SEASONAL FORECASTING USING COUPLED MODELS AT NCEP

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Summary: A system for routine multi-season climate forecasts based on dynamical coupled models has been implemented at the National Centers for Environmental Prediction (NCEP). The phenomena that lies behind much of the potential predictability on these timescales is the El Nino/Southern Oscillation (ENSO) phenomena. This results primarily from coupled ocean-atmosphere interactions in the Pacific. The forecast system consists of an ocean general circulation model (OGCM) for the Pacific basin coupled to a reduced spatial resolution version of NCEP's global atmospheric medium range forecast model (MRF). Since the memory of the climate system is thought to reside primarily in the ocean, at present initialization is provided only for that component of the system. Those initial conditions are determined by combining in situ thermal data using the techniques of data assimilation with an OGCM simulation forced with observed wind stresses. A two stage process is used in the forecasting. Monthly forecasts for tropical Pacific sea surface temperatures (SST) are produced out to a year in advance. These are post-processed to remove systematic errors and then used in an ensemble forecast for air temperature and rainfall variations that currently are run out to seven and a half months.

Currently the focus in the community is on the forecast of tropical SST anomalies in the central and eastern Pacific, i.e. El Nino. The primary measure of skill is area averaged SST anomaly in a region called Nino-3: 150W-90W, 5S-5N. Most current prediction systems beat a persistence forecast in this region, with skill for some continuing out to six seasons. For many systems the skill levels show a strong seasonality. Loss of skill occurs in the spring, e.g. the springtime prediction barrier. The NMC coupled forecast system has highest skill levels for forecast starting in summer and fall. Anomaly correlation skill scores for the Nino-3 region start at about .95 and remain above .8 for about two seasons. Root mean square errors start about .35 deg C. and grow slowly until the following late Spring when they grow rapidly. Forecasts starting in Spring maintain about the same skill levels as forecasts starting at other times for the first season and then show more rapid error growth. Intradecadal variations in skill exist. All current forecast system have shown little skill since 1992, especially past the first season. The use of data assimilation to determine the initial conditions considerably enhances forecast skill for the NMC system. However, future skill improvements will come primarily from improvements in the forecast models.

Forecasts of air temperature and rainfall variations associated with ENSO are just beginning. The most robust tropical to midlatitude teleconnections response, both observationally and in the models, occurs in the Pacific/North American sector. This is modulated seasonally and is strongest in northern hemisphere winter. Hence much of the attention an NMC to date has been for North America for the winter season. Ensembles of forecasts and averages over a season are required in order to average over weather noise and to isolate the climate signal. By its nature the average of an ensemble forecast gives the average response. However, nature only performs a one realization ensemble and the climate signal might not be well resolved for any individual event. Averages over several ENSO events, i.e. composites, for nature and the model for both warm and cold events are useful for evaluating the suitability of an AGCM for climate forecasting. Observationally and for the model, composites for warm cases are more stable than those for cold cases. This implies that warm case anomalies are more predictable than cold case ones. The model ensemble response is much more stable than nature. The challenge in the future will be to predict deviations from the composite. Observed rainfall variations, especially over the southern one third of the United States are much more stable than overall North American temperature variations. This indicates that a different physical process dominates rainfall variations. However, the model's composite rainfall response in not as stable as nature's indicating that technical improvements are needed to improve the skill in this area. The individual members of the ensembles have about the same skill as nature for temperature but are much worse for rainfall. ENSO related climate variations account for only part of the observed climate variations over North America the past 45 years. Intradecadal variations, especially for wintertime temperature, have been equally important since about 1978. The origin of these at present is unclear and they are not well developed in model simulations with observed SSTs.

1. INTRODUCTION

The past decade has seen the development of a variety of techniques for predicting multiseason variations in tropical Pacific sea surface temperatures and the associated atmospheric impacts. Currently the central paradigm is one of a two-tiered climate forecast system. The first stage is the prediction of tropical Pacific sea surface temperatures. Several categories of forecast models are used: statistical, dynamical ocean with a statistical atmosphere, intermediate coupled ocean-atmosphere models, and coupled general circulation ocean-atmosphere models. The forecast system at NCEP is of this last category, i.e.. coupled GCMs. Initialization of these is currently carried out either by using the past history of the surface winds to spin up the ocean component of the system or using ocean data assimilation along with the past history of the winds to provide the initial conditions. This latter approach is used at NCEP. A more detailed history of the development of the El Nino prediction activities presumably has been covered in a previous talk and will not be elaborated upon here. This discussion will give a short overview of the NCEP coupled forecast system and recent experiences with it.

The second stage is the forecast of ENSO, i.e. the atmospheric surface temperature and rainfall variations associated with the tropical Pacific SST variations. Forecasts of tropical SST variations at present use only single forecasts or averages of a few forecasts from consecutive months. Atmospheric forecasts, especially for midlatitudes, require the use of ensembles of forecasts using an AGCM. It is safe to say that this is a field in its infancy. Issues such as the need or utility of initialization of the AGCM forecasts, the optimal choice of ensemble sizes, strategies for running and processing the ensembles and so on are just now beginning to be explored and hence will not be discussed. What separates short term climate forecasting from numerical weather prediction is that to zero order for ENSO there is a well defined average response. The character of this was suggested some time ago from observational studies (Ropelewski and Halpert, 1986). The basic test for forecast models is to be able to simulate this response. Without having such a well-defined target to shoot for, the development of a capability for skillful climate forecasts would be a long process indeed with no clear end in sight. The primary difficulty is defining the climate signal in individual cases in the presence of energetic 'weather noise'. This is why ensemble forecasts are required and composites are useful first tools. Although ENSO is thought to be a major source of climate variability on these timescales, it is not the only one. Having identified the ENSO related signal, it is then easier to examine the non-ENSO related variations. These are some of the issues that will be examined during this seminar.

2. FORECASTS OF TROPICAL PACIFIC SST

The coupled forecast model used at NCEP is described in Ji, et. al. (1994). It consists of the GFDL OGCM configured for the Pacific Ocean and a global atmospheric GCM which is a modified climate MRF with a spectral resolution of T40 and 18 vertical levels. Three versions of this model have been tested and used in forecasting. They differ in their formulation of the fluxes between the ocean and atmosphere. All use anomaly coupling for the wind stress; the Hellerman and Rosenstein (1983) stress climatology is used for the mean annual cycle of stress. The first version used anomaly coupling for short wave flux and full coupling for sensible, latent, and longwave heat fluxes. The second version used negative feedback for the net anomalous heat flux and a model output statistics (MOS) correction for the stress anomalies. The most recent version uses anomaly coupling for all components of the heat flux. During the coupled forecasts the fluxes the ocean experiences are a combination of climatological and anomalous ones. However, the atmosphere sees the total SST field from the ocean model. The ocean initial conditions are produced through the use of an ocean data assimilation system (Ji, et. al., 1995). No observed data are assimilated into the atmospheric initial conditions.

The time history of the performance of the two recent versions of the model in predicting SST variations in the Nino-3 region for the period 1982 to 1995 at three different lead times is shown in figure 1. In an overall sense these two models capture the observed low frequency variations. Largest errors for each occurred in the transitions between the warm and cold events which tend to happen in the springtime. The forecasts at shorter leadtimes are clearly better. The observed post-1992 variability was of a different character. The events were of a shorter duration and, except perhaps at the 1 season leadtime, not predicted. As will be discussed during the seminar, none of the other forecast systems were able to do any better on these events; some did considerably worse. A major factor making these events more difficult to predict was that there was little evidence in the subsurface thermal field, e.g. the memory of the system, that the warmings would occur. The various experiments at NCEP to try to improve the forecasts for these events intangibly suggest that the more fully coupled a system is the higher the likelihood that the forecast might have captured the warming.

A summary of the performance of the model as a function of the starting season and leadtime indicates that the most skillful forecasts are those initiated in the summer and fall. The skill levels for these drop when the following spring is reached 6 to 9 months later. Spring forecasts lose their skill the fastest. Most forecast models have this general dependence of skill on season, hence the origin of the term ‘the springtime prediction barrier’. A recent study suggests that better initialization might remove this barrier. Chen, et. al., (1995) found that with the use of a ‘coupled’ data assimilation for which observed and coupled model winds were blended at the time the ocean initial conditions were being determined, the loss of skill during this period was basically eliminated. However, this did not improve the post 1992 forecast skill.

At NCEP the assimilation currently is solely used for the ocean. The overall experience is that the use of data assimilation to produce the ocean initial conditions for the forecasts does lead to improvements in forecast skill. However, the results appear to be seasonally dependent. Forecasts for two versions of the NMC coupled model initiated from late spring to fall show improved skill when data assimilation is used. However, the positive impact is less for forecasts initiated during the winter months. One role that data assimilation does for the NMC system is to correct for large systematic

