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AIRS Version 6.6 and Version 7 Level-1C products

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ABSTRACT

The Atmospheric Infrared Sounder (AIRS) introduces new Level-1C (L1C) products. AIRS Version 6.6 L1C processing addresses data quality and sampling issues as well as spectral drift, making a clean, easy to use product. This will be the first version of AIRS L1C permanently hosted at the Goddard Earth Science DAAC, making it easy for users to access.

A later Version 7 L1C will incorporate v7 Level-1B (L1B) calibration improvements and use a modern netCDF4 format.

We focus on the spectral changes in the AIRS instrument and the new L1C feature that corrects for it.

Keywords: Atmospheric Infrared Sounder, AIRS, calibration, hyperspectral infrared sounding

1. INTRODUCTION

AIRS has produced a continuous record of L1B calibrated radiances from September 2002 to present, over 17 years. This product has been successfully used for retrievals of not just temperature and water vapor profiles but also many minor constituents, clouds, and surface properties. These radiances are also important inputs for numerical weather prediction[1].

Despite these successes, certain aspects of the AIRS instrument make the raw L1B product difficult to use in some circumstances:

1) Discontinuities in the spectral coverage (by design of the AIRS instrument)

2) Occasional bad radiance values (due to radiation hits and dead or poorly performing detectors)

3) Changes in the spectral calibration (due to small misalignments over the course of the mission)

In 2014, AIRS released a preliminary AIRS v6.1 L1C product[2] which addressed #1 & #2. We are now ready to release an updated AIRS v6.6 L1C product which also addresses #3. The format remains similar to AIRS v5 L1B and AIRS v6.1 L1C, but now a complete record will be publicly available at the Goddard Earth Sciences DAAC https://disc.gsfc.nasa.gov/. This adjustment will improve the basis for day/night and long-term comparisons of AIRS data. It should be noted that for channels that do not have poor performance, the L1C keeps the original L1B radiances. The algorithm for determining when to substitute a channel with a replacement (based on PC reconstruction) was discussed in Manning 2014.

2. AIRS LEVEL-1B AND LEVEL-1C PRODUCTS

The AIRS v5 L1B product has been available since 2007 and has been used by the AIRS v5 and v6 Level-2 retrievals and many others. For each spectrum, the main data is included in 2378 elements of the "radiances" array. The 2378 elements are generally in increasing order of wavenumber, but because of the physical structure of the instrument there are sometimes spectral gaps or overlaps between spectral regions observed with different detector module arrays.

The upcoming AIRS v7 L1B product[3] will improve the radiometric calibration and will be in a new netCDF4 format, similar to the NASA Cross-track Infrared Sounder (CrIS) product [https://disc.gsfc.nasa.gov/datasets/SNPPCrISL1B_V2/summary?keywords=CrIS].

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The AIRS v6.1 L1C product is based on the AIRS v5 L1B. It reports radiances on a more continuous set of wavenumbers and synthesized radiance values where there are gaps in spectral coverage and where the downlinked values are unreliable[4]. In order to conserve resources, the public availability of AIRS v6.1 L1C has been limited to a 1-month rolling archive of the most recent data.

The upcoming v6.6 L1C update will also be based on the AIRS v5 L1B but incorporate new corrections to compensate for the changing spectral sampling grid to provide a stabilized, publicly available product on a fixed spectral grid.

V7 L1C will bring together the v7 L1B calibration and formatting improvements with v6.6 L1C and further L1C refinements.

Table 1. Current and near-future AIRS Level-1 versions.

	Level-1B		**Level-1C**		
	v5 L1B	**v7 L1B**	**v6.1 L1C**	**v6.6 L1C**	**V7 L1C**
Release date	2007	Expected late 2019	2015	Expected late 2019	Expected 2020
Availability	Full record	Full record	Rolling 1-month archive	Full record	Full record
Channel set	Non-monotonic 2378 channels with 10 gaps and 6 overlap regions		Monotonic 2645 channels with one gap 1615-2180 cm^{-1}		
User quality control	Users must check QC flags, and channel properties for bad channels. Also check noise levels and flags within the L1B for calibration problems.	Simplified problem flagging.	Always usable unless an entire spectrum is missing. Optionally check noise and flags to exclude synthesized values or second-order issues.		
Spectral stability	Unstable with orbital cycle and long-term change each about 1% of SRF width		Stabilized within 0.2% of SRF width		
Format	HDF-EOS	netCDF4	HDF-EOS	HDF-EOS	netCDF4

3. SPECTRAL VARIATION

3.1 Characterizing spectral variations

The shapes of AIRS spectral response function (SRF) shapes are stable except for a small modulation due to "channeling"[6], but their spectral centroids can vary by about 1% of the SRF width, or 8 parts per million (ppm) frequency. These variations were first reported by Strow etc. in 2006[7]. In addition to long-term changes, there are spectral changes with orbital (100 minutes) and seasonal periods. These are assumed to result from changes to the optics between the grating and the detectors, partly from thermal effects and partly from relaxation. The full range of this variation is less than 1 μm of motion of the focal plane, which is equivalent to 2% of SRF width.

