A Comparison of Sea Surface Temperature Climatologies

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ABSTRACT

Six global and two regional Pacific monthly sea surface temperature climatologies were compared. The climatologies were based on either surface marine observations or oceanographic cast (surface plus subsurface temperatures) observations. Although the cast data is more accurate than the surface marine, the data density of the cast observations is much more sparse. In this study, the surface marine climatologies were generally found to be superior to the cast climatologies. The individual differences between the climatologies are described and evaluated.

1. Introduction

An accurate sea surface temperature (SST) climatology is important in examining the measurements to be used in a SST analysis and is critical in producing a useful SST anomaly field. Currently available SST climatologies have different spatial resolutions, are derived from observations from different measurement systems, are based on different analysis periods and were analyzed by a variety of techniques, both objective and subjective.

In this paper SST climatologies are investigated on space and time scales that have important climatic impact. The emphasis is placed on open ocean monthly climatological differences of 1°C or more which are coherent over spatial scales of at least 500 km. Using these scales, the differences between six global and two regional SST climatologies are examined for each month. Large differences among the climatologies are identified and, where possible, explained.

2. Data

Open ocean *in situ* SST measurements can be divided into two broad classes: surface temperature measurements made along with subsurface measurements, and surface observations only. The first class, henceforth called cast data, consists of oceanographic station data (e.g., Nansen casts or salinity–temperature–depth casts) as well as expendable and mechanical bathythermograph (BT) casts. The BT's, although less accurate than the oceanographic station data, have typical SST accuracies of several tenths of a degree C (Tabata, 1978a). The second class, the surface marine weather data, consists of bucket, engine intake, and buoy temperatures. The intake temperatures, which dominate the surface marine data since the Second World War, are the least accurate of these data with accuracies on the order of one degree C. Tabata (1978b) and others found intake temperature observations had biases of up to several tenths of a degree C depending on season and ship position.

Although the cast observations are more accurate than the suface marine observations, they constitute approximately only 4% of the total number of SST observations in the historical data base (Reynolds, 1982). An example of the spatial coverage is shown in Fig. 1 for Levitus' (1982) cast data for all July's. The ~100 000 observations are not sufficient to adequately cover the Southern Hemisphere. Fig. 2 shows the July spatial coverage for the Pacific Ocean for both classes of SST data from Reynolds (1982). The addition of almost 1.5 million surface marine observations has improved the Northern Hemisphere coverage and much improved the coverage from the equator to approximately 40°S. Thus, a choice between cast or surface marine data is equivalent to a choice between greater accuracy or better coverage.

Two of the global sets examined were based primarily on cast data. Both consist of data on a 1° latitude–longitude grid and include subsurface temperature fields. The Levitus (1982) (henceforth L) cast climatology was derived from all data in the National Oceanographic Data Center's (NODC) files through 1976 and was processed by the objective technique described in Levitus and Oort (1977). The Robinson and Bauer (henceforth RB) climatology was analyzed both subjectively and objectively for the North Pacific (1942–69), (Robinson, 1976), the North Atlantic (1946–70), (Robinson *et al.*, 1979) and the Southern Hemisphere (1942–74), (unpublished) using cast data, which only partially overlaps the NODC cast files, plus shore station data. Surface marine observations from the National Climatic Center (NCC) were also

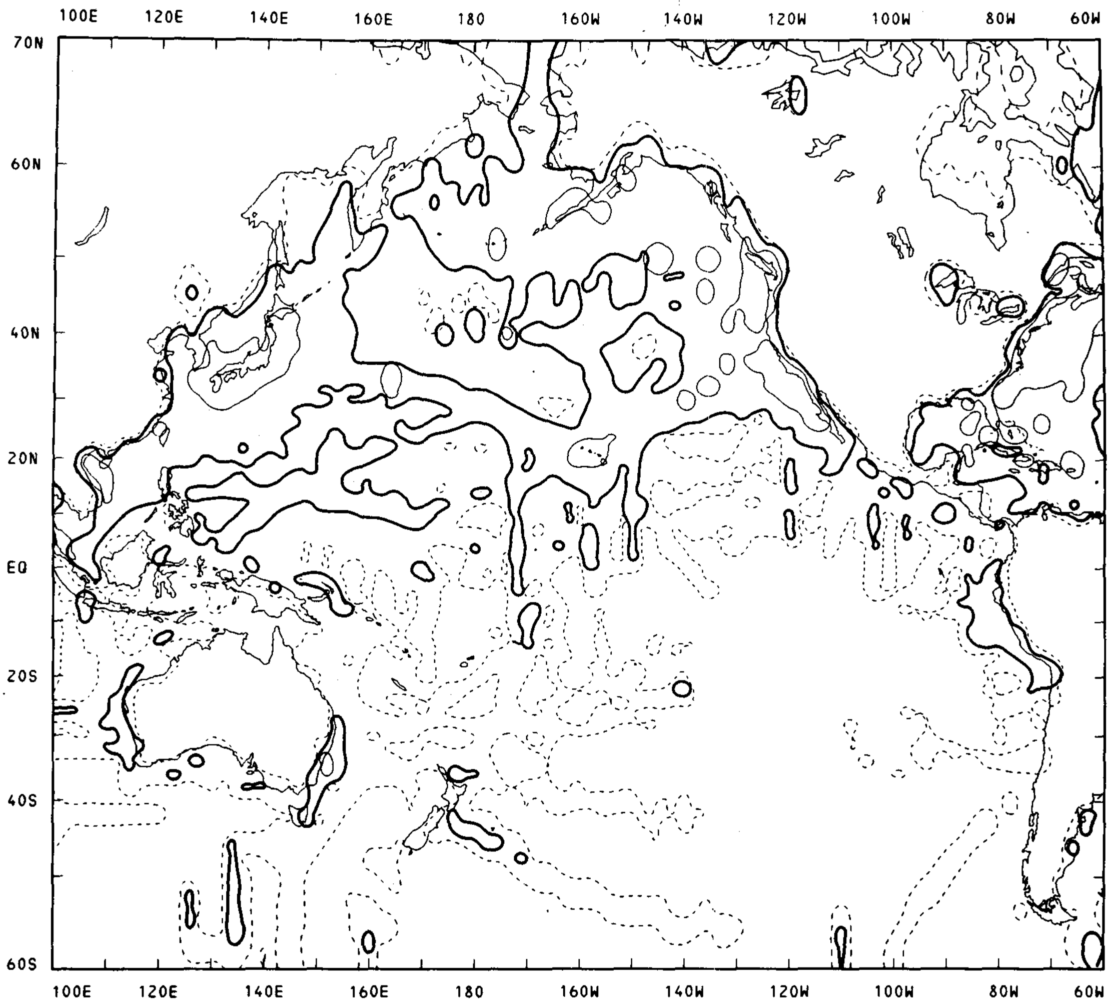

FIG. 1. Data density of cast SST measurements on a 2° grid for the Pacific Ocean for July. The dashed lines indicate a contour interval of one observation per grid quadrangle, the heavy solid lines indicate ten observations, and the light solid lines indicate 100 observations.

used by RB to subjectively fill in regions where the cast data was too sparse.

The other global 1° resolution SST climatology was processed by Reynolds (1982) (henceforth R) from an NCC data summary (all observations through 1971 to 1976, depending upon the ocean basin) of cast and surface marine temperatures. NCC had previously averaged the observations on a 5° grid and produced twelve hand contoured analyses of monthly mean SST fields, as well as other marine fields, in the *U.S. Navy Marine Climatic Atlas of the World* (1981). However, since this resolution is inadequate to resolve small scale features such as western boundary currents, R analyzed the 1° data summary using a nonlinear filter based on a median smoothing process (Rabiner *et al.*, 1975). By using medians rather than weighted means, extreme points are systematically eliminated from the initial data without excessive smoothing of extrema or gradients. Finally, a five-point binomial filter (Holloway, 1958) was used to smooth the remaining minor grid-scale noise.

Alexander and Mobley (1976) (henceforth AM) formed their global climatology from two different monthly climatologies derived primarily from surface marine observations. The 2½° resolution National Center for Atmospheric Research (NCAR) climatology was used for the Southern Hemisphere and a 125 × 125 polar stereographic Fleet Numerical Weather Center climatology was used for the Northern Hemisphere. Both fields were linearly interpolated onto a 1° grid and then blended across the equator. The data coverage for the entire set varies, depending on location, but includes data for the period 1854–1972.

