Stratospheric impacts of a parameterization of GWs generated by flow imbalance

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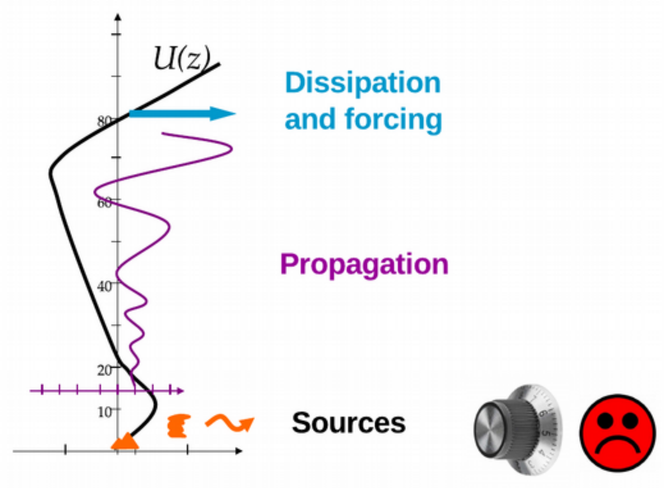
Parameterizations of non-orographic GWs



Plougonven et al. (QJRMS under revision)

<u>Source-based parameterizations of non-orographic GWs:</u>

- Convection → Beres et al 2004, 2005; Song and Chun 2006; Choi and Chun 2013; Lott and Guez 2013; Bushell et al 2015; Kang et al 2017.

- Fronts / jet imbalance

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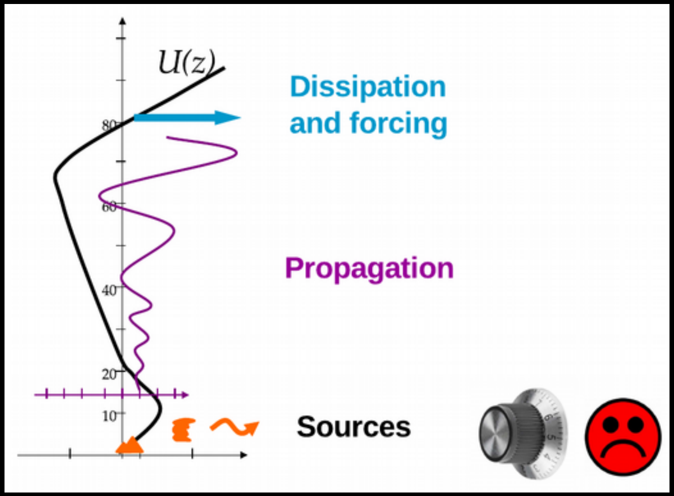

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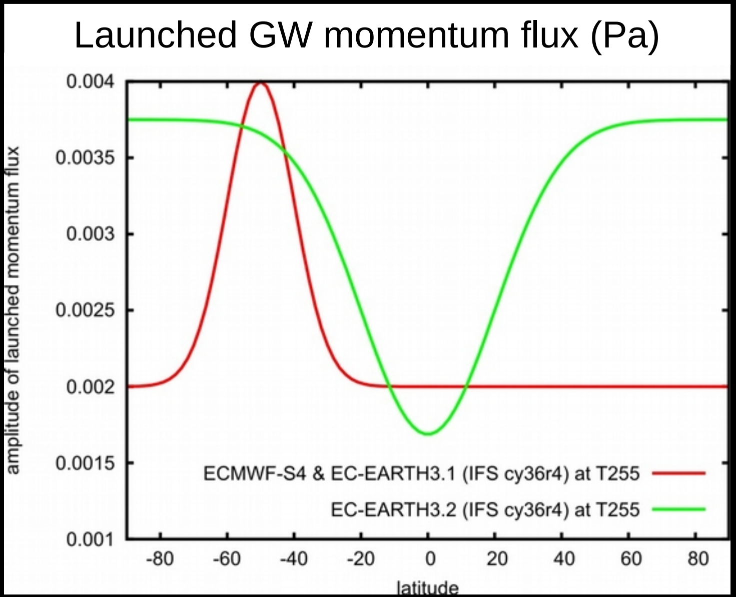

Courtesy of J. von Hardenberg & J. García-Serrano

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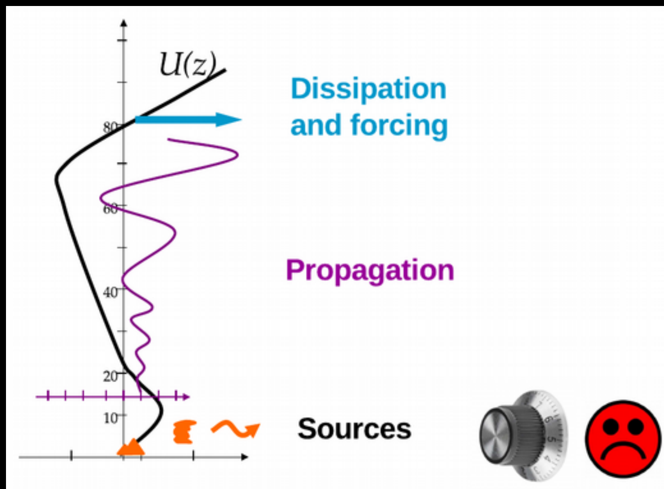

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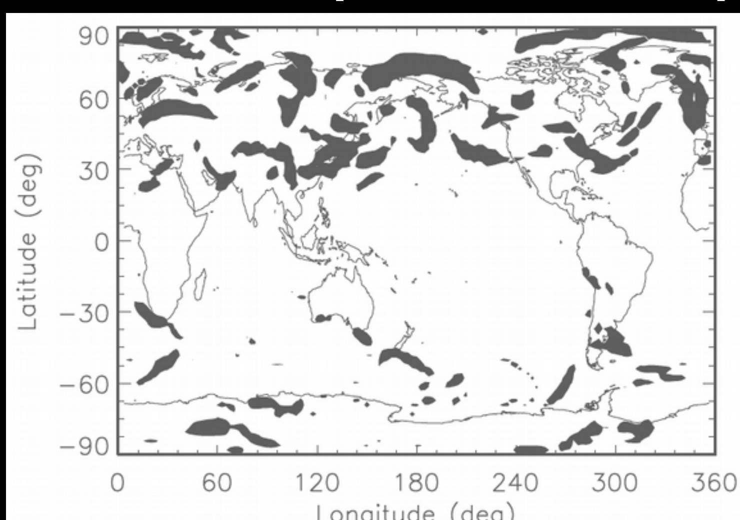
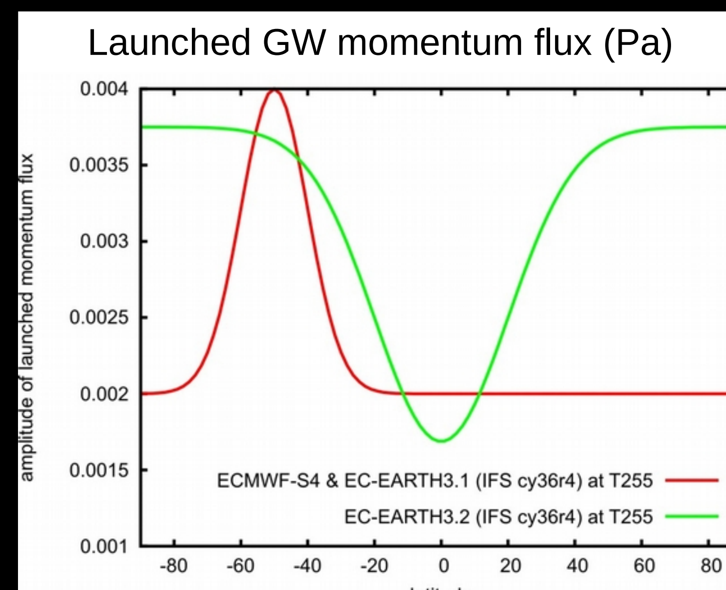
- Fronts / jet imbalance → Charron and Manzini 2002; Richter et al 2010

CESM-WACCM *[Richter et al 2010 JAS]*





Courtesy of J. von Hardenberg & J. García-Serrano

Goal

Link the amplitude of the GWs to the intensity of their sources in fronts / jet imbalances (→ resolved dynamics)

↓

Impacts on the stratospheric circulation?

Stochastic parameterization of GWs

Lott et al. 2012 GRL

- Lindzen-type parameterization (monochromatic waves).
- Instead of launching the entire spectrum of GWs, a stochastic approach is used (Eckerman 2011, Lott et al 2012) → stochastically sampling the spectrum each time step.
    - Only 8 waves are launched, randomly choosing GW stress, horizontal wavenumber and intrinsic phase speeds.

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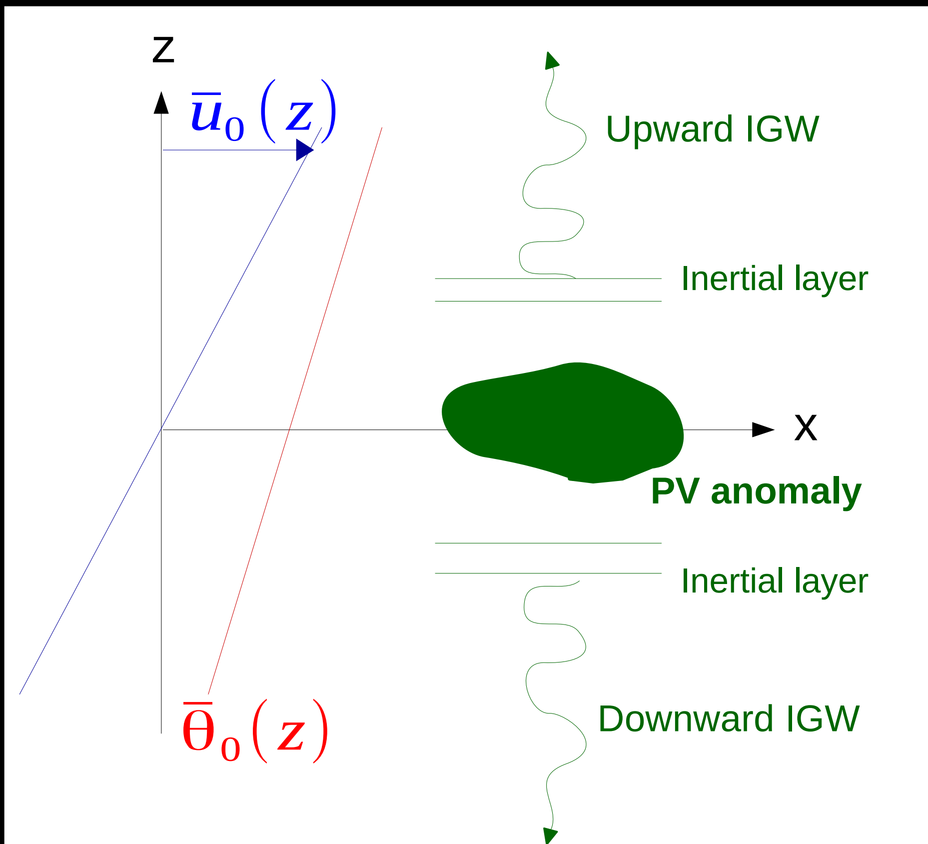
Informed by observations?

