Momentum Budget Analysis of the Migrating Diurnal Tide in WACCM4: Effects of Gravity Wave Forcing and Advection

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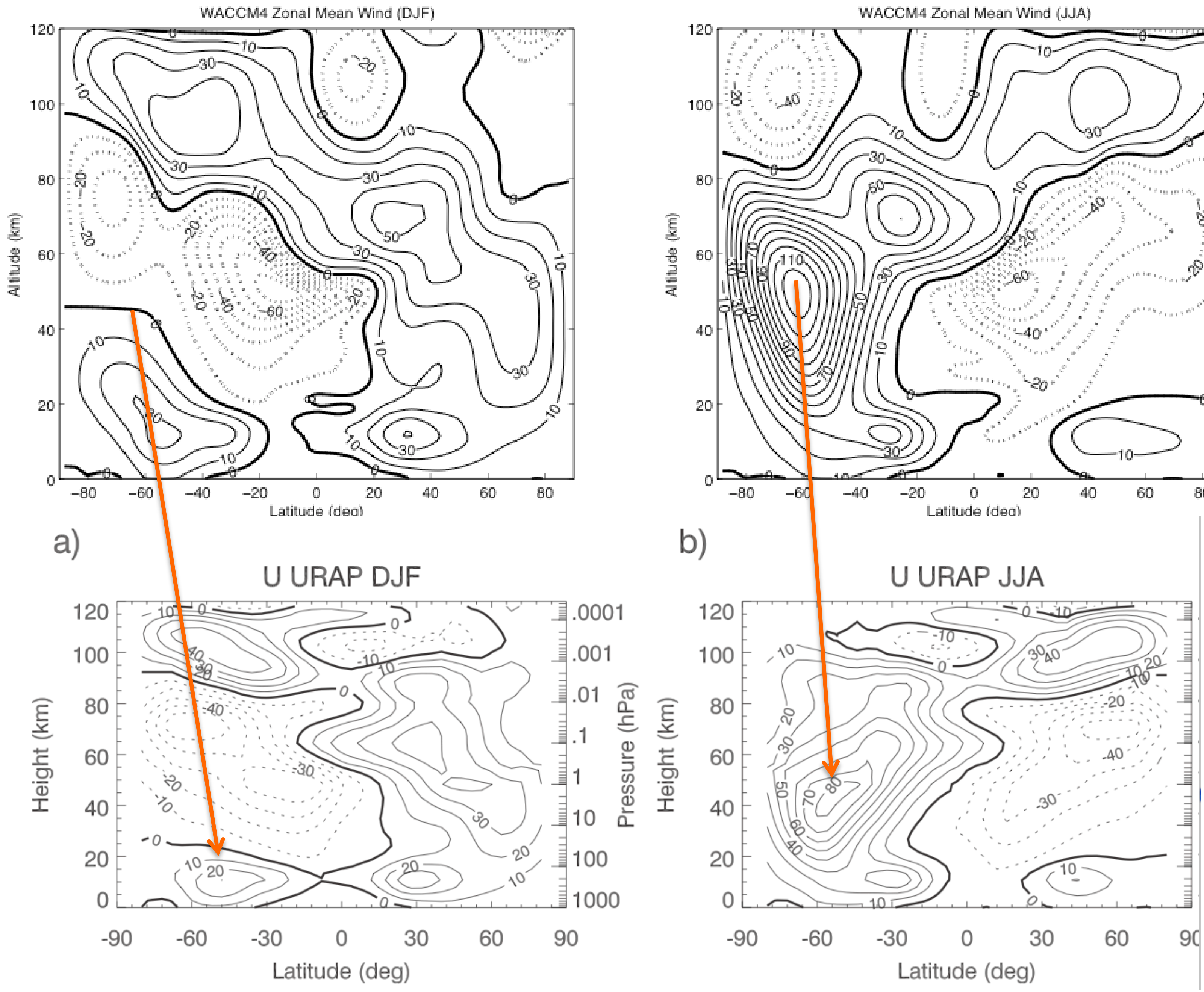
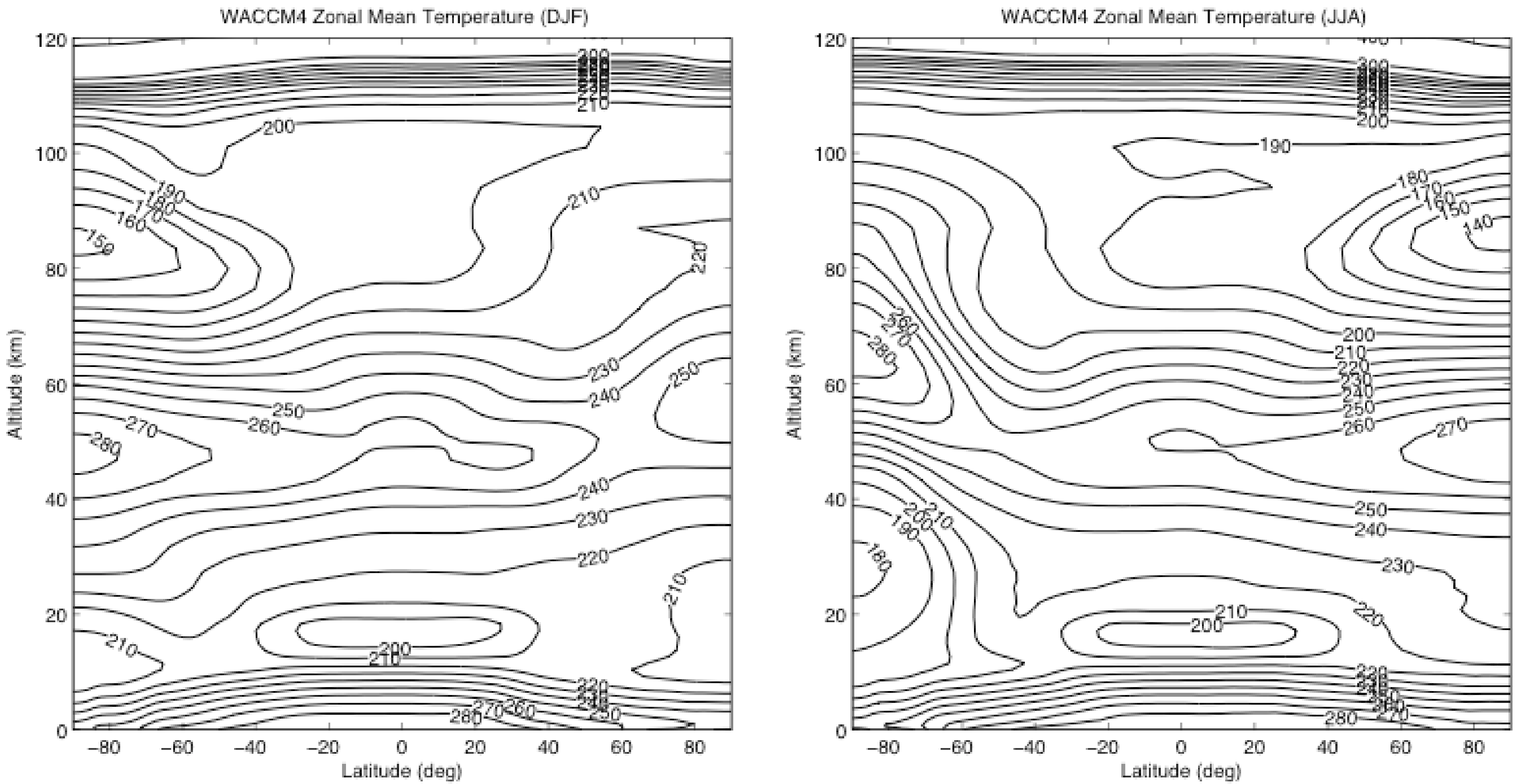
Mean Winds

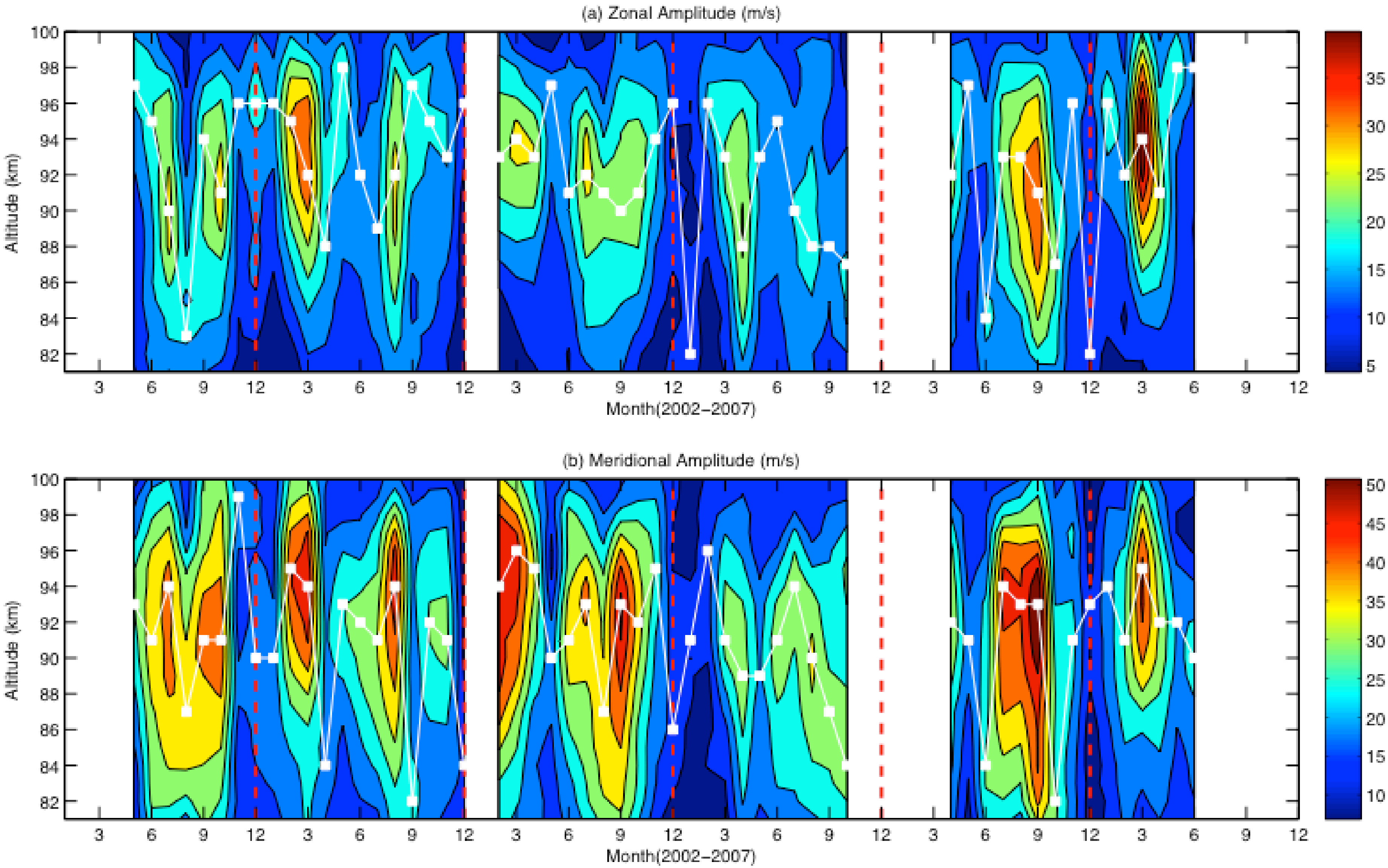


[Richter et al., 2010]

