A Global Monthly
Sea Surface Temperature
Climatology

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Preface

A new global 2° × 2° monthly sea surface temperature (SST) climatology, primarily derived from a 1950 to 1979 based SST climatology from the Climate Analysis Center (CAC), is presented and described. The purpose of developing this climatology is to provide a well documented and improved global SST climatology which can be used as a reference for defining SST anomalies, as a specified oceanic lower boundary condition in atmospheric general circulation models, and to validate ocean and coupled climate model simulations. The CAC climatology has been modified by using data from the Comprehensive Ocean-Atmosphere Data Set (COADS) to improve the SST estimates in the regions of the Kuroshio and the Gulf Stream. This results in considerably larger and more realistic SST gradients in these regions. This modified climatology is smoothed in time using a truncated Fourier series to eliminate mean annual cycle fluctuations of three months or less and, finally, some spatial smoothing is applied over the high latitude southern oceans.

This new SST climatology, which we call the Shea-Trenberth-Reynolds (STR) climatology, is compared with the Alexander and Mobley (AM) SST climatology previously used by the NCAR Community Climate Model (CCM). Significant differences are noted. Generally, the STR climatology is warmer in the northern hemisphere and in the subtropics of the southern hemisphere during the northern winter. It is often colder south of 45°S in all months. For example, at T42 resolution, the largest differences are more than 5°C in the Kuroshio and Gulf Stream regions. In the mid-high latitude southern oceans, the SSTs are often more than 2°C lower. In addition, the STR climatology is temporally and spatially less noisy than the AM SST climatology.

Global SST anomalies spanning the period 1982 to June 1990 are presented and discussed. The largest anomalies are associated with the El Niño and La Nina events in the tropical Pacific. However, because of changes in procedures in producing the 1982 to 1990 SSTs compared with the CAC climatology, the anomalies in certain regions are really compensating for deficiencies in the climatology and should not be intrepreted as true climate anomalies.

Some of the mapped quantities presented in this atlas include: (a) the twelve monthly and annual mean SST fields, (b) SST differences between successive months, (c) monthly SST differences from the annual mean, (d) monthly SST differences from the zonal mean,
(e) the amplitude, phase and percent variance explained by the first three harmonics of the annual cycle, (f) monthly differences between the AM and STR SST climatologies, and (g) selected seasonal SST anomalies from 1982 to 1990.

Acknowledgments

We would like to thank Amy Solomon for providing considerable graphics advice and computer programs. We thank Mike McPhaden for providing SST data at 110°W on the equator. We thank Drs. Roland Madden and David Williamson for reviewing the manuscript. This work was partially supported by NASA contract W-17,225 entitled “A case study of the drought of 1988 on regional and global scales using climate models and remote sensing.”
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 (1974, 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. In particular, Shea (1986) produced a climatological atlas that included SSTs using the 30–year base period of 1950 to 1979. The spatial resolution was 2.5° latitude by 2.5° longitude. Several quality control criteria were applied in processing the COADS and the fields were analyzed using an objective iterative-correction procedure with the Alexander-Mobley climatology as a first guess. The major disadvantage of this SST climatology is that, generally, it does not extend poleward of 45°S. The reason for this limitation is that Shea required each monthly SST value contained within the COADS to have been derived from a minimum of three observations. This considerably reduced the spatial sampling distribution south of 45°S.
More recently, Reynolds and Roberts (1987) (and see Reynolds, 1988) developed a $2^\circ \times 2^\circ$ 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 $-1.8^\circ$C; the freezing point of sea water at a salinity concentration of 35 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 GOADS 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, April, July and October. 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 using a version of the objective analysis technique employed by Shea (1986). 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 and Pacific for January, April, July and October are displayed in Figs. 3 to 18. The SST contours for the Gulf Stream in the merged climatology more closely follow the topography of the Continental Shelf (Fig. 19). This is especially evident during
Fig. 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) April.
Fig. 1. Sea ice coverage (black) and areas where the shape of the SST fields was derived by satellite climatology (hatched area), for (c) July and (d) October.
Fig. 2. Areas where SSTs from the COADS 2° box summaries were merged onto CAC climatology. The numbers refer to the weights applied to the COADS 2° box SSTs. Areas where the weight is 1.0 (0.0) indicate that only the COADS 2° box (CAC) climatology was used. In boundary areas a linear combination of the SSTs was used.
Fig. 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.

Fig. 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.
Fig. 5. SST contours for the merged January SST climatology (solid) and the CAC climatology (dashed) in the Kuroshio 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.

