Observations of Secondary Wave Manifestation Arising from Migrating Diurnal Tide-Quasi Two-Day Wave Interaction

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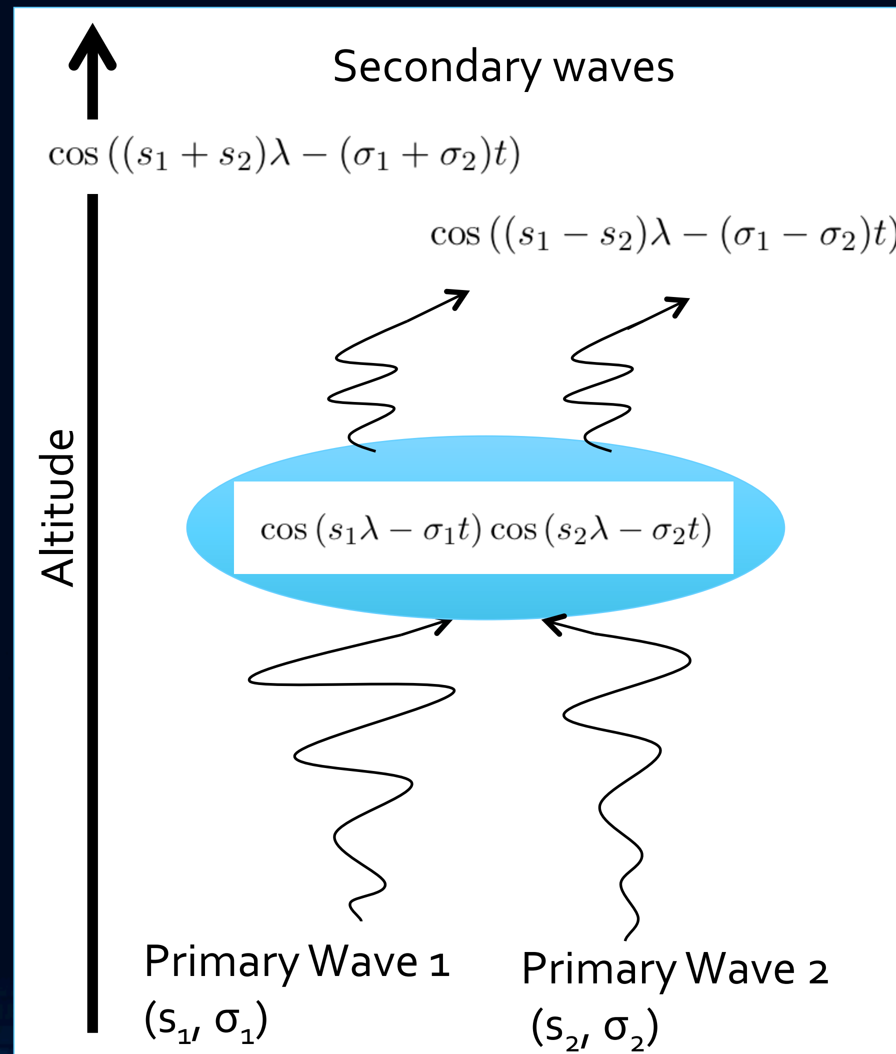
Nonlinear Wave-Wave Interactions

Sources of Tides/PWs

- Solar Driven Processes in the Lower/ Upper Atmosphere
- Lunar gravitational
- **Nonlinear wave-wave Interactions**

Theory of Nonlinear Interactions (Teitelbaum, 1991)



Previous Work on Nonlinear Interactions

Ground-Based Studies

- Numerous studies showing evidence of primary wave and secondary wave periodicities at the same location

Limitations

- Ground-based studies cannot provide global information

Satellite-Based Studies

- Recent evidence of secondary waves on a global scale

Limitations

- Certain wave-wave interactions are difficult to observe (QTDW-DW1) due to aliasing

Modeling-Based Studies

- Modeling studies using general circulation models (GCMs) support that secondary waves can be generated in the atmosphere

