Gravity Wave Coupling and MLT Measurements

Observations from the DEEPWAVE campaign on 4 July 2014

Katrina Bossert

Collaborators: David C. Fritts, Christopher C. Heale, Martina Bramberger, Jonathan Snively, Bifford P. Williams, Pierre-Dominique Pautet, Michael J. Taylor, Steve Eckermann, Andreas Dornbrack
GWs from the Stratosphere to MLT

OH airglow observations demonstrate strong stationary perturbations as well as moving perturbations.

GWs were observed in both the MLT and the stratosphere from Na and Rayleigh Lidar Respectively.

AMTM temperatures averaged over the airglow layer demonstrate significant temperature perturbations.
Stratospheric Observations

- Apparent MWs observed during all passes
- Horizontal Wavelength Spectra ~40-90 km
  (120 km present during first pass)
- Some variation in wavelength with time and location may be dependent
  on mountain terrain and wind speed/direction
• Each flight pass observed a superposition of both eastward and westward oriented GWs.
• Wavelet analysis demonstrates a range of 40-90km horizontal wavelengths
• MWs are expected to have a westward propagation
Distinguishing MWs

Correlations Between Passes

Westward phase orientation

- $R = 0.66$
- 9:53-10:24 UT

Eastward phase orientation

- $R = 0.23$
- 8:19-8:50 UT

Weaker correlations between passes indicate phase movement over time.

MWs should have stronger correlations between passes (zero or close to zero phase speed).

Despite similar wavelengths, eastward versus westward orientations show significant differences between passes.
Propagation to the MLT

Leg 4 8:19-8:50 UT

Temperature Filtered Total RF16

Na T weighted, 86km altitude

Density Perturbation RF16

Filtered Temperature

8:19-8:50
Propagation to the MLT

6:46-7:13 UT

7:22-8:09 UT

8:19-8:50 UT

8:59-9:44 UT

Propagation time from 40 km- 90km is ~30-60 minutes.

\[ c_{gz} = \frac{N_{km}}{(k^2 + m^2)^{3/2}} \]

Comparison of successive legs accounts for the propagation time offset and demonstrates similar spectra.
Both eastward and westward GWs were visible throughout the flight in both the stratosphere and MLT.
Correlations Between Sodium Flight Legs

MWs present in airglow, but not clearly defined on every pass.

Many waves are present in the airglow, making correlations between MWs in the lidar less effective.
Changing Background Environment

Leg 2
Background Temperature

Leg 4
Background Temperature

Leg 6
Background Temperature

Leg 10
Background Temperature

6:46-7:13
8:19-8:50
9:53-10:24
11:59-12:31
Propagation Environment

**NAVGEM Winds and Temperatures**

*ECMWF Winds*

- Each pass, winds near 50km decrease
- MW “valve layer” present

\[ |u'_H| \leq |c_H - \overline{U}_H| \]

Effects of saturation lead to dissipation
Conclusions

• GWs with similar spectra are observed in both the stratosphere and MLT regions during a high forcing event

• Both westward and eastward GWs are observed in the stratosphere-MLT on all passes

• Westward propagating waves in the stratosphere have a stronger correlation between passes, but this changes in the MLT region

• GWs observations in the MLT may vary more due to changing background environment
Spectral Momentum Flux in the MLT

Momentum Flux from MW Events
RF 22 Mixing Ratios

LPF data:
Stopband 12km
Passband 24km

- Multiple horizontal scales present in addition to ~240 km MW
- MW harmonics present

Difficult to calculate temperature due to:
- high resolution mode/no temperatures available
- low sodium densities on bottom side of layer
- discontinuous sodium across a given altitude
Temperatures can be calculated from the single frequency density measurements via the following methods:

- Density perturbation amplitude
- Mixing ratio

Modeled Data

Model Output from Heale et al., 2017
Modeled Methodology and Validation

Density perturbation method uses perturbation amplitude with respect to background density gradient

\[ \rho_s' e^{-i\omega t} = \left[ \left( \frac{g}{N^2} \frac{T'}{T} \right) \left\{ \frac{\bar{\rho}_s}{H} + \frac{\delta \bar{\rho}_s}{\delta z} \right\} - \frac{\bar{\rho}_s T'}{T} \right] e^{-i\omega t} \]

Mixing ratio uses displacement distance \(dz\) with respect to a mean altitude to calculate \(T'\) based on background temperature gradient and adiabatic lapse rate

- Mixing ratio \(T'\) better estimate for large deviations from Na layer
- Density amplitude \(T'\) better estimate for perturbations within the layer
Sodium Density Temperature Perturbation
Calculations for RF22 (mixing ratio T’)

U estimated from Kingston meteor radar

N² estimated from Lauder Rayleigh Lidar and SABER (Bossert et al, 2015)
RF 14 MW event

Leg 1

Leg 2

Leg 3

Leg 4
- First pass, ~80km wave apparent in OH intensity (no sodium data available)

- Observed wave may possibly perturb OH layer (SABER observation at same time as OH observations. At location B, the OH layer is displaced to 79km)
RF 14 Sodium Density Measurements

Leg 3

\[ \rho_i e^{-i kt} = \left[ \left( \frac{g}{N^2} \frac{T'}{T} \right) \left[ \frac{\partial \rho}{\partial z} + \frac{\partial \rho}{\partial z} \right] - \frac{\rho_i T'}{T} \right] e^{-i kt} \]

\(T'\) from densities shows similar perturbations as the AMTM

Peak OH at 82km FWHM of 7km
Spectral Momentum Flux

Density $T'$

Temperature Amplitude $T_p$

Momentum Flux Amplitude $T_p \ (m^2 s^{-2})$

Mean wind profile (6 hours beginning 1/7/2014, 4:00 UT)

Mean wind profile (6 hours beginning 1/7/2014, 6:00 UT)

Map with time stamp 7:04-7:41
Conclusions

• Temperature perturbations can be extracted from single frequency sodium densities in the following ways:
  • Mixing ratio contour displacement
  • Sodium density perturbation amplitude

• Mixing ratios give a more accurate calculation for large deviations from the layer, and density perturbation amplitudes give a more accurate calculation within the layer

• MWs have a spectra associated with them, resulting in varying MF across the spectra
Questions