GW emission by PV anomalies in sheared flows



Linear emission of GWs by PV anomalies in vertical sheared wind
(Spontaneous adjusment problem)

Lott et al (2010, 2012 JAS)

<u>GW momentum flux emitted:</u>

$$F = \frac{\rho_r g^2}{f \theta_r^2 N^3} (\rho_r q_r \sigma_z)^2 \frac{e^{-\pi \frac{N}{\partial_z U}}}{4}$$

PV anomaly

Squared root of Richardson number

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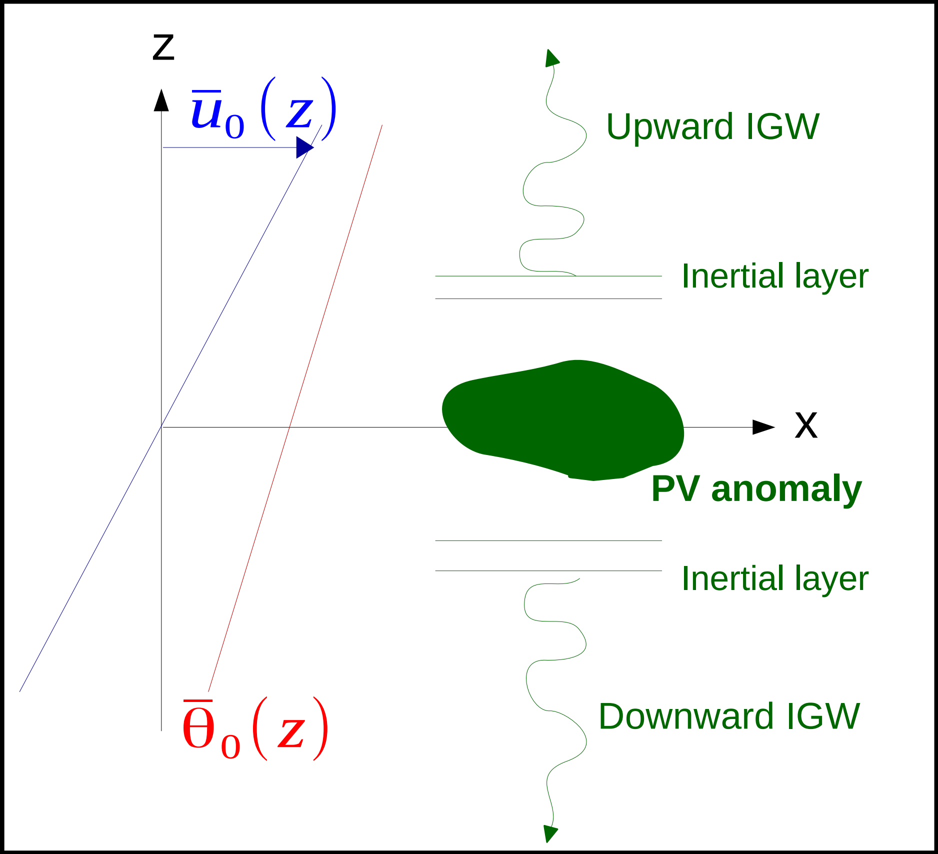

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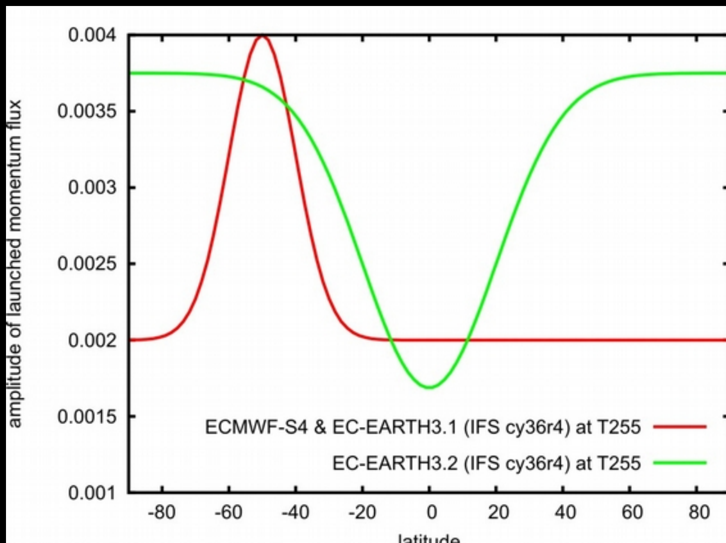
Squared root of Richardson number

Each parameterized monochromatic wave carries:

$$\vec{F}_n^{z_l} = G \frac{\vec{k}}{\|\vec{k}\|} \int_0^{z_{TOP}} \rho_0 N \zeta_r^2 e^{-\pi \sqrt{\mathrm{Ri}}} dz$$

de la Cámara and Lott 2015 GRL

Absolute momentum flux at launch level



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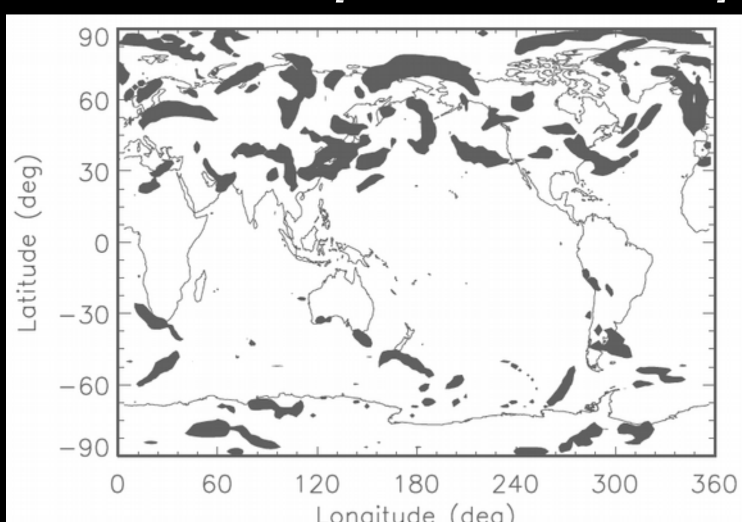
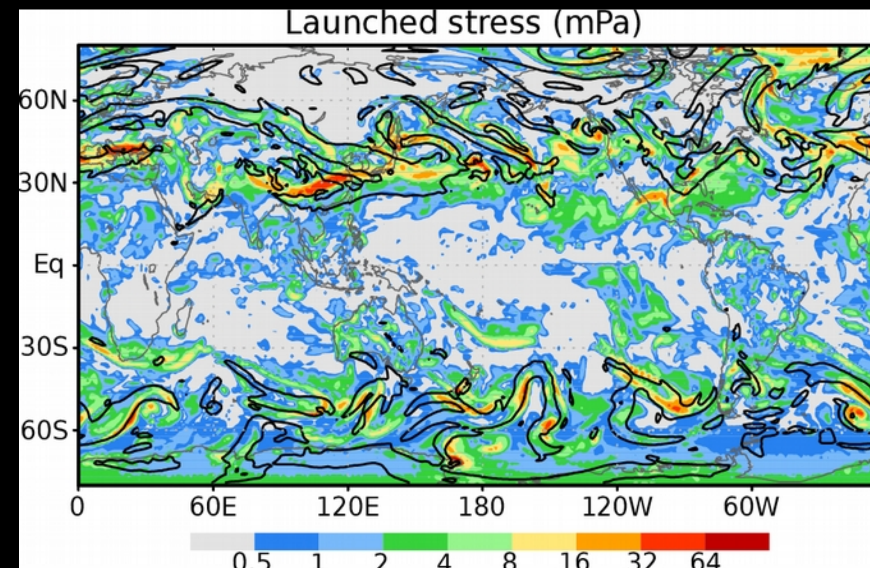




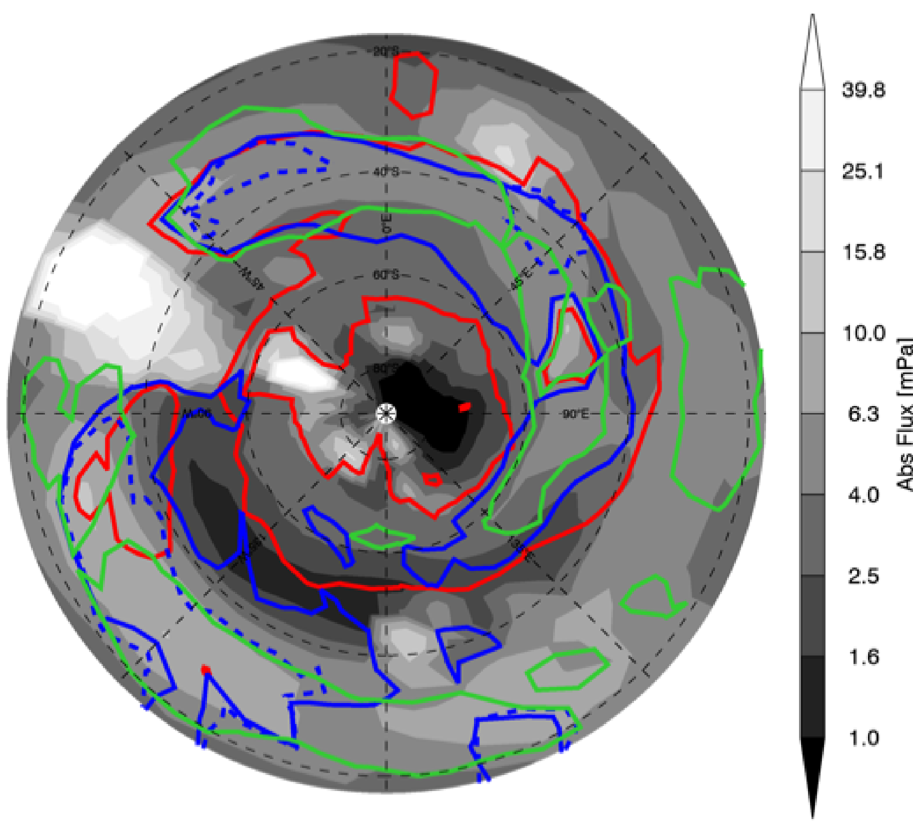
de la Cámara and Lott 2015 GRL

$$\vec{F}_n^{z_l} = G \frac{\vec{k}}{\|\vec{k}\|} \int_0^{z_{TOP}} \rho_0 N \zeta_r^2 e^{-\pi \sqrt{\mathrm{Ri}}} dz$$

Are we launching GWs from the “right” places?

Absolute GW momentum flux at 100 hPa (JJA)

GEOS Nature run – hor. res. 7km



Adapted from Holt et al. 2017 QJRMS

- Precipitation (blue)
- Frontogenesis function at 600 hPa (red)
- $q_r^{\,2} e^{-\pi \frac{N}{\partial_z U}}$ at 600 hPa (green)

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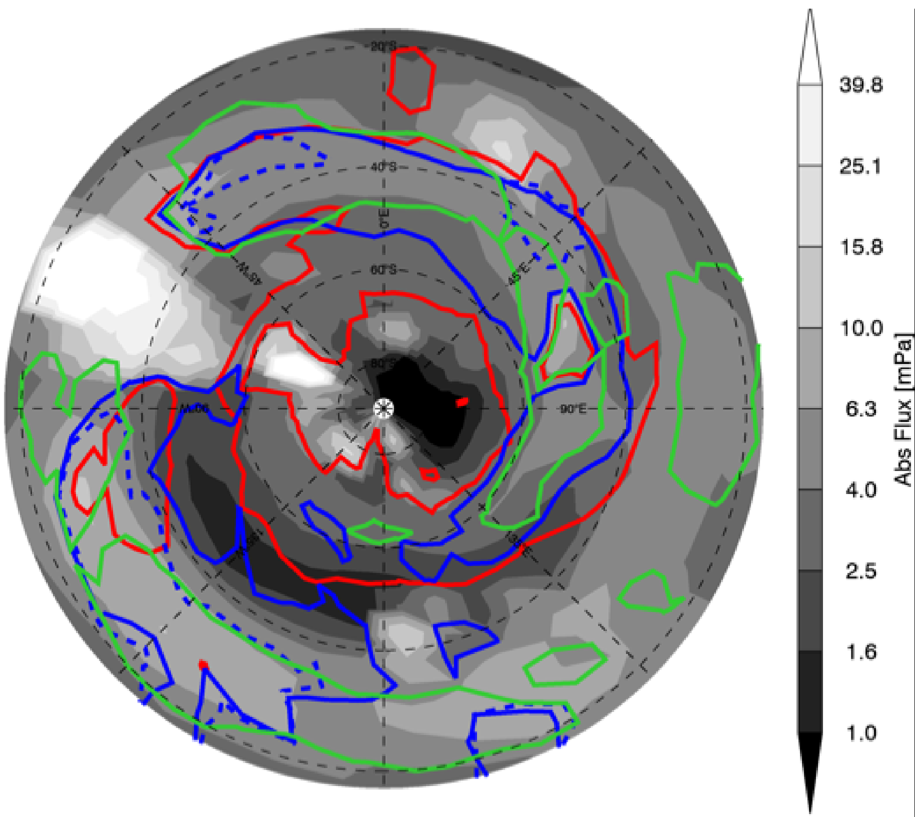

