Untangling the tropical tropopause layer with an idealized moist model: Tropical vs. extratropical control

Martin Jucker (University of Melbourne)
Edwin P. Gerber (New York University)

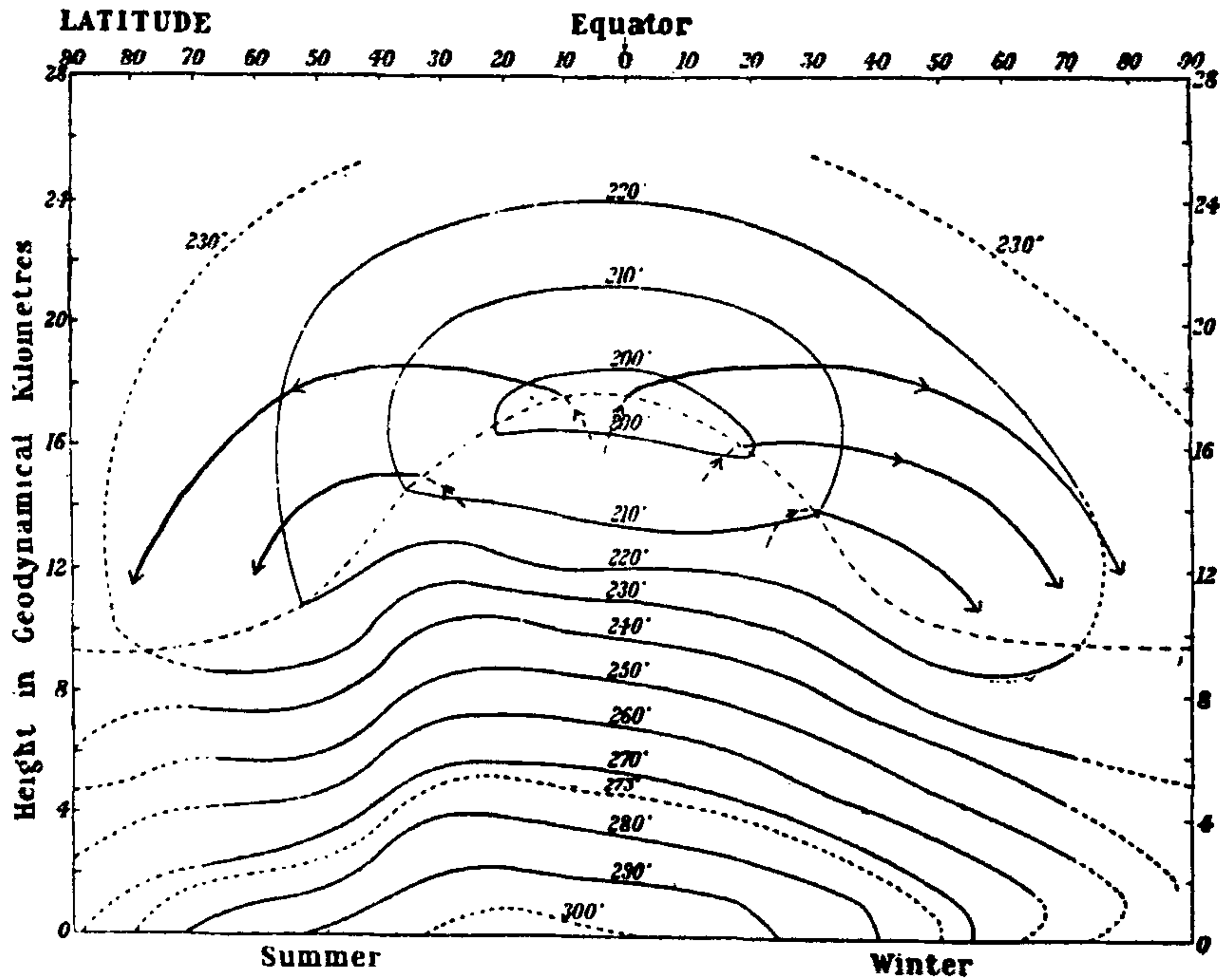
Thanks to the US National Science Foundation for their support.

551·510.5

EVIDENCE FOR A WORLD CIRCULATION PROVIDED BY THE MEASUREMENTS OF HELIUM AND WATER VAPOUR DISTRIBUTION IN THE STRATOSPHERE

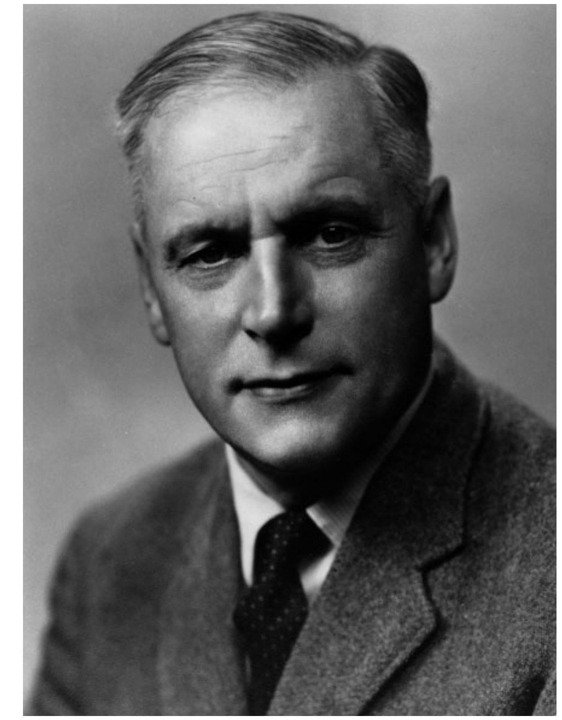
By A. W. BREWER, M.Sc., A.Inst.P.

(Manuscript received 23 February 1949)



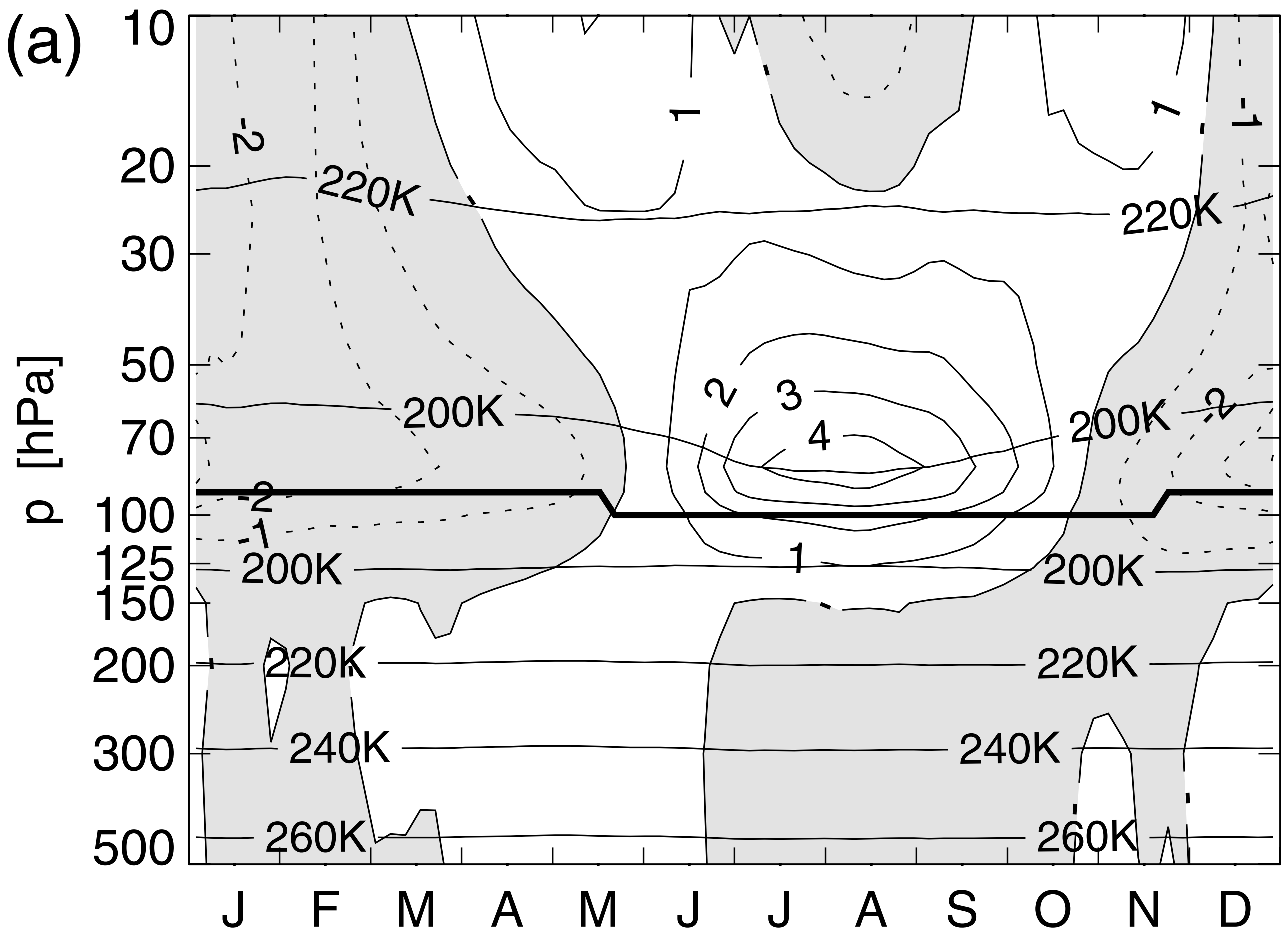
Isotherms over the Globe

FIG. 5. A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause.



The tropical tropopause layer's notable annual cycle

$\overline{T}$ deviation
from annual mean



[Fueglistaler et al. 2009]

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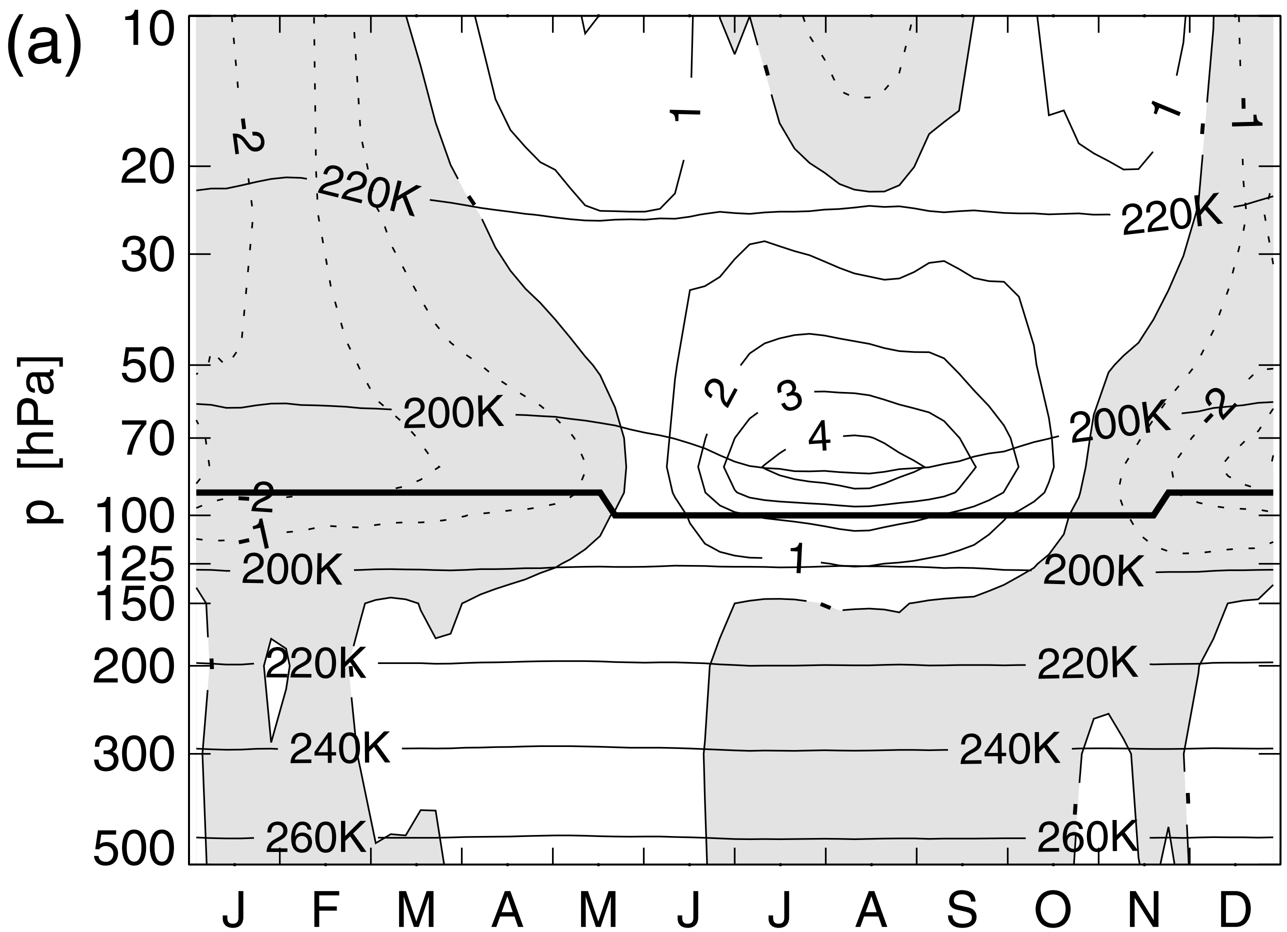
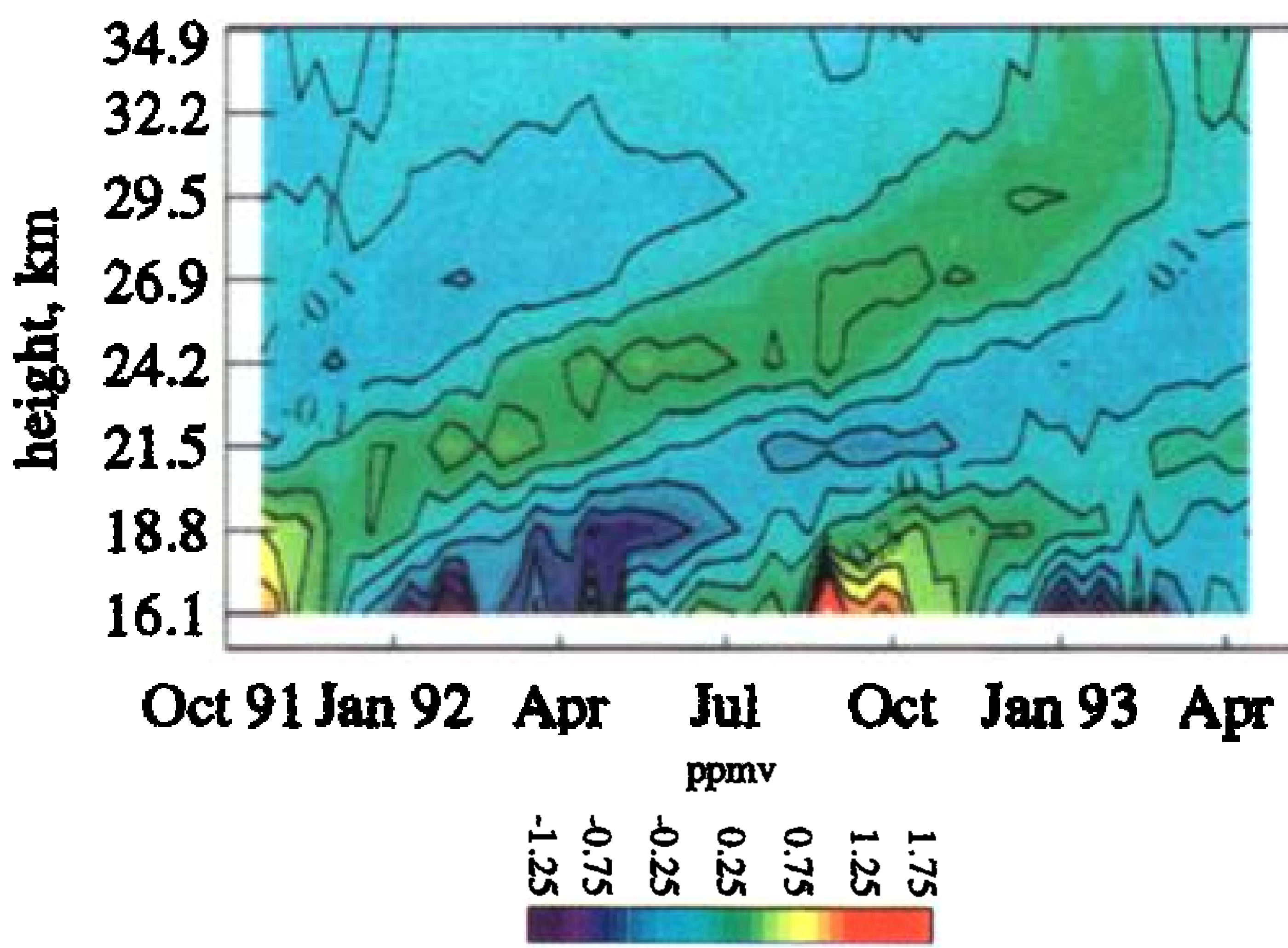


Microwave Limb Sounder water vapor measurements



[Fueglistaler et al. 2009]

[Mote et al. 1996]

What drives the annual cycle in the TTL temperature?