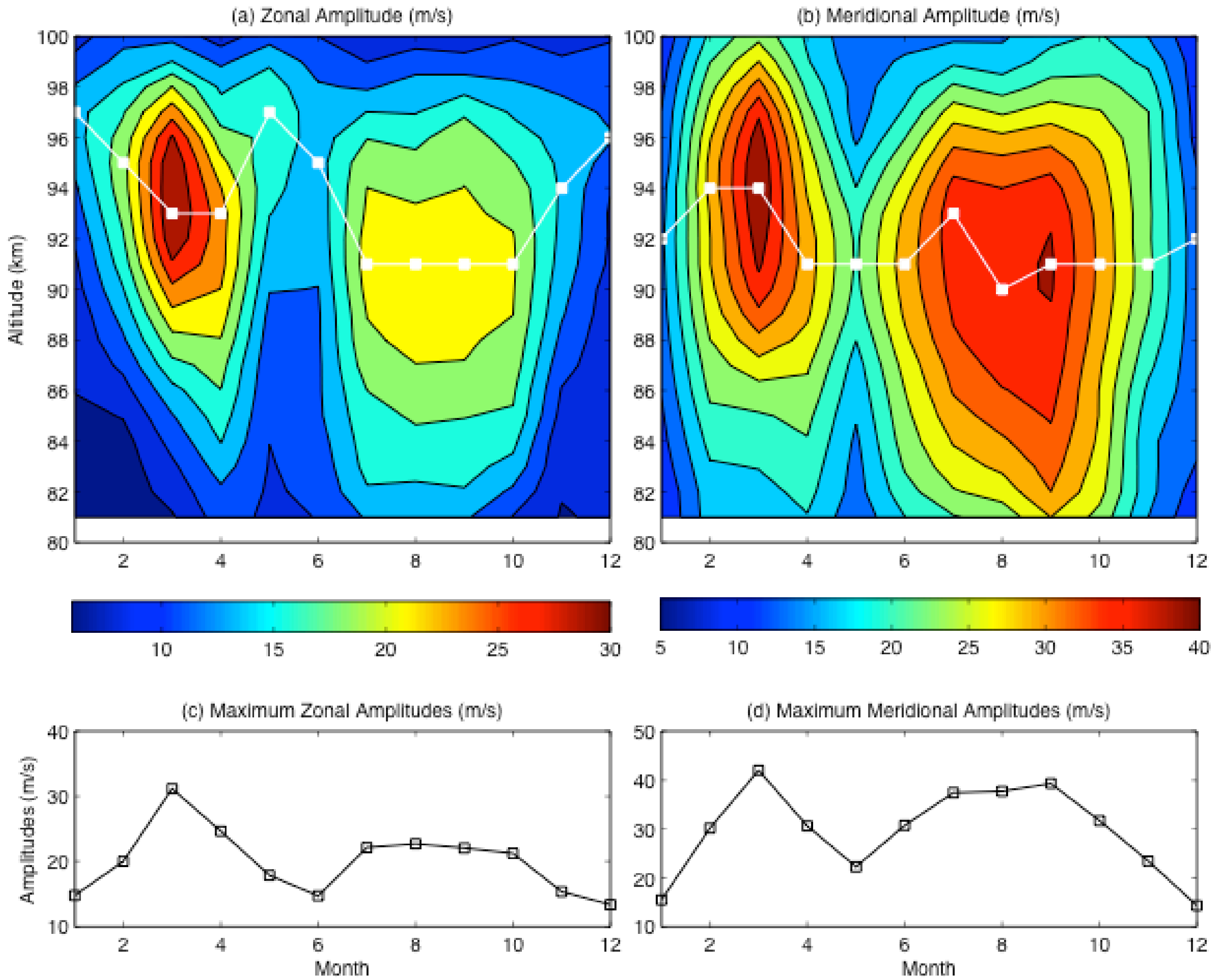
Mean Temperature



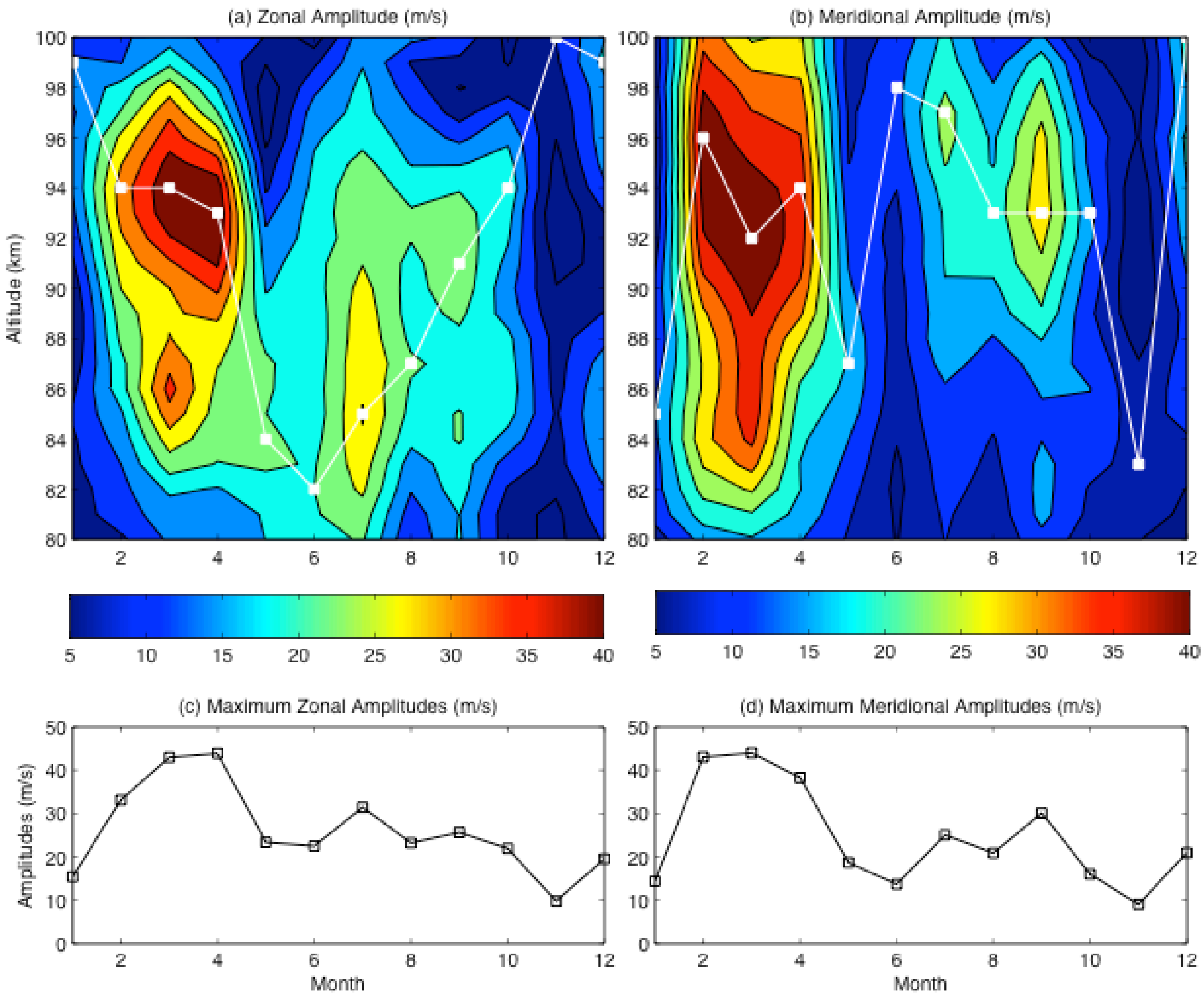
Meteor Radar Observation
Amplitude of the diurnal tide (Maui, HI, 21°N)



