NSRC Atmosphere - Ionosphere Coupling Science Opportunities:

Sub-Orbital Studies of Gravity Wave Dynamics in the Mesosphere, Thermosphere, and Ionosphere

Dave Fritts

NorthWest Research Associates/CoRA Division
Boulder, CO

Outline

1. motivations for GW studies in the MTI

2. GW sources, penetration, & scales in the MTI

3. some anticipated neutral and plasma responses

4. conceptual measurement strategies

1. Why do we care about Gravity Waves (GWs) in the Mesosphere, Thermosphere, and Ionosphere (MTI)?

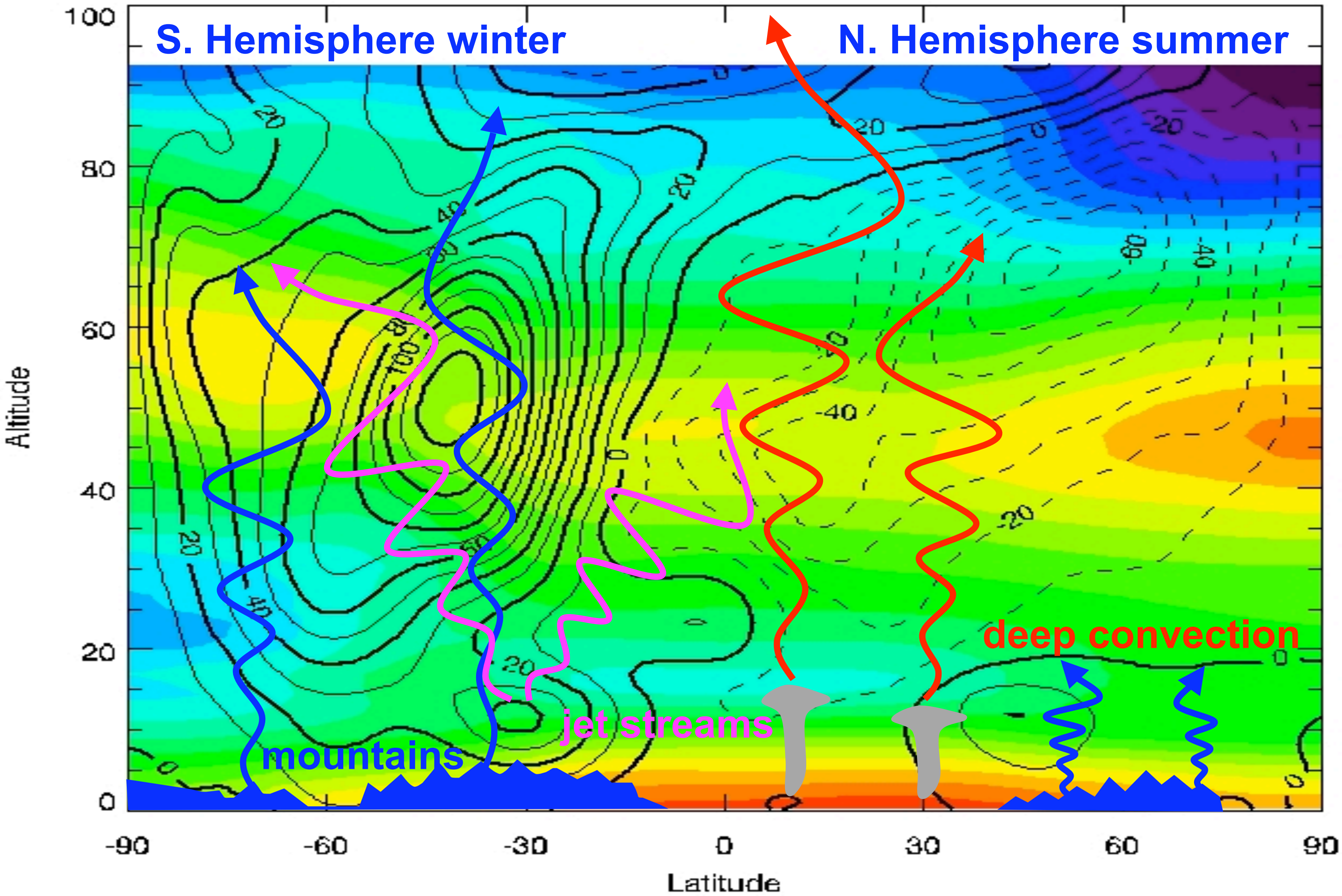
- they have major effects throughout the atmosphere and ionosphere:
  - dominant transports of energy and momentum
  - significant turbulence and mixing
  - large variations in MTI winds and temperatures, with likely impacts on plasma processes
- require parameterization in weather & climate models
- least understood & most important neutral dynamics
- neither ground-based nor satellite instruments adequately define their characteristics and effects

2. What are the dominant sources of GWs that penetrate to high altitudes?

What factors impact GW penetration?

What GW scales are important at TI altitudes?

Gravity waves have many sources
- penetration depends on character, season, & latitude



Convective GWs clearly impact the MLT
- also penetrate to much higher altitudes

Concentric GWs
over deep convection
viewed from Fort Collins
(z ~87 km)

