Comparison of Sea Surface Temperatures Obtained from an Aircraft Using Remote and Direct Sensing Techniques

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ABSTRACT

A comparison of sea surface temperatures is made between aircraft precision radiation thermometer (PRT-5) and aircraft deployed expendable bathythermographs (AXBT) drops. These observations were obtained using the NCAR King Air aircraft for an experiment in the Gulf of California during March 1984. The average difference between the sea surface temperatures reported by the first temperature observed in each AXBT drop and the PRT-5 is −0.07°C with a standard deviation of 0.57°C. The difference in temperature between the two observations increases at lower wind speeds. Based on 116 case studies, differences of 1–2°C exist between the surface and the upper meter of the ocean when wind speeds are less than 5 m s^{-1}.

1. Introduction

Instrumented aircraft have been widely used as observational platforms for atmospheric and oceanographic surveys. Their mobility clearly is an asset when observations have to be obtained accurately with high resolution under rapidly changing conditions.

During March 1984, the atmospheric and oceanic circulation in the Gulf of California (Mexico) was studied in an international cooperative research program involving Scripps Institution of Oceanography (USA) and Centro de Investigaciones Cientificas y de Educacion Superior de Ensenada, (CICESE, Mexico). An instrumented King Air aircraft operated by the National Center for Atmospheric Research (NCAR) was used to define the spatial variability of the atmospheric fields as well as the air–sea fluxes of momentum, heat and moisture. In addition to atmospheric observations, the sea surface temperature was continuously tracked with an infrared thermometer, and the vertical profile of ocean temperature was surveyed with AXBTs. This note compares the measurements between temperature at the surface and the upper meter of the ocean, and concludes that observations can be significantly different for wind speeds lower than 5 m s^{-1}.

The base of operations for the aircraft was in Guaymas, Sonora, Mexico. Typical research flight tracks are shown in Fig. 1, extending from Guaymas to the northern part of the Gulf of California. The overflights were conducted during midday at a nominal altitude of 30 m above sea level (except during AXBT launches, which were made at an altitude of 60 m). Atmospheric soundings to higher altitudes were also obtained during these flights.

2. The aircraft instrumentation

A Beechcraft Super King Air (Model B200T) was used in this experiment. This research aircraft has an extensive array of instruments (Zrubek and Phillips, 1983) including a noseboom mounted gust probe and inertial navigation system (Lenschow, 1972). This instrumentation obtains measurements of state parameters and the three-dimensional wind field that are suitable for turbulence calculations up to 10 Hz. Intercomparisons between atmospheric observations made from the plane and moored buoys are described by Friehe *et al.* (1984). In general, the intercomparisons are very favorable considering the different altitudes at which observations are made.

A newly developed airborne data system with extensive real time display and hard copy display was used during the research flights (Knowlton, 1983). Both the vertical profiles of temperature as recorded by the AXBTs and the sea surface temperatures remotely observed by the PRT-5 were available in real time during the overflights.

The sea surface temperature is remotely sensed through an infrared thermometer (Barnes PRT-5)[1] op-

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[1] Barnes Engineering Company, Stamford, CT 06904-53.

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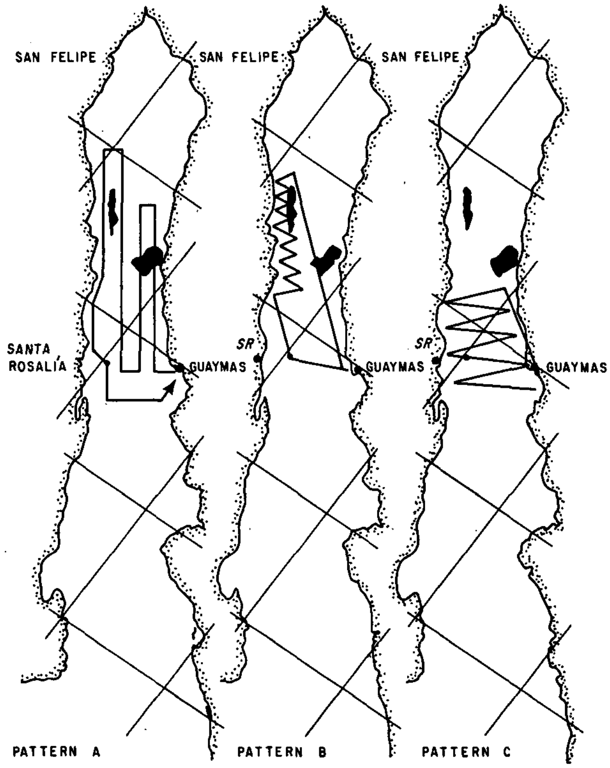

