Concentric gravity waves generated by deep convection on the Great Plains

Space physics we can hold on our hands

Jia Yue
UMET, Arecibo, Puerto Rico

June, 2012

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

Rose cloud

Courtesy of NASA
Viewed from
Space Shuttle

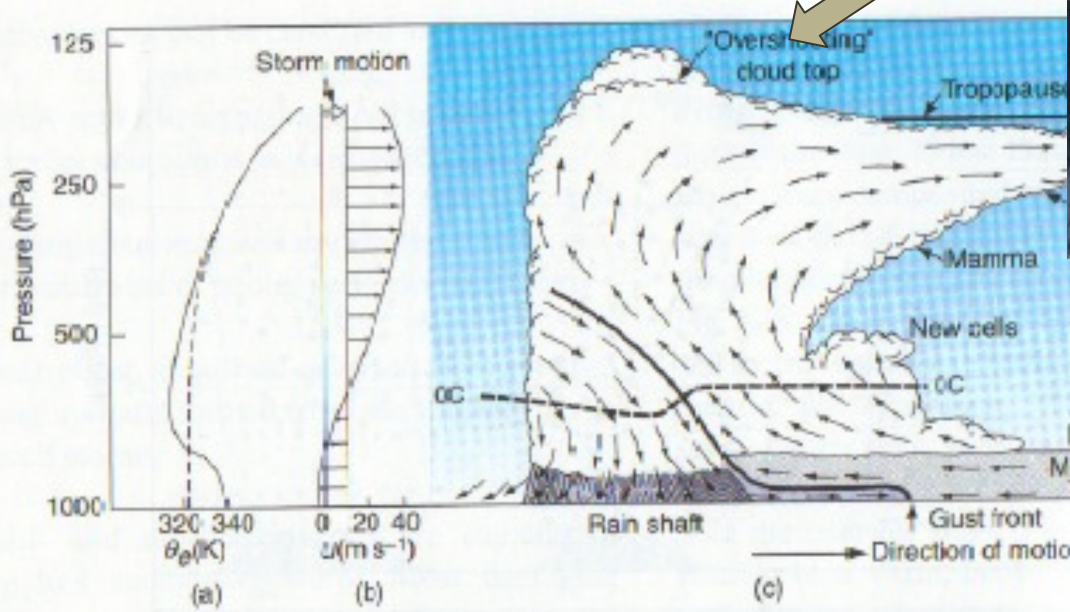
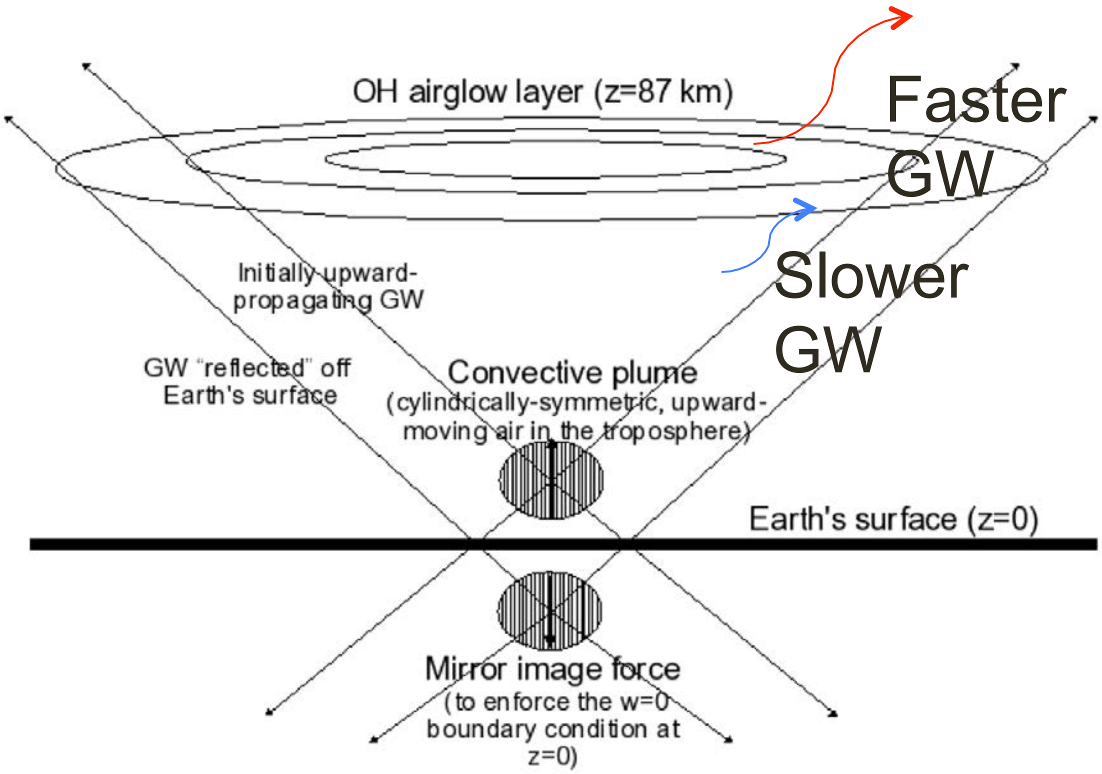


Fig. 8.49 Schematic of an idealized multicell storm developing in an environment with strong vertical shear in the direction of the vertically averaged wind. The vertical profile of equivalent potential temperature θ_e in the environment is shown at the left together with the wind profile. Arrows in the right panel denote motion relative to the moving storm.

Wallace and Hobbs

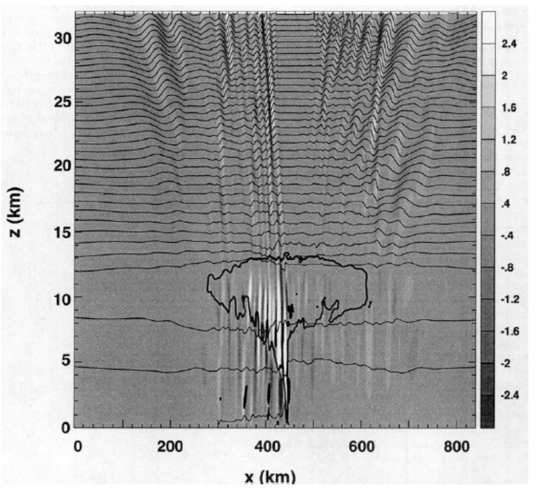
Dispersive GWs:

