Comparison of Ship-Observed Sea Surface Temperature with Measurements from Drifting Buoys and Expendable Bathythermographs: 1980-95

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1. Introduction

Systematic changes in observational and instrumental methods are major factors that may introduce false climate trends into the surface marine climate record, e.g., the largely undocumented mixture of shipboard measurements of sea surface temperature (SST) taken by bucket versus engine room intake. Compounding the heterogeneities within ship data, during the past few decades there have been a significant increases in the numbers of automated measurements from drifting and moored buoys, as well as oceanographic profile data from instruments such as expendable bathythermographs (XBT). This preliminary study attempts to identify near-global patterns of SST differences between three selected platform types: ships, drifting buoys, and temperatures extracted from the uppermost levels of XBT profiles.

2. Data and Method

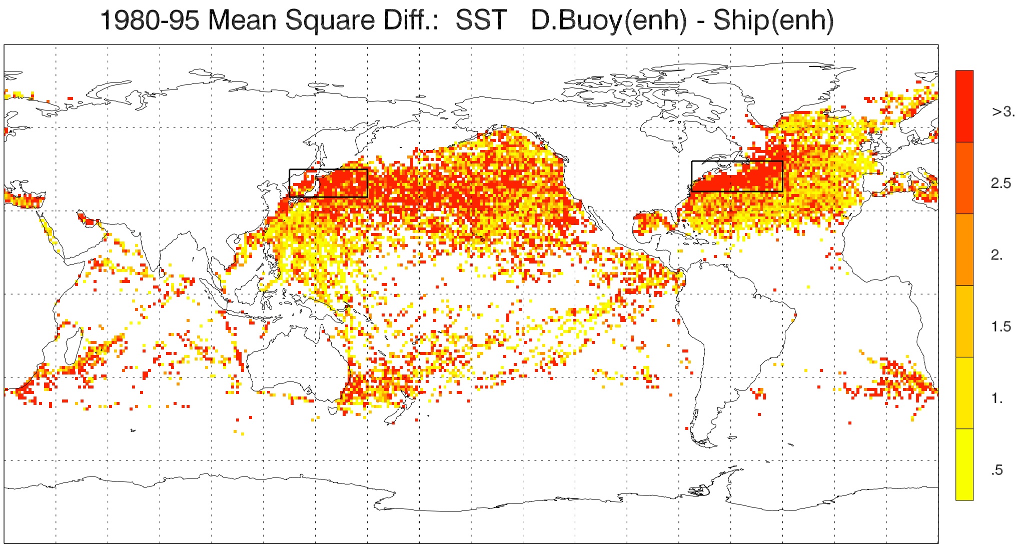
First, we created single-platform monthly mean SST fields with 1° latitude × longitude resolution for the period of 1980-95 using COADS Release 1a individual marine reports from ships, drifting buoys, and XBTs respectively. We then compared the monthly mean SST from the drifting buoys and XBTs to that from ships, limited to 1° boxes containing at least one observation from both platform types (to ensure matching geographic comparisons). When creating monthly means, we used relaxed trimming limits the same as those used in a enhanced (enh) version of COADS.

3. Results

Over the globe, the buoy/ship and XBT/ship differences approximately follow a Gaussian distribution. For a global average, the buoy-SST is about 0.1°C colder then the ship-SST with standard deviation of 1.9°C; and the XBT-SST is 0.1°C warmer with standard deviation of 1.2°C.

However, the buoy/ship and XBT/ship comparisons show large variations in different latitudinal belts. In the tropical zone (30°S-30°N), the probability distributions of the buoy/ship and XBT/ship differences are similar to the global distribution. In contrast, we find wide areas of large mean-square differences in the northwest Pacific Ocean and northwest Atlantic Ocean (30°N-60°N) in both the buoy/ship and XBT/ship comparisons. And, in the 30°N-60°N zone, the mean square differences are larger in the western part of the Pacific and Atlantic Oceans (fig.1).

