Importance of Gravity Wave Forcing for Springtime Antarctic Polar Vortex Breakdown as Revealed by ERA5

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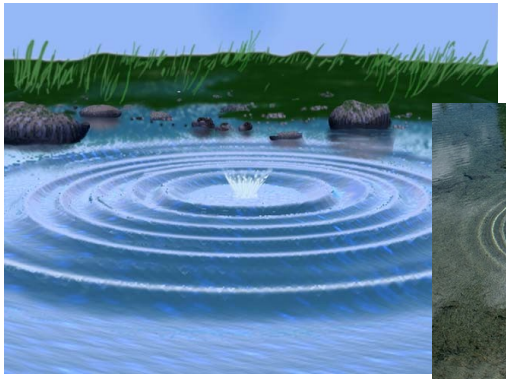
25th March 2021

In Pictures : Gravity Waves



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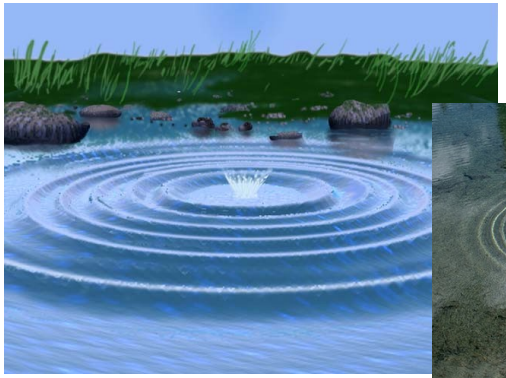

In Pictures : Gravity Waves

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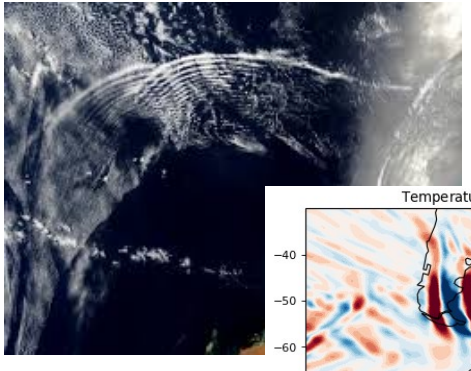
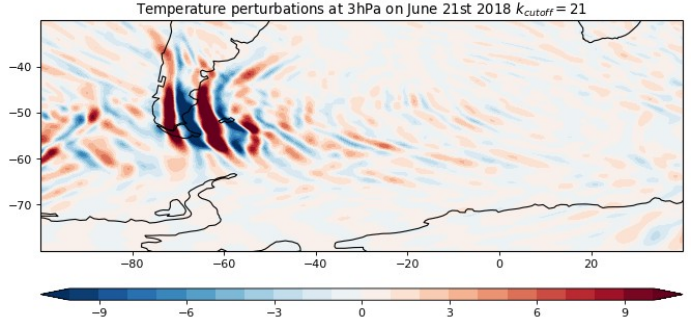




Role of Gravity Waves in the Middle Atmosphere

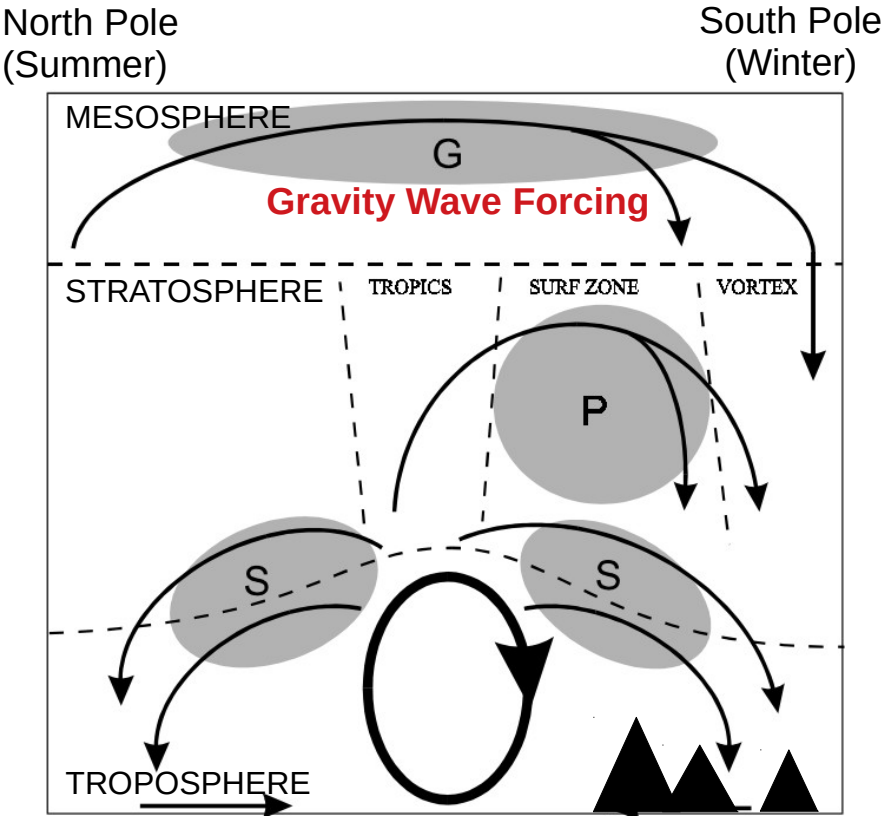
Key drivers of middle atmospheric circulation -

Mesosphere : drive pole-to-pole circulation

Stratosphere : Key role during vortex adjustment, vortex breakdown.

Source : Orography, storm tracks, secondary generation etc.

Central Problem : What does the atmospheric gravity waves spectrum look like?
Observations? Modeling?