- **Dynamics**: more upwelling in boreal winter than summer
  - extratropical planetary waves forcing stronger in NH winter than SH winter *[e.g. Yulaeva et al. 1994, Chen and Sun 2011]*
  - tropical planetary waves excited by convection (warm pool) respond to annual variations wind structure *[e.g. Ortland and Alexander 2014]*
  - synoptic wave forcing has a greater annual cycle in the is NH than SH *[e.g. Jucker et al. 2013]*
  - All three are important [*Randel et al. 2008, Grise and Thompson 2013*]
- **Radiation***:* annual cycle of ozone (which is itself driven by cycle in upwelling); *Fueglistaler et al. 2011* show it explains ~ 2 K

Model Hierarchy

QG

clouds,
aerosols,
chemistry
(full GCM)

Inspired by Held 2005

Model Hierarchy

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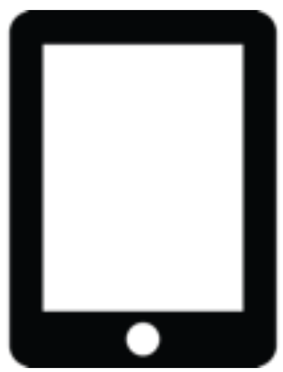
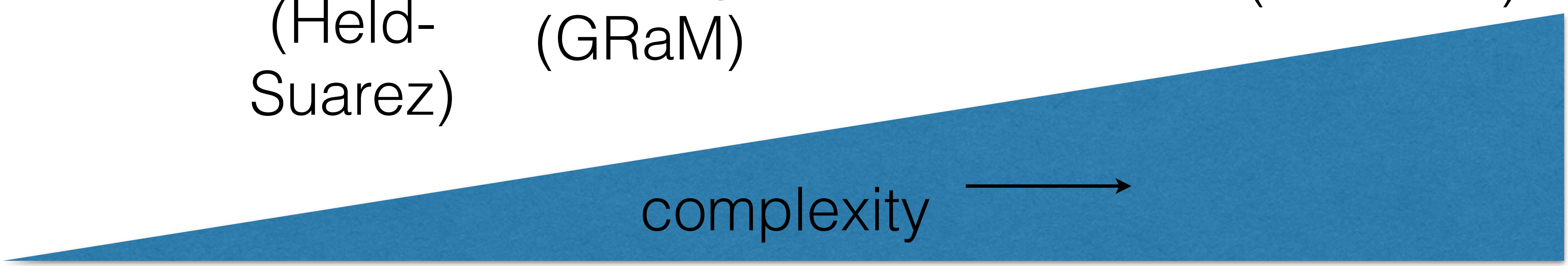


dry primitive equation dynamics (Held-Suarez)

gray radiation + latent heating (GRaM)

clouds, aerosols, chemistry (full GCM)



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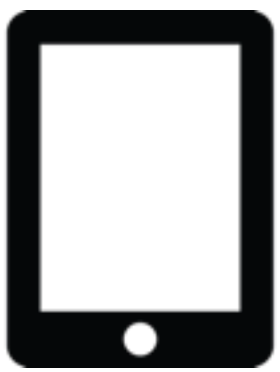
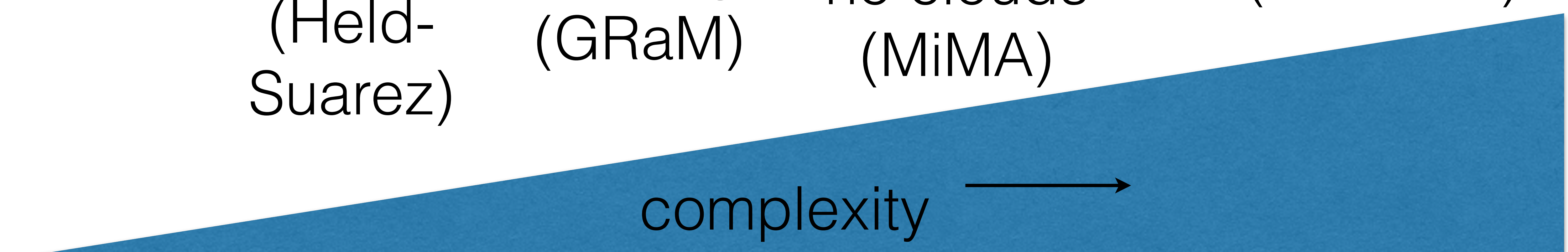


dry primitive equation dynamics (Held-Suarez)

gray radiation + latent heating (GRaM)

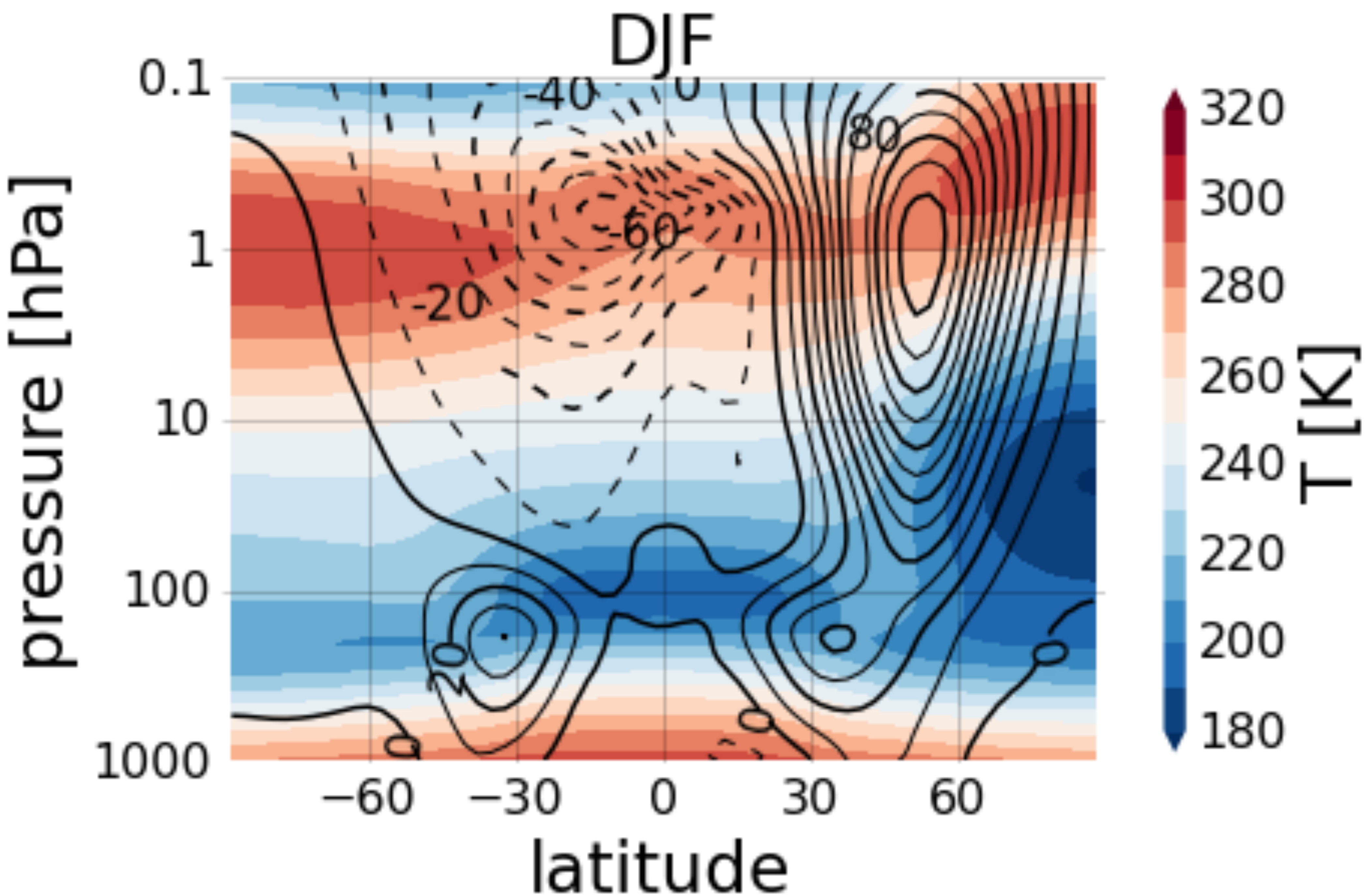
full radiation, moisture; no clouds (MiMA)

clouds, aerosols, chemistry (full GCM)



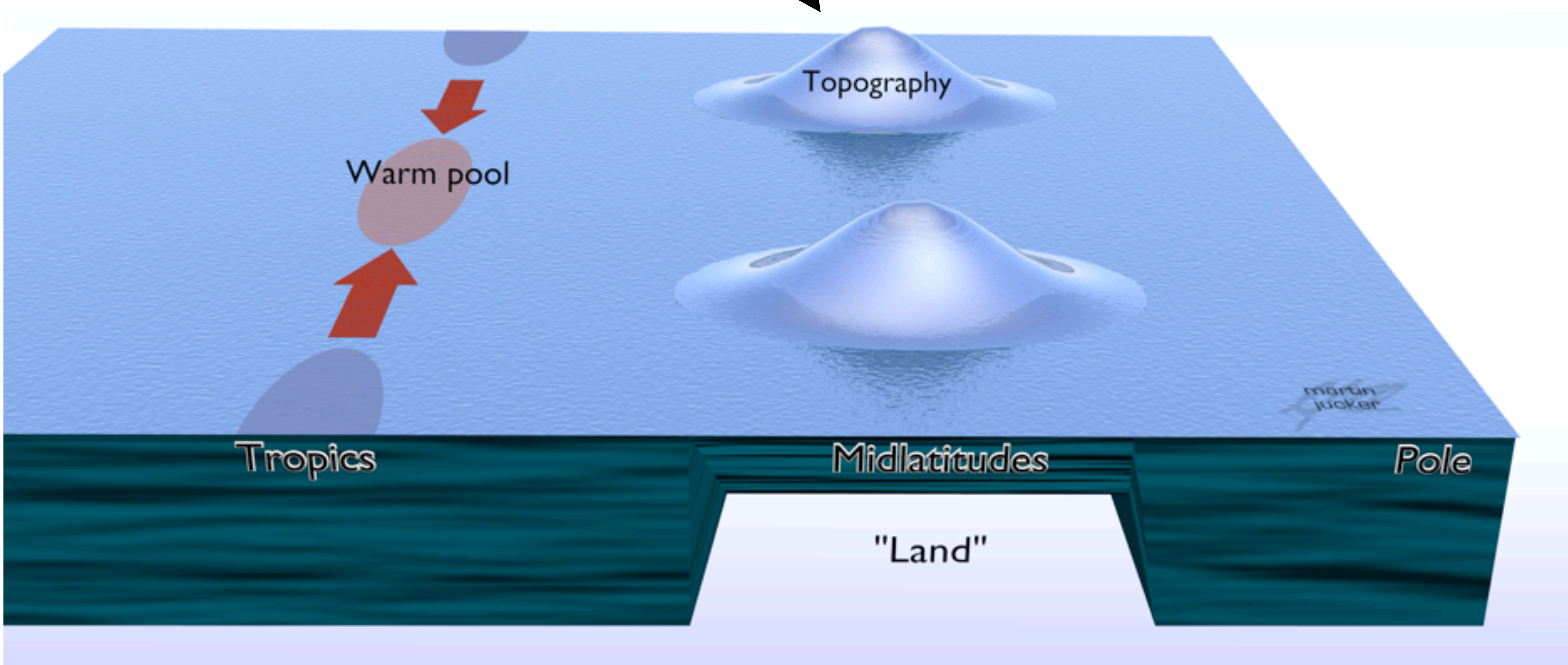
Inspired by Held 2005

A reasonable climatology



Representing the key forcings in an idealized model

1. extratropical planetary waves: midlatitude topography



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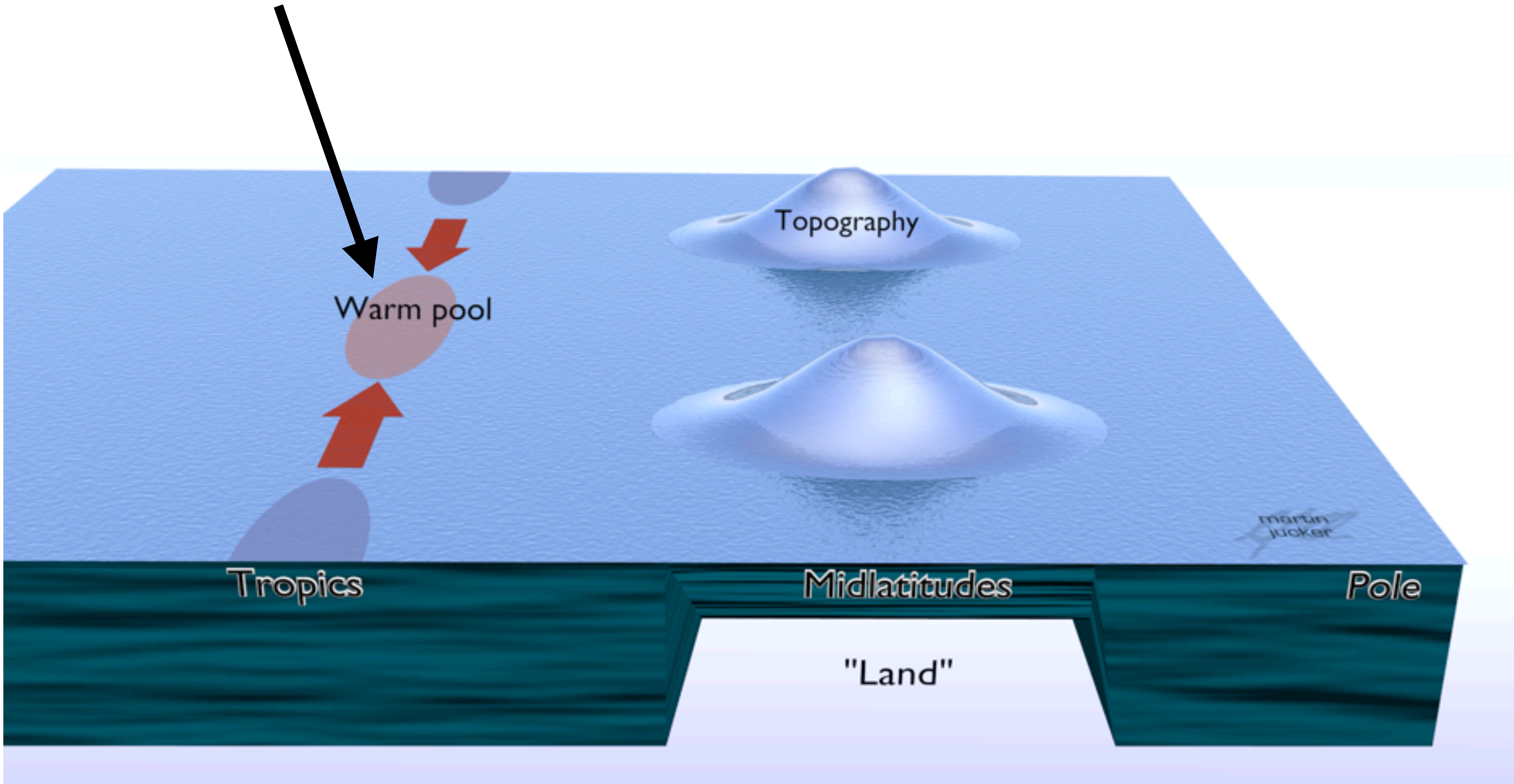
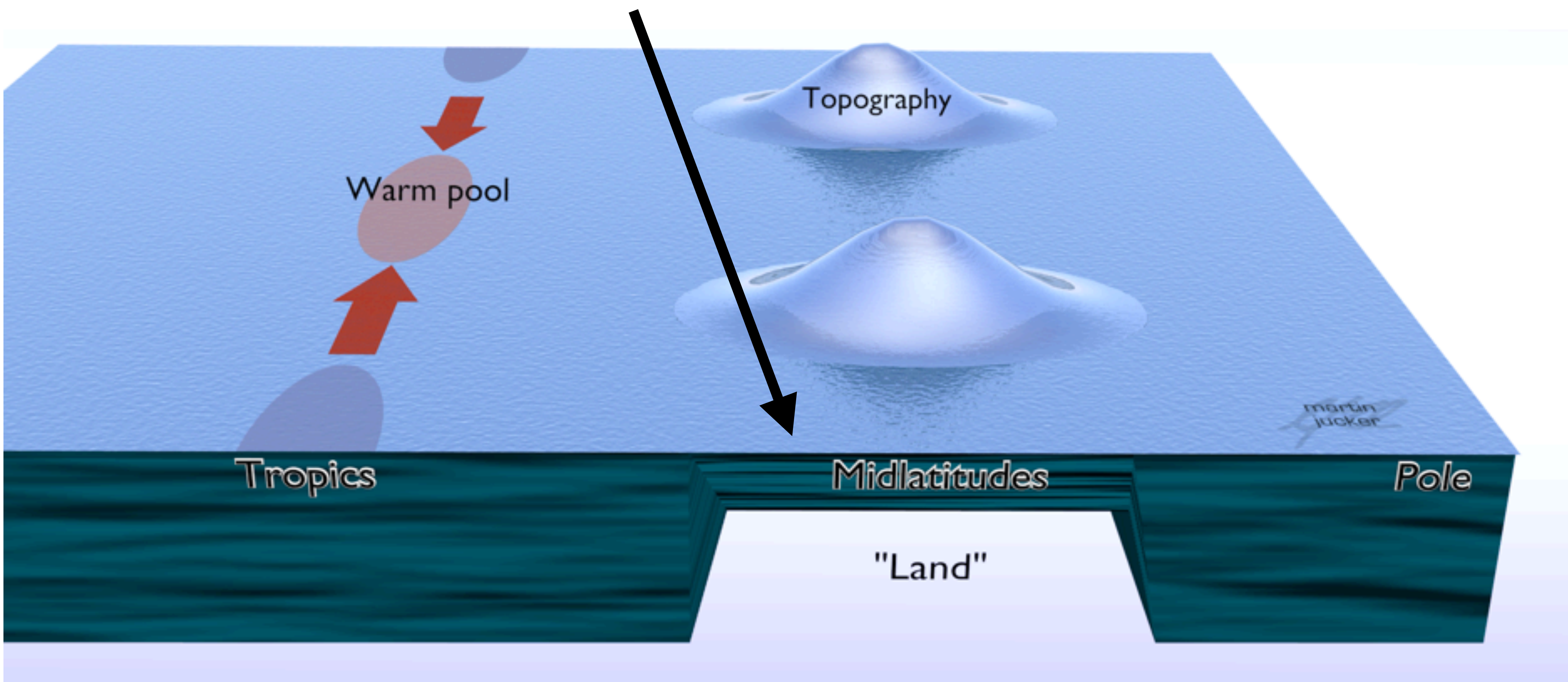


