Three-Dimensional Characterization of Atmospheric Gravity Waves Using Thermal Radiance Imagery from AIRS and AMSU-A

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Integrating Separate AMSU-A and AIRS Research on Stratospheric Gravity Waves

**AMSU-A-only Research**
- Eckermann and Wu, ACP, 2006
- Eckermann et al., ACP, 2006

**AIRS-only Research**
- Alexander and Barnet, JAS, 2007

**Combined Analysis of Synchronous AIRS/AMSU-A Radiances from Aqua for Gravity Waves**
**Analysis of Gravity Waves in AIRS/AMSU/HSB (AAH) Temperature Retrievals**

**SCIENCE GOAL:** Global 3D Characterizations of Stratospheric Gravity Waves for Constraining Subgrid-scale Parameterizations of Large-scale Gravity Wave Effects in NWP & Climate Models
Illustrate Overall Science Goals in Application to One Orographic Gravity Wave Event

1. Are Gravity Waves Resolved in AMSU-A Thermal Radiances?
Temperature Perturbations at 90 hPa: +24 hour forecast for 14 January 2003 at 1200 UTC

(a) ECMWF IFS (T511L60)
(b) NOGAPS-ALPHA (T239L60)
(c) COAMPS (10×10 km Nest)

(d) ECMWF IFS (T511L60)
(e) NOGAPS-ALPHA (T239L60)
(f) COAMPS (10×10 km Nest)

(g) ECMWF IFS (T511L60) Cross Section
(h) NOGAPS-ALPHA (T239L60) Cross Section
(i) COAMPS (10×10 km Nest) Cross Section

AMSU-A Ch.9
AMSU-A Channel 9 Brightness Temperature Perturbations ($T'_B$)

AMSU-A EOS Aqua 1229 UTC

Max = 0.518 K
Min = -0.899 K
Are Gravity Waves Resolved in AMSU-A Thermal Radiances?

Looks Promising...

→ Validate Using 3D Forward Model
Extension to Other AMSU-A Channels

(a) AMSU-A on NOAA-15

Channels 9, 10, 11, 12, 13, 14
Model-Data Comparison by 3D Forward Modeling
(Simulate AMSU-A Measurement of Modeled $T(X,Y,Z)$ Fields)

\[
T_B(X_j, Y_j, Z_j) = \int \int \int \frac{Z_{sat}}{W_j(X - X_j, Y - Y_j, Z - Z_j)} T(X,Y,Z) \, dX \, dY \, dZ
\]

ECMWF IFS

NOGAPS-ALPHA

COAMPS®

AMSU-A Data

Channel 9: 60-90 hPa
Cross Sectional Comparisons
Point-by-Point Comparisons

(a) NOAA-16 1221 UTC Cross Section

(b) EOS Aqua 1229 UTC Cross Section

(c) NOAA-15 1641 UTC Cross Section

(d) NOAA-17 2023 UTC Cross Section
Are Gravity Waves Resolved in AMSU-A Thermal Radiances?

Yes!

*(but not as well as in AIRS radiances…)*

What about other AMSU and AIRS Channels?
AMSU-A Channels 9-14 Radiances: 14 January 2003

Increasing altitude

Aqua Overpass
Multichannel AIRS Radiances: 14 Jan 2003

[a] AIRS at ~2.5 hPa

Channel 75 (667.775 cm$^{-1}$)

[b] AIRS at ~10.0 hPa

Channel 79 (668.787 cm$^{-1}$)

[c] AIRS at ~30.0 hPa

Channel 72 (667.018 cm$^{-1}$)

[d] AIRS at ~80.0 hPa

Mean of Channels 92, 98, 104, 105, 110, 111, 116, 117, 122, 123, 128, 129, 134, 140.
New Science from This Mountain Wave Observation

What Causes the Abrupt Phase Line Orientation Change at the Channel 11-12 Interface at ~10 hPa?
Wind Speeds and Directions

(b) 14 January 2003: 1200 UTC

(b) Wind Hodograph

(60.9°N, 8.1°E)

- 1.2 hPa
- 2.7 hPa
- 5.2 hPa
- 80.4 hPa
- 12.3 hPa
- 54.6 hPa
- 247.1 hPa
- 849.0 hPa

meridional wind (m s⁻¹)

zonal wind (m s⁻¹)
Mountain Wave Modeling

Fourier-Ray $T'$ solutions for 3D elliptical obstacle

AMSU-A Radiance Pert.
Ch 09 (1200 UTC)

Min = 3.333 K
Min = 1.329 K
Min = 8.674 K
Min = 8.658 K
Min = 8.148 K
Min = 8.518 K

Max = 27.9K
Max = 29.8K
Max = 37.0K
Max = 15.2K
Max = 8.9K
Max = 3.1K

Min = 27.6K
Min = 25.7K
Min = 15.4K
Min = 20.3K
Min = 8.5K
Min = 9.2K

$\Delta T$ = 3.10K
$\Delta T$ = 3.31K
$\Delta T$ = 4.11K
$\Delta T$ = 2.26K
$\Delta T$ = 0.99K
$\Delta T$ = 1.02K

AIRS Science Team Meeting, Greenbelt, MD, 9-12 October, 2007
Validation of High-Resolution High-Altitude NWP Models
High-Resolution NWP Model Runs

explicitly-resolved mountain wave breaking and drag
NWP Model Validation using AMSU-A
Future Work