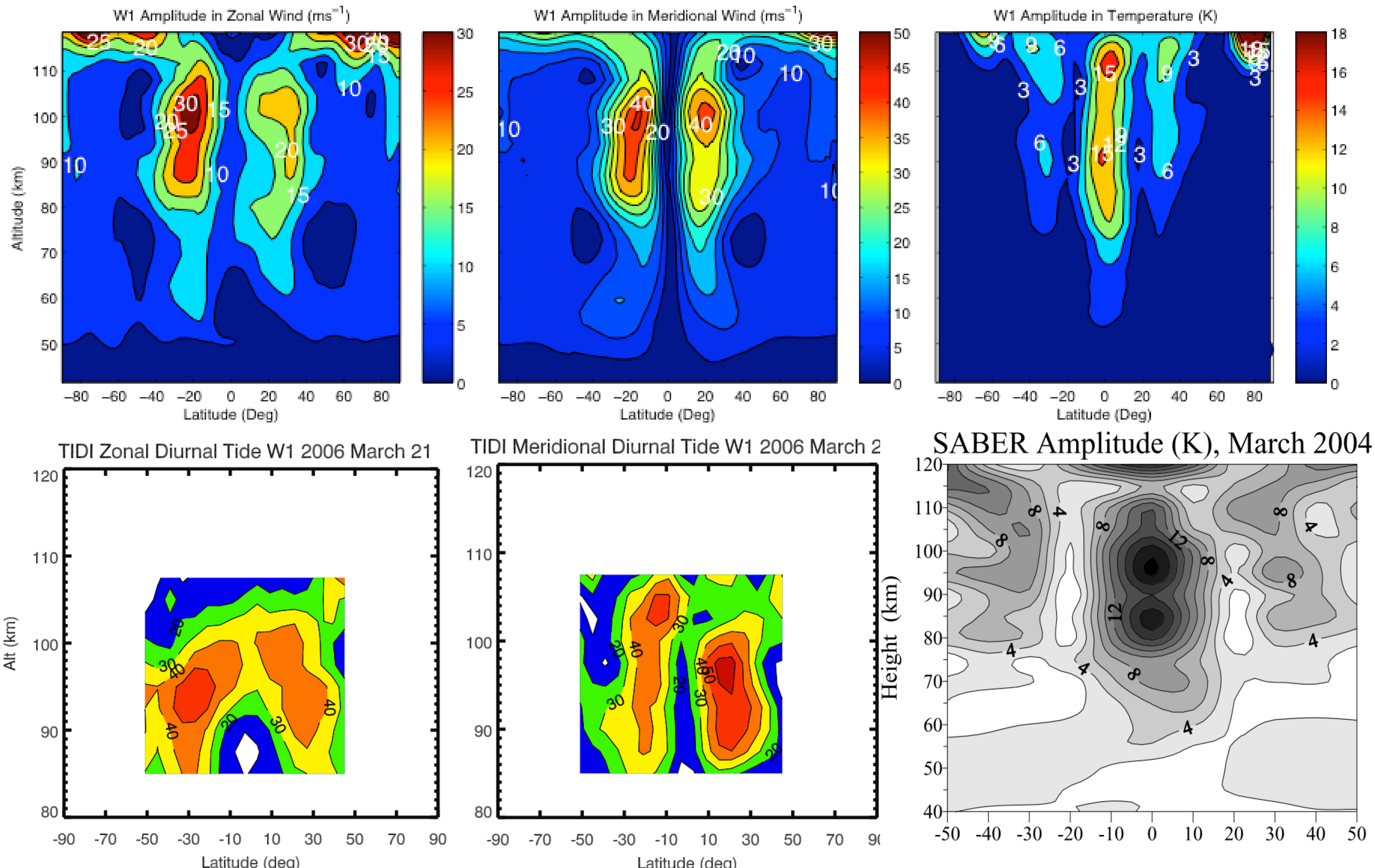
Semiannual Oscillation (SAO) of amplitude (Maui, 21ºN)



SAO of Amplitude   Cerro Pachon, Chile (30°S)



Tidal Amplitudes



[Wu et al., 2008]

[Mukhtarov et al., 2009]

Momentum Budget Analysis

$$\frac{\partial u}{\partial t} = fv - \frac{1}{a\cos\phi}\frac{\partial \Phi}{\partial \lambda} - \vec{V}\cdot\nabla u + \frac{uv}{a}\tan\phi + F_{GW,x} + F'$$

A B C

[Chapman and Lindzen, 1970]

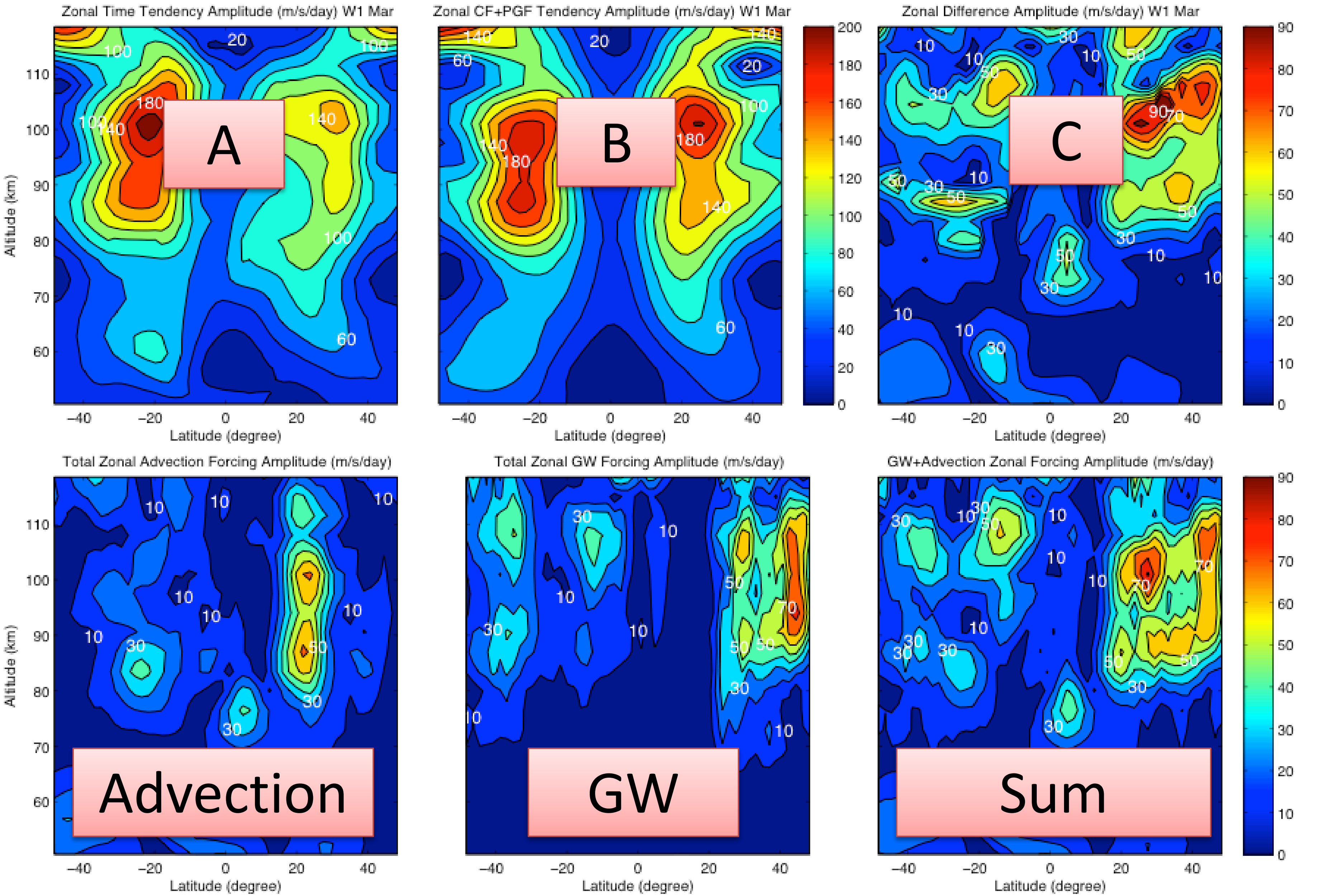
Advection Term:
$$-\vec{V}\cdot\nabla u = -\left(\frac{u}{a\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{v}{a}\frac{\partial u}{\partial \phi} + w\frac{\partial u}{\partial z}\right)$$

Linear advection Term:

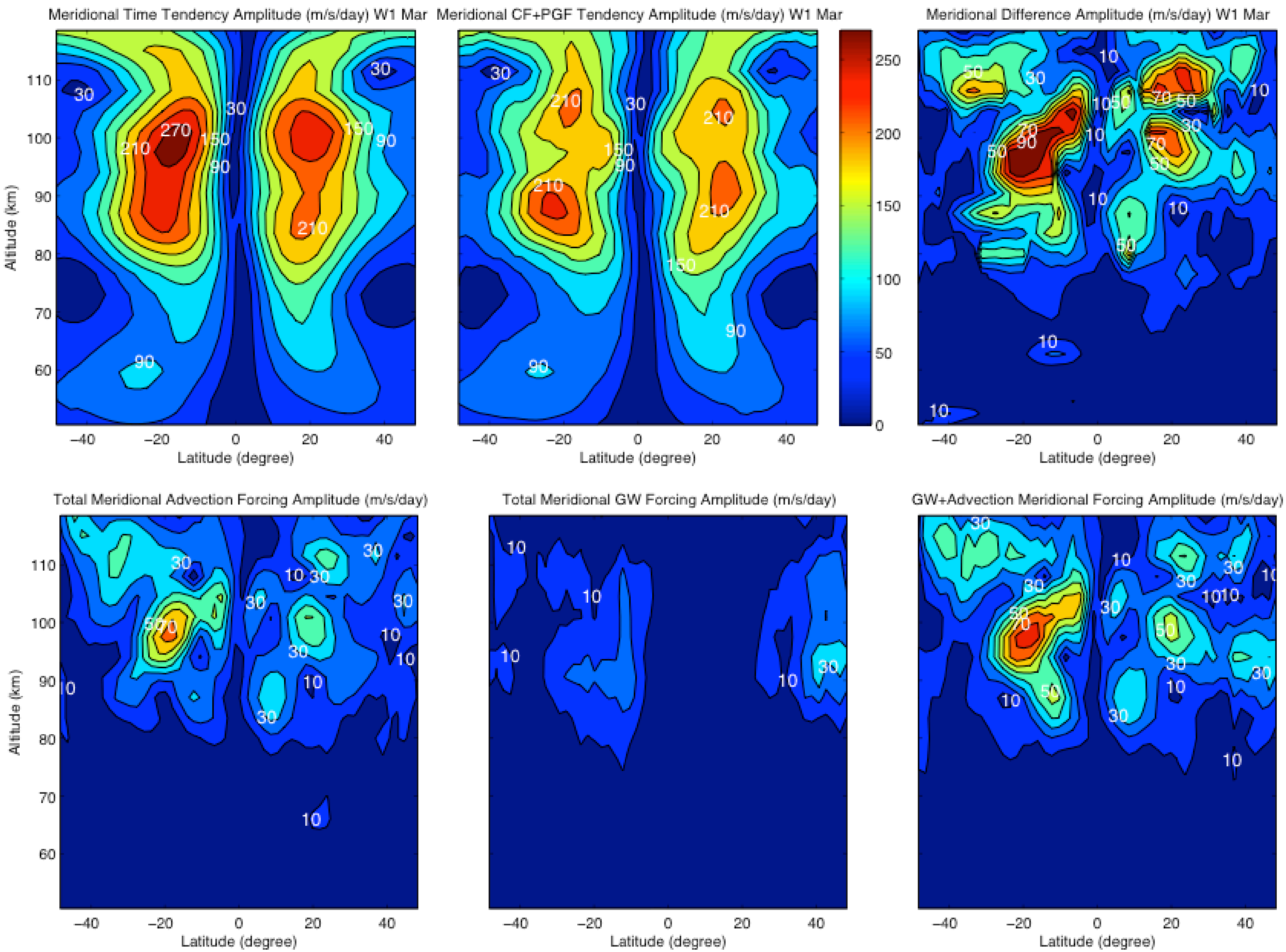
$$\begin{Bmatrix} u = \bar{u} + u' \\ v = \bar{v} + v' \\ w = \bar{w} + w' \end{Bmatrix} \Rightarrow F_{LinAd,x} = -\left(\frac{v'}{a}\frac{\partial \bar{u}}{\partial \phi} + w'\frac{\partial \bar{u}}{\partial z}\right) - \left(\frac{\bar{u}}{a\cos\phi}\frac{\partial u'}{\partial \lambda} + \frac{\bar{v}}{a}\frac{\partial u'}{\partial \phi} + \bar{w}\frac{\partial u'}{\partial z}\right)$$

