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COMPARISON OF VARIOUS SEA SURFACE TEMPERATURE FIELDS

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1. ABSTRACT

Different estimates of the monthly mean sea surface temperature (SST) fields are intercompared. Fields derived from ship data alone differ substantially in high SST gradient regions and in areas of low data density. These differences exhibit seasonal and interannual variations which are spatially correlated. The large bias and variability preclude interchangeable use of different SST products derived from ships alone.

The difference between SST fields from ships and similar fields derived from a blend of satellite and ship data show many of the characteristics noted above, north of 30°N. However, inclusion of satellite data results in a warm bias that is substantially larger than that found between ship-only products. The difference fields south of 30°N are of order one standard deviation or more with the blended product again generally being warmer. The difference fields are regional in nature at all latitudes. Thus global or zonal

averaging of the fields, as is done in many papers comparing satellite SST's with other estimates, could lead to erroneous conclusions regarding the degree of comparability between the fields.

2. INTRODUCTION

Knowledge of the oceans' surface temperature is valuable in a variety of areas of research. As a result, a number of different analyses are currently being made to give maps of sea surface temperature (SST). These maps are available at a variety of time intervals from daily through monthly averages. They cover different spatial scales from those associated with frontal zones to the global ocean.

In view of the proliferation of SST products, it seems important to determine if they are all providing the same basic information. For instance, Barnet et al (1979) showed large differences existed between in situ data and satellite derived SST in the central Tropical Pacific. To initiate a broader comparison we have concentrated on monthly mean SST products for the Atlantic and Pacific Oceans. The prime question we addressed was: Do different SST products give similar estimates of the temperature field over both space and time? If differences do occur, we will not attempt to say which SST product is correct, for indeed there is no way to know for sure. We will, however, contrast the differences where possible with natural interannual variability of SST to see if the differences are important for climate studies. Our primary purpose is to determine if there are potential problems in the SST products, not to do an extensive evaluation of them.

In the following section we compare SST fields developed from in situ data; mainly synoptic ship reports. These differences are then contrasted with those obtained by comparing a product derived by blending satellite and in situ measurements with one of the in situ-only products. The SST products were selected solely on the basis of being the most conveniently available for analysis given the time and resources available for this study.

3. SST PRODUCTS DERIVED FROM SHIP OBSERVATIONS

3.1 Temporal Comparison

Different methods of constructing SST products could possibly lead to rather large differences between them. To investigate this we subtracted monthly temperatures derived from the National Climatic Center's historical sea surface temperature (HSST) summary product, T_{HSST}, from the monthly product of the National Marine Fisheries Service (NMFS), Southwest Fisheries Center in La Jolla, California (T_{SWFC}). These two products are developed in very different ways. The HSST data were obtained by averaging all available data within large ocean areas to give a single SST value for each area/month. The data came from ships' logbook reports (TDF11). Clearly, shifts in the geographical distribution of reports within the regions can have an impact on the final monthly average, particularly if there are large natural SST gradients in the averaging area. The SWFC data were computed as simple averages over 5° latitude/longitude squares. The input for the calculations was the radioed ship reports available over the global weather reporting network at synoptic periods. The 5° SWFC data were summarized into Marsden Squares for direct comparison with T_{HSST} at several selected sites (Fig. 1, inset). The regions selected for comparison were either data rich and/or thought important to climate change.

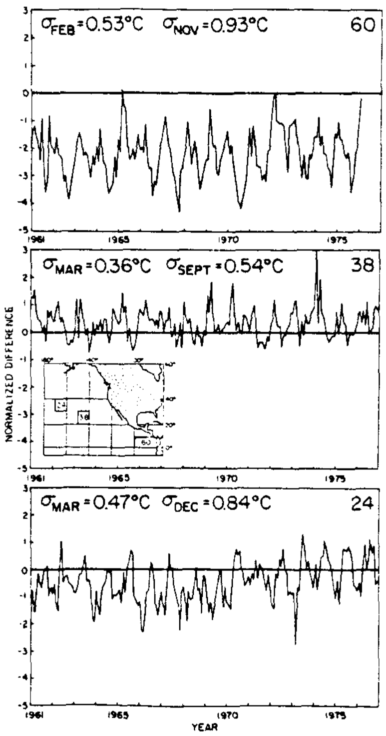

Fig. 1: The difference between sea surface temperature estimated by the National Marine Fisheries Service minus that estimated from the historical sea surface temperature project in key regions of the Pacific. The differences have been normalized by the standard deviation associated with the NMFS field. The inset of the middle panel shows the location of the regions. Their identification number is given in the upper right hand corner of each panel. The seasonal extremes in standard deviation associated with each region are indicated.