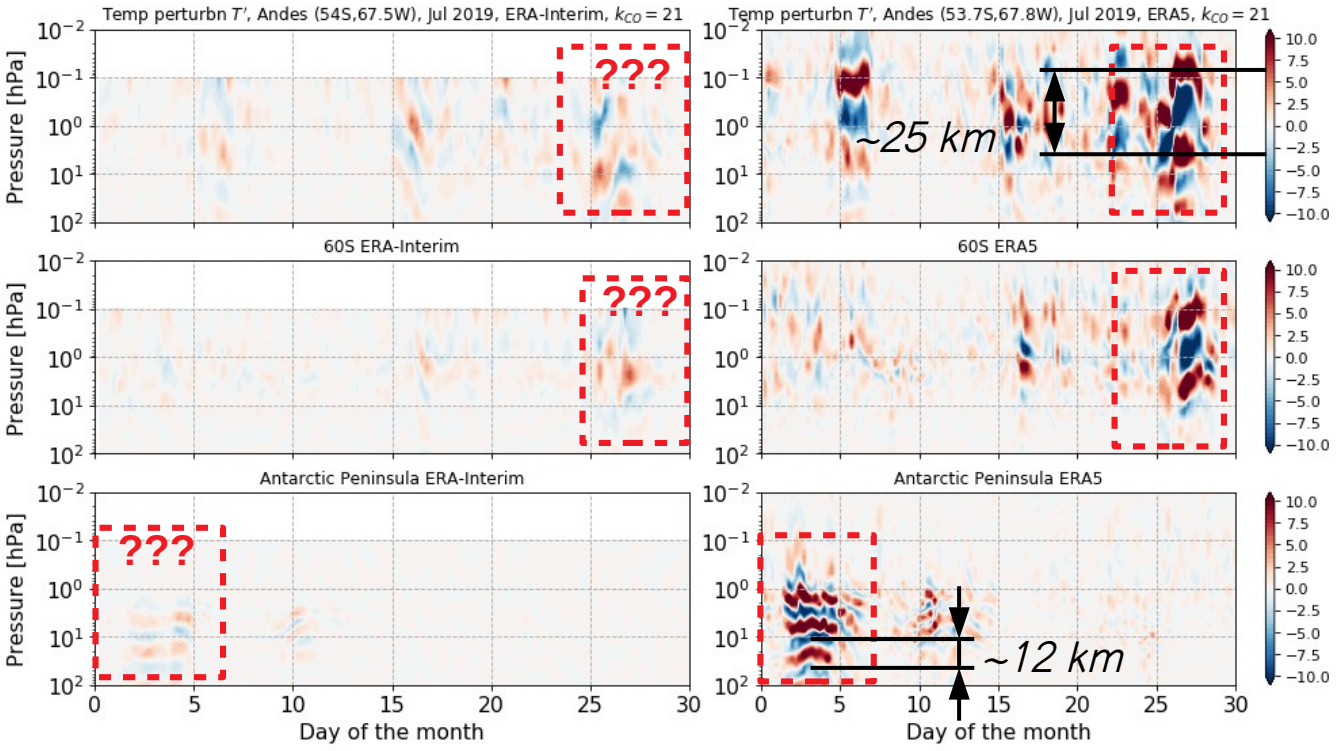


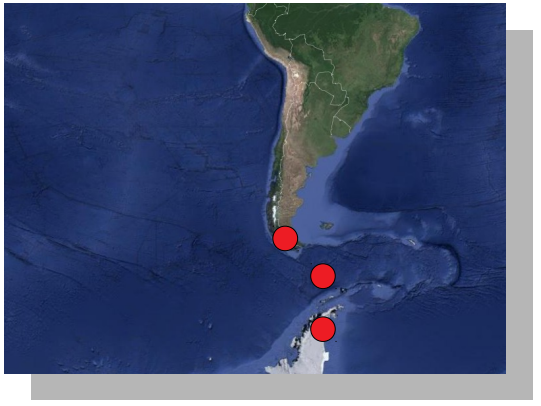
Source : Plumb (2002)

ERA-Interim has no gravity waves; ERA5 does!

ERA-Interim (0.75°, L60)

ERA-5 (0.3°, L137)

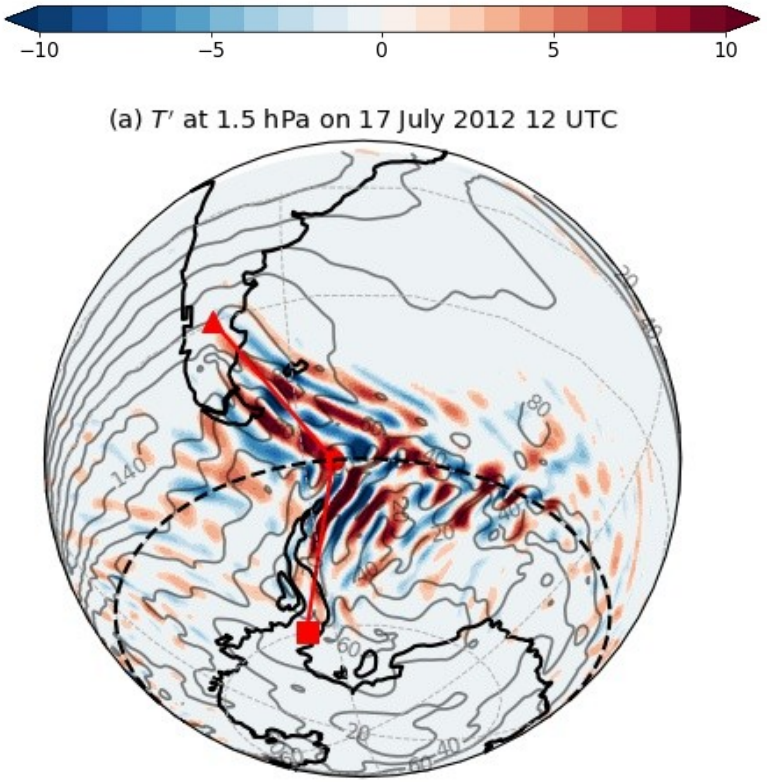




Point-based temperature perturbations by filtering off the first 20 zonal wavenumbers.

