

A comparison of NMC and CAC sea surface temperature analyses

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1. INTRODUCTION

Since 21 July 1982 ECMWF has been using the operational NMC sea surface temperature analyses as received over the GTS to specify the sea surface temperature in the data assimilation and forecasts. The quality of these analyses came into question during the recent El Nino event when they failed to capture some very large anomalies (up to 5°C) over large parts of the Pacific; these anomalies were identified by subsequent analyses by the CAC. Heckley (1983) has compared the NMC operational SST analyses with the CAC analyses for the period May, 1982 to June, 1983. The object of this study is to consider the differences in techniques used to produce these analyses.

2. DATA SOURCES AND AVAILABILITY

Direct sea surface temperatures are obtained from ship reports, fixed and drifting buoys, and BATHY/TESSAC reports; remote measurements are obtained from satellites. These data differ in instrument accuracy, position accuracy, measurement depth and areal extent. SST data, transmitted by ships in their routine weather reports, are measured at sea water intakes located on the ship's hull, 4 to 8 metres below the water line. Fixed buoys provide reliable temperature measures within one metre of the surface but are confined to coastal regions. Drifting buoys also measure temperatures less than a metre below the surface and provide valuable data in the tropics and southern oceans. XBT (expendable bathythermograph) reports provide the most accurate data available for ocean surface temperatures but are concentrated in areas of special projects and shipping lanes. Satellite measurements are the most satisfactory in terms of distribution and quality. They exhibit less variability than ship "intake" temperatures over a region, but at the same time may be subject to biases. Further, there are many ocean areas around the world that are obscured by clouds for extended periods of time, severely limiting the number of satellite observations. Fig. 1 is an example

of the satellite data coverage for the Atlantic region for September, 1983; it shows large geographical variations in the number of satellite SST reports during the month. The number and location of fixed buoys, drifting buoys and XBT data for September, 1983 are shown in Fig. 2. As mentioned earlier, the fixed buoys are confined to the coastal regions. There are some useful drifting buoy data over the equatorial Pacific. There are more XBT data but they are mostly confined to the shipping lanes. Fig. 3 contains all the information in Fig. 2 but also includes ship observations. It is clear that the ship data far outnumber the buoy data, even in the tropics, but they are largely confined to the northern extratropics. Even in this accumulation over a whole month there are large regions where there are no direct SST observations at all.

The quality of sea surface temperature reports from merchant ships has been evaluated by Tabata (1978). Fixed buoy and ocean station P data, averaged over 3 day periods, were compared with ship data in their vicinity in the NE Pacific Ocean. Ship data were found to be $0.2^{\circ} \pm 1.5^{\circ}$ warmer than the buoy and station data (Tabata states that the buoys are comparable to ocean station P which was determined to have an accuracy of $\pm 0.2^{\circ}\text{C}$). These results agree with those of James and Fox (1972) who made a comparison of intake temperatures versus bucket temperatures using data taken under the auspices of the WMO. They reported that for 13876 observations, ship intake temperatures were $+ 0.3^{\circ} \pm 1.3^{\circ}\text{C}$ warmer than bucket temperatures.

The satellite estimates the average temperature over a 100 km square. A set of edited ship reports when compared with satellite data, within 100 km and a 24 hour period, produced global daily mean differences during July, August and September, 1978, which ranged between -0.2° to $+0.8^{\circ}\text{C}$, with an RMS deviation near $\pm 2.5^{\circ}\text{C}$ (Casely, 1978). Aerosols from the El Chichon eruption have

