Update on gravity wave sources and their impacts on the southern polar vortex

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AMWG 2025 Winter Meeting, Boulder CO, Feb. 3 2025

Outline

- Background
- High resolution runs
- GW Sources for CAM7
- Summary and Plans

The problem

- Southern winter and spring polar vortex in CAM7 is too strong and cold. Also in CAM6 but not as bad. Long standing multi-model problem (McLandress et al. 2012)

- Not amenable to tuning of gravity wave sources in CAM6 (and earlier): fronts, convection, mountains (e.g. Richter et al. 2010)

- CAM7 vs CAM6:
  - higher vertical resolution,
  - cubed-sphere spectral element dycore instead of latlon FV □no polar filters and tapers in CAM7

- Solutions … Resolution? New or modified GW sources?

References

Richter, J. H., F. Sassi, and R. R. Garcia, 2010: Toward a Physically Based Gravity Wave Source Parameterization in a General Circulation Model. *J. Atmos. Sci.*, **67**, 136–156, https://doi.org/10.1175/2009JAS3112.1

McLandress, C., T. G. Shepherd, S. Polavarapu, and S. R. Beagley, 2012: Is Missing Orographic Gravity Wave Drag near 60°S the Cause of the Stratospheric Zonal Wind Biases in Chemistry–Climate Models?. *J. Atmos. Sci.*, **69**, 802–818, https://doi.org/10.1175/JAS-D-11-0159.1.

Zonal-mean winds and temperatures in CAM7 and ERA5

CAM7 = recent version (1-degree/ne30) with CAM6 GW sources (frontal, convective, orographic)

Windy, cold bias in southern hemisphere winter (JJA) stratosphere
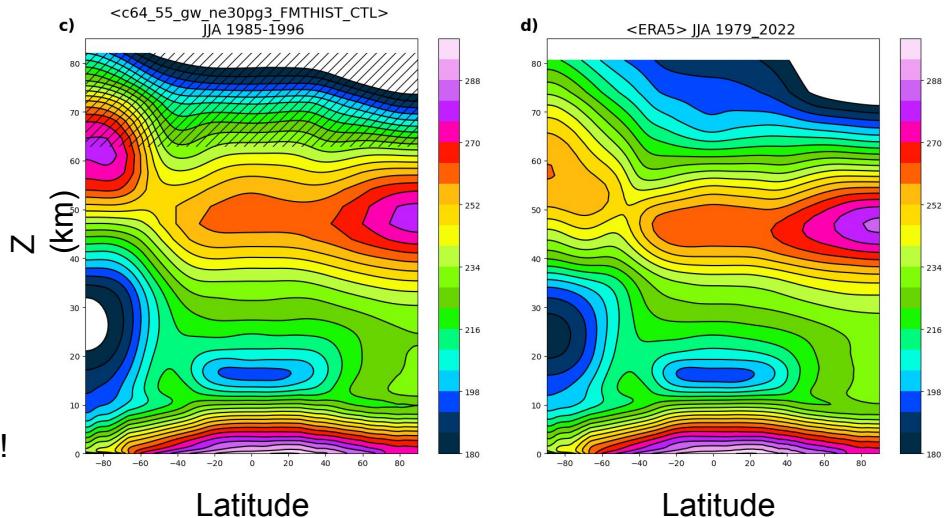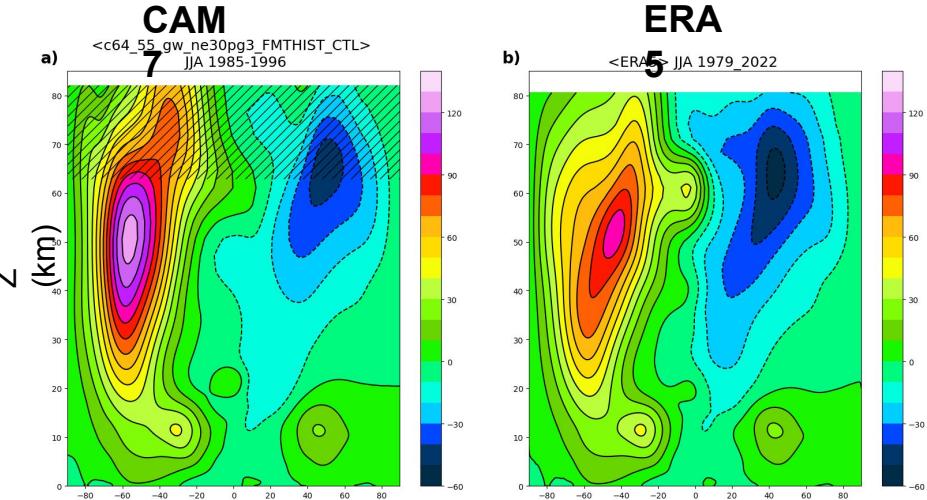
Extends into springtime (SON)
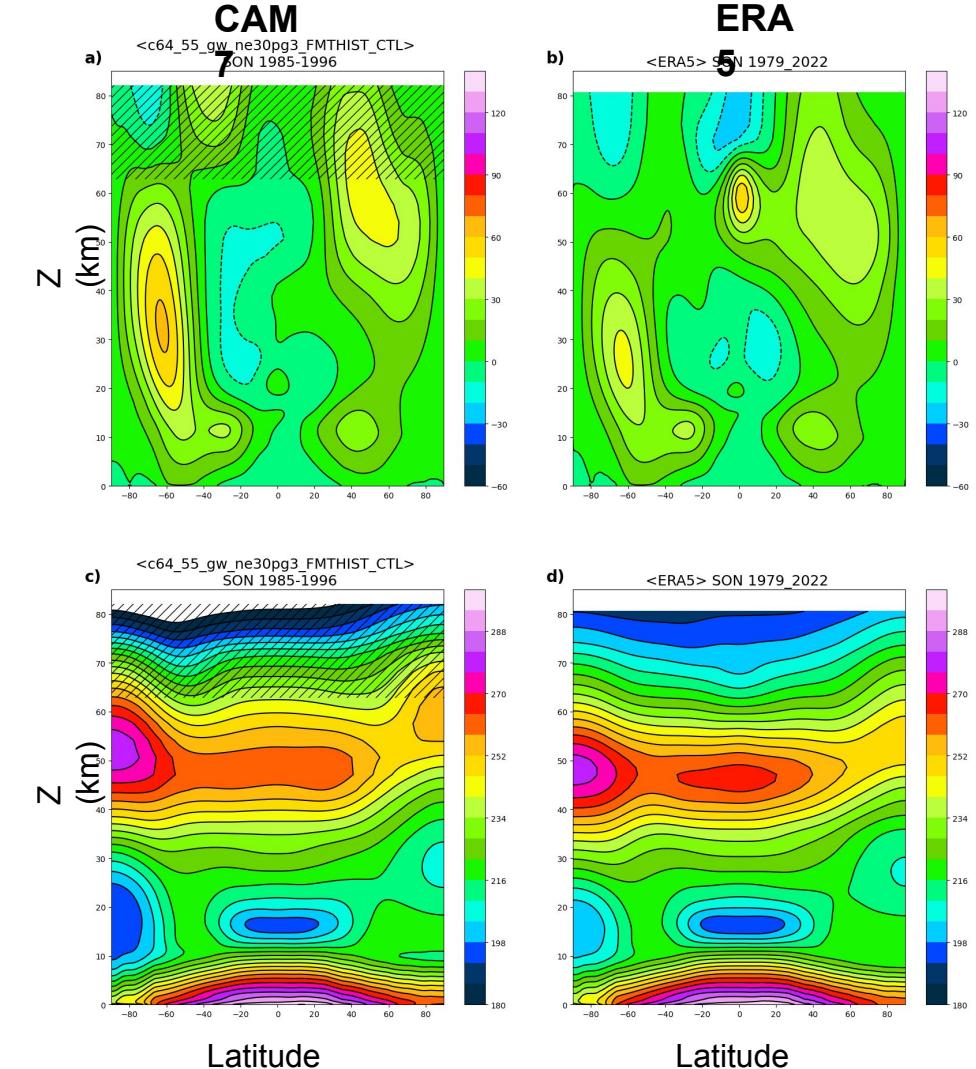
Note: "Z(km)" is relative to surface!