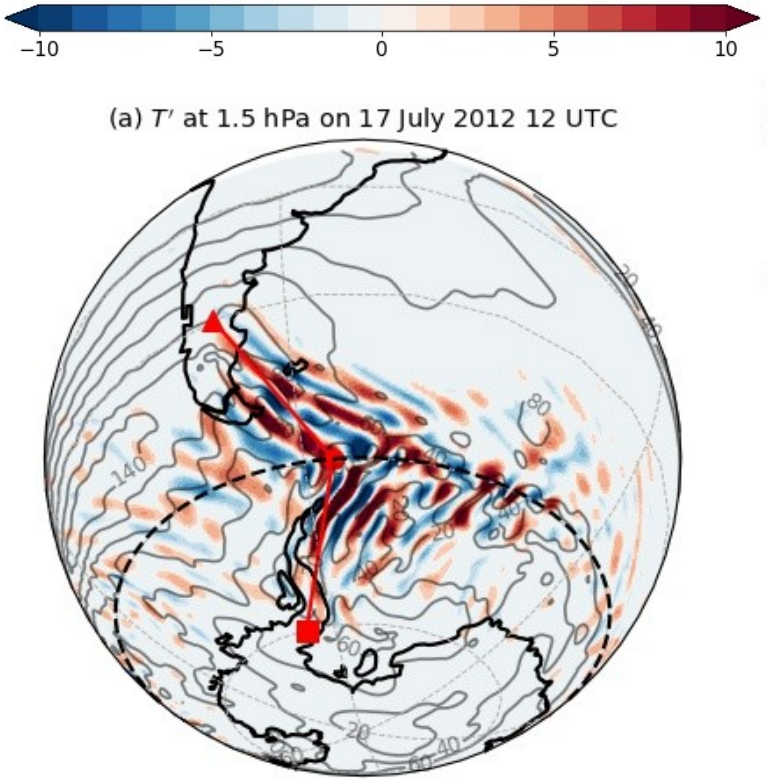
Clear GWs in ERA5. ERA-I only faintly resolves the gravity waves.

ERA-5 resolves a broad spectrum of GWs



ERA5 temperature perturbations T'
zonal wavenumbers 21 and higher

ERA-5 resolves a broad spectrum of GWs



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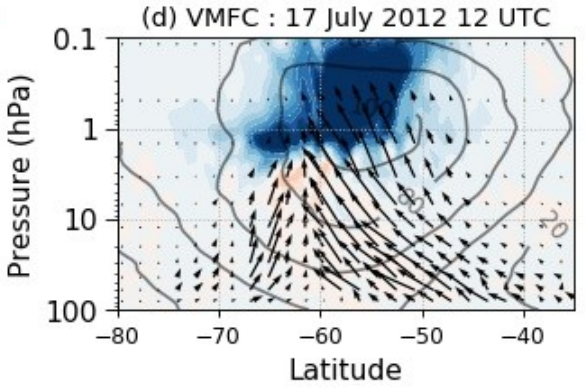
(Units : m/s/day)



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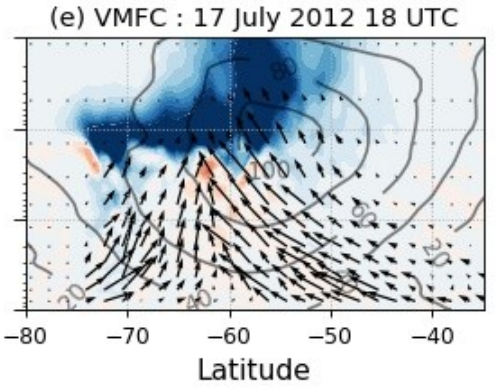


Colors : resolved GW forcing

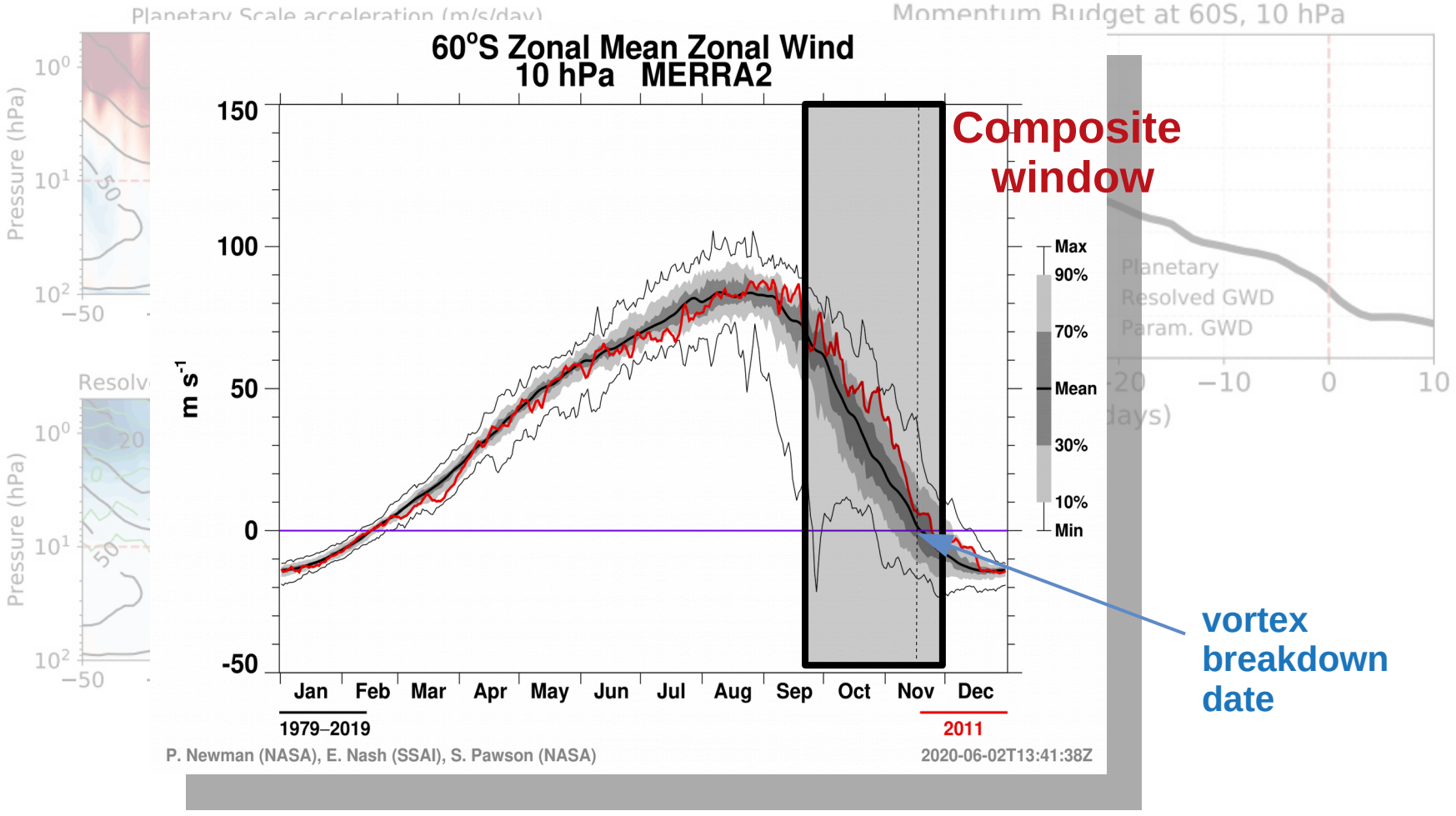
$$\text{VMFC} : -\overline{u'\omega'}_p$$