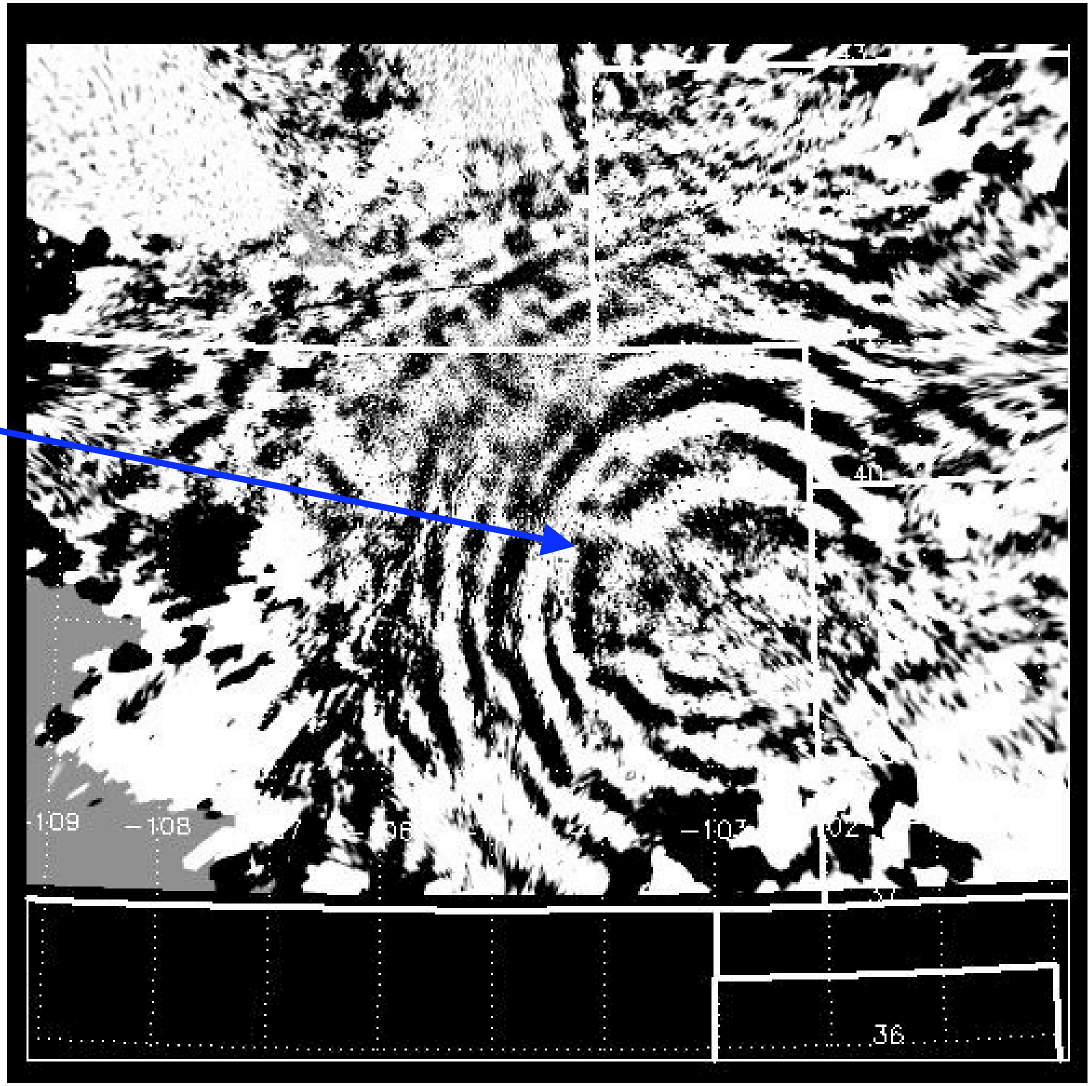
λ_h ~30 to 50 km,
c_p ~20 to 50 m/s

at lower altitudes

λ_h ~100 to 500 km,
c_p ~100 to 300 m/s

in the TI

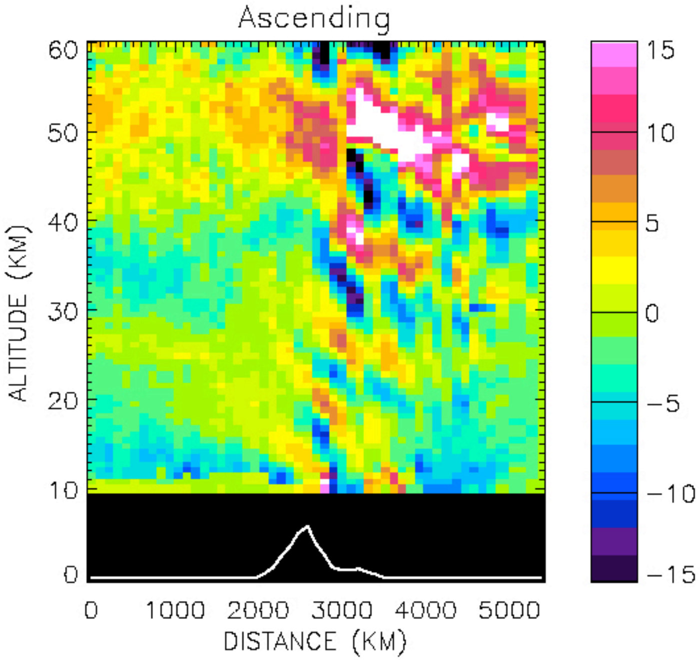
(Yue et al., 2009)



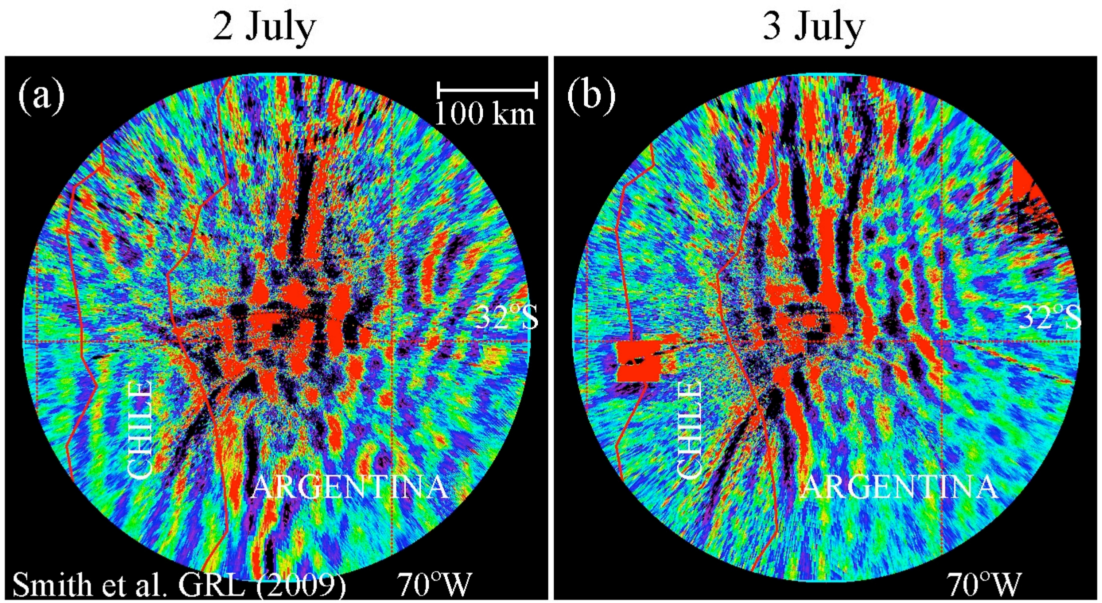
MWs also penetrate into the MLT at some sites

- large temperature and wind perturbations

larger-scale MWs to ~60 km



small-scale MWs at ~87-95 km



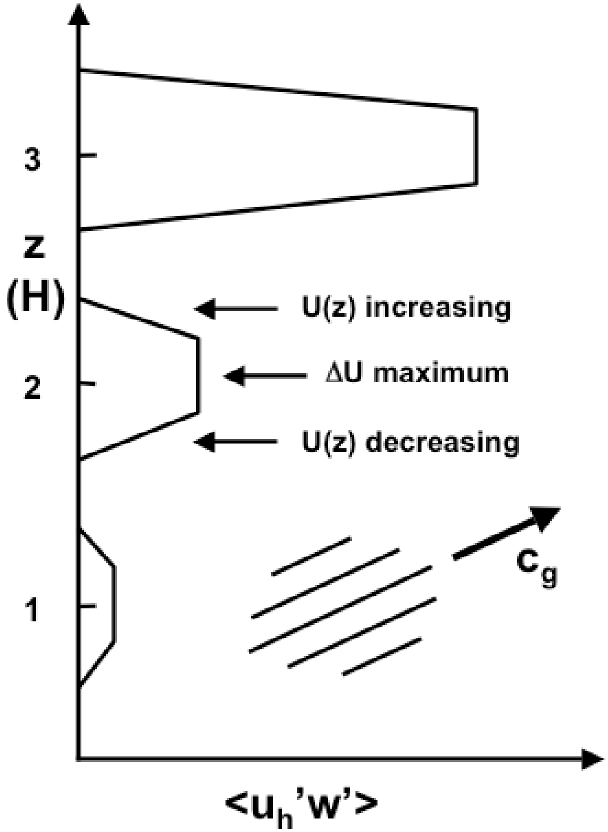
- MWs cannot penetrate far into TI

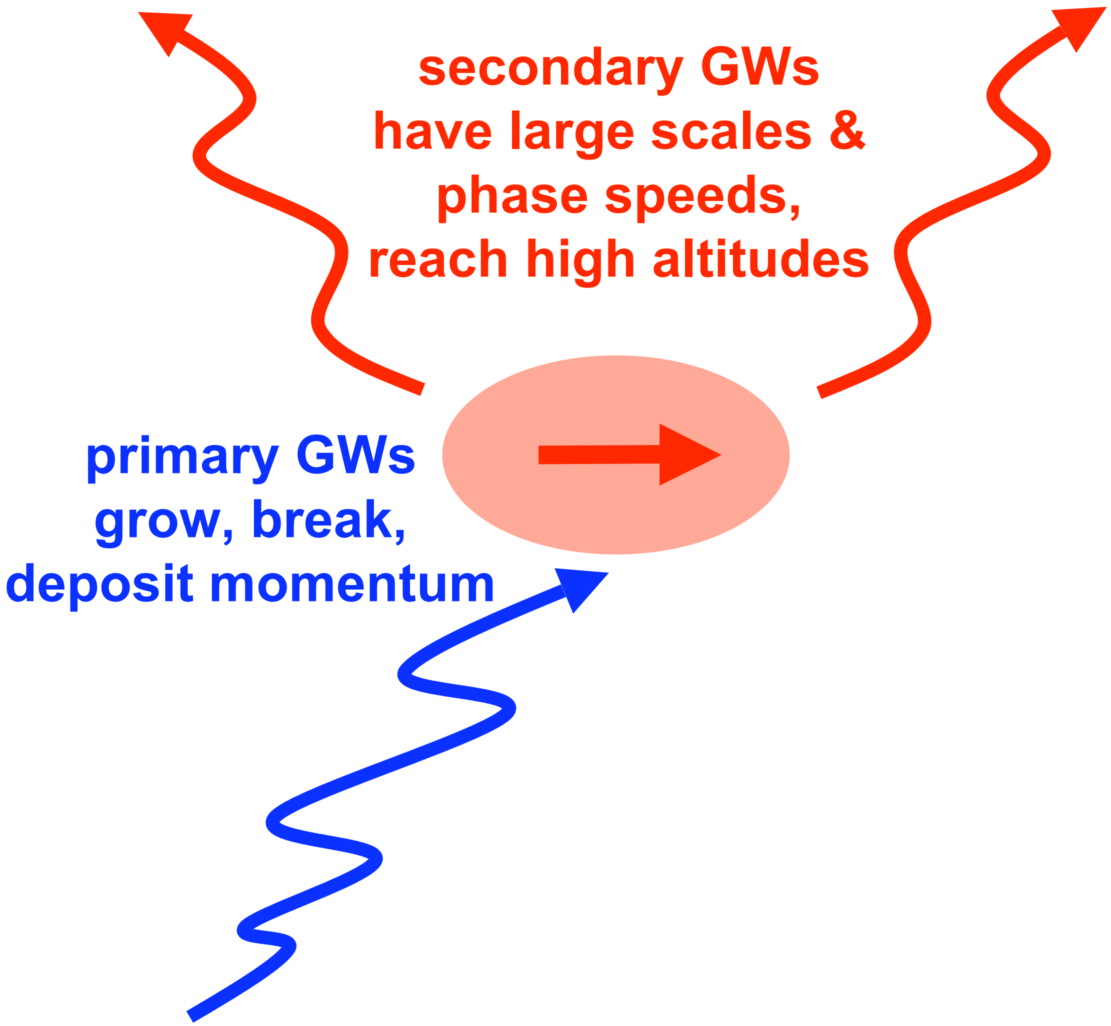
- but they have <u>large momentum transport</u>