Limitations

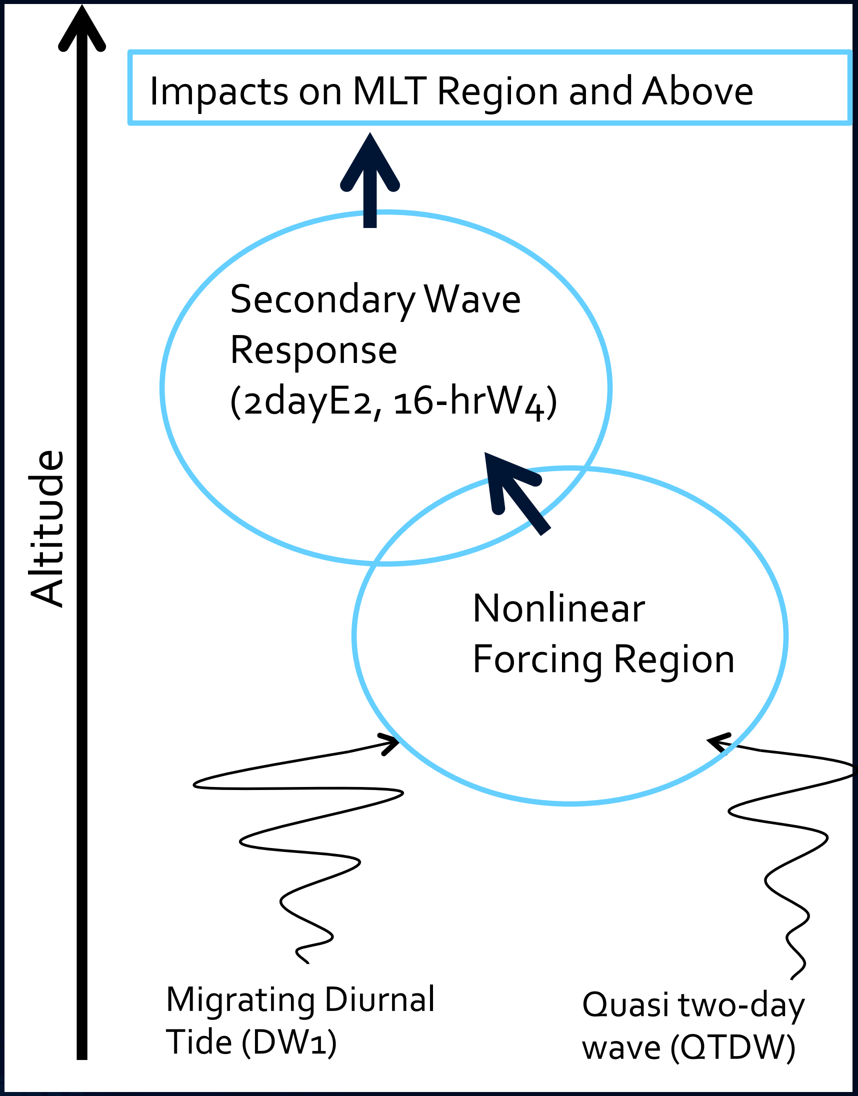
- GCMs are complex
- Lack of observational basis

Science Questions

1. Where in the atmosphere is DW1 and QTDW interacting to force secondary waves and where do significant secondary wave responses occur?

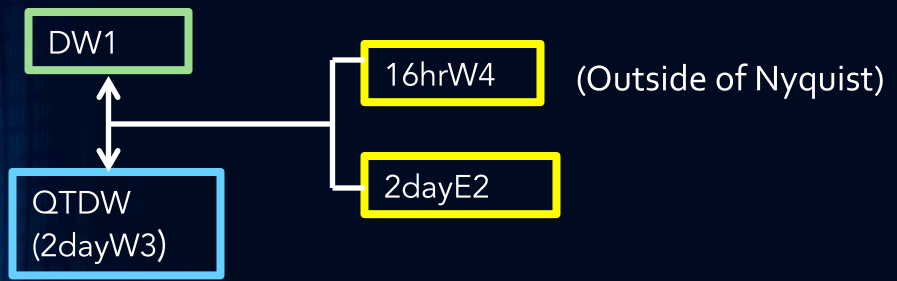
2. How does the nonlinear forcing region affect the structure and propagation of the resulting secondary waves?

