Horizontal and Vertical Wave Parameters of Thermospheric Gravity Waves, and Relationship to Neutral Winds

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High-resolution, single-beam measurements of gravity waves (GWs) have been made at the Arecibo Observatory (AO) for decades. Features include:

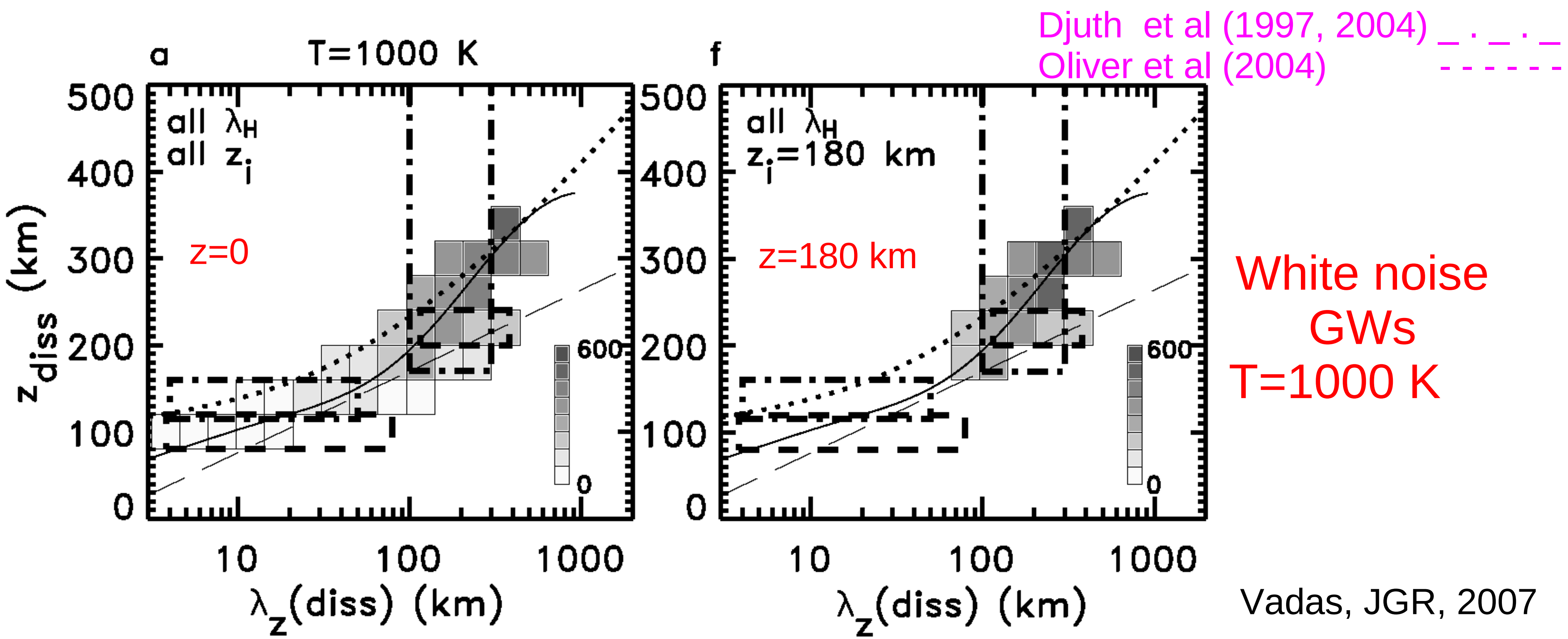
- Vertical wavelength of the spectrum increases exponentially with altitude (Djuth et al, 1997, 2004)
- GWs are omnipresent, although typically appear as discreet wave packets (Djuth et al, 2004; Livneh et al, 2007)

Consequence of single-beam: no horizontal information (including propagation direction). Therefore, GW sources are unknown, although speculations have been made (Djuth et al, 2010).

CEDAR Hine workshop, 1000-1200 Tuesday, June 25, 2013

Given the wave packet nature of the GWs in the thermosphere, a dissipative dispersion relation was derived which allowed for the determination of the parameters of a GW as a function of time explicitly (Vadas and Fritts, 2005). No steady state approximation was made. This dispersion relation was incorporated into a 3D ray trace program (e.g., Vadas, 2007; Vadas and Fritts, 2009).