WACCM

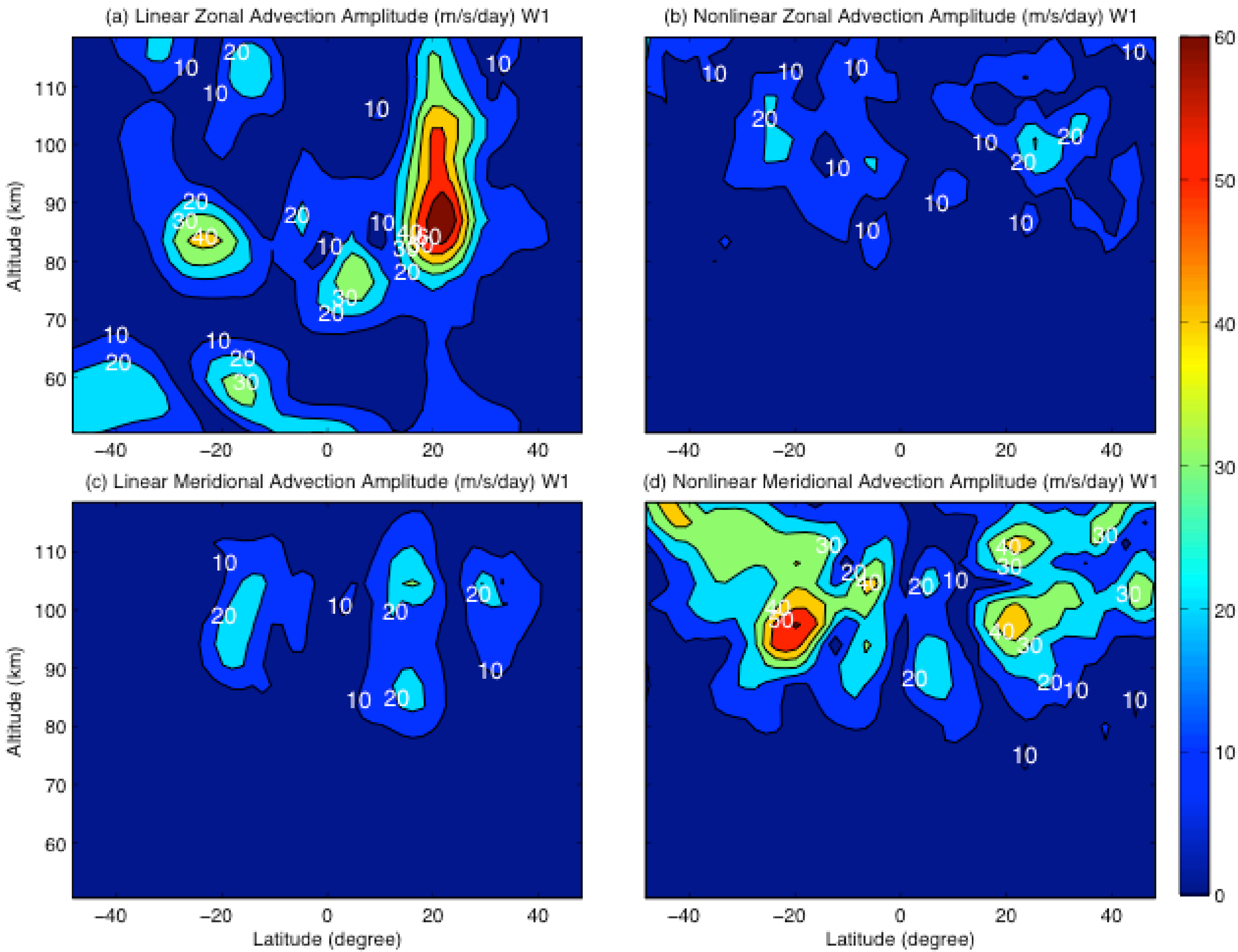
Amplitude of Time Tendency (Zonal Wind)



Amplitude of Time Tendency (Meridional Wind)

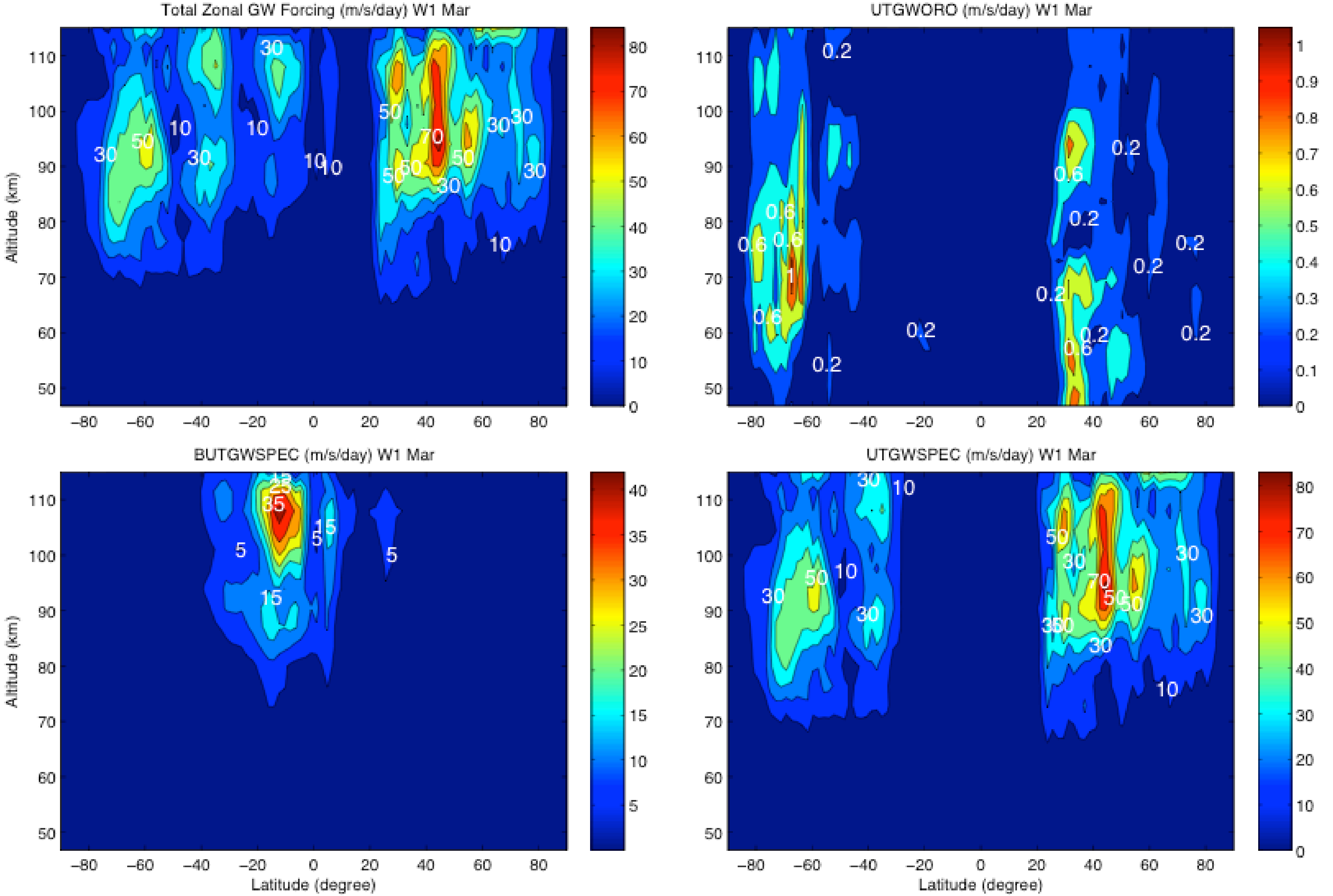


Which advection is more dominant?



GW sources

Frontogenesis > Convection> Orography



Equivalent Rayleigh Friction

[Miyahara and Forbes, 1991]

$$\frac{\partial u'}{\partial t} = F'$$

$$u' = \hat{u}(t)e^{i(\omega t - s\lambda)} = a(t)e^{i(-\varphi(t))}e^{i(\omega t - s\lambda)} = a(t)e^{i(\omega t - s\lambda - \varphi(t))}$$

$$F' = \hat{F}_u(t)e^{i(\omega t - s\lambda)}$$

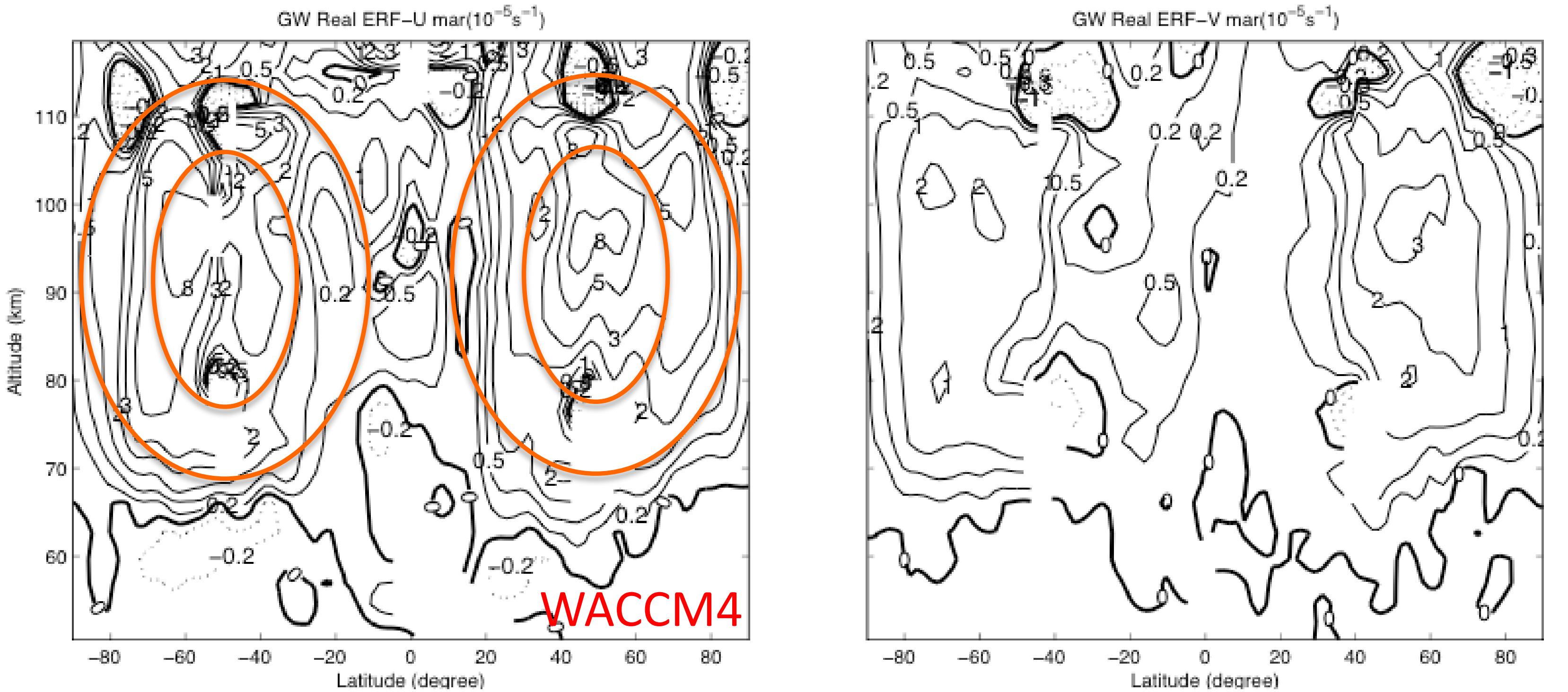
Define the Equivalent Rayleigh Friction as:

