Improvements to an SST climatology using COADS

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1. Introduction

A global sea surface temperature (SST) climatology which includes sea ice is useful as a reference for estimating the anomalies and thus the variability of SSTs. In addition, the climatology can be used to form part of the lower boundary specification for atmospheric general circulation models (GCMs) and for verifying oceanic and coupled climate models. It is important that the SST climatology be accurate both spatially and temporally for meaningful results. For example, large-scale tropical convection, which is of fundamental importance in the atmospheric general circulation, will be inhibited if tropical SSTs are too low.

The SST and sea ice climatology currently used by the NCAR Community Climate Model (CCM) is from Alexander and Mobley (1976). It was derived from the SST climatology of Washington and Thiel (1970) which was primarily based upon maps digitized from the U.S. Navy's Hydrographic Office (1944) and about 10 years of data from the U.S. Navy Fleet Numerical Weather Center (FNWC) operational analyses. For Arctic sea ice Alexander and Mobley used the U.S. Navy Fleet Weather Facility (1958) monthly ice charts and for the Antarctic they used the monthly mean ice pack limits of the Navy Hydrographic Office (1957). After interpolating the Washington and Thiel and FNWC SST climatologies to a one degree grid, they merged the northern hemisphere SSTs from FNWC with the southern hemisphere SSTs of Washington and Thiel.

The development of the Comprehensive Ocean-Atmosphere Data Set (COADS; Slutz et al. 1985) has formed the foundation for new SST climatologies. Recently, Reynolds and Roberts (1987) (and see Reynolds 1988) developed a 2° x 2° SST climatology derived mainly from the COADS for the same base 30-year period 1950 to 1979. In addition, they used the climatological ice data from a ten-year data set from the Glaciological Data Center, Boulder, Colorado, and satellite-derived SST fields for the 1982 to 1985 period. The latter were used to objectively determine the *shape* of the SST field in areas not adequately covered by COADS ship data or sea ice information. In ice covered regions, the SSTs were set to -1.8°C, the freezing point of sea water at a salinity concentration of 32-33 parts per thousand (ppt). This SST/sea ice climatology, which henceforth will be called the Climate Analysis Center (CAC) SST climatology, forms the foundation for the development of our new SST climatology.

2. Methodology

Although the initial COADS release contained data only through 1979, preliminary SST values are available through 1989. However, the 1980 to 1989 period is influenced significantly by the huge 1983 El Niño event and another El Niño event in 1986-87. Trenberth (1990) and Trenberth et al. (1989) have noted that the sequence of three consecutive ENSO (El Niño-Southern

Oscillation) events (1976-77, 1982-83 and 1986-87) without any strong opposite Cold Events to provide balance is unprecedented in the past hundred years. Consequently, these recent events appear to be quite anomalous and it was considered undesirable to include them all in the climatology.

Recorded measurements of SSTs began in the 1850s. From that time to the present, there has been a shift in instrumentation from uninsulated bucket temperatures to ship injection temperatures. Because the injection temperatures tend to be warmer than those from the buckets, the change in instrumentation results in a measurement bias. Folland et al. (1984) discuss this change and recommend a correction for SST observations made prior to 1942. This correction assumes that the type of measurement is known. Because of the uncertainties in the instrument changes and the warming in the 1980s, we have chosen to base our climatology on the period 1950 to 1979. This restriction has been modified, as was done in the CAC climatology, in data sparse regions.

The CAC climatology has two disadvantages. First, a powerful median smoother and a two-dimensional spatial smoother were used to derive the gridded fields. The median smoother has the advantage of removing extreme values but it also degraded the original 2° resolution to approximately 6° (Reynolds and Roberts, 1987). The effect of spatial smoothing is especially evident in areas of strong SST gradients such as in the neighborhoods of the Kuroshio and the Gulf Stream. Second, the SST data for each month were analyzed independently. No explicit effort was made to ensure temporal consistency. Consequently, difference maps between adjacent months often reveal noisy features in data sparse areas that are almost certainly spurious and undesirable in a climatology. However, the use of new sea ice boundaries to anchor the SSTs at high latitudes plus the use of satellite data input over otherwise data sparse areas makes the CAC climatology generally preferable to other SST climatologies.