Methodology
Estimate the primary waves and secondary waves from satellite observations (EOS Aura-MLS and TIMED-SABER)



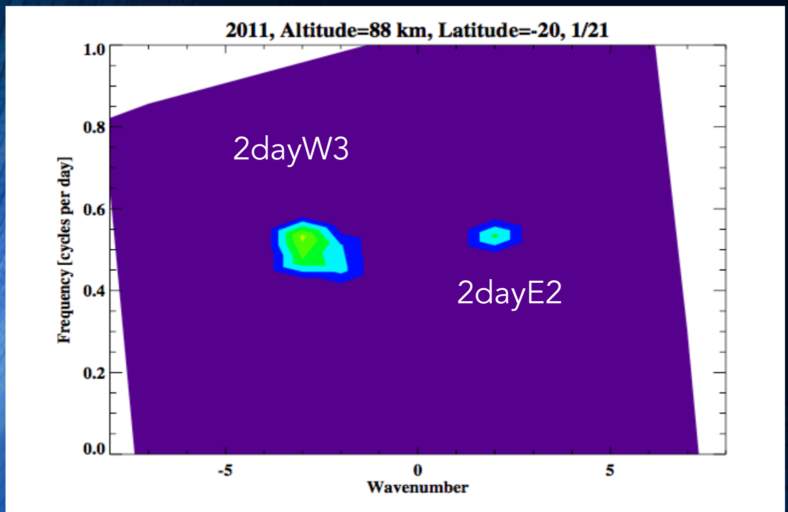
Secondary Wave Response

Primary Waves Secondary Waves

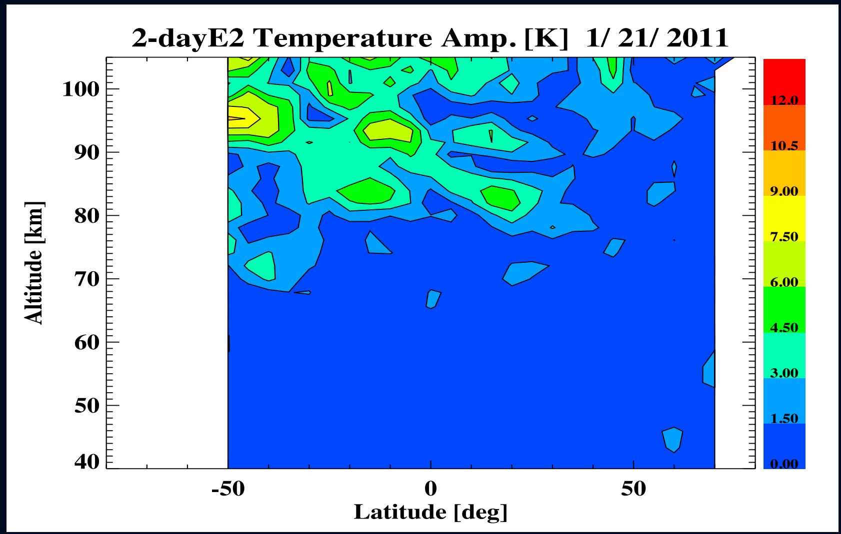


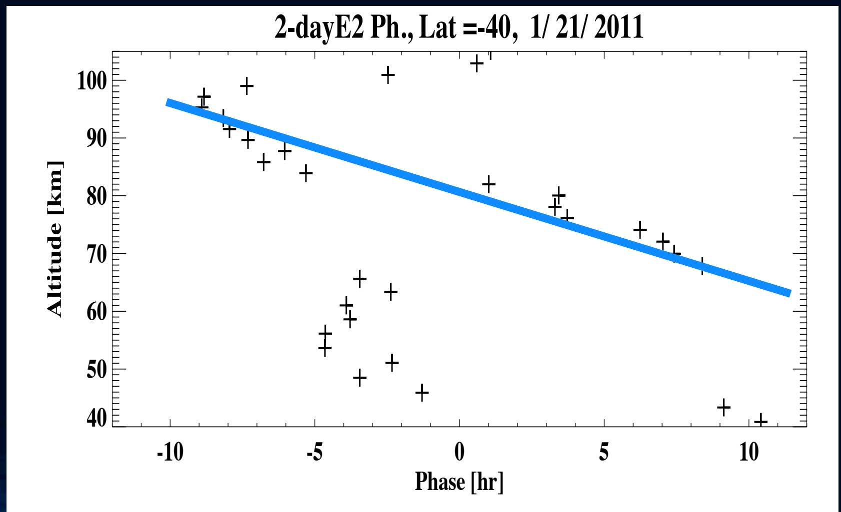
- FFSM (*Salby*, 1982) method completely separates the QTDW and 2-dayE2 from each other
- 2-dayE2 signal represents 2-dayE2/16hrW4 secondary wave activity