Surface marine observations from the U.S. Navy's consolidated data set (Caton and Kuhn, 1978) were used by R. Slutz (personal communication, 1982) (henceforth S) to produce monthly SST fields on a 5° grid for the period 1946–78. A regional set of

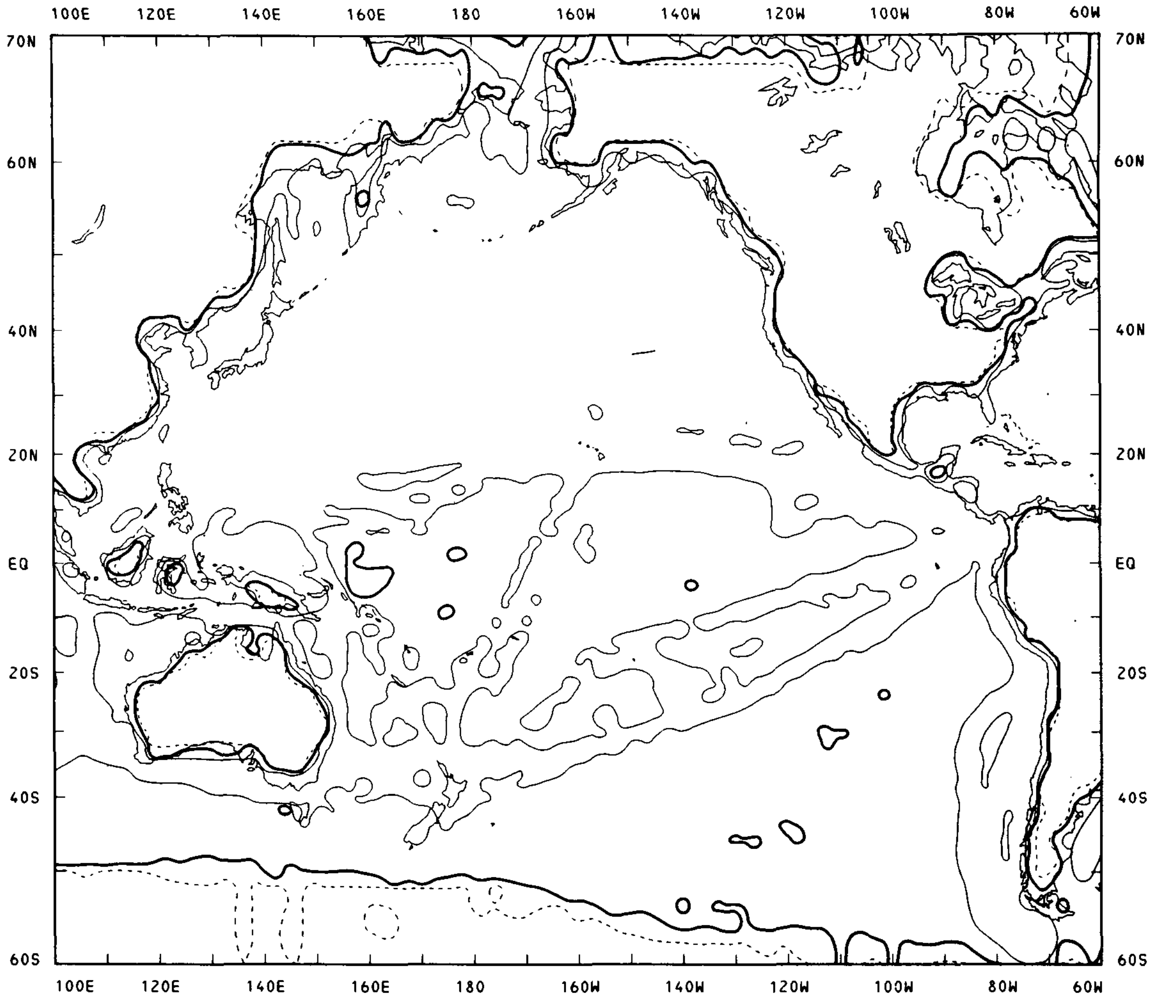

FIG. 2. Data density of surface marine SST measurements on a 2° grid for the Pacific Ocean for July (see also Fig. 1).

monthly SST fields derived from surface marine observations (1947–80) in the Pacific (20–60°N) was independently produced, as described by Born *et al.* (1973) (henceforth B), on a 2° grid. Climatological averages for each month were produced from the S and B fields and then linearly interpolated onto a 1° grid. An equatorial Pacific regional climatology was also linearly interpolated onto a 1° grid from Rasmusson and Carpenter's (1982) (henceforth RC) 2° grid summary of marine observations (1947–76) between 30°S and 30°N.

The remaining monthly global climatology was produced (Holl *et al.*, 1981) (henceforth H) from 5-day averages of surface marine data (1946–78) on a 3° Mercator grid by an objective computer analysis (Holl *et al.*, 1979). Monthly averaged climatological fields were computed and linearly interpolated to a 1° resolution. A brief summary of each climatology is given in Table 1.

It is difficult to reconstruct all the details for each analysis step for every climatology. However, it should be pointed out that the fields used in the H, R, and RB climatologies were not interpolated across land–sea boundaries. Furthermore, the RB climatology was the only climatology which attempted to maintain boundary current gradients. In addition the RB climatology was the only one which was directly smoothed in time (see Robinson, 1976). The time series of the B and H fields were, however, influenced by the preceding field in time and this will also effectively temporally smooth these climatologies. Reynolds (1982) plans to investigate the effect of temporal smoothing for the R climatology.

Satellite SST fields offer coverage which is much better than that available from ships (e.g., Miyakoda and Rosati, 1982). However, the biases between the ship and satellite-derived SST fields can be as high as 4°C (Barnett *et al.*, 1979). Furthermore, the period of record of the better satellite fields (Strong and Pritchard, 1980) began in May 1976. The period (1976 to present) is too short to eliminate interannual fluctuations from any climatology. In addition, the ac-

TABLE 1. Summary of monthly sea surface temperature climatologies studied.

Name (abbreviation)	Institution	Original spatial resolution (deg)	Type of data (period)	Region	Reference
1. Robinson and Bauer (RB)	Compass Systems San Diego, CA	1	Cast (1942–79)	Global (78°S–73°N)	Robinson (1976); Robinson *et al.* (1979)
2. Levitus (L)	GFDL/NOAA Princeton, NJ	1	Cast (1901–76)	Global (78°S–90°N)	Levitus (1982)
3. Reynolds (R)	NMC/NWS/NOAA Washington, D.C.	1	Surface marine (1854–1976)	Global (41°S–61°N)	Reynolds (1982)
4. Alexander and Mobley (AM)	Rand Los Angeles, CA	≥2.5	Surface marine (1854–1972)	Global (to ice limits) (70°S–80°N)	Alexander and Mobley (1976)
5. Slutz (S)	ERL/NOAA Boulder, CO	5	Surface marine (1946–78)	Global (68°S–78°N)	Caton and Kuhn (1978)
6. Born *et al.* (B)	Scripps Institution of Oceanography, La Jolla, CA	2	Surface marine (1947–80)	Regional Pacific (20–60°N)	Born *et al.* (1973)
7. Rasmusson and Carpenter (RC)	NMC/NWS/NOAA Washington, D.C.	2	Surface marine (1946–76)	Regional Pacific (30°S–30°N)	Rasmusson and Carpenter (1982)
8. Holl *et al.* (H)	Meteorology International Inc., Monterey, CA	3 (Mercator)	Surface marine (1946–78)	Global (68°S–68°N)	Holl *et al.* (1981)

curacies of the retrievals have recently been improved by a multi-channel technique (McClain, 1980) and degraded by the volcanic eruption of El Chichon (A. Strong, personal communication, 1982). Since these problems make the satellite SST fields suspect, no attempt was made to undertake any analysis of a satellite SST climatology.

