

High Lapse Rates in AIRS Retrieved Temperatures In Cold Air Outbreaks

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Abstract

The Atmospheric Infrared Sounder (AIRS) experiment, on NASA's Aqua spacecraft, uses a combination of infrared and microwave observations to retrieve cloud and surface properties, plus temperature and water vapor profiles comparable to radiosondes throughout the troposphere, for cloud cover up to 70%. The high spectral resolution of AIRS provides sensitivity to important information about the near-surface atmosphere and underlying surface.

A preliminary analysis of AIRS temperature retrievals taken during January 2003 reveals extensive areas of superadiabatic lapse rates in the lowest kilometer of the atmosphere. These areas are found predominantly east of North America over the Gulf Stream, and, off East Asia over the Kuroshio Current. Accompanying the high lapse rates are low air temperatures, large sea-air temperature differences, and low relative humidities. Imagery from a Visible / Near Infrared instrument on the AIRS experiment shows accompanying clouds. These lines of evidence all point to shallow convection in the bottom layer of a cold air mass overlying warm water, with overturning driven by heat flow from ocean to atmosphere.

An examination of operational radiosondes at six coastal stations in Japan shows AIRS to be oversensitive to lower tropospheric lapse rates due to systematically warm near-surface air temperatures. The bias in near-surface air temperature is seen to be independent of sea surface temperature, however. AIRS is therefore sensitive to air-sea temperature difference, but with a warm atmospheric bias. A regression fit to radiosondes is used to correct AIRS near-surface retrieved temperatures, and thereby obtain an estimate of the true atmosphere-ocean thermal contrast in five subtropical regions across the north Pacific. Moving eastward, we show a systematic shift in this air-sea temperature differences toward more isothermal conditions. These results, while preliminary, have implications for our understanding of heat flow from ocean to atmosphere. We anticipate future improvements in the AIRS retrieval algorithm will lead to improved understanding of the exchange of sensible and latent heat from ocean to atmosphere, and more realistic near-surface lapse rates.

1. Introduction

Cold continental air over warm ocean currents is a common feature of the winter hemisphere. Large air-sea thermal contrasts have been studied extensively in the Gulf of Mexico (Wang et al., 1998), the Labrador Sea (Renfrew and Moore 1999), and the Gulf Stream adjacent to both North America (Xue and Pan, 2000; Colucci et al., 1999) and Europe (Heggem et al., 1998). In the northern hemisphere, cold air over warm ocean is most prevalent in the subtropical western Pacific Ocean off Asia during winter (Chen et

al., 1999). In that region very cold temperatures develop in the high pressures over eastern Siberia. Outflow from Siberia over the warm waters of the Kuroshio current leads to large thermal contrast between ocean and air. Here we examined observations in the vicinity Japan to understand the air Atmospheric Infrared Sounder satellite experi

Our analysis is based on two temperat operational radiosondes from several sites in the radiosondes launched from these sites du is the Atmospheric Infrared Sounder experi (Aumann et al., 2003). Launched in May 2 2002, AIRS provides over 300,000 daily 1 profiles of temperature and humidity, and trac microwave and infrared information (Susskir obtained with a nadir spacing of 50 km betw footprints wide, or about 1650 km, with foc edges. All results presented here pertain to v not significantly different than the version 2003. In this study we match the AIRS orbits at the sites shown in Figure 2. The two dat hours since the AIRS overpasses East Asia time) while sondes are launched at 0 and 12 U

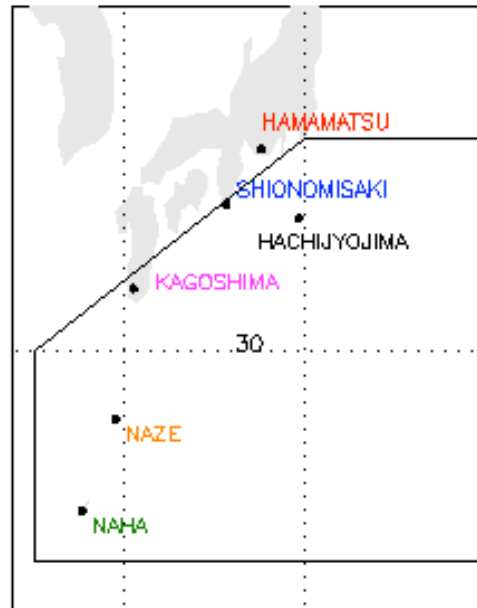


Figure 1. Locations of radiosondes used in this study. The outline denotes Region I discussed below.

