryland, College Park MD, June 19, 1991.

Heddinghaus, T. R. and D. M. Le Comte, "Over a century of monitoring and disseminating agricultural weather data: The Weekly Weather and Crop Bulletin," presented at the National Weather Association Fourteenth Annual Meeting, New Carrollton, MD, October 15-19, 1990.

Hou, Y., K. A. Campana, K. Mitchell, S. K. Yang and L. L. Stowe, "Evaluation an experimental satellite-derived cloud data set for real-time use," presented at the Workshop on Aerosol-Cloud-Climate Interactions IAMAP/IUGG Vienna, Austria, August 11-24, 1991.

Janowiak, J. E., "Comparison between satellite derived rainfall estimates and model precipitation forecasts in the Tropics," presented at the NMC/NCAR Reanalysis Workshop, Camp Springs, MD, April 26, 1991.

Janowiak, J. E., "Status of GPCP activities at CAC," presented to the Working Group on Data Management of the Global Precipitation Climatology Project, Laurel, MD, May 20, 1991.

Janowiak, J. E., "Performance of GPI rainfall estimates during the First Algorithm Intercomparison Project," presented at the GPCP Algorithm Intercomparison Workshop, Laurel, MD, May 22, 1991.

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* There were 37 additional presentations that were either published in a Proceedings or Preprint Volume of a formal scientific meeting, but are only listed in Section 7.2.

Janowiak, J.E., P. A. Arkin, and T. H. Lee, " A comparison of satellite-derived rainfall estimates with ground-based observations over Japan," presented at the International Union of Geophysical Scientists, Vienna, Austria, August 16, 1991.

Janowiak, J. E., T. H. Lee and P. A. Arkin, "A comparison between satellite-derived rainfall and ground observations, Part I: IR-based satellite estimates," presented at the AGU Spring Meeting, Session on Remote Sensing of Precipitation, Baltimore, MD, May 29, 1991.

Kousky, V. E., "Update on the Southern Oscillation," presented at the Climate Systems Monitoring Meeting, Helsinki, Finland, August 26-30, 1991.

Laver, J. D. and L. Thomas, "Accessibility of NOAA'S current climate data and products in the era of enhanced climate services," presented at the AMS/ Seventh IIPS Conference, New Orleans, LA, January 16, 1991.

Lee, T. H., J. E. Janowiak and P. A. Arkin, "A comparison between satellite-derived rainfall and ground observations, Part II: Microwave Based Satellite Estimates," presented at the AGU Spring Meeting, Session on Remote Sensing of Precipitation, Baltimore, MD, May 29, 1991.

Leetmaa, A., "Model - based analyses for the Pacific Ocean," (Invited Talk), presented at the Annual AGU Meeting, San Francisco, CA, December 5, 1990.

Leetmaa, A., "Progress in coupled model studies at NMC," presented at the Epocs Council Meeting, Miami, FL, January 21-23, 1991.

Leetmaa, A., "Estimation of the net surface heat flux in the Pacific," presented at the Epocs Council Meeting, Miami, FL, January 21-23, 1991.

Lehman, R. E., "Accurate climatological tools for projecting monthly gas sales and monitoring annual conservation trends," presented at the Conference on PC Applications in the Gas Industry, Chicago, IL, May 6-8, 1991.

Lehman, R. E., "New CAC Products for Climate Impact Evaluation," presented at the Workshop on Climate Predictability and Global Change in the Southeast U. S., Univ. of Alabama, Huntsville, Al, June 3-4, 1991.

Livezey, R. E., "Seasonal predictability and prediction in the extratropics," presented at the WMO Training Workshop on Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations, Nanjing, China, October 15-19, 1990.

Livezey, R. E., "Status and recommendations for long-range forecasting," presented at the WMO Workshop on Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations, Nanjing, China, October 15-19, 1990.