Ocean areas covered by sea ice and areas where the satellite values were used to help define the SST fields are displayed in Fig. 1 for January and July. In general, the regions influenced are poleward of about 40°S and it is only during the short southern hemisphere summer, from December through February, that ship observations provide coverage over parts of the southern oceans.

For a number of proposed GCM simulations it is important that the SSTs be accurately represented especially in regions of large SST gradients such as off the east coasts of Asia and North America. An extensive comparison with the original COADS SST 2° box summaries indicated that the SST estimates, and consequently the SST gradients in the CAC climatology, could be improved considerably in some areas. The most serious deficiencies were in the Kuroshio and Gulf Stream regions and in these regions there was a sufficient number of observations in each 2° square in the COADS data base to provide a more detailed analysis. In addition, there are some other areas where the CAC climatology may have been adversely affected by the smoothing, but the adequacy of the data base for devising corrections in these regions is marginal. Some examples are given but the new climatology will also be deficient in these areas. However, in the Kuroshio and Gulf Stream regions, it was decided to merge the SSTs from the COADS 2° box summaries into the CAC climatology. Prior to merging, the COADS 2° box summary SSTs were regionally interpolated to the same 2° grid used in the CAC climatology. Figure 2 shows the regions chosen for merging and the weights applied to the SSTs. Where the weights are 1.0, in the Pacific and Atlantic, the objectively analyzed COADS 2° box summary SSTs were used, but over most of the grid, where weights in Fig. 2 are zero, the CAC values were used. In boundary areas, the SSTs were determined by the linear combination of the CAC and the regionally interpolated SSTs. No discontinuities resulted from this procedure because the boundary was selected to be in areas where there was excellent agreement between the two.

SST contours and differences between the original CAC climatology and the merged climatology in the Atlantic for January are displayed in Figs. 3 and 4. (Shea et al. (1990) present similar figures for other months and the Pacific.) The SST contours for the Gulf Stream in the merged climatology more closely follow the topography of the Continental Shelf (Fig. 5). This is especially evident during the winter months and agrees much better with the hand analyzed contours in atlases from as early as 1944 (Hydrographic Office, 1944). The SST differences can be greater than 3°C in the open ocean and more than 5°C at coastal areas. The merged climatology has stronger gradients, generally by about 1.5° to 3°C per 4° latitude, throughout the year. The reason for the differences is directly related to the aforementioned smoothers used to develop the CAC climatology. The inescapable conclusion is that while smoothing is necessary and desirable in general, because of the uneven data distribution, it has adverse effects in regions of strong gradients. Effectively, we have applied a weaker smoother regionally to retain the gradients in a more realistic fashion.

The temporal consistency of the merged SST climatology was examined and subsequently improved by performing a Fourier analysis on the twelve monthly values at each grid point. The amplitude, phase and percent-variance explained by the resulting six harmonics were calculated. The results revealed that the contributions of the last three harmonics over the open oceans were spatially incoherent and essentially noise. Even the amplitude of the third harmonic is small. It barely reaches 0.5°C over the North Pacific. Therefore, the annual cycle at each grid point was recreated by a Fourier synthesis using the first three harmonics only. This procedure was not performed in areas where sea ice was present during any of the months. Finally, a light nine-point spatial smoother (Shea et al., 1990) was passed over the SST data from 40°S to the Antarctic sea ice line to remove any local small-scale features from the high southern latitude SST fields. The fields in these regions are most uncertain because of the few observations available and the spotty coverage. Later, we present the amplitudes and phases of and the percentage variance explained by the first three harmonics.

