Lessons Learned from AIRS: Improved Determination of Surface and Atmospheric Temperatures Using Only Shortwave AIRS Channels

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AIRS

AIRS is a grating detector array spectrometer launched on Eos Aqua in May 2002. It provides information about surface and atmospheric temperature, water vapor and constituent profiles, and clouds.

Measures upwelling radiance $\hat{R}_i$ in 2360 spectral channels $i$ between 650 cm$^{-1}$ and 2665 cm$^{-1}$.

$$\frac{\nu_i}{\Delta \nu_i} \approx 1200 \quad \Delta \nu_i \text{ goes from } 0.5 \text{ cm}^{-1} - 2.2 \text{ cm}^{-1}$$

Spatial resolution $\approx 13$ km at nadir from 705 km orbit.

Referred to as AIRS Field of View (FOV).

AIRS was accompanied by AMSU-A:

- Microwave temperature profile sounder
  - Spatial resolution $\approx 45$ km at nadir
  - Referred to as AIRS Field of Regard (FOR)

  9 AIRS FOV’s fall within one FOR.

AIRS was designed specifically to have very low noise at short wavelengths. IASI, a high spectral resolution IR interferometer on METOP-A, has much higher noise at short wavelengths.
AIRS and IASI NEDT evaluated for a tropical atmosphere
Overview of AIRS Science Team Retrieval Methodology

Physically based retrieval system

Independent of GCM except for surface pressure - used to compute expected radiances

Uses cloud cleared radiances $\hat{R}_i$ valid for AIR FOR to determine the solution

$\hat{R}_i$ represents what AIRS would have seen in the absence of clouds

Derivation of $\hat{R}_i$ is updated in different steps of the retrieval process

**Basic steps**

Initial cloud clearing produces $\hat{R}_i^0$ - based on statistical initial guess using observed radiances $R_i$

Sequentially determine surface parameters, $T(p)$, $q(p)$, $O_3(p)$, $CO(p)$, $CH_4(p)$, using $\hat{R}_i^0$

Each step uses its own set of channels

Generate error estimates $\delta T(p)$, $\delta q(p)$ and use for Quality Control (QC)

Retrieval system can be used with AIRS/AMSU radiances or in “AIRS Only” mode without AMSU radiances

Goddard DISC had been analyzing AIRS/AMSU data using AIRS Version-5 algorithm

Retrieveds are near real time

Analyzed data from September 2002 through the present

AIRS Science Team Version-6 algorithm will become operational in late 2011
Objectives of AIRS/AMSU

Provide real time observations to improve numerical weather prediction via data assimilation

Could be $R_i$ (used by NCEP, ECMWF) or $T(p), q(p)$

Accuracy of $\hat{R}_i, T(p), q(p)$ degrades slowly with increasing cloud fraction

There is a trade-off between accuracy and spatial coverage

  - Assimilation of soundings or radiances only in clear cases limits utility of the data
  - Assimilation of poorer quality retrievals can degrade forecast skill

Provide observations to measure and explain interannual variability and trends

  - Must provide good spatial coverage but also be unbiased
  - Can be less accurate than needed for data assimilation

Use of AIRS product error estimates allows for QC optimized for each application

  - Tighter QC is better for data assimilation
  - Looser QC is better for climate applications
Significant Improvements in AIRS Retrieval Methodology

Improvements in AIRS Version-5

Improved radiative transfer parameterization accounts for effects of Non-Local Thermodynamic Equilibrium (non-LTE)

Allows for complete use of 4.3 μm CO₂ sounding channels to determine T(p)

Following theoretical considerations:

\[ \hat{R}_i \] for 15 μm CO₂ channels are used only for cloud clearing coefficients

Gives clear column radiances \( \hat{R}_i \) for all channels

\( \hat{R}_i \) for 4.3 μm CO₂ channels are used to determine temperature profile T(p)

This allows for accurate T(p) soundings under more difficult cloud conditions

Further improvements in Version-6

Only shortwave window channels are now used to determine \( T_{\text{skin}} \), shortwave surface spectral emissivity \( \varepsilon_{\text{SW}}^{(v)} \), and bi-directional reflectance \( \rho_{\text{SW}}^{(v)} \)