Increased Resolution

- Increased horizontal resolution to dx~27km (ne120) and dx~14km (ne240)

- Prescribed SSTs (F-case runs) with new 93-level vertical grid – top near 85km dz~500m throughout free troposphere and lower stratosphere

- In anticipation of well resolved frontal circulations, frontal GWs were disabled *(turns out not to be great choice at ne120 ....)*

# More resolution is the answer. ….. !!!

Model Cost:

ne30/dx=100km ~7,000 pe-hrs/simulated_year

ne120/dx=27km ~448,000 pe-hrs/simulated_year

ne240/dx=14km ~5,000,000 pe-hrs/simulated_year (extra slow-down in dycore needed for stability)
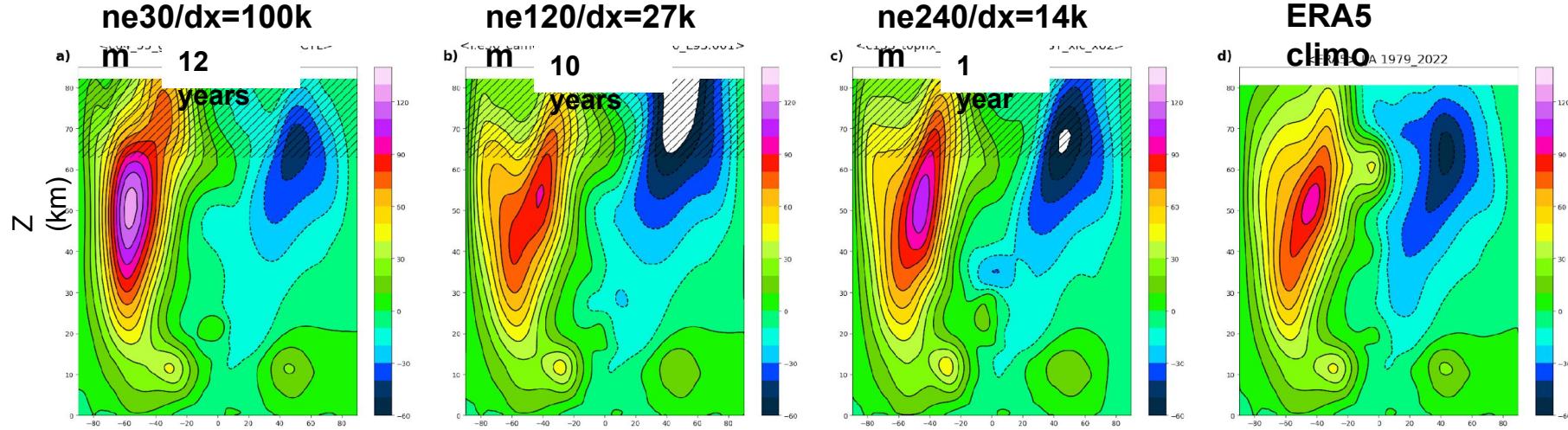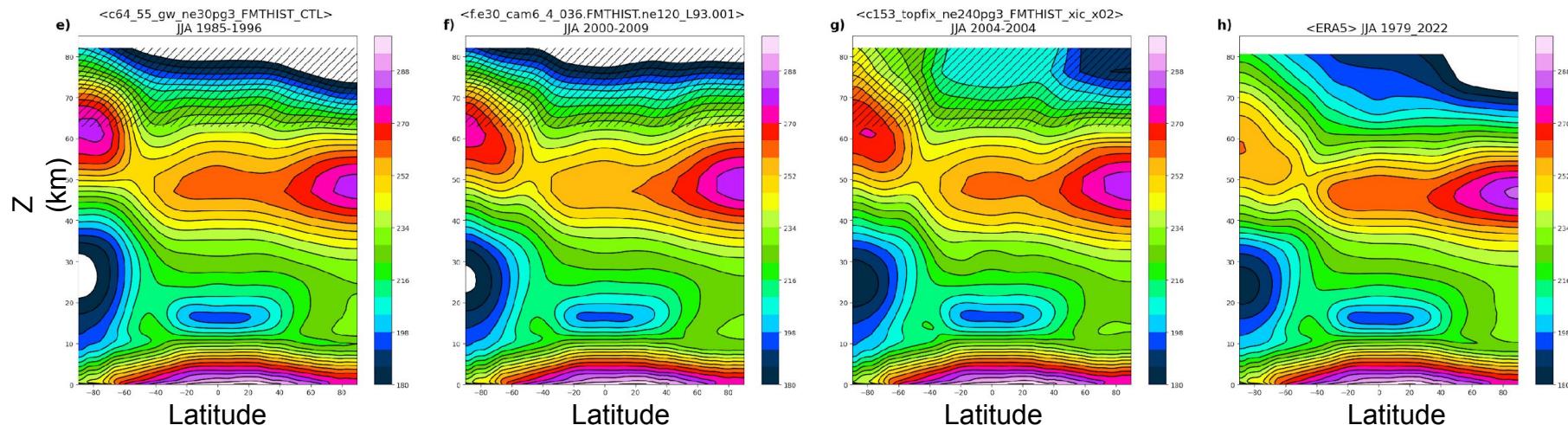
Red/blue shading□ω' at Z=44km; Grey Shading □ |vorticity| at 5km; Black contours □ sea level press.