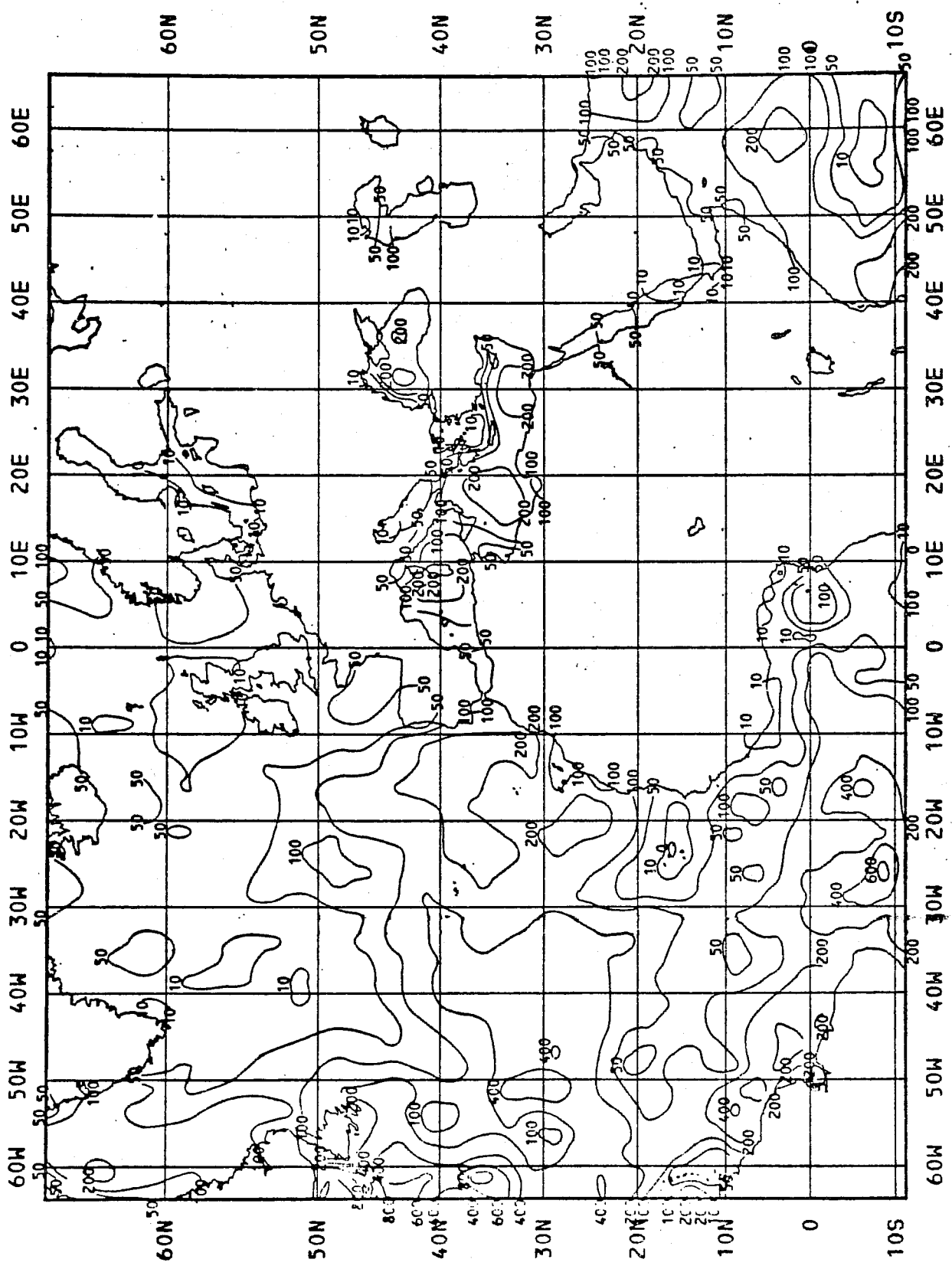


Fig. 1 Number of satellite SST observations accumulated during September 1983

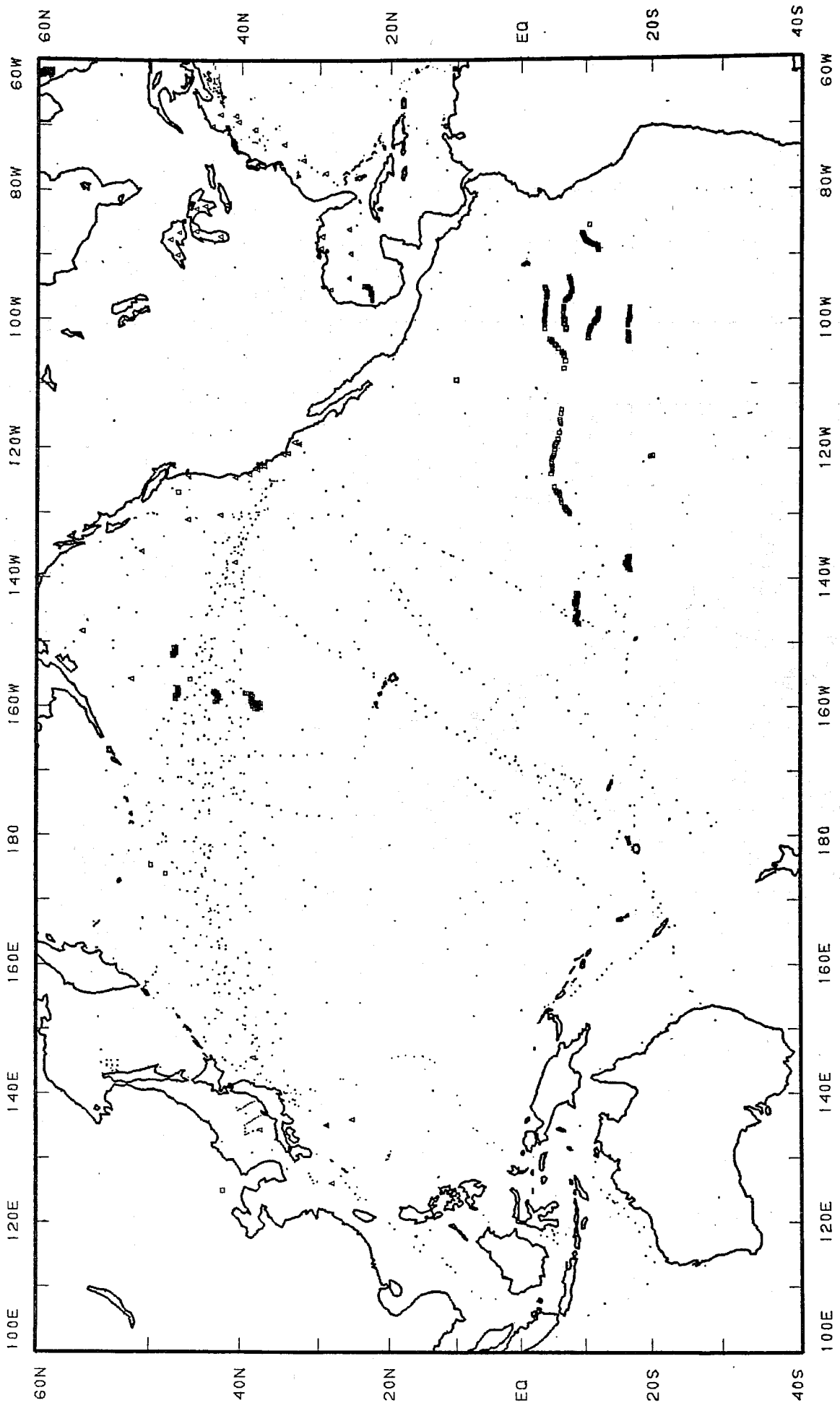


Fig. 2 September 1983 GTS SST OBS: Fixed buoy (Δ), drift buoy (\square), XBT (\bullet)

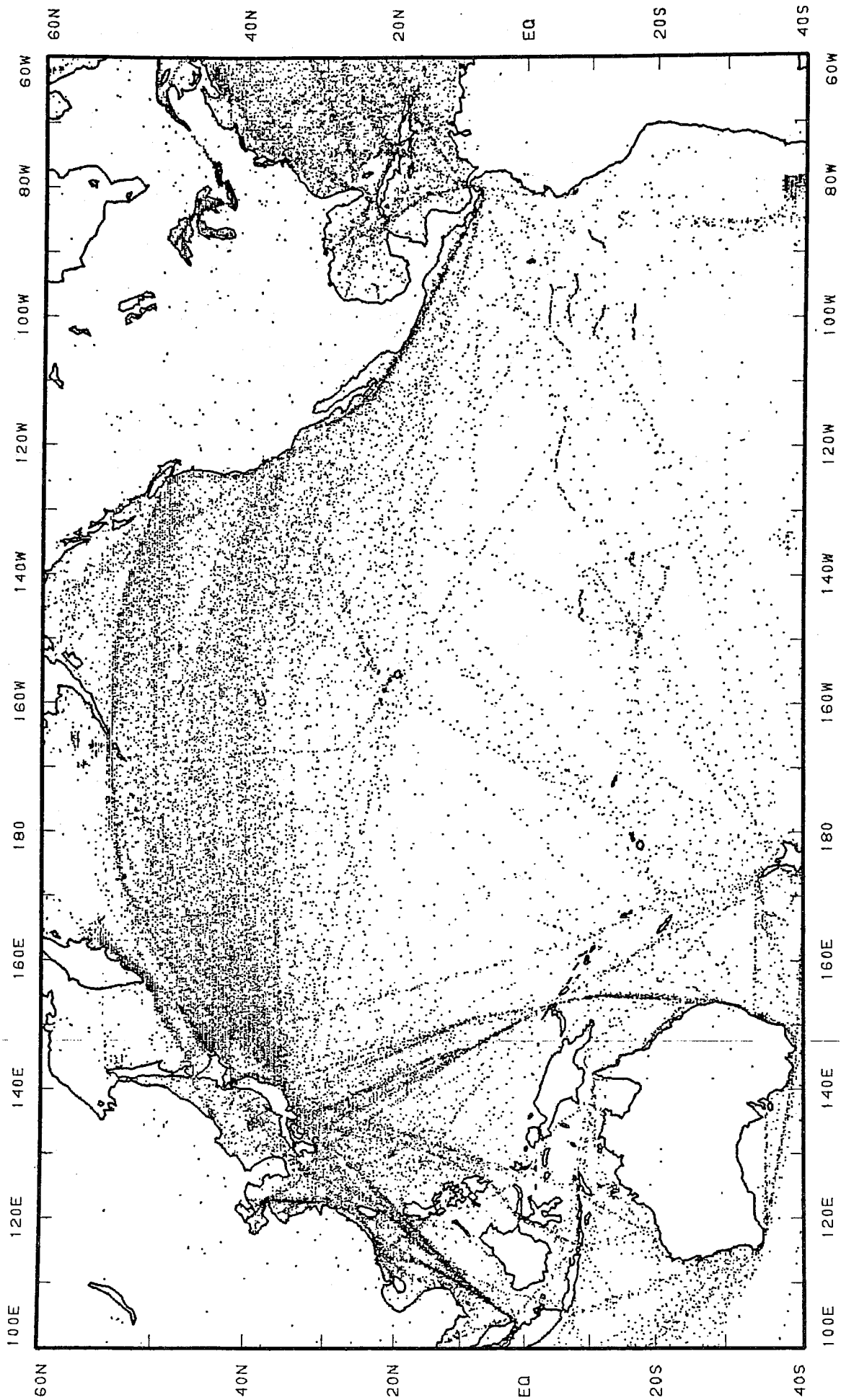


Fig. 3 September 1983 GTS SST OBS: Ship, fixed buoy, drift buoy, and BXT

resulted in cold biases in the satellite SST estimates of -1°C to over -2°C ; these biases are functions of both position and time (Strong, 1983).

3. THE OPERATIONAL NMC SST ANALYSES

3.1 Description of technique

These are described briefly in Gemmill and Larson (1978). Analyses are performed on alternate days (i.e. data are accumulated over two days) for the Northern and Southern Hemispheres on a 129×129 polar stereographic grid which has a mesh length of 202.6 km at 80° (N/S) and 102.1 km at the equator.

Observations taken from surface platforms (ships, buoys, XBT's) are partitioned from satellite observations within the analysis. This is accomplished by executing the analysis scheme first for all surface data and then a second time for satellite observations.