White noise and deep convective plume spectra of GWs were ray-traced into the thermosphere. The results were found to agree well with the AO and MU observations (Vadas, 2007)



White noise GWs T=1000 K

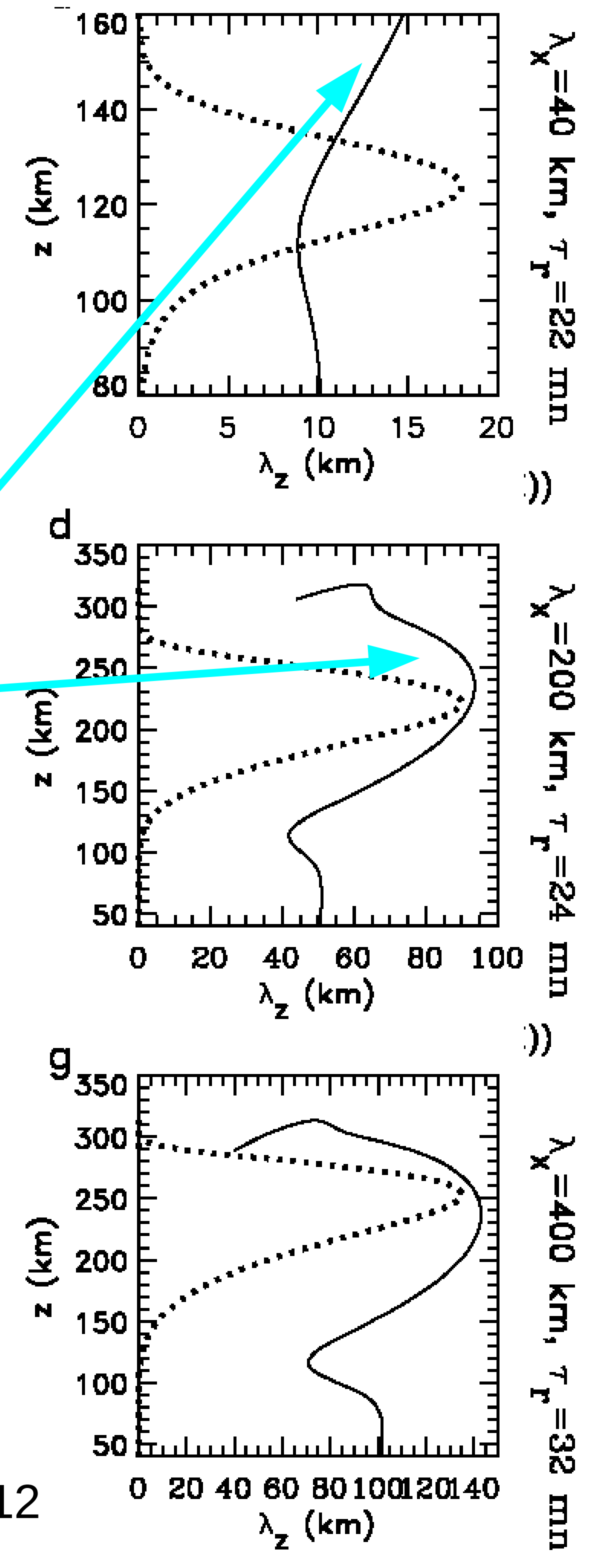
Vadas, JGR, 2007

Are the GWs in the thermosphere over AO steady state (e.g., full wave model of Waltersheid and Hickey, 2011), or discreet wave packets?

Major difference between theories:

GW wave packet theory: For an individual GW, λ_z increases rapidly in z until the altitude where the momentum flux u_H'w' is maximum=z_{diss}. Above z_{diss}, λ_z decreases with altitude in a zero-wind environment unless T increases, in which case λ_z increases slowly in z. (e.g., Vadas and Nicolls, JGR, 2012).

Steady state theory: For an individual GW, λ_z increases exponentially above z_{diss} (Waltersheid and Hickey, 2011).

