Improved products for assimilation and model validation from the Atmospheric Infrared Sounder (AIRS) on Aqua

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ABSTRACT

The Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft was launched on May 4, 2002. AIRS acquires hyperspectral infrared radiances in the 3.7-15.4 um spectral region with spectral resolution of better than 1200. Key channels from the AIRS Level 1B calibrated radiance product are currently assimilated into operational weather forecasts at NCEP and other international agencies. Additional Level 2 products for assimilation include the AIRS cloud cleared radiances and the geophysical retrieved temperature and water vapor profiles. The AIRS products are also used to validate climate model vertical and horizontal biases and transport of water vapor and key trace gases including Carbon Dioxide and Ozone. The wide variety of products available from the AIRS make it well suited to study processes affecting the interaction of these products.

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 horizontal resolution and the current best estimate summary of the performance of the product and 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 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. The third type of 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. 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.

1.2 Data Access

All AIRS products are available at the Goddard Earth Sciences Data and Information Services Center (GES/DISC) at http://daac.gsfc.nasa.gov. In addition to data products, data readers, user guides and verification/validation reports are

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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	Resolution (km)	Uncertainty Estimate (Version 5)	Validation Status (Version 5)
Radiances			
AIRS IR Radiance	13.5	<0.2%	Stage 3
AIRS VIS/NIR Radiance	2.3	15-20%	Stage 1
AMSU Radiance	45	1-3 K	Stage 3
HSB Radiance	13.5	1-3 K	Stage 3
Core Products			
Cloud Cleared IR Radiance	45	1.0 K	Stage 2
Sea Surface Temperature	45	1.0 K	Stage 2
Land Surface Temperature	45	2-3 K	Stage 1
Temperature Profile	45	1 K / km	Stage 2
Water Vapor Profile	45	15% / 2km	Stage 2
Total Precipitable Water	45	5%	Stage 2
Fractional Cloud Cover	45	20%	Stage 2
Cloud Top Height	15	1 km	Stage 2
Cloud Top Temperature	45	2.0 K	Stage 2
Neccesary Products*			
Total Ozone Column	45	5%	Stage 2
Ozone Profile	45	20%	Stage 2
Land Surface Emissivity	45	10%	Stage 1
IR Dust**	45	0.5 K	Stage 1
Research Products			
Carbon Monoxide	45	15%	Stage 2
Methane	45	2%	Stage 1
Carbon Dioxide**	45	1-2 ppm	Stage 1
OLR	45	5 W/m2	Stage 1
HNO3**	45	0.2 DU	Stage 1
Sulfur Dioxide**	45	1 DU	Stage 1

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 by assimilating 1 in 18 footprints [2, 3] an additional 5 hours on the 5 day forecast has been shown to be possible. 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 (CCR's)". The CCR's make use of a methodology to remove the effects of the cloud using 3x3 AIRS FOV's and a first guess usually based on regression on the cloudy radiances against ECMWF. The CCR's offer significantly more FOV's and early research indicates that additional forecast improvement can be achieved assimilating them directly. Understanding the error estimate that go along with the CCR's is required for this assimilation to be successful. Dialogue is underway in this area.

Another way to get significant forecast improvement from the AIRS is to assimilate directly the temperature and water vapor profiles. Recent work has shown that assimilation of temperature profiles offers considerable improvement that was not realized before [4]. 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 [5]. Additionally, AIRS temperature and moisture profiles are being used operationally by NWS weather forecast offices in their Advanced Weather Information Processing System (AWIPS) as a supplement to the coarsely spaced twice daily weather balloon observations. 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.

3. CLIMATE MODEL VALIDATION

Global climate change is of critical cost to our world as the consequences of climate change affect the lives and livelihood of millions of people. Quantifying the climate forcings due to increased greenhouse gas emissions are relatively straightforward in climate models, but the largest uncertainties are associated with the cloud and water vapor feedback processes. 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. Results have shown that several major climate models have considerable errors in the vertical and horizontal distribution of water vapor on an annual climatology [6, 7, 8]. 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) [9].