Livezey, R. E., "Skill characteristics of U.S. long-range forecasts," presented at the ICS/ICTP/WMO International Technical Conference on Long-Range Weather Prediction Research, Trieste, Italy, April 11, 1991.

Mo, K. C., "Diagnostics and monitoring of re-analysis climate statistics," presented at the NMC/NCAR Re-Analysis Workshop, Camp Springs, MD, April 25-26, 1991.

Nagatani, R. M., "Availability and access of NMC support data for UARS," presented at the UARS Data Systems Working Group (DSWG) Meeting, Port Jefferson, NY, February 11, 1991.

Nagatani, R. M., "Quality of stratospheric datasets at NMC," presented at the Models and Measurements Committee Meeting of NASA's High Speed Research Project (HSRP), Washington, D.C., March 13, 1991.

Nagatani, R. M., A. J. Miller, G. C. Tiao, X. F. Niu, G. C. Reinsel, D. Wuebbles, and K. Grant: "Observed lower stratospheric ozone and temperature Trends from radiosondes and ozonesondes compared with model trends," presented at the IUGG/IAMAP Meeting, Session M10.4, Modelling and Observations of Ozone and Other Minor Constituents, Vienna, Austria, August 11-24,1991.

Nagatani, R. M., D. A. Salstein, D. M. Kann, and A. J. Miller, "Report of the Sub-Bureau for Atmospheric Angular Momentum," IUGG/IAG Special Study Group 5-98 Meeting, Vienna, Austria, August 15, 1991.

O'Lenic, E. A., "Creating a long-range forecast," presented at the Workshop on Climate Predictability and Global Change: Issues in the Southeast, Huntsville, AL, June 3-4, 1991.

Rodenhuis, D. R., "Near real-time climate assessment," presented at the Annual Meeting of the American Association for State Climatologists, Fairbanks, AK, August 5-9, 1991.

Rodenhuis, D. R., "Status of ASOS," presented at the Annual Meeting of the American Association for State Climatologists, Fairbanks, AK, August 5-9, 1991.

Rodenhuis, D. R., "The RCC Program," presented at the Annual Meeting of the American Association for State Climatologists, Fairbanks, AK, August 5-9, 1991.

Rodenhuis, D. R., "Current climate assessment," presented at the Special Workshop on Climate Monitoring, State Hydrological Institute, Leningrad, USSR, September 16, 1991.

Ropelewski, C. F., "Real-time monitoring and prediction of ENSO and its impacts," presented at the WMO Technical Conference on El Niño and its Climatic Implications, Montevideo, Uruguay, December 4-9, 1990.

Ropelewski, C. F. "The current state of the Southern Oscillation," presented at the TOGA Panel Meeting, Miami, FL, January 23, 1991.

Ropelewski, C. F., "The state of the Southern Oscillation," presented at the Eight Annual Pacific Climate Workshop, Asilomar, CA, March 10, 1991.

Ropelewski, C. F., "The use of AVHRR derived vegetation index for climate monitoring," presented at the Eight Annual Pacific Climate Workshop, Asilomar, CA, March 11, 1991.

Ropelewski, C. F. "Data requirements for real-time climate monitoring," presented at the NOAA Workshop on the Quality and Continuity of Environmental Data, Silver Spring, MD, April 11-12, 1991.

Ropelewski, C. F. "The current state of the Southern Oscillation," presented at the TOGA Advisory Panel Meeting, Washington, D.C., April 29, 1991.

Ropelewski, C. F. "Is the climate changing?," presented at the Workshop on Climate Predictability in the Southeast U.S., Univ. of Alabama, Huntsville, AL, June 3-4, 1991.

Ropelewski, C. F. "The Southern Oscillation and climate variability in the Southeast," presented at the Workshop on Climate Predictability in the Southeast U.S., Univ. of Alabama, Huntsville, AL, June 3-4, 1991.

Ropelewski, C. F., "Sampling uncertainties in estimates of global temperature," presented at the Global Climate Perspectives Workshop, Boulder, CO, June 25-27, 1991.

