Evaluation of NMC's Operational Surface Fluxes in the Tropical Pacific

Richard W. REYNOLDS and Ants LEETMAA

Climate Analysis Center
NMC/NWS/NOAA
Washington, DC 20233, U.S.A.

A major part of our effort at the Climate Analysis center (CAC) consists of the evalutation of surface fields from the data assimilation/forecast cycle of the NMC medium range forecast (MRF) model. This is done using direct comparison of the NMC fields with independent data and by comparing the response of the CAC tropical ocean model to different forcing fields. Here, we evaluate the accuracy of the NMC surface winds and surface heat flux fields. Because sea surface temperature (SST) is an important parameter in the coupling of atmospheric and oceanic models, a high resolution SST product is also presented.

To determine the accuracy of different surface wind analyses in the tropical Pacific, we have compared the NMC MRF surface winds analyses with independent wind observations from Pacific Marine Environmental Laboratory (PMEL) meteorological buoys. In an initial study, Reynolds et al., (1989) evaluated the NMC analysis for a six-month period (February 1 through July 31, 1987). The study reported here is a continuation of the comparison. The starting date of this comparison was selected to be September 1, 1987, because NMC implemented a higher resolution forecast model in August 1987.

Preliminary results of this new comparison have been completed for daily winds for a one year period (September 1, 1987 to August 31, 1988) using eight PMEL buoys located within five degrees of the equator. The long-term mean winds for the period are shown in Figure 1. The results show that the zonal NMC and PMEL wind components agree to within 1.1 m.s^{-1} except at 5°N, 110°W. However, the agreement in the meridional component is generally worse especially at 5°N, 110°W. These results are similar to the results from the 6-month comparison.

Cross-correlation statistics were computed between pairs of the daily wind time series at the same locations. The correlations (not shown) varied from 0.15 to almost 0.7. At all locations the zonal correlations are superior to the meridional correlations. The correlations were all significantly different from zero except the meridional correlation at 5°S, 110°W.

Figure 2 shows the time series of the PMEL and NMC meridional wind components for the one year period (366 days) at 5°N, 110°W. This is the location and wind component with the worst agreement in the long term mean. (Both time series have been smoothed by a five-point binomial filter for visual clarity). The two time series are similar during the first 30 days. After this period, a strong bias (over 5 m.s^{-1}) develops which persists until approximately day 120. This bias corresponds to the seasonal shift of the Intertropical Convergence Zone (ITCZ). This bias corresponds to the seasonal shift of the Intertropical Convergence Zone (ITCZ). During the period of high bias, the ITCZ shifted close to the position of the buoy. This suggests that the NMC analysis may tend to underestimate tropical divergent and convergent areas. (Missing buoy winds are due to instrument problems.)

