Preprocessing of the Direct-broadcast Data from the Atmospheric Infrared Sounder (AIRS) Sounding Suite on Aqua Satellite

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Abstract

We present a preprocessing system for the Atmospheric Infrared Sounder (AIRS) sounding suite onboard Aqua satellite. With its unprecedented 2378 channels in IR bands, AIRS aims at achieving the sounding accuracy [s1]of a radiosonde (1 K in 1-km layer for temperature and 10% in 2-km layer for humidity). The core of the preprocessor is the International MODIS / AIRS Processing Package (IMAPP) that performs the geometric and radiometric correction to compute the Earth's radiance. Then we remove spurious data and retrieve the brightness temperature (Tb). Since we process the direct-broadcast data almost for the first time among the AIRS direct-broadcast community, special attention is needed to understand and verify the products. This includes the pixel-to-pixel verification of the direct-broadcast product with reference to the full-orbit product, which shows the difference of less than 10^{-3} K in IR Tb.

1. Introduction

Aqua, launched in May 2002, is a major satellite mission of the Earth Observing System (EOS), an international program centered at the U.S. National Aeronautics and Space Administration (NASA; Parkinson 2003). The mission goal of Aqua is to monitor the water cycle of the Earth with a view to examining the indication of 0.4% increase in the rate the cycle, that is, the rate of precipitation and evaporation. To meet this goal Aqua is equipped with six sensors onboard, all measuring water-related parameters in the ocean and atmosphere. Among these, the Atmospheric Infrared Sounder (AIRS) is an innovative sensor that has 2378 spectral channels between 650 and 2665 cm^{-1} (15.4 and 3.7 μm, respectively) with the spectral resolution of $\lambda/\Delta\lambda$= 1200. AIRS was designed to meet the retrieval of meteorological parameters, which one was able to address only inadequately by HIRS-2 (High Resolution Infrared Sounder) that has 19 channels and $\lambda/\Delta\lambda$= 100.

With this unprecedented spectral resolution, AIRS aims at matching the sounding accuracy of a radiosonde (1 K in 1-km layer for temperature and 10% in 2-km layer for humidity). To assist AIRS, the Advanced Microwave Sounding Unit (AMSU-A1 and A2) and Humidity Sounder for Brazil (HSB) operate in microwave bands for temperature and moisture sounding. AIRS/AMSU/HSB from a sounding suite on Aqua.

The data from all six sensors on Aqua are direct-broadcasted to local users, meaning that whoever with an X-band antenna system may receive the data with no restriction and charge. Such direct-broadcast (DB) policy enables the near-real time processing of the data within a couple of hours, enabling the enhanced capability for prompt monitoring of weather events. Since the release of preprocessing algorithms and source codes is the general policy, DB also benefits understanding of calibration processes. Although the Korea Meteorological Administration (KMA) has direct-received Aqua data since the beginning of 2003, the preprocessing of AIRS data has been postponed until the release of the pre-processing software in Nov. 2003.

In this article, we present the AIRS/AMSU preprocessing system to obtain brightness temperature from AIRS/AMSU DB data. Then we will perform the verification of the brightness temperatures by comparing with the products from EOS DAAC (Distributed Active Archive Center) in USA. In addition to AIRS data processing, DB data from the Aqua's passive microwave imager are also being processed operationally as well at KMA, and its system is described elsewhere (Kim *et al.* 2003). HSB does not operate since early 2003, thus is not described here.

Table 1. AIRS/AMSU/HSB key parameters.

	AIRS visible/ NearIR	AIRS IR	AMSU	HSB
Orbit, km	705 (sunsynchronoys, ±82 latitude)			
Repeat cycle, day	16			
Swath, km	1650	1650	1690	1650
Resolution, km at nadir	2	13.5	40.5	13.5
# foot prints /scan	720	90	30	90
# spectral bands	4 (0.4-1.0 μm)	2378 (650 - 2665 cm^{-1})	15 (23-90 GHz)	4 (150-190 GHz)
Data size/ scene (MB)	20	118	0.5	1

2. AIRS/AMSU instruments and calibration algorithms

The key parameters of AIRS sounding suite are summarized in Table 1 and Fig. 1. AIRS has an additional instrument in visible and near-IR bands for daytime cloud clearing. Aqua orbit is designed to have local passing time of 1:30pm and to augment Terra's observation at 10:30am. The footprints of the instruments are collocated to achieve 1-K/1-km retrieval accuracy in cloudy conditions such that there are three AIRS/HSB pixels per AMSU (Fig. 1). Also one AIRS IR pixel corresponds to 8×9 AIRS visible/NIR pixels.