Fig. 6. January SST differences between the merged climatology and the CAC climatology in the Kuroshio area. Negative differences are indicated by dashed contours. The numbers are the differences (0.1° C). The contour interval is 0.5°C.
Fig. 7. SST contours for the merged April 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.

Fig. 8. April 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.
Fig. 9. SST contours for the merged April SST climatology (solid) and the CAC climatology (dashed) in the Kuroshio 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.

Fig. 10. April SST differences between the merged climatology and the CAC climatology in the Kuroshio area. Negative differences are indicated by dashed contours. The numbers are the differences (0.1° C). The contour interval is 0.5°C.
Fig. 11. SST contours for the merged July 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.

Fig. 12. July 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.
Fig. 13. SST contours for the merged July SST climatology (solid) and the CAC climatology (dashed) in the Kuroshio 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.

Fig. 14. July SST differences between the merged climatology and the CAC climatology in the Kuroshio area. Negative differences are indicated by dashed contours. The numbers are the differences (0.1° C). The contour interval is 0.5° C.
Fig. 15. SST contours for the merged October 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.

Fig. 16. October 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.
Fig. 17. SST contours for the merged October SST climatology (solid) and the CAC climatology (dashed) in the Kuroshio 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.

Fig. 18. October SST differences between the merged climatology and the CAC climatology in the Kuroshio area. Negative differences are indicated by dashed contours. The numbers are the differences (0.1°C). The contour interval is 0.5°C.
Fig. 19 Bottom topography of the western Atlantic. Depths are in meters. The contour interval is 500m.
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. Levitus (1982) examined the impact of smoothing on SST analyses in the North Atlantic (see his Appendix A), and his “standard” analysis has gradients similar to those in the CAC climatology, whereas his “test” analysis, featuring weaker smoothing, contains values similar to those in the merged product. 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 (which correspond to periods of 12, 6, 4, 3, 2.4, and 2 months) 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 (see Appendix A) 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 (Figs. B26 to B32) 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 20 shows the SST differences between the CAC climatology and the lightly smoothed COADS 2° box summaries for January, April, July and October 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. Consequently, primarily because of the spatial smoothing in the CAC analysis, the cold upwelling tongue of water along the equator (Figs. B1–B13) 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. In section 5 the time series at this location are compared. Off the west coast of South America the SST differences (Fig. 20) show that at gridpoints in close proximity to land the SSTs should be lower by more than 2°C in some months. 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 than presented in Figs. B1–B13 in this region, but the evidence for this needs to be confirmed.
Fig. 20 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 January and April. The plotted numbers represent the differences (0.1°C). Dashed contours indicate negative values. The contour interval is 0.5°C.
Fig. 20 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 and October. The plotted numbers represent the differences (0.1°C). Dashed contours indicate negative values. The contour interval is 0.5°C.
3. The Shea-Trenberth-Reynolds SST climatology

The main figures for the atlas are presented together in Appendix B and briefly discussed here. In the main text we continue to present figures that clarify the procedures and characteristics of the new climatology. Hereafter, the new SST climatology will be called the STR (Shea-Trenberth-Reynolds) SST climatology to aid in differentiating it from other climatologies.

The STR 2° × 2° monthly and annual SST climatological fields are shown in Figs. B1–B13. The areas covered by sea ice are the same as those of the CAC climatology. For the annual mean, if sea ice was present for six or more months the annual mean was arbitrarily set to −1.8°C which is the freezing point of sea water at 35 ppt, otherwise the annual mean is set to the average of the SSTs during months with no sea ice. To illustrate the effect of the procedures previously described, Figs. 21 and 22 show the differences between the CAC climatology and the STR climatology for January and July. Over most of the domain, differences are small although the different SSTs in regions affected by the Kuroshio and the Gulf Stream are clearly indicated. In addition, the STR climatology is smoother due to the effects of using the first three harmonics of the annual cycle and the spatial smoothing poleward of 40°S.

