Preface to special section: Validation of Atmospheric Infrared Sounder Observations

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1. Introduction

[1] The papers in this special section describe validation comparisons for the Atmospheric Infrared Sounder (AIRS) experiment on NASA's Aqua spacecraft. AIRS produces daily, high accuracy, high vertical and horizontal resolution profiles of temperature, water vapor and minor gases, along with cloud and surface properties over most the Earth's surface [*Aumann et al.*, 2003]. The primary scientific goal of AIRS, along with other Aqua instruments, is an improved understanding of the atmospheric branch of the hydrological cycle [*Parkinson*, 2003]. Other science objectives of AIRS include improved understanding of climate processes, and of minor gas distributions. AIRS also has the more immediate and practical objective of improving weather forecasts [*Le Marshall et al.*, 2005]. These goals are reached through a complex set of instruments and processing algorithms. The tangible results of the AIRS experiment are data in the form of calibrated spectral radiances [*Pagano et al.*, 2003; *Lambrigtsen*, 2003], radiance estimates from forward models of radiative transfer [*Strow et al.*, 2003; *Rosenkranz*, 2003], and geophysical state estimated through retrieval algorithms [*Susskind et al.*, 2003]. The following papers report on comparisons of the AIRS data with other observations of comparable or better accuracy and precision. AIRS validation serves two primary purposes. First, it establishes the integrity of the instruments and algorithms used to generate estimates of geophysical conditions. Second, it constrains the uncertainties in those estimates. These are necessary steps in supporting scientific conclusions reached using the AIRS data.

[2] The AIRS instrument is a near-nadir cross-track sounding hyperspectral infrared spectrometer. AIRS operates in concert with two microwave instruments: the Advanced Microwave Sounding Unit (AMSU) and the Humidity Sounder for Brazil (HSB) [*Lambrigtsen*, 2003]. (HSB ceased operating in February 2003.) The AIRS/AMSU/HSB calibrated radiances are processed through a retrieval algorithm [*Susskind et al.*, 2003] to generate estimates of atmospheric state. Those estimates have their best vertical resolution in the troposphere. Root-mean-squared uncertainties on those estimates were specified prior to launch of Aqua (e.g., 1 K temperature uncertainty in 1 km thick layers in the troposphere) [*Aumann et al.*, 2003]. AIRS, AMSU and HSB directly observe several million spectra daily, and processing algorithms yield retrievals at about 300,000 locations per day. The combination of stringent performance specifications and large data volume has necessitated a systematic validation approach, addressing increasingly complex scenes from tropical ocean to polar night [*Fetzer et al.*, 2003].

[3] The papers described below demonstrate that the AIRS calibrated radiances and retrieved geophysical products generally meet or exceed the prelaunch specifications. The retrieved quantities show little variation in uncertainty as a function of cloud amount. However, AIRS retrieval yield is a rapidly decreasing function of cloud amount; at about 80% cloudiness essentially no infrared radiances are used in the retrieval processes. Also, AIRS performance has not been demonstrated for all conditions and products. Calibrated and forward calculated radiances meet performance specifications for conditions varying from the cold poles to warm tropics. The retrieval system performs well over extrapolar land in the free troposphere ($\sim$2–15 km above the surface) and over extrapolar oceans at all tropospheric altitudes. The AIRS retrieval algorithms have not been optimized for polar winter conditions, so no such results are presented in these papers.

2. Overview of the Special Section

[4] This special section contains nineteen papers, roughly grouped by topic. The first five papers describe the validation of directly observed infrared radiances. *Tobin et al.* [2006a] validate the absolute calibration of AIRS infrared radiances, observed for clear scenes over the Gulf of Mexico in autumn. *Walden et al.* [2006] examine infrared radiation observations for very cold, dry conditions. Infrared radiances observed for maritime tropical Atlantic conditions, but with widely varying amounts of water vapor and dust in the Saharan Air Layer (SAL), are the primary focus of *Nalli et al.* [2006]; this work includes a preliminary examination of AIRS retrieved quantities. The latter two papers describe field campaigns and the associated in situ observations from a variety of instruments. *Tobin et al.* [2006b] exploit the information content of AIRS infrared observations to evaluate another instrument on the Aqua satellite. *Aumann et al.* [2006] compare AIRS radiances with forecast models estimates of sea surface temperatures.

[5] Three studies address the performance of the forward radiative transfer models, the foundation of the AIRS physical retrieval algorithms. *Strow et al.* [2006] use ground truth from several sensors to assess the uncertainties in the AIRS infrared forward model. R. Saunders et al. (A comparison of radiative transfer models for simulating AIRS radi-

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ances, submitted to *Journal of Geophysical Research*, 2005) describe forward models used in several data assimilation schemes. *Rosenkranz and Barnet* [2006] evaluate the performance of the AMSU and HSB microwave forward models.

[6] *Rosenkranz* [2006] uses ground-based microwave radiometry to evaluate one aspect of the microwave retrieval algorithm.

[7] Two papers establish the utility of in situ observations, particularly water vapor profiles, used for validation of AIRS products. *Whiteman et al.* [2006] describe a dedicated campaign to intercompare a variety of sensors utilized in AIRS temperature and water vapor validation. Observations obtained during that campaign were used by *Miloshevich et al.* [2006] to extend the calibration of radiosondes to very cold, dry conditions. This correction is particularly effective for Vaisala sondes, several hundred of which have been launched for AIRS validation.