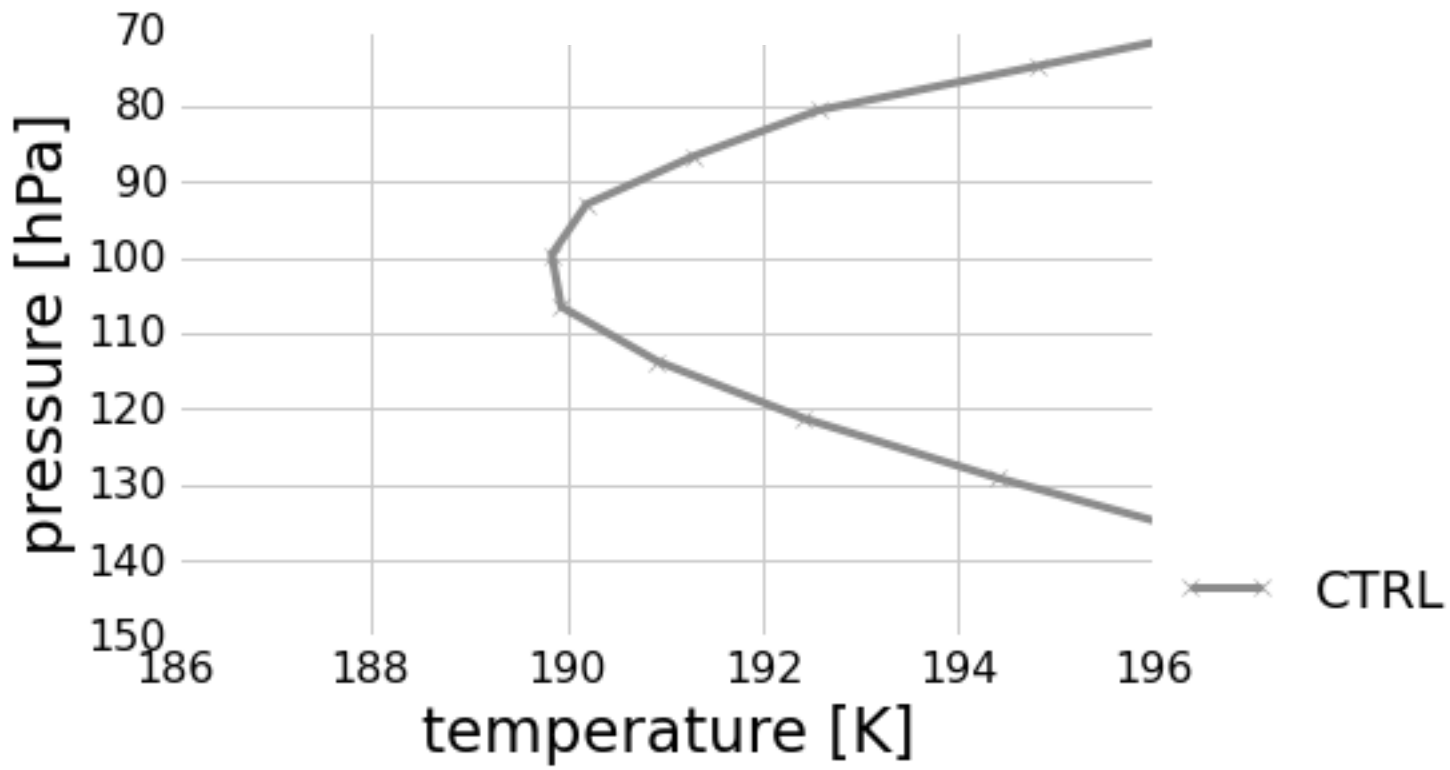
Representing the key forcings in an idealized model

1. extratropical planetary waves: midlatitude topography
2. tropical planetary waves: oceanic heat flux in tropics
3. synoptic wave activity: reduced heat capacity in NH

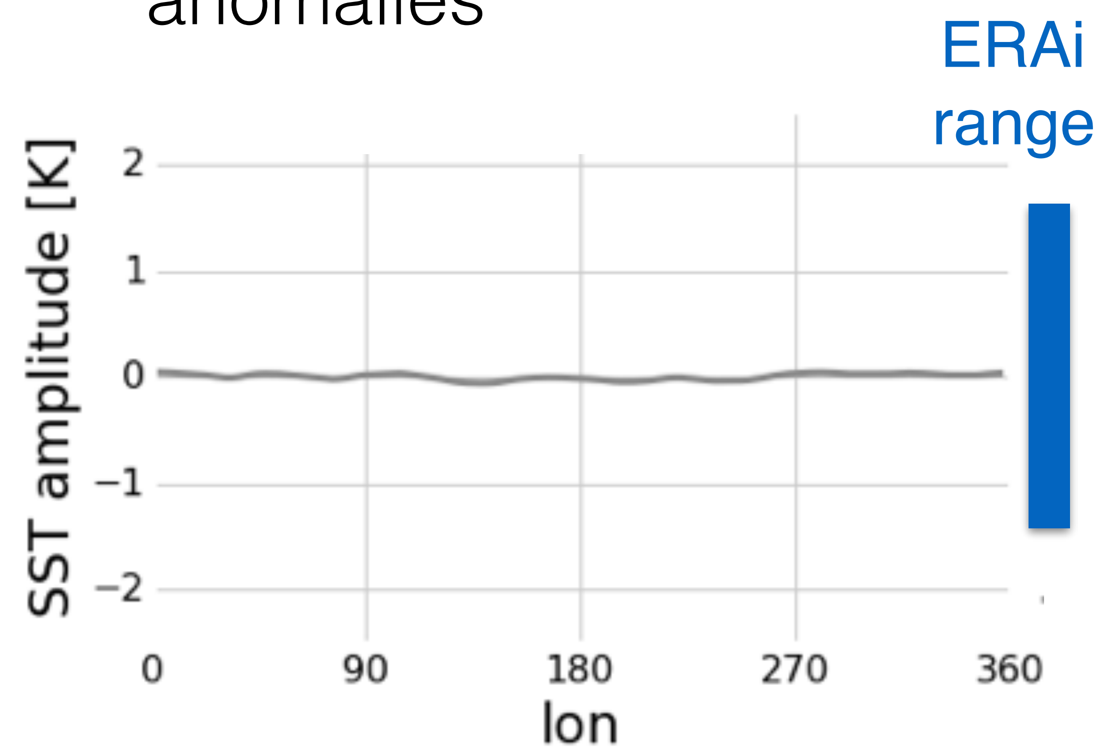


Tropical planetary waves control annual mean cold point structure

Tropical annual mean temperature profiles



Tropical mean zonal SST anomalies



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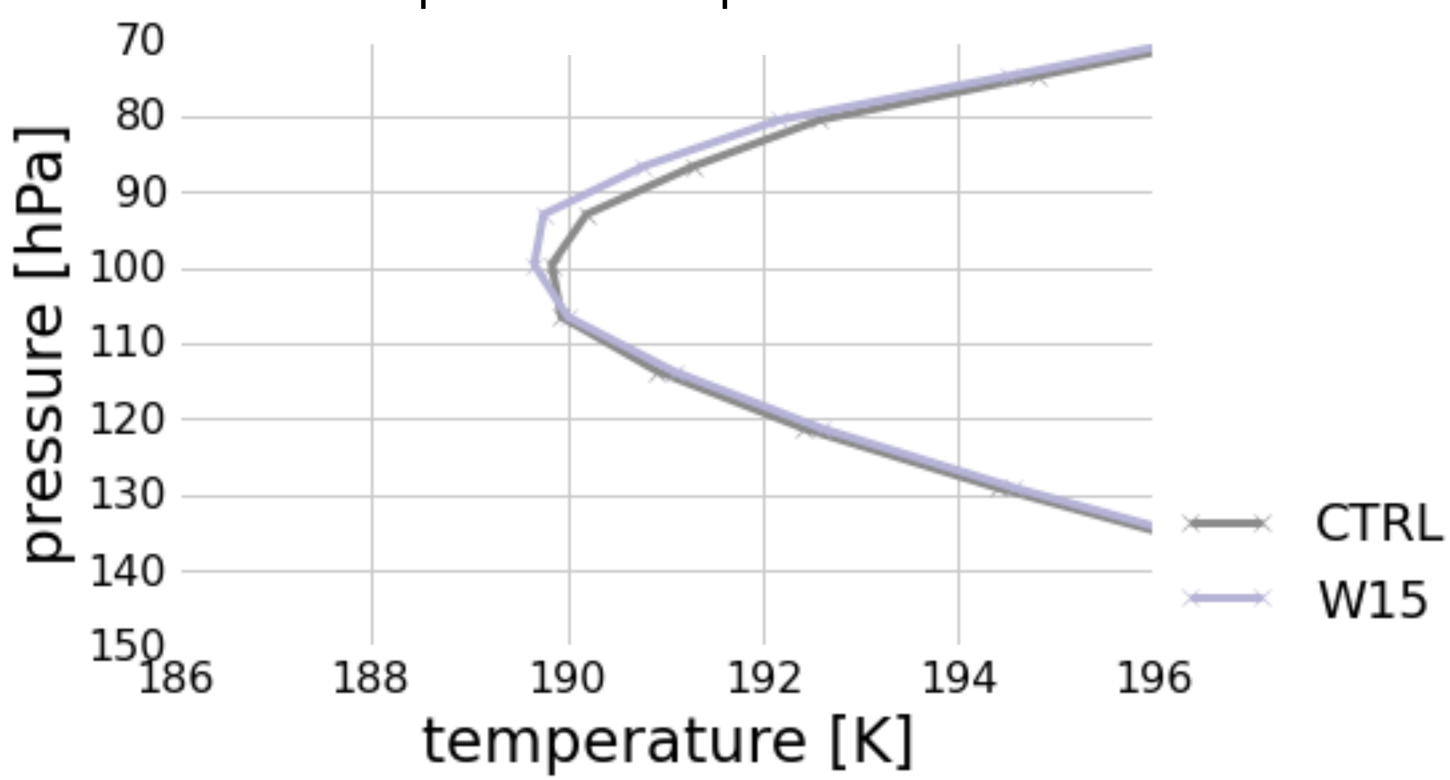

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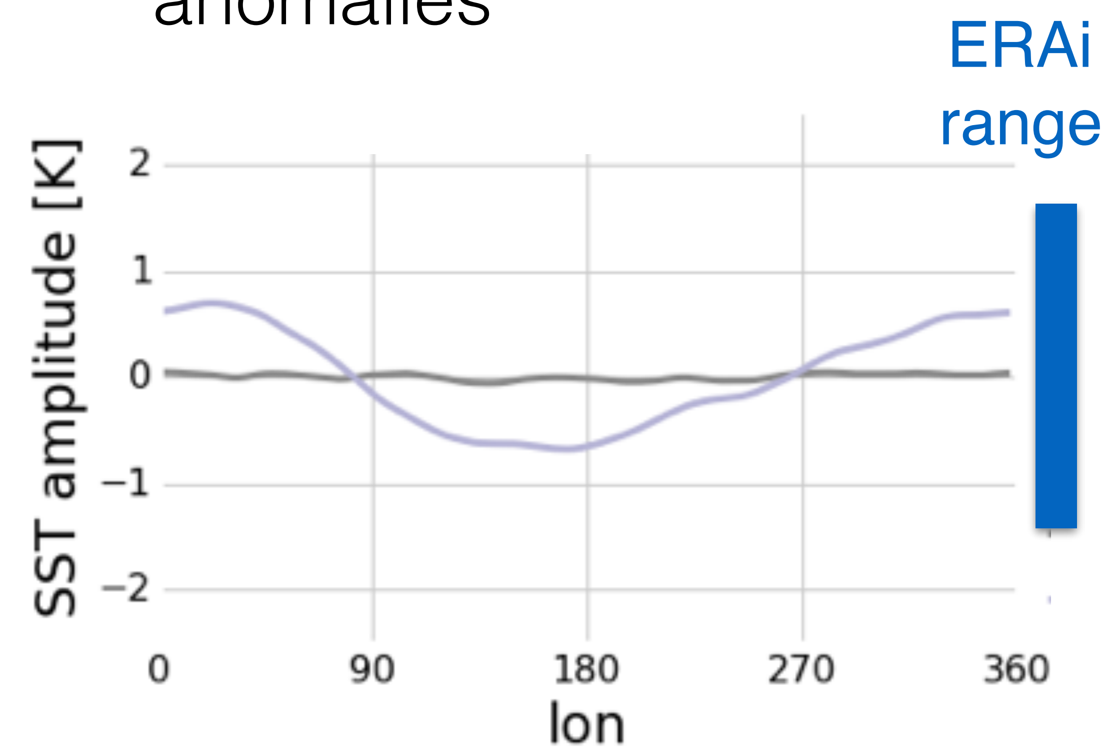

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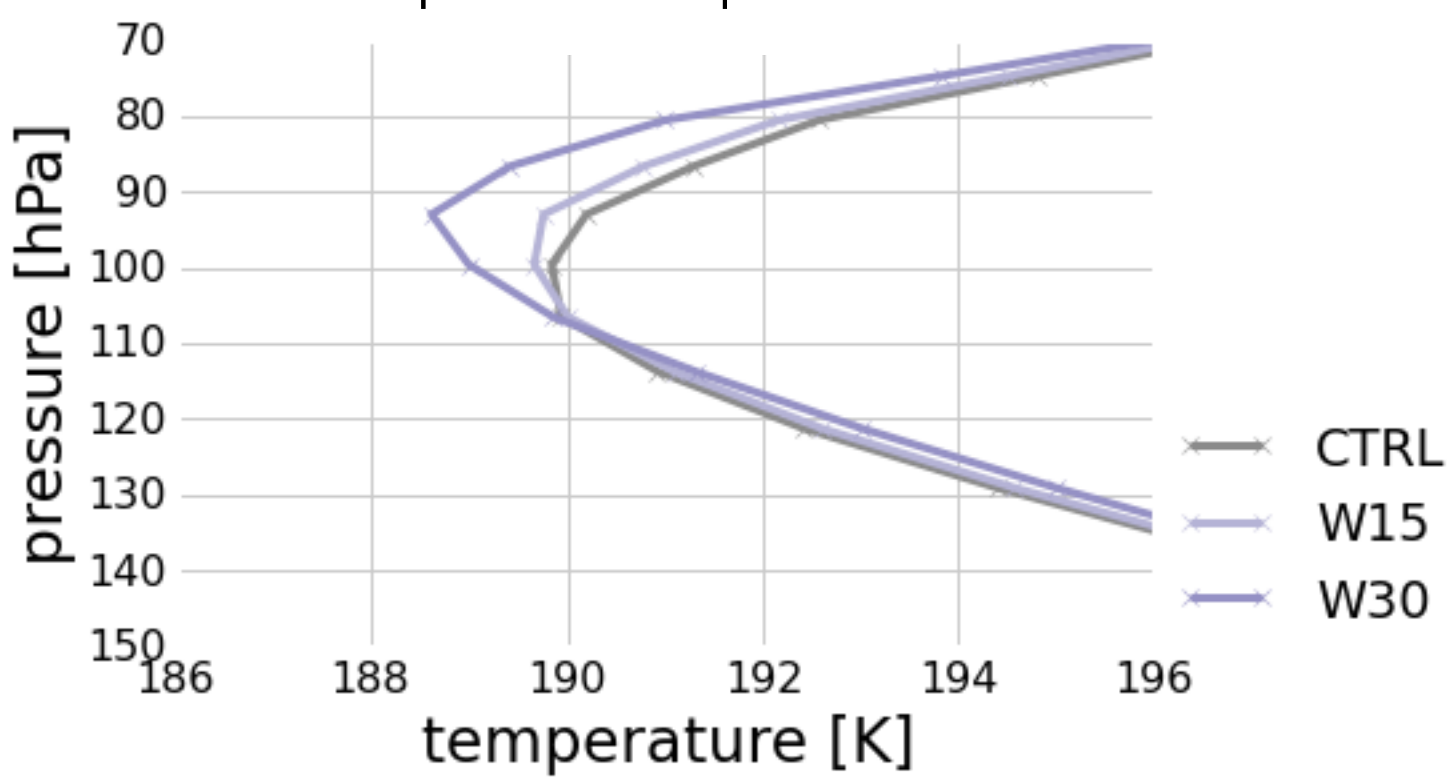

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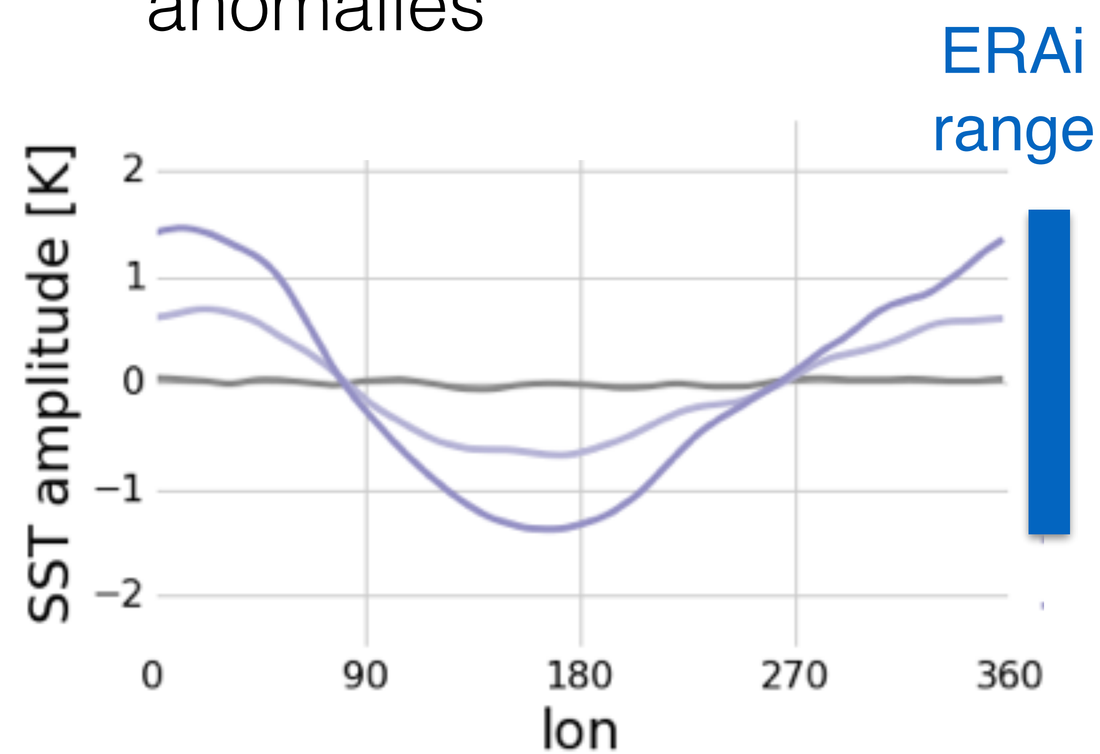