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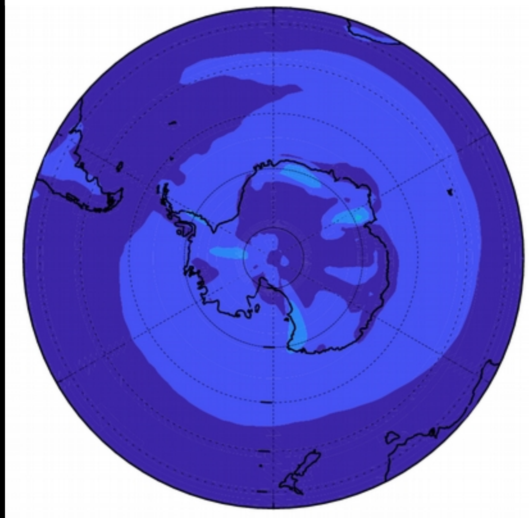
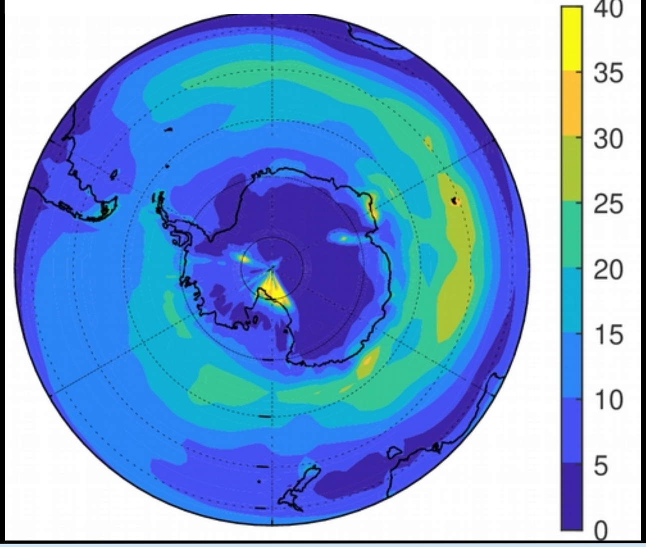
WACCM (Richter et al 2010)



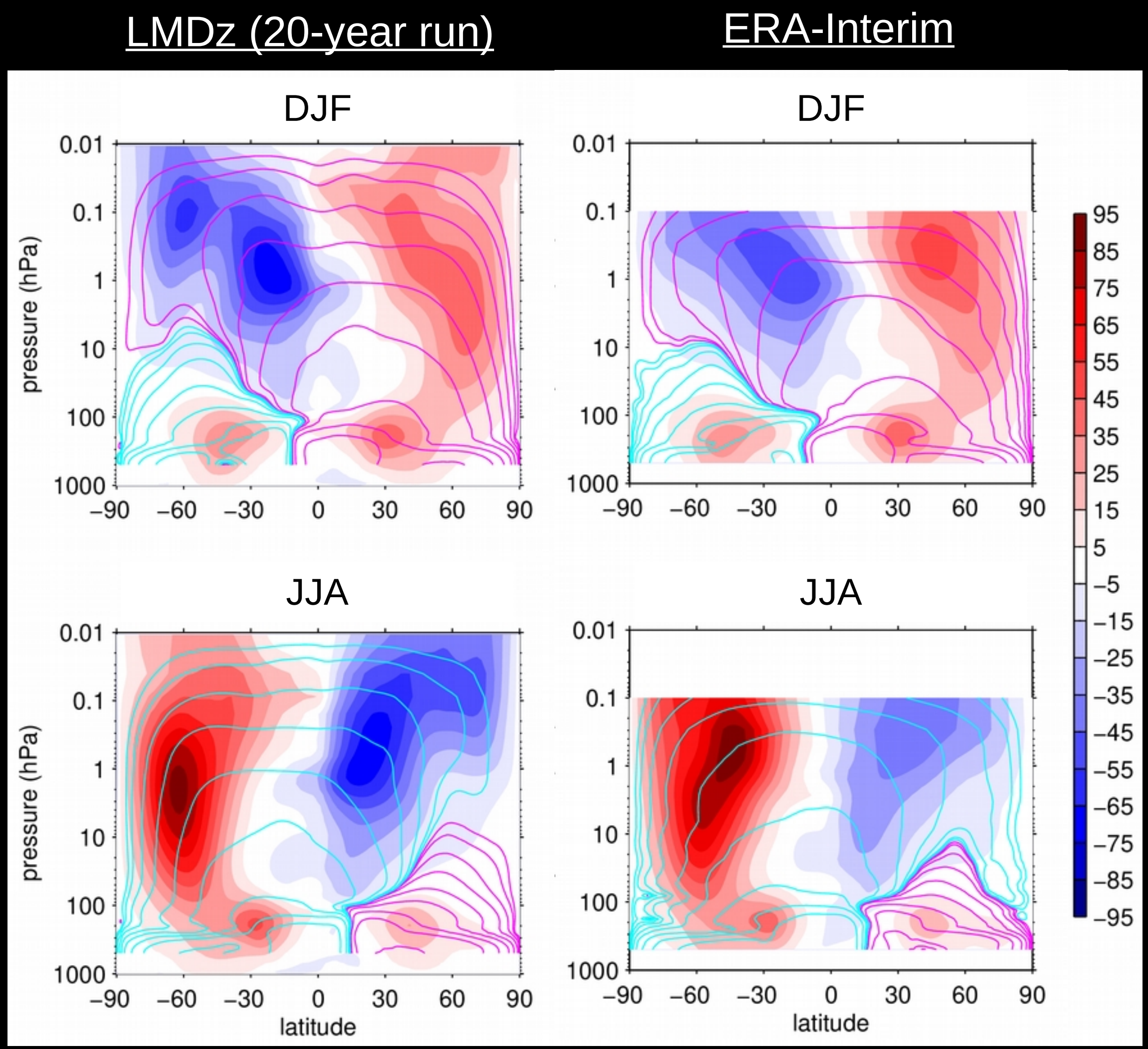
WACCM with PV source



Holt and de la Cámara in preparation

Zonal-mean U and residual streamfunction – LMDz GCM

LMDz GCM
3.75°x2.5°, 72 levels (top at 0.01 hPa)
Atmosphere-only runs

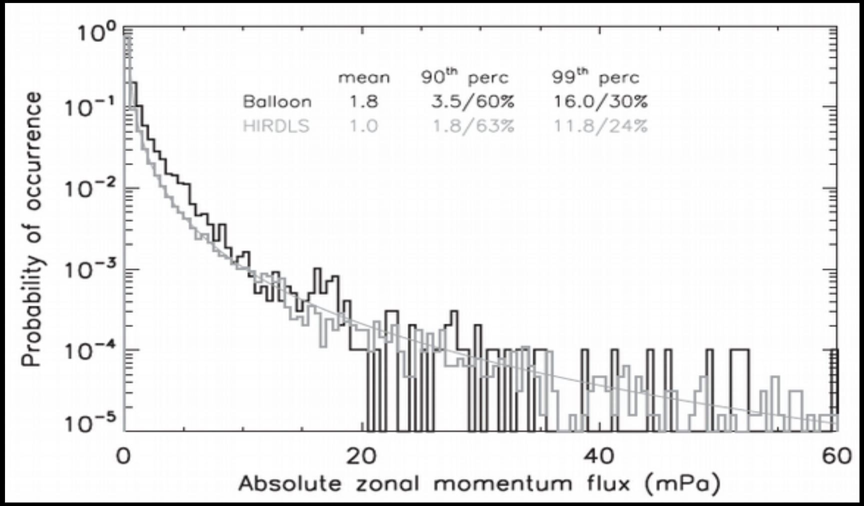


New features in the GW parameterization

GW stress coupled with resolved dynamics:

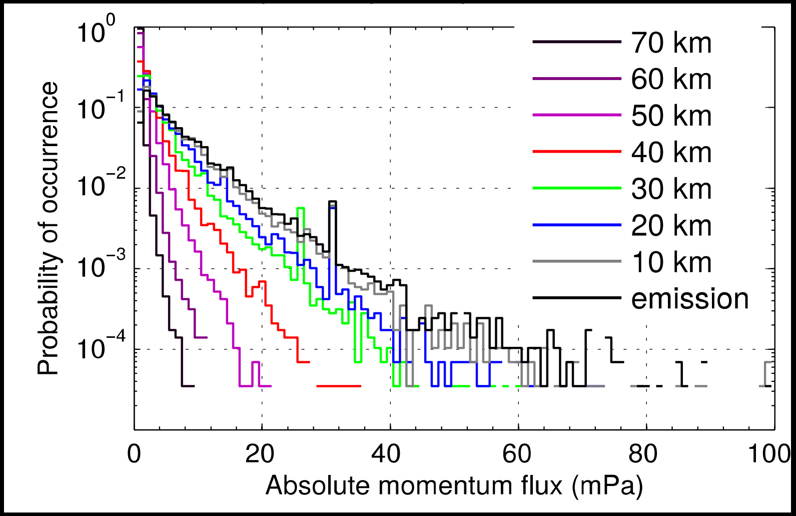
- **<u>Momentum flux intermittency</u>**: sporadic, large events, in qualitative agreement with observations *(e.g., Hertzog et al 2012, Wright et al 2013, Jewtoukoff et al 2015, Alexander 2015)*

Satellite & balloon observations



Hertzog et al. 2012 JAS

Frontal GW parameterization



de la Cámara and Lott 2015 GRL

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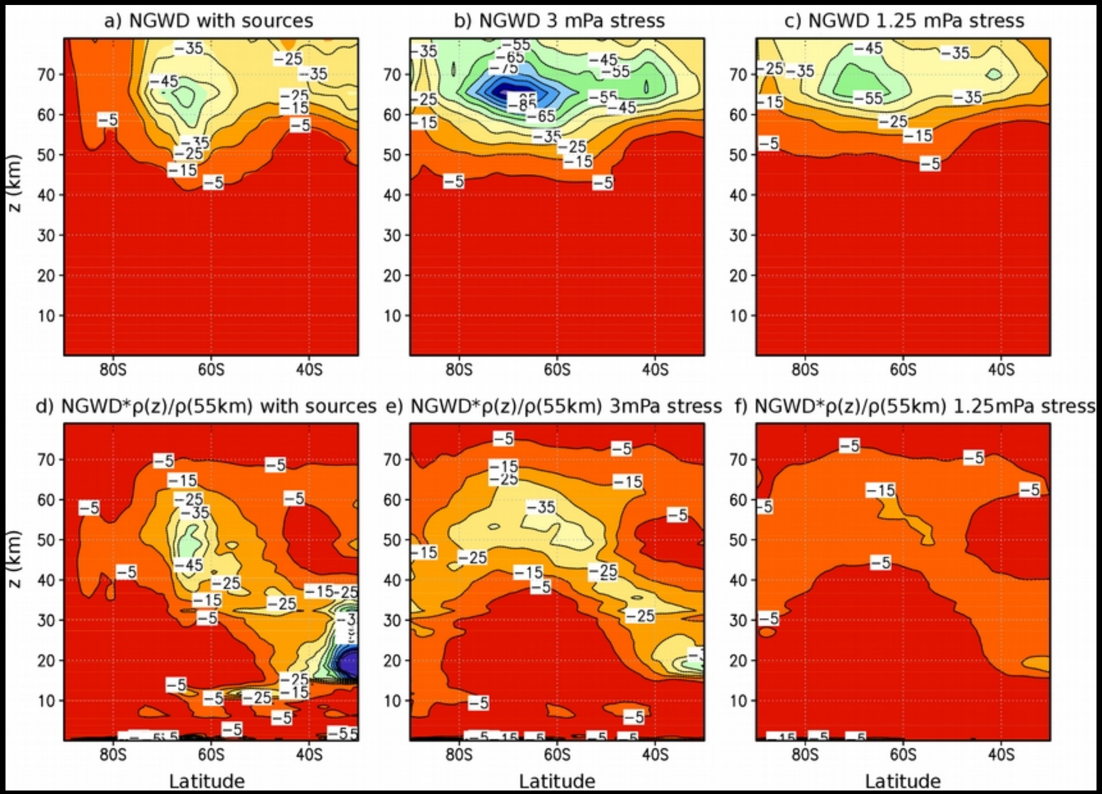