Zonal means from the STR climatology for each month (Fig. 23) show that the warmest waters (>28°C) are, generally, between the equator and 10°N latitude with maxima occurring in May and October. To illustrate some large-scale differences between the northern and southern hemispheres (NH and SH, hereafter) a Fourier analysis of the monthly zonal means was performed. The results indicate that, for the annual zonal means, NH oceans are warmer than those of the SH at corresponding latitudes (Fig. 24a). For example, the annual zonal mean at 40°N is ~17°C versus ~14°C at 40°S and 5°C at 60°N versus 1°C at 60°S. The maximum amplitude of the first harmonic of the zonal mean SSTs is ~5.25°C and it occurs at 40–45°N latitude while the maximum amplitude in the SH is about half that of the NH (~2.7°C) and occurs between 30°S and 35°S (Fig. 24b). The minimum amplitude occurs at about 6–8°N which corresponds to the annual mean position of the Inter-Tropical Convergence Zone and the warmest region in Fig. 23 and Fig. 24a. The phase of the zonal means (Fig. 24c) shows that south of 10°S the SST maxima occur in February while north of 15°N the maxima occur in late August or early September. Between 10°S and 15°N there is an abrupt change of phase.
Fig. 21. Differences (°C) between January SSTs using the STR and CAC climatologies (STR–CAC). Dashed contours indicate negative values. The contour interval is 0.25°C.

Fig. 22. Differences (°C) between July SSTs using the STR and CAC climatologies (STR–CAC). Dashed contours indicate negative values. The contour interval is 0.25°C.
Fig. 23. Latitude-time cross-section of zonal means for the STR SST climatology. The ordinate is latitude, the abscissa is time in months (January is 1, February is 2, etc.). The SSTs are in °C and the contour interval is 1° C.
Fig. 24. (a) Annual zonal mean SST (°C), (b) amplitude of the first harmonic of the monthly zonal means (°C), and (c) the phase of the first harmonic (months). A phase of 2.0 corresponds to mid-February. Positive latitudes are north; negative latitudes are south.
The annual cycles of area weighted (cosine latitude) monthly SSTs in Figs. B01-B13 for six ocean areas are shown in Fig. 25 and the values are reproduced in Table 1. The areas are: (a) the globe, (b) the northern hemisphere, (c) the southern hemisphere, (d) 25°S to 25°N, (e) 25–90°N, and (f) 25–90°S. The annual cycle of monthly global mean SSTs varies from ~19.2°C in January to ~19.8°C in August. Although the range (~0.6°C) is small it potentially represents a large change in heat storage by the world's oceans although the exact amount will depend upon the depth of ocean involved. The mean NH SSTs are always warmer than those of the SH due in part to the inclusion of the large area of high latitude cold waters in the SH. The maximum difference (~6.5°C) occurs in August and the minimum difference (~1.2°C) occurs in February. The reason the global monthly means are not the average of the NH and SH means is that the SH oceans are much more extensive. In spite of this the annual cycle of global SSTs follows that of the NH. This is because the area north of 25°N exhibits the largest change of SSTs from 13.8°C to 19.8°C while south of 25°S the SSTs vary from 11.7°C to 14.1°C. The oceans south of 25°S are slightly warmer than the area north of 25°N (14.1°C versus 13.8°C) only during February and March.

Table 1. Area weighted monthly SSTs for the STR climatology for six different ocean areas: (A) the globe, (B) the northern hemisphere, (C) the southern hemisphere, (D) 25°S to 25°N (E) north of 25°N, and (F) south of 25°S.

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Fig. 25. Area weighted monthly SSTs for the STR climatology for six different ocean areas: (A) the globe, (B) the northern hemisphere, (C) the southern hemisphere, (D) 25°S to 25°N, (E) north of 25°N, and (F) south of 25°S. The abcissa is time in months (mid-January is 1, mid-February is 2, etc.). The ordinate is SST (°C).
Figures B14–B25 illustrate month-to-month SST differences which measure the rate of change of SST per month. These no longer reveal the noisy, spatially incoherent features, that were present when similar maps (not shown) were plotted for the original CAC climatology. The largest month-to-month increases over the open ocean occur from June to July in the NH. Over most of the northern Pacific the maximum increases are approximately 3–3.5°C/month while in the Kuroshio and the Gulf Stream the maximum SST increases are more than 5°C/month. In the SH the largest increases (>2°C) occur in the southern Indian Ocean between November and December. The largest decreases (>3°C) in the NH occur between September/October and October/November. Although well known, it is interesting to note that the SST warming/cooling cycle is not symmetric in time and that the rates of heating and cooling are different. This is illustrated in Figs. 26 and 27 which show latitude-time cross-sections for two longitudes (170°W and 30°W, respectively) in the mid-Pacific and mid-Atlantic. In the mid-Pacific the maximum rate of increase in SSTs occurs from June to July (~3.7°C/mo) while the maximum rate of cooling (~3.0°C/mo) occurs between September and October. Both occur at about 40°N. The transition from maximum warming to maximum cooling occurs over about a four-month period. The maximum SH warming/cooling rates are weaker (~1.8 and ~1.5°C) than those in the NH and occur at ~38°S. The maximum heating and cooling rates at 30°W in the Atlantic are less than in the North Pacific (2.5°C and ~2.0°C, respectively) at the same latitudes.