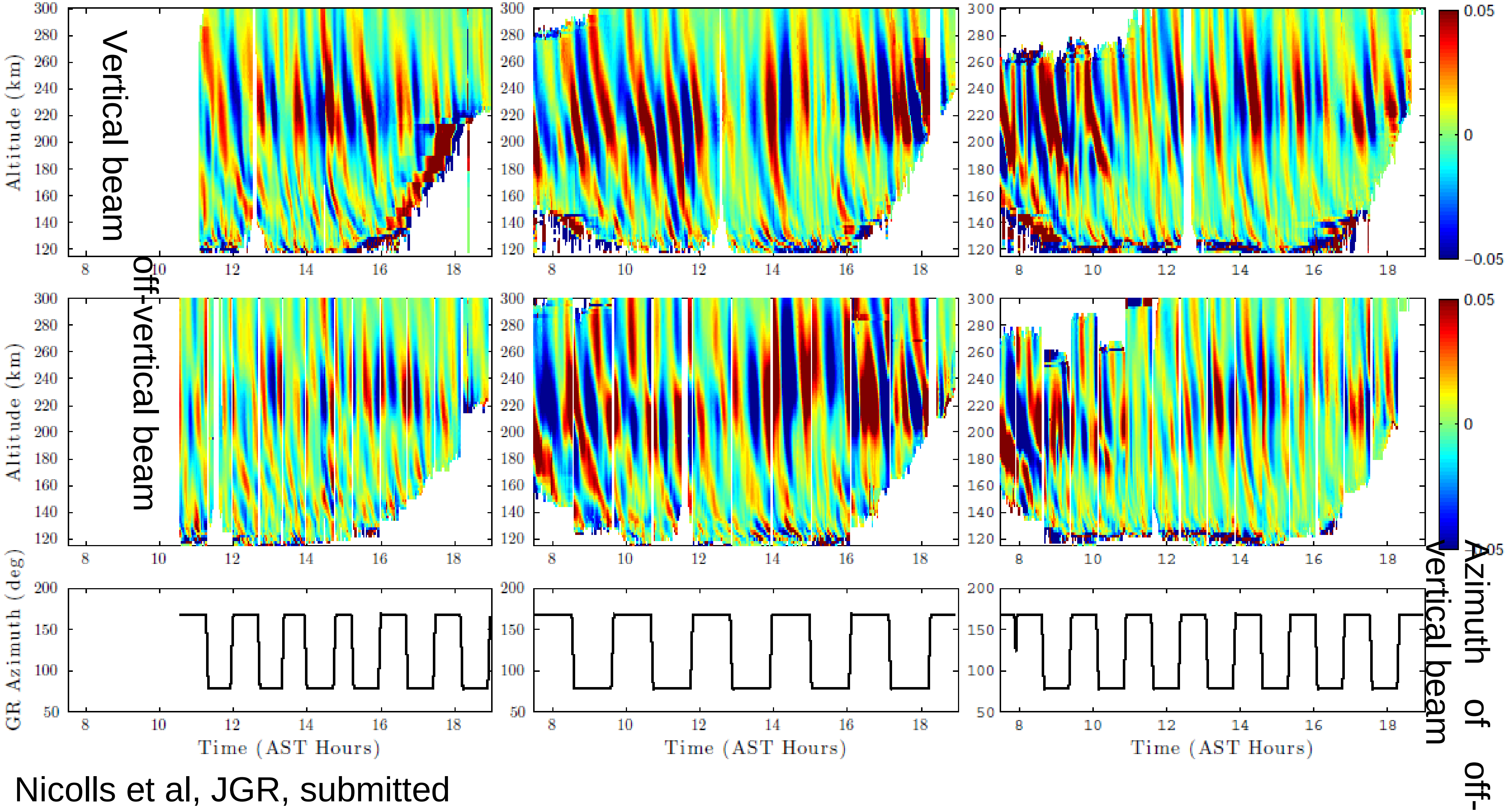


Vadas and Nicolls, JGR, 2012

New multi-day dual beam observations are helping to answer these questions

