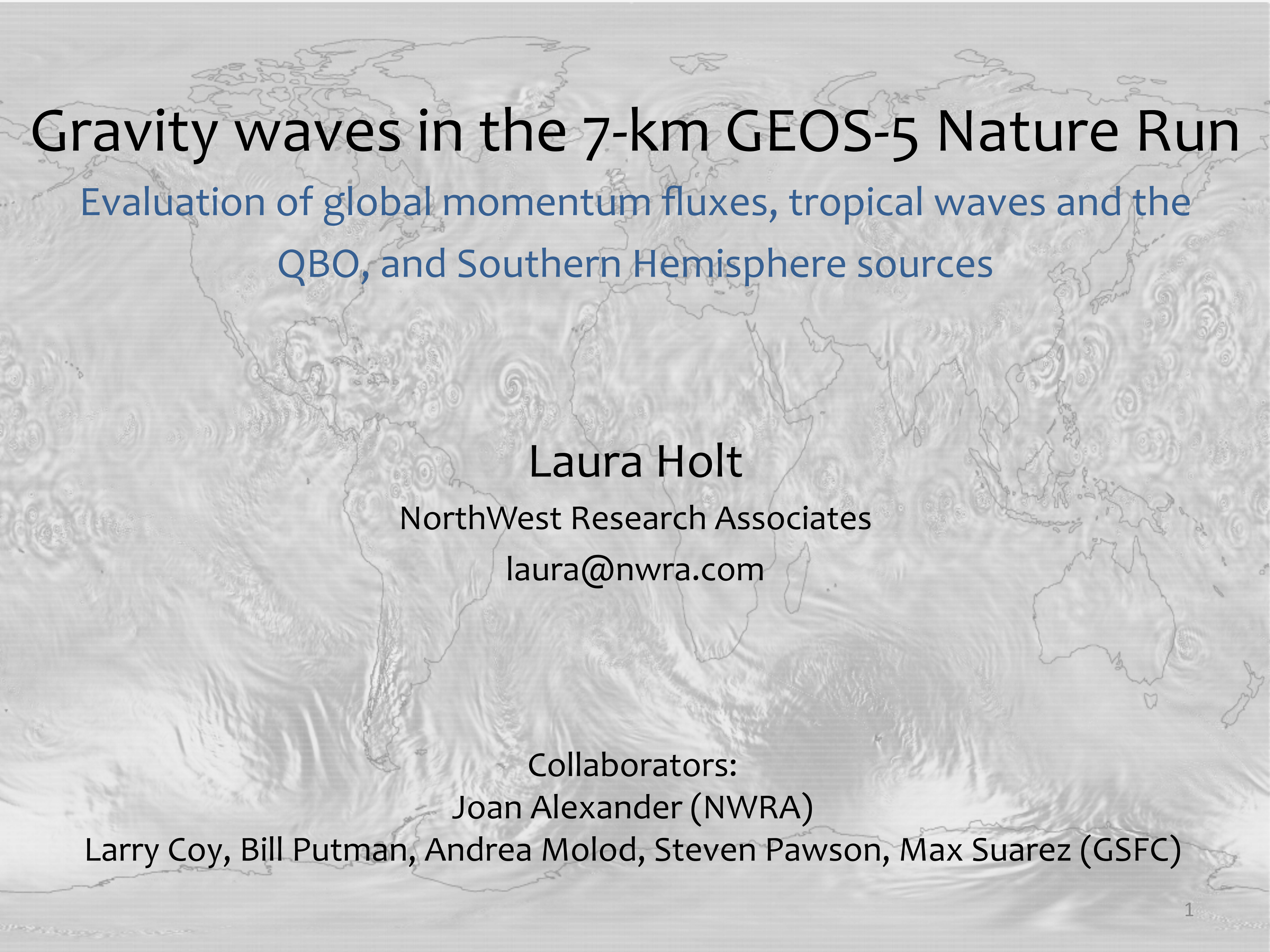

Gravity waves in the 7-km GEOS-5 Nature Run

Evaluation of global momentum fluxes, tropical waves and the QBO, and Southern Hemisphere sources

Laura Holt
NorthWest Research Associates
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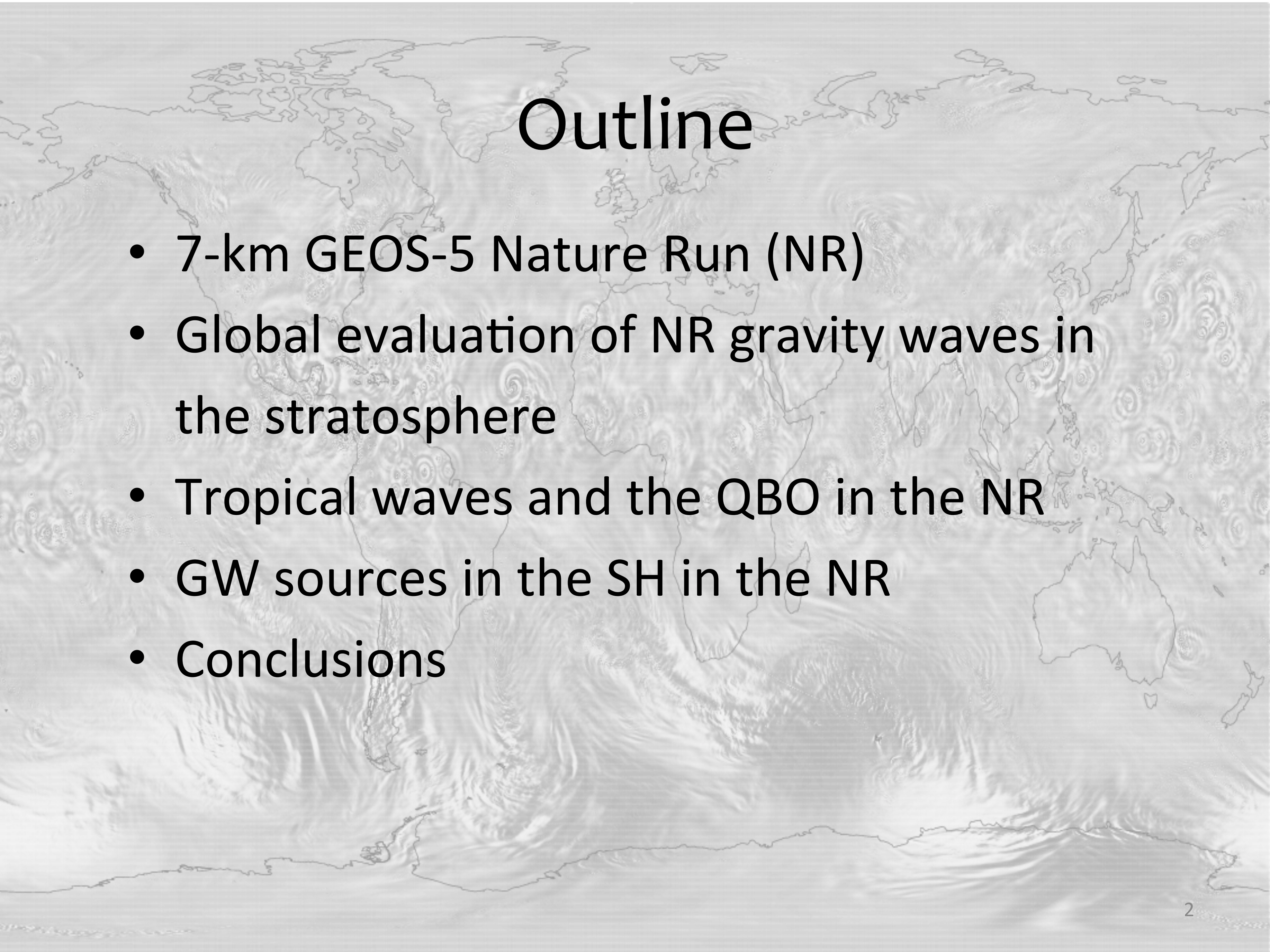
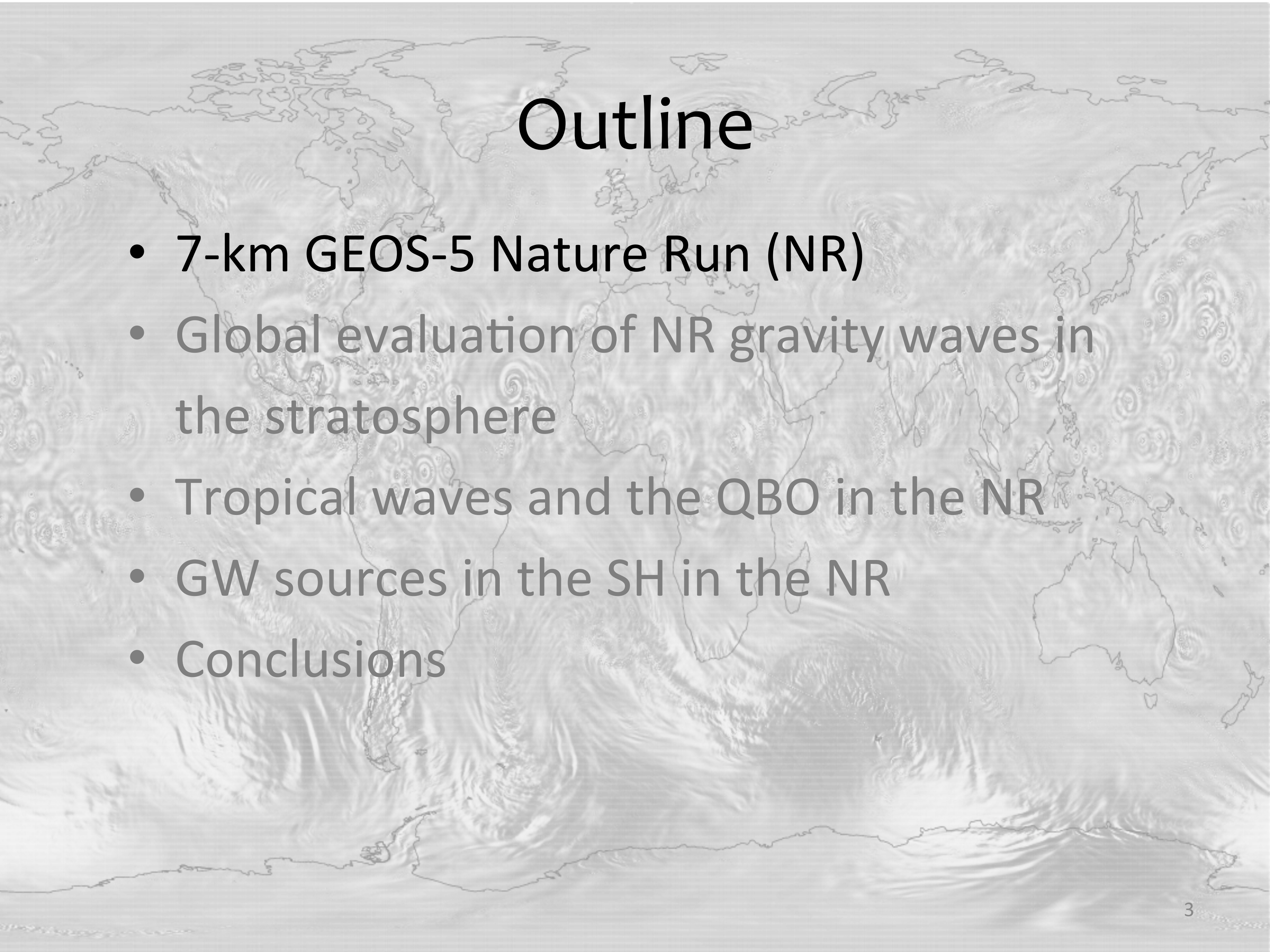
Collaborators:
Joan Alexander (NWRA)
Larry Coy, Bill Putman, Andrea Molod, Steven Pawson, Max Suarez (GSFC)



Outline

- 7-km GEOS-5 Nature Run (NR)
- Global evaluation of NR gravity waves in the stratosphere
- Tropical waves and the QBO in the NR
- GW sources in the SH in the NR
- Conclusions



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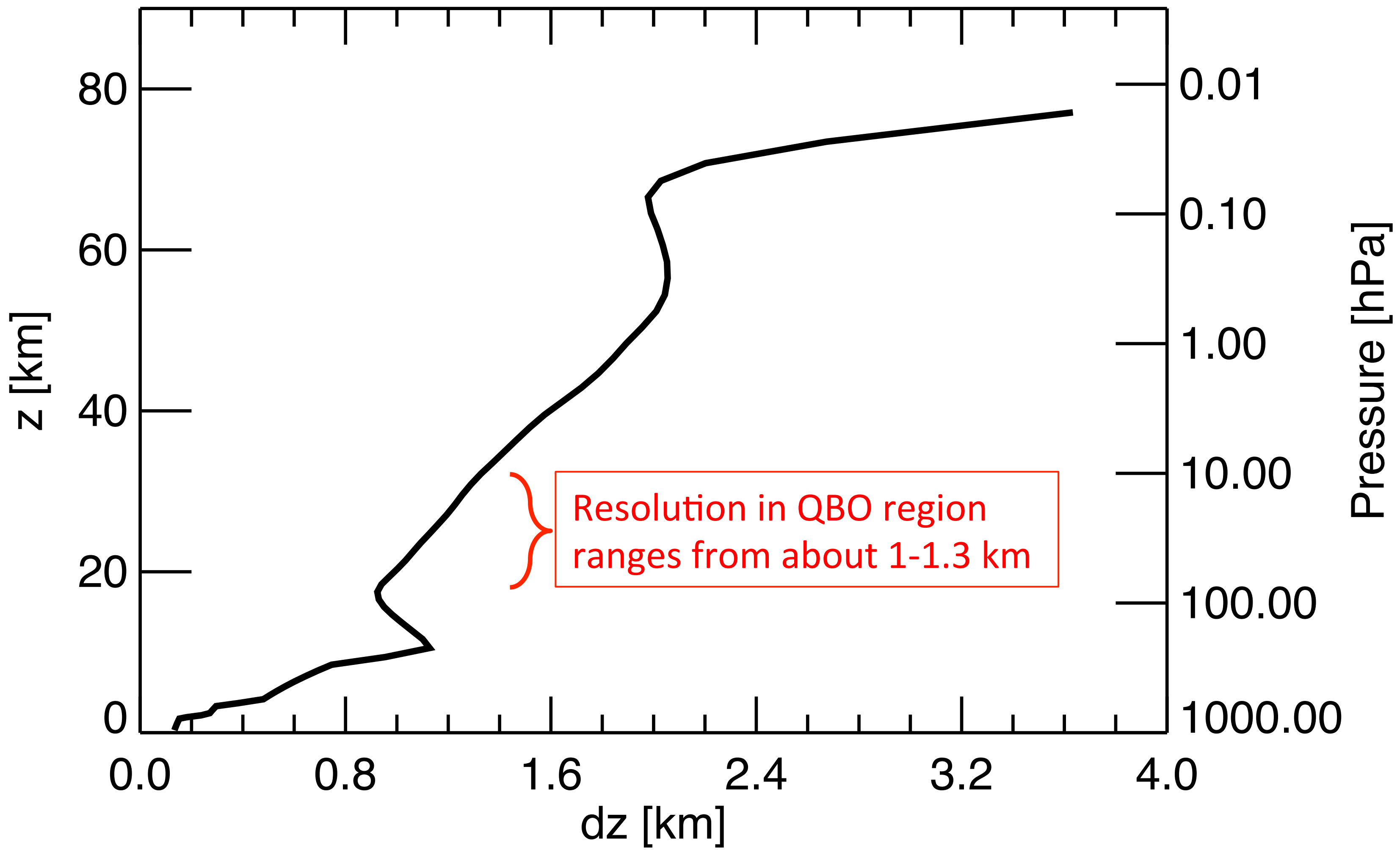
7-km GEOS-5 NR