Z=44 km

2004-07-01 00Z

fld1: Omg_44km, fld2: abs_zeta_5km
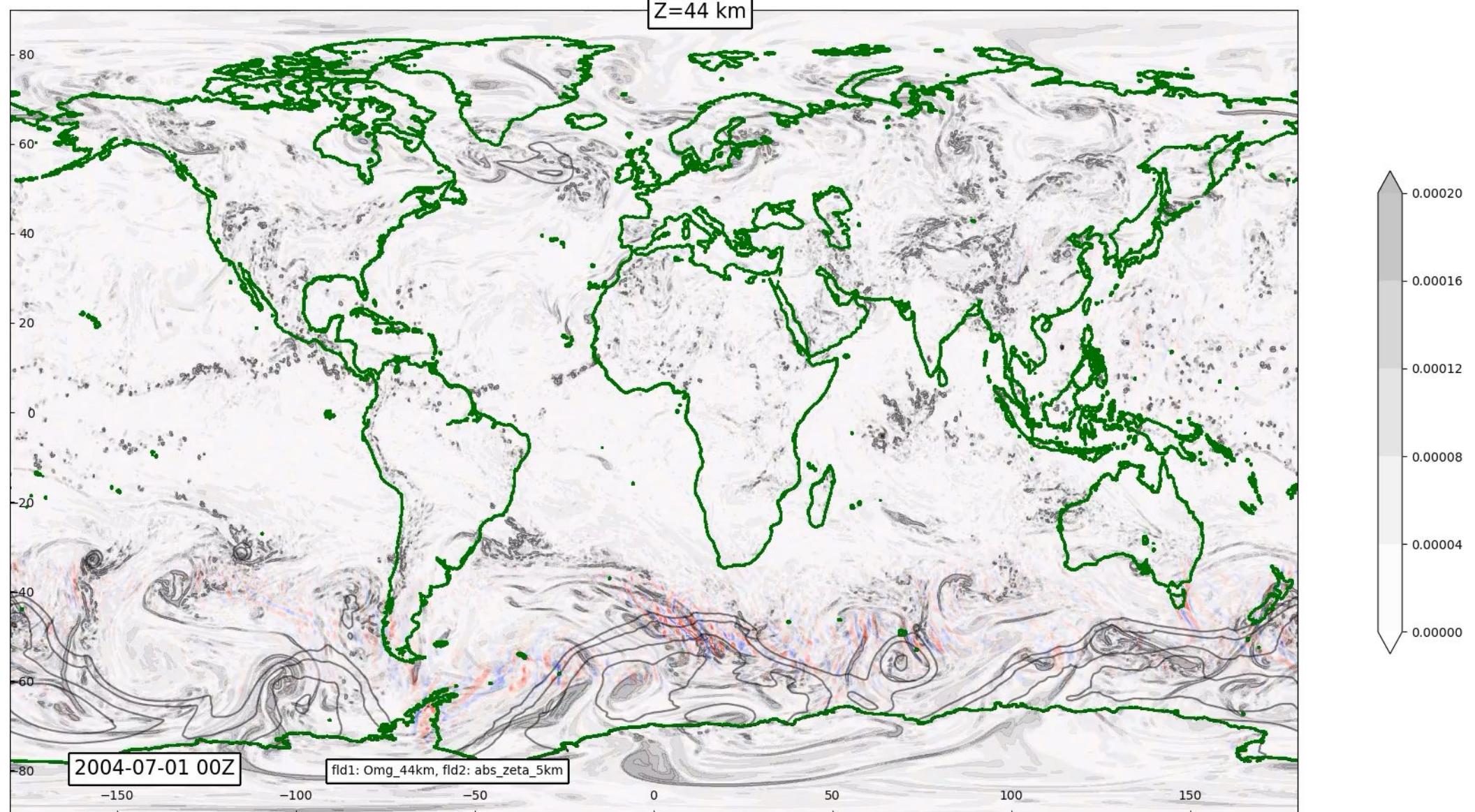
More resolution is the answer. ….. !!!

Resolved momentum flux $u'\omega'$ increases with resolution …. ☐ more drag

ne30/dx=100km

ne120/dx=27km

ne240/dx=14km

$\overline{u'\omega'}$ <c153_ne30pg3_FMTHIST_x05>
JJA 2004-2004

$\overline{u'\omega'}$ <c153_topfix_ne120pg3_FMTHIST_xic_x02>
JJA 2004-2004
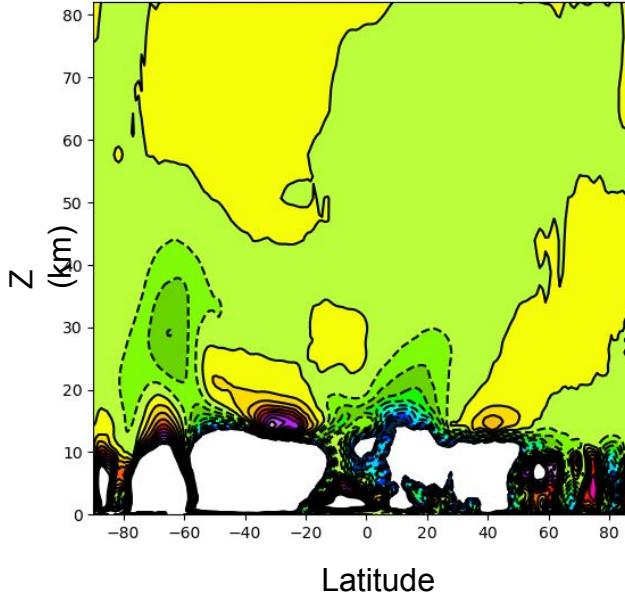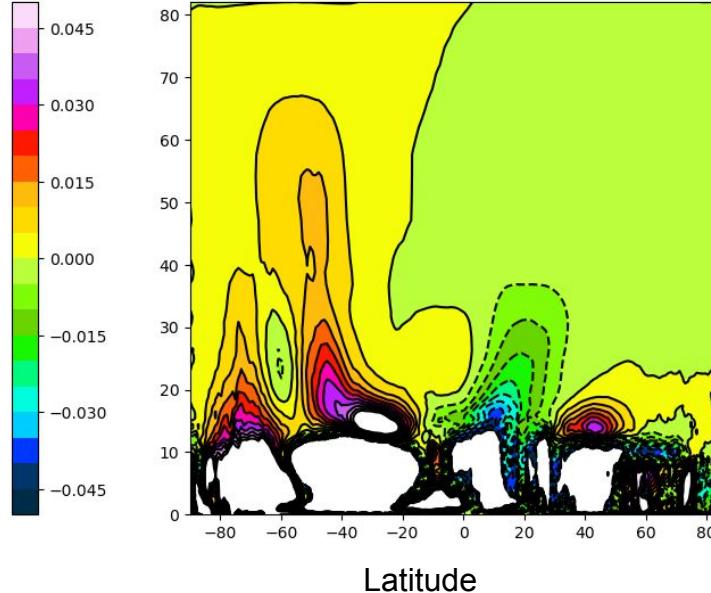
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JJA 2004-2004
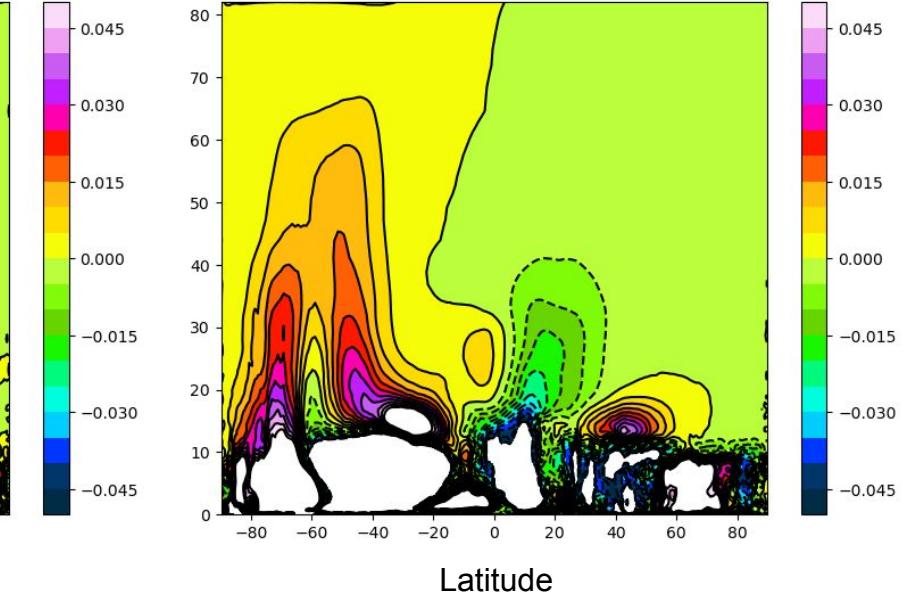
New or modified GW sources

- Pre-CAM7 sources
  - Deep Convection: broad phase speed spectrum -100 to 100 m/s. Not very active at high latitude.
  - Orography: zero phase speed. Limited leverage in SH
  - Fronts: Also broad phase speed spectrum -100 to 100 m/s. This turns out to limit its usefulness
- At last year's AMWG we proposed a "moving mountain" source, i.e., low phase speed GW forced by relatively steady but horizontally-moving circulations in the lower troposphere. First attempt keyed-off of PBL momentum fluxes.