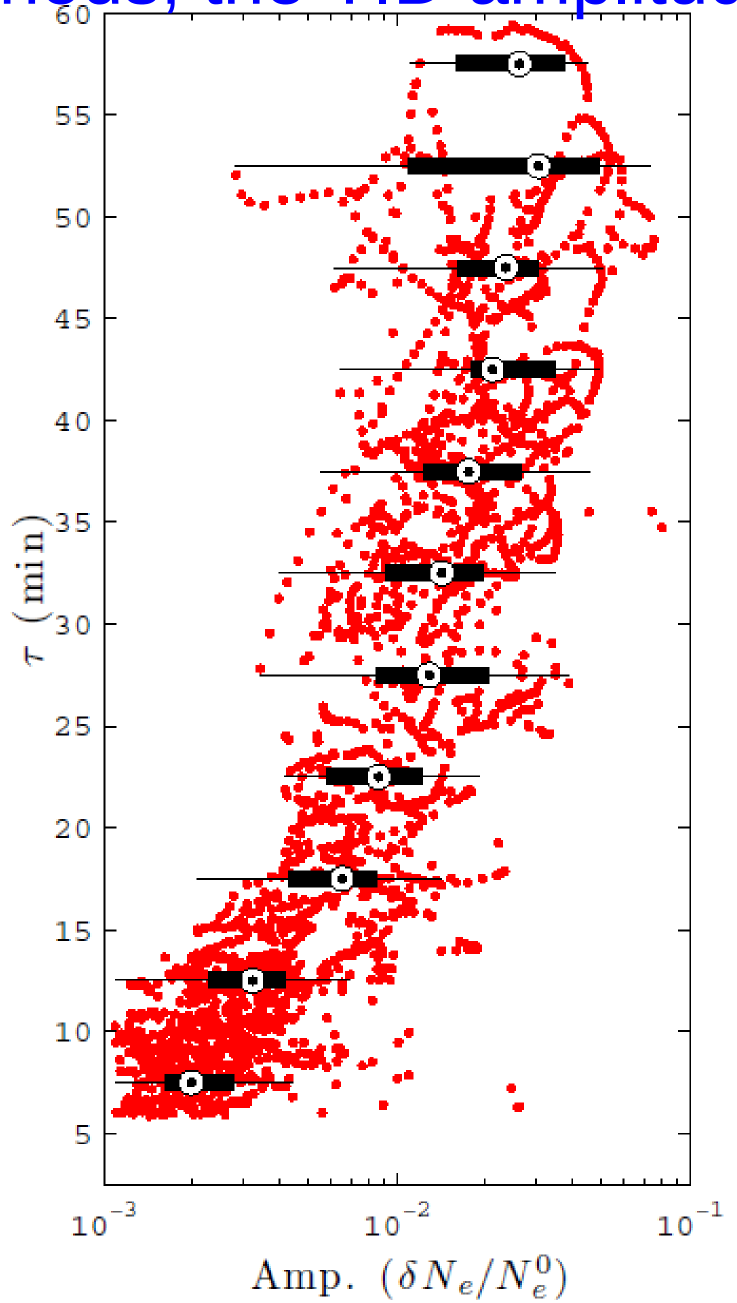
- fixed vertical beam
- off-vertical beam which rotated 90 degrees every few hours