- 2-year, free-running simulation produced with GEOS-5
- 7-km horizontal resolution (0.0625°)
- Non-hydrostatic
- Cubed sphere, finite volume numerics
- Non-orographic parameterized gravity wave drag after Garcia and Boville, 1994
- 2nd order divergence damping
- Relaxed Arakawa-Schubert moist physics scheme

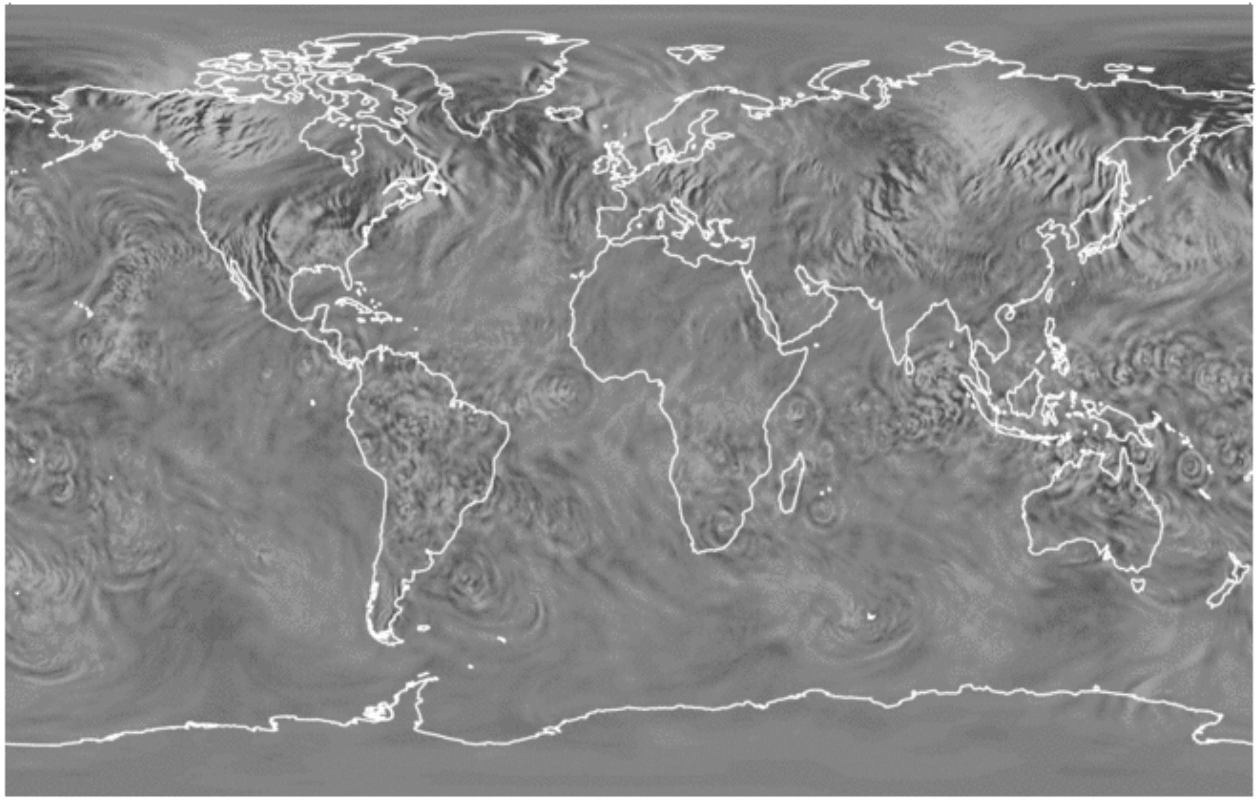
NR vertical resolution

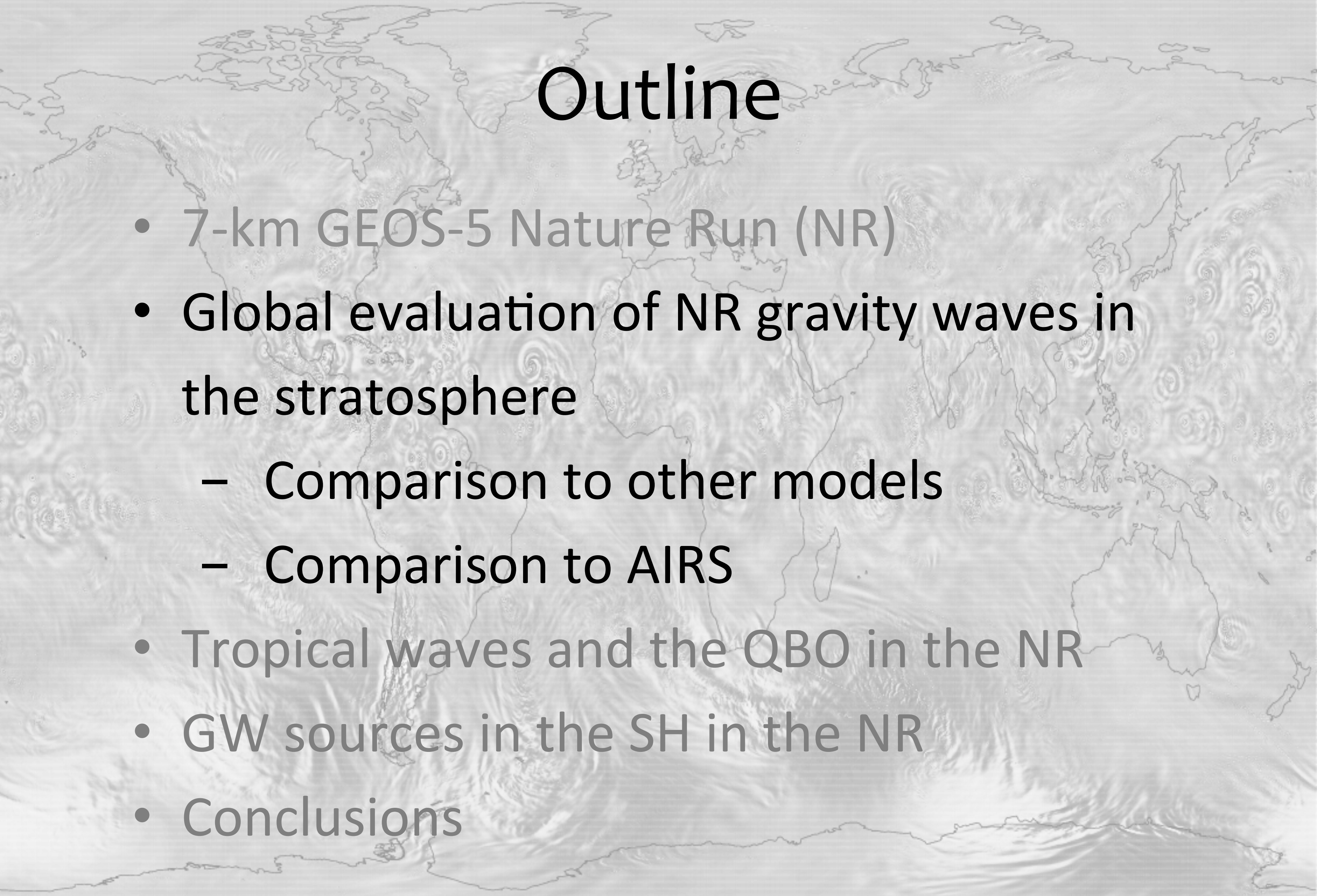


Resolution in QBO region ranges from about 1-1.3 km

NR vertical velocity on 100 hPa level

January 1





Outline

- 7-km GEOS-5 Nature Run (NR)
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  - Comparison to other models
  - Comparison to AIRS
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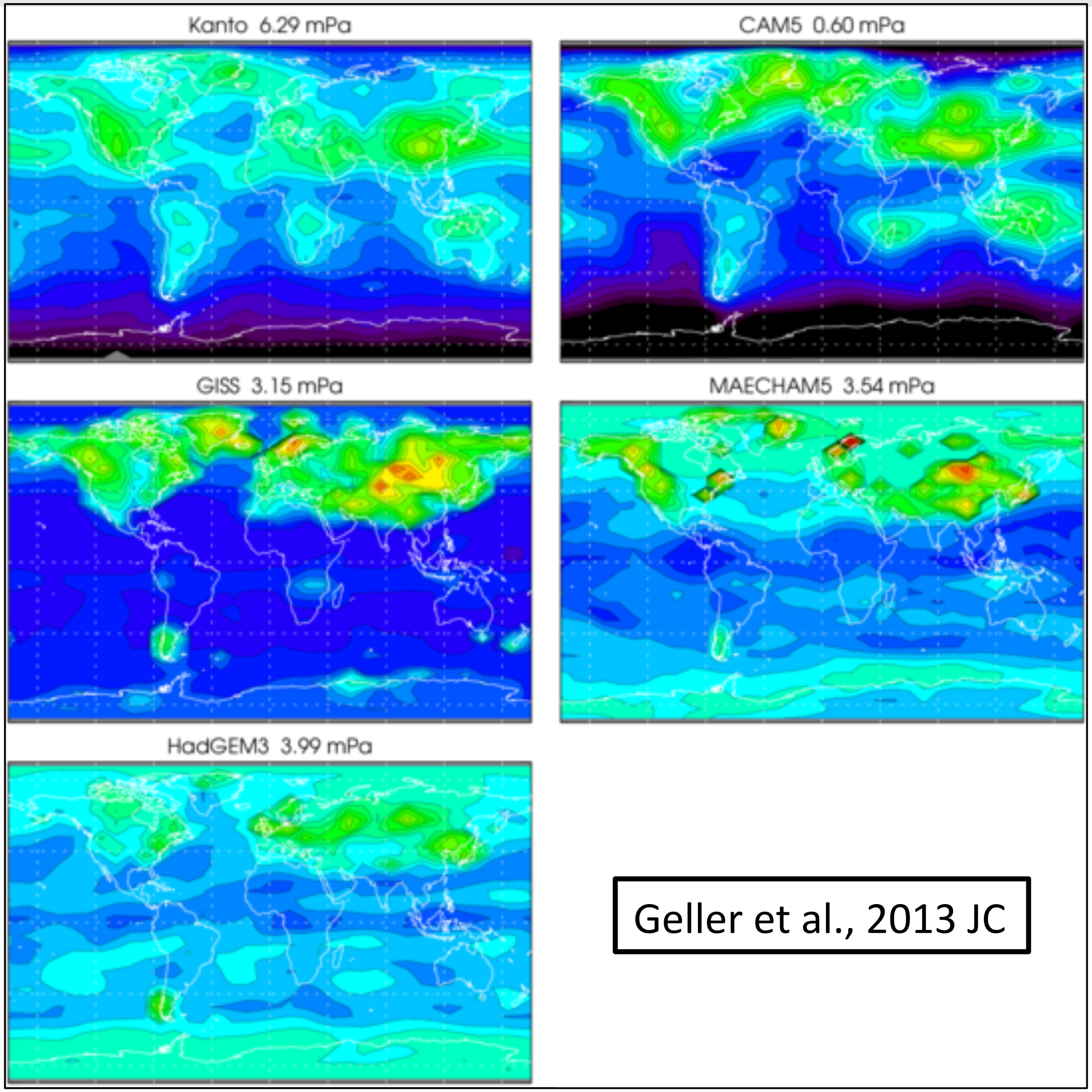
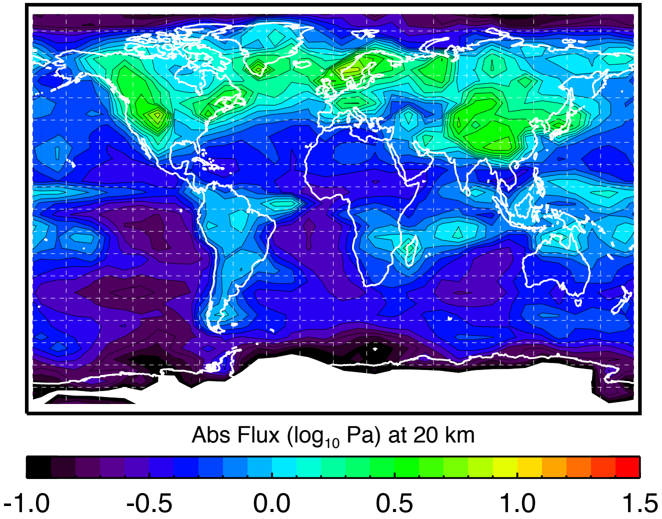
January Absolute GW Momentum Flux at 20 km



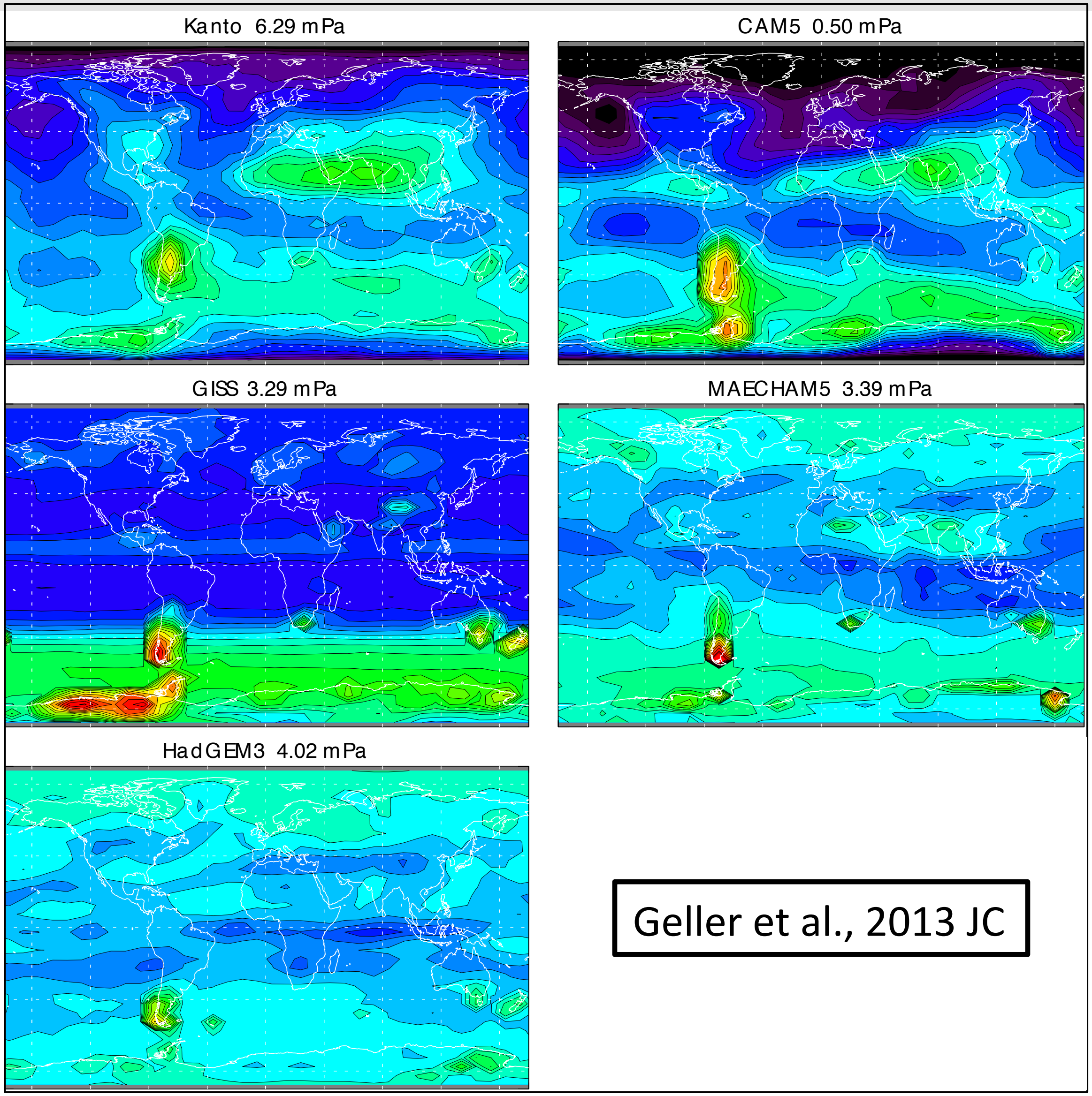
Geller et al., 2013 JC

Nature Run 0.6 mPa
(Resolved GWs < 1000 km)