3. Comparisons

The six global and two regional climatologies were evaluated on a 1° latitude–longitude grid centered on the half degree, covering the area from 61°N to 41°S for all global climatologies. Outside of these limits, SST observations were sparse during the local winter. The Pacific Ocean was treated separately from the Atlantic and Indian Oceans in view of its central importance in climate variability studies (Namias and Cayan, 1981). An emphasis was placed on the month of July because of large differences between the climatologies due to sparse winter data in the Southern Hemisphere and because of the important connection between summer midlatitude North Pacific anomalies and fall circulation over the North Pacific (Namias, 1976; Davis, 1978).

An overall summary of the root mean square (rms) differences between the global fields is given in Table 2 (Pacific Ocean), and in Table 3 (Atlantic and Indian Oceans) for both January and July. The January and July comparisons are shown above and below the diagonal, respectively. Data from the following oceanic seas were not included in the comparisons: the Baltic, Mediterranean and Red Seas, the Gulfs of Carpentaria and California, the Persian Gulf, the Sea of Japan, and Hudson Bay.

The rms values have been underlined in Table 2 or 3 when both January and July differences between two climatologies were ≤0.6°C. On the basis of this criteria the R climatology is similar to both the AM and the S climatologies for the Pacific as well as the Atlantic and Indian Oceans. In addition, the R climatology is also similar to the RB climatology for the Pacific Ocean. However, the AM, S, and RB climatologies show poorer agreement among themselves. This may arise because of the coarser resolution of the AM and S climatologies, which lead to individual interpolation differences in areas of strong gradients.

The two regional climatologies were also compared with the six global climatologies to determine differences on smaller scales. The rms differences (Table 4) show that the B climatology had differences larger than 0.6°C when compared with the RB and H climatologies. Only the L climatology had differences larger than 0.6°C when compared to the RC climatology.

Separate difference maps are now shown to examine in more detail the comparisons summarized in Tables 2–4. To minimize the number of maps displayed, the R climatology was selected as a temporary "standard of comparison." The R climatology for July is shown in Figs. 3 and 4; the remaining fields may be found in Reynolds (1982).

a. Pacific Ocean

The differences between the RB and the R climatologies for July are shown in Fig. 5. Apart from some small grid-scale differences, the two most important differences are found in the eastern equatorial Pacific and the eastern midlatitude North Pacific. The RB SST's are as much as 2°C lower along the coast of Peru and westward along the equator to 130°W. This difference is present in all months but tends to be strongest in November and December when it extended as far west as the international dateline. The cause of the differences may be due to inadequate sampling of the El Niño warming events by the sparse cast data. In the other region centered at 155°W and 45°N, the RB SST's are more than 1°C higher than the R climatology. The positive difference persists from April through October and is greater than 2°C in May and June. Robinson (personal communication, 1982) pointed out that their data in this region covered only the period 1942 through 1952. Since the cast data, (Fig. 1) should be adequate to sample in the North Pacific, the temperature difference is probably due to the different time periods sampled.

The comparison of the July L cast climatology and the R climatology is shown in Fig. 6. The major differences between the RB and R climatologies do not appear in this comparison. This is further evidence that the differences are not the result of the type of SST measurement. However, the L and R climatologies show substantial differences (>3°C) south of 10°S. The differences are due to "eddy-like" features which are imbedded in the L temperature fields. Comparisons of L and R climatologies for other months also show similar differences, primarily in the Southern Hemisphere. Although the L climatology was processed by an objective technique, their procedure may be inadequate in regions of sparse cast data.

The comparison between the July S and R climatologies shows better agreement (Fig. 7). The differences which occur in the eastern equatorial Pacific and north of the Kuroshio Extension in the western midlatitude Pacific, are primarily due to the coarse 5° S resolution which smoothes the narrow band of cold equatorial upwelling and relaxes the Kuroshio gradient. There is some suggestion of questionable data in the S climatology along the equator at 160°E and south of 35°S.

The July comparison of the AM and R climatologies (Fig. 8) shows similar differences in the eastern equatorial Pacific and along the Kuroshio Extension. The AM climatology also shows higher SST's in the Gulf of Alaska. The AM climatology seems to have spread the warmer Alaskan coastal water farther into the Gulf of Alaska than any of the other climatologies.

The regional B and regional RC climatologies show even smaller differences when compared to the July

TABLE 3. The rms differences (°C) of the six global climatologies for January (above diagonal) and July (below diagonal) for the Atlantic and Indian Oceans between 61°N and 41°S and between the east coast of the Americas and 101°E (see also Table 2).

	RB	L	R	AM	S	H
					January	
RB	—	0.7	0.7	0.8	0.8	0.6
L	0.6	—	0.7	0.8	0.8	0.6
R	0.6	0.7	—	0.6	0.6	0.4
AM	0.8	0.8	0.5	—	0.8	0.6
S	0.7	0.6	0.5	0.6	—	0.5
H	0.7	0.7	0.8	0.9	0.6	—
	July					

TABLE 2. The rms differences (°C) of the six global climatologies for January (above diagonal) and July (below diagonal) for the Pacific Ocean between 61°N and 41°S and between 99°E and the west coast of the Americas. Values are underlined when both January and July differences are ≤0.6°C.

	RB	L	R	AM	S	H
					January	
RB	—	0.8	0.6	0.8	0.7	0.6
L	0.7	—	0.7	1.0	0.7	0.7
R	0.6	0.8	—	0.6	0.6	0.4
AM	0.7	0.9	0.5	—	0.8	0.6
S	0.6	0.7	0.4	0.6	—	0.5
H	0.9	0.9	0.9	1.0	0.7	—
	July					

TABLE 4. The rms differences (°C) between the two regional climatologies and the six global climatologies (see also Table 2).

	B North Pacific (21–59°N and 131°E–111°W)		RC Equatorial Pacific (29°S–29°N and 101°E–71°W)	
	January	July	January	July
RB	0.7	0.6	0.5	0.5
L	0.6	0.5	0.5	0.7
R	0.5	0.5	0.3	0.3
AM	0.6	0.4	0.6	0.5
S	0.4	0.4	0.4	0.4
H	0.4	0.7	0.3	0.4

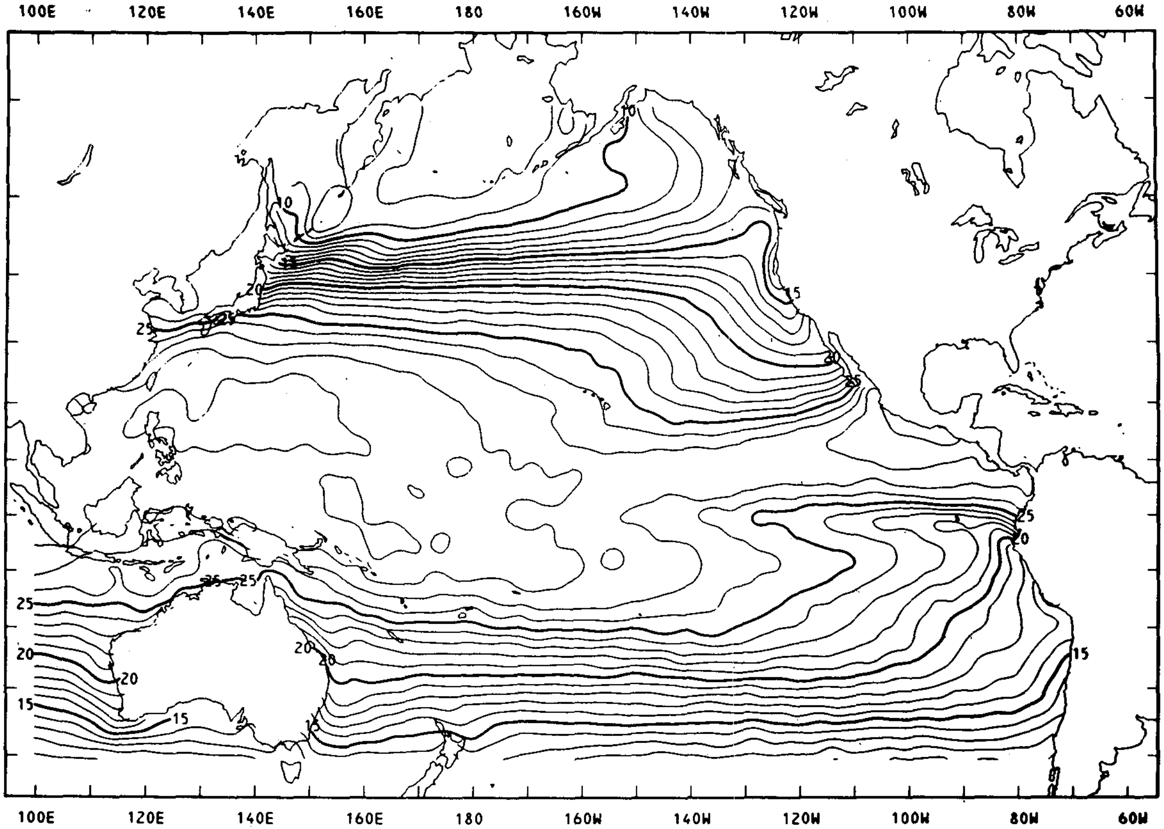

FIG. 3. July SST mean R climatology for the Pacific Ocean on a 1° grid. The contour interval is 1°C; heavy lines indicate contour intervals of 5°C.