The difference (T_{SWFC} - T_{HSST}) was computed for each month between 1961-1976. Remember these are not anomalies but differences in actual SST. To put them into perspective, they were divided by the SWFC standard deviation of monthly SST (σ_{SWFC}). Thus the differences introduced by analysis methods can be directly related to a self-consistent measure of natural climatic fluctuations in SST.

The difference between the data sets is substantial. The region off Central Americal (Fig. 1, upper) shows a large bias between the two SST products of over two standard deviations (>1.5^{o}C). The scatter about this bias is also approximately $\pm 2\sigma$. The differences are largest in the early fall (typically October) and smallest in early spring (typically March). This seasonal signal in the difference field is roughly 2σ. Note that it is out of phase with the seasonal variations in standard deviation (Fig. 1, upper).

Region 38, on the data rich shipping lanes between the west coast and Hawaii, shows that a bias is still present but in the opposite sense (T_{SWFC} warmer) and smaller, roughly 0.5σ ($\sim$0.5^{o}C). The seasonal character of the scatter persists and is roughly 1.5σ ($\sim$1^{o}C). T_{SWFC} tends to be warmer than T_{HSST} in the late winter and spring but colder in late summer to early fall.

Region 24 shows many of the same properties as Regions 38 and 60. In addition there is a disturbing low frequency component in the temporal variability that one might mistakenly attribute to natural climatic fluctuations.

In summary, it is clear that the two data sets compared here have substantial temporal differences between them. Some of the problem was traced to shifts in the sampling centroids of the HSST set. The SST differences are as large or larger than typical natural variations that occur in the selected areas (according to any one data set). The differences have both annual and interannual time scales. Each data set, by itself, may be useful for climate studies but it is clear that the two data sets cannot be used either together or interchangeably without serious risk of faulty conclusion. A more complete discussion of the differences and similarities between the HSST and SWFC SST fields is given by Steiner

3.2 Spatial Comparison

This comparison involved two different products derived from virtually the same input data, the radioed synoptic ship reports. One might expect better agreement than obtained above from somewhat different, but still highly overlapping, data sets.

The first SST product came from the NMFS Pacific Environmental

Group (PEG). The radioed reports are obtained directly from the Fleet Numerical Oceanographic Center (FNOC) and made available to PEG where they are edited and then averaged by 1^o square. The 1^o averages are then averaged in 5^o boxes to obtain a 5^o temperature for each month (T_{PEG}). These values were compared with the FNOC product derived from virtually the same data and projected onto 63 x 63 grid spanning the Northern Hemisphere. A new FNOC analysis is developed every 12 hours by successive interpolation of the observed values, plus climatology in data poor areas. The monthly mean of the 12 hourly fields (T_{FNOC}), which was rather smooth, was projected onto the T_{PEG} 5^o grid, the differences ($T_{PEG} - T_{FNOC}$) computed and normalized by σ_{FNOC}, the standard deviation with respect to a long term monthly mean. Four January and four July difference fields were constructed in this manner.

Typical maps of $(T_{PEG} - T_{FNOC})/\sigma_{FNOC}$ are shown in Figure 2. Analysis of the January data showed that the largest discrepancies occur routinely in the following areas: 1) off the east coasts of the continents, where the strong SST gradients associated with the Gulf Stream, Kuroshio and their seaward extensions introduce tremendous sampling and analysis problems; differences of $1\sigma(\sim 2-3^oC)$