FIG. 1. Research flight patterns for the Gulf of California experimental area. The islands are indicated with black areas.

erating in the 9.5–11.5 μm spectral pass-band. The advantage in using the 9.5–11.5 μm region is that water reflectivity is a minimum in the region, averaging about two-thirds less than for the 8–14 μm region (Weiss, 1970).

The sensing with the PRT-5 thermometer was through a hole in the skin of the aircraft. No corrections were made for water vapor absorption in the air column below the aircraft or for nonideal emissivity of the sea surface. Gasparovic (1982) has shown that water vapor absorption of the emitted radiation between the sea surface and the PRT-5 at the 60 m flight level will decrease the apparent SST by up to 0.3°C. The flight data from soundings indicate these errors to be smaller in magnitude. Saunders (1970) reported that correction for nonblackness error can be between 0.5° to 0.7°C under clear sky conditions and lesser values when clouds are present. Temperature differences across the oceans' cool skin can be about 0.2°C under conditions prescribed by Paulson and Simpson (1981). During the Gulf of California Experiment in March 1984, the sensible heat flux was usually downward and the net radiative flux appears to be larger than the upward latent heat flux, so we would expect a hot skin condition. At 30 m and at 60 m altitudes, the sea surface viewing areas are, respectively, 0.9 and 3.4 m^2. The PRT-5 radiation thermometer senses the temperature of the top 20 μm of the water surface. The calibration for the range of operation (0°–43°C) was checked with an infrared black body source (EPLAB Model BB16T) before and after the field program. During the field program, the calibration was checked with a portable black body source (Everest Interscience Model 1000S). The stability of PRT-5 was found to be better than 0.15°C.

The AXBT sonde is packaged in a cylindrical housing 12 cm in diameter and 91 cm in length. Contained within this package is a parachute, VHF transmitter, signal-conditioning electronics, sea water battery, a floatation bag with a wire monopole antenna, and an active probe system. After launching the AXBT from the aircraft the descent is controlled by a small parachute. After water impact, the sea water battery activates, the float system inflates, and the buoy housing and parachute system is discarded. Temperature profiling begins approximately 42 s after battery activation when the probe is released from the surface. The temperature profile is obtained by converting temperature to frequency in the probe, transmitting those data up the hard wire link to the surface electronics and modulating the data on one of the VHF carrier frequencies (170.5, 172.0, and 173.5 MHz) to the aircraft. A receiver–processor unit on the aircraft converts the AXBT frequency versus time data into temperature versus depth information. (See Black and Schricker, 1978.) About one minute after completion of the descent of the probe, the transmitter is shut off and the floatation bag scuttled, thereby allowing the package to sink. For additional details, see Sessions *et al.* (1976).

The AXBT sonde unit (Sippican Model AN/SSQ-36, N00163-81-C-0287, 1983) has a quoted depth accuracy of ±5% and a temperature accuracy of ±0.55°C when using fall rate specifications of

$$D = 1.52t$$

where D = depth in meters, and t = elapsed time after probe release in seconds; temperature is converted to frequency with the following expression:

$$F = 1440 + 36T$$

where F is frequency in Hertz, and T is temperature in degrees Celsius. The accuracies of the deep sondes (760 m) were studied by Bane and Sessions (1984), who found their accuracy depended upon the formula chosen for frequency-to-temperature conversion and fall rate.