The initial step of the analysis procedure, shown in Fig. 4, is to form a first guess anomaly field by subtracting from the previous analysis the climatology. The first guess field is used as a "standard" against which the observations are compared. In order to ensure that this field is reliable, large anomalies are reduced unless they are supported by observations within the last ten days. The observations are weighted relative to each other based on the type and age of the report. These weights are then summed at each grid point having more than one report during the past ten days and the total "coverage value" is used in limiting the first guess anomalies. This means that unless there have been enough observations over the last ten days in a particular region, anomalies will be removed from the first guess anomaly field.

The anomaly field is then smoothed to avoid abrupt spatial changes and added to the climatological field to form the first guess. The data are then analysed in a series of five passes through the procedure shown in Fig. 5. In each pass, the first guess field is interpolated at the location of each report through a non-linear interpolation scheme. The analysed field resulting from each pass becomes the first guess for the next pass.

At the location of each observation, a difference is formed by subtracting the interpolated first guess value from the report. The difference is then compared to a tolerance which varies with each pass and for each type of report (the tolerances decreasing with each pass). If the tolerance is exceeded, the report is rejected for the current pass. All reports are checked during each pass. Since the resulting analysed field is used as the first guess for the next pass, reports initially rejected may be accepted later if the previously accepted reports have modified the temperature field in such a way as to reduce the difference between it and the rejected report.

For each accepted observation, the difference is weighted relative to others on the basis of its age and type. A percentage of this weighted difference is used to correct the first guess at the four grid points surrounding the observation. The actual percentage of the difference is inversely proportional to the distance between the grid point and the observation. At each grid point, the weighted differences from each report lying within one mesh length are accumulated, averaged and added to the first guess to form the new value of the temperature field. The influence of the accepted reports is spread to grid points not connected through a conditional relaxation method

