Application of radiative transfer to slanted line-of-sight geometry and comparisons with NASA EOS Aqua data

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Introduction

(A)TOVS / AIRS soundings: usually considered as «vertical soundings»

This study: apply RT codes to simulate radiances from NWP background along slanted line-of-sights

Outline:
- Slanted RT calculations implementation
- Results with GMAO analysis background
- Results with ECMWF 6-hour forecast background
Geometry 101

EOS Aqua

zenith

AIRS pixel

line-of-sight
AIRS scans up to 49.5 degrees on each side, i.e. up to 59 degrees Satellite Zenith Angle.
Geolocation Parameters Necessary for Implementing Slanted RT Calculations

EOS Aqua

Satellite Zenith Angle
Satellite Azimuth Angle
lat, lon
RT codes require $T, q, O_3$ on a fixed set of pressure levels $P_{RT \ j}$

- Extract $T, q, O_3$ from background fields at the vertical of the footprint at pressures $P_{RT \ j}$ neglecting atmospheric horizontal gradients,
  
  ➡️ **VERTICAL RT CALCULATIONS**

**OR:**

- Extract $T, q, O_3$ from background fields along the slanted LOS at pressures $P_{RT \ j}$
  
  ➡️ **SLANTED RT CALCULATIONS**
Geolocation procedure

- Extract the model pressure profile \( P_{NWP \, i} \) above the footprint \((\text{lat}, \text{lon})\).
- Extract height profile \( H_{NWP \, i} \) at \((\text{lat}, \text{lon}, P_{NWP \, i})\).
- For each height \( H_{NWP \, i} \):
  - Rotate location \((\text{lat}, \text{lon}, H_{NWP \, i})\) by *the appropriate angle in the appropriate plane*
    - Obtain new location \((\text{lat}_k, \text{lon}_k)\).
  - Extract pressure and height profiles at \((\text{lat}_k, \text{lon}_k)\).
  - Find pressure \( P_{NWP \, k} \) at height \( H_{NWP \, i} \).
  - Extract \( T_{NWP \, k}, q_{NWP \, k}, O_3_{NWP \, k} \) at location \((\text{lat}_k, \text{lon}_k, P_{NWP \, k})\).
- Interpolate profile \( T_{NWP \, k} \) (and \( q_{NWP \, k}, O_3_{NWP \, k} \)) from pressures \( P_{NWP \, k} \) to pressures \( P_{RT \, j} \).
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AIRS 20050126H00A Satellite Zenith Angle
Application of radiative transfer to slanted line-of-sight geometry and comparison with NASA EOS Aqua data; Full, Hunter, and Lacis, ITSC-14, 2005

AIRS 20050126H00A Satellite Azimuth Angle
RT Calculations and Evaluations

- Apply RT code to calculate brightness temperatures $B$
  - $T, q, O_3$ from vertical path: obtain $B^v$
  - $T, q, O_3$ from slanted path: obtain $B^s$

- Compare
  - the differences $B^s - B^v$ with
  - the AIRS detector noise (converted from NEDT @ 250K est. from AIRS Science Team to NEDT @ scene B.T.)

- Compare with observed B.T. denoted $O$:
  - Evaluate whether $(O - B^s)$ is smaller than $(O - B^v)$
Study #1

Background:
- hybrid analysis NCEP+GMAO+ozone,
- 1°x1.25° hor. res.

AIRS Observations:
- 281 channel subset, 16 Dec 2002,
- scenes selected as clear by GMAO cloud-screening,
- **bias-correction** (tuning) using background predictors

RT code:
- UMBC Stand-Alone Radiative Transfer code for AIRS (SARTA)
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+ : maximum difference $|B^s - B^v|$  
solid line : AIRS detector noise

Stratospheric temperature channels
Surface channels (mountains blocking path)
Ozone and water channels
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\[ + : \text{standard deviation of } (B^s - B^v) \]

Average effect below the detector noise for most channels.
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\[
+ : \ |O - B^y| - |O - B^s| < 0 : \text{degradation} \quad > 0 : \text{improvement}
\]

Analyses capture well ozone and mid-tropospheric water vapor, temperature gradients
Does less well for highest-peaking water and temperature channels
Study #1: Summary

❖ Most significant differences, when compared to detector noise at scene temperature, occur for:
   - window channels: slanted LOS geometry leads sometimes to a different lat,lon for the lowest defined model level because of terrain elevation
   - water vapor channels (effect of w.v. gradients): differences on the order of detector noise, ~0.1K
   - high-peaking channels (effect of temp. gradients): differences up to 0.2K std dev, but < AIRS detector noise

❖ When compared with AIRS observations:
   - Degradation with LOS calc. for high-peaking channels
   - Improvement for most water vapor and ozone channels
Study # 2

- **Background:**
  - ECMWF 6-hour forecast,
  - gridded at 1°x1° hor. res.

- **AIRS observations:**
  - 133 AIRS channels selected for use at MF, 26 Jan 2005,
  - scenes selected as clear by MF cloud-screening,
  - **no bias correction**

- **RT code:**
  - RTTOV-8
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+ : standard deviation of \((B^s - B^v)\)  
* : detector noise
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AIRS 20050126H00A $B_s - B_v$ (693 cm$^{-1}$)

Lower stratospheric CO$_2$ channel (peaking at 122hPa)

SMALL EFFECTS IN THE TROPICS
Mid-tropospheric water vapor channel (peaking at 560 hPa)

Larger effects in the Tropics and South (summer) hemisphere

\[ \text{AIRS 20050126H00A ABS} (B_s - B_v) > 0.1K \ (1437 \text{ cm}^{-1}) \]

AIRS 20050126H00A \[ \text{ABS} \left( B_s - B_v \right) > 0.1 \text{K} (1368 \text{ cm}^{-1}) \]

Lower tropospheric water vapor channel (peaking at 795 hPa)
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+ : std dev of (O – B̅) minus std dev of (O – B̅)
<0 : degradation     >0 : improvement

!!Small numbers!! Stdev Differences < 0.01K
Improvement on the CO₂ and H₂O channels
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\[ + : \quad 100 \frac{\text{std dev of } (O - B^v)}{\text{NEDT}} - \text{std dev of } (O - B^s) \]

<0 : degradation  >0 : improvement

Small differences for the CO\(_2\) channels (\(~1\%\) of NEDT)

Differences up to 8 % of NEDT for the water vapor channels
Study #2: Summary

AIRS data used at MF do not include high-peaking channels or ozone channels:

- Most effects of horizontal gradients on water vapor channels
- Largest differences for the water vapor channels occur in the Tropics and South (summer) hemisphere
- With slanted LOS RT, reduction of std. dev. of (O–B) up to 8% of NEDT @ scene B.T., when compared to vertical RT calculations
Conclusions

Investigation of the effects of horizontal gradients on calculated AIRS radiances

When compared to AIRS detector noise, larger effects for high-peaking (temperature) channels and water vapor channels, but in general small effects for NWP applications

Comparison with observed AIRS radiances:

- GMAO study: improvement in the fit to observations found for ozone channels, but degradation for high-peaking CO₂ channels
- ECMWF and GMAO studies: slanted calculations fit better the observations for mid/upper tropospheric water vapor and temperature channels