STATUS REPORT – EOS Aqua Validation

VALIDATION OF THE ATMOSPHERIC INFRARED SOUNDER OVER THE ANTARCTIC PLATEAU

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Date: 5 April 2004

Overview:

We have continued to use Dome Concordia, Antarctica as a site for calibration and validation of NASA's Atmospheric Infrared Sounder (AIRS). Based upon results of the first field season of this type, performed in January 2003, we improved many aspects of our experiment when we returned to the field in December 2003 and January 2004. We again measured upwelling and downwelling spectral infrared radiances with the Polar Atmospheric Emitted Radiance Interferometer (PAERI), but from 25 meters above the snow surface rather than from a 6-meter tower. The AIRS Mobile Observing System (AMOS) was used again to map changes in surface radiation at spatial scales of kilometers. High-quality radiosondes were launched to obtain atmospheric temperature and humidity profiles. Surface meteorological measurements and total-column ozone measurements were routinely made by other groups at Dome C throughout the field season.

Validation Goals:

Our goals for this project continue to be to provide validation data for both Level-1 and Level-2 products derived from the AIRS instrument. In accordance with the AIRS team, we have initially concentrated on clear-sky conditions. We have derived top-of-the-atmosphere (TOA) radiances from radiative transfer calculations that use radiosonde data and ground-based retrievals of spectral emissivity and skin temperature of the snow surface as input. We have archived radiosonde data from the austral summer Antarctic, derived from radiosondes, and have made preliminary comparisons of temperature profiles to AIRS Level-2 retrievals. In addition, we have compared ground-based retrievals of the spectral emissivity of snow from PAERI measurements to Level-2 retrievals. These comparisons have shown that AIRS is producing realistic retrievals over Antarctica, but that improvements can be made. In the near future, we plan to begin to look at cloudy-sky conditions by retrieving cloud microphysical properties from the PAERI data for Level-2 validation.

Second Field Experiment:

Our second, and final, field experiment at Dome Concordia occurred from 3 December 2003 until 2 February 2004. Radiosondes were launched during this time period in collaboration with the astrophysics groups from the University of Nice and the University of New South

Wales. The Polar Atmospheric Emitted Radiance Interferometer (PAERI) was operated from 15 December 2003 until 29 January 2004; the AIRS Mobile Observing System (AMOS) operated from 21 January until 29 January. During the six weeks of PAERI operation, there were approximately 275 to 300 Aqua overpasses over Dome C; six or seven overpasses per day, three to four between about 2 and 4 pm local and three between 10 pm and 12 am local. About one third of these overpasses had near-nadir viewing angles within 22.5° of nadir. Extremely clear skies were observed on 16 days during the six weeks of measurements. A total of ninety (90) Vaisala radiosondes were launched during this field season, sixty RS90 sondes and thirty RS80-GA sondes. The RS90 sondes were used exclusively during clear-sky conditions because their humidity measurements at low temperature are superior to those made by the RS80-GA sondes. Both RS90 and RS80-GA sondes were used during cloudy times. There were 24 radiosondes launched on clear days that were timed with Aqua overpasses.

Experimental Improvements:

Our measurements from our first field experiment in January 2003 prompted us to make changes in our experimental approach for the second field season in December 2003/January 2004. The measurements from January 2003 showed:

- Large differences in the surface temperature (2 – 4 K) over small spatial scales of 2 to 4 feet.
- The upwelling radiance from the surface might be dependent on the azimuthal viewing angle because of how the sun heats (and shades) the wind-blown snow drifts (sastrugi) on the surface.
- A large diurnal cycle of surface temperature (around 15 K) in summer under clear-sky conditions, so that the surface temperature changes rapidly at certain times of day.

The experimental improvements for 2003/2004 included:

- Placing the PAERI higher off the surface by re-locating it from its original 6-meter tower to 24-meters above the surface on the U. Washington's 32-meter tower, which increased the ground footprint of the PAERI from approximately 1 foot to 4 foot diameter. Also, six PAERI view angles were concatenated together to create an effective footprint of 4 feet by 24 feet.
- Matching the AIRS azimuthal viewing angle for many of the near-nadir views. Also, the spatial variation in upwelling radiance was measured (from the top of the 32-meter tower) as a function of both zenith and azimuthal angles using an instrument similar to the AMOS.
- Using a higher temporal sampling rate of PAERI data acquisition to sample six ground footprints in rapid succession along the surface. These scans were accomplished in a short time period so that any changes in the diurnal cycle were negligible.