New or modified GW sources

Simple GW source based on turbulent momentum fluxes in CLUBB

New simple GW source based on vorticity

Launch level momentum flux *(currently estimated from CLUBB mom fluxes* clubb_l_predict_upwp_vpwp= .true. *)*

Launch level

Steering level

Momentum flux is set to scaled vorticity magnitude

Launch level
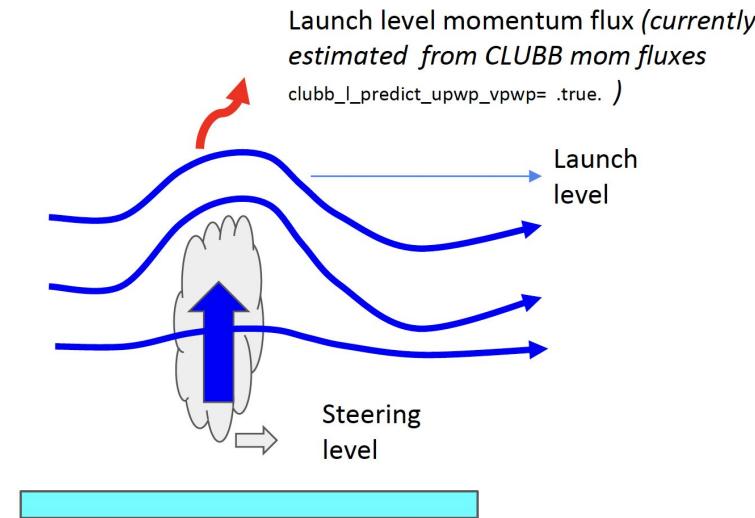
Steering level

Steering level ~100's m
Launch level ~100's to 1000 m
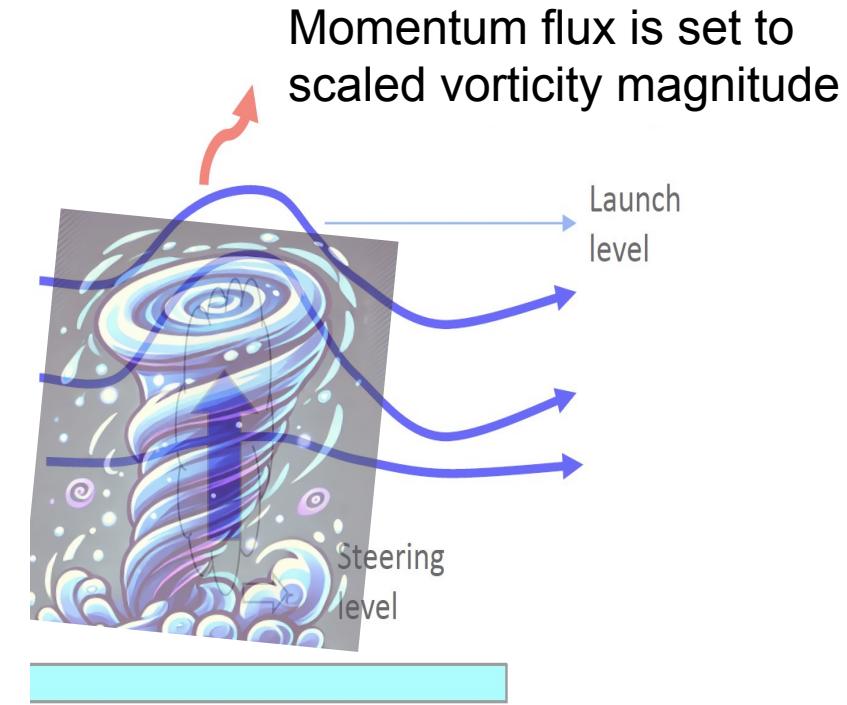
Steering level ~1000's m
Launch level ~1000's m

New or modified GW sources

- PBL momentum flux GW source and vorticity source give comparable results.

- Vorticity source is in the literature (Lott et al. 2012; de la Camara and Lott 2015) and is supported by ne240 results

- PBL source is difficult to validate …

Time-longitude Hovmoellers from ne240 run; June 2004; 46S to 36S
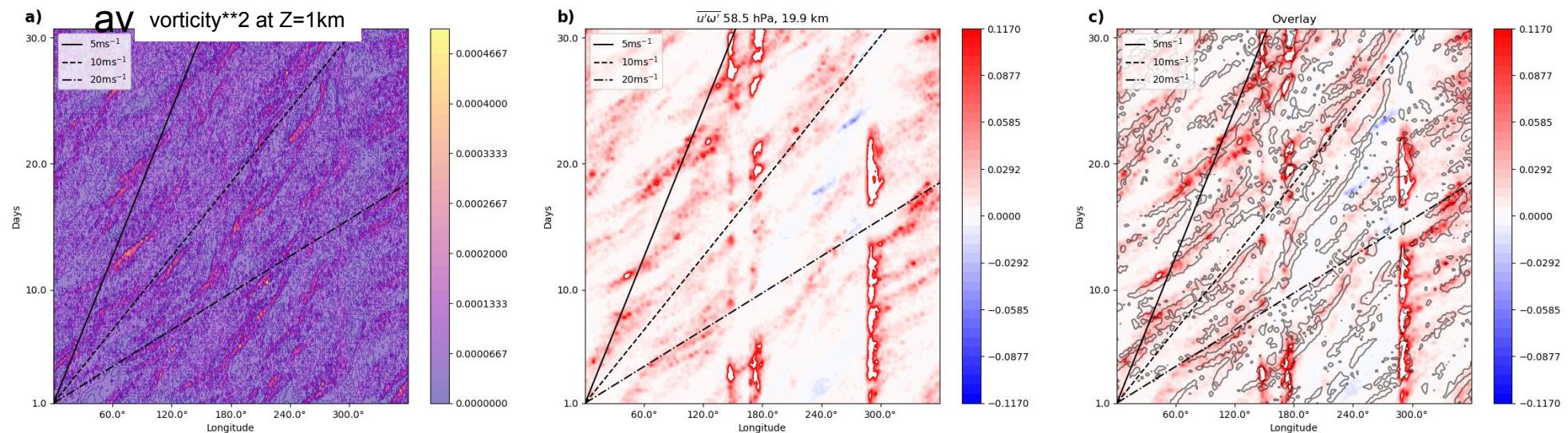
References

de la Cámara, A., and F. Lott (2015), A parameterization of gravity waves emitted by fronts and jets. *Geophys. Res. Lett.*, 42, 2071–2078. doi: 10.1002/2015GL063298..

