On the interaction of the migrating diurnal tide with inertia gravity waves generated by tropical heating

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GW influence on tide structure

- GW interaction with the tide impacts tide amplitude and phase structure;
- Ortland and Alexander (2006): tuned the source spectra in the Alexander-Dunkerton GW parameterization so that a tide model reproduced the observed tide structure;
- Perhaps it is ill-conceived to attribute all GW influence to small-scale GWs?
- There is a rich spectrum of large-scale IGW forced by tropical latent heating;
- This presentation compares the interaction of both large-scale IGW and parameterized GW with the tide.

Model details

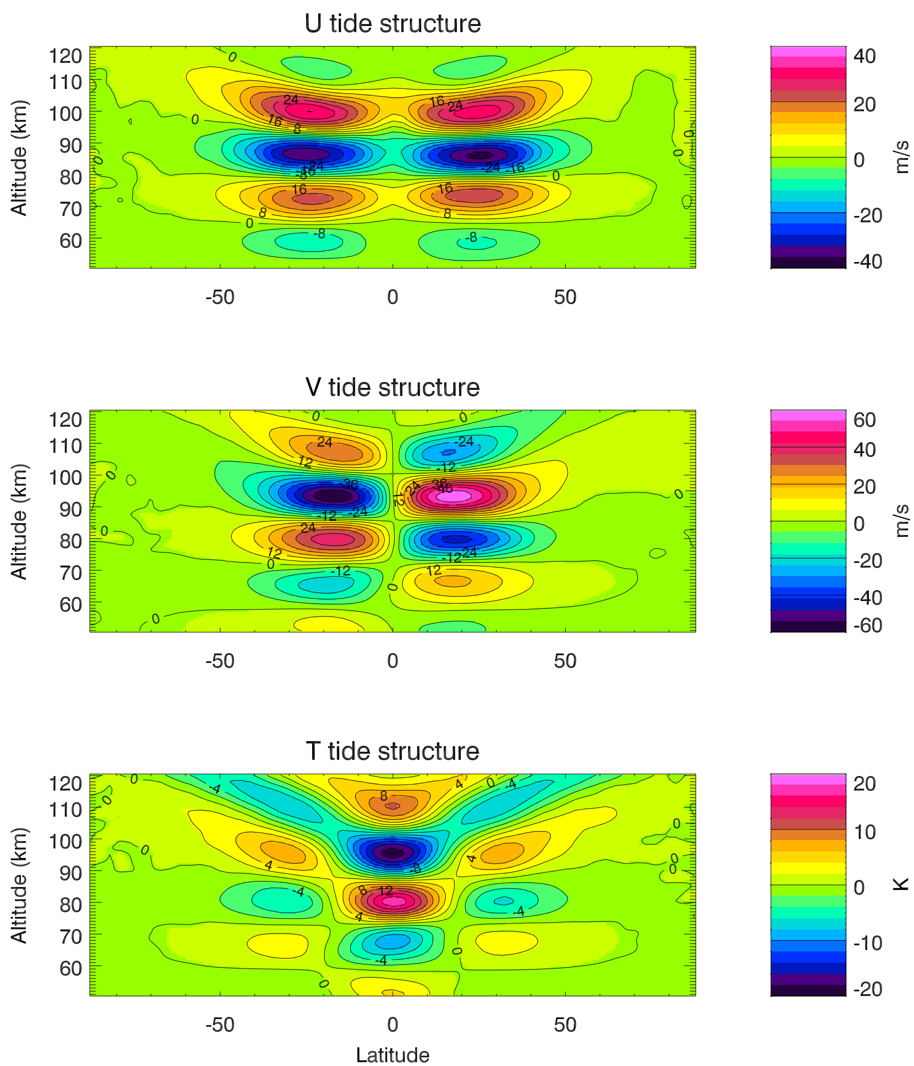
- Time-dependent primitive equation model run at T40 horizontal and 1 km vertical resolution up to 150 km;
- IGW spectrum is forced by convective latent heating derived from TRMM total column rainfall and infrared cloud top brightness data every 3 hours;
- The tide is forced by water vapor heating derived from H_2O observations. No O_3 heating is used.
- Small-scale GWs parameterized by Alexander-Dunkerton scheme;
- Initialization:
  - zonal mean winds=0
  - zonal mean temperature=climatological average vertical profile
- Constant vertical eddy and molecular diffusion profiles shape tide amplitude profile and provide dry convective adjustment
- Simulations:
  1. Tide only
  2. Tide + GW param
  3. Tide + IGW
  4. Tide + GW + IGW

Structure of the migrating diurnal tide

Shown at t=0 and longitude=0

- Zonal wind and temperature are symmetric about the equator, meridional wind is asymmetric

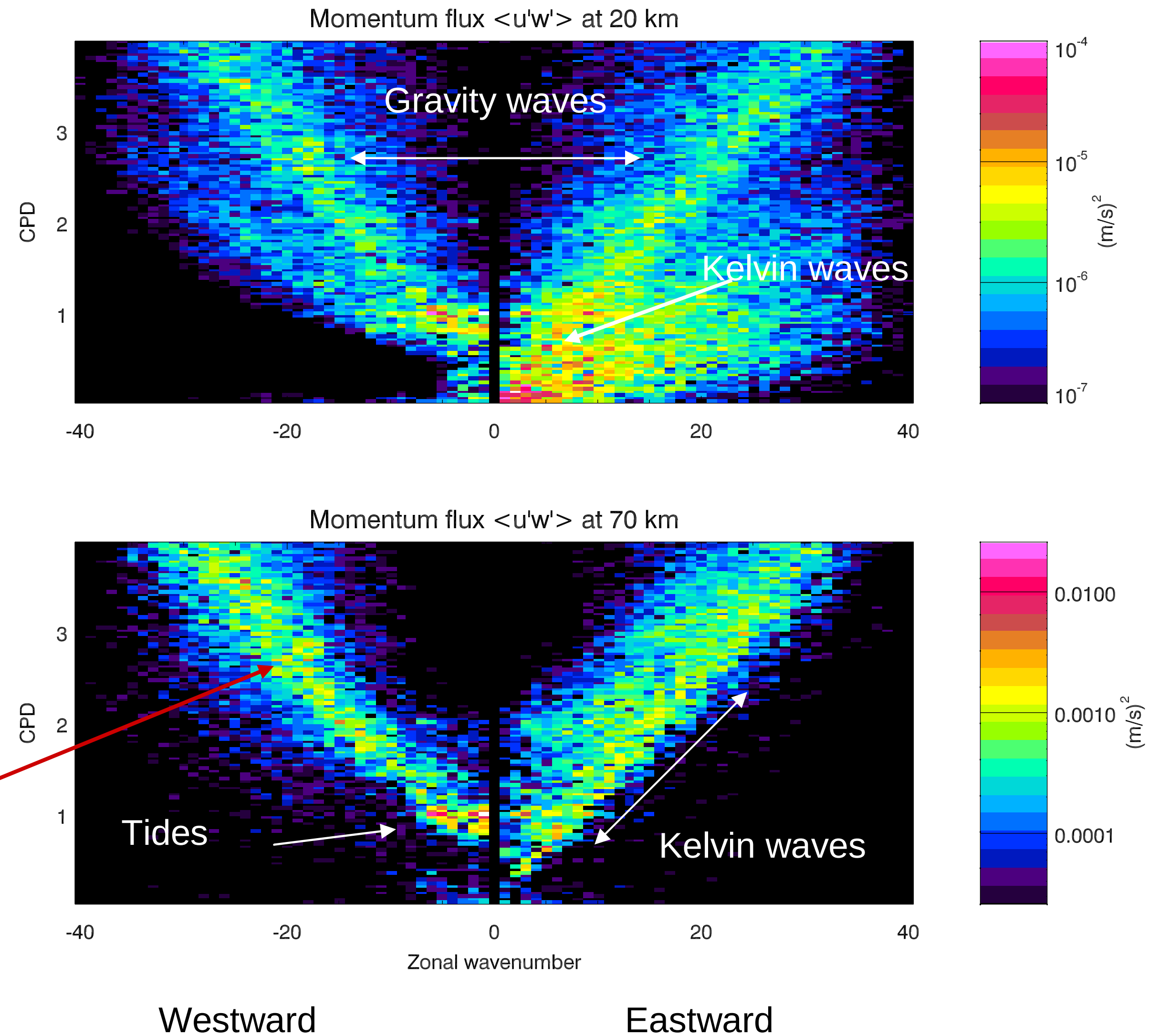
- Peak amplitude occurs around 95 km



Momentum flux spectrum
Averaged 15S-15N

- Spectrum does not propagate conservatively;
- The flux spectrum at higher altitudes is primarily shaped by nonlinear interactions among waves in the spectrum.
- Waves with lower phase speed are dissipated more rapidly.