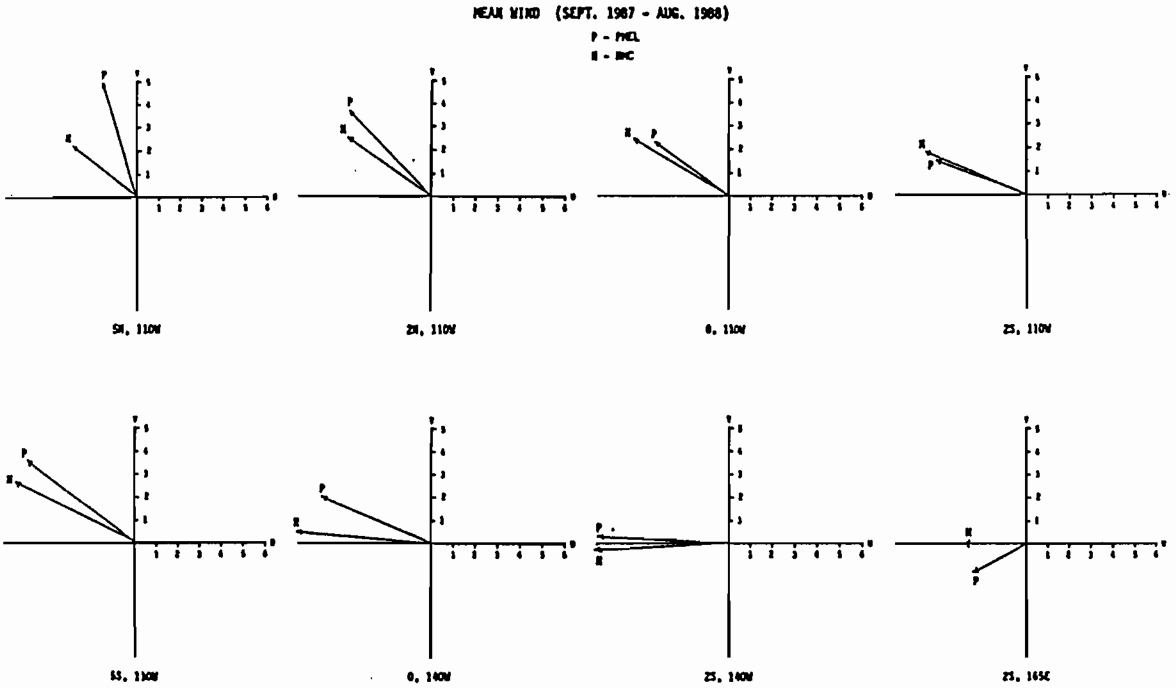

FIG.1. The long-term mean (September 1, 1987 - August 31, 1988) surface wind vectors at the 8 buoy locations in the tropical Pacific. The vectors were from PMEL buoys (labeled P) and the NMC operational analysis (labeled N).

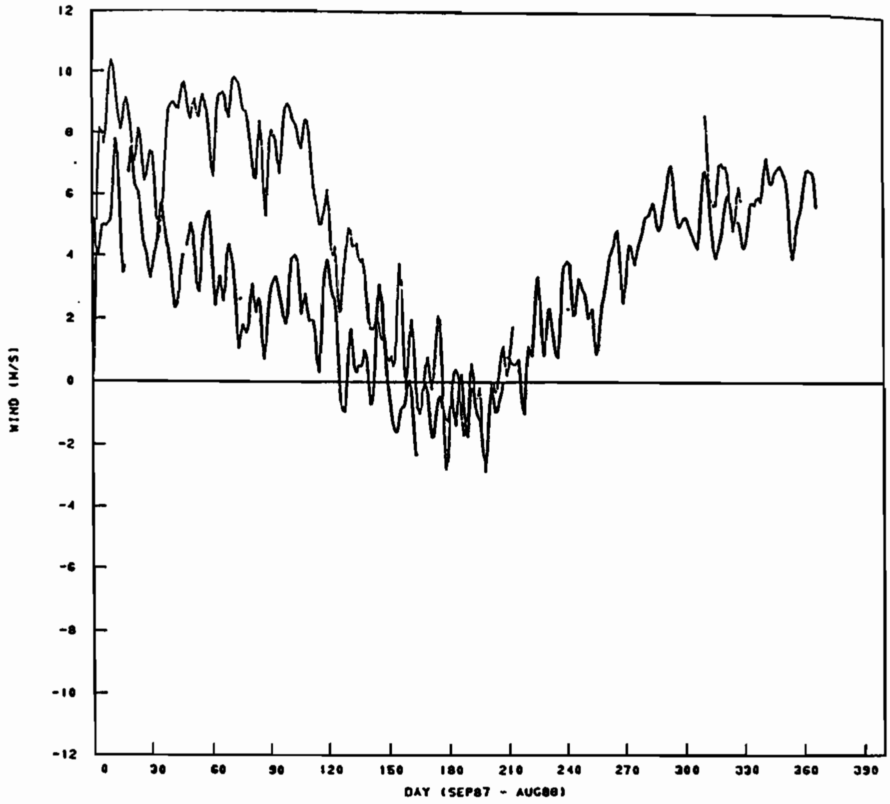

FIG.2. Daily time series (see text) of the meridional wind components of PMEL (light line) and NMC (heavy line) at 5°N, 110°W. The time series have been smoothed by a five-point binomial filter.