The amplitude, phase and percent-variance explained by the first three harmonics of the annual cycle are illustrated in Figs. B26–B32. A phase of 1.0 means that the maximum occurs in mid-January and a phase of 12 means a maximum in mid-December. Only the amplitude is shown for the third harmonic. The amplitudes and phases for the first two harmonics are consistent with those of Levitus (1987) who compared the annual cycle of SSTs derived using two different but not independent data sets. With the exception of the tropics and the northern Indian Ocean, the first harmonic generally explains more than 90% of the variance. In the equatorial western Pacific, the SST annual cycle has small amplitude, with the amplitude of the first harmonic less than 0.5°C and explaining less than 30% of the variance in some locations. The largest amplitudes of the first harmonic (8–10°C) are just off the east coasts of Asia and North America at about 50°N to 60°N. In contrast, at 50°S to 60°S the amplitudes are less than 2°C although they increase 2°C to 3°C in the subtropics of the SH.
Fig. 26. Latitude-time cross-section of the month-to-month SST differences (°C) at 170°W longitude in the mid-Pacific. January minus December is plotted at month 1, February minus January is plotted at month 2, etc. The contour interval is 0.5°C.

Fig. 27. Latitude-time cross-section of the month-to-month SST differences (°C) at 30°W longitude in the mid-Pacific. January minus December is plotted at month 1, February minus January is plotted at month 2, etc. The contour interval is 0.5°C.
The amplitudes of the second harmonic are generally considerably smaller than those of the first harmonic. The largest magnitudes are in the northern Pacific and Atlantic Oceans and over the southern oceans. For example, over the northern Pacific the amplitudes are 1°C to 1.5°C while those of the first harmonic are generally 3°C to 6°C. Over the central Arabian Sea the first two harmonics each explain about half of the variance. Although the second harmonic explains a greater fraction of the variance in the western Pacific, the amplitudes are small (<0.5°C).

Figures B33–B44 show the departure of each month’s values from that of the annual mean at each grid point. These plots complement the previous plots by providing a different perspective of the annual cycle. The differences are consistent with those of Halpert and Ropelewski (1989) who provide similar maps for 30°S to 30°N. The largest differences over the open oceans (>6°C) occur in August in the north central Pacific. In regions such as the Kuroshio and Gulf Stream the differences are even larger. Over the mid-high latitudes of the SH the maximum departures are generally about 3°C although SSTs west (east) of South America depart by approximately 3.8°C (4.5°C) in March (January). A cross section (Fig. 28) showing the differences between the monthly zonal means and the annual zonal mean show that the maximum differences are about +6.1°C in August and -4.4°C in February and March at 40°N. The SH differences are smaller (~3.0 and -2.5°C) and occur at 30-35°S. The differences at any particular longitude can vary considerably from this mean picture, as is indicated in Figs. 29 and 30. At 30°W the difference between the monthly mean climatological SSTs and the annual zonal mean is always positive, reemphasizing the importance of the Gulf Stream in the warmth of the North Atlantic, while in the Pacific (170°W) there is a clear annual cycle about the mean.

Figures B45–B56 display the SST differences from zonal means of each month. The most obvious feature is that the eastern sides of the oceans are cooler than the western sides, a signature associated with the large subtropical anticyclonic wind-driven ocean gyres. In the tropical Pacific the east-west SST gradient provides the basis for forcing the atmospheric Walker Circulation. The contrast across the Pacific is weakest in March–April and strongest (as much as 11°C at 10°S) in October corresponding to the associated annual cycle in the surface wind stress in the trade winds which influence both advection and upwelling.

Also of note in the departures of SSTs from the zonal means is the relative warmth of the North Atlantic, near Europe. Over the southern oceans, the warmth of the South
Fig. 28. Latitude-time plot of the difference between monthly zonal means and the annual zonal means (°C) for each month. "1" corresponds to January, etc. Dashed contours indicate negative values. The contour interval is 0.5°C.
Fig. 29. Latitude-time plot of the difference between monthly means at $170^\circ$W in the central Pacific and the annual zonal means ($^\circ$C). "1" corresponds to January, etc. Dashed contours indicate negative values. The contour interval is $0.5^\circ$C.
Fig. 30. Latitude-time plot of the difference between monthly means at 30°W in the central Atlantic and the annual zonal means (°C). "1" corresponds to January, etc. Dashed contours indicate negative values. The contour interval is 0.5°C.
Pacific relative to the South Atlantic and southern Indian Oceans is clearly revealed in all months. In particular, the region south and southeast of New Zealand averages about 5°C warmer than the region from about 30°W to 100°E.
4. Comparison: The Alexander-Mobley and STR SST climatologies