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



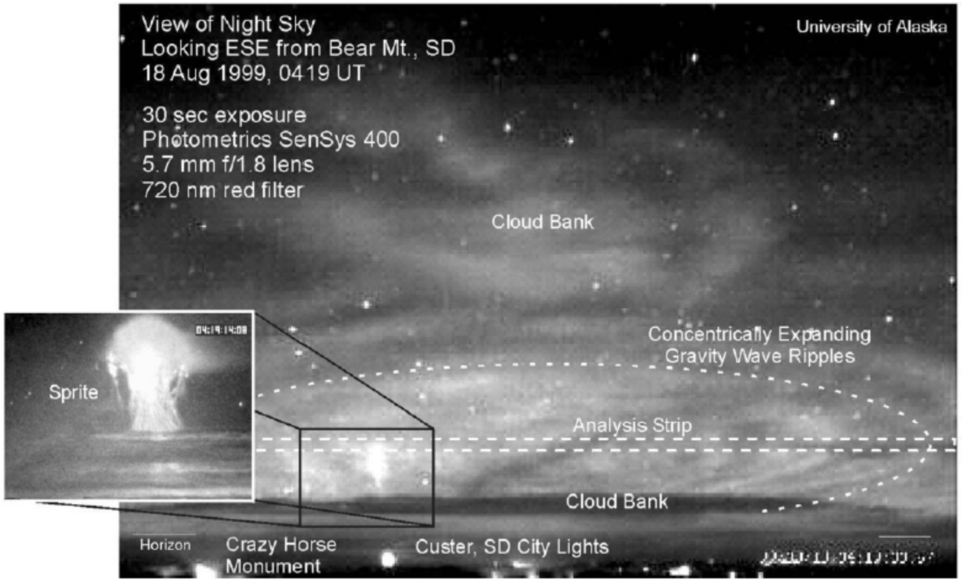
Faster GW

Slower GW

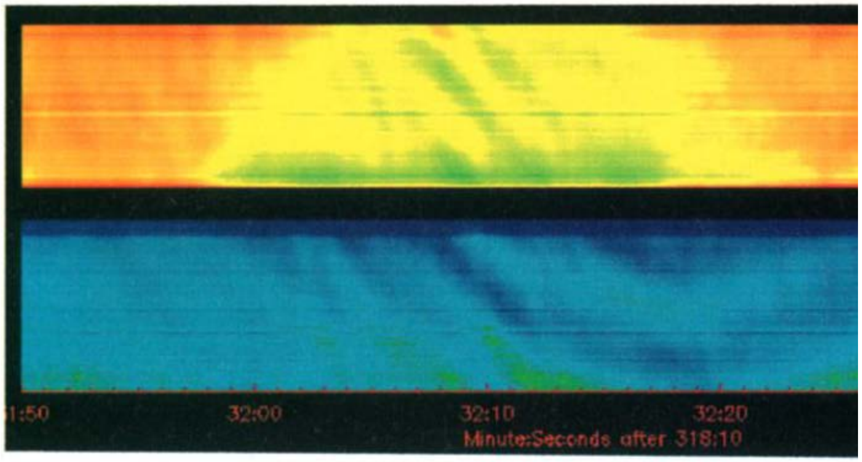


Alexander et al., 2005

Pioneer works: first identified by Tayler and Hapgood [1998] using an airglow camera



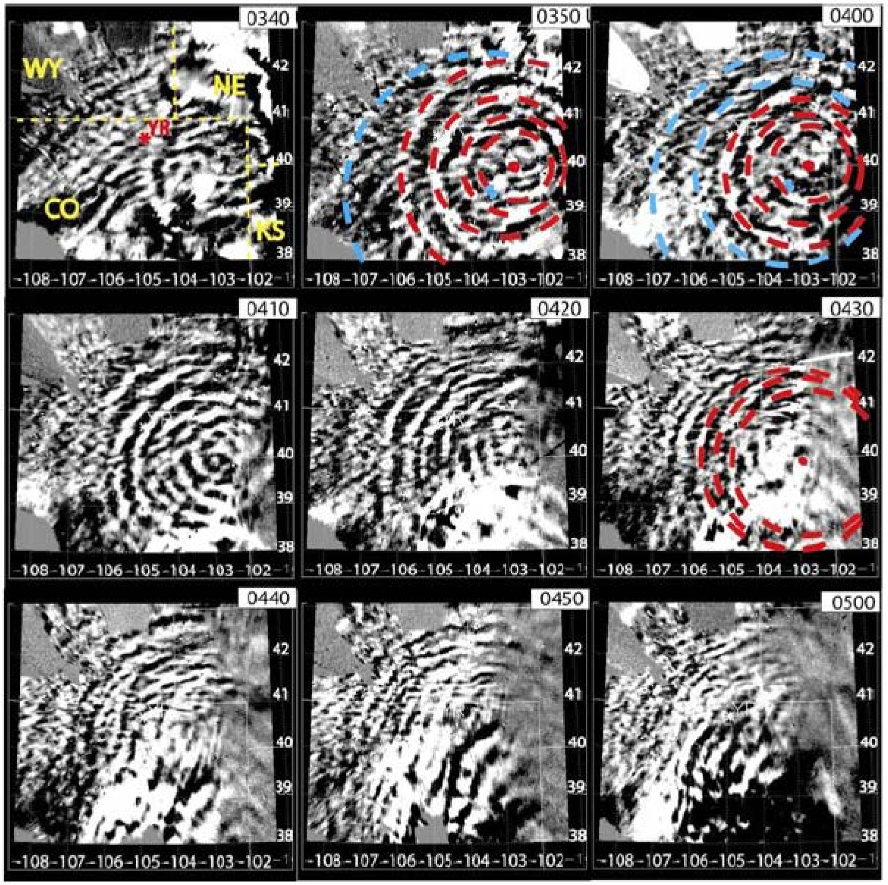
Sentman et al., 2003



Dewan et al., 1998

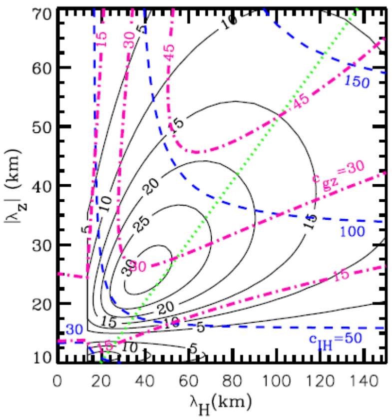
Simple CGW event: 11 May 2004 (Yue et al. JGR, [2009)]

A sequence of OH differenced airglow images (OH layer ~ 87 km)



Dispersion of GWs when propagating (GW101)