Arrows : energy flux

$$\vec{E} = (\overline{p'v'}, \overline{p'\omega'})$$

- Possible to study propagation properties (not possible with parameterizations) and estimate mean forcing.

Role of GWs during the Polar Vortex Breakdown

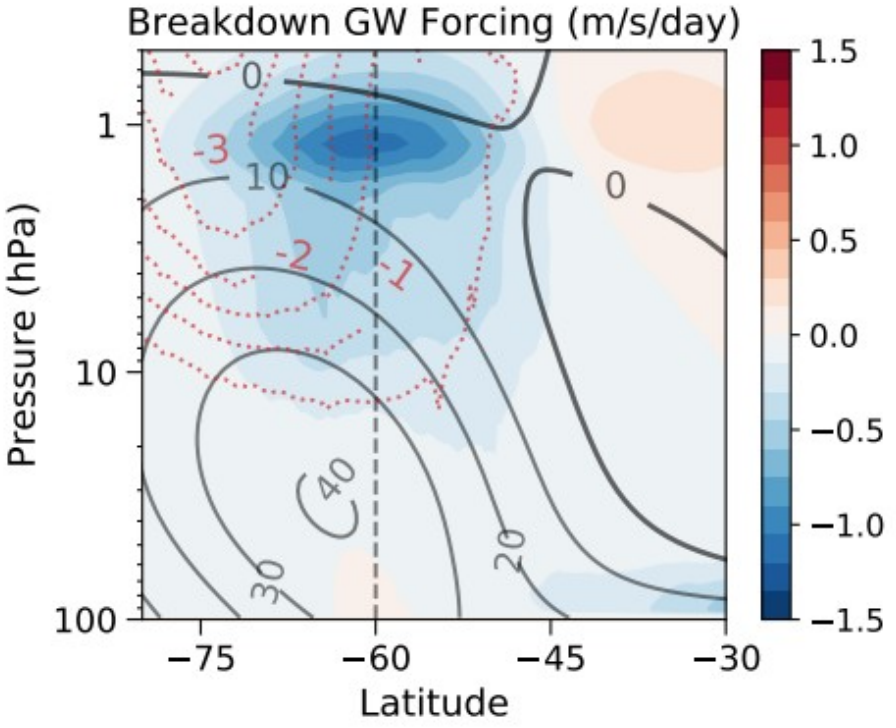


How much springtime forcing do GWs provide?

Color :

VMFC : $-\overline{u'\omega'}_p$

Black Curves :
Zonal wind (m/s)



Color : Resolved GW forcing
Red dotted : Parameterized GW forcing

GW Forcing of up to -3 m/s/day during the breakdown period

Zonal Mean Momentum Budget

<------- mean meridional circulation -------> <----- wave forcing ---->

$$\overline{u}_t = \underbrace{\left(f - \frac{1}{R\cos\phi}(\overline{u}\cos\phi)_\phi \right)\overline{v}^*}_{\text{Coriolis}} - \overline{\omega}^*\overline{u}_p + \underbrace{\frac{1}{R\cos\phi}\vec{\nabla}\cdot\vec{F}}_{\text{EPFD}} + \underbrace{\overline{X}}_{\text{PGWD}}$$

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Planetary scale acceleration