In addition to the Kuroshio and Gulf Stream areas, there are several other regions where the CAC climatology may have been adversely affected by the smoothing. However, in these other areas, the adequacy of the COADS 2° box summary data base for deriving consistent spatial and temporal corrections was marginal. *Thus no corrections were applied in these regions and, as a result, the new climatology also contains similar deficiencies.* These areas include a narrow band about the equatorial Pacific, the west coast of South America and the waters between 35° and 50°S south and east of South Africa.

Figure 6 shows the SST differences between the CAC climatology and the lightly smoothed COADS 2° box summaries for July for the easternmost portion of the equatorial Pacific and the west coast of South America. Generally, the lightly smoothed COADS data within +/-4° of the equator and east of the dateline are 0.5 to 1.0°C lower than the CAC SSTs although in some months differences were more than 1.5°C (see Shea et al. 1990). Consequently, primarily because of the spatial smoothing in the CAC analysis, the cold upwelling tongue of water along the equator is not properly resolved, thus reducing its full extent. Further evidence for the warm equatorial bias in the CAC climatology comes from long-term moored buoy measurements at 110°W on the equator. McPhaden and Hayes (1990) concluded there was a warm bias in the CAC climatology of ~1°C. Off the west coast of South America the SST differences show that at gridpoints in close proximity to land the SSTs should be lower by more than 2°C in some months (see Shea et al. 1990). This is an area of coastal upwelling where the surface water is cold. Farther from the coast the SSTs should be warmer by more than 1.5°C. It is this type of detail which is eliminated by the use of strong smoothers.

Using the same methodology the SSTs between 35°S and 45°S and 15°E and 70°E near the retroflection region south of South Africa are often more than 2°C lower than those derived using lightly smoothed data while the SSTs between 45°S and 50°S are warmer, but the data base to establish this is poor. In other words, there is some indication that gradients should be even stronger in this region, but the evidence for this needs to be confirmed.

3. Summary

A new SST climatology (called the Shea-Trenberth-Reynolds climatology) has been derived from an SST climatology primarily based upon data from 1950 to 1979 developed by Reynolds and Roberts (1987). SSTs from COADS were merged onto the CAC climatology to locally improve the SST estimates in areas affected by the Kuroshio and the Gulf Stream, and steps were taken to make this climatology more consistent spatially and temporally than either the CAC or the Alexander-Mobley SST climatology. More importantly, there are climatologically important differences in the STR SST climatology in terms of their expected effects when used as a lower boundary condition in driving an atmospheric GCM. Results are also more realistic in the Kuroshio and the Gulf Stream regions although further improvements are warranted in the tropical Pacific, off the west coast of South America, and south and east of South Africa.