Frequency-Wavenumber Spectrum (Jan 2006)



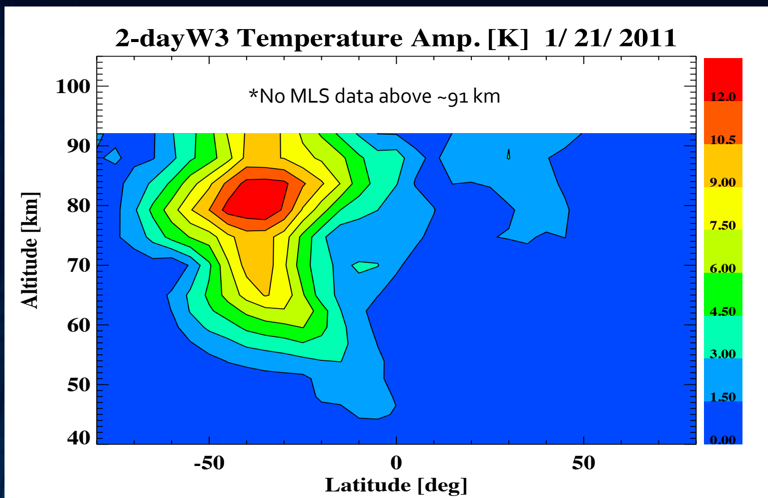
Secondary Wave from SABER



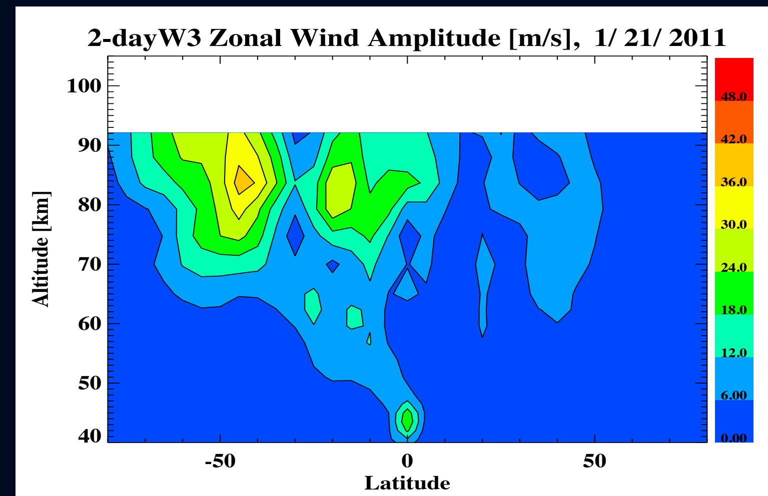


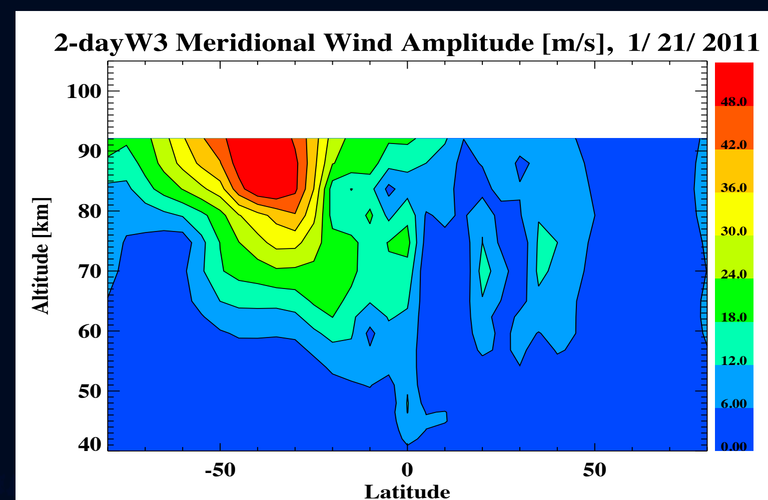
QTDW Temperatures, Winds

QTDW Temperature from Salby Method



Derived QTDW Winds





Compute QTDW u′ and v′ using momentum balance

$$\frac{\partial u'}{\partial t} + \frac{\bar{u}}{a\cos\phi}\frac{\partial u'}{\partial\lambda} - \hat{f}v' = -\frac{1}{a\cos\phi}\frac{\partial\Phi'}{\partial\lambda}$$