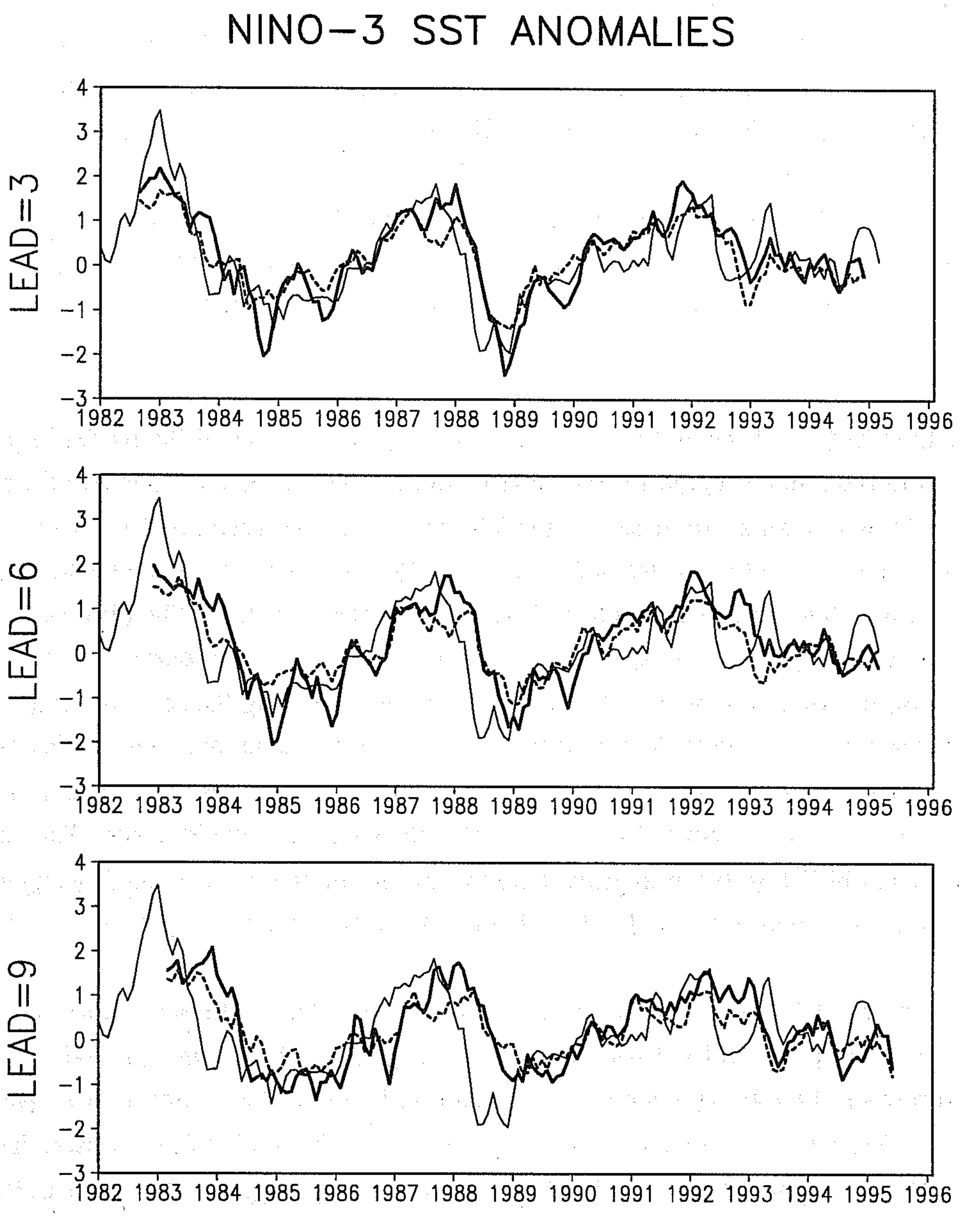


Fig. 1 Time history of the performance of the two recent versions of NCEP's coupled models in forecasting area averaged SSTs in the Nino-3 region at lead times of 3, 6, and 9 months. The thin curve in each panel shows the observed variations. The dashed and heavy curves show the forecasts. Each point on these curves represents a single forecast value at that time. The leads are in units of months.

errors in the ocean's mean field which appear to result from problems with the ocean model formulation. During forecasts, when assimilation is not present,, the ocean state relaxes back to its own erroneous climatology. This relaxation contributes to a systematic forecast error whose spatial structure has many of the characteristics of the El Nino signal. At present it is not clear how this systematic error contributes to errors for individual events, i.e. does it reduce the overall forecast skill.

3. MIDLATITUDE FORECASTS

As mentioned in the introduction the idea of an 'average' ENSO related response for rainfall and temperature variations goes back to Ropelewski and Halpert (1986). At that time the concept of the canonical El Nino event, i.e. one which always followed the same progression of events over a two year period, was popular. Since that time no canonical ENSO events have occurred; each appears to be somewhat different. Nevertheless, the idea of a canonical or 'composite' response is a useful one, especially over North America where the ENSO related climate signal can be obscured by weather 'noise'. By compositing over all possible ENSO events, the average rainfall or temperature response can be identified. The zero order test for a forecast model is to see if it can duplicate this same response when forecasts or simulations with observed SSTs are averaged over the same ENSO events.

The problem of identifying the climate signal in the presence of shorter period atmospheric variability requires that temporal averages be taken. Practice has shown that for monthly averages the climate signal to weather noise ratio is unfavorable for detection of the climate signal (Kumar and Hoerling, 1994). Seasonal averages appear to be a good compromise and allow for detection of seasonal variations of the climate signal. Ensembles of model simulations or forecasts are used to further enhance the climate signal. Nature, of course, for any given year only performs one member of such an ensemble. The ensemble forecasts are probabilistic. A mean anomaly and the spread about the mean can be defined. Preliminary studies at NCEP suggest that there doesn't seem to be much temporal variation in the spread, e.g. good simulations/forecasts have about the same spread as do the poorer ones. In essence the process of using ensembles generates the 'composite' response to a given situation (distribution of SST). Nature for any given season produces one realization that can lie anywhere in a probabilistic distribution. It is only by compositing many events that the mean climate shift (signal) can be discerned with any reliability. There have been too few observed events to say much with confidence about the shape of this distribution. While the first challenge of numerical climate prediction is the accurate prediction of the mean (composite) signal, the ultimate challenge is the prediction of deviations from this for any given season.

The basic premise behind the idea of compositing is that there is a robust, stable, ENSO related climate response. (That this is true will be demonstrated in the remainder of the seminar.) For short term weather this in general is not true (an exception being a phenomena such as a hurricane). No doubt the spectrum of climate variability involves more than just ENSO related variations; indeed as will be shown for the North American sector, another dominant signal is one related to intradecadal variations which is strongly modulated on the seasonal timescale. Nevertheless, the ENSO related signal is distinct enough and the numerical tools exist to explore it so that is represents a good entry point into this new activity. Having identified the ENSO related part of the variability, the remainder can be isolated and more easily attacked. There is a strong seasonality in the character and amplitude of the ENSO related signal over North America. The focus in the seminar will be on the January/February/March (JFM) season. This is the time of the year that the signal is the strongest and hence most amenable for study. Brief mention will be made of the seasonal variations in this ensemble response after the discussion of JFM phenomena.

3.1 **ENSO response over the North American sector**

A variety of types of numerical experiments are being used at NCEP to study climate variability. The atmospheric GCM is the same one used in coupled forecast system, i.e. a T40 18 level version of NCEP's operational medium range forecast model. Much of what will be discussed herein is derived from a recently completed 13 member ensemble experiment that is forced with observed SSTs for the period January 1950 to March 1995. The SST analysis used for this was produced by Reynolds, et.al. (1995) and uses a global EOF reconstruction to produce spatially coherent fields in regions of sparse data coverage, e.g. like the Tropics. Other types of numerical experiments include: 'perpetual' January runs with a variety of specified SST anomalies; annual cycle runs with observed or composite ENSO SST anomalies; forecasts with forecast SSTs. Central to all these studies is the use of observational data to produce suitable composites to be used to evaluate the numerical studies.

Historically a variety of definitions of the state of SST anomalies in the tropical Pacific have been used to define when an El Nino or ENSO is taking place. The amplitude of SST anomalies along the west coast of South American or in the NINO-3 area usually is only indirectly related to whether significant shifts have taken place in the regions of large scale tropical convection. These shifts are a prerequisite for modifications to take place to the global atmospheric circulation patterns. A more direct measure of that are tropical SST anomalies in the central Pacific (i.e the region 140W-180W, 5N-5S). Hence for defining which years to use in composites, amplitudes of SST anomalies in this region are used. If anomalies in this region are greater that +/- .8 deg. C, for these studies this constitutes an ENSO event. Using this criteria the JFM's of 1958, 1966, 1969, 1973,1983, 1987, 1992, 1995 constitute warm events, and 1950, 1951, 1955, 1956, 1971, 1974, 1976, 1985, 1989 constitute cold events: a total of 17 strong cases. The SST anomaly threshold at which a teleconnected response to midlatitudes occurs is around .5 deg. C.. Hence a separate category could be defined of minor events; these are those in which the anomaly amplitudes are within .4 to .8 deg. C. This would add another 15 cases for a total of 32 cases out of 46 in which composites can be examined.

3.2 **A model ENSO response**

To illustrate the nature of the model's ENSO response an experiment was carried out in which at day zero a realistic temperature anomaly was introduced in the central tropical Pacific and remained fixed in a perpetual January simulation. A total of sixty two month long atmospheric runs, each starting with a different initial condition, were carried out. The ensemble average of these can be used to study the evolution of the ENSO response. Each day in the ensemble average represents a two month average of model fields. By day three the tropical response is spreading out from the region of the SST anomaly (figure 2). A Kelvin wave signal propagates the information about the heating zonally toward the east. There is a suggestion of a much slower Rossby wave like signal, with off equatorial maxima extending the signal towards the west. Weak subtropical highs are developing in both hemispheres and weak lows further poleward. After the first week the general global pattern, although of weak amplitude, is well developed. In the equatorial region the signal has propagated around the globe leading to a general elevation of the tropical height fields which results in a general enhancement of the subtropical jet streams. The enhancement is greatest in the region to the north of the thermal anomaly. In the North American sector a Pacific-North American (PNA) like pattern is well established. The amplitude of this overall pattern increases until it thresholds in about two weeks. After that there are fluctuations, especially in midlatitudes, resulting from higher frequency phenomena.

Associated with this evolution in the height field are circulation changes that produce temperature and rainfall anomalies (figures 3 and 4). Over North America the signature characteristic of ENSO emerges by the second week. The fields in this case are weekly averages (i.e. 14 months of integration). The temperature pattern has above normal temperature over most of the continent; largest values are located in the northwest and a small region of below normal temperatures is located in the south. One region of above normal rainfall is located along the southern edge of the U.S. and a second impinges onto the U.S. west coast in central California.