[8] Five papers compare AIRS retrieved temperature and water vapor with radiosonde observations. L. McMillan et al. (Radiosonde humidity corrections and AIRS moisture data validation, submitted to *Journal of Geophysical Research*, 2005) use a combination of operational radiosondes and Global Positioning System observations of total water vapor to characterize water vapor profiles, and compare them with AIRS retrievals. M. Szczodrak et al. (Measurements of temperature and humidity profiles over the ocean: Comparisons of AIRS retrievals with ship-based remote sensing, in situ measurements and ECMWF analysis, submitted to *Journal of Geophysical Research*, 2005) use data obtained from the field campaign described in the radiance validation paper by *Nalli et al.* [2006] to evaluate AIRS retrievals and a forecast model reanalysis. In a similar study, *Gettelman et al.* [2006] validate an AIRS climatology, and climate model simulations, using observations obtained from the field campaign described in the radiance validation paper by *Walden et al.* [2006]. *Tobin et al.* [2006c] use several hundred profiles, based on dedicated radiosondes launched at two well-instrumented sites, to evaluate AIRS observations. *Divakarla et al.* [2006] utilize two forecast models, another satellite sounding system, and a very large set of operation radiosondes to assess AIRS performance for such conditions as land/ocean type, latitude, and cloud amount.

[9] Three papers describe global comparisons between AIRS and other satellite data sets or model reanalyses. *Fetzer et al.* [2006] exploit collocated observations from another Aqua instrument to characterize the effects of clouds on AIRS observational and sampling biases. *Susskind et al.* [2006] describe updates to the AIRS retrieval algorithm implemented since the prelaunch configuration presented by *Susskind et al.* [2003]. They also compare AIRS retrieved quantities with reanalysis fields from the European Center for Medium-range Forecasting (ECMWF) to show the effects of clouds on AIRS observational biases. *Cho and Staelin* [2006] describe a technique for obtaining the cloud-free portion of the AIRS infrared radiance and use ECMWF fields to confirm its efficacy.

3. Additional Studies

[10] This special section contains only a partial description of AIRS validation results. Absent from the work presented here are results for AIRS retrieved cloud properties, and for cold polar conditions. Also, upper tropospheric water vapor is incompletely addressed in these papers. B. Kahn et al. (Towards the characterization of upper tropospheric clouds using AIRS and MLS observations, submitted to *Journal of Geophysical Research*, 2006) compare AIRS cloud properties with ground-based lidar and radar observations and another satellite instrument's inferred cloud properties. AIRS upper tropospheric humidity validation results are described by *Gettelman et al.* [2004], *Hagan et al.* [2004] and *Froidevaux et al.* [2006]. Clouds, upper tropospheric water vapor, and winter polar regions are currently the highest priority for AIRS validation.

[11] Other studies have addressed specific phenomena in the AIRS data. They are briefly (and incompletely) reviewed here for readers unfamiliar with these results. *Kahn et al.* [2005] show the potential of AIRS for improved understanding of very thin clouds. The effectiveness of AIRS in observing trace gases has been demonstrated in several studies. *McMillan et al.* [2005] present global fields of carbon monoxide. *Engelen et al.* [2004], *Crevoisier et al.* [2004], *Aumann et al.* [2005] and *Chahine et al.* [2005] demonstrate that AIRS radiances embody changes in atmospheric carbon dioxide. *Gettelman et al.* [2004] examine retrieved upper tropospheric ozone. *Carn et al.* [2005] monitor volcanic sulfur dioxide and ash output with AIRS spectra. Other studies have examined AIRS sensitivity to dust [*Pierangelo et al.*, 2005]. The prospects of a retrieval combining AIRS high spectral resolution information with high spatial resolution information from a companion instrument on Aqua is shown by *Li et al.* [2004]. The utility of AIRS calibrated spectra in understanding climate processes is demonstrated by *Huang and Yung* [2005]. Note that many of the quantities in the studies just described are not currently included in AIRS retrieved products. Other studies exploit the AIRS core capability of temperature and humidity profiling; for example, *Fetzer et al.* [2004] characterize the planetary boundary layer, and *Waugh* [2005] examines upper tropospheric processes. Many current studies are addressing global-scale climate processes in AIRS retrieved temperature and humidity fields. For example, *Tian et al.* [2006] characterize the Madden-Julian Oscillation with AIRS observations. Additional references can be found in the above studies and in the work by *Chahine et al.* [2006].

[12] The papers in this special section, along with the studies just discussed, clearly demonstrate the value of AIRS data in characterizing a wide range of atmospheric phenomena. However, potential users of the AIRS retrieved quantities are urged to proceed with caution. Many questions remain unanswered about resolution and sensitivity thresholds of even fundamental quantities like temperature and humidity. Also, complex surface emissivity is still a challenge to the AIRS retrieval algorithms, and clouds can introduce sampling biases into AIRS climatologies. However, similar challenges accompany any new, large and complex data set. Reaching scientifically meaningful conclusions with AIRS requires broad knowledge, care and ingenuity, but these are the essence of observational science. Many studies to date show the usefulness of the AIRS observations in improving our understanding of the atmosphere.

[13] Potential users of the AIRS data are encouraged to contact the authors of the papers in this special section, or any of the other papers discussed above. This body of work

represents a collaborative effort by a large group of people. That group has much insight into this data set; that insight is as important as the numbers contained in the AIRS data. The AIRS data are available from the NASA Goddard Space Flight Center's Distributed Active Archive Center (DAAC) system through the Internet at http://disc.gsfc.nasa.gov/AIRS/index.shtml/. Available data include calibrated radiances, retrieved products, and retrieved quantities mapped onto regular daily grids. This site also contains documentation, sample readers, analysis tools and overviews of the science issues addressed by the AIRS project.

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