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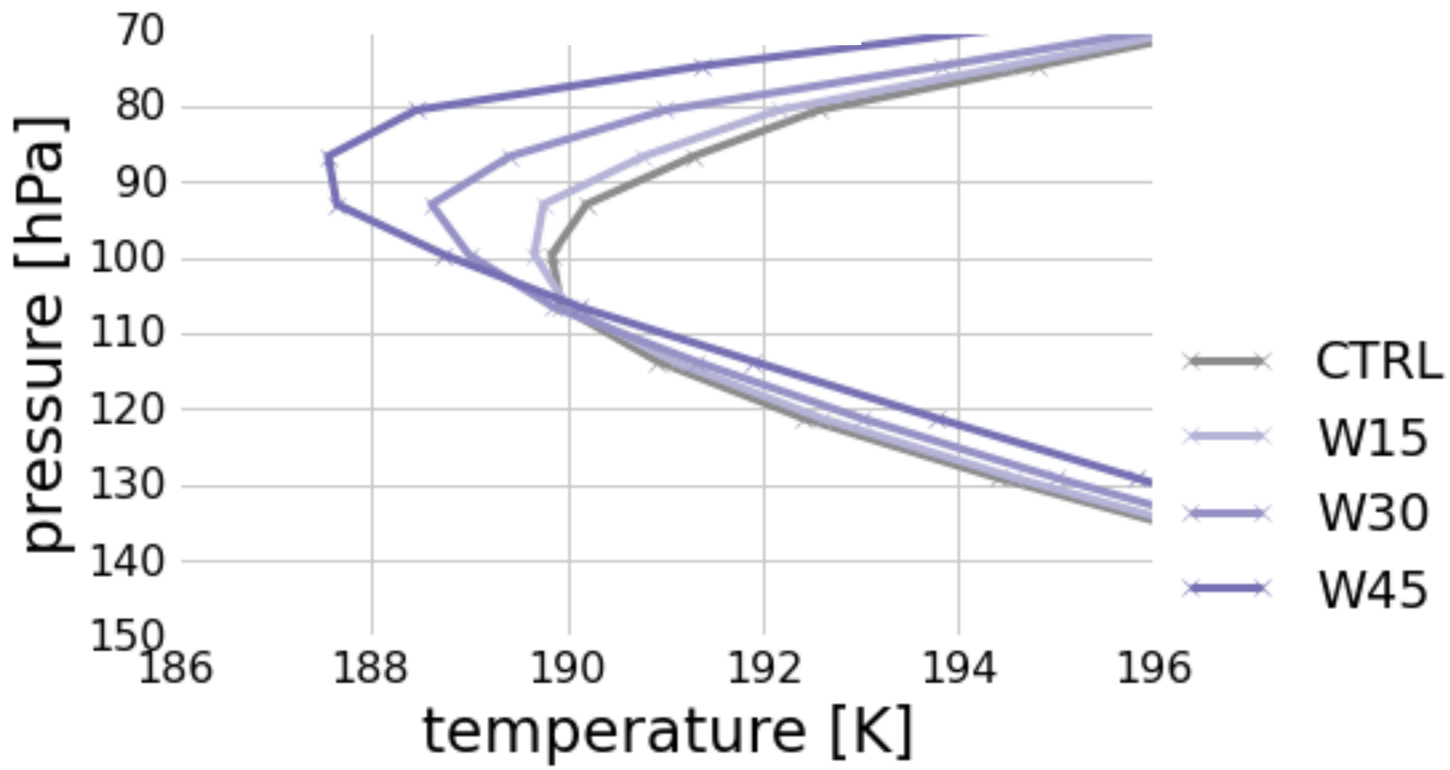

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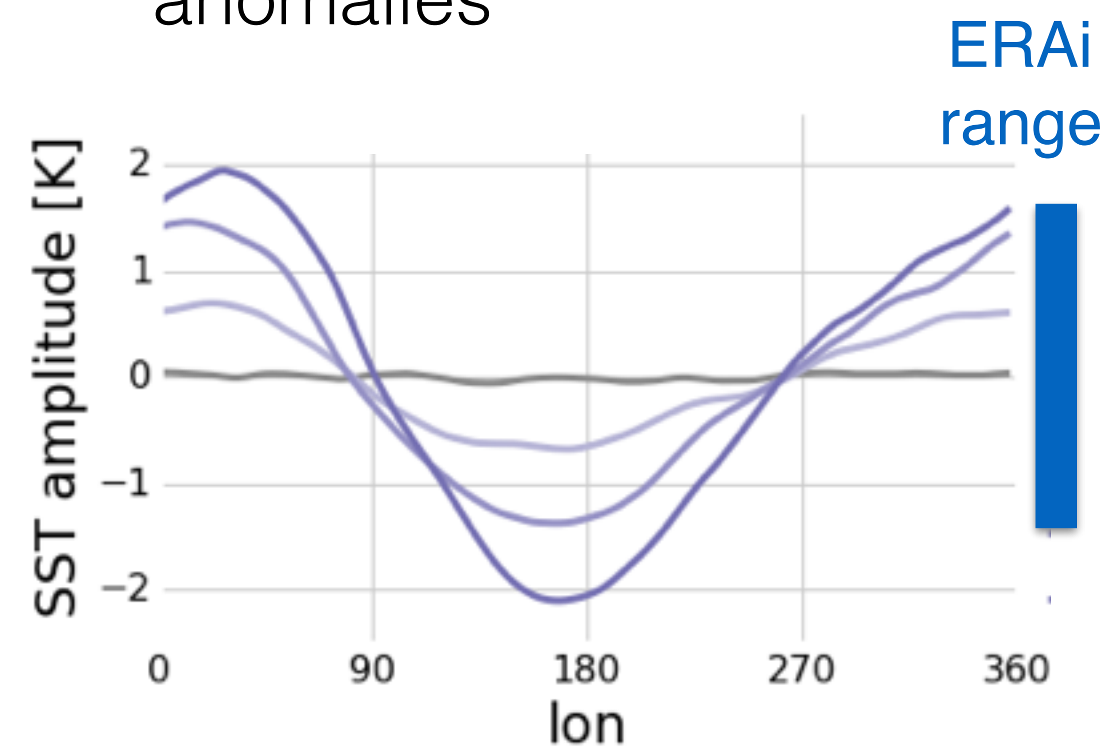
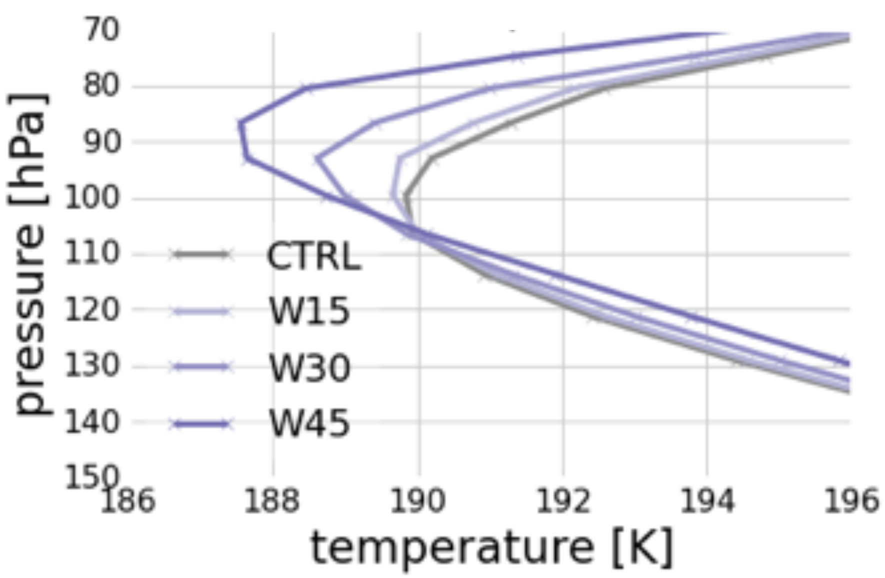
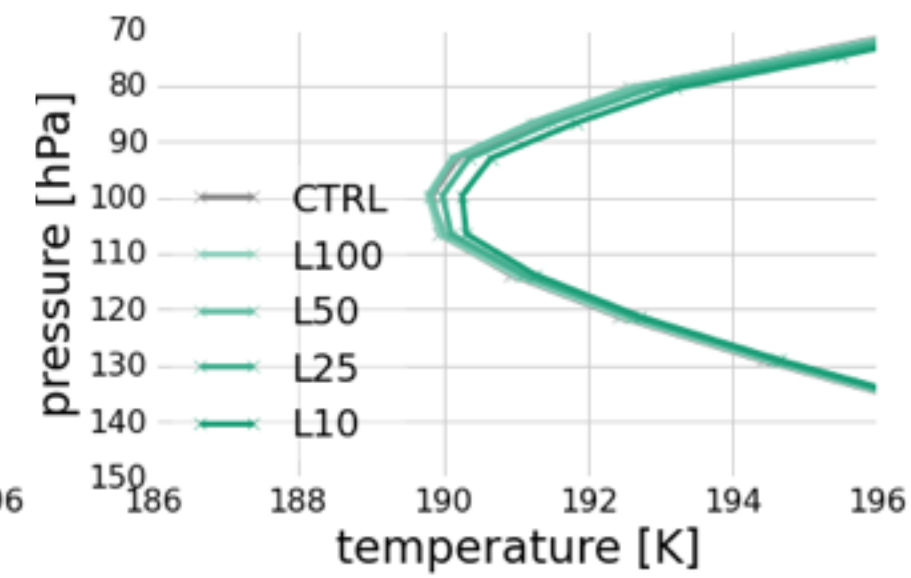
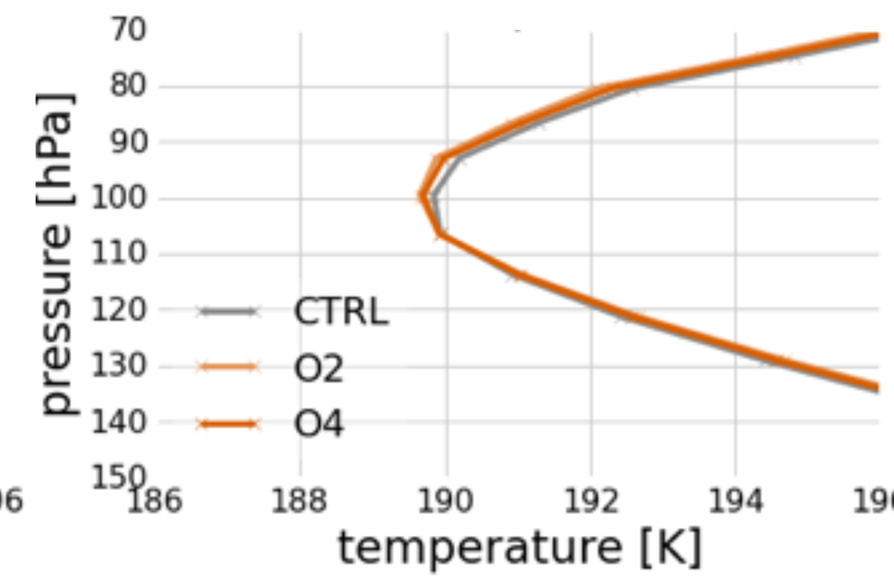


Tropical planetary waves control annual mean cold point structure

“warmpool” tropical waves	“land-sea contrast” synoptic waves	topography planetary waves







Tropics:

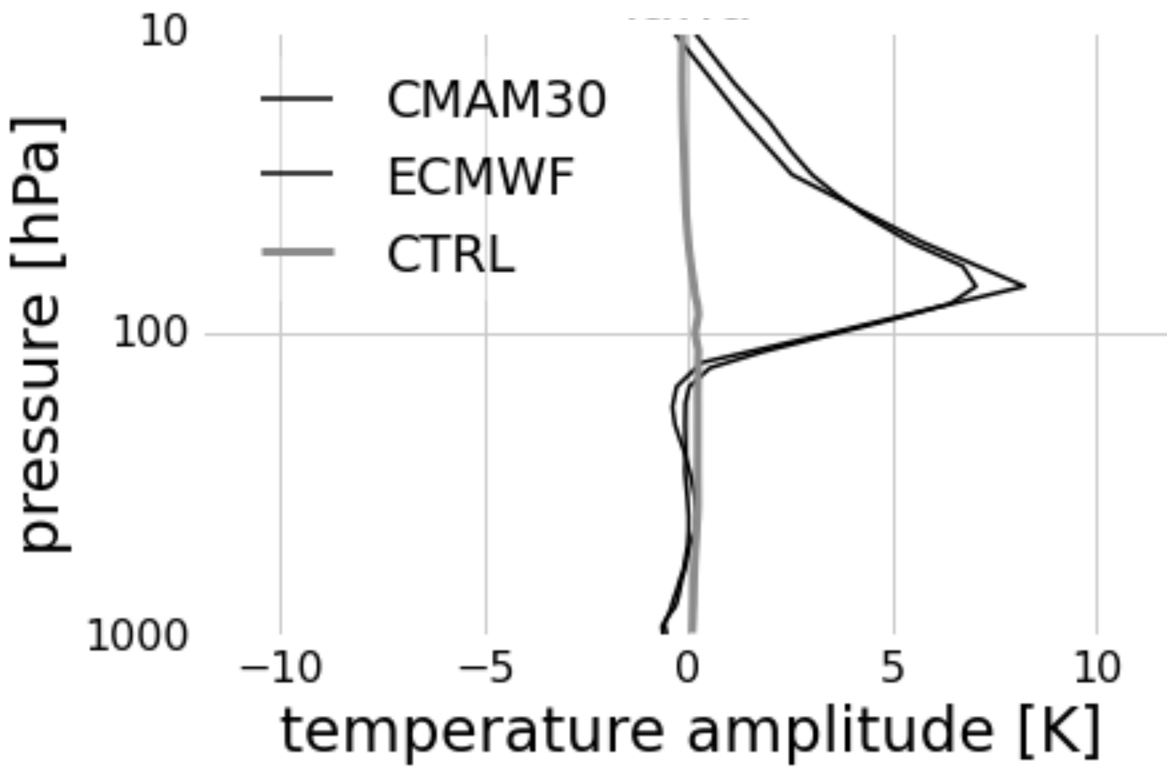
Strong effect on height, temperature, and sharpness

Extratropics:

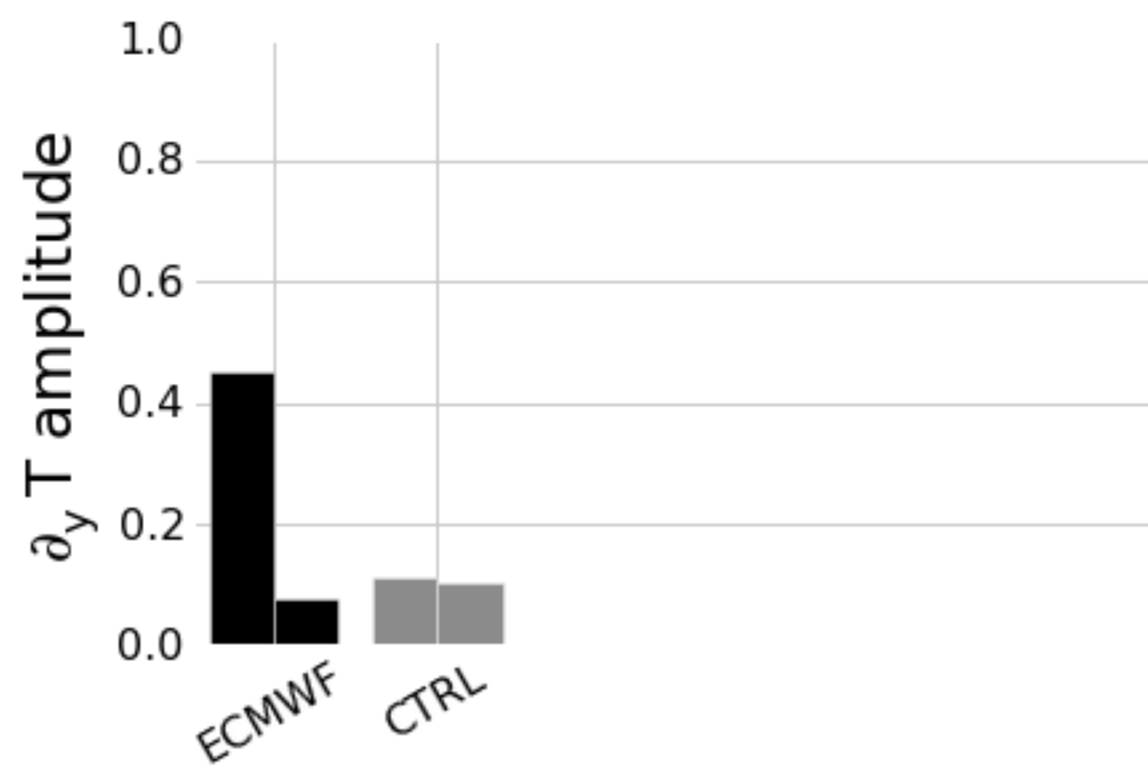
Neither land-sea contrast nor orographic facing have a strong effect on annual mean cold point structure