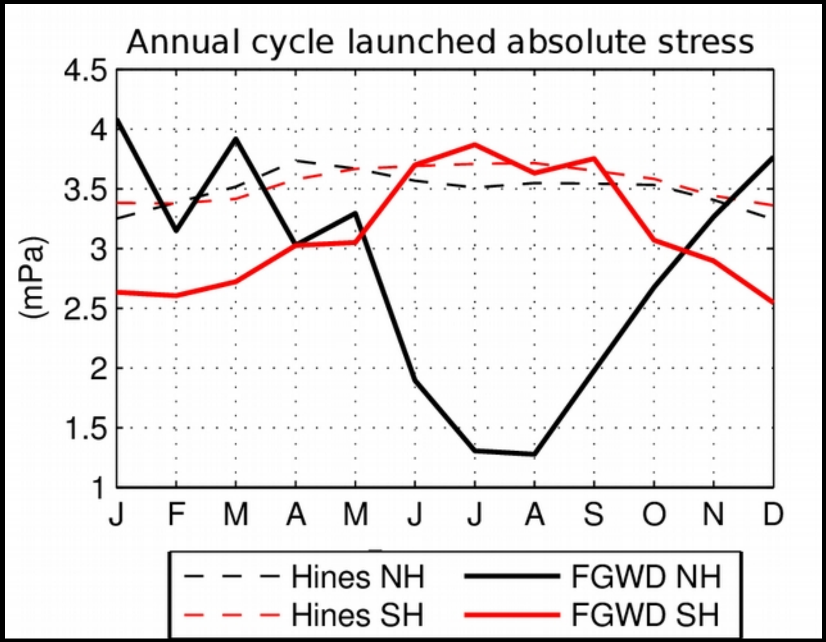
GWs carrying large MFs become unstable and break at lower altitudes

de la Cámara et al. 2016 JAS

New features in the GW parameterization

GW stress coupled with resolved dynamics:

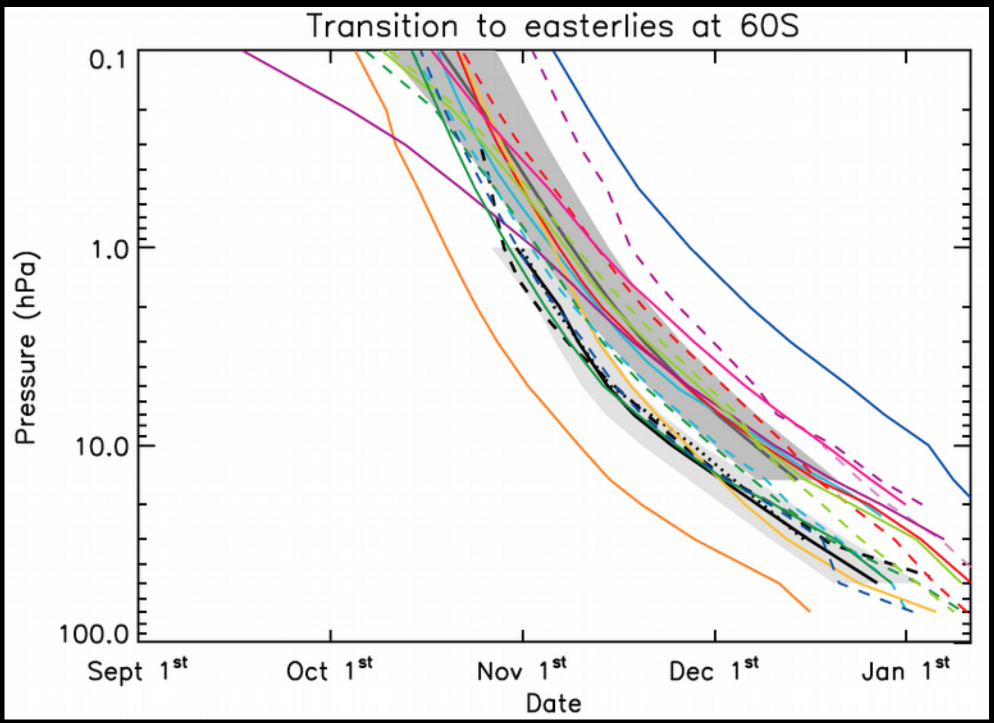
- Momentum flux intermittency: sporadic, large events, in qualitative agreement with observations *(e.g., Hertzog et al 2012, Wright et al 2013, Jewtoukoff et al 2015, Alexander 2015)*
- **Annual cycle in the GW stress at the level of emission** / Launched GW MF changes if climate changes



de la Cámara and Lott 2015 GRL

Impact of GW intermittency: The SH final warming

Final warming date bias in CCMVal-2 models



Butchart et al. 2011 JGR

Insufficient parameterized GW drag at 60°S as a cause of the late final warming bias
(McLandress et al. 2012 JAS)

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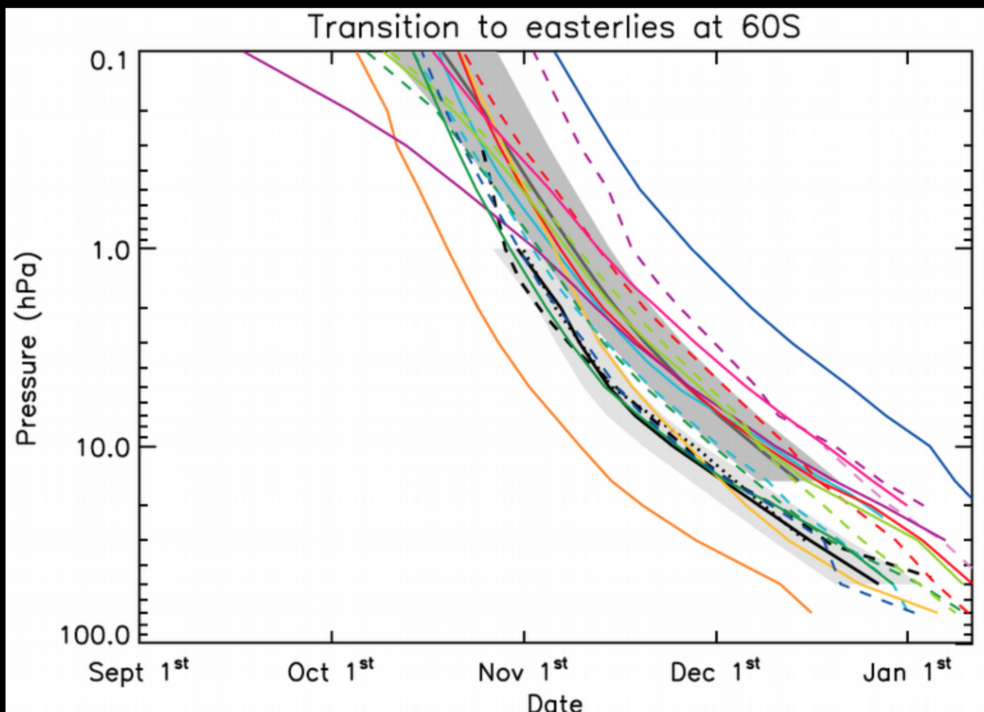
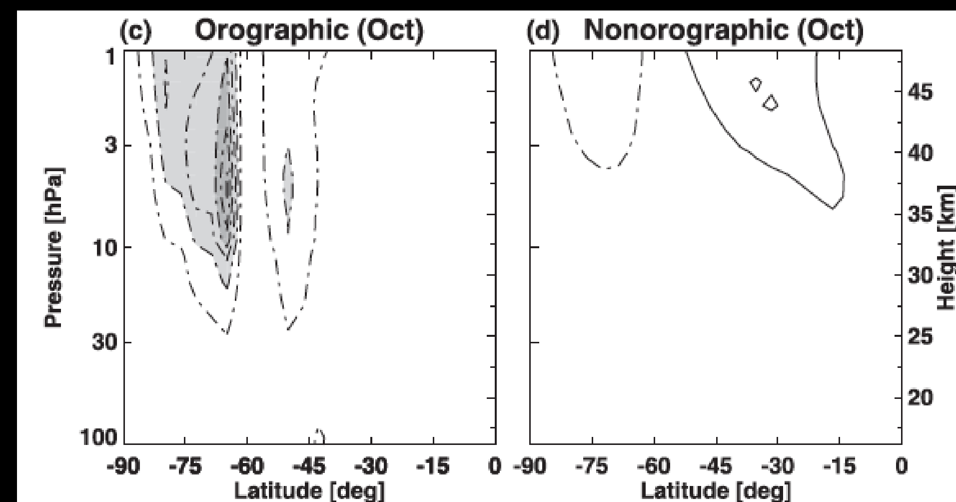


Butchart et al. 2011 JGR

GW drag in CMAM *(McLandress et al 2012)*



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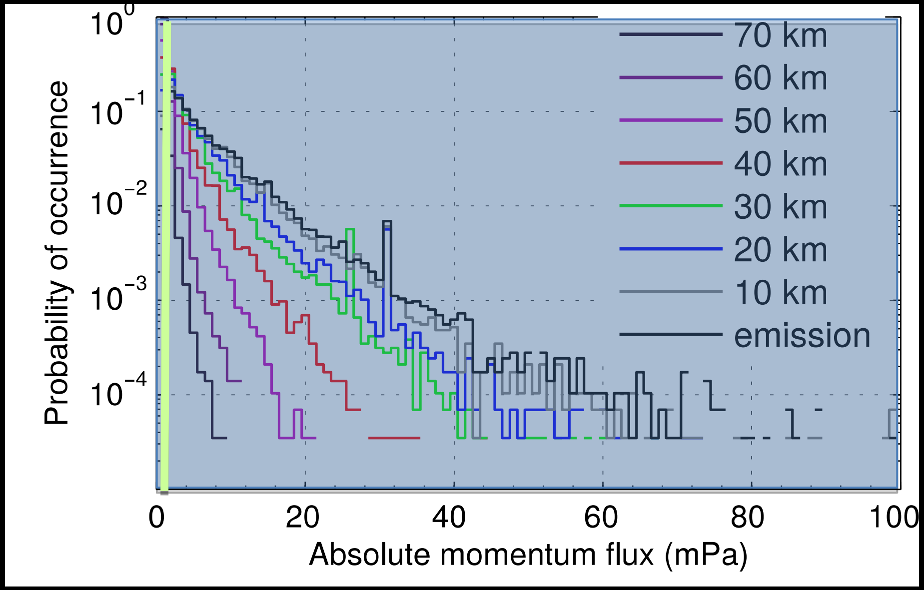
Impact of GW intermittency: The SH final warming

Model experiment: We **remove MF intermittency** by fixing the launched stress to a constant value

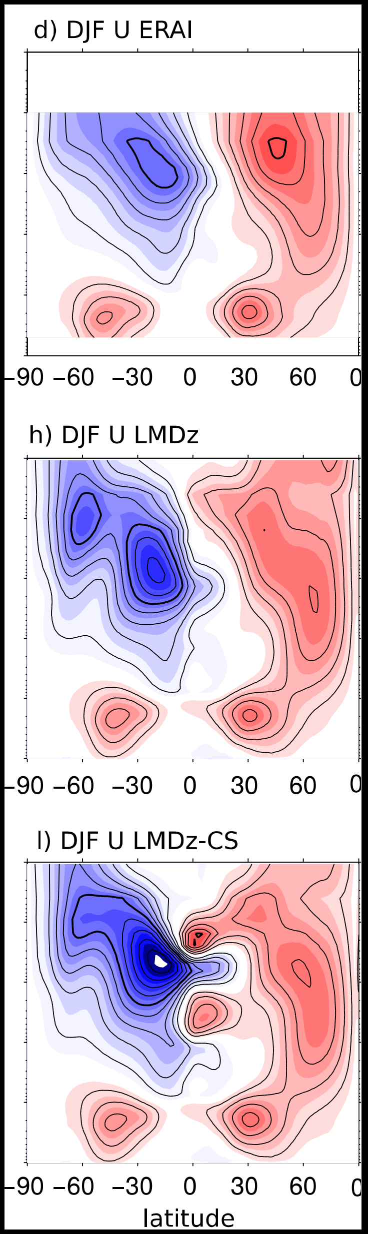


Launched stress = 1 mPa

ERA-Interim

LMDz **with** GW intermittency (from the PV sources)