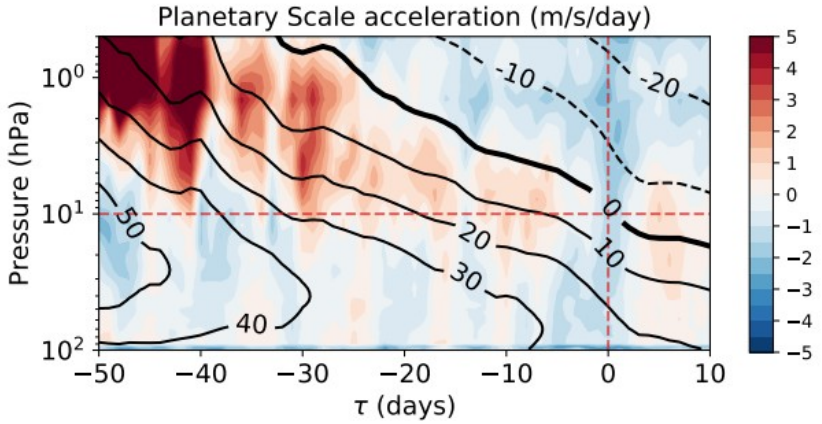
Coriolis + EPFD - VMFC

Gravity wave forcing

VMFC + PGWD

Role of GWs during the Polar Vortex Breakdown

at 60S



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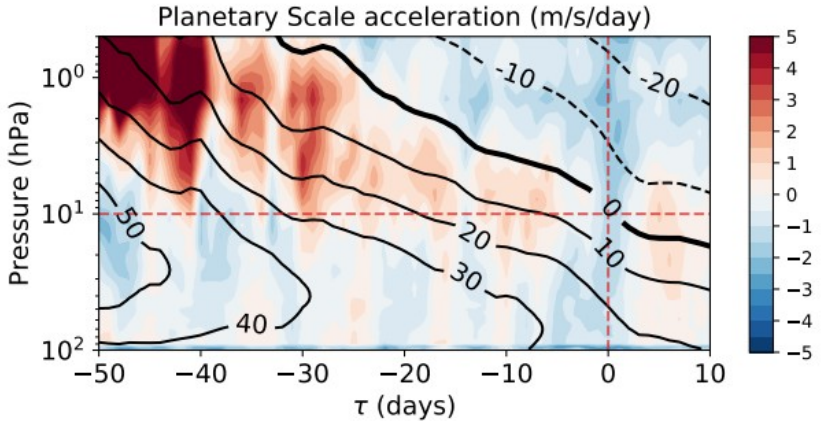

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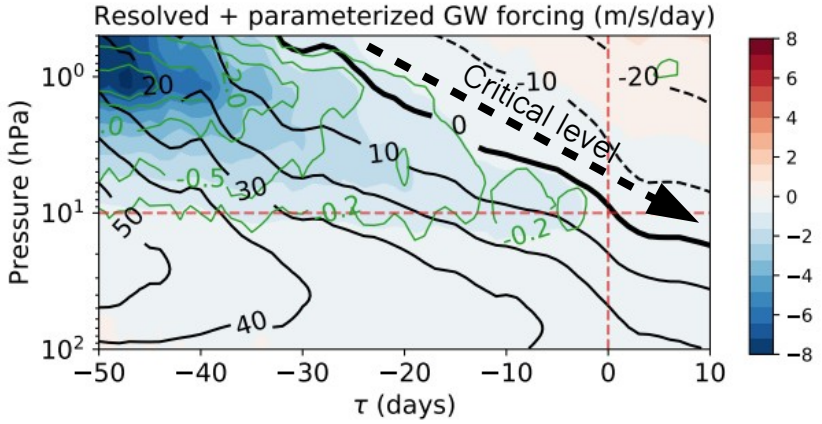

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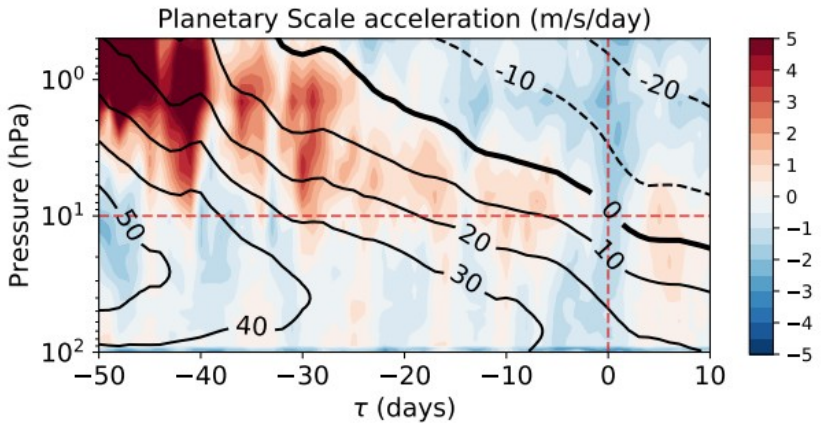
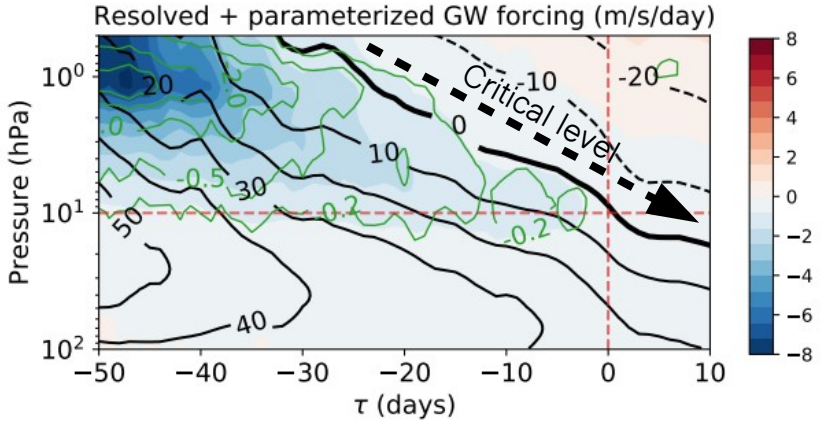
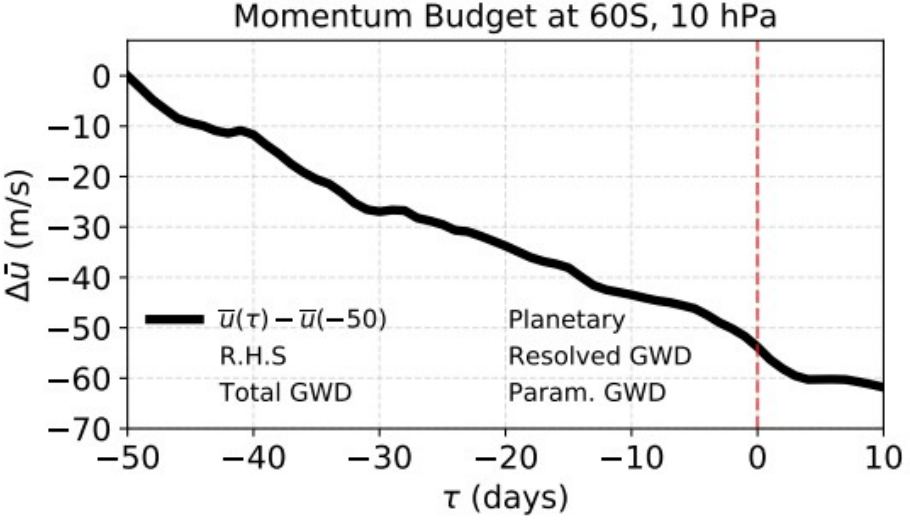