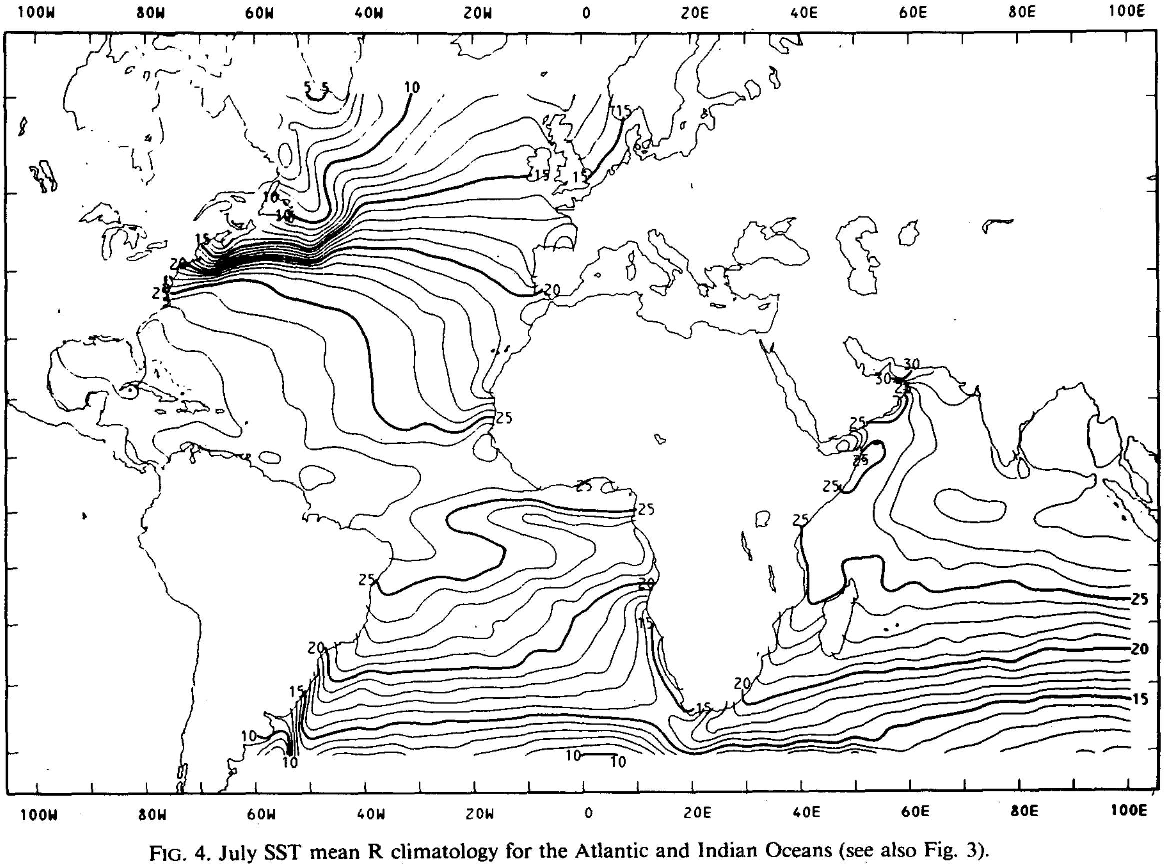

FIG. 4. July SST mean R climatology for the Atlantic and Indian Oceans (see also Fig. 3).

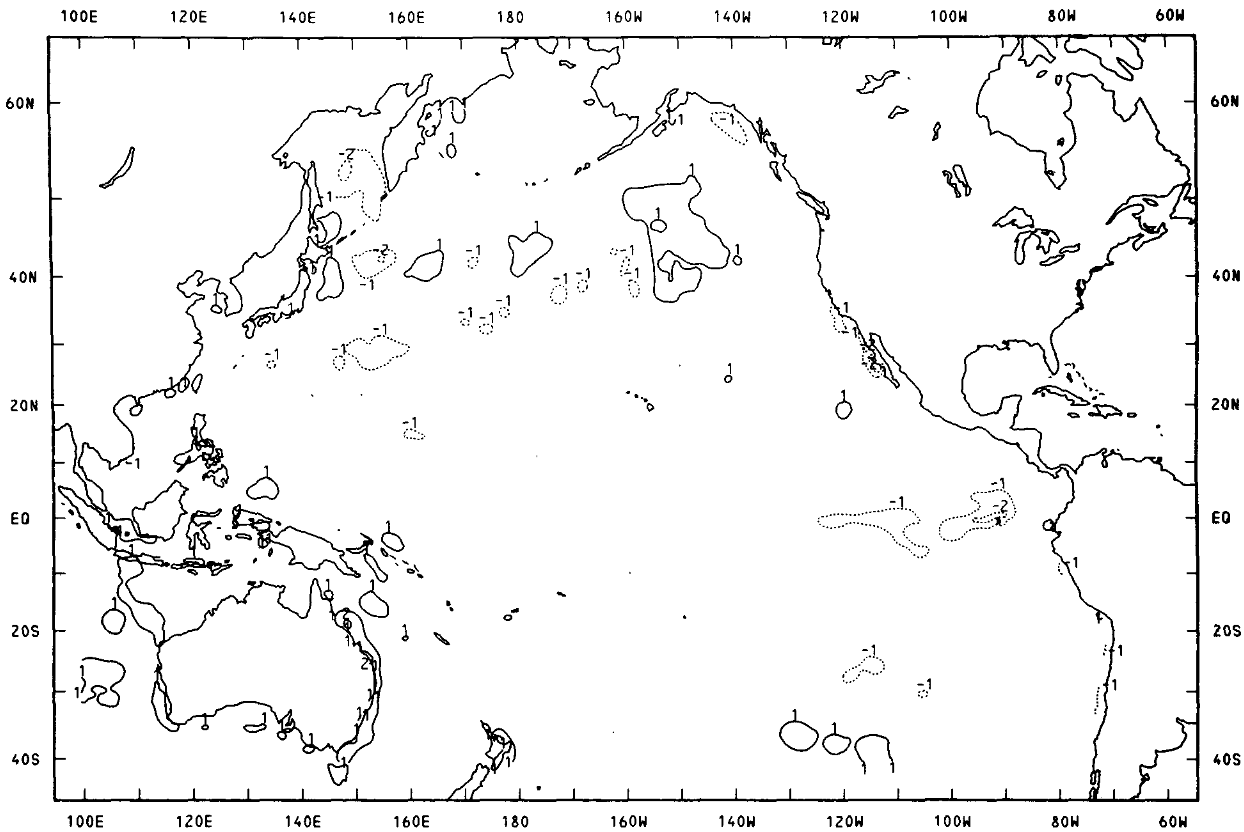

FIG. 5. July SST (°C) for the Pacific Ocean on a 1° grid between the RB and R climatologies. The dashed lines indicate negative differences; the solid lines indicate positive differences.