Spectral peak roughly corresponds to waves with phase speed=60 m/s



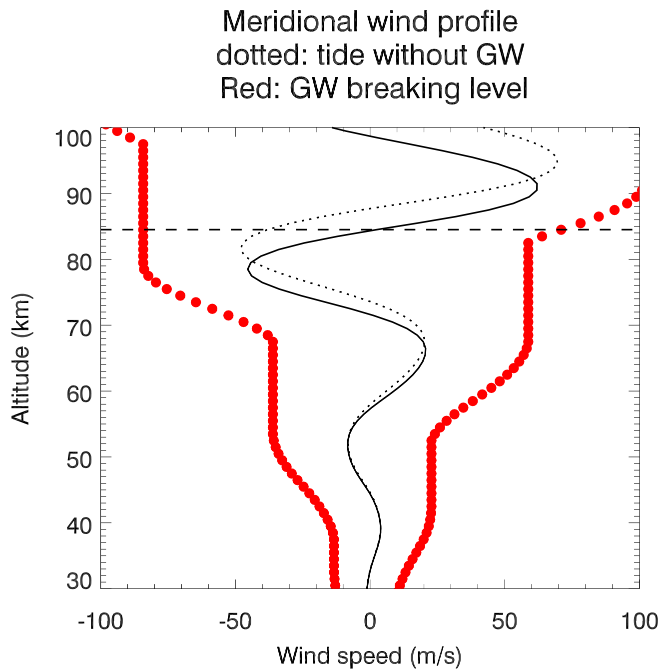
The influence of other waves on the tide enters through the nonlinear advection (flux divergence)

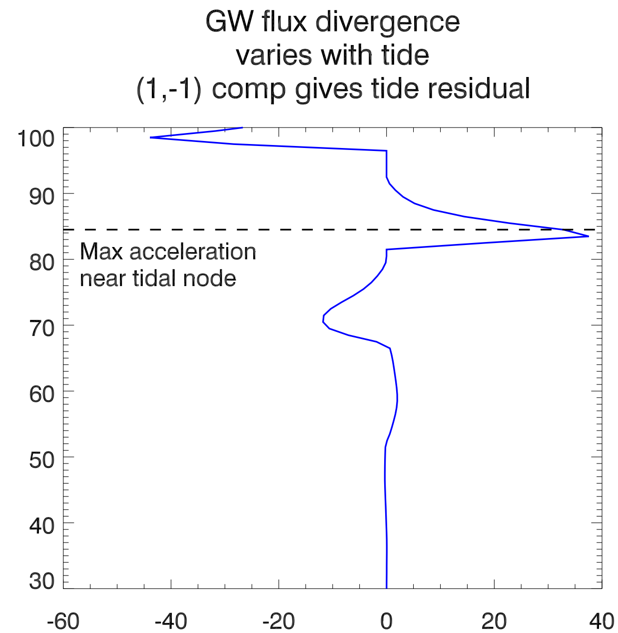
example: zonal momentum equation

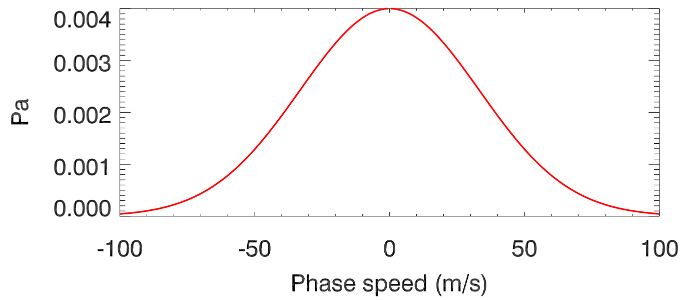
$$\frac{\partial u}{\partial t} - fv + \Phi_x = \overbrace{-\frac{1}{\rho}\left\{\frac{1}{2}\frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z}\right\} + \frac{1}{\rho}\frac{\partial}{\partial z}\rho K_{zz}\frac{\partial u}{\partial z}}^{\text{Residual forcing terms}}$$

- For the tide, consider (s,ω)=(1,–1cpd) component of this equation;
- For small-scale GWs, the GW parameterization assumes:
- Tide winds field acts as a stationary mean flow for GW propagation;
- (1,-1) component of the residual terms force a correction (pseudo-tide) to the tide solution forced by troposphere heating alone;
- We shall also examine nonlinear terms for large-scale IGW resolved in a numerical model.

Tide modulation of GW momentum flux divergence





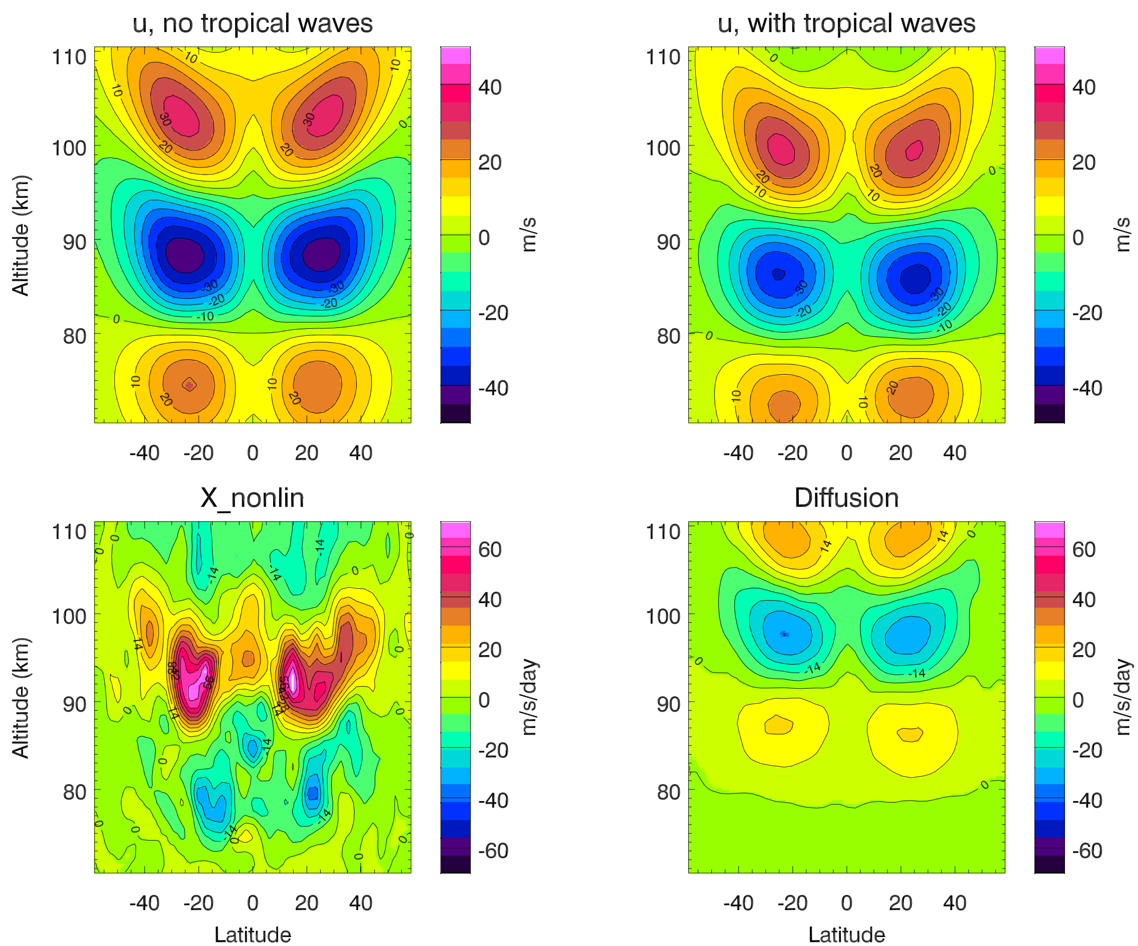


GW source spectrum

Interaction of the tropical wave spectrum with the migrating tide

- The top panels show the migrating tide u field without and with the presence of tropical waves. The wave interaction diminishes the tide amplitude by about 20% and shortens the vertical wavelength.

