AIRS/AMSU/HSB Version 6 Changes from Version 5

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1 Introduction

No significant changes have been made to the Level 1 processing for V6, and Level 1 products will continue to contain the V5 label. The only change was a table upload in January 2012 switching the redundancy configuration of the IR detectors to recover 90 channels that had been marked “bad” over the years due to radiation exposure (Pagano, T.S, Broberg, S., Aumann, H., Elliott, D., Manning, E., Strow, L, “Performance Status of the Atmospheric Infrared Sounder Ten Years after Launch”, Proc. SPIE 8507-02, Kyoto, Japan (2012)). Some new capabilities, collectively identified as Level 1C, will be available as tools and will be described in a separate document when they are released.

Changes to Level 3 products are outside of the scope of this document. They will be described in a separate document:

V6_L3_User_Guide.pdf

In Level 2 processing, a major change has been made in the first guess used to the retrievals in V6 as compared to V5. In place of a linear regression we are using a neural network to generate the first guess. This change has ramifications both in increased yield and accuracy and in the error characteristics of the final retrieval. The use of the neural network first guess has improved the retrievals in more difficult cases. A second major change is that the surface temperature is now determined from the shortwave channels only, along with emissivity and reflectance in the shortwave region. In addition we have made a change to the first guess emissivity over land. We also have a new suite of cloud products for V6.

See the discussion of the Neural Network in the paper:

Milstein, A. B., and W. J. Blackwell (2016), Neural network temperature and moisture retrieval algorithm validation for AIRS/AMSU and CrIS/ATMS, J. Geophys. Res. Atmos., 121, 1414–1430, doi:10.1002/2015JD024008.

The training set for the V6 Neural Network was drawn from ECMWF temperature, skin temperature, and water vapor mixing ratio fields from every fourth day between 1 December 2004 and 31 January 2006.

In V5, retrievals thought to be more than 90% cloudy were rejected with the microwave state given as the solution. Various other error checks also caused the entire retrieval to be discarded, leading to a total rejection rate of about 17%. In V6, it was desired to provide some information for all cases where possible, and these restrictions were removed. We now produce stratospheric retrievals in essentially all cases where data are present, except when the retrieval is unable to complete due to computational instabilities (usually completely overcast cases). Less than 1% of cases now fail entirely. This change in philosophy (and the improved first guess form the neural network) has dramatically increased yield in the upper atmosphere.

In the absence of a failure of additional AMSU channels forcing a changeover to our AIRS-only mode of retrieval (i.e., infrared-only retrievals), the underlying retrieval methodology has changed only slightly between V5 and V6. The separation of shortwave and longwave surface properties is significant. In addition, we have updated and improved the RTA, modified channel sets, and added and clarified quality indicators. The Outgoing Longwave Radiation (OLR) product uses an entirely different forward algorithm. For the existing cloud and Outgoing Longwave Radiation (OLR) products, the spatial resolution has been changed to the AIRS spot size rather than the AMSU spot size.

There has been a major overhaul of the Quality Control flagging in that now almost every variable has an associated quality flag with a corresponding name, making it clearer for users which data are recommended for use. Users will need to modify the variable names used for Quality Control.

Level 3 processing has a number of changes noted below which we believe improve the representativeness of the product. In addition, both standard and support products are available at Level 3 and contain new parameters.

The changes in Level 2 and Level 3 processing mean that all data products will be substantially different in V6 when compared to previous versions. The new quality indicators and error estimates will impact the way the user filters data products. The new data products expand research options.

The version numbers that appear in the AIRS Product Files are slightly different, depending upon the product due to a staged delivery of processing code to the GES DISC. They are:

- **Level 1B AMSU-A and HSB Products**: v5.0.0.0
- **Level 1B AIRS Products**:
    - **V5**.0.0.0 prior to Jan 21, 2012
    - **V5**.0.21.0 starting Jan 21, 2012
- **Level 1B Calibration Subset Product**: v5.0.16.0 is still available. It will be superseded by v6.0.x at some point in the future.
- **Level 2 Products**:
    - **Level 2 AIRS+AMSU and IR**-Only standard, support, and cloud-cleared radiance products: v6.0.7.0
    - **Level 2 AIRS+AMSU+HSB**: TBD v6.0.x
    - **Level 2 CO_2**; TBD V6.x

- **Level 3 Products**:
  - **Level 3 AIRS+AMSU and IR**-Only standard, support, and quantized products: v6.0.9.0
  - **Level 3 AIRS+AMSU+HSB** standard, support, and quantized products: TBD v6.0.x
  - **Level 3 CO_2**; TBD V6.x

2 Calibration/Validation Status

The status of V6 calibration/validation is provided in the document:

V6_Data_Disclaimer.pdf

3 Changes from V5 to V6

3.1 Level 2 Retrieval Flow

The sequence of retrieval steps is slightly different between V6 and V5. The major changes are:

- Replacement of the cloudy regression stage by a neural network solution of temperature and water vapor.
- Removal of the clear regression stage.
- Separation of the surface retrieval into a shortwave-only step, including the surface temperature, and a subsequent long-wave emissivity step.