2. The Synoptic Situation

Figure 2 illustrates the synoptic situation commonly encountered in the vicinity of Japan during wintertime. Figure 2 was obtained with the AIRS Visible / Near Infrared imager that shares its fore optics with the AIRS infrared spectrometer (Gautier et al., 2003). As is readily apparent from Figure 2, the predominant atmospheric flow is from the northwest, and across the relatively warm water of the Sea of Japan. Cloud cover along the northern half of the large island of Honshu, along with generally clear skies to the south, suggest foehn conditions. The cloud cover both windward and leeward of Honshu

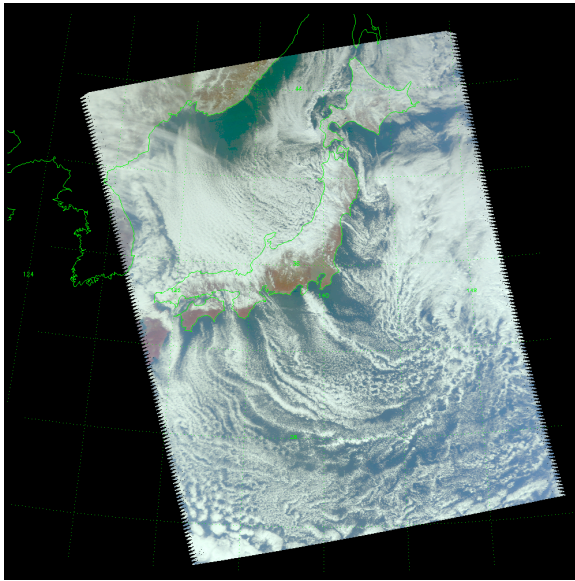


Figure 2. AIRS Visible/Near Infrared image during overpass of east Asia on 2 January 2003. The image show six minutes of observations and corresponds to AIRS granule 2003.01.03.038.

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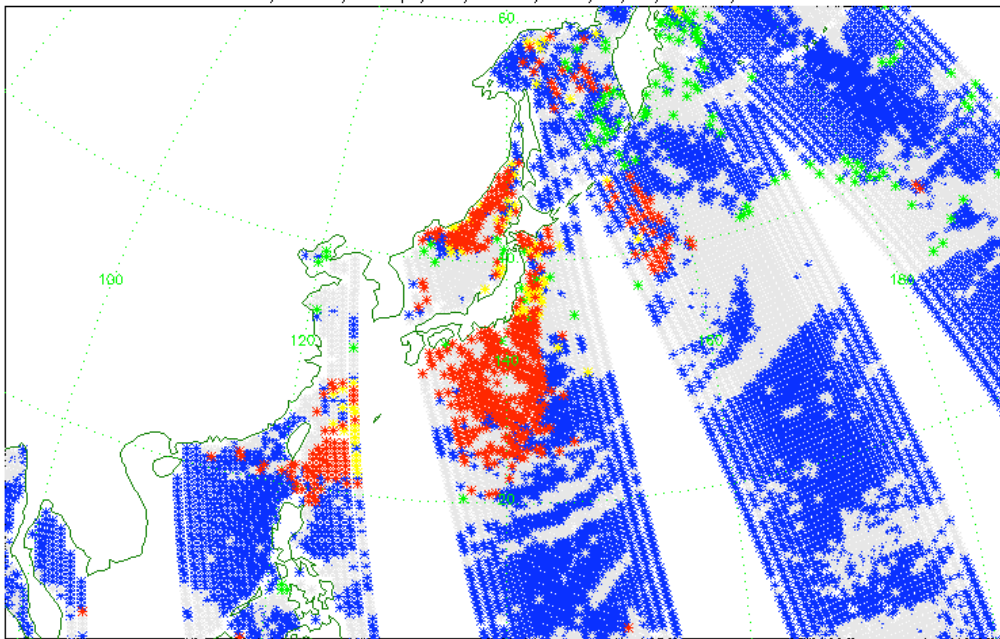


Figure 3. Locations of retrieved AIRS unstable lapse rates on 2 January 2003, for full infrared retrievals (red) and partially convergent infrared retrievals (green and yellow). Neutral or stable profiles are shown in blue, and gray marks non-convergent infrared retrievals. Figure 2 is the Visible / Near Infrared image from the Japan overpass in the center of this image.

are consistent with shallow convection where cold air overlies warm ocean (Atkinson and Zhang, 1996), in this case the Kuroshio Current

Figure 3 shows the locations of superadiabatic lapse rates in the AIRS temperature retrievals. A comparison of Figures 2 and 3, comprising data taken on the same day, shows that AIRS detects unstable temperature profiles over extensive cloud-free areas to the east of Japan.