Ropelewski, C. F., "Global drought monitoring using the precipitation anomaly classification (PAC)," presented at the Global Climate Perspectives Workshop, Boulder, CO, June 25-27, 1991.

Ropelewski, C. F., "ENSO and biennial variability," presented at the IUGG/IAPSO Symposium on Low-Latitude Ocean-Atmospheric Coupling, Vienna, Austria, August 12-17, 1991.

van den Dool, H. M., "Introduction to CAC and predictability," presented at the Workshop on Climate Predictability in the Southeast U.S., Univ. of Alabama, Huntsville, AL, June 3-4, 1991.

Yang, S. K., "Cloud parameterization in the NMC's Medium Range Forecast Model," presented at the Fourth CERES Science Team Meeting, NASA Langley Research Center, Hampton, VA, November 14-15, 1990.

Yang, S. K., "Evaluation of the new ERBE S-4G product," presented at the 28th ERBE Science Team Meeting, Scripps Institution of Oceanography, La Jolla, CA, February 28, 1991.

Yang, S. K., "NMC T80 NWP model runs for April 1989 Surface Radiation Budget Experiment," presented at the Fifth CERES Science Team Meeting, Hampton, VA, April 30 - May 2, 1991.

Yang, S. K., S. S. Zhou and L. M. McMillin, "Evaluation of the NOAA/NESDIS TOVS cloud product," presented at the Workshop on Aerosol-Cloud-Climate Interactions IAMAP/IUGG, Vienna, Austria, August 11-24, 1991.

Zhou, S. S., L. M. McMillin and S. K. Yang, "An improved cloud retrieveal algorithm using HIRS2/MSU radiance measurements," presented at the 6th International TOVS Study Conference, Airlie, VA, May 1-6, 1991.

7.4 Seminars And Briefings

Barnston, A. G., "Principal Components Analysis as a data analysis tool", presented at the NASA/Langley Research Center, Hampton, VA, September 11, 1991.

Bell, G. D., "Mid-tropospheric cutoff cyclogenesis," presented at a CAC-Sponsored Seminar, Camp Springs, MD, March 14, 1991.

Bell, G. D., "Potential vorticity evolution during cutoff cyclone formation." presented at National Meteorological Center Seminar, Camp Springs, MD, April 8, 1991.

Bell, G. D., "Monthly and seasonal (MAM 1991) climate reviews," presented at NMC/Climate Analysis Center Briefings, Camp Springs, MD, April 9, May 7, and June 11, 1991.

Bell, G.D., "Mid-Troposheric Cutoff Cyclogenesis," presented at a NMC Seminar, Camp Springs, MD, May 15, 1991

Chelliah, M., "Examination of co-variability in tropical convection and global circulation," presented at a CAC-Sponsored Seminar, Camp Springs, MD, November 15, 1990.

Chelliah, M., "Monthly and seasonal (DJF 1990-91) climate reviews," presented at NMC/Climate Analysis Center, Briefings, Camp Springs, MD, January 8, February 12, and March 12, 1991.

Chen, W-Y., "Establishment, maintenance, and demise of an Atlantic block," presented at a CAC-Sponsored Seminar, Camp Springs, MD, October 2, 1990.

Chen, W-Y., "Rapid establishment and demise of a 30-day long Atlantic blocking episode," presented at NASA/GSFC, Greenbelt, MD, November 29, 1990.

Chen, W-Y., "Diagnosis of regime transition mechanism of blocking flow," presented at a CAC-Sponsored Seminar, Camp Springs, MD, March 7, 1991.

Gelman, M. E., "Status of FMH for rawinsonde observations," presented before Committee for Basic Services, Working Group for Upper Air Observations, OFCM, Rockville, MD, January 23, 1991.