At source



Vadas et al., JGR, 2009

period

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

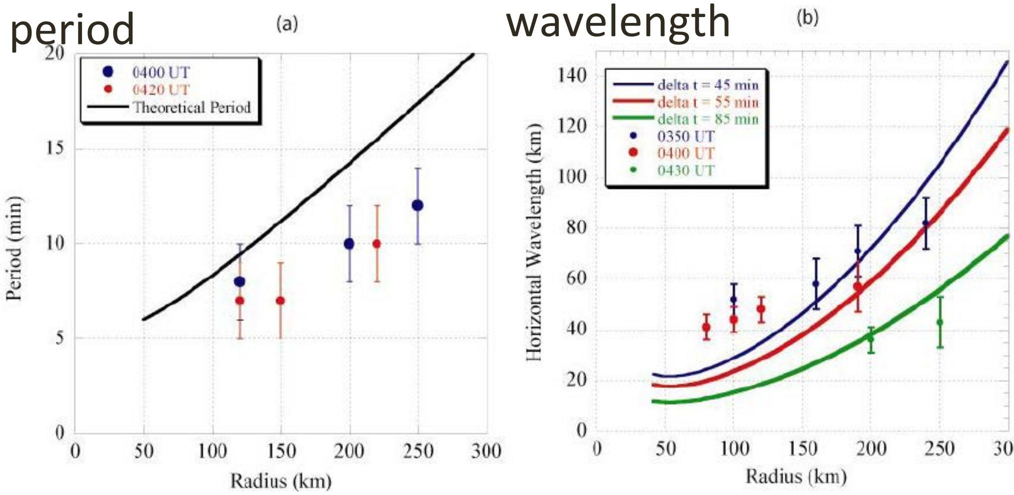
Zenith angle

Small period = small angle = shorter distance from the epicenter

Small horizontal wavelength = slower velocity = longer propagating time

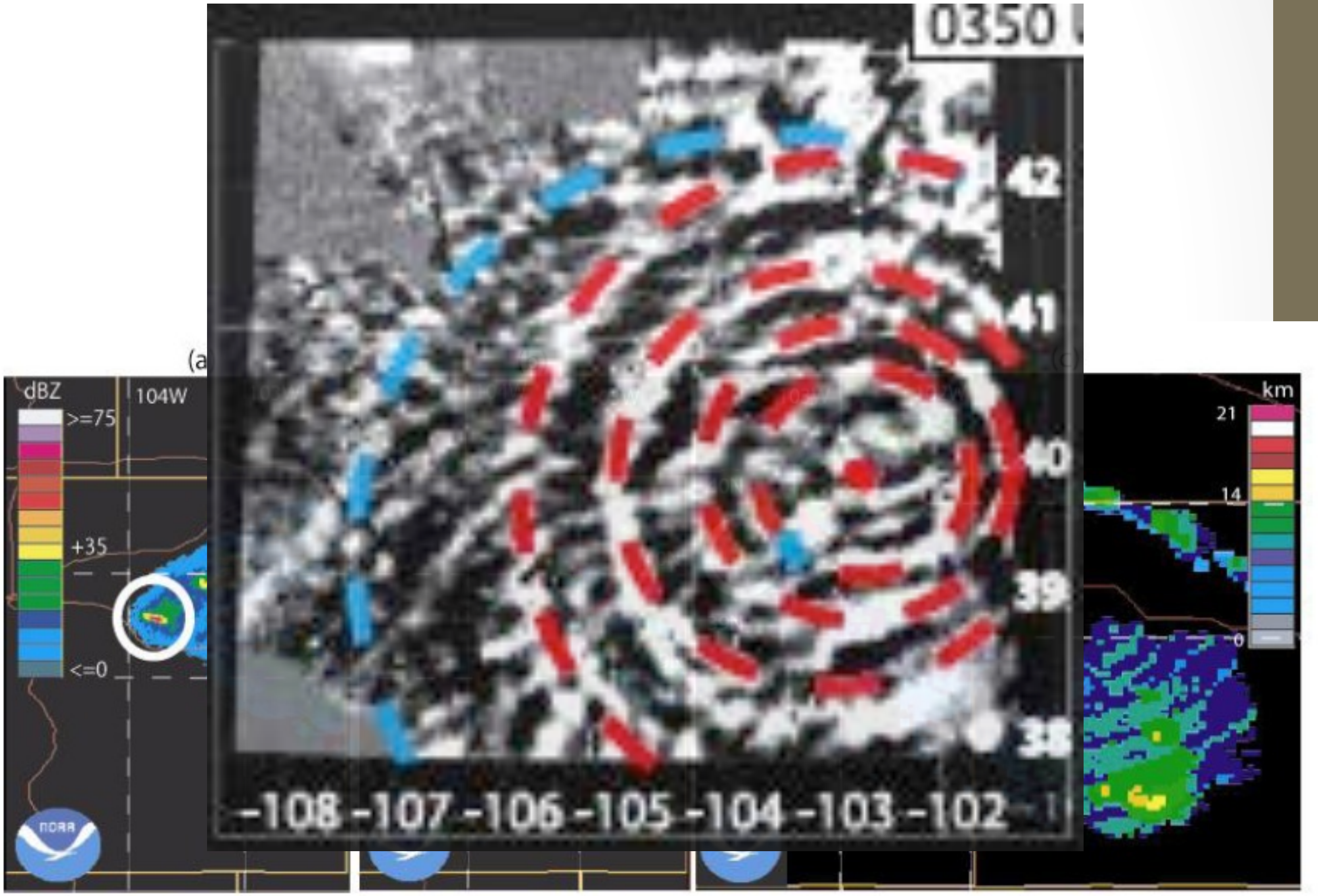
period

Horizontal wavelength



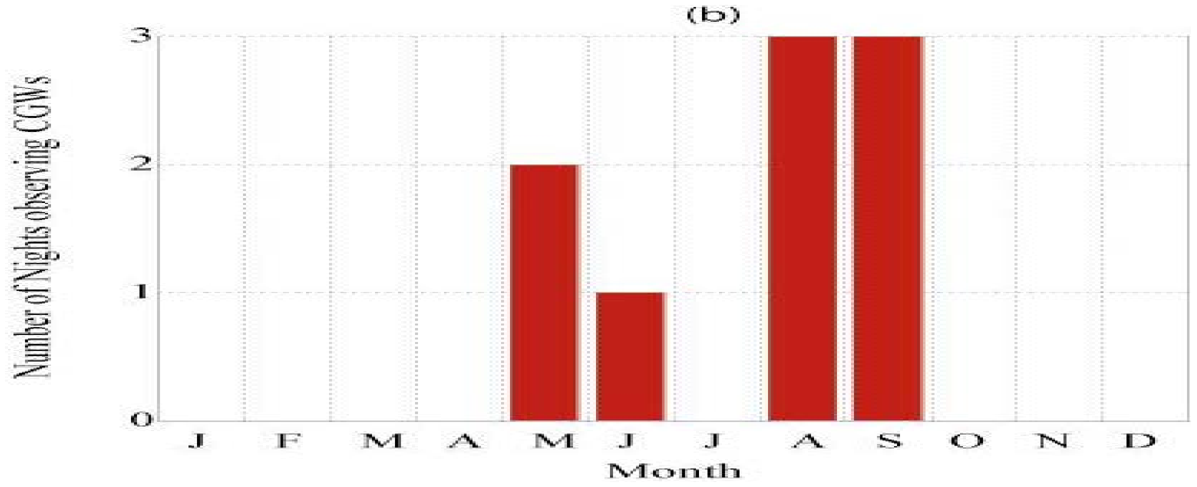
At OH layer

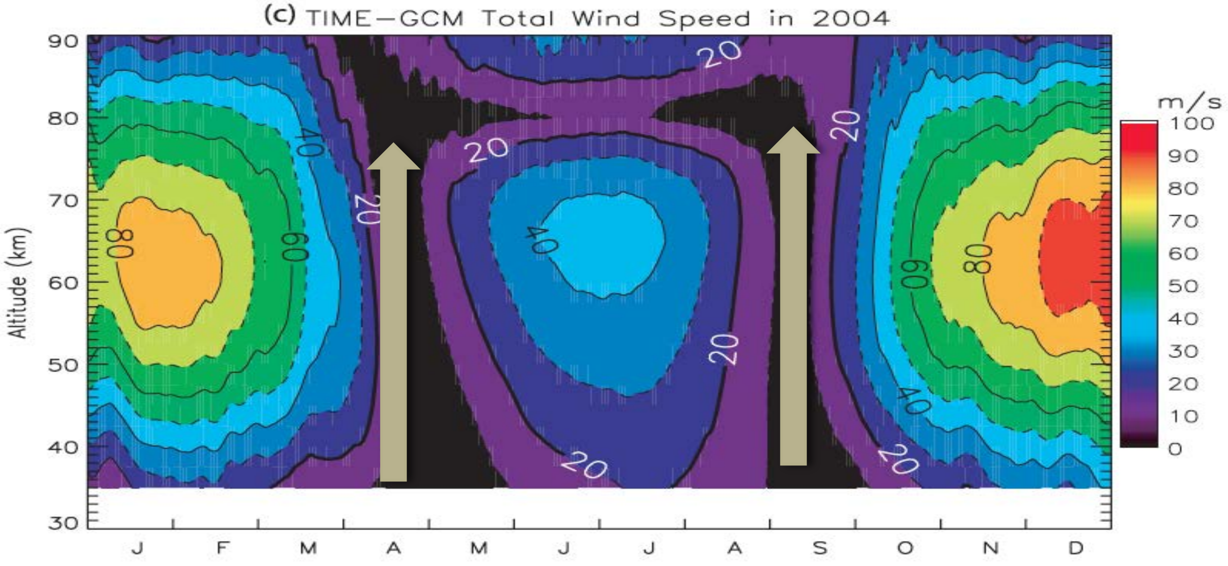
Determination of GW sources: NEXRAD radar reflectivity and echo top height