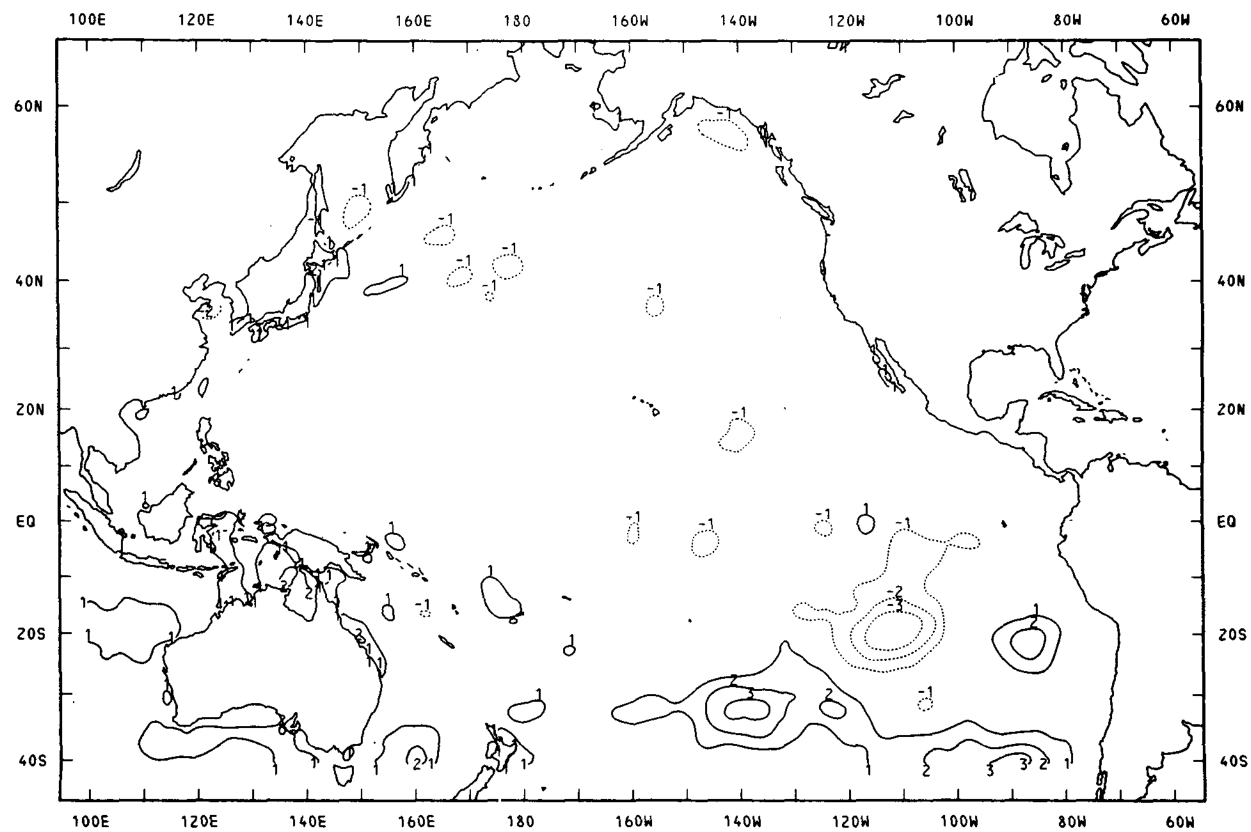

FIG. 6. As in Fig. 5, but between the L and the R climatologies.

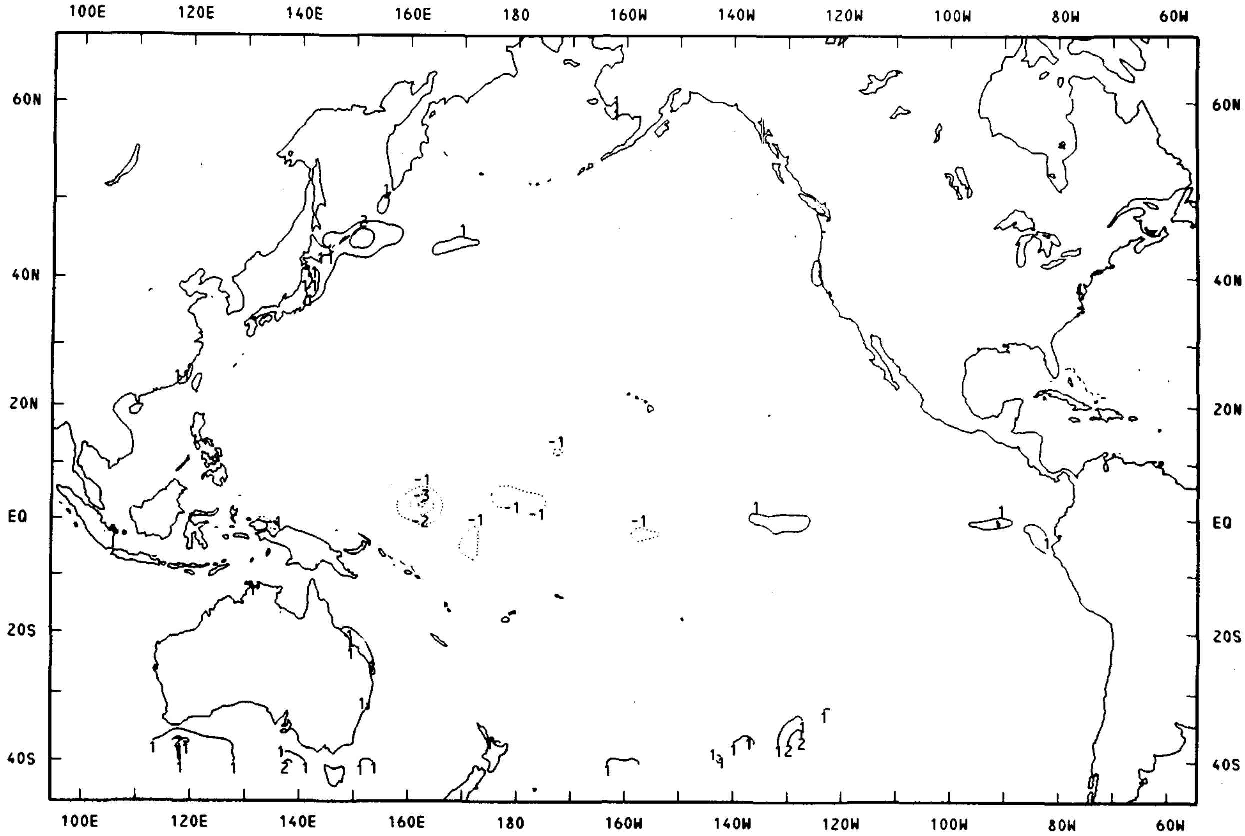

FIG. 7. As in Fig. 5, but between the S and R climatologies.