The positive temperature signature in the northwest is a robust feature of many models simulations of ENSO and presumably of nature. A good representation of its existence would be a large area average of anomalous temperature from 40 N to 65 N and 90W to 120W. The time history of this since 1950 shows several interesting features (figure 5). Three different estimates of this are presented. The first is from the observations. The second is from the 13 member ensemble run with observed SSTs. The third is from the Canonical Correlation Analysis (CCA) forecast run done for cross validation at NCEP. The CCA is in essence a linear regression between various fields, in this case global SSTs and 500 mb heights and land air temperatures (Barnston, et.al. 1992; Graham, et.al., 1987a,b). The CCA is one of the two statistical tools used at the Climate Prediction Center of NCEP for producing the operational multi-season climate forecasts. The largest amplitude temperature anomalies for the model are almost one for one associated with the SST anomalies in the central Pacific. Hence the model effectively teleconnects information about the state of tropical SSTs to this sector of North America. The observations, unfortunately for forecasting, don't show this relationship nearly as well. Out of the classification used earlier, anomalies of the correct sign are not present for 1966, 1969, 1971, 1976, 1985, 1989; however, for these last two years the anomalies do represent a significant drop relative to their surrounding years. Nature shows that over the past 46 winters only in

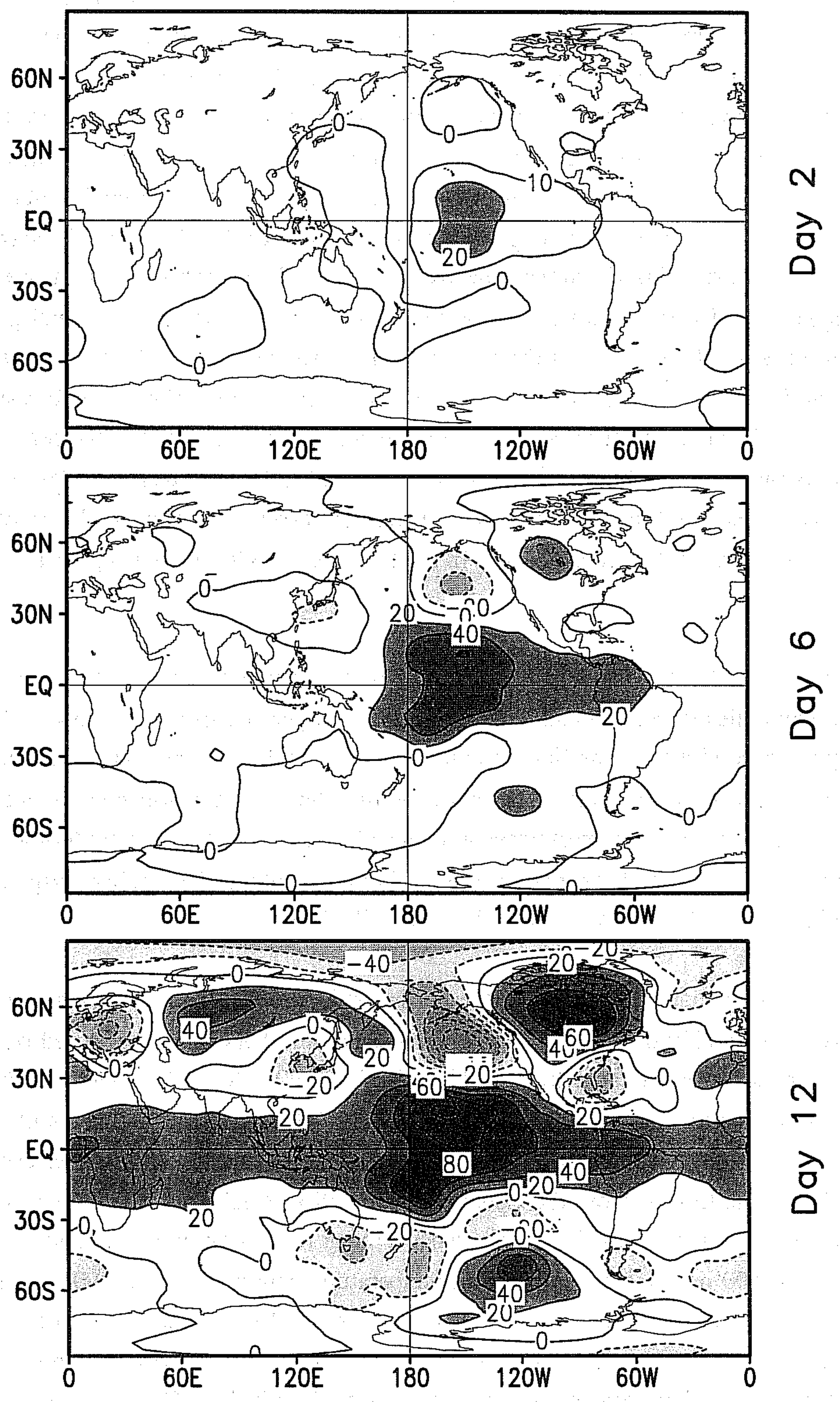


Fig. 2 The evolution of the anomalous 200 mb height field after the introduction of an El Nino like SST anomaly in the central tropical Pacific. The fields are an average of 60 AGCM runs all starting with slightly different initial conditions. The amplitudes of the anomalies threshold in about three weeks. The variations thereafter represent the variability introduced by weather noise.

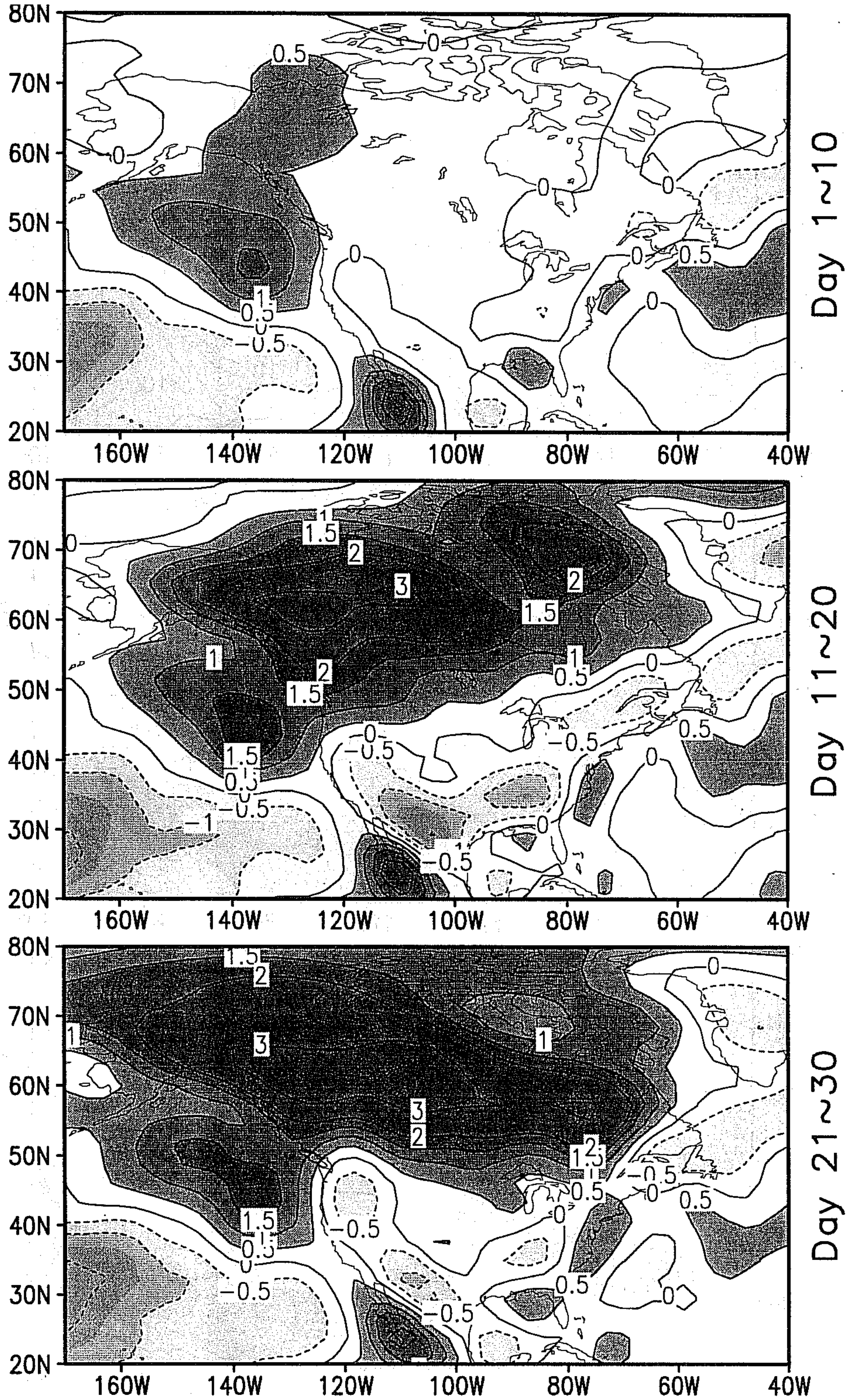


Fig. 3 The evolution of the surface air temperature anomaly from the AGCM experiment discussed in Fig. 3. The units are in degrees Celcius. Ten day averages are used to average over the naturally occurring weather noise in midlatitudes in order to resolve the signal caused by the SST forcing.

