Improving Weather and Climate Prediction with the AIRS on Aqua

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ABSTRACT

The Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft was launched on May 4, 2002. Early in the mission, the AIRS instrument demonstrated its value to the weather forecasting community with better than 6 hours of improvement on the 5 day forecast. Now with over six years of consistent and stable data from AIRS, scientists are able to examine processes governing weather and climate and look at seasonal and interannual trends from the AIRS data with high statistical confidence. Naturally, long-term climate trends require a longer data set, but indications are that the Aqua spacecraft and the AIRS instrument should last beyond 2016. This paper briefly describes the AIRS products, reviews past science and weather accomplishments from AIRS data product users and highlights recent findings in these areas.

Keywords: Atmosphere, Sounding, AIRS, Aqua, Weather, Climate, Temperature, Water Vapor

1. INTRODUCTION

The Atmospheric Infrared Sounder (AIRS) is a hyperspectral infrared instrument on the EOS Aqua Spacecraft, launched on May 4, 2002. AIRS has 2378 infrared channels ranging from 3.7 μm to 15.4 μm and a 13.5 km footprint. The AIRS is a "facility" instrument developed by NASA as an experimental demonstration of advanced technology for remote sensing and the benefits of high resolution infrared spectra to science investigations[1]. AIRS, in conjunction with the Advanced Microwave Sounding Unit (AMSU), produces temperature profiles with 1K/km accuracy on a global scale, as well as water vapor profiles and trace gas amounts for CO_2, CO, SO_2, O_3 and CH_4. AIRS data are used for weather forecasting, climate process studies and validating climate models[2]. For more information see http://airs.jpl.nasa.gov.

1.1 Standard Products

A list of the primary AIRS/AMSU/HSB standard deliverable products from Version 5.0 are given in Table 1. The product file type and the current best estimate summary of the performance of the product are listed in the second and third columns respectively. The fourth column lists the validation status of the product to identify the regions where the product has been demonstrated to be valid. Products are provided globally regardless of their validation status.

The products are divided into three types. Level 1B products are calibrated and geolocated upwelling radiances from the four major subsystems on the AIRS/AMSU system. There are 2378 infrared AIRS spectral channel radiances, 4 Vis/NIR AIRS spectral channel radiances, 15 microwave channels from the AMSU, and 4 from the HSB. HSB data are still available for the first 9 months of the mission, but since the HSB is no longer operational, recent data are unavailable. The second type of data are the Level 2 products. Level 2 products are geolocated geophysical quantities, usually offered on the scale of the AMSU footprint which is approximately 45 km at nadir. This is due to the cloud clearing methodology involving a 3x3 matrix of raw AIRS footprints and one AMSU footprint. The third type of data product are Level 3 products. Level 3 products are gridded spatially (1 degree latitude and longitude bins) and temporally (1 day, 8 day and monthly) and usually contain all standard Level 2 products. We also list research products for AIRS (at a low state of validation) at the bottom of the table. Recently CO_2 and CO were added to the core products due to their maturity and value to the scientific community. CO_2 data are post processed and resident in a separate file. Definitions of the validation types is given below the table, but generally products are ready for scientific investigations when their validation status has reached stage 2. Level 3 CO_2 are currently available and Level 2 should be available by the end of calendar year 2009.

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1.2 Data Access

All AIRS products are available at the Goddard Earth Sciences Data and Information Services Center (GES/DISC) at http://disc.sci.gsfc.nasa.gov. In addition to data products, data readers, user guides and verification/validation reports are also available at this location. Additional information on the AIRS Project and science applications can be found at the AIRS home page http://airs.jpl.nasa.gov.