- likely strong sources of secondary GWs

Alexander et al. (2008) **Smith et al. (2009)**

Body forces due to GW breaking may have large effects at high altitudes

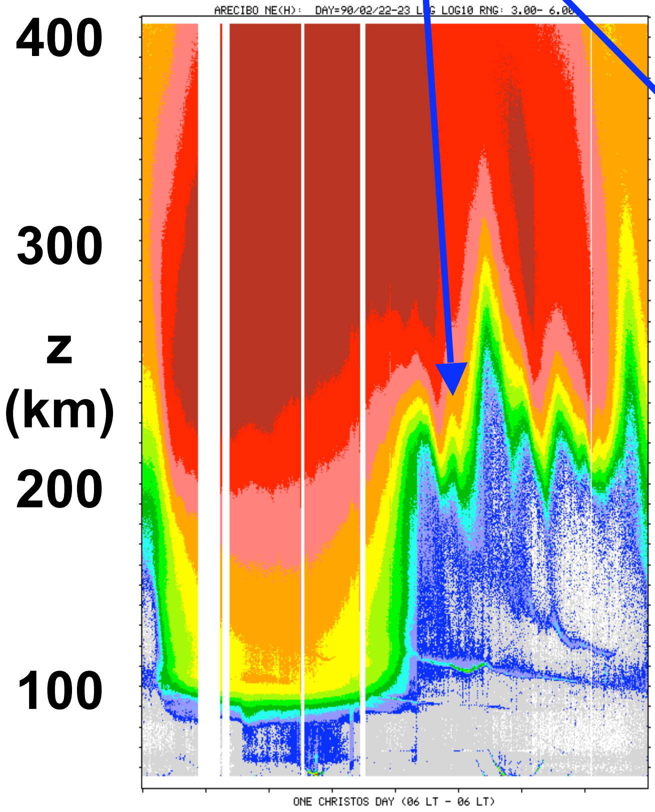




GWs transport momentum,
$\Delta U \sim 1/\rho$
$\Rightarrow$ large flow accelerations
where they dissipate

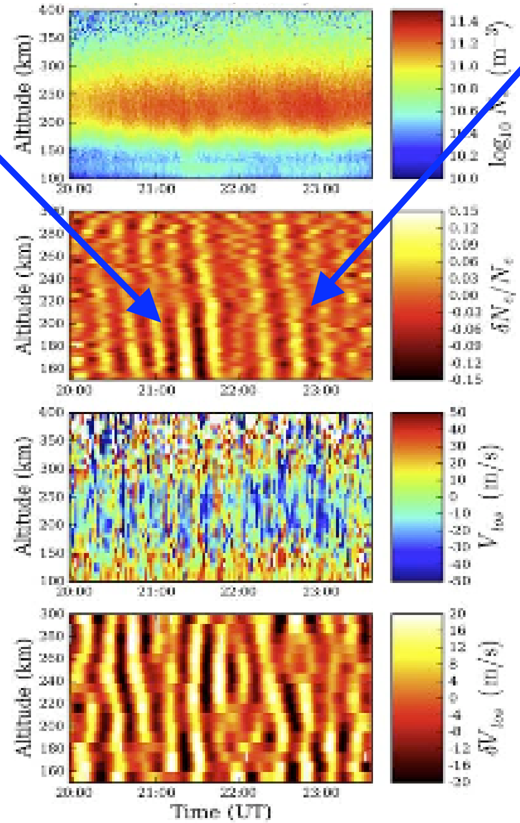
What GW scales are important in the TI?