See **V6_Retrieval_Flow.pdf** for a step-by-step comparison of V5, V6 and V6 AIRS-Only retrieval flow.

3.2 Climatology Update

Both the regression and the neural network fill the water and temperature profiles above a certain level with a climatological profile as described below. V5 used a profile derived from UARS observations. V6 uses a profile derived from European Centre for Medium-Range Weather Forecasts (ECMWF) model runs. The V6 climatology has mean values per 1-degree lat/lon grid square for each month, separately for day and night and separately for land and ocean. It is derived from ECMWF forecasts for 2004-2008, interpolated to AIRS observation locations.

3.2.1 Modifications to Regression Stage

Although updated regressions were generated for V6, the operational system does not use them and instead uses a neural network first guess state. The regressions remain available and could be used in future systems.

3.2.2 Stochastic Cloud Clearing/Neural Network First Guess State

The First Guess State is derived in a two-step process (Blackwell, et al., "AIRS/AMSU Atmospheric Profile Retrievals Using Stochastic Cloud Clearing and a Neural Network," submitted to IEEE TGRS). First, Stochastic Cloud Clearing (Cho C., D. H. Staelin (2006), Cloud clearing of Atmospheric Infrared Sounder hyperspectral infrared radiances using stochastic methods, J. Geophys. Res., 111, D09S18, doi:10.1029/2005JD006013) is used to estimate the clear column AIRS radiances given an AMSU-A observation collocated with a 3×3 array of IR observations over a field of regard. Second, a neural network is used to estimate the temperature and water vapor profile from the cloud cleared radiances produced by SCC. The SCC and NN operators are both trained using AIRS/AMSU observations co-located to ECMWF six-hour analyses on a 0.5-degree grid. Training segments are coarsely stratified according to latitude, season, day/night, and surface type/pressure. Algorithm inputs are the AIRS and AMSU-A radiances, scan angle, solar zenith angle, and forecast surface pressure. An "AIRS only" algorithm variant was also produced.

For levels with pressure less than 1.6 hPa, the shape of the profile is provided by the ECMWF climatology instead of by the neural net. The climatology profile is shifted so that there is no discontinuity.

For levels with pressure less than 118 hPa the water vapor profile is similarly provided by the ECMWF climatology.

3.3 Level 2 Microwave-Only Retrieval Stage

3.3.1 Failure of AMSU-A Channels 4 and 5

Early in the V5 operational period, AMSU-A channel 4 became noisy. Its use was discontinued as of October 1, 2007. Its radiance value was replaced by a value determined by a regression from the remaining AMSU channels. A small degradation in results resulted from this loss of information, most notably in the boundary layer over Greenland.

AMSU-A channel 5 slowly degraded throughout 2009-2010, with steadily increasing noise. Beginning in mid-2010 the noise level increased more rapidly, increasing from 0.5 K in January 2010 to 1.0 K in February 2011. By February 2012 the level had increased to 2.0 K and continued to climb. Since the channel 5 radiance is a key component of the V5 quality control, our estimates of retrieval errors increased and the reported yield declined during this period, although the retrievals themselves degraded only slightly with the increasing noise in this channel.

Both AMSU-A channels 4 and 5 have been excluded from the AIRS/AMSU (AIRXRET) V6 processing in all respects so that there will be no discontinuity in the processing algorithm for this data stream . This results in some degradation in the microwave-only products, especially the microwave surface emissivity, where precipitation can cause incorrectly high surface emissivity to be reported.

AMSU-A channels 4 and 5 were operating normally at the time that HSB was operational (start of mission to 5 Feb 2003). We have included these channels in the AIRS/AMSU/HSB (AIRHRET) V6 processing.

3.3.2 AMSU A Tuning

V5 tuning for AMSU was based on clear-air ocean retrieved profiles from AIRS for the period of 2003→2005. Now we have a larger dataset extending to 2007, and it contains some data over land as well. In comparison to the ocean, land provides a better background for the window channel tuning because the measurements are less sensitive to the atmosphere and not at all dependent on wind speed.

The V5 tuning coefficients were pure offsets (depending only on channel and scan position). For AMSU channels 1→4 and 15, the new coefficients are slopes which will be multiplied by the observed antenna temperature to get the tuning correction. This is a more correct way to compensate for sidelobe contributions.

AMSU channels 5→14 retain the offset form as before, because the corrections seem to involve transmittance as well as sidelobes. However, the variation of these channels is less than in the case of the window channels, so the difference between offset or slope correction is small. Still, the error of this simplified approximation may be noticeable in some channels under some circumstances.