Annual Cycle of TTL Temperature

Tropical mean July - Jan temperature profiles



Extratropical mean NH/SH July-Jan T gradient



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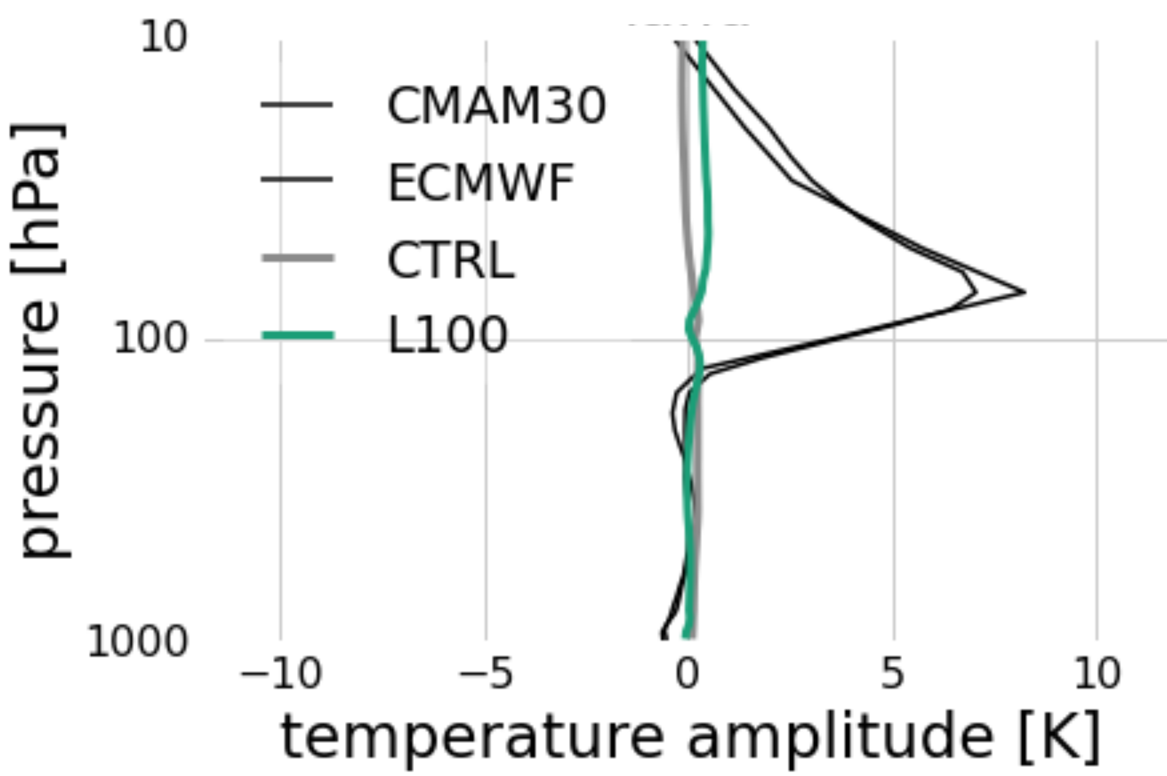

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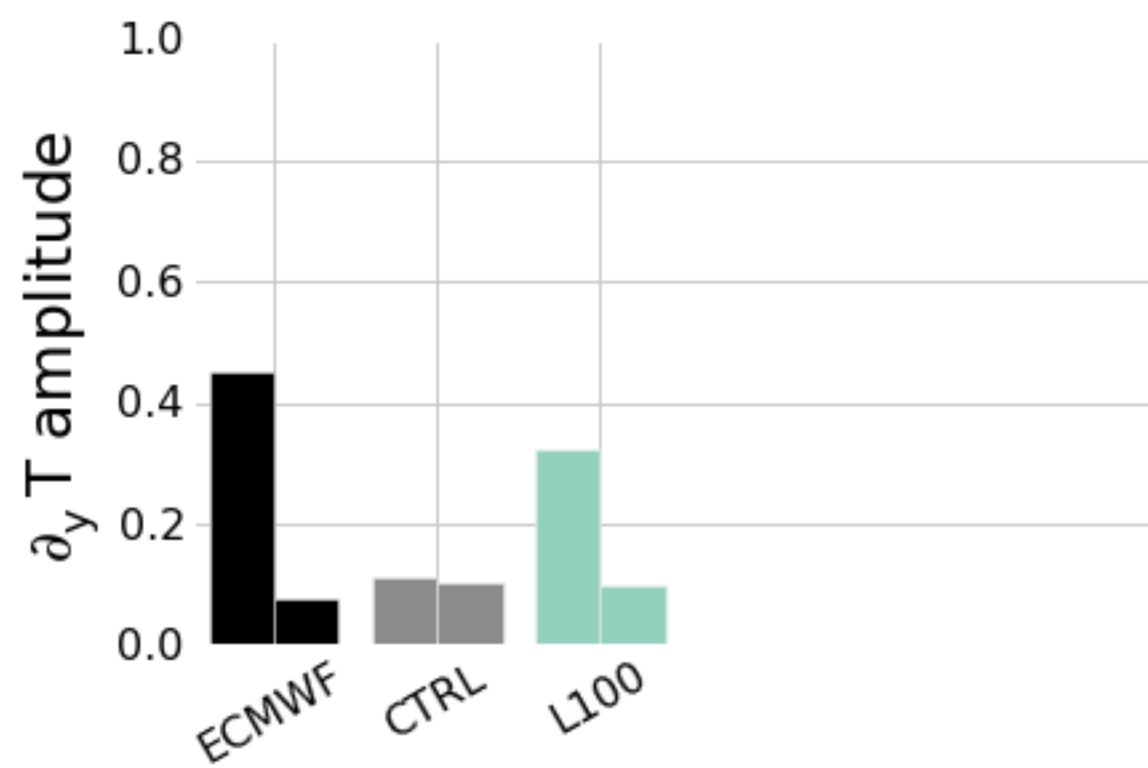

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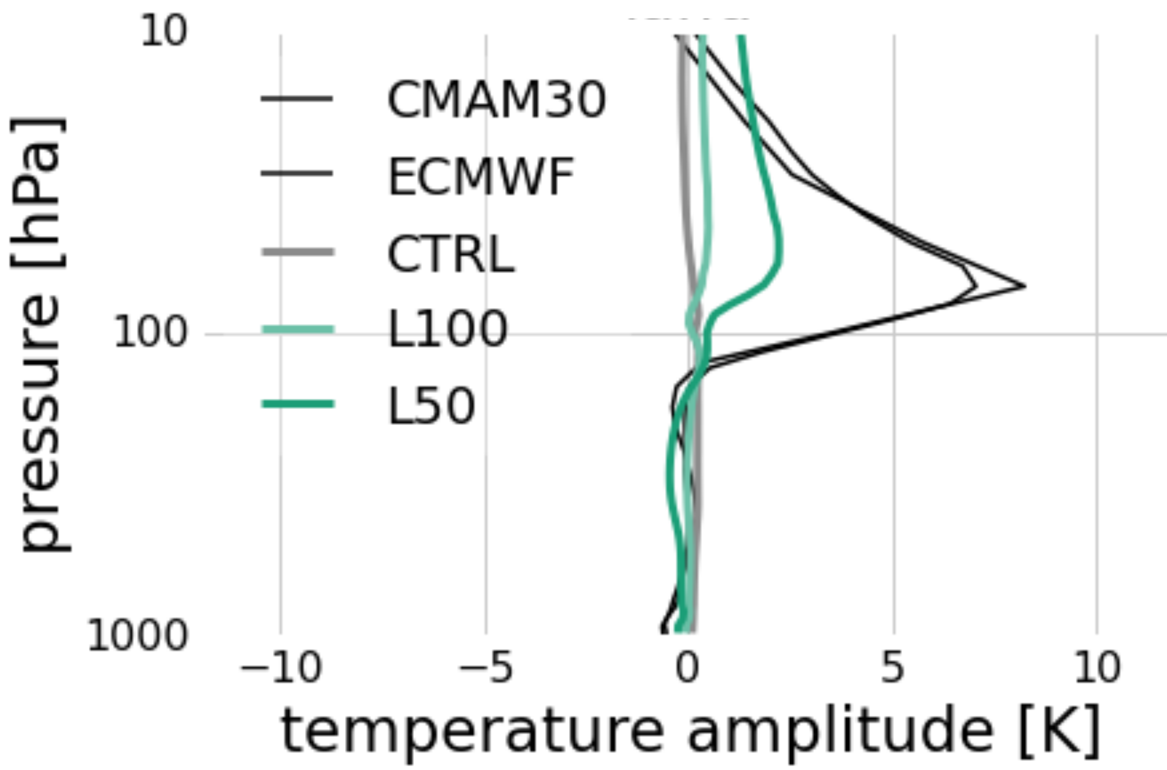

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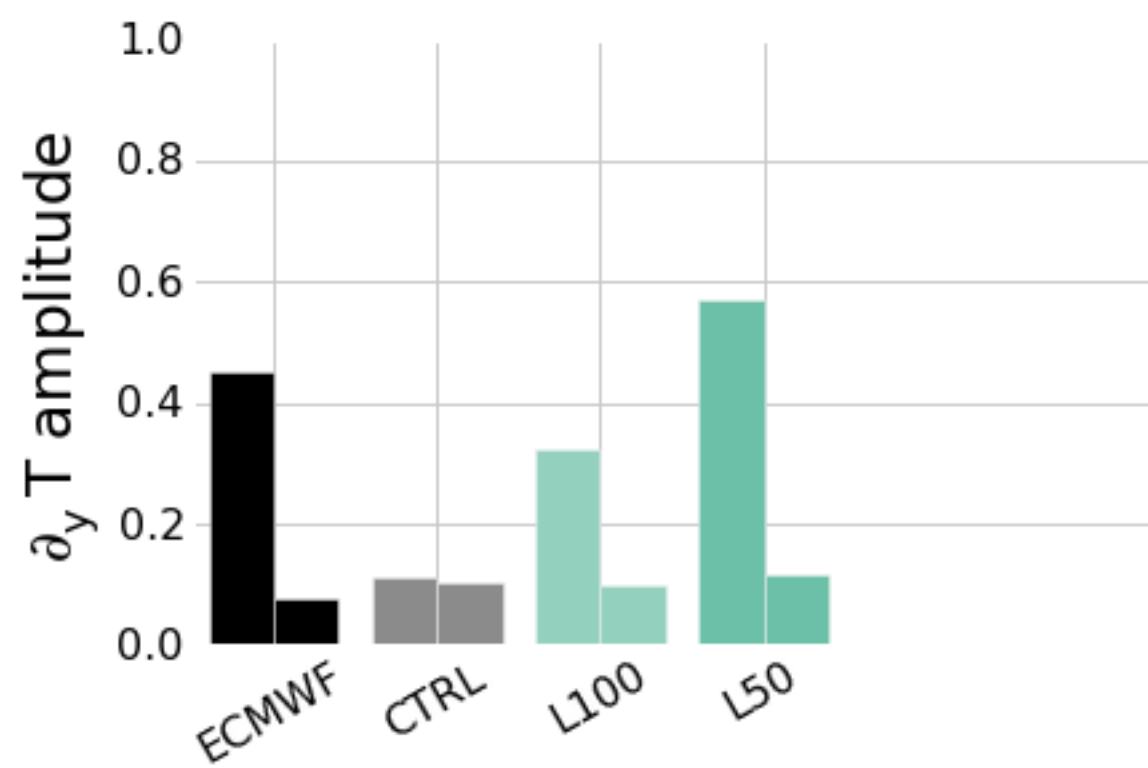

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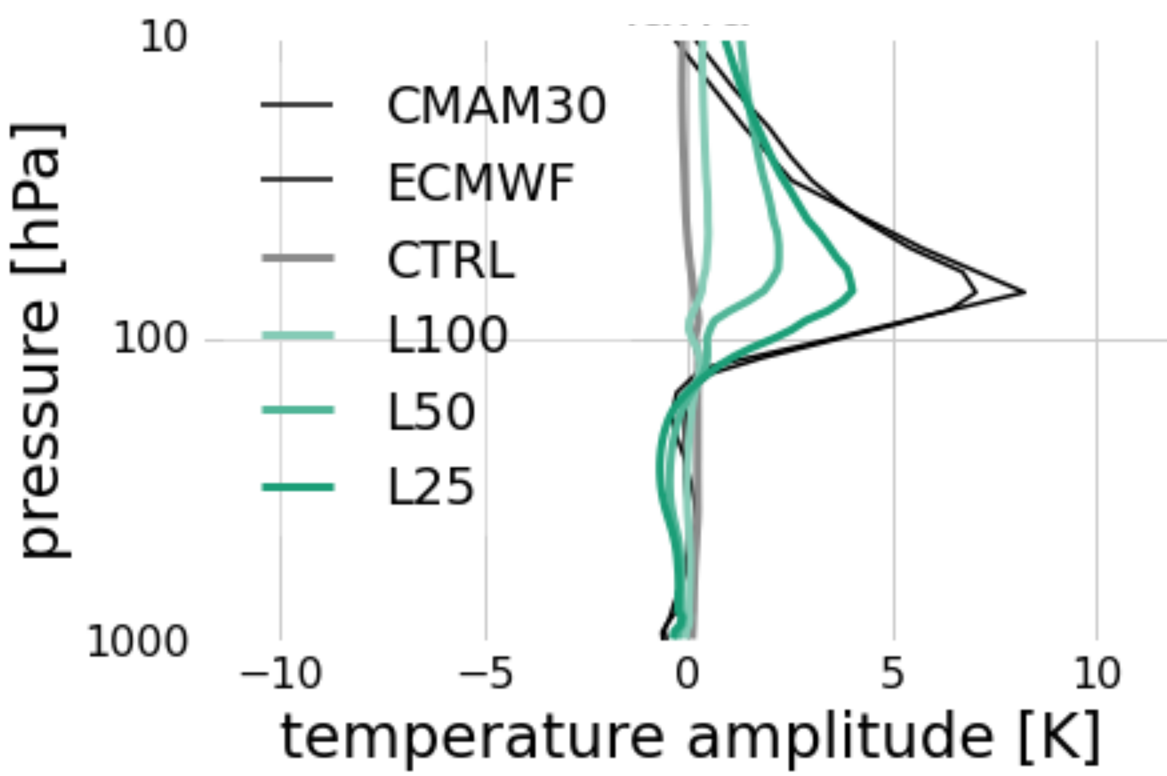

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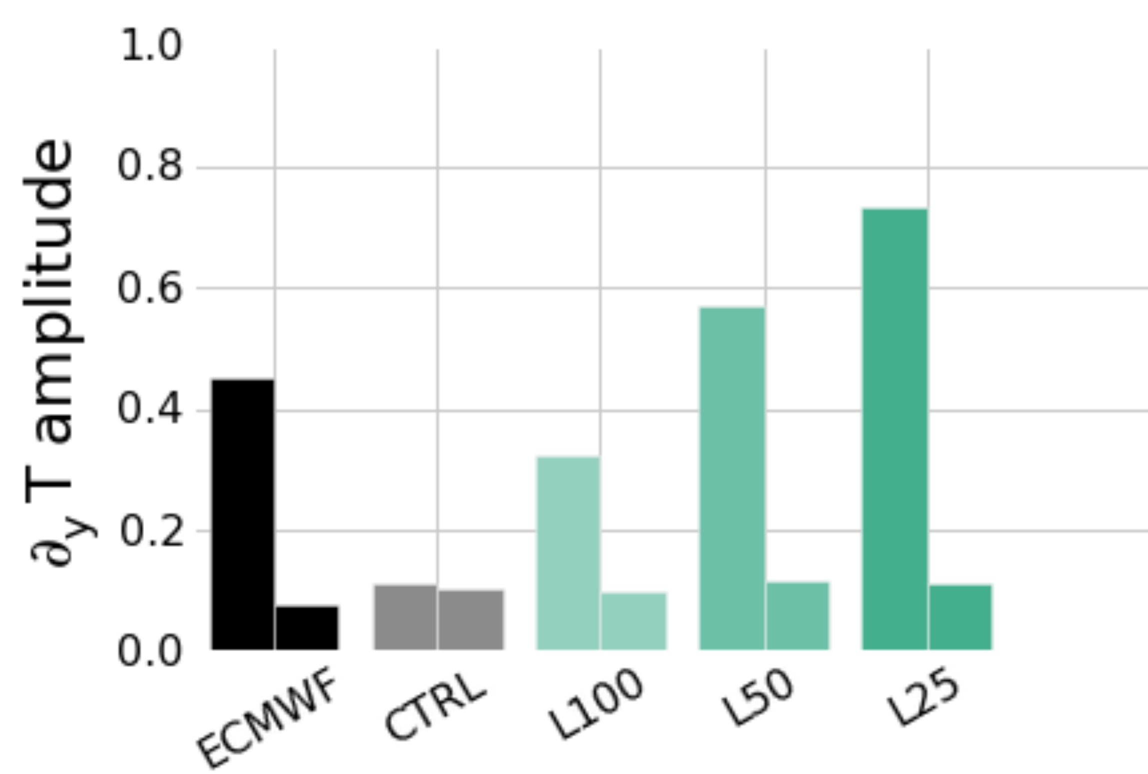

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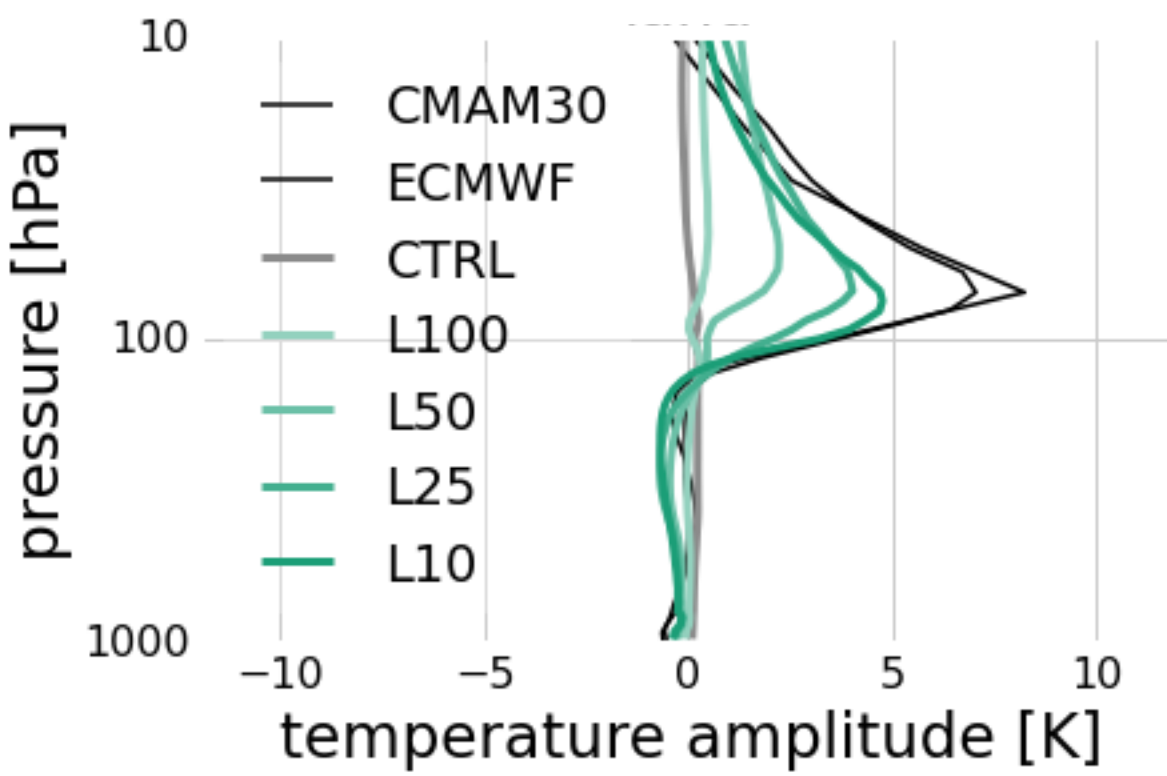