The STR $2^\circ \times 2^\circ$ SST climatology has been interpolated to R15 and T42 grids for use with the CCM. This also enabled comparisons to be readily made with the SST climatology currently used by the CCM derived from Alexander and Mobley (1974, 1976; hereafter, the AM SST climatology). Figures B57-B68 show the monthly differences using the T42 grids. Other quantities (not shown), such as month-to-month differences and annual cycle information (amplitudes, phases and percent variance) indicate that the AM SST climatology contained many small-scale features of questionable veracity and it is often these features that show up in the difference maps.

In the northern winter, the STR climatology is generally warmer in the NH and in the subtropics of the SH outside of the equatorial belt. However, it is often colder south of $45^\circ$S most of the year except for the region of the Campbell Plateau, southeast of New Zealand, where the reverse applies. From May to December it is mostly cooler in the tropical Pacific, especially in the western regions from August to November. These differences, of over $1^\circ$C, especially in October, are comparable to the SST anomalies observed in many El Niño events, and so it is likely that they will greatly influence the tropical convection and rainfalls in CCM simulations. Such changes should significantly alter the results of SST anomaly experiments, such as those simulating the impacts of El Niños on the atmospheric circulation. Latitude-time cross sections (Figs. 31 and 32) at $168.8^\circ$W and $28.1^\circ$W longitude (mid-Pacific and mid-Atlantic) help illustrate, more specifically, these comments. In the mid-Pacific the STR climatology is $1.3^\circ$C cooler near the equator in November and a little warmer ($\sim 0.5^\circ$C) in March. The relative warmth of the STR climatology in the vicinity of the Campbell Plateau is apparent with the SSTs being $2.4^\circ$C warmer in February. In the mid-Atlantic the STR SSTs are almost always warmer than the AM climatology north of about $35^\circ$S. South of this latitude the STR SSTs are generally considerably cooler (e.g., $-3.4^\circ$C) in June.

Some of the differences between the two climatologies can be explained by data differences. The AM climatology used data prior to 1942, while the STR climatology did not. The data prior to 1942 were not adjusted as suggested by Folland et al. (1984). If the data distribution had been uniform for the entire period of record, the cold bias of the data
Fig. 31. Latitude-time plot of the difference between the STR SST climatology and the CCM climatology based upon Alexander and Mobley (1976) at ~168.8°W. (°C) The grid resolution is T42. "1" corresponds to January, etc. Dashed contours indicate negative values. The contour interval is 0.25°C.
Fig. 32. Latitude-time plot of the difference between the STR SST climatology and the CCM climatology based upon Alexander and Mobley (1976) at ~28.1°W. (°C) The grid resolution is T42. "1" corresponds to January, etc. Dashed contours indicate negative values. The contour interval is 0.25°C.
prior to 1942 would make the STR climatology warmer than the AM climatology. This explains the overall difference between the two climatologies. The differences shown in the figures are complicated by large changes in the data distribution (e.g., see Oort et al., 1987). Thus some regions are influenced by data prior to 1942 while other regions are relatively unaffected. Furthermore the corrections suggested by Folland et al. (1984) are just average corrections and undoubtedly should be more complicated functions of season, latitude, etc.
5. Global SST and anomaly fields from 1982 to June 1990

The CAC operationally produces global monthly SSTs, called the blended analysis, using the methodology described by Reynolds (1988) with the following two modifications. First, monthly sea ice limits are now available and used to set the SSTs over ice covered regions to $-1.8^\circ$C. In this modified procedure, these ice simulated SSTs determine the external boundary conditions while the in situ SSTs (in regions with sufficient observations) determine the internal boundary conditions. In the remaining interior regions, the solution satisfies a Poisson equation which is forced by the Laplacian of the satellite SSTs. This change only affects the blended product south of $50^\circ$S and north of $60^\circ$N. The methodology is similar to that used to derive the CAC climatology which was the basis for the STR SST climatology previously described. Second, the final 1–2–1 binomial smoother is not applied to the CAC blended analyses. This means that SST gradients in the blended analyses will be larger than in the original CAC climatology.

When there is a bias in the climatology owing to the methods of analysis, a major concern is whether anomalies will be correctly analyzed. In analyzing the anomaly field even using identical procedures, the bias may not be the same because of the sparseness of the data base in individual months. It should be noted that the analysis procedures are not the same. In the monthly analysis, all data is first converted to anomalies using the CAC climatology. All analysis procedures are done using these anomalies. Because the procedures are nonlinear, the monthly analysis is not independent of the climatology. The conversion of all data to anomalies assures that climatological gradients will be preserved in data sparse regions.