Lott, F., R. Plougonven, and J. Vanneste, 2012: Gravity Waves Generated by Sheared Three-Dimensional Potential Vorticity Anomalies. *J. Atmos. Sci.*, **69**,

JJA 1985-1996

Zonal wind

No moving mountains

Vorticity source

PBL u'w', v'w' source

ERA5 climo

Temperature

Latitude

Latitude

Latitude
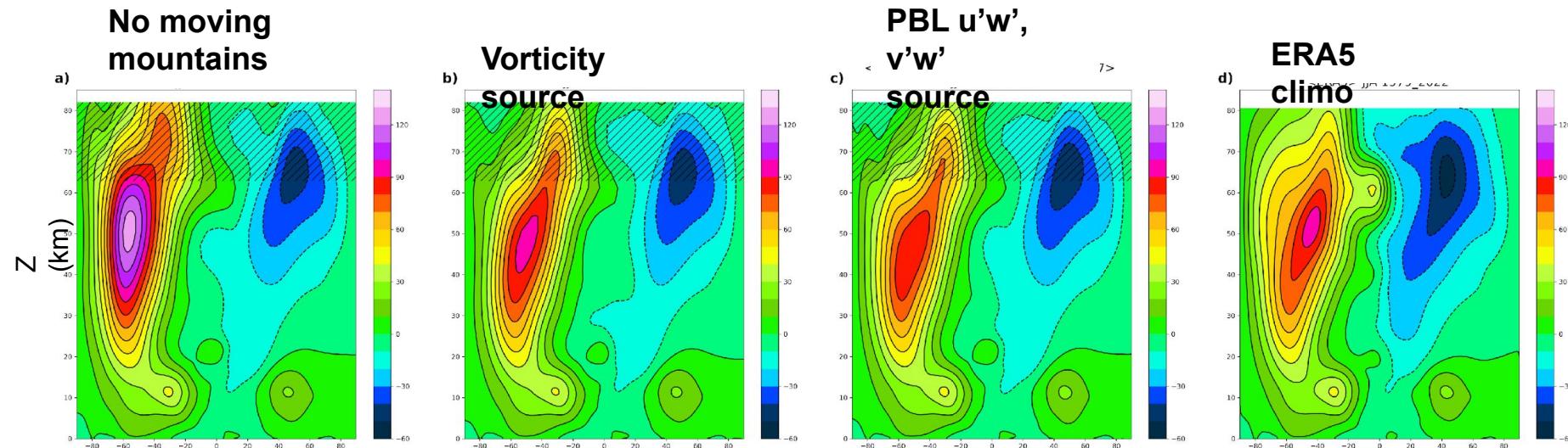
Latitude
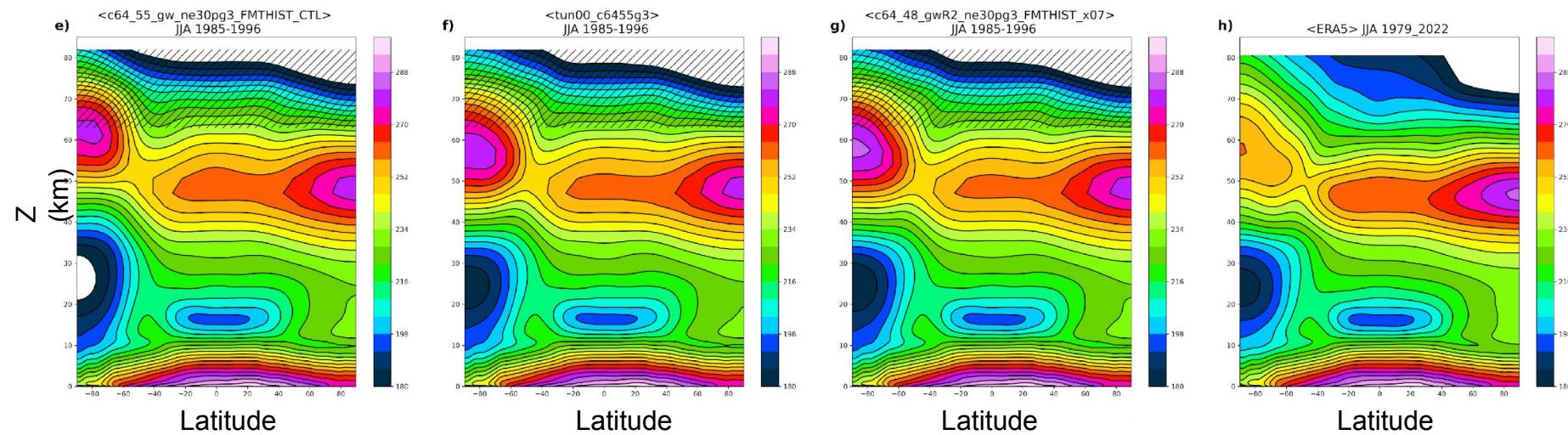
Steering ~ 3km
Launch ~ 6km

Steering ~ 500m
Launch ~ 1km

Tendencies produced by different GW sources (JJA)

Mountains

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JJA 2014-2014

Front

<ndg01c_c6455g3> UTGWSPEC
JJA 2014-2014
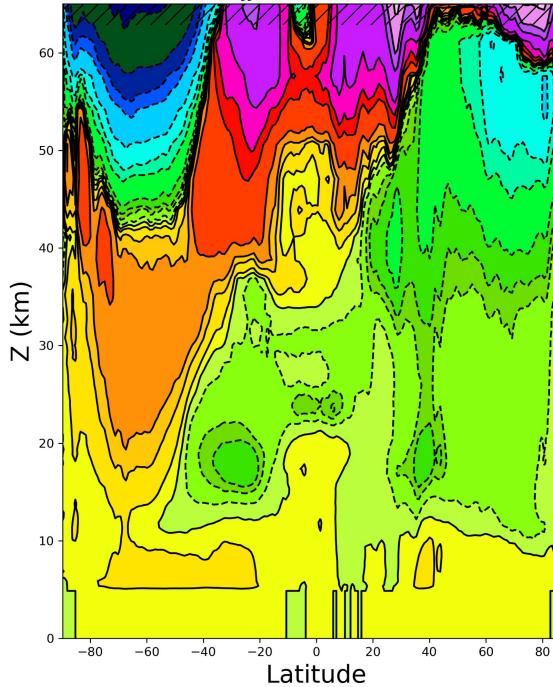
"Moving Mountains"
(vorticity source)

<ndg01c_c6455g3> UTGW_MOVMTN
JJA 2014-2014

Tendencies produced by different GW sources (JJA)

Mountains

b)   <ndg01c_c6455g3> UTGWORO
JJA 2014-2014
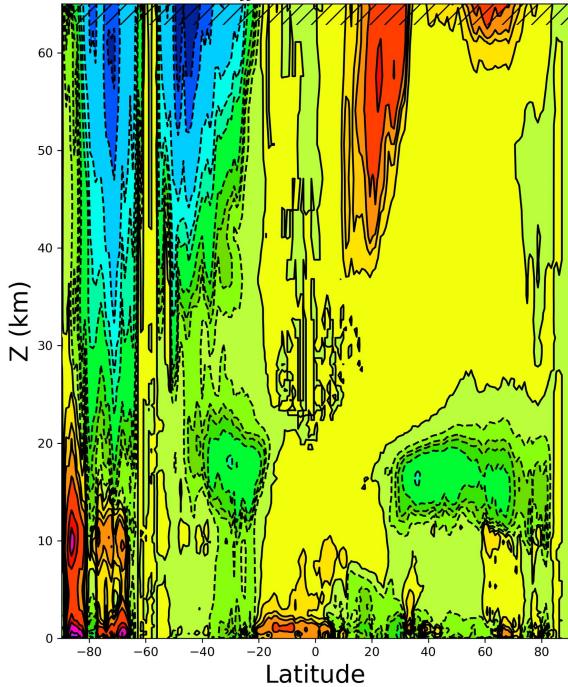
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Front

b)   <ndg01c_c6455g3> UTGWSPEC
S   JJA 2014-2014
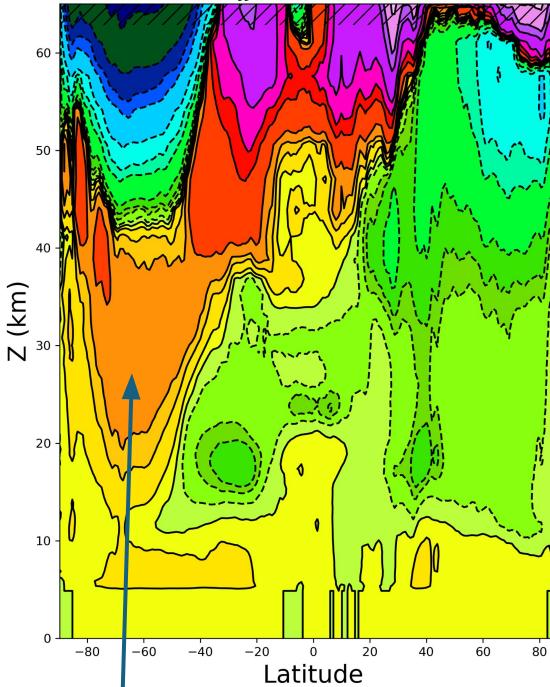
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substantial flow **acceleration(!!)**
in SH vortex