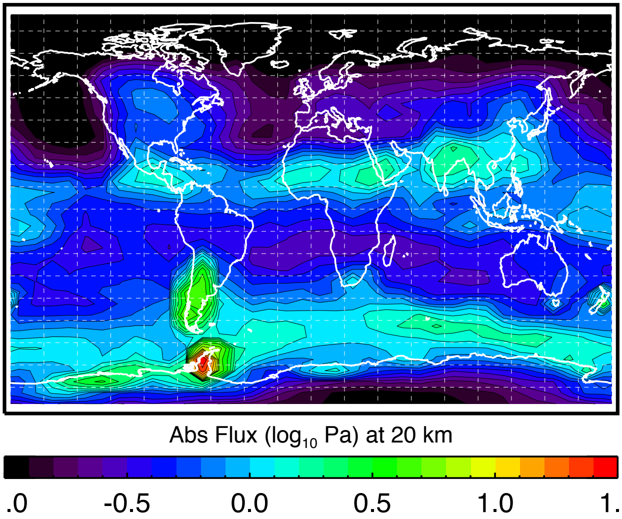
- Global variations very realistic
- Mean values on the low end (comparable to CAM5)

July Absolute GW Momentum Flux at 20 km



Geller et al., 2013 JC

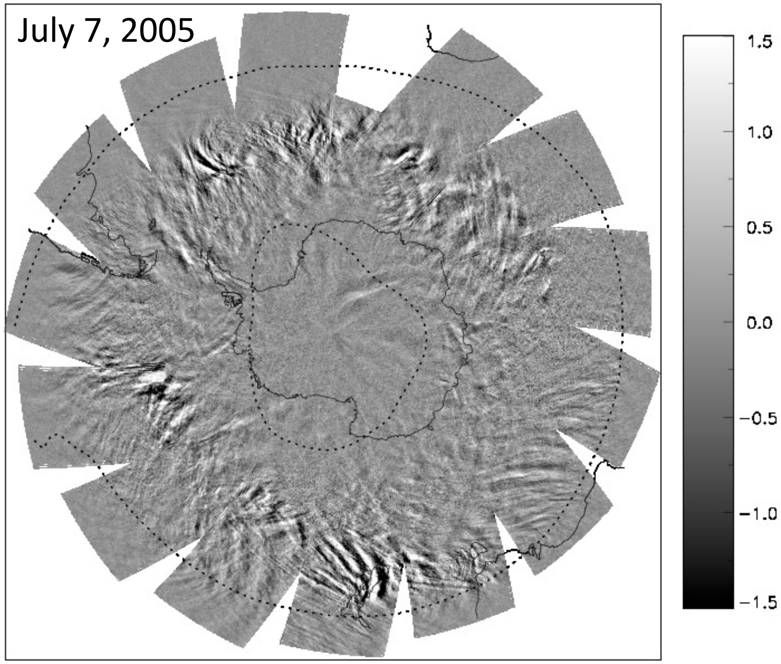
Nature Run 0.6 mPa
(Resolved GWs < 1000 km)



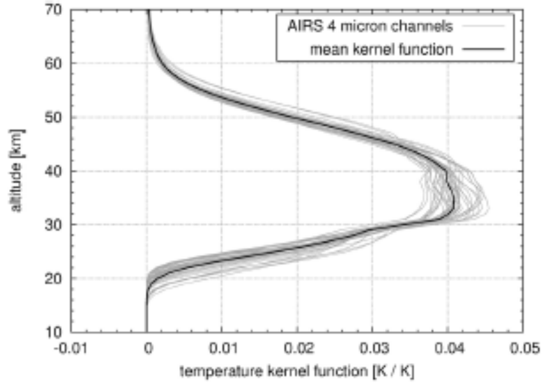
- Global variations very realistic
- Mean values on the low end (comparable to CAM5)

AIRS and NR brightness temperature (T_b) anomalies (< 500 km)

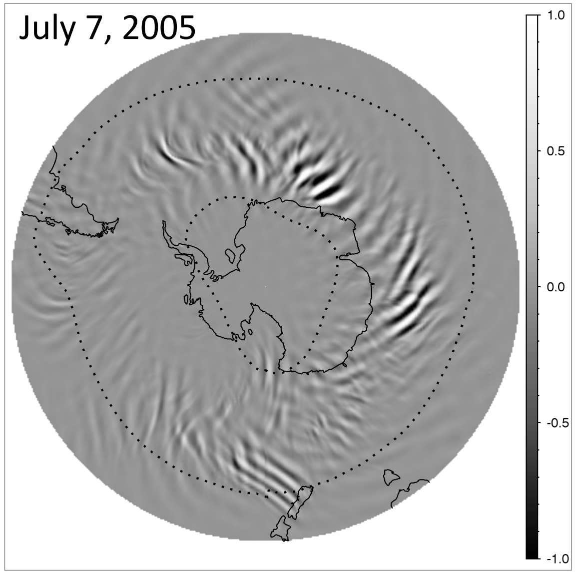
AIRS



July 7, 2005



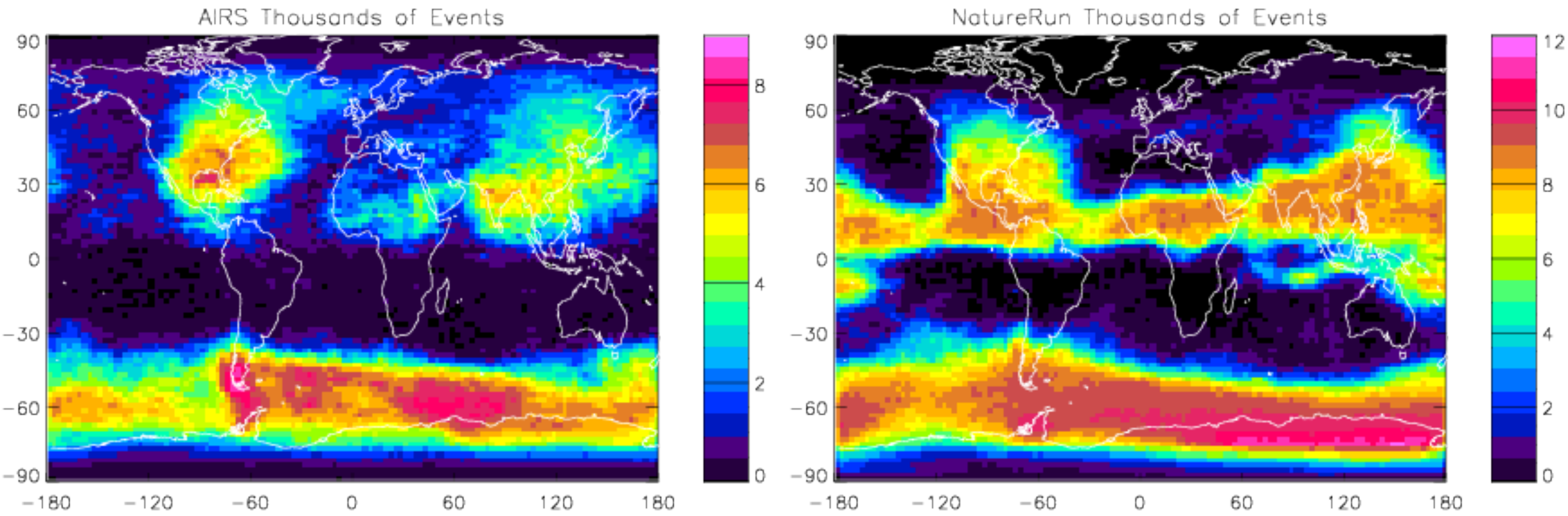
NR



July 7, 2005

Dashed lines are 40 m/s wind in lower stratosphere

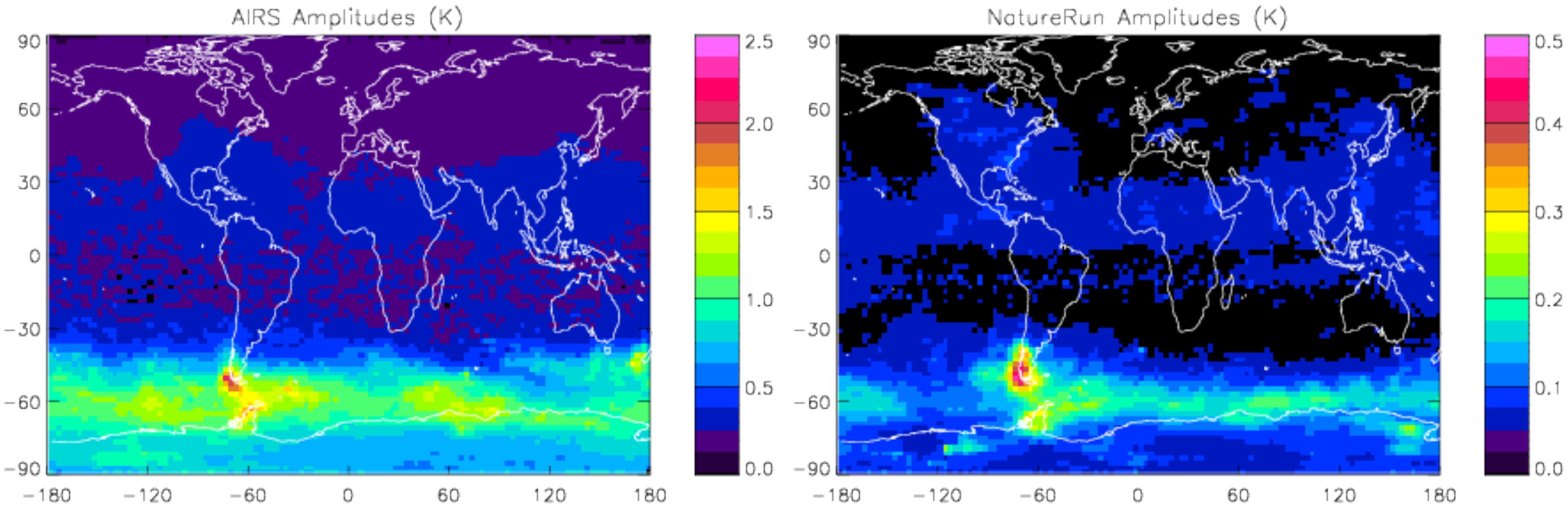
July AIRS & NR T_b sampled at AIRS locations: Number of events



- For AIRS, events identified as amplitudes > 3*noise(T)
- For Nature Run, events identified amplitudes > 0.02K

Events occur with similar global patterns

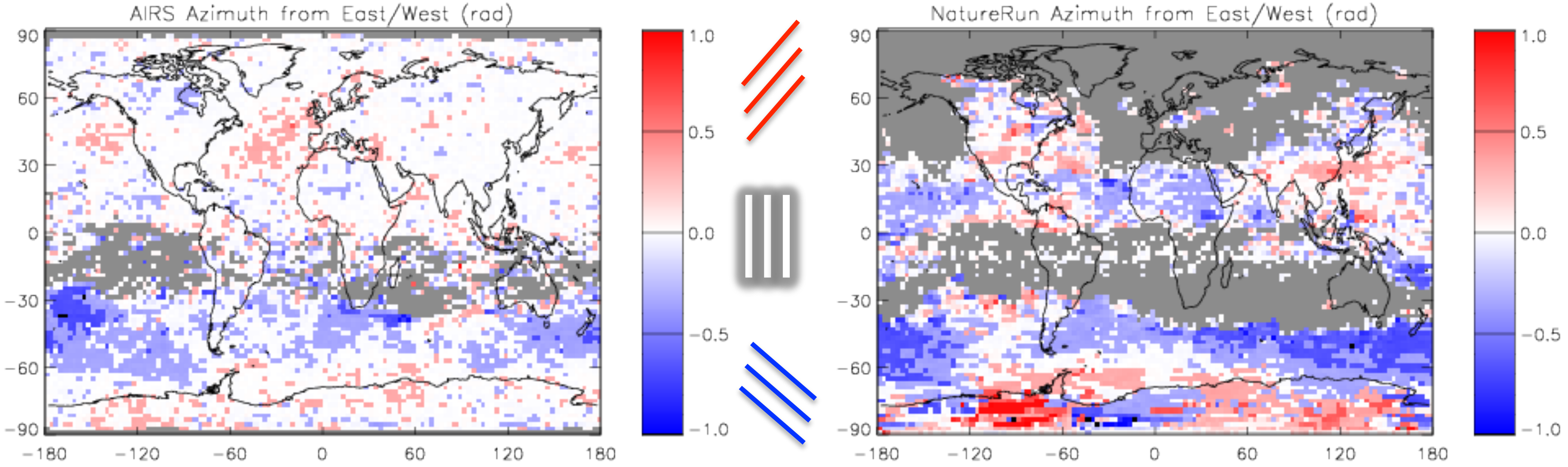
July AIRS & NR T_b sampled at AIRS locations: Amplitudes



- AIRS amplitudes are about 5x larger than NR
- Global patterns are very similar

July AIRS & NR T_b sampled at AIRS locations: Propagation direction

Phase Line Orientation



Gray = little or no data

- At 30-40km altitude, AIRS sees waves propagating latitudinally into the jets (e.g. Sato et al., 2009)
- Nature run shows this even more clearly
- AIRS waves propagate mostly within +/- 30 degrees from zonal except in SH winter