To examine the effect of the analysis procedures, we have compared the CAC operational monthly analyses at $110^\circ$W at the equator with time series from a moored buoy (McPhaden and Hayes, 1990; kindly provided by M. McPhaden). The results, shown in Fig. 33, reveal not unexpectedly (cf. Fig. 20) that the bias in the CAC analysis is largest when there is a strong distinctive cold tongue, as in late 1983 and during 1988, but the bias vanishes during the El Niño events of 1982–83 and in 1987 when the temperatures were $>27^\circ$C. It is during these times that the local gradients are greatly reduced so that spatial smoothing has little effect on the analyzed values. The comparison of the anomalies relative to the STR climatology shows that the analyzed anomalies are not as large. Presumably
Fig. 33. (a) Comparison between SSTs from the CAC operational analyses at 110°W at the equator (dashed line) and a moored buoy (solid line; see McPhaden and Hayes 1990). (b) Differences between curves in (a). (c) Anomalies for each data set are relative to the STR climatology. The abscissa is time from January 1982 to April 1990. The ordinate units are °C.
they are still representative when the anomalies are averaged over broader areas, but the CAC analysis does not capture the full extent of the events in the center of the cold tongue. These aspects need to be borne in mind in interpreting the CAC products.

Seasonal SST anomaly fields for 1982 to 1990 are shown in Figs. B69–B103. The seasons presented are: December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON). (The 1982 DJF season anomalies were calculated from \((2 \times \text{January} + \text{February})/3\).) The anomaly fields often seem to reveal systematic anomalies. To highlight these, we have computed the differences between the 1982 through 1989 annual mean and the STR annual mean climatology (Fig. 34). There are a number of things of note; some of the differences shown are believed to reflect real decadal changes in SSTs but it is likely that some of the changes are spurious and arise from differences in the way the fields were produced. In the tropical Pacific, differences of 0.5°C are abundant but are believed to be real and associated with the two ENSO events 1982–83 and 1986–87, and perhaps some longer-term trends (see Trenberth, 1990; Nitta and Yamada, 1989). Indeed, it was because we recognized the extreme nature of the 1982–83 ENSO that we chose the 1950–79 period as the base period for the climatology. Linked to the tropical Pacific changes are the cooler than normal water in the North Pacific (Trenberth, 1990).

It is not as clear whether the anomalies in the North Atlantic are entirely real. In analyzing the surface wind stress and Sverdrup transport in the North Atlantic for 1982–1986 Trenberth et al. (1989) found evidence for a stronger subtropical gyre than in the Hellerman and Rosenstein (1983) climatology. However, in both the Gulf Stream and Kuroshio current areas the anomaly map (Fig. 34) bears some resemblance to the correction patterns we introduced in those regions (Figs. 5 to 18), although with smaller amplitude. At least in part, these differences are consistent with the different analysis procedures and the fact that the CAC no longer applies the final 1-2-1 smoother to the blended anomalies. Apparent strong anomalies to the southeast of Africa and South America may also arise simply from changes in smoothing or analysis procedures and from changes in data distribution, in this case the introduction of satellite data. Off the west coast of South America, anomalies are also apt to be sensitive to data density and analysis procedures, as noted above. Therefore, in certain areas, the anomaly fields should be interpreted as
Fig. 34. SST differences between the 1982 through 1989 annual mean SSTs and the STR annual mean SSTs. Dashed lines indicate negative values. The contour interval is 0.25°C.
consisting of the real climate anomaly plus a correction to the CAC climatology.

The total SST fields for the 1982 to 1990 produced by CAC therefore partly compensate for deficiencies with the CAC climatology. At the same time, the total SST fields are not compatible with the STR climatology. We have experimented with adding the anomaly fields to the STR climatology and generating new anomaly fields by subtracting the STR climatology from the total fields but biases exist in both sets of results. For the present it seems necessary to accept the CAC fields as the best available but recognize that the anomaly fields partially compensate for biases in the CAC climatology.