23-25 July, 2009, the AO



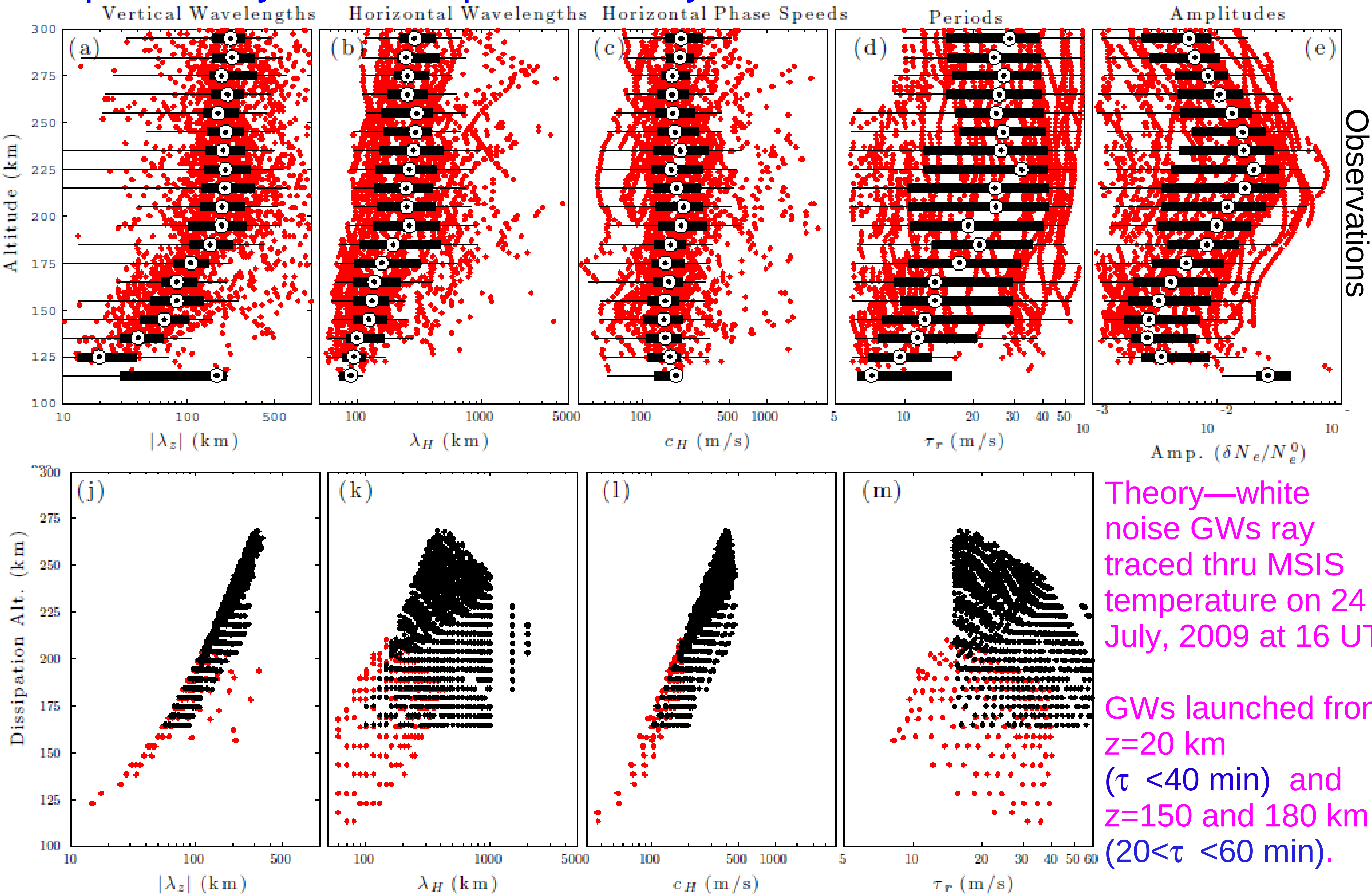
Nicolls et al, JGR, submitted

TID amplitudes increase rapidly with increasing GW period from τ~5 to 40 min
For larger periods, the TID amplitude increases slowly



Nicolls et al, JGR, submitted

GW spectral properties change substantially with altitude. Can be explained by GW dissipative theory.