To help quantify these results with the other products, the monthly pseudo stress fields produced at Florida State University (henceforth, FSU) (see Goldenberg and O'Brien, 1981) for details, and the monthly wind stress climatology of Hellerman and Rosenstein (1973) (henceforth, H&R) were used. To avoid the non-linearity in converting between monthly averaged winds and monthly averaged wind stress, the daily averaged winds from the buoys and NMC were converted to daily pseudo stresses and averaged. The H&R climatological wind stress were converted to constant pseudo stress by approximating the H&R drag coefficient as a constant of 1.4 x 10^{-3}. Monthly differences between the buoys and the NMC, FSU and H&R pseudo stresses were computed if there were at least 25 days of buoy data per month. Table 1 shows the RMS errors of the three analyses relative to the buoys. At each buoy location the RMS errors are usually the worst for the FSU analysis. The H&R climatology and the NMC analysis alternate in having the lowest RMS error. Although climatology does as well as NMC, this result may not apply to other periods, especially El Nino periods.

	ZONAL			MERIDIONAL		
BUOY	H&R	NMC	FSU	H&R	NMC	FSU
5°N/110°W	3.9	7.5	9.7	21.1	36.1	32.5
2°N/110°W	10.2	6.6	10.2	5.4	10.6	11.2
0° /110°W	7.5	10.3	10.1	10.3	4.5	7.6
2°S/110°W	7.3	7.3	10.0	11.5	4.0	10.2
5°S/110°W	7.2	7.1	10.0	10.2	9.9	10.3
0° /140°W	12.5	13.0	16.5	4.9	10.3	8.6
2°S/140°W	9.6	4.8	15.1	12.5	4.1	10.1
2°S/165°E	13.9	6.5	12.2	4.9	8.4	10.2

Table 1. The monthly RMS error (in $m^2.s^{-2}$) between the buoy wind pseudo stress and the pseudo stress from the H&R climatology and the NMC and FSU surface wind analyses for the period : September 1987 - August 1988.

These surface wind comparisons will be continued. They will be of special interest during the next year when more PMEL buoys become operational and when the PMEL data are made available on the GTS. Because of the present deficiency of low-level wind observations in the tropical Pacific, the addition of the PMEL wind data to the GTS should significantly improve the quality of the assimilated surface wind analyses. This assumption will be tested as soon as possible.

Surface heat and momentum fluxes are computed at NMC in the boundary layer of the MRF model. These fluxes became available during last December 1989, and a daily archive was begun at CAC to save these fields. Comparisons of monthly averages of the sensible and latent heat fluxes and the net short wave and long wave radiation with the climatology of Oberhuber (1988) show that the MRF fields show some important features, e.g. the ITCZ, correctly but can have biases. In particular, each month (e.g. see fig.3) showed a large positive net heat flux into the ocean. This would result in a larger global warming than is observed in the changes in monthly SSTs. Much of the error is due to inadequate cloud cover in the MRF which results in large net incoming radiative fluxes. We plan to continue these evaluations.

The present TOGA sea surface temperature (SST) analysis is a monthly product which is designed to use both *in situ* (ship and buoy) and satellite data. This product "blends" the two types of observations by using an *in situ* analysis to define "ground truth" temperature values in regions of frequent *in situ* observations and a satellite analysis to define the shape of SST field in regions with little or no *in situ* data. This technique permits the automatic adjustment of possible satellite biases for each analysis period. The automatic adjustment of satellite biases is the major advantage of the blended technique. To provide accurate *in situ* "ground truth", the *in situ* analysis is spatially smoothed by a median filter which degrades the resolution to approximately 6 degrees. This affects the resolution of the blended product. The degradation of spatial resolution is the major disadvantage of the blended technique. Complete details of the analysis techniques can be found in Reynolds (1988).