3. Comparisons of Radiosondes and AIRS Retrieved Temperature Profiles

Figure 4 shows potential temperature profiles from AIRS and from operational radiosondes launched from Hachijyojima, on 2 January 2003 at 0 Z. The time and spatial separation of the two profiles in Figure 4 are roughly 4 hours and 100 km, respectively.

Figure 4 illustrates well the nature of the unstable AIRS retrievals whose locations are marked in Figure 3. While the radiosonde potential temperature profile in Figure 4 is nearly constant from the surface to an altitude of about 1 km, the AIRS profile has a distinctive kink toward a slightly higher near-surface value. (A potential temperature inversion, as seen here, is one manifestation of an unstable lapse rate.) This result holds for many of the sonde-AIRS comparisons during January 2003. We conclude from these comparisons that the unstable AIRS temperature profiles marked in Figure 3 are in fact spurious. The apparently unstable profiles are a manifestation of height-dependent biases in the AIRS temperature retrievals seen as a slight warming of near surface temperatures accompanied by slightly colder temperatures at 850 hPa relative to ECMWF. (See Figure 36 on page 56 of Fetzer et al. 2003). This height-dependent bias acts to distort a otherwise neutrally stable profile toward instability.

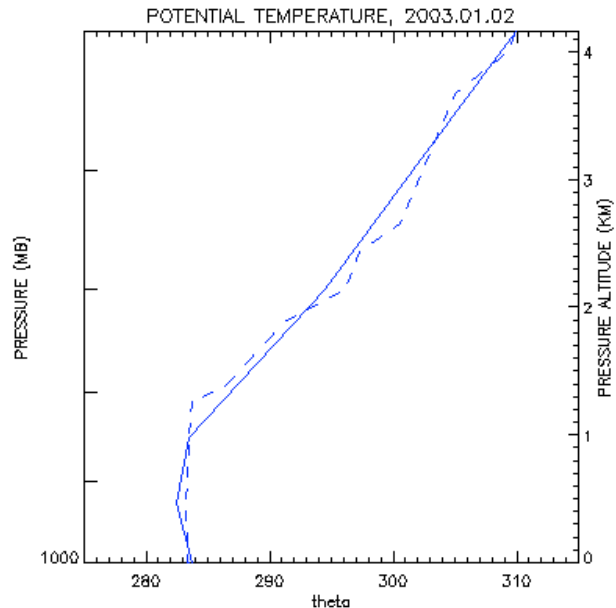


Figure 4. Potential temperature from AIRS (solid) and Hachijyojima (dashed) during the overpass shown in Figure 2.

4. Validating AIRS Near-Surface Temperatures

We now examine further the nature of the AIRS near-surface temperature. Figure 5 shows the AIRS retrieved 1000 hPa temperature, versus the lowest altitude temperature from the matched radiosondes launched from the six locations marked in Figure 1. The warm bias in the AIRS near-surface temperature is apparent in Figure 5. The mean bias of 2.4 K is comparable to the standard deviation of the difference of 2.3 K. Also apparent in Figure 5 is the temperature dependence of the bias: AIRS tends to be too warm as the near-surface temperature decreases. Indeed, the lowest biases for any location in Figure

5 is seen at Naha on the Island of Okinawa at 25 N latitude, where temperatures are also highest.

Figure 6 shows the difference between the temperatures in Figure 5 as a function of AIRS retrieved air-sea surface temperature (SST) difference. (AIRS SST are reasonable well understood; see Fetzer et al. 2003) Note that there is no significant trend as a function of thermal contrast between air and ocean in Figure 6. Two conclusions can be reached from Figure 6. First, as shown in Figure 5 AIRS has a warm bias in its near surface temperature retrieval that increases with decreasing SST. Second, the thermal contrast between ocean and atmosphere does not further bias the near-surface air temperature. We now show the variability of air-sea thermal contrast in five regions across the subtropical north Pacific Ocean.