Outline

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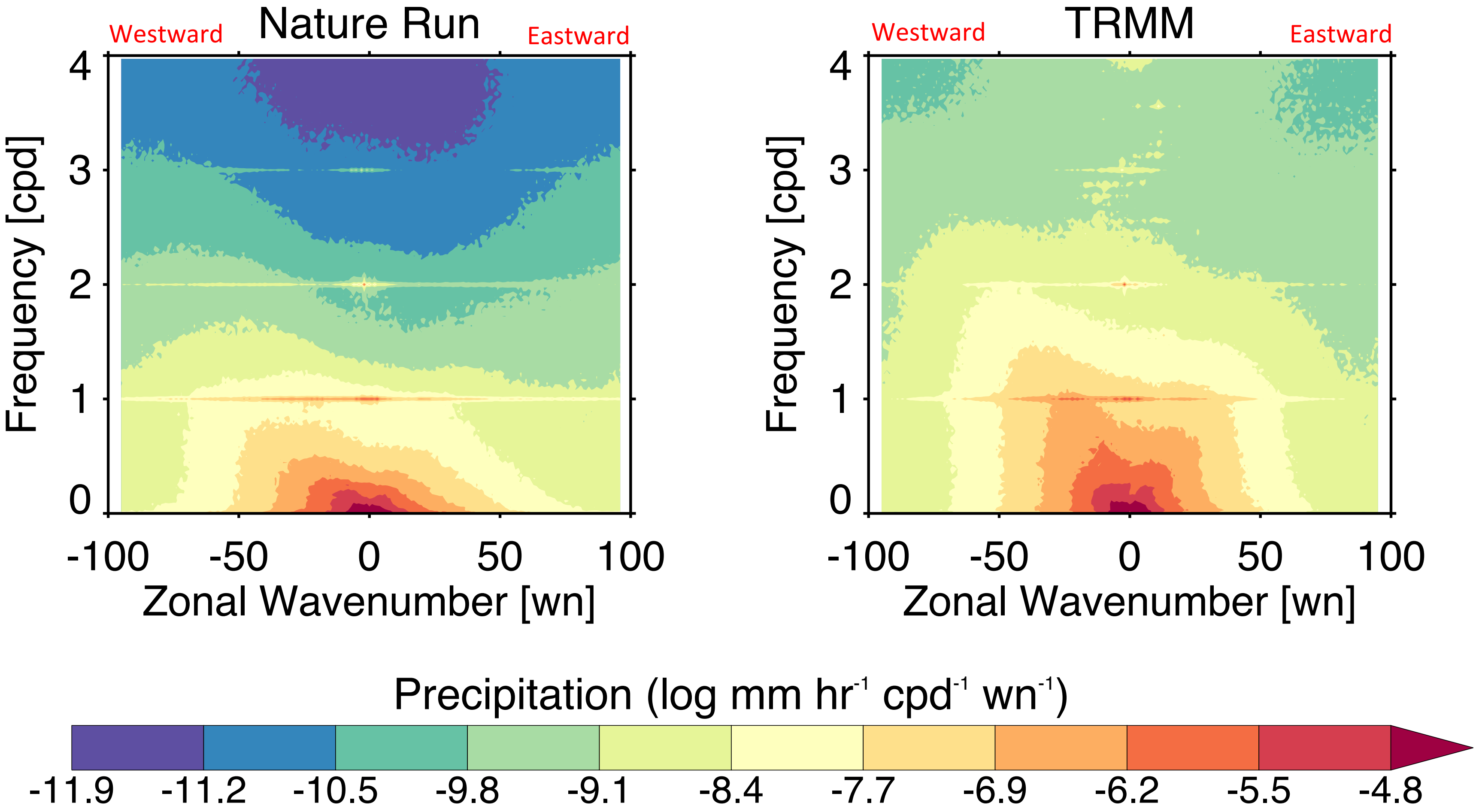
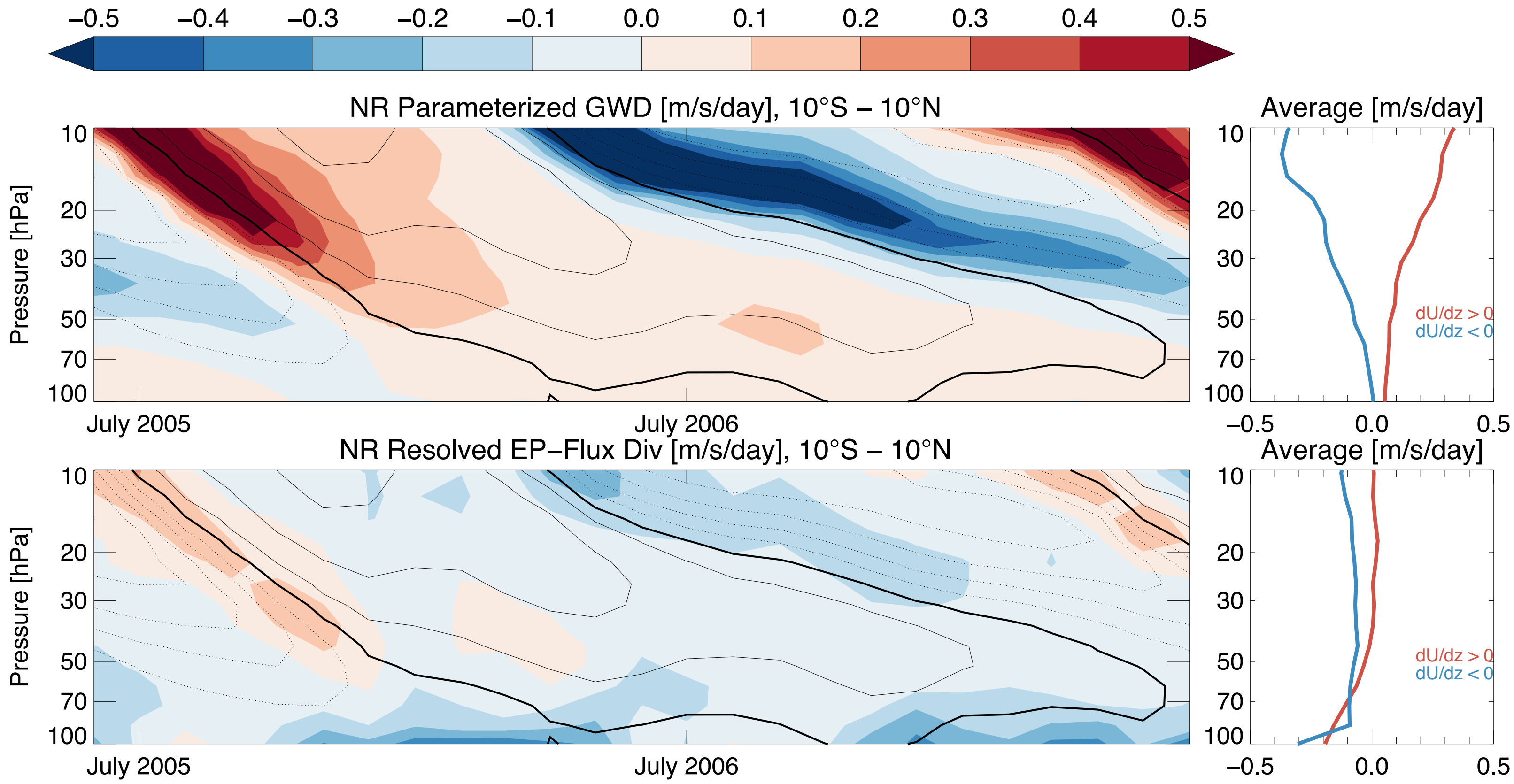
  - Evaluation of tropical waves in the NR
  - QBO in NR and resolved waves
- GW sources in the SH in the NR
- Conclusions

NR produces broad range of convectively coupled waves in tropics



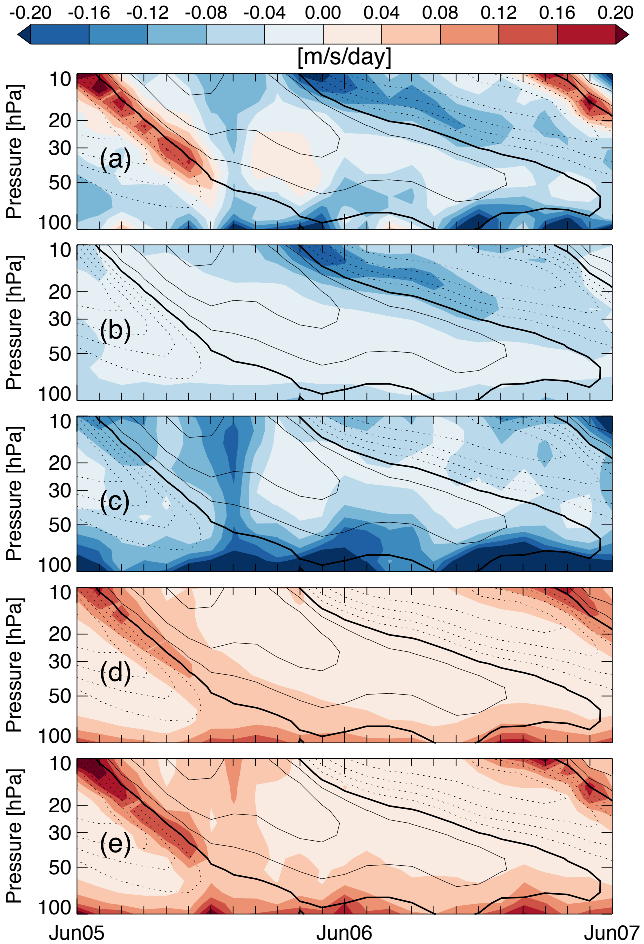
TRMM spectrum reproduced from Kim and Alexander, 2013

NR parameterized GWD and resolved EP-flux divergence



Resolved EP-Flux divergence < 25 % of parameterized GWD

NR vertical EP-Flux divergence from different wavenumber-frequency bins



Total EP flux divergence

Westward small-scale waves

Westward large-scale waves

Eastward small-scale waves

Eastward large-scale waves

Small-scale

$|k| \geq 12$

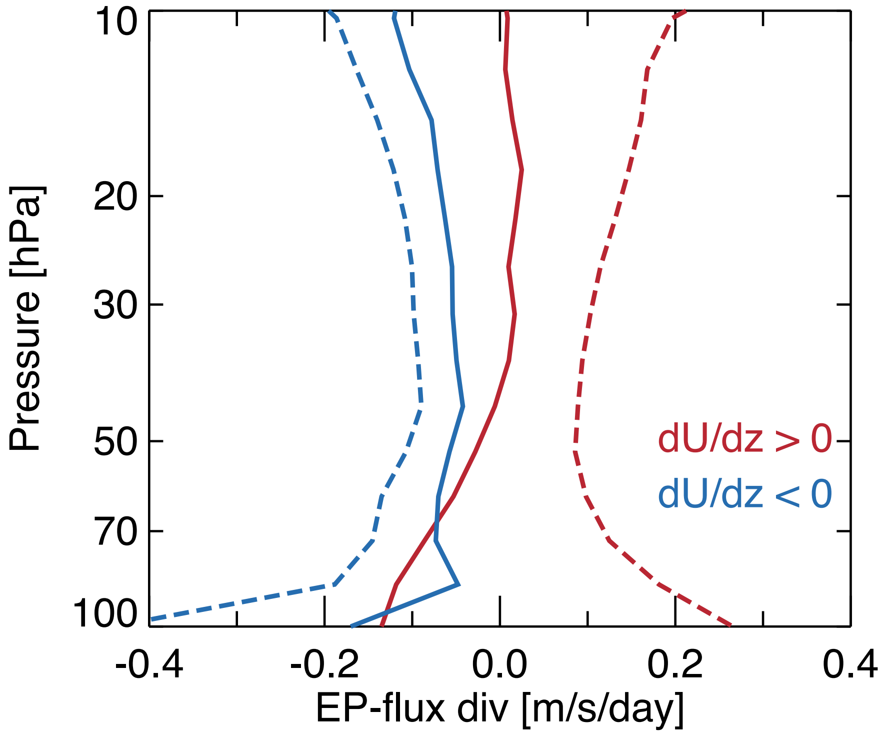
Large-scale

$1 \leq |k| \leq 11$ ($\lambda_x \approx 3600$ km)

$\omega < 1.0$ cpd

- High-frequency, small scale GWs dominate during westward shear phase
- Kelvin waves provide half of the forcing in eastward shear phase
- In agreement with previous studies (e.g. Kawatani et al., 2010)

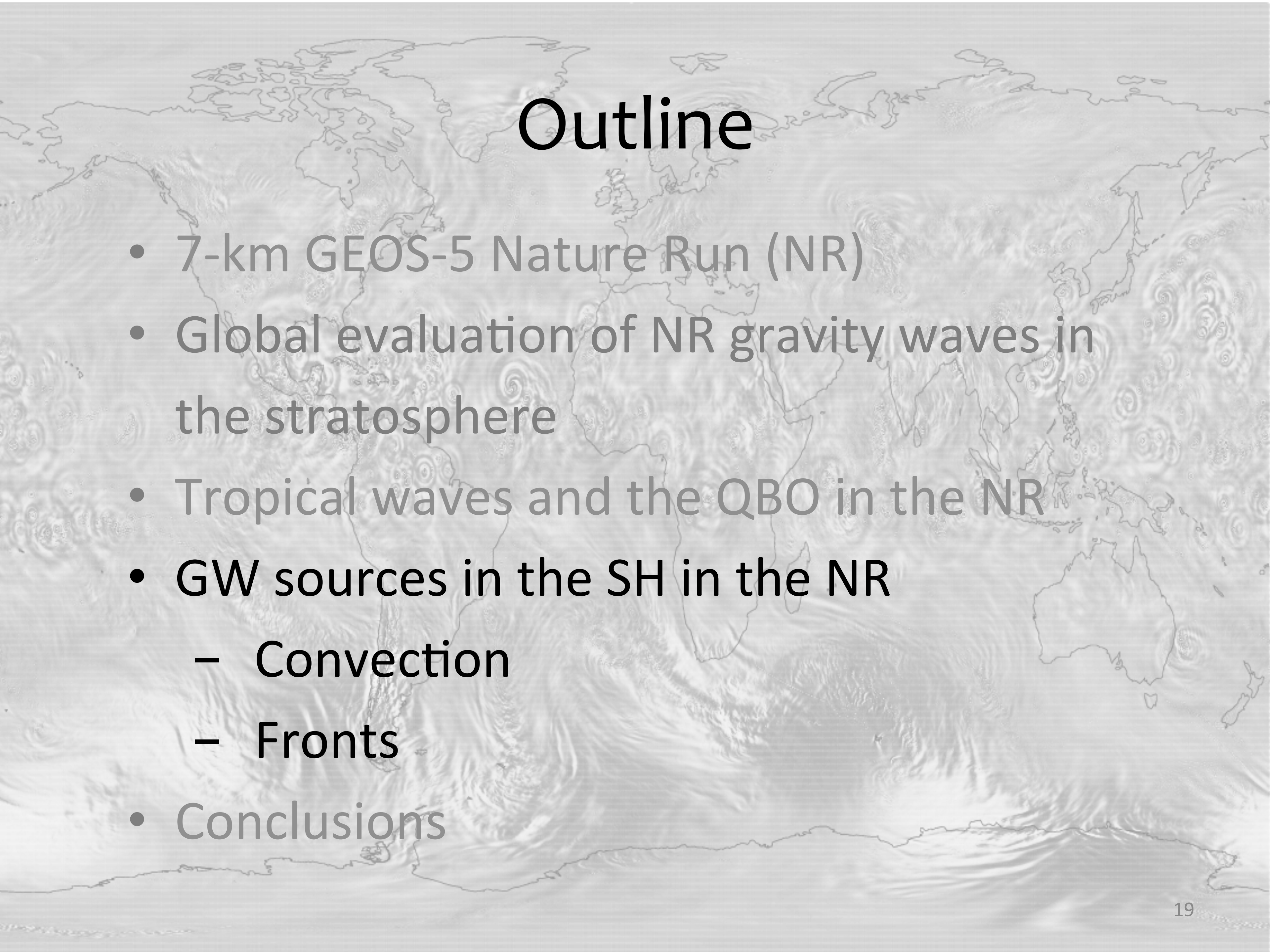
NR EP-flux divergence averaged over shear zones



Solid lines = Total EP flux divergence in eastward shear (red) and westward shear (blue) zones

Dashed lines = Only eastward (westward) EP flux divergence in eastward (westward) shear zones

Large amount of cancelation in both shear zones and especially in westerly shear zones. Probably due to vertical resolution and dissipation.