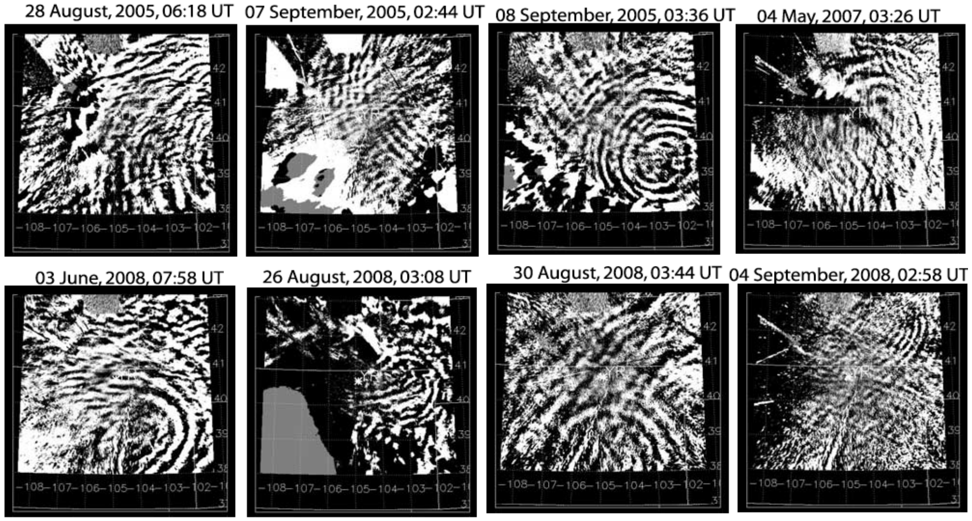
Climatology of concentric GWs in 2003-2008: 9 nightlong events out of ~800 clear nights

Little wind filtering of GWs near equinoxes


(b)


(c) TIME−GCM Total Wind Speed in 2004

Strong convection located at the center of each concentric GWs ~1 hour before weak wind found in the radiosonde