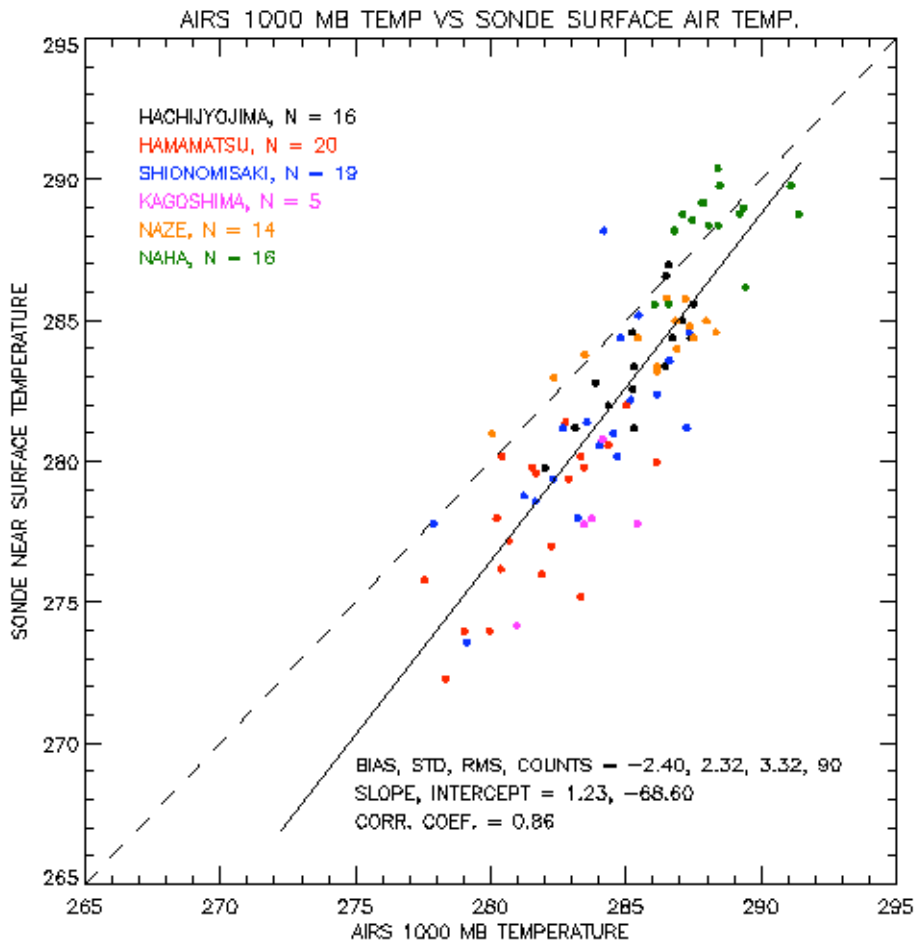


Figure 5. Sonde near-surface temperature versus AIRS retrieved 1000 hPa temperature.