GW periods ~20 min - 2+ hr, λ_z ~100-300+ km @ z >200 km

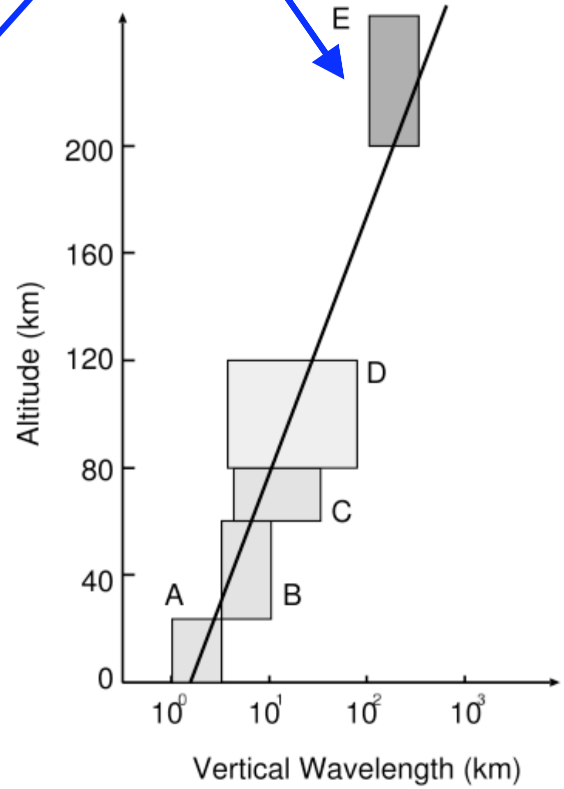


AO ISR - Haldoupis

PFISR T ~20 min
GWs in N_e and V

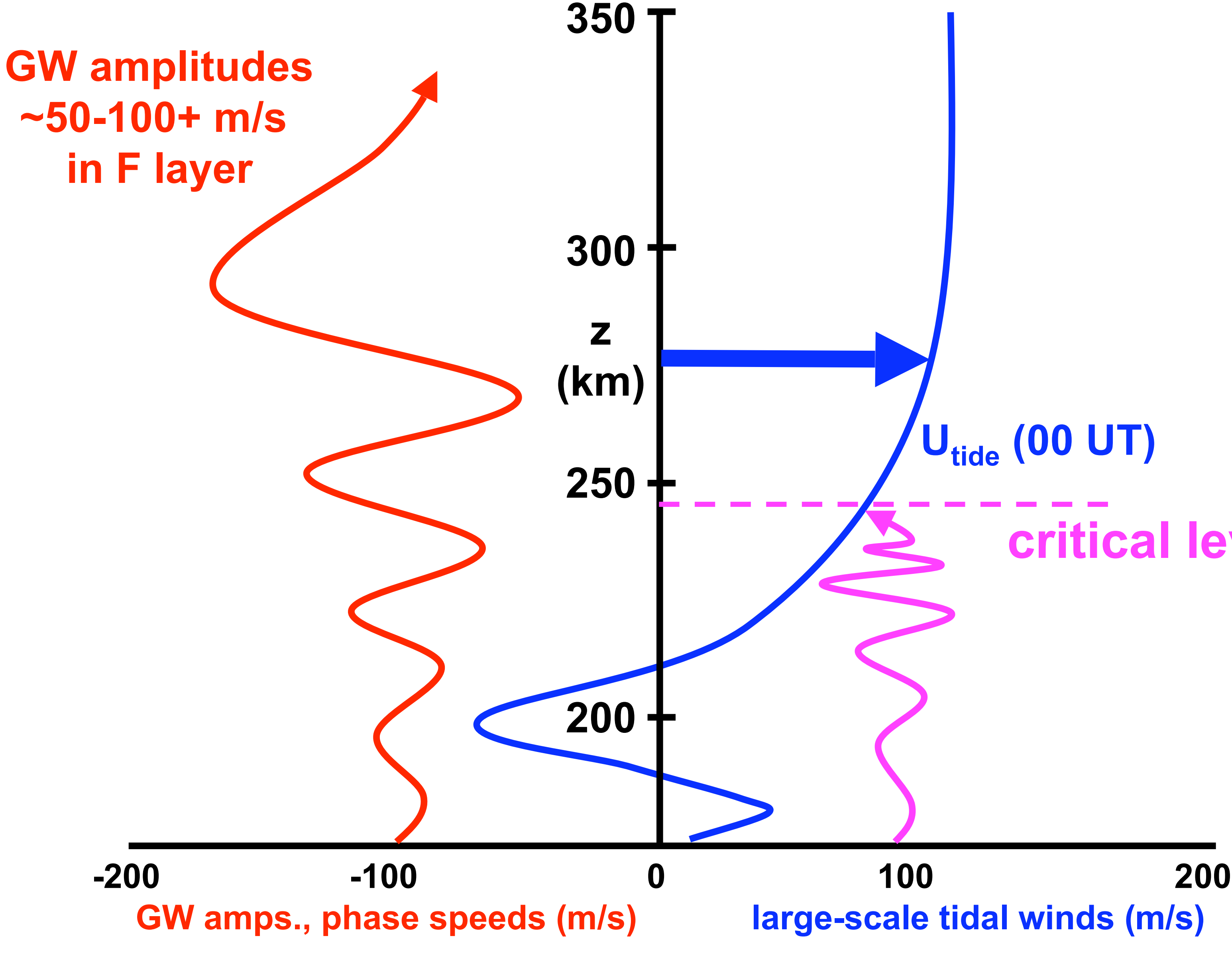


Vadas and Nicolls (2008)



MU radar
Oliver et al. (1997)

Eastward F-layer winds
- allow enhanced westward GW propagation to high altitudes



GW λ_h that penetrate from the LA to high altitudes are very restricted:

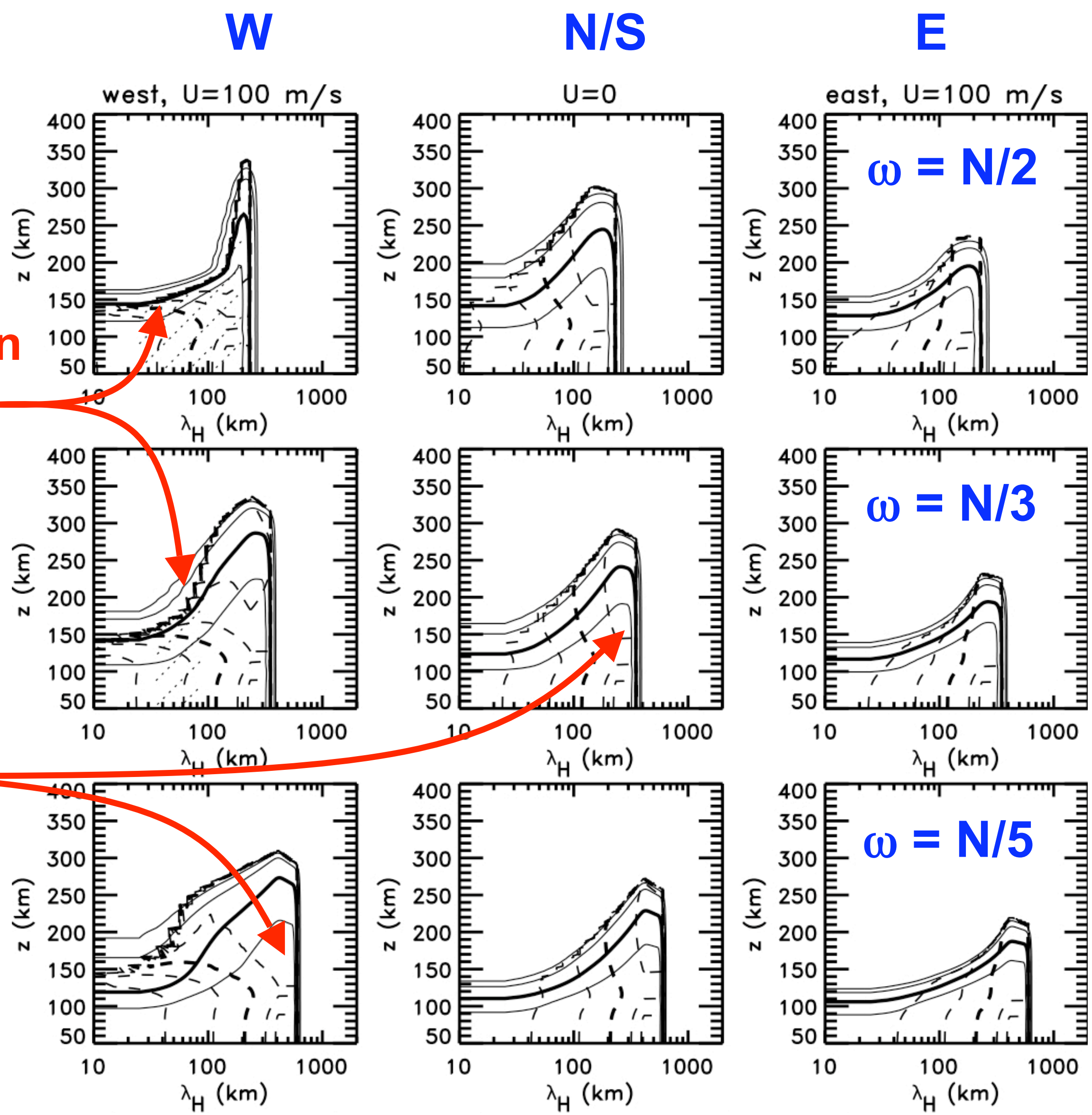
λ_h ~ 100 - 500 km

- small λ_h limited by reflection (turning levels - large k_h)

- large λ_h limited by $1/4H^2$ (GWs evan. - small k_h)

Fritts and Vadas (2008)