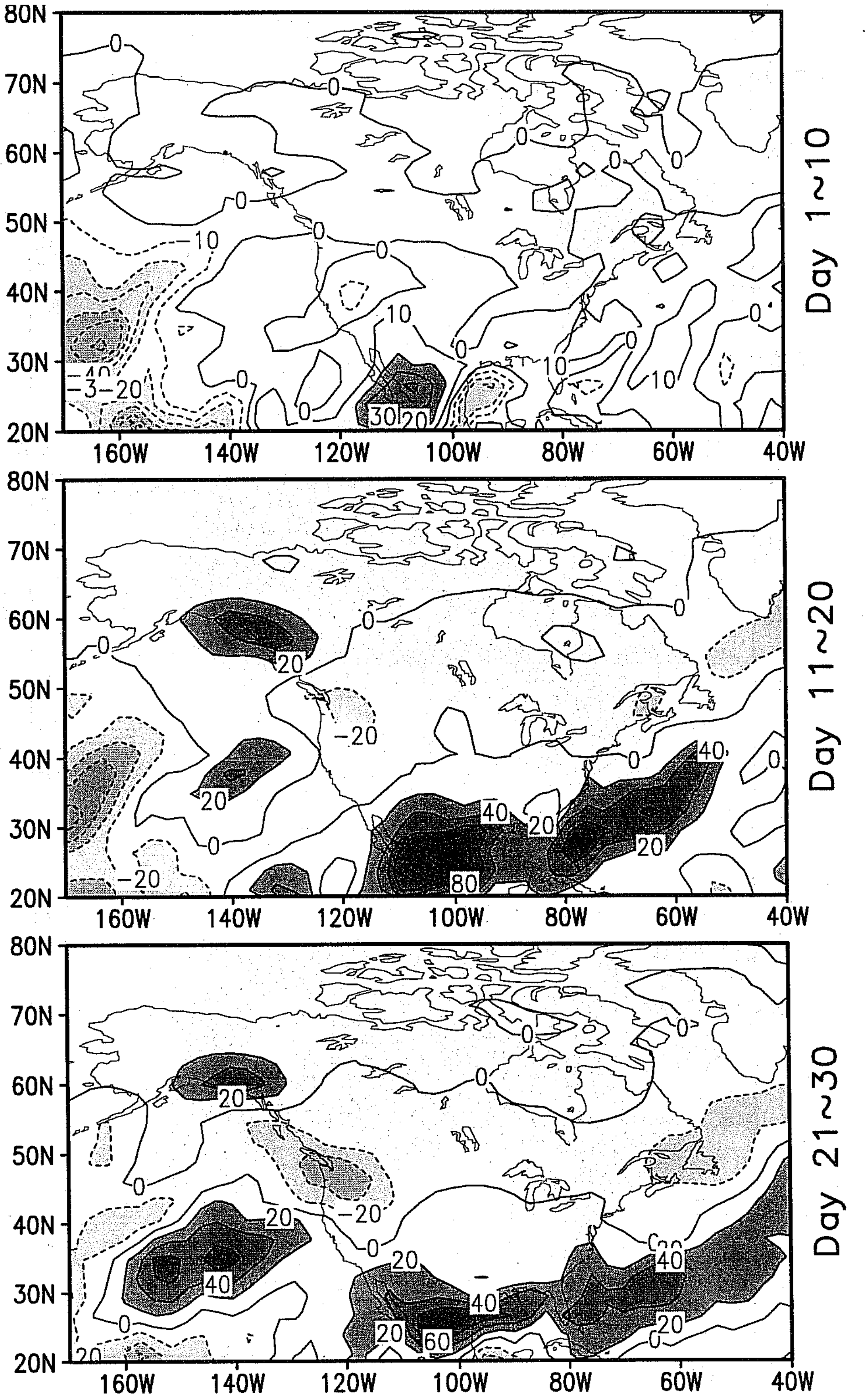


Fig. 4 The evolution of the rainfall anomaly from the experiment shown in Fig. 2. The units are in millimeters per month.

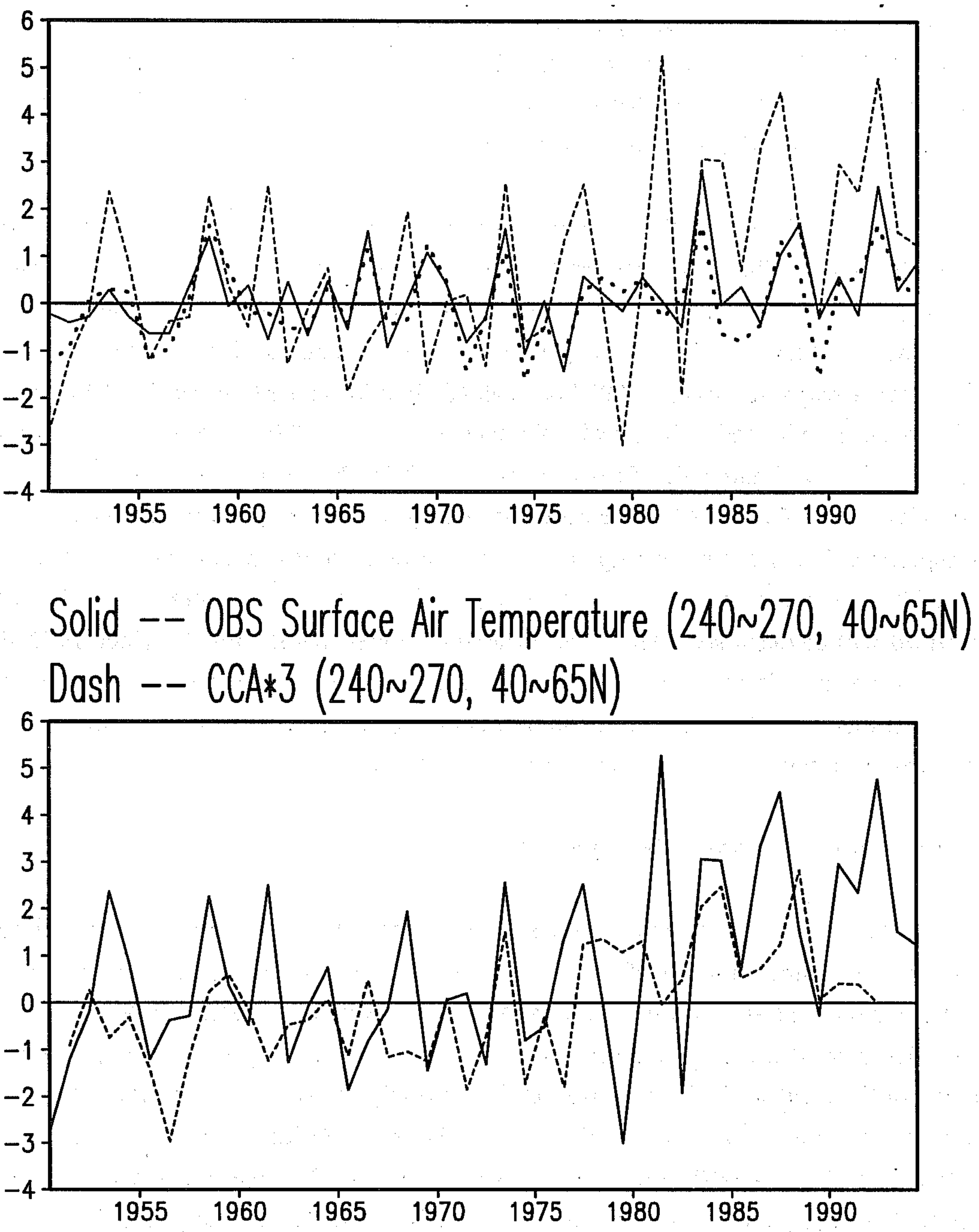


Fig. 5 The evolution of area averaged temperature over the northwestern part of North America. The area lies between 240E-270E and 40N to 65N. In the upper panel the curve denoted by short dashes (the one with the largest amplitude variations) is the observed temperature anomaly. The solid curve is the average from the 13 member ensemble AGCM run that was forced with observed SSTs for this period. The curve denoted by dots is the observed area averaged SST anomaly in the region 180E - 220E and 5S - 5N. Note the close correspondence between this curve and the model temperature anomalies for almost all changes in the SST anomaly. The lower panel shows the observed curve again, this time it is solid, and the CCA value from the cross-validation computation multiplied by three. The units are in degrees Celcius for all curves.

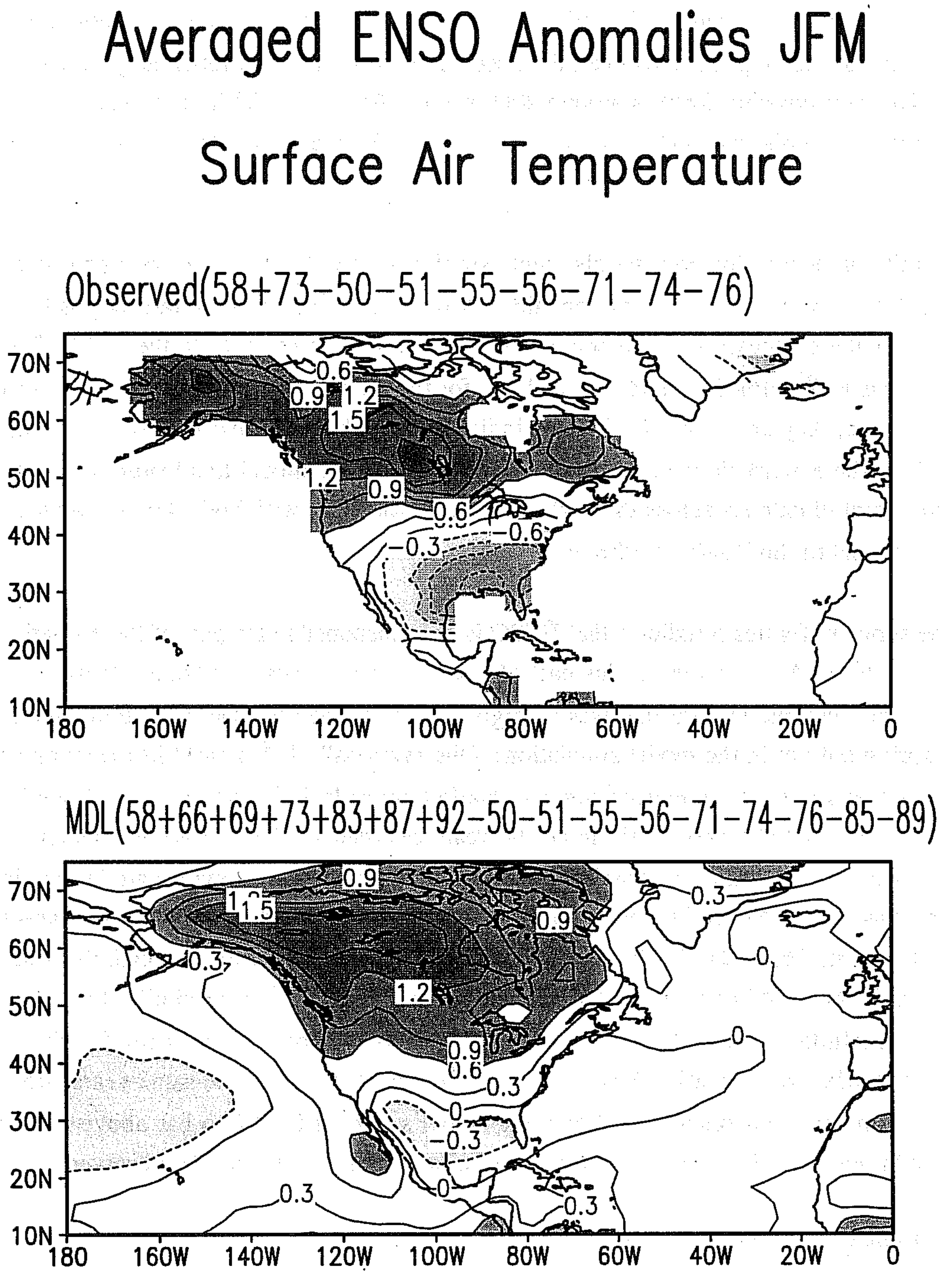
about 65 per cent of the possible ENSO cases the characteristic temperature signal occurs in the northwestern North American. Hence, regardless of what a model forecast system would do - in fact it does it in about 90 % of the cases, a practical upper limit for overall skill for this past 45 years is about 70%. The rainfall signature in the southern U.S. appears to be more robust and appears in some form in all the cases. This will be discussed more fully later.