at 60S





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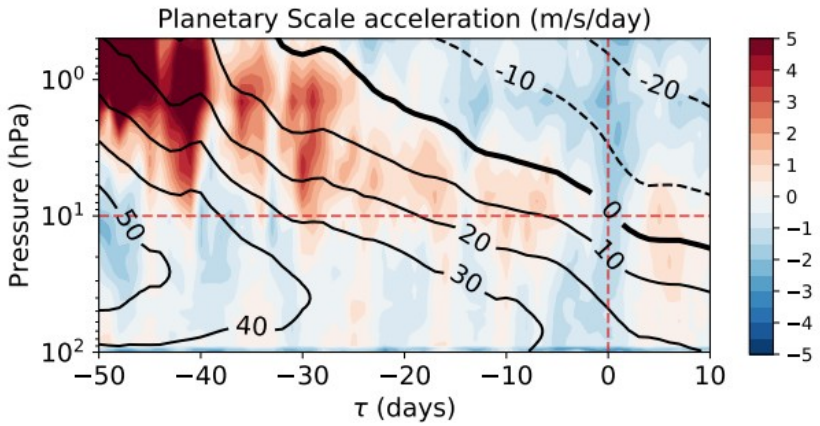
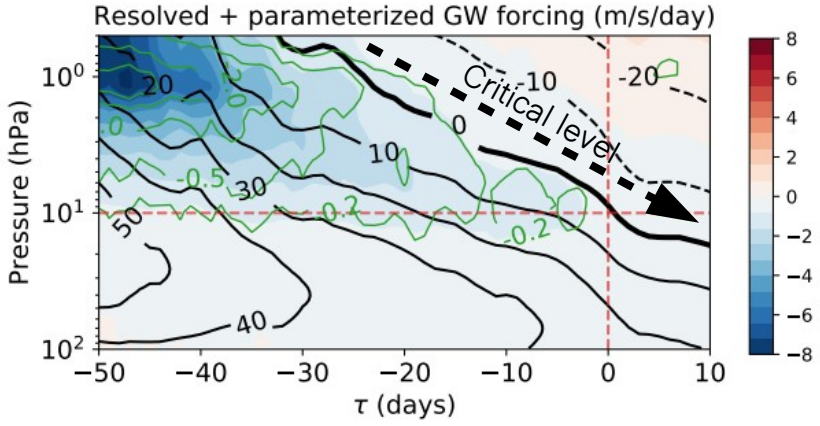
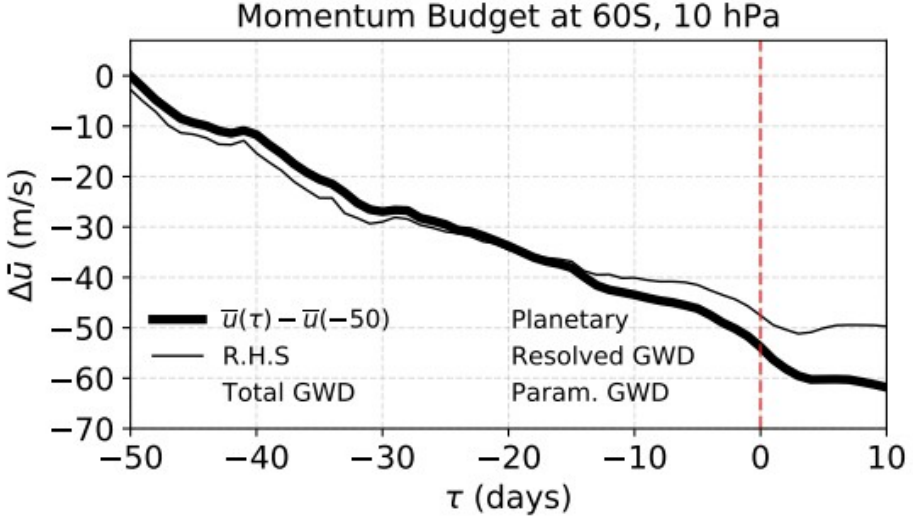