LMDz **without** GW intermittency



de la Cámara et al. 2016 JAS

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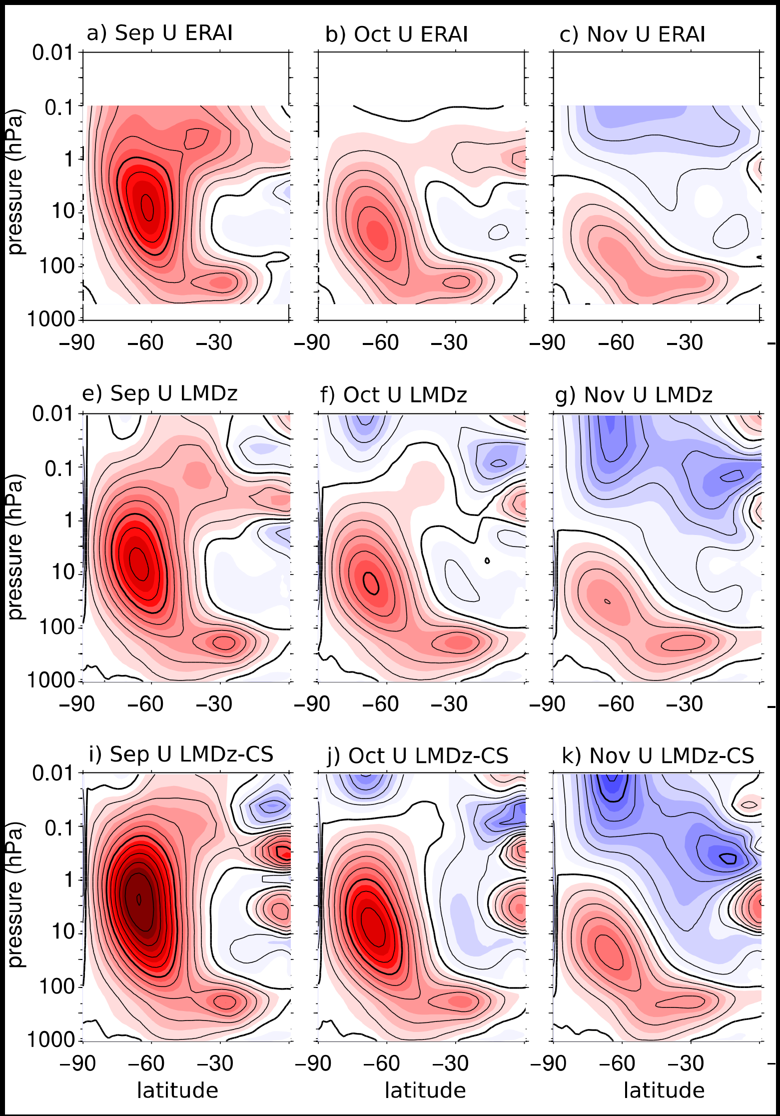

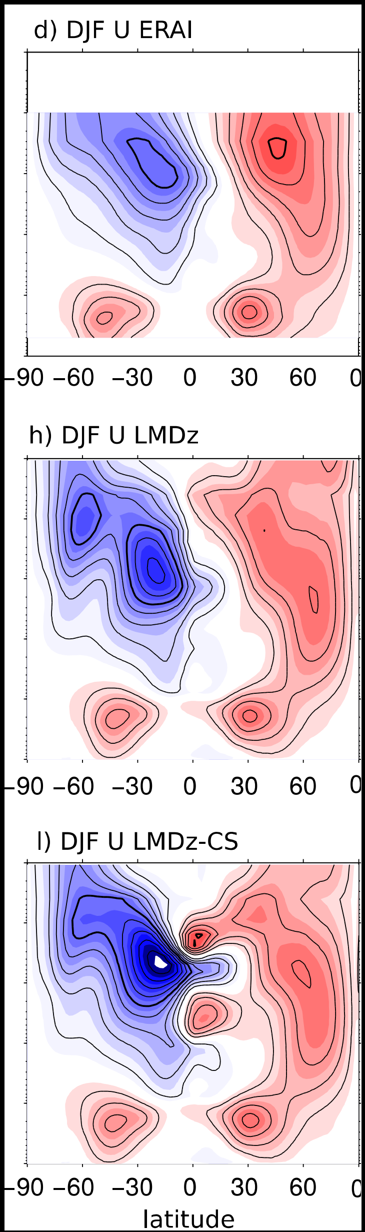

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de la Cámara et al. 2016 JAS

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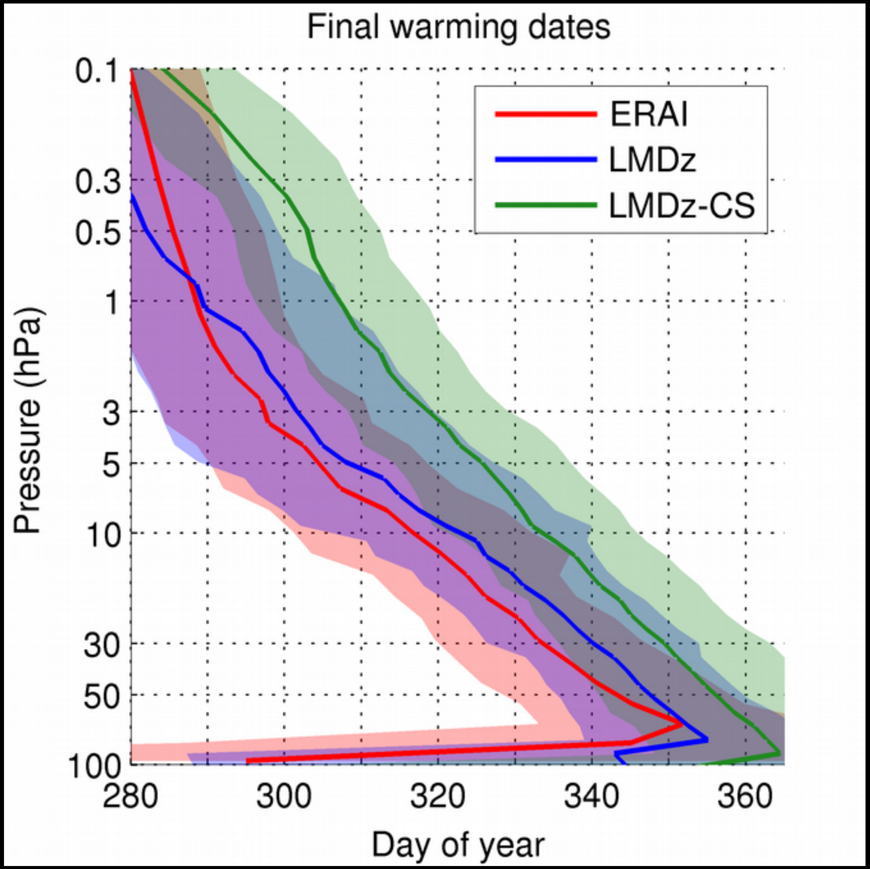


ERA-Interim

LMDz **with** GW intermittency (from the PV sources)

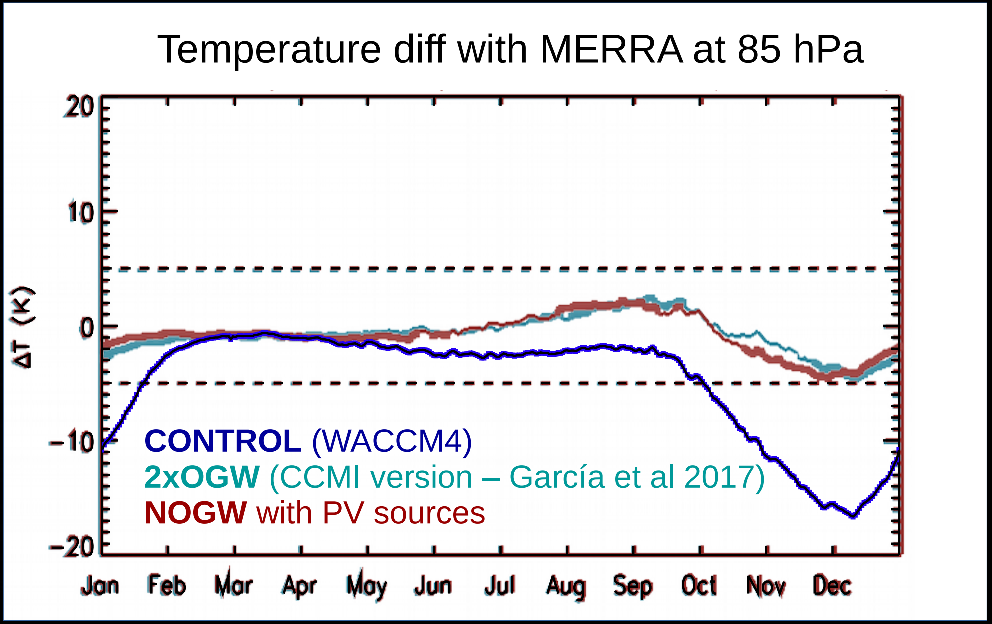
LMDz **without** GW intermittency

The transition from westerlies to easterlies occurs 5-10 days earlier in the simulation with GW intermittency (coming from interactive sources)

de la Cámara et al. 2016 JAS

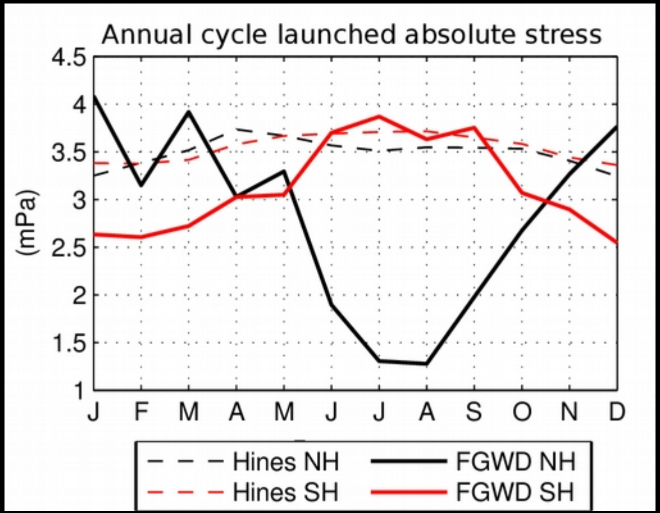
Impact of GW intermittency: The SH final warming

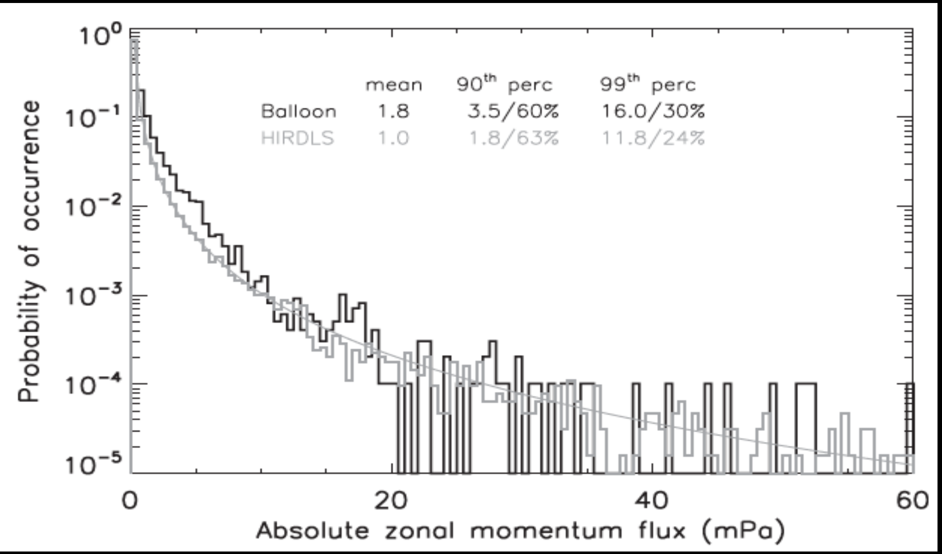
Results are also encouraging in other models → reducing the cold pole bias in WACCM



Impact of annual cycle of launched stress

<u>Model experiment</u> (GWLOG): We remove interactive GW source, and include MF intermittency by imposing a lognormal distribution in the launched stress.