Table 1. AIRS Standard and Research Products and their Validation Status

AIRS Product	Product Type	Accuracy (V5)	Val Status (V5)
Core: Radiances			
AIRS IR Radiance	L1B-AIRS	<0.2K	Stage 3
AIRS VIS/NIR Radiance	L1B-VIS	15-20%	Stage 1
AMSU Radiance	L1B-AMSU	1-3 K	Stage 3
HSB Radiance	L1B-HSB	1-3 K	Stage 3
Core: Geophysical			
Cloud Cleared IR Radiance	L2	1.0 K	Stage 2
Sea Surface Temperature	L2	1.0 K	Stage 2
Land Surface Temperature	L2	2-3 K	Stage 1
Temperature Profile	L2	1 K / km	Stage 3
Water Vapor Profile	L2	15% / 2km	Stage 3
Total Precipitable Water	L2	5%	Stage 3
Fractional Cloud Cover	L2	20%	Stage 2
Cloud Top Height	L2	1 km	Stage 2
Cloud Top Temperature	L2	2.0 K	Stage 2
Carbon Monoxide	L2	15%	Stage 2
Carbon Dioxide	Post-Proc	1-2 ppm	Stage 1
Core: Necessary*			
Total Ozone Column	L2	5%	Stage 2
Ozone Profile	L2	20%	Stage 2
Land Surface Emissivity	L2	10%	Stage 1
IR Dust	L1B-Flag	0.5 K	Stage 1
Research Products			
Methane	L2	2%	Stage 1
OLR	L2-Support	5 W/m2	Stage 1
HNO3	L1B-Post	0.2 DU	Stage 1
Sulfur Dioxide	L1B-Flag	1 DU	Stage 1

*Necessary Products are required to retrieve accurate temperature profiles (1K/km) in all conditions

Validation Status Definitions (Common to all Aqua Instruments)

Stage 1: Validation Product accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program effort.

Stage 2: Validation Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.

Stage 3: Validation Product accuracy has been assessed, and the uncertainties in the product well-established via independent measurements made in a systematic and statistically robust way that represents global conditions.

2. WEATHER FORECAST IMPROVEMENT

The most fundamental product from AIRS are the calibrated radiances and geolocation in the Level 1B data product. The upwelling infrared spectrum contains a wealth of information about the state of the atmosphere including temperature profile, water vapor, and the trace gases mentioned above. The AIRS radiances are assimilated into Global Circulation Models (GCM's) at weather prediction centers worldwide including NCEP, ECMWF and the UK Met Office. A significant positive impact has been achieved. Six hours on the 5 day forecast has been achieved at the National Center for Environmental Prediction (NCEP) and the European Center for Medium-Range Weather Forecast

(ECMWF) by assimilating 1 in 18 footprints and an additional 5 hours on the 5 day forecast or more has been shown to be possible [2, 3]. AIRS radiances are also being assimilated into regional weather forecast models with significant forecast improvements of regional scale processes and local precipitation estimates out to 48 hours.

Operational agencies assimilating the AIRS radiances usually assimilate upper atmospheric channels less affected by clouds. Techniques are under development to assimilate information down to the cloud tops. Also available in the Level 2 product are "Cloud Cleared Radiances" (CCRs). The CCRs make use of a methodology to remove the effects of clouds using 3x3 AIRS FOV's and a first guess based on regression on the cloudy radiances against ECMWF in Version 5. The CCRs offer significantly more FOV's and early research indicates that additional forecast improvement can be achieved assimilating them directly. NCEP's preference is to build the cloud clearing directly into the operational assimilation system. Limitations in funding have been the only obstacle to proceeding along these lines.