Provision was made within the King Air to store up to 12 sondes and to launch these through a tube. The launch system was tested prior to the field program. The deployment of a sonde is illustrated by a sequence of three photographs (Fig. 2) taken from the NCAR Sabreliner, which was used as a chase plane during these tests.

A total of 125 AXBTs were launched in 19 research missions. Of these, 100 units had the operational depth capabilities of 305 m and twenty-five units had the

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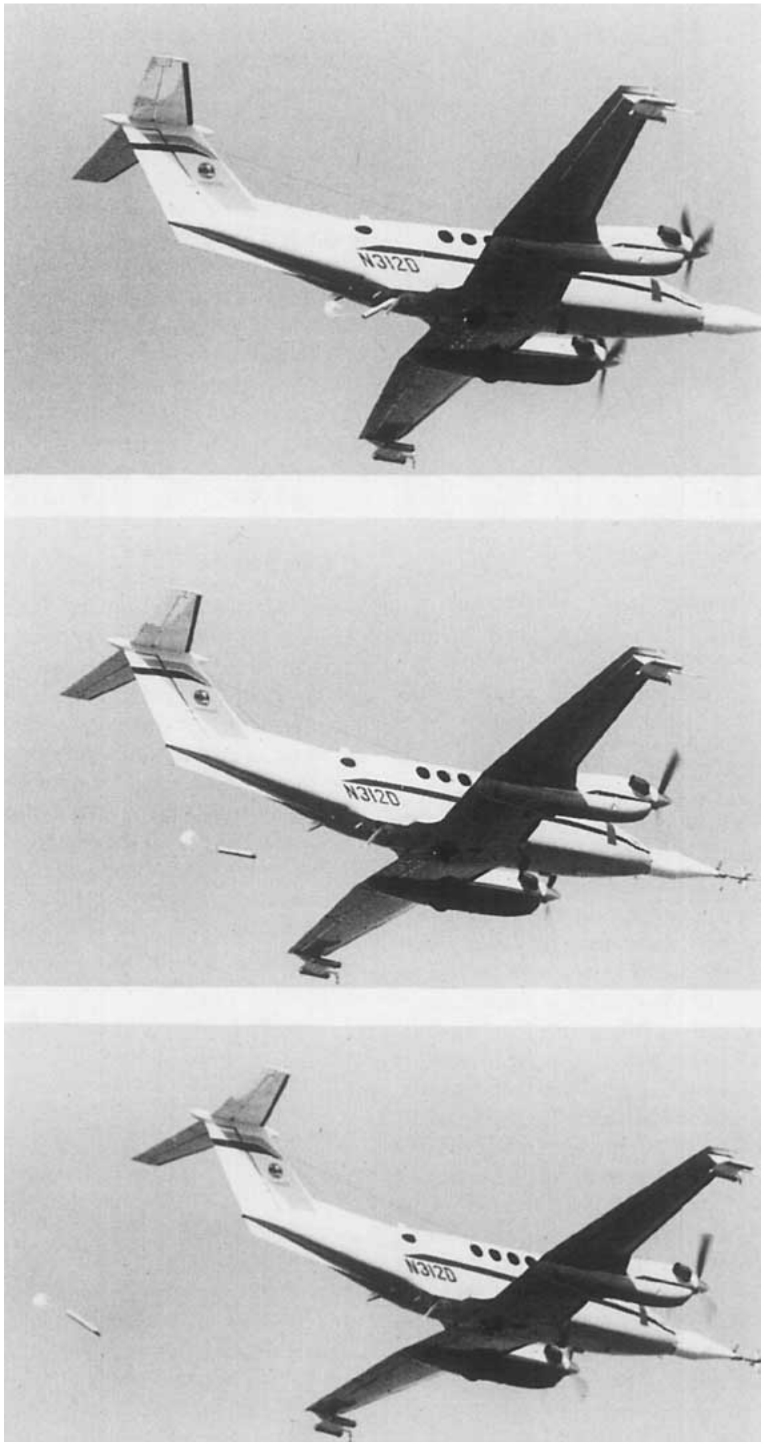