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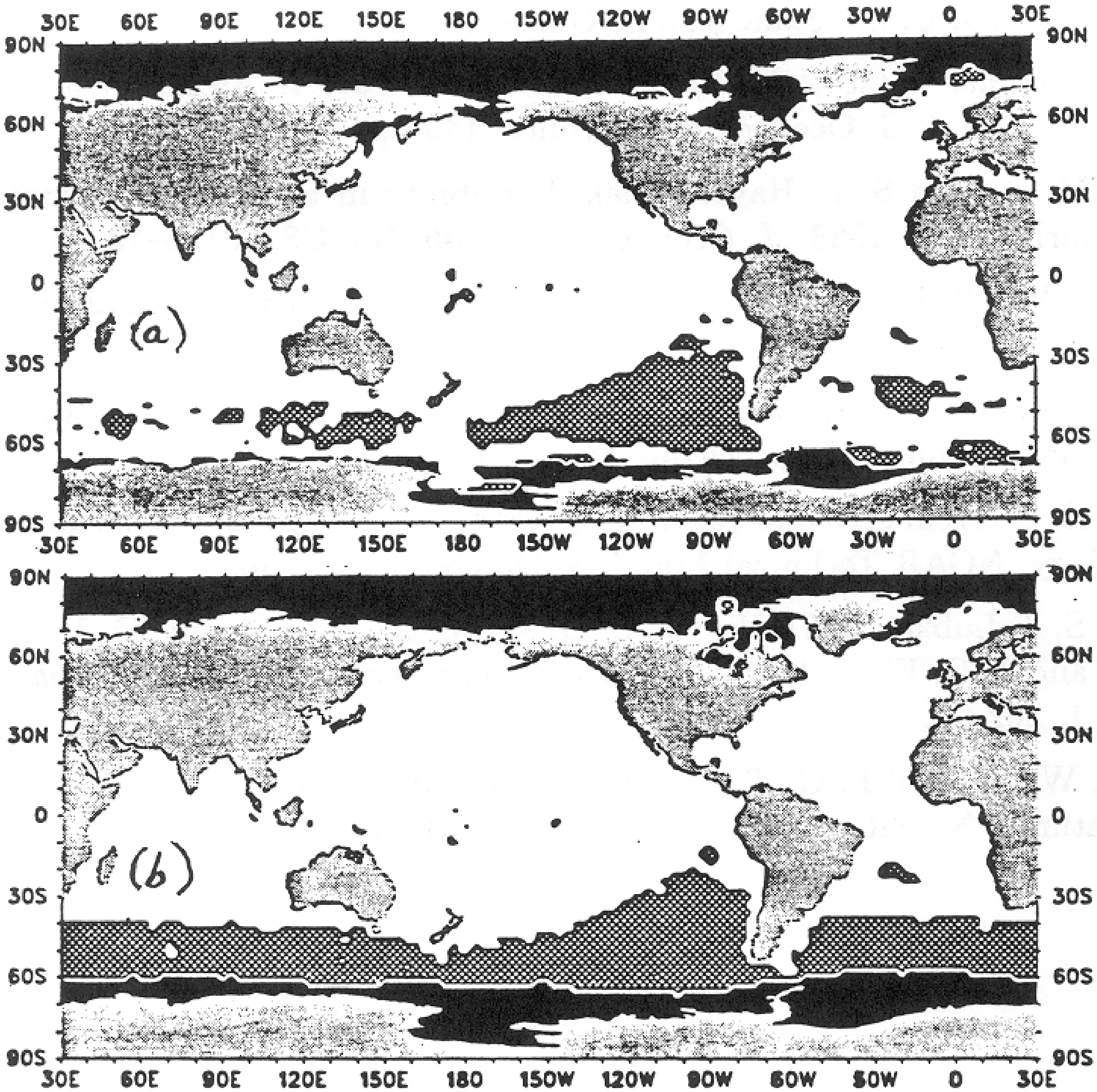

Figure 1. Sea ice coverage (black) and areas where the shape of the SST fields was derived by satellite climatology (hatched area), for (a) January and (b) July.