"Moving Mountains"
(vorticity source)

b)   <ndg01c_c6455g3> UTGW_MOVMTN
JJA 2014-2014
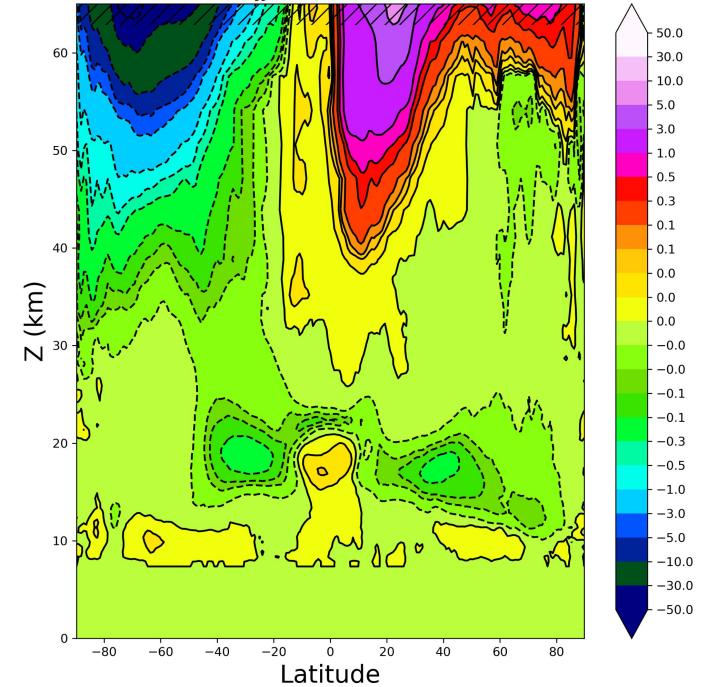
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Some, overlap between moving mountains
and frontal scheme aloft (Z>50km). Not
necessarily bad, but should be investigated.

Summary and Future work

- "Moving mountain" source improves SH polar vortex simulation (*not shown today - no degradation of NH*)

- Tuning continues – expect steering and launch levels for moving mountain will be more important than source of lower bondary momentum flux

  - Possible collaboration: automated tuning via Ensemble Kalman inverse project (Will Chapman, Hamid Pahlavan NWRA)
  - Looking into overlaps between current frontal scheme and moving mountains

- Nudging runs both to ERA5 and to ne240 may provide insights

- Hoping that Loon Balloon momentum flux data* can provide validation for schemes

* Green, B., Sheshadri, A., Alexander, M. J., Bramberger, M., & Lott, F. (2024). Gravity wave momentum fluxes estimated from Project Loon balloon data. *Journal of Geophysical Research: Atmospheres*, 129, e2023JD039927. https://doi.org/10.1029/2023JD039927

Thanks

Extra Slides

Current status (DJF)
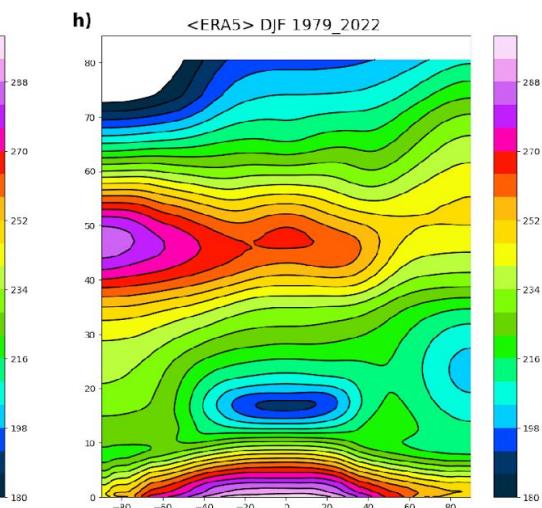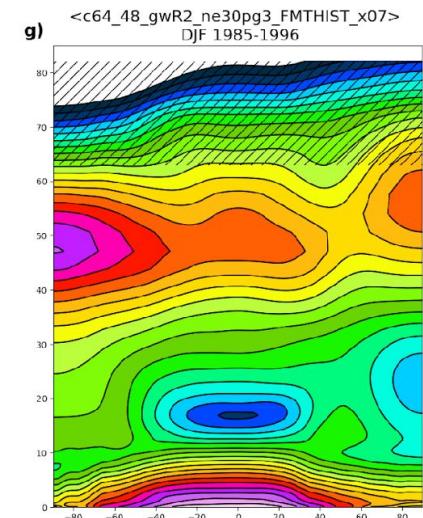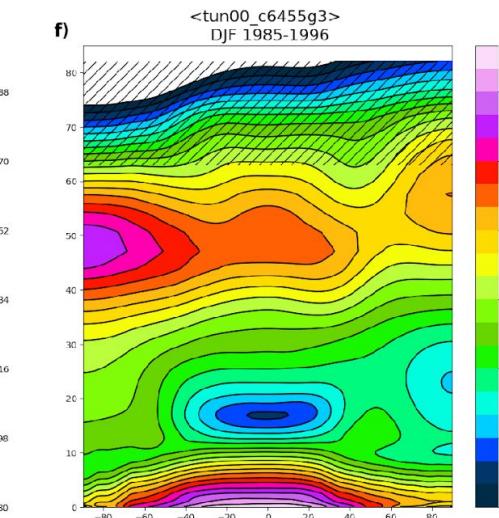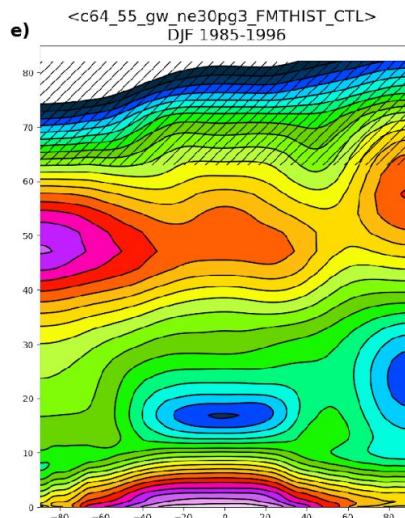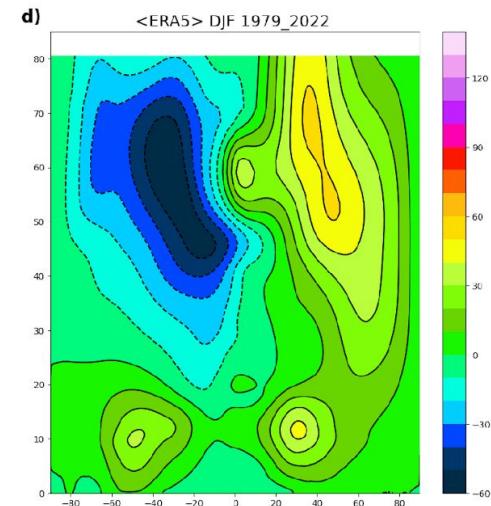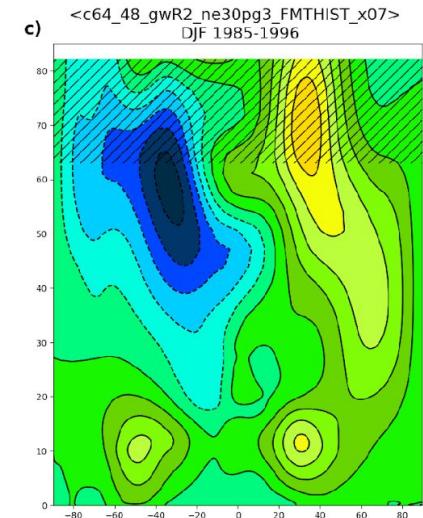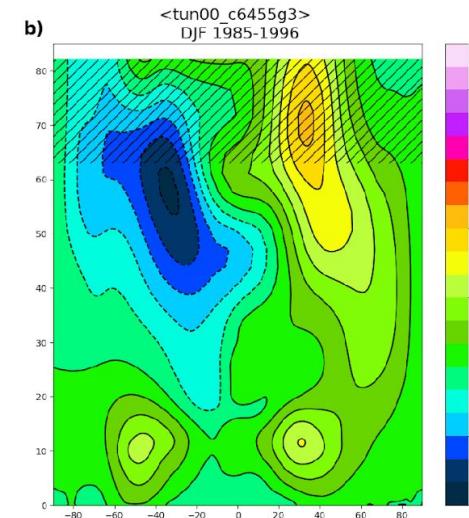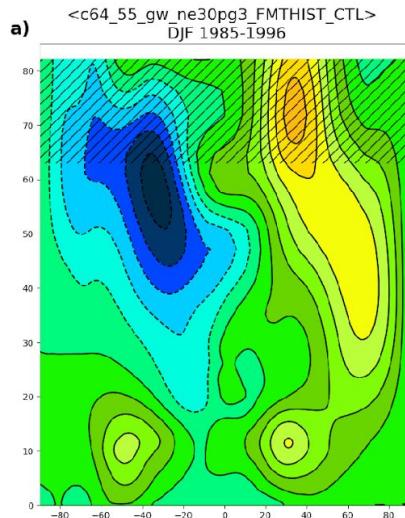
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DJF 1985-1996

