Probing the interactions between resolved and parameterized waves

Edwin P. Gerber

Center for Atmosphere Ocean Science
Courant Institute of Mathematical Sciences
New York University

Questions

- Can we quantify the uncertainty in climate change integrations associated with parameterized gravity waves?

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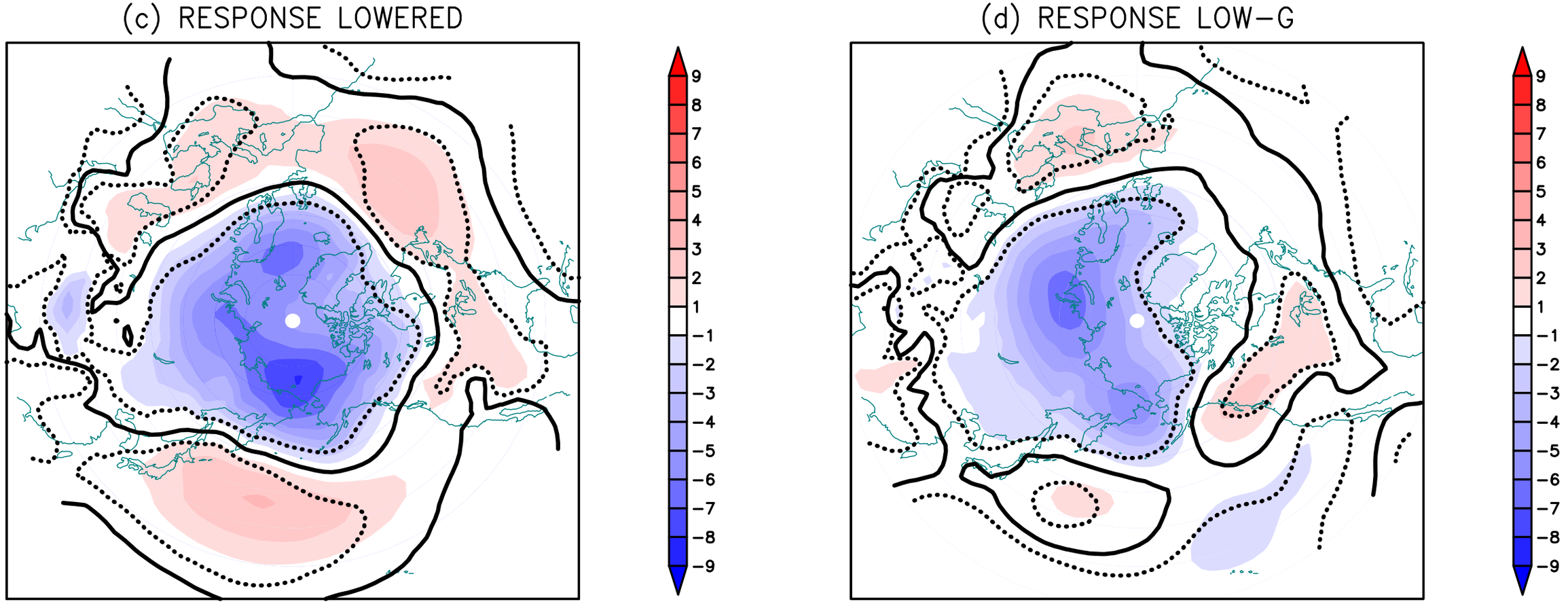
SLP response to doubled CO2, CMAM



[Sigmond et al. 2008, Sigmond and Scinocca, 2010]

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➥ develop an idealized GCM framework to investigate interactions between resolved and parameterized waves

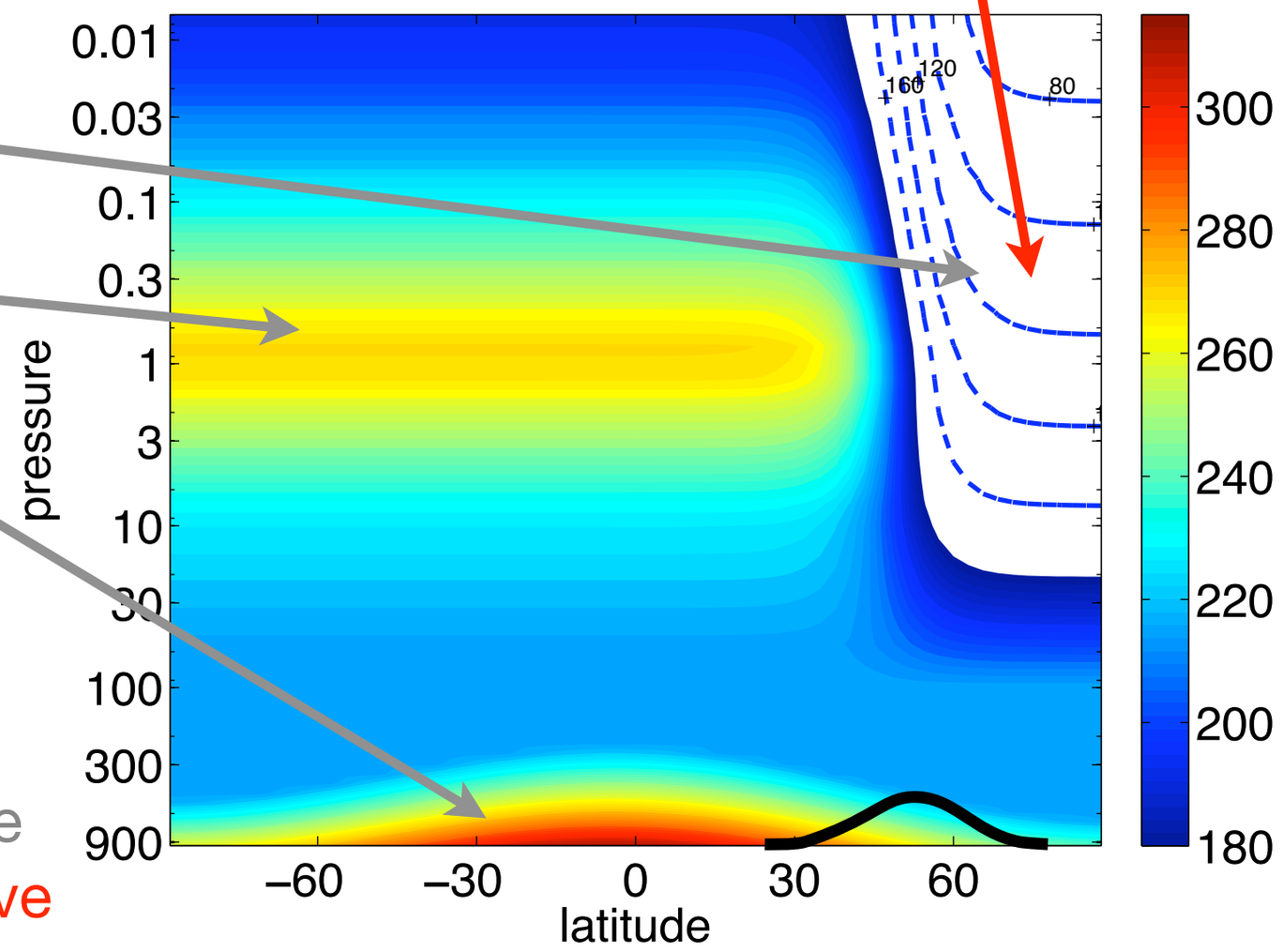
- How predictable is the response to perturbations of the parameterized gravity waves?

➥ experiments designed to maximize interaction with resolved waves

An idealized Atmospheric GCM

- dry primitive equations on the sphere
- Newtonian relaxation of temperature to radiative-convective equilibrium profile
  - Variable strength polar vortex *[Polvani and Kushner, 2002]*
  - US Standard Atmosphere
  - *Held and Suarez [1994]* troposphere
- Simple large scale topography *[Gerber and Polvani, 2009]*
- Rayleigh friction at bottom (surface drag) and at top (crude gravity wave parameterization)

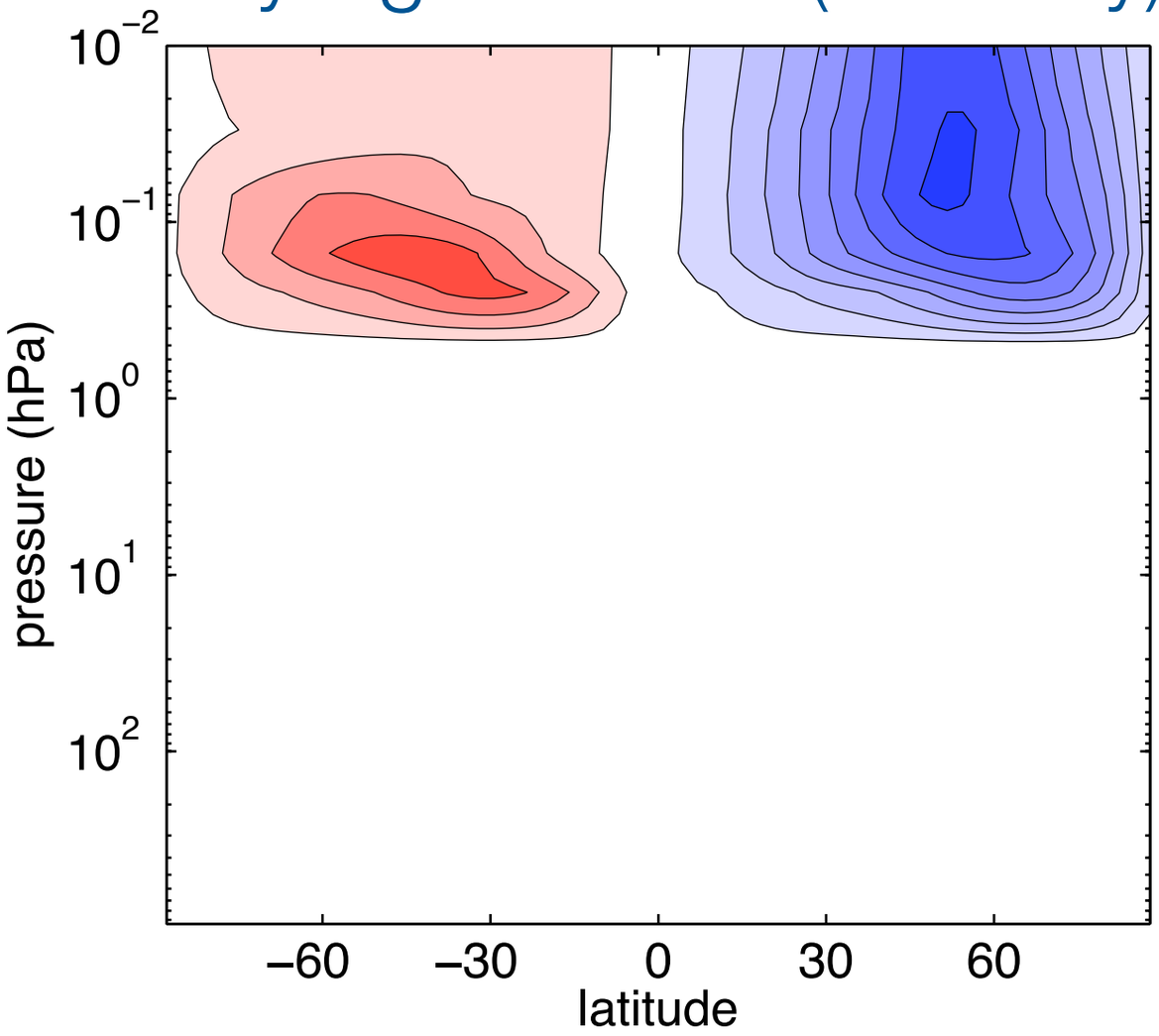
vary cooling w/ parameter γ



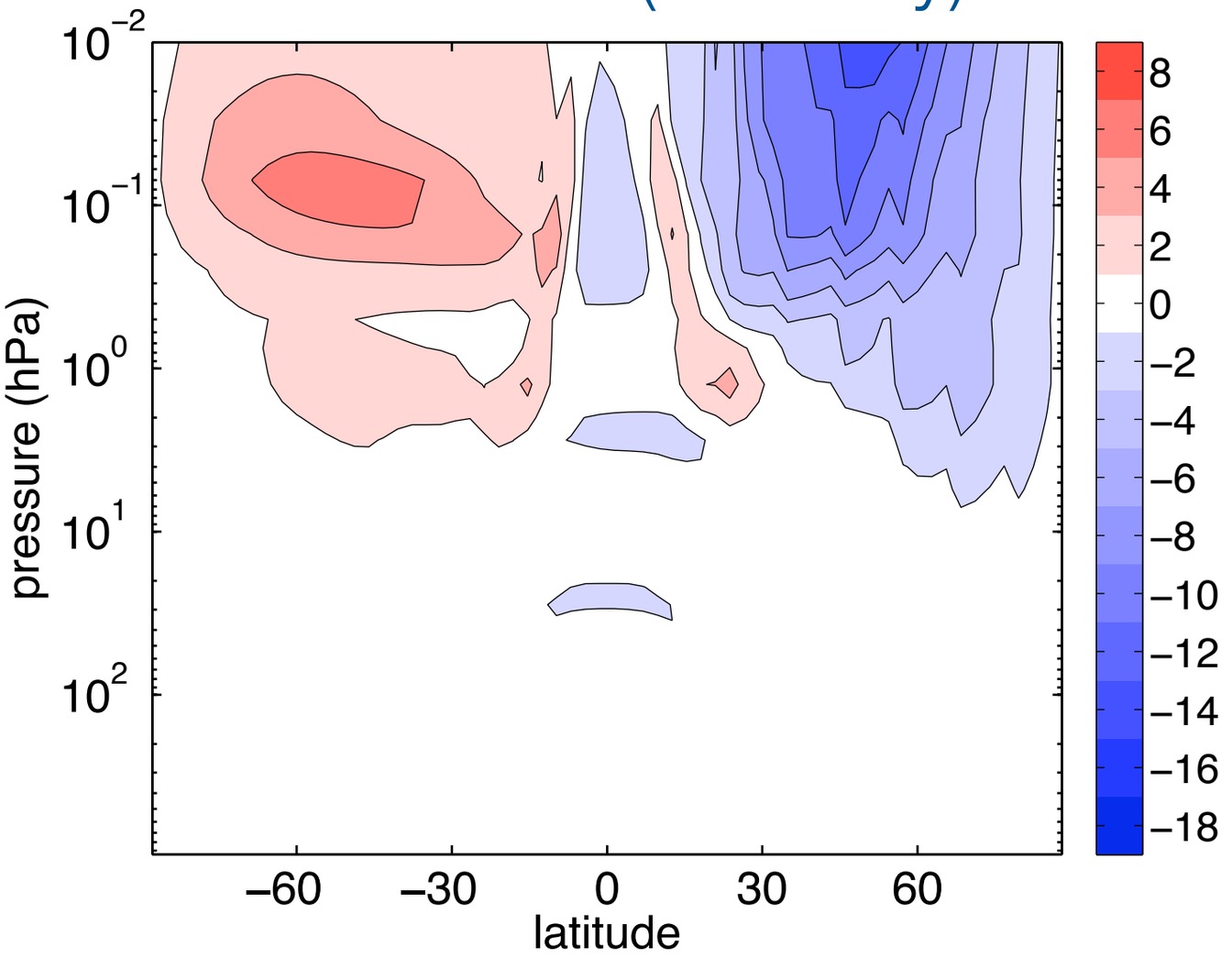
Replace Rayleigh Friction with Alexander-Dunkerton (1999) GWP

- Spectral source, approximates effect of intermittency on wave breaking
- Used to parameterized non-orographic GWD in GFDL coupled climate model

Rayleigh Friction (m/s/day)



A-D GWD (m/s/day)



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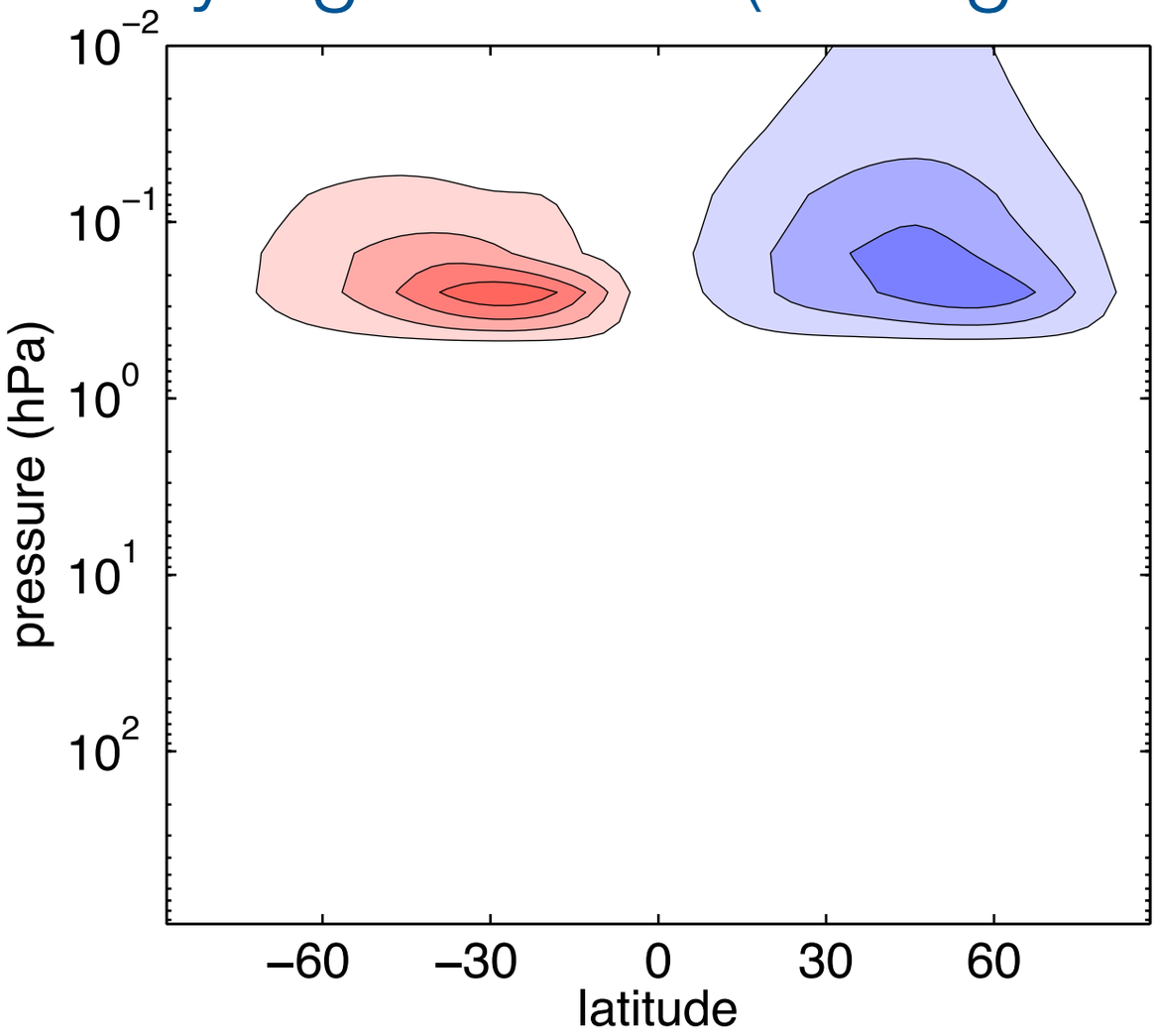
Rayleigh Friction (10^9 kg ms^{-2})



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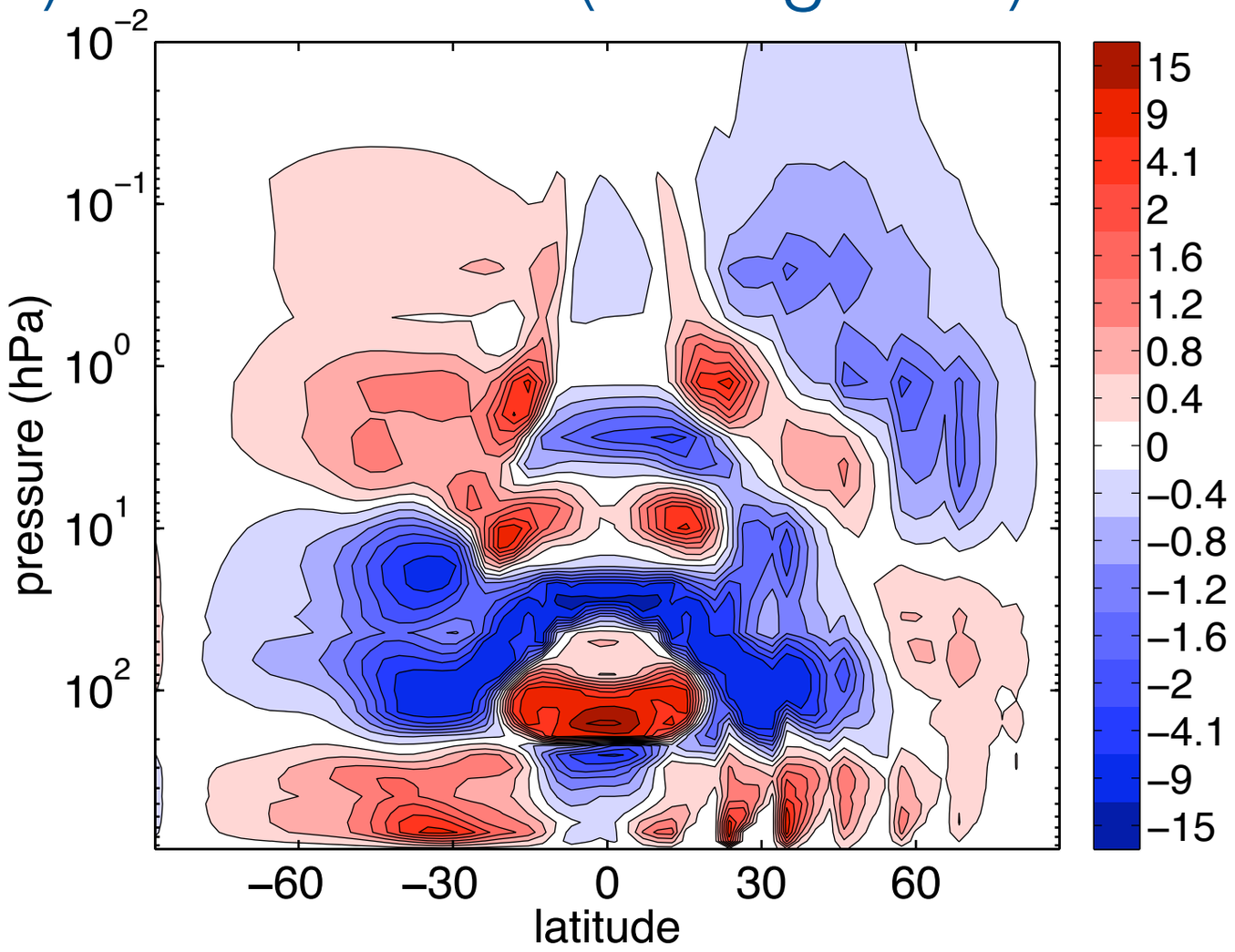
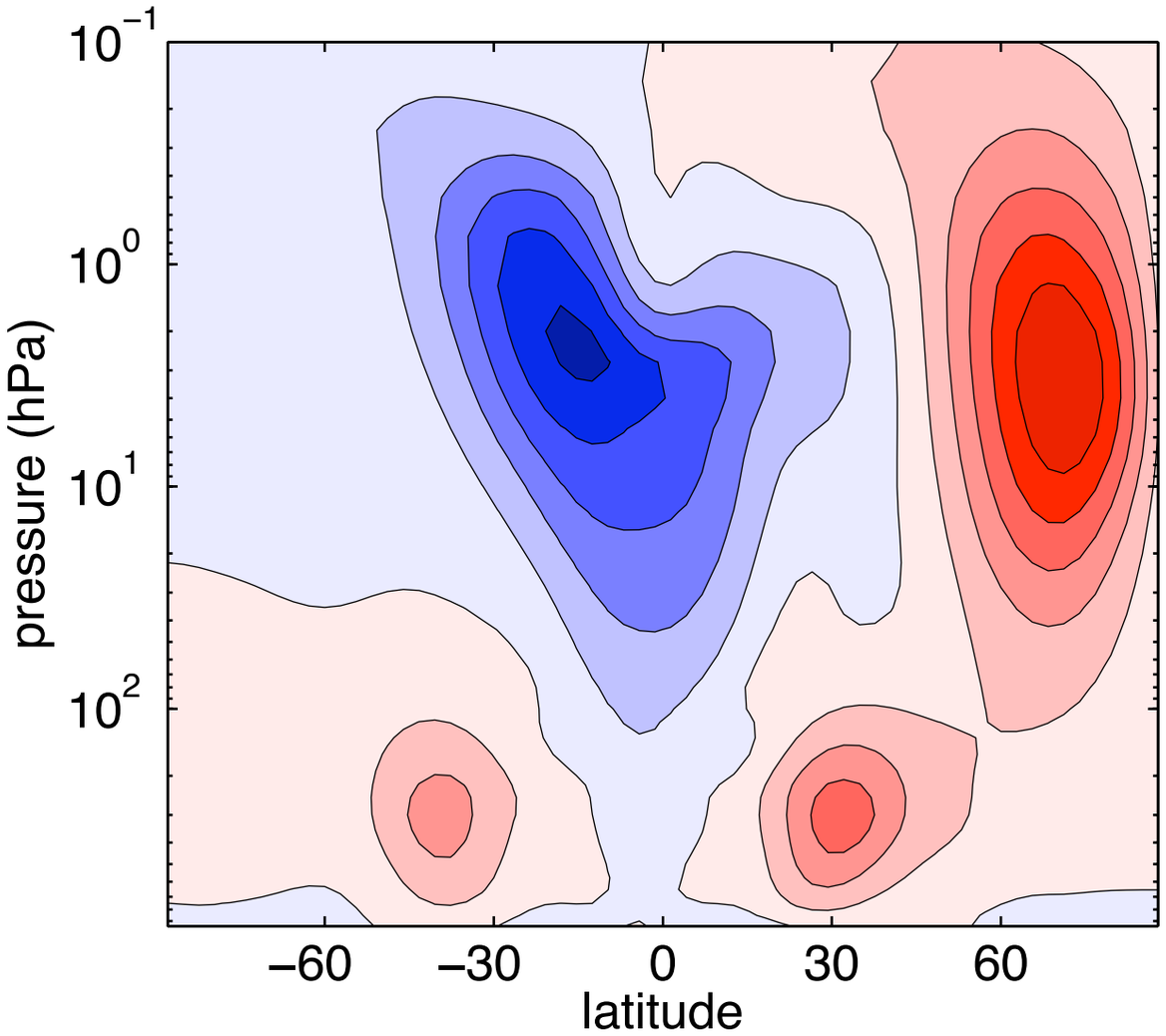


Retuning the model ...

- For same equilibrium temperature forcing, vortex is too weak in new model

ū, **γ**=4 (Rayleigh Friction)



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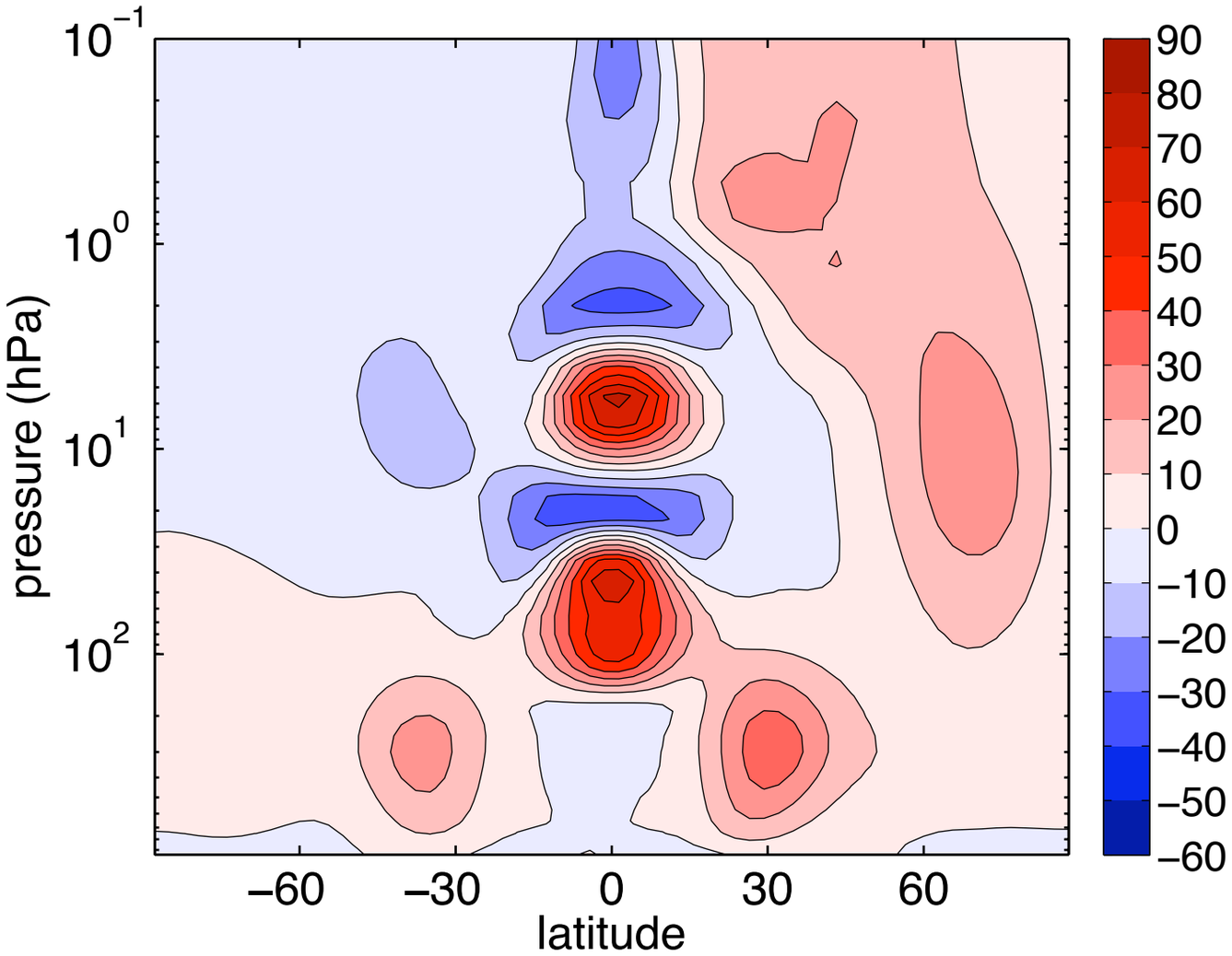

Retuning the model ...