One of the most important parts of AIRS preprocessing is the radiometric calibration that determines the accuracy of radiance.

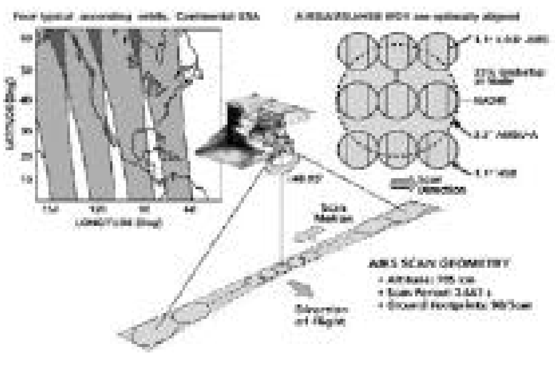

Fig. 1. Geometry of AIRS/AMSU/HSB cross-track imaging (center) with a picture of a swath (left) and the footprint configuration of the three instruments (right). Courtesy of Jet Propulsion Lab. (JPL).

Both AIRS and AMSU employ onboard calibrators that provide the cold and warm references for non-linear calibration of raw observation counts (Pagano *et al*. 2003; Lambrigtsen 2003). Since AMSU is not a new instrument, here we focus on AIRS calibration only.

AIRS requires two types of calibration: radiometric and spectral. Radiometric calibration utilizes the cold sky view (CSV) and the warm onboard blackbody calibrator (OBC), and their calibration data determine the radiance as follows:

$$N_{sc,i,j} = \frac{a_0(\theta_j) + a_{1,i}(dn_{i,j} - dn_{sv,i}) + a_{2,i}(dn_{i,j} - dn_{sv,i})^2}{1 + p_r p_t \cos[2(\theta_j - \delta)]} \quad (1)$$

$N_{sc,i,j}$: scene radiance at ith scan, jth footprint
θ : scan angle. $\theta = 0$ is nadir.
$dn_{i,j}$: observation count in digital number
$dn_{sv,i}$: space view offset from CSV
a_0 : radiometric offset arising from polarization
$a_{1,i}$: gain derived from OBC and CSV
$a_{2,i}$: nonlinearity factor
$p_r p_t$: polarization product
δ : phase of polarization

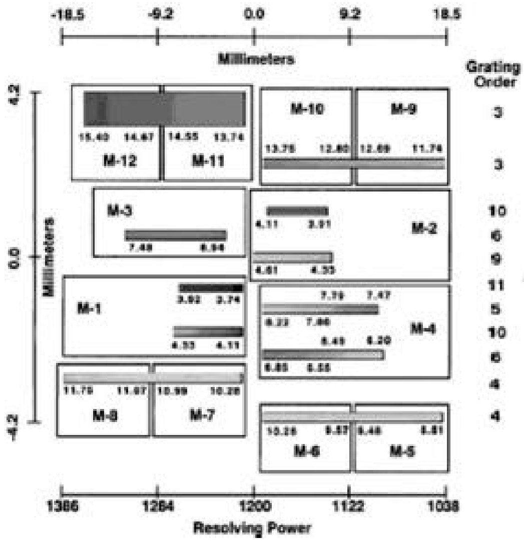

Fig. 2. AIRS 2-dimensional detector array. *Mi* indicates the detector number. Two-decimal numbers are wavelengths.

Fig. 3. Block diagram of the AIRS pre-processing SW, consisting of IMAPP core and surrounding processes.

$a_{2,i}$, $p_r p_t$ and δ are determined before the flight and are fixed, whereas a_0 and $a_{1,i}$ are computed every scan using onboard calibrator measurements.

The spectral calibration aims at ascertaining that the grating mechanism correctly disperse the incoming radiation into the AIRS two-dimensional IR detector arrays (Fig. 2). By adjusting the spectral grating model using in-orbit data, the center frequency of the IR spectra is determined within 1% error thus meeting the requirement (Gaiser *et al*. 2003).

3. Preprocessing and brightness temperature retrieval

The preprocessing SW consists of the IMAPP (International MODIS/AIRS Processing Package) and supporting modules. IMAPP was developed and distributed by Space Science Engineering Center, U. Wisconsin-Madison, based on Jet Propulsion Laboratory (JPL)'s core modules. The input Level 0 data should not contain any bad packets. For this one needs to correct or remove the bad packets using Reed-Solomon decoding during Level 0 data generation. For AIRS, IMAPP converts Level 0 observation counts into Level 1B radiance values in the units of mW m-2 sr-1 cm-1. IMAPP also performs geolocation, i.e., assigning latitude and longitude values to each pixel.