Hertzog et al. 2012 JAS

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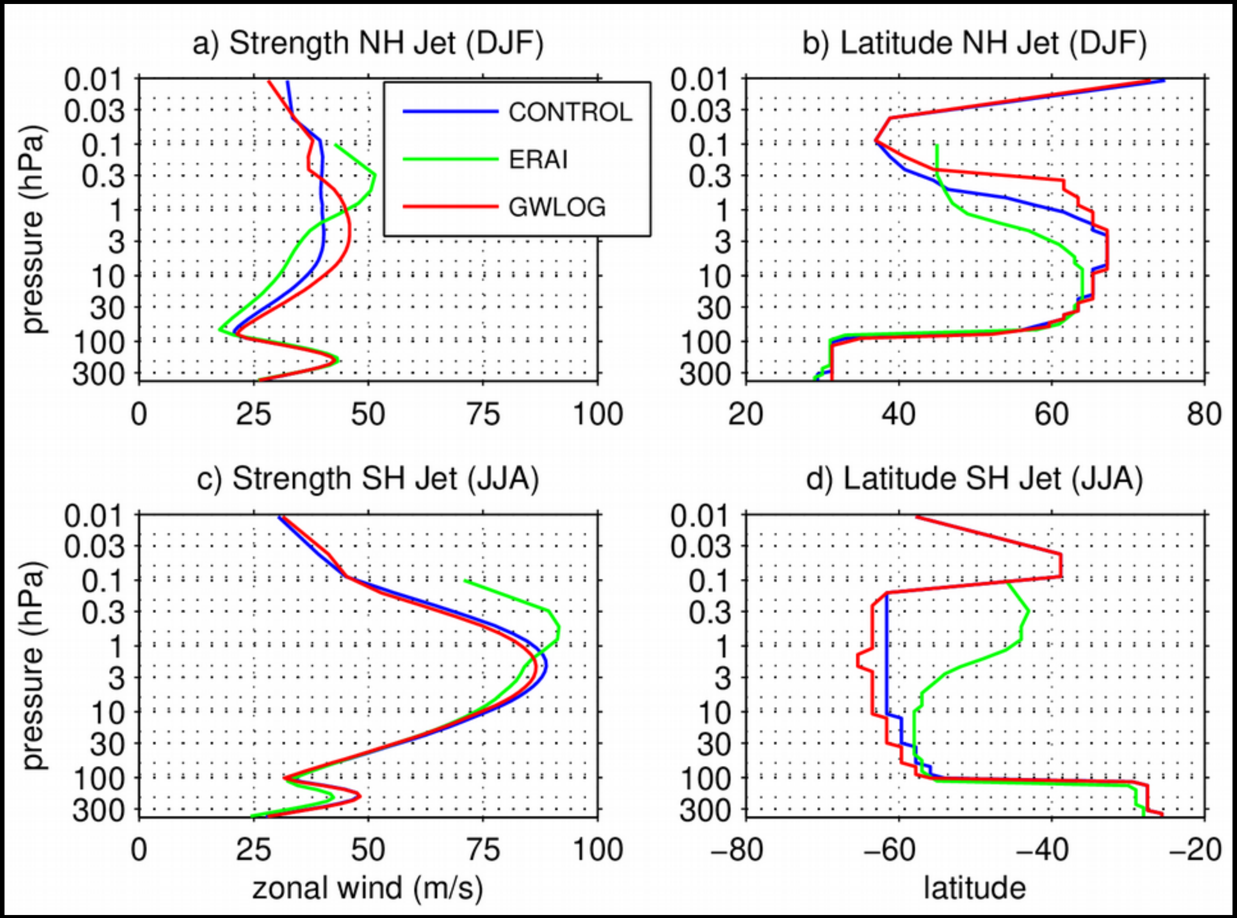

de la Cámara et al. 2016 JAMES

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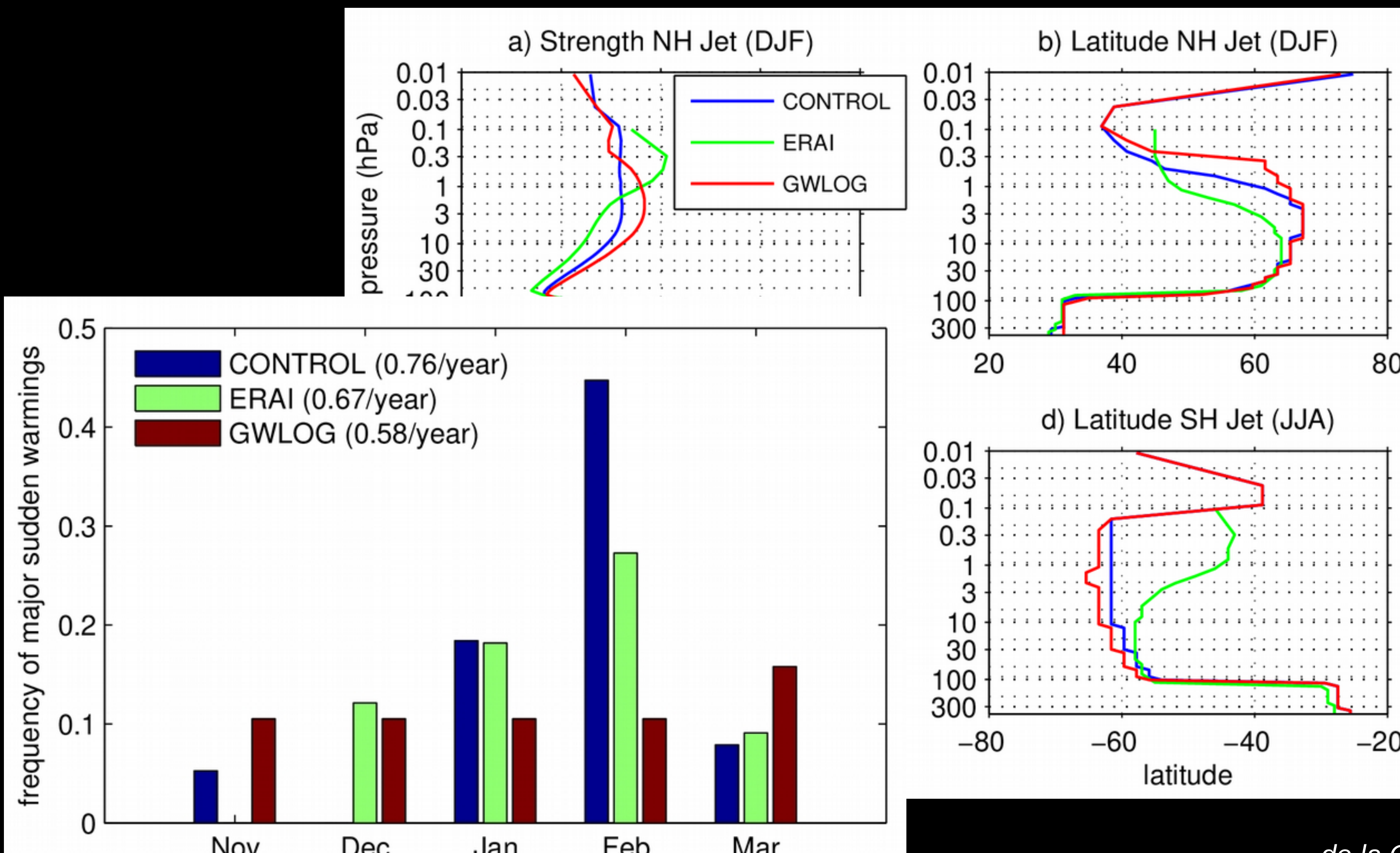

de la Cámara et al. 2016 JAMES

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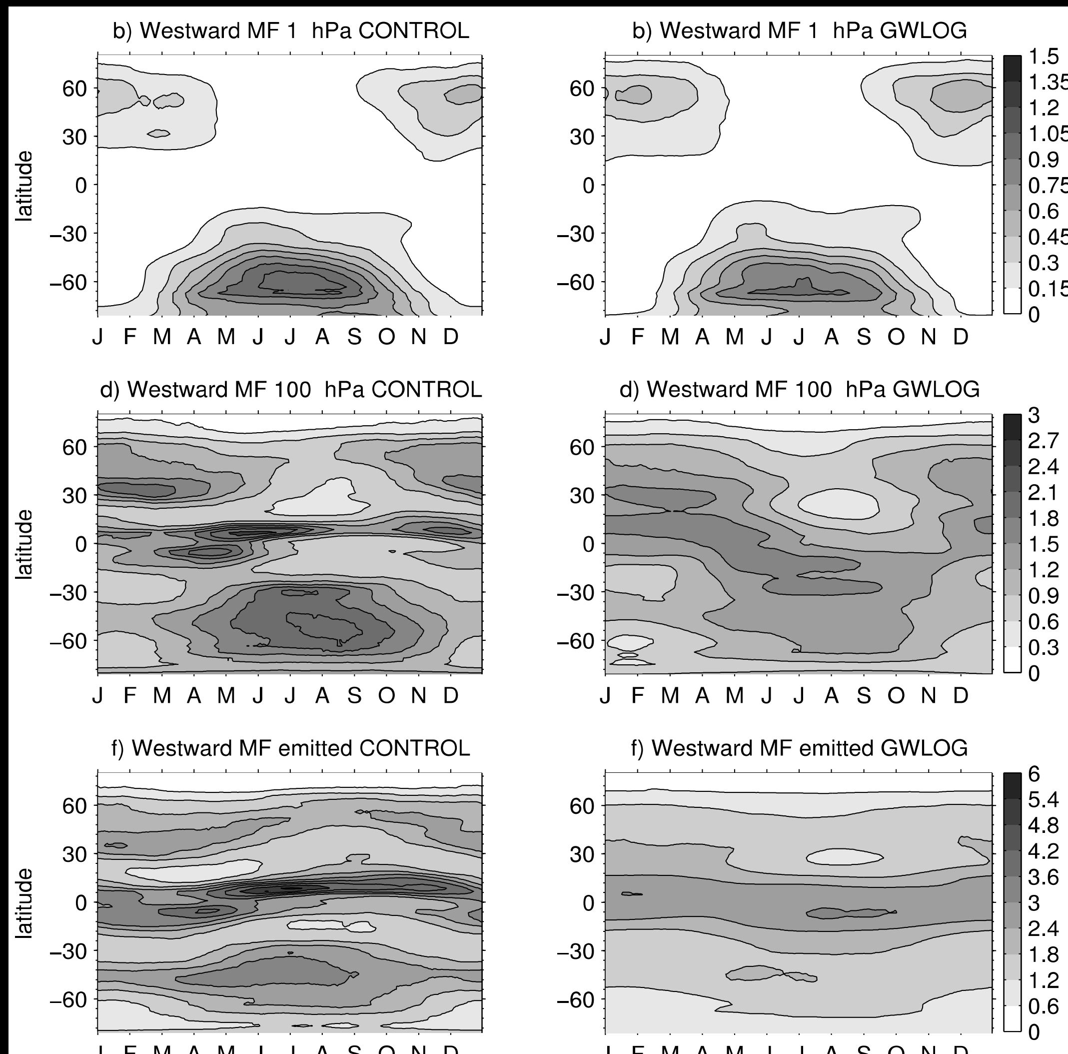
Impact of annual cycle of launched stress

Annual cycle of the westward GW momentum flux

CONTROL
(with sources)