The new tuning coefficients were calculated with an updated transmittance algorithm based on recent spectroscopy (Tretyakov et al., 2005, “60 GHz Oxygen Band: precise broadening and central frequencies of fine structure lines, absolute absorption profile at atmospheric pressure and revision of mixing coefficients,” J. Mol. Spectros. v.231, pp.1-14, doi: 10.1016/j.j,s.2004.11.011) which has been validated by ground-based radiometric measurements (Cadeddu et al, 2007, “Measurements and retrievals from a new 183 GHz water vapor radiometer in the Arctic, IEEE Trans. Geosci. Rem. Sens. v.45, pp.2207-2215, doi: 10.1109/TGRS.2006.888970). The revised transmittance must be accompanied by revised tuning.

Tuning for HSB is a correction for two weak ozone lines in the passband of HSB channel 3, which were not included in the transmittance algorithm. This is being done as an alternative to adding ozone as an argument to the transmittance routine, which would require code changes in numerous places since many MW routines don't use structures.

3.3.3 Use of Dynamic Noise

To better respond to the changing noise levels of the microwave channels, the channel noise estimates in the microwave-only retrievals are taken from the dynamic noise levels reported with each granule in V6 instead of the static noise levels used in V5. This ensures that if any more AMSU channels degrade in the future then the retrieval will deemphasize those channels automatically.

The logic that dynamically determines which AIRS IR channels are to be used in the retrieval has also been modified to reduce the incidence of channels being ignored because of static information. In V5, channels would only be used if the measured noise level was between 0.5→1.5 times the expected noise value. For V6, the minimum is removed and the maximum is only important if the measured noise level is over 0.5 K. Also the “cold scene noise” flag from L1B is no longer examined, so in v6 channels can be used even when this flag is set.

3.4 Update of AIRS-Only Level 2 Retrieval Capability

Currently AIRS and AMSU form an instrument suite and the Level 1 data from both instruments are normally combined in the Level 2 processing to produce a single Level 2 product. AIRS is the critical instrument, and a contingency plan is ready in the event of failure of AMSU. V6 includes an AIRS-only capability in the Level 2 software which produces results nearly as good as the combined AIRS/AMSU product except under very cloudy conditions. AIRS-Only Level-2 and Level-3 products will be available for the full mission in addition to AIRS/AMSU products. If AMSU should fail, users can shift to AIRS-only.

Two deficiencies in the V5 AIRS-Only system have been mitigated:

1. The surface classification in the absence of the microwave channels relies on an estimate of surface temperature. In very cloudy cases this estimate was poor in V5 resulting in erroneous surface classifications. In V6 we use, for surface classification purposes only, the forecast surface temperature from the NOAA Global Forecast System (GFS) forecast. This has reduced the number of erroneous classifications.
2. The quality control in V5 AIRS-only was not strict enough for the climate quality control (Qual=1) which is used in generating L3 products, leading

to inferior L3 products for some parameters. The quality control has been improved, and the neural network first guess has improved the retrievals in the more difficult cases.

3.4.1 Failure of AMSU-A2

AMSU-A2 failed 24 September 2016, resulting in the loss of two microwave channels: 23.8 GHz and 31.4 GHz. A comparison of the AIRS/AMSU and AIRS-Only products is provided in the document:

http://disc.sci.gsfc.nasa.gov/AIRS/documentation/v6_docs/v6releasedocs-1/V6_L2_Performance_and_Test_Report.pdf

3.5 Time-varying Frequencies

The V6 retrieval includes a model of how the frequencies of each AIRS channel vary slightly with orbital, seasonal, and long-term patterns, as well as cross-scan Doppler shifts. These frequencies are passed into the RTA so that the minimization of "*Observed-Forward_Calculated"* (OBS-CAL) radiances in all retrieval steps is performed at the correct frequency.

3.6 RTA Update

The AIRS fast forward model used by V6 (AIRS RTA V6) is the same basic model as used in V5 (AIRS RTA V107), but with some algorithm changes and additions to improve the accuracy and increase flexibility. The changes and additions are:

- Transmittance tuning changes (affecting CH_4 and N_2O sensitive channels)
- Additional CO_2 (secant angle) and non-LTE (CO2 amount) predictors
- Correction of the solar secant angle calculation beyond 80 degrees
- Two RTA file sets, one before and one after October 25, 2003 due to an AIRS instrument warm-up occasioned by the safing of the Aqua platform due to a solar coronal mass discharge.
- Coefficient sets are pre-calculated for three sets of frequencies, slightly offset from one another, and are interpolated to the predicted instantaneous frequencies for the observation.