We now briefly discuss the seasonal SST anomaly fields (Figs. B69–B103). Several large-scale features are noted. In particular, the 1983 ENSO contains the most striking large-scale anomalies. This event began in mid-1982 and persisted until the mid-to-latter part of 1983. Above normal SSTs were present throughout the equatorial Pacific during this period. The largest seasonal SST anomalies (3.6°C) occurred in the equatorial east-central Pacific during the DJF 1983 season. Another ENSO occurred from mid-1986 through 1987. The positive anomalies were of similar spatial extent but were less than those of 1982-83. The maximum seasonal anomaly of 2.2°C occurred in JJA 1987. The 1988 La Niña which began in MAM 1988 and lasted about one year is also clearly seen in the cool equatorial waters. The maximum seasonal anomalies (−2.9°C) occurred in SON 1988. Also of note are the generally colder than normal SSTs in the North Pacific during the 1980s, reflecting the unusual nature of this particular period when there were three El Niño events in succession prior to the onset of the 1988 La Niña (Trenberth et al., 1989; Trenberth, 1990). Trenberth et al. show that significant changes in the Sverdrup circulation occurred in the North Pacific as a consequence of a deeper and eastward shifted Aleutian Low pressure system for the period 1980 to 1986.

A different perspective of this same period may be obtained by looking at latitude-time cross-sections of 3-month running means of the anomalies for this period at selected longitudes. The longitudes selected were: (a) 170°W (mid-Pacific), (b) 164°E (western Pacific), (c) 110°W (eastern Pacific), (d) 30°W (mid-Atlantic), and (e) 90°E (mid-Indian). Cool SSTs are present virtually the entire period in both the North Pacific from 35°N to 50°N (Figs. 35a and 35b) and in the North Atlantic north of 50°N (Fig. 35d). The El Niño and La Niña events are most obvious in the eastern Pacific (Fig. 35c). In the mid-Atlantic
and mid-Indian Ocean (Figs. 35d and 35e) the equatorial waters generally exhibited only small anomalies as contrasted with the significant departures in the equatorial Pacific during this period.
Fig. 35. Latitude-time plots of 3-month mean SST anomalies for (a) 170°W and (b) 164°E. The abscissa is year (82=1982) and each tic mark is one month. Dashed contours indicate negative values. The contour interval is 0.5°C.
Fig. 35. Latitude-time plots of 3-month mean SST anomalies for (c) 110°W and (d) 30°W. The abscissa is year (82=1982) and each tic mark is one month. Dashed contours indicate negative values. The contour interval is 0.5°C.
Fig. 35. Latitude-time plots of 3-month mean SST anomalies for (e) 90°E. The abscissa is year (82=1982) and each tic mark is one month. Dashed contours indicate negative values. The contour interval is 0.5°C.
6. Summary

A new SST climatology (called the STR 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.

Comparisons with the AM climatology demonstrate that the STR climatology is warmer in the northern hemisphere. Poleward of 45°S the STR climatology is generally colder. At T42 resolution, the STR climatology is more than 5°C warmer off the east coasts of Asia and North America while in the mid-high latitude southern oceans the SSTs are often more than 2°C lower.

We have noted that caution must be used in interpreting the CAC SST anomalies for 1981 to 1990 as true anomalies because, in certain regions, the anomalies partially compensate for deficiencies in the CAC climatology.
References


Appendix A
The nine-point smoother

We define a rectangular 9-point grid with grid spacing $\Delta$ and label the center point 0 and the surrounding points 1 through 8, beginning in a corner.

Then the general form of a 9-point smoother is

$$\overline{f_0} = f_0 + \frac{p}{4}(f_2 + f_4 + f_6 + f_8 - 4f_0) + \frac{q}{4}(f_1 + f_3 + f_5 + f_7 - 4f_0)$$

If $q = 0$ then the expression becomes the classical 5-point smoother. The 5-point smoother with $p = 0.5$ and $q = 0$ eliminates $2\Delta$ waves and $4\Delta$ waves are reduced in amplitude by 50%.

If $\frac{1}{2}p = \nu(1 - \nu)$ and $q = \nu^2$ the smoother becomes the Shuman (1957) 9-point smoother. The latter, with $p = 0.5$ and $q = 0.25$ is what was generally used here. It eliminates $2\Delta$ waves in each direction entirely and fairly strongly damps other wavelengths; $4\Delta$ waves in each direction are reduced in amplitude by 77%, $8\Delta$ waves are reduced by 29%. For features of wavelength of $4\Delta$ in one direction by infinite wavelength in the other direction, the amplitudes are reduced by 50%.