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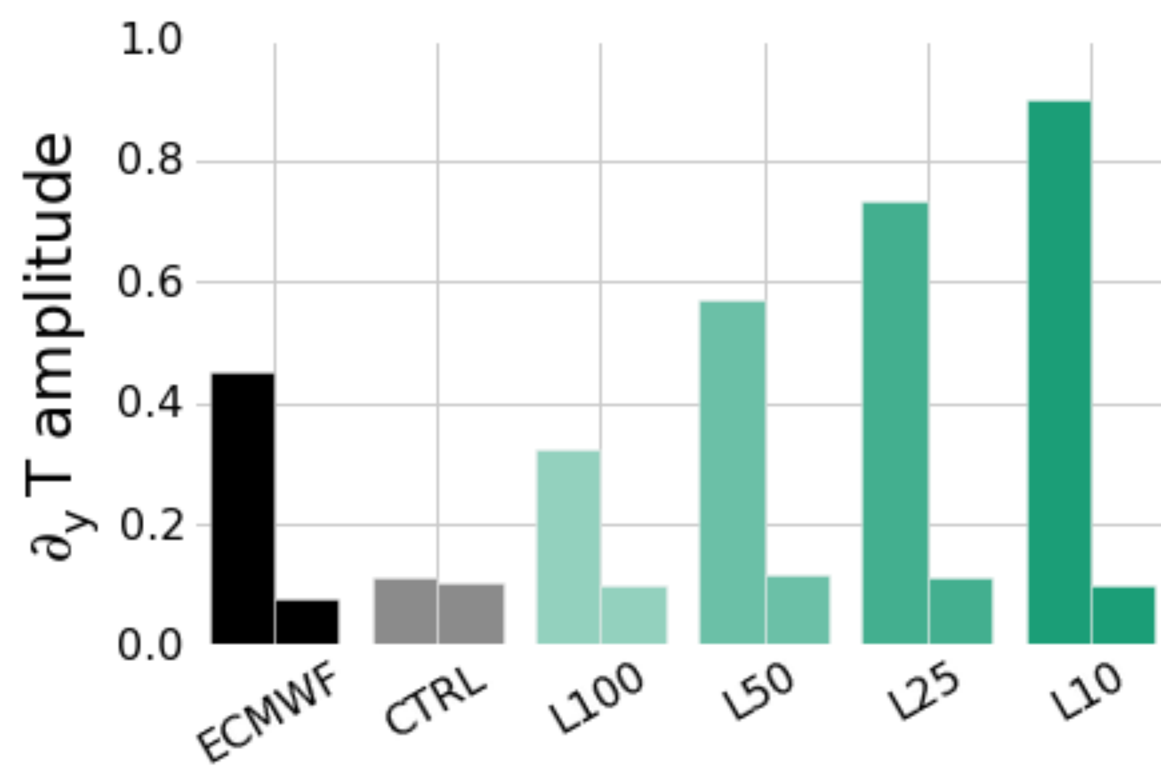
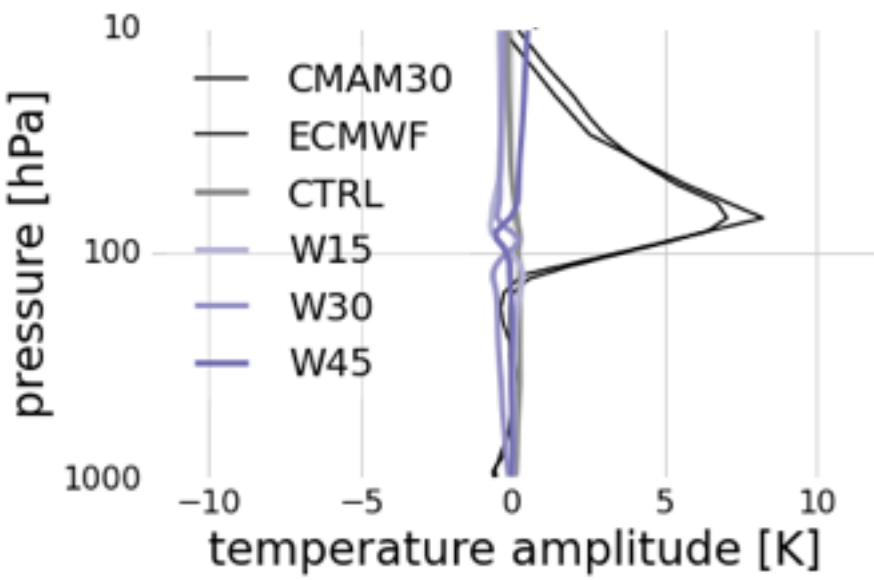
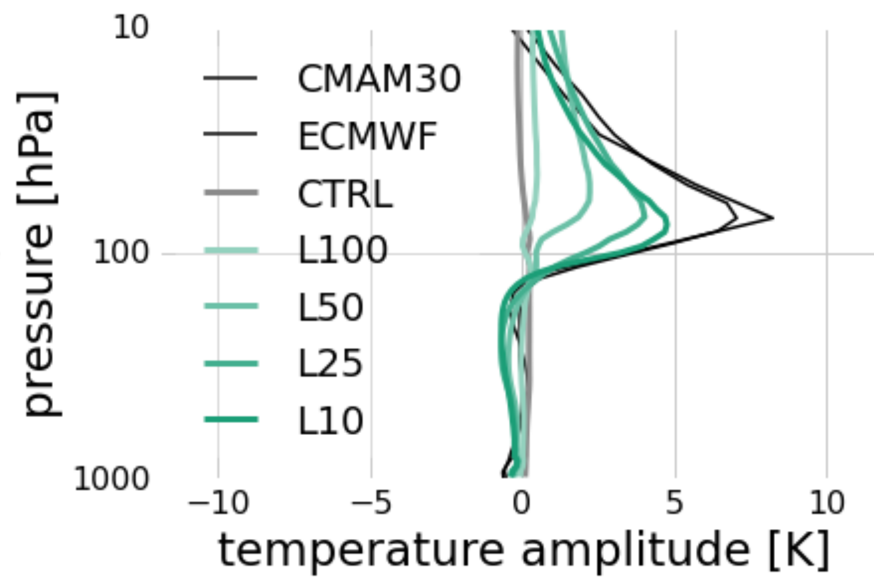


Annual Cycle of TTL Temperature

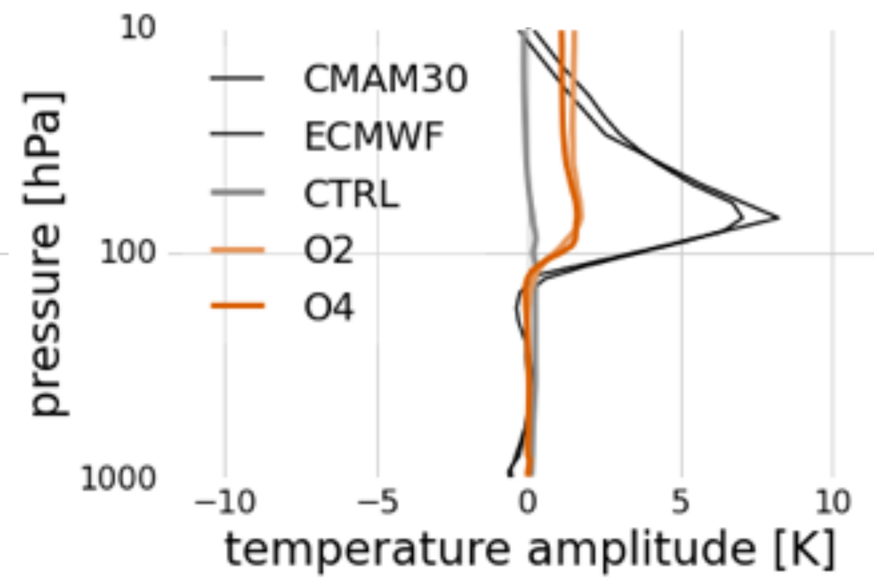
“warmpool”
tropical waves



“land-sea contrast”
synoptic waves



topography
planetary waves



Tropics:

No annual cycle anywhere.

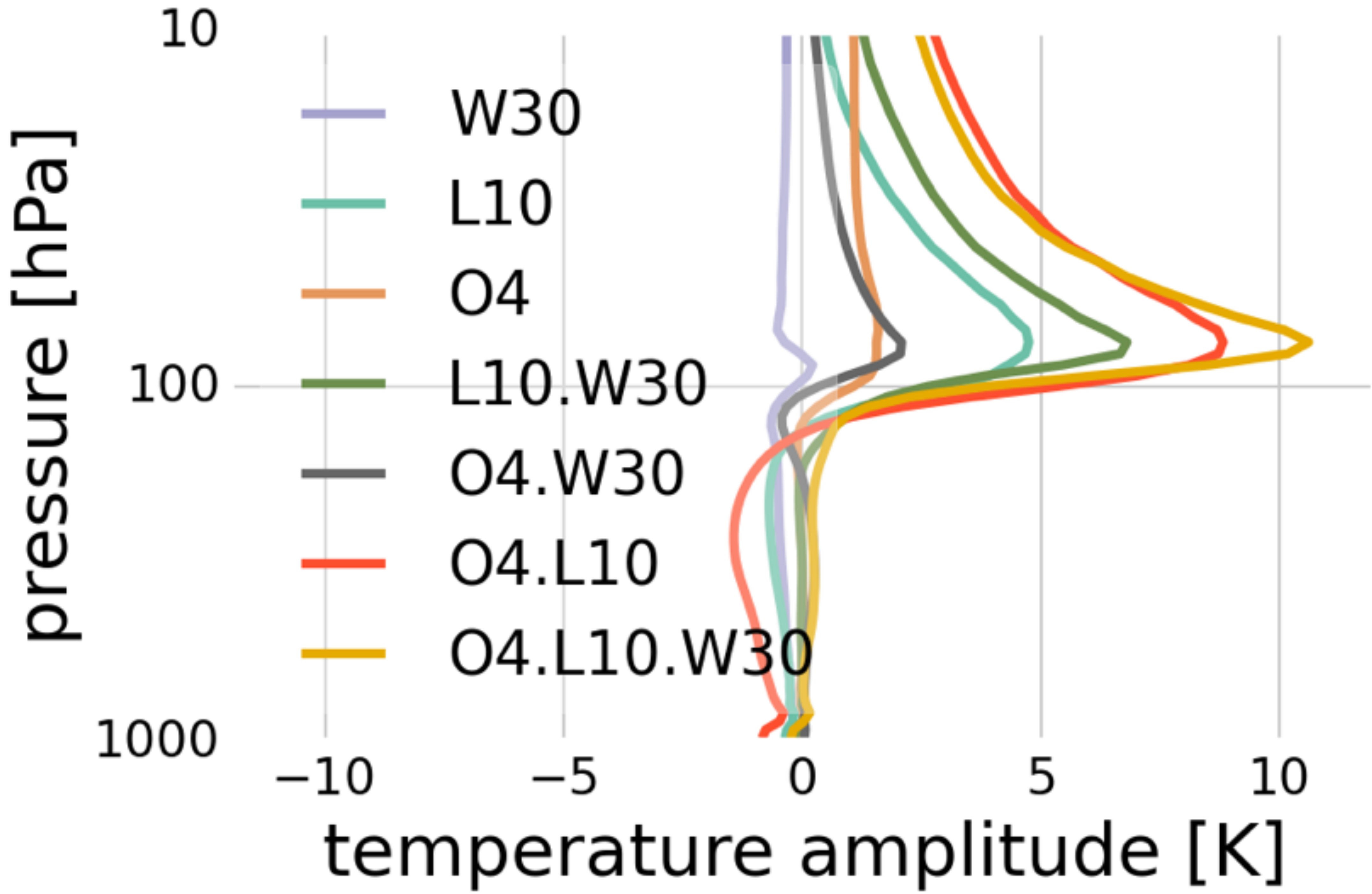
Land-sea contrast:

Strong dependence, peak in TTL.

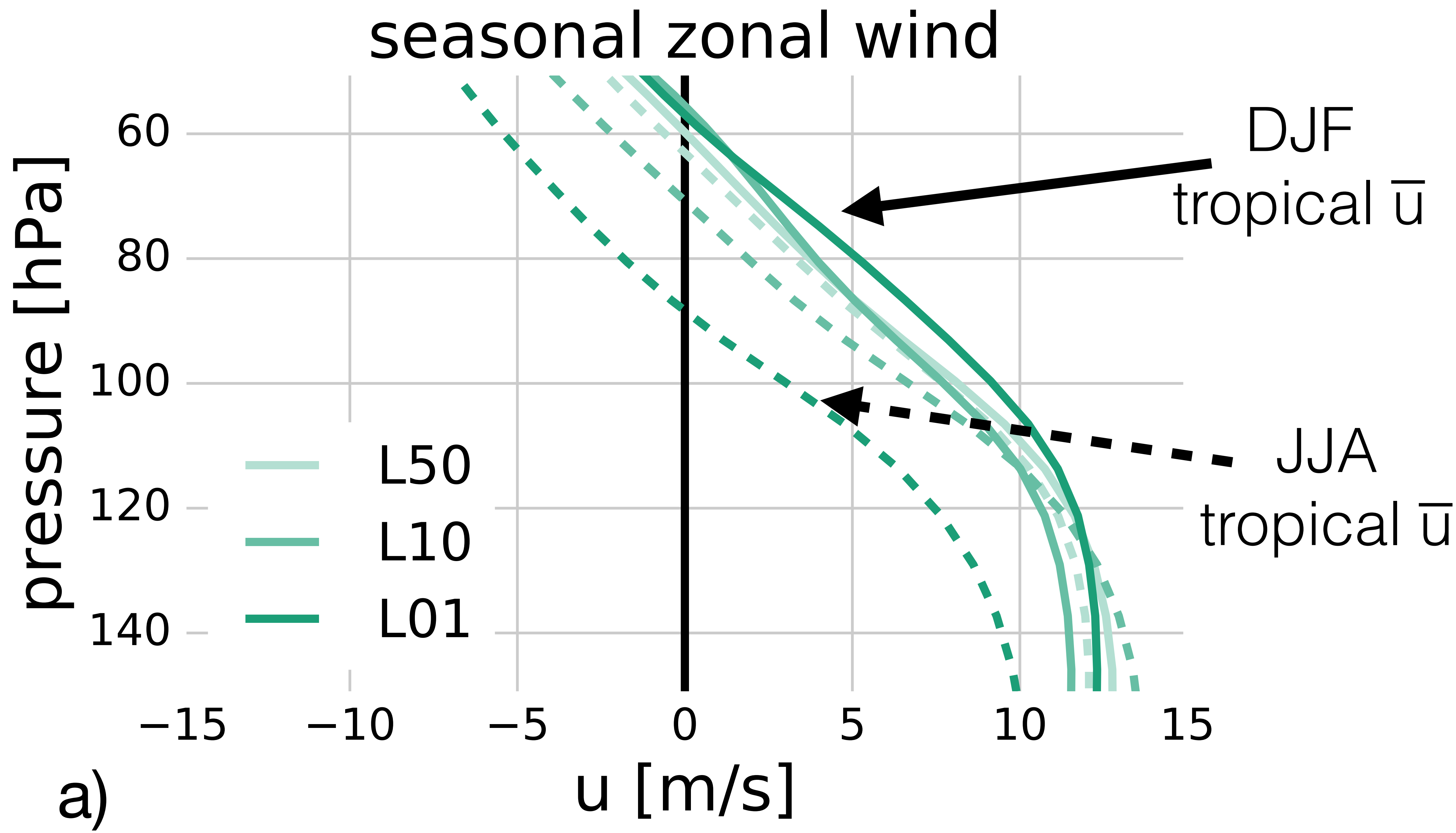
Midlat topography:

Weak dependence, throughout strat.