Spurious data exist in the AIRS radiance. Two types of information are available for filtering the bad data. First, a channel characteristic file defines which channel is operating well or not. The file is updated irregularly but every half a year or so.

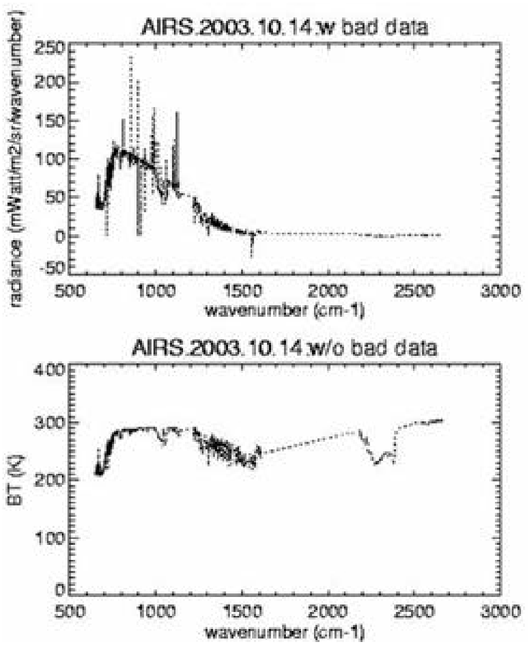

Fig. 4. Bad data filtering and retrieval of brightness temperature for a granule 098.

Second, AIRS data provide quality flag information that reports noise level, moon contamination and detector mode. For AMSU, generally no quality flagging is applied. One should note that AMSU channel 7 is faulty.

The filtered AIRS radiance is then converted into brightness temperature (Tb) using the inverse of Planck function B_ν :

$$B_\nu = \alpha_1 \nu^3 / \left[\exp(\alpha_2 \nu / T) - 1\right]$$

(2)

B_ν IR radiance

ν : wave number in cm^{-1}

a_1 : $2hc^2$ (h Planck's constant, c the speed of light)

a_2 : hc/κ (κ Boltzman constant)

T : brightness temperature.

For AMSU, the relationship between radiance and Tb is linear (Rayleigh-Jeans approximation). Therefore AMSU calibration converts the observation count to Tb for AMSU.

Fig. 4 shows the results of spurious data filtering and Tb retrieval for AIRS IR data. The bad data are effectively removed. The retrieved Tb successfully shows several absorption bands at around 700 and 2350 cm^{-1}

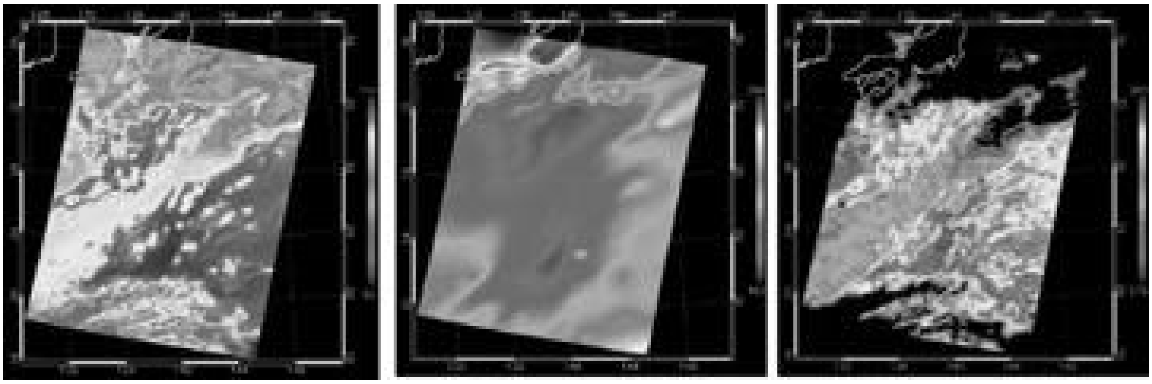

Fig. 5. From left to right: browse images of AIRS 11 μm channel, AMSU channel 1 and sea surface temperature retrieved from the KMA DB night data. Date: 2003.11.12. Units in Kelvin.

for CO_2, 1000 cm^{-1} for ozone and 1300 cm^{-1} for water vapor. These bands are used for sounding.

Fig. 5 shows an example of AIRS / AMSU Tb images. The scene is about 50% cloudy and in AIRS scene, clouds are present diagonally along the bottom and top of the image. Since AMSU channel 1 (23Ghz) is transparent to clouds, the cloud signature is not apparent. Near the top left and bottom left of the AMSU image, there are bright blobs, which are most likely influenced by the radiation from rain condensation.