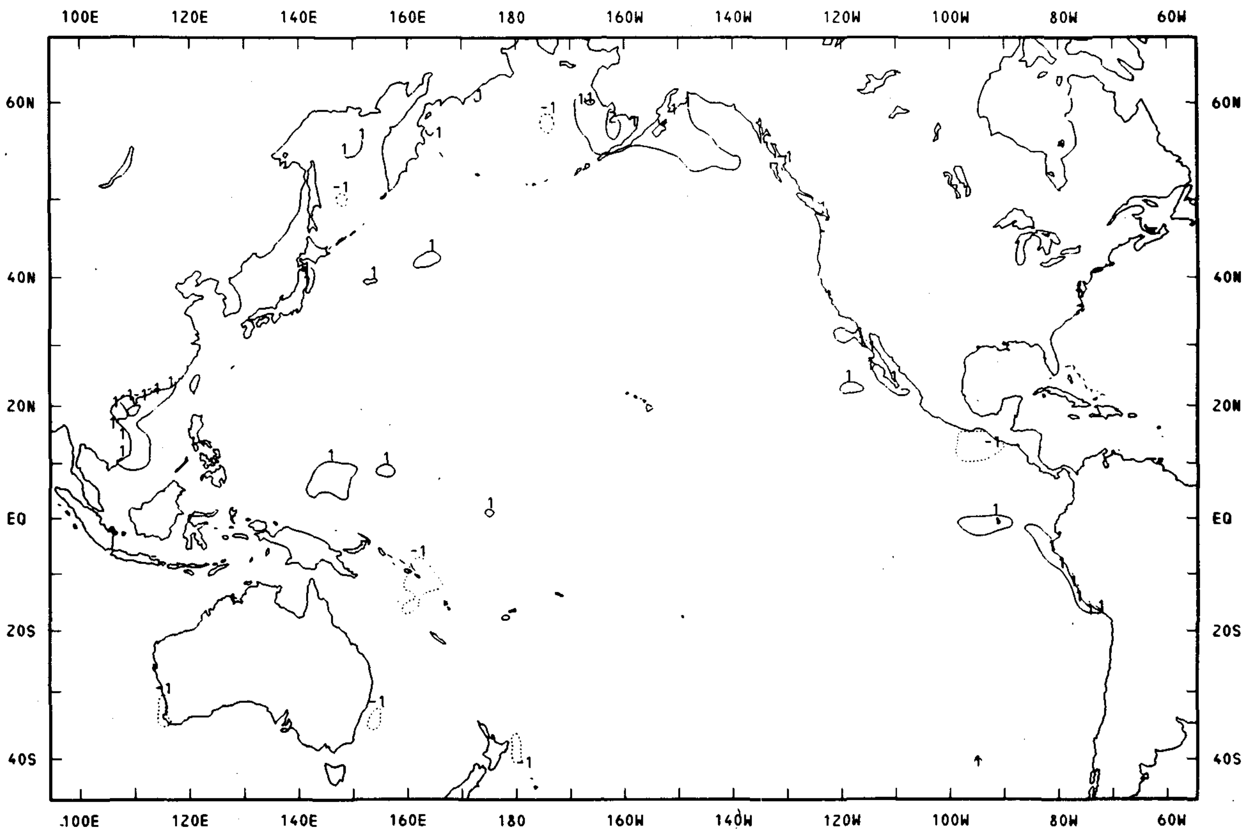

FIG. 8. As in Fig. 5, but between the AM and the R climatologies.

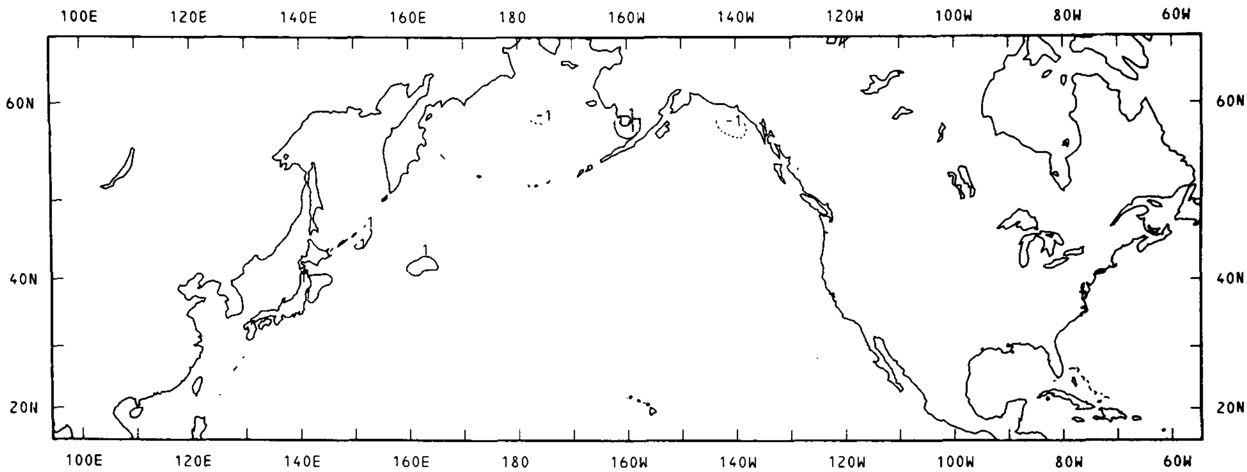

FIG. 9. As in Fig. 5, but between the B and the R climatologies.

R climatology in Figs. 9 and 10, respectively. Although these climatologies use similar surface marine data observations, they were processed differently. The B climatology was obtained from averages of subjectively smoothed monthly fields; the RC climatology was computed directly from objective averages of all data for each month. However, the surface marine data densities are apparently large enough so that these analysis differences are not important.

Unfortunately, not all of the analyses with the surface marine data are in such close agreement. Fig. 11 shows comparison between the July H and R climatologies. Here, differences along the equator can be partially explained by the H climatology's coarser 3° Mercator resolution. More troubling are comparisons in the sparse data of the eastern South Pacific where the H climatology shows SST's >3°C higher than those of the R climatology. Differences of similar magnitude appear in the northern midlatitudes, both along 40°N and north of 50°N. Here the H SST's are the lowest of all the climatologies studied. This difference is surprising since the data coverage, (Fig. 2) appears adequate for an analysis on this scale. The comparisons with the R climatology for other months show that these midlatitude differences persist from May through October and are near maximum in July and August. Tables 2 and 4 also show substantial rms increases from January to July when the H climatology is compared with all other climatologies covering this area.

Tables 2 and 4 also indicate that the AM climatology should show evidence of a seasonal difference. Fig. 12 shows the comparison between the January AM and R climatologies. The AM climatology shows SST's lower than that of R north of 50°N, in the Sea of Okhotsk, off the north coast of Australia, and in several regions south of 20°S. Since it doesn't occur in the S, B or RC comparisons with the R climatology, it suggests that the AM climatology may have a winter low temperature bias.

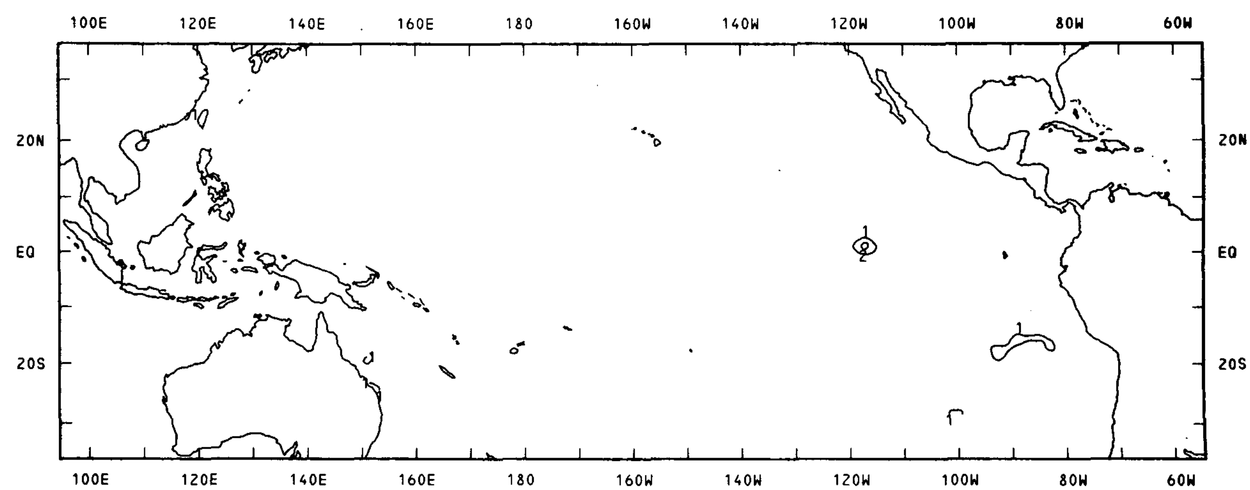

FIG. 10. As in Fig. 5, but between the RC and the R climatologies.