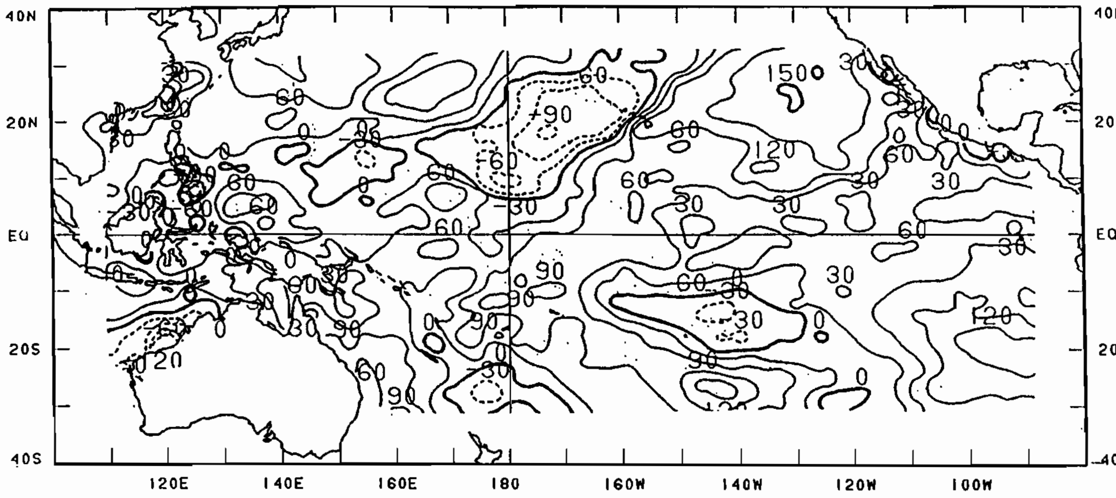

FIG.3. The NMC net heat flux anomaly for March 1989. The anomaly is computed relative to the climatology of Oberhuber (1988). The contour interval is 30 W.m^{-2}. Negative contours are dashed.

To improve the spatial and temporal resolution of the SST analysis, a weekly higher resolution analysis was designed. The analysis is done on the grid of the CAC tropical Pacific ocean model (Philander and Seigel, 1985) which has a zonal grid spacing of 1° and meridional spacing of 1/3° within 10° of the equator. The model provides a dynamically consistent first guess SST for an optimum interpolation (OI) analysis (Gandin, 1963) which uses expendable bathythermograph (XBTs) as well as the ship, buoy and satellite data used by the blended analysis. Because the improved resolution results in fewer observations per grid interval, careful quality control of the data is required. The quality control was provided by a regional data base management system which permits evaluation and comparison of the various data sets and analyses.

The weekly SST analysis is of sufficient resolution to define the tropical instability waves and the eastern boundary and eastern equatorial upwelling regions. Figure 4 shows the blended and the OI analyses for April 1989. The monthly OI field is formed by averaging four weekly analyses made during the month. Although the four week averaging process smooths any instability waves, the upwelling regions are better represented by the OI analysis. The difference between the two analyses (lower panel of fig.4) shows that the differences between the two analyses are small in other regions.

The data base for the OI separates daytime and nighttime satellite retrievals. The retrievals are done using the Advanced Very High Resolution (AVHRR) instrument. Because the satellite observations measure a "skin temperature" (i.e. the temperature of a surface layer on the order of millimeters) while the *in situ* observations measure a "bulk