In the northwest Pacific and northwest Atlantic Oceans, SST measured by drifting buoys is generally colder than the ship-SST and both the buoy/ship and XBT/ship comparisons show month-to-month variation with amplitude of about 1 to 2 °C. Table 1 shows spatial average of the sixteen-year (1980-95) mean of the XBT/ship, and the drifting-buoy/ship differences in the northwest Pacific (35°N-45°N, 130°E-160°E) and northwest Atlantic (37°N-47°N,75°W-40°W) oceans (indi-



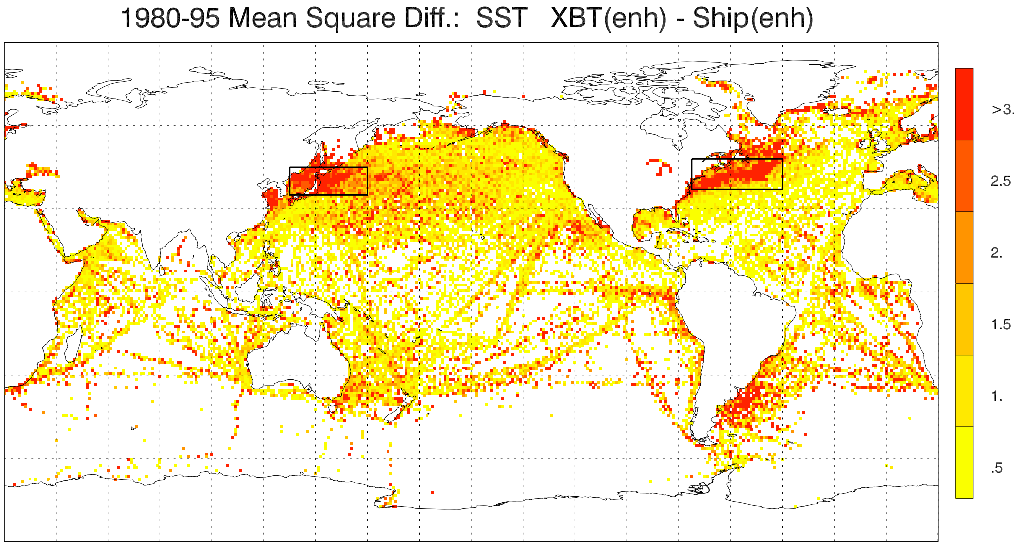


Fig.1 Spatial pattern of mean square differences between the SST measured by drifting buoys, XBT, and the SST observed by ships. The boxes in the northwest Pacific ocean and northwest Atlantic ocean indicate the areas for which spatial average of the buoy/ship and XBT/ship differences are shown in table 1.

cated by the boxes outlined in fig.1). The XBT-SSTs are colder than ship-SST during April and vice versa during October in both the north Pacific and north Atlantic regions. Also, in both regions, the buoy-SSTs are more colder than ship-SST during April than other months that are shown in table 1.

What is the major cause of the XBT/ship and buoy/ship difference in the northwest Pacific and northwest Atlantic region? Is it due to errors or biases in the ship observations, or in the measurements by the automatic instruments? To address this issue, we further separated the ship-SST into bucket measurements and engine-intake measurements and compared the bucket-SST, intake-SST with the buoy- and XBT-SSTs (table 1). In wide area in the north Pacific ocean temporal coverage of the bucket-SST is about half of the intake-SST. However, the number of bucket observations inside the box in fig.1 is large enough to allow the temporal coverage of monthly means of the bucket-SST being comparable to the coverage of intake-SST.

In the northwest Atlantic, the intake-SST is very close to the XBT-SST. Therefore the major XBT/ship difference in the northwest Atlantic may be attributed to the ship(bucket)/XBT difference. However, in the northwest Pacific, the intake-SST is about half degree colder than the XBT-SST during April. In the northwest Pacific both the intake/XBT and bucket/XBT difference are not negligible.

Compared to the drifting-buoy-SST, the intake-SSTs are in general warmer in both regions during all listed months. On the other hand, the bucket-SST is colder than the buoy-SST in the north-west Pacific but warmer in the northwest Atlantic. Both the bucket/buoy and intake/buoy difference can be larger than half a degree.

The fact that the ship/buoy and ship/XBT differences are of same magnitude with regard to both the bucket and intake methods used by ships, may indicate that errors or biases are present both in the ship and automated SST data. For example, the buoy-SST is more than 2 degree colder than the ship-SST in the northwest Atlantic, and this difference is more likely due to some instrumental error in the buoys. Further analysis on this issue will require sufficient metadata about the buoys, since geographical and temporal variations may exist in the automated instruments.