at 60S





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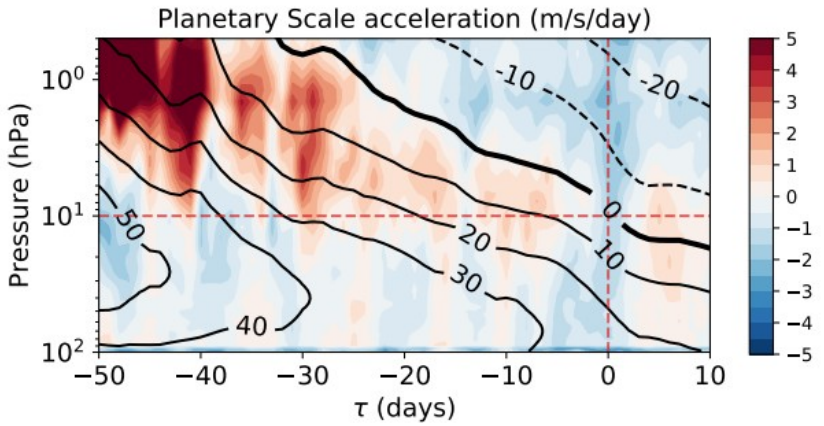
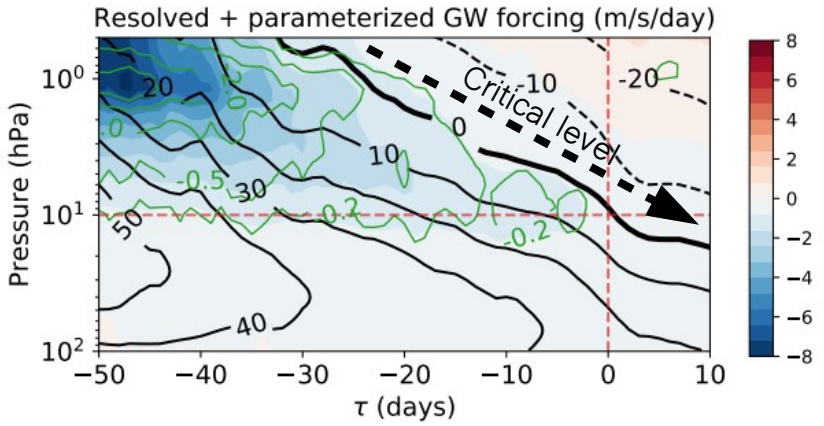
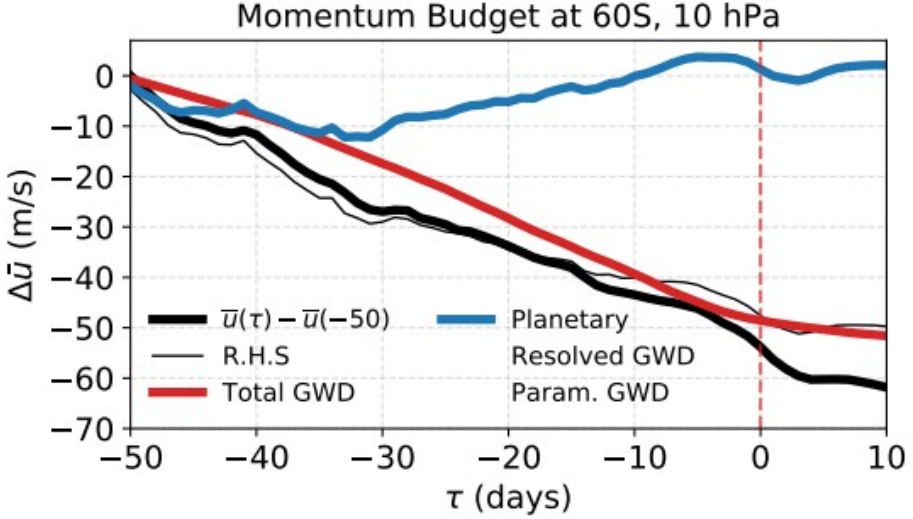


at 60S

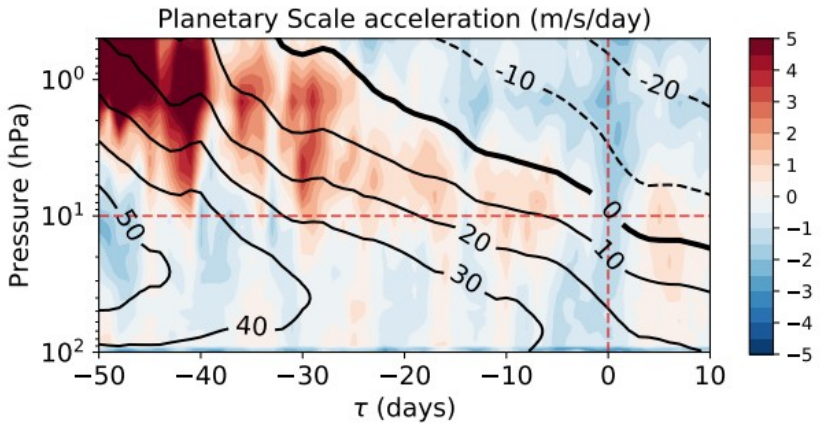




- Initially, comparable deceleration from both large scale and small scale terms.
- Subsequently, planetary scale wave-mean flow interactions provide net acceleration

Role of GWs during the Polar Vortex Breakdown

at 60S



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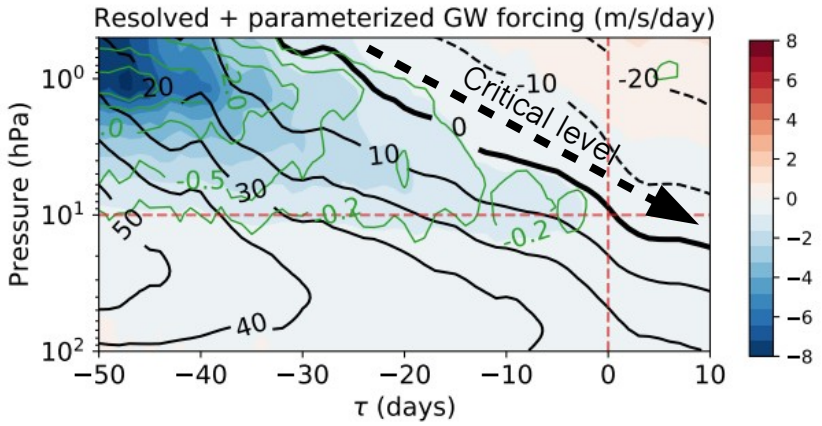
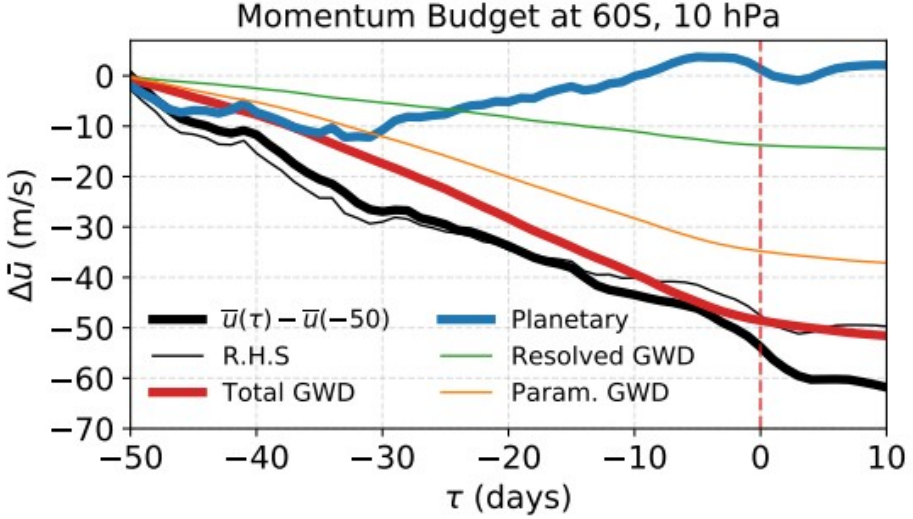
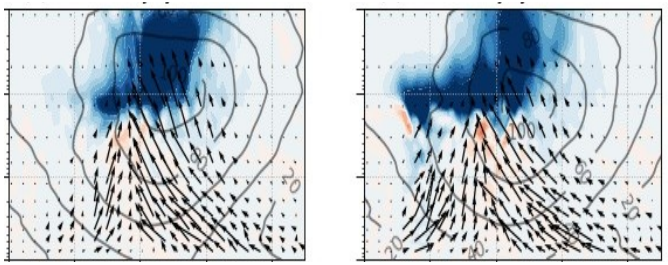