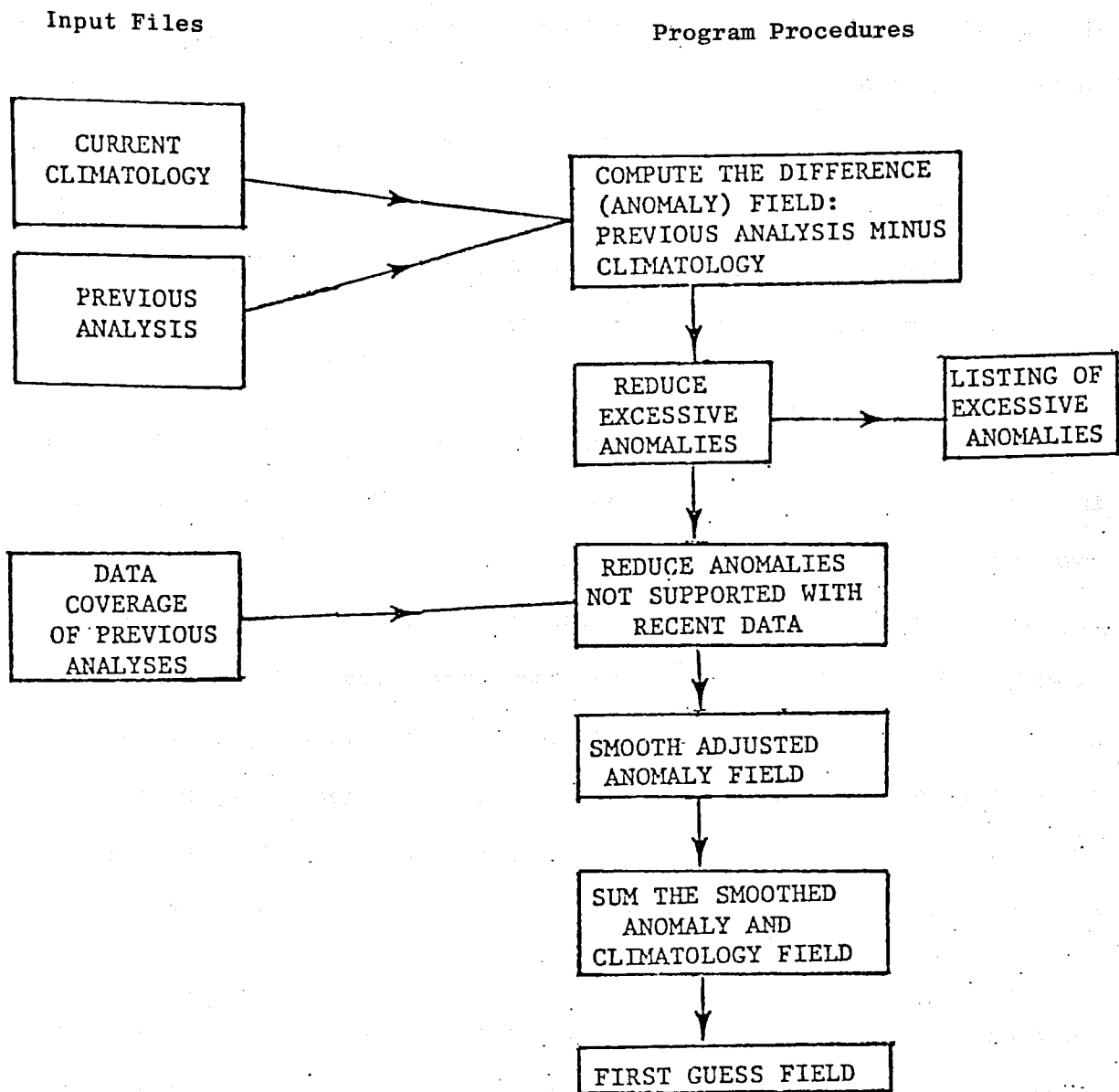


Fig. 4 Flow diagram of the first guess step

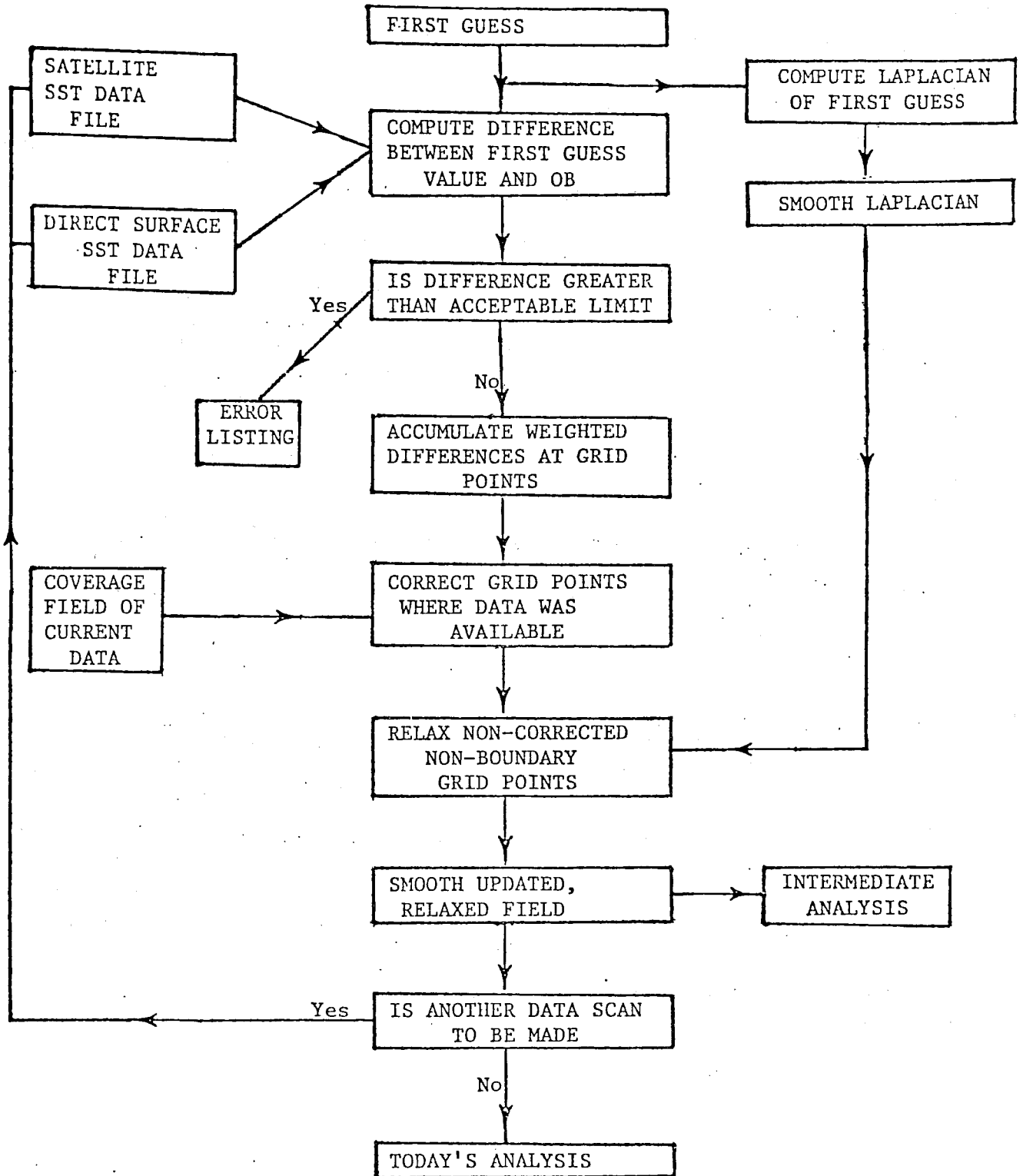


Fig. 5 Flow diagram of analysis step

(Carstensen, 1962). The relaxation formula is

$$T_n = T_{n-1} + 0.32 (\nabla^2 T_{n-1} - \nabla^2 T_0)$$

where T_0 is the first guess field and T_n is the field after n iterations. The residual $(\nabla^2 T_{n-1} - \nabla^2 T_0)$ is calculated at each grid point which has not been corrected by observations and added to the temperature field at these points. If the residual at each grid point is less than a small, pre-determined number everywhere on the grid, the relaxation is considered to have "converged" to the correct solution. If this is not the case additional iterations are performed until the convergence criterion is met.

The number of reports which were accepted in the final pass at each grid point are stored as a coverage field to be used to constrain the first guess in later analyses.

The entire analysis procedure is then executed again for satellite data and the difference between the surface data only analysis and combined surface and satellite analysis is stored as a satellite data impact field.

3.2 Recent modifications to the analysis scheme

The global SST analysis began in January 1979. The following is a chronology of modifications to the scheme.

June 1979 The "window" of acceptance of satellite data was reduced. This was done because of large bias problems with these data.

Sept. 1979 Satellite data excluded in North Hemisphere
 (30°N to pole).

March 1981 Change in climatology to Robinson-Bauer. This was done
 because a higher resolution climatology was needed,
 especially in coastal regions.

Nov. 1981 Begin use of Multi-channel SST satellite retrievals.
 Satellite data now more accurate.

May 1982 Increase satellite data coverage to North Pole.
 A consequence of the more accurate satellite data.

August 1982 Exclude satellite data in northern subtropical zone
 due to volcanic debris contamination (10°N-30°N).
 Aerosol contamination producing large negative biases
 in satellite retrievals.

Dec. 1982 Increase the "window" of acceptance of satellite data
 in the eastern tropical Pacific. Because of the large
 anomalies due to El Nino, the satellite data were being
 rejected as they differed too much from the first guess
 field.

Feb. 1983 Increased the anomaly limit in the eastern tropical
 Pacific.

There is a suggestion that they may estimate the satellite biases as a function of latitude from the previous month's analyses and use this information to partially correct the biases in the current analyses. This would be an interim measure as they are working on a new analysis system.

They hope to disseminate the data in tenths of a degree within the next few months, but they are not sure of the time schedule. They think that it is only possible to disseminate GTS data on a 5 degree grid as it is not geared up for other formats.

3.3 Limitations of the scheme

The basic limitation of the scheme is the integration period of two days which is too short to gather significant amounts of direct data (see Figs. 1-3 where the integration period is 31 days). It is easy to see from 3.1 that any observation that differs by more than a few degrees from climatology is going to be thrown out unless it is supported by other data, past and present. With an integration period of two days this support is not easy to obtain, especially as a strong constraint by climatology is used to control the errors in satellite data.

I was given to understand that the code is extremely complex and that the original programmer has left.

It is intended to construct an entirely new analysis system which will be based upon optimum interpolation and where the integration period will be longer (1 month? Not yet decided). It is expected that this will be operational by the end of 1984.

4. CAC SST ANALYSES

The CAC SST analysis is a direct computation of a monthly mean analysis. All direct SST data (ships, buoys, XBT's) obtained from the GTS are averaged in situ on a two degree regular grid. No satellite data are used and no attempt is made to control the quality of ship data in terms of position or temperature errors. Fig. 3 shows the data available for September, 1983. This is a fairly typical distribution, note that there are many ships merrily sailing across the continents. The resulting gridded averages for the Pacific are shown in Fig. 6; observations over land and observations outside of four standard deviations about the mean (climatology) are discarded. In addition, to prevent the high frequency of observations from buoys overwhelming the ship observations, each buoy observation is weighted as if it were only 1/10th of an observation. The dotted regions correspond to regions of no data (filled with interpolated values), cf. Fig. 3. This is a very rough field with many questionable features. The anomaly field is now constructed by subtracting the NCC climatology from the "raw" analysis, Fig. 7. The anomaly field is even more dubious than the SST field.

In order to extract the large scale signal from the noise, some further processing is carried out. First any anomaly greater than an absolute value of 8°C is eliminated. Any anomaly which is not supported by data in any of the four surrounding grid points is eliminated. A non-linear filter is used based on computation of medians (Rabiner et al., 1975) in first the east/west and then the north/south directions. The use of medians rather than weighted means objectively eliminates extreme values from the analysis field rather than blending them in. This filter is first applied to the data on a four degree resolution grid. The unfiltered two degree anomaly values are discarded if they differ by more than 3°C from the four degree resolution

filtered fields. The filter is now applied to the remaining two degree anomaly values. Next, if the number of monthly observations contributing to the original gridded value is greater than 30, the filtered value is replaced by the original value. When the number of observations was between 15 and 10 the field at these grid points is adjusted according to the relation

$$T = rT_o + (1-r) T_f$$

where T_o is the original gridded value, T_f is the filtered value, $r = (n-15)/15$ and n is the number of observations. These adjustments affect about 10% of the filtered values.

Finally, the field is smoothed by applying a linear five-point binomial filter (Holloway, 1958) in the East-West and in the North-South.

The resulting field is shown in Fig. 8, again the stippled regions are those of no data, cf. the "raw" field shown in Fig. 7. The screening processes eliminated less than 1% of the data.

The analysis scheme requires no manual intervention. The weakness of the scheme lies in its total reliance on direct data; as seen in Fig. 3, even when data are accumulated over a whole month there are large regions that are data void.