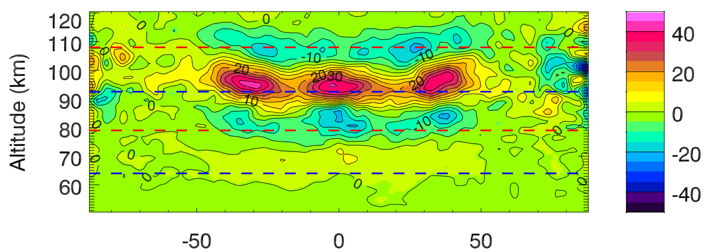
- The bottom panels compares the residual terms: nonlinear forcing and diffusive damping. Advection terms are a factor of 2 larger than turbulent eddy diffusion term;



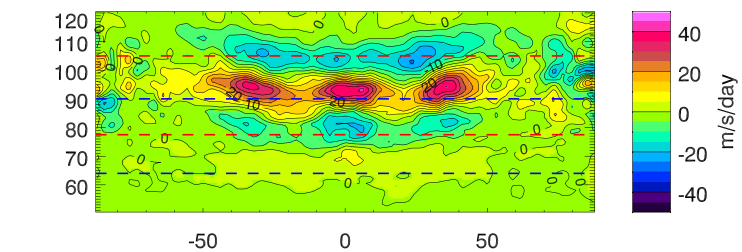
Comparison of IGW and GW residual force

zonal momentum equation

IGW residual force
IGW only

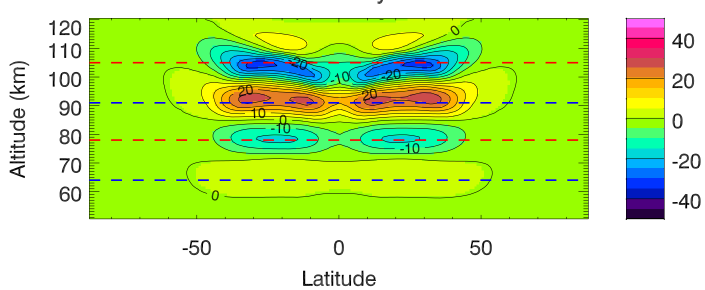


IGW residual force
IGW + GW

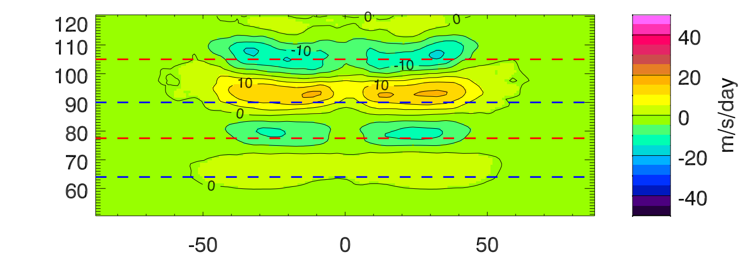


Maximum amplitude occurs near nodes in the tide wind field

GW residual force
GW only



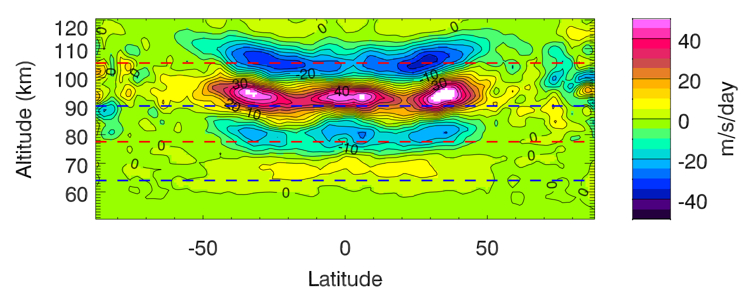
GW residual force
IGW + GW



Note:

GW residual force decreases with the addition of IGW

IGW+GW residual force
IGW + GW



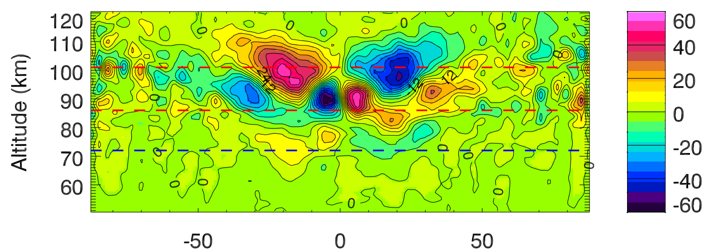
IGW residual force essentially unchanged by addition of GW