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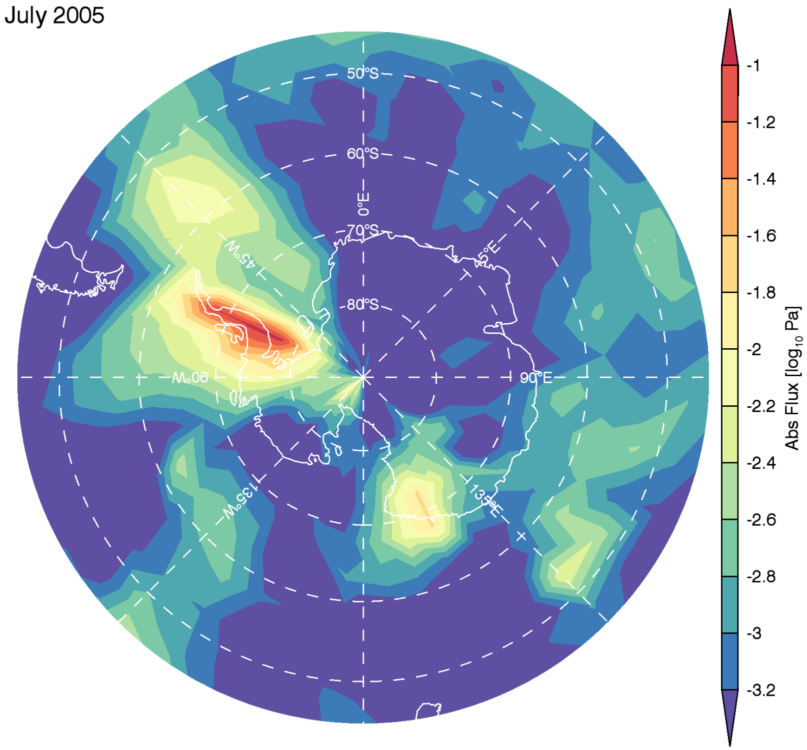
  - Convection
  - Fronts
- Conclusions

GW sources in the SH

GW (<1000 km) Abs Mom Flux at 15 km



Binned to 10° lon x 5° lat

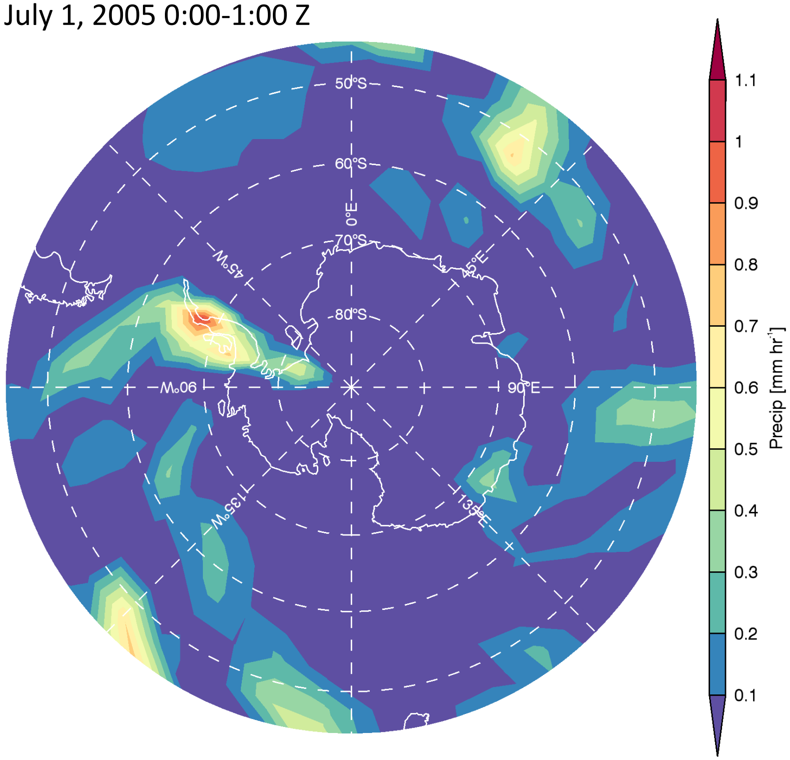
Can we relate large-scale diagnostics of convection and fronts in the troposphere to the GW momentum flux in the lower stratosphere?

Convection

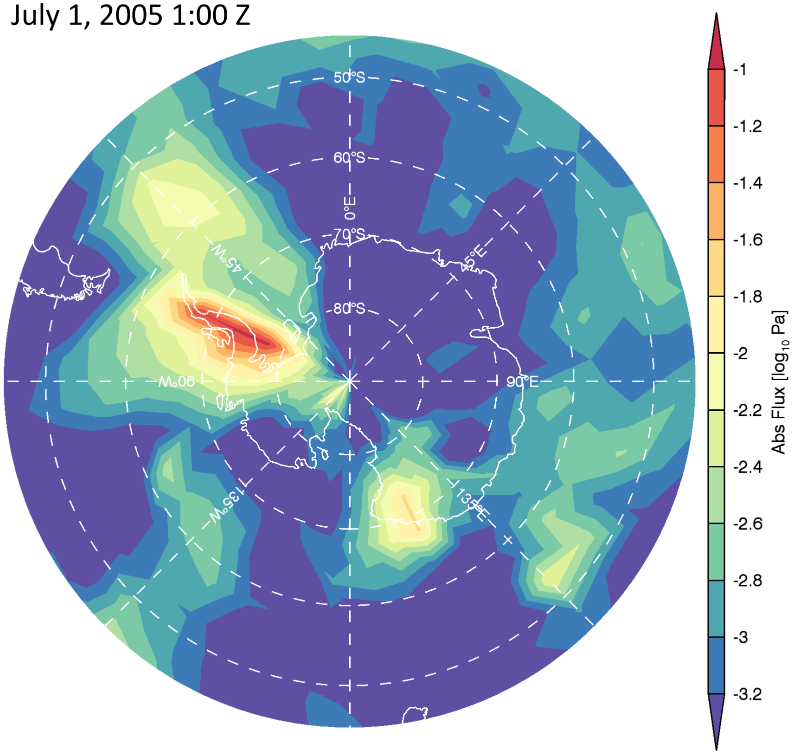
July 1, 2005 Precipitation
(hourly average)

GW (<1000 km) Abs
Mom Flux at 15 km

July 1, 2005 0:00-1:00 Z

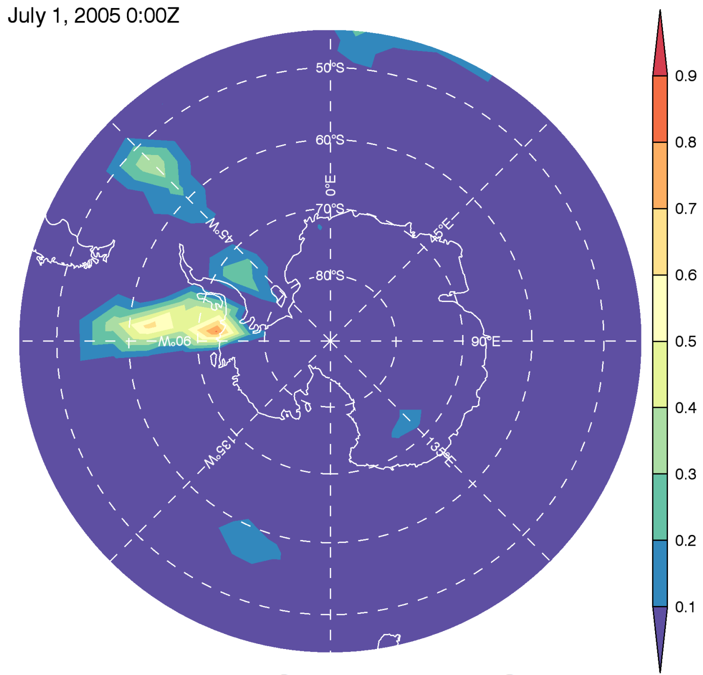


July 1, 2005 1:00 Z

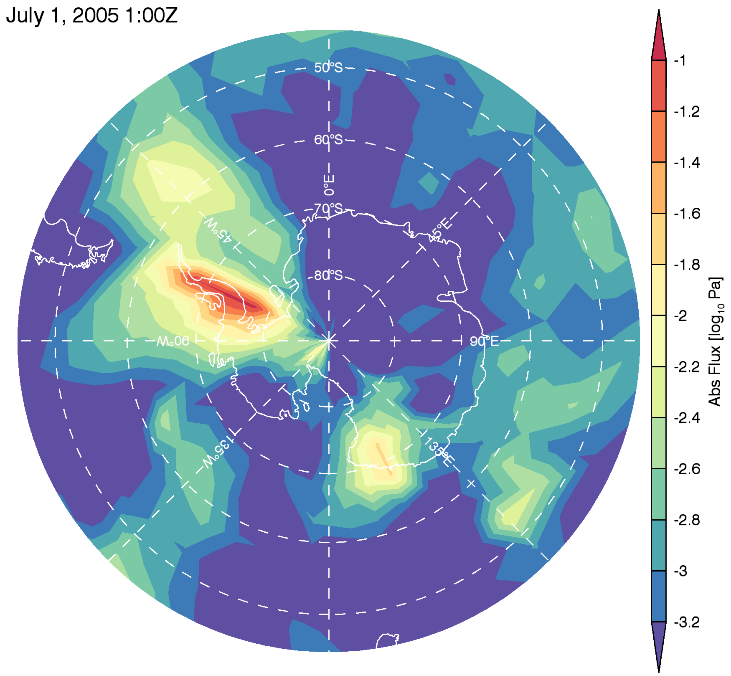


Frontogenesis function

Frontogenesis function at 600 mbar



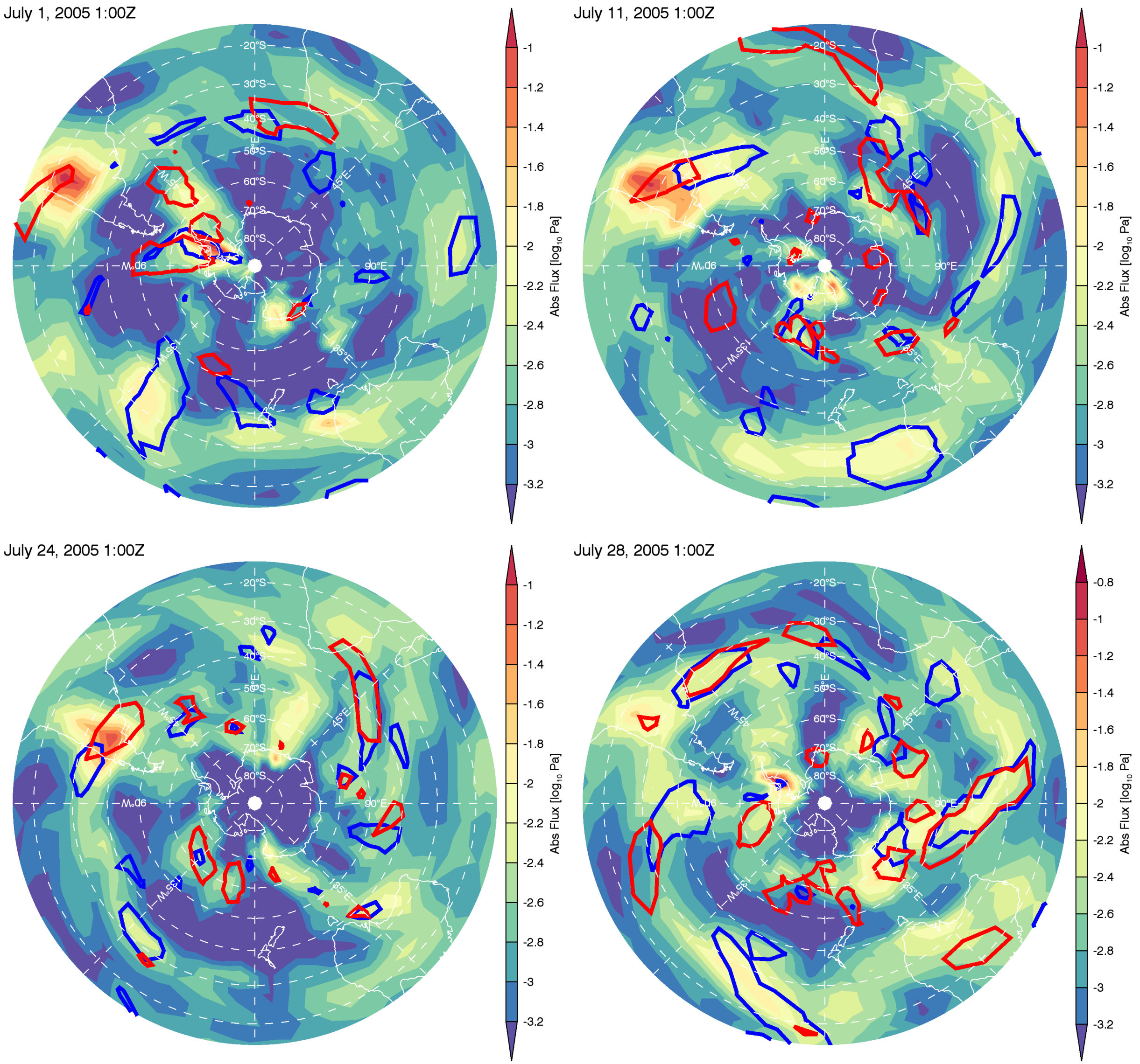
GW (<1000 km) Abs Mom Flux at 15 km



$$\begin{aligned}\frac{1}{2}\frac{D|\nabla\theta|^2}{Dt} = &-\left(\frac{1}{a\cos\phi}\frac{\partial\theta}{\partial\lambda}\right)^2\left[\frac{1}{a\cos\phi}\frac{\partial u}{\partial\lambda}-\frac{v\tan\phi}{a}\right]\\ &-\left(\frac{1}{a}\frac{\partial\theta}{\partial\phi}\right)^2\left[\frac{1}{a}\frac{\partial v}{\partial\phi}\right]-\left(\frac{1}{a\cos\phi}\frac{\partial\theta}{\partial\lambda}\right)\left(\frac{1}{a}\frac{\partial\theta}{\partial\phi}\right)\\ &\times\left[\frac{1}{a\cos\phi}\frac{\partial v}{\partial\lambda}+\frac{1}{a}\frac{\partial u}{\partial\phi}+\frac{u\tan\phi}{a}\right] \qquad (2.1)\end{aligned}$$