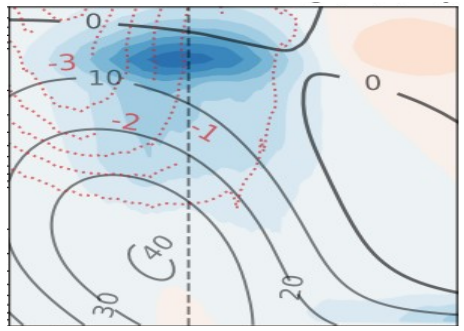


- GWs provide steady deceleration throughout the breakdown period
- Total GWD provides more than 75% of the *total necessary wind deceleration*
- GW forcing comparable to PW forcing (not shown)

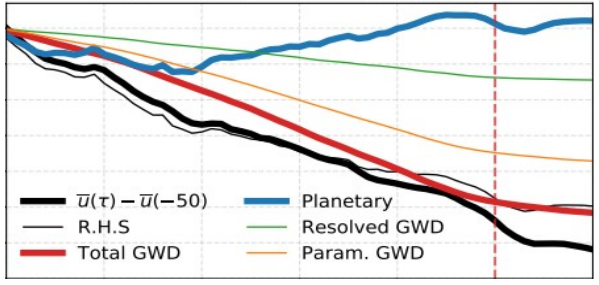
Conclusion



ERA5 resolves a broad spectrum of gravity waves! Makes it possible to estimate their forcing during the vortex breakdown. First time in a reanalysis product.



Contribution of these GWs to the mean zonal winds can be significant - deceleration of up to -10 m/s/day during peak winters and -3 m/s/day in late winters.



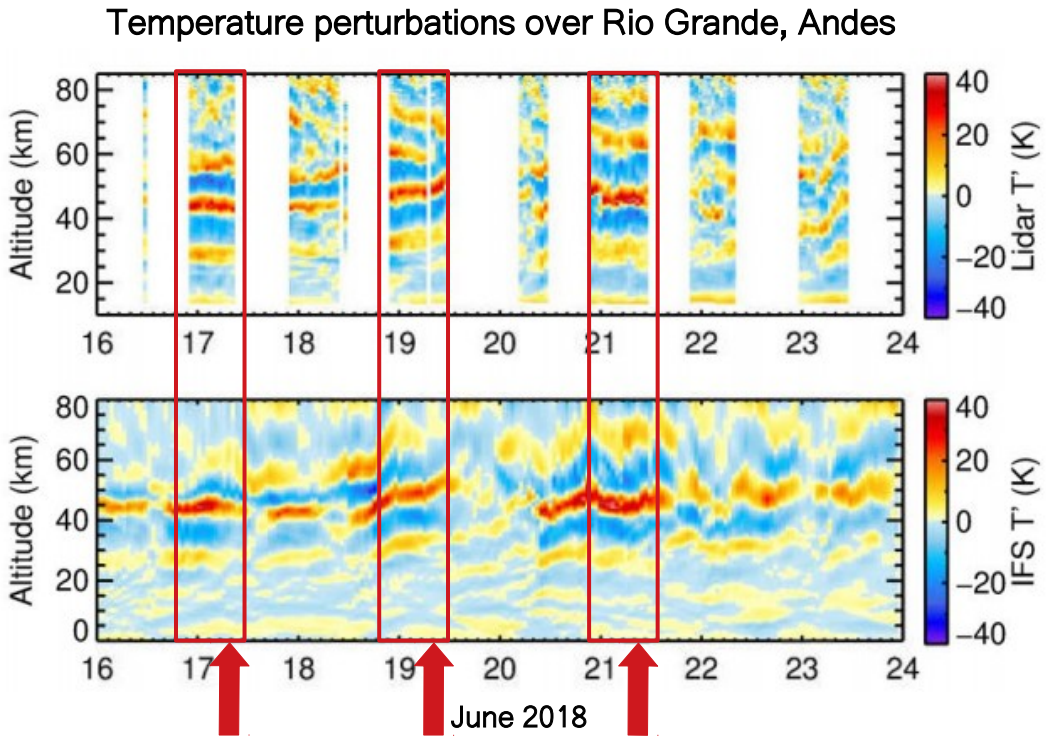
Composites around the vortex breakdown date shows that gravity waves can provide up to three-fourths of the *total necessary* zonal wind deceleration at 10hPa around 60S.

Supplementary

GWs in Observations and HighRes NWPs match

Observational Campaign over Andes

High-resolution IFS forecast system



- Strong agreement between observations and high resolution Numerical Weather Prediction (NWP) models in resolving a broad spectrum of GWs
- A similar comparison with ERA5 and ERA Interim revealed similar perturbations in ERA5 but very weak perturbations in ERA Interim.

Source : Kaifler et al. (2020), *Sci Rep*

GW Forcing Across Reanalyses