- For same equilibrium temperature forcing, vortex is too weak in new model
- Adjust radiative profile to get stratospheric jets correct

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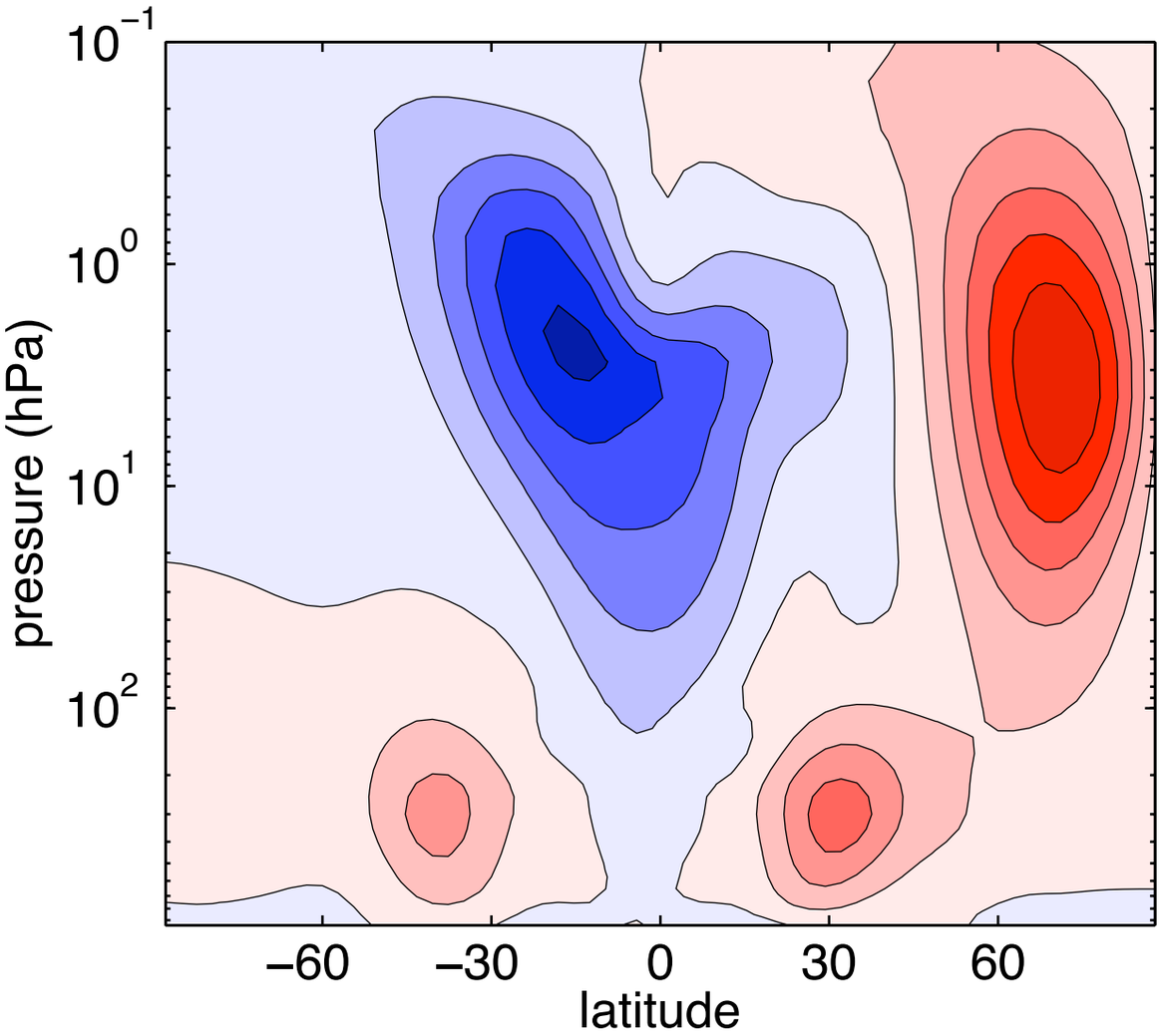
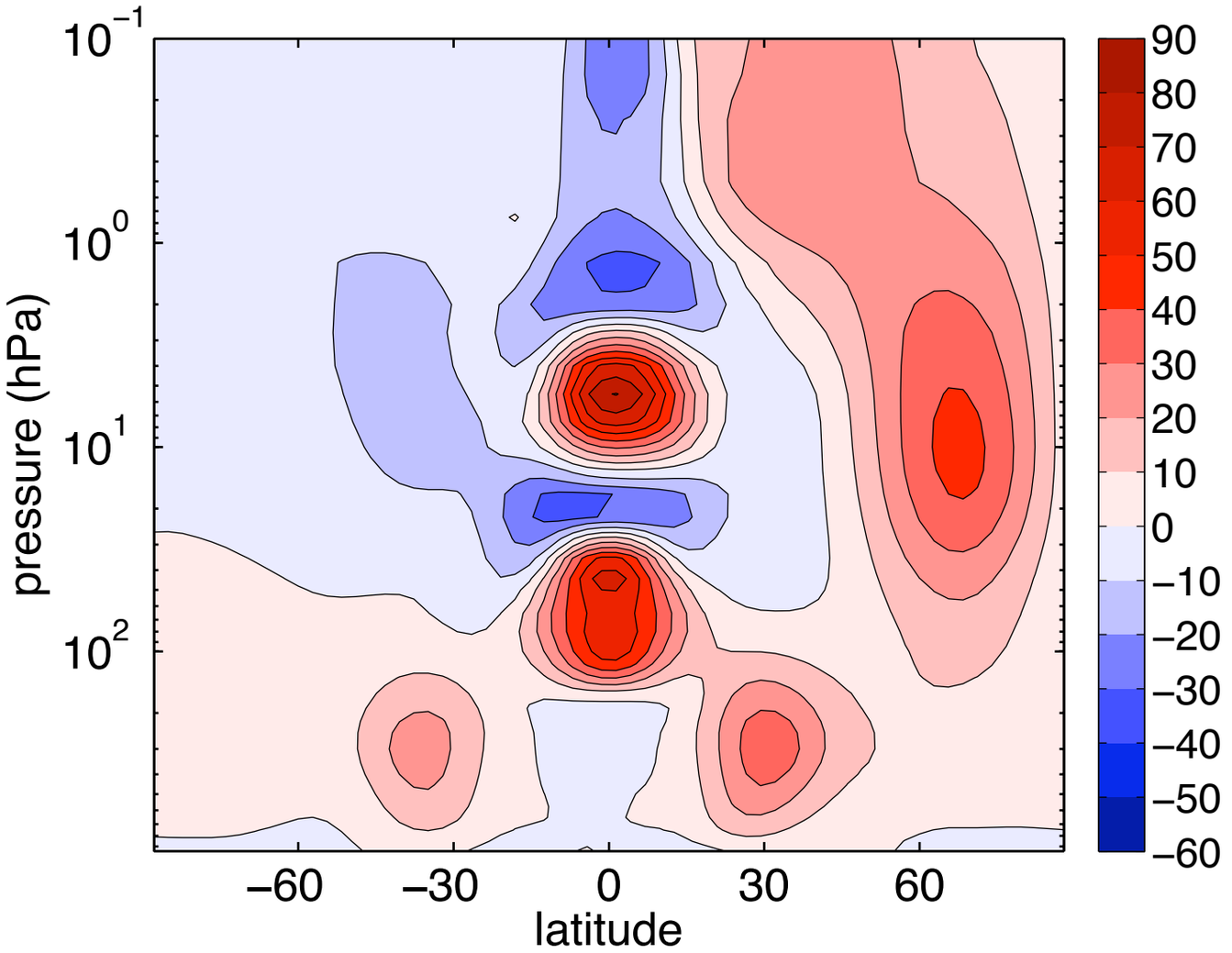
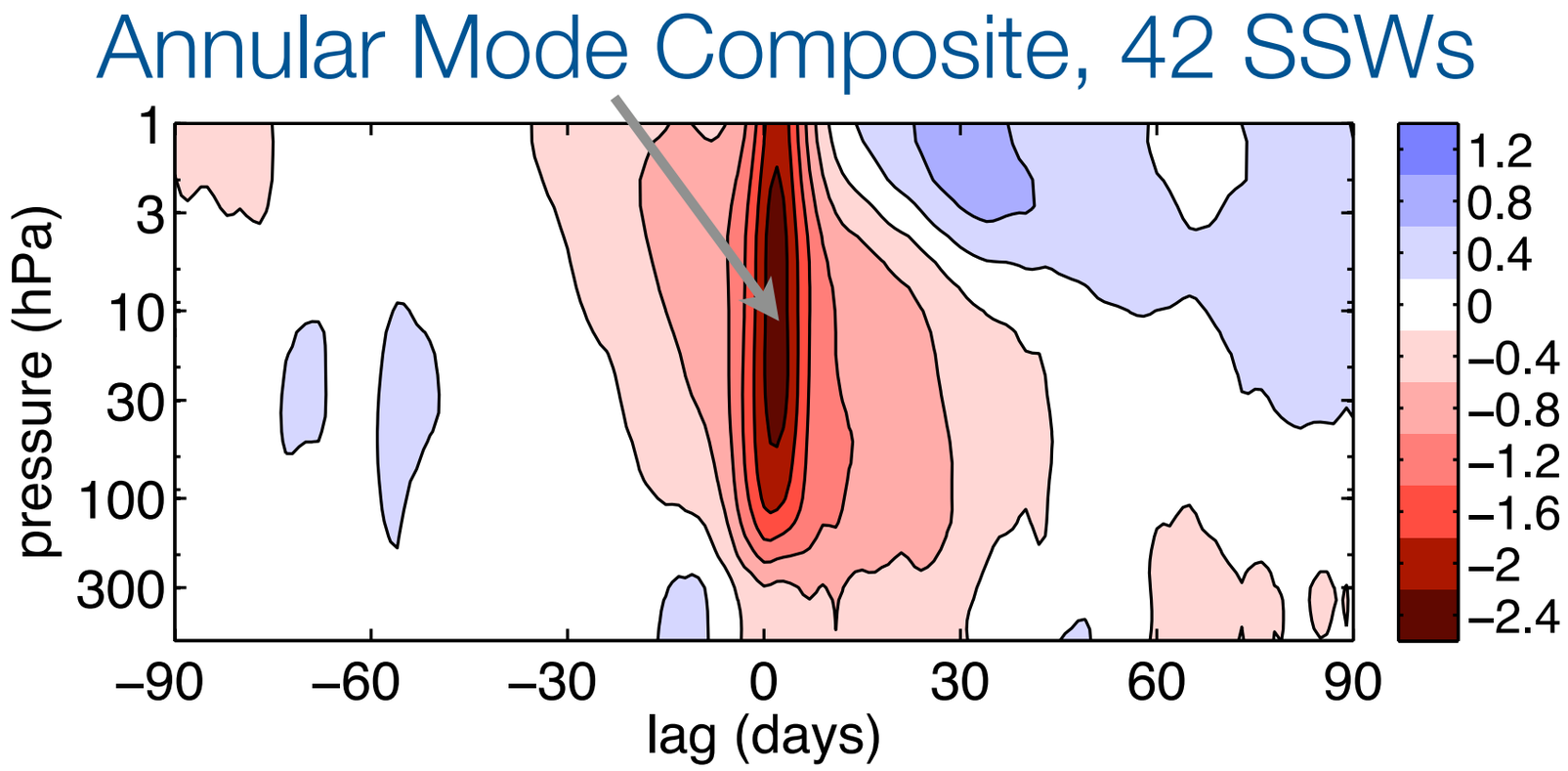


ū, γ=6 (A-D GWP)



Model captures Stratosphere-Troposphere Coupling



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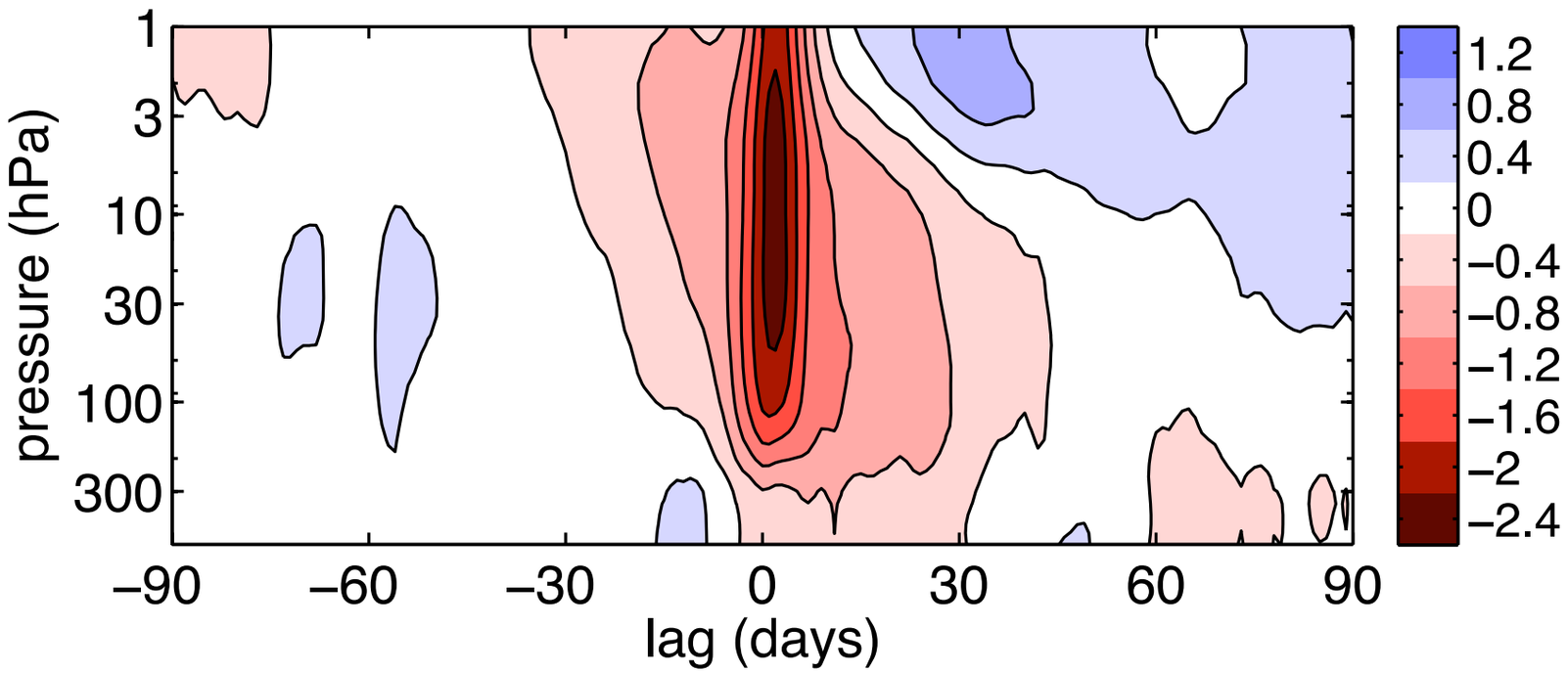
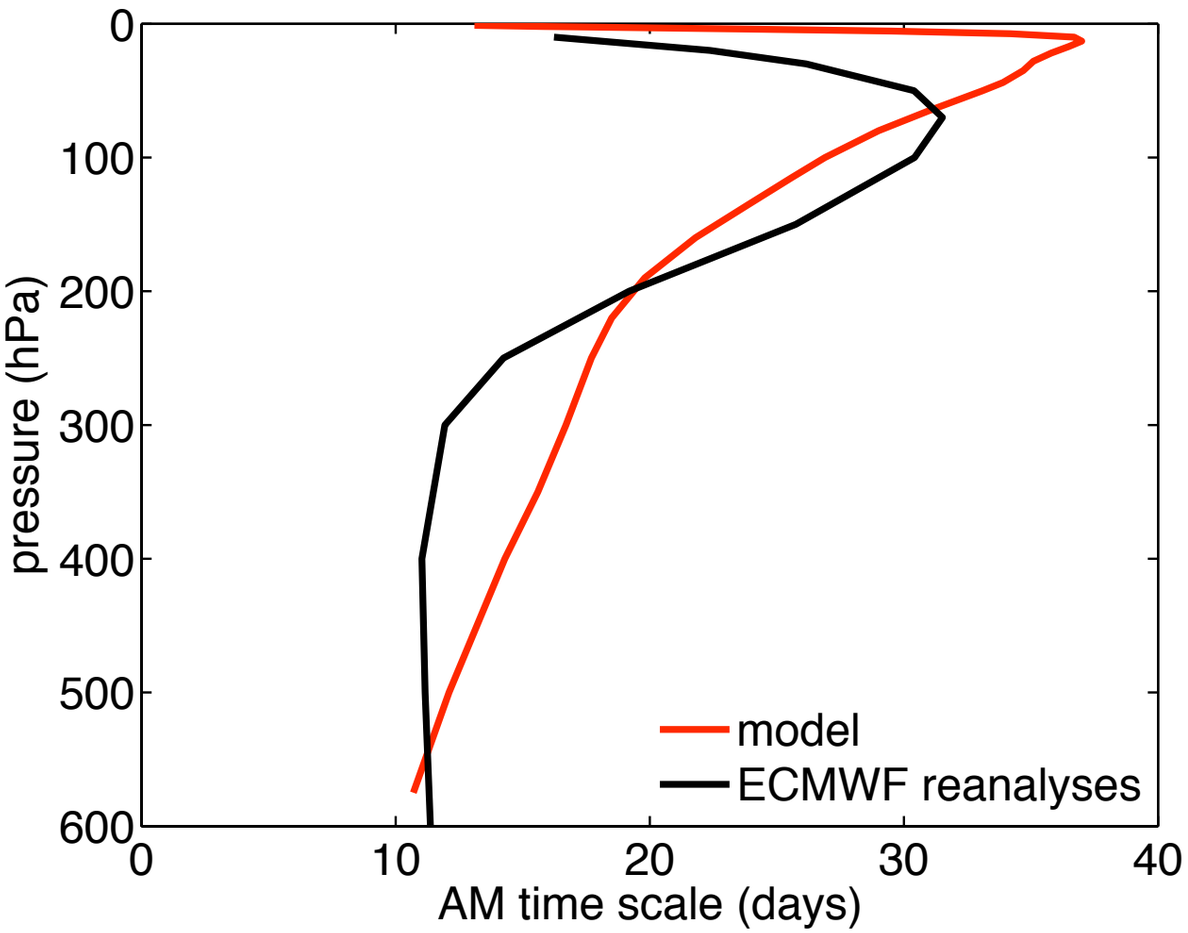
Annular Mode Composite, 42 SSWs



Annular Mode Time Scale



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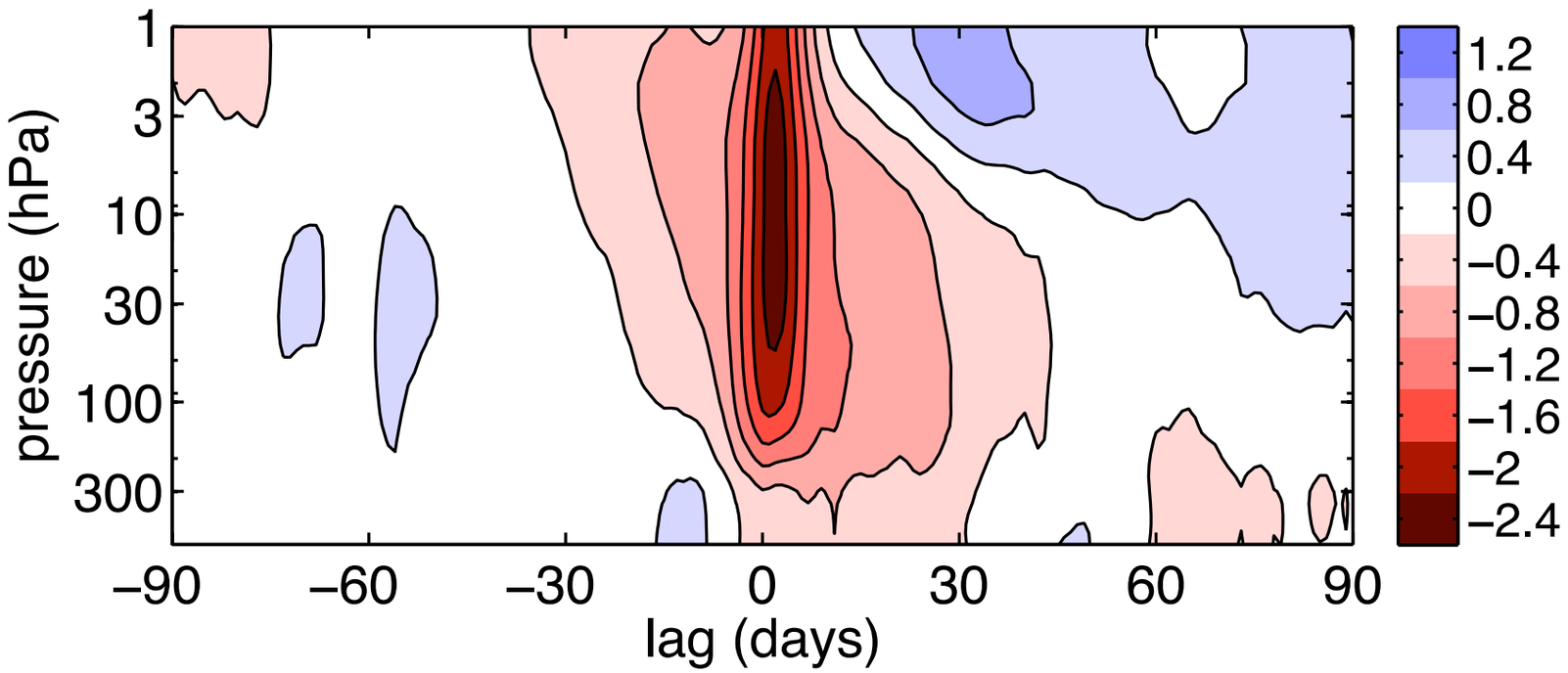

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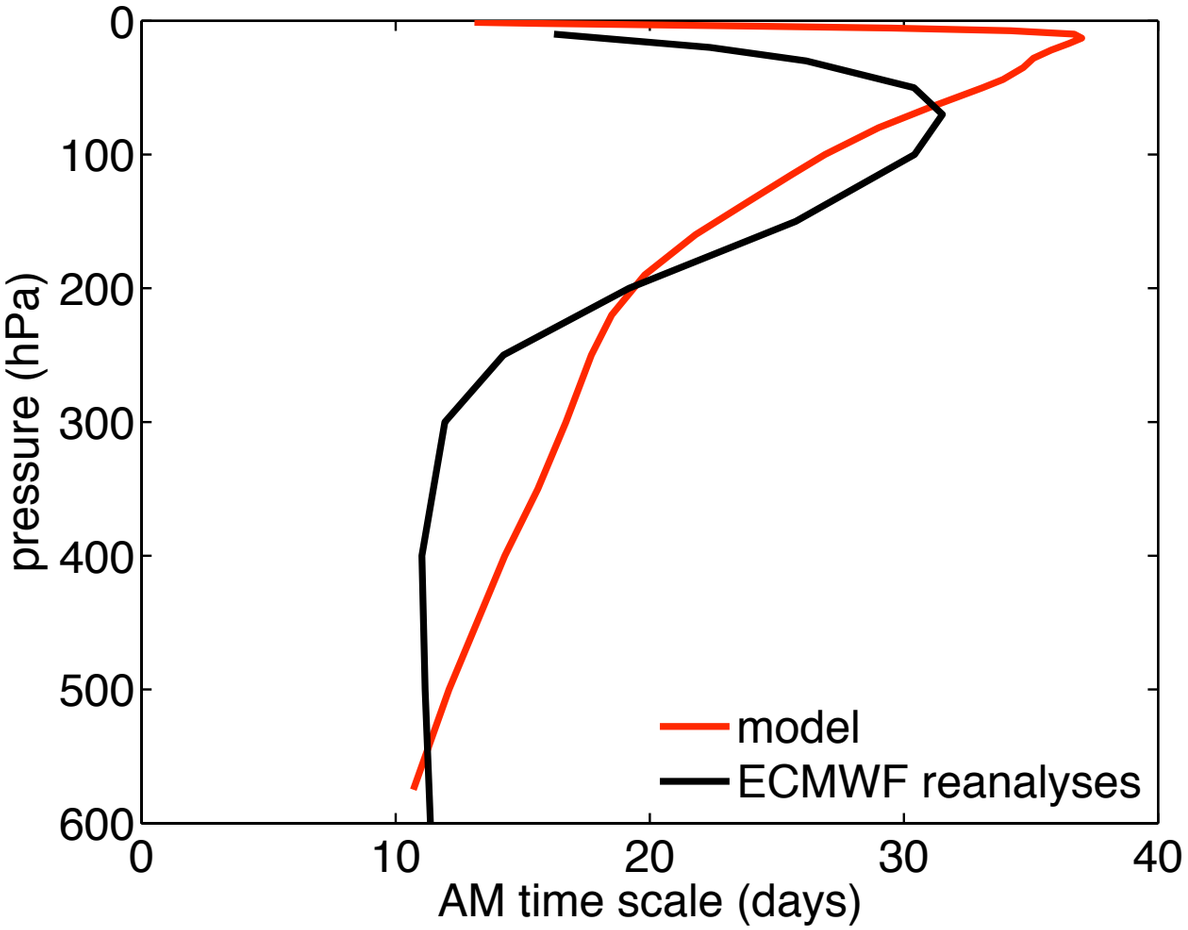
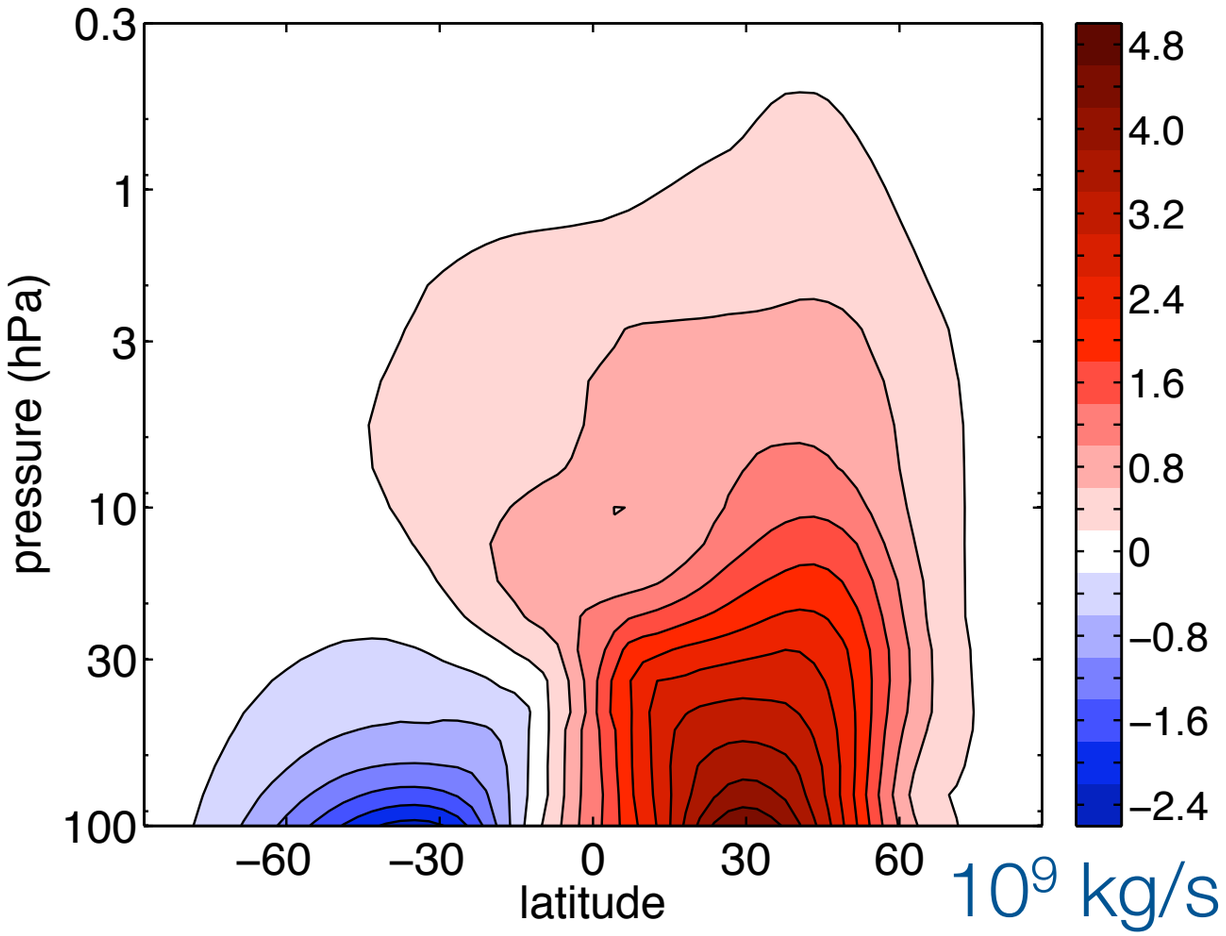