What makes up the month-to-month variations in the buoy/ship and XBT/ship comparison? In the last two

Table 1 Regional average of 16-year Mean Difference in SST Measured by Various Methods
(Units: °Celsius)

	N. Pacific (130E-160E, 45N-55N)				N. Atlantic (75W-40W,42N-53N)			
	Jan.	Apr.	Jul.	Oct.	Jan.	Apr.	Jul.	Oct.
XBT-Ship	0.02	-0.43	0.05	0.18	-0.02	-0.41	-0.14	0.12
XBT-Ship(bucket)	0.56	-0.27	0.01	0.49	0.22	-0.45	-0.28	0.19
XBT-Ship(intake)	-0.23	-0.48	0.02	0.05	-0.06	0.02	0.06	0.10
D.Buoy-Ship	0.04	-0.79	-0.30	-0.10	-0.09	-2.16	-0.86	-0.12
D.Buoy-Ship(bucket)	0.61	0.16	0.16	-0.05	0.17	-2.21	-1.23	-0.01
D.Buoy-Ship(intake)	-0.21	-0.67	-0.34	-0.48	-0.25	-2.41	-0.66	-0.16
SST-MAT	5.72	0.31	-0.84	1.6	3.88	0.54	-0.89	1.73
Ship: intake - bucket	0.64	0.27	0.15	0.33	0.35	0.03	-0.36	0.34

rows in table 1, we compare the annual variation of differences between SST and marine air temperature (MAT), with the annual variation of differences between the intake-SST and bucket-SST. Since the month-to-month variation of the intake/bucket difference follows closely to the variation of the air-sea temperature difference, air temperature influence appears to be a major factor that causes the difference between intake and bucket measurements (Bottomley et al., 1990; Kent et al., 1991; Folland and Parker, 1995). In contrast, the month-to-month variations in the buoy/ship and XBT/ship comparison do not follow the variation of air-sea temperature difference. Therefore we infer that air temperature influence are not the only cause for the buoy/ship and XBT/ship differences.

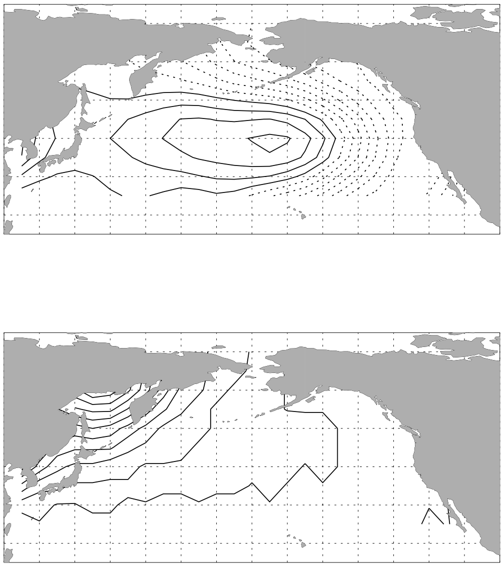


Fig.2a Upper panel: EOF-1 of the ship-SST. or the period 1950-95. Contour interval is 0.1. Bottom panel: Difference between the EOF-1 of SST from both ship and XBT and the EOF-1 of ship-SST. Contour interval is 0.01. The domain is the north Pacific ocean (15°N-75°N, 120°E-100°W).

Does adding the buoy-SST and XBT-SST to ship-SST induce significant changes in climate analysis? By comparing some conventional analyses, e.g., linear trend estimation, empirical orthogonal function analysis (EOF), etc., we found that adding the measurements by drifting buoys and XBTs to the ship observations has a negligible impact on the trend of global SST and patterns in large-scale climate variations. For example, linear trend in global average of the ship-SST is 0.42 ± 0.004 °C/100 year for the period of 1950 to 1990, while a trend of 0.44 ± 0.004 °C/100 year is seen in the global average of SST from both ship and XBT.