3.6.1 Transmittance Tuning

The transmittance tuning (applied as optical depth multipliers) used in V4 was based on a limited amount of validation data available at the time the fast model was finalized in January 2004. Over the next two years a much larger amount of validation data become available, and this has been used to improve the transmittance tuning in V5. A more detailed discussion of the validation data and the effects of tuning can be found in [Strow, L.L., S. E. Hannon, S. De Souza-Machado, H. E. Motteler, and D. C. Tobin (2006), Validation of the Atmospheric Infrared Sounder radiative transfer algorithm, JGR, 111, D09S06 (2006), doi:10.1029/2005JD006146].

For the most part the changes to tuning are relatively minor, affecting computed Brightness Temperature (BT) spectra at the few tenths of a Kelvin level or less. The main change is to "fixed" gases in the 15 and 4.3 μm regions. Unlike V4, the V5 tuning was extended to stratospheric channels (based upon AIRS retrievals, as very little in situ validation data is available). The tuning of the 4.3 μm channels took into consideration non-LTE effects. Some relatively minor changes were made to tuning in shortwave channels affected by N_2O.

The changes to water tuning are minor, the main changes being near 880 and 1320 cm^{-1} where the old tuning appeared to have been influenced by HNO_3. The CH_4 tuning near 1305 cm^{-1} was adjusted by 2% on the recommendation of the retrieval team to reduce biases in retrieved CH_4. Finally, a significant change has been made to ozone in the 10 μm region. This tuning attempts to account for changes to ozone line parameters in the recent HITRAN 2004 databases versus the HITRAN 2000 upon with the V5 fast model is based.

The version 6 RTA used the same validation database and methodology as V5.

3.7 Time Variable CO_2 Climatology Updated

In V4 and earlier, the CO_2 was assumed to be constant over time and fixed throughout the atmosphere at 370 ppmv. The RTA remains linear for deviations from this value of ±10 ppmv.

V5 incorporated a global average linear time-variable CO_2 volume mixing ratio to assure linearity for the indefinite future:

$$CO2\_ppmv(t) = 371.92429 + 1.840618 \times \Delta t$$

Δt is the time between the current FOV and 0^{hr} UT on Jan 1, 2002

$$\Delta t = \left(t_{FOV} - t_{0UT\_01Jan02}\right)$$

and is expressed in fractions of a year. The coefficients were derived via linear fit to the time variation of CO_2 observed at Mauna Loa. V5 introduced a CO2 profile for the first guess with all vertical elements set to the volume mixing ratio calculated via the preceding algorithm.

In V6, we use the same global time-variable process to calculate the profile of volume mixing ratio, but with new coefficients derived via fit to marine GLOBALVIEW-CO2 from start of 2002 to end of 2009:

$$CO2\_ppmv(t) = 371.789948 + 2.026214 \times \Delta t$$

In both V5 and V6 the linear fit to the time variation of CO_2 is applied globally to avoid non-linear effects in the RTA calculation that could arise from very large differences between a fixed assumed and the true CO_2 concentration over the time span of the mission, while at the same time not introducing geospatial or seasonal variations that might leak into the post-processing CO_2 retrieval. The associated quality factor, CO2ppmv_QC, is set to the value 2 because CO_2 is not retrieved in the main AIRS retrieval stage. It is retrieved in a separate post-processing stage at a different spatial resolution.

3.8 Day/Night Boundary and the Retrieval of Reflectance

In V5, retrievals with solar zenith angle greater than 89.9 deg were considered to be night cases and the retrieval of bidirectional solar reflectance was not attempted. With the improvement to the RTA for solar zenith angles greater than 80 degrees, it became impossible to solve for bidirectional solar reflectance between 89.5 and 89.9 degrees because of the reduced contribution from the surface. For V6, the reflectance solution is not attempted beyond solar zenith angles of 89.0 degrees. The reflectance is retained in the forward calculation but held at its first guess value. No discernible discontinuity results from this extremely small contribution to the channel radiance. This change only affects polar cases due to the 1:30 AM/PM sun synchronous orbit of Aqua.

This does not carry over to the VIS/NIR product. The VIS/NIR product is not created when a granule's **DayNightFlag** is "Night". This occurs when the solar zenith angle of the subsatellite point (not an FOV) at both the beginning and the end of the granule is greater than 90 degrees. Some of the discarded granules do have corner FOVs with solzen < 90 degrees, but that discarded data volume is minuscule.

3.9 Retrieval Changes

3.9.1 Surface Emissivity First Guess Changes

In V5, a synthetic surface surface regression was used based on a subset of AIRS window channel radiances for the first guess over land (Zhou et al. 2008). In V6, a surface climatology was constructed from the 2008 monthly MODIS MYD11C3 emissivity product, and extended to the AIRS IR frequency hinge-points using the baseline-fit approach described by Seemann et al (2008).