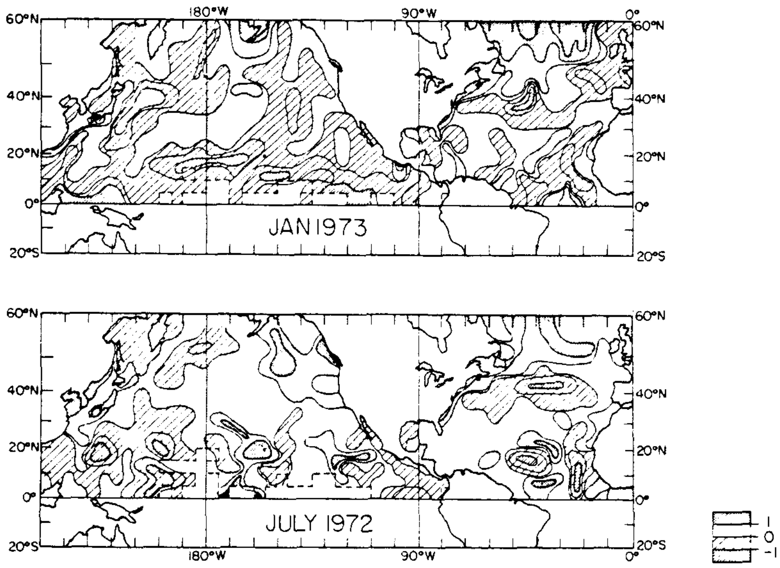

Fig. 2: SST fields from the Pacific Environmental Group minus the SST fields from the Fleet Naval Oceanographic Center. The differences have been normalized by the FNOC standard deviation and the results contoured at intervals of 0.5σ. These normalized difference fields, taken during periods of large SST anomaly, are typical of those found in other January and July's.

are common in these areas; 2) in the central and eastern portions of the Pacific below 20°N where the observation density is low, where $T_{FNOC} > T_{PEG}$ by roughly 0.5-1σ (0.5-1°C) suggesting, perhaps, the influence of climatology on the SST field; 3) off Newfoundland and Greenland, which are data poor areas, $T_{PEG} > T_{FNOC}$ by about 1-2σ ($\sim 1^\circ$C); and 4) there is a general tendency for $T_{FNOC} > T_{PEG}$ in the Pacific, independent of position, while the reverse is true in the Atlantic. The value of the difference is about 0.5°C for both cases. The number of positive differences in the Atlantic is roughly twice the number of negative values, while in the Pacific the negatives outnumber the positives in approximately the same proportion. There seems no good explanation for this, unless it is again due to inclusion of climatology in the FNOC product.

During July most of the above conclusions hold. If anything, the magnitude of the differences in the areas noted in 1) and 3) are somewhat larger and show more year-to-year variability. Item 4, the general bias, still exists only now $T_{PEG} > T_{FNOC}$ in both oceans. The ratio of positive differences to negative is roughly 2 to 1.

In summary, different SST products derived from the same basic data set of ship reports differ from each other by amounts large relative to climatology in areas of high SST gradient (Gulf Stream, Kuroshio, etc.) and/or low observation density. In data rich areas the two sets agree much more closely but still tend to have a significant, though small, bias. The large differences, when they occur, are time dependent and tend to have large space scales similar to SST anomalies from any one data set. It is concluded, again, that different SST products, used interchangeably in climate studies, may introduce a high risk of erroneous results.

4. SATELLITE/SHIP DERIVED SST PRODUCTS

The blended satellite/ship SST product used in this section came from the National Meteorological Center (NMC) and spans the period April 1979 - January 1980. The data was available numerically on a 2° grid as monthly averages. Details of the construction of these fields may be obtained from Larson (personal communication). The analysis method has undergone changes over the above time period, as NMC strives to improve its analysis. The result of these changes will be evident below.

4.1 Temporal Comparison: Satellites vs. In Situ

A limited number of runs of the operational NMC global SST analysis system were made in which each in situ SST report (from ship injections, XBT's, fixed and/or drifting buoys) were compared to all TIROS-N retrievals falling within 50 km of its location and 3 days of the observation time. TIROS-N retrievals are provided by the National Environmental Satellite Service and consist of a temperature which is intended to be representative of a 50 x 50 km area. The center of the square is the position of the retrieval. The TIROS-N SST was subtracted from the in situ SST, the resulting differences were edited for gross errors and the remaining values summarized by latitude bands for each run. This zonal averaging process, which has often been used in previous satellite SST comparisons, is potentially a dangerous step as we shall see below.