Residual Mean Circulation

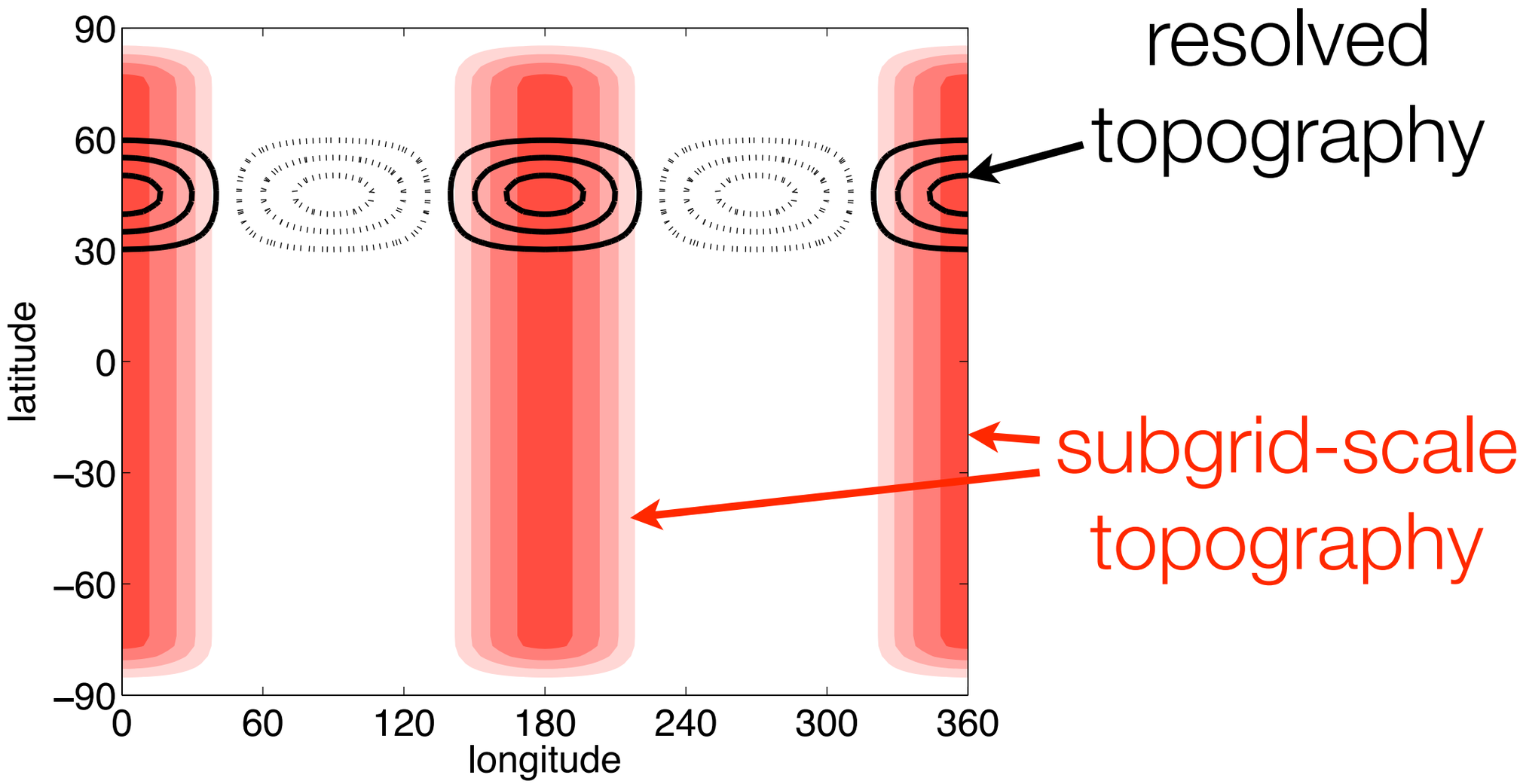


Orographic Gravity Waves: Pierrehumbert Scheme

- Used in GFDL's coupled climate models CM2 and CM3.
- Lindzen-like scheme
  - Estimate wave flux from low level flow, subgrid-scale topography parameter
  - Wave breaking determined by comparing flux against a saturation flux. Momentum is deposited slowly, as saturation flux decays with height.
- Tends to allow small amount of flux reach near model lid; trivial amount of momentum, but leads to numerical issues.

Experimental Setup:
Maximize interaction with resolved planetary waves

- Wavenumber 2 topography creates a standing waves in stratosphere
- Subgrid-scale topography with large scale wave number 2 pattern



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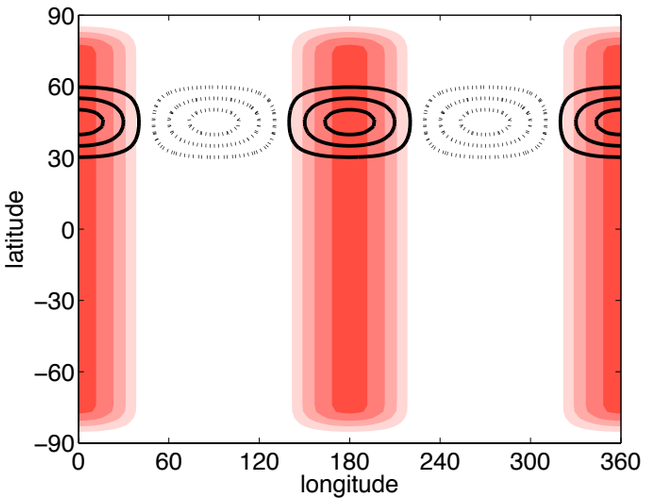

phase shift = 0°

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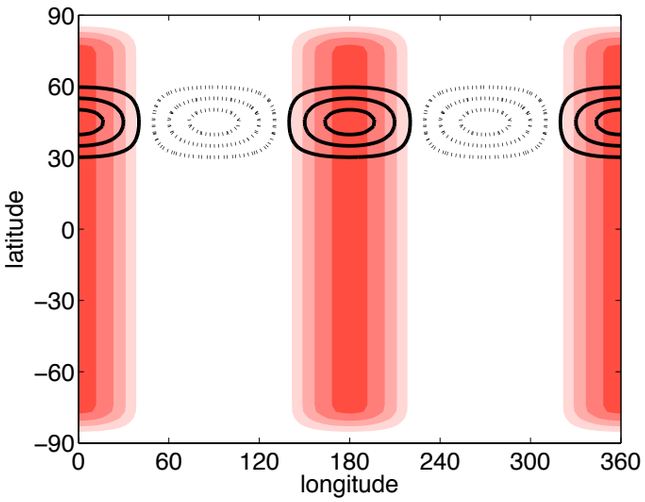

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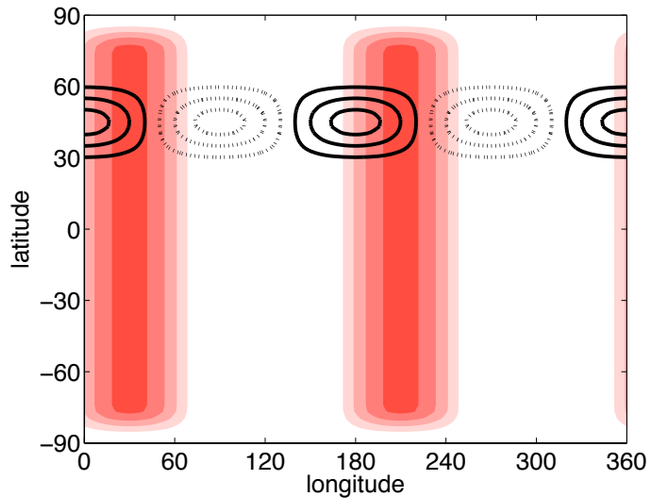

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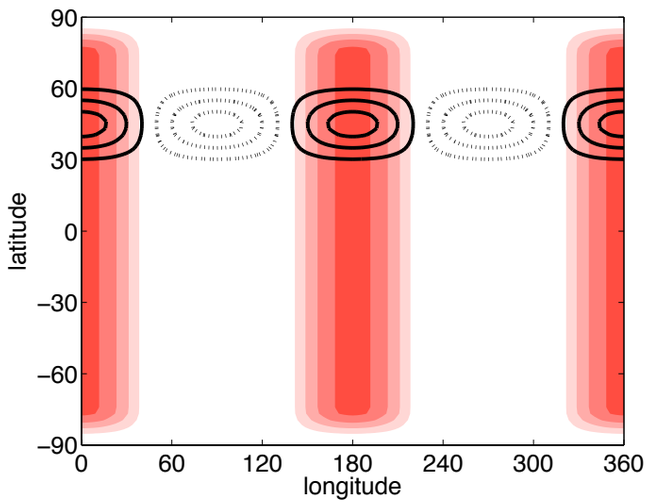
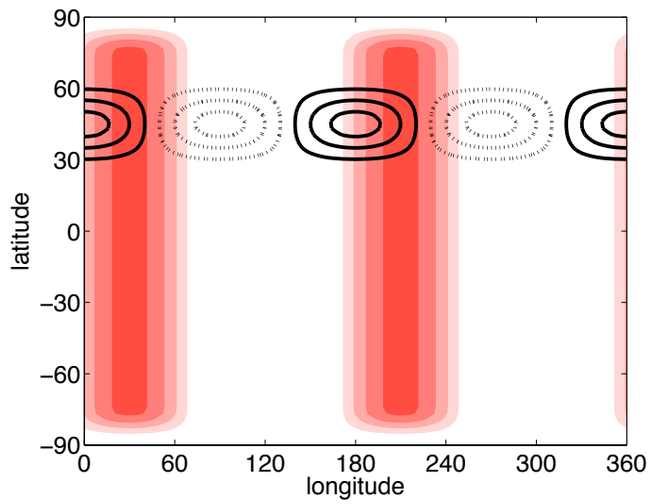


phase shift = 0°



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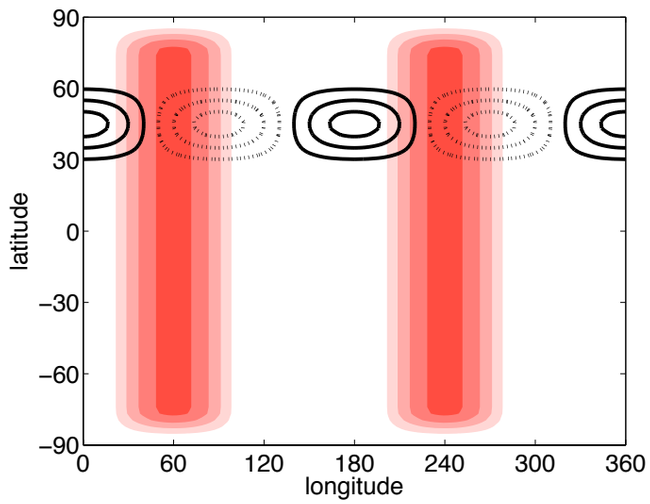
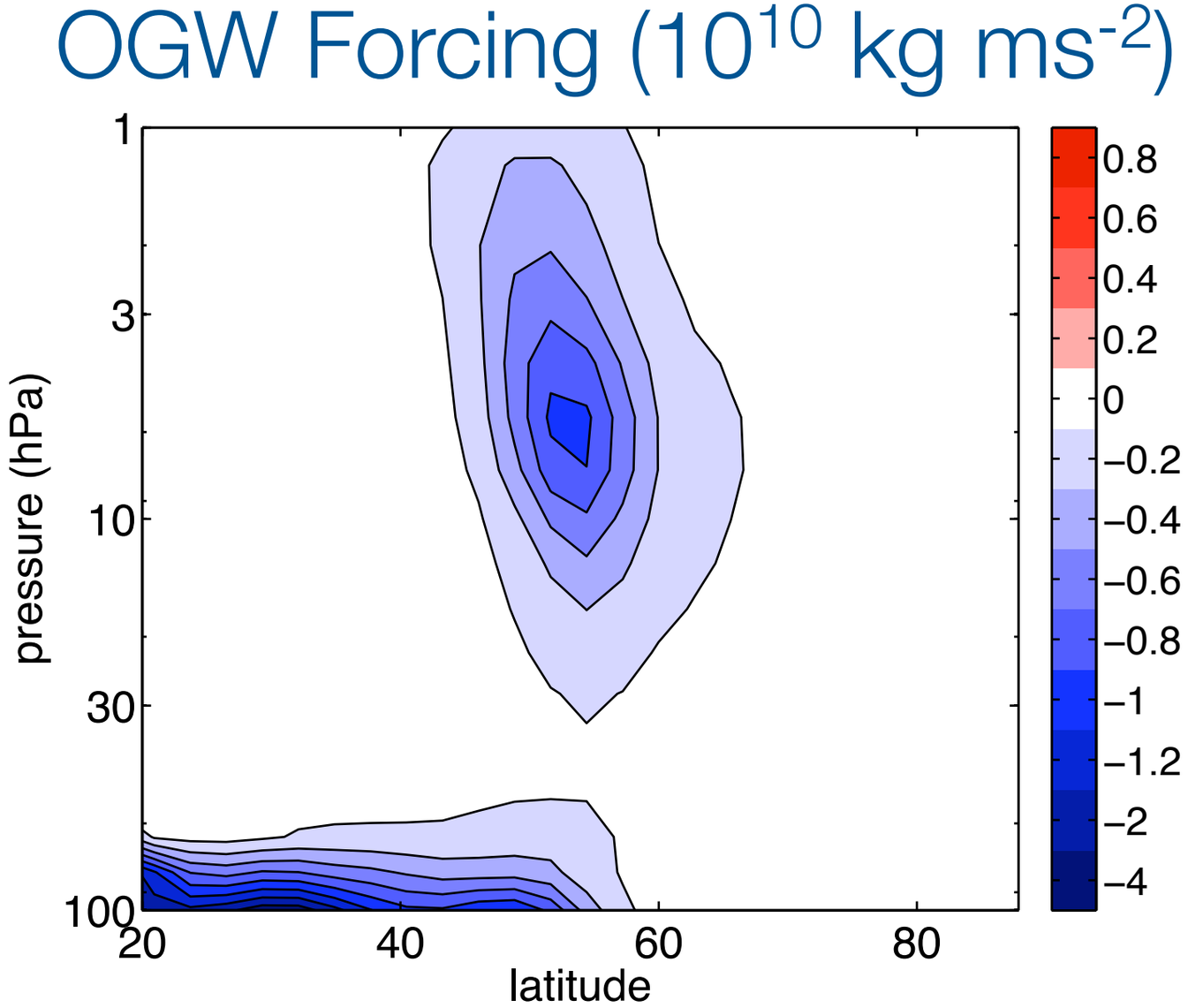


phase shift= 60°

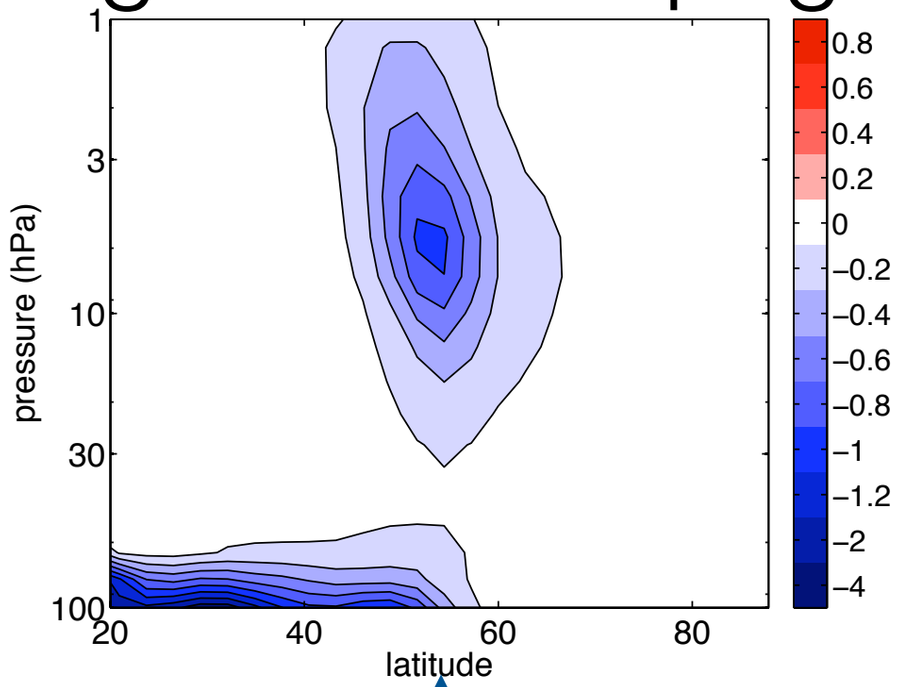
...

Impact of orographic gravity wave parameterization



(for phase shift = 0 integration,
10,000 day mean, perpetual January)

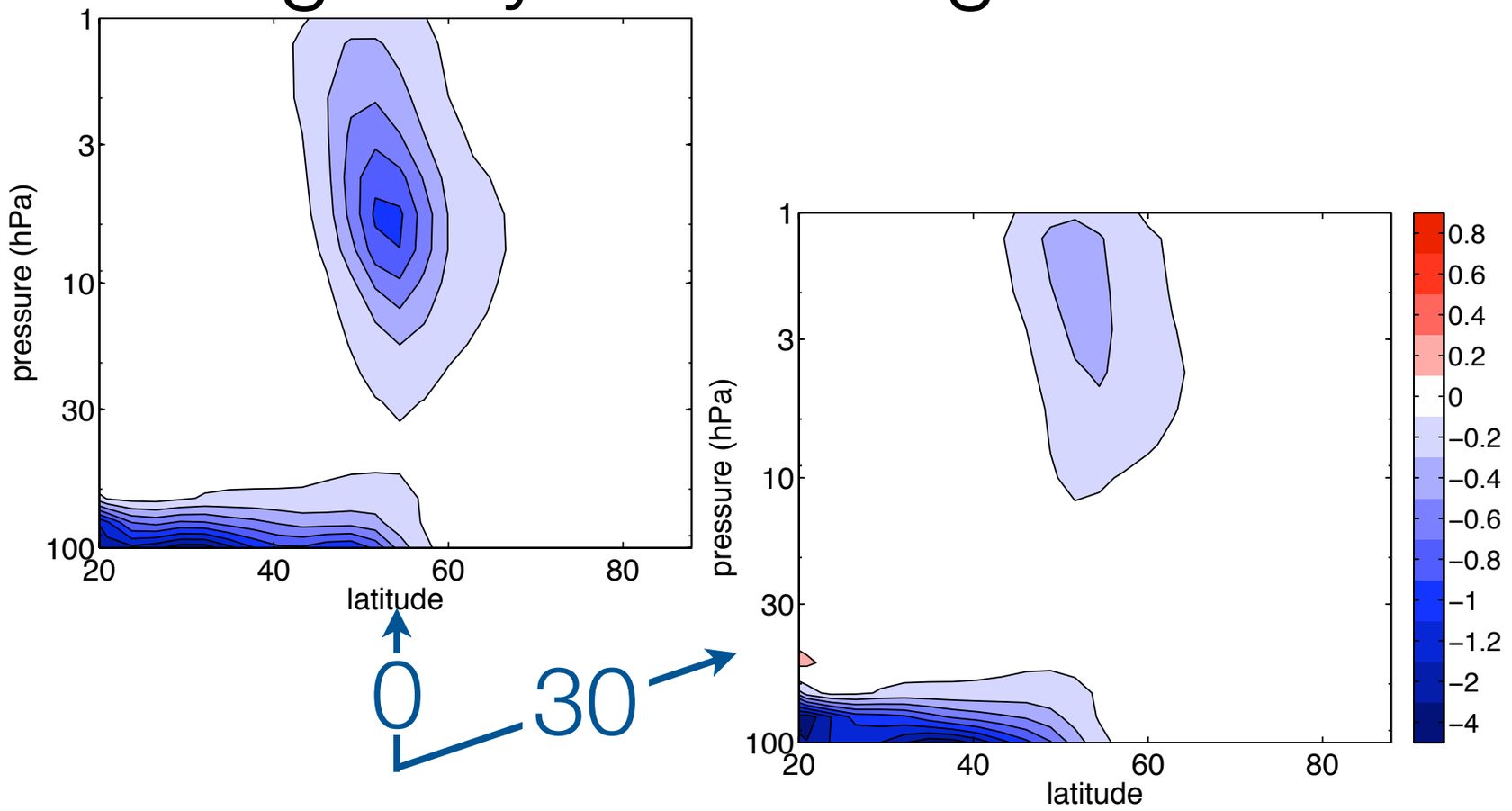
Vary phase of subgrid-scale topography



0

phase angle between subgrid-scale and resolved topography

Large perturbations in gravity wave drag ...



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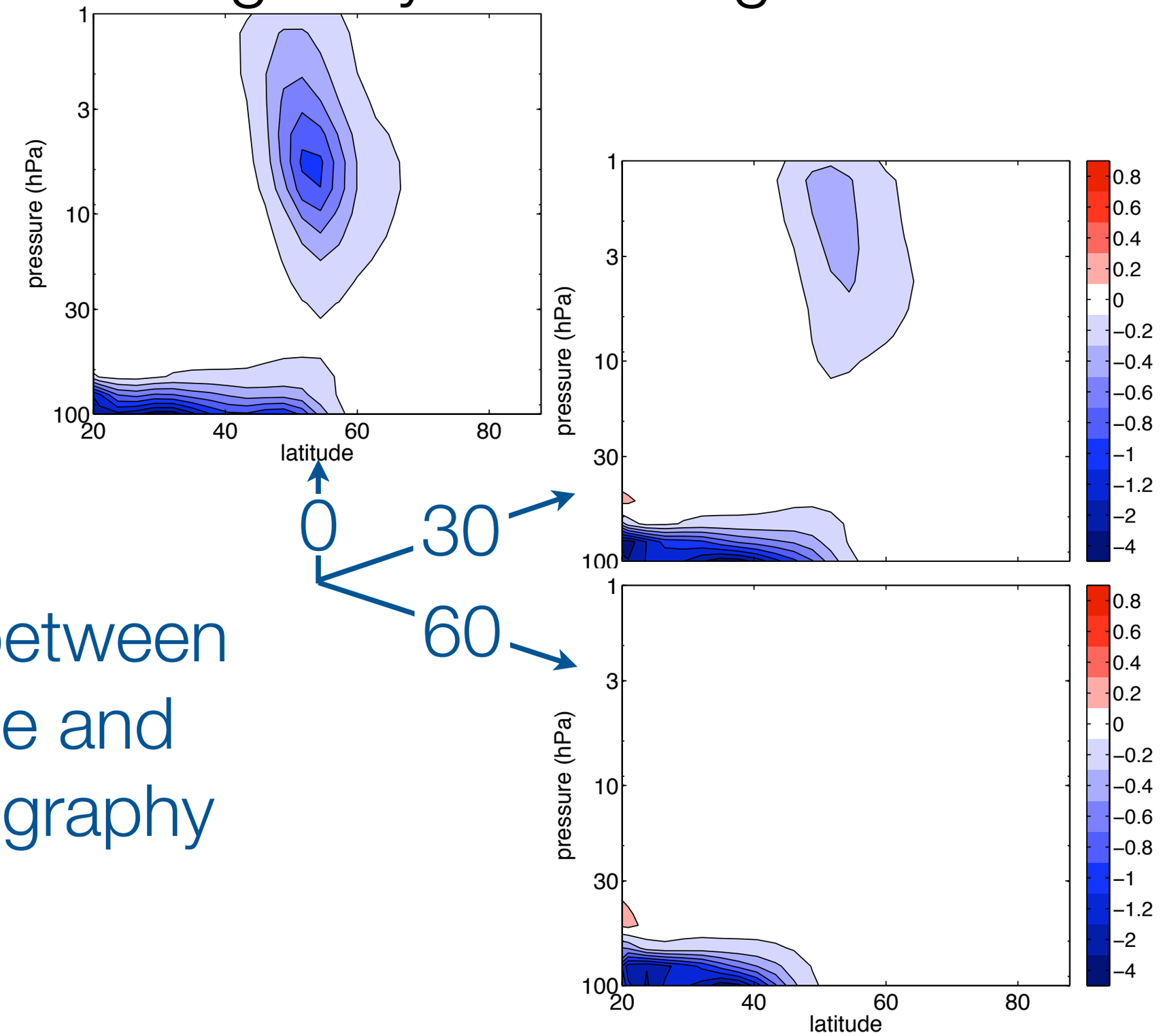

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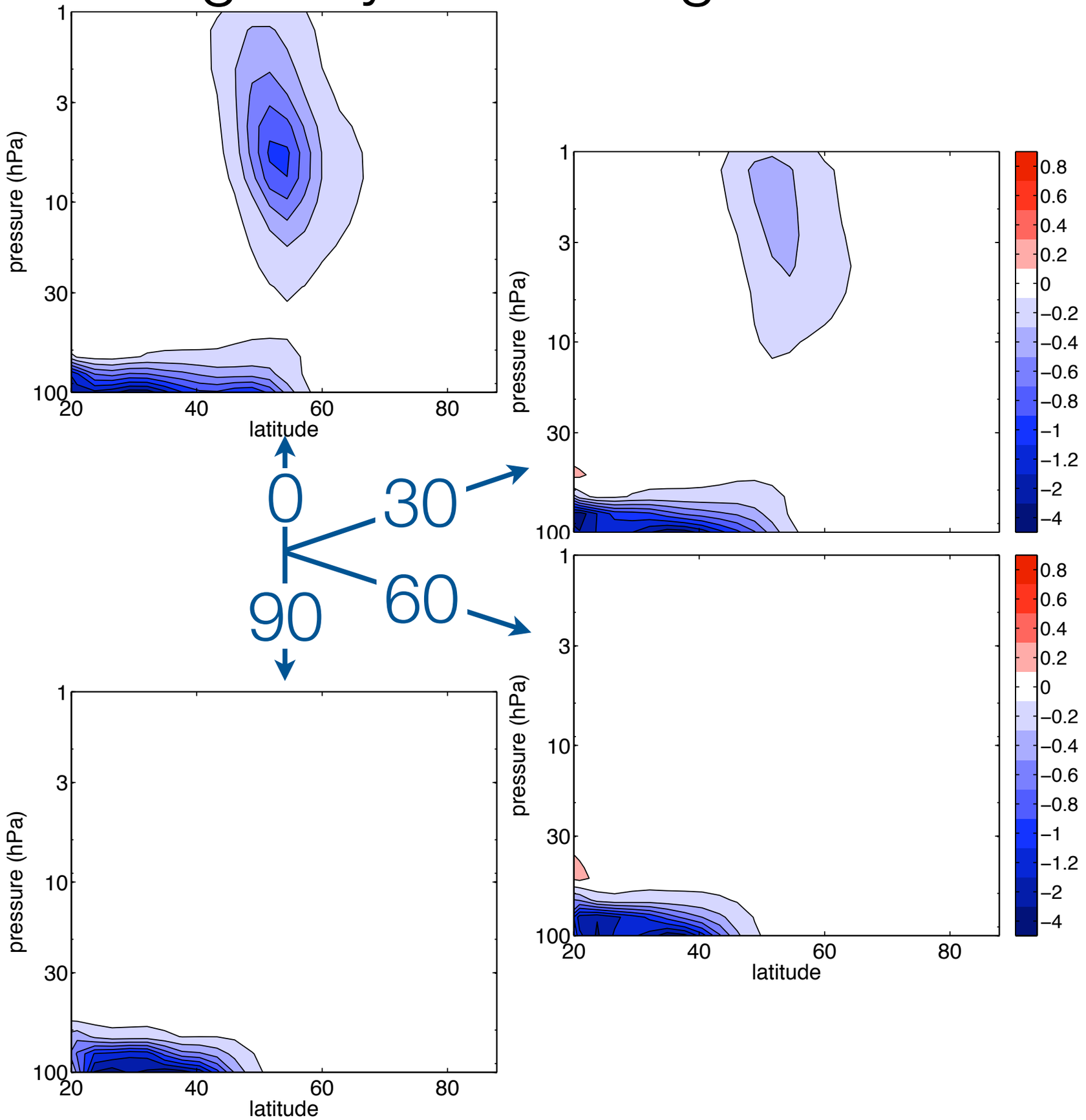