Zhou, L., M. Goldberg, C. Barnet, Z. Cheng, F. Sun, W. Wolf, T. King, X. Liu, H. Sun, and M. Divakarla (2008), Regression of surface spectral emissivity from hyperspectural instruments, IEEE Trans. Geosci. Remote Sens., 46(2), 328–333, doi:10.1109/TGRS.2007.912712

Seemann, Suzanne W., Eva E. Borbas, Robert O. Knuteson, Gordon R. Stephenson, Hung-Lung Huang, 2008: Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multispectral Satellite Radiance Measurements. J. Appl. Meteor. Climatol., 47, 108–123, doi: http://dx.doi.org/10.1175/2007JAMC1590.1

The detailed description is in 3.a.3 "baseline fit procedure" pp112-114.

Over ice and snow surface classes, V5 used an emissivity value of 0.992 for all IR frequencies as a first guess. For V6, a new first guess emissivity based on measured spectra is used instead. This guess is derived from spectra measured by the MODIS team at Mammoth Lake. There are significant differences between ice and snow and among separate snow observations, but we only know if a given observation is frozen or not, so we use the MODIS "snow 1" spectrum, which is intermediate between snow and ice. The original spectra and more information can be found at http://www.icess.ucsb.edu/modis/EMIS/html/water.html

A number of special cases arise using this scheme because the MODIS product does not cover small islands and some frozen surfaces. These rare cases are treated as follows:

1. If the case is land but MODIS provides no value at that location, a static globally averaged emissivity spectrum is used for the land portion. Poleward of 65 degrees latitude, an average of the static spectrum and the ice spectrum is used if the case is more than 10% land by our reference map.
2. If the case is ocean (determined from our reference map) but MODIS provides a value, a dry lake bed is possible and MODIS is used for cases where the elevation is greater than 3 m. This case sometimes trips for legitimate inland lakes but MODIS usually provides reasonable values in those cases.
3. If the case is determined to be frozen but MODIS provides a value, we use the average of the MODIS value and the Mammoth Lake derived value.

3.9.2 Surface Emissivity Retrieval

There are major changes to the surface emissivity retrieval in V6 and a very significant improvement in yield and accuracy for surface temperature and emissivity over land and ice surfaces. A detailed description of these changes is described by Susskind and Blaisdell (2008).

Susskind, J., and J. Blaisdell (2008), Improved surface parameter retrievals using AIRS/AMSU data, Proc. SPIE Int. Soc. Opt. Eng., 6966, 696610, doi:10.1117/12.774759.

In V5, the surface temperature, longwave emissivity (with three degrees of freedom), and shortwave emissivity and reflectance (with one degree of freedom each) were retrieved simultaneously using 15 longwave and 10 shortwave window channels. In V6, these have been separated into individual steps.

In V6, an initial shortwave effective reflectance is retrieved first, with one degree of freedom. Next, the surface temperature and shortwave emissivity and reflectance (with four degrees of freedom each) are retrieved using 57 shortwave window channels. This is a significant theoretical change. The longwave emissivity is retrieved subsequently (with six degrees of freedom) without changing the surface temperature.

In V5, the emissivity and reflectance perturbations were additive internally; in V6 they are multiplicative. This formulation better maintains the shape of the first guess, and no longer permits unphysical emissivity values greater than 1.00.

In V5, a series of hinge points were used to describe the emissivity spectral shape over land and water. This has been consolidated to use the same 39 hinge points (formerly used over land) for all retrievals, simplifying the output and removing some extra bumps from the retrieved emissivities.

3.9.3 CO Retrieval Changes

CO first guess has been updated. In V5 the first guess was the MOPITT first guess with AFGL above 7 hPa. In V6 there are now separate 100 layer first guess profiles for the Northern and Southern hemispheres with monthly granularity, based on MOZART monthly mean hemispheric profiles, with a linear interpolation in latitude for the transition between the NH and SH which takes place over the latitude range from 15N to 15S. The calculation for the transition is performed layer-by-layer over this latitude range via the following algorithm:

$$x = \left(15 - lat\right)/30$$

$$CO\_profile(lat) = \left(1 - x\right) \times NH\_CO\_profile + x \times SH\_CO\_profile$$

See the documents

AIRS V6_CO_First_Guess_Profiles.pdf
AIRS V5_CO_First_Guess_Profile.pdf

for tables of both the V6 and the V5 first guess profiles.

3.9.4 CH4 Retrieval Changes

Methane retrieval has been modified extensively, including:

- changing from 7 to 10 vertical functions
- new channels and damping
- new tuning to the absorption coefficient in the peak CH4 channels near the Q-branch
- a new first guess from a NOAA fit to in-situ data and a model with latitude dependence.

See the document

AIRS V6_CH4_First_Guess_Profiles.pdf

for the algorithm by which the first guess profile is calculated and an example table of the V6 first guess profile at latitudes 45S, 00N and 45N.

