INFRA-RED SOUNDERS
Part 2: Results Using AIRS Version 5

Joel Susskind
NASA GSFC

Workshop on Applications of Remotely Sensed Observations in Data Assimilation

August 7, 2007
Objectives of AIRS/AMSU

Provide real time observations to improve numerical weather prediction

- Could be \( \hat{R}_i \) (used by NCEP, ECMWF) or \( T(p), q(p) \) (used by Robert Atlas)
- 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
- Using soundings or radiances only in clear cases limits utility of the data

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
- Must not contain systematic data gaps in certain regions
- Error estimates and quality flags provide options for use in either weather or climate applications
- Version 5 quality flags are based on fixed error estimate thresholds
- The user can assign different quality flags as they see fit
Generation of Empirical Error Estimates $\delta X_i$

**This step is done after physical retrieval is otherwise completed**

**Methodology used for** $\delta S ST, \delta T(p), \delta W_{tot}/W_{tot}$ **is identical**

Uses 16 internally computed values of convergence tests $Y_j$ (**13 in V5 AO**)

Thresholds of 12 $Y_j$ terms are used in Version 4 quality control

$\delta X_i$, error estimate for $X_i$, is computed according to

$$\delta X_i = \sum M_{ij} Y_j$$

**Determination of $M_{ij}$**

Use profiles with “truth”

$$\Delta X_i = |X_i - X_i^{\text{TRUTH}}|$$

Each profile now has $\Delta X_i$, $Y_j$

$M_{ij}$ found which minimizes RMS $|\delta X_i - \Delta X_i|$

$M_{ij}$ generated using all September 29, 2004 cases in which IR retrieval is accepted

ECMWF taken as “truth” to provide $\Delta X_i$

$M_{ij}$ tested on January 25, 2003 - used once and for all

Same basic approach is used for $\delta \hat{R}_i, \delta q(p)$
Methodology Used for V5 Quality Control

**Temperature Profile T(p)**

Define a profile dependent pressure, \( p_g \), above which the temperature profile is flagged as good - otherwise flagged as bad.

Use error estimate \( \delta T(p) \) to determine \( p_g \).

Start from 70 mb and set \( p_g \) to be the pressure at the first level below which

\[ \delta T(p) > \text{threshold for } n \text{ (currently } = 3\text{) consecutive layers} \]

Temperature profile statistics include errors of \( T(p) \) down to \( p = p_g \).

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**Sea surface temperature \( \text{SST} \)**

Flag SST as good if \( \delta \text{SST} < 1.0K \).

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**Total precipitable water \( W_{\text{tot}} \)**

Flag \( W_{\text{tot}} \) as good if \( \delta W_{\text{tot}} / W_{\text{tot}} < 0.35 \).

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**Clear column radiance \( \hat{R}_i \)**

Flag \( \hat{R}_i \) as good if \( \delta \hat{R}_i < 0.9K \) in brightness temperature error units.
Thresholds for T(p) - Computation of $p_g$

$p_g$ is the highest pressure at which $\delta T(p) > \delta(p)$ for 3 consecutive levels

$\delta(p)$ is defined at 3 pressures: $\delta(70\text{ mb}), \delta(p_{surf}/2)$, and $\delta(p_{surf})$

$\delta(p)$ is linearly interpolated in ln $p$ between these 3 values

Separate threshold values for $\delta(p)$ are set for non-frozen ocean and for land/ice

Version 5 uses Standard thresholds optimized for weather and climate simultaneously

We have done forecast impact experiments with other thresholds: Medium and Tight

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<tr>
<th>Table 1</th>
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<tr>
<td>Temperature Profile Thresholds (K)</td>
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<tr>
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<th>Ocean</th>
<th>Land/Ice</th>
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<tr>
<td></td>
<td>$\delta T_{70}$</td>
<td>$\delta T_{mid}$</td>
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<tr>
<td>Standard</td>
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<tr>
<td>Medium</td>
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<tr>
<td>Tight</td>
<td>1.75</td>
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Quality Flags for Accepted Retrievals

QC = 0 (Best)  QC = 1 (Good)  QC = 2 (Do not use)

Use for data assimilation  Use for Level 3

Temperature Profile
Version 5
QC T(p) = 0  if  $p \leq p_g$
QC T(p) = 1  over land if  $p \geq p_g$ and $p_g \geq 300$ mb
QC T(p) = 2  otherwise (QC never = 1 over ocean)

Version 4
QC T(p) = 0 within three distinct pressure ranges if ad-hoc individual tests are passed
QC T(p) = 1 for $p \geq 500$ mb if mid-tropospheric temperature test is passed - both land and ocean
QC T(p) = 2 otherwise