Ground-based Instrument Calibration:

The PAERI was again calibrated in the field after it was shipped to Dome C using a standard infrared source. As in January 2003, calibration tests were performed by viewing an infrared source at 318 K and 253 K and then comparing the PAERI measurements to theoretical values derived from knowledge of the source's temperature and spectral emissivity; the calibration of all the infrared sources used with the PAERI are traceable to NIST standards. As in January 2003, the PAERI was calibrated to within 0.02-0.03 K at 318 K and to within 0.05 K at 253 K. The low-temperature calibration is especially significant because the radiance conditions of this test were very similar to the actual radiances being measured for AIRS validation (that is, a cold snow surface with high emissivity at temperatures between about 230 and 245 K). Therefore, the absolute calibration of the PAERI measurements in the field is excellent.

A new calibration strategy was implemented with the AMOS instrument in 2003/2004. One of the NIST-traceable infrared sources was placed permanently in the snow (and in the shade) at ambient temperature. This source was then used as a transfer standard between the PAERI and AMOS. Before and after each sled run, the AMOS instrument viewed this source. The source was not fully equilibrated during calibration because the AMOS instrument is equipped with a large-capacity fan to ventilate its front window, and this fan was driving relatively warm ambient air into the cold source. Despite this, a comparison of AMOS-calibrated data to the PAERI (Figure 1) shows good agreement. Note that the PAERI measurements were made over a single area, while the AMOS measurements were made along a 3-km triangular track, so some of the small brightness temperature differences may be due to spatial features over the large area sampled by the AMOS. More AMOS tests will be analyzed to determine if these data can be used to characterize changes in the surface brightness temperature over large scales (kilometers). AMOS calibrations were also conducted in the field

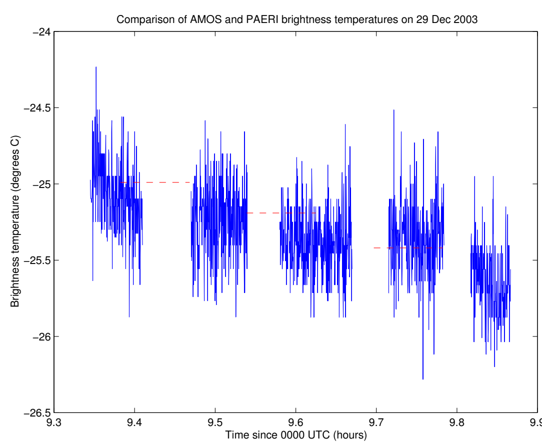

Figure 1. Comparison between surface brightness temperatures measured by the PAERI (red line; averaged) and the AMOS sled-based instrument (blue line). The spread of values from the AMOS instrument are due to temperature differences measured across wind-blown snow drifts called sastrugi. The decline in brightness temperature seen in both datasets is due to the surface cooling off in the afternoon (0900 UTC is 1600 local). The gaps in the AMOS data are where the snowmobile stopped along the track.

using a separate target with an emissivity of 0.98 for comparison with previous laboratory results.

Validation Data Examples:

After completing our field experiment in early February, we have performed quality control on the data taken under clear skies. In particular, the radiosonde data needed to be corrected in the upper atmosphere (in the stratosphere), where the temperatures drop below about -50 C and the time lag of the humidity sensor becomes long (minutes). This was accomplished by setting the stratospheric values to humidities similar to those measured by CMDL frost-point hygrometers at South Pole Station. Figure 2 (left panels) shows a collection of 17 sondes, launched under clear skies, at Dome C in December 2003 and January 2004. The position of the tropopause shifted during the observational period. The surface temperature also changes significantly depending on the time of day that the sonde was launched. The humidity profiles also show a lot of variation in the lowest few kilometers. The humidities are believed to be accurate throughout most of the troposphere because the atmospheric temperatures are above -50 C.

The right panel of Figure 2 shows the lower portion of two RS90 temperature profiles compared with temperature retrievals from AIRS. The agreement is fairly good. The retrievals throughout most of the troposphere are low by about a degree or two (except near the surface), but the shape of the profiles is similar to the sonde profiles. It will probably be impossible to retrieve the structure of the surface temperature inversion and its daily cycle from AIRS, so it might be useful to use the surface skin temperature (derived from window channels) as the lowest level in the profile.