Charron and Manzini, 2002 JAS

SH gravity wave sources



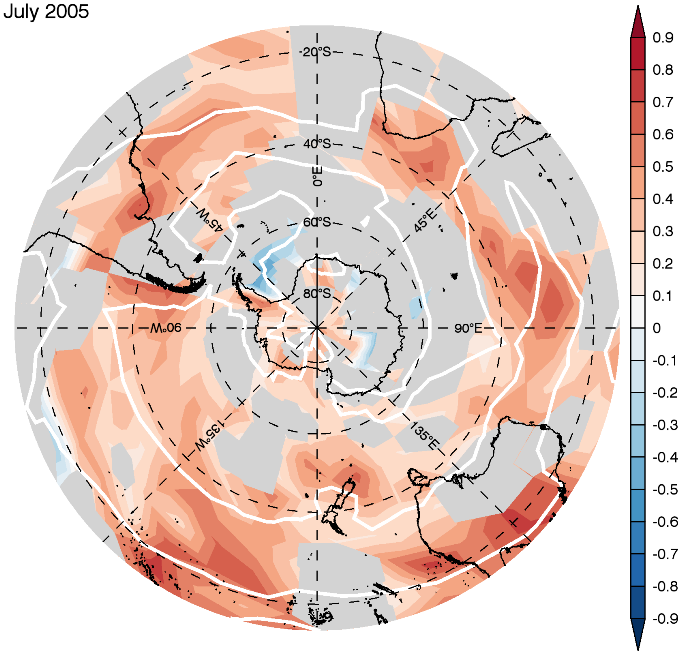
Precipitation

Fronts

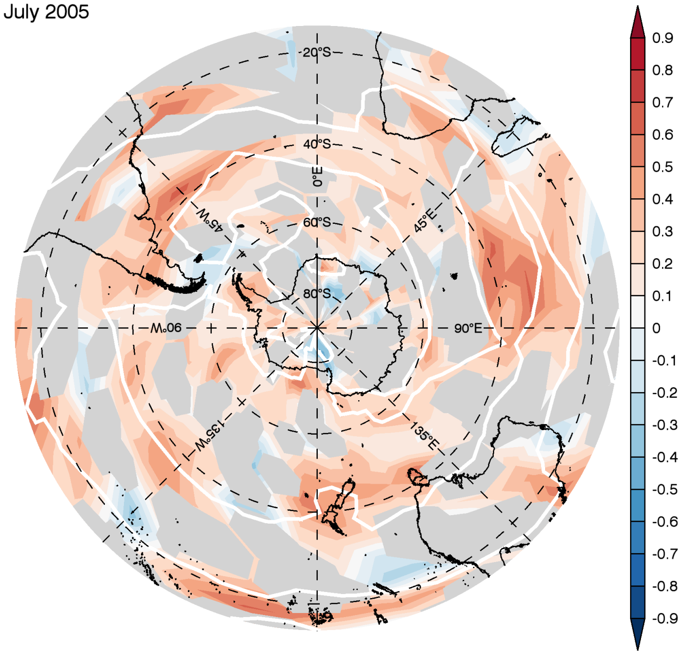
SH gravity wave sources

Spearman rank correlation with GW momentum flux for July

Precipitation



Fronts



Convection is an important source of GWs in the SH in NR

Conclusions

- Global pattern of gravity wave absolute momentum flux in NR compares well to other models but global mean values are on the lower end
- NR is similar to AIRS in global pattern but NR waves have smaller amplitude and longer wavelength
- Resolved small-scale waves in tropics are well-represented and behaving realistically in NR
- Still need parameterized GWs to get QBO—vertical resolution? Dissipation?
- A look at SH sources highlights the importance of convection

Thank You

Absolute GW Momentum Flux

$$\mathbf{M}^2 = \left(1 - \frac{f^2}{\hat{\omega}^2}\right)\rho_0^2[(\overline{u'w'})^2 + (\overline{v'w'})^2]$$

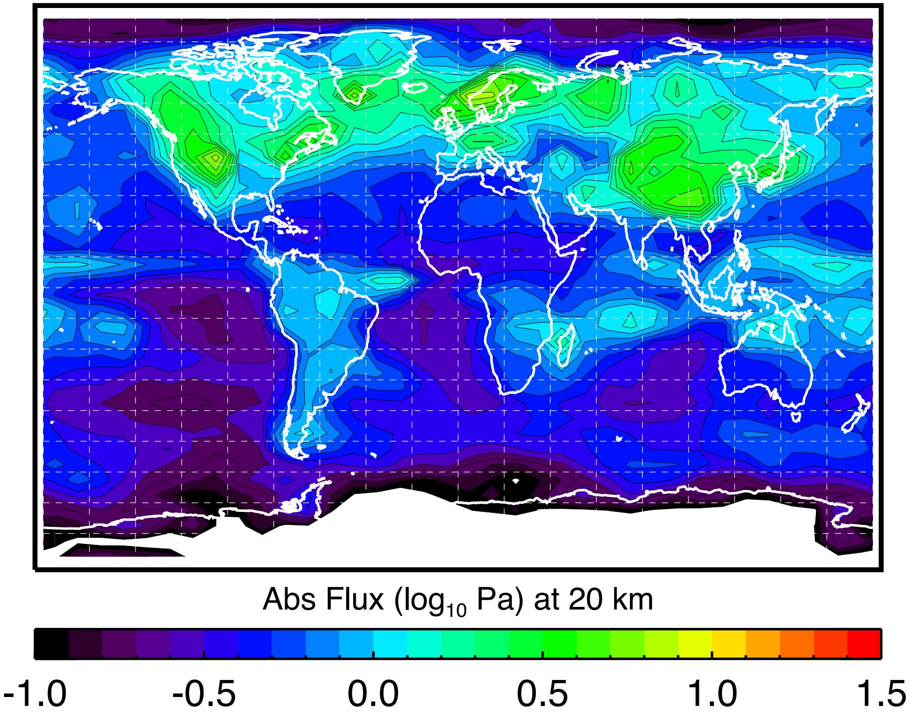
$$= \rho_0^2 w'^2(u'^2 + v'^2)\left[1 - \frac{f^2}{\hat{\omega}^2}\right]\left[1 + \frac{f^2}{\hat{\omega}^2}\right]^{-1}, \qquad (1)$$

where $\frac{f^2}{\hat{\omega}^2} = \left(\frac{fg}{w'N^2}\right)^2\left(\frac{T'}{T_0}\right)^2.$