\( \hat{R}_i \) in longwave window channels are used in a subsequent retrieval step to determine \( \varepsilon_{\text{LW}}^{(v)} \) given \( T_{\text{skin}} \)

This provides accurate surface soundings under more difficult cloud conditions

Version-6 also has other improvements compared to Version-5
Sample AIRS Cloud Free Brightness Temperature Version 6 Channels

*Cloud Clearing*  *Temperature Profile*  *Surface Skin and T(p)*
*Water Vapor*  *Ozone*  *CO*
*CH₄*  *LW Emissivity*
Methodology Used for \( T(p) \) Quality Control

Version-5

Define a profile dependent pressure, \( p_{\text{best}} \), above which the temperature profile is flagged as good - otherwise flagged as bad

Use error estimate \( \delta T(p) \) to determine \( p_{\text{best}} \)

Start from 70 mb and set \( p_{\text{best}} \) to be the pressure at the first level below which \( \delta T(p) > \) threshold \( \Delta T(p) \) for 3 consecutive layers

Temperature profile statistics include errors of \( T(p) \) down to \( p = p_{\text{best}} \)

Version-5 used \( \Delta T(p) \) thresholds optimized simultaneously for weather and climate: \( \Delta T^{\text{standard}}(p) \)

Subsequent experience showed \( \Delta T^{\text{standard}}(p) \) was not optimal for data assimilation (too loose) or for climate (too tight)

Use of new tighter thresholds \( \Delta T^{\text{tight}}(p) \) resulted in retrievals with lower yield but with RMS errors \( \approx 1 \text{K} \)

Performed much better when used in data assimilation experiments

Version-6

QC is analogous to Version-5 but has tight thresholds \( \Delta T_A(p) \) for data assimilation and loose thresholds \( \Delta T_C(p) \) for climate applications

\( \Delta T_A \) thresholds define \( p_{\text{best}} \) and \( \Delta T_C \) thresholds define \( p_{\text{good}} \)

\( \Delta T_A \) thresholds designed to give RMS errors \( \approx 1 \text{K} \)

\( \Delta T_C \) thresholds are used to generate level-3 gridded products
Forecast Impact Tests using Version-5 T(p)

Forecast impact tests were done at GSFC using GOES-5

Ran four sets of experiments, covering different seasons and years.
   October 15 – November 19, 2005
   August 10 – September 16, 2006
   April 15 – May 18, 2008

Four sets of assimilations were performed for each time period
   Control – uses no AIRS data but all other observations assimilated operationally
   Radiance – assimilates AIRS radiances as done operationally
   AIRS Standard assimilates AIRS T(p) down to \( p_{\text{best}} \) defined by standard thresholds
   AIRS Tight assimilates AIRS T(p) down to \( p_{\text{best}} \) defined by tight thresholds

7-day forecasts run from each 0 Z Analysis for each experiment

The accuracy is judged against anomaly correlation of 7-day forecasts vs.
   ECMWF Analysis for that time
An anomaly correlation of 1.0 represents a perfect forecast.
An anomaly correlation of 0.6 is the lower bound of a useful forecast.
AIRS Tight improves 7-day forecast skill by about 4 hours.
AIRS Science Team Version-6 algorithm determines tropospheric $T(p)$ and $T_{\text{skin}}$ using only shortwave channels 2197 cm$^{-1}$ – 2664 cm$^{-1}$. The 15 μm tropospheric sounding CO$_2$ channels are used only for cloud clearing (as in Version-5)

**Use of only shortwave channels to determine $T_s$ and tropospheric $T(p)$ results in:**
- “AIRS Only” retrievals that are comparable to AIRS/AMSU
  - Slightly lower yield with comparable accuracy
- Improved soundings of $T(p)$ and SST, day and night
  - Improvements are larger with increasing cloud cover
- Performance during day is actually superior to performance at night
  - Higher yields and lower errors, especially at larger cloud fraction

This new approach is practical with AIRS because
- Solar radiation reflected by the surface is solved for in the surface retrieval step
- Solar radiation reflected by clouds is accounted for in the cloud clearing step
- **AIRS channels have very low noise at short wavelengths**

This approach is not practical with IASI because shortwave NEDT is too large.

It is optimal for future (GEO) high-spectral resolution IR sounders to have low NEDT out to 2500 cm$^{-1}$. There is no need for a GEO MW sounder.