Lessons Learned with the AIRS Hyperspectral Sensor

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Thanks to: ASL Group Members: Scott Hannon, Sergio De Souza-Machado, and Howard Motteler.
Overview

- RTA update (SARTA/kCARTA)
  - Non-LTE
  - Clear sky
- Minor gases
- Progress on detecting, modeling mineral dust with scattering RTA
- Doing climate with hyperspectral sensors
Bias summary of Non-LTE: Ignore black line

![Graph showing bias summary of Non-LTE](image)
Global Behavior of Non-LTE (July 1-15)

Day: 2361 cm\(^{-1}\)

Night: 2361 cm\(^{-1}\)

Day - Night: 668 - 2361 cm\(^{-1}\)
Zoom of Bias and Std’s for Non-LTE
Bias vs Solar Angle: No Non-LTE Fix
Bias vs Solar Angle with Non-LTE Fix
15 $\mu m$ Bias vs Solar Angle, No Non-LTE Emission
Work by H. Aumann (NASA/JPL)

The 600 mK cold bias is explained to 10 +/- 120 mK

The accuracy at 2616 cm$^{-1}$ in the 290-305 K range is 10 +/- 120 mK with stability of <16 mK/year for all data from 200209-200508 (JGR 2006)
SRF Shape (fringes) Introduce Bias: Understood, not fully implemented
Slight frequency shifts: Important for climate
A great RTA validation dataset exists

**Table:** Number sonde launches, LIDAR observations, coincident with AIRS.

<table>
<thead>
<tr>
<th>Name</th>
<th>Technique</th>
<th># of Coincident Sondes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARM TWP Phase1</td>
<td>RS-90</td>
<td>154</td>
</tr>
<tr>
<td>ARM TWP Phase2</td>
<td>RS-90</td>
<td>178</td>
</tr>
<tr>
<td>ARM TWP Phase3</td>
<td>RS-90</td>
<td>163</td>
</tr>
<tr>
<td>ARM SGP Phase1</td>
<td>RS-90</td>
<td>125</td>
</tr>
<tr>
<td>ARM SGP Phase2</td>
<td>RS-90</td>
<td>171</td>
</tr>
<tr>
<td>ARM SGP Phase3</td>
<td>RS-90</td>
<td>160</td>
</tr>
<tr>
<td>Mcmillan/ABOVE</td>
<td>RS-90</td>
<td>195</td>
</tr>
<tr>
<td>Minnett</td>
<td>RS-90</td>
<td>146a</td>
</tr>
<tr>
<td>Vömel</td>
<td>FP</td>
<td>29</td>
</tr>
<tr>
<td>Whiteman/LIDAR</td>
<td>SRL</td>
<td>23</td>
</tr>
</tbody>
</table>

a. Includes RS-80 sondes not used here.

**Table:** Summary of number of clear observations over ocean at night.

<table>
<thead>
<tr>
<th>Name</th>
<th>% Clear</th>
<th># Sonde/Lidar Profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARM TWP</td>
<td>15</td>
<td>38</td>
</tr>
<tr>
<td>Mcmillan/ABOVE</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Minnett</td>
<td>25</td>
<td>23</td>
</tr>
</tbody>
</table>
RS-90 Validation Campaign Bias Results

![Graph showing bias results](image-url)
RS-90 vs ECMWF Biases: 24 Month Avg

![Graph showing B(T) in K vs Wavenumber (cm⁻¹)](image)

- **Graph a.** B(T) in K vs Wavenumber (cm⁻¹)
- **Graph b.** Sonde Bias
- **Graph c.** ECMWF Bias
BUT (the bad news): We had to empirically adjust transmittances (using ARM-TWP 1)
Adjustments in units of optical depths

- Fixed Gases
- Water Lines
- Water Continuum
Adjustments in units of optical depths: Zoom of Fixed Gases (CO$_2$)
Day/Night RS-90 and Frost-Point Differences

Mean night vs day biases for a. all RS-90 sondes, b. Vömel’s (NOAA/CMDL) frost-point hygrometers
Minor gases need to be well understood to:

1. Validate the RTA
2. Use hyperspectral sensors for climate

Plus, we might find something interesting.

Stratospheric “interference” a big problem? (Especially important for polar work with hyperspectral.)
Variable CO$_2$: ECMWF for T(z)
And it’s global variation
CO$_2$ Variability Important for Weather and Climate

![Graph showing CO$_2$ variability](image)

- Val Period
- Mission Life
Latest CO$_2$ from AIRS, 38 Months: $\sim$25-45 Deg
CH$_4$ Interferes with H$_2$O

![Graph showing the interference between CH$_4$ and H$_2$O](image.png)
CH$_4$

October 2003: $\nu = 1254$ cm$^{-1}$

![Graph showing CH$_4$ changes](image)
Volcanic SO$_2$ and Ash are seen
May 2004 Monthly Means of HNO$_3$