Geller et al., 2013 JC

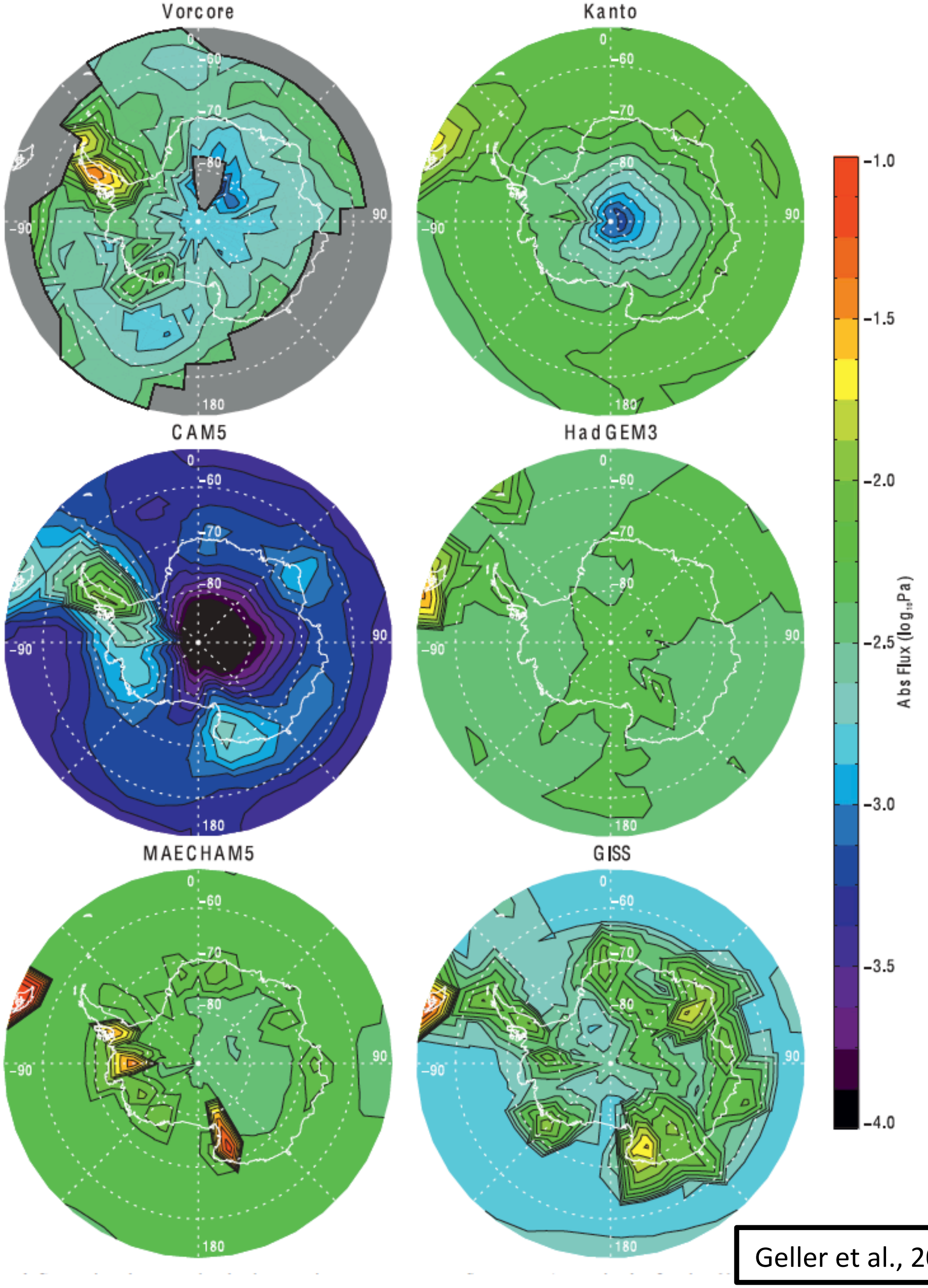
*Primed variables < 1000 km

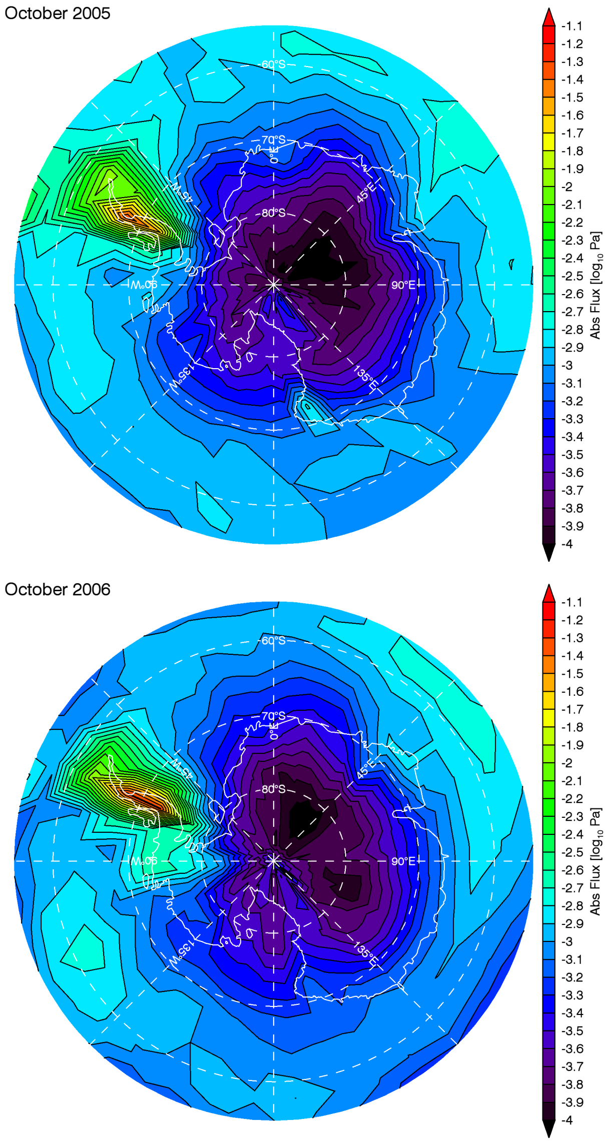
Nature Run January average



Nature Run Abs Mom Flux from Resolved GWs < 1000 km at 20 km

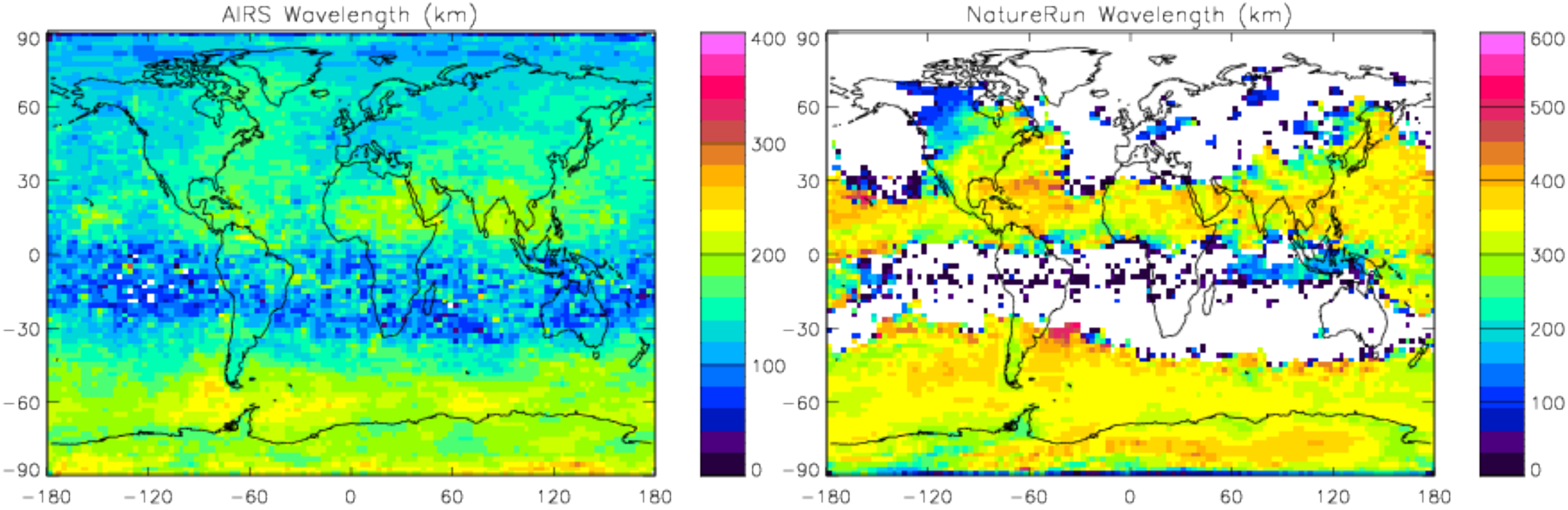
October 2005





Geller et al., 2013 JC

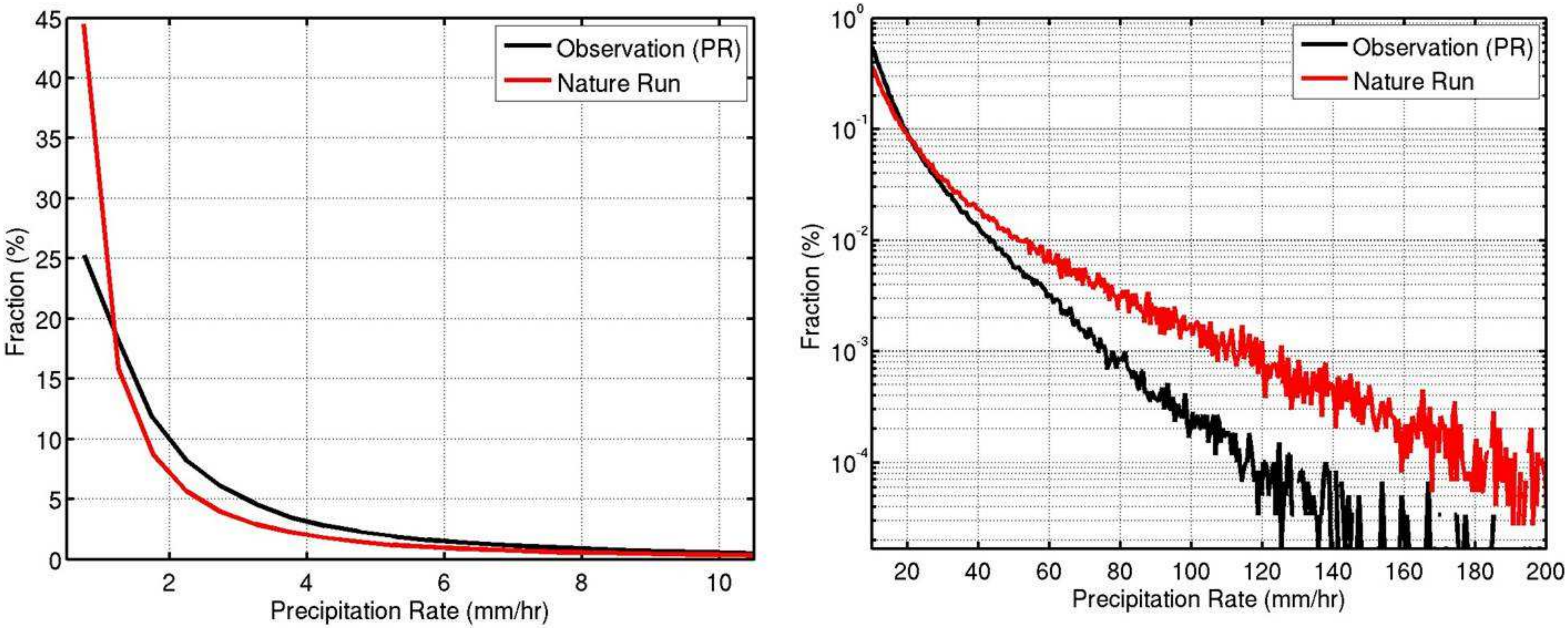
AIRS & NR T_b sampled at AIRS locations: Wavelengths



White = little or no data

AIRS Wavelengths are about 2x smaller than NR

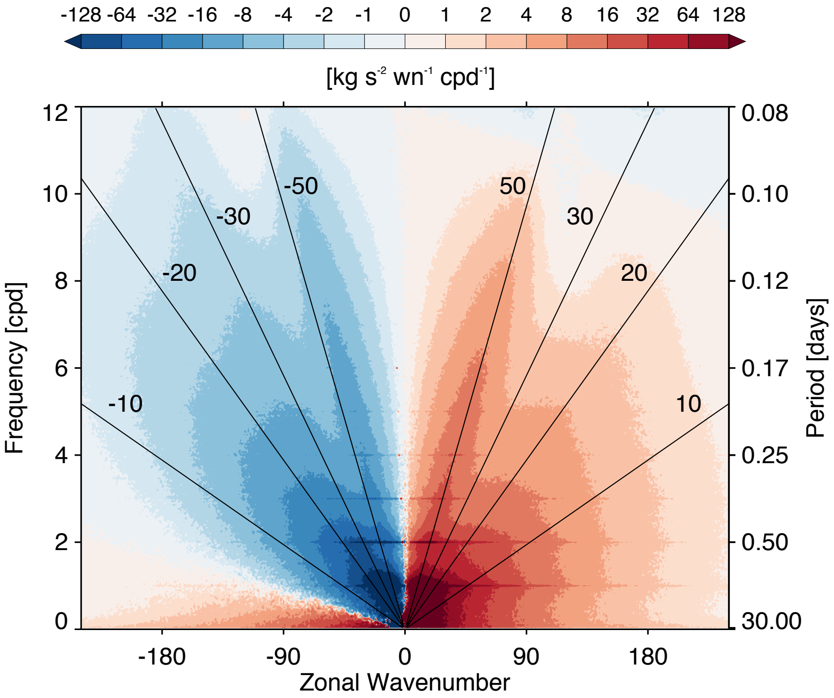
Probability distribution of surface precipitation compared to TRMM



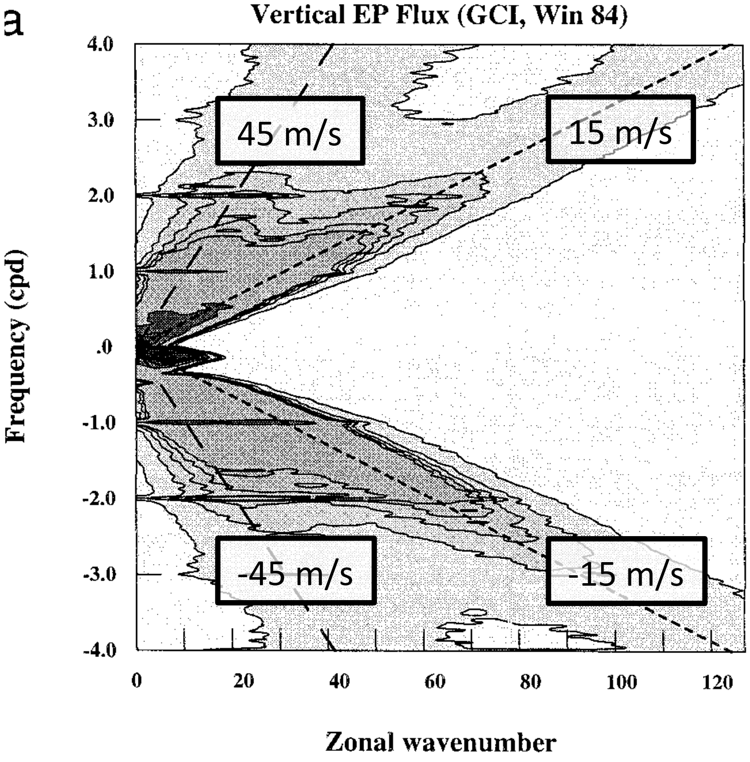
- NR > TRMM for light precipitation (<1 mm/hr) and heavy precipitation (> 20 mm/hr)
- NR < TRMM for precipitation between 1 and 20 mm/hr

NR vertical EP-Flux compared to that derived from Global Cloud Imager

NR



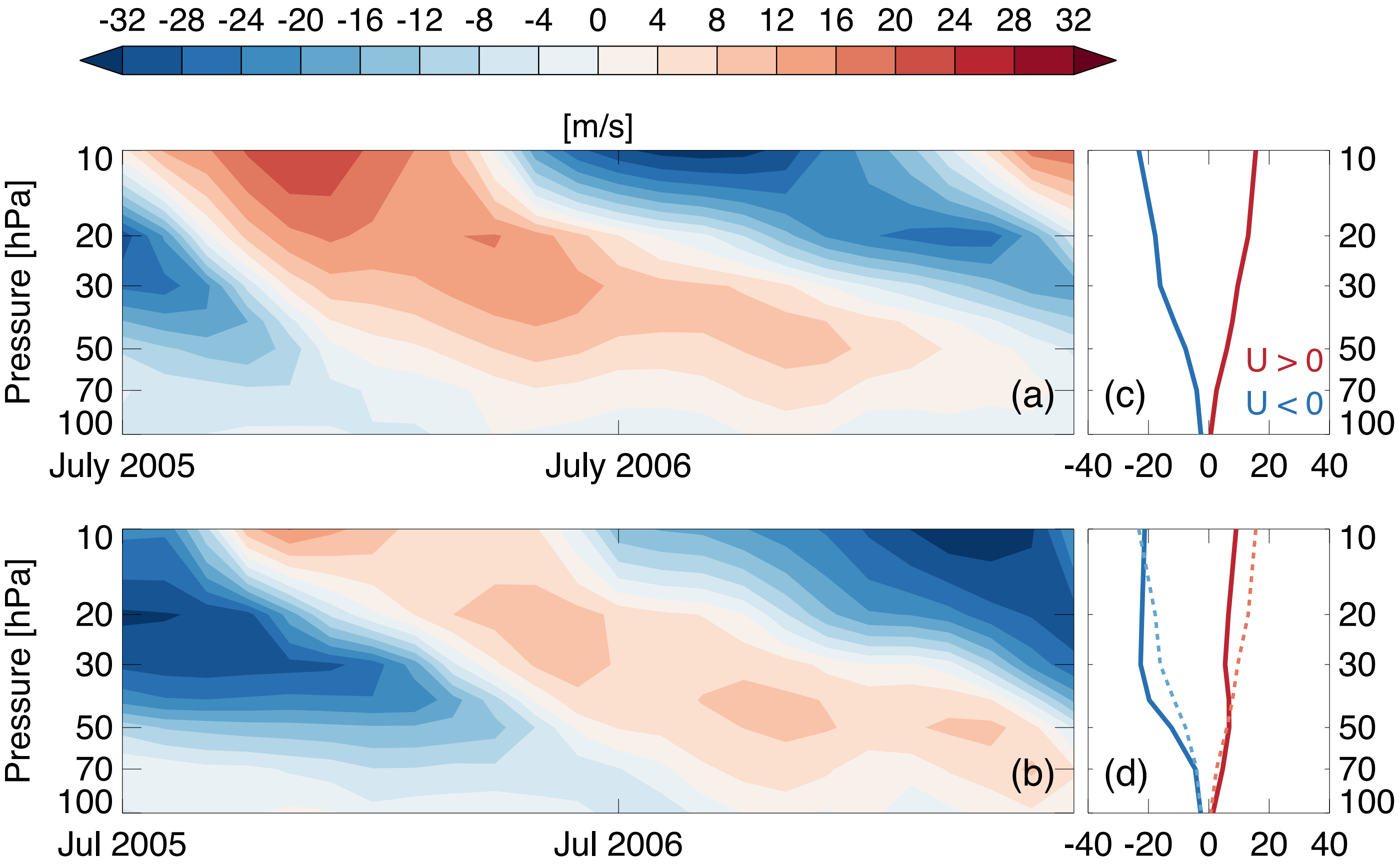
GCI



- Double lobe structure is present in NR
- NR captures the high phase speed lobe

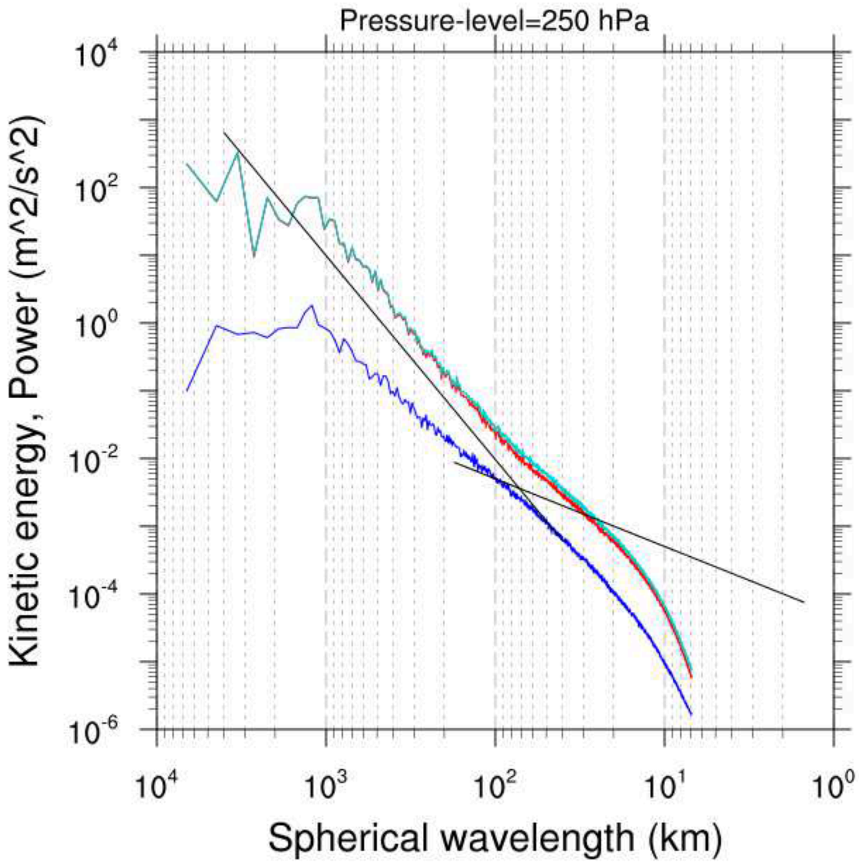
Ricciarduli and Garcia, 2000 JAS

NR and MERRA-2 QBO



Holt et al., 2016 JAS, under review

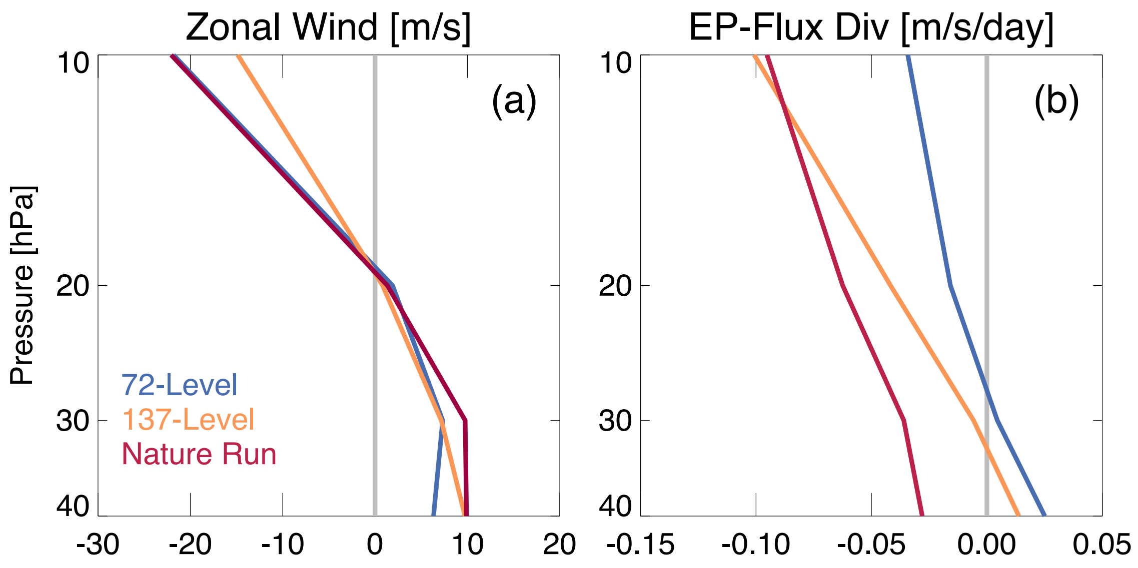
Dissipation?