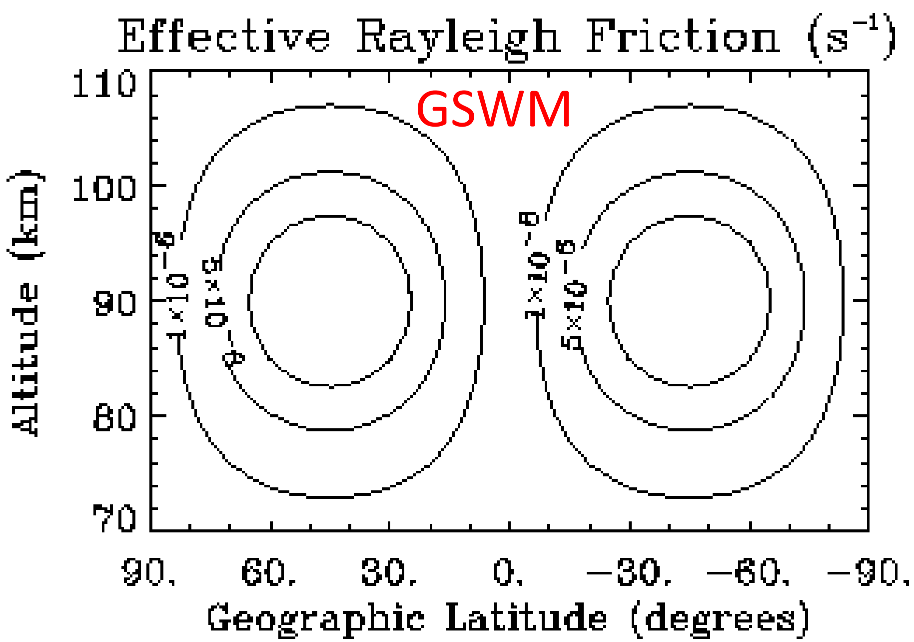
$$ERF = -\frac{\hat{F}_u}{\hat{u}} = -\frac{\frac{\partial a(t)}{\partial t}}{a(t)} - i(\omega - \frac{\partial \varphi(t)}{\partial t})$$

Real Part of ERF determines the amplitude change and imaginary part determines the phase change.

$$real(ERF) > 0 : Amplitude \qquad Decrease$$

$$imag(ERF) < 0 : Phase \qquad Advance$$

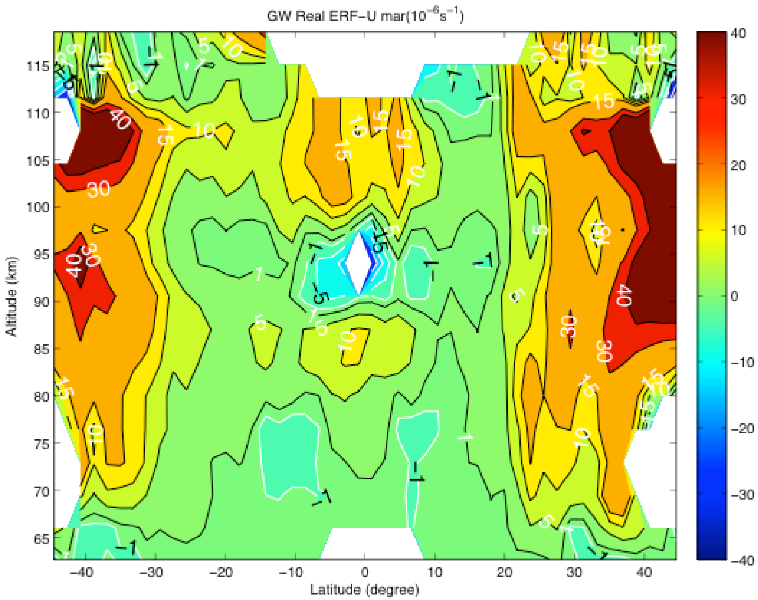




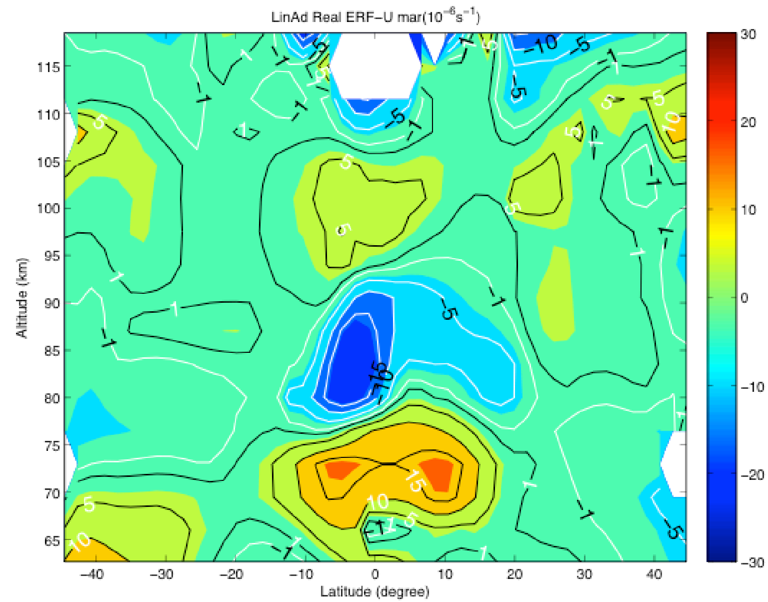
[Hagan et al., 1995]

ERF Real Part (Zonal Wind)