Nonlinear impact on TTL temperature annual cycle with combined forcings



planetary waves keenly sensitive to annual cycle in zonal wind



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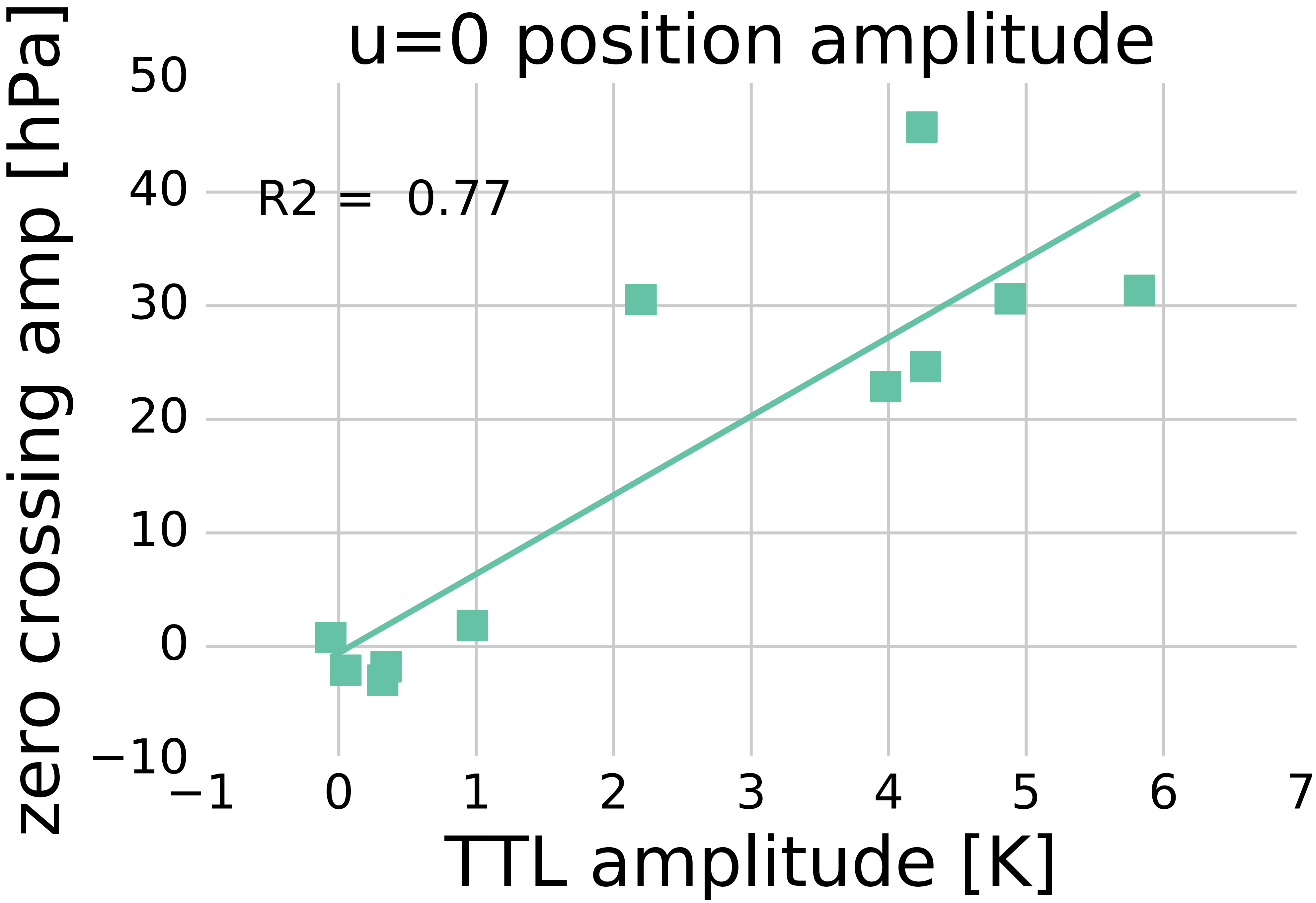


Conclusions

- propose a new step in the hierarchy of idealized atmospheric models
- tropical planetary waves critically control mean TTL structure
- asymmetry in synoptic variability of NH and SH alone can drive a large fraction of TTL annual cycle
- planetary waves (from tropics or midlatitudes) substantially amplify impact of synoptic variability

Geosci. Model Dev., 9, 3413–3425, 2016
www.geosci-model-dev.net/9/3413/2016/
doi:10.5194/gmd-9-3413-2016

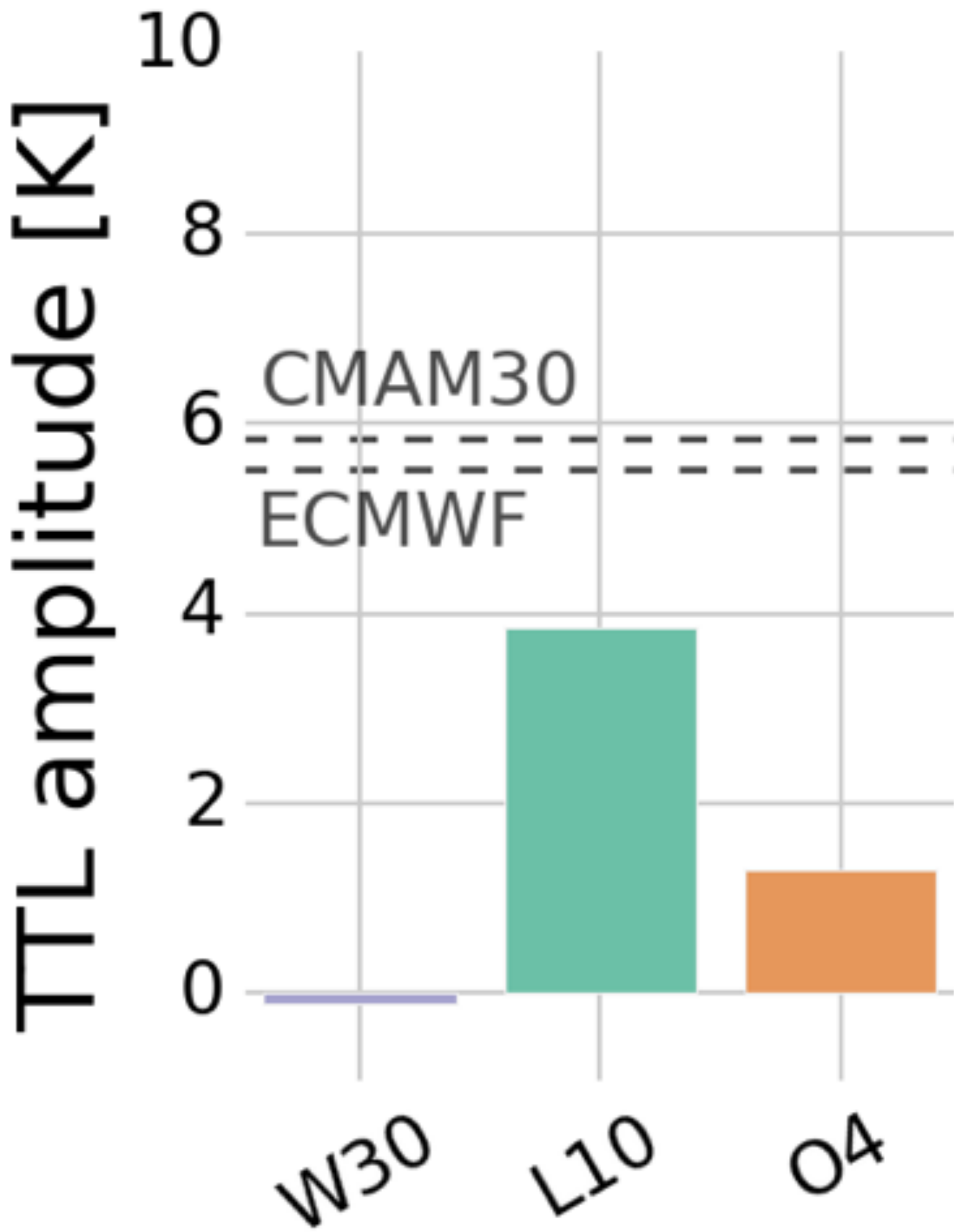
Geoscientific
Model Development
Open Access

The Dynamics and Variability Model Intercomparison Project (DynVarMIP) for CMIP6: assessing the stratosphere–troposphere system

(better vertical resolution though UTLS and stratosphere diagnostics for momentum + heat transport)

Extra slides …

Nonlinear impact on TTL temperature annual cycle with combined forcings



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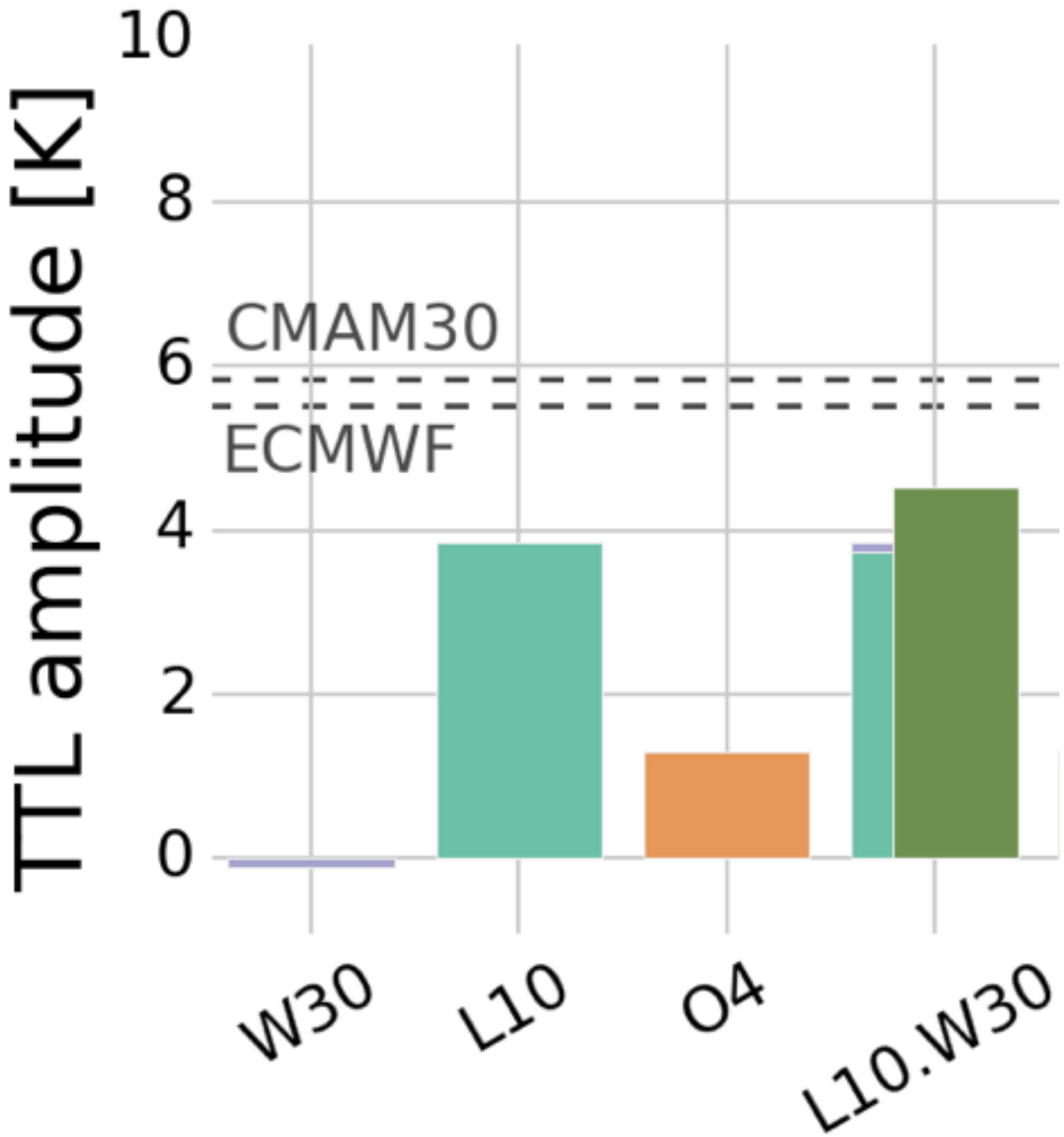

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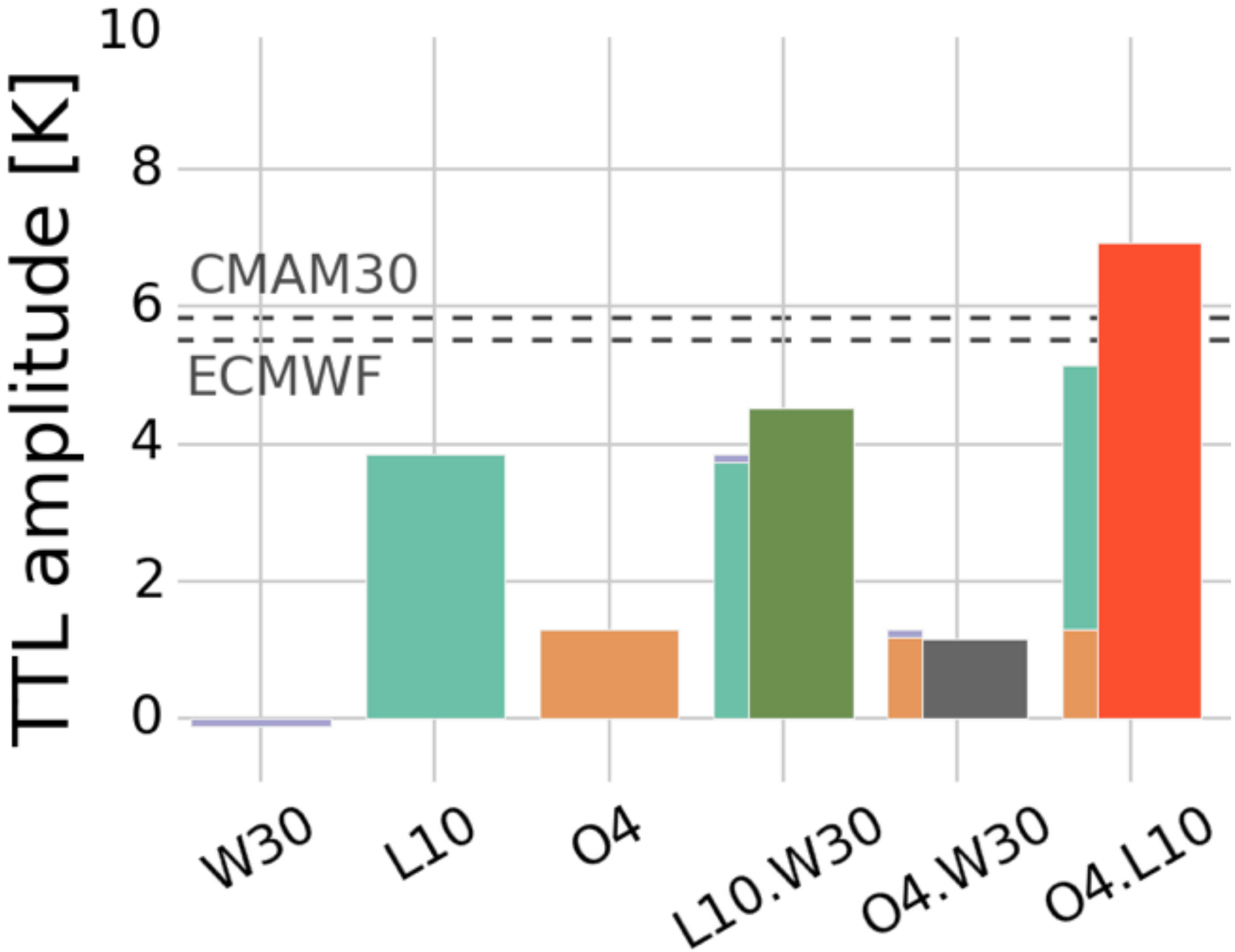