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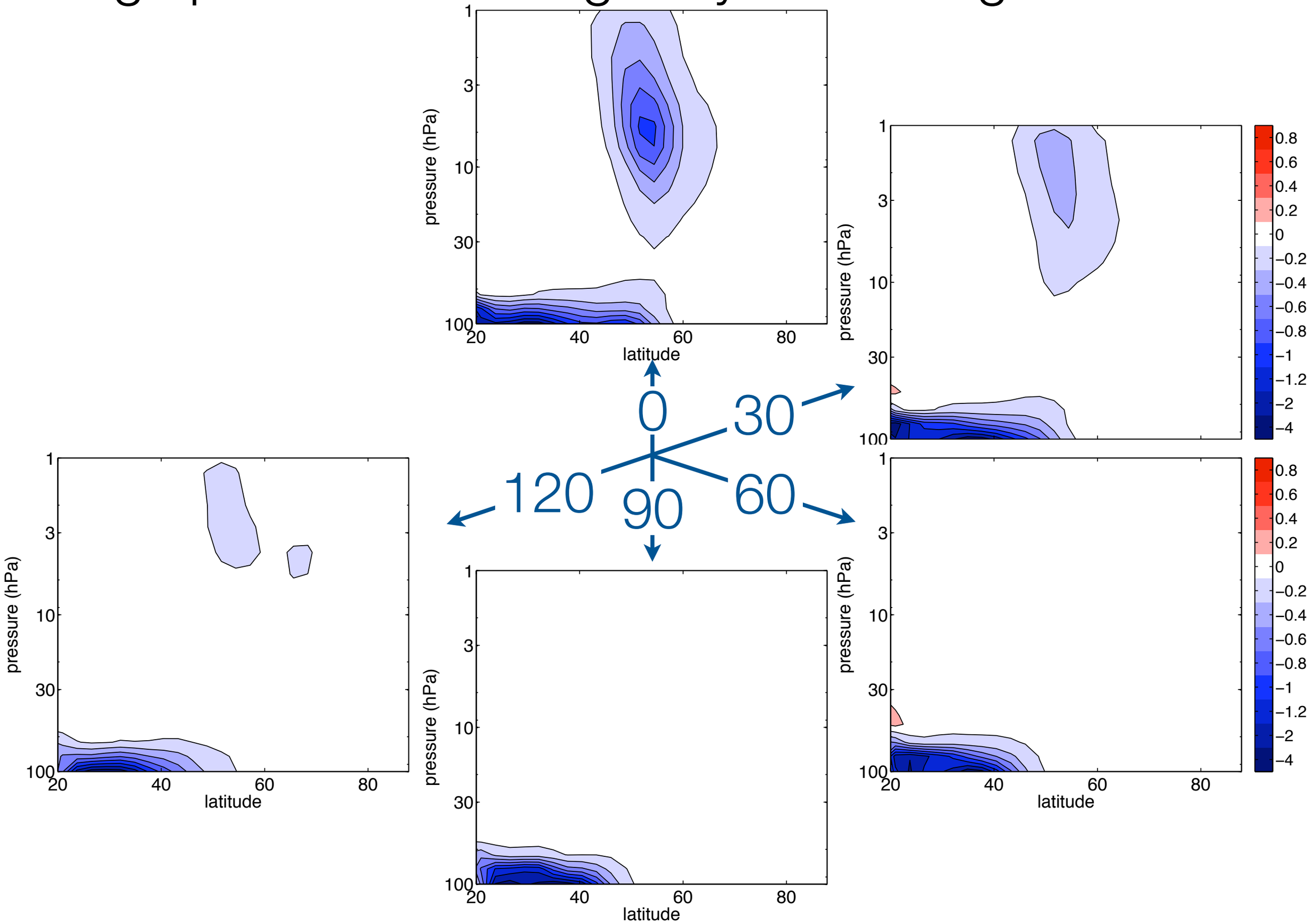

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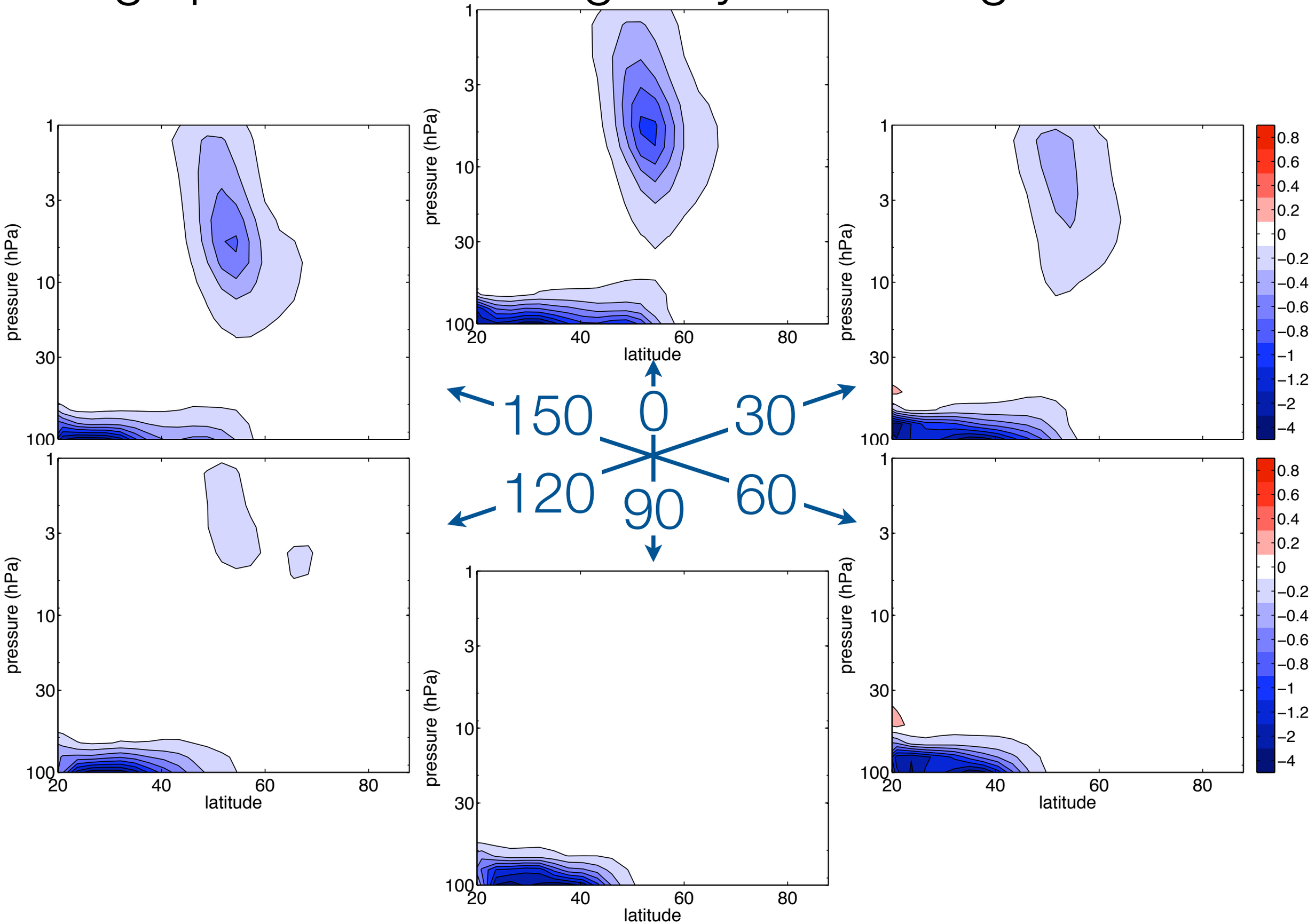

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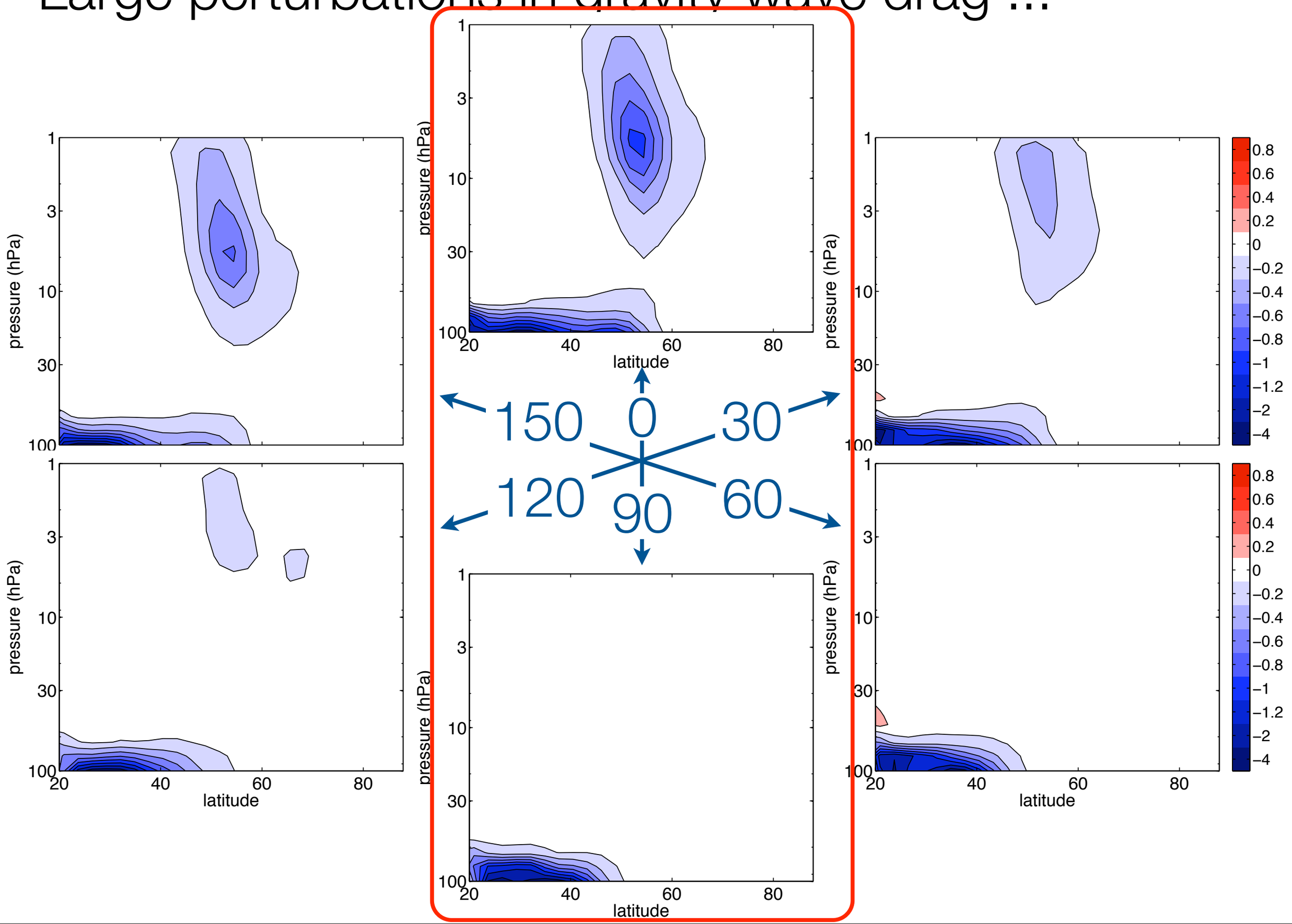
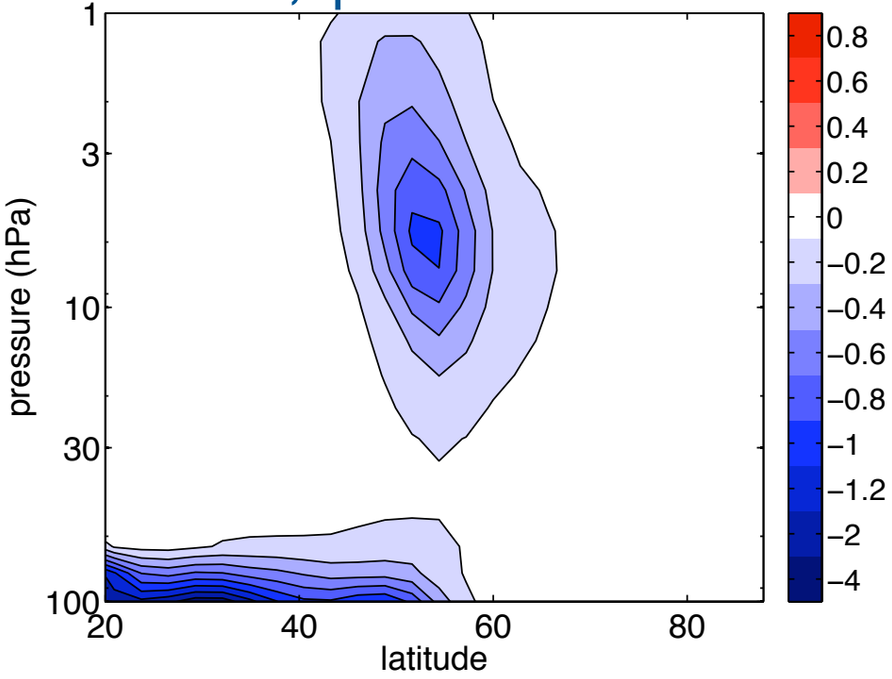
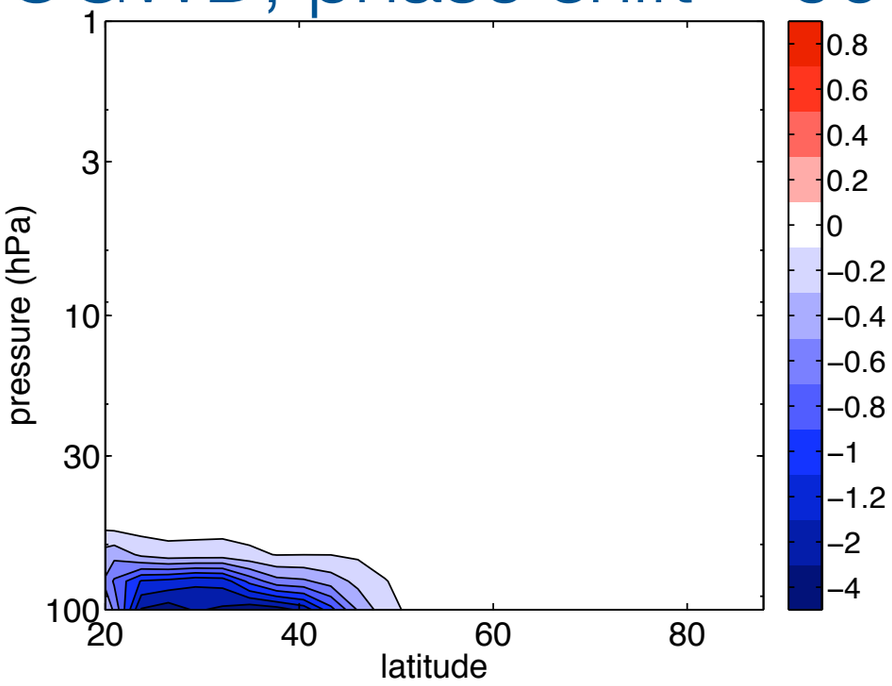


Difference in gravity wave drag

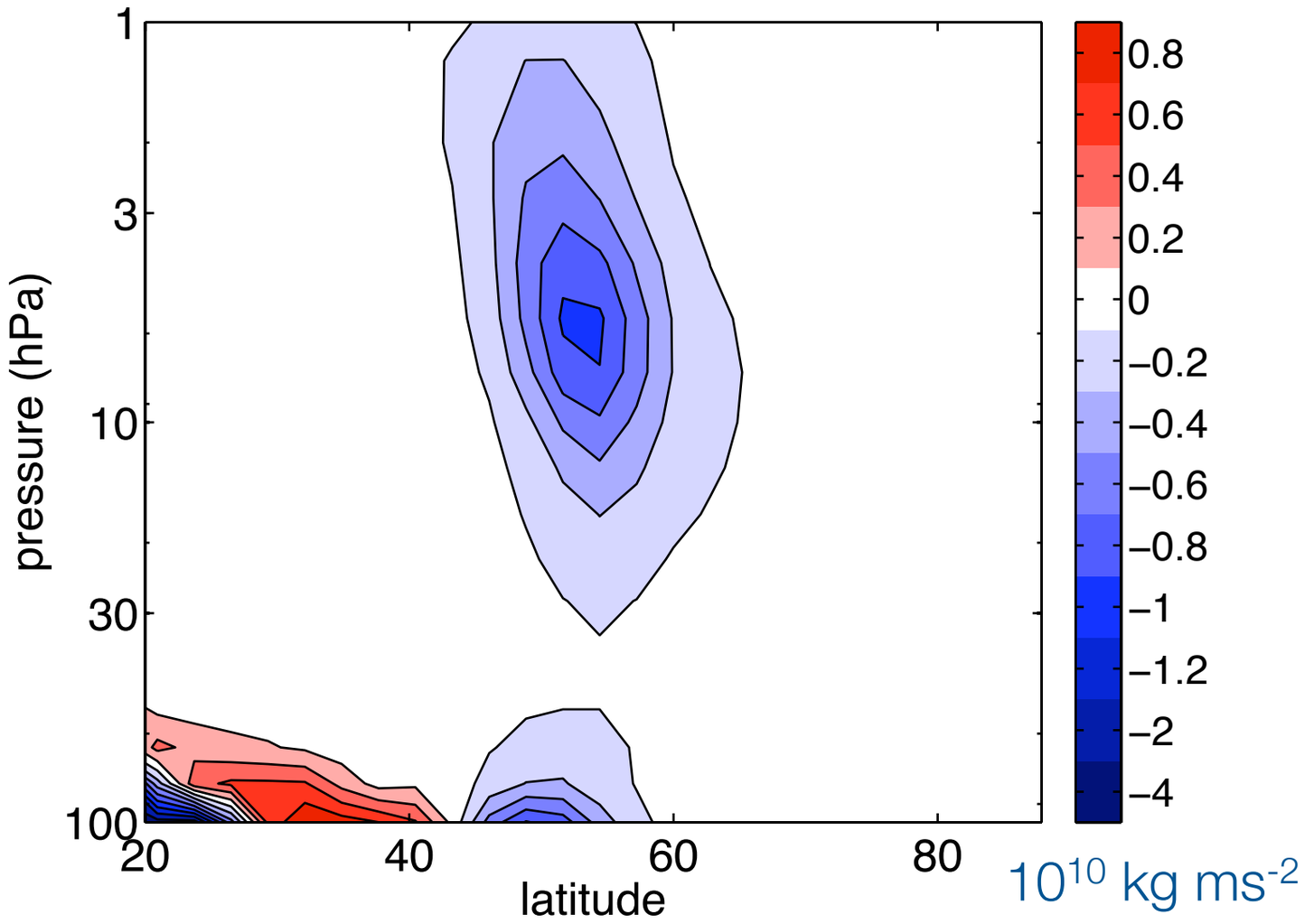
OGWD, phase shift = 0



OGWD, phase shift = 90



Difference in OGWP Torque



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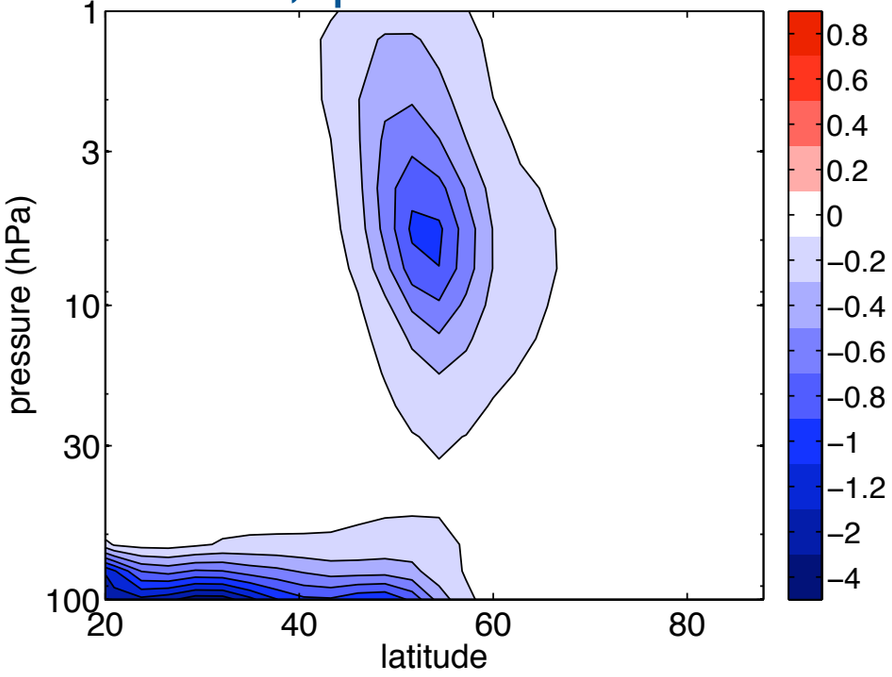

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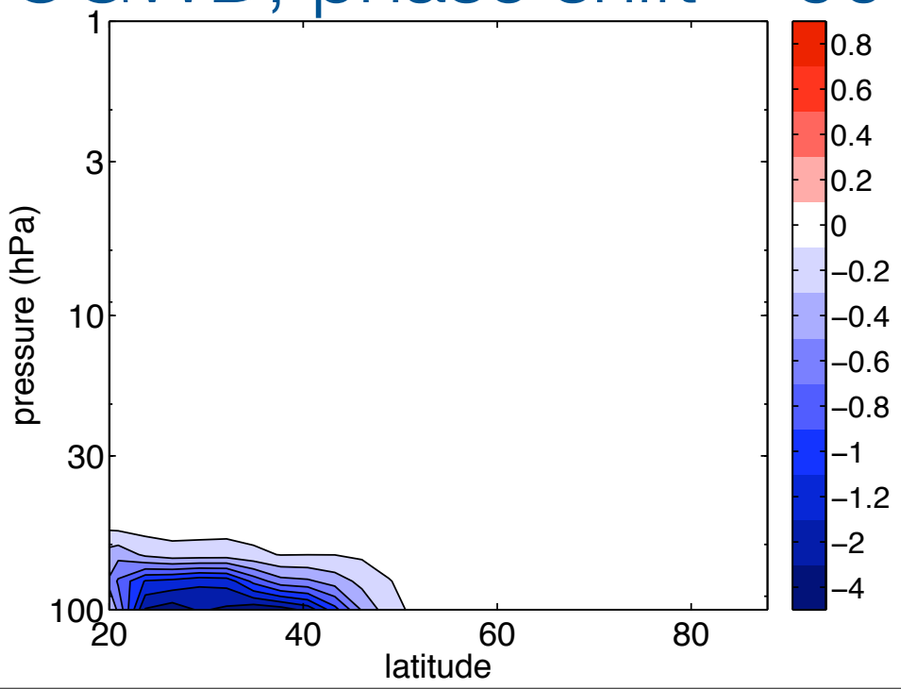
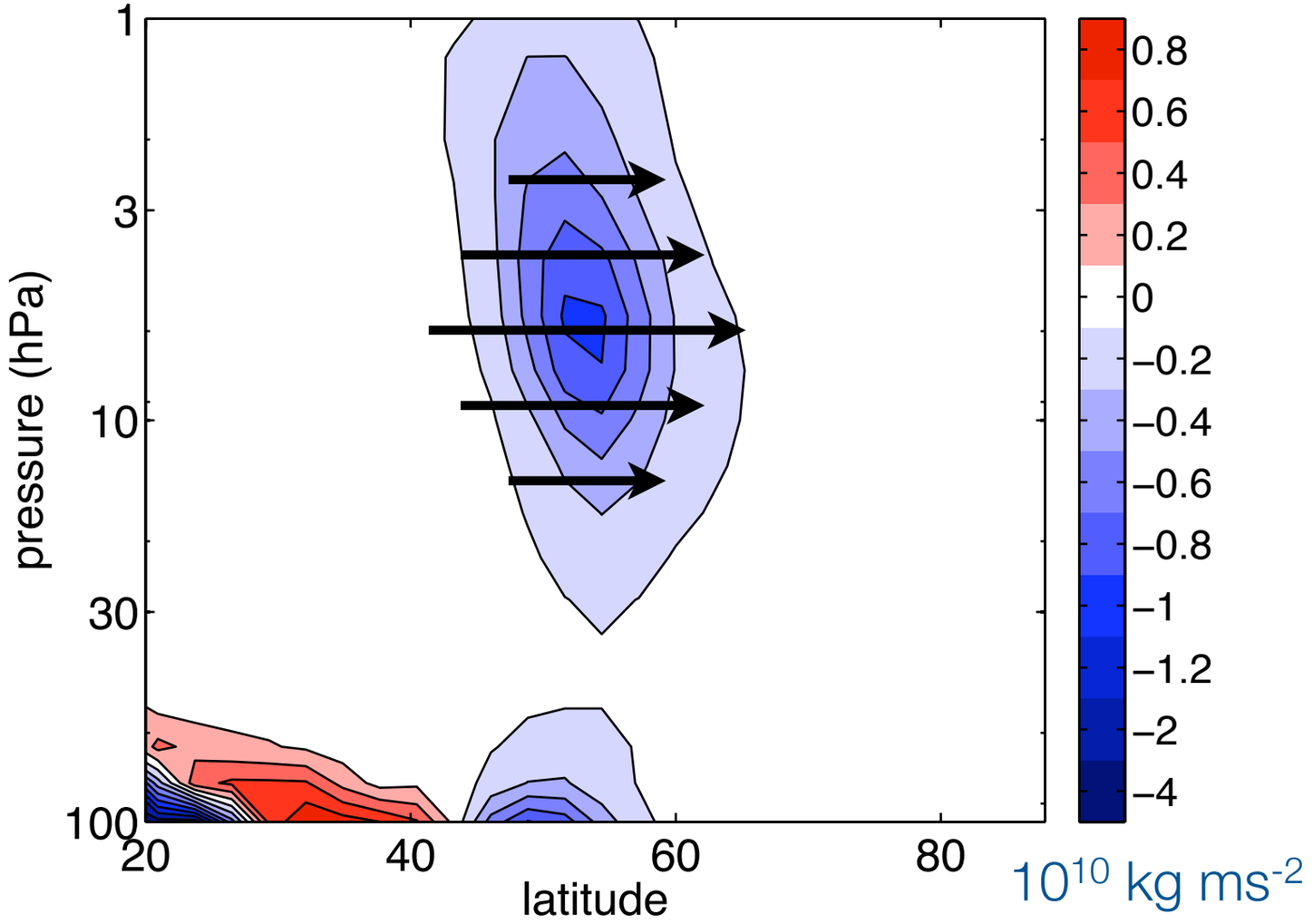
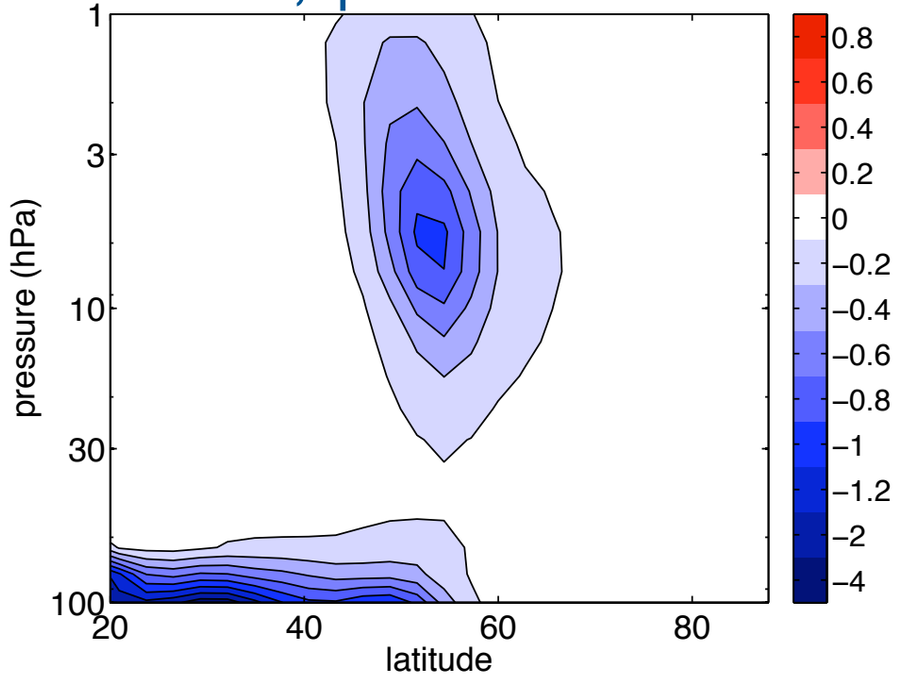


In steady state, torque must be balanced by meridional flow ...