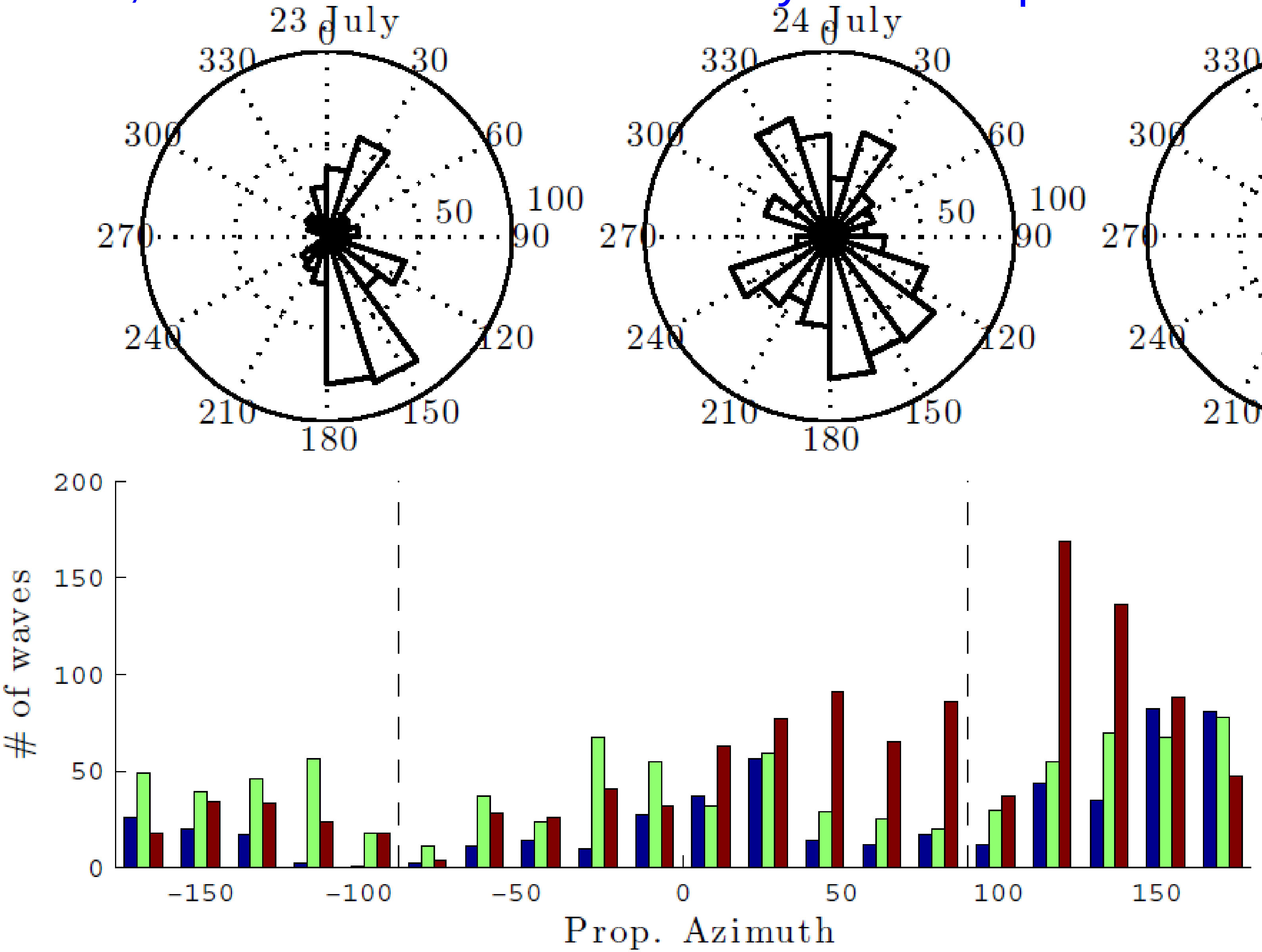
Theory—white noise GWs ray traced thru MSIS temperature on 24 July, 2009 at 16 UT.

GWs launched from z=20 km (τ <40 min) and z=150 and 180 km ($20<\tau$ <60 min).

Red:zero wind. Black: Wind rotates with altitude in mesosphere, with amplitude of 100 m/s

Nicolls et al, JGR, submitted

Nearly all GWs are propagating Sward, SEward, NEward, and Eward, from the southern US, the Caribean, and northern South America. Thus, most of these GWs are likely from deep convective sources.



Nicolls et al, JGR, submitted

Future work will reverse ray trace these waves, in order to identify (if possible) their sources

What about individual GWs?

Follow the phase lines up in altitude (Vadas and Nicolls, 2009; Djuth et al, 2010)

Convert electron density perturbations to ion velocity perturbations via a simplified single-ion electron continuity equation with no chemistry and diffusion

$$V'_{ion} \simeq \frac{\omega_r}{\sin I}\frac{\delta N_e}{N_e^0}\left[\frac{-i}{N_e^0}\frac{dN_e^0}{dz} + k_{H||}\cot I + \left(m - i\left\{\frac{1}{2H} + \frac{1}{g}\frac{dg}{dz}\right\}\right)\right]^{-1}$$