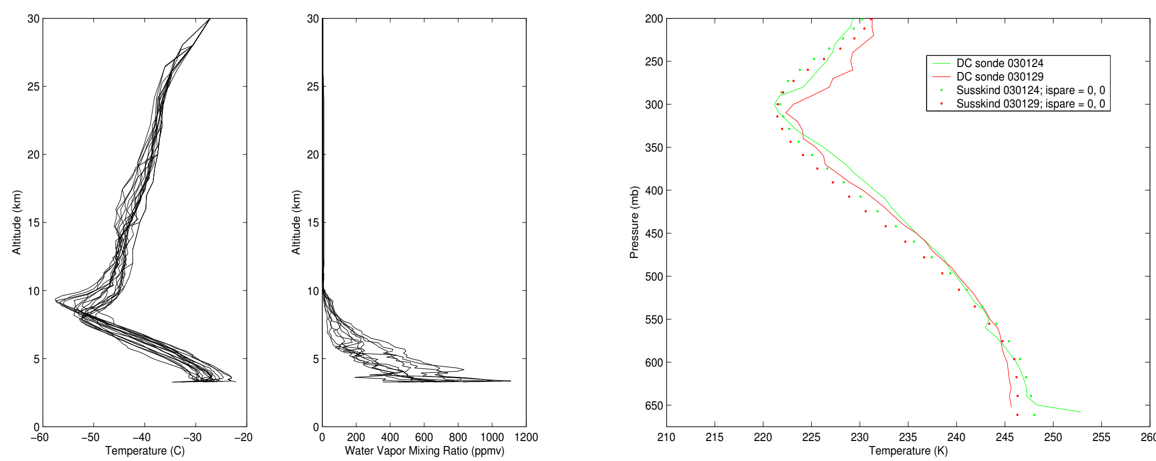

Figure 2. Left two panels) Vaisala RS90 radiosonde profiles of temperature and humidity obtained at Dome Concordia, Antarctica under clear skies in December 2003 and January 2004. Right panel) Comparisons of Vaisala RS90 radiosondes to AIRS temperature retrievals.

We have also performed radiance validation for fourteen of our best test cases. Figure 3 shows examples of these comparisons. The blue circles represent the upwelling radiance from the snow surface measured by the PAERI. The green line is the top-of-the-atmosphere (TOA) radiance calculated using the AIRS kCARTA radiative transfer model. Temperature and humidity profiles from the radiosonde data were used as input to kCARTA, as well as the surface skin temperature and spectral emissivity derived from the PAERI. The difference between the blue circles and the green line is the correction for atmospheric conditions over Dome C, which at window-region wavenumbers is less than 0.1 K. The red line represents the radiance measured by the AIRS instrument over Dome C. These two cases show excellent agreement between the TOA calculations and the AIRS measurements for both daytime conditions (250 K, -23 C) and nighttime conditions (233 K; -40 C). Four of our initial fourteen comparison cases show large temperature differences (1 – 4 K) between the calculations and AIRS measurements, with AIRS colder than the TOA measurements. We are currently investigating the cause of these differences, which might be due to sub-visible clouds within the AIRS field-of-view.