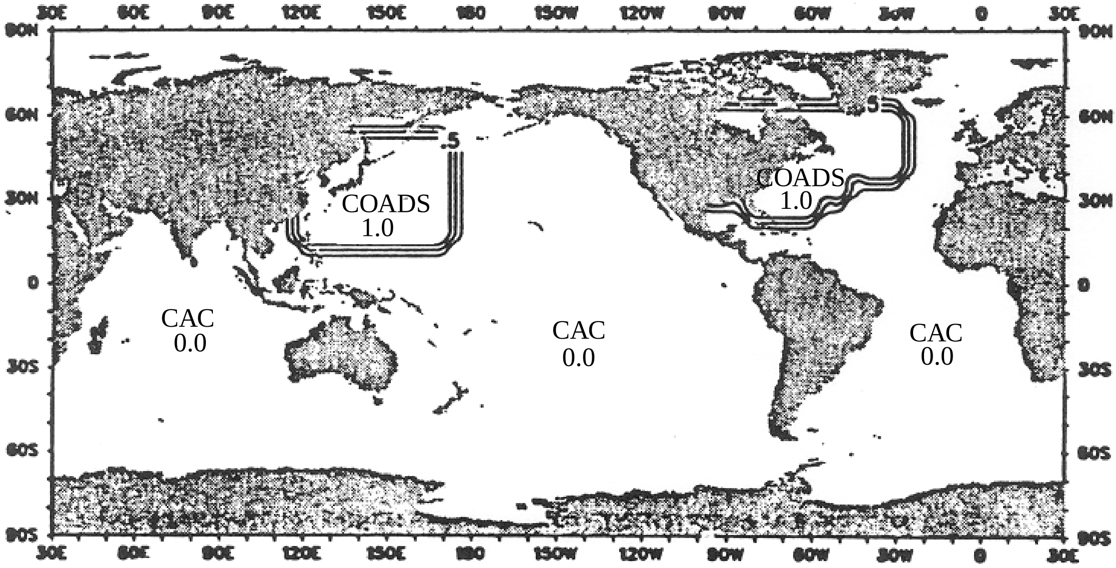

Figure 2. Areas where SSTs from COADS 2° box summaries were merged into CAC climatology. The numbers refer to the weights applied to the COADS 2n box SSTs. Areas where the weight is 1.0 (0.0) indicate that only the COADS 2° box (CAC) climatology was used. In boundary area a linear combination of the SSTs was used.

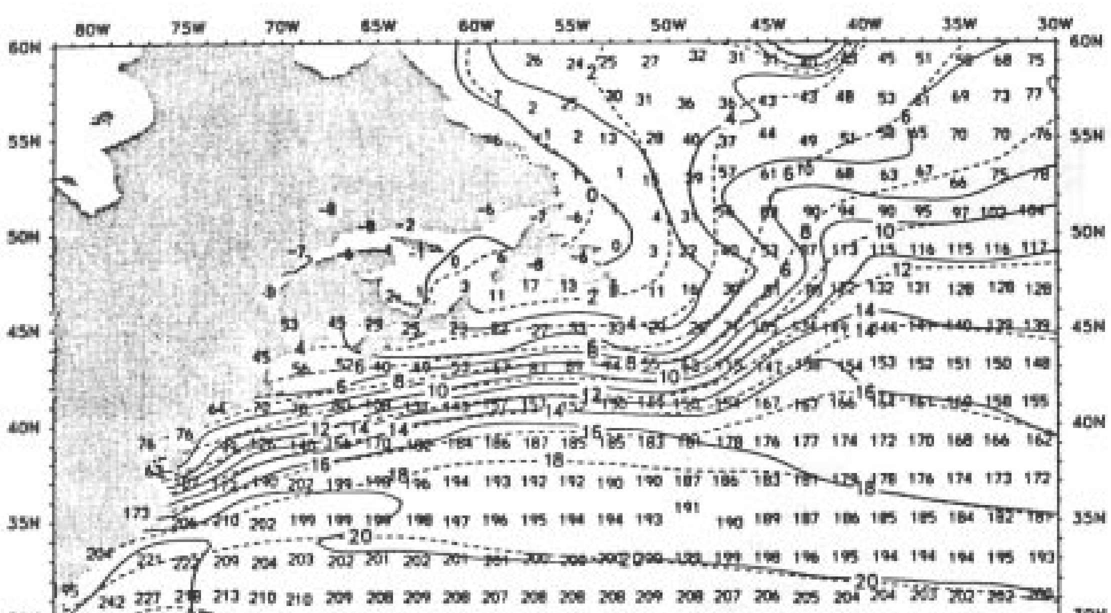

Figure 3. SST contours for the merged January SST climatology (solid) and the CAC climatology (dashed) in the Gulf Stream area. The numbers indicate the mean SSTs (0.1°C) from the COADS 2° box summaries plotted at the center of mass of the observations. The contour interval is 2°C.