Difference in gravity wave drag should imply significant change in circulation

OGWD, phase shift = 0



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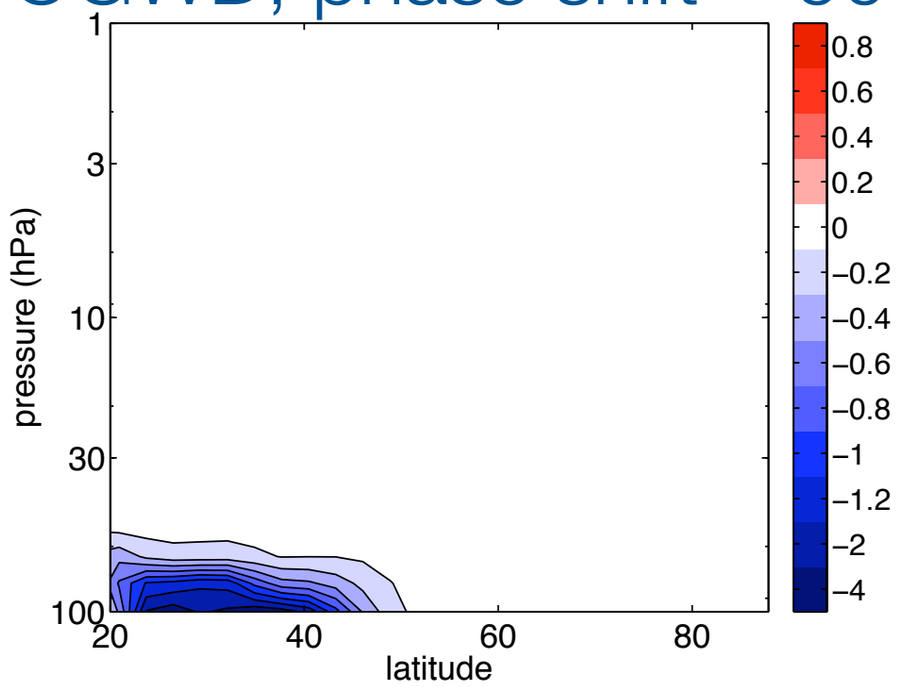
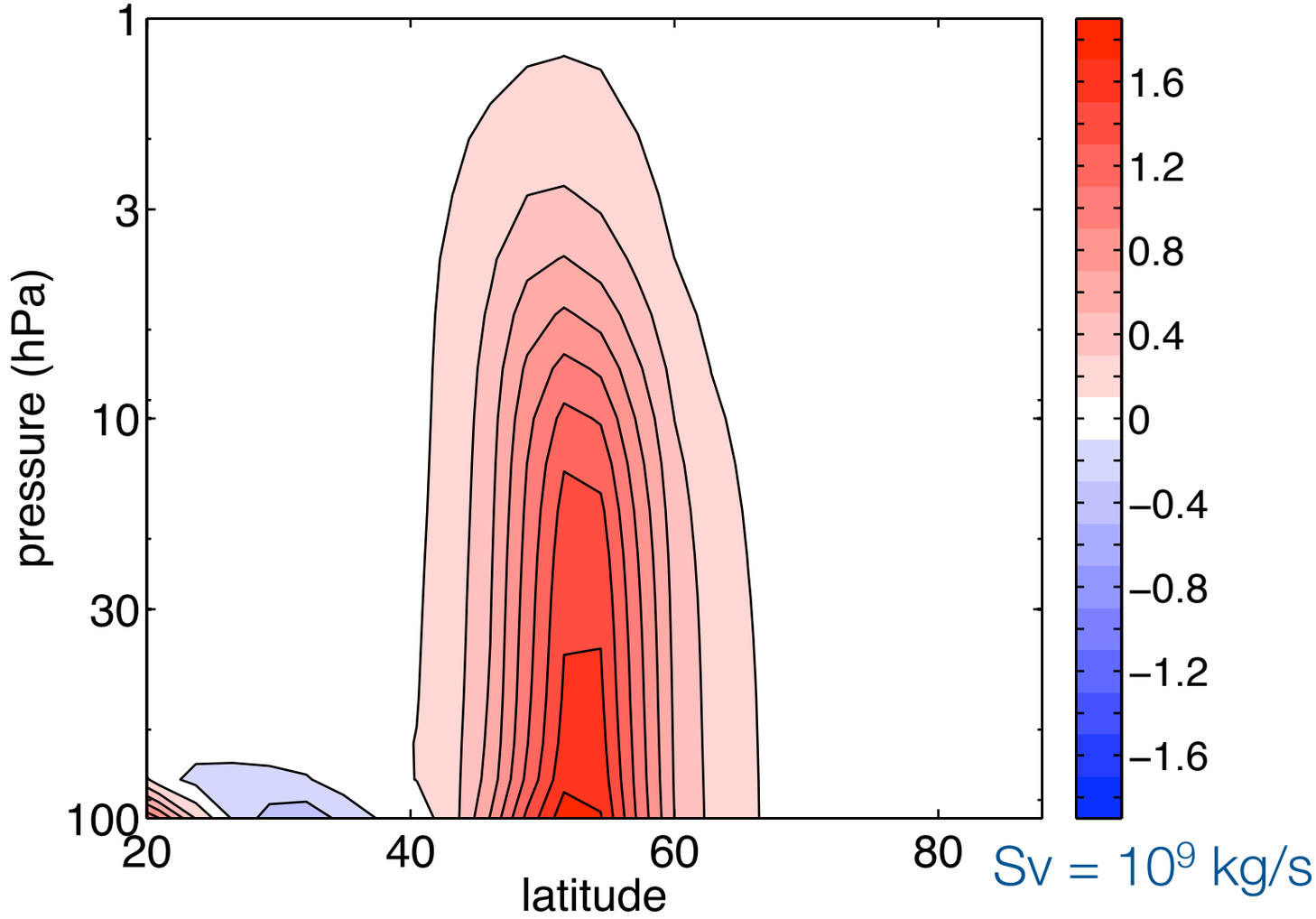


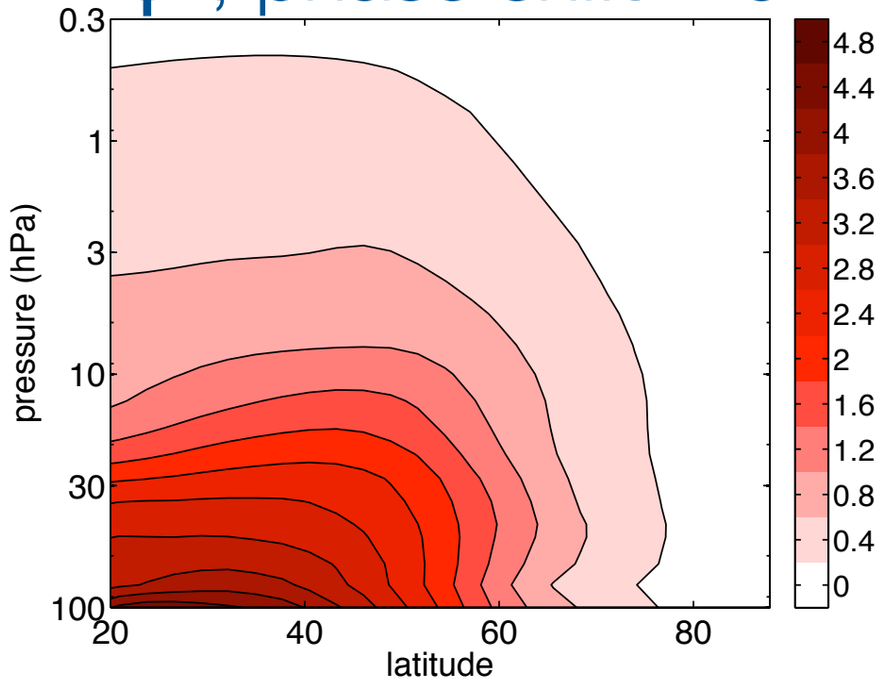
$\Delta\psi_{DC}^{*}$, suggested by DWC



Sv = 10^9 kg/s

... but, there's hardly any difference in the actual residual mean circulation!

ψ^*, phase shift = 0



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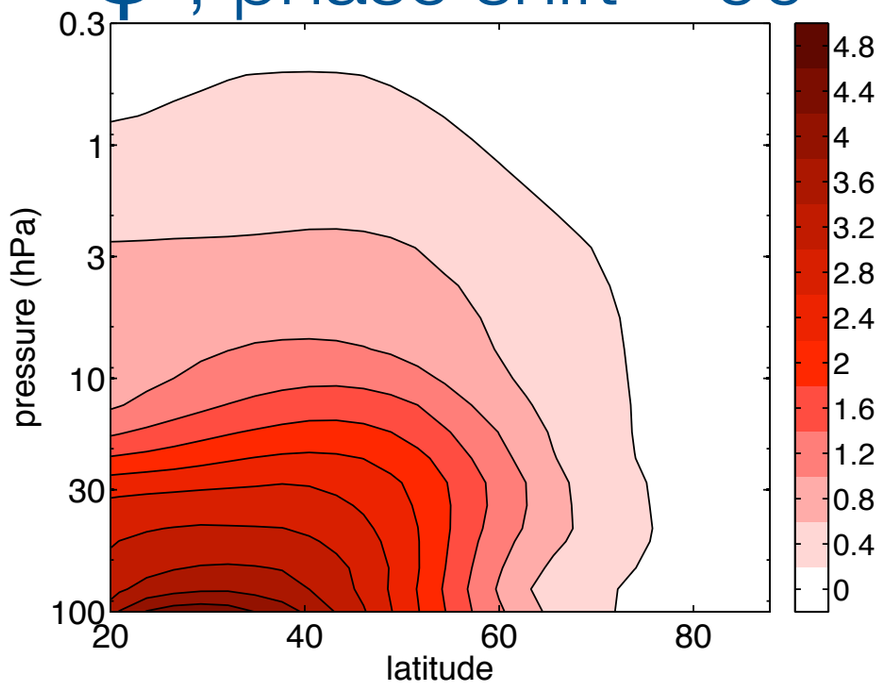
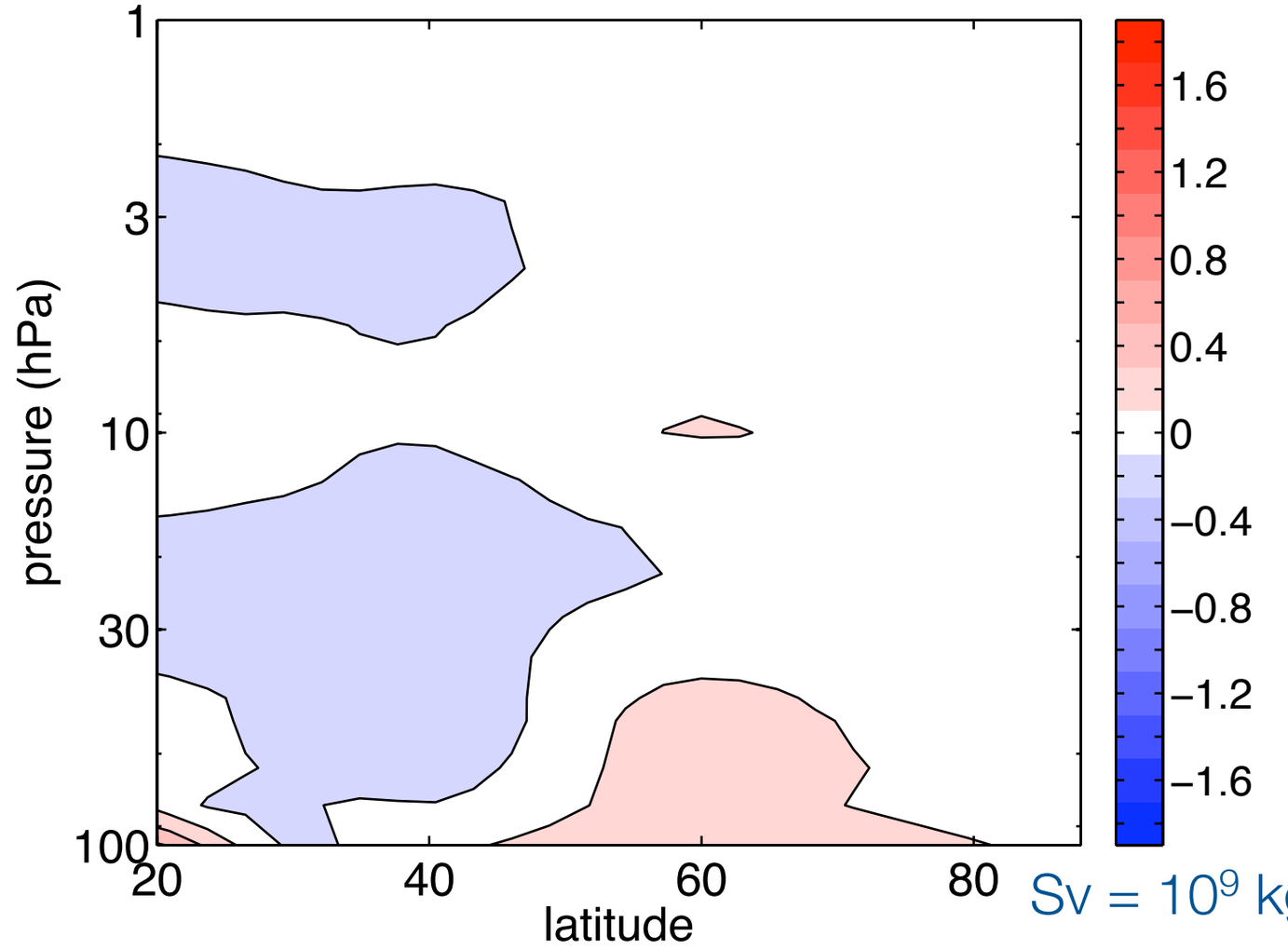


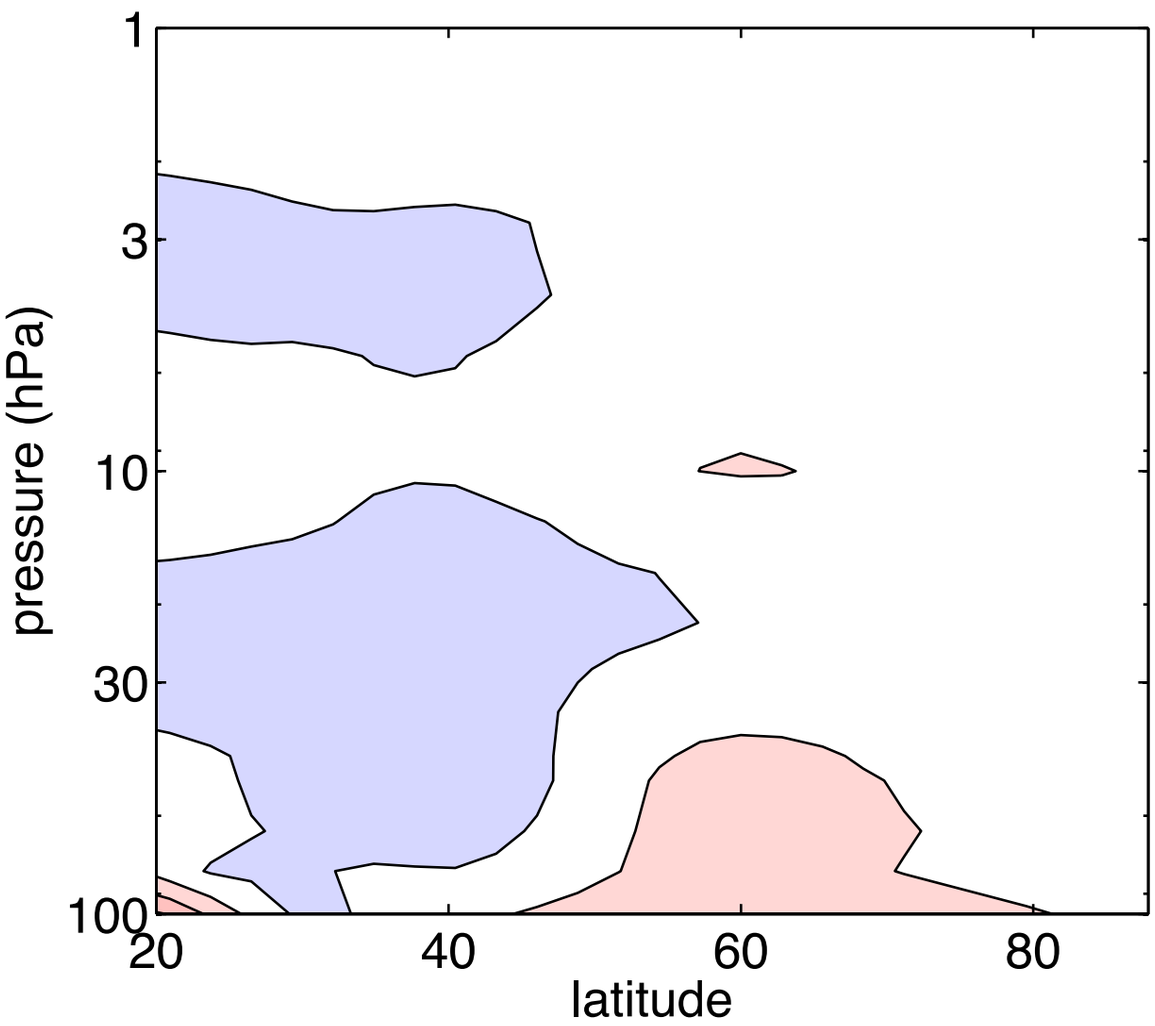
$\Delta\psi^*$, the difference in the TEM circulation



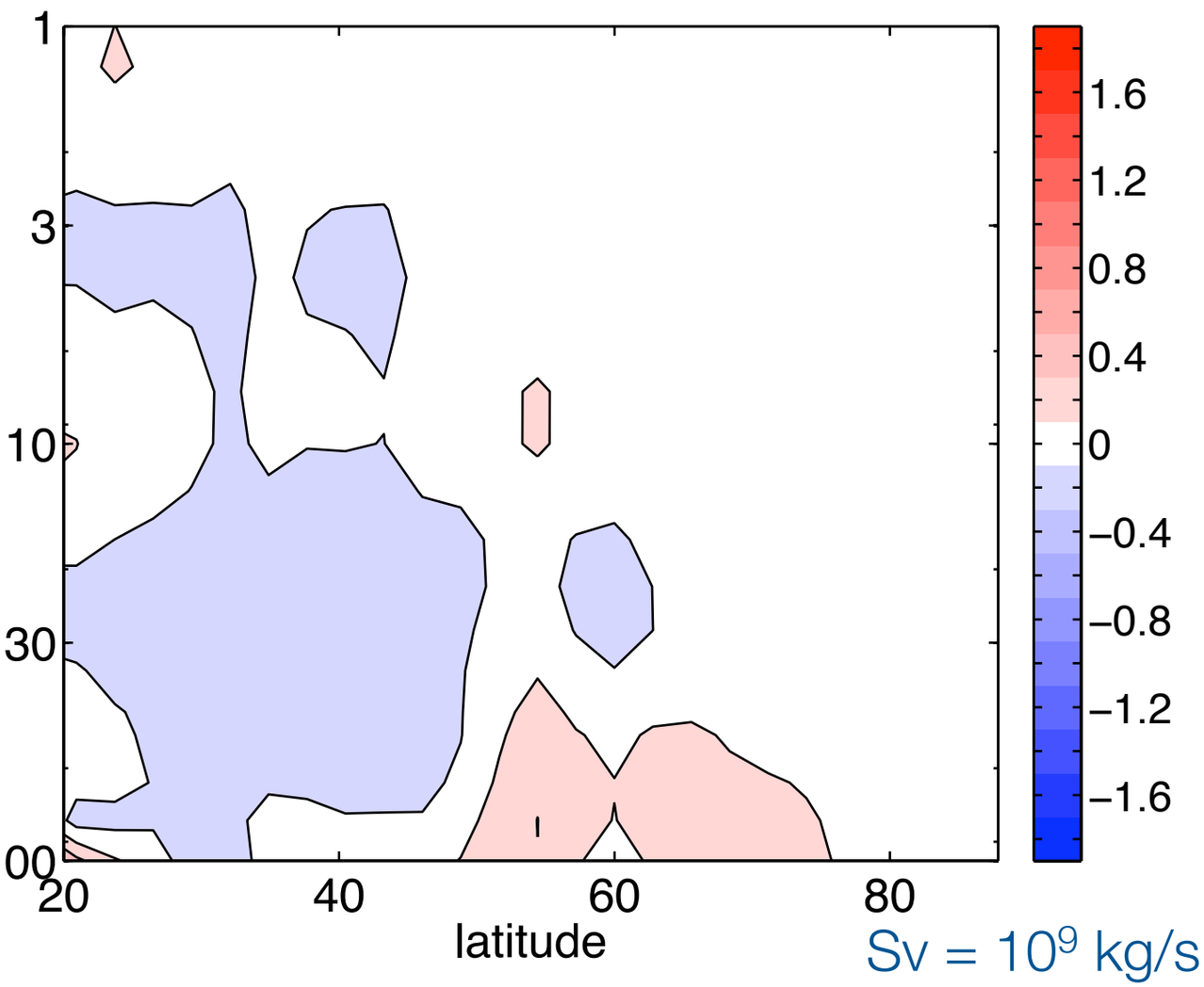
Sv = 10^9 kg/s

Downward control is not the problem ...

Observed $\Delta\psi^*$



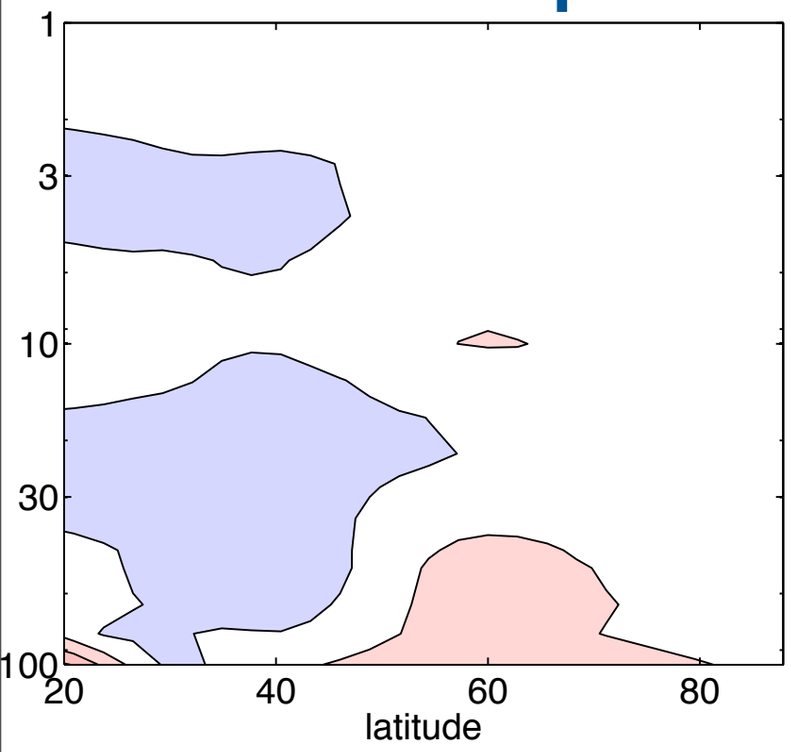
$\Delta\psi_{DC}^*$, computed with downward control



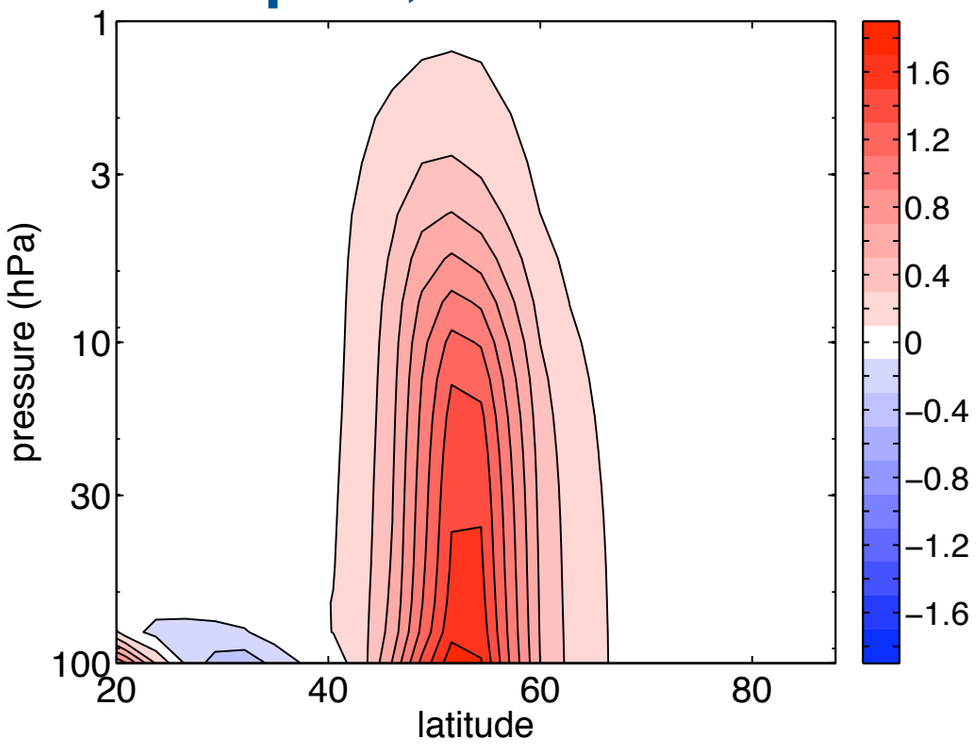
Sv = 10^9 kg/s

Rather, rest of circulation compensates for OGWD

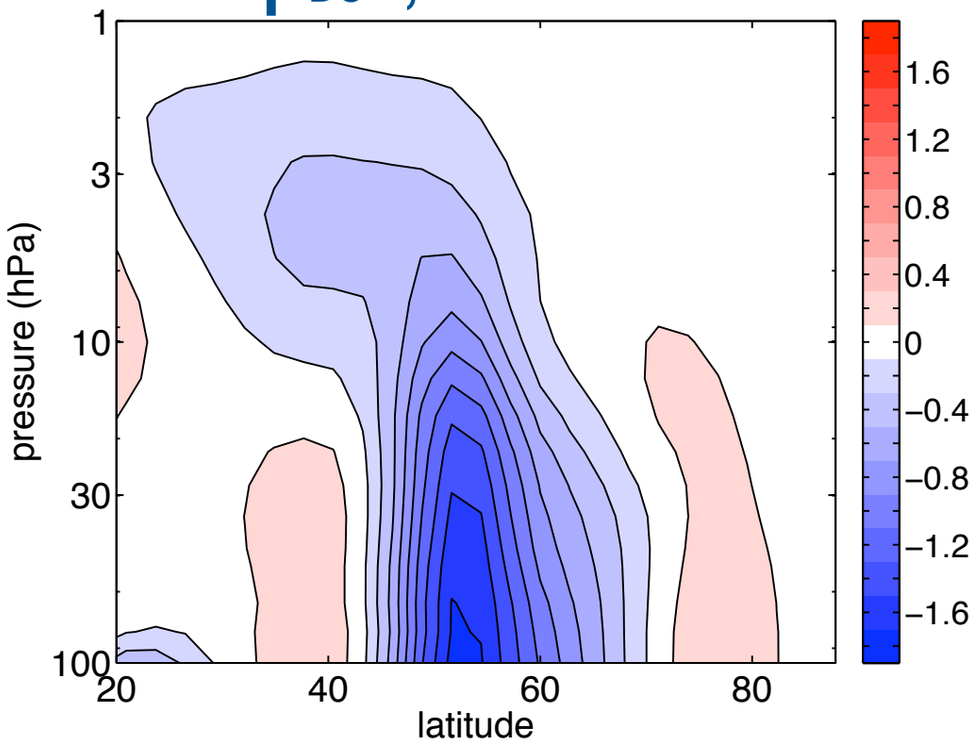
actual $\Delta\psi^*$



$\Delta\psi_{DC}{}^*$, OGWD



$\Delta\psi_{DC}{}^*$, wave 2



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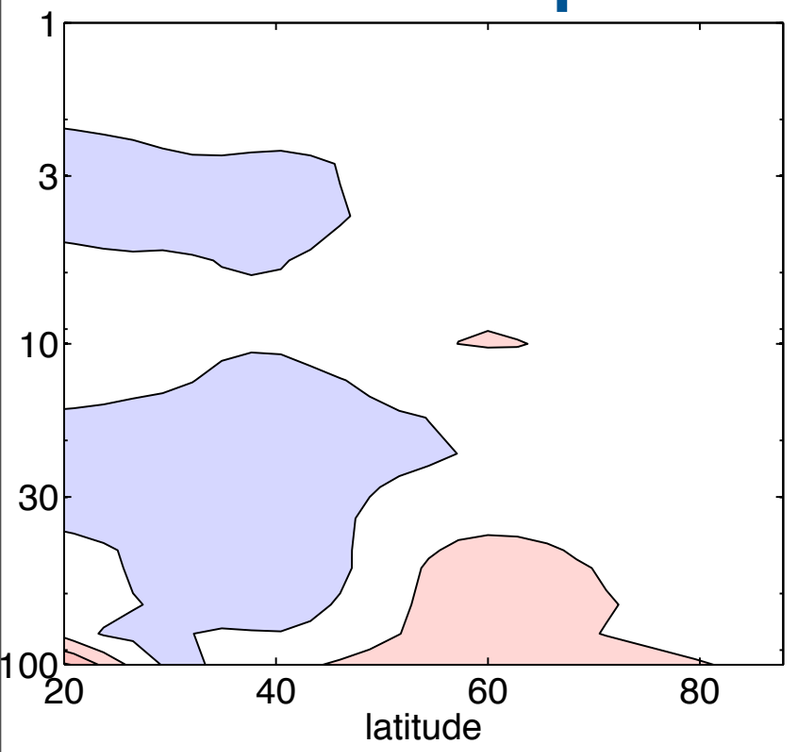