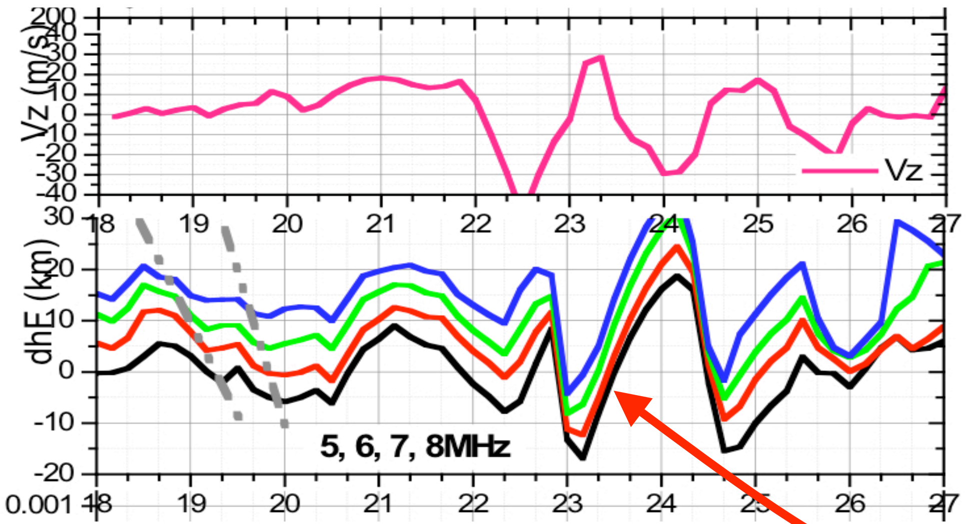
GW prop. in E wind of 100 m/s

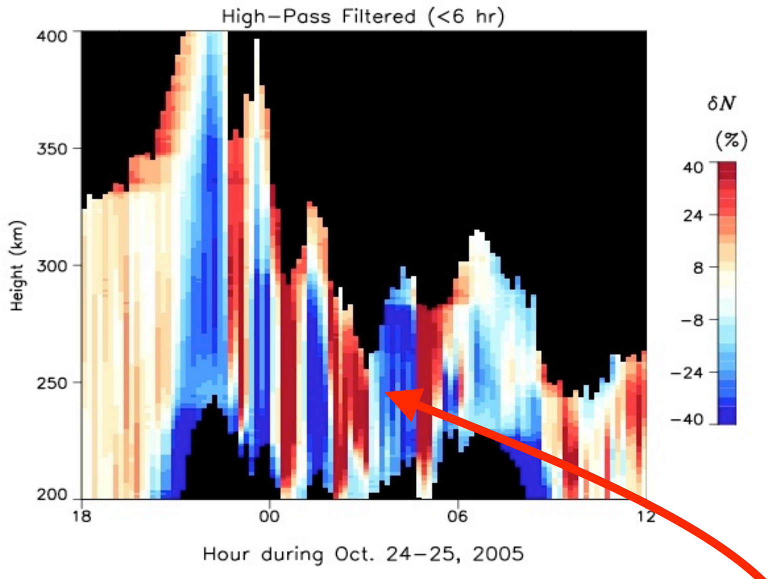


3. What are some anticipated neutral and plasma TI responses that could motivate more quantitative studies in the MTI?

SpreadFEx measurements - 24-25 October 2005

Digisondes (Fortaleza and Sao Luis)





downward phase, periods

=> GWs

large δN_e => large GW amps,

$\delta\rho$ ~5-10%

w' ~10-30 m/s

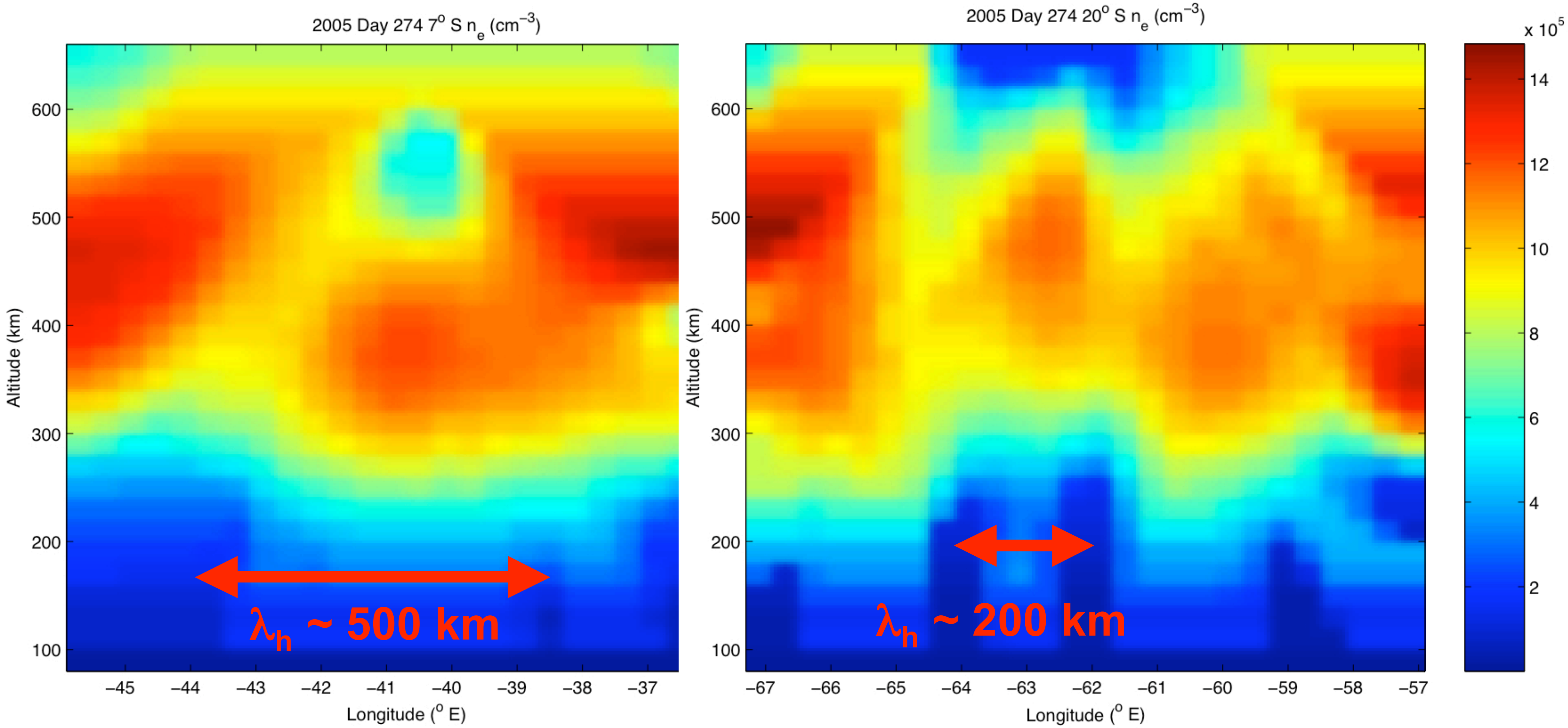
u' ~20-50 m/s

Abdu et al. (2009)

TIMED/GUVI 1356 tomography

- define bottomside and topside F-layer densities

=> apparent linkage of perturbations from bottomside to topside F layer



Kamalabadi et al. (2009)

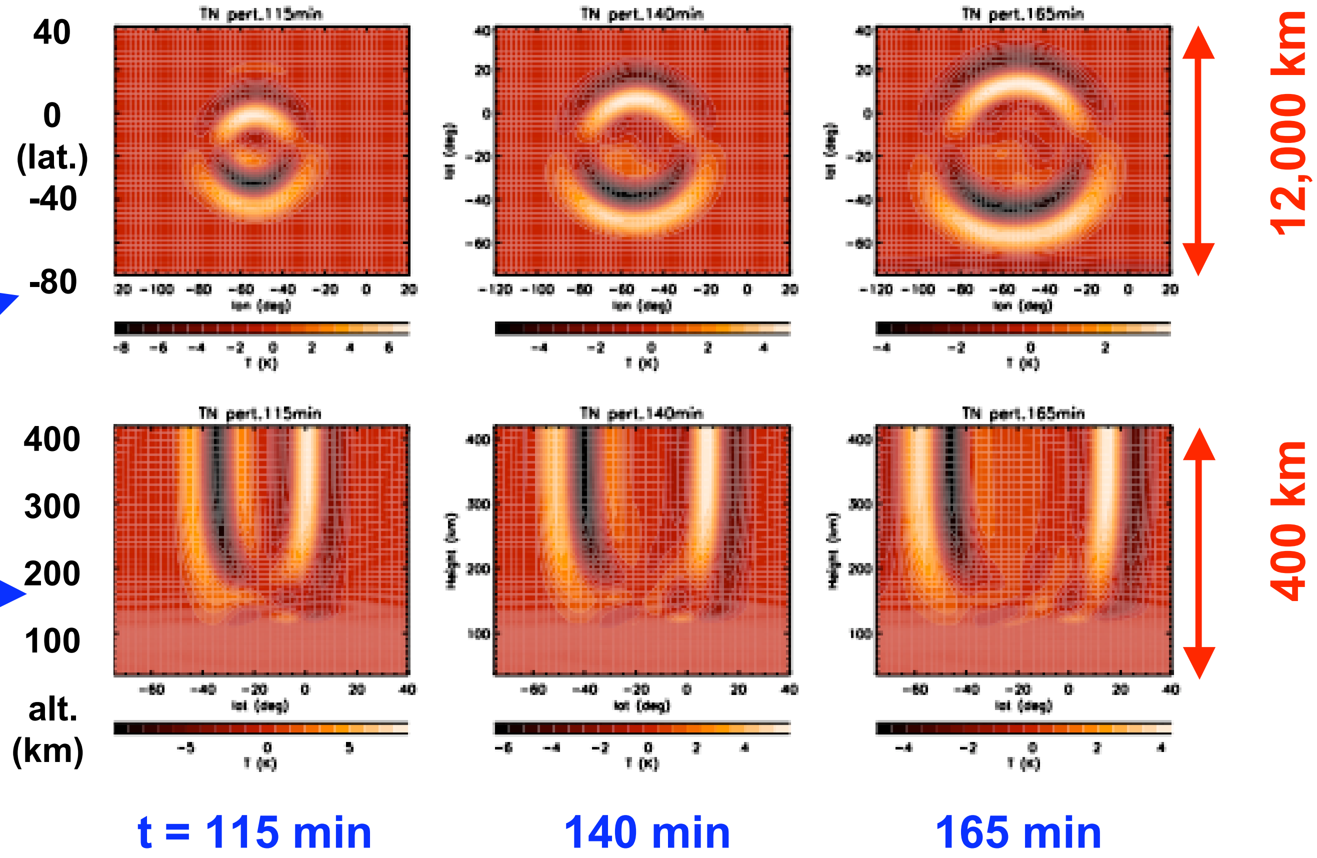
GW breaking at lower altitudes

Gaussian body force at ~180 km
=> large-scale GW at z ~250-400+ km ~1 - 2 hours later