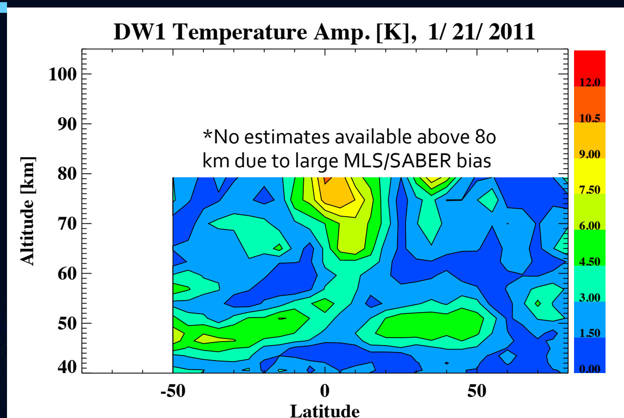
$$\frac{\partial v'}{\partial t} + \frac{\bar{u}}{a\cos\phi}\frac{\partial v'}{\partial\lambda} + \tilde{f}u' = -\frac{1}{a}\frac{\partial\Phi'}{\partial\phi}$$

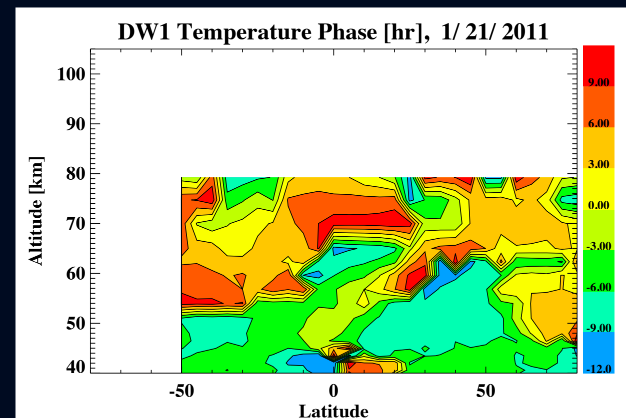
Derived gradient background zonal wind

QTDW geopotential height from MLS observations

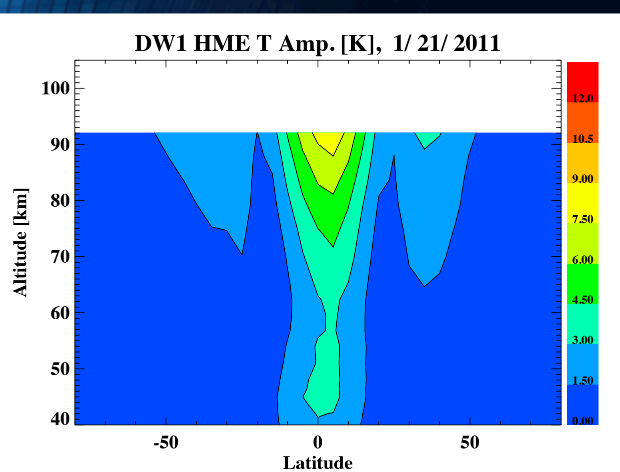
DW1 Temperature, Winds

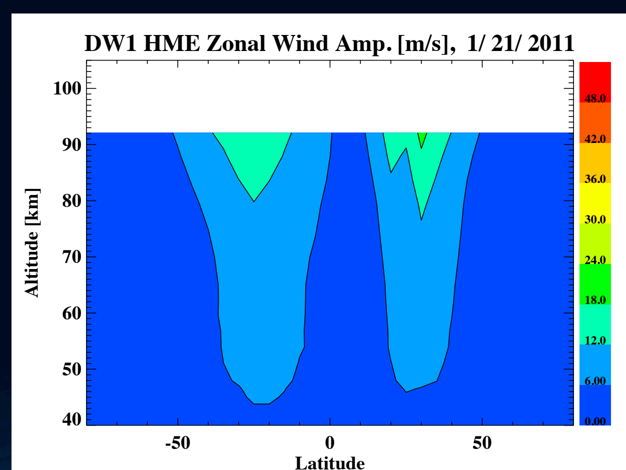
Short-term temperature estimates of DW1 from combined MLS/SABER data (Nguyen and Palo, 2013)