A light filter is obtained if we set $p = 0.5$ and $q = -0.25$. It also eliminates $2\Delta$ waves but retains $4\Delta$ waves with about 80% of their amplitude and has no effect on any waves with infinite wavelength in the other direction.
Appendix B

ATLAS
B1: Mean fields

Figs. B1–B13. Monthly and annual STR SST climatology. Black areas indicate sea ice. The contour interval is 2°C except for the dashed contours which indicate the 27 and 29°C isotherms.
STR: JUNE SST CLIMATOLOGY
STR: SEPTEMBER SST CLIMATOLOGY
STR: OCTOBER SST CLIMATOLOGY
Figure showing the December Sea Surface Temperature (SST) Climatology.
B2: Month-to-month differences

Figs. B14–B25: Month-to-month differences for the STR SST climatology. Negative differences are indicated by dashed lines (°C). The contour interval is 0.5°C.
STR: (JAN-DEC) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY .5
STR: (FEB-JAN) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY .5
STR: (MAR-FEB) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY .5
STR: (APR-MAR) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY .5
STR: (MAY-APR) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY .5
STR: (JUN-MAY) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY 00
STR: (JUL-JUN) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY 00
STR: (OCT-SEP) SST DIFFERENCES

CONTOUR FROM -5 TO 5 BY .5
**B3: Harmonics of the annual cycle**

Figs. B26–B32: Amplitude (°C), phase and percent variance explained for the first three harmonics of the annual cycle of the STR SST climatology. A phase value of 1.0 means maxima in mid-January.
STR: AMPLITUDES OF HARMONIC 1

CONTOUR FROM 0 TO 10 BY .5
STR: PERCENT VARIANCE EXPLAINED BY HARMONIC 1

CONTOUR FROM 0 TO 100 BY 10
STR: PHASES OF HARMONIC 1

CONTOUR FROM 0 TO 13 BY 1
STR: PERCENT VARIANCE EXPLAINED BY HARMONIC 2

CONTOUR FROM 0 TO 100 BY 10
STR: PHASES OF HARMONIC 2

CONTOUR FROM 0 TO 13 BY 1
B4: Departures from the annual mean

Figs. B33–B44: Differences between monthly SSTs the annual mean SSTs for the STR SST climatology. Negative differences are indicated by dashed lines (°C). The contour interval is 0.5°C.
STR SST DIFFERENCES: (FEB - ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (MAR - ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (APR - ANNUAL)
CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (MAY-ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (JUN - ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (JUL-ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (AUG-ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (OCT-ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
STR SST DIFFERENCES: (NOV-ANNUAL)

CONTOUR FROM -10 TO 10 BY .5
B5: Departures from zonal means

Figs. B45–B56. Differences in SSTs from the zonal means for each month from the STR climatology. Negative differences are indicated by dashed lines (°C). The contour interval is 1°C.
STR: FEB SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
STR: MAR SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
STR: APR SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
STR: MAY SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
STR: JUL SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
STR: AUG SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
STR: OCT SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1

H4.6
H3.2
H3.0
H4.6

0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

STR: NOV SST DIFFERENCES FROM ZONAL MEANS

CONTOUR FROM -10 TO 10 BY 1
B6: STR – Alexander-Mobley differences

Figs. B57–B68: Monthly differences between the STR SST climatology and the AM climatology after interpolating the STR SST climatology to T42. Negative differences are indicated by dashed lines (°C). The contour interval is 0.5°C.
MAR: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
MAY: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
JUN: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
AUG: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
OCT: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
NOV: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
DEC: STR-AM DIFFERENCES AT T42

CONTOUR FROM -5 TO 5 BY .5
B7: Seasonal SST anomalies 1982–MAM 1990

Figs. B69–B103: Seasonal SST anomalies for the period 1982 through March–April–May of 1990. The winter of 1982 was obtained using \((2 \times \text{January} + \text{February})/3\). The seasonal labels are: DJF means December–January–February, MAM means March–April–May, JJA means June–July–August, and, SON means September–October–November. Negative anomalies are indicated by dashed lines (°C). The contour interval is 0.5°C.
STR: SST SEASONAL ANOMALIES: MAM 1983

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: JJA 1983

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: JJA 1984

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: SON 1984

Contour from -10 to 10 by .5
STR: SST SEASONAL ANOMALIES: DJF 1985

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: MAM 1985

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: MAM 1986

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: SON 1986

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: DJF 1988

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: MAM 1988

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: JJA 1988

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: SON 1988

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: DJF 1989

CONTOUR FROM -10 TO 10 BY .5
STR: SST SEASONAL ANOMALIES: MAM 1989

CONTOUR FROM -10 TO 10 BY .5

nm ki L a I a -- . I --- . i I I~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~I evIe
VIVU
STR: SST SEASONAL ANOMALIES: SON 1989

CONTOUR FROM -10 TO 10 BY .5