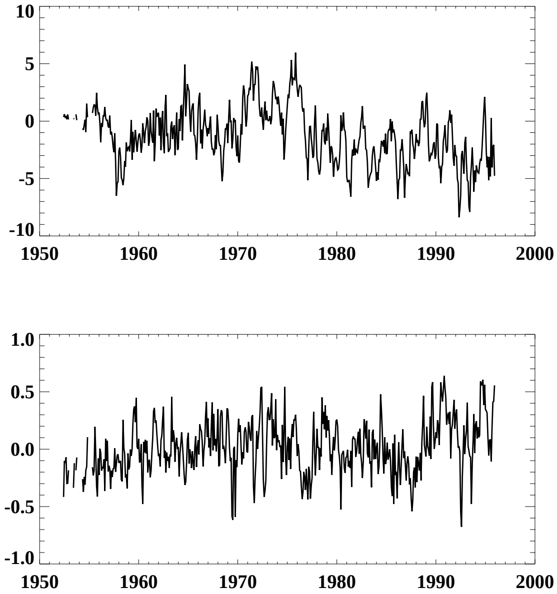


Fig.2b Upper panel: PC-1 of monthly mean SST anomalies in the north Pacific ocean (15°N-75°N, 120°E-100°W).Bottom panel: Difference between the PC-1 of SST from both ship and XBT and the PC-1 of SST from ship.

So far, we found that the impact of blending the ship-SST with the automatic measurements is also negligible impact to the EOF analysis. This is illustrated in fig.2 and fig.3. Fig.2 shows the spatial pattern and temporal variation of a leading EOF mode (EOF-1) in the SST in the north Pacific ocean. We calculated the mode using the ship-SST and the ship-and-XBT SST respectively and obtained almost the

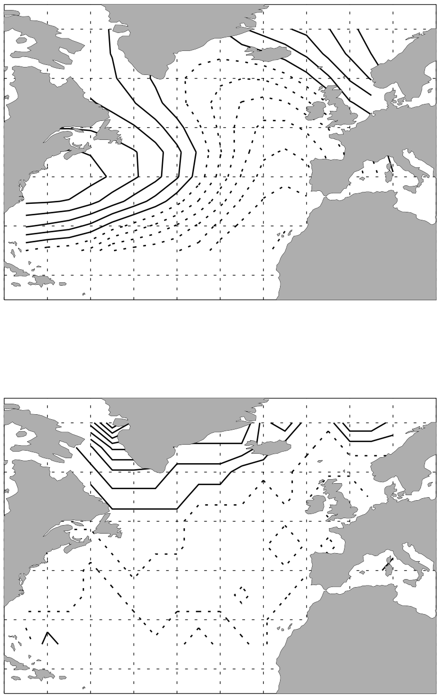


Fig.3a Same as fig.2a except for the north Atlantic ocean (15°N-75°N,280°E-380°E).

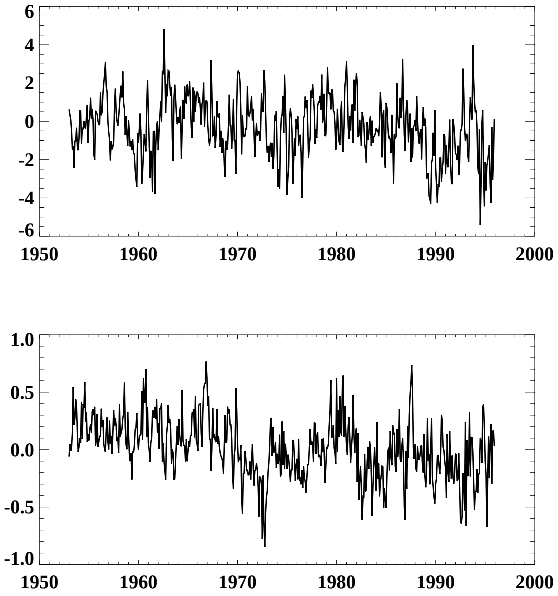


Fig3b Same as fig.2b but for the north Atlantic ocean (15°N-75°N,280°E-380°E).

same result. The time series of the EOF-1 mode obtained from the two SST data sets are hardly to be distinguished by eye when we put them in a same plot. In order to show the difference between the EOF-1 of the ship-SST and the one of ship-plus-XBT SST, we have to use a contour interval and units that are one order smaller than that used to show the mode itself. For the north Atlantic ocean, the difference between the EOF-1 modes in the ship-SST and the ship-and-XBT SST is also about an order smaller than the magnitude of the mode itself (fig.3).

4. Summary

The difference between ship-SST and the SST measured by drifting buoys and XBT is larger in the northwest Pacific and northwest Atlantic oceans. The difference has month-to-month variation but does not closely follow the annual cycle in air-sea difference. So far, we have found little impact on climate analysis from the difference by blending the ship-SST with the automated measurements. Reason for the small impact is probably that the percentage and geographic coverage of monthly mean data from these automated instruments is still relatively small comparing (less then thirty percent) to that from ship observations.

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