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 hyperespectral infrared is particularly good at detecting cirrus clouds [10]. 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. Scientists have improved the understanding of the process of supersaturation in the stratosphere using AIRS data; an important result for understanding the role of clouds on global warming [11]. Scientists have related reduced cloudiness and downwelling radiation to the associated ice loss in the arctic region [12].

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 [13]. 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 [14].

The most significant trace gas retrieved by AIRS for the study of anthropogenic effects on climate is carbon dioxide. AIRS CO2 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 [15]. Global monthly maps of CO2 have been generated (Figure 1), and identify global transport patterns in the mid-troposphere. These results will aid climate modelers in parameterization of mid-tropospheric transport processes of CO2 and other gases. The accuracy of AIRS CH4 is about 1.2-1.5% depending on different altitudes, which should be able to map seasonal variation of CH4 and can provide valuable information of atmosphere in mid-upper troposphere [16]. AIRS Scientists have observed a significant summer enhancement of CH4 in high northern hemisphere which correlates well with soil temperature and is most likely due to northern wetland emission in summer.

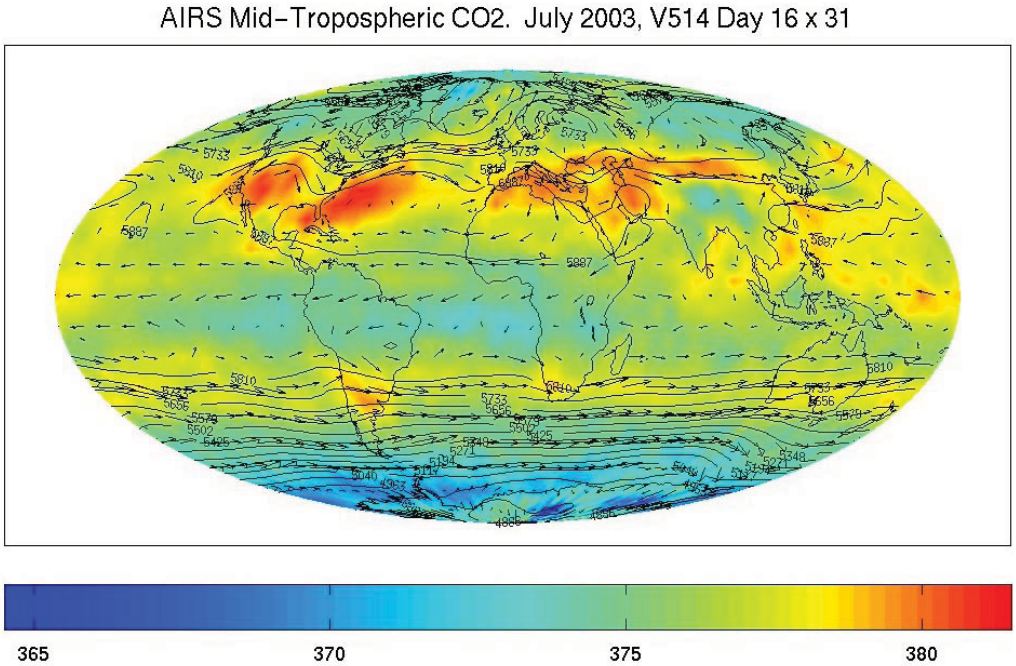

Figure 1. AIRS Mid-Tropospheric Carbon Dioxide for July 2003. These data aid in understanding global distribution and transport of CO2 in support of climate modeling. Overlaid on the figure are geopotential height contour lines and wind vectors.

5. CONCLUSIONS

Calibrated radiances from the Atmospheric Infrared Sounder on the EOS Aqua spacecraft are used routinely for weather forecast at Numerical Weather Prediction centers worldwide. Geophysical products retrieved from the AIRS instrument include temperature and water vapor profiles, surface properties, cloud properties and atmospheric composition. These products are particularly useful for understanding processes used in climate models. The AIRS data are joined by the European Infrared Atmospheric Sounding Interferometer (IASI) on MetOp and soon to be joined by the Cross-track Infrared Sounder (CrIS) on NPOESS. AIRS has demonstrated the value of hyperspectral infrared to the weather and climate communities and has paved the way for effective use of these instruments in the future.

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