28 August, 2005, 06:18 UT

07 September, 2005, 02:44 UT

08 September, 2005, 03:36 UT

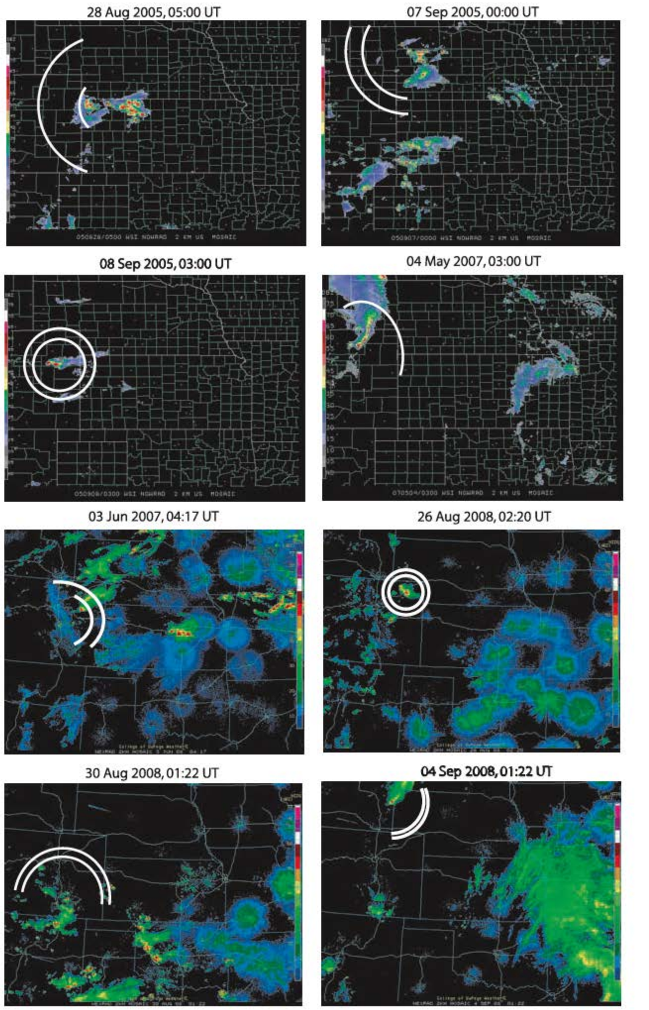
04 May, 2007, 03:26 UT

03 June, 2008, 07:58 UT

26 August, 2008, 03:08 UT

30 August, 2008, 03:44 UT

04 September, 2008, 02:58 UT


28 Aug 2005, 05:00 UT

07 Sep 2005, 00:00 UT

08 Sep 2005, 03:00 UT

04 May 2007, 03:00 UT

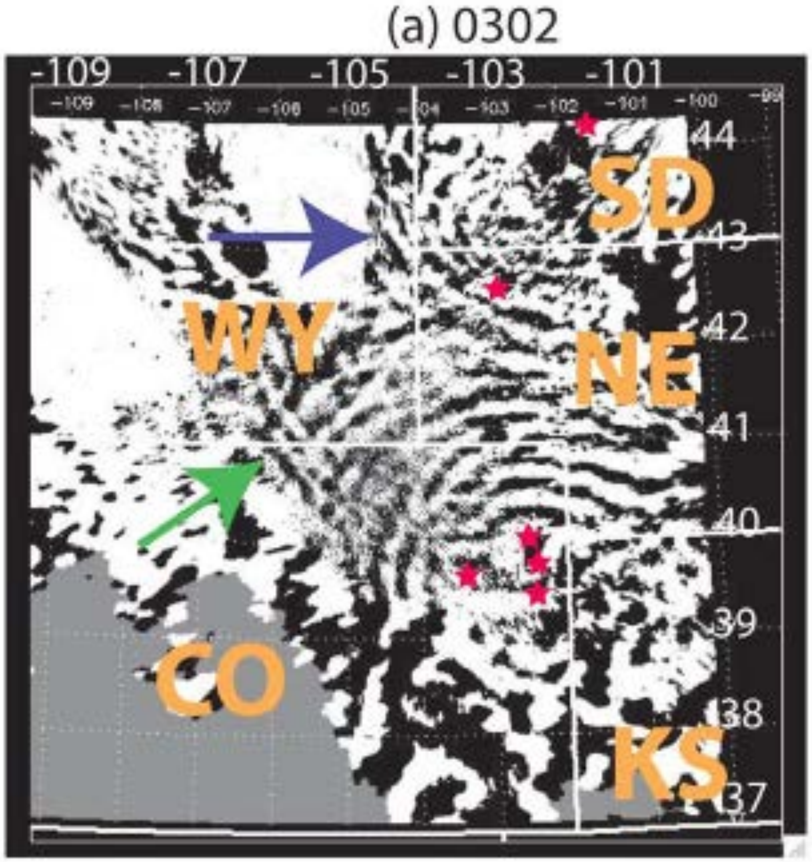
03 Jun 2007, 04:17 UT

26 Aug 2008, 02:20 UT

30 Aug 2008, 01:22 UT

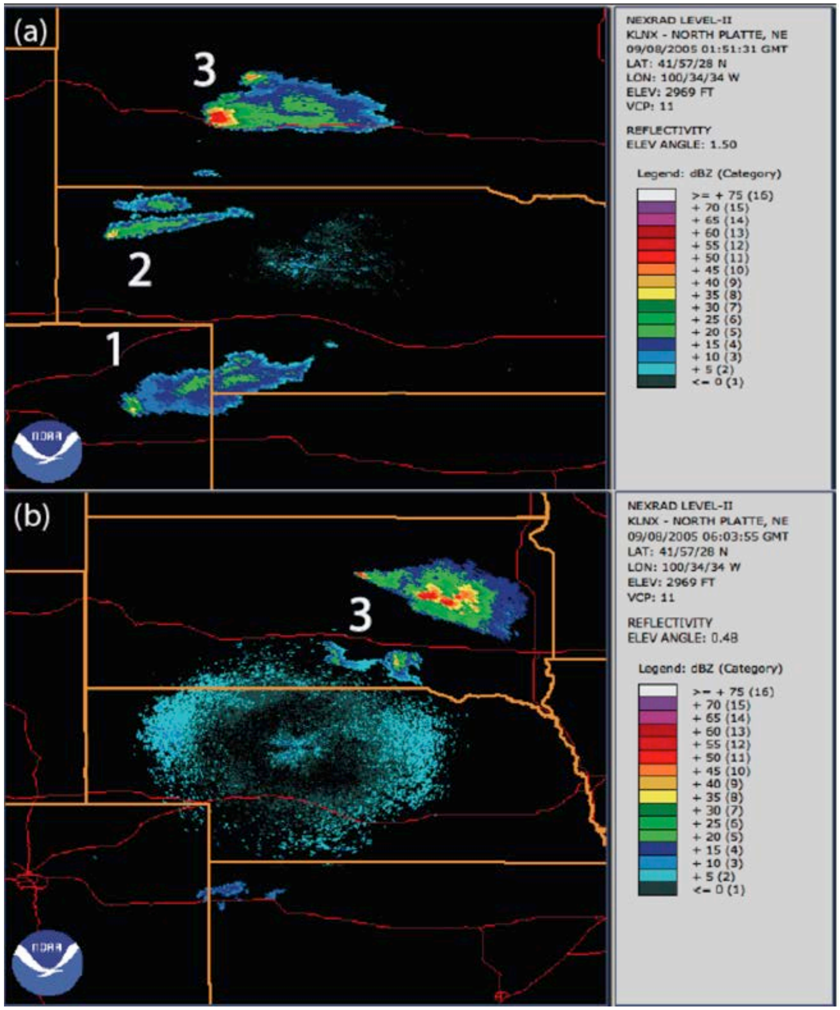
04 Sep 2008, 01:22 UT

Complex GW event: 08 Sep 2005 (lasts 6 hours)

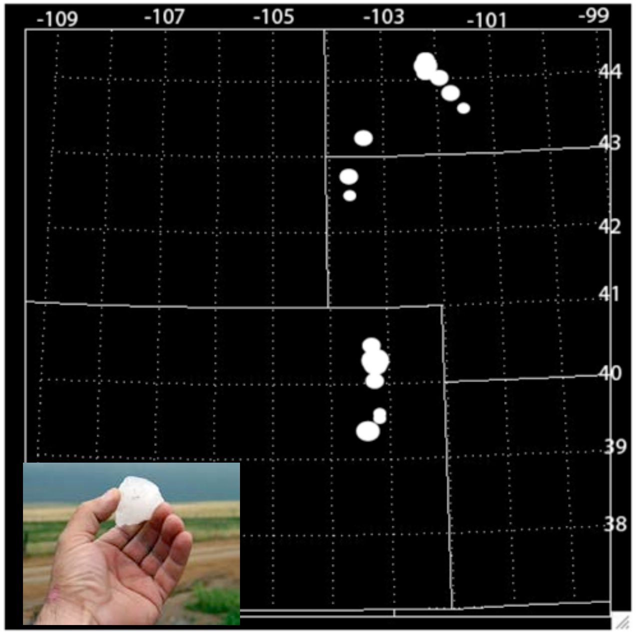


Vadas, Yue and
Nakamura, JGR, 2012

GW sources: a number of thunderstorms on the Great Plains



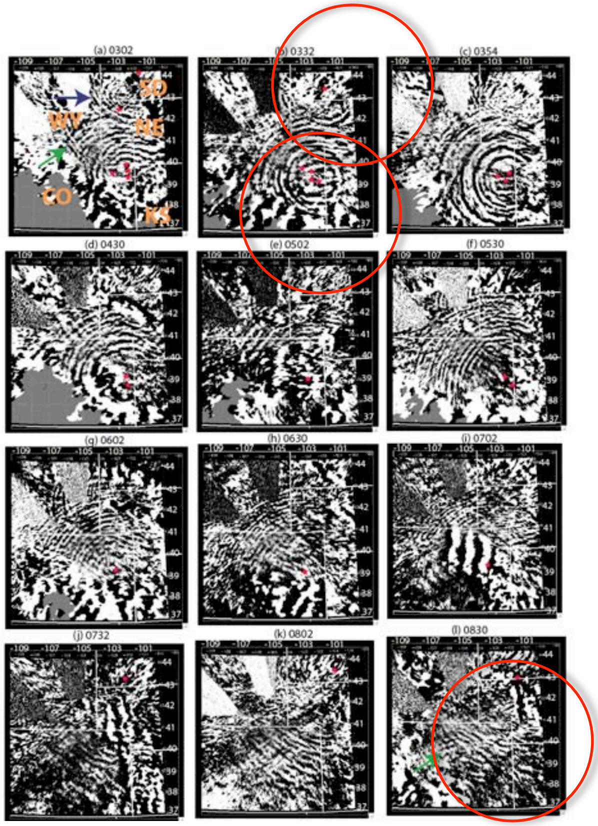
Hail distribution
(0.75”-3”)

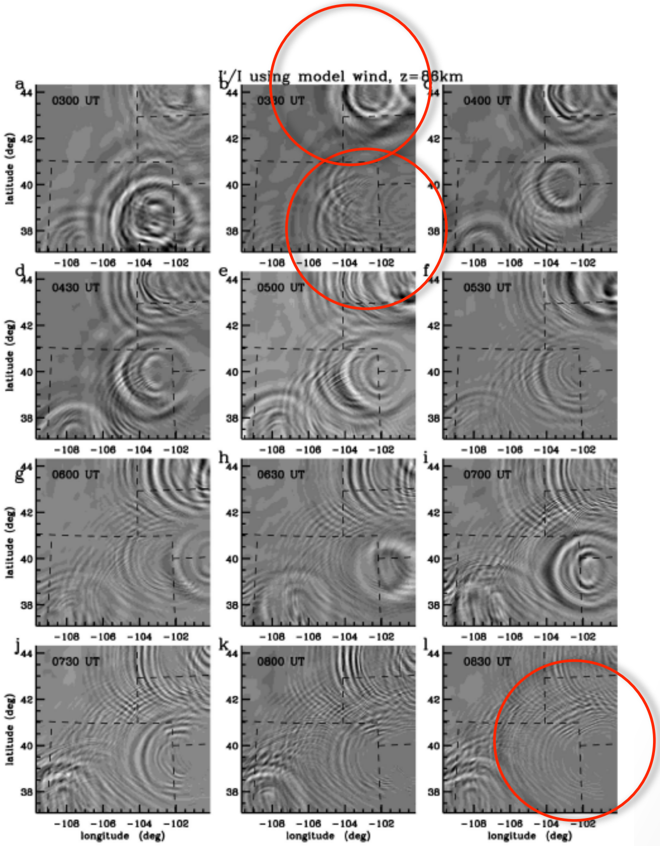


Both hail and concentric GW are the products of strong updraft and moisture in a thunderstorm