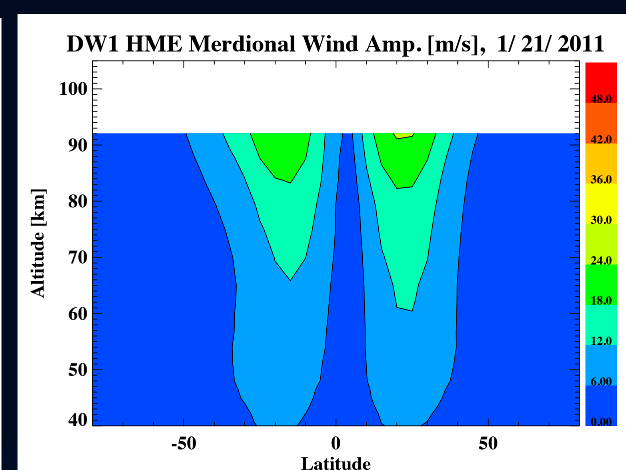




Fit to Global Scale Wave Model (GSWM) Hough Mode Extensions to derive horizontal winds







Nonlinear Forcing Term

Dynamics of the atmosphere are governed by conservation of momentum, energy, mass and ideal gas law

Conservation of momentum (zonal, meridional) and energy

$$\frac{\partial u}{\partial t} + \{\frac{u}{acos\phi}\frac{\partial}{\partial \lambda} + \frac{v}{a}\frac{\partial}{\partial \phi} + w\frac{\partial}{\partial z}\}u - \frac{uv\tan\phi}{a} + \frac{uw}{a} = F_{Cor,x} + F_{Pressgrad,x} + F_{fric,x} + F_{other,x}$$

$$\frac{\partial v}{\partial t} + \{\frac{u}{acos\phi}\frac{\partial}{\partial \lambda} + \frac{v}{a}\frac{\partial}{\partial \phi} + w\frac{\partial}{\partial z}\}v + \frac{u^2\tan\phi}{a} + \frac{vw}{a} = F_{Cor,y} + F_{Pressgrad,y} + F_{fric,y} + F_{other,y}$$

$$\rho c_v \left[\frac{\partial T}{\partial t} + \{\frac{u}{acos\phi}\frac{\partial}{\partial \lambda} + \frac{v}{a}\frac{\partial}{\partial \phi} + w\frac{\partial}{\partial z}\}T\right] = Work + Heat$$

Advection

Dependent Field Variables

u=zonal wind vel.

v=meridional wind vel.

w=vertical wind vel.

T=Temperature

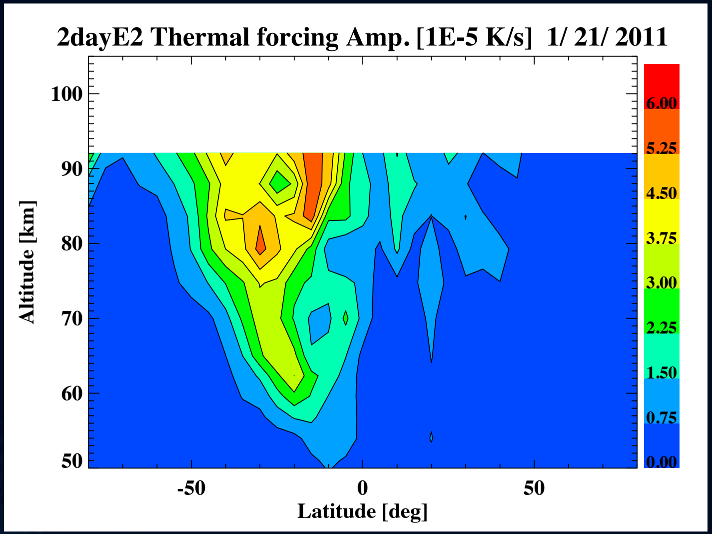
Assume u, v, w, T are composed of 2 primary waves

$$f = f_1' + f_2' = A_1cos(s_1\lambda - \sigma_1 t + \theta_1) + A_2cos(s_2\lambda - \sigma_2 t + \theta_2)$$