Halpert, M. S., "Monthly and seasonal (JJA 1991) climate reviews," presented at NMC/Climate Analysis Center, Briefings, Camp Springs, MD, July 9, August 8, and September 10, 1991.

Huang, J., "Small ice cap instability in an energy balance model," presented at a CAC-Sponsored Seminar, Camp Springs, MD, October 18, 1990.

Janowiak, J. E., Comparisons between GPCP rainfall estimates and NMC model precipitation forecasts," presented at a NMC/ Development Division Weekly Forum, Camp Springs, MD, November 15, 1990.

Janowiak, J. E., "Results of the comparison of IR-based rainfall estimates from the NOAA-10 satellite with corresponding estimates from various algorithms applied to SSM/I data," NESDIS briefing, Camp Springs, MD, November 17, 1990

Janowiak, J. E., "Status of GPCP activities at CAC," presented at the NESDIS Research and Development Council Meeting, Camp Springs, MD, December 12, 1990 .

Janowiak, J. E., "Tropical rainfall: Satellite estimate vs. MRF and ECMWF model forecasts," presented at a CAC-Sponsored Seminar, Camp Springs, MD, February 14, 1991.

Kousky, V. E., "Real-time monitoring at the CAC," presented at the Finnish Meteorological Institute, Helsinki, Finland August 23, 1991.

Laver, J. D. "The CAC/RCC program management plan," presented at the RCC Leader's Meeting, New Orleans, LA, January 15, 1991.

Laver, J. D. "Update on Regional Climate Centers management and activities," presented at the Climate Services Management Council Meeting, Asheville, NC, March 8, 1991.

Leetmaa, A., "Air-sea interaction in the tropical Pacific," presented at a CAC-Sponsored Seminar, Camp Springs, MD, December 13, 1990.

Leetmaa, A., "Coupled model studies at NMC," presented at the Climate Services Troika Meeting, Asheville, NC, March 8, 1991.

Livezey, R.E., "Perspective on DERF: State of the art and recommendations for future direction," presented at a CAC-Sponsored Seminar, Camp Springs, MD, November 8, 1990.

Livezey, R.E., "Some long-range forecasting activity at USSR hydrometeorology center: A joint experiment in seasonal empirical prediction," presented at a CAC-Sponsored Seminar, Camp Springs, MD, December 18, 1990.

Livezey, R. E., "Some skill characteristics of CAC long-range forecasts," presented at the University of Maryland, College Park, MD, March 14, 1991.

Long, C. S., "Stratospheric assessment of spectral statistical interpolation (SSI) analysis," briefings for Director/NMC, Camp Springs, MD, April 4 and 24, 1991.

Miller, A. J., "The Stratospheric Monitoring Program," presented at the U.S. Naval Academy, Annapolis, MD, March 12, 1991.

Mo, K., "Monthly and seasonal (SON 1990) climate reviews," presented at NMC/Climate Analysis Center Briefings, Camp Springs, MD, October 7 , November 9, and December 11, 1990.

Mo, K., "The 200-mb vorticity budget during the 1986-89 ENSO cycle as revealed by NMC analyses," presented at a CAC-Sponsored Seminar, Camp Springs, MD, November 29, 1990.

Mo, K., "A striking WPO event during November 1990," presented at UCLA, Los Angeles, CA, January 24, 1991.

Mo, K., "The impact of sea-surface temperature on the monthly forecasts," presented at UCLA, Los Angeles, CA, February 8, 1991.

Mo, K., "Real-time climate monitoring," presented at San Jose State Univ., San Jose, CA, Feb. 20, 1991; and at the University of Utah, Salt Lake City, UT, March 5, 1991.

Murphy, A. H., "On the theory of forecast verification," presented at a CAC-Sponsored Seminar, Camp Springs, MD, March 28, 1991.

Reynolds, R. W., "The advantage of the Optimum Interpolation analysis in SST", presented at a CAFTI Meeting, Camp Springs, MD, January 30, 1991.