Another feature which is evident from the observed and CCA time series is the persistent change starting in the late 1970's. Much has been written about a climate shift starting around this time (Trenberth, et.al.,1993). Although the model simulated anomalies tend to be positive after this time, it is clear that the observed response is much larger and persistent. Large positive anomalies, when the model doesn't have a response, occur in 1977 (a weak El Nino in the eastern Pacific, 1981 (no tropical SST anomaly), 1984 and 1986 (weak cold anomalies), and 1990 (a weak positive anomaly). It is likely that the observed anomalies during the major ENSOs that occurred during this time period - 1983, 1985, 1987, 1989, 1992, 1995 - are contaminated by this intradecadal trend. The CCA signature is especially dominated by this signal (as it should be since it is a least squares fit to the data), and its ENSO signatures during this latter time period are difficult to distinguish. The structure of the trend signal will be discussed later. This discussion implies that the ENSOs since 1977 should not be used in the compositing because the anomaly fields are strongly impacted by the intradecadal trend. This reduces the available cases for compositing and biases the composite to cold events since nature did not exhibit a response in the warm years of 1966 and 1969.

3.3 **Rainfall and temperature anomaly composites**

Compositing for the large warm events and large cold events separately shows that by in large the composites for each are mirror images of each other, with the cold ones being the negative of the warm ones. On the other hand, the warm ones are of slightly larger amplitude. For this discussion the average composite is constructed by combining the warm one with the negative of the cold one. The spatial structure of the resultant looks like both but is of slightly smaller amplitude than the warm ones. For the observed rainfall all the significant events before 1977 identified earlier are used. For temperature the years 1966 and 1969 were not used because it was clear that the response in those years did not look anything like the composite. It should be noted that the rainfall anomaly for 1966 and 1969 did look like the average ENSO response; this is one indication that the physical mechanisms that generate the rainfall and temperature anomalies are somewhat different. It will be shown later that the rainfall composite is also a more regular feature of ENSO than the temperature one. For the model fields all the years with significant SST anomalies were used, including those after 1976. The model anomaly fields just do not have a robust intradecadal trend (figure 5) and look much the same before and after 1977. The use of all the years for the model yields a more stable estimate of the composites. As will be shown later, the model's ensemble response for temperature is very similar from event to event.

In an overall sense the observed and model's temperature composites are similar (figure 6). Both



Averaged ENSO Anomalies JFM

Surface Air Temperature

Observed(58+73-50-51-55-56-71-74-76)

MDL(58+66+69+73+83+87+92-50-51-55-56-71-74-76-85-89)

Fig. 6 The air temperature anomaly composites for times when the SST anomalies in the region indicated in Fig. 5 are larger than +/- .8 deg. Celcius. The upper panel shows the observed composite and the lower one the model one for the JFM season. The captions above the figures indicate which years went into these. The units are in degrees Celcius.

show below average temperatures for the southern part of the U.S. and a zonally oriented band of positive anomalies centered around 55 to 60 N. The peak amplitudes in the warm anomalies for both are between 1.5 and 2.0 deg. C.. However, the observed composite has a much larger area of negative anomalies. The zero crossing for it is around 40N whereas for the model it is around 32N. Peak negative values for the observed are over 1 deg C, whereas, for the model they are about a third of this.

The rainfall composites for both are also quite similar (figure 7). The primary signal is one of enhanced rainfall over about the southern one third of the U.S.. Regions with largest positive values are the primarily the southeast and California. The eastern third of the U.S. to the north of this for the observed case has well defined negative anomalies; for the model, although the anomalies in this region are negative, they are weak. Both show indications of above normal rainfall extending northward along the eastern slope of the Rocky mountains. In the model this feature is weaker. Below normal rainfall extends across the northern third of the U.S., with both showing a weak enhancement of this in the Pacific northwest.

The time series in figures 5 indicate that ENSO is only responsible for part of the climatic variability over North America during this past 45 years. Starting around 1978 a persistent intradecadal signal became evident that was strongly present in the observation of temperature for winter and spring but not in the model simulations. Observationally **it is absent** in the summer and fall. The spatial structure of the temperature and rainfall anomaly fields for this are shown in figure 8. These were constructed by compositing all the years between 1977 and 1991 for which a strong SST anomaly was not present in the tropical Pacific. The temperature anomalies are largest in the northwestern quadrant of North America. Positive anomalies are found in the northwest and negative ones to the southeast. While the ENSO related anomaly was largely zonally oriented, this one is rotated counterclockwise 45 degrees from that. The rainfall anomaly is very similar to that for ENSO but of weaker amplitude. The southern half of the U.S. exhibits above normal rainfall, with below normal rainfall further to the north. A composite of the model fields for the same years shows essentially no temperature anomaly; however, the model's rainfall field also has above normal rainfall for the southern one half of the U.S. with a somewhat larger amplitude that the observed.

3.4 **Correlations with individual years**

To examine the stability of these pattern, they were correlated against all the cases when there were significant positive or negative SST anomalies in the previously defined index area. The model's ensemble composites were correlated against the individual model's ensemble average anomaly fields and the observed against the observed. Additionally each member of the ensemble was correlated with the composite and the mean of these correlations computed for each year. This latter estimate should closely resemble that being done with the observational fields since nature performs only one realization. A summary of the results of these correlations is presented in Table 1. When appropriate two rows of correlations are presented for each category. The upper one includes all years when

RAINFALL

	model-ensemble	observations	model-members
COLD (all)	.22	.50	.11
COLD (good)	.43 (3)	-	.19 (3)
WARM (all)	.46	.59	.23
WARM (good)	.56 (1)	-	.24 (1)

TEMPERATURE

	model-ensemble	observed	model-members
COLD (all)	.53	.30	.25
COLD (good)	.77 (2)	.58 (3)	.34 (2)
WARM (all)	.88	.47	.53
WARM (good)	-	.68 (2)	-

Table 1. Correlations of composites with model ensemble members, model members of ensembles, and observed fields over North America.

DJF season	model version 9	model version 10
8206-9205	0.86	0.79
8306-9305	0.72	0.76
8406-9405	0.73	0.82
8506-9595	0.70	0.77

all seasons	model version 9	model version 10
8206-9205	0.79	0.76
8306-9305	0.65	0.68
8406-9405	0.64	0.69
8506-9505	0.59	0.64

Table 2. Correlation Skill Score for Nino-3 over 10 year periods for the winter season and also for yearly average (all seasons averaged) for two versions of the NCEP coupled forecast system.

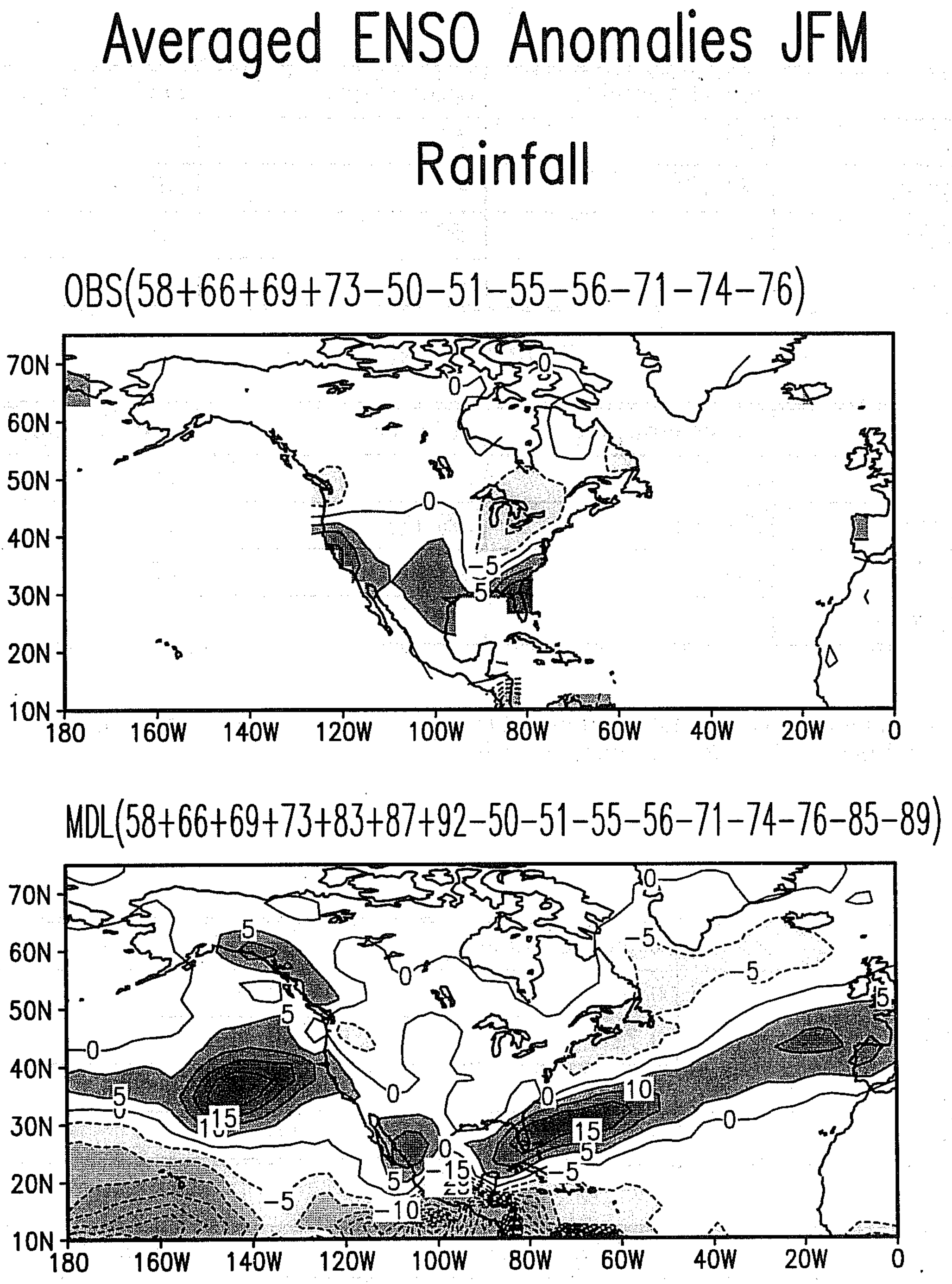


Fig. 7 The rainfall anomaly composites for times when the SST anomalies in the region indicated in Fig 5 were larger than +/- .8 deg. Celcius. The upper panel shows the observed composite; the lower panel shows the model composite. The captions above the figures indicate which years went into these. The units are in millimeters/month. These are for the JFM season.