Forecast improvement using AIRS has also been demonstrated by assimilation of AIRS temperature profiles. Assimilation of AIRS temperature profiles improves the anomaly correlation score in the northern hemisphere from 0.82 to 0.85, a significant improvement for one instrument [4]. Another study of assimilating AIRS profiles examined the forecast impact to tropical cyclone Nargis in the Northern Indian Ocean [5]. In this study a control run assimilated the conventional and satellite data currently operational without AIRS data, while the AIRS run assimilated AIRS quality controlled temperature retrievals. In the control run, the cyclone dissipates and fails to make landfall, while the AIRS run successfully produces the cyclone within 50 km of true location in 5 of the 7 daily forecasts preceding landfall. In another study, modelers at NASA's SPoRT have found that assimilation of temperature and water vapor into the regional models can improve prediction of pressure anomalies and rainfall [6]. These asynoptic profiles provide mesoscale spatial resolution information of changing moisture and stability fields important for convective weather development over the continental United States. At this time, assimilation of water vapor channel radiances or water vapor profiles has a negative affect on the forecast models, it is believed because the models are not yet ready to assimilate this type of information.

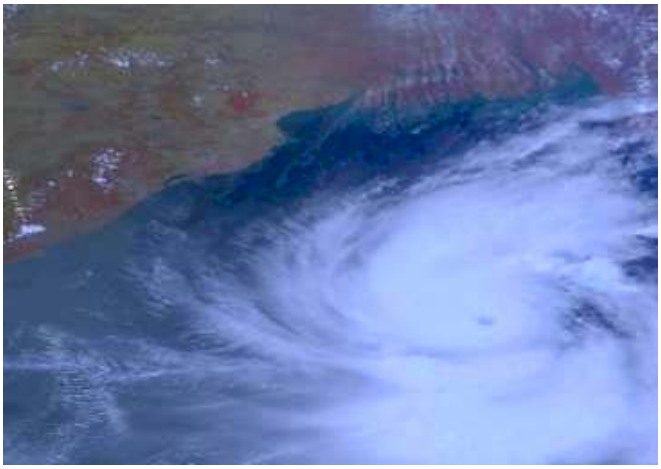

Figure 1. Tropical Cyclone Nargis, May 1, 2008. Assimilation of AIRS temperature profiles successfully predicts location within 50 km in 5 of the 7 daily forecasts preceding landfall.

3. CLIMATE MODEL VALIDATION

Models require validation of their "climatology", and usually use reanalysis from forecast centers. Like the weather models, the water vapor fields in the reanalysis are limited in their accuracy. AIRS data provide the best source of global three dimensional water vapor fields available. Several independent studies were performed using AIRS data to evaluate the climatology of water vapor fields in the major climate models used today. Results have shown that the models have considerable errors in the vertical and horizontal distribution of water vapor on an annual climatology [7, 8, 9]. It is believed this is a consequence of compensating errors in the vertical distribution of the water vapor climatology. Drier lower troposphere air is compensated by a wetter upper troposphere in the models to produce an overall correct outgoing longwave radiation (OLR) [10].

Quantifying the climate forcings due to increased greenhouse gas emissions are relatively straightforward in global climate models, but the largest uncertainties are associated with the cloud and water vapor feedback processes. Until now, observations of upper tropospheric water vapor were limited, making validation of model water vapor feedback with increasing surface temperature problematic. In one study, a positive correlation was seen between sea surface temperature and AIRS water vapor data at 250 mb. This indicates a "positive" upper tropospheric water vapor feedback with increased surface warming [11]. More water at upper altitudes with global warming produces even warmer

temperatures. Another study compared water vapor zonal profiles for a warm year (2007) with a cooler year (2008). In this study a significant increase was seen in the warmer year in the upper troposphere with the biggest changes in the tropics, again confirming water vapor feedback is positive with increased global warming [12].

Clouds also play a very important role in climate science. Solar reflective sensing instruments such as MODIS, GOES and MISR provide vital information on the cloud shortwave response to the climate system. Cloudsat provides exceptional cloud profiles and phase information. Infrared also has an important role in understanding clouds. In particular, the hyperspectral infrared is particularly good at detecting and characterizing cirrus clouds [13]. These clouds have a tendency of providing a negative feedback (warming effect) since they radiate at a lower temperature and are not as effective in shielding solar radiation. AIRS provides this information simultaneously and co-located with temperature and water vapor allowing scientists to better understand the processes affecting cloud formation. Recently, scientists have used AIRS data to provide better identification of cloud thermodynamic phase (liquid or ice) [14]. Cloud phase is important for studying processes affecting clouds, temperature and precipitation. In another study, scientists have related reduced cloudiness and downwelling radiation to the associated ice loss in the arctic region [15].