Dashed lines are nodal lines
for the tide u field in each case

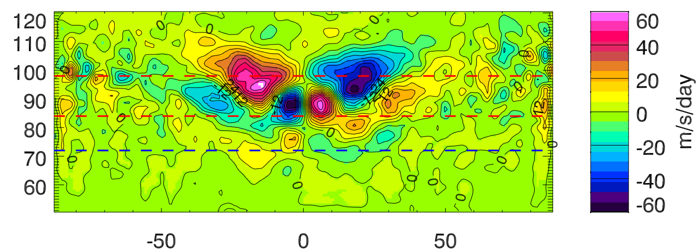
Comparison of IGW and GW residual force

meridional momentum equation

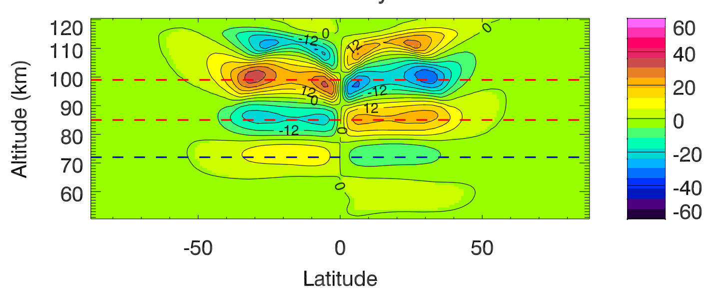
IGW residual force
IGW only



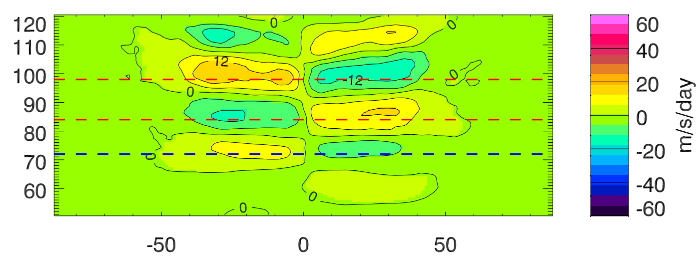
IGW residual force
IGW + GW



GW residual force
GW only

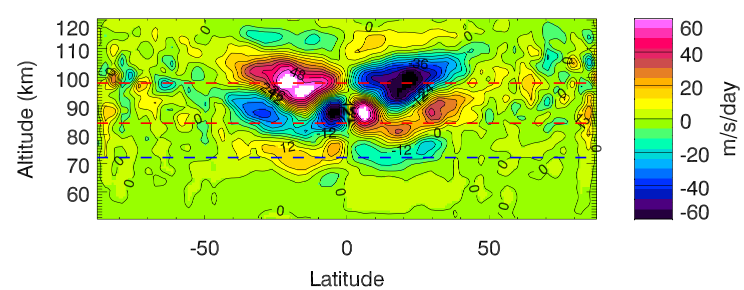


GW residual force
IGW + GW



Dashed lines are nodal lines
for the tide v field in each case

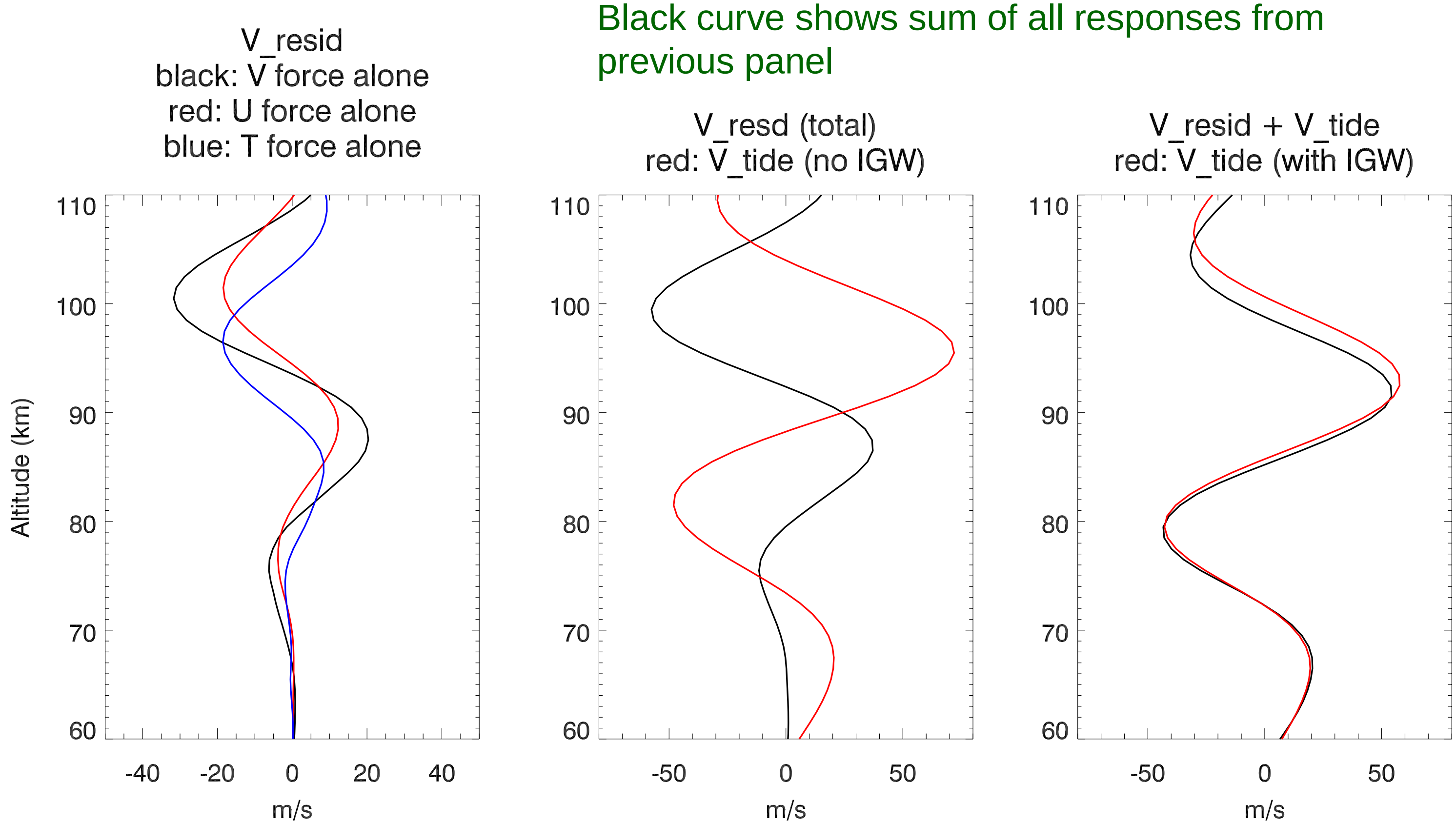
IGW+GW residual force
IGW + GW



Response to various components of the residual forcing

Residual force determined from IGW run and then used to force three separate new runs

Black curve shows sum of all responses from previous panel



Response to meridional residual force is the largest

Residual heating only occurs in the IGW run (blue curve) and has significant response

GW and IGW effects on tide vertical structure

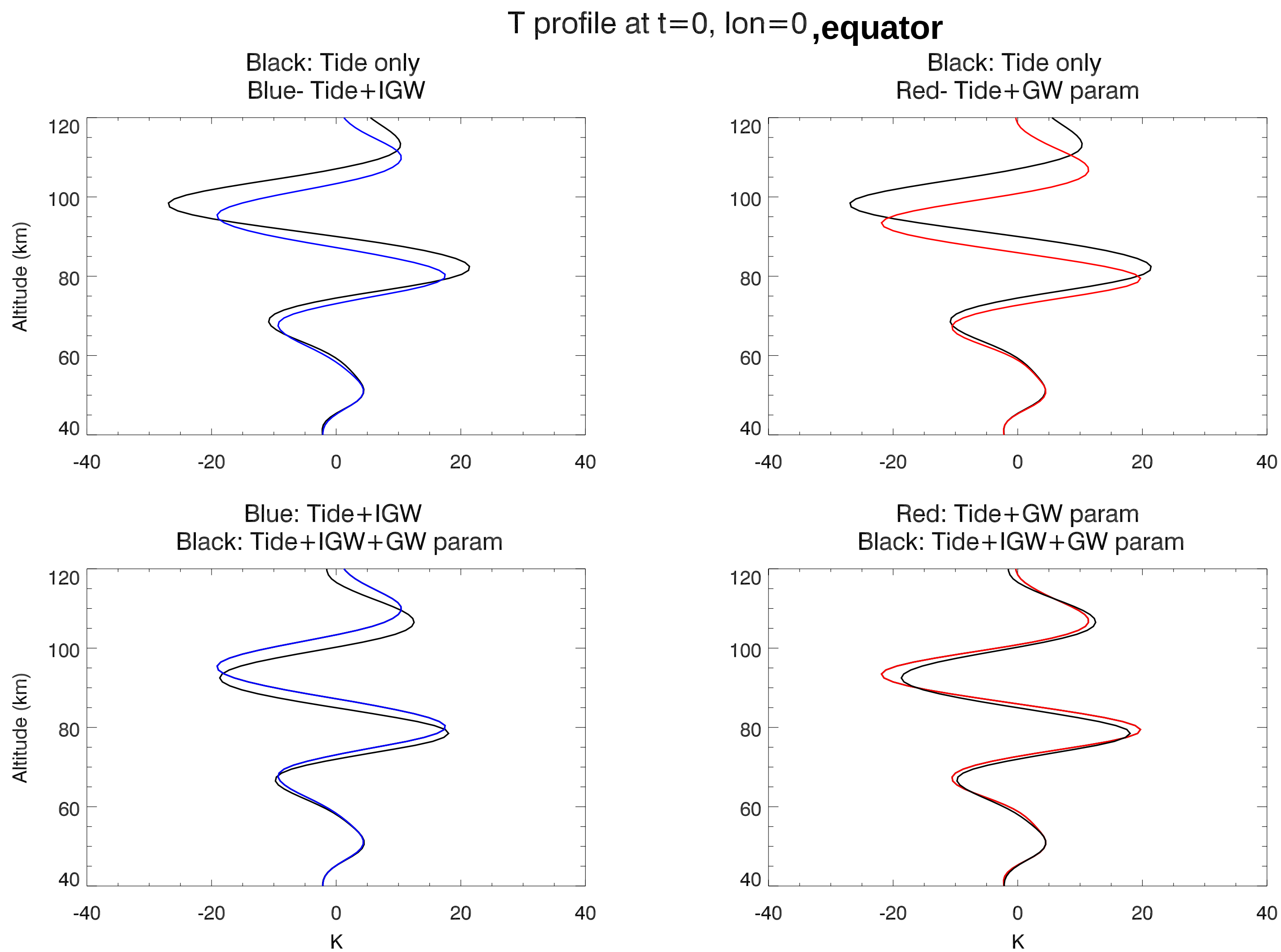
Main effects:
Phase advance (shorter vertical wavelength)
Slight reduction in amplitude

Changes due to IGW and GW are similar;