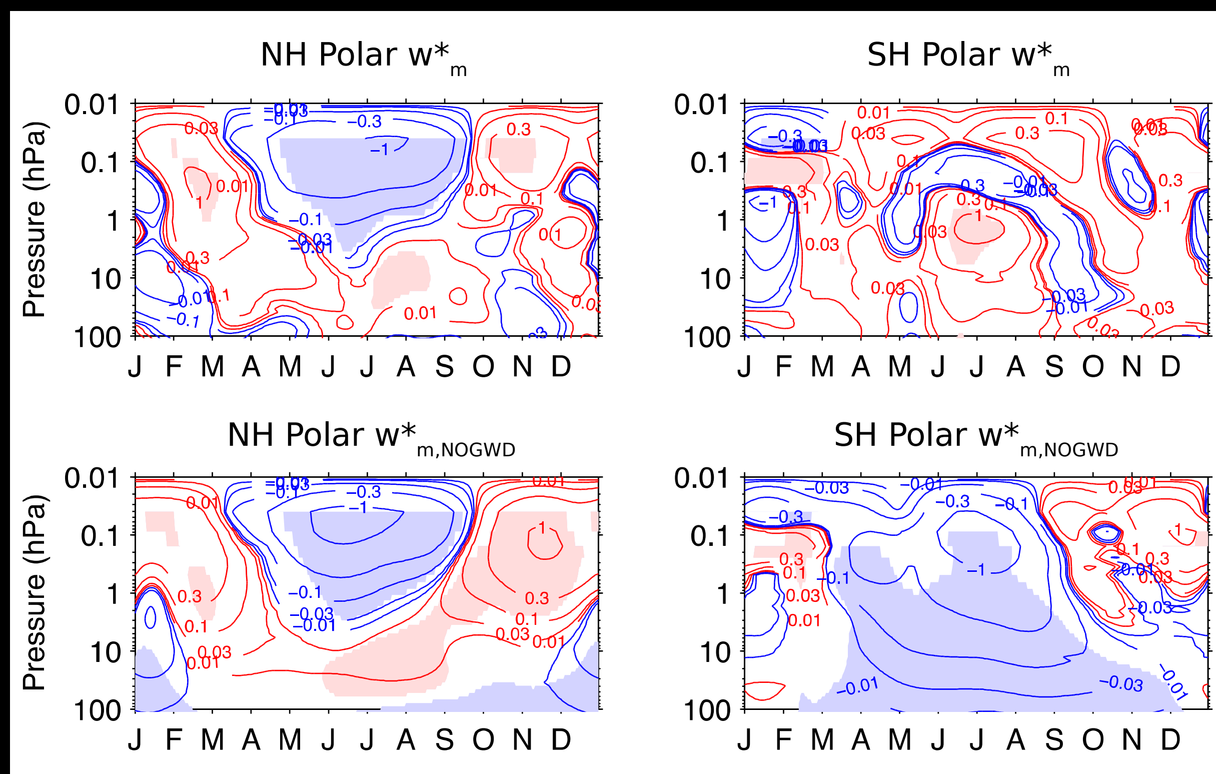
GWLOG
(without sources)

de la Cámara et al. 2016 JAMES

Impact of annual cycle of launched stress

Seasonality of polar downwelling

Sources minus **no-sources**



$$\bar{w}^*_m(\phi,z) = \frac{-e^{z/H}}{\int_{\phi_1}^{\phi_2} a\cos\phi \, \mathrm{d}\phi}\left\{\int_z^\infty \frac{e^{-z'/H}\cos\phi}{\hat{f}(\phi,z')}\left[\mathrm{DF}(\phi,z') + \bar{X}(\phi,z') - \frac{\partial\bar{u}(\phi,z')}{\partial t}\right]\mathrm{d}z'\right\}_{\phi_1}^{\phi_2}$$

de la Cámara et al. 2016 JAMES

An update in the GW source function

$$\vec{F}_n^{z_l} = G \frac{\vec{k}}{\|\vec{k}\|} \int_0^{z_{TOP}} \rho_0 N \zeta_r^2 e^{-\pi \sqrt{\mathrm{Ri}}} dz$$

Control

$$\vec{F}_n = G_u \frac{\vec{k}}{\|\vec{k}\|} \rho_0 N \zeta_r^2 e^{-\pi \sqrt{\mathrm{Ri}}}$$

SW2

Launching waves at all levels

Ribstein et al. in prep

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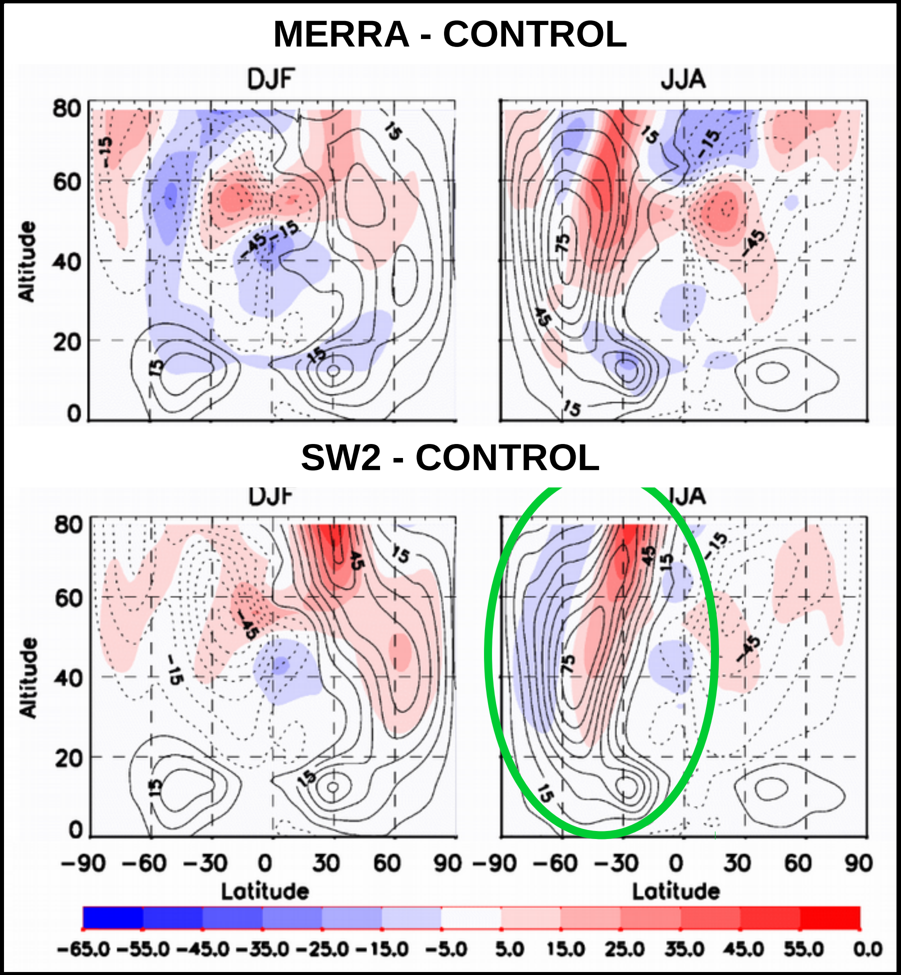


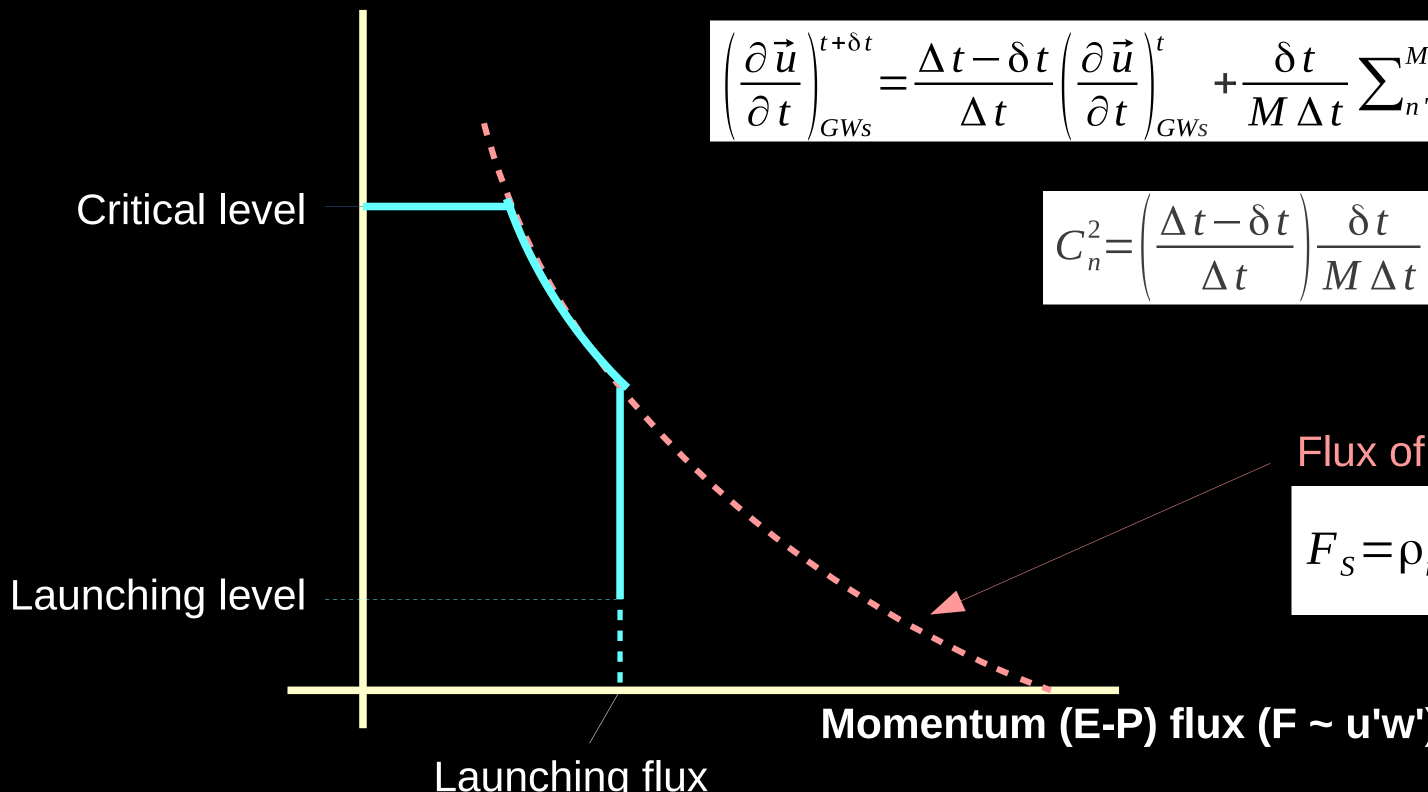
Reduction of the equatorward tilt bias in the SH winter jet.

Ribstein et al. in prep

Conclusions

- Pameterization of GWs generated in flow imbalances where the lauched momentum flux is derived from the model resolved dynamics.
- Including explicit GW sources in parameterizations is, at the very least, harmless to the climatology of the model (LMDz, WACCM).
- Momentum flux intermittency and annual cycle of the emitted MF are improved.
    - Significant reduction of the late SH final warming date bias.
    - Amplification of the BDC in the both the stratosphere and mesosphere by ~10%.