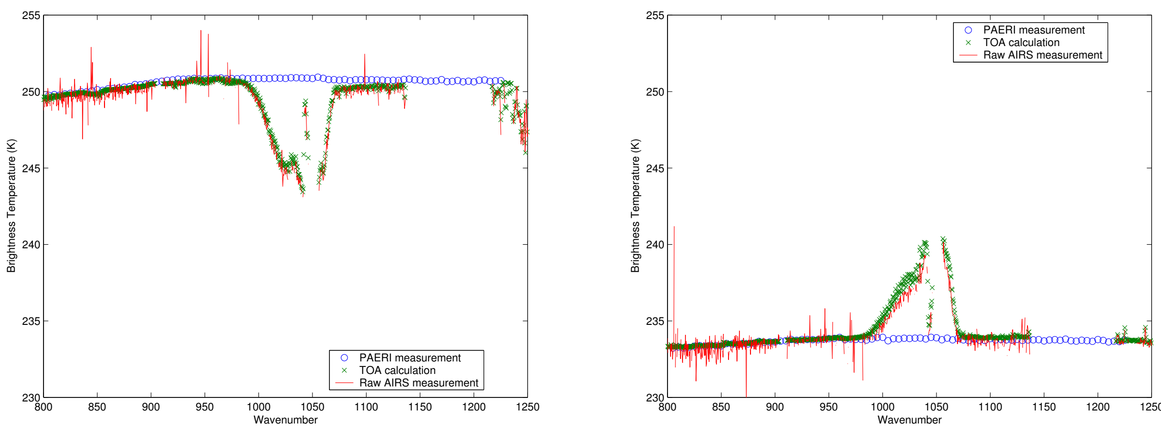

Figure 3. Comparisons of AIRS raw radiances with top-of-the-atmosphere radiances derived from ground-based measurements made by the Polar Atmospheric Emitted Radiance Interferometer (PAERI). Left panel) 27 December 2003, 0821 local time, right panel) 14 January 2004, 1438 local time.

Figure 4 shows a preliminary comparison of spectral emissivity retrieved from AIRS with values derived from the PAERI. The emissivity retrieval from AIRS is too low, and has a significant spectral shift toward low wavenumbers.

Data Archival and Contact with AIRS Science Team members:

We have archived our radiosonde temperature and humidity profiles from January 2003 at JPL after finishing their quality control. We have performed quality control on about 20% of our 2003/2004 radiosondes after returning from the field in mid-February 2004. The upwelling radiances measured by the PAERI in January 2003 have not been archived due to the difficulties we encountered in interpreting them because of the small ground footprint of the PAERI during that initial field season. We have made the downwelling PAERI radiances from January 2003 available to Larrabee Strow and Scott Hannon at UMBC for comparisons with their water vapor continuum model.

In addition, Penny Rowe, a PhD candidate in Chemistry at the University of Washington, is using some of the downwelling PAERI spectra from January 2003 to derive the temperature

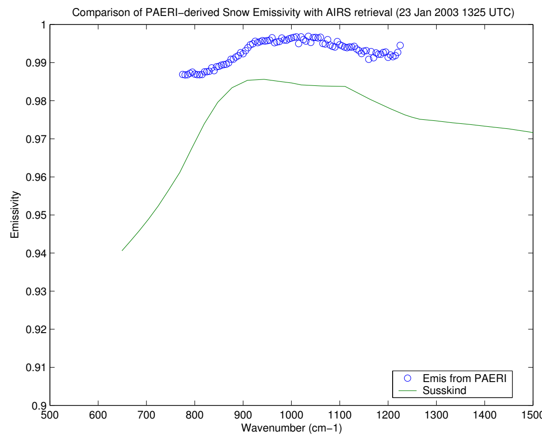

Figure 4. Comparisons of spectral infrared emissivity derived from AIRS radiances with those derived from ground-based PAERI measurements on 23 January 2003 at 1325 UTC. The emissivity measurements from the PAERI have been scaled to values from Dozier and Warren (1982) at 1200 cm^{-1}.

dependence of the water vapor continuum for low temperatures. Her preliminary results are in general agreement with theoretical predictions from Ma and Tipping (D. Tobin, pers. comm., 2003) that show a positive temperature dependence (relative to the MT-CKD continuum) from about 1250 to 1400 cm^{-1} and negative temperature dependence from 1400 to 1600 cm^{-1}.

The downwelling PAERI spectra for both field seasons have been made available to Wallace McMillan at UMBC as well. We hope to work together to retrieve carbon monoxide and possibly ozone from the Dome C spectra.

Our group has received AIRS retrievals from both JPL and Chris Barnet/Dave Susskind. Our working arrangement has been for them to provide retrievals to us and then we compare them with our ground-based data and provide feedback on the quality of those retrievals.

Our group has been working closely with Richard Brandt and Stephen Warren from the University of Washington to develop a new technique for retrieving spectral emissivity of snow from the PAERI data. The techniques used by Peter Minnett (U. Miami) and the MAERI instruments for retrieving the emissivity of ocean water do not apply directly to snow, because snow is a more diffuse reflector than water. Therefore, our retrieval method must account for reflected radiance coming from all zenith and azimuthal angles into the PAERI field-of-view. On the other hand, the Antarctic Plateau is an ideal location for accurately retrieving surface emissivity because the downwelling radiance from the atmosphere (at window frequencies) is very small. Since at most frequencies the reflection is also quite small, the primary component of the surface brightness temperature is the emission from the surface snow, not the reflection of the atmosphere from the surface.