TIME GCM response to Gaussian body forcing

lat. - long. cross sections @ z = 250 km

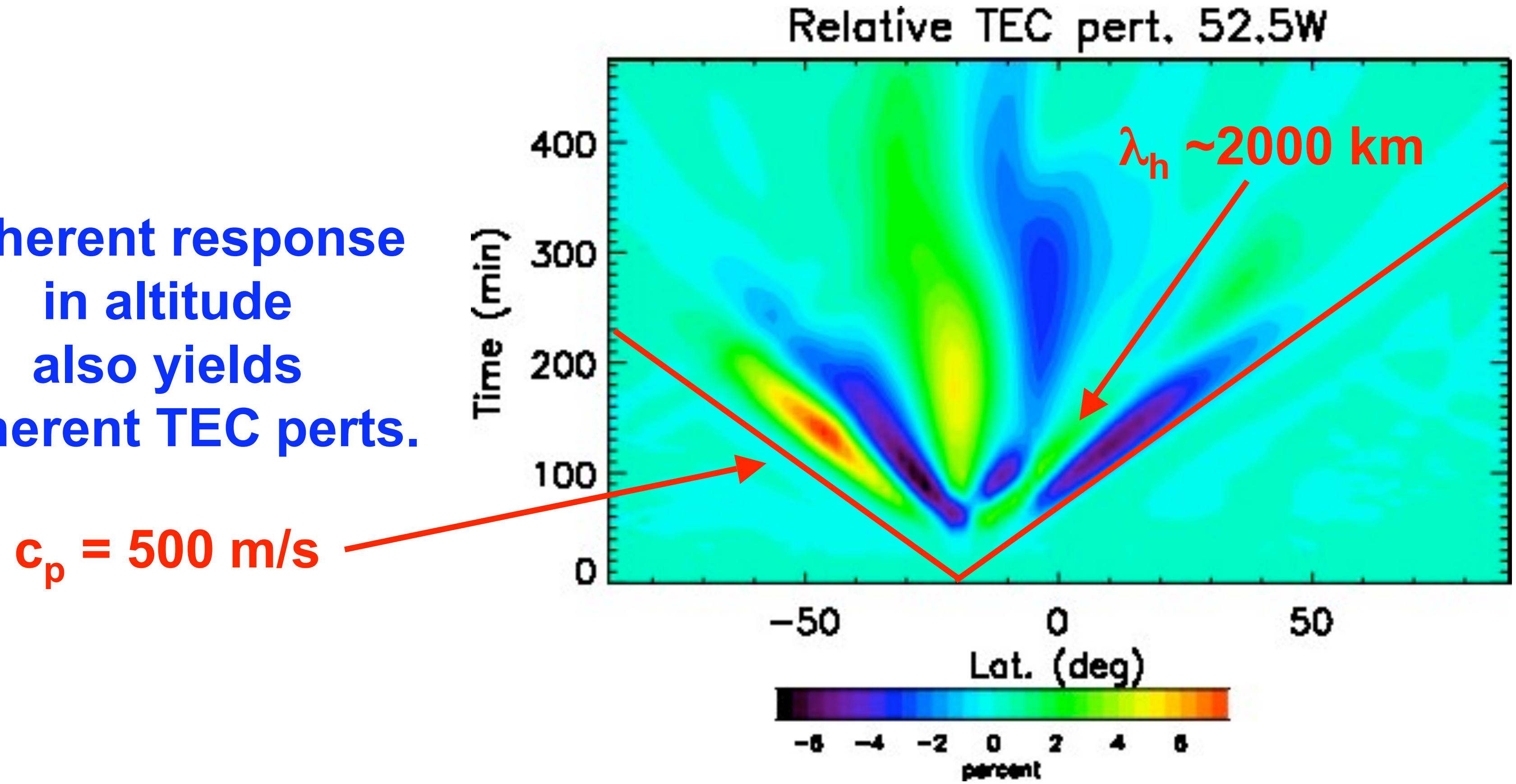
lat.-alt. cross sections



Vadas and Liu (2009)

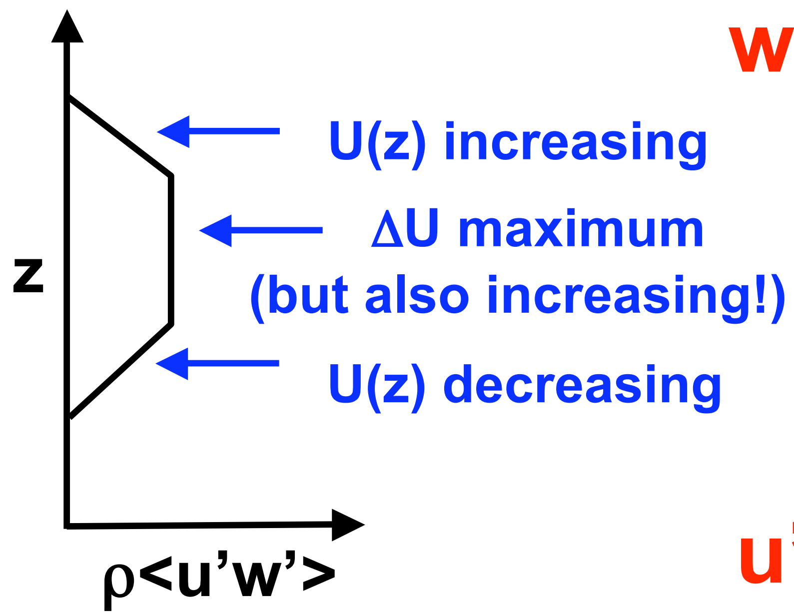
Secondary GWs also have deep responses, impacts on electron densities

coherent response
in altitude
also yields
coherent TEC perts.