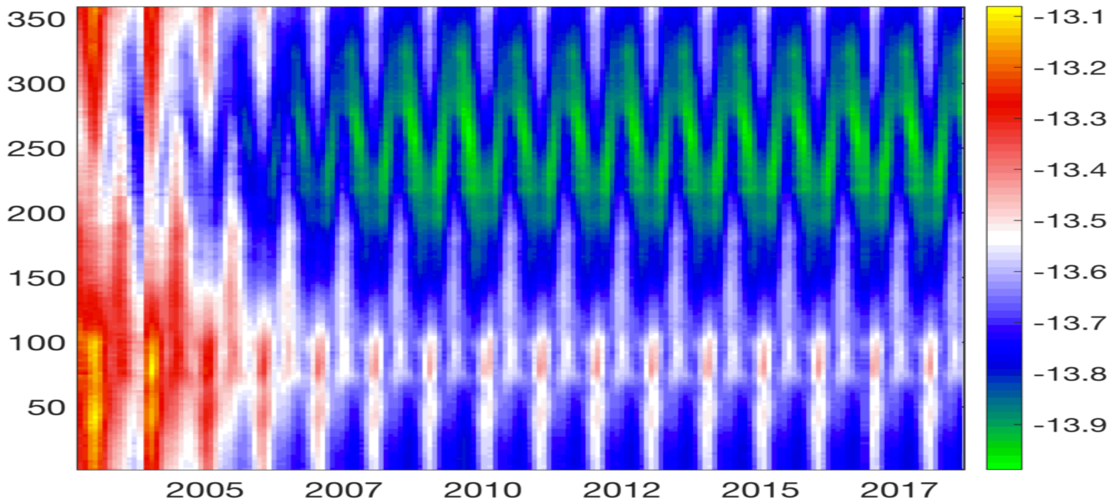

Figure 1. Modelled focal plane shift for module M-03 as a function of year (x axis) and orbit phase in degrees from nighttime southward equator crossing (y axis).

In addition, there is a Doppler shift of up to ~1.4 ppm at the highest scan angles. This results from the orbit of the EOS-Aqua platform. As the spacecraft travels North-South in a polar orbit, the Earth is rotating below it, with spectra on one side coming from areas that are rotating toward the spacecraft while those on the other side are getting farther away.

Figure 2 shows observed and calculated frequency shifts as a function of scan position. The slope is opposite sign for ascending/day vs. descending/night because when the spacecraft is northbound/ascending during day the area to the West (early cross-track (xtrack) scan positions) is moving towards the spacecraft and the area to the east is moving away. When the spacecraft is southbound at night the west is still moving towards the spacecraft, but now that is the later part of the scan.

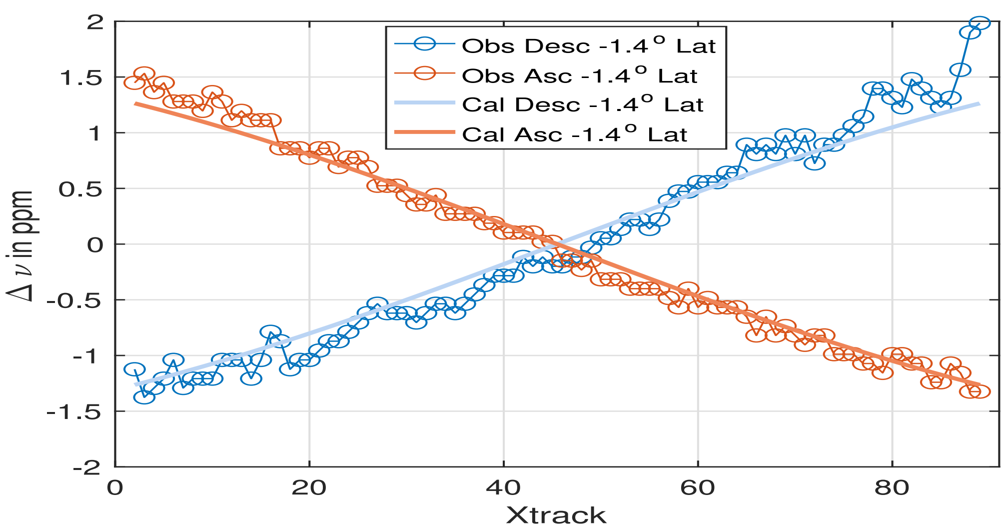

Figure 2. Doppler shift for module M-10 as a function of scan position for a band near 1.4 degrees South latitude. Circles are measurements; thick lines are calculated values.