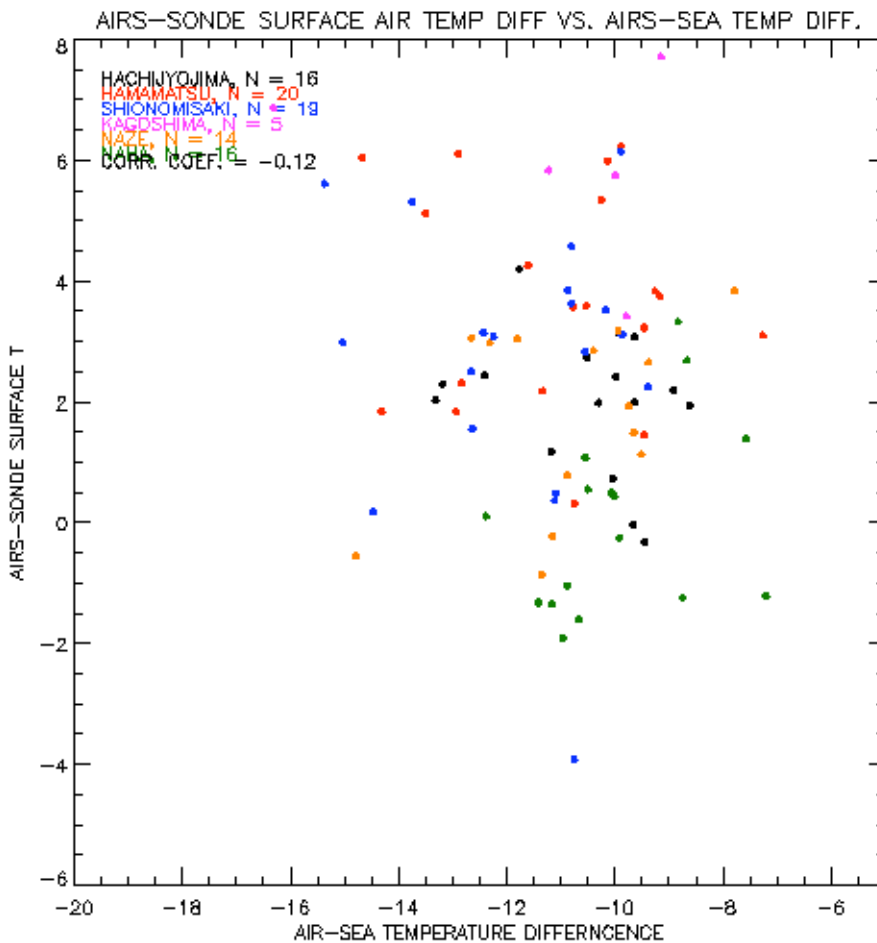


Figure 6. Difference between AIRS and sonde near-surface temperature (as shown in Figure 5) versus AIRS retrieved air-sea temperature difference.

5. Variability in Atmosphere-Ocean Temperature Differences

In the previous section we concluded that AIRS is sensitive to the temperature difference between near-surface atmosphere and ocean, but with a 2 K warm bias in the atmosphere. We now show air-sea temperature difference frequency distributions for five regions in the North Pacific Ocean during January 2003. All regions are between 25 and 35 north latitude; region I is outlined in Figure 1. The other four regions are II: 150 to 165 E, III: 165 to 180 E; IV: 165 to 180 W and, V: 150 to 165 W. These five regions extend in a band from Japan to just north of Hawaii. To correct for the known bias in the lowest part of the atmosphere we perform a regression correction using the formula shown in Figure 5.

Figure 7 shows the occurrence frequency of the adjusted difference between SST and 1000 hPa atmospheric temperatures retrieved by AIRS for January 2003 in Regions I to V. The shift in air-sea temperature differences moving westward across the Pacific is readily apparent in Figure 7. This shift is reflected in the trend from a mean difference

of -7.3 K in Region I off Japan, to -4.9 K in Region V north of Hawaii. The slight bimodality in Region II is presumably related to the mixed presence of cold Siberian or warm subtropical air masses in this region.

Figure 8 shows air-sea temperature differences, with air temperature corrected by linear regression, for the five regions shown in Figure 7 during the first and second halves of January 2003. The bimodality seen in Region II in Figure 7 is apparent in several curves in Figure 8. Region II is strongly bimodal during the first 16 days of the month, but more weakly so during the second 15 days. Note the modest variability in mean differences in Figures 7 and 9, despite readily apparent changes in the shape of the distribution.

The results presented here have important implications for air-sea exchange processes. For example, sensible heat flow from warm ocean into the cold atmosphere, consistent with the large air-sea thermal differences in Region I in Figures 7 and 8, drives the shallow convection readily apparent in Figure 1. Air-sea thermal differences observed by AIRS also have implications for large-scale baroclinic instability. The warm bias in near-surface temperatures described above suggest care in the interpretation of these results, however.