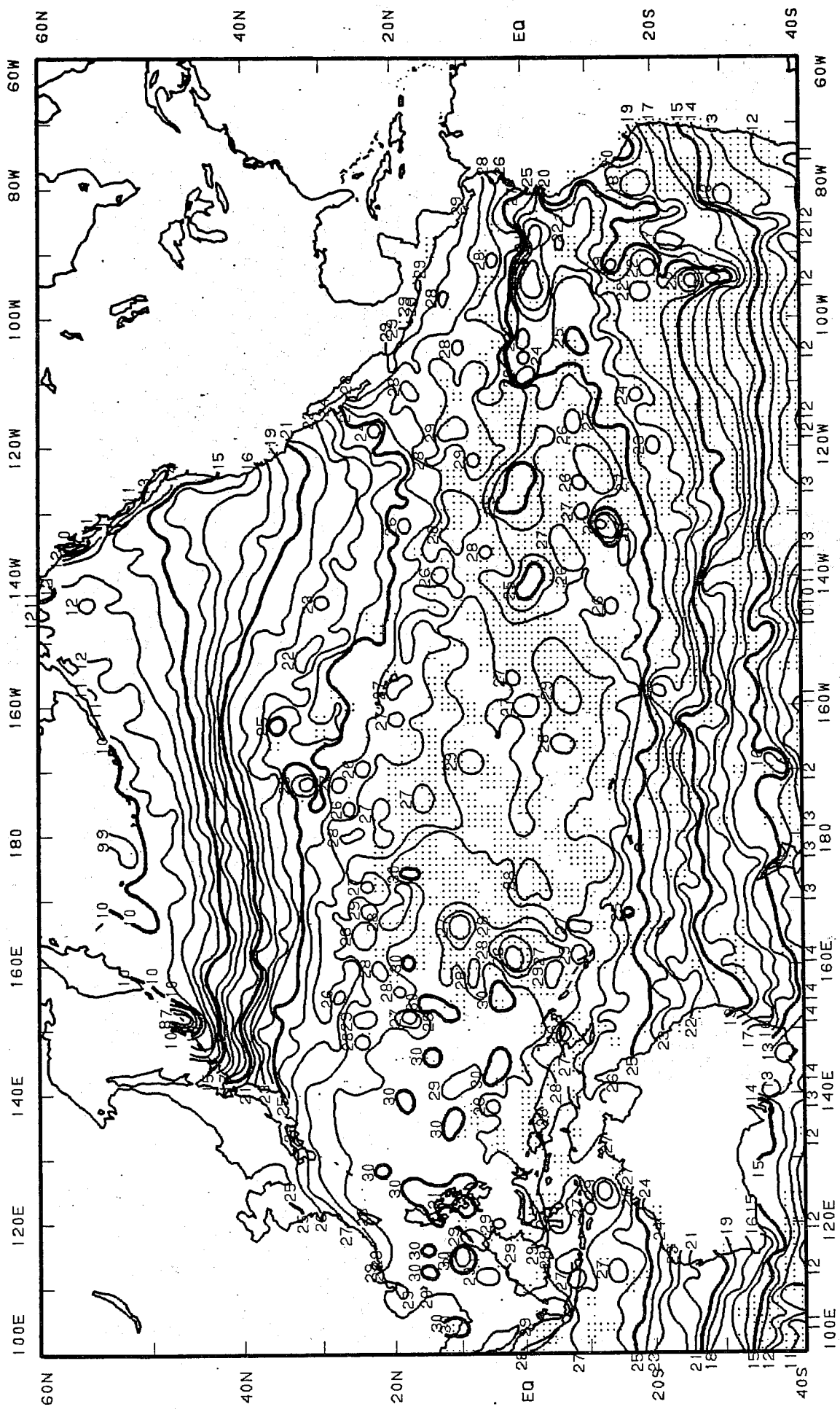


Fig. 6 Raw SST field for September 1983

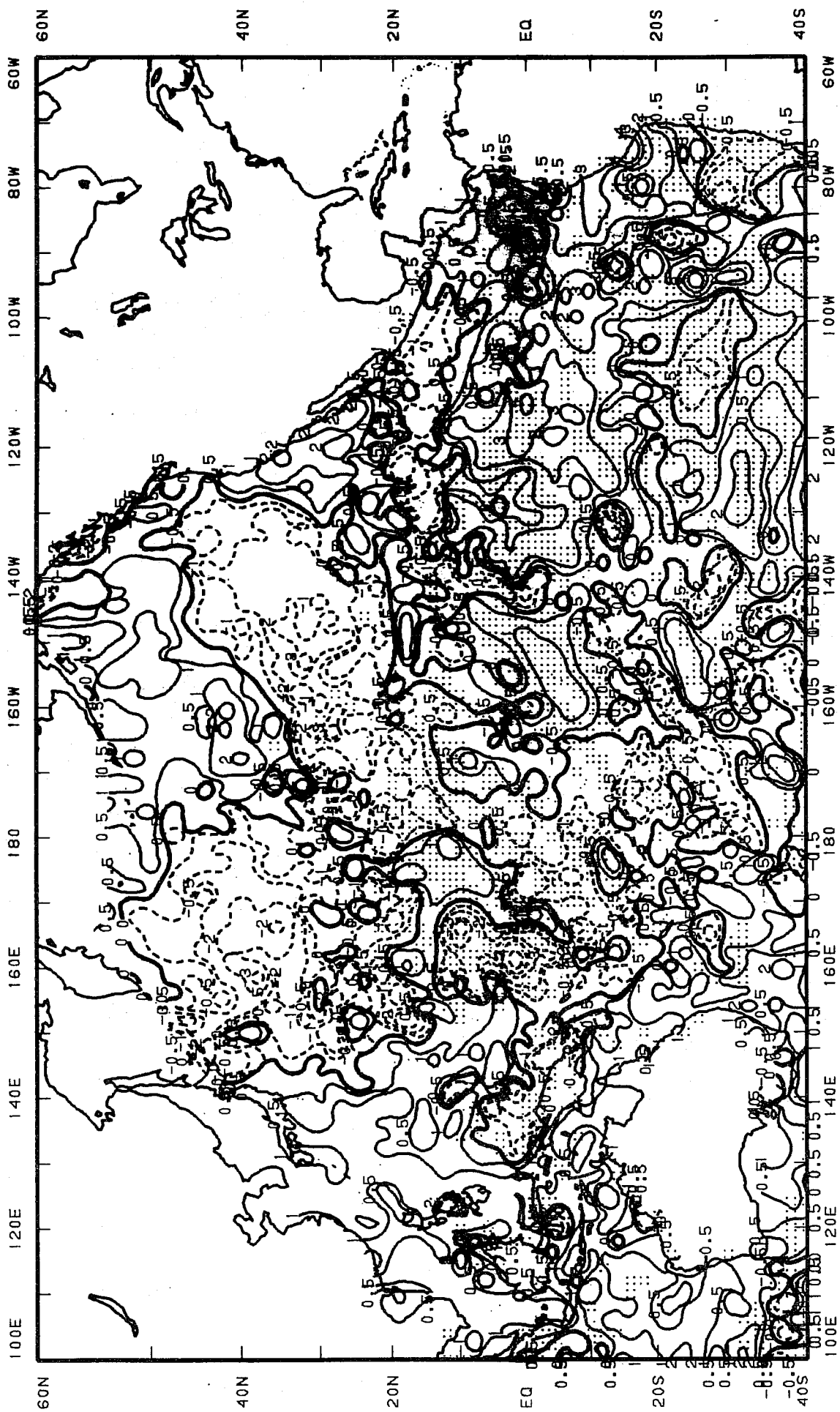


Fig. 7 Raw SST anomalies for September using NCC climatology