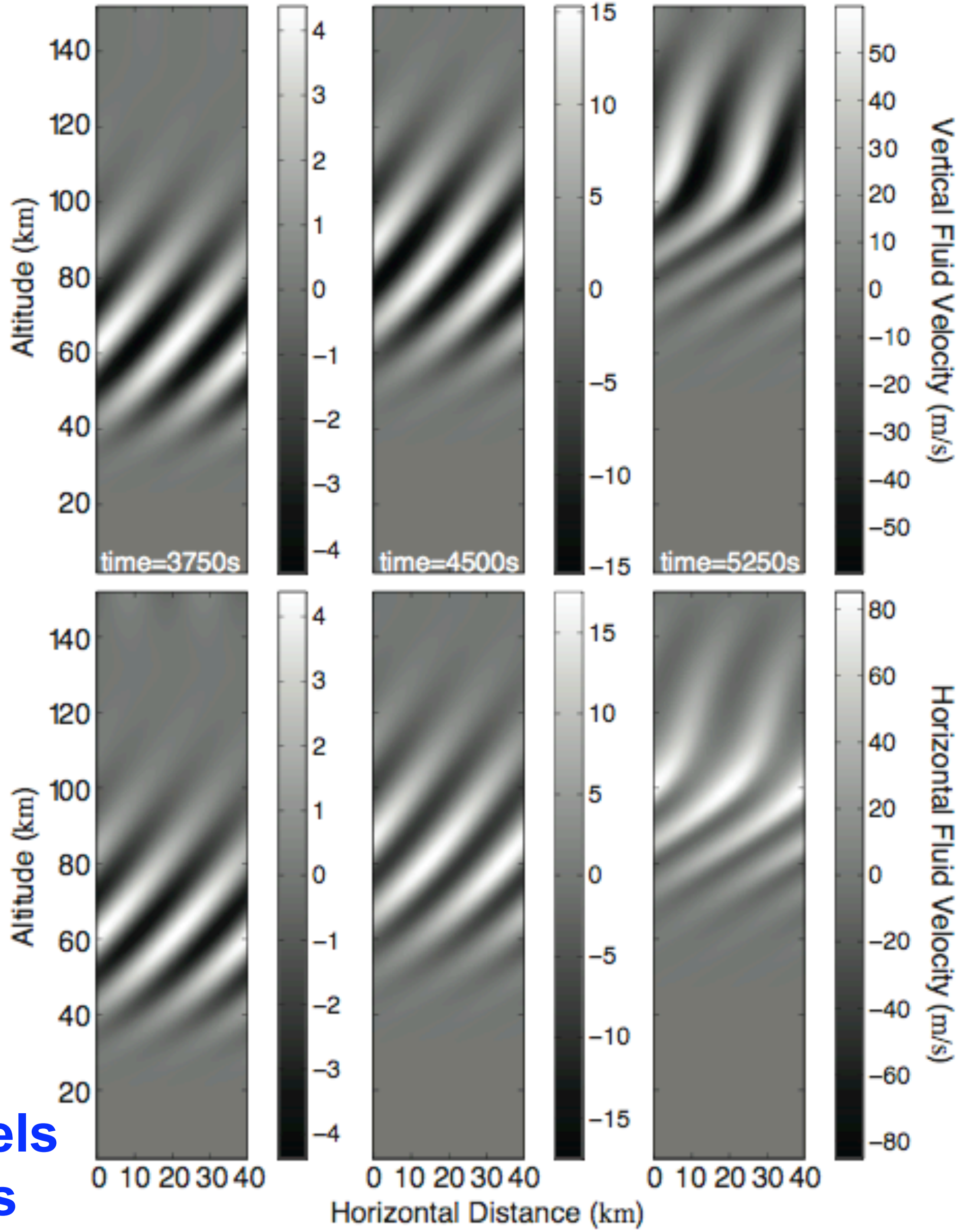
Vadas and Liu (2009)

GW - mean flow interactions become <u>very</u> pronounced in MTI for large-amp. GWs



w'

u'



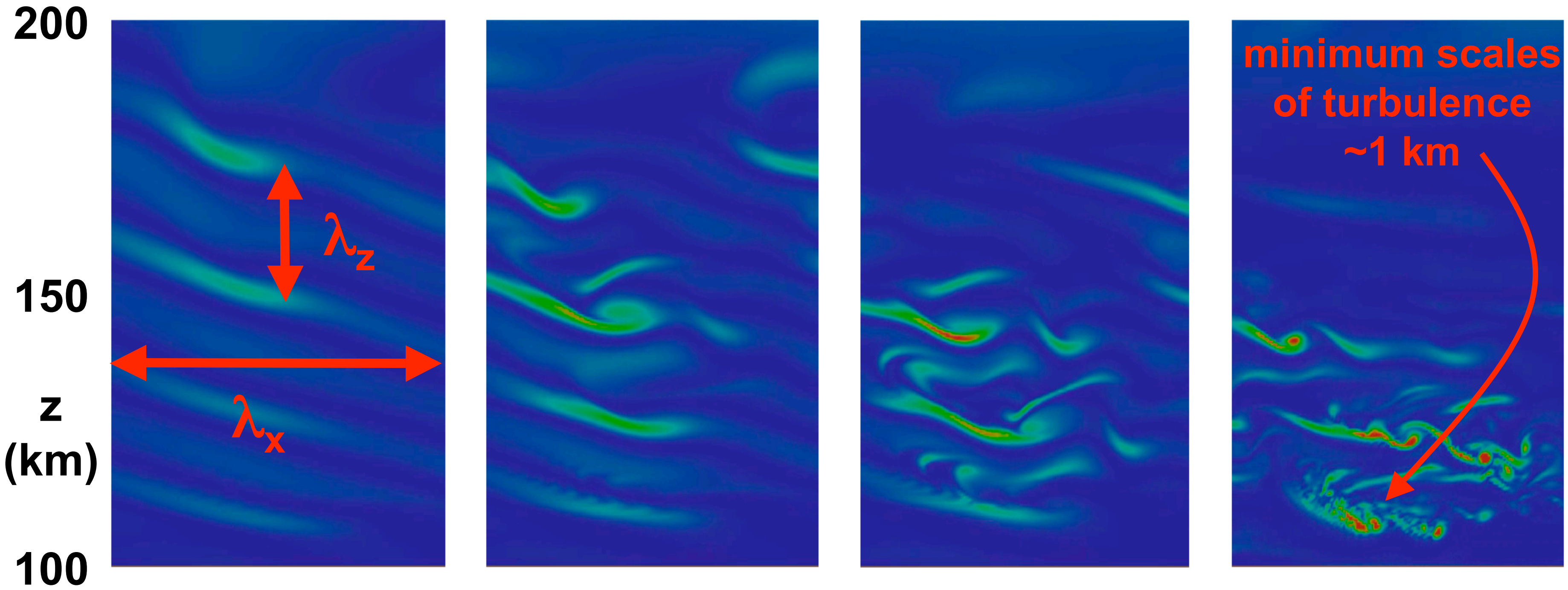
$\Delta U \sim \langle u'w'\rangle\, \Delta t/c_{gz} \sim 1/\rho \sim e^{z/H}$

⇒ large variations of c_p
⇒ Ability to "outrun" critical levels
⇒ enhanced instability dynamics

Lund et al. (2010)

GW breaking @ z ~ 100-200 km

λ_x ~30-100 km, λ_z ~10-30 km,
u' ~ c-U ~ 50-100 m/s, ω ~ N/3, Re ~10^3-10^6



Convective GWs easily achieve large amplitudes in LT
=> instability and turbulence extend to high altitudes
=> "turbopause" is likely an artifact of lack recognition
of larger-scale turbulence structures in the LT

4. What measurement strategies might address these dynamics?

Desire sensitivity to:

- **dominant spatial and temporal scales**
  (~10 km at 80 km alt. to ~100+ km at 200 km alt.)
- **temperature and wind perturbations in 2D or 3D**
- **a wide range of altitudes (*in situ* & remote sensing)**
- **correlations between neutral and plasma features**