- NR KE spectrum follows n^{-3} law for large scales
- NR KE spectrum falls off sharply as horizontal wavelength approaches smaller scales

Characteristic of unrealistically large dissipation at the smallest resolved model scales

Vertical resolution?



Control—1° horizontal resolution

Doubled vertical resolution

Horizontal resolution increase to 0.0625°

- Increasing the horizontal resolution by 16x leads to 4x larger EP flux divergence near 0 m/s wind line
- Doubling vertical resolution leads to 2x larger EP flux divergence near 0 m/s wind line

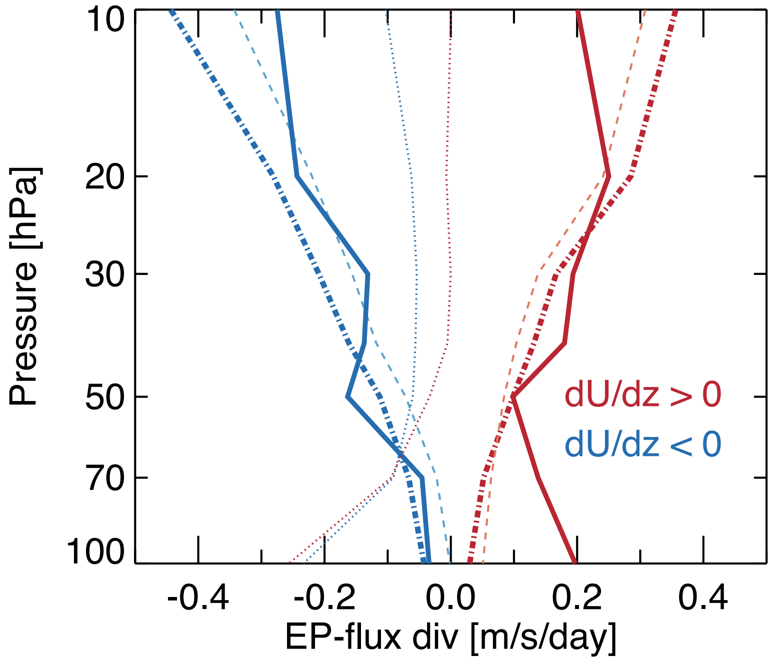
NR vertical EP-flux div compared to MERRA-2 total zonal forcing

$$\underbrace{\frac{\partial \bar{U}}{\partial t} + \bar{w}^{*}\frac{\partial \bar{U}}{\partial z}}_{\boxed{1}} = \underset{\boxed{2}}{\bar{X}} + \underset{\boxed{3}}{\left(\rho_0 a\cos\phi\right)^{-1}\vec{\nabla}\cdot\vec{F}}$$

solid

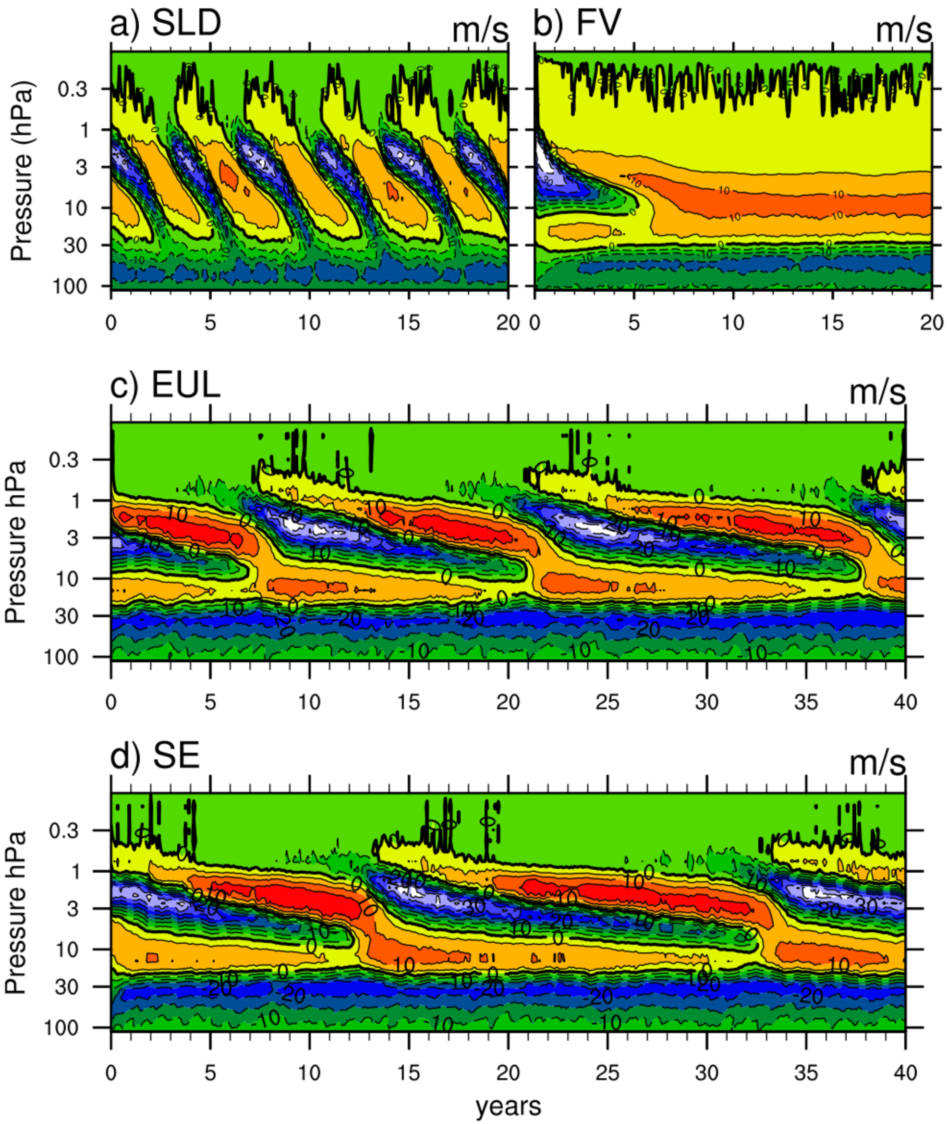
dashed

dot-dash



Without large amount of cancelation perhaps the parameterized GWD could be tuned down

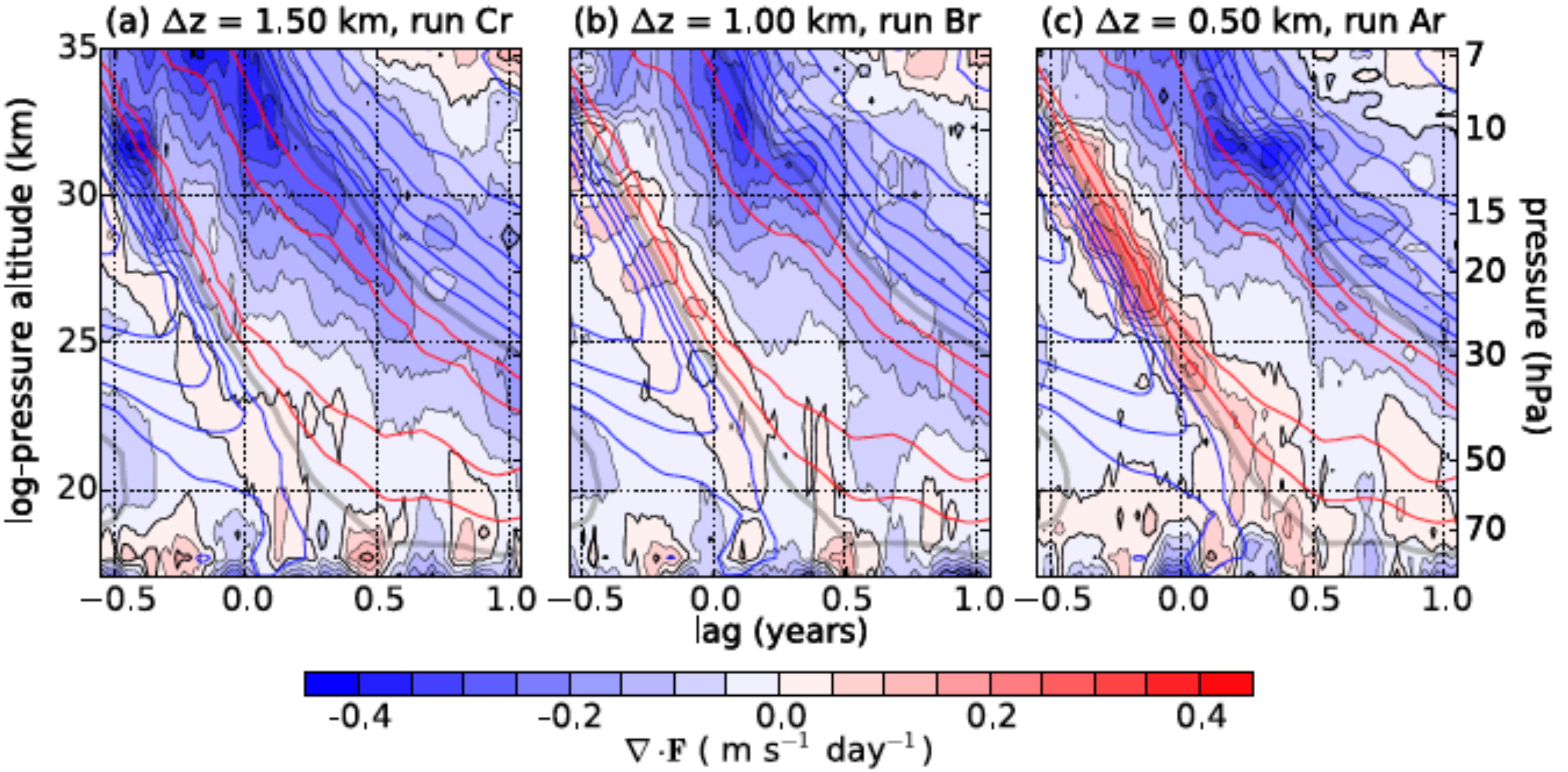
Influence of dynamical core choice?



- Dry GCM dynamical cores
- QBO-like oscillations in all but FV
- Measures of wave activity much lower in FV

Yao and Jablonowski, 2015 JAS

Vertical resolution?



Anstey et al., 2016 JAS

Geostrophic adjustment

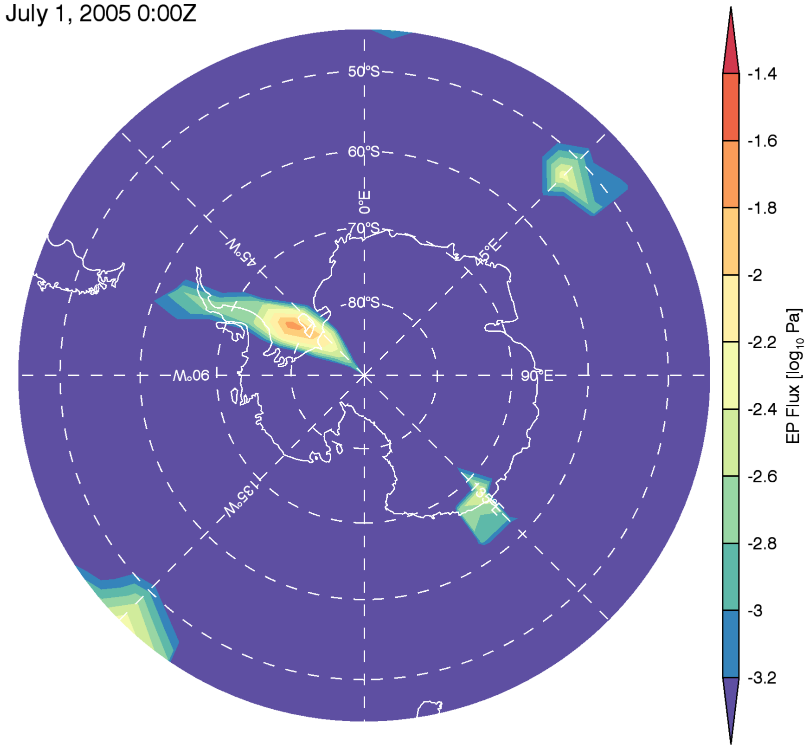
Spontaneous emission of gravity waves from PV anomalies in a vertical shear produce a gravity wave EP-flux given by:

$$F = \frac{F_0}{4} e^{-\pi\sqrt{J}}$$

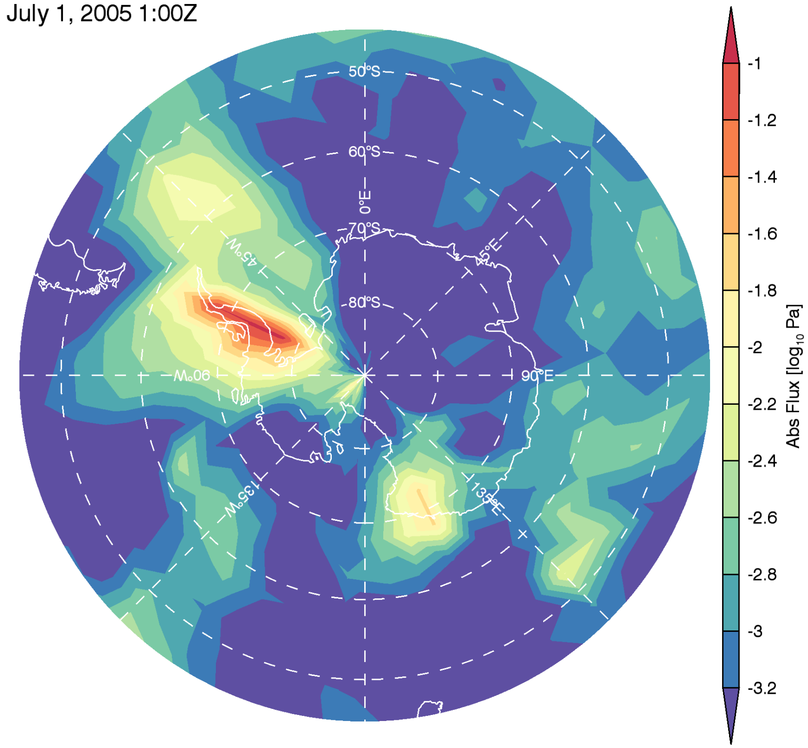
J=Richardson number

Lott et al., 2010 JAS

Estimate of EP-flux due to PV anomalies



EP-Flux due to GW launched from PV anomalies near tropopause



GW (<1000 km) Abs Mom Flux at 15 km