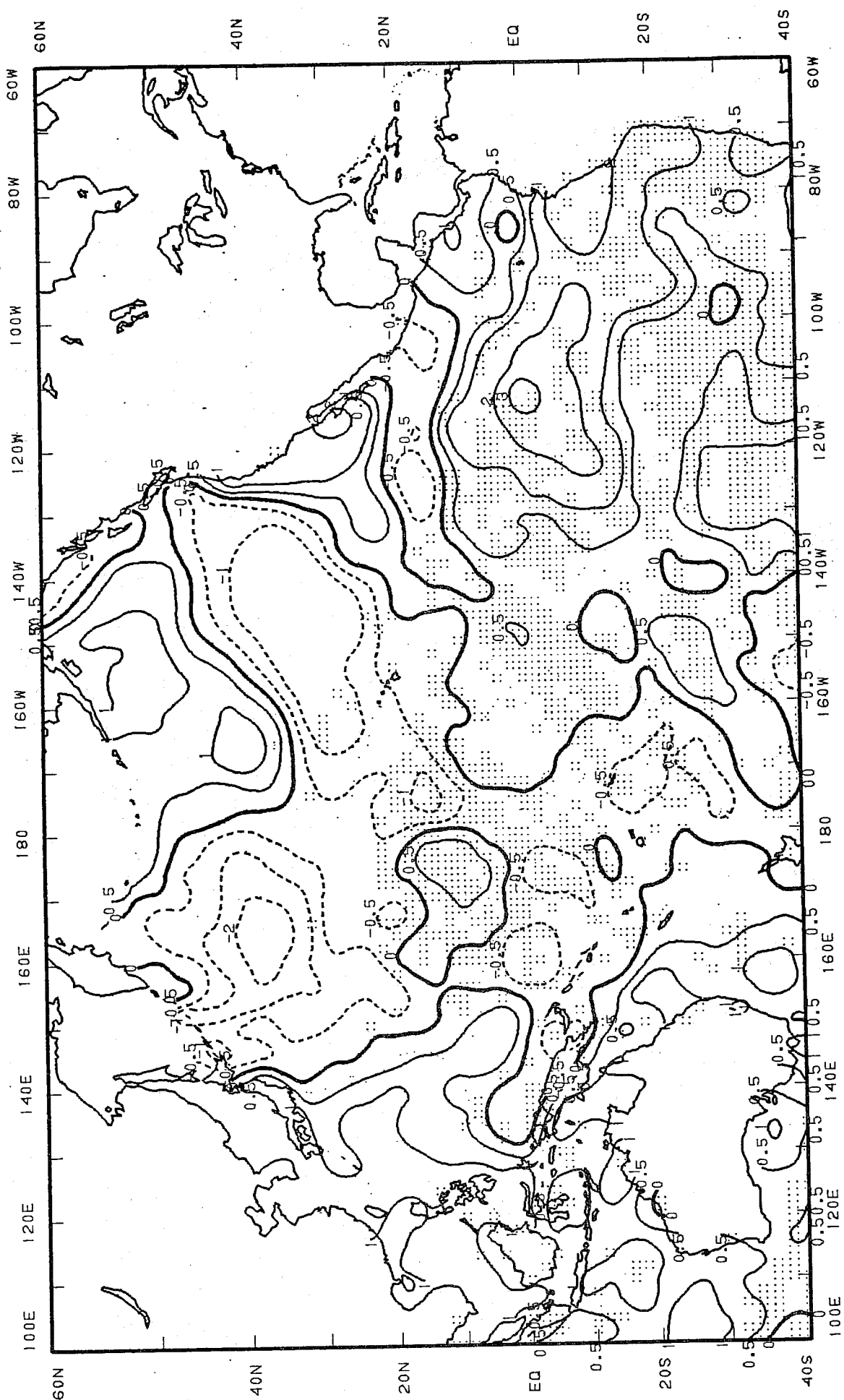


Fig. 8 Anom: SST anomalies for September 1983 (CAC analysis and climatology)

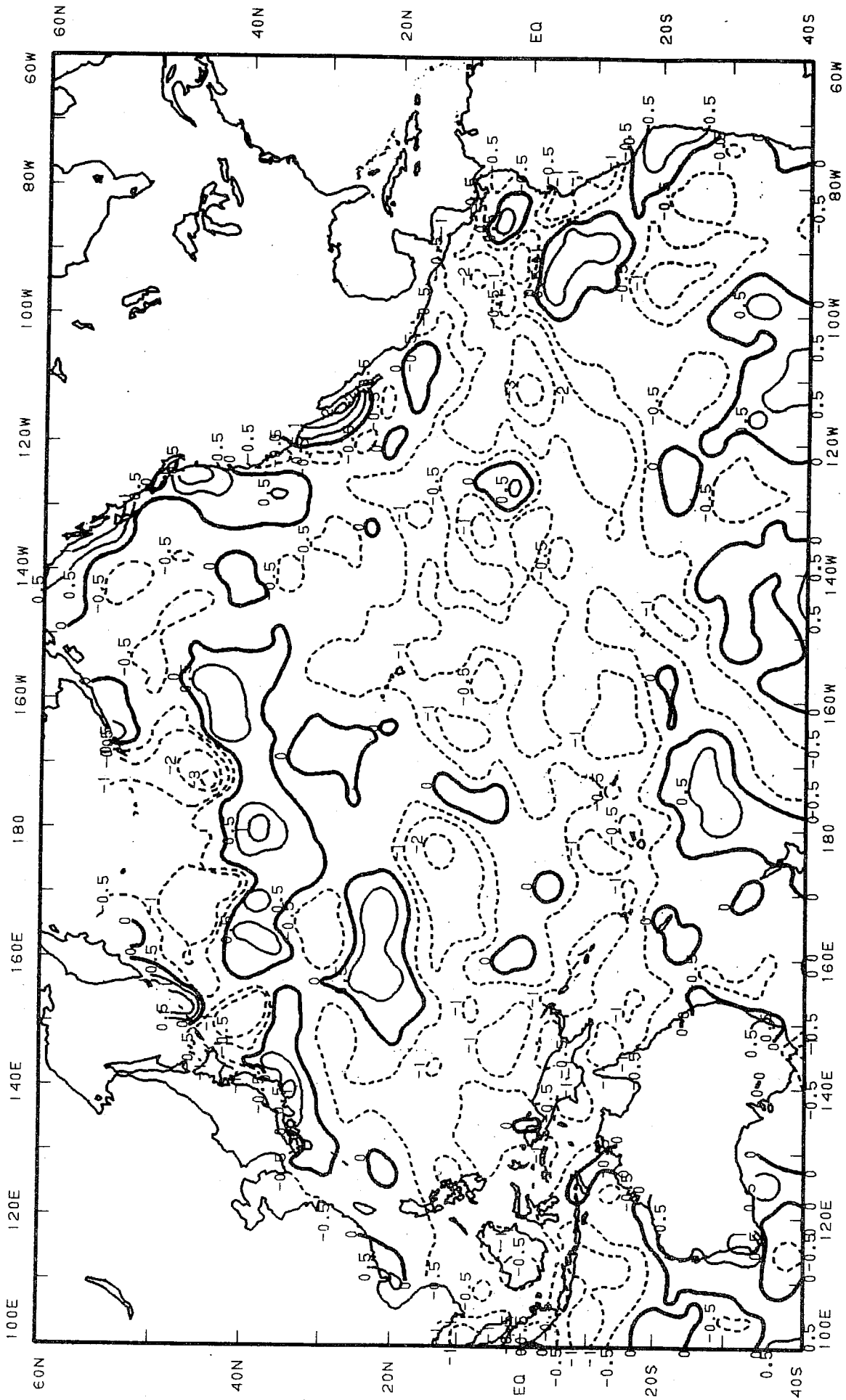


Fig. 9 SST differences for September 1983 (NESS-CAC)