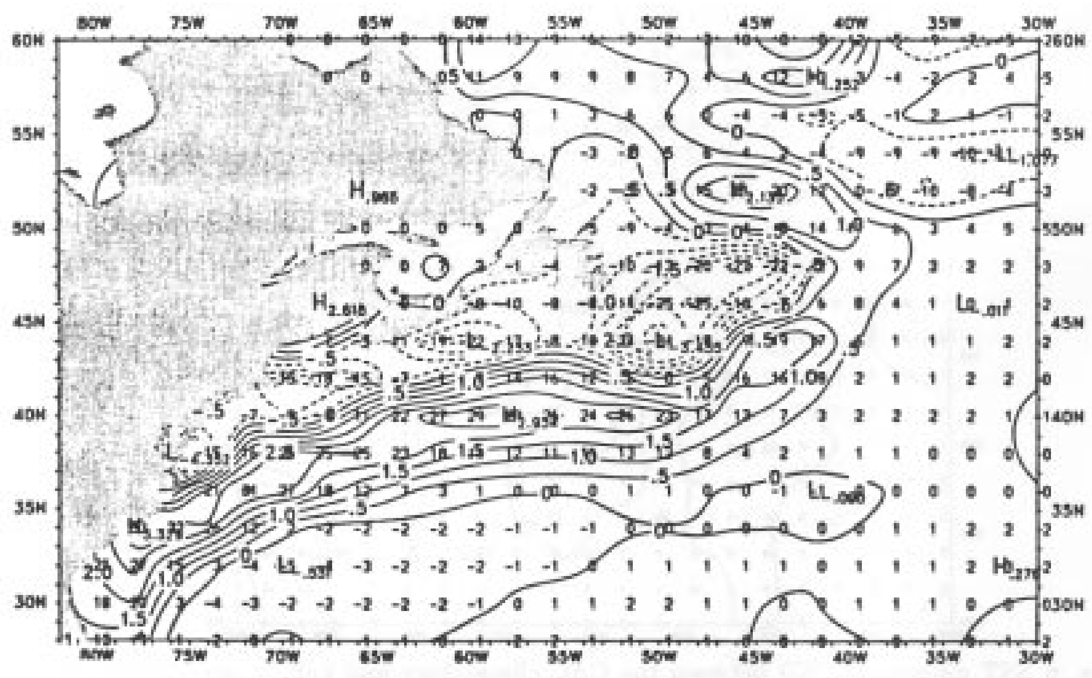

Figure 4. January SST differences between the merged climatology and the CAC climatology in the Gulf Stream area (merged-CAC). Negative differences are indicated by dashed contours. The numbers are the differences (0.1°C). The contour interval is 0.5°C

