Air-Sea Temperatures Measured With Scanning Microwave and Infrared Radiometers in Nauru99

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Introduction

Previously we described the deployment of two scanning radiometers on the National Ocean and Atmospheric Administration (NOAA) R/V Ronald H. Brown (RHB) in the Tropical Western Pacific during the Nauru99 cruise, primarily in the vicinity of Nauru Island at about 0° latitude, 166° E longitude (Shaw et al. 2000). This paper presents further analysis and results from air-sea temperature difference measurements with these radiometers during the Nauru99 experiment. We deployed similar microwave and infrared radiometers, both vertically scanning radiometers that measure emission on the edge of a uniformly mixed atmospheric gas absorption line (O_2 for the mm-wave, and CO_2 for the IR). For both radiometers the horizontal atmospheric view is calibrated with a high-quality in situ temperature sensor. The air-sea temperature difference is derived from the AC-coupled radiometer voltage differences between the air and water views. The same calibration uncertainty applies to both air and water measurements, so the differential temperature derived from the radiometer is more robust than subtracting two independent sensor readings. Furthermore, the radiometric signals relate to the important skin temperature rather than the bulk water temperature. Boundary-layer air temperature profiles are also being retrieved, but those results are not discussed here.

Scanning Radiometers

The radiometer system comprises similar vertically scanning microwave and infrared radiometers. The microwave instrument measures emission on an oxygen absorption band at 5-mm wavelength (60 GHz), while the infrared instrument measures emission on a carbon dioxide absorption band near 14-µm wavelength. Both radiometers are designed for precise, continuous measurements of air-water temperature difference and for recovery of air temperature profiles (height from 0 to 300 m). The original 5-mm radiometer was designed and built at the Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia (Trokhimovski et al. 1998), and the infrared scanning radiometer was designed and built at the NOAA Environmental Technology Laboratory in Boulder, Colorado (Shaw et al. 2001).

The high atmospheric absorption of both radiometer channels allows us to use the radiance (or brightness temperature) at the horizontal view as one calibration point. We measure the air temperature near the radiometers with a high-quality in situ probe and assume horizontal homogeneity over the several hundred meter path length, which dictates a minimum temporal averaging time during which time a pocket of air can be carried by the wind from one end of the horizontal path to the other (30 sec for a 5 m/s wind). Deployment with on-board calibration targets could provide measurements with higher temporal resolution.

The microwave radiometer is a total power system with automatic compensation of the direct current in the output signal (a compensation-type radiometer). The radiometer employs no additional modulation, except for the antenna beam rotation at 2 Hz. A single frequency of 60.5 GHz is used with a total bandwidth of 4 GHz and a 3-dB beamwidth of 6°. The same measurements provide information about air temperature profiles in the lower atmosphere. Similarly, the infrared radiometer is based on a simple single-lens and bandpass filter design, with a photovoltaic HgCdTe photodiode detector cooled with liquid nitrogen to 77 K. There is no chopper or modulation mechanism other than the scan mirror rotating together with the microwave mirror at approximately 2 Hz. The filter bandwidth provides an atmospheric scan similar to the microwave radiometer, but the oceans-surface emission from arises from an emissivity of nearly 0.98, in contrast to the 0.45 microwave emissivity. The infrared radiometer optical filter has a 14.2 μm center wavelength and a 1.1 μm bandpass. The infrared full-angle field of view is approximately 1°. Both radiometers and the Vaisala HMP 233 temperature and humidity sensor were mounted on a boom that extended 5 m beyond the port side of the RHB. The height of the boom was 10 m ASL.

Air-Sea Temperature Difference Measurements

The two radiometers were mounted on opposite sides of the boom, such that they viewed similar but not identical regions of the atmosphere and ocean. However, both instruments measured a common region around the zenith and nadir directions. Plots of the radiometer signals versus scan angle and discussion of the instrument calibration and data processing steps are presented elsewhere (Shaw et al. 2000; 2001) so here we show only the retrieved air-sea temperature differences.