I= local dip angle, D= declination angle of magnetic field, δN_e= TID amplitude,

N_e^0= background electron density,

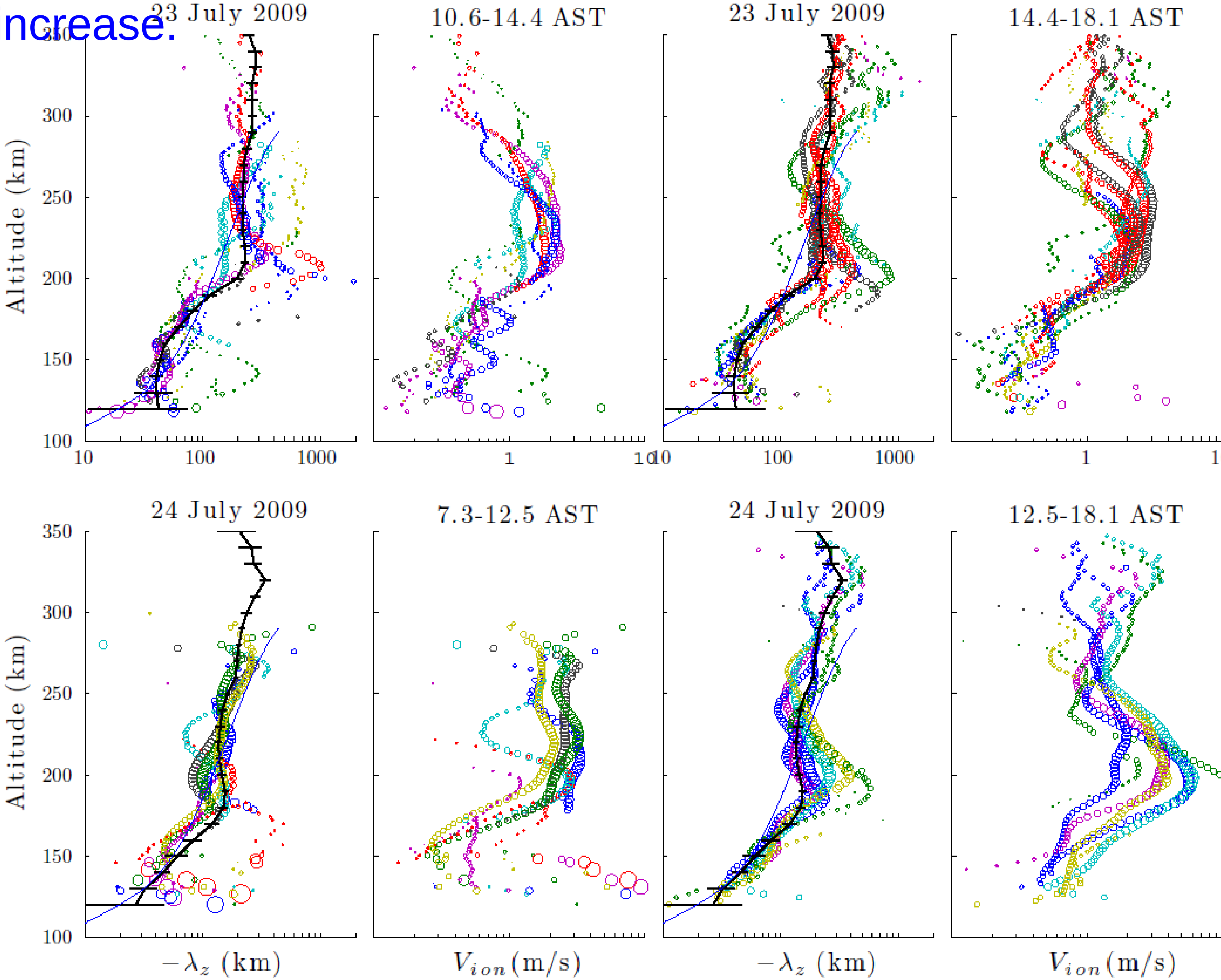
k_H=horizontal wavenumber, m=vertical wavenumber, ω_r= wave frequency,

ψ=wave propagation direction, $k_{H||} = k_H \cos(\psi - D)$,

V'_{ion} α g(z) exp(z/2H). Here, we set dg/dz=0

Nicolls et al, JGR, submitted

λ_z stays approximately constant above z_{diss} in the AO data for nearly every case. In cases where it increases, it is not an exponential increase.