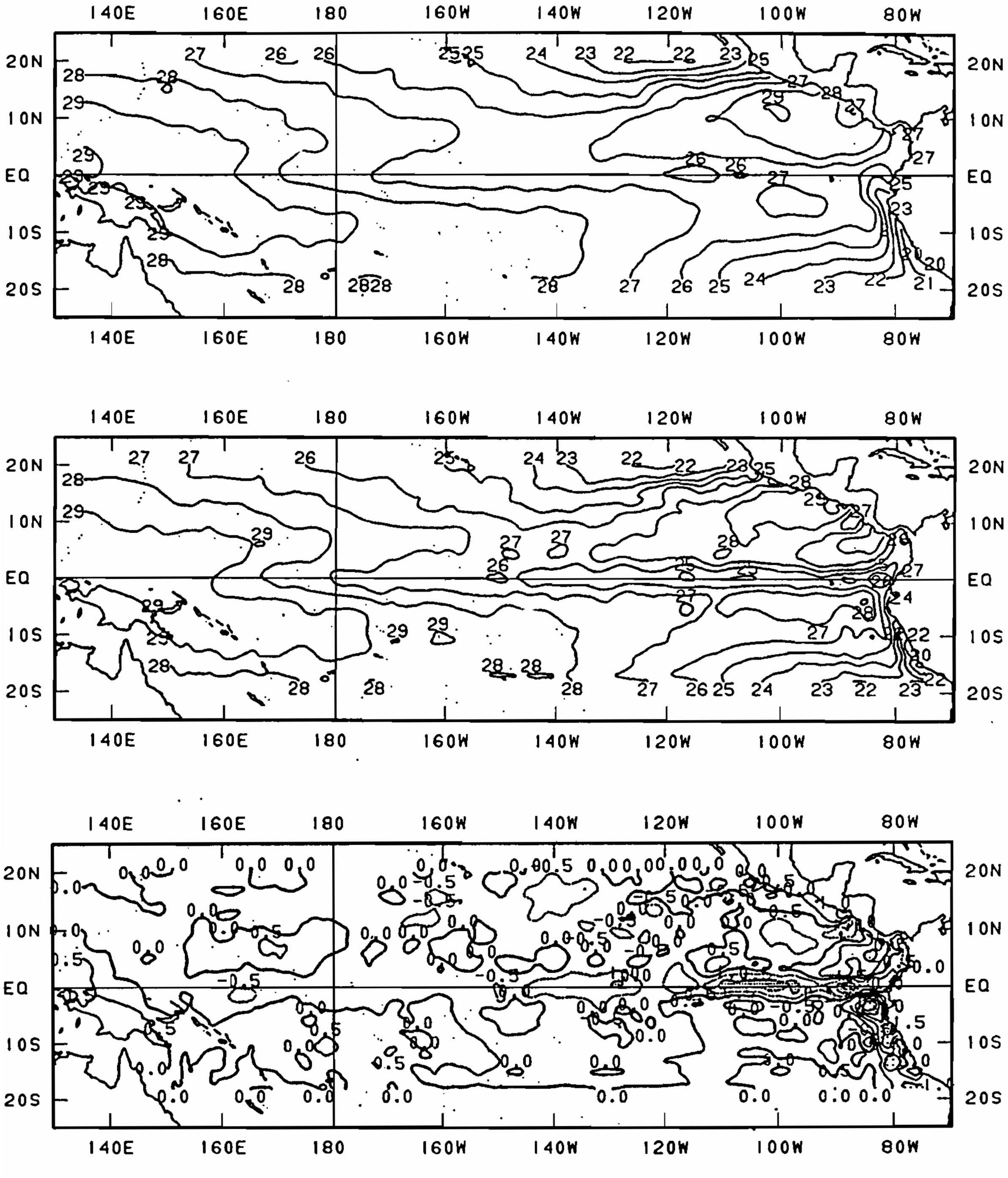

FIG.4. The blended SST analysis (upper panel) and OI analysis (middle panel) for April 1989. The difference between the OI and the blend (lower panel). The contour interval is 1°C (upper and middle panels); the contour interval is 0.5°C (lower panel). The 0°C contour is a heavy line; negative contours are dashed.

temperature" (i.e. the temperature of a surface layer on the order of meters), the satellite algorithms were adjusted to produce a "bulk" value by regression against drifting buoys (see McClain et al., 1985).

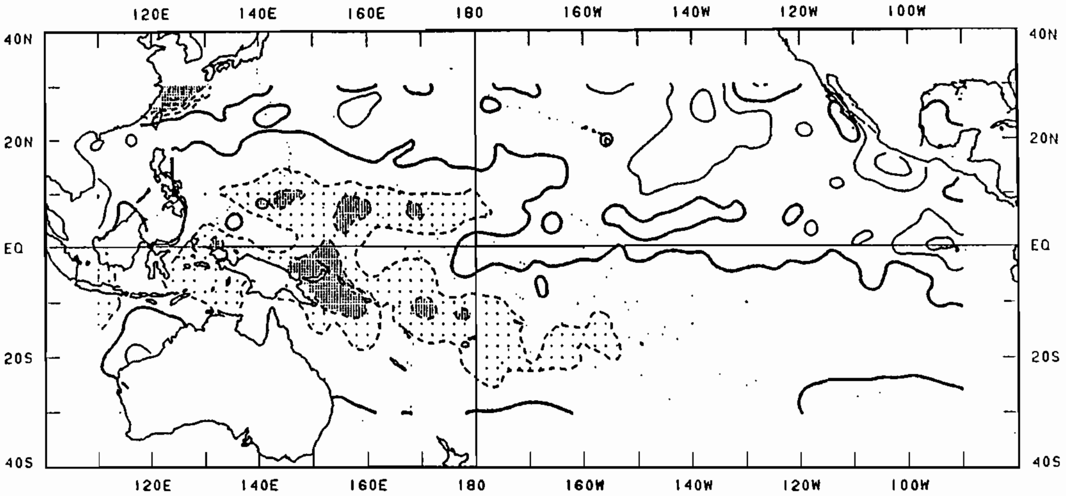

FIG.5. The difference between the daytime and nighttime satellite analysis for the tropical Pacific for April 1989. The contour interval is 0.5° C. The 0°C contour is a heavy line; negative contours are dashed. Dotted regions indicate differences between -0.5° C and -1°C. Stippled regions indicate differences less than -1°C.