FIG. 2. The airborne deployment of a sonde shown in sequence.

depth capabilities of 760 m. Of all 125, only 6 failed to operate, and some of these failures were attributed to launching outside of the recommended "launch envelope" in strong and gusty winds exceeding 15 m s^{-1}. Three units provided very noisy intermittent signals, thereby rendering the data useless. Figure 3 shows an AXBT probe temperature profile versus depth by using the formula discussed earlier.

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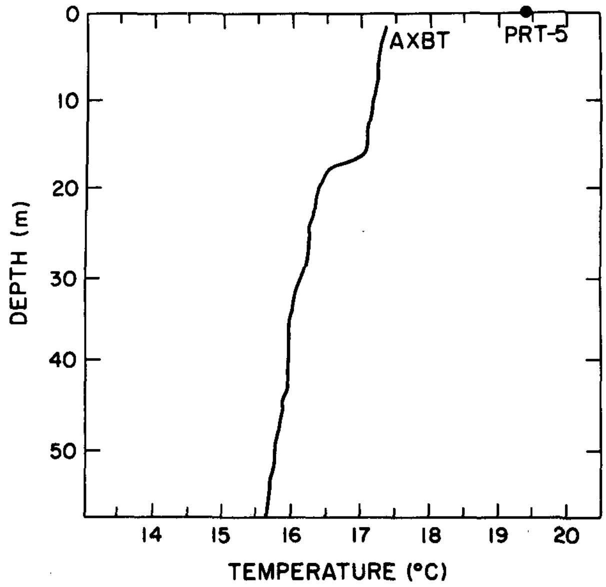

FIG. 3. An AXBT temperature profile versus depth.

3. Comparison of the AXBT and PRT-5 observations

A comparison of the AXBT and PRT-5 temperatures is shown as a scatter plot in Fig. 4. Taken as a whole, the points cluster around a line of slope unity. The mean difference between the AXBT and PRT-5 temperature measurements is −0.07°C with a standard deviation of 0.57°C.

During the flights, it appeared that the largest discrepancies between the two water temperature observations occurred when the wind speed was low. The difference in sea surface temperatures is shown as a function of the wind speed at 60 m level in another scatter plot in Fig. 5. It can be seen that both the mean temperature difference (AXBT–PRT-5) and the scatter deviation of the temperature difference decreases with increasing wind speed. Typically, the temperatures observed by the PRT-5 were higher than those reported by the AXBT when there exists a large difference. This difference may well reflect the presence of real vertical temperature gradients since the PRT-5 observations is made at the very surface, while the first temperatures reported by the AXBT are from 40 cm beneath the surface. Such a vertical gradient would be expected to be at a maximum near midday, when the flights were conducted, and when the wind speed is small.

Friehe *et al.* (1984) compared aircraft PRT-5 observations of sea surface temperature to the temperature of the water 1 m beneath the surface measured from a moored buoy in the CODE experiments. The two sets of measurements differed by a consistent bias of order 1°C; the PRT-5 was colder, and the reason remained unexplained.

Comparisons from 18 AXBT sondes and simultaneous airborne PRT-5 measurements are reported by Black and Schricker (1978). After correcting the PRT-5 data for atmospheric effects, they find that "the mean difference was ±0.16°C with a standard deviation about this mean of ±0.12°C." More recently, LaViolette and Kerling (1983) showed 120 comparisons made in the Alboran Sea. These comparisons, made from four different flights, have mean differences ranging between 0.03°C and −0.38°C, with standard deviations of 0.27° to 0.65°C.