4. ATMOSPHERIC COMPOSITION

The profile of ozone and the total burden are produced from the AIRS retrieval as a necessary part of the temperature and water vapor retrieval. Scientists have successfully retrieved other trace gases including, CO, CH4 and CO2 from AIRS because of the value to Earth Science and paucity of available data sets from other observational platforms.

AIRS measures the total column and profile of ozone with approximately 2 pieces of information in the boundary between the tropopause and the stratosphere. This makes the AIRS ozone ideal for studies of stratospheric-tropospheric exchange during severe convection events and the global transport of ozone through the Brewer-Dobson circulation. AIRS ozone data have undergone rigorous validation using aircraft data and ozonesondes [16]. AIRS' 1600 km cross-track swath and cloud-clearing retrieval capabilities provide daily global CO maps over approximately 70% of the Earth. Validation indicates AIRS CO retrievals are approaching the 15% accuracy target set by pre-launch simulations [17]. The most significant trace gas retrieved by AIRS for the study of anthropogenic effects on climate is carbon dioxide. AIRS CO_2 retrievals use an analytical method for the determination of carbon dioxide and other minor gases in the troposphere from AIRS spectra. The AIRS data have been shown to be accurate to ±1.20 ppmv of the aircraft observations [18]. Global monthly maps of CO_2 have been generated (Figure 2), and identify global transport patterns in the mid-troposphere. These results will aid climate modelers in parameterization of mid-tropospheric transport processes of CO_2 and other gases. The accuracy of AIRS CH_4 is about 1.2-1.5%, depending on altitude, which should provide the ability to map seasonal variation of CH_4 and provide valuable information of the global methane distribution in mid-upper troposphere [19]. AIRS Scientists have observed a significant enhancement of methane in the mid to upper troposphere in the summer season that is consistent with model predictions [20].

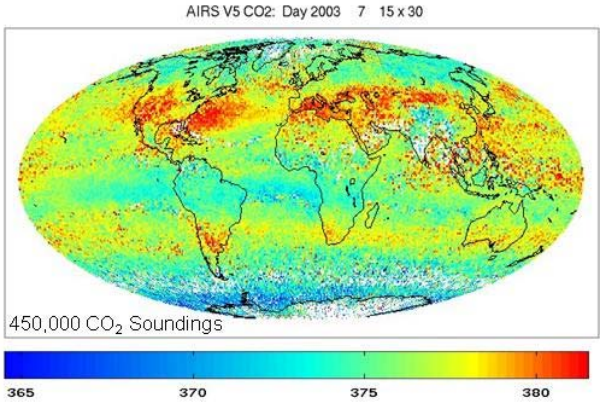

Figure 2. AIRS Mid-Tropospheric Carbon Dioxide for July 2003. These data aid in understanding global distribution and transport of CO2 in support of climate modeling.

5. CONCLUSIONS

The Atmospheric Infrared Sounder provides a wide range of geophysical products well suited to improving weather and climate predictions. AIRS radiances are routinely assimilated into the operational forecast and have demonstrated a positive improvement. Significant additional improvement is possible with assimilation of more radiances and frequencies or assimilation of cloud cleared radiances and temperature profiles. AIRS geophysical products have proven extremely valuable for validating processes involved in weather and climate and for tracking global distributions of water vapor, carbon dioxide and other important greenhouse gases. AIRS should be operational at least through 2016 and has demonstrated sufficient stability to trend radiances over this timeframe. Improvements are planned to the

Version 6 AIRS products to remove static biases and trends to ensure that the geophysical products are also suitable for trending over long time frames at levels consistent with the small changes expected in climate.

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