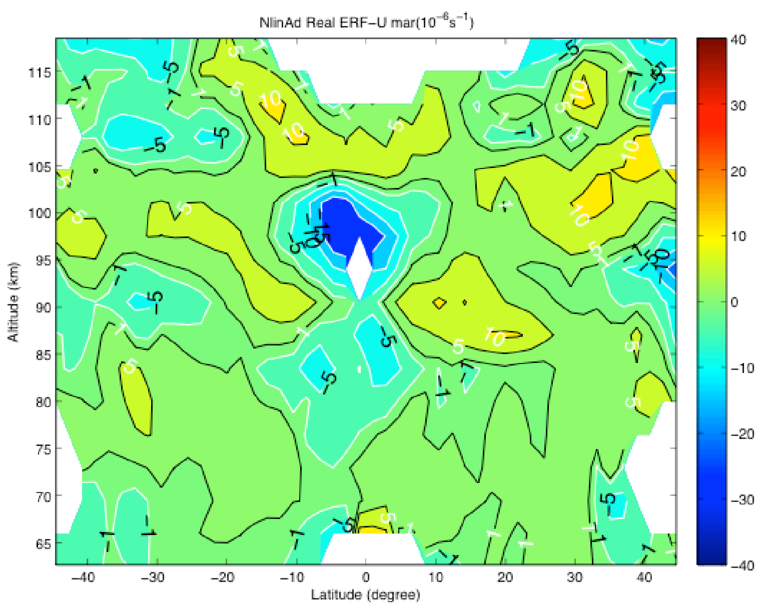
Gravity Wave



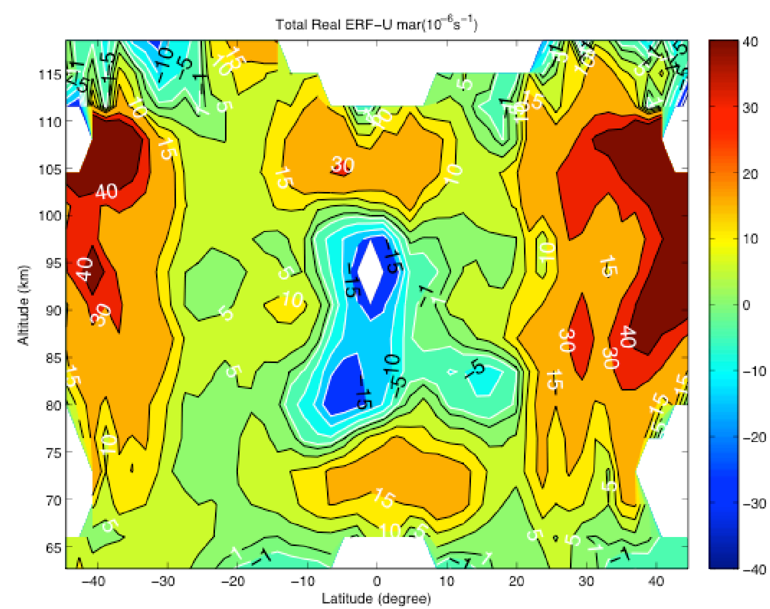
Linear Advection



Nonlinear Advection

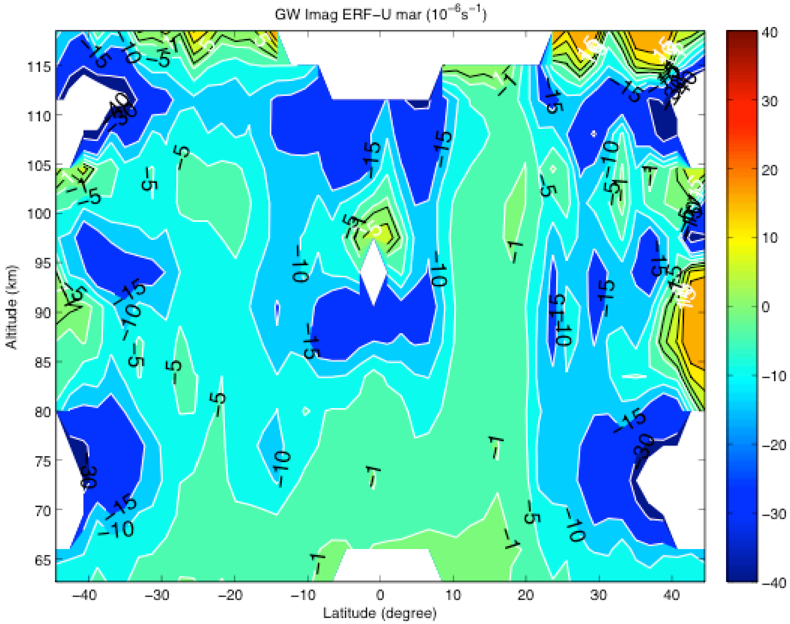


Total

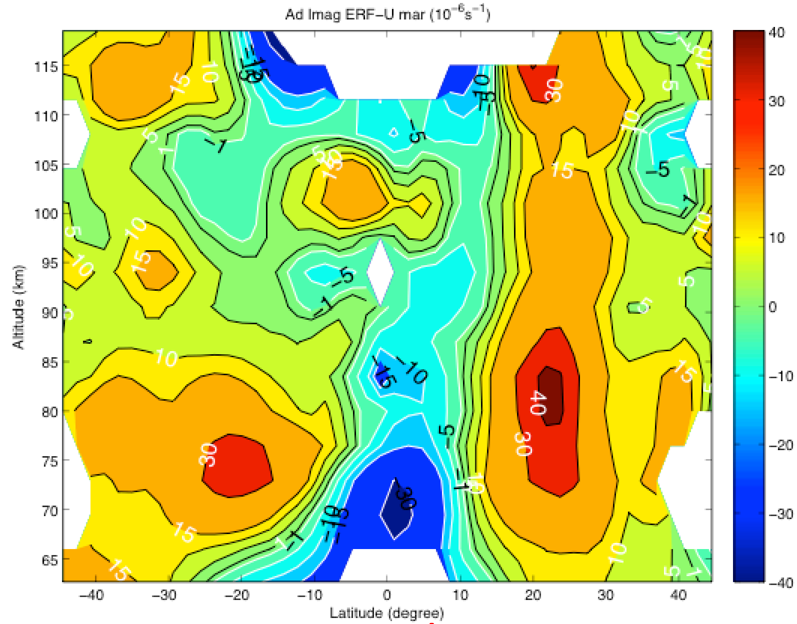


ERF Imaginary Part (Zonal Wind)

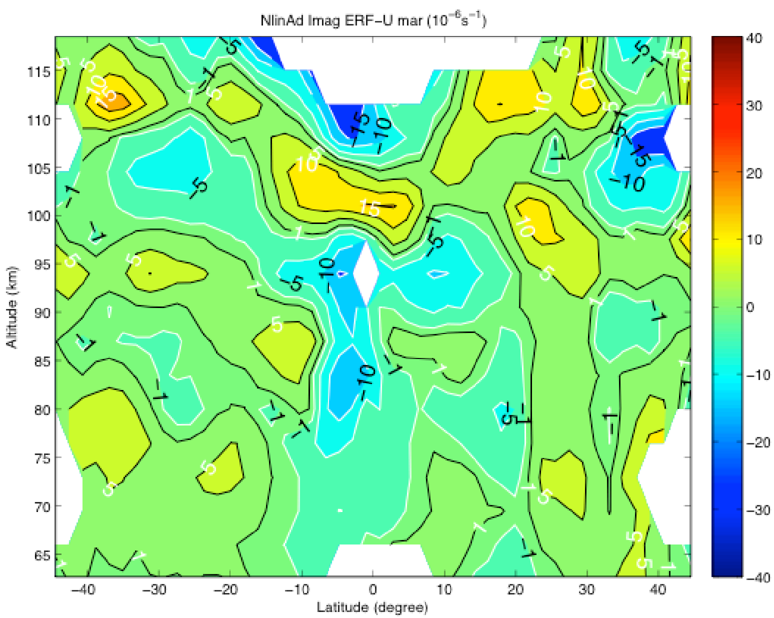
Gravity Wave



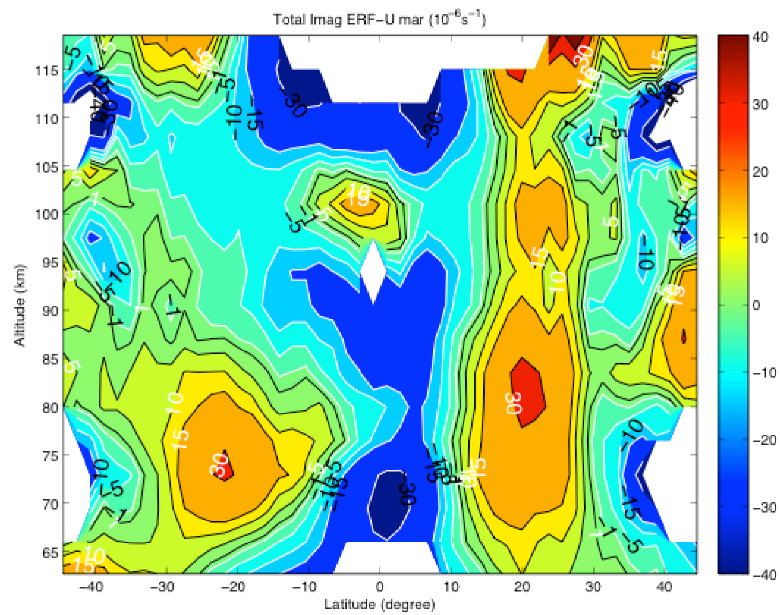
Linear Advection



Nonlinear Advection

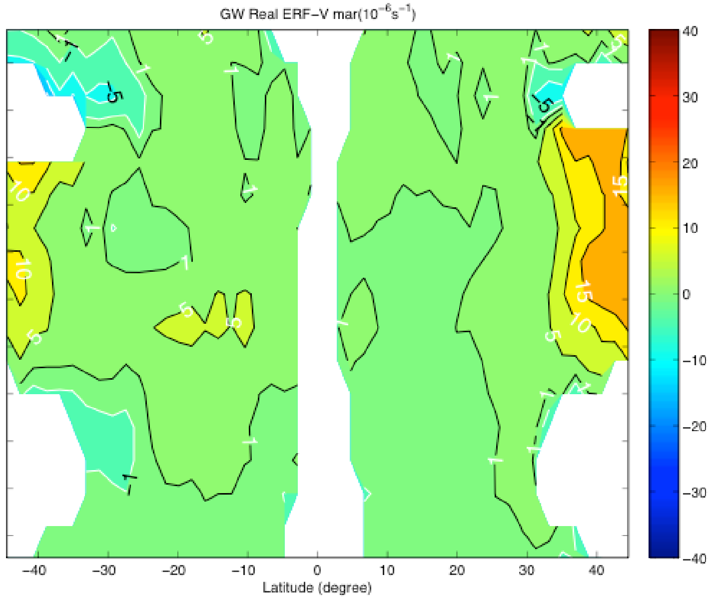


Total

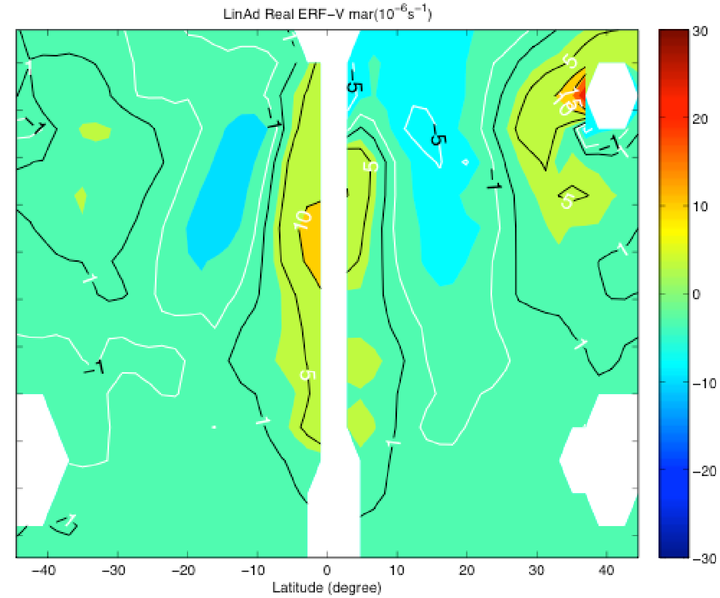


ERF Real Part (Meridional Wind)