In a paper by Legeckis and Bane (1983), a detailed comparison was made between multichannel infrared (3.7 and 11 μm) temperatures measured by the TIROS-N satellite and aircraft PRT-5 radiometer and 50 AXBT measurements over the Gulf Stream between Cape Hatteras and Savannah, Georgia. A bias of 1.2°C was found between the aircraft radiometer and AXBT measurements, and part of this bias was attributed to the PRT-5 calibration errors.

4. Conclusions

Sea surface temperatures observed remotely, either using a radiometer or expendable sondes, agree with each other with errors less than 1°C. In this respect the observations reported here confirm earlier reports. Furthermore, the amplitude of the differences between radiometer and *in situ* temperature observations varies as a function of wind speed. One natural cause of this difference may be that the temperature difference between the "skin" of the ocean and the upper meter of the water column should decrease to low values when vertical mixing is induced by higher wind speeds. Our data indicate that caution should be exercised when interpreting sea surface temperature measurements

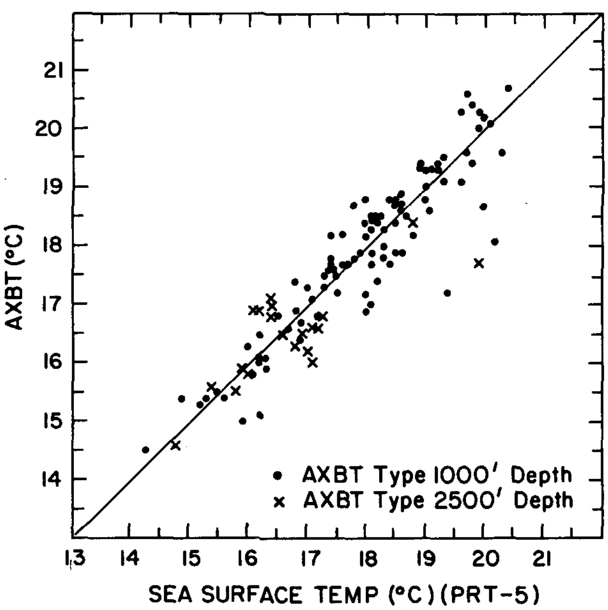

FIG. 4. Scatter diagram of temperatures observed by the PRT-5 and the near-surface AXBT temperature.

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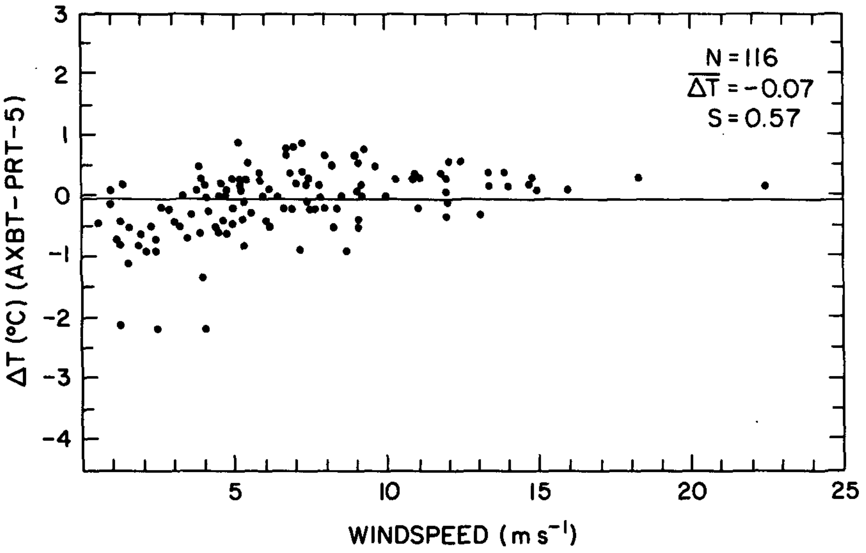

FIG. 5. Scatter diagram of the difference in sea surface temperature as measured by remote radiometer from the aircraft and by AXBT versus the flight level wind speed.

with those of the upper meter of ocean structure. Vertical temperature gradients of 1°–2°C can exist near the surface at wind speeds less than 5 m s^{-1}.

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