3.10 Empirical Error Estimates

V6 employs empirical error estimates for the quality control of both Level 2 products and Level 3 products in the same general way that V5 did. See the document:

V6_L2_Quality_Control_and_Error_Estimation.pdf

In V5 the error prediction and quality control thresholds were different day and night, and land and ocean surface classes; in V6 the globe is subdivided into land, ocean, and frozen surface classes.

In V5 Cloud Cleared Radiance error estimates were provided for all channels; in V6 channel-by-channel quality flags have been added.

3.11 Modified Channel Sets Used in the Retrieval Stages

See the document

V6_Retrieval_Channel_Sets.pdf

for a list of the channel sets used by the retrieval algorithm, identified by function. It also contains figures showing their location in the AIRS spectrum.

- The cloud clearing and cloud parameter retrieval channel set has been extended slightly.
- The surface temperature retrieval stage has been modified to use only the 4 μm channels, and 4 μm surface channels have been added to the temperature profile retrieval step.
- The channel set employed by the methane retrieval stage has been modified to increase sensitivity.
- The channel sets have been modified slightly to avoid degraded channels and to increase the separation of parameters.

3.12 L2 Trend Reduction

V5 had spurious cooling trends in tropospheric temperature as well as spurious trends in cloudiness and yield. These were mostly caused by unaccounted-for changes in CO_2, N_2O, and instrument frequencies. Mitigation included:

- Updated first guess from a regression with trends to a neural net without significant trends.
- Removed N_2O-sensitive channels
- Updated assumed CO_2 background trend
- Removed CO_2 noise covariance matrix entry

A slow progressive drop in yield from beginning of mission was due to impact of loss of channels (due to radiation hits on detector arrays) on the V5 regression stage and the subsequent QC utilization of the lowering regression score as part of the error estimate. V6 recovers almost all of these channels through modification of the gain tables, which control whether the “A” side or the “B” side of a channel in the detector array is used and does not use the regression score as part of error prediction. A more rapid progressive drop in yield of the V5 MW/IR retrieval began in early 2011 due to the steady degradation of AMSU channel 5 and its causing rejection of retrievals due to increased noise in an error predictor. V6 ignores AMSU channels 4 (which failed earlier) and 5 throughout the mission.

3.13 L3 Gridding Weights Retrievals by AIRS FOVs

V5 includes a retrieval in a grid box average if the AMSU FOV centroid fell with the grid box. V6 accounts for retrievals straddling more than one grid box by weighting the retrievals by the number of AIRS FOVs whose spatial locations fall within a grid box. Thus the V6 counts (TotalCounts and <basename>_ct values) for a grid box are the number of AIRS FOVs that fall within it. Thus these values are approximately a factor of 9 larger than the values reported in 5.

4 Level 2 Standard Product QA and Error Estimates

The most important change between V5 and V6 visible to the user of AIRS products is the enhanced product-specific quality indicators and improved error estimates.

For V6 each retrieved physical quantity now has its own matching quality indicator and error estimate. The names of the quality indicators are the same as the name of the corresponding parameter with "_QC" appended to the name. Where a parameter is an array, such as **TAirStd**, the corresponding quality indicator **TAirStd_QC** is also an array of the same dimension. All **Qual_*** have been removed. The quality flags for quantities are now named according to the associated quantity as **<quantity>_QC**, and they appear for every quantity, including at every level of profiles. The error estimates continue the V5 convention of having the name of the parameter with "Err" appended, for this example an array named **TAirStdErr.**

The marking of temperature and water profiles by **PBest** and **PGood** continues as in V5. **Users are encouraged to use PBest and PGood for temperature and water vapor if it simplifies their analysis.**

Please read the documentation for an extended discussion of these quality indicators and the estimated errors.

V6_L2_Quality_Control_and_Error_Estimation.pdf

The quantities on which the new quality indicators are based are included in the Level 2 Support Product. We do not encourage second-guessing of the threshold values that were used to set the quality indicators in the Level 2 Standard Product. However we do offer caveats and suggestions by which users may further refine their filtering of retrieved products in

V6_L2 _Products_User_Guide.pdf.

We urge researchers to carefully read both these documents.

5 Error Corrections to Existing Products

There are no major algorithmic error corrections from V5 to V6.

6 Enhancements to Existing Products

Please refer to the document

V6_L2 _Product_User_Guide.pdf

for a detailed discussion of each AIRS Level 2 Standard Product.

6.1 Format changes

L2 and L3 products now have DOIs and dimension scales. Fields are ordered in a more logical grouping.