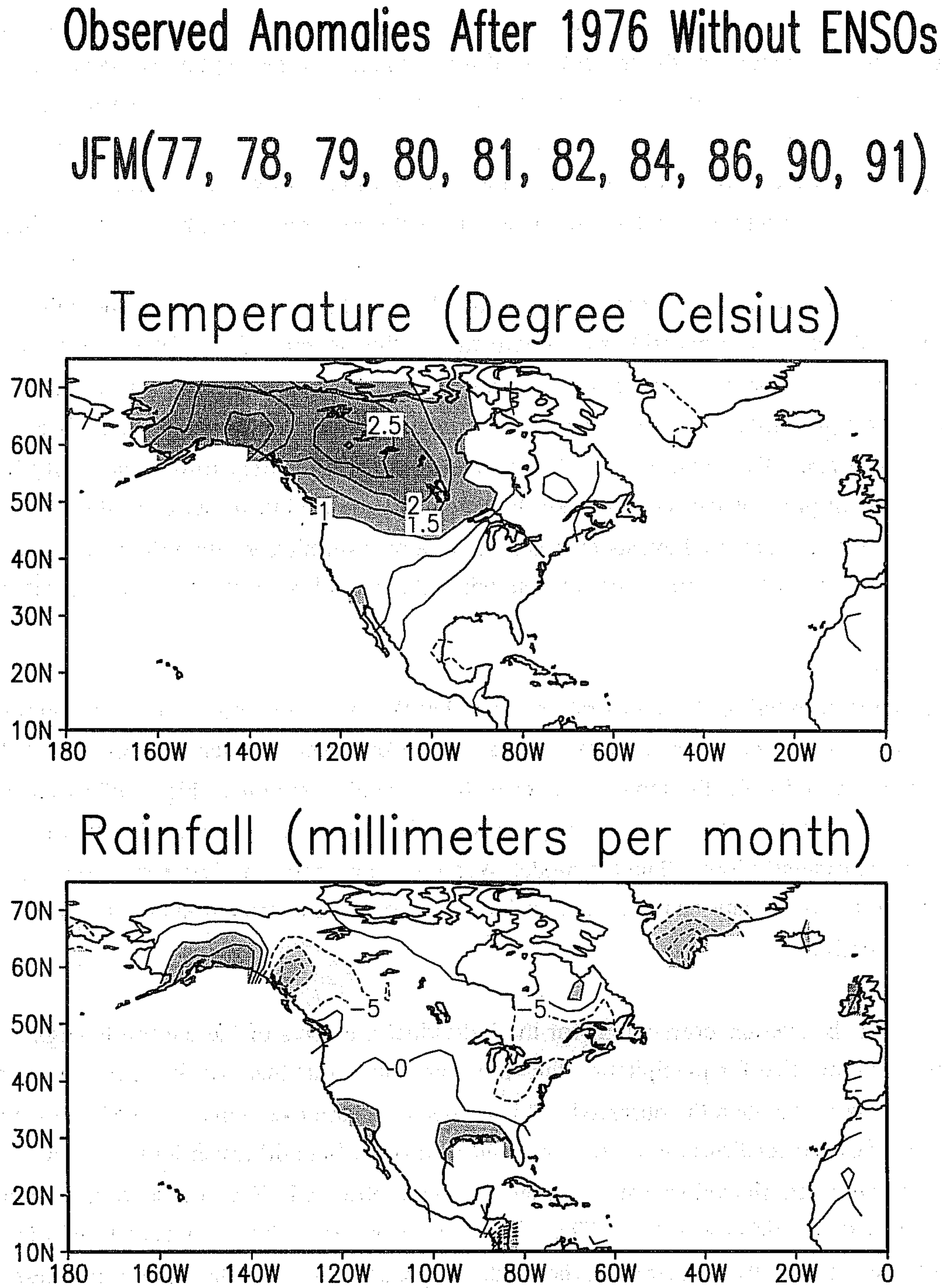


Fig. 8 The temperature (upper panel) and rainfall (lower panel) anomaly composites for the JFM season for the intradecadal trend. The years used are indicated in the caption above the figures.

significant temperature anomalies were present in the tropical Pacific. Hence this is representative of the skill if the composite were used as a forecast in conjunction with the SST anomaly field from the tropics. This value also represents the lower limit of the ultimate forecast skill since presumably as techniques come on line to forecast deviations from the composite the skill will increase. The lower one shows the correlation when the members with negative correlation, i.e.. those that clearly did not look like an ENSO impact, were excluded. This value is an estimate of how stable the anomaly field is from event to event. The numbers in the parentheses indicate how many members were excluded.

Examination of these correlation figures for rainfall show that the observed fields are very stable despite the fact that there is considerable spatial structure to this anomaly field. Every time there is a strong SST anomaly, the composite pattern in general form is present. The correlations for the warm events are slightly higher than they are for cold events indicating that the warm response is more robust than the cold one. The overall values for the model are considerably lower, especially for the cold events. These improve when the obviously bad members are excluded, but even then are still not as good as the observed. The cold events also had more poorer simulations than the warm ones. When the one bad case for the warm years was excluded, the overall correlation was comparable to the observed.

Interestingly the correlations for temperature show that the model ensembles are much more stable than the observed. In essence for each warm case the model produced the warm composite. When the two cold cases are excluded for the model, the correlations are also extremely high indicating that there is little variation from case to case in the pattern that is produced. The overall correlations for the observed are consistently lower than the model. Again the cold cases are less robust than the warm cases. Even when the obviously bad cases are excluded, the observed correlations are lower than those for the model ensembles.

Examination of the average correlations for the individual members of the ensemble (right column, Table 1) shows that for precipitation the values are much less than for the ensemble means, which themselves were less than the observed. This remains the case even when the bad years were excluded. Warm year correlations are larger than cold year ones, but still much less than the observed. For temperature the values were comparable to the observed. Warm case values are again significantly larger than cold case values. The general correspondence between model and observed values suggests that at least for temperature, the model response is of about the same robustness as nature's and in general it behaves similarly to nature in that warm responses are more robust than cold ones. The general implication is that temperature forecasts during cold events will be less skillful than during warm events. For rainfall, improvements need to be made to the model or the way the model is run in order to achieve the level of skill nature suggest is obtainable. Simulations with idealized SST anomalies seem to have a more repeatable rainfall response than those with observed SST. This suggest that the temporal and spatial variability in tropical and midlatitude SST anomalies somehow contributes to the variability in the rainfall response.

3.5 Forecast for JFM 1995

In the fall of 1994 positive SST anomalies in the central tropical Pacific were already well established (figure 9). Our coupled model forecasts indicated that positive SST anomalies would continue through the winter. Based on our experience with the AGCM when forced with similar SST anomalies, it was reasonable to expect that something like the composite response (figures 6 and 7) would be the forecast. It came as quite a surprise that the actual forecast made in mid-November looked quite different. The forecast indicated that: much of North America would have below normal temperatures; the southeast would have above normal rainfall; the west coast of the U.S. would have below normal rainfall; the height fields did not look warm ENSO-like. A number of different experiments were carried out to understand why the forecast response was so different than the expected and ultimately the observed one.

A feature which we hadn't paid attention to were the large positive anomalies in midlatitudes and in the Indian Ocean that were also present at this time (figure 9). For the ensemble forecasts the SST field is constructed by using the forecast SSTs within 15 degrees of the equator in the Pacific. Elsewhere the observed anomalies at the time of the forecast were persisted for a season and then damped to zero in the next season. The tropical forecast anomalies at this time were positive, but weak (of order .5 deg. C.). Hence for this forecast the SST anomalies were strong in midlatitudes and in the Indian Ocean and weak in the tropics. Experience suggest that with this AGCM tropical anomalies of about .5 deg. C. are at the threshold for getting an ENSO like response in the extratropics. In retrospect the potential for a poor forecast should have been evident. A number of experiments were tried using different combinations of SST anomalies: a) persisted SST anomalies were used everywhere, b) only tropical Pacific SST anomalies were used and persisted; c) only tropical Pacific forecast anomalies were used; d) only the observed midlatitude anomalies were used and persisted.

Experiment a) had close to a composite like response except that the U.S. west coast was still forecast to have below normal rainfall. This occurred because the height field was shifted westward by about 30 degrees relative to the composite. The end result of this is that the resulting anomalous circulation in this region was offshore (i.e. off the continent) rather than onshore. Experiment b) gave the composite response, including above normal rainfall for California. Experiment c) gave essentially a weak composite response. Experiment d) gave results very close to the initial forecast. Compared to what happened (figure 10) the best results came from experiment b), i.e strong tropical Pacific SST anomalies with no midlatitude anomalies. Midlatitude anomalies have an impact on this model, but the model response seems to be incorrect. Even in the presence of a strong tropical SST anomaly, a strong midlatitude SST anomaly for this model degrades the result. With a weak tropical anomaly , it dominates and can give the wrong result.