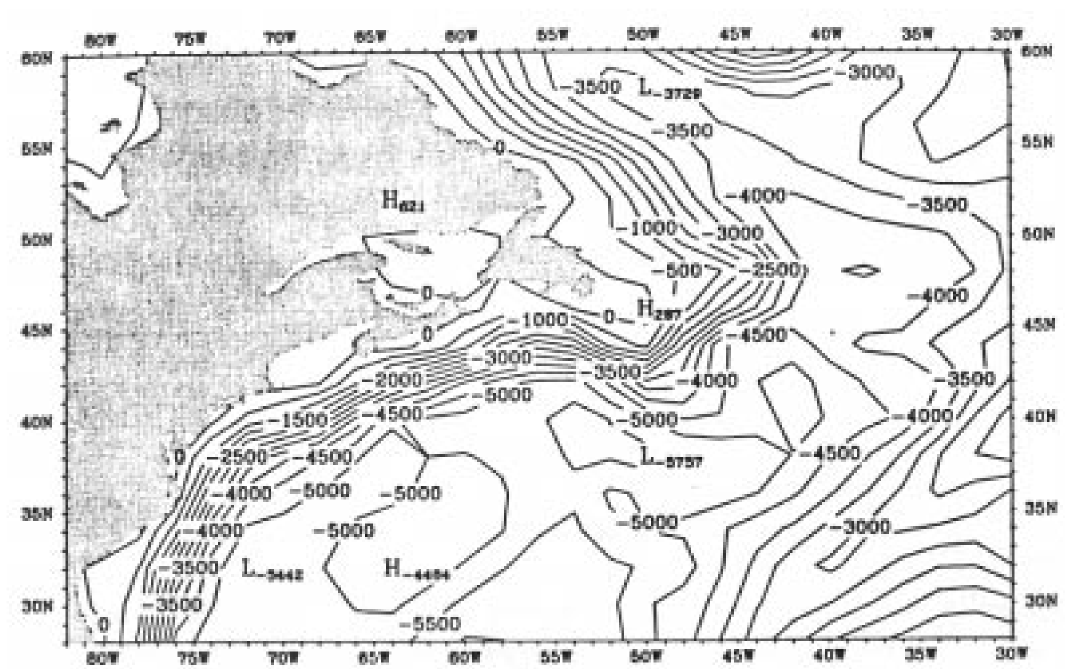

Figure 5. Bottom topography of the western Atlantic. Depth are in meters. The contour interval is 500 m.

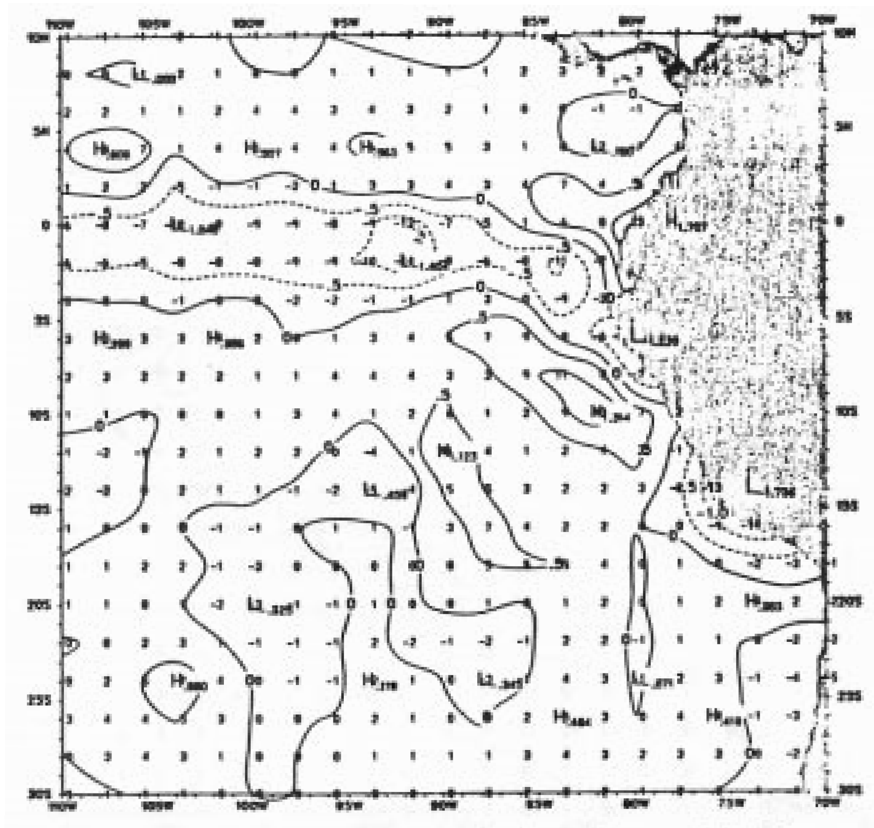

Figure 6. SST differences (°C) between the CAC climatology and lightly smoothed COADS 2° box summary data for the easternmost Pacific and the west coast of South America in July. The plotted number represent the differences (0.1°C). Dashed contours indicate negative values. The contour interval is 0.5°C