6.2 Level 2 Standard Temperature and Moisture Products

The V6 retrieval yield in the troposphere is greatly increased over that of V5, and the decreasing yield trend (~1%/yr) for V5 retrievals has been removed in V6. The V5 temperature bias trend with respect to collocated *in situ* measurements (-0.05 K/yr) has also been substantially reduced in V6.

Please refer to Section 3.1.2 of

V6_L2_Performance_and_Test_Report.pdf

for additional details.

6.3 Level 2 Standard Cloud Products

V6 cloud product is substantially improved over that in V5. The cloud parameters solved for are the tops of two flat black clouds at different levels, with different fractions among the nine AIRS spots that are contained within the AMSU footprint (and retrieval FOV). In V5 the nine spots were constrained to have the same cloud pressure among the nine spots; in V6 this restriction has been removed and different cloud fractions and pressures are output for each AIRS spot. In some cases this small number of output parameters may not be very realistic, but the retrieval algorithm finds a best radiative fit to this output format. The cloud-clearing algorithm is not constrained to this type of cloud; cloud clearing by its nature works with cloud formations, which can have any fixed vertical structure while varying in cloud amount. Up to four cloud formations are allowed.

A number of changes within the cloud retrieval have enhanced the number of cases that converge. This has also increased the number of low clouds retrieved.

In the cases when a reasonable IR surface retrieval is not possible due to heavy cloud cover, the cloud product using the surface temperature from the neural network state (and marked Quality 1). In the very few cases where no IR retrieval is possible, the cloud product is calculated at AMSU resolution from the first guess. In these cases, the fractions reported for all nine spots are set to the same value and these cases are marked Quality 2 (do not use). In V5 about 13% cases were calculated at AMSU resolution; in V6 less than 1% of cases are done this way.

The higher quality temperature and moisture profile retrievals do not correspond to higher quality retrievals of cloud fields. In fact they may have just the opposite quality tendencies. This is not unexpected as a stronger cloud radiative signature is associated with a more accurate cloud temperature, pressure, and amount. Thus, scenes in which it is more difficult to retrieve temperature and moisture profiles contain more accurate cloud retrievals with smaller associated uncertainties.

6.4 OLR Products

There has been a major upgrade to the OLR calculations, replacing the V5 Metha and Susskind (1999) algorithm with the V6 AER algorithm due to Iacono et al. (2008). In addition, the OLR products are now calculated at the AIRS resolution, making use of the AIRS resolution cloud fields, as well as averaged to the AMSU resolution for consistency with V5. Since the only difference among the associated AIRS spots is the cloud retrieval, the clear-sky OLR remains constant over the AMSU Field of Regard.

Metha, A and J. Susskind, JGR, Outgoing longwave radiation from the TOVS Pathfinder Path A data set, *J. Geophys. Res.*, **104**, 12193 doi:10.1029/1999JD900059, 1999.

Iacono, M.J., J.S. Delamere, E.J. Mlawer, M.W. Shephard, S.A. Clough, and W.D. Collins, Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models, *J. Geophys*. Res., **113**, D13103, doi:10.1029/2008JD009944, 2008.

7 New Products

See the document

V6_L2 _Products_User_Guide.pdf

for a more detailed discussion of the following new products.

7.1 Level Products

The AIRS retrieval uses layer mean quantities for water vapor, ozone, carbon monoxide, and methane. Previous versions of AIRS products reported only column totals and layer quantities for these gases. The primary products in V6 Level 2 Standard and Support Products for all gases are now level products (values at the specific pressure level upon which they are reported) instead of layer products (slab values reported on the bounding pressure level nearest to the surface). The level quantities are derived from the internal 100-layer quantities by a smoothing spline, tuned to reflect information content and atmospheric variability. See the Algorithm Theoretical Basis Document:

AIRS_Layers_to_Levels_ATBD.pdf

7.1.1 L2 Standard Product Level and Layer Example:

H2OMMRStd	layer WV mass mixing ratio
H2OMMRLevStd	level WV mass mixing ratio
O3VMRLevStd	level O3 volume mixing ratio
COVMRLevStd	level CO volume mixing ratio
CH4VMRLevStd	level CH4 volume mixing ratio

QC for level quantities are also reported. Please note that the QC for level quantities may be different than those for layer quantities reported on the same level.

V6 retains layer products in the L2 Support Products for backward compatibility.