Because the OI cannot correct satellite biases, it is necessary to eliminate or correct biased satellite data. To illustrate that biases occur in the satellite data, the April 1989 monthly difference between the daytime and nighttime satellite retrievals is shown in figure 5 for the tropical Pacific. In the western tropical Pacific there is a large region where the daytime temperatures are more than 0.5°C colder than the nighttime temperatures. This pattern has persisted since NOAA 11 became operational in November 1988. Comparison with buoy SST data from the data base showed that the daytime satellite data were biased cold in the western Pacific. To avoid this bias only nighttime satellite data was used in the OI analysis. Although, both daytime and nighttime data were used in the blended analysis, the automatic adjustment technique corrected much of the satellite bias. This is illustrated by the small difference between the OI and the blend in the western Pacific.

To examine the biases with time, figure 6 shows the monthly anomaly time series for the blended analysis and analyses using only *in situ* (ship and buoy) and only satellite data for all ocean areas between 20°S and 20°N. The anomalies from the *in situ* analysis (dotted) and blended anomalies (heavy line) are almost identical to each other. However, the satellite analysis (light line) shows a strong warming trend over the period. In these results, there is little evidence of any important trends in either the *in situ* or the blended anomaly time series.

The satellite retrieval algorithm was affected by the aerosols injected into the stratosphere by the April 1982 eruptions of the El Chichon volcano. This resulted in a negative bias in satellite SST retrievals from April 1982 through the end of 1983 which has a major effect on the satellite trends. During our period of interest, two El Nino/Southern Oscillation event (1982-83 and 1986-87) caused anomalous SST warming of the tropical oceans, primarily in the Pacific. Figure 6 shows both these warmings in the *in situ* and blended analyses. Because of the effect of the El Chichon aerosols, the satellite analysis does not show the warming associated with the 1982-83 event.

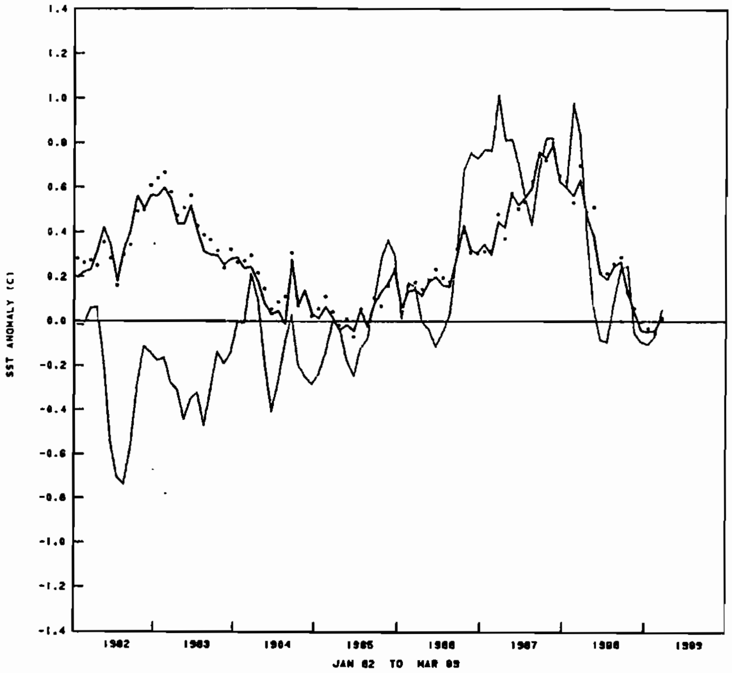

FIG.6. Time series of the SST anomalies for all ocean regions between 20°S and 20°N. The satellite anomaly is indicated by a light line; the blended anomaly is indicated by a heavy line; the *in situ* anomaly is dotted.

The OI technique shows great promise. During the next year we will be implementing a global ocean model and will be extending the OI method to the global domain. However, careful adjustment of the satellite data will be required before they are assimilated into the analysis. We are now testing and developing these methods.

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