Reynolds, R. W., "A new global high-resolution SST analysis," presented at a CAC-Sponsored Seminar, Camp Springs, MD, April 4, 1991.

Rodenhuis, D. R., "Climate apocalypse," presented at the Federal Executive Institute, Charlottesville, VA, June 12, 1991.

Ropelewski, C. F., "Climate assessment: A review of the decade, 1981-1990," presented at the Climate Services Management Council Meeting, Asheville, NC, March 8, 1991.

Ropelewski, C. F., "The decade of the 1980's: Variability and trends," presented at the Naval Postgraduate School, Monterey, CA, March 14, 1991.

Ropelewski, C. F. "An overview of the Climate Analysis Center," presented at the NMC Seminar for NWS Support Personnel, Camp Springs, MD, June 13, 1991.

Schultz, P., "NCAR-GCM hydrology: How bad is it?," presented at a CAC-Sponsored Seminar, Camp Springs, MD, May 23, 1991.

van den Dool, H.M., "Weather update: Assessment of upcoming winter," presented at the Dept. of Energy and Petroleum Industry Research Foundation, Washington, D.C., October 2, 1990.

van den Dool, H.M., "Medium and long-range forecasting at CAC," presented at von Humboldt University, Berlin, FRG, January 3, 1991.

van den Dool, H.M., "Low-frequency waves and traveling storm tracks," presented at the Royal Netherland Meteorological Institute, de Bilt, Netherlands, January 8, 1991.

van den Dool, H. M., "Ten year integration of the NMC model," presented at the Climate Services Troika Meeting, Asheville, NC, March 8, 1991.

van den Dool, H. M., "A 10-year run with the MRF model," presented at: AMIP, Berkeley, CA, April 5, 1991; Naval Post Graduate School, Monterrey, CA, April 9, 1991; DERF Workshop, Camp Springs, MD, April 24, 1991; and at a NMC Seminar, Camp Springs, MD, May 20, 1991.

7.5 Grant Program

CAC continued its support to universities and private institutions to undertake diagnostic studies and research that contribute directly to the improvement of CAC's operational monitoring and prediction programs. The results from each project are reported in the literature and in final reports to CAC. Each institution, title of study and principal investigator is listed below.

Start Date	Institution	Title	Principal Investigator
May 1991 (Renewal)	University of Maryland	Cooperative Institute for Climate Studies	Ellingson
Aug. 1991 (Renewal)	University of Chicago	Statistical Analysis of Stratospheric Temperature Data for Trend Analysis	Tiao
Aug. 1991 (New)	University of Washington	An Investigation on the Use of CD-ROM for Climate Application and Research	Mass
Aug. 1991 (Renewal)	UCAR	Scientific Program	Anthes

REGIONAL CLIMATE CENTERS PROGRAM

Start Date	Institution	Title	Principal Investigator
Mar. 1991	University of Nevada	Western RCC	Warburton
May 1991	University of Nebraska-Lincoln	High Plains RCC	Hubbard
May 1991	So. Carolina Water Resources Commis.	Southeastern RCC	Smith
June 1991	University of Illinois	Midwestern RCC	Kunkel
June 1991	Cornell Univ.	Northeastern RCC	Knapp
Aug. 1991	Louisiana St. University	Southern RCC	Muller

7.6 CAC - Sponsored Seminar Series

Speaker: Dr. Wilbur Chen
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Eastablishment, Maintenance, and Demise of an Atlantic Block"

Date: October 2, 1991

Speaker: Dr. Chung-Hsiung Sui
Laboratory For Atmospheres
NASA/GSFC
Greenbelt, MD

Title: "Observed and Simulated Multiscale Phenomena in the Tropical Western Pacific"

October 4, 1990

Speaker: Dr. Larry L. Stowe
NOAA/NESDIS
Office of Research & Applications
Camp Springs, MD

Title: "The Development of Cloud and Aerosol Climatologies at NOAA/NESDIS"