Land skin temperature, emissivity - same for Version 5 and Version 4
QC = 1  if QC surf air = 1
QC = 2  otherwise

Sea surface temperature - same for Version 5 and Version 4
QC = 0 if tight test is passed
QC = 1 if standard test is passed

Constituent test
Passed if $\frac{\delta W_{tot}}{W_{tot}} \leq 0.35$ in Version 5
Passed with ad-hoc test in Version 4
QC q(p) = 2 if constituent test fails, QC q(p) = 0 or 1 if constituent test is passed
QC q(p) = 0 only if QC T(p) = 0
300 mb Temperature (K)  
Retrieved minus ECMWF  
January 25, 2003  
V5

(a) 300 mb Temperature Errors
(b) 300 mb Temperature Predicted Errors
(c) Error when $P_{300} \geq 300$ mb
(d) Predicted Error minus Absolute Value Error

GLOBAL MEAN = -0.15  STANDARD DEV = 1.48
GLOBAL MEAN = 0.98  STANDARD DEV = 0.61
GLOBAL MEAN = -0.13  STANDARD DEV = 1.18
GLOBAL MEAN = -0.13  STD = 0.87  CORR = 0.52
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Layer Mean RMS Temperature (°C)
Global Differences From "Truth"
January 25, 2003
Global

Percent of IR/MW Cases Included
January 25, 2003
Global

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<tr>
<th>PRESSURE (mb)</th>
<th>RMS</th>
<th>V4</th>
<th>VS Standard</th>
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Percent

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Surface Skin Temperature (K) Retrieved minus ECMWF January 25, 2003

(a) All IR SST Errors

(b) Predicted SST Errors

(c) Error when Predicted Error is 1.0

(d) Predicted SST Error minus Absolute value SST Error

GLOBAL MEAN = -1.61 STANDARD DEV = 4.46

GLOBAL MEAN = 2.46 STANDARD DEV = 2.08

GLOBAL MEAN = 0.03 STANDARD DEV = 0.84

GLOBAL MEAN = -0.22 STD = 2.64 CORR = 0.76
Sea Surface Temperature (K)

QC = 0 and 1

AIRS Version-5 minus ECMWF
January 2004 minus January 2003

Global Mean = -0.01
Standard Dev. = 0.60
Corr. = 0.48

AIRS Version-4 minus ECMWF
January 2004 minus January 2003

Global Mean = 0.07
Standard Dev. = 0.73
Corr. = 0.32

AIRS Version-5
January 2004

Global Mean = -0.19
Standard Dev. = 0.64

AIRS Version-4
January 2004

Global Mean = -0.35
Standard Dev. = 0.64
Clear Column Radiances Error Estimates $\delta \hat{R}_i$

$$\hat{R}_i = \bar{R}_i + \sum_{j=1}^{9} \eta_j (R_{i,j} - \bar{R}_i)$$

If all $\eta_j$ were perfect

$$\delta \hat{R}_{i,\text{per}} = \left[ \left( \sum_{j=1}^{9} \frac{1}{9} \left( 1 + \sum_{j=1}^{9} \eta'_j - \eta_j \right) \right)^2 \right]^{1/2}$$

$$\text{NEAN}_i = A \text{ NEAN}_i \approx \sum_{j=1}^{9} \left[ \eta_j^2 \right]^{1/2} \text{ NEAN}_i$$

$A$ is the channel noise amplification factor

Larger $\eta$'s (more cloud clearing) results in more channel noise in $\hat{R}_i$

If channel $i$ does not see clouds, we set all $\eta_j = 0$ $A = 1/3$ (noise reduction)

Errors in $\eta_j$ will result in additional errors in $\hat{R}_i$, which are correlated from channel to channel

We set

$$\delta \hat{R}_i = (A \text{ NEAN}_i) + \left[ \sum_{k=1}^{6} \hat{M}_{i,k} \delta T(p_k) \right] + \hat{M}_{i,7} \left[ \delta W_{\text{tot}} / W_{\text{tot}} \right]$$

Where $\delta T(p_k)$ is the error estimate for $T(p_k)$ and $\delta W_{\text{tot}} / W_{\text{tot}}$ is the fractional error estimate for $W_{\text{tot}}$

Coefficients of $\hat{M}$ are generated analogously to coefficients of $M$

Use $R_{i,\text{CLR}}$ computed from ECMWF as $\hat{R}_i^{\text{truth}}$
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Clear Column Brightness Temperature minus "Truth"
January 25, 2003
Global
650 to 756 cm⁻¹