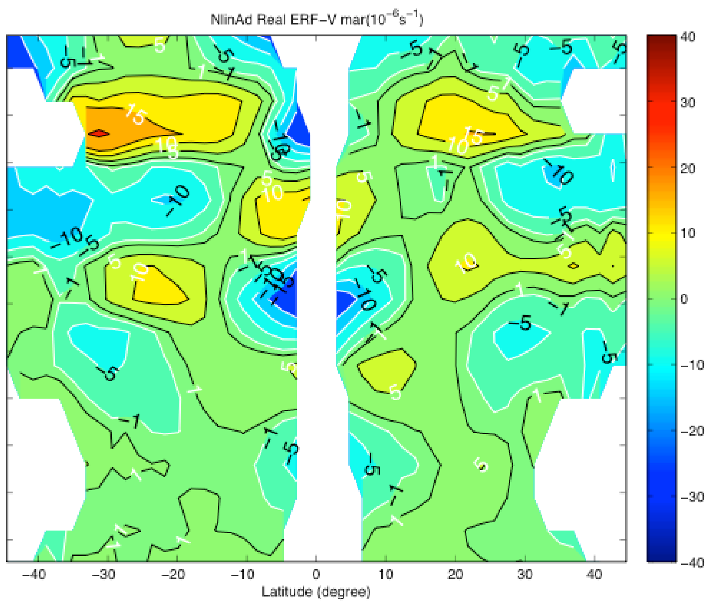
Gravity Wave



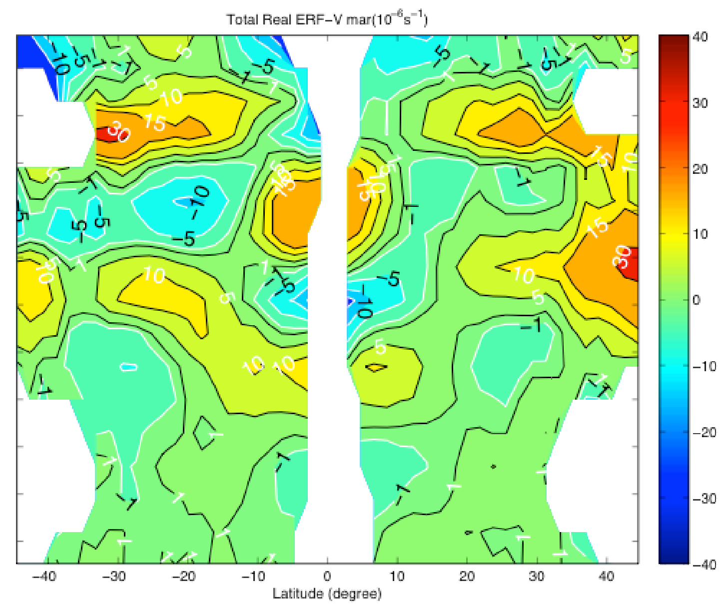
Linear Advection



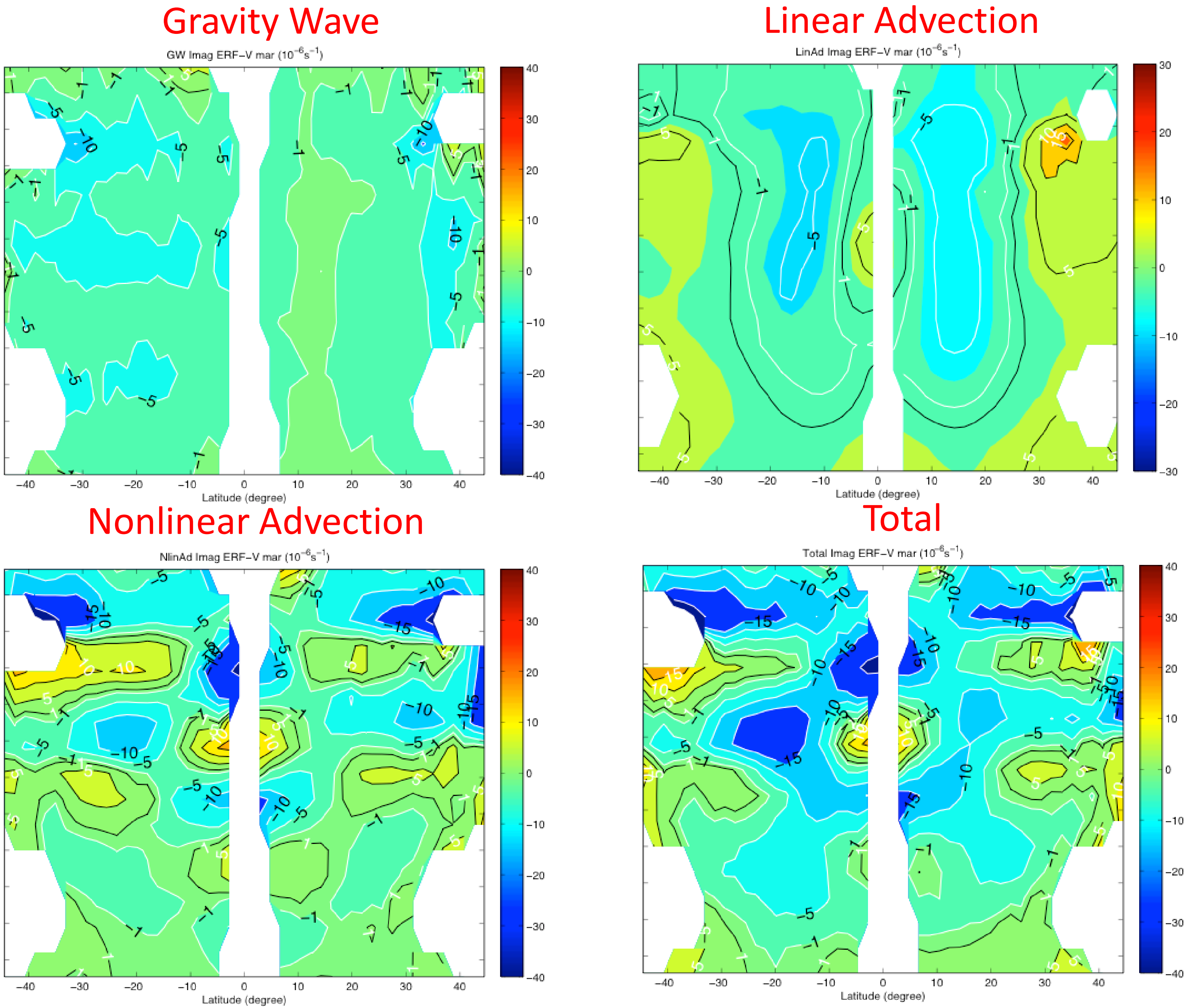
Nonlinear Advection



Total

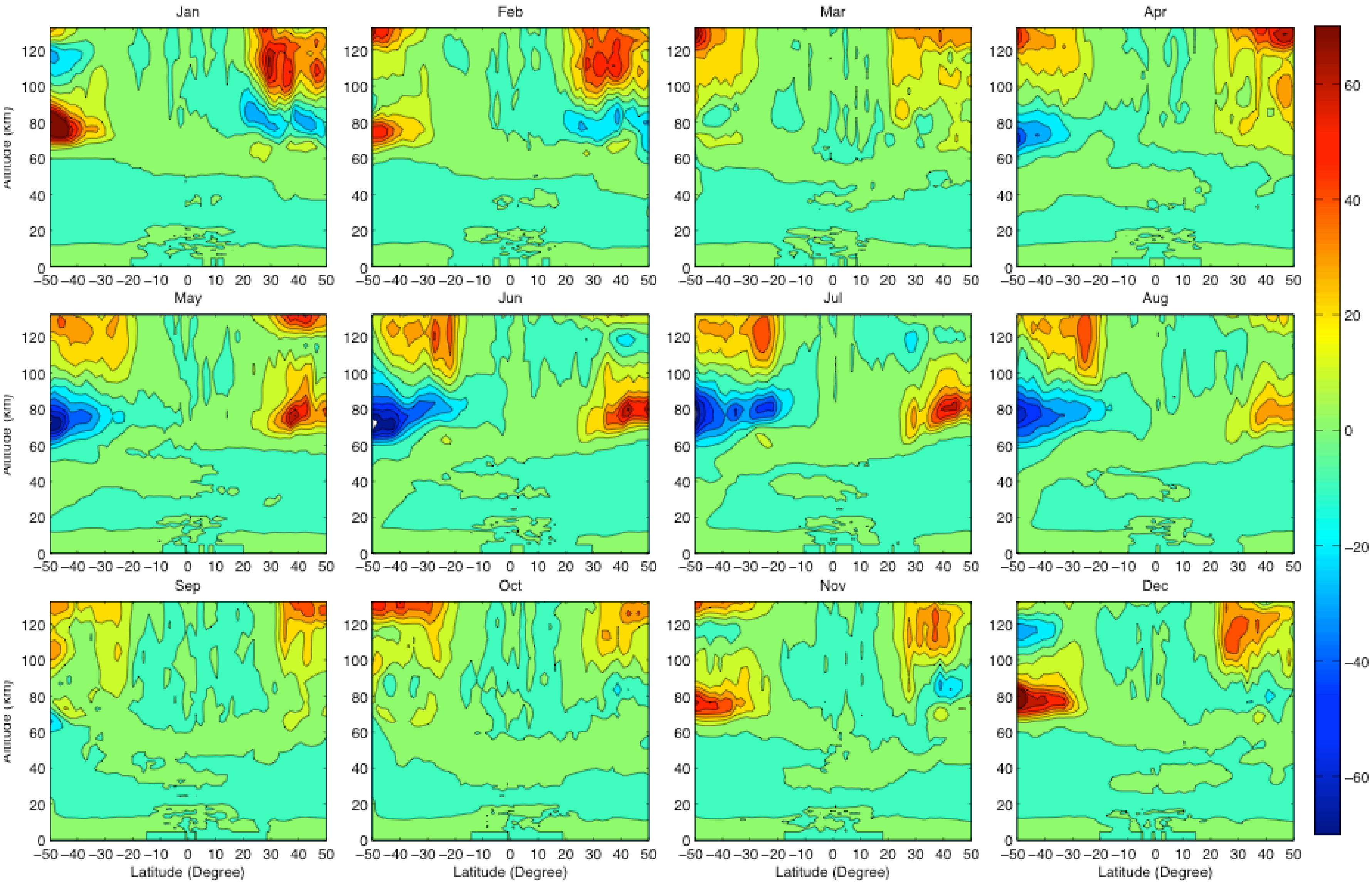


ERF Imaginary Part (Meridional Wind)