Date: October 11, 1990

Speaker: Ms. Jin Huang
Department of Atmospheric Sciences
University of Illinois
Champaign - Urbana, IL

Title: "Small Ice Cap Instability in an Energy Balance Model"

Date: October 18, 1990

Speaker: Prof. Ferd Baer
Department of Meteorology
University of Maryland
College Park, MD

Title: "Optional Vertical Levels and Three-Dimensional Truncation In Models"

Date: October 23, 1990

Speaker: Dr. Robert E. Livezey
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Perspectives on Dynamic Extended and Long-Range Forecasting: State of the Art and Recommendations for Future Directions"

Date: November 8, 1990

Speaker: Dr. Stephen J. Colucci
Department of Soil, Crops, and Atmosphere
Cornell University
Ithaca, NY

Title: "Planetary Scale Climatology of Explosive Cyclogenesis and Blocking: Implications for Long-Range Forecasting"

Date: November 13, 1990

Speaker: Dr. Muthuvel Chelliah
RDS, Corporation
Contract Scientist, NMC/CAC
Camp Springs, MD

Title: "Examination of Co-Variability In Tropical Convection and Global Circulation"

Date: November 15, 1990

Speaker: Dr. Kingtse Mo
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Dr. Eugene Rasmusson
Dept. of Meteorology
University of Maryland
College Park, MD

Title: "The 200 MB Vorticity Budget during the 1986-89 ENSO Cycle As Revealed by NMC Analyses"

Date: November 29, 1990

Speaker: Dr. Siegfried Schubert
Laboratory For Atmospheres
NASA/GSFC
Greenbelt, MD

Title: "Persistence And Predictability"

Date: December 6, 1990

Speaker: Dr. Stanley Grotch
Lawrence Livermore National Laboratory
Livermore, CA

Title: "Zonal Statistics: GCM Intercomparisons"

Date: December 10, 1990

Speaker: Dr. Ants Leetmaa
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Air-Sea Interaction in the Tropical Pacific"

Date: December 13, 1990

Speaker: Dr. Robert E. Livezey
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Some Long-Range Forecasting Activity at the USSR Hydrometeorological Center: A Joint Experiment In Seasonal Empirical Prediction"

Date: December 18, 1990

Speaker: Dr. Zoltan Toth
NRC- Post Doctoral Program
NWS/National Meteorological Center
Camp Springs, MD

Title: "Global And Local Characteristics Of The Extra-Tropical NH WinterTime Circulation Phase Space"

Date: January 24, 1991

Speaker: Dr. G. Garik Gutman
NOAA/NESDIS
Satellite Research Laboratory
Camp Springs, MD

Title: "Climatology of Land Surfaces from NOAA AVHRR Observations"

Date: January 31, 1991

Speaker: Dr. Ilya Polyak
Invited Speaker

Title: "Multivariate Stationary and Non-Stationary Stochastic Models and their Applications to Climatology"

Date: February 8, 1991

Speaker: John E. Janowiak
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Tropical Rainfall: Satellite Estimate vs. MRF and ECMWF Model Forecasts"

Date: February 14, 1991

Speaker: Dr. G.V. Gruza & Dr. E.Y. Rankova
Institute For Global Climate And Ecology
Moscow, USSR

Title: "Monitoring And Probabilistics Forecasts of Short-Term Climate Fluctuations"

Date: February 21, 1991

Speaker: Dr. Wilbur Chen
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Diagnosis of Regime Transition Mechanism Of Blocking Flow"

Date: March 7, 1991

Speaker: Dr. Gerald Bell
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "Mid-Tropospheric Cutoff Cyclogenesis"

Date: March 14, 1991

Speaker: Dr. Chi-Dong Zhang
Dept. of Meteorology
Penn State University
State College, PA

Title: "Climatological Relationship between SST and OLR over the Tropical Pacific Ocean"

