Concentric gravity waves generated by deep convection on the Great Plains

Space physics we can hold on our hands

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Outline

• Convective gravity wave generation mechanism: updraft within a thunderstorm and tropopause overshooting, nonlinear forcing and diabatic heating.

• Concentric gravity wave events on the Great Plains observed by an OH all-sky imager in 2003-2008.

• Simultaneous Ground-based and satellite observations of convectively generated gravity waves in the stratosphere and MLT. Cause TID?

• Toward a global climatology of convectively generated gravity waves for GCMs.
Wave source: deep convection and overshooting at the tropopause, diabatic heating

Air displacement in a highly stable stratosphere excites gravity waves

Nonlinear forcing and diabatic heating

Wallace and Hobbs

Courtesy of NASA
Viewed from Space Shuttle
Dispersive GWs:

- Instantaneous forcing leads to a broad spectrum of GWs
- Dispersive nature of GWs causes the waves to spread out in space and time as a function of period and wavelength

Alexander et al., 2005
Pioneer works: first identified by Tayler and Hapgood [1998] using an airglow camera

Sentman et al., 2003

Dewan et al., 1998
Simple CGW event: 11 May 2004 (Yue et al. JGR, [2009])

A sequence of OH differenced airglow images (OH layer ~ 87 km)
Dispersion of GWs when propagating (GW101)

At source

\[ \omega^2 = \frac{N^2 k_h^2}{k_h^2 + m^2} = N^2 \cos^2 \alpha, \]

Small period = small angle = shorter distance from the epicenter

Small horizontal wavelength = slower velocity = longer propagating time

Vadas et al., JGR, 2009

At OH layer

Horizontal wavelength

Period

Radius (km)

At 6400 UT

Radius (km)

At 6420 UT

Theoretical Period

At 6440 UT

Period (min)

Horizontal Wavelength (km)

At 6420 UT

At 6440 UT

At 6460 UT

At 6480 UT

At 6500 UT
Determination of GW sources: NEXRAD radar reflectivity and echo top height
Climatology of concentric GWs in 2003-2008: 9 nightlong events out of ~800 clear nights

Little wind filtering of GWs near equinoxes
Strong convection located at the center of each concentric GWs ~1 hour before weak wind found in the radiosonde
Complex GW event: 08 Sep 2005 (lasts 6 hours)

Vadas, Yue and Nakamura, JGR, 2012
GW sources: a number of thunderstorms on the Great Plains

Both hail and concentric GW are the products of strong updraft and moisture in a thunderstorm.
Vadas’s Ray tracing program vs. observations

- Implement multiple plumes (~ 100) in 3000 km*3000km area from GOES
- Lindzen’s type saturation scheme
- Hourly temperature and wind profiles from the TIME-GCM + radiosonde
Concentric GWs observed simultaneously from ground and space

- **Ground-based airglow imager:** continuous time coverage, sensitive to small scale GWs, can’t detect large scale GWs, blocked by clouds
- **AIRS on Aqua Satellite:** twice a day; insensitive to small scale GWs (50 km<1000km); global coverage; not interfered by weather condition
03 June 2008, 09 UT, 03 LT
Aqua satellite descending orbits
(Yue and Hoffmann, 2012)
GWs generated by a point source can potentially propagate upward to the ionosphere and form concentric patterns in TEC.

http://youtu.be/avxucheErk4
Large-scale convectively generated gravity wave in the daytime

Brightness temperature perturbation (4 micron) [K]

GPS TEC map over eastern US

Brightness temperature perturbation (1231/cm) [K]

From Xinan Yue
From the climatology of convectively generated GWs in the north America to a global characteristic of convectively generated gravity wave sources

May to August

Deep convection

Hoffman and Alexander, 2010
Thank you and enjoy the fantasy movie made by Thomas Ashcraft from Lamy, NM on April 15 2012!
Conclusive remarks

- The great Plains are ideal place to observe concentric GWs from deep convection.
- Atmospheric GW dispersion relation tested (first time observationally?).
- Compared to Vadas’s ray trace model with background conditions and convective sources.
- Simultaneous observations of convectively generated GW made by an airglow imager and AIRS experiment.
- Using AIRS and mesoscale model like WRF, now we can characterize the global distribution of convectively generated GWs for GCMs and other applications.
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