Future Work:

We have been recently working on radiance validation with our new 2003/2004 dataset. We have initially concentrated on only 14 near-nadir overpasses that had coincident radiosonde profiles. However, there are approximately 30 to 50 off-nadir overpasses that we plan to look at in the near future. These additional comparisons have the potential to provide some statistical significance to our field validation project.

In addition, we will be comparing our RS90 temperature and humidity profiles with AIRS retrievals. As shown above, we expect to be able to provide valuable feedback to Chris Barnet and others once the attention of the AIRS team turns to retrievals over land.

At the AIRS Science Team meeting in Greenbelt, MD in late March 2004, a small group of validation scientists met to discuss retrievals of spectral emissivity. Many tasks were identified that could potentially improve the current emissivity retrieval algorithm, particularly over ocean. However as the AIRS team begins to concentrate on retrievals over land, Mous Chahine suggested that perhaps the team should retrieve an emissivity ratio (in addition to the "raw" emissivity) to avoid some of the problems with the retrieval. It was decided that because of the unique characteristics of the Antarctic Plateau, Dome C could provide valuable data to check the retrievals of the "relative emissivity". We have provided Chris Barnet with particular wavenumbers to retrieve the emissivity relative to because the emissivity of snow at these wavenumbers is so high (> 0.998). Retrieving the relative emissivity over the Antarctic Plateau should be easier than at other locations because of extremely small contribution from the intervening atmosphere.

After finishing our work on radiance, temperature, humidity, and emissivity validation, we plan to turn our attention to clouds. We plan to use the retrieval algorithms from Mahesh et al. (2003a, 2003b) to retrieve cloud-base height, infrared optical depth, and effective radius. This work should begin in the summer or autumn of 2004.

The initial results from our two field seasons will be summarized in one, possibly two, papers, which will be submitted to the special AIRS validation issue of J. Geophys. Res in the autumn of 2004. The first paper will address using the Antarctic Plateau as a validation site for AIRS. It will contain the results of a current Master's student from our group, Lance Roth, including Level-1 radiance validation. The second paper will contain comparisons of our field measurements to AIRS Level-2 products, including temperature, humidity, and surface emissivity. Future papers will discuss the results of our validation of cloud properties over Dome C.

Professional Activities:

Invited presentation at the Symposium for Astronomy and Astrophysics at Concordia, *The First Measurements of the Infrared Sky Brightness over Dome Concordia,* Capri, Italy, 28-30 April 2003.

Poster presentation at the 7th AMS Conference on Polar Meteorology and Oceanography, *Validation of the Atmospheric Infrared Sounder over the Antarctic Plateau*, W. Lance Roth and Von P. Walden, Hyannis, MA, 12-16 May 2003.

Presentation at the AIRS Science Team meeting, *An Update on AIRS Validation Activities at Dome Concordia, Antarctica,* Greenbelt, MD, 30 March – 1 April 2004.

Educational Outreach:

W. Lance Roth, MS student at U. Idaho, "The Use of the Antarctic Plateau as a Validation Site for the Atmospheric Infrared Sounder (AIRS)", expected completion date is May

2004.

Mark Ellison, MS student at U. Idaho, "Cloud Properties from Dome C, Antarctica for AIRS Validation", to begin thesis work in summer of 2004.

Penny Rowe, PhD candidate at U. Washington, "Measurements of the Foreign-broadened Continuum of Water Vapor at Low Temperatures", expected completion date is Autumn 2004 (using PAERI spectra from Dome C to derive the temperature dependence of the water vapor continuum).

***References*:**

Dozier, J. and Warren, S.G., 1982: Effect of viewing angle on the infrared brightness temperature of snow. Water Res. Res., 18, 1424-1434.

Mahesh, A., V.P. Walden, and S.G. Warren, 2002a: Ground-based infrared remote sensing of cloud properties over the Antarctic Plateau. Part I: Cloud-base heights. J. Appl. Met., 40, 1269-1278.

Mahesh, A., V.P. Walden, and S.G. Warren, 2002b: Ground-based infrared remote sensing of cloud properties over the Antarctic Plateau. Part II: Cloud optical depths and particle sizes. J. Appl. Met., 40, 1279-1294.