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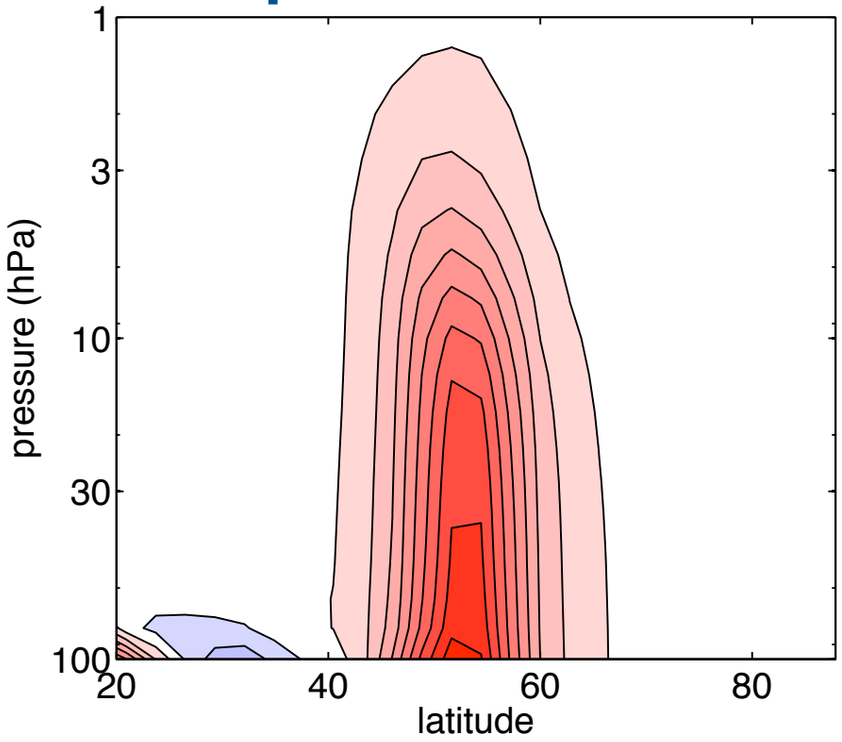
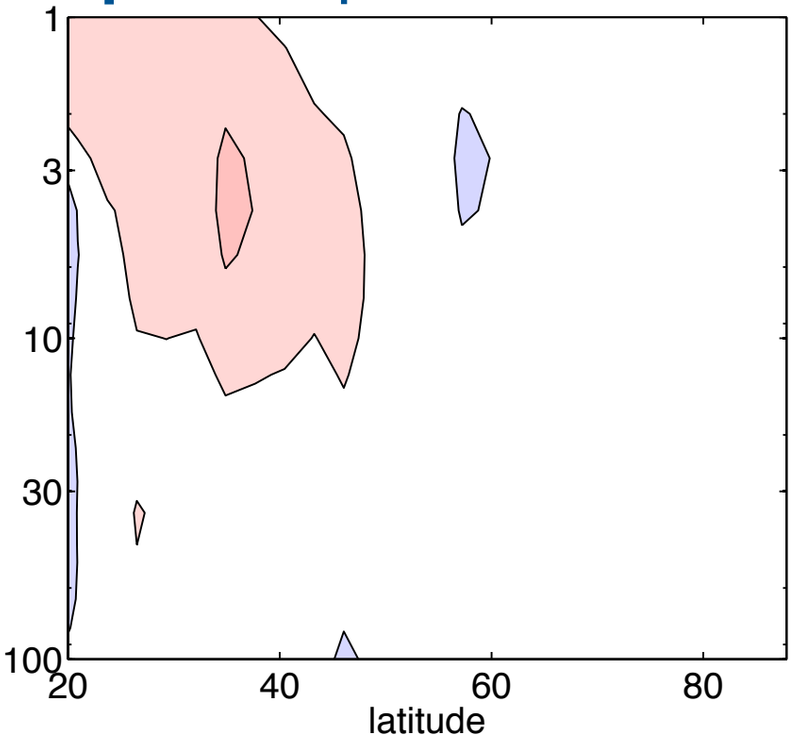
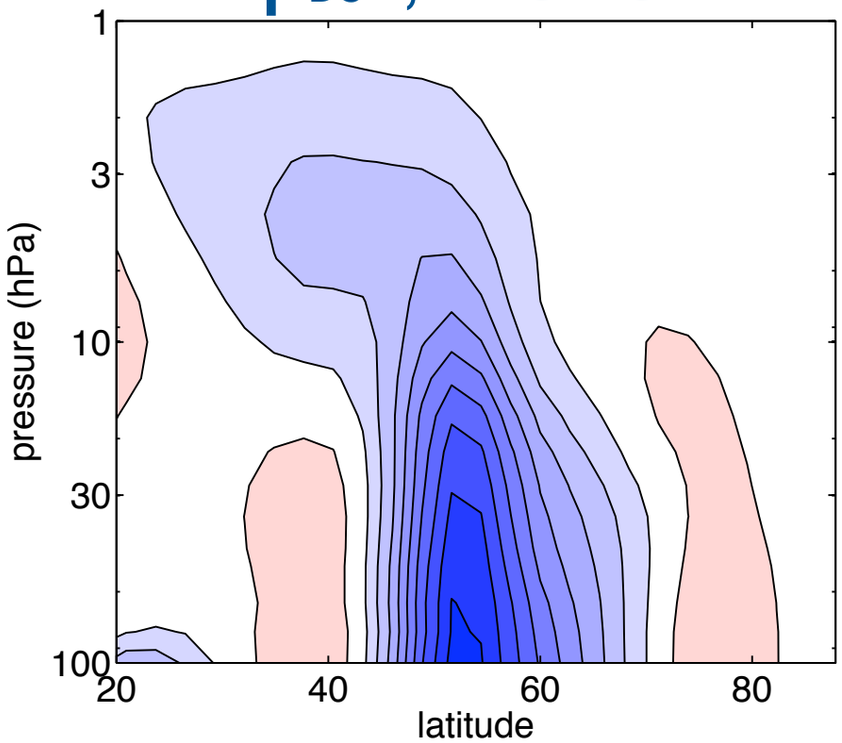