Date: March 21, 1991

Speaker: Prof. Allan H. Murphy
Oregon State University
UCAR Visiting Scientist, NMC/CAC
Camp Springs, MD

Title: "On the "Theory" of Forecast Verification"

Date: March 28, 1991

Speaker: Dr. Richard W. Reynolds
NOAA/National Weather Service
NMC/Climate Analysis Center
Camp Springs, MD

Title: "New Global High-Resolution SST Analysis"

Date: April 4, 1991

Speaker: Dr. K. M. Lau
Laboratory For Atmospheres
NASA/GSFC
Greenbelt, MD

Title: "Dynamics Of Atmospheric Teleconnections During Northern Summer"

Date: April 18, 1991

Speaker: Dr. James Carton
Department of Meteorology
University of Maryland
College Park, MD

Title: "Seasonal Salinity and Fresh Water Balances in the Tropical Atlantic Ocean"

Date: May 2, 1991

Speaker: Dr. Majib Latif
Max-Planck Institute For Meteorology
Hamburg, FRG

Title: "Predictability of Enso"

Date: May 21, 1991

Speaker: Mr. Peter Schultz
RDS, Corp.
Contract Scientist, NMC/CAC
Camp Springs, MD

Title: "NCAR GCM Hydrology: How Bad Is It?"

Date: May 23, 1991

Speaker: Dr. Glenn White
NMC/Development Division
NOAA/National Weather Service
Camp Springs, MD

Title: "Systematic Errors in the MRF and Other Models"

Date: May 30, 1991

Speaker: Dr. Daniel S. Wilks
Dept. of Meteorology
Cornell University
Ithaca, NY

Title: "Estimating The Monthly And Seasonal Precipitation Distributions Using the 30-Day and 90-Day Outlooks"

Date: June 20, 1991

7.7 Visitors

NAME	AFFILIATION	DATE
Dr. C-H. Sui	Laboratory for Atmospheres NASA/GSFC Greenbelt, MD	Oct. 2, 1990
Dr. D. Webster Dr. G. Schaefer	Actg. Director General Actg. Chief, Hydromteor. Research Division	Oct. 10, 1990
J. Sandilands R. Morris	Climate Services Data Management Canadian Climate Center Downsview, Canada	
Dr. M. Takeuchi	Dept. of Civil & Environmental Engineering, Yamanashi University Kofu, Japan	Oct. 21, 1990
Prof. F. Baer	Dept. of Meteorology Univ. of Maryland College Park, MD	Oct. 23, 1990
Prof. A. H. Murphy	Visiting Scientist, UCAR Oregon St. University Corvallis, OR	Nov. 1990 - Nov. 1991
P. Csapo	Hungarian Meteorological Service Budapest, Hungary	Nov. 7, 1990
Dr. S. Colucci	Dept. of Soil, Crops and Atmosphere Cornell University Ithaca, NY	Nov. 13, 1990
Dr. K. Vinnikov	State Hydrological Inst. Leningrad, USSR	Nov. 19, 1990
J. Canby	National Geographic Washington, D.C.	Nov. 20-29, 1990
Dr. K. Katsoras	University of Washington Seattle, WA	Dec. 4, 1990
Dr. K. Weikman Dr. M. Hoerling	NOAA/ERL Boulder, CO	Dec. 5, 1990
Dr. A. Shabbar	Canadian Climate Center Downsview, Canada	Dec. 5, 1990