All these preprocesses, including the Level 2 generation as will be described later, are fully automated after being triggered by an incoming Level 0 data. It takes about 10 minutes for the whole processes to finish on a 3GHz Linux machine.

4. Verification

DB data are received while a satellite is within the sight of a ground station. Thus the length of the data is variable. In an example given in Fig. 6, DB data cover three granules (a granule is defined to be 6-minute long. The granule definition repeats every 16-day repeat period). Since IMAPP products are divided into granules, inevitably we will have partial granules whose length is less than 6 minutes. Then the question arises how accurate the radiance and Tb of the DB's partial granule are with respect to EOS DAAC standard products.

The fundamental reason for the difference lies in the radiometric calibration. The offset and gain values (a_0 and $a_{1,i}$ in Eq. 1) are averaged in the directions of along-track and

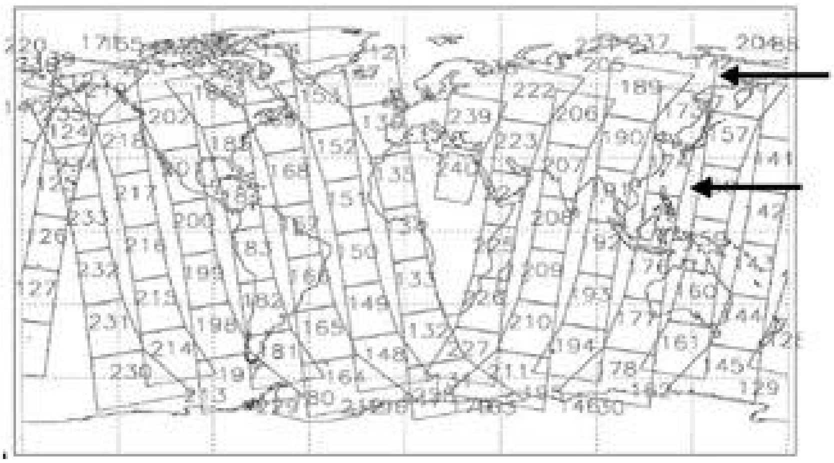

Fig. 6. AIRS granule definition. Two arrows indicate the beginning (granule 172) and the end (granule 174) of a KMA DB data. Modified using EOS DAAC's original plot.

across-track. For AIRS, a_0 is averaged across-track on one scanline only and $a_{1,i}$ is over an entire granule along- and across-tracks. Therefore when an AIRS partial granule from DB data is shorter than a DAAC full granule in terms of the number of valid scanlines, $a_{1,i}$ will be different from EOS DAAC's value.

The difference in $a_{1,i}$ is at maximum 0.2% of $a_{1,i}$ when the number of valid scanlines is only 6 out of a full granule's 135 (Fig. 7). With the increase of the number of valid scanlines, the difference becomes less. The difference in terms of the radiance is similar to the gain difference: for a partial granule with ~ 20 scanlines, the difference is less than 1% (Fig. 8).

AMSU averages the gain and offset over 9 scanlines (an AMSU granule has 45 scan lines). Precise evaluation of the difference between DB and DAAC data for AMSU are not available at present.

JPL recommends that one should use only a middle granule (e.g., granule 173 in Fig. 6) for scientific research, since it does not have any bad scanlines and therefore its radiance is identical to DAAC data.

5. Summary

We have performed the preprocessing of AIRS/AMSU data to generate brightness temperatures (Tb) from KMA's direct-broadcast (DB) data. The goal is to provide an environment for temperature and moisture sounding in the future. AIRS Tb from DB matches perfectly with the EOS DAAC standard product for a full granule.

For a partial granule, however, the DB data are accurate better than 0.2% error. SST, Preprocessing of the Direct-broadcast Data from the Atmospheric Infrared Sounder (AIRS) Sounding Suite on Aqua Satellite

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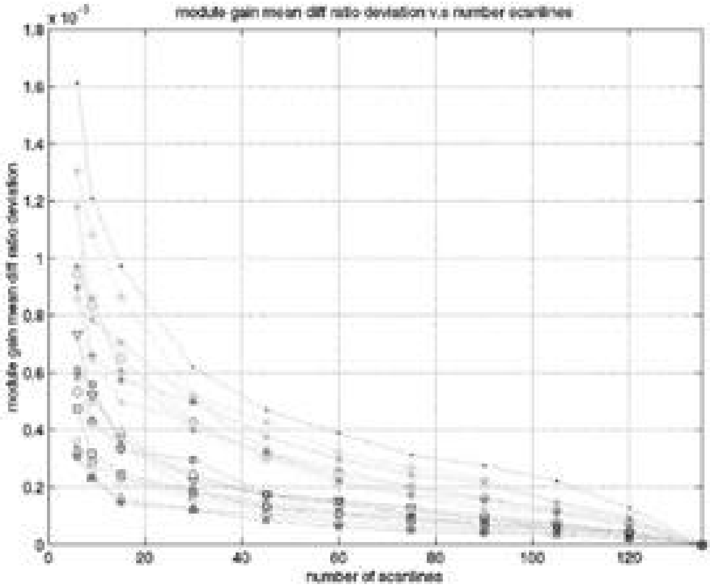