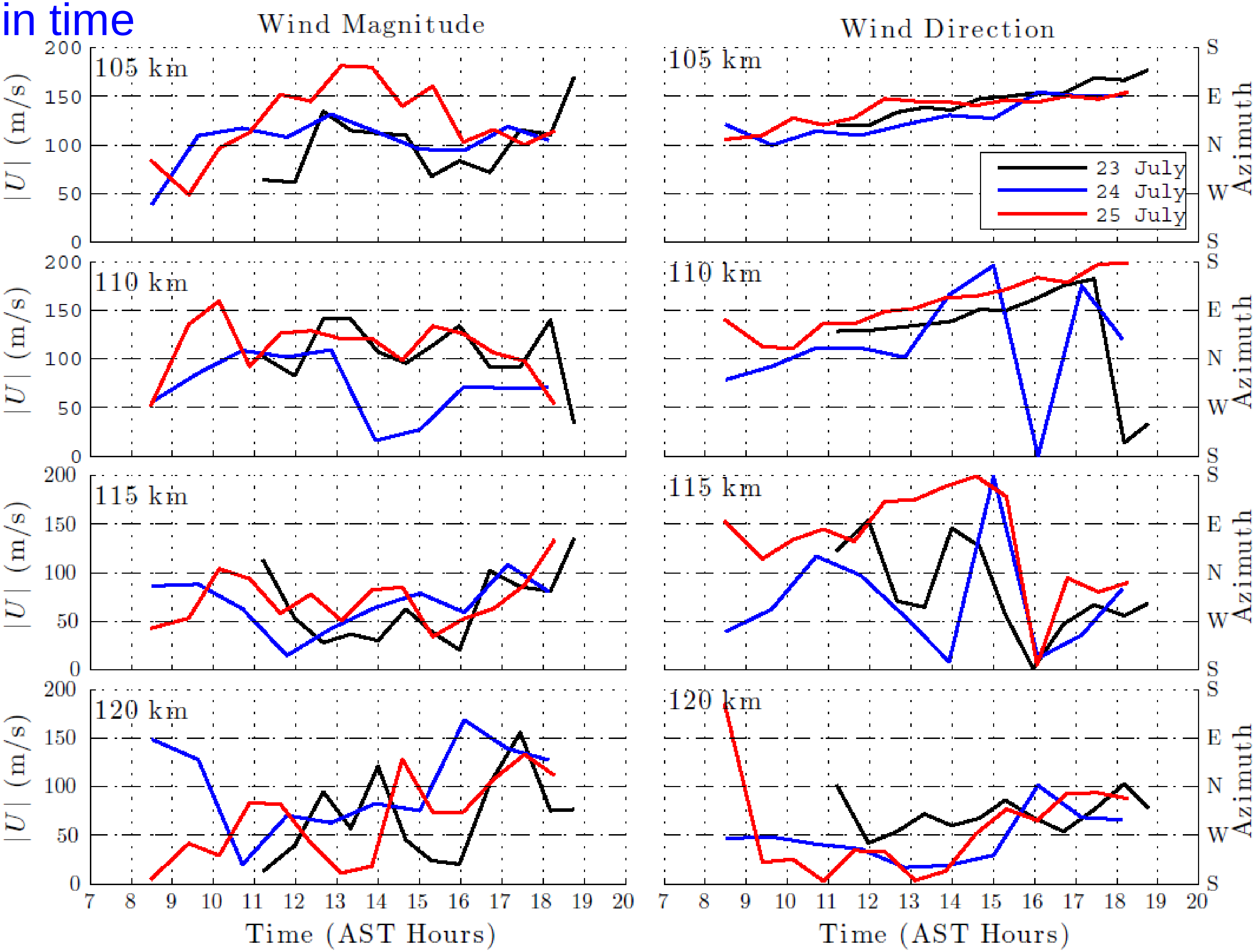


Trace individual wave packets in altitude (color-coded). Marker sizes are proportional to electron density perturbation amplitude.

Nicolls et al, JGR, submitted

Therefore, AO thermospheric GWs propagate as wave packets, not steady state wave fields

E region neutral winds also measured. Amplitudes are as large as 100-200 m/s, similar to Larsen et al results! Winds generally rotate clockwise in time



July 23: black

July 24: blue

July 25: red

Nicolls et al, JGR, submitted