7.1.2 L2 Support Product Level and Layer Example:

H2OCDSup	layer WV column (molecules/cm^2)
H2OMMRLevSup	level WV mass mixing ratio (gm/kg)
H2O_VMR_eff	Trapezoid effective WV volume mixing ratio
O3CDSup	layer O3 column (molecules/cm^2)
O3VMRLevSup	level O3 volume mixing ratio (ppv)
O3_VMR_eff	Trapezoid effective O3 volume mixing ratio
COCDSup	Layer CO column (molecules/cm^2)
COVMRLevSup	Level CO volume mixing ratio (ppv)
CO_VMR_eff	trapezoid effective CO volume mixing ratio
CH4CDSup	layer CH4 column (molecules/cm^2)
CH4VMRLevSup	level CH4 volume mixing ratio (ppv)
CH4_VMR_eff_10func	trapezoid effective CO volume mixing ratio

7.2 Thermodynamic/Ice Cloud Products

Four primary new cloud products are provided in the L2 Support Product: cloud thermodynamic phase, ice cloud optical thickness, ice cloud effective diameter, and effective ice cloud top temperature. The cloud thermodynamic phase is based on a series of spectral radiance tests and the presence of cloud, according to the AIRS Standard L2 effective cloud fraction product. The ice cloud optical thickness, ice cloud effective diameter, and effective ice cloud top temperature are retrieved on AIRS FOVs that contain ice, according to the cloud thermodynamic phase product, using an optimal estimation retrieval post-processor after completion of the AIRS Standard L2 retrieval. The remaining new cloud products are either quality control indicators, error estimates on the retrieved quantities, or detailed aspects of the initial guess and information content of the primary retrieval parameters.

7.3 Spectral OLR

The OLR products are now reported in 16 spectral bands in the L2 Support Product (**OLRBand**), averaged to the AMSU resolution. The bands (cm^{-1}) are:

10→350	700→820	1180→1390	2080→2250
350→500	820→980	1390→1480	2250→2380
500→630	980→1080	1480→1800	2380→2600
640→700	1080→1180	1800→2080	2600→3250

7.4 Boundary Layer Height

The pressure at the top of the planetary boundary layer (**bndry_lyr_top**) and associated quality control are reported in the L2 Support Product at the resolution of the AMSU FOV, since the vertical positioning of thermodynamic profile gradients are used to locate the top of the PBL. This height is reported in units of pressure (hPa). The boundary layer top height is the pressure of the level with the largest gradient of a relative humidity (relative to liquid phase of water) layer profile calculated on the support pressure layer grid. This product is considered a derived rather than a retrieved parameter, and so no error estimate is provided.

Reference; Martins, J. P. A., J. Teixeira, P. M. M. Soares, P. M. A. Miranda, B. H. Kahn, V. T. Dang, F. W. Irion, E. J. Fetzer, *and* E. Fishbein (2010), Infrared sounding of the trade-wind boundary layer: AIRS and the RICO experiment, Geophys. Res. Lett., 37, *L24806, doi:*10.1029/2010GL045902.

7.5 Climatological Quantities

These fields are derived from climatologies, not from AIRS retrievals, but are included in the AIRS L2 support product files for use when analyzing AIRS data.

V5 L2 support product provided climatology values for CO2 (**CO2ppmv**) and MODIS land surface emissivity from MODIS MYD11C3 for one year. V6 adds MODIS land surface emissivity expanded to 10 hinge points using the methodology of Seemann and Borbas (see section 3.9.1) (**MODIS_emis_10_hinge**) , MODIS land surface temperature (**MODIS_LST** plus associated info in **MODIS_LST_***), and values extracted from ECMWF climatology for temperature and water vapor (**TSurfClim**, **TSurfAirClim**, **TAirClim**, **H2OCDClim**). The MODIS land surface emissivity at 10 hinge points is used as a first guess in the retrieval and the CO2 is used as a fixed background. The other fields are provided only for user reference.

7.6 Forecast Quantities

These fields are derived from the NOAA NCEP GFS forecast, not from AIRS retrievals, but are included in the AIRS L2 support product files for use when analyzing AIRS data.

Forecast surface temperature (**tsurf_forecast**) was included in v5. V6 L2 support adds 2 components of 10-meter wind (**Forecast_Wind_U**, **Forecast_Wind_V**).

Forecast surface temperature is used in the IR-only version of the AIRS retrieval only to identify frozen vs nonfrozen ocean cases when AMSU cannot provide that information. Wind data is extracted from the forecast only for use when analyzing AIRS data.

8 Products Moved from L2 Standard Product to L2 Support Product

The following products appearing in the V5 L2 Standard Product have been moved to the L2 Support Product in V6:

- Cloud fields on AMSU 45-km spots (**numCloud**, **TCloudTopStd**, **PCloudTopStd**) These are replaced in L2 Std by **nCld**, **TCloudTop**, and **PCloudTop**, all on AIRS 15-km spots. The coarser fields are retained in L2 support, but users are encouraged to use the finer ones.
- A number of low-level internal quality indicators (**Tdiff_IR_4CC1**, **TSurfdiff_IR_4CC1, CC1_Resid**, …)

9 Products Removed from L2 Standard Product

All **Qual_*** have been removed. The quality flags for quantities are now named according to the associated quantity as **<quantity>_QC**, and they appear for every quantity, including at every level of profiles.