Figure 1 shows a 24-hour time-series plot of air-sea temperature difference retrieved from the 5-mm radiometer (blue dots) and calculated from independent bulk-water and air temperature measurements (solid line). The bulk water temperature was measured with a floating sensor at about 5-cm depth, while the in situ, air temperature was measured on the RHB mast approximately 15 m ASL (Hare et al. 2000). The plot of Figure 1 constitutes the only air-sea temperature difference results that we showed previously (Shaw et al. 2000). In that previous presentation we pointed out that the daytime data (~0-6 and 18-24 UTC) agree reasonably well, but the nighttime data (6-18 UTC) are significantly

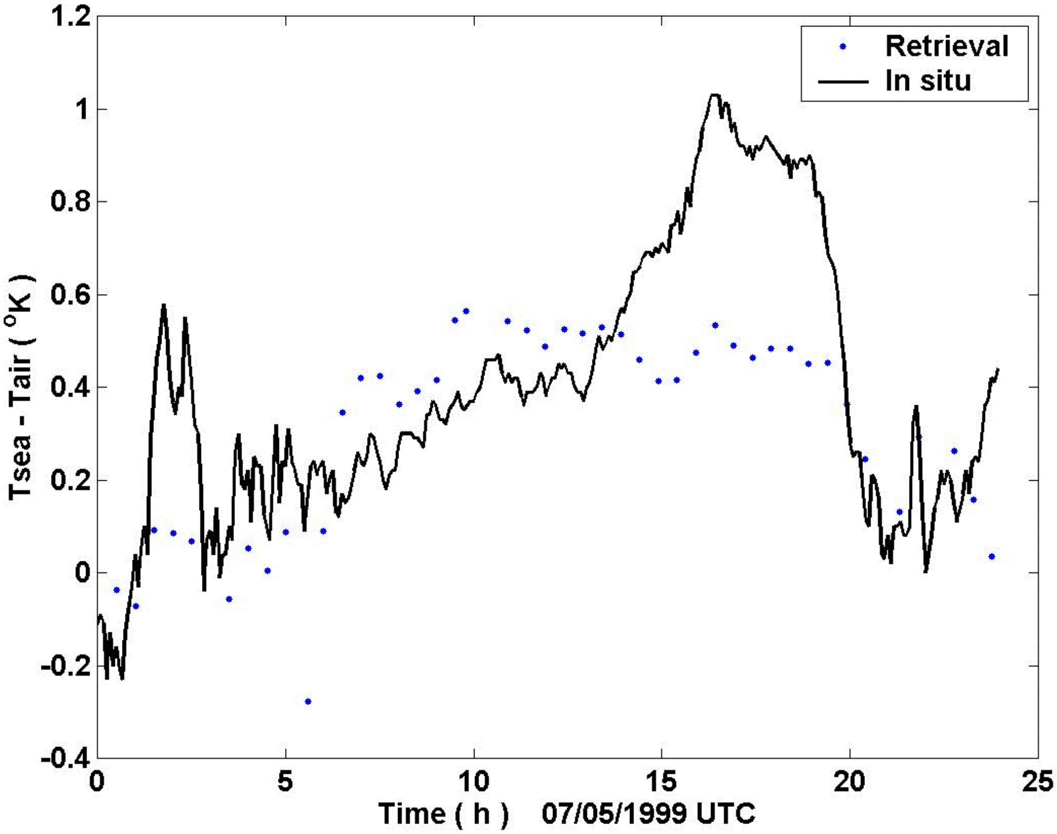

Figure 1. Air-sea temperature difference retrieved from the microwave scanning radiometer (blue dots) and measured with bulk air and water sensors (solid line).

different. During the night, cooling of both the air and water skin results in little change in radiometrically derived temperature difference; however, the bulk water temperature stays relatively constant, leading to a changing bulk air-water temperature difference (see Figure 2). The magnitude of the diurnal difference we see between the bulk and skin measurements approaches 1K, which is consistent with other measurements during the same experiment (Minnett 2000).