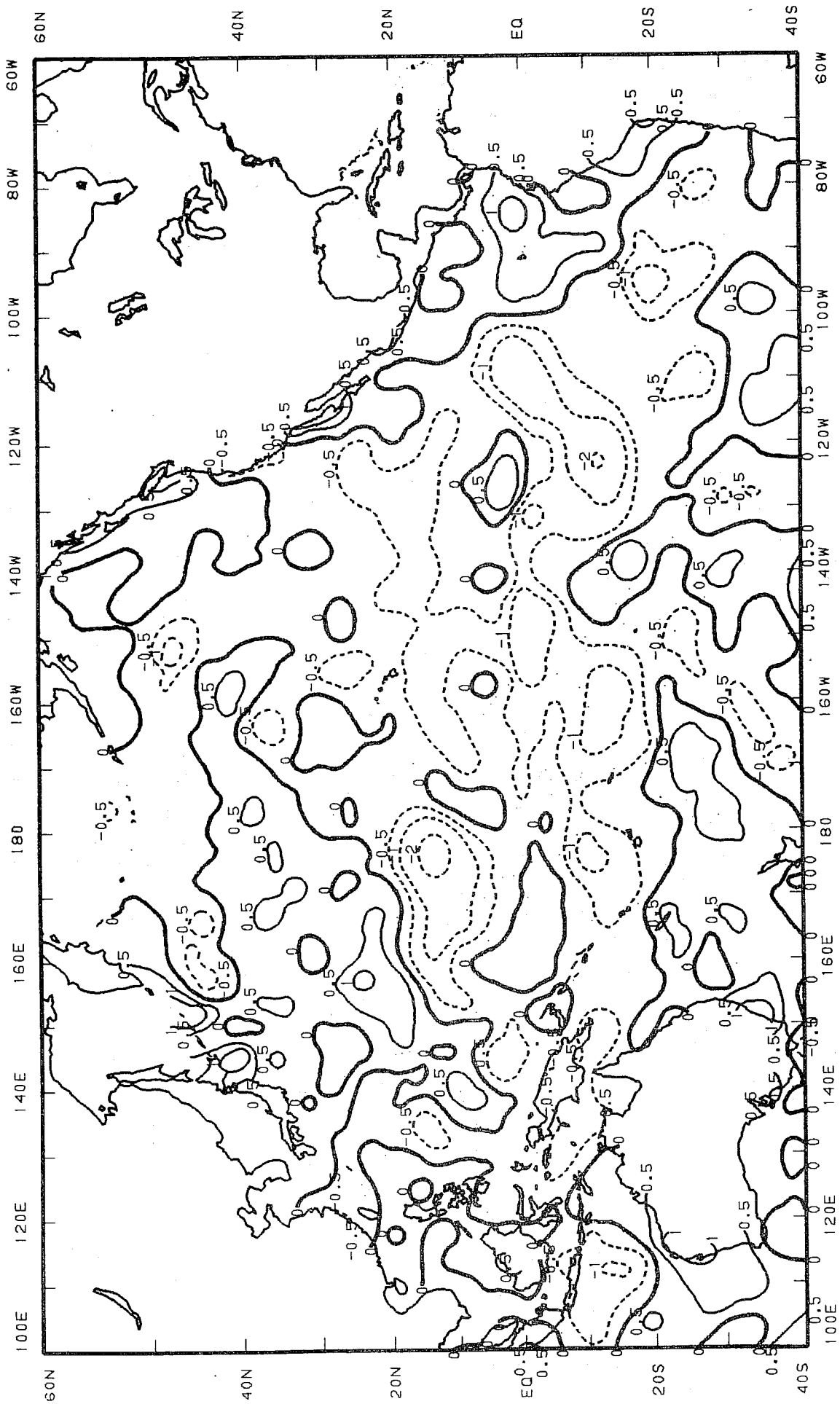


Fig. 10 SST differences for September 1983 (NMC-CAC)