Vadas's Ray tracing program vs. observations

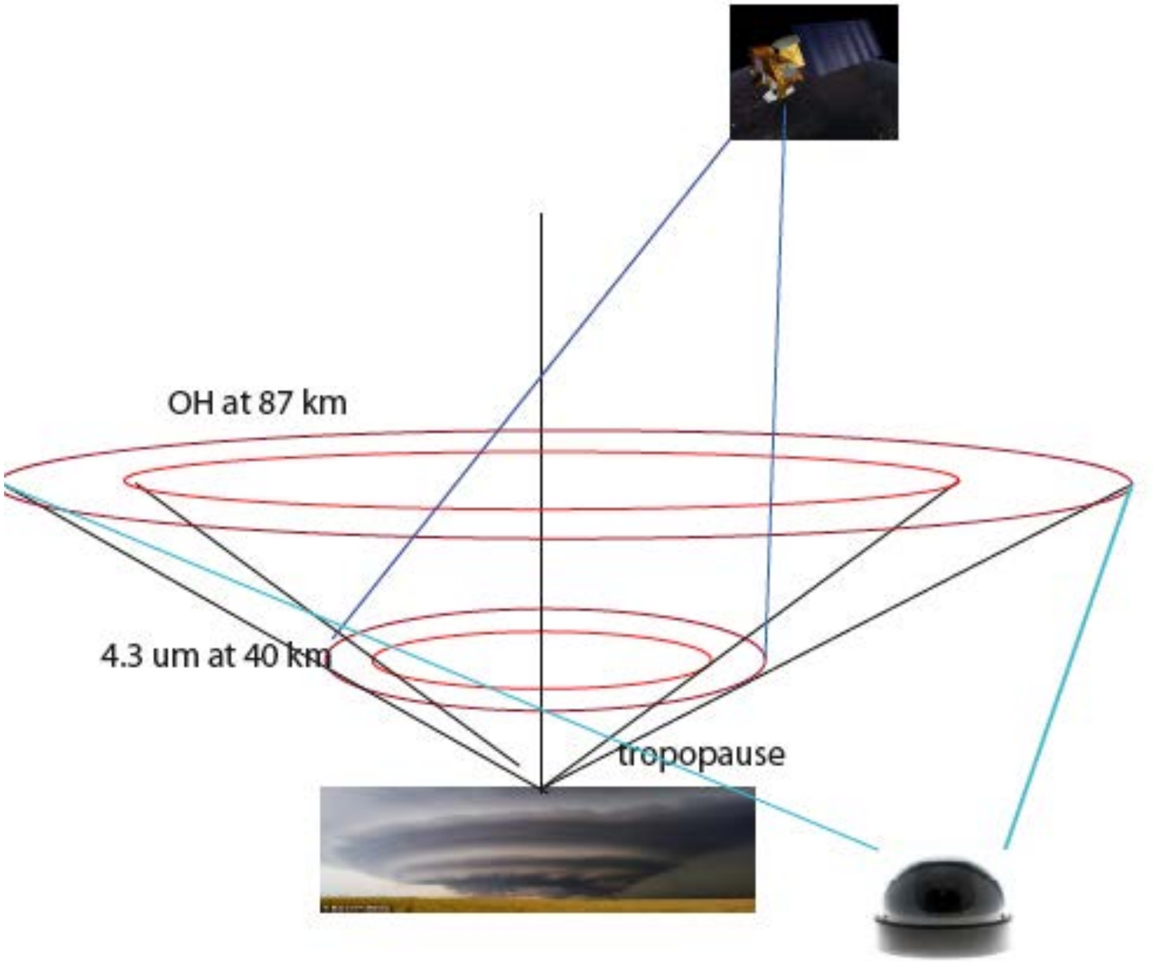
- Implement multiple plumes (~ 100) in 3000 km*3000km area from GOES
- Lindzen's type saturation scheme
- Hourly temperature and wind profiles from the TIME-GCM + radiosonde



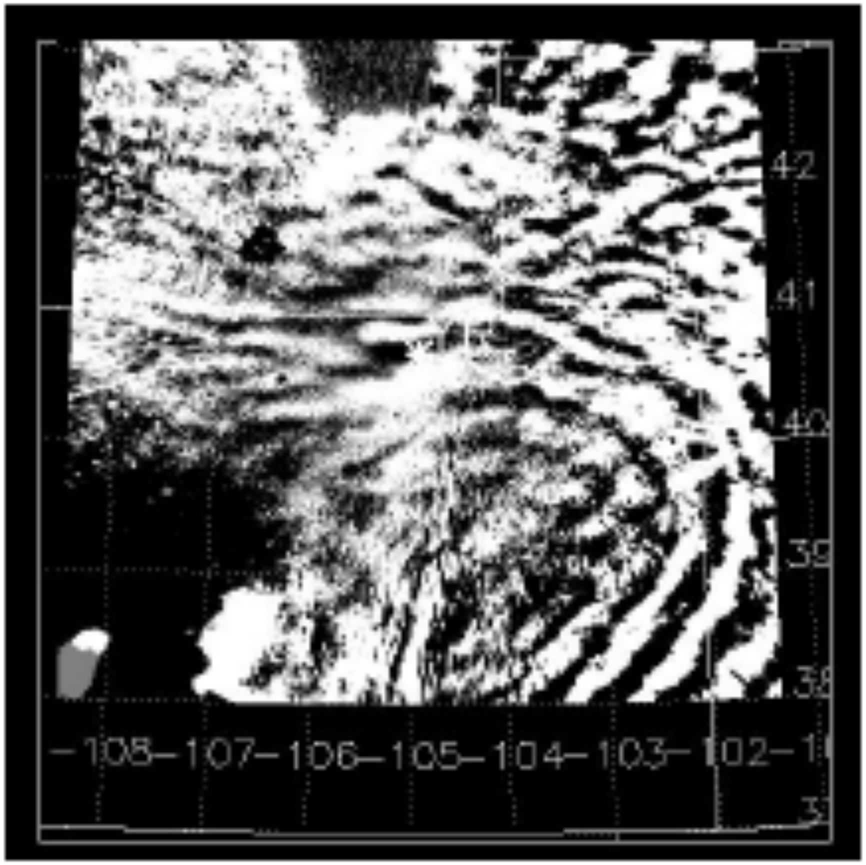


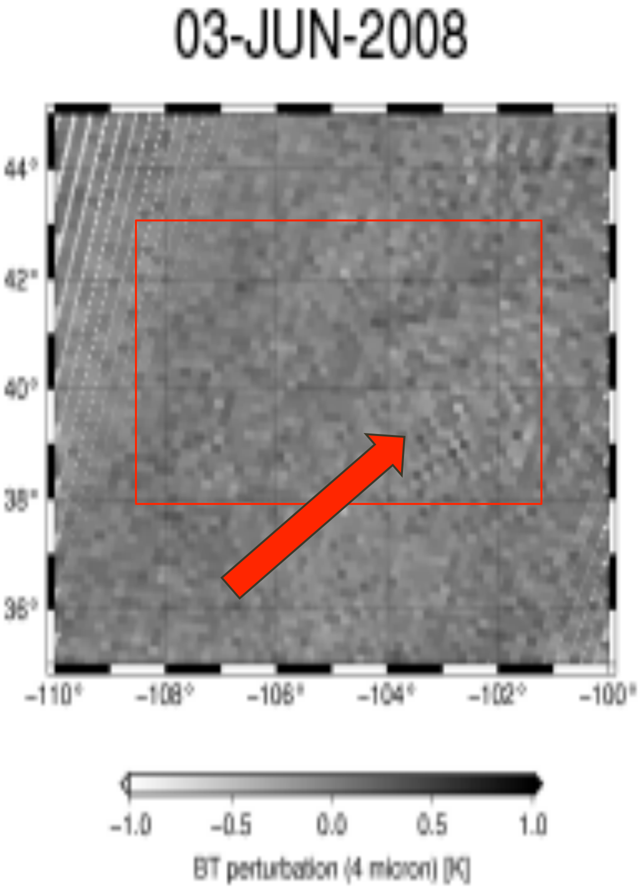
Concentric GWs observed simultaneously from ground and space

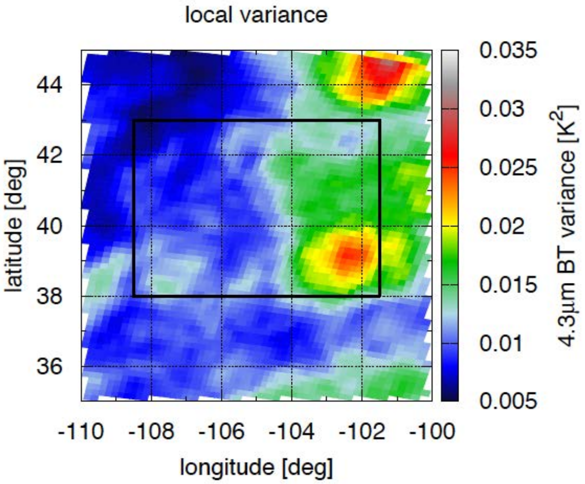
- Ground-based airglow imager: continuous time coverage, sensitive to small scale GWs, can’t detect large scale GWs, blocked by clouds
- AIRS on Aqua Satellite: twice a day; insensitive to small scale GWs (50 km<1000km); global coverage; not interfered by weather condition



03 June 2008, 09 UT, 03 LT
Aqua satellite descending orbits
(Yue and Hoffmann, 2012)

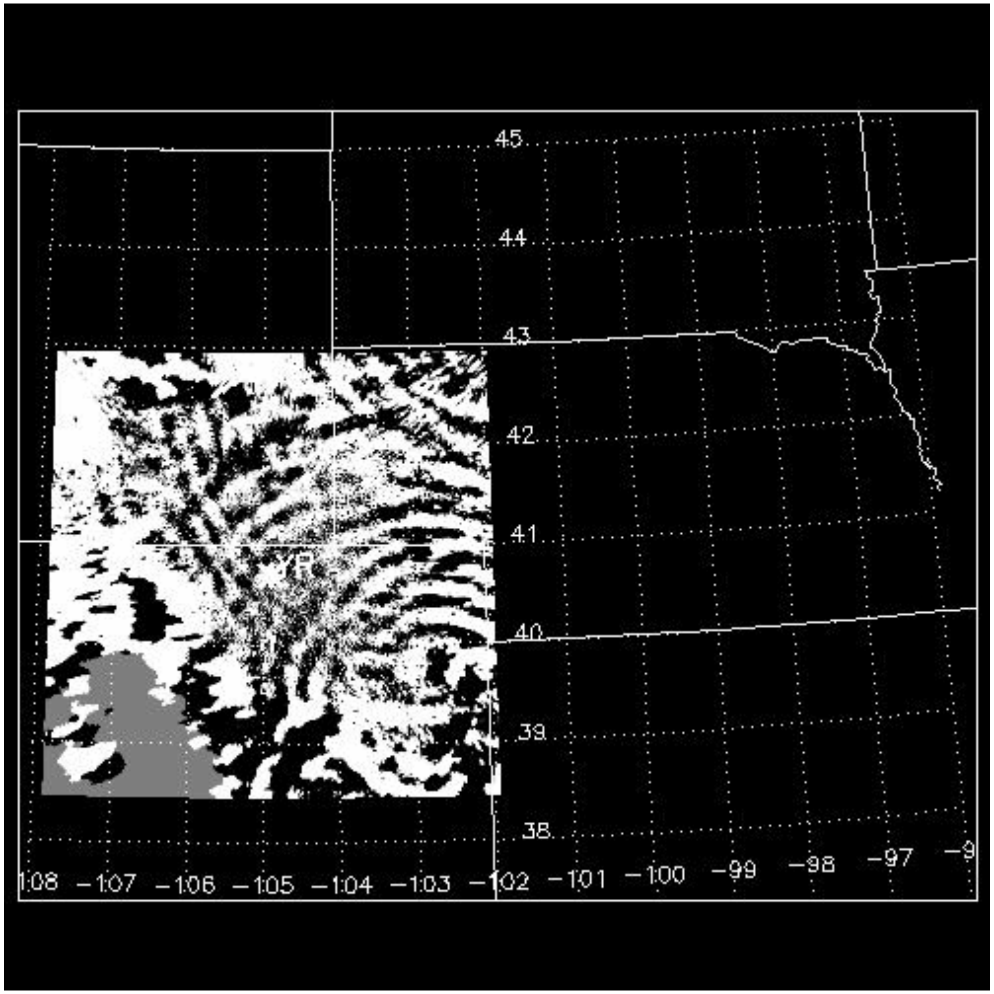


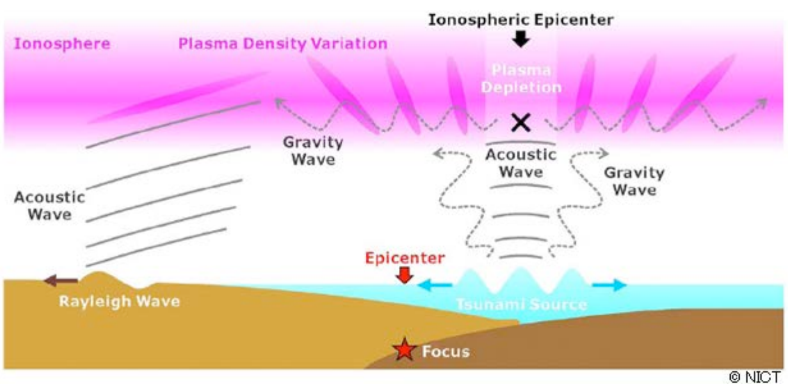

03-JUN-2008


local variance

GWs generated by a point source can potentially propagate upward to the ionosphere and form concentric patterns in TEC

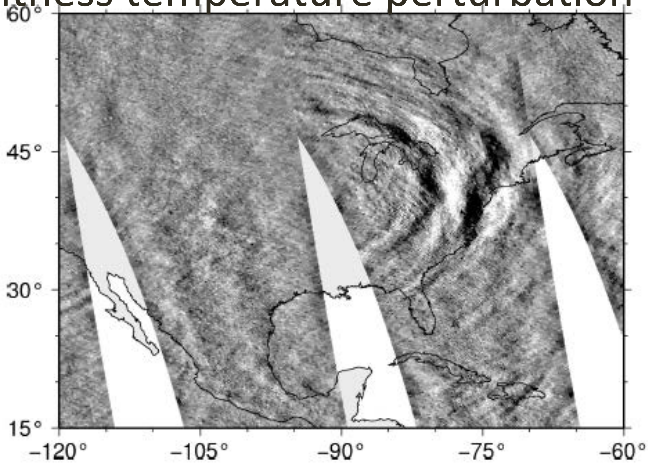
http://youtu.be/avxucheErk4

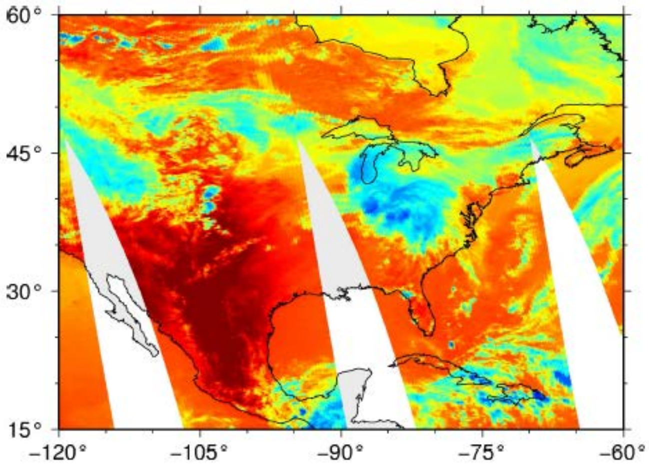




Large-scale convectively generated gravity wave in the daytime

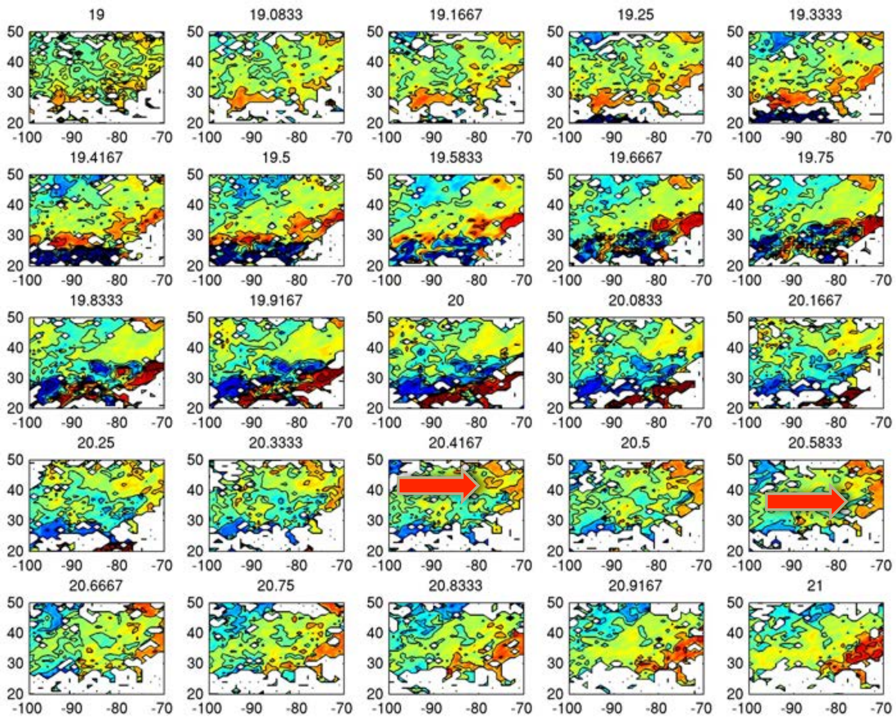
Brightness temperature perturbation (4micron) [K]





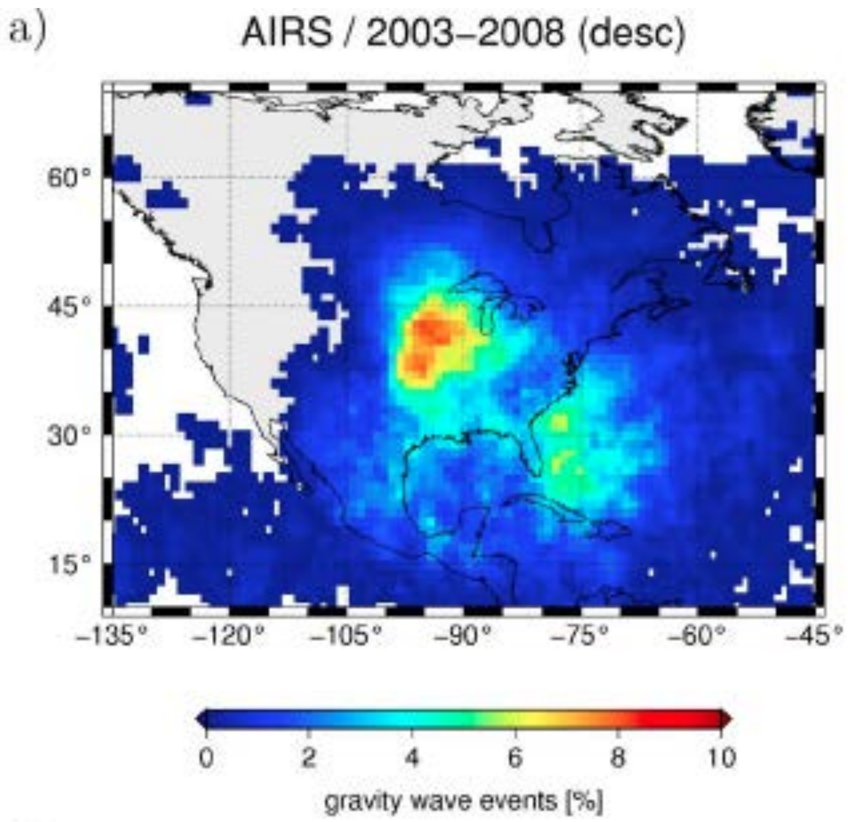
Brightness temperature perturbation (1231/cm) [K]

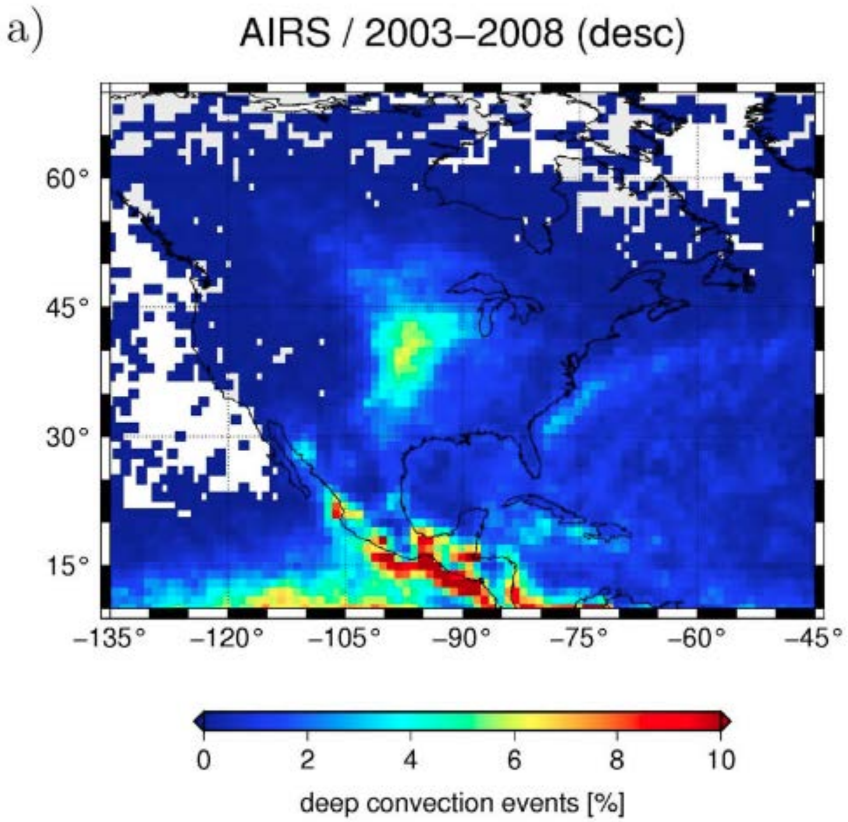
GPS TEC map over eastern US



From Xinan Yue

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





gravity wave events

Deep convection

May to August

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.

Acknowledgments:

- Takuji Nakamura: NIPR, Japan (owner of the airglow imager)
- Sharon Vadas: NWRA (provide ray tracing results)
- Walter Lyons (babysitter of the imager)
- Lars Hoffmann: Jülich Supercomputing Centre, Germany (analyzing AIRS data) and Joan Alexander
- Joe She
- Xinan Yue: UCAR (analyzing GPS TEC data)