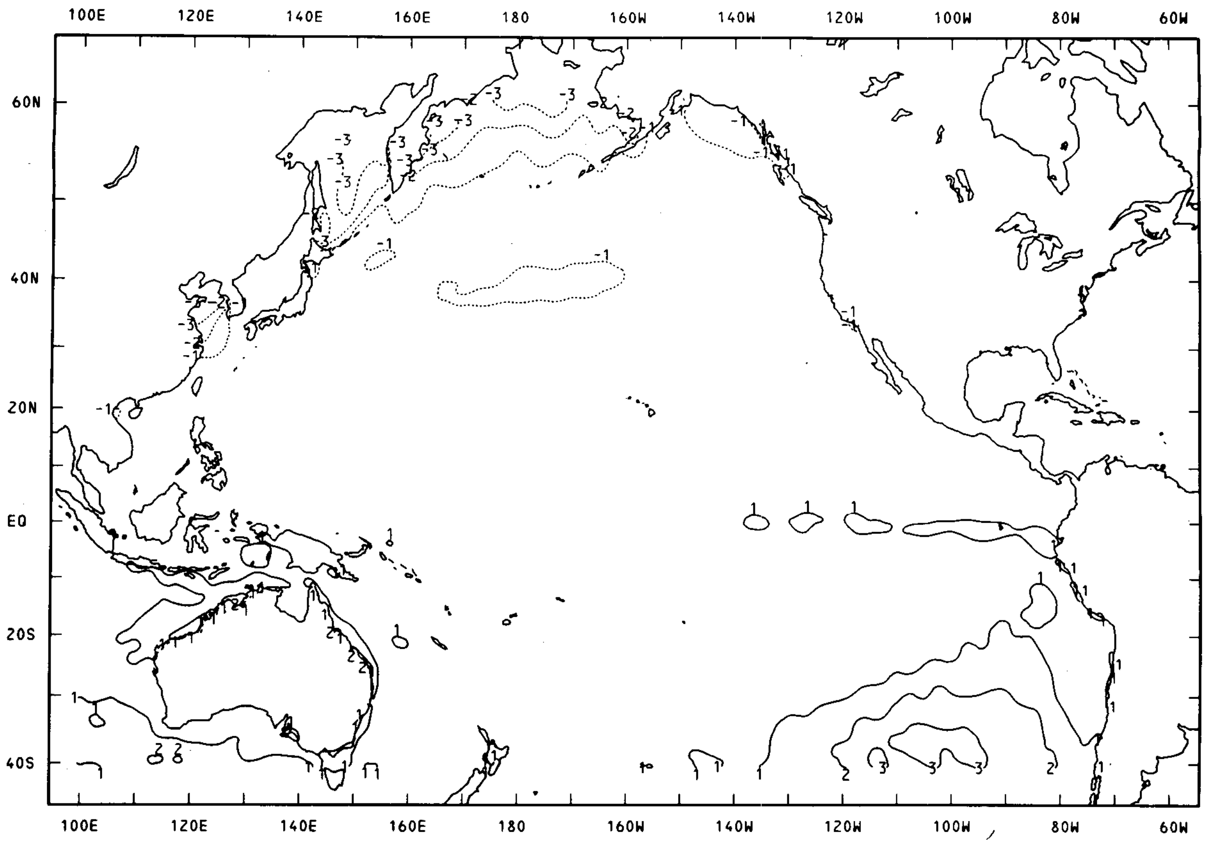

FIG. 11. As in Fig. 5, but between the H and the R climatologies.

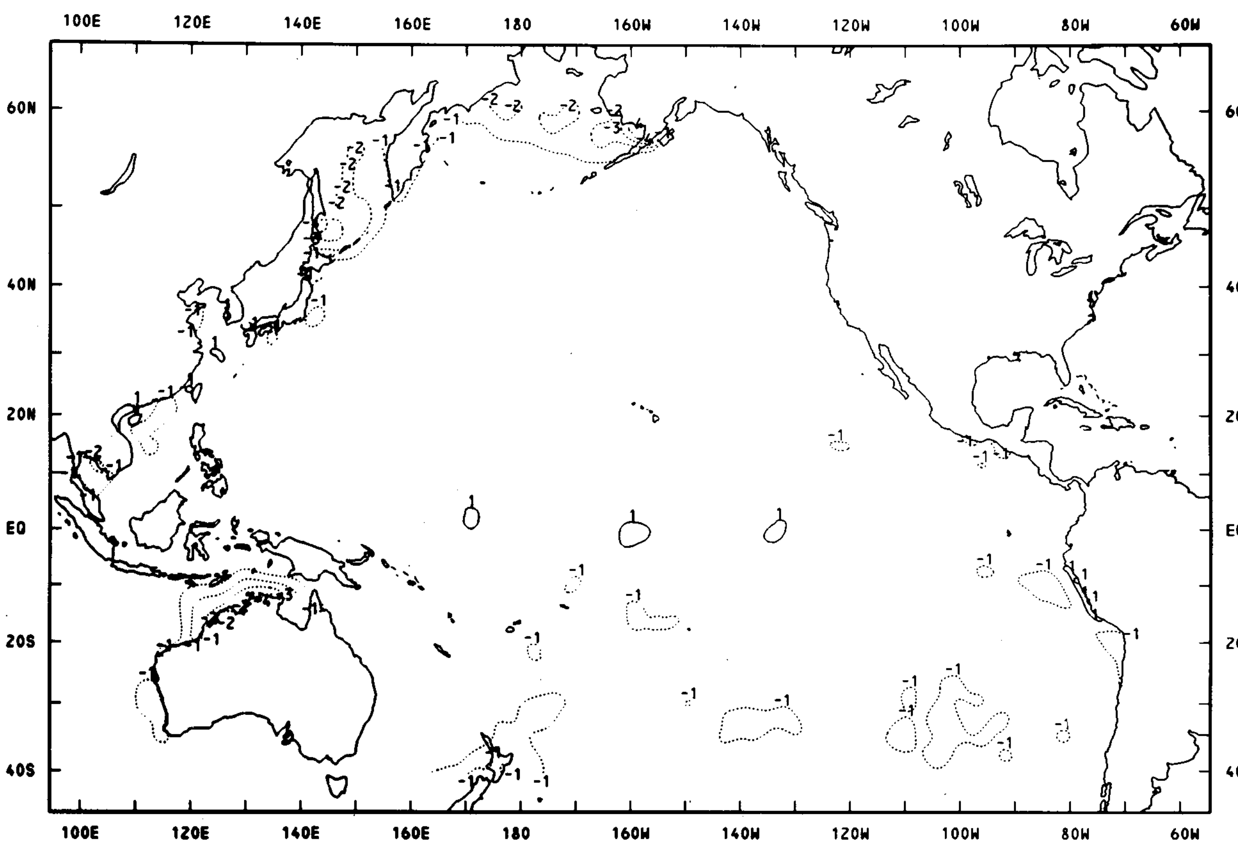

FIG. 12. As in Fig. 5, but for January, between the AM and the R climatologies.