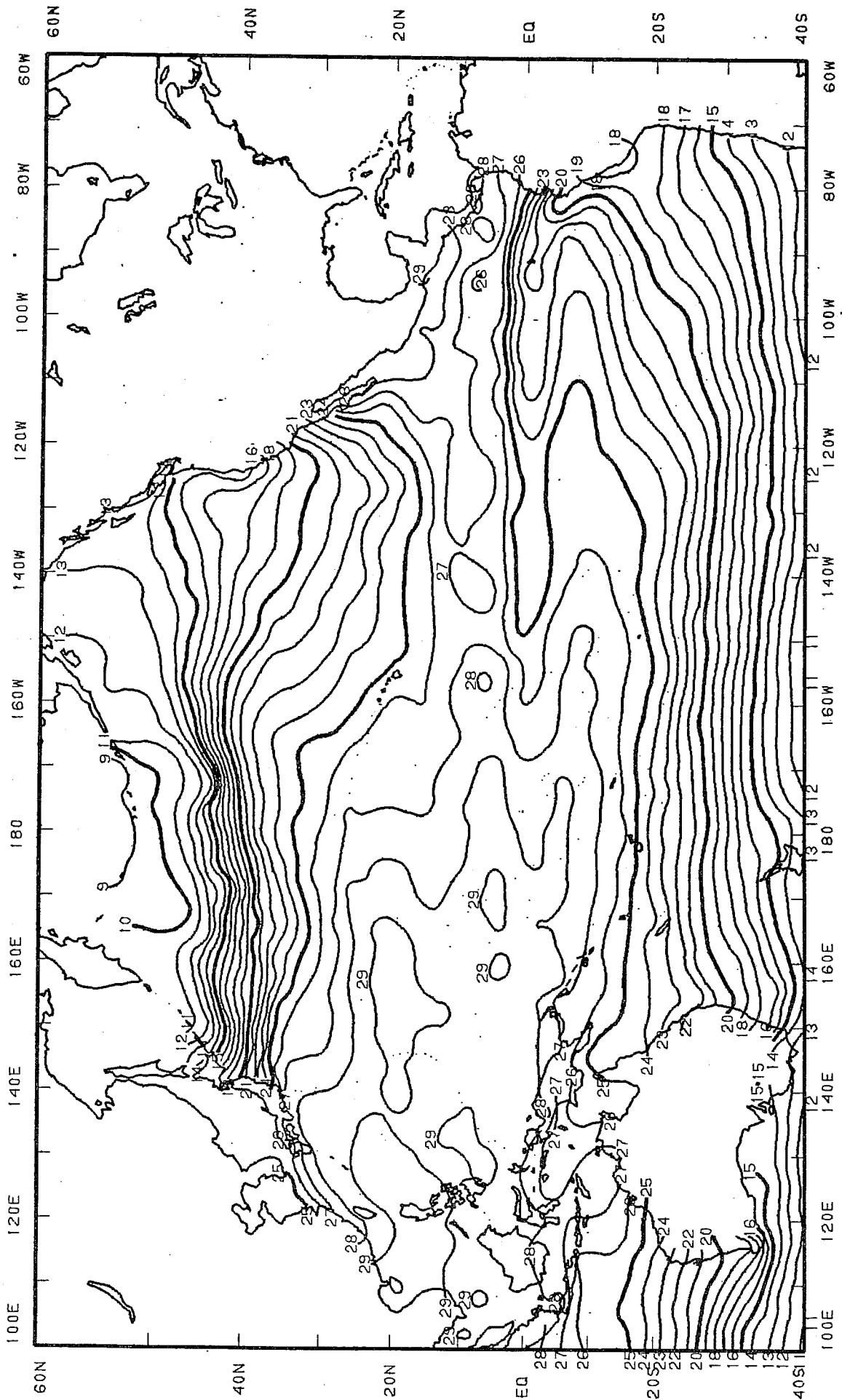


Fig. 11 NESS SST field for September 1983

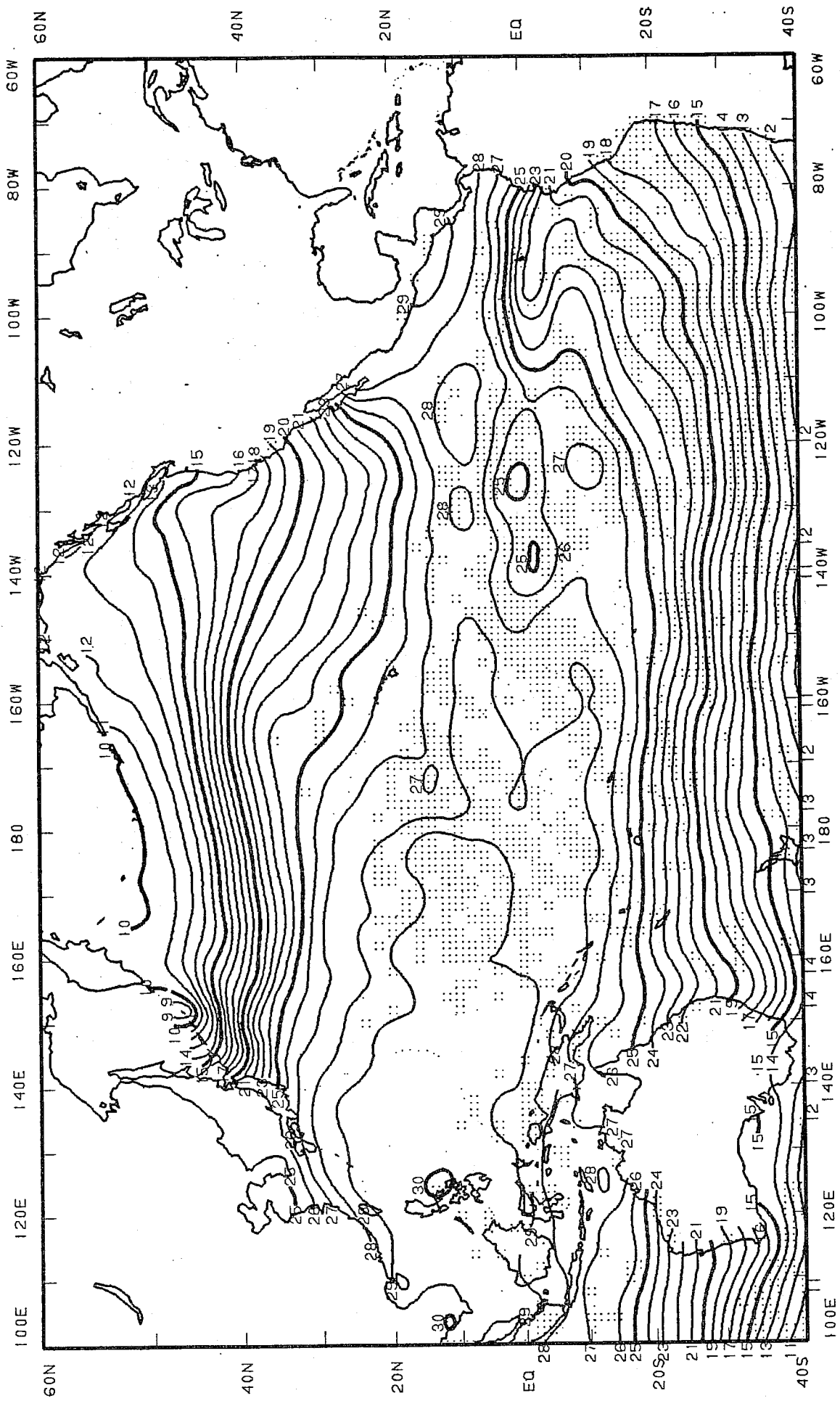


Fig. 12 Anom: SST field for September 1983 (CAC analysis)

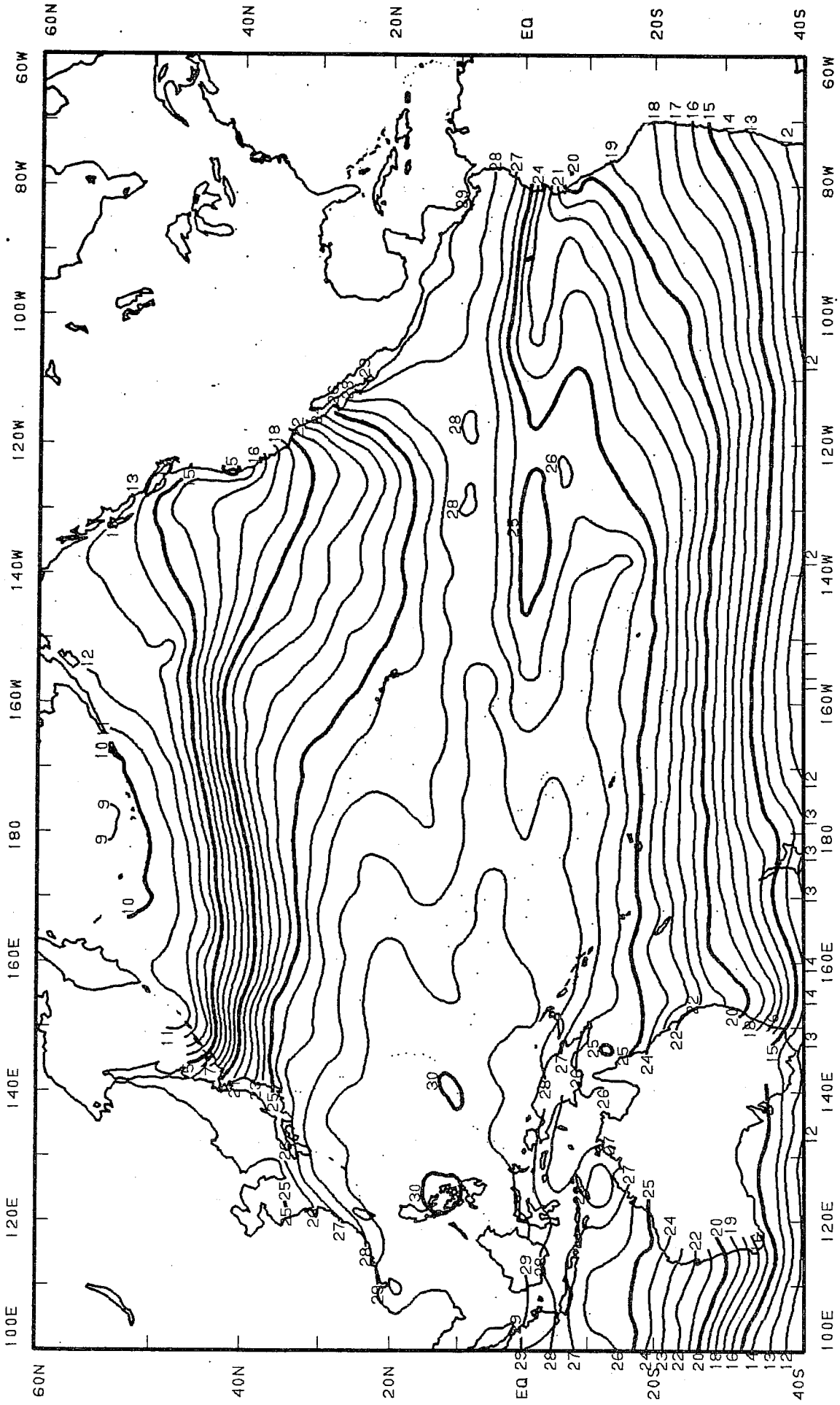


Fig. 13 NMC SST field for September 1983

5. DISCUSSION OF THE DIFFERENCES

Fig. 9 shows the difference between an analysis based purely on satellite data and the CAC analysis (which is based purely on direct data). As we should expect there appears to be an overall negative bias (effect of aerosols on satellite retrievals). The differences along the coasts are presumably related to the large amount of relatively accurate buoy data available in these regions. Comparing Fig. 9 with the stippled areas of Fig. 8, it is important to note that away from the coasts and in the tropics, the largest differences are near to these stippled areas, i.e. where the CAC analysis has no data.

The difference between the monthly mean of the NMC operational analyses and the CAC analysis is shown in Fig. 10. The NMC analysis has the advantage of being able to use both direct and satellite data but has the disadvantage of only being able to accumulate data over two days. Comparing with Fig. 9 one sees that the coastal differences have been reduced as have the northern hemisphere extratropical differences in general. The tropical differences have been reduced slightly, but once again we should note that the largest differences occur over data sparse regions.

A comparison between the total fields is also quite revealing. Fig. 11 shows the field derived from satellite data alone, Fig. 12 is the CAC analysis and Fig. 13 is the monthly mean of the NMC analyses. The satellite data shown in Fig. 11 is an aesthetically rather pleasing field, it shows the cold tongue of water extending westwards from Peru into the Pacific with tight gradients on its northern edge. The CAC field, in Fig. 12, has a rather poorly defined tongue and rather weak gradients. The NMC analyses, Fig. 13, do a slightly better job.

6. CONCLUSIONS

The satellite data have large biases which are a function of time and position, however, in the absence of other observations this is still valuable data.

The CAC analyses try to get over the problem of poor satellite data by only doing monthly mean analyses, hoping to collect enough direct observations so that satellite data are unnecessary. Even when data are accumulated over a month there are large data sparse regions, especially in the tropics and southern hemisphere.

The NMC analyses have the advantage of combining the direct observations and the satellite data in a plausible manner, but have the serious disadvantage of accumulating observations over only a two day period. This period is insufficient to accumulate a satisfactory number of direct observations.

In summary, it would seem that an NMC type system with an accumulation period of about 15 days would perform satisfactorily.

ACKNOWLEDGEMENTS

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