Fully Integrated AIRS/AMSU Analysis of a Variety of Gravity Wave Events

- Collaborative characterization of global gravity wave properties, sources, and momentum fluxes using all the tools we have available in the AIRS/AMSU kit....
Stratospheric Gravity Waves Generated by Deep Tropical Convection: 14 Jan 2003
The End

Thanks!
Backup Slides Follow…


SOLVE-II DC-8 Flight of 14 January 2003

Photo from the NASA DC-8 of mountain wave PSCs over south-western Scandinavia on 14 January 2003 (courtesy Paul Newman, NASA GSFC)

Mountain Wave PSCs

Aerosol Backscatter Coefficients (ABR) from NASA Langley Lidar on DC-8
Mean Sea Level Pressures

(a) 14 January 2003: 0000 UTC

(b) 14 January 2003: 1200 UTC
High Tropopause with High Relative Humidity

12 UTC on 14 January, 2003 on the 217.0 mb surface

Trop (EPV=2.5)   Asc (4 mb/hr)   Desc (4 mb/hr)
Time Evolution

AMSU-A on 4 Satellites (8 overpasses per day)

**AMSU-A Observations**

- (a) EOS Aqua 0118 UTC
  - Max = 0.318 K
  - Min = -0.253 K

- (b) NOAA-16 0226 UTC
  - Max = 0.267 K
  - Min = -0.269 K

- (c) NOAA-15 0650 UTC
  - Max = 0.273 K
  - Min = -0.334 K

- (d) NOAA-17 1033 UTC
  - Max = 0.412 K
  - Min = -0.686 K

- (e) NOAA-16 1221 UTC
  - Max = 0.439 K
  - Min = -0.814 K

- (f) EOS Aqua 1229 UTC
  - Max = 0.518 K
  - Min = -0.899 K

- (g) NOAA-15 1641 UTC
  - Max = 0.375 K
  - Min = -0.714 K

- (h) NOAA-17 2023 UTC
  - Max = 0.339 K
  - Min = -0.778 K

**Forward-Modeled NOGAPS-ALPHA**

- (a) NOGAPS-ALPHA $T_{\text{Ramp}}$ 0100 UTC
  - Max = 0.071 K
  - Min = -0.189 K

- (b) NOGAPS-ALPHA $T_{\text{Ramp}}$ 0200 UTC
  - Max = 0.256 K
  - Min = -0.220 K

- (c) NOGAPS-ALPHA $T_{\text{Ramp}}$ 0700 UTC
  - Max = 0.393 K
  - Min = -0.284 K

- (d) NOGAPS-ALPHA $T_{\text{Ramp}}$ 1000 UTC
  - Max = 0.544 K
  - Min = -0.409 K

- (e) NOGAPS-ALPHA $T_{\text{Ramp}}$ 1200 UTC
  - Max = 0.448 K
  - Min = -0.484 K

- (f) NOGAPS-ALPHA $T_{\text{Ramp}}$ 1200 UTC
  - Max = 0.436 K
  - Min = -0.488 K

- (g) NOGAPS-ALPHA $T_{\text{Ramp}}$ 1700 UTC
  - Max = 0.403 K
  - Min = -0.642 K

- (h) NOGAPS-ALPHA $T_{\text{Ramp}}$ 2000 UTC
  - Max = 0.348 K
  - Min = -0.688 K
### Very High Resolution Numerical Weather Prediction (NWP) Model Runs

<table>
<thead>
<tr>
<th>NWP Model</th>
<th>Resolution</th>
<th>$\Delta\phi$ ($\Delta x$)</th>
<th>$p_{TOP}$ ($z_{TOP}$)</th>
<th>Vertical Coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF IFS</td>
<td>$T_L 511$ L60</td>
<td>0.35° (~40 km)</td>
<td>0.1 hPa (~65 km)</td>
<td>hybrid $\sigma$-p</td>
</tr>
<tr>
<td>NOGAPS-ALPHA</td>
<td>T239 L60</td>
<td>0.5° (~55 km)</td>
<td>0.005 hPa (~85 km)</td>
<td>hybrid $\sigma$-p</td>
</tr>
<tr>
<td>COAMPS®</td>
<td>169x169 L85</td>
<td>30x30 &amp; 10x10 km$^2$ (nest)</td>
<td>(~33 km)</td>
<td>$\sigma$</td>
</tr>
</tbody>
</table>

### Vertical Resolutions $\Delta Z$

![Graph showing vertical resolutions $\Delta Z$ for different models](graph.png)

- $j = 15, 16$
- $j = 1, 30$
3D Temperature Weighting Functions From AMSU-A Channel 9

Brightness temperature (microwave radiance) = 3D AMSU-A Measurement Weighting Function

Atmospheric temperature

2D Cross Sections in (Y,Z) Plane

Horizontal “Footprints” (X,Y) Plane

(ΔX,ΔY)~50-150km, ΔZ~8km

Suggests AMSU-A Channel 9 Radiances Might Resolve Long Wavelength GWs (λ_y>150km, λ_z>10 km)
Objective Validation of Subgrid-scale Orographic Gravity Wave Drag Schemes

Single column tests using +24 hour T79L60 NOGAPS model fields

1) Palmer et al. (1986) profiles (not shown) yield large surface drags (due to low surface Froude numbers) but no GWD elsewhere

2) Webster et al. (2003) scheme (opposite)

Objective AIRS/AMSU evaluation: Scheme #2 wins here