Deep Stratospheric Gravity Waves Imaged from Satellites in Support of DEEPWAVE Science

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1. The Office of Naval Research (ONR) through NRL’s base 6.1 research program
2. NASA, through a research grant under AO NH09ZDA001N-TERRAQUA: The Science of Terra and Aqua
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1. Gravity-Wave Detection in Nadir Radiance Scene
2. Pre DEEPWAVE Climatologies
3. Proof-of-Concept Nowcasting/Validation during DEEPWAVE Practice Field Phase
4. Science Motivation and Goals

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Satellite GW Product: Executive Summary

• Gravity waves (GWs) are an “accidental detection” in nadir radiances

• First noted ~5-7 years ago as a result of advances in nadir sounding technology, particularly:
  • Improved footprint (horizontal) resolution (~100 km → ~10 km): horizontal wavelength
  • Improved precision and reduced noise in radiometric detection channels (NEDTs ~ 0.1-0.5 K): wave amplitude
  • Hyperspectral imagery (more channels → height profiles)

• We have crude forward RT models of GW detection in nadir imagery
  • Partial detection only, and most GWs are not observed at all
  • Fails in the troposphere due to cloud moisture contamination
  • GW detectability changes as background winds vary, making separation of geophysical and instrumental signals tricky
Variation of Gravity-Wave Vertical Wavelength with Winds

\[ \frac{2c \bar{U} \cos \varphi}{N} \]

\( \varphi \)  wind vector azimuth
\( \lambda_z \)  gravity-wave vertical wavelength
\( c \)  gravity-wave phase velocity (\( c \approx 0 \))
\( N \)  background buoyancy frequency
\( \bar{U} \)  background wind speed
AIRS 40 hPa Radiance Channels

AIRS channels 64, 88, 90, 94, 100, 106 & 118 (665.015–678.839 cm$^{-1}$)

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Individual Channel Radiances 64,…,118

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Mean Channel Radiance 64,…,118

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AIRS channel 71 (666.773 cm$^{-1}$).

see Hoffmann and Alexander (JGR, 2009)
Eckermann et al. (GRL 2009)
Wavelength Phase Space for Satellite GW Detection

adapted from Preusse et al. (JGR 2008)
Previous Satellite Studies: Aura MLS July 2005

Wu and Eckermann (JAS 2005)

Mean Zonal Winds (m s$^{-1}$)

Satellite GW Variances

5.0 hPa

$10^{-3}$ K$^2$
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Greater Australia/New Zealand Region

Eckermann and Wu [GRL 2012]
Hemispheric Perspective

- Broad band of enhanced variance over Southern Ocean
- Clearly nonorographic sources
- Well correlated with midlatitude spiral jet

Southern Ocean to Antarctica

AIRS 3hPa
2003-2011
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Near-realtime Aqua Level 1b Radiances

Overpass Statistics
- **Christchurch**: Closest ascending overpass at 03.02 UTC, Closest descending overpass at 14.13 UTC.
- **Hobart**: Closest ascending overpass at 04.67 UTC, Closest descending overpass at 15.78 UTC.
- **Macquarie Island**: Closest ascending overpass at 02.98 UTC, Closest descending overpass at 14.19 UTC.
- **Sturgeon Island**: Closest ascending overpass at 04.95 UTC, Closest descending overpass at 12.61 UTC.
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Rich Variable Wave Structure: Not Understood
Specific Science Questions for DEEPWAVE

**Question:** Which stratospheric gravity waves are and are not resolved in satellite imagery?

**Closure:** Coincident “ground truth” NGV deep GW measurements during satellite overpasses, forward modeled into satellite radiances

**Question:** What are the origins of rich variable 3D GW structures seen in satellite GW swath imagery in the DEEPWAVE RAO?

**Closure:** DEEPWAVE NGV measurements and detailed 3D modeling

**Questions:** What are the dominant sources of GWs in DEEPWAVE RAO? What are the relative flux contributions of GWs of various sources to the stratospheric circulation and climate?

**Closure:** DEEPWAVE NGV measurements, detailed 3D modeling and parameterization
Questions?
Backup Slides follow....
NSF DEEPWAVE Mission: June-July 2014

Remote-Sensing from the NSF/NCAR Gulfstream V

- Airglow temp. imager
- Na Lidar wind & temp.
- Rayleigh Lidar density & temp.
- Rayleigh Lidar wind & temperature
- Microwave Temperature Profiler
- Dropsondes

Temperatures
- Thermosphere
- Mesosphere
- Stratosphere
- Troposphere
- Tropopause
- Stratosphere
- Mesopause
- Thermosphere

Topographic elevation
- Outer NGV Envelope
- Observational Site
- City/Airport

Predictability Flight
- Overpass/Ferry Flight
- GW Racetrack Flight
Channel Averaging: 100-2 hPa

50 raw channel radiances → 12 net channel radiances


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<tr>
<th>Pressure (hPa)</th>
<th>Channel numbers</th>
<th>Noise (K²)</th>
<th>NEdT (K²)</th>
<th>Zonal mean</th>
<th>Map</th>
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<td>3.54</td>
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<tr>
<td>100</td>
<td></td>
<td>0.026</td>
<td>0.014</td>
<td>0.67</td>
<td>4.73</td>
</tr>
</tbody>
</table>
Isolating Small-Scale Gravity-Wave Perturbations from AIRS Level 1b Swath Radiance Imagery

Fit large-scale radiance structure in swath imagery:

- Smooth raw radiances along track using a 33-point running average (660 km)
- Fit every cross-track scan (90 points) of these smoothed radiances using a sixth-order polynomial (to capture both geophysical cross-track gradients as well as limb effects)
- Smooth fitted fields further using 15-point along-track running average

Subtract these fits of large-scale structure from raw radiances to isolate small-scale perturbation structure in the swath imagery.
AIRS RMS Brightness Temperatures
June-August 2003-2011

(a) Topographic Elevation

(b) RMS AIRS Radiance: 100 hPa

(e) RMS AIRS Radiance: 10 hPa

(f) RMS AIRS Radiance: 2 hPa
Previous Satellite Studies: Aura MLS July 2005

Wu and Eckermann (JAS 2008)

Ascending 37 km

\[ 10^{-3} \, K^2 \]