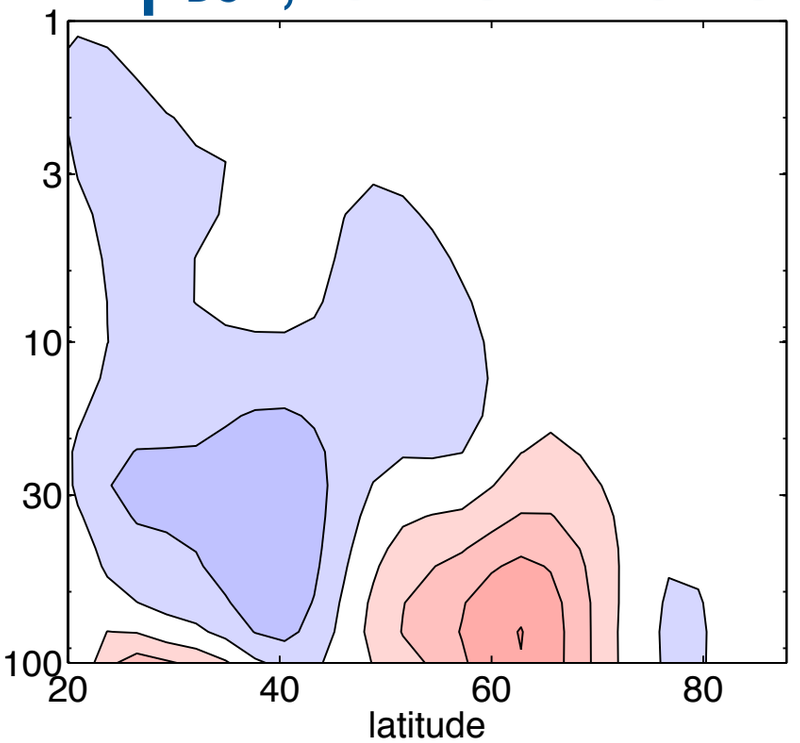
$\Delta\psi_{DC}^*$, spectral GWD



$\Delta\psi_{DC}^*$, wave 2

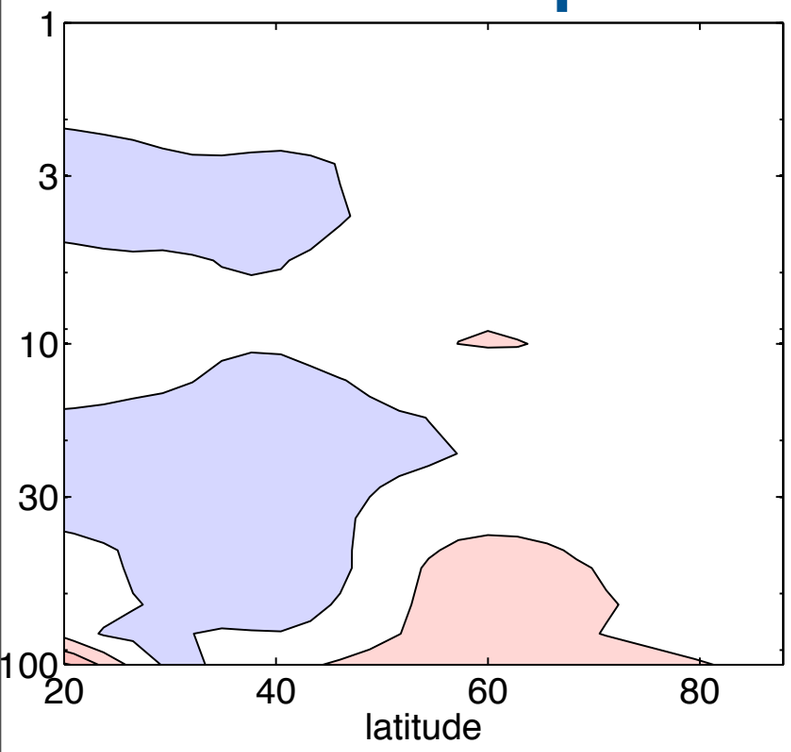


$\Delta\psi_{DC}^*$, other waves

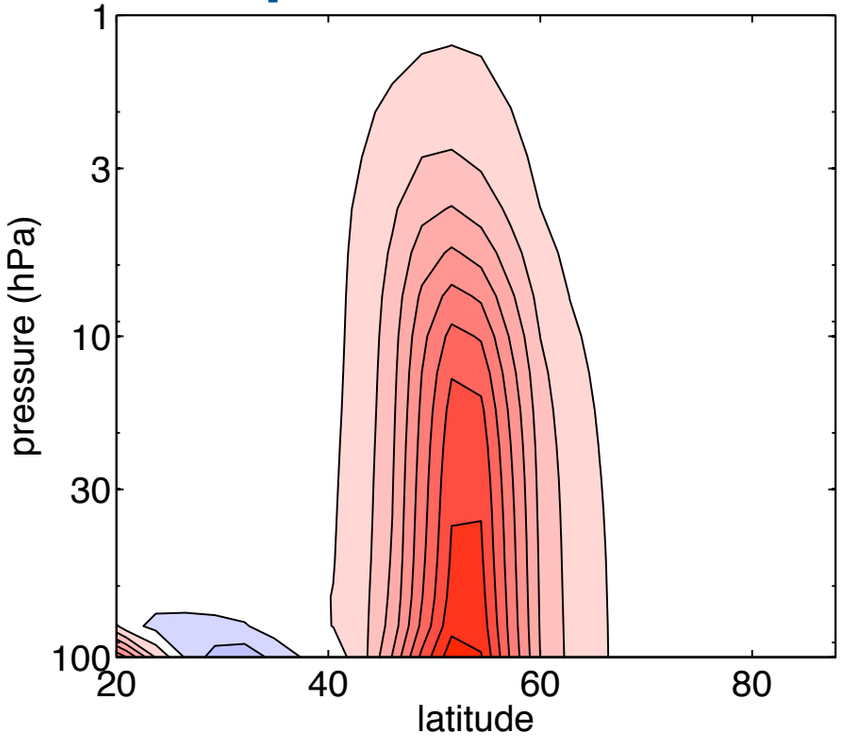


Rather, rest of circulation compensates for OGWD

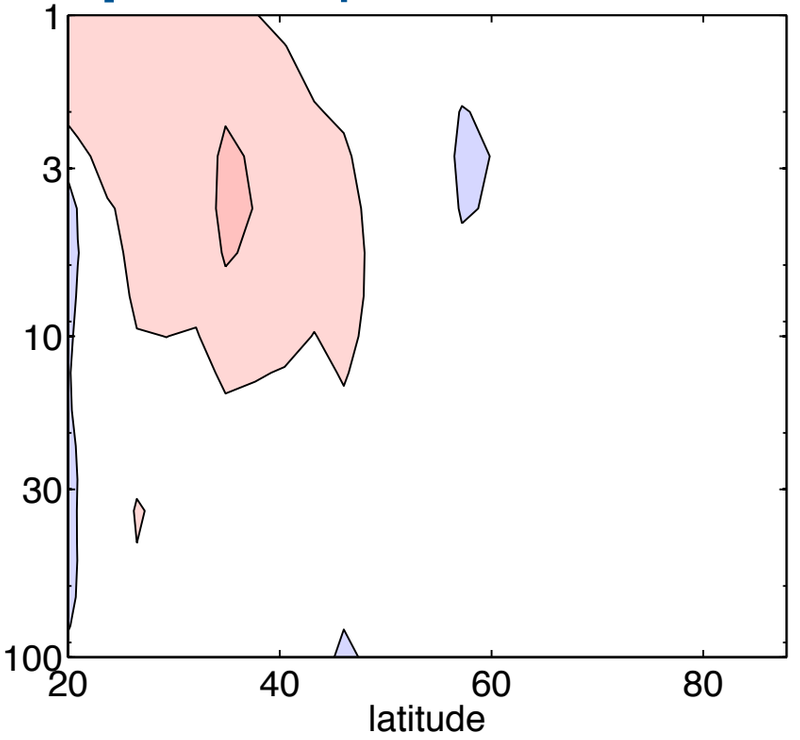
actual $\Delta\psi^*$



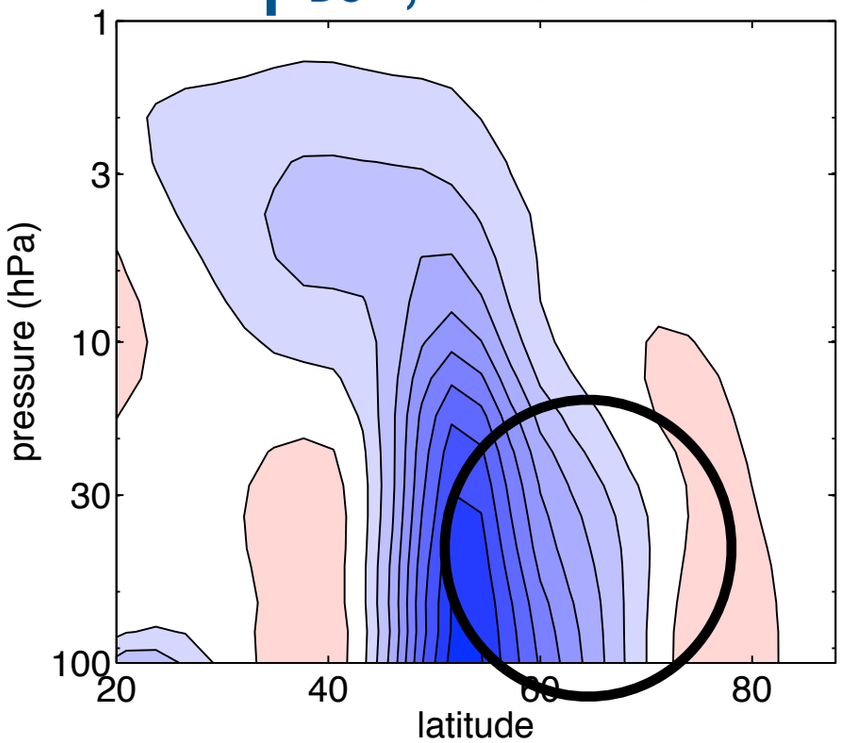
$\Delta\psi_{DC}^*$, OGWD



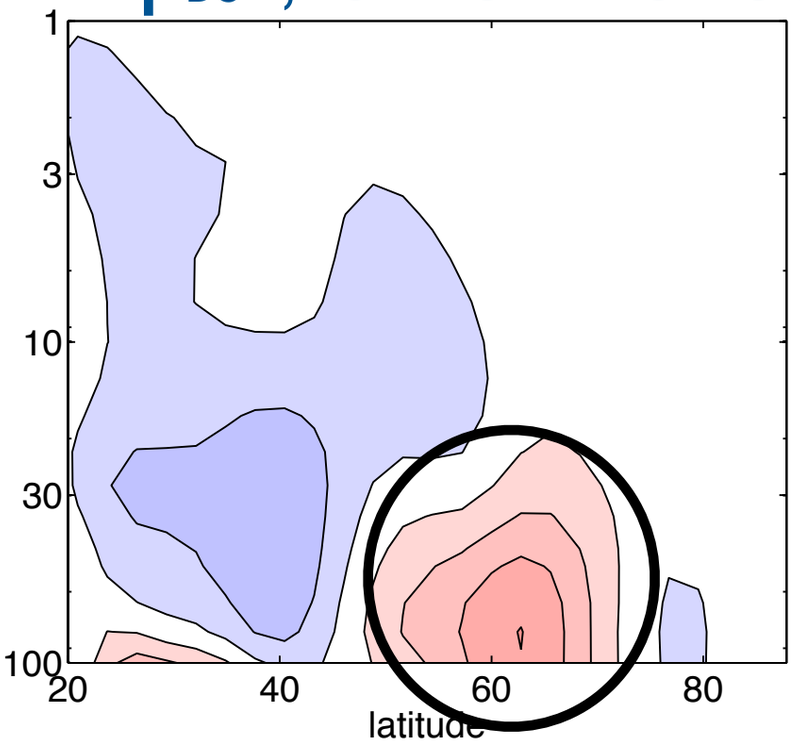
$\Delta\psi_{DC}^*$, spectral GWD



$\Delta\psi_{DC}^*$, wave 2

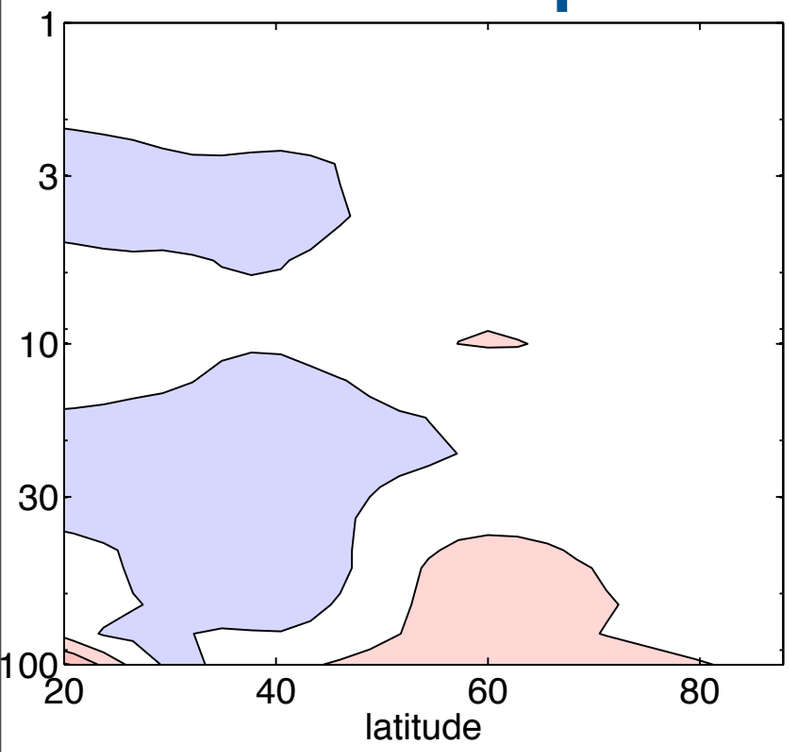


$\Delta\psi_{DC}^*$, other waves

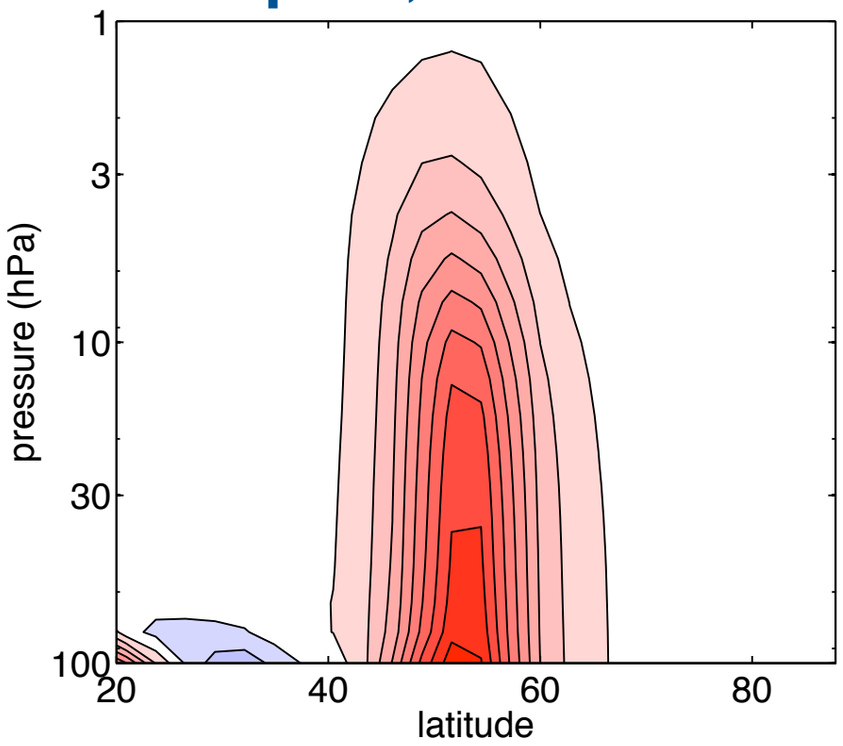


Rather, rest of circulation compensates for OGWD

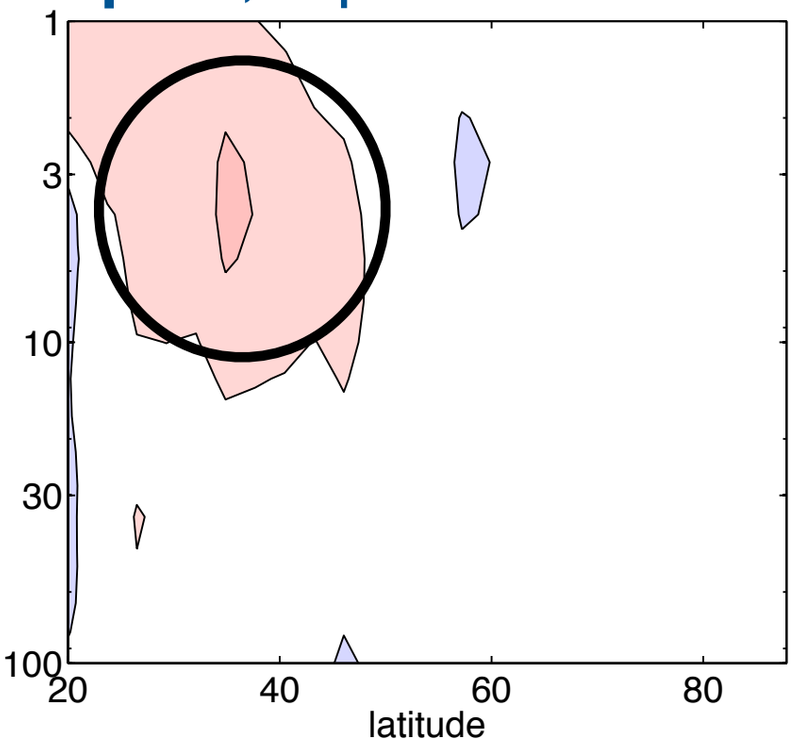
actual $\Delta\psi^*$



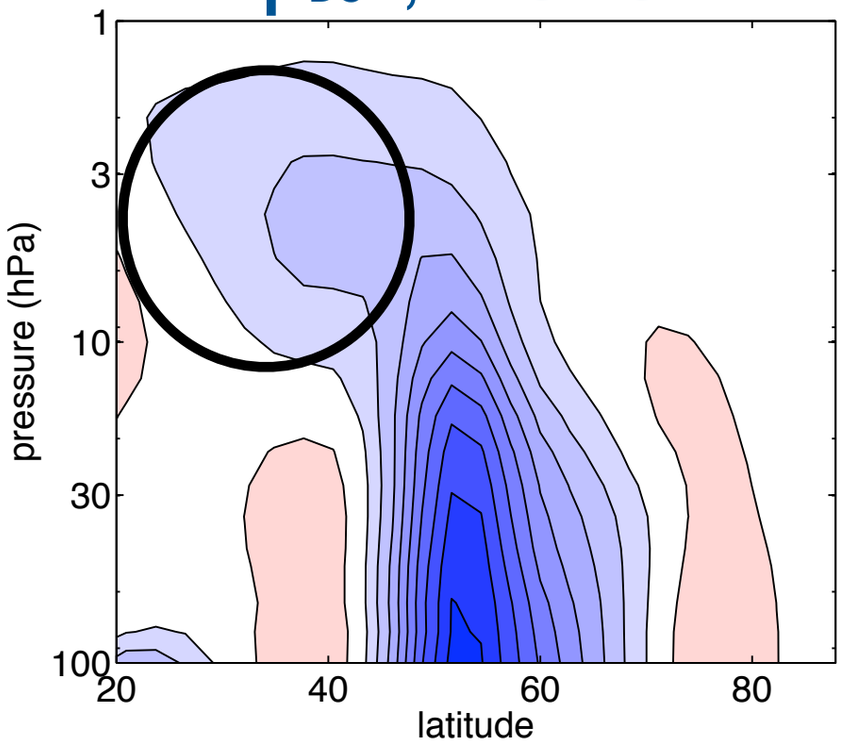
$\Delta\psi_{DC}^*$, OGWD



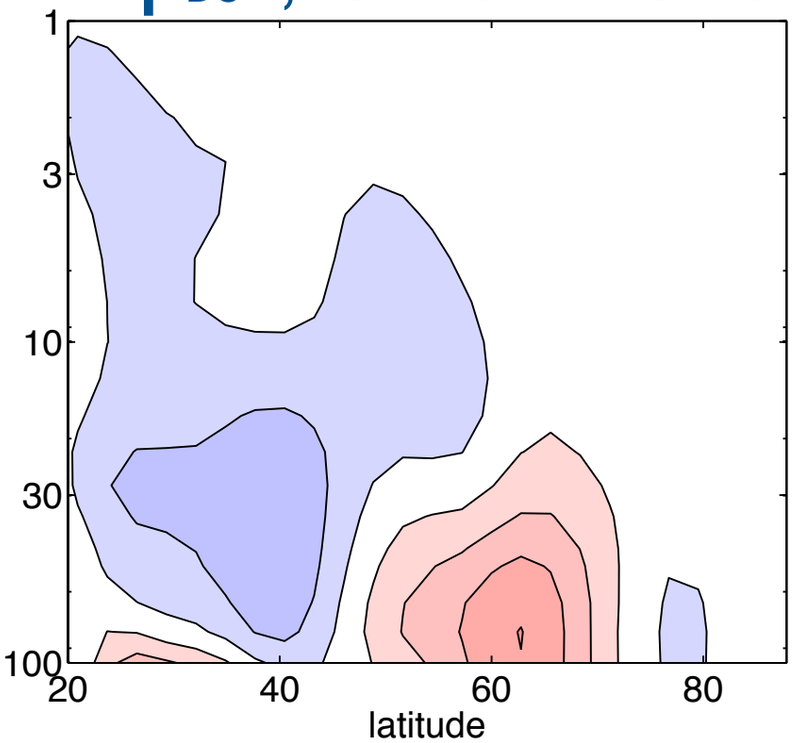
$\Delta\psi_{DC}^*$, spectral GWD



$\Delta\psi_{DC}^*$, wave 2

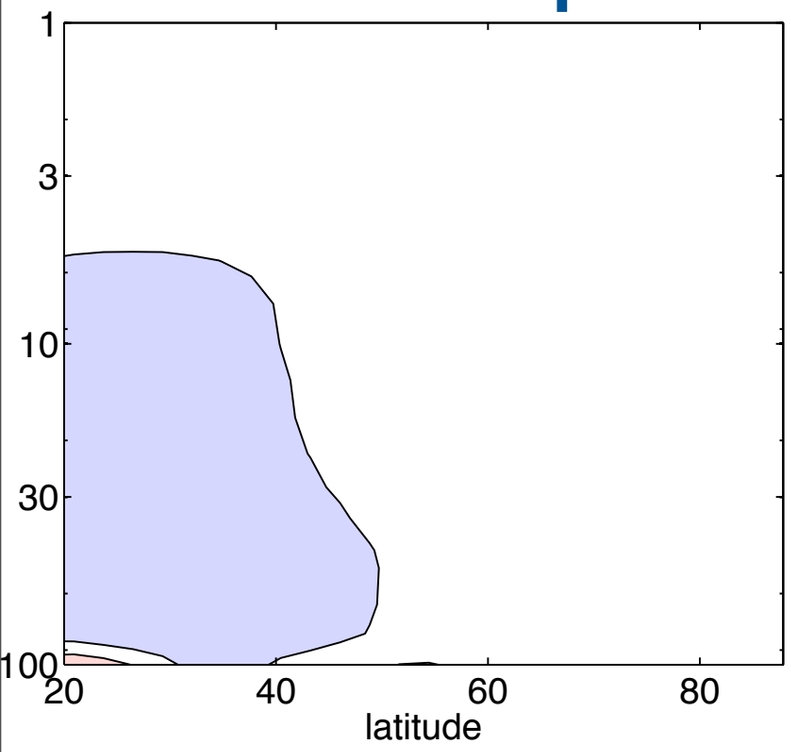


$\Delta\psi_{DC}^*$, other waves

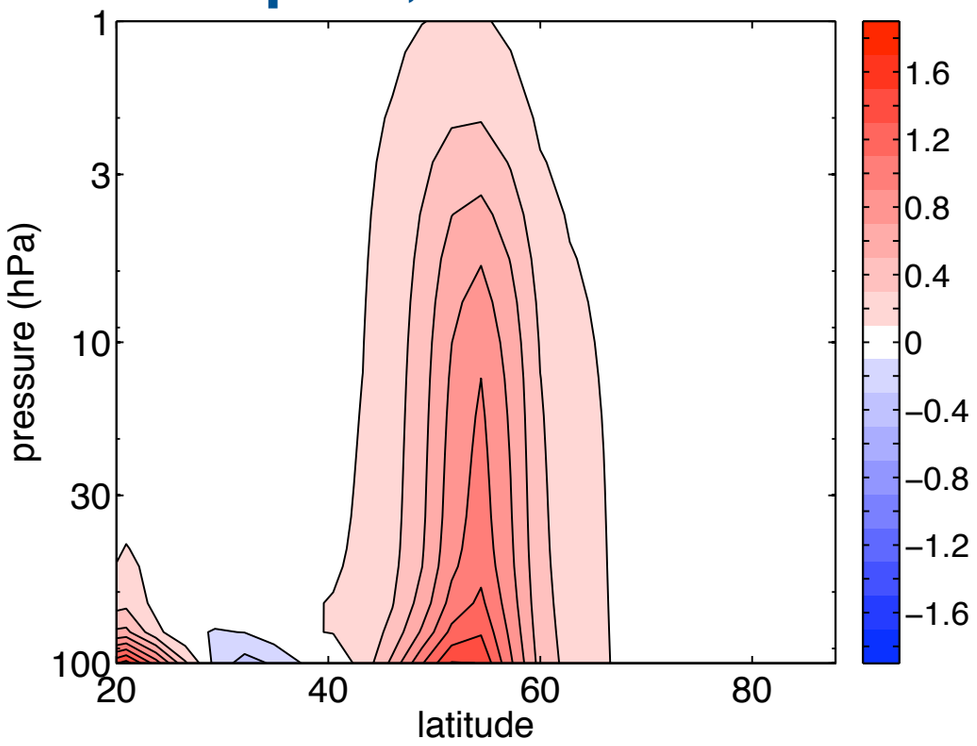


Aside: same experiment w/o spectral GWP

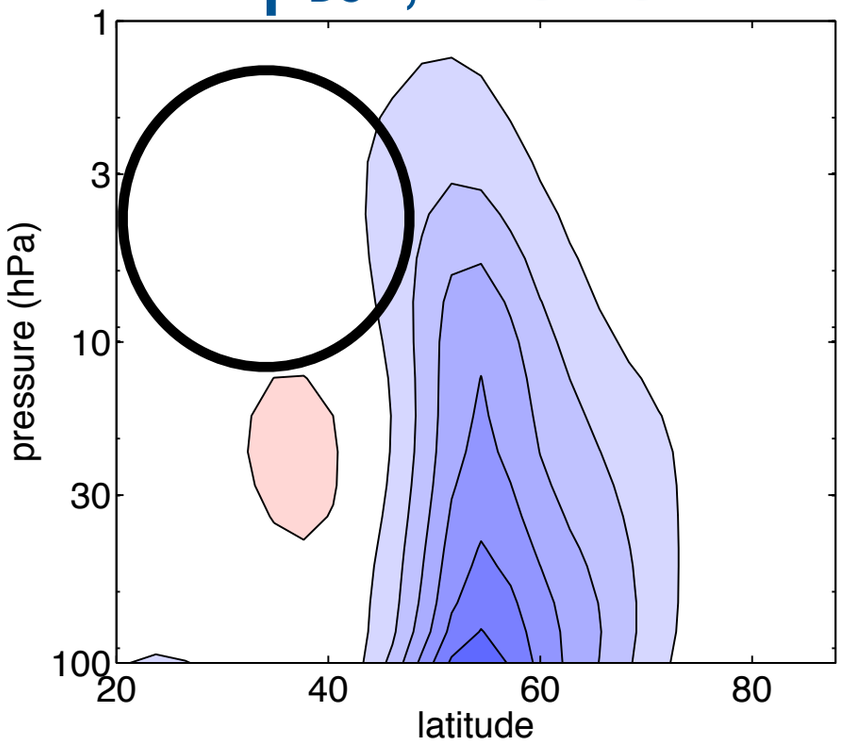
actual $\Delta\psi^*$



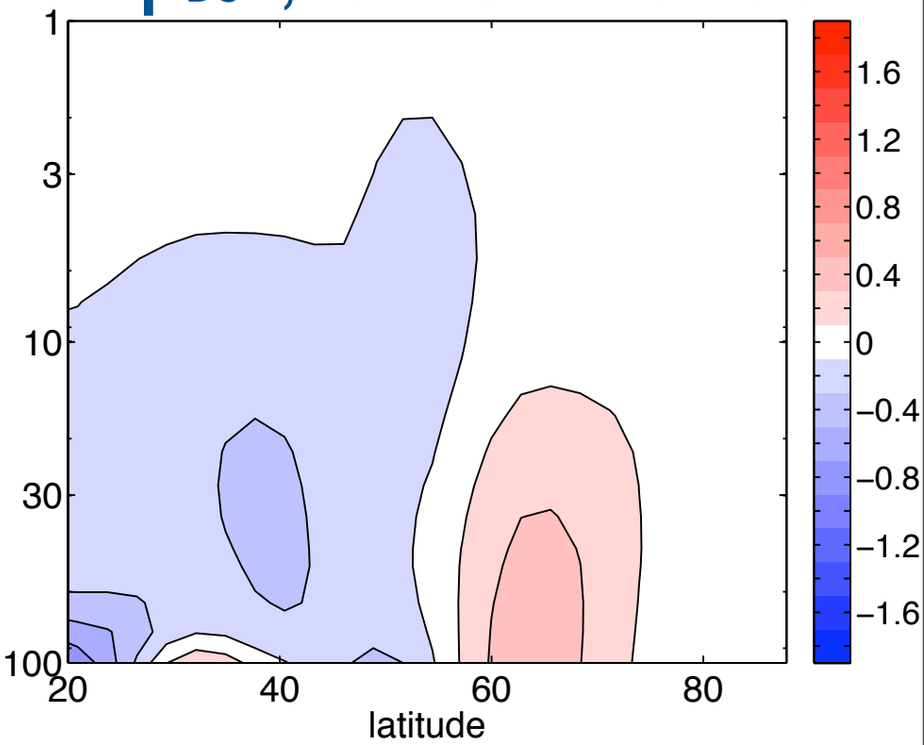
$\Delta\psi_{DC}^*$, OGWD



$\Delta\psi_{DC}^*$, wave 2



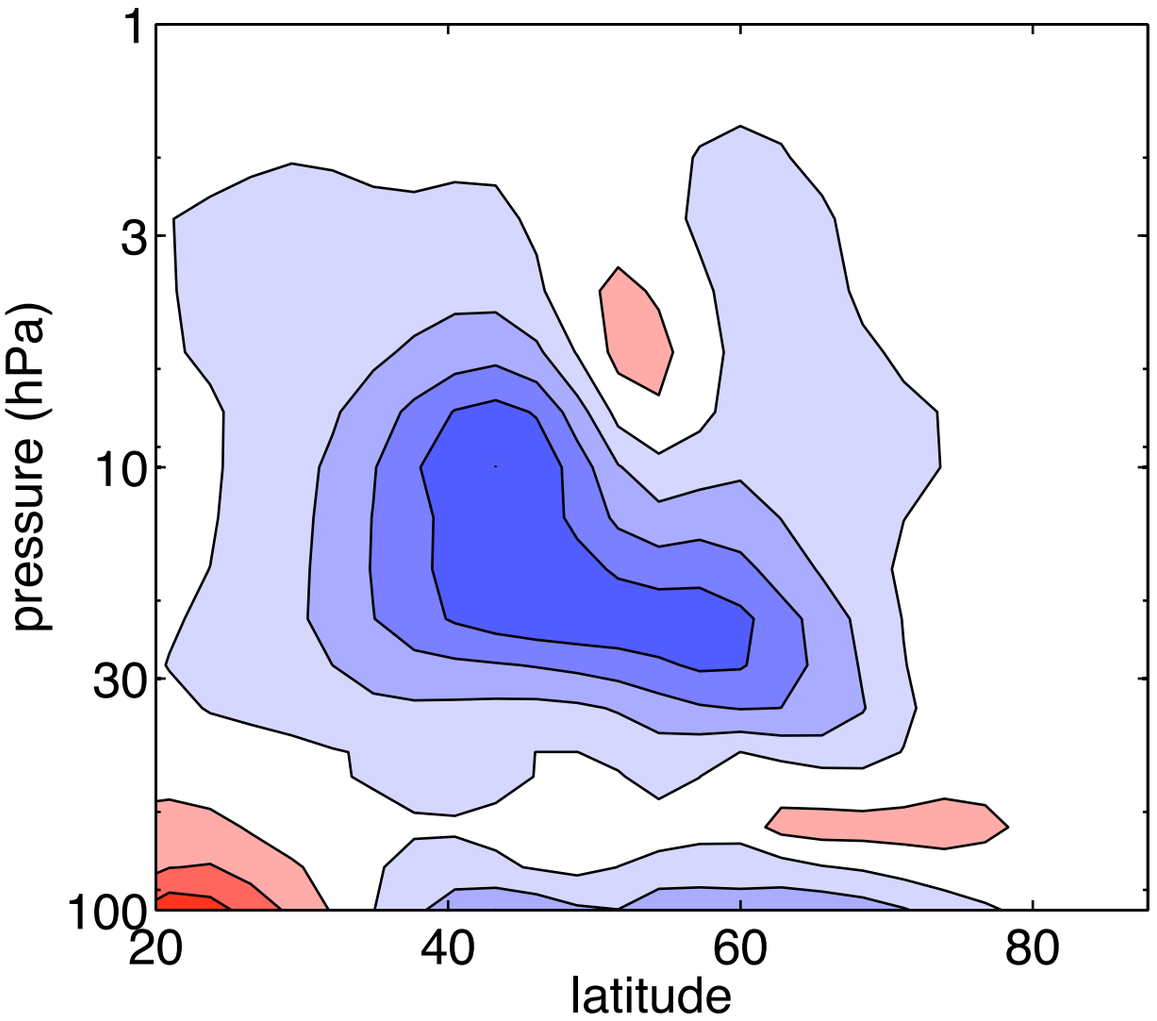
$\Delta\psi_{DC}^*$, other waves



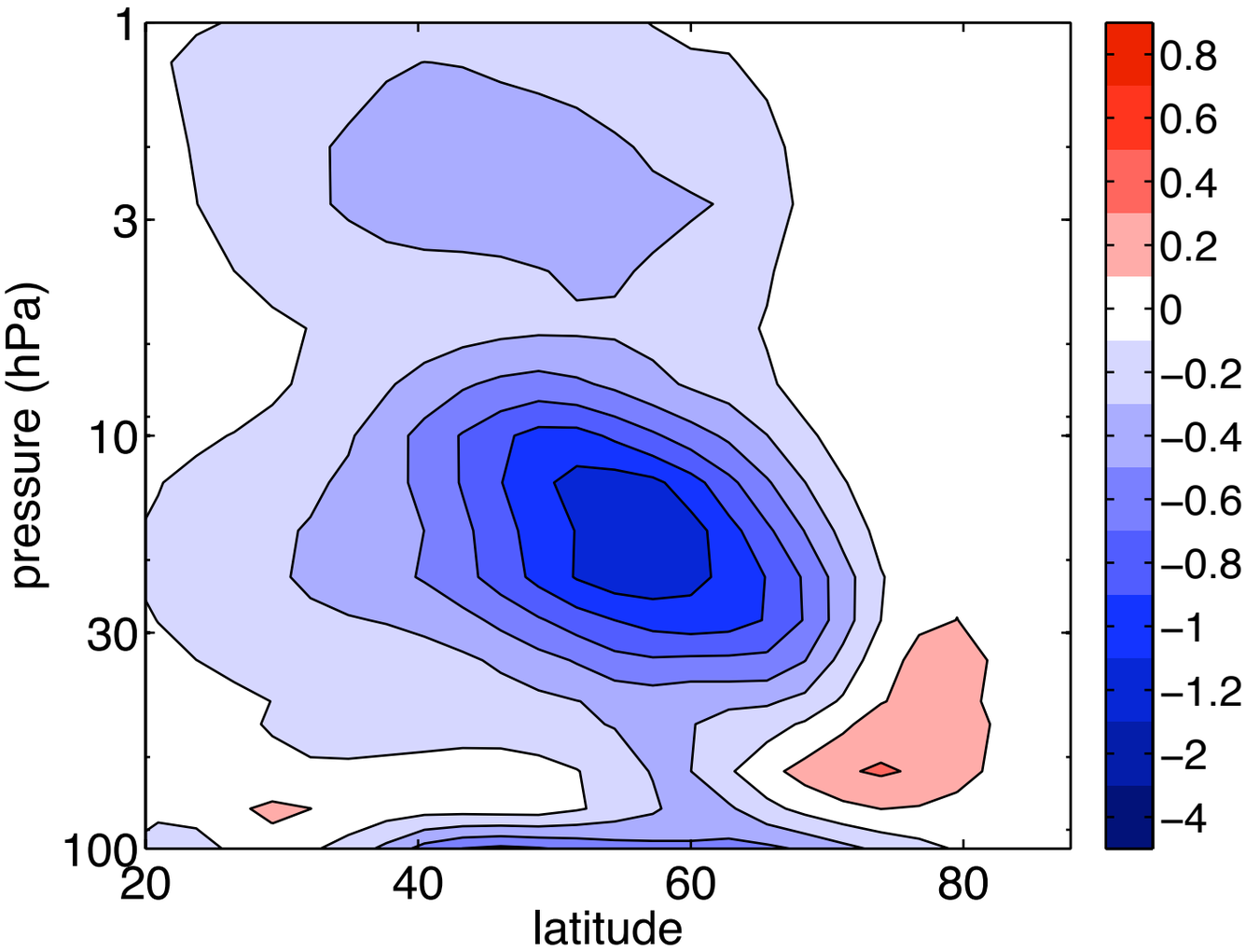
Possible Mechanisms

$\nabla \cdot F$, wavenumber 2 (10^{10} kg ms^{-2})

phase shift = 0°

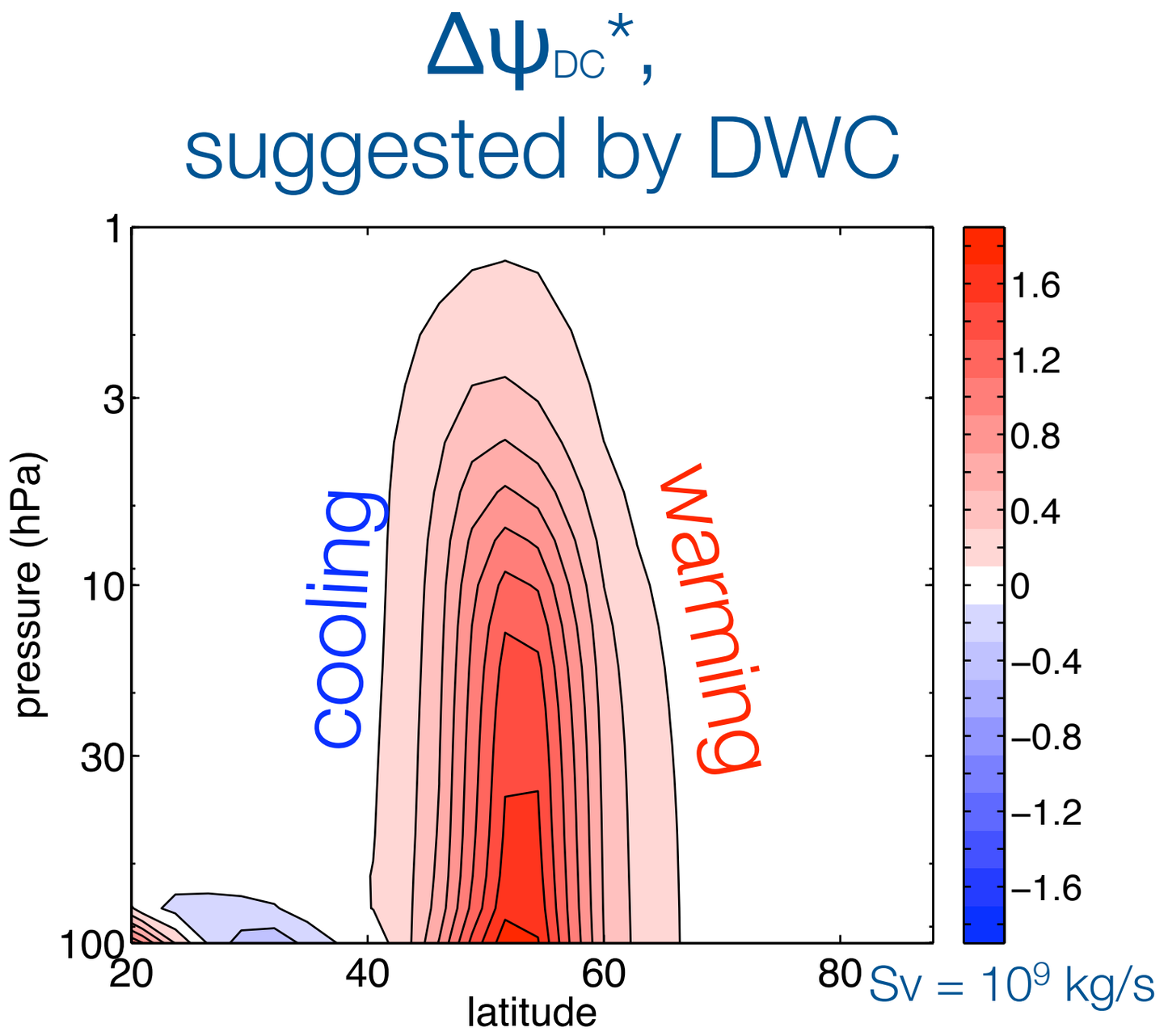


phase shift = 90°



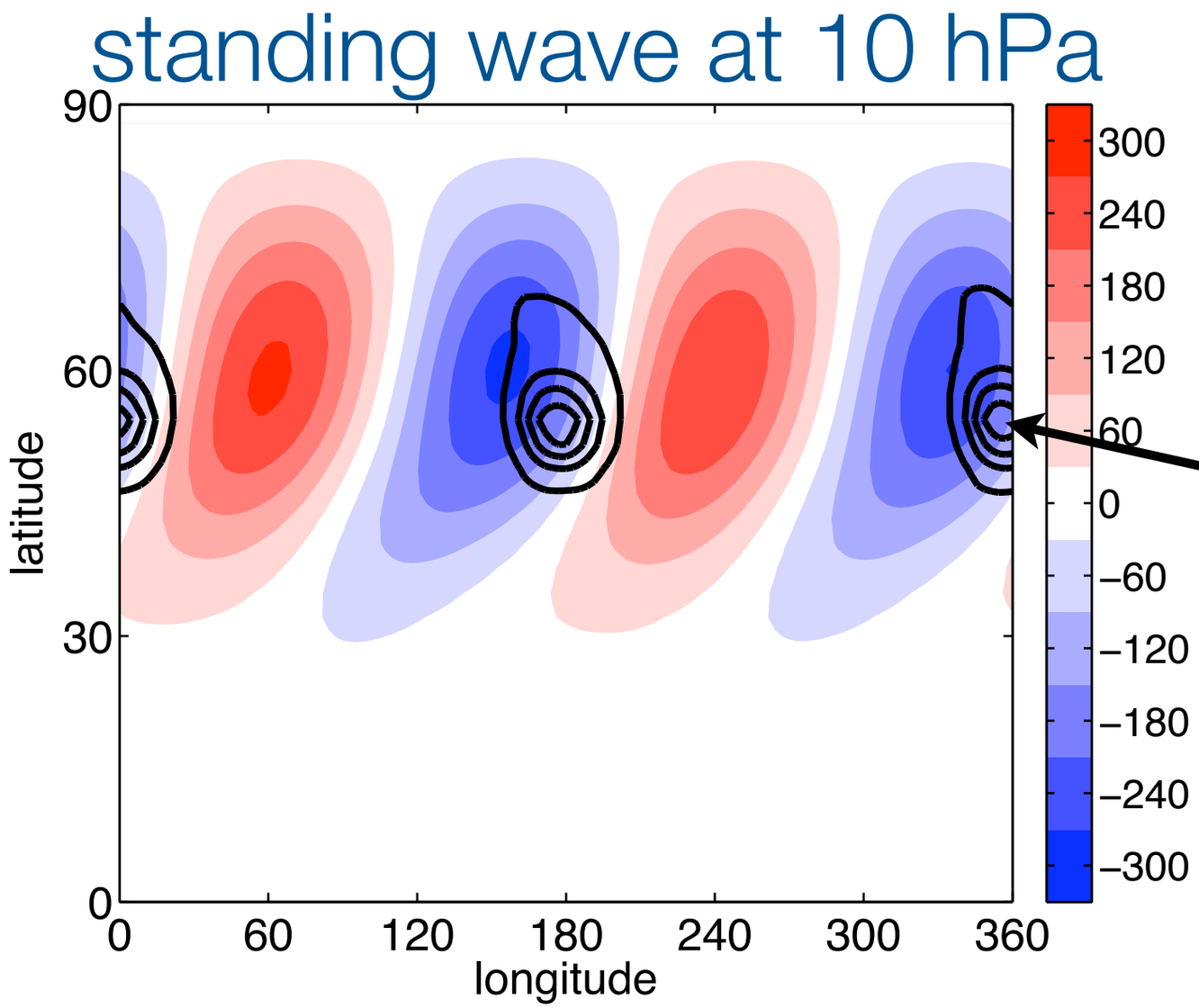
Possible Mechanisms

- GWD perturbation would modify temperature and wind structure, redirecting resolved waves



Possible Mechanisms

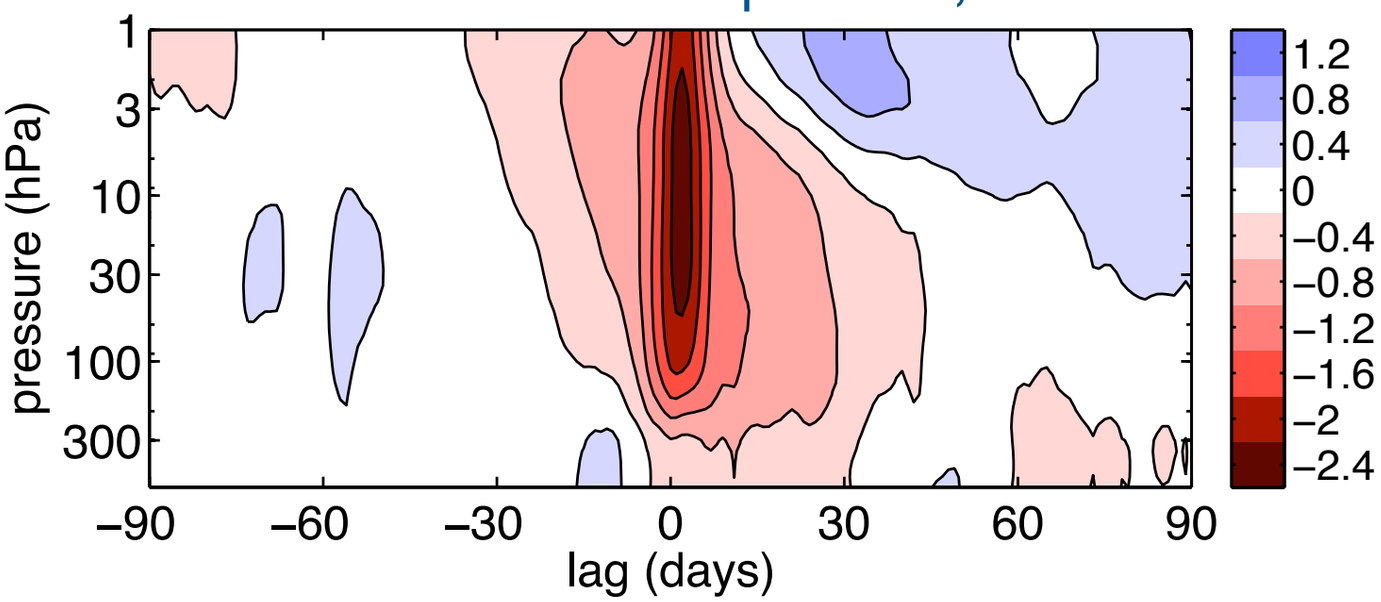
- GWD perturbation would modify temperature and wind structure, redirecting resolved waves
- GWD has zonal structure, can directly interact with resolved waves



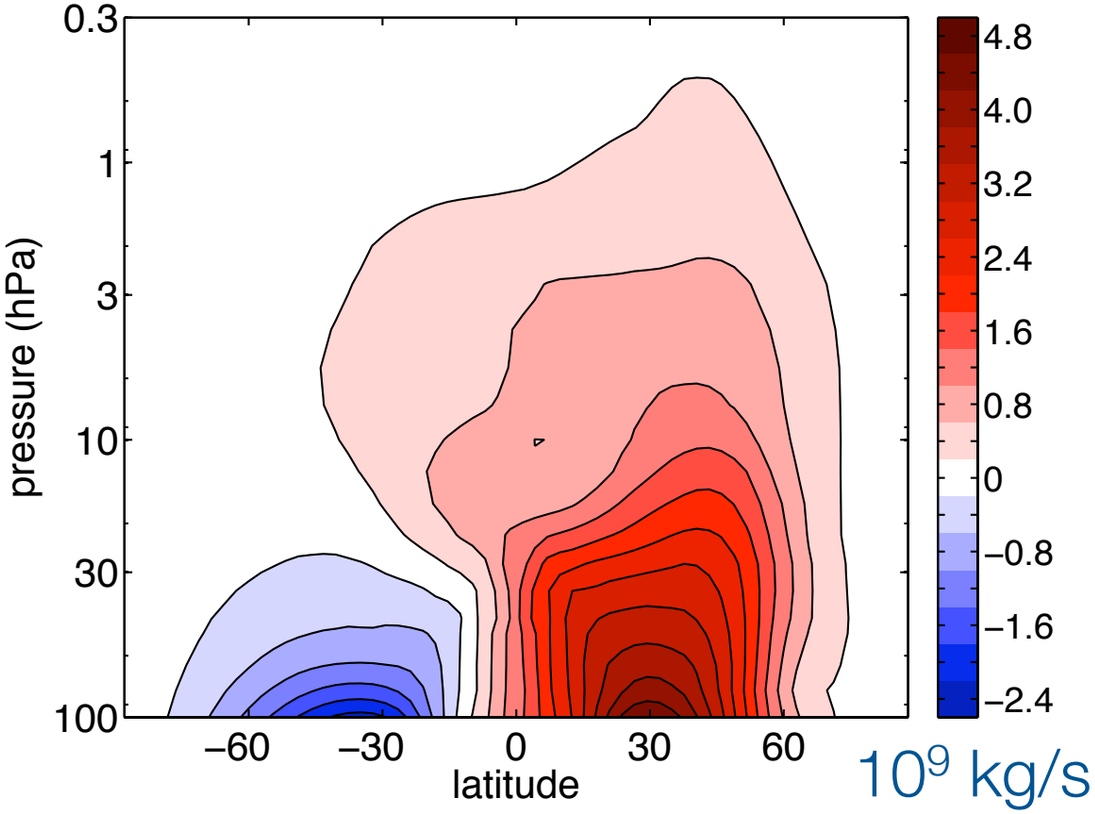
Conclusions

- We've developed a (relatively) idealized framework for studying the interaction between gravity wave parameterizations and the resolved circulation