Dr. S. Schubert	Laboratory for Atmospheres NASA/GSFC Greenbelt, MD	Dec. 6, 1990
Dr. S. L. Grotch	Lawrence Livermore National Laboratory Livermore, CA	Dec. 10, 1990
Dr. V. Gowariker	Secretary of Science and Technology New Delhi, India	Dec. 12, 1990
Dr. J. P. Gupta	Counsellor (Science) Embassy of India Washington, D.C.	Dec. 12, 1990
Dr. P. R. Pisharoty	IMO Prize Winner New Delhi, India	Dec. 12, 1990
B. Gezaw	Director, Ethiopian Early Warning System Adis Abbaba, Ethiopa	Dec. 12, 1990
Dr. M. Mak	Univ. of Illinois Champaign-Urbana IL	Dec. 12, 1990
J. Christy	Univ. of Alabama Huntsville, AL	Dec. 13, 1990
J. Purvis D. Smith	Southeast Regional Climate Center Columbia, SC	Dec. 17, 1990
Prof. G. V. Gruza Prof. E. Ran'kova	Inst. for Global Climate and Ecology Moscow, USSR	Jan. 8-Mar. 5, 1991
Dr. M. Kayano	INPE Sao Paulo, Brazil	Jan.-May 1991
Prof. J.M. Wallace	Univ. of Washington Seattle, WA	Jan 9, 1991
F. Zwiers	Canadian Climate Centre Downsview, Canada	Mar. 1, 1991
Prof. J. Young	Univ. of Wisconsin Madison, WI	Mar. 11, 1991
N. Hoffman	MIC, WSFO San Francisco, CA	Mar. 11, 1991
A. Haffer	MIC, WSFO Phoenix, AZ	Mar. 11, 1991

Dr. C-D. Zhang	Dept. of Meteorology Penn St. University State College, PA	Mar. 21, 1991
Dr. N. Gershon	Mitre, Space Systems Div. McLean, VA	Mar. 21, 1991
M. Roos	Cal. Dept. of Water Res. Sacremento, CA	Mar. 25, 1991
Dr. I. Burton	Director, Natural & Human Sciences and Integration Atmos. Envir. Service Ottawa, Ontario, Canada	Apr. 9, 1991
Dr. K-M. Lau	Laboratory for Atmospheres NASA/GSFC Greenbelt, MD	Apr. 18, 1991
Dr. S. L. Grotch	Lawrence Livermore National Laboratory Livermore, CA	Apr. 24, 1991
Dr. A. Oort	NOAA/GFDL Princeton, NJ	Apr. 24, 1991
Dr. J. Lanzante	NOAA/GFDL Princeton, NJ	Apr. 26, 1991
Dr. D. Salstein	AER Inc. Cambridge, MA	Apr. 26, 1991
L. Mooney	MIC, WSFO Denver, CO	Apr. 29, 1991
C. Liles	MIC, WSFO Albuquerque, NM	Apr. 29, 1991
Dr. P. D. Joseph	NOAA/ERL/CIRES Boulder, CO	Apr. 30, 1991
Dr. J. Carton	Dept. of Meteorology Univ. of Maryland College Park, MD	May 2, 1991
D. Salmon	Knight-Ridder - Global Financial News Kansas City, KS	May 8, 1991
P. Roebber	McGill University Montreal, Canada	May 20, 1991
Dr. M. Latif	Max-Planck Institute for Meteorology Hamburg, FRG	May 21, 1991

Dr. S. Mullen	University of Arizona Tuscon, AZ	May 23, 1991
Dr. R. Muller	Southern Regional Climate Center New Orleans, LA	May 24, 1991
D. Smith	Southeastern Regional Climate Center Columbia, SC	May 24, 1991
Dr. S. Gadgil	Indian Inst. of Science Bangalore, India	June 4, 1991
Dr. M. Crowe	World Climate Data Programme, WMO Geneva, Switzerland	June 8, 1991
Dr. D. S. Wilks	Cornell University Ithaca, NY	June 20, 1991
Dr. J. Nogues-Paegle	University of Utah Salt Lake City	June 24-27, 1991
Dr. A. Johannsson	UCAR, Visiting Scientist Univ. of Stockholm Stockholm, Sweden	Aug. 1 - Oct. 31, 1991
Dr. K. S. Vasan	C.E.O., Research Data Systems Corporation Greenbelt, MD	Sep. 23, 1991