Note that while the long-term, seasonal, and orbital shifts are considered defects of the AIRS instrument, the Doppler shift is just a natural consequence of the orbital geometry. Nonetheless, even Doppler shifts can complicate use of the data and should be removed in the v6.6 L1C product.

3.2 Impact of spectral variations

Figure 3 shows the calculated impact of spectral changes for a clear tropical ocean spectrum. It shows the difference between a spectrum calculated for nominal spectral centroids and one where the centroids were shifted by 8 ppm from their nominal positions. These changes are generally less than the noise level (0.1-0.5 K), and are even smaller for cloudy or polar scenes. The largest changes are for channels that are situated on the edges of spectral lines, and most researchers already avoid such channels because their poor vertical sounding resolution. But even changes of under 0.1 K can be important for climate trending and may show up in other situations, like comparisons of day and night conditions.

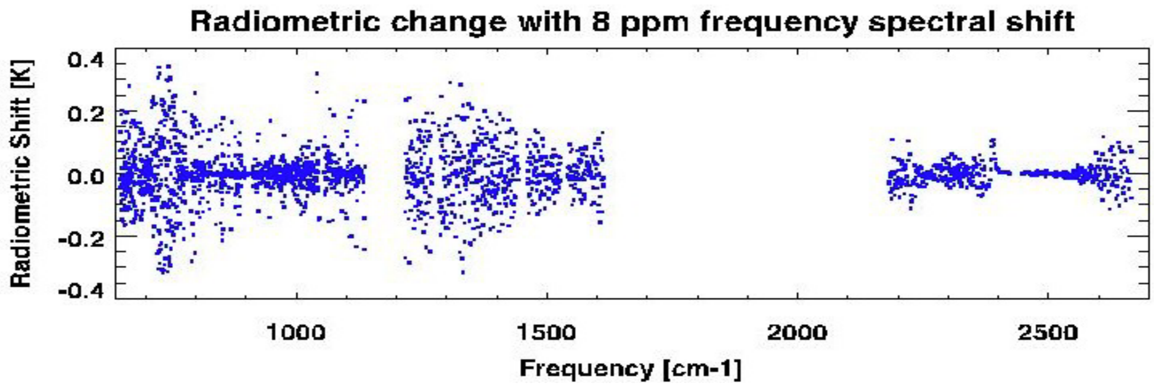

Figure 3. Radiometric change in a simulated AIRS clear tropical ocean spectrum for a frequency shift of 8 ppm, or 1% of SRF width. [From Manning 2009.]

3.3 Spectral variation model

Instantaneous spectral shifts were measured using upwelling spectra, finding the maximum correlation offset with reference computed spectra. Independent measurements were made for each detector module to determine their spectral offset from a pre-launch grating model. This work determined that most modules moved in unison due to thermal changes, etc. The M-03 module, dominated by water vapor, was found to give the cleanest and most accurate measurements of both instrument spectral shifts and Doppler shifts, and was consequently used to model the long-term frequency calibration. These longer term seasonal shifts and drift were fit to a numeric model with a constant, linear or exponential term (depending on the module), and a seasonal sinusoid and several harmonics.

The orbital variations were binned into 2-degree orbital phase bins, per detector module. Figure 1 above shows results of this model for Module M-03.

The model includes linear or exponential long-term drift and several very small discontinuities where the instrument temperature changed in 2003, 2010, and 2014.

The general pattern of long-term spectral drift is a relaxing exponential, stabilizing around early 2010. Most modules show this pattern, but Modules M-04a and M-04c show a slower drift. M-04a and M-04c share a physical substrate on the focal plane of the AIRS instrument. Modules M-06 and M-02a do not have enough spectral contrast to allow direct measurements, but are assumed to move with the majority. See Figure 4.