Figure 3 shows newly retrieved air-sea temperature difference from the scanning infrared radiometer (Shaw et al. 2001). In this figure the red crosses indicate infrared measurements and the solid blue line indicates data from the same bulk water and air temperature sensors described above. In these data we also see a similar behavior, with the radiometrically derived temperature difference typically greater during the day and less during the night, relative to the bulk difference.

Summary and Future Plans

The scanning microwave and infrared radiometers performed well during the Nauru99 cruise. The data are being used to retrieve air-sea temperature difference and air-temperature profiles in the bottom 300 m above the surface. Initial air-sea temperature retrievals from the two radiometers both differ in a

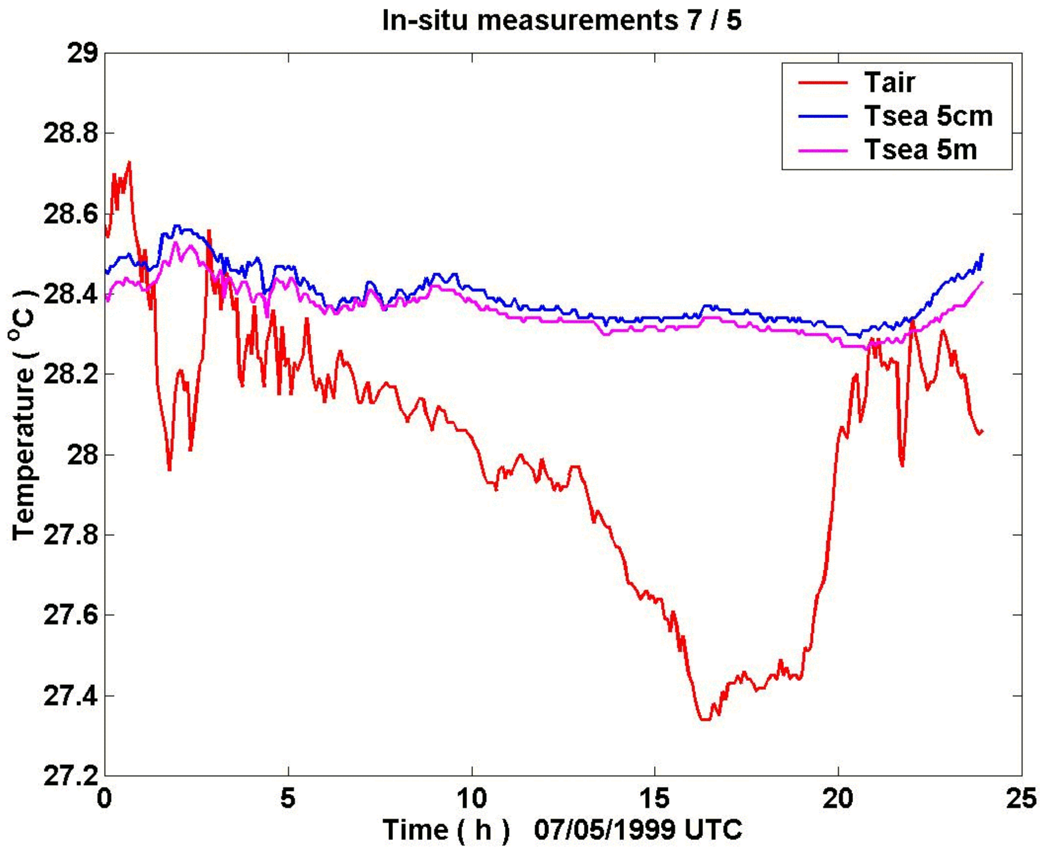

Figure 2. Bulk air temperature (red curve) and bulk water temperature at 5 cm (blue line) and 5 m (purple line) depths. The bulk water temperatures remain approximately equal during day and night, while the air temperature changes. The water skin temperature (not shown) follows the air temperature closely, producing a diurnal variation in agreement between bulk and radiometric air-sea temperature differences.