Annular Mode Composite, 42 SSWs



Residual Mean Circulation



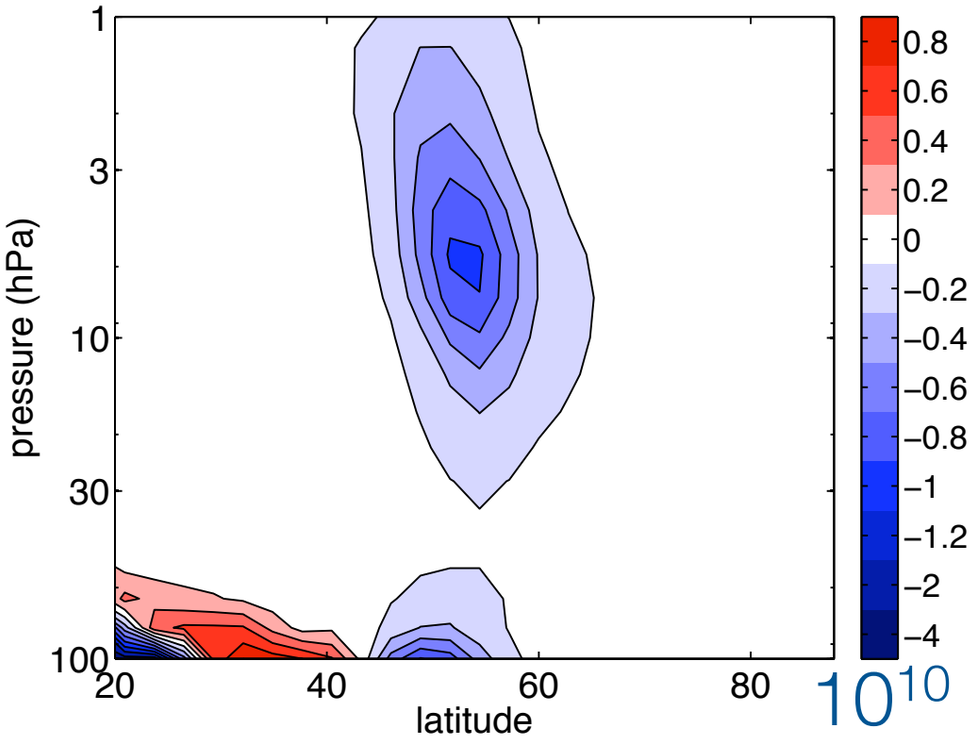
10^9 kg/s

Conclusions

- We've developed a (relatively) idealized framework for studying the interaction between gravity wave parameterizations and the resolved circulation

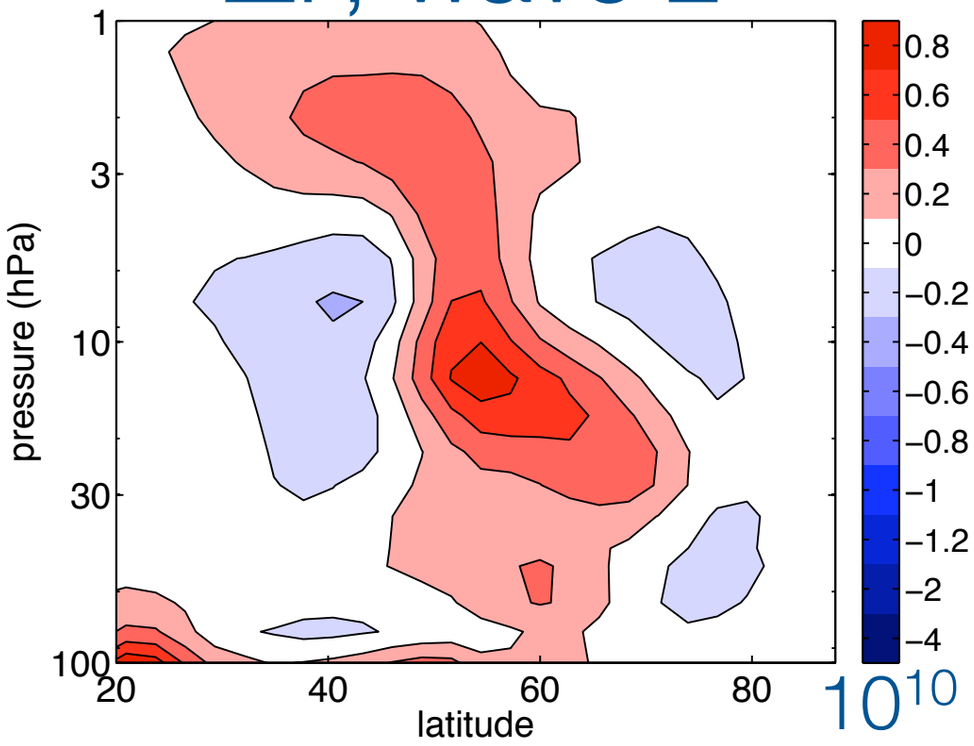
- Perturbation experiments show that the response to changes in gravity wave drag can be hard to predict: compensation between resolved and parameterized wave forcing

ΔF, OGWD



10^{10} kg ms^{-2}

ΔF, wave 2



10^{10} kg ms^{-2}

Conclusions

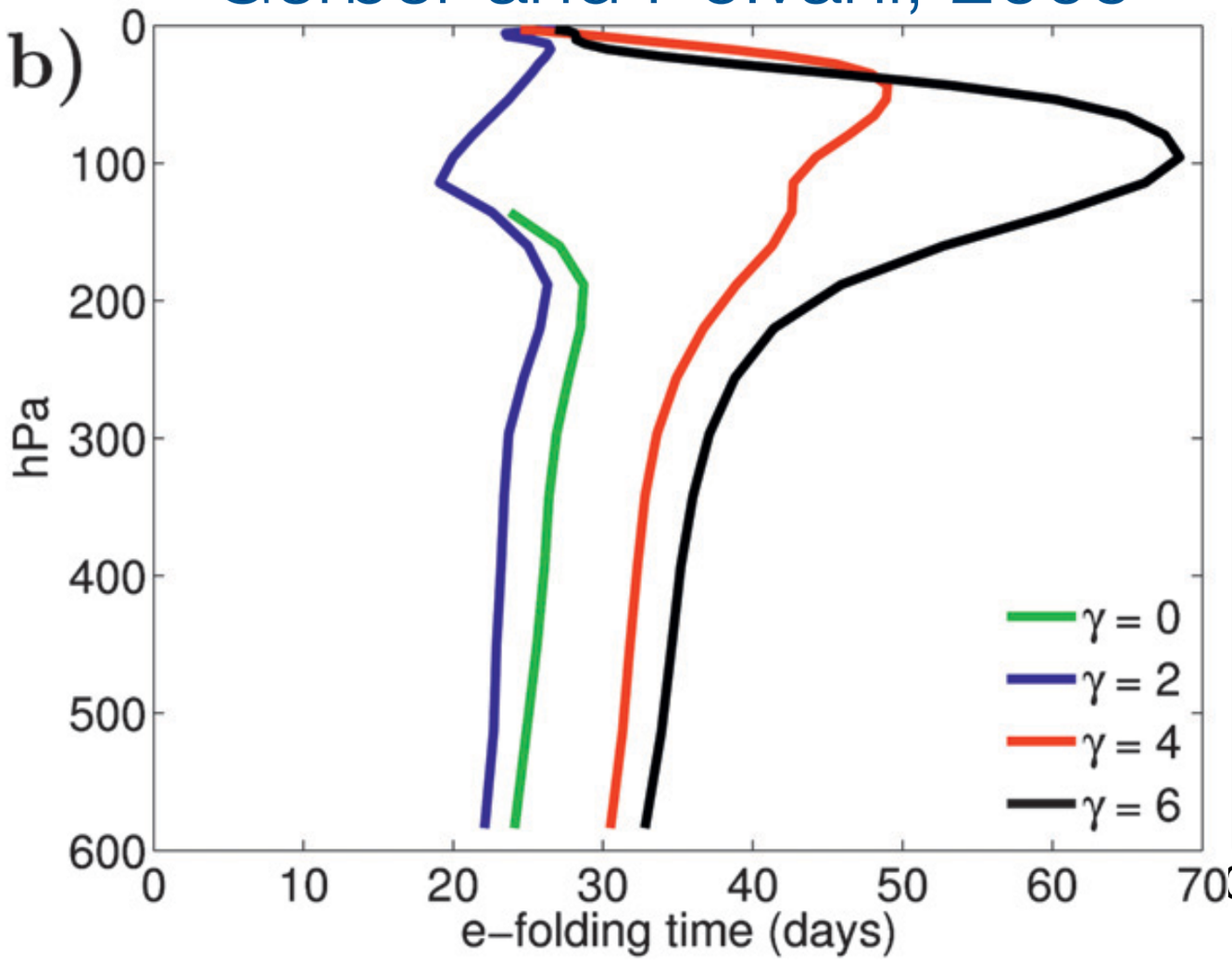
- We've developed a (relatively) idealized framework for studying the interaction between gravity wave parameterizations and the resolved circulation

- Perturbation experiments show that the response to changes in gravity wave drag can be hard to predict: compensation between resolved and parameterized wave forcing

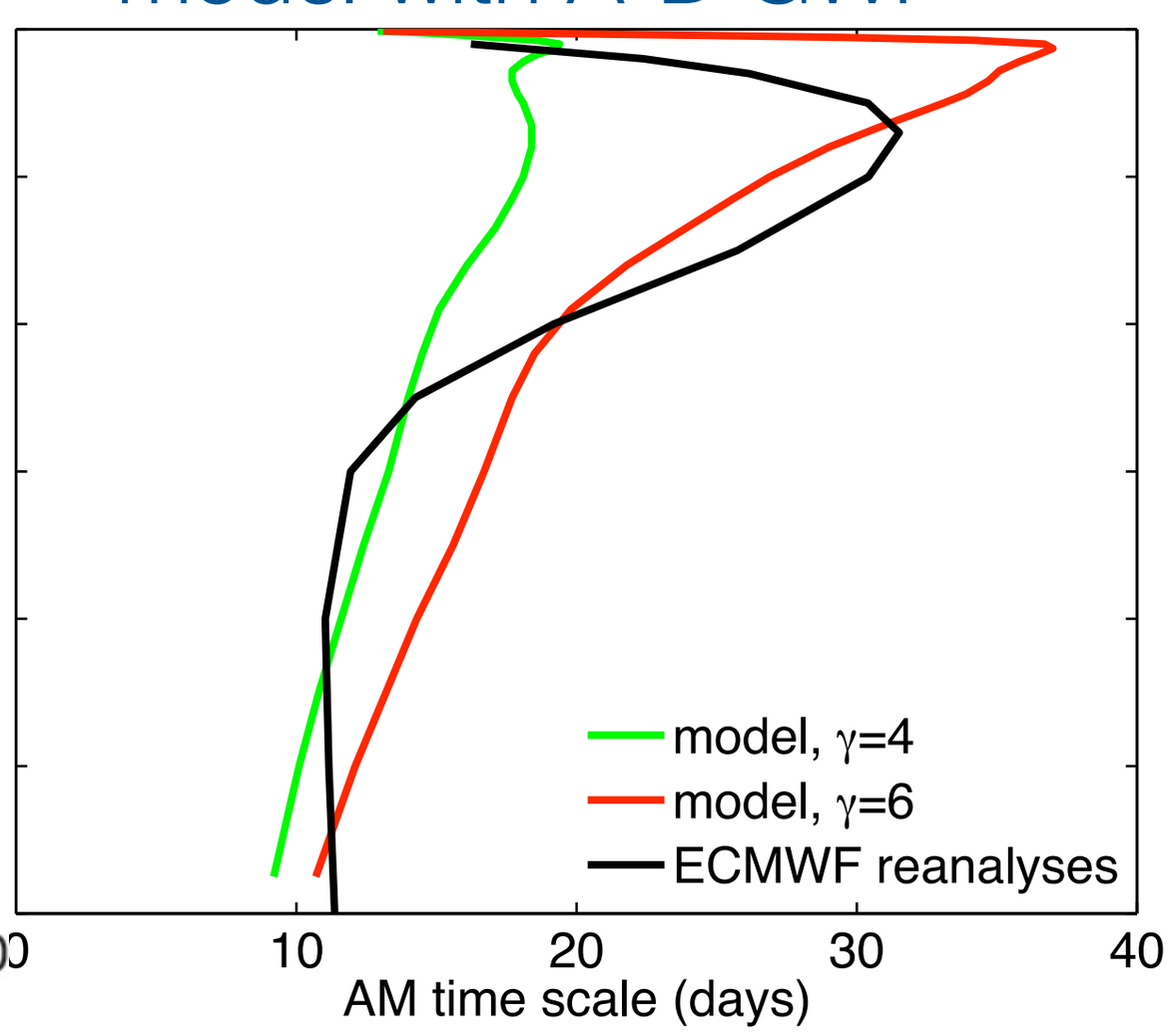
- Suggests large scale constraints on the structure of the residual mean circulation in the stratosphere

Annular mode e-folding time scale: stratospheric variability impacts troposphere

Gerber and Polvani, 2009



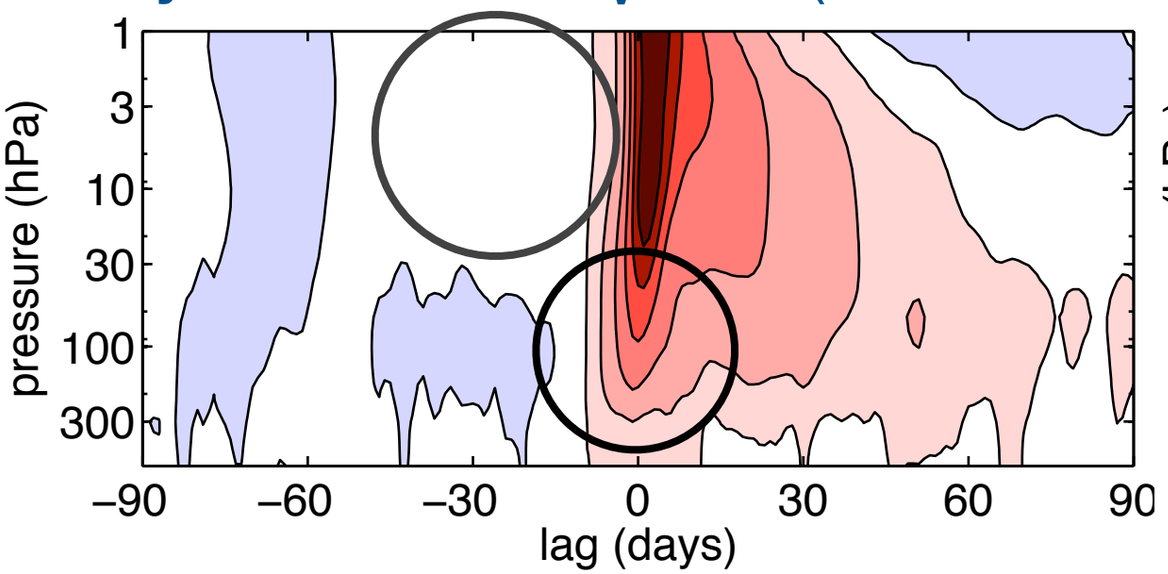
model with A-D GWP



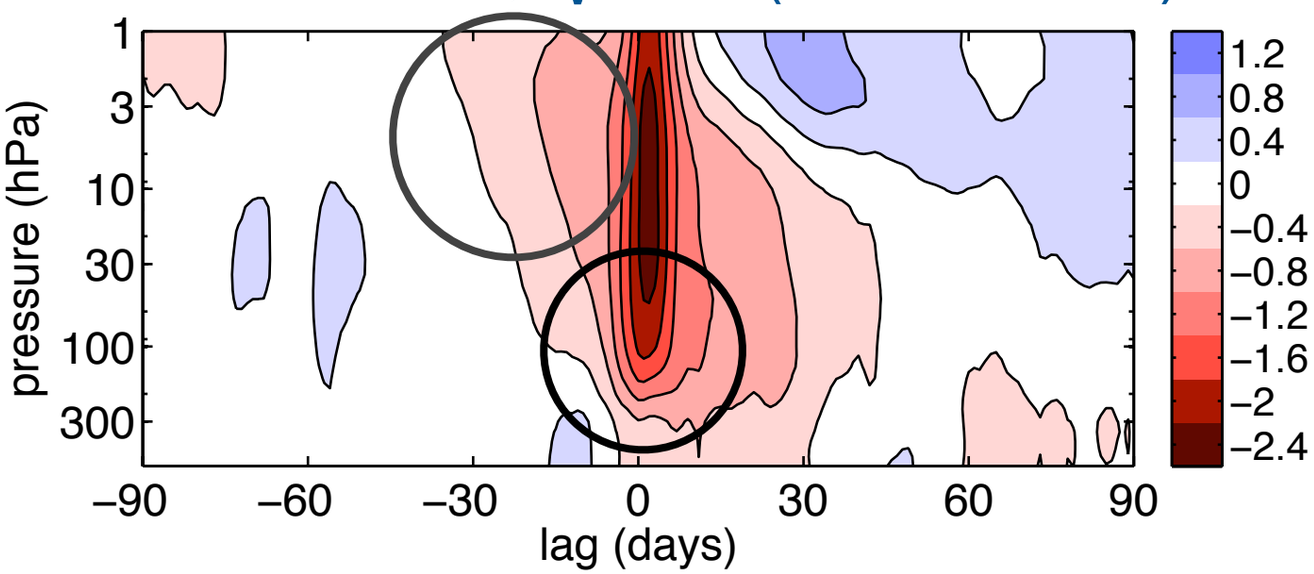
previously reported results are robust

Impact of A-D scheme on the annular mode and SSWs

Rayl. Friction, γ=4 (46 events)

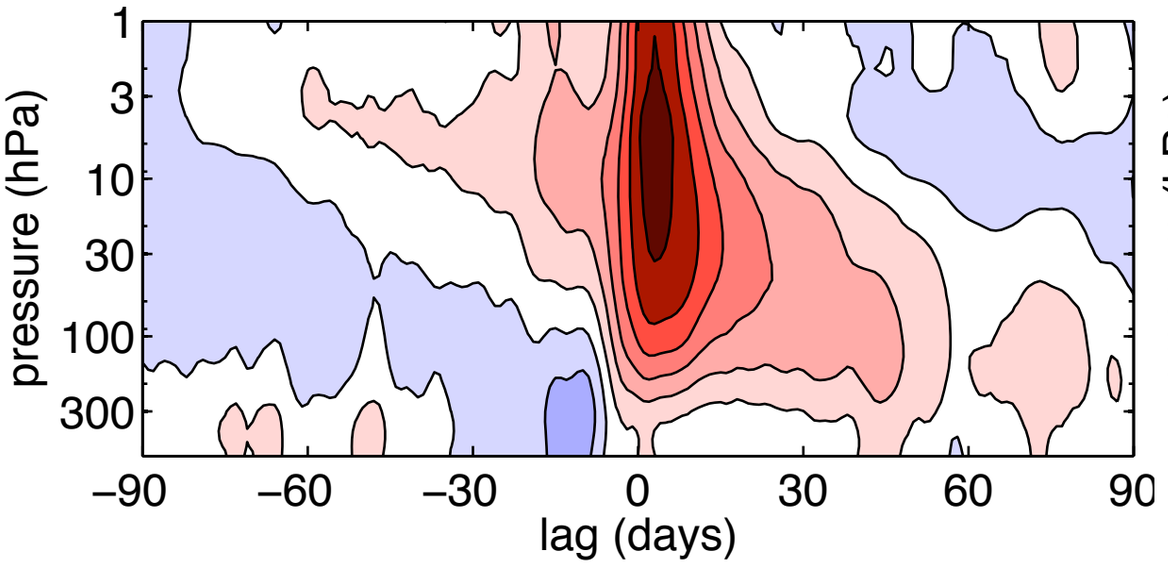


A-D GWP, γ=6 (42 events)

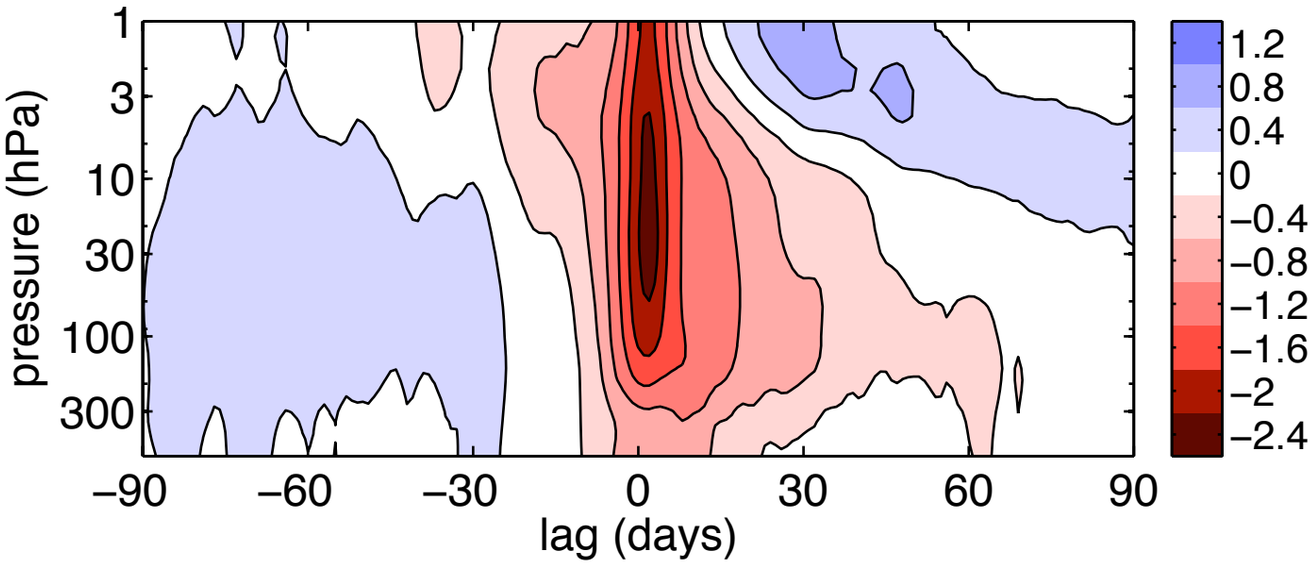


A-D spectral + Orographic GWP, γ=6

phase shift = 0° (29 events)

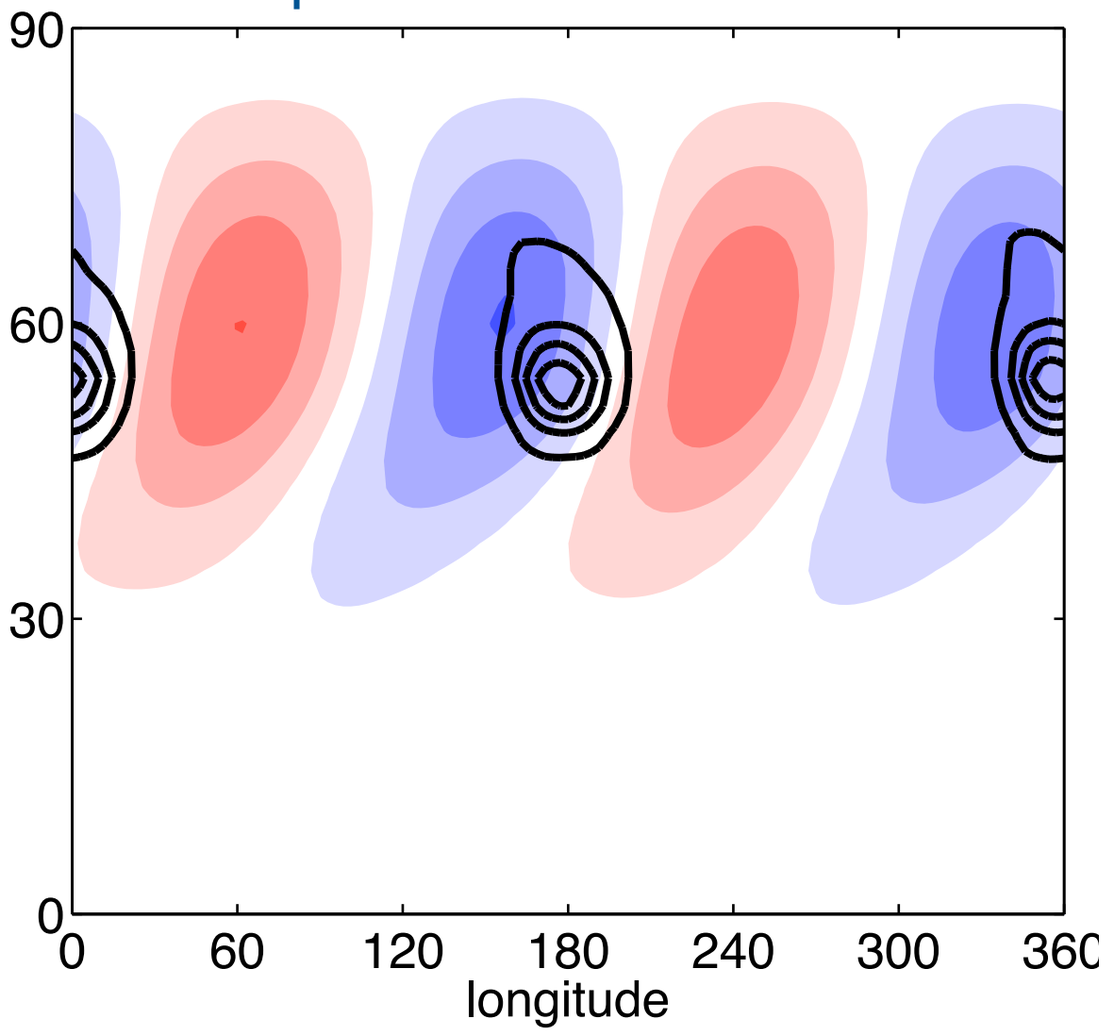


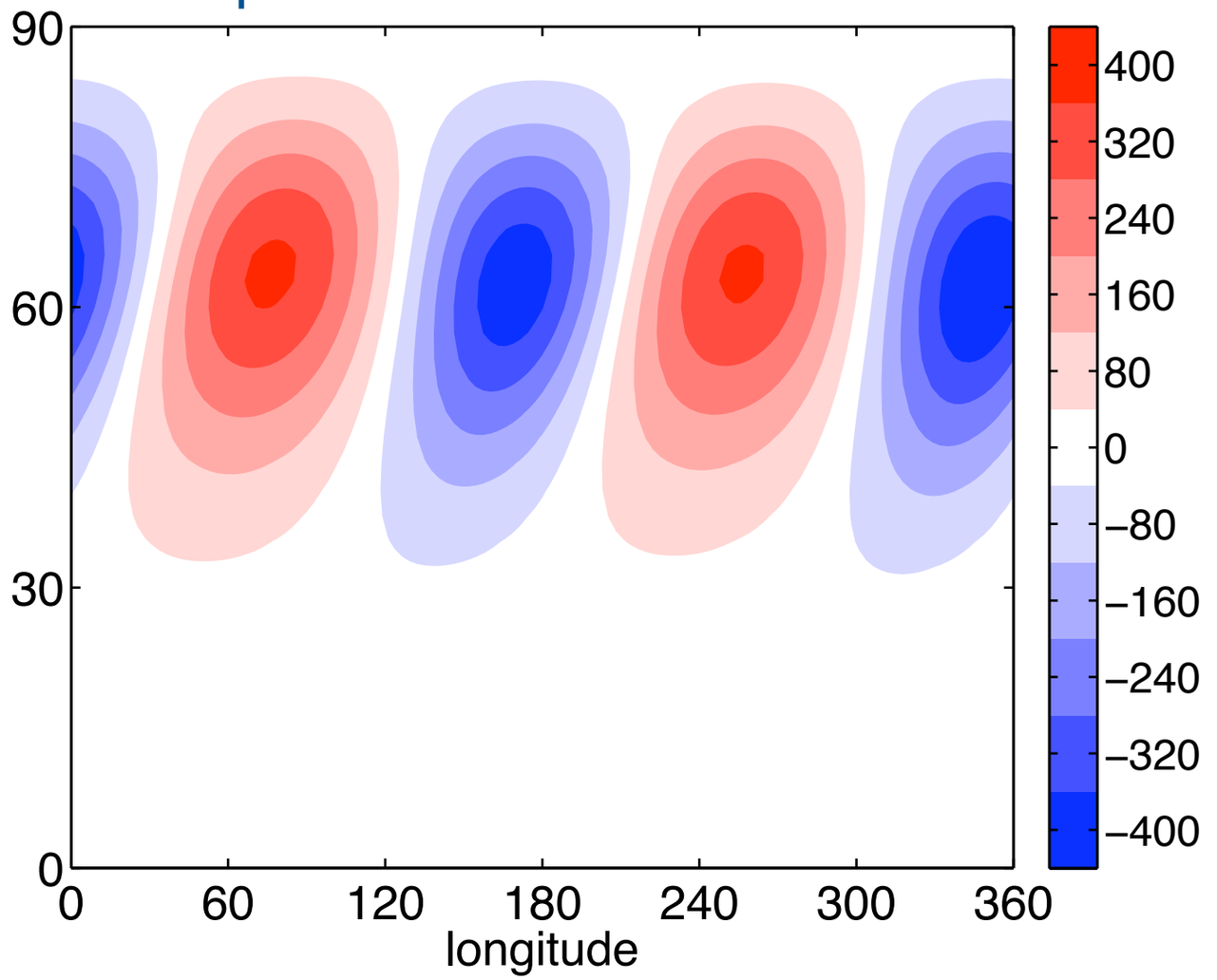
phase shift = 90° (41 events)



Interaction between OGWD and stationary waves

z’ (shading) and OGWD at 10 hPa





Residual Mean Streamfunction