As a result of this experience (and the following month's forecasts which had similar problems), the actual forecast procedures have been modified in two ways. The initial SST anomalies outside the tropical Pacific are damped in essence to zero by the time the official forecast starts (a lead time of 1.5

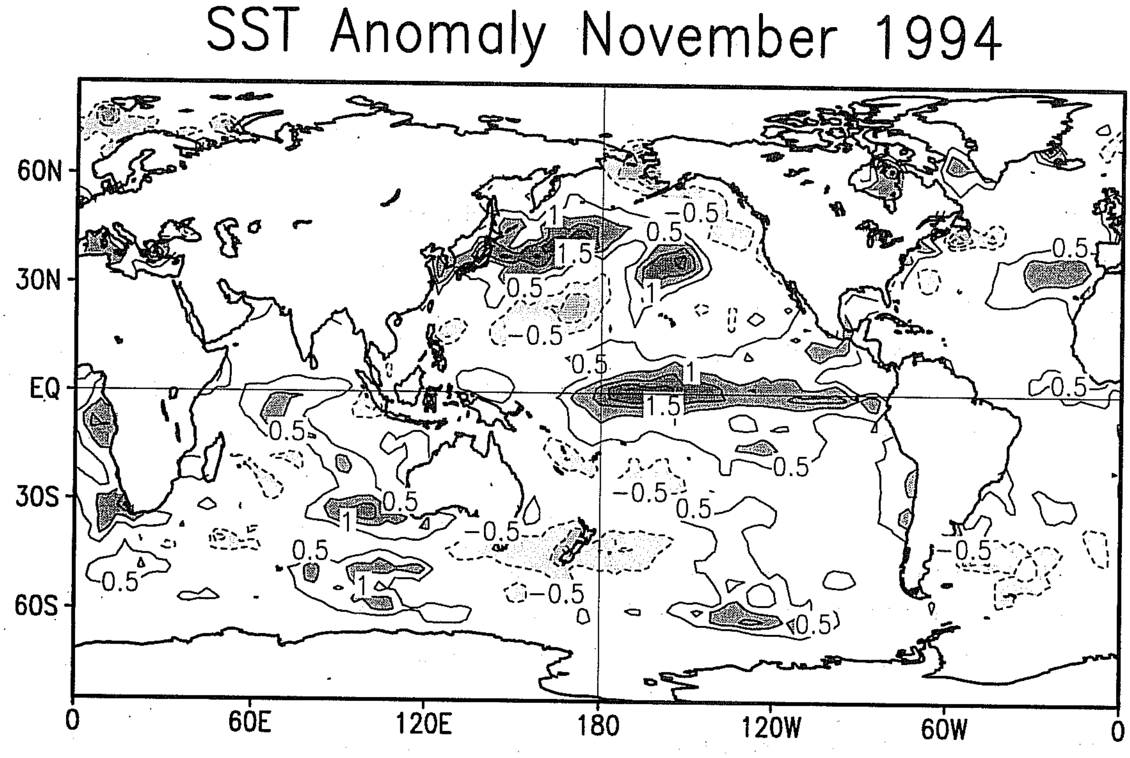

SST Anomaly November 1994

Fig. 9 The observed sea surface temperature anomaly for November 1994. Note the strong anomalies in the equatorial Pacific, the equatorial Indian Ocean, and in the midlatitude Pacific. The units are in degrees Celcius.

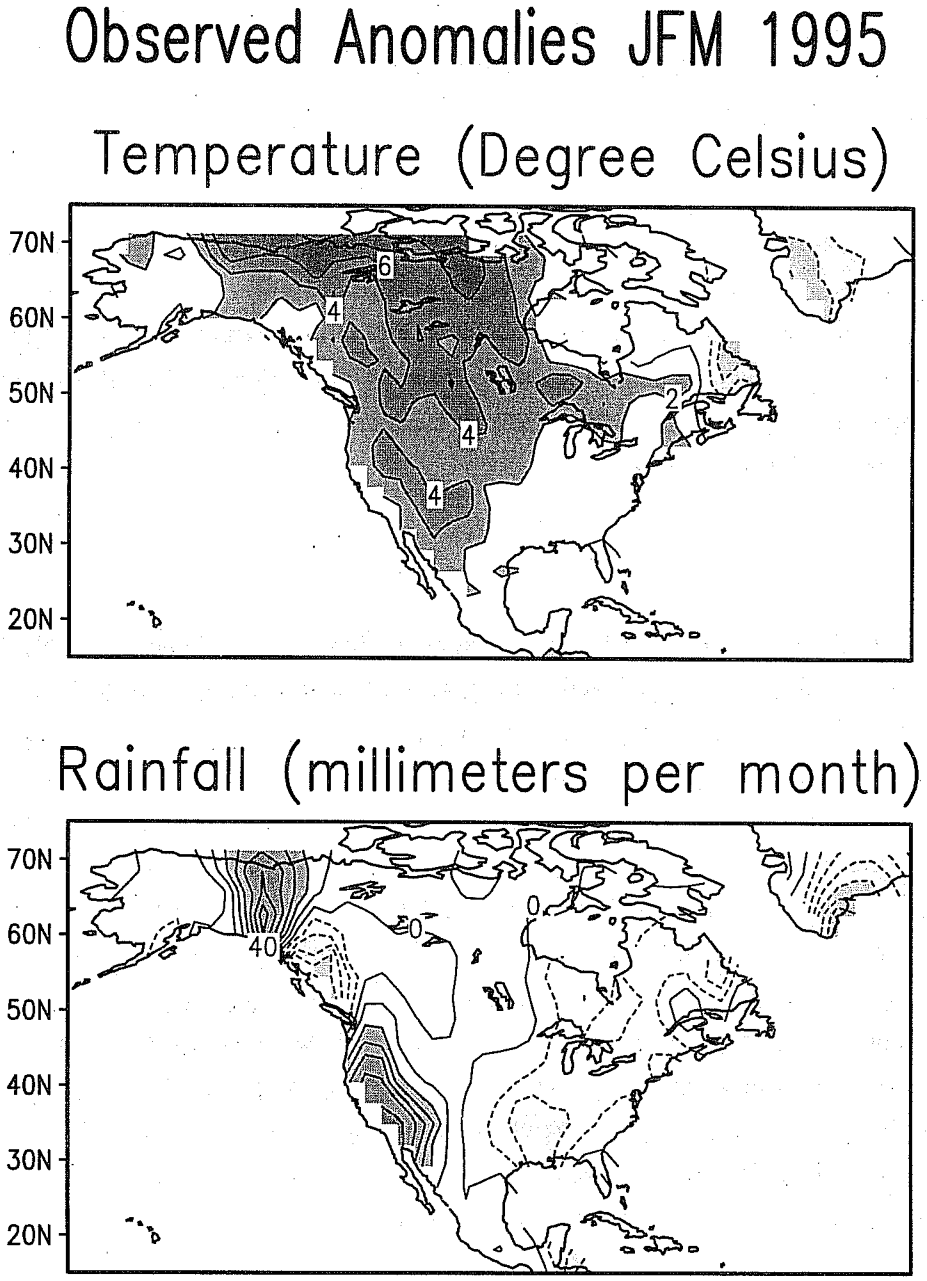


Fig. 10 The observed air temperature and rainfall anomalies for the JFM season in 1995.

months is used for these forecasts). Secondly a second set of ensembles is run in which for the first season of the forecast the tropical SST anomaly consists of a combination of the observed anomaly at the initial time and the forecast anomaly. The overall anomaly goes from all observed initially to all forecast after a season in a linear fashion. This latter ensemble attempts to correct for forecast anomaly amplitude discrepancies for the first season.

A comparison of the observed JFM 1995 response with the ENSO and intradecadal composites show that a probably significant contribution to the temperature signal was made by the intradecadal signal. For rainfall much of the southeast was drier than normal, with only southern Florida having above normal rainfall - an amplification of the below nomal rainfall structure in this region in the composite. The big signal was the record breaking flooding in California. The differences point to the fact that composites are of limited use as forecast tools and the next challenge is to forecast the deviations from these - if that is possible.

4. DISCUSSION

The framework of a system for multi-season forecasting has been implemented at NMC and a modicum of forecast skill has been achieved. In a general sense this can be viewed as a gross capability to i) forecast El Nino, and ii) to forecast the average atmospheric response to El Nino. In practice the ensemble technique with the current level of sophistication in the AGCM and the forecast SSTs, produces atmospheric responses which from event to event are more similar to each other than are the observed ones to each other. In a way this is fortuitous because at present it is not know what part of the observed response for individual events is related to ENSO, other climate signals, or weather noise. Hence being able to define a composite ENSO response and being able to forecast this is the zero order test for models. The discussion herein was for the winter season when the teleconnected response is strong. Similar analyses should be done for the other seasons when the response will be different and weaker. Such studies are also underway at NCEP. The composites, if forecast accurately, give the lower limit of the ultimate forecast skill. To go beyond this will require the ability to forecast deviations from these composites. Presumably only a portion of these deviations are predictable and arise from spatial and amplitude variations in the boundary forcing. The rest result from noise and cannot be predicted.