GW shortens wavelength a bit more

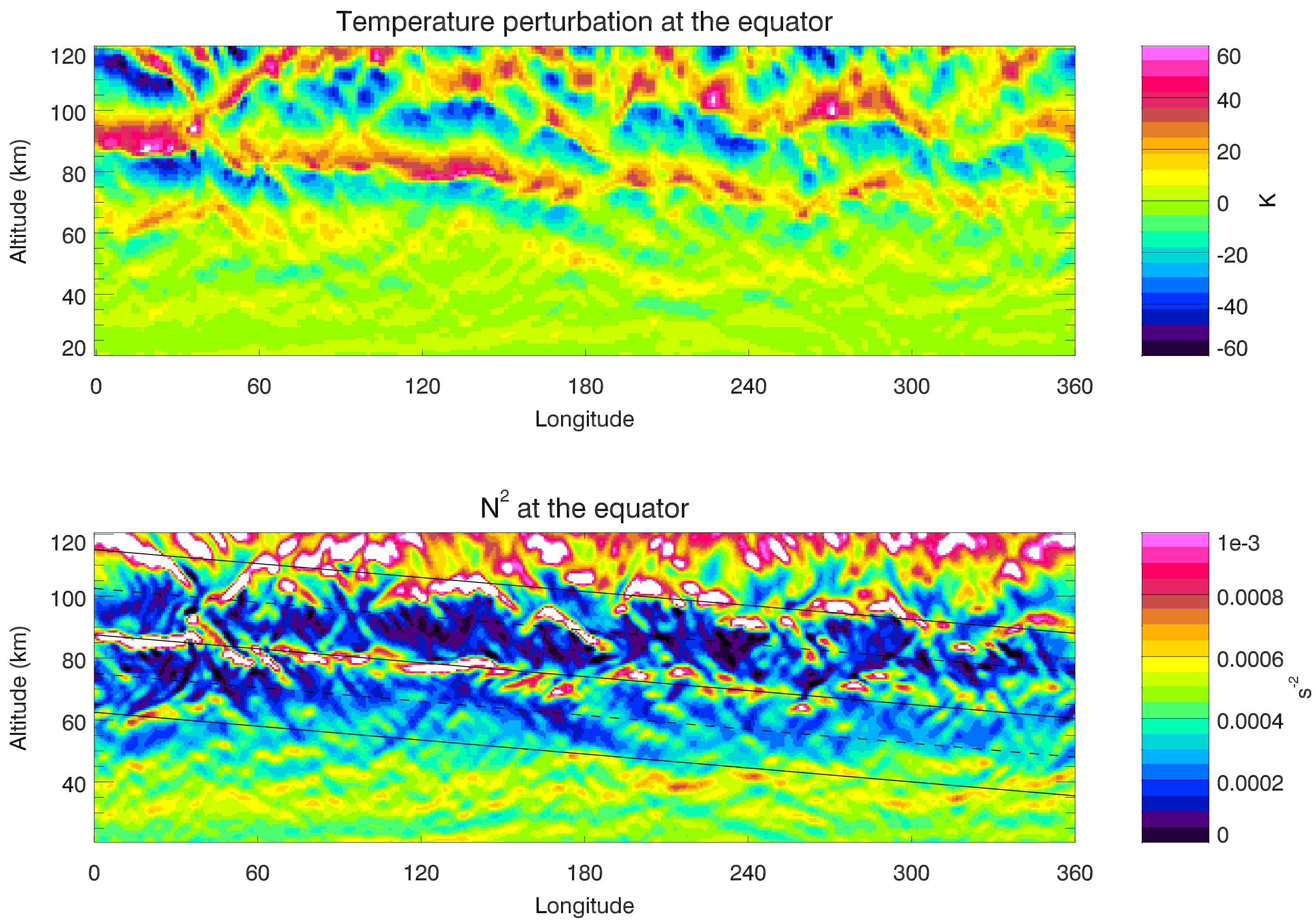
IGW decreases amplitude a bit more

Addition of GW to IGW induces only a small additional change to the tide



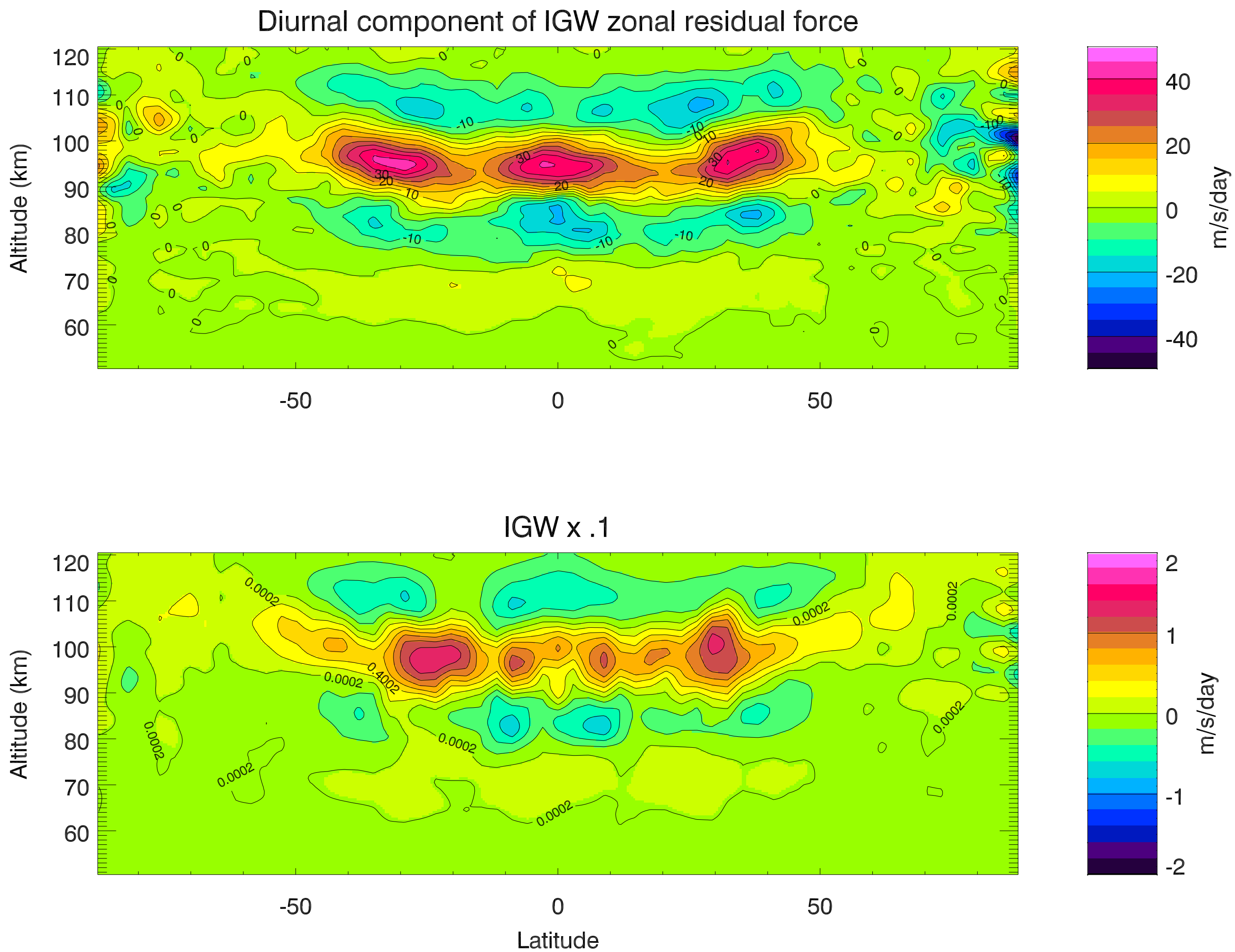
How does the tide modulate the IGW spectrum?
One possibility: wave saturation