Summaries of the comparisons by season for the latitude bands of 0^{o} to 10^{o}N and 45^{o}N to 55^{o}N are presented below. Table 1 shows the number of paired measurements and runs (in brackets) from which they were derived. Each run represents a different synoptic situation separated by at least a few days. Table 2 shows the differences between the satellite SST and the in situ observations summarized by seasons. An adequate climatology was not available to normalize these numbers by a standard deviation as in Section 2.

Table 1

Number of Paired In Situ/TIROS-N Reports and Runs (Parenthesis) From Which They Were Derived

$0-10^{o}$N	Injection	XBT	Drifting Buoy	Fixed Buoy
Spring 1979	86(9)	24(2)	0	0
Summer 1979	324(9)	14(2)	45(7)	0
Fall 1979	396(13)	83(5)	101(8)	0
45^{o}N-55^{o}N				
Spring 1979	150(5)	60(7)	0	12(3)
Summer 1979	254(7)	28(2)	30(3)	9(4)

In the region 0 - 10^{o}N, a warming of TIROS-N SST measurements relative to in situ observations occurred over the entire period studied. By fall, the initial positive mean difference of $\sim 1^{o}$C had decreased to nearly zero. This does not imply that by fall all satellite retrievals were correct -- only that the average bias had disappeared in this latitude band. Much of this change is thought due to changes by the National Environmental Satellite Service in the algorithm that is used to estimate SST from the raw satellite data.

In the band 45^{o}N-55^{o}N, TIROS-N retrievals were on the average slightly warmer (0.1^{o}C) than co-located in situ measurement in the spring, but by summer this bias had increased substantially to $\sim 1^{o}$C. As at 0^{o}-10^{o}N, the various types of in situ data were quite consistent with the exception of a limited number of XBT/TIROS-N pairs collected during the summer. After early October satellite

Table 2

In Situ/Satellite Intercomparison

$0\text{-}10^{\circ}N$	Ship Mean (Std. Dev.) $^{\circ}C$	XBT Mean (Std. Dev.) $^{\circ}C$	Drifting Buoy Mean (Std. Dev.) $^{\circ}C$	Fixed Buoy Mean (Std. Dev.) $^{\circ}C$
Spring 1979	1.0 (1.3)	0.9 (0.6)	- -	- -
Summer 1979	0.6 (1.1)	-0.2 (0.1)	0.4 (0.5)	- -
Fall 1979	-0.1 (1.0)	0.0 (1.1)	0.0 (0.5)	- -
$45^{\circ}N\text{-}55^{\circ}N$				
Spring 1979	0.1 (1.2)	-0.2 (0.3)	- -	-0.1 (0.3)
Summer 1979	-0.8 (1.4)	-1.9 (0.9)	-0.7 (0.3)	-1.0 (0.2)

data were dropped from the NMC operational analysis north of $30^{\circ}N$, thus pairs are not available for fall in this band.

In summary, it appears that the satellite/ship product, averaged in zonal bands around the globe, improved between spring and fall, 1979 in the tropics relative to in situ measurements. Much of this apparent improvement resulted from algorithm changes which now require additional independent testing. Additional tests must also determine if the zonal averaging allows large differences of opposite sign in the same band to cancel each other (see below). At higher latitudes the time trend of the differences is substantial. In addition, the differences are large enough (Table 2) to raise serious doubts as to the usefulness of the satellite data in developing an operational SST product at mid to high latitude. It is not known if the difference at these latitudes has a seasonal component, or is due to instrumental drift or to algorithm difficulties.

4.2 Spatial Comparison

Monthly summaries of radioed ship SST (T_{SHIP}) on a 2° grid in both oceans were subtracted from T_{NMC}, normalized by σ_{FNOC} and projected on to a 5° grid. The resulting differences are directly comparable with those of Section 2.2 (Fig. 2) and demonstrate the effect of satellite SST on the blended NMC product. Typical results for July 1979 and January 1980 are shown in Figure 3.