- RTA modified to include variable HNO$_3$
- Used L2 retrievals, just varied scalar multiplier of HNO$_3$ column
- HNO$_3$ unit is (observed column)/(reference column). Reference column is $\approx 10^{14}$ mol/cm$^2$
- Ocean only
HNO₃ Signal in Polar Granule Residuals

![Graph showing HNO₃ signal in polar granule residuals with wavenumber range from 800 to 1400 cm⁻¹ and bias in K and HNO₃ concentration changes.](graph.png)
Very Rough Validation versus MIPAS
GEOS-CHEM: Sept. 20-21, 2004, 430 and 600 mbar

Night:

Day:

HNO₃ 20040921 18 GMT at 430 hPa (6.5 km)

HNO₃ 20040921 12 GMT at 600 hPa (4.2 km)
B(T) Influence for 1X Change in HNO$_3$, Channel 1440

- About 5 channels this sensitive
- 189 AIRS channels have $\text{dB(T)}/\text{d(HNO}_3 = 1\text{X}) > 0.1\text{K}$
AIRS Dust Observations: Scattering SARTA

- We have observed many dust outbreaks, with quantitative analysis over oceans using SARTA-scattering
- Paper in GRL on Medit. case (comparisons to MODIS)
- Some differences in spectral structure (index of refraction)
- Observed volcanic ash clouds
- Hyperspectral IR sees dust throughout tropical Atlantic in summer: *Important to include in assimilation/retrieval for hurricane applications?*
- Developing a dust flag for next AIRS processing cycle. Hopefully future reprocessing will include dust optical depth. More work needed on how to handle dust vertical structure and interfering clouds.
- SARTA/kCARTA now has scattering based on paper by Chou, Lee, Tsay, Fu; Parameterization for Cloud Longwave Scattering for use in Atmospheric Models in Journal of Climate, vol 12, pg 159 (January 1999)
- Two layer clouds possible, so can have water plus ice, or water plus dust. Very fast with analytic Jacobians.
Mediterranean Dust Storm
Derived Optical Depths at 900 cm$^{-1}$: Scattering SARTA
MODIS vs AIRS-derived Optical Depths
Spectral Effects of Dust

\[ \Delta BT \text{ (K)} \]

\[ \text{Wavenumber cm}^{-1} \]

(a) (b) (c) (d)
Day 1: Dust Flag

Sahara Dust 07/16/2005
Day 2: Dust Flag

Sahara Dust 07/17/2005
Day 3: Dust Flag

Sahara Dust 07/18/2005
Day 4: Dust Flag

Sahara Dust 07/19/2005
Day 5: Dust Flag

Sahara Dust 07/20/2005
Day 6: Dust Flag

Sahara Dust 07/21/2005
Day 7: Dust Flag

Sahara Dust 07/22/2005
Day 8: Dust Flag

Sahara Dust 07/23/2005
April 8, 2006

Dust Map for 2006.04.08
April 9, 2006

Dust Map for 2006.04.09
April 12, 2006
April 13, 2006
April 14, 2006

Dust Map for 2006.04.14
April 15, 2006

Dust Map for 2006.04.15
April 16, 2006
April 17, 2006

Dust Map for 2006.04.17
AEROSE Dust Study

May 2005 AIRS-STM
March 7, 2004: (AEROSE) Duststorm off W. Africa
• "X" marks location of ship
• Lots of cloud contaminating the scene
• Weight $\Delta BT(900\text{cm}^{-1},961\text{ cm}^{-1})$ more strongly

SSM, UMBC
- Left slide is false color visible image
- Right slide is $\log_{10}(\text{red}/\text{blue})$, so higher values imply AIRS is looking at something other than warm blue ocean!
- “X” marks position of ship
Photometer indicates “dusty” sky
Cannot simultaneously fit AIRS and MAERI data
Also might have sunglint problems??
blue = obs, green = clear calc, red = cloudy calc
AIRS sim : dust from 900 mb down, $D \approx 1.5$ um, 
$\tau(900\text{cm}^{-1}) \approx 1.02$
MAERI sim : dust from 900 mb down, $D \approx 2.5$ um, 
$\tau(900\text{cm}^{-1}) \approx 0.4$
Can we use hyperspectral IR sensors for climate studies

Lot’s of issues

- Sampling errors with clear?
- How do climate with cloudy FOVS?
- Tie sensor’s radiometric cal (AIRS to IASI to CrIS)
- Minor gases
- Different spectral response functions

We have sub-setted “clear” ocean-only FOVS since AIRS started operation. Now have 38 month data set (always growing).

A quick look at what this data set sees:
Biases versus ECMWF have SST and TCW “retrieved”
Bias/Obs Differences, $\Delta t = 2$ Years: Mid Lat
Bias/Obs Differences, $\Delta t = 2$ Years: Mid Lat:Zoom
Bias/Obs Differences, $\Delta t = 2$ Years: Mid Lat:Zoom
Bias/Obs Differences, $\Delta t = 2$ Years: High Lat
Conclusion

Doing climate with hyperspectral sensors will require a lot of work, but we have the capability to produce an excellent radiometric record with AIRS.