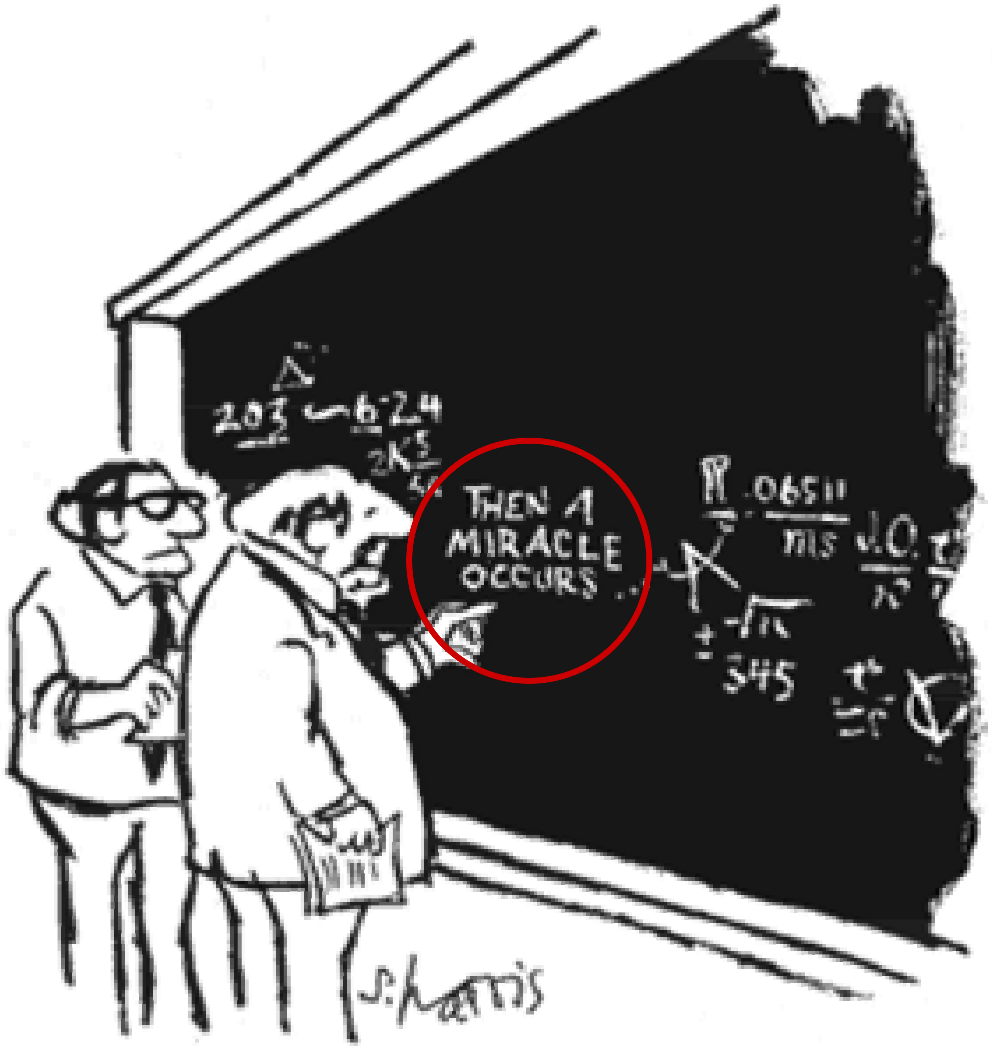
regions of convective instability exist with IGW alone, so does the tide make this more likely to occur at a particular phase?



Simulation with IGW forcing reduced by factor of 10

No convective instability occurs and yet the residual force has the same structure





"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

Weakly nonlinear triad interactions

- Mutual advection of tide and wave $w_{s,\omega}$ in the IGW spectrum produces residual forces $F_{s+1,\omega-1}$ and $F_{s-1,\omega+1}$;

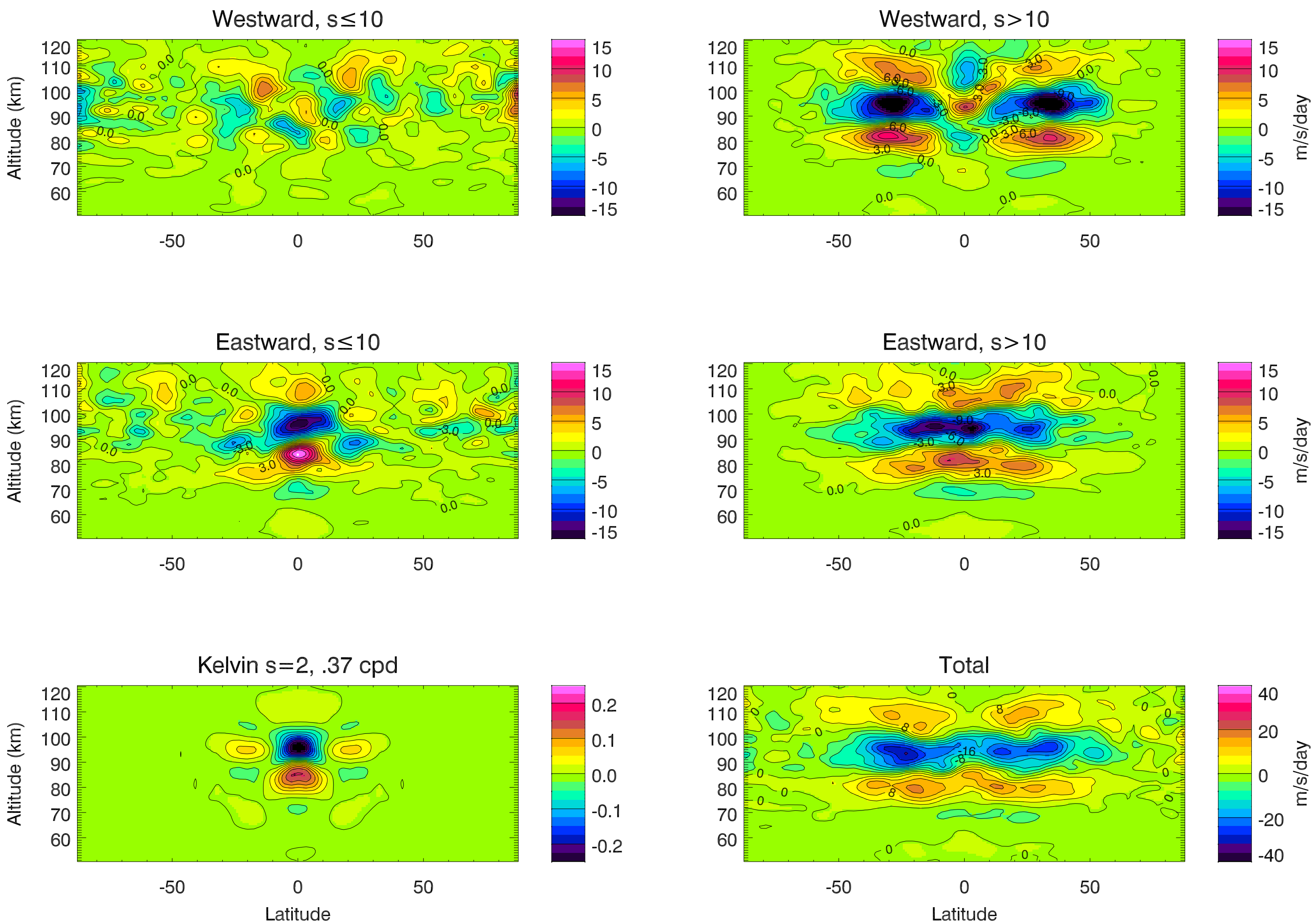
- Mutual advection of $w_{n,\omega}$ and the responses $w_{s+1,\omega-1}$ and $w_{s-1,\omega+1}$ to these residual forces produces residual forces $F_{1,-1}$ and $F_{-1,1}$ (among others);

- The sum over all s and ω produces the total tide residual force, whose response is the pseudo-tide;

- Miracle: the phases of the individual $F_{1,-1}$ and $F_{-1,1}$ for all s and ω are coherent.