Mean Clear Column Brightness Temperature

STD (°K)

650 660 670 680 690 700 710 720 730 740 750

Wavenumber, cm⁻¹

Version 5 CCR predicted 0.90 Noise Version 4 Mid-Trop Good

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Forecast Impact Test

Experiments run with GSFC GOES-5 data assimilation system

- Forecasts run at 1° x 1° resolution
- Analysis using NCEP GSI analysis at 1° x 1° resolution

Data period covers January 1, 2003 - January 31, 2003

Control uses all data NCEP used operationally at that time

- Assimilates all satellite data but AIRS, including Aqua AMSU radiances

Control + AIRS adds V5.0 global quality controlled T(p) retrievals

- Assimilated as if radiosonde data
- \( \delta T(p) \) is used as the measurement error

27 independent forecasts run from each analysis

Forecasts verified against NCEP analysis
Experiment 1: Assessment of Trade-Off of Spatial Coverage and Overall Accuracy

We compared forecasts from four assimilations

1a Control
1b AIRS V5 Standard QC
1c AIRS V5 Medium QC
1d AIRS V5 Tight QC

Data assimilated in all three AIRS experiments is identical, except for computation of $p_g$
Sea Level Pressure

N Hem Extra Tropics

Sea Level Pressure

S Hem Extra Tropics

Anomaly Correlation

Day

- Control
- AIRS Version 5 Standard
- AIRS Version 5 Medium
- AIRS Version 5 Tight
Findings of Experiment 1

All three AIRS data assimilation experiments improved forecast skill significantly compared to the control
Northern hemisphere extra-tropics improvement in 5 day forecast skill
   3 hours for Tight QC, 5 hours for Medium QC and Standard QC
Southern hemisphere extra-tropics improvement in 5 day forecast skill
   4 hours for Tight QC, 6 hours for Medium QC and Standard QC
Medium QC performed slightly better than Standard QC, which was optimized for climate
Tight QC lost substantial impact as a result of reduced spatial coverage
We are performing more experiments to find optimal trade of accuracy and coverage for data assimilation
Experiment 2: Test of The Importance of Assimilation of Tropospheric Temperatures

Motivation

Tony McNally at ECMWF stated that most of the impact of AIRS radiances on ECMWF analysis comes from 15μm stratospheric sounding channels—claims only stratospheric information is important.

We compared forecasts from four assimilations:

2a  Control – same as 1a
2b  AIRS V5 Medium QC – same as 1c
2c  AIRS V5 Medium QC but only down to 200 mb
2d  AIRS radiance assimilation – uses primarily stratospheric AIRS radiance information

Data assimilated in all three AIRS experiments is identical, except for computation of $p_g$
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Findings of Experiment 2

Assimilation of AIRS temperature soundings only down to 200 mb (2c) produced no forecast impact

Most important information is coming from tropospheric temperatures in partial cloud cover

Assimilation of AIRS radiances unaffected by clouds (2d) was only slightly better than (2c)

AIRS cloud free radiances contain some tropospheric information - but is sub-optimal

Assimilation of AIRS radiances should perform better if

1) Use $\hat{R}_i$, together with error estimates

2) Do not use water vapor or ozone channels (Joanna Joiner wrote a paper on this)

   Assimilation of these radiances makes problem highly non-linear

   Positive impacts shown when we assimilated only AIRS T(p)

3) Make better use of AIRS 4.2 $\mu$m channels - day and night

   • Perform surface parameter retrieval step before assimilation step to obtain $T_s, \varepsilon_i, \rho_i$

   Allows for use of lower tropospheric sounding 4.2 $\mu$m channels

   • Install new RTA that accounts for non-LTE so all 4.2 $\mu$m channels can be used

We will try experiments doing 1) and 2) in the near future
Some Planned Improvements for Version 6

Improved retrieval of $\varepsilon_i, \rho_i$ - especially over land

Will result in better yield and higher accuracy of lower tropospheric $T(p)$

Higher spatial resolution retrievals

Version 5 produces 1 AIRS retrieval per 3x3 array of AIRS footprints

45 km x 45 km at nadir 150 km x 80 km at end of scan

Version 6 will produce 1 AIRS retrieval per 1 (cross track) x 3 (along track) AIRS footprints

15 km x 45 km at nadir 50 km x 80 km at end of scan

Should help retrievals, especially over land (less surface variability in FOR)

Provide stratospheric temperature soundings in overcast conditions

Possibly down to cloud level

Optimize quality flags separately for climate and data assimilation purposes
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