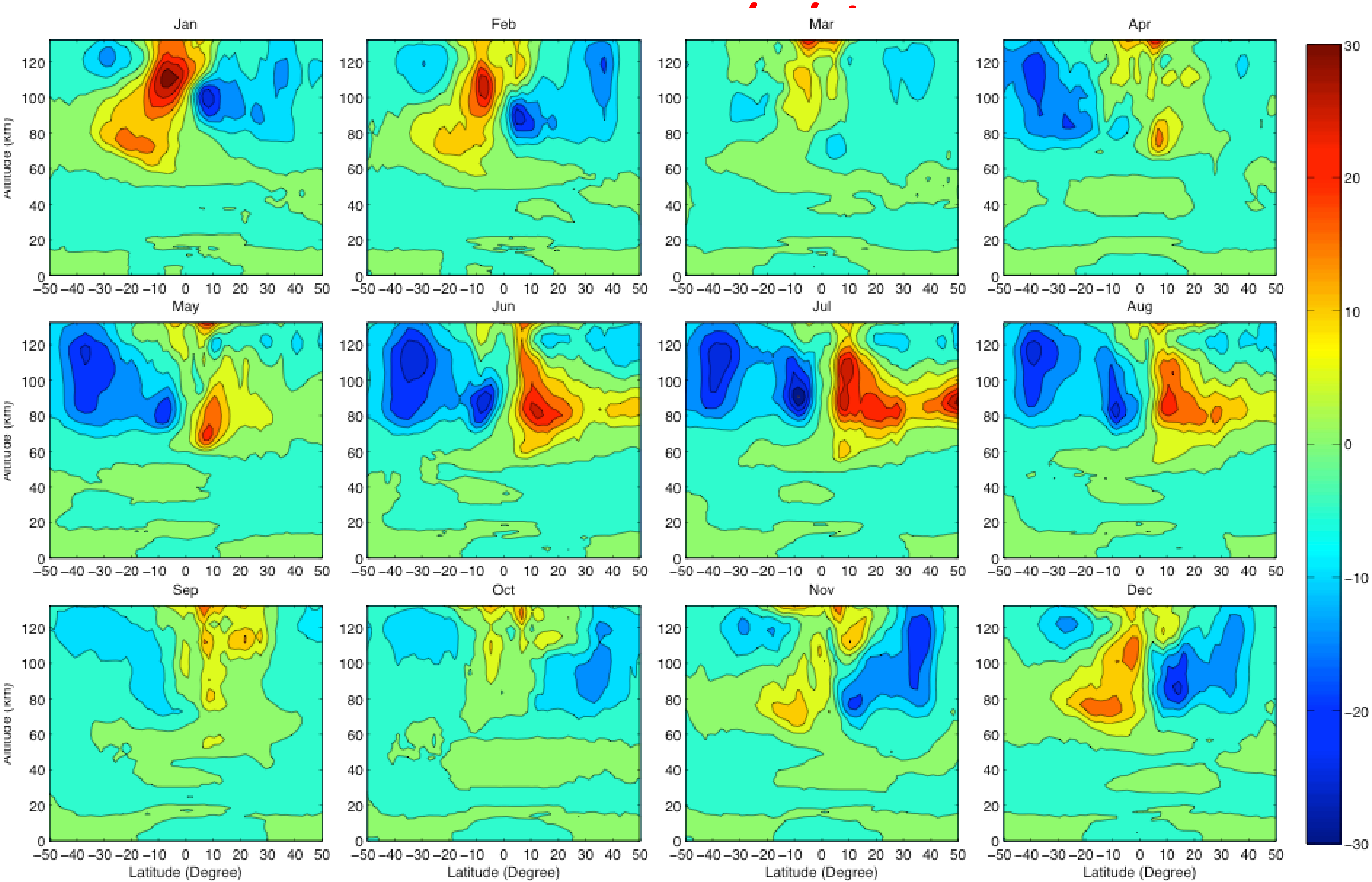


Frontogenesis-GW drag to mean flow

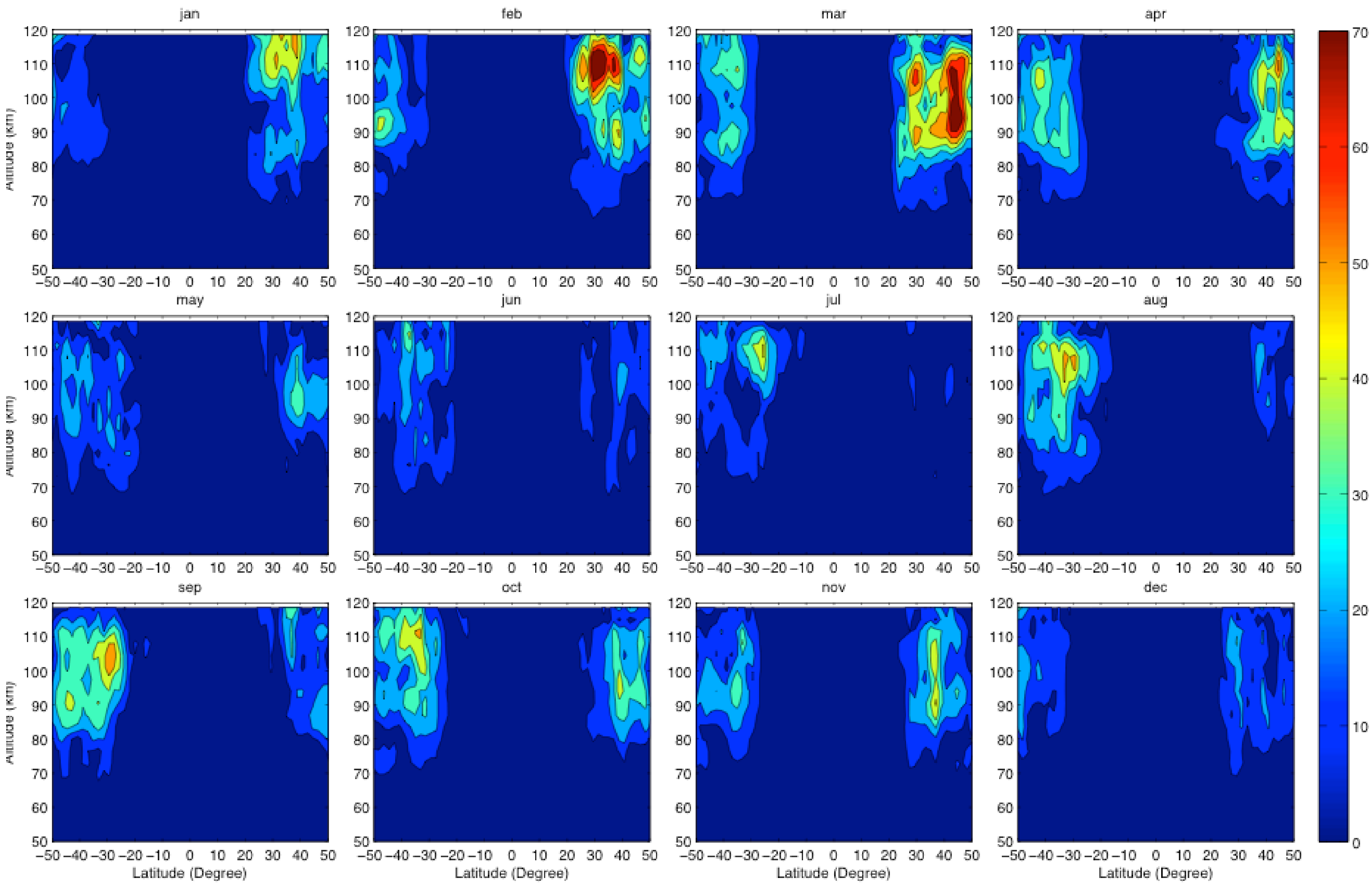
Units: m/s/day



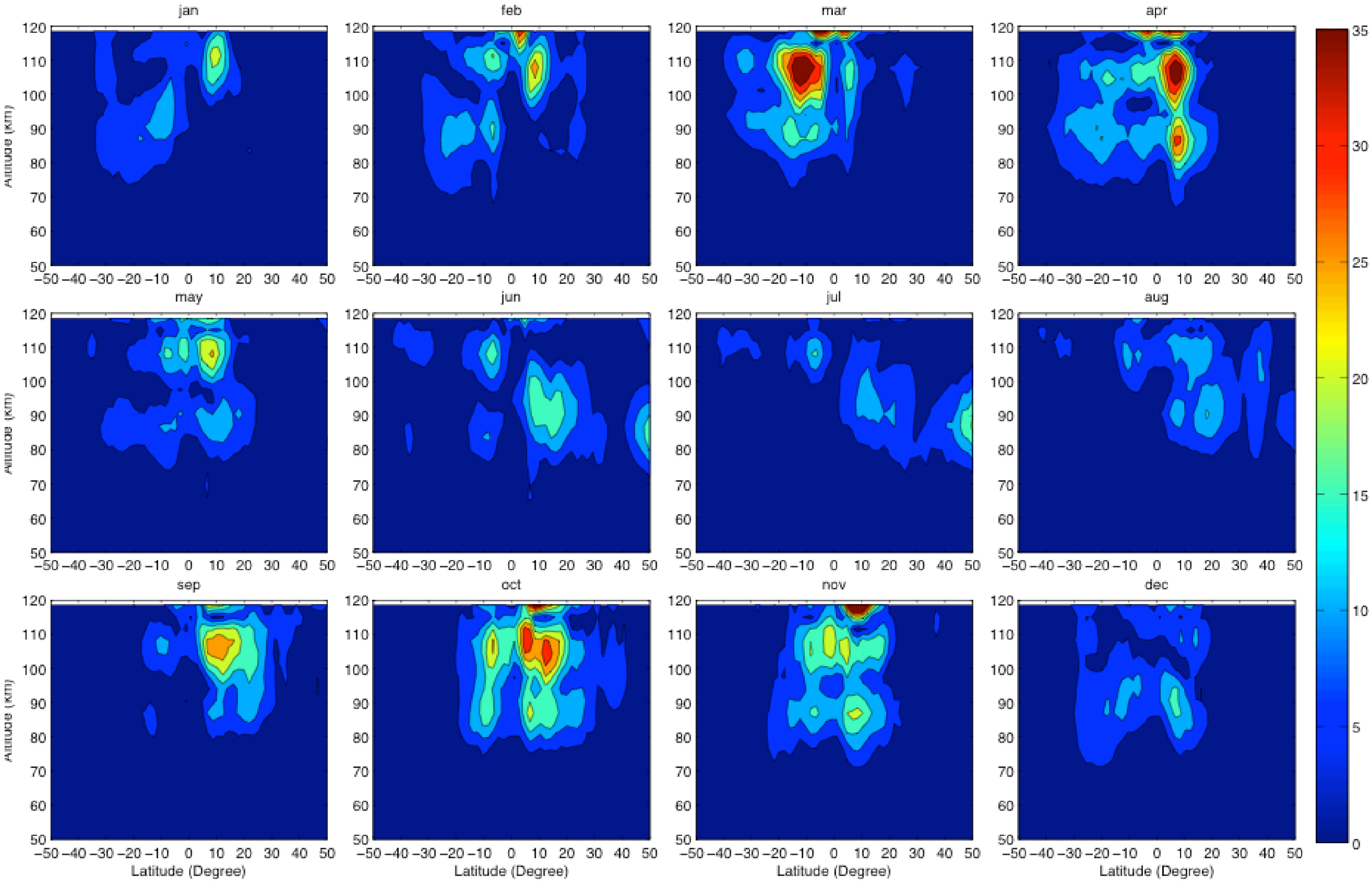
Convection-GW drag to mean flow
Units: m/s/day



Frontogenesis-GW drag to the migrating diurnal tide



Convection-GW drag to the migrating diurnal tide



Conclusions

- Advection and GW drag are two most important terms to account for the momentum budget of the migrating diurnal tide.

- For zonal wind, the magnitudes of linear advection and GW forcing are comparable while for the meridional wind, advection is more dominant.

- GW drag always damps the tide and advances its phase.

- For the zonal wind, GW is most responsible to change the amplitude and linear advection to the change of tidal phase. In meridional wind, nonlinear advection is the most significant factor to change both amplitude and phase of tide.

- GW drag is strongly modulated by the migrating diurnal tide, the seasonal variation of GW forcing is more like a feedback to that of the tidal modulation, rather than a cause for the seasonal variation of tide.


Thank you!