Various components of the tide residual force

Zonal direction



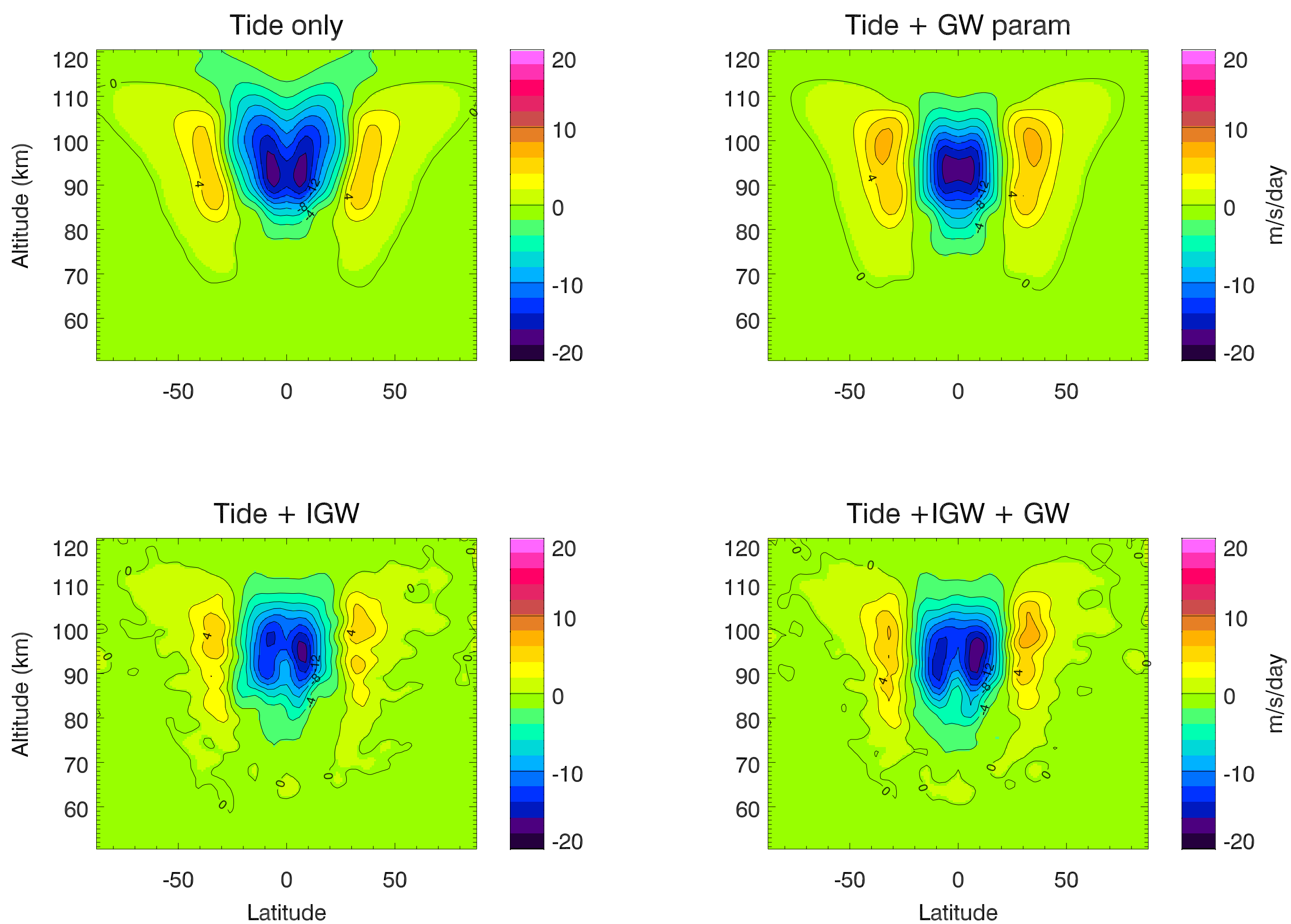
Conclusions

- GW parameterizations do the right thing for the wrong reasons (R. Garcia).
- Both IGW and GW produce similar residual forcing for the tide, and therefore essentially equivalent changes in the tide structure.
- One does not need to invoke GW wave drag to explain the deviation of the migrating tide from classical tide structure – the presence of the IGW spectrum is sufficient. However, GW breaking may be at least partly responsible for the eddy diffusion that is used here.
- IGW residual forcing arises from tide modulation of the IGW spectrum via triad interaction, not modulation of wave saturation
- When both IGW and GW are present the IGW filter the GW and reduce the GW effect on the tide so that it is almost negligible. The GWs do alter the IGW structure, but do not change the way IGW interact with the tide

Dynamical consequences of tide/GW interaction: Mean flow forcing by the tide

Migrating diurnal component of EP-flux divergence

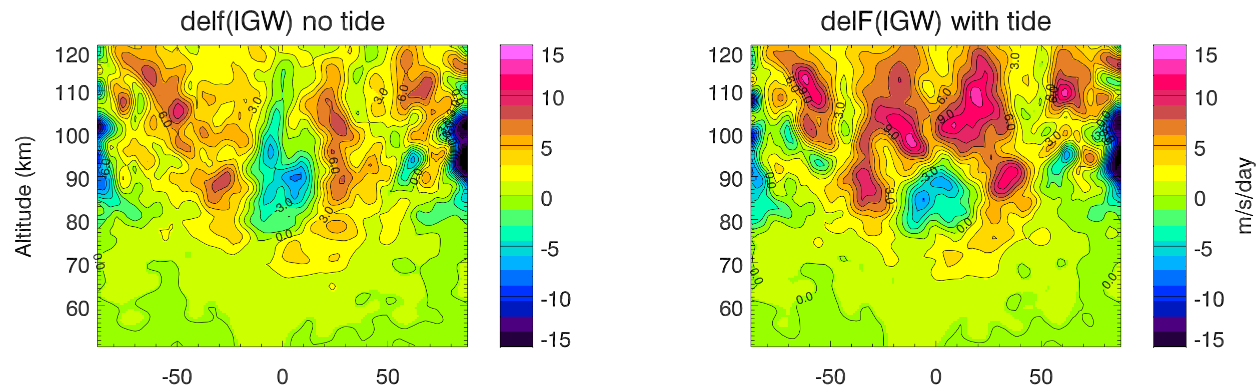
Both IGW and GW (in any combination) have similar effect on the EP-flux divergence of the tide: structure becomes narrower and lower



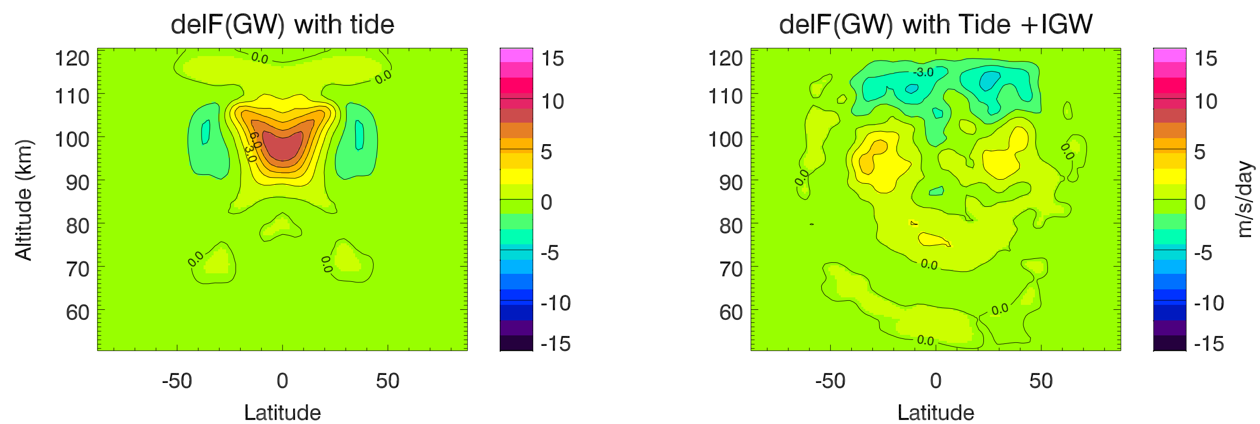
Mean flow forcing by IGW and GW

Tide changes EP-flux divergence of the IGW and GW primarily via the tide change in the mean flow