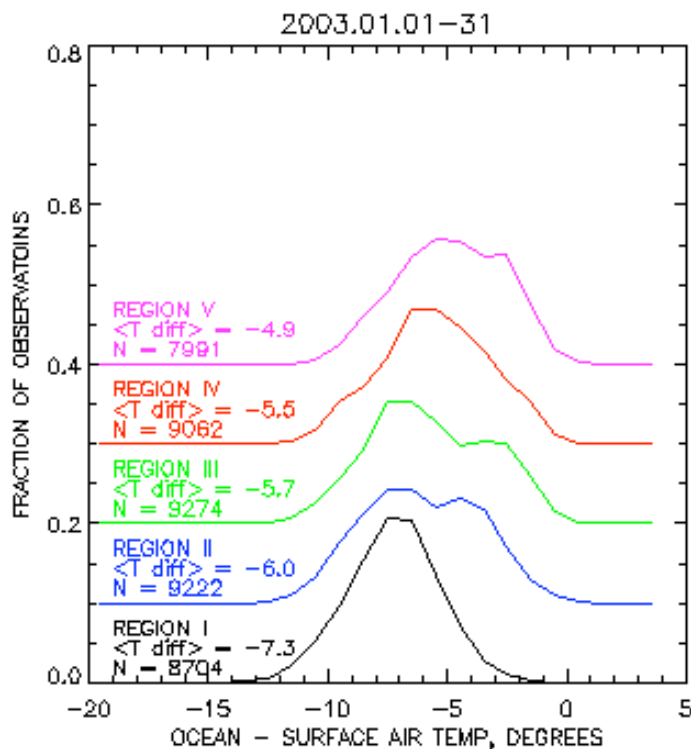


Figure 7. Occurrence frequency of air-sea temperature difference for five regions across the North Pacific, as described in text, for January 2003. Results for successive regions are shifted upward by 0.1. Also shown are the mean air-sea temperature differences, and total number of samples.

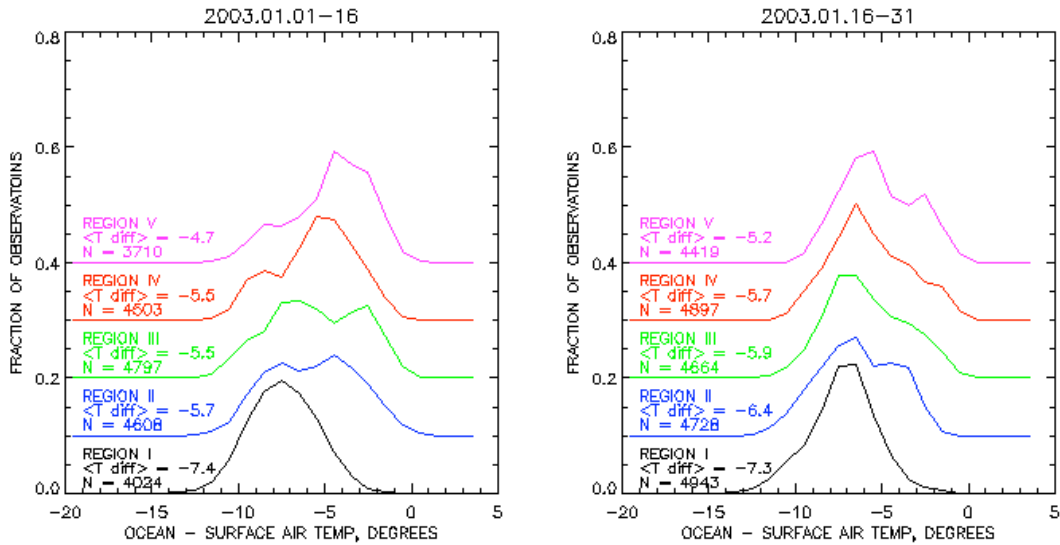


Figure 8. As Figure 7, 1-16 and 16-31 January 2003.

6. Summary, Conclusions, and Future Work

Observations from the Atmospheric Infrared Sounder experiment show large areas of superadiabatic lapse rates in retrieved lower atmospheric temperatures in those geographic regions where cold air move over warm ocean. To ascertain the legitimacy of these lapse rates, we compare the thermal structure of the lower atmosphere in AIRS retrievals with operational radiosondes from several sites south and east of Japan during January 2003. The superadiabatic lapse rates are indeed spurious, and related to a known height-dependent bias in AIRS retrievals. We show that AIRS has a 2 K warm bias in near-surface air temperatures. Despite this bias, AIRS is seen to be sensitive to air-sea thermal contrasts. We present occurrence frequencies of atmosphere-ocean temperature differences for five regions extending across the subtropical north Pacific between Japan and Hawaii in January 2003. The thermal contrast between atmosphere and ocean is seen to decrease moving eastward across the Pacific with the ocean, on average, warmer than the overlying atmosphere.

These results have important implications for sensible heat exchange between ocean and atmosphere, but must be used with caution because of the lower atmosphere temperature bias. Results presented here underscore the importance of validating AIRS and other satellite sensors with available in situ observations. In future, we expect a more realistic representation of AIRS near surface temperatures. Errors in the surface emissivity of less than 1% can lead to detectable biases in retrieved products, as may be occurring here. The next public release of AIRS retrieval upgrades will be in Fall 2004, and surface emissivity is an expected improvement for these version 4.0 data.

In addition to temperature, the AIRS retrieval system generates humidity profiles. As with temperature, water vapor is being validated against a variety of correlative data

sets. A combination of near-surface temperature and humidity estimates will lead to better estimates of sensible and latent heat fluxes from ocean to atmosphere.

7. References

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