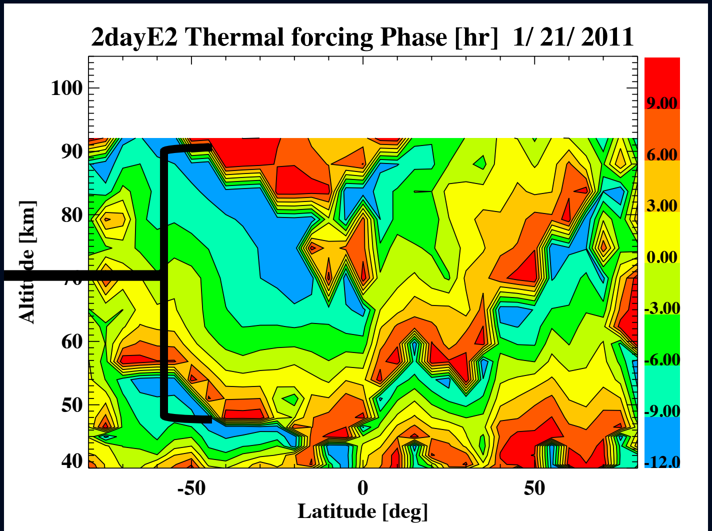
Products of primary waves through nonlinear terms → Zonal momentum forcing; Meridional momentum forcing; Thermal forcing

Thermal Forcing of Secondary Waves

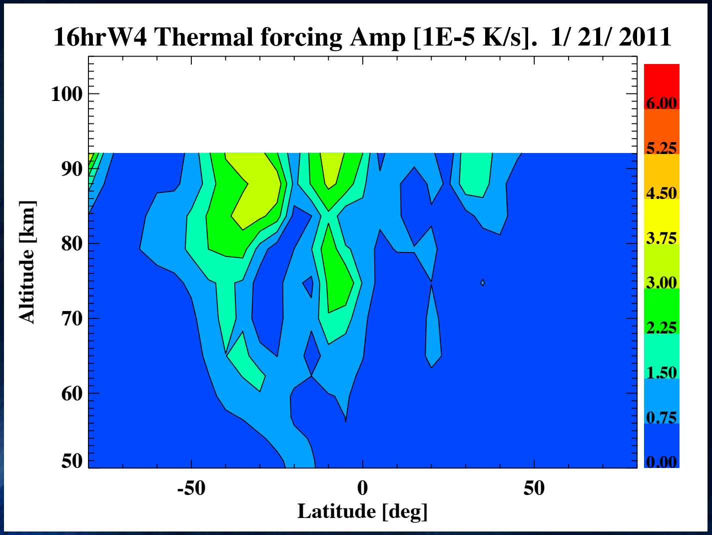
2-dayE2 Thermal Forcing



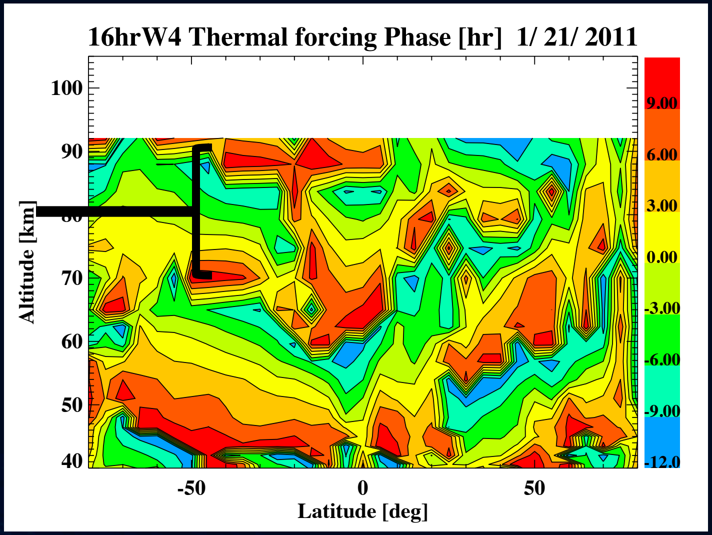
40km



16hrW4 Thermal Forcing



20km



Conclusions/Future

Summary

- Investigates the forcing and manifestation of secondary waves arising from DW1-QTDW interaction from satellite observations

Future

- Global Scale Wave Model (GSWM) will be utilized to investigate the relationship between nonlinear forcing region and the secondary wave response
- Determine potential impact on the MLT and IT systems

Acknowledgements
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GSWM Secondary Wave Response