Fig. 7. In the abscissa there is the number of valid scanlines in a partial granule. In the ordinate, vs. the ratio of difference in gain ($a_{1,i}$ in Eq. 1) to a full granule's $a_{1,i}$. The gain difference refers to the difference in $a_{1,i}$ between partial and full granules. Different curves correspond to different frequencies of AIRS. Courtesy: JPL.

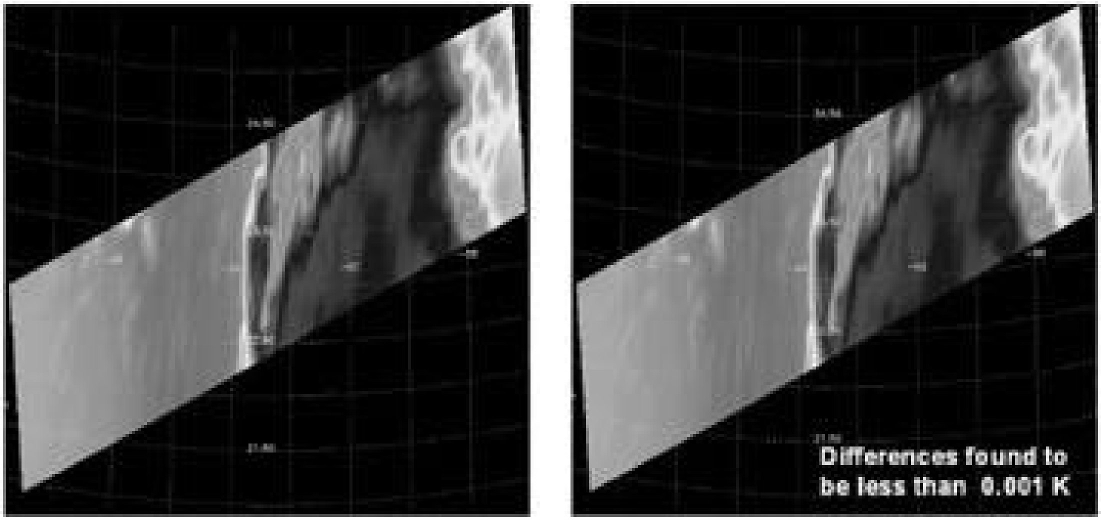

Fig. 8. EOS DAAC granule (a partial granule is extracted from a full EOS DAAC granule for comparison) and DB granule with about 20 scanlines. Courtesy: JPL.

derived by a simple linear regression equation after cloud filtering, appears reasonable and thus demonstrates usefulness of AIRS data. Further work is needed to improve the cloud rejection and to validate against buoy data.

6. Acknowledgements

This work is supported by KMA. We acknowledge the support as following: SSEC for providing IMAPP, JPL for technical advice and validation results, AIRS team of NESDIS for kind and helpful assistance and J.S.Lee at SATREC for helpful discussions.

7. References

Gaiser, S.L., Aumann, H.H., L.L. Strow, S.E. Hannon and M. SWeiler, 2003: In-flight spectral calibration of the Atmospheric Infrared Sounder, *IEEE Trans. Geosci. Remote Sens.*, **41**, 287-297.

Kim, S.B., J.H. Shin, Y.J. Im, S.O. Park, K.R. Kim and H.S. Park, 2003: Brightness temperature retrieval using direct broadcast data from the passive microwave imager on Aqua satellite, *J. Korean Soc. Remote Sensing*, submitted.

Lambrigtsen, B.H., 2003: Calibration of AIRS microwave instruments, *IEEE Trans. Geosci. Remote Sens.*, **41**, 369-378.

Pagano, T.S., Aumann, H.H., D.E. Hagan and K. Overoye, 2003: Pre-launch and inflight calibration of the Atmospheric Infrared Sounder (AIRS), *IEEE Trans. Geosci. Remote Sens.*, **41**, 265-273.

Parkinson, C.L., 2003: Aqua: an Earth-observing satellite mission to examine water and other climate variables, *IEEE Trans. Geosci. Remote Sens.*, **41**, 173-183.