similar fashion from bulk temperatures. These systematic differences can be explained as arising from the higher variability in skin water temperature compared with the bulk water temperature. We are continuing to refine the retrieval techniques for the scanning radiometers and in our presentation next year we will show a detailed comparison of air-sea temperature differences retrieved from both radiometers and from the in situ sensors. Future work will also be directed at retrieving air-temperature profiles and comparing them with other data.

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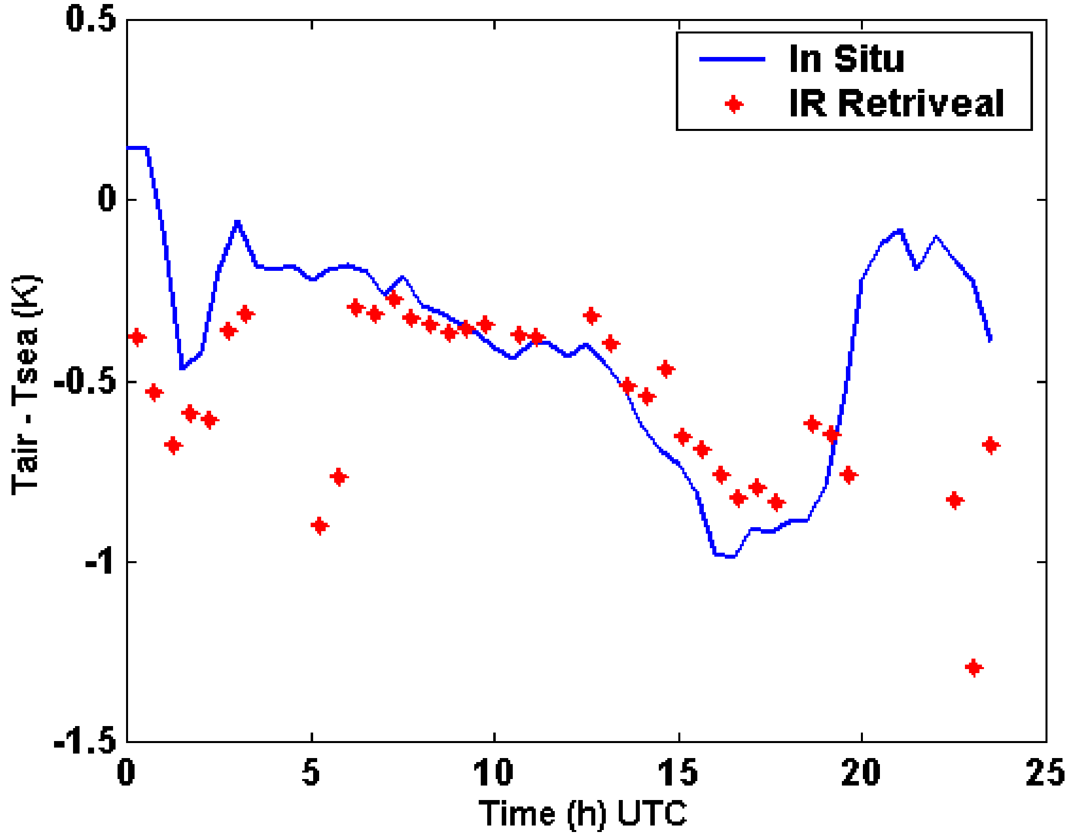

Figure 3. Air-sea temperature differences retrieved from the scanning infrared radiometer (red crosses) and from bulk air and water temperature sensors (blue line). The infrared data show a diurnal variation similar to the microwave data, exhibiting smaller air-sea temperature difference during the night and larger during the day, relative to the bulk measurements.

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