Few waves (say M=8) are launched each δt=30mn, but their effect is redistributed over **Δt=1day:** around 400 waves are active at the same time!



$$\left(\frac{\partial \vec{u}}{\partial t}\right)^{t+\delta t}_{GWs} = \frac{\Delta t-\delta t}{\Delta t}\left(\frac{\partial \vec{u}}{\partial t}\right)^{t}_{GWs} + \frac{\delta t}{M\,\Delta t}\sum_{n'=1}^{M}\frac{1}{\rho}\frac{\partial \vec{F}^{z}_{n}}{\partial z}$$

$$C_n^2 = \left(\frac{\Delta t-\delta t}{\Delta t}\right)\frac{\delta t}{M\,\Delta t}, \qquad \vec{F} = \sum_{n=1}^{\infty} C_n^2 \vec{F}_n$$

Flux of a saturated wave:

$$F_S = \rho_r \frac{|\hat{\omega}^3|}{2N} e^{-z/H} S_c^2 \frac{k^{*2}}{\|\vec{k}^4\|}$$

- We represent the subgrid scale vorticity with a stochastic series:

$$q' = \sum_{n=1}^{\infty} C_n q_n'$$

where

$$q_n' = \Re\left[\hat{q}_n e^{i(\vec{k}_n \cdot \vec{x} - \omega_n t)}\right]$$

$$\vec{k}_n, \hat{\omega}_n = \omega_n - \vec{U} \cdot \vec{k}_n$$

chosen randomly

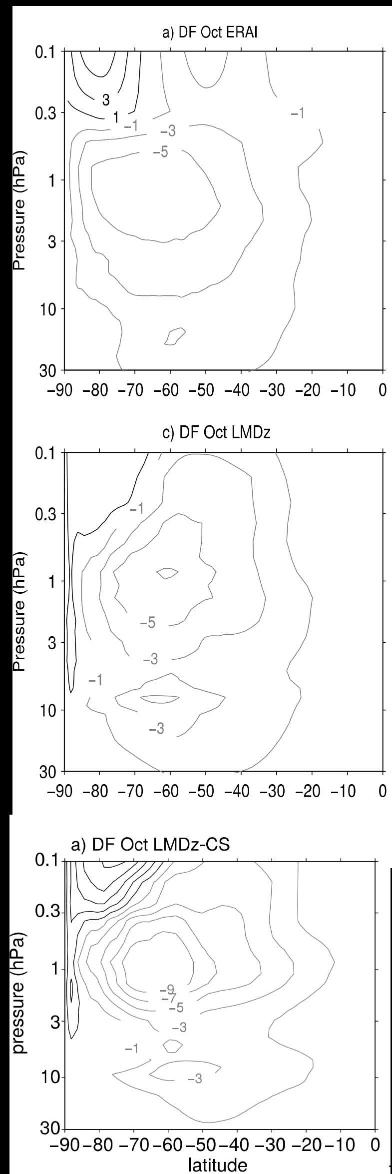
$$\mathcal{F} = \frac{\rho_r g^2}{f \theta_r^2 N^3} (\rho_r q_r \sigma_z)^2 \frac{e^{-\pi \frac{N}{\partial_z U}}}{4} \quad \longrightarrow \quad \mathcal{F}_n = \frac{\rho_r N}{4 f} (\zeta_r \sigma_z)^2 e^{-\pi \frac{N}{\partial_z U}}$$

- Momentum (EP) flux (F ~ *ρ u'w'*) at the launching altitude:

$$\vec{F}_n^{z_l} = G_0 \frac{\Delta z}{4 f} \frac{\vec{k}}{\|\vec{k}\|} \int_0^{z_{TOP}} \rho_0 N \zeta_r^2 e^{-\pi \sqrt{J}} dz$$

1. Impact of GW MF intermittency: the SH final warming

EP-flux divergence (October SH)

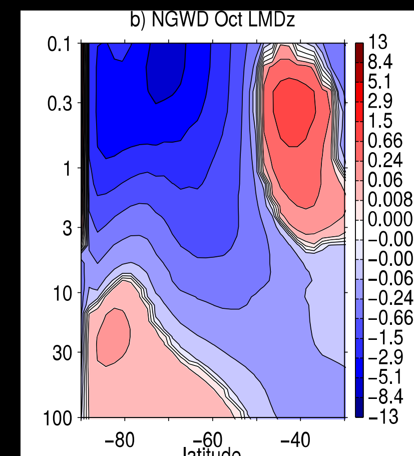


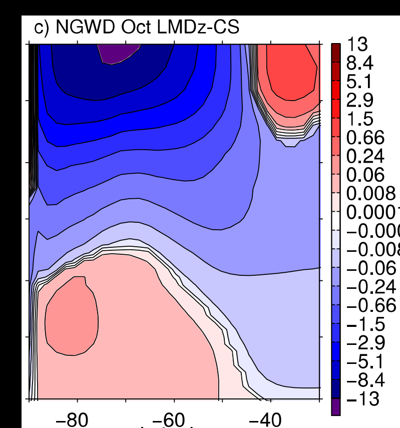
ERA-Interim

LMDz **with** GW intermittency
(from the PV sources)

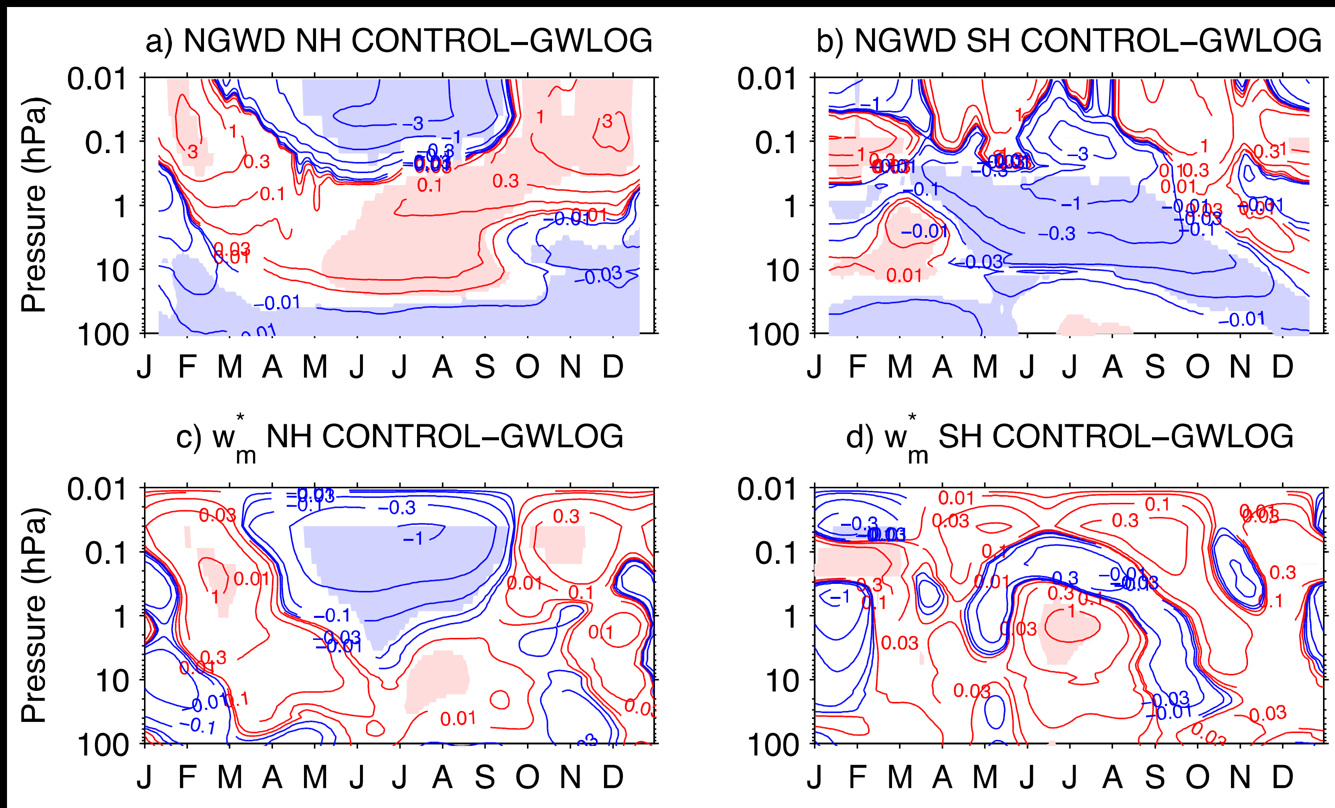
LMDz **without** GW intermittency

NOGW drag (October SH)





de la Cámara et al. 2016 JAS



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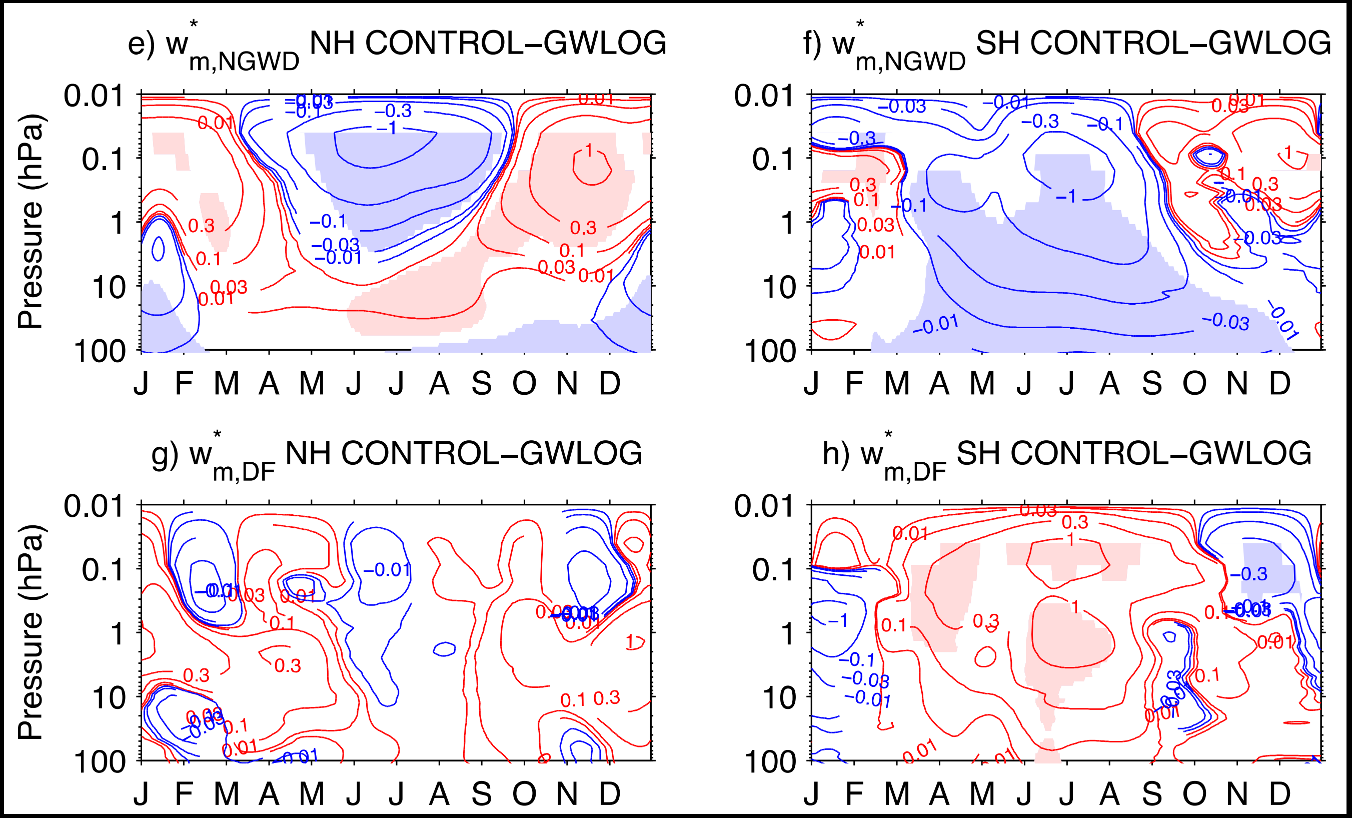
Sources minus no-sources

$w^*_{m,NGWD}$ (mm/s)

$w^*_{m,DF}$ (mm/s)



$$\bar{w}^*_m(\phi, z) = \frac{-e^{z/H}}{\int_{\phi_1}^{\phi_2} a\cos\phi\,\mathrm{d}\phi} \left\{ \int_z^{\infty} \frac{e^{-z'/H}\cos\phi}{f(\hat{\phi}, z')} \left[\mathrm{DF}(\phi, z') + \bar{X}(\phi, z') - \frac{\partial \bar{u}(\phi, z')}{\partial t} \right] \mathrm{d}z' \right\}_{\phi_1}^{\phi_2}$$