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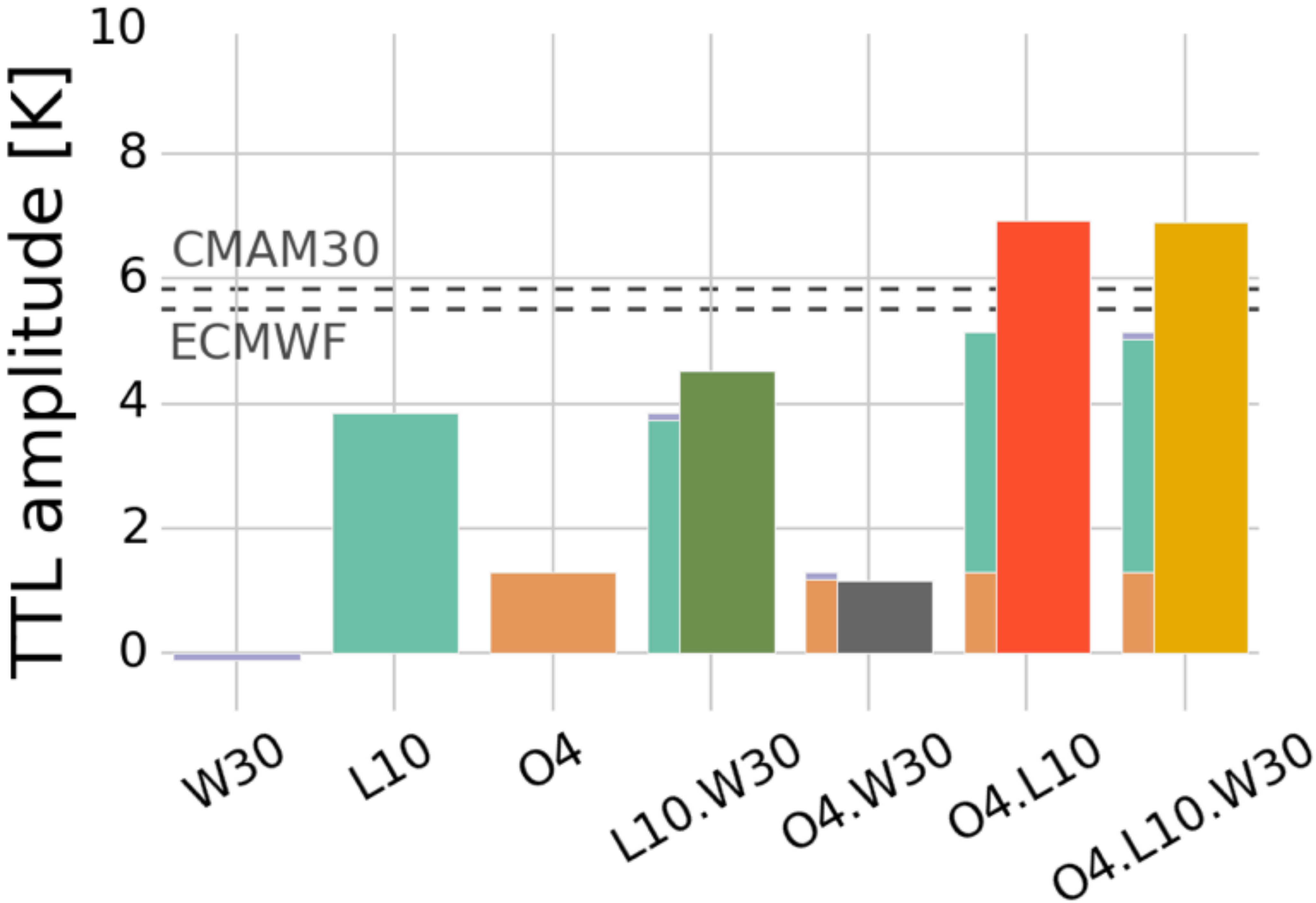
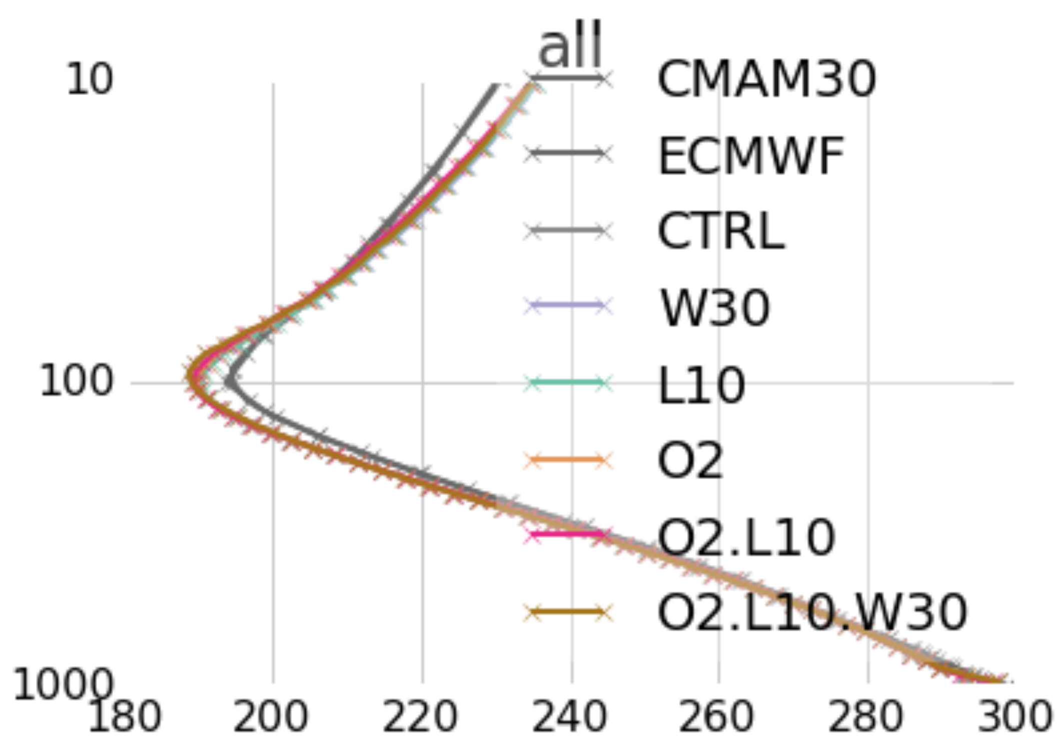
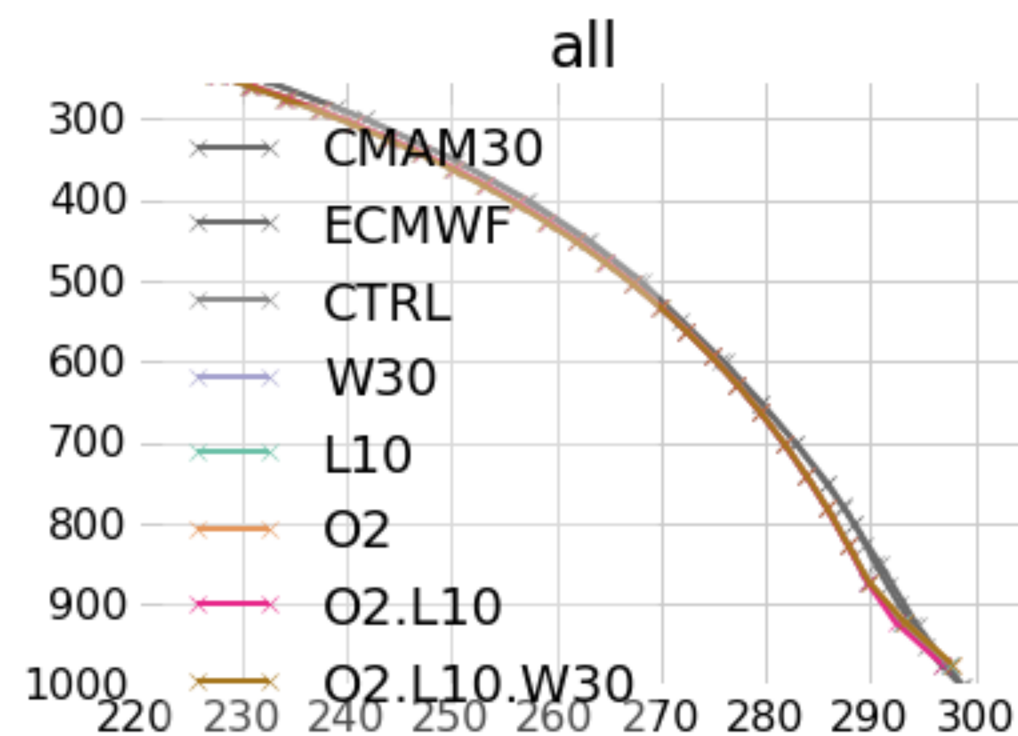


Tropical temperature profiles

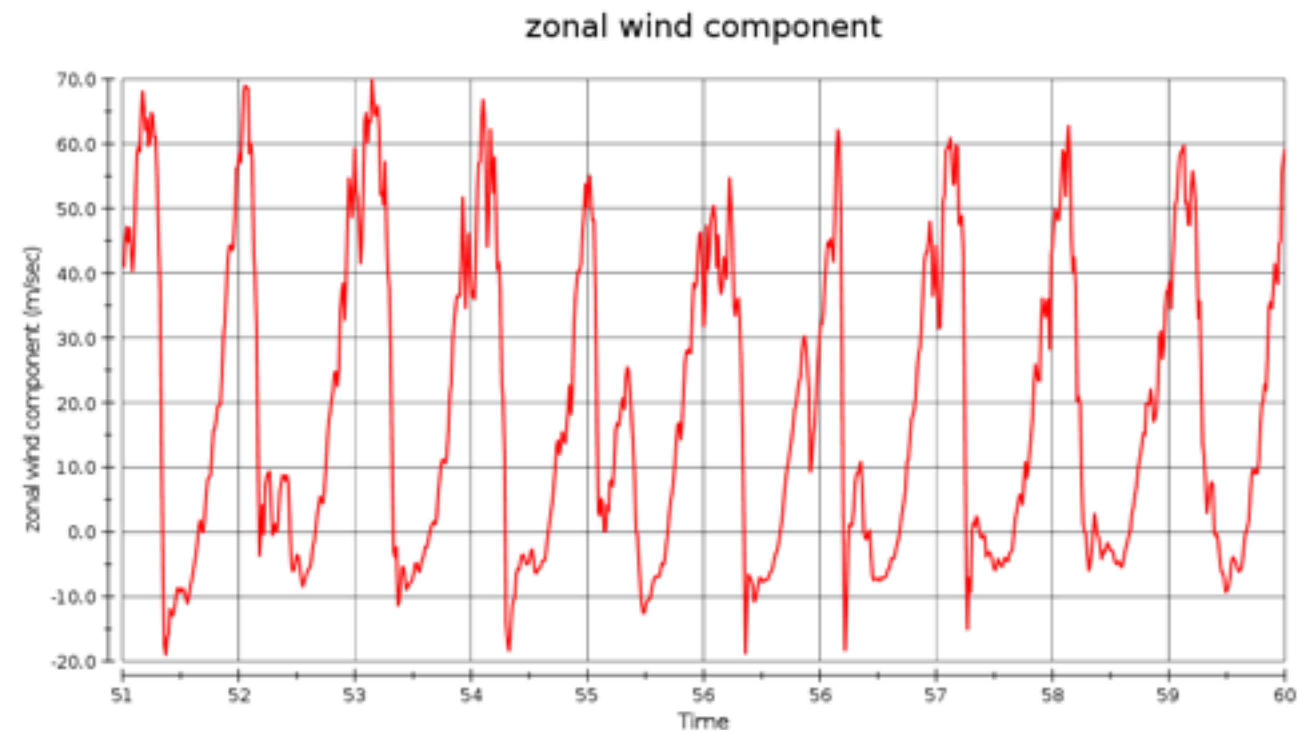
- MiMA has different lapse rates throughout the column, so matching to reanalysis is difficult.
- Our choice was to match in mid-troposphere, and subsequently have the same tropical temperature at 700hPa for all simulations (adjusting albedo)



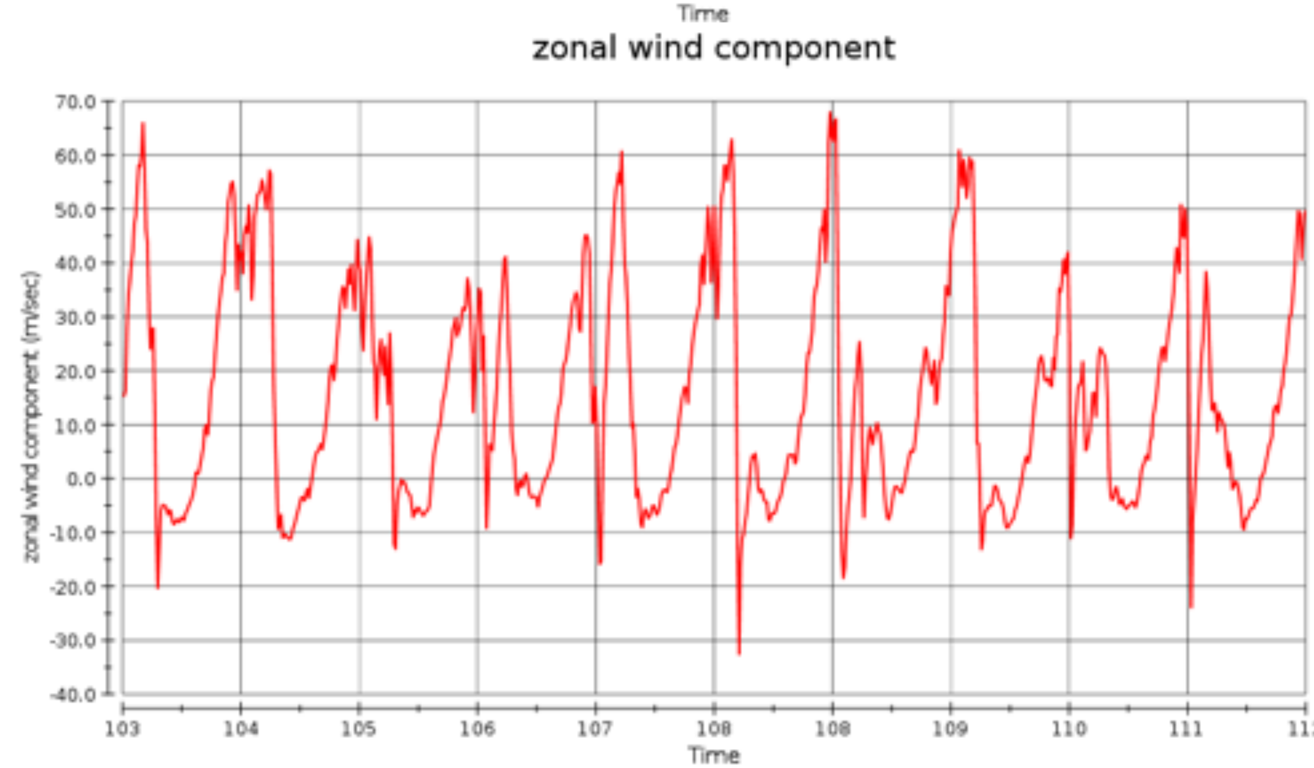


SSW frequency

- 2 Gaussian mountains (4km)

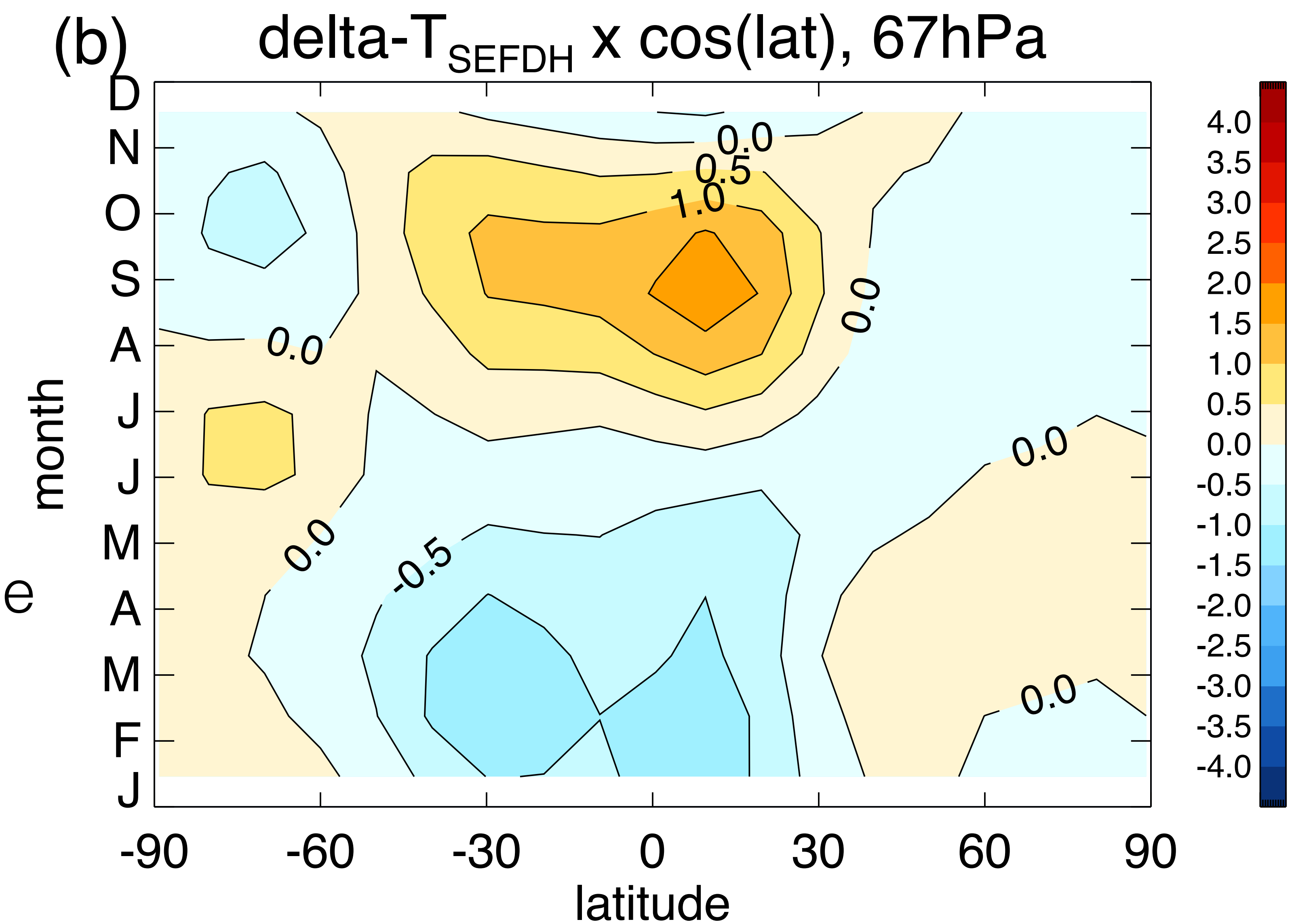


- 2 Gaussian mountains (4km); 10m land



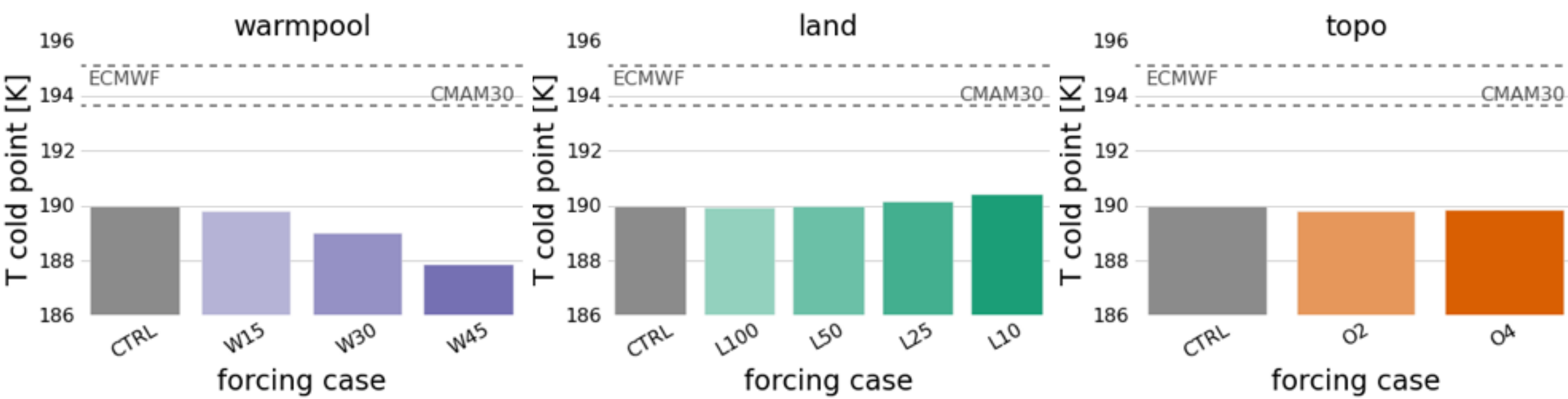
Ozone influence on annual cycle in TTL

- *Fueglistaler, Haynes, and Forster (2011), Fig 5(b)*:



Only ~2K (of 8K) can be attributed to O3.

Annual Mean Cold Point Structure



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