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DJF 1985-1996

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DJF 1985-1996

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DJF 1985-1996

h) <ERA5> DJF 1979_2022

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effgw_movmtn_pbl: 1.0d0

use_gw_movmtn_pbl: .true.
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Extreme PPE (JJA)

Extreme PPE (DJF)

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JJA 2014-2014

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JJA 2014-2014

c) <ndg02b_c6455g3> UTGW_MOVMTN
JJA 2014-2014

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a) Title Placeholder

b) Title Placeholder

c) Title Placeholder
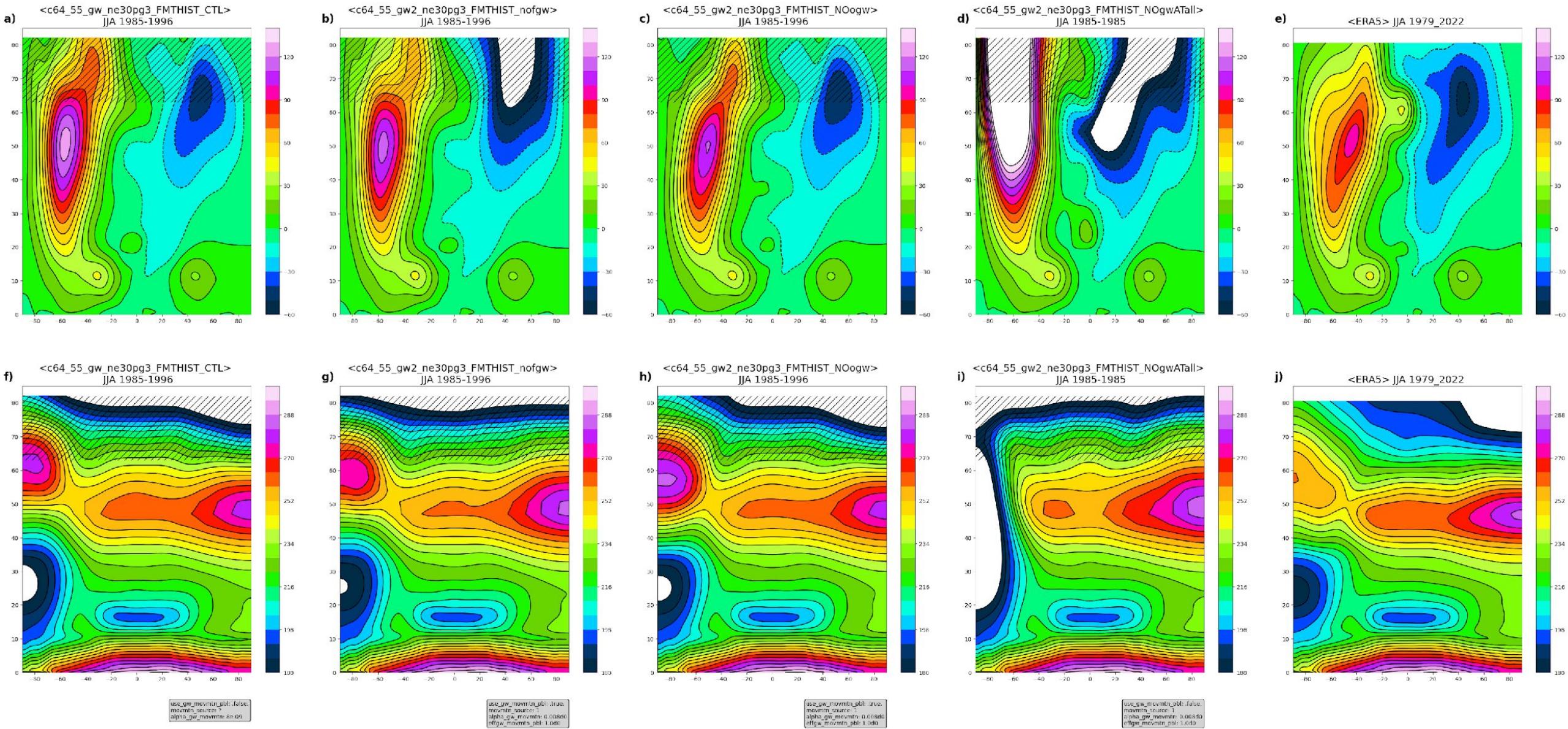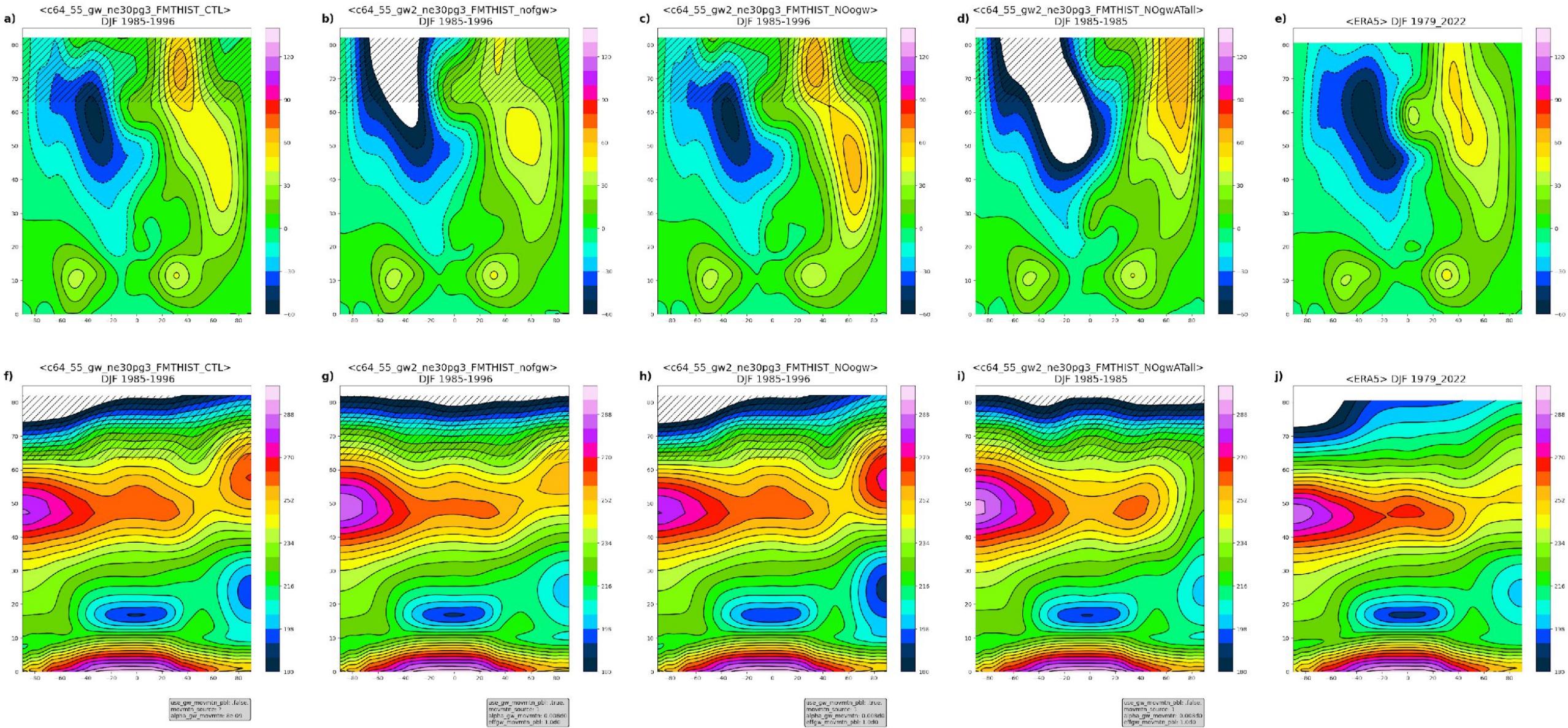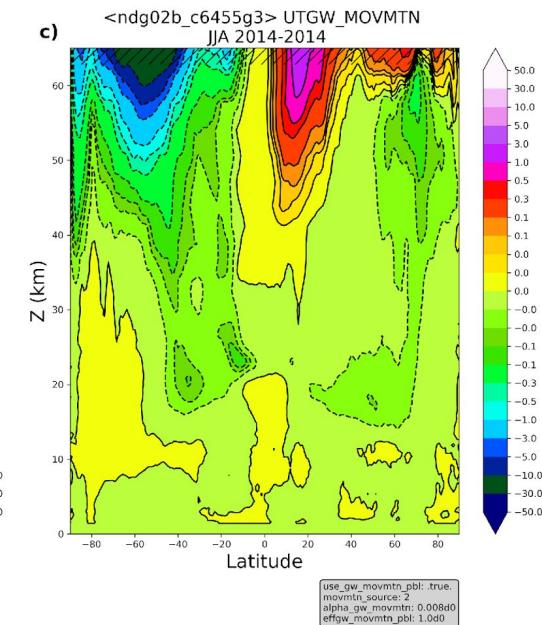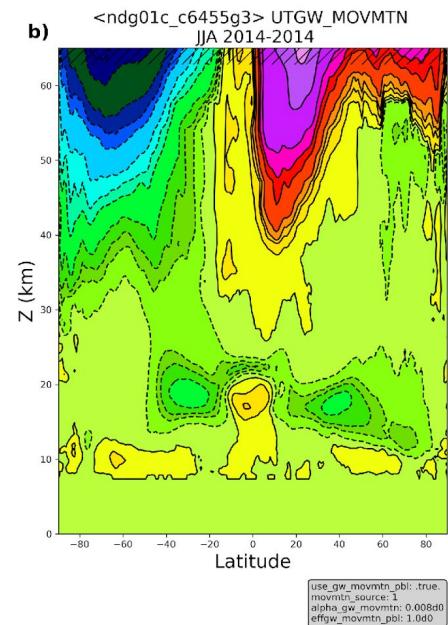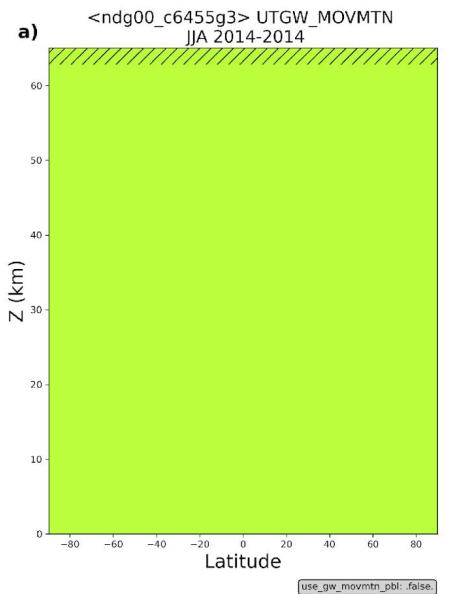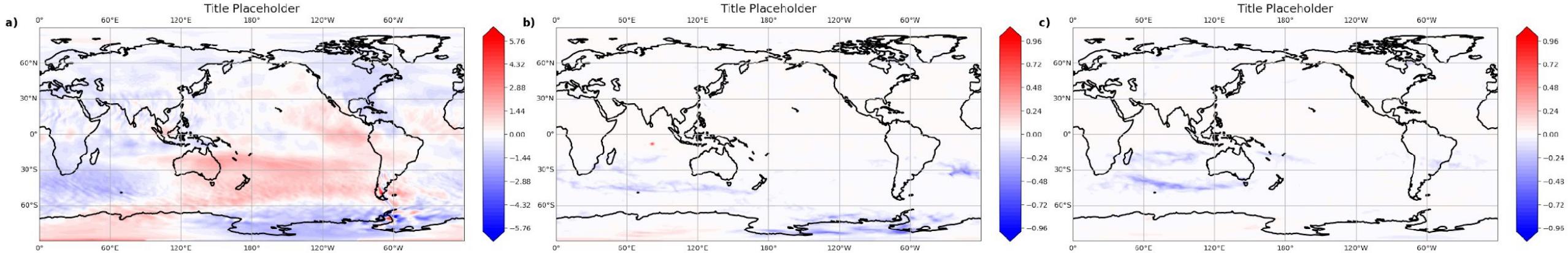
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