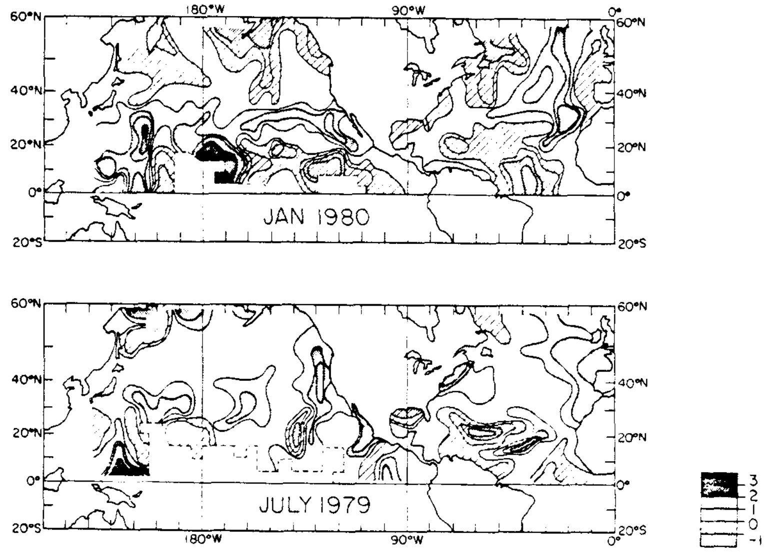

Fig. 3: The SST difference fields obtained by subtracting in situ measurements from the National Meteorological Center SST product (i.e. NMC-Ship). The differences are again normalized by the standard deviation from the FNOC data fields making them directly comparable with Figure 2.

The largest differences in Figure 3 occur south of 30°N where both satellite and ship data contribute to T_{NMC}. Values of one or more standard deviations are common. The differences are generally positive and always demonstrate high spatial coherence. The differences in this region are consistently larger than those associated with ship-only SST products (Fig. 2). The changes in satellite algorithm noted above are not apparent but then the limited ship data does not allow a comparison over the whole tropical region.

In latitudes above 30°N the differences are largest in the regions of high SST gradient (off the east coasts of the continents and in the northern-most regions of the oceans. Note the large bias ($0.5 - 1.0\sigma$) over the midlatitude ocean in July. The problem largely, but not completely, disappeared in October when the satellite data was deleted from the analysis.

The largest differences in both oceans are again rather regional in nature. For instance, in the data rich areas off the coasts of California, Mexico and Central America, $T_{NMC} > T_{SHIP}$ by $1-2^{\circ}$C in nearly all months irrespective of algorithm changes, etc. Much the same situation occurs off the west coast of North Africa and in the western equatorial Pacific. We can only conjecture as to the reasons for these regional variations. It is clear, however, that zonal or global averaging will seriously distort these characteristics of the difference fields.

In summary, the blended satellite/ship SST fields are in many respects similar to the ship/ship differences north of 30°N after October 1979. Prior to that time there is a substantial bias between the two fields that is apparently due to the satellite SST's. Besides this bias, the major differences are regional in nature, e.g., along the eastern margins of the oceans. Below 30°N the differences are 1σ or more, spatially coherent and have long time scales. They again have a regional character. It may be concluded that zonal averaging, as we did in the previous section, may give an overly optimistic estimate of the comparability of SST products. Such gross averaging should be avoided in further intercomparison work.

5. CONCLUSIONS

A limited intercomparison of supposedly similar maps of monthly mean SST for the North Pacific and Atlantic Oceans lead to the following conclusions:

a) Differences between SST products derived from in situ data alone exceed one standard deviation in areas of high SST gradient and/or low data density. These differences seem due to the editing/averaging/smoothing methods used on the reported data plus the inclusion of climatology in some products and not others. In any event, the difference field can have large time and space scales reminiscent of naturally occuring SST anomalies.

b) Differences between satellite influenced SST products and those derived solely from in situ data are spatially similar to, but numerically larger than noted above. The deletion of satellite data north of 30°N reduces the difference field to levels comparable to those obtained from ship/ship intercomparisons alone. South of 30°N the satellite influenced products seem to be biased over much of the ocean, particularly near the eastern margins and in the western equatorial Pacific.

c) The highly regional nature of the differences between SST fields makes it unwise to express their dissimilarities in terms of zonal and/or global averages. Such characterization may lead to an overly optimistic view of their correspondence.

d) The differences between SST fields produced with <u>or</u> without satellite data can be so large as to preclude the interchangeable use and/or blending of any two fields without serious risk of erroneous conclusion.

e) The time is ripe for those who construct SST products to collectively agree on a common method of analysis.

6. ACKNOWLEDGEMENTS

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