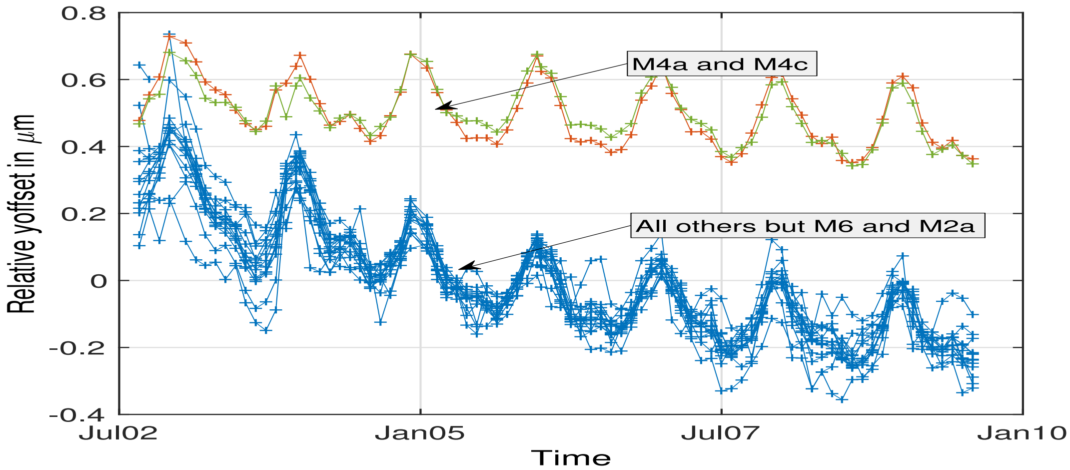

Figure 4. Measured spectral shifts over the first 7 years of the AIRS mission.

3.4 Spectral variation correction methodology

Spectral variations are corrected by using a cubic polynomial to interpolate and then applying a second-order correction factor to compensate for rapidly changing curvature. Details are in Manning 2009, section 2.2.

4. RESULTS

Test results show that the subtle effects of spectral shifting can be minimized. For this study we applied spectral correction to zonally-averaged radiances and used our shift determination methodology to evaluate the effective shift in the transformed spectra.

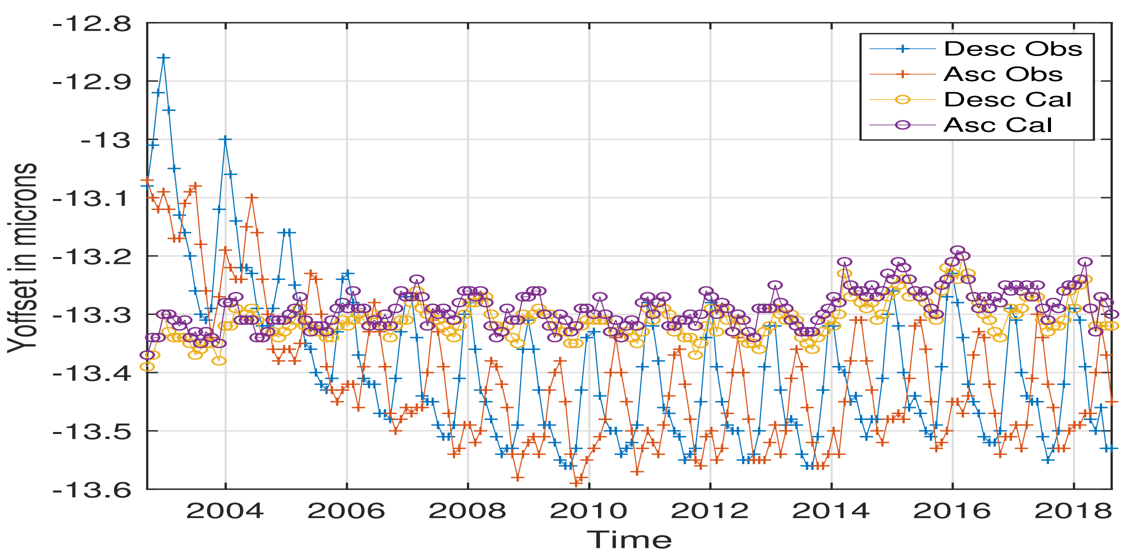

Figure 5. Module M-03 equatorial shifts measured before and after corrections are applied.

In Figure 5 we see that the overall range of variations has been reduced more than 3x, and that the residual variation is much less systematic, and so less likely to show up in climate trending or seasonal differences. The small jump in March 2014 was due to a short shutdown of AIRS and has now been included in the spectral module.