Easterly mean U results in enhanced westerly IGW and GW forcing above 90 km

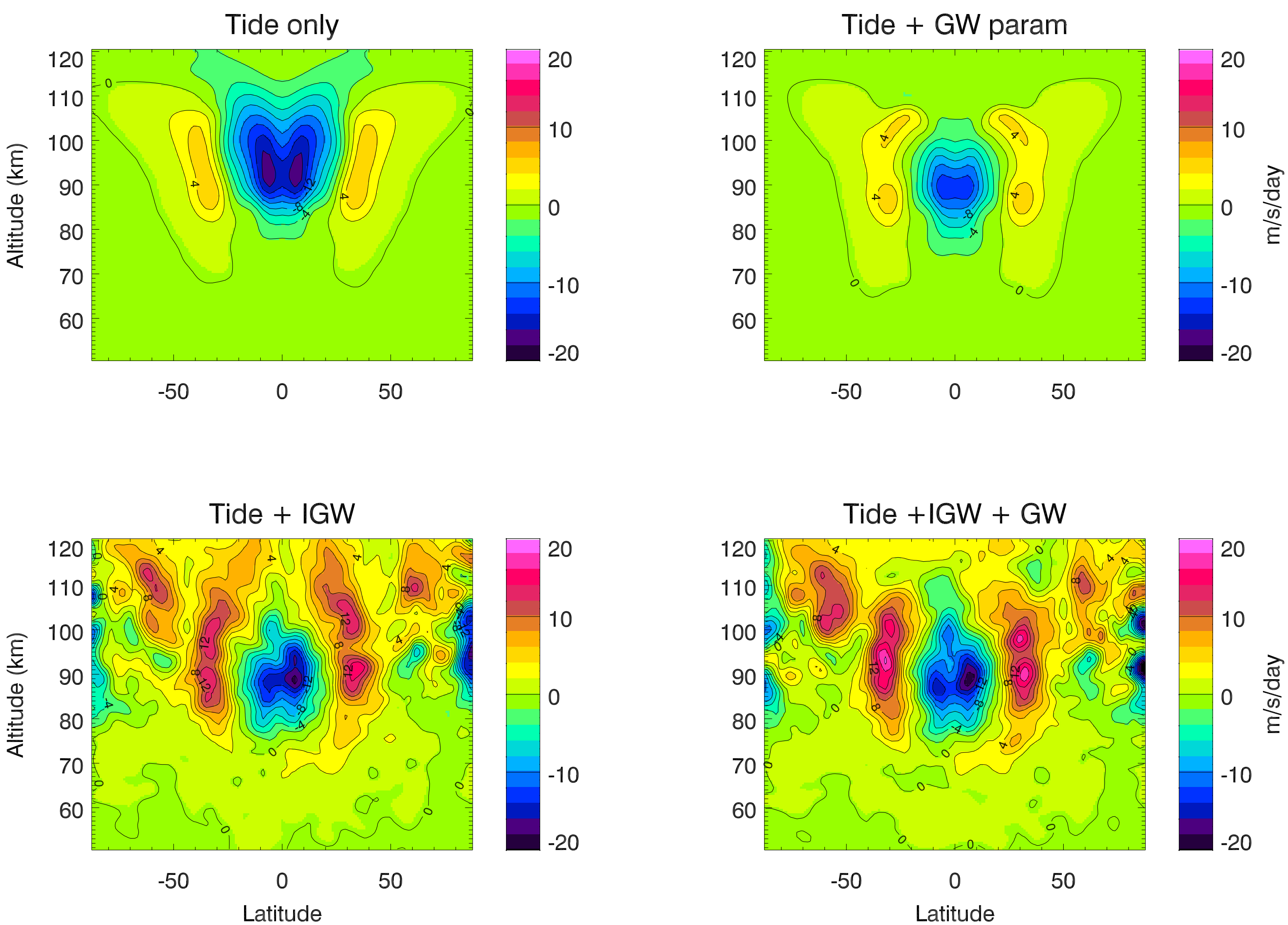


With no tide, GW force is essentially zero. Presence of IGW filters GW and reduces/alters its EP-flux divergence

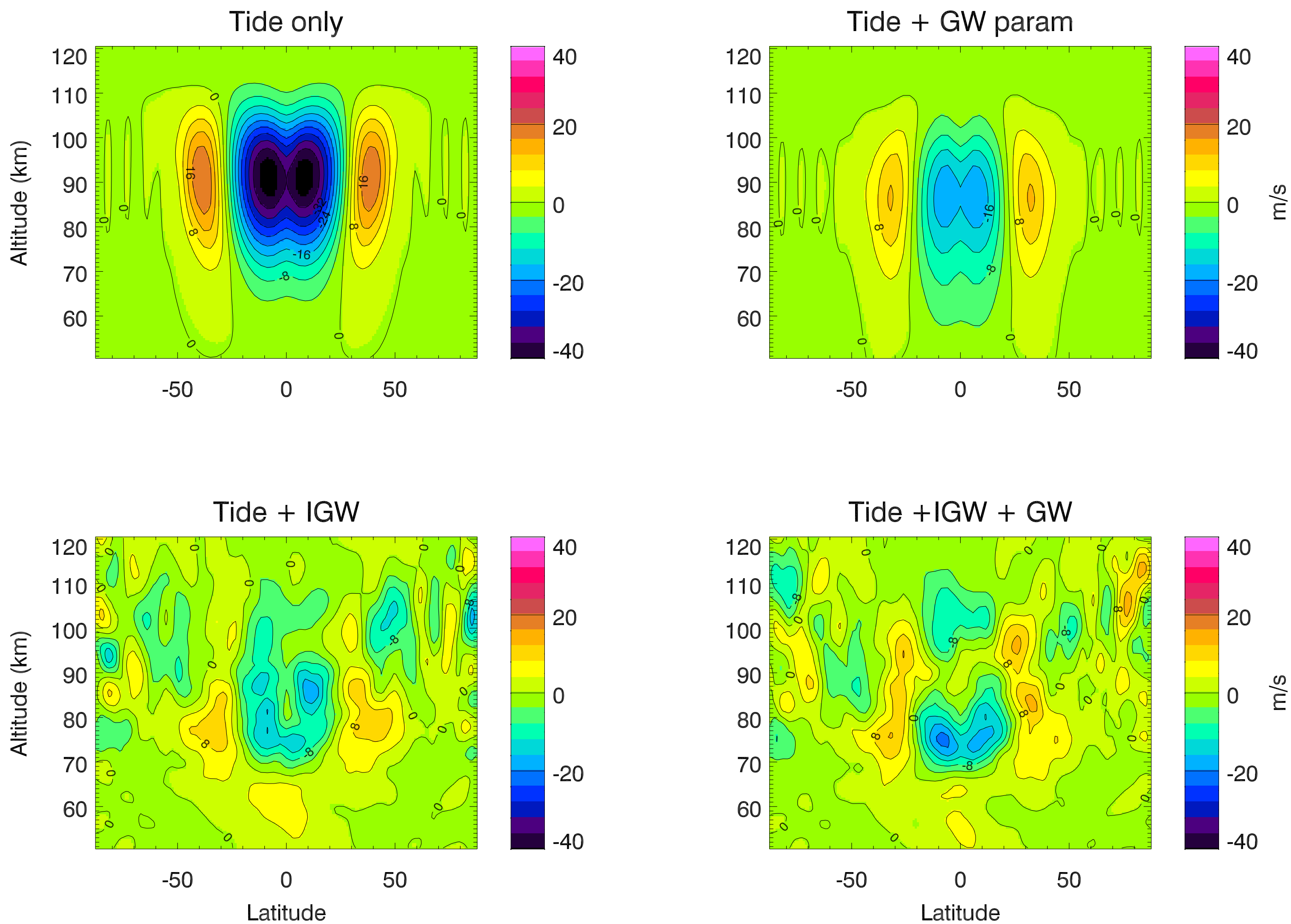


Total (tide +GW) EP-flux divergence

GW/IGW moderate the tide EP-flux divergence, both through changes in the tide forcing and by adding EP-divergence with opposite sign



Zonal mean U
GWs and IGWs reduce effect of tide alone



Seasonal variation of tide amplitude

vary IGW heating and background zonal mean (UARS/HRDI for 1993)

Top: the seasonal variation of the tide u amplitude, averaged from 90-100 km, 25S-35N.

Black: HRDI/UARS 1993

Green: model, tide only

Red: model, tide+wave spectrum.

Bottom: variation of the nonlinear forcing term. The mean winds do not modulate the propagation of the resolved wave spectrum significantly enough to reproduce the observed tide variability.