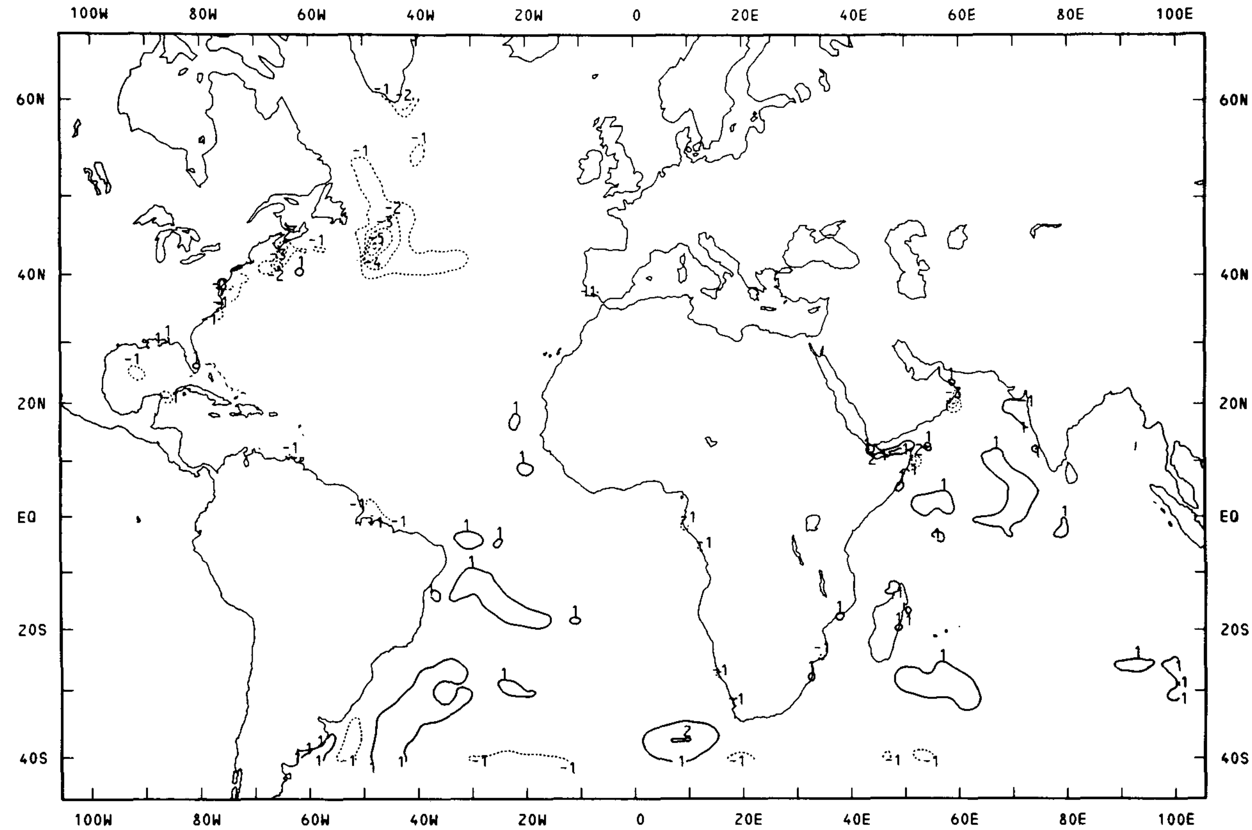

FIG. 13. As in Fig. 5, but for the Atlantic and Indian Oceans between the RB and the R climatologies.

b. Atlantic and Indian Ocean

The results for the Atlantic and Indian Oceans were similar to the results in the Pacific. Fig. 13 shows the difference between the RB and the R July climatologies. The major difference occurs near 43°N and 50°W where the RB temperatures are up to 5°C lower than the R temperatures. The difference is due to the fact that the RB climatology shows an intrusion of cold Labrador Water into the Gulf Stream. The intrusion is not shown in any of the other climatologies or in the unfiltered July NCC data summary shown in Reynolds (1982). Thus this feature may be due to the subjective RB technique of avoiding any smoothing of boundary current gradients. The L climatology (not shown) has smoothed the Gulf Stream more than the R climatology, and shows both positive and negative differences near the Gulf Stream when compared to the R SST's. Both the RB and L climatologies also show higher SST's compared to the R climatology in the South Atlantic and Indian Oceans. However, the L fields again have temperature perturbations in the Southern Hemisphere which are similar to those shown in the Pacific.

The S, AM and R surface marine climatologies again agree better with each other than they did with the cast data. Fig. 14 shows the S and R climatological difference for July. The higher cast SST's in the South Atlantic and Indian Oceans, compared to the R climatology, are now absent except south of 30°S. The S 5° spatial resolution also smoothes the Gulf Stream gradients resulting in the warm and cold differences west of 40°W along 40°N. The AM climatology, (not shown), behaved in a similar manner to that of S except its rms differences relative to other climatologies again increased in winter.

The comparisons between the H climatology and the other climatologies show larger rms differences in July than in January. These July differences are primarily due to higher SST's in the equatorial Atlantic and everywhere south of 20°S. The sign of the departures is similar to that in the Pacific but the deviations are smaller.

4. Summary

Three of the global surface marine climatologies (the AM, the S and the R) and the two regional Pacific (the B and RC) surface marine climatologies were fairly consistent with each other. There were, however, some differences in this group. The AM SST's were lower than the other climatologies in Northern Hemisphere winter. The S climatology was limited by its relatively coarse 5° resolution and tended to poorly resolve the Gulf Stream and Kuroshio.

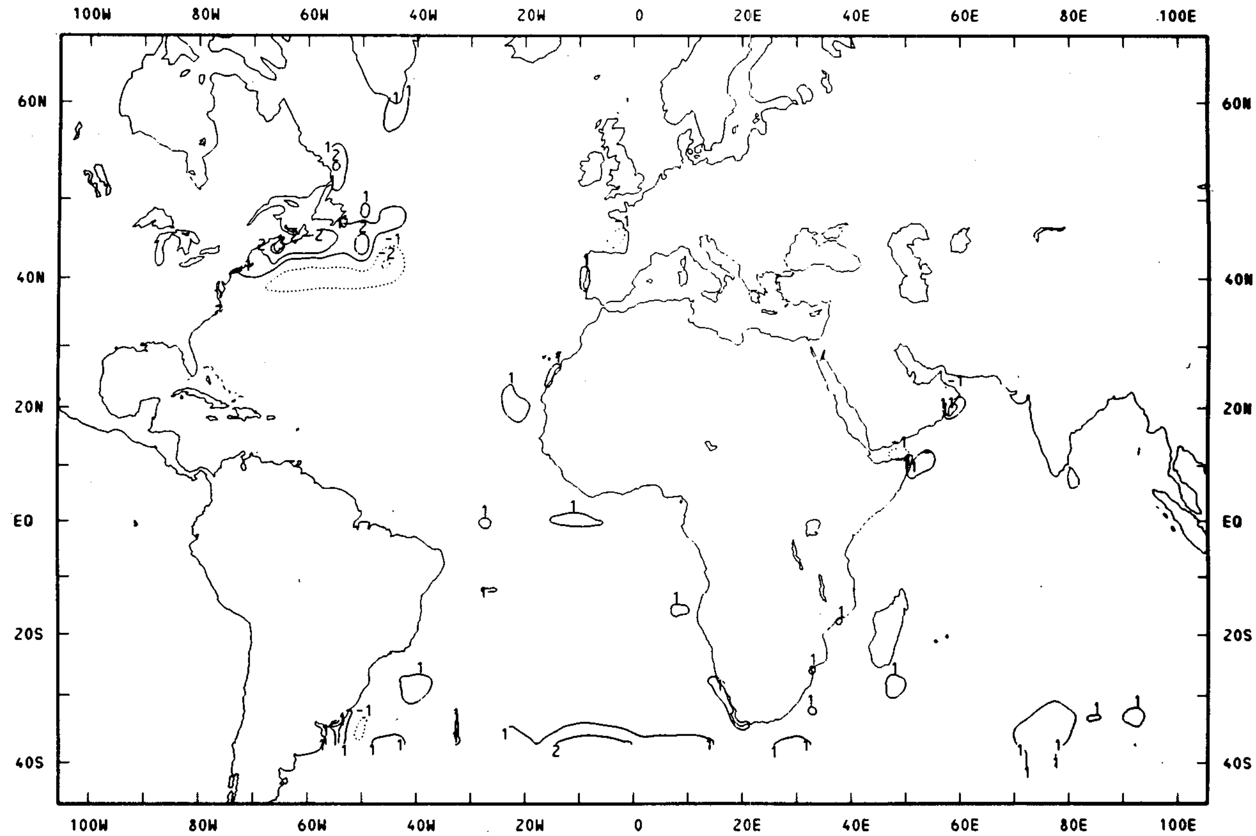

FIG. 14. As in Fig. 5, but for the Atlantic and Indian Oceans between the S and the R climatologies.

The two cast global climatologies (RB and L) showed important differences with each other and with the other climatologies. The RB SST's were higher than other climatologies in the eastern midlatitude north Pacific in the months from May to October and lower along the eastern equatorial Pacific in all months. The L SST's showed Southern Hemisphere fluctuations of several degrees (compared to the others) which were not coherent between adjacent months. The L climatology also smoothed the Gulf Stream gradients as much as the 5° resolution S climatology. However, it is important to recall that the RB and L climatologies also include subsurface fields. Any analysis which requires subsurface information, e.g., an oceanic heat budget, should use a climatology with consistent surface information.

The H climatology was only in agreement with the other surface marine climatologies in Northern Hemisphere winter. In the summer, the H SST's were higher than the other climatologies in the Southern Hemisphere and along the Equator. In addition, the H climatology showed summer SST's in the midlatitude north Pacific which were lower than the other climatologies.

It is difficult to recommend the best climatology on the basis of these inter-comparisons alone. However, the climatologies which showed consistent differences compared to all the other climatologies have been identified. The R climatology rarely showed these differences and was among the climatologies with the highest resolution. Thus, although the R climatology is presently not defined north of 61°N and south of 41°S, it appears to be one of the more useful of the global climatologies considered here.

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