The predictable aspects of such deviations will most likely depend on details of the spatial structure and amplitude of the boundary forcing anomalies. Estimating the sensitivity of the atmospheric response to other than the classical El Nino SST anomaly is an important first step. Simulations have been done with the NCEP model in which a thermal anomaly is moved in steps of 15 degrees of longitude along the equator from the western Indian ocean to the eastern Pacific. Not unexpectedly the response varies considerably depending on the location of the SST and hence atmospheric heating anomaly. Only fields from two locations will be discussed here because they are potentially relevant to the intradecadal response and hence to Europe. When the heating anomaly is around 80E to 120 E a strong anomalous positive height field anomaly is located over northwestern North America (figure

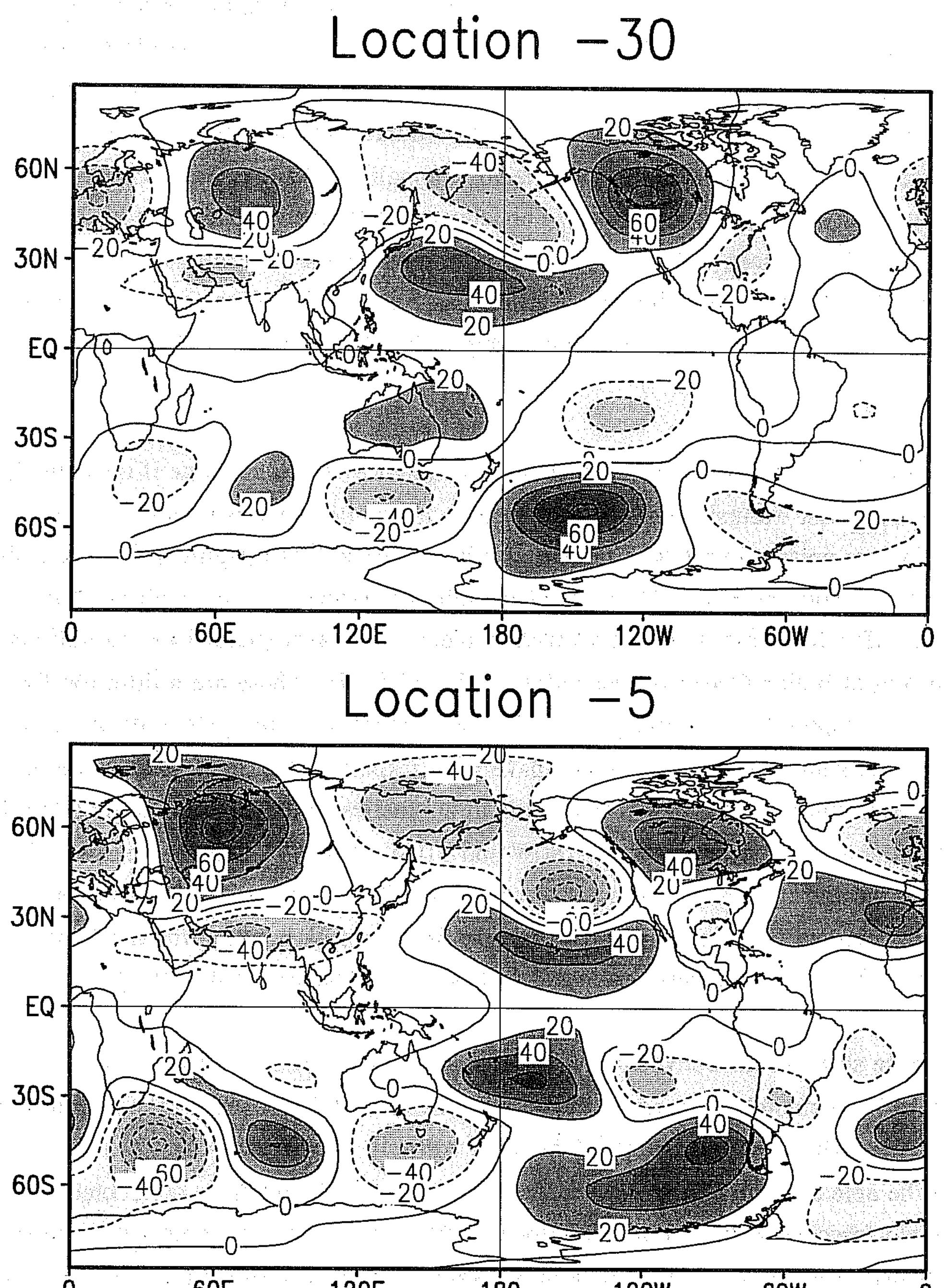


Fig. 11 The anomalous 200 mb height fields for two experiments when the SST anomaly was in the central equatorial Indian Ocean (upper panel) and in the central eastern equatorial Pacific (lower panel). These are two year averages from perpetural January simulations.

11). This has associated with it an anomalous temperature field that looks very much like the intradecadal trend signal shown in figure 8. When the heating anomaly is located in the eastern central Pacific, a classic PNA like structure is present over North America. Interestingly there is a North American Oscillation (NAO) like pattern over the Atlantic for this position of the SST anomaly. The NAO is a zonally oriented pattern with low height anomalies between about 45 and 75 N and positive height anomalies further to the south. This appears to be the other feature of the intradecadal trend signal. The NAO has been conspicuously absent in most of the experiments with the NMC AGCM, but conspicuously present in the observations this last decade. These experiments suggest that the presence of certain modes in seasonal averages might depend on the location of the anomalous tropical heating.

The observational data sets are of little use before the late 1970's to examine if over the open ocean such large east-west excursions of the precipitation anomalies have occurred. However, one can examine the variations present in model simulations with observed SSTs (figure 12). These show for the JFM season that before the late 1970s most of the rainfall anomalies were centered between about 160E and 140W. After that time two changes were evident. Persistent (trend-like) rainfall anomalies appeared in the central Indian Ocean between about 70E and 100E. These are a little too far to the west to generate the response shown in figure 11, but their persistence and proximity to the right location suggests that something like this could have been responsible for part of the trend signal. Additionally starting with the 1983 El Nino the rainfall anomalies in the central Pacific started to be located further to the east, i.e. between about 180W and 110W, than they had been earlier. This is especially true for the spring season. In the observations the NAO was only weakly present before the 1980's and is most evident in the spring. This is suggestive of a link between the increasing occurrence of the NAO and the general eastward shift of the convection in the late 1980's.

To capture these shifts in the convection, forecasting of SST has to move beyond El Nino. Variations need to be accurately forecast throughout the tropical belt not just in the central and eastern Pacific. Are such forecasts feasible? Only time will tell. However, indications are that we certainly should be able to do better than we can at present. At NMC we have conducted a variety of forecasts or pseudo-forecasts using initial conditions established with and without data assimilation. Pseudo forecasts use observed forcing fields with the same heat flux formulation as one of our coupled models, i.e. negative feedback. The indications from these experiments are that the best forecasts/simulations come from: i) initialization with data assimilation and using the observed forcing; ii) from the use of observed forcing with no data assimilation; iii) the coupled forecasts using data assimilation. The observed forcing in this case was the FSU pseudostress product (Goldenberg, et.al., 1981) which is primarily based on surface marine reports. This has considerable room for improvement. There is a large difference in skill between what we can forecast now and what we could do if our coupled model's wind stresses were comparable in quality to the FSU ones. Is this too much to hope for? We think not.

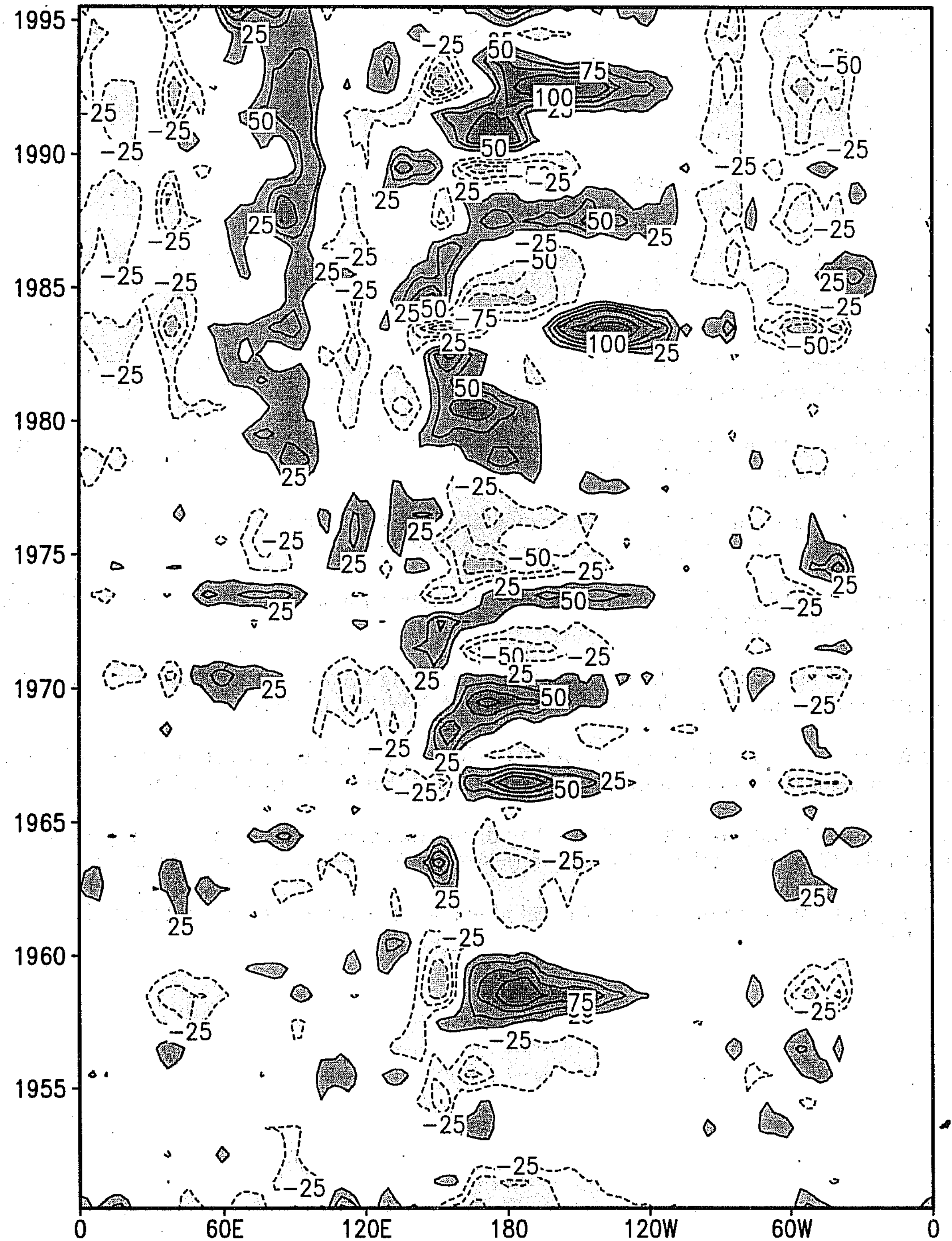


Fig. 12 The anomalous rainfall averaged from 10S to 10N from the 13 member ensemble run forced with observed SSTs. The mean annual cycle that was removed was for the period 1950 to 1980. The units are millimeters/month.

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