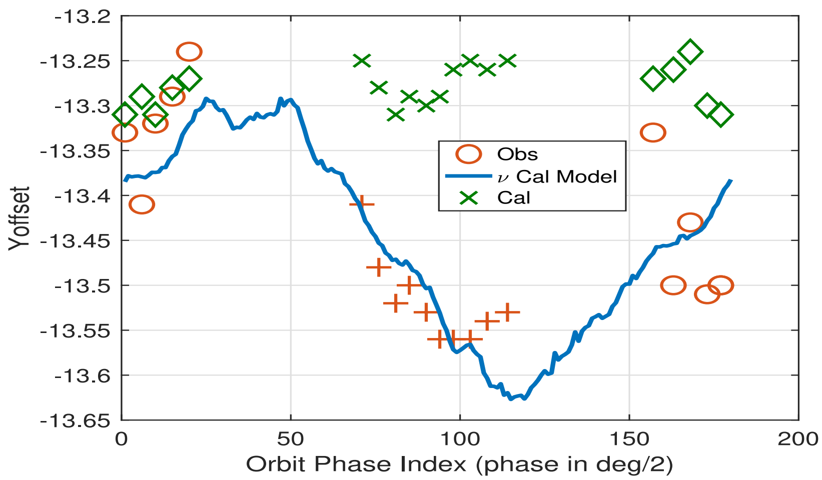

Figure 6. Module M-03 measured shift before and after correction. Red symbols are for uncorrected radiances while green symbols are corrected. Circles and diamonds are for nighttime data while + and x are day.

Figure 6 shows that the orbital variation has also been reduced to low-magnitude random variation. This will ensure that no systematic effects show up in day/night or north/south comparisons.

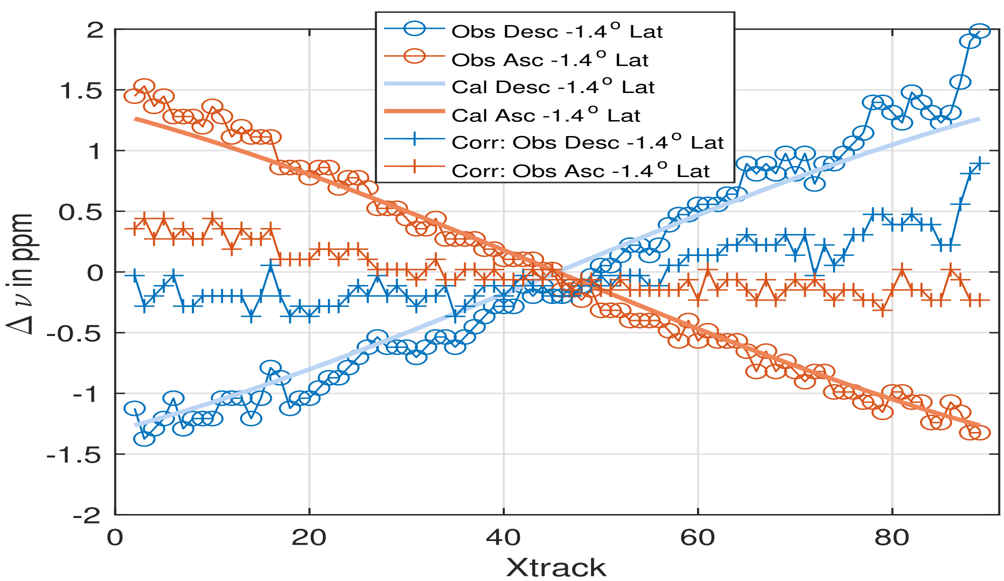

Figure 7. Module M-10 equatorial spectral shifts measured with uncorrected and corrected spectra.

Figure 7 shows that the effects of the Doppler shift have been greatly reduced.

5. DISCUSSION

The results shown above in section 4 are preliminary because they adjust averaged spectra. More realistic tests, with shifting applied to individual noisy spectra, show similar results.

One important application of AIRS Level-1C is in the production of the new Climate Hyperspectral InfraRed Product (CHIRP) (L. Larrabee Strow, UMBC)[6]. This product will transform AIRS data along with CrIS data from S-NPP and JPSS-1/NOAA-20 platforms to create a continuous 20+ year radiance record, suitable for climate research. Data from Infrared Atmospheric Sounding Interferometer (IASI) will also be incorporated. This effort requires that AIRS data first be converted from Level-1B to Level-1C. This pre-conditioning gives a continuous spectrum with high quality data everywhere. This is important because resampling to the common CHIRP SRFs requires continuous coverage and the influence of errors can be spread beyond the original channel frequency.

6. CONCLUSIONS

The AIRS instrument is remarkably stable and its 16-year record is an important baseline for climate studies. Even the spectral shifting, with a magnitude generally under 0.1 K, can be minimized, leaving residual systematic errors under 0.03 K.

Once the L1C product has been released publicly, it should become the default for most users. It not only greatly reduces the effect of spectral shifts, but also simplifies quality control and provides the continuous coverage needed to resample to other SRFs, including MODIS and CHIRP.

ACKNOWLEDGEMENT

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