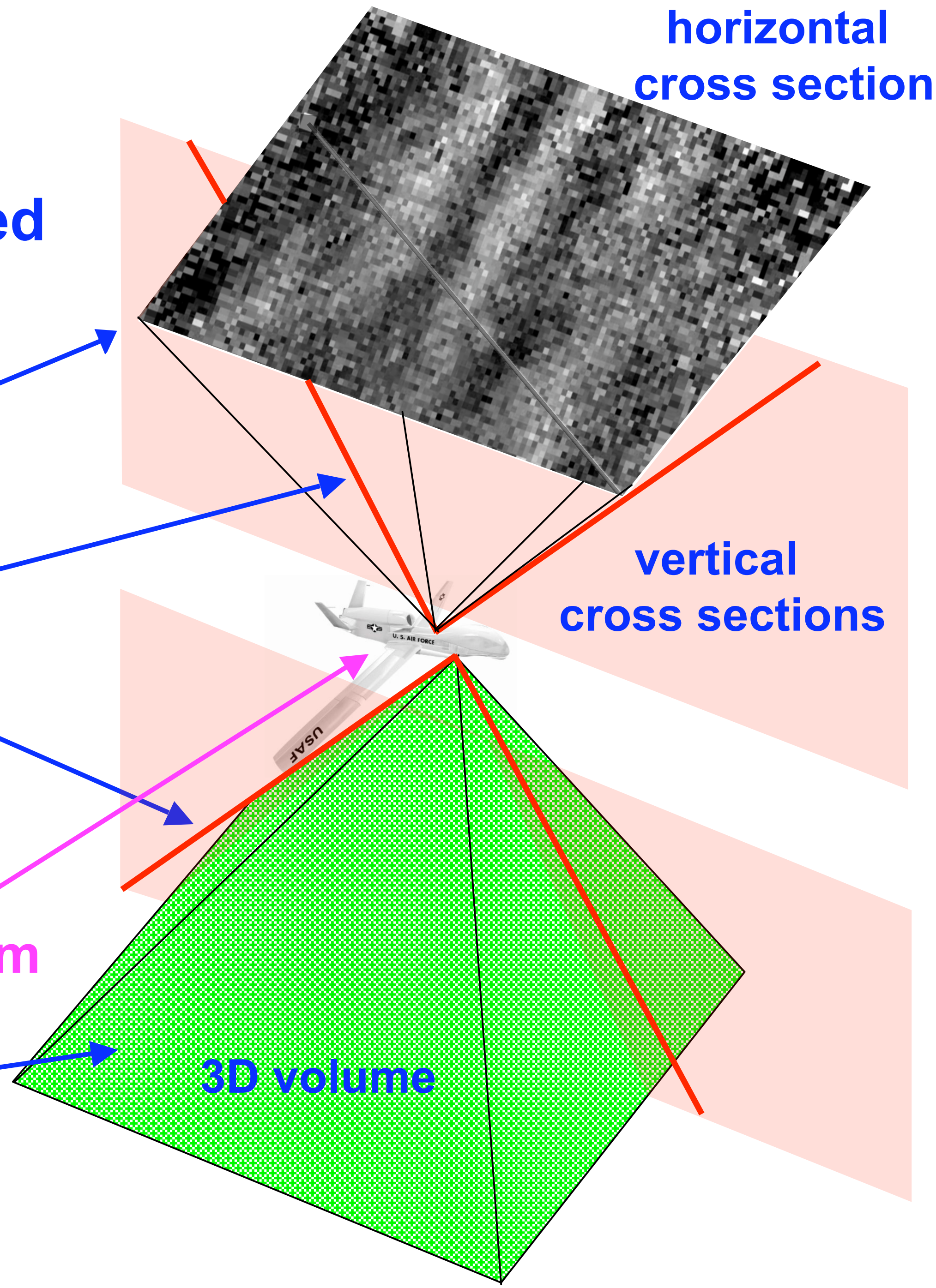
Suborbital measurements can mimic satellite spatial sampling with ground-based resolution and accuracies

- 2D airglow imaging above, T(x, y, t)

- lidar sampling above or below, V(x, z, t), T(x, z, t)

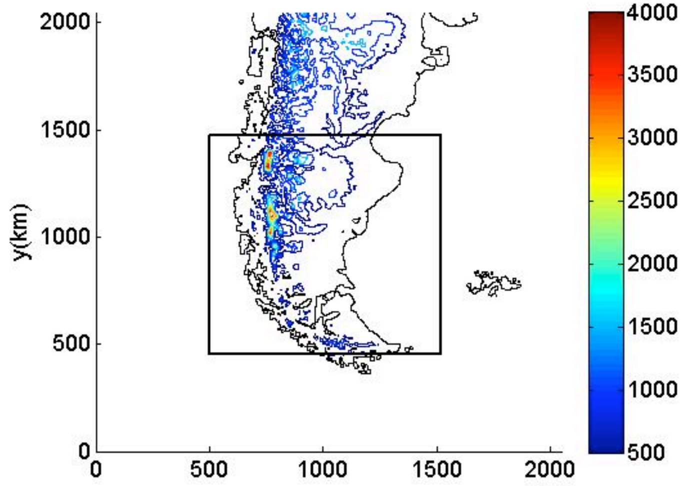
in situ sampling of small-scale dynamics ~50-150 km

3D thermal imaging T(x, y, z, t) ~10 - 90 km

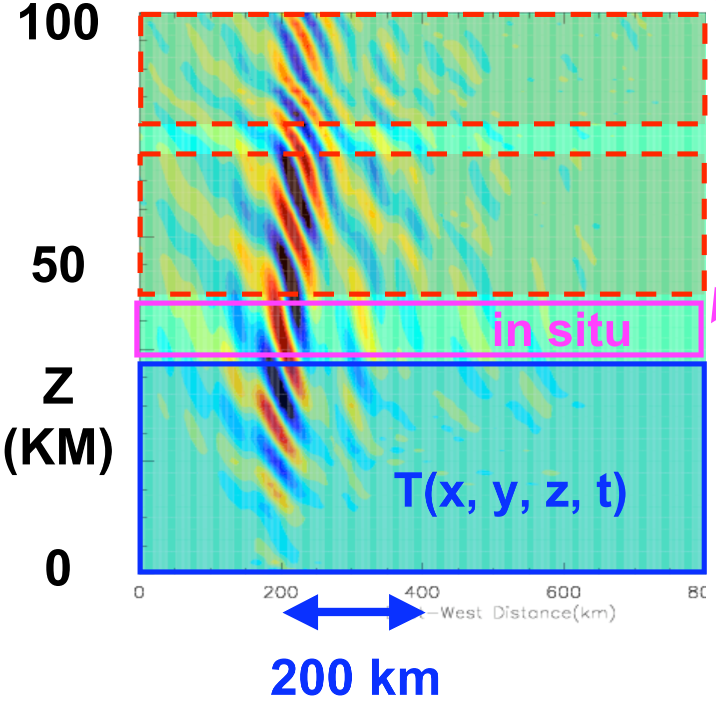


MWs (ray tracing) over southern Andes in winter

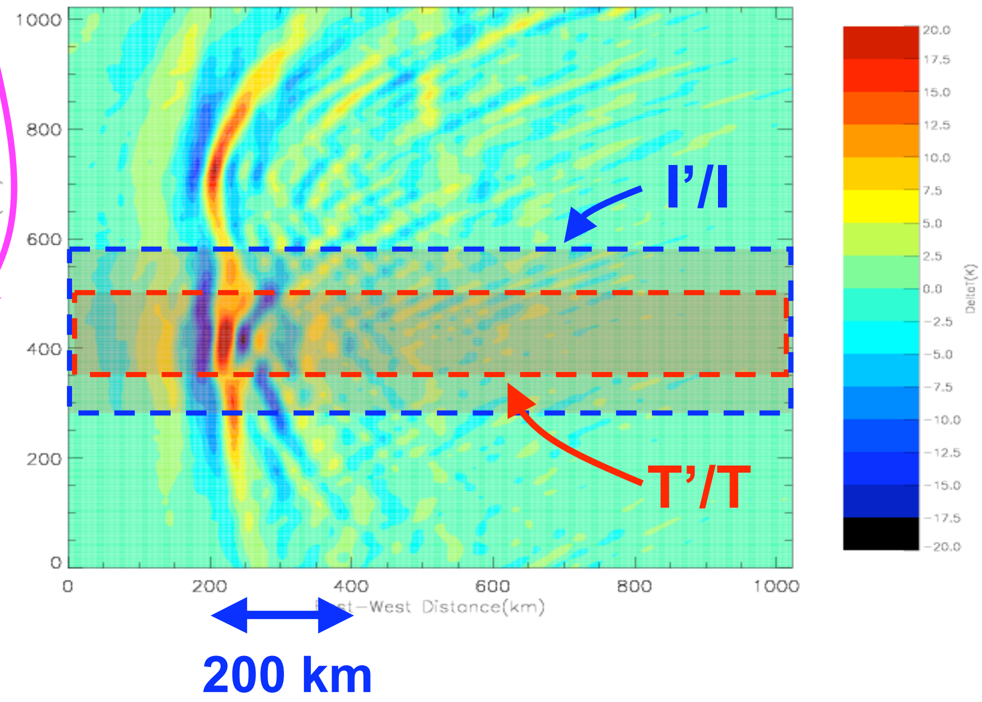
UAV or balloon at ~20-100 km
=>
current instrumentation would achieve sampling from ~0 to 100 km (UAV @ ~40 km)



vehicle at ~40 km



(x,y) cross section at z = 87 km



Summary

1. Important GW dynamics <u>occur at all altitudes</u> throughout the MLT (~50 to 300 km)
2. Current ground-based and satellite instruments <u>do not provide</u> the needed measurements
3. Sub-orbital platforms with various instrumentation (*in situ* and remote sensing) <u>could address a range of scientific needs</u> from altitudes of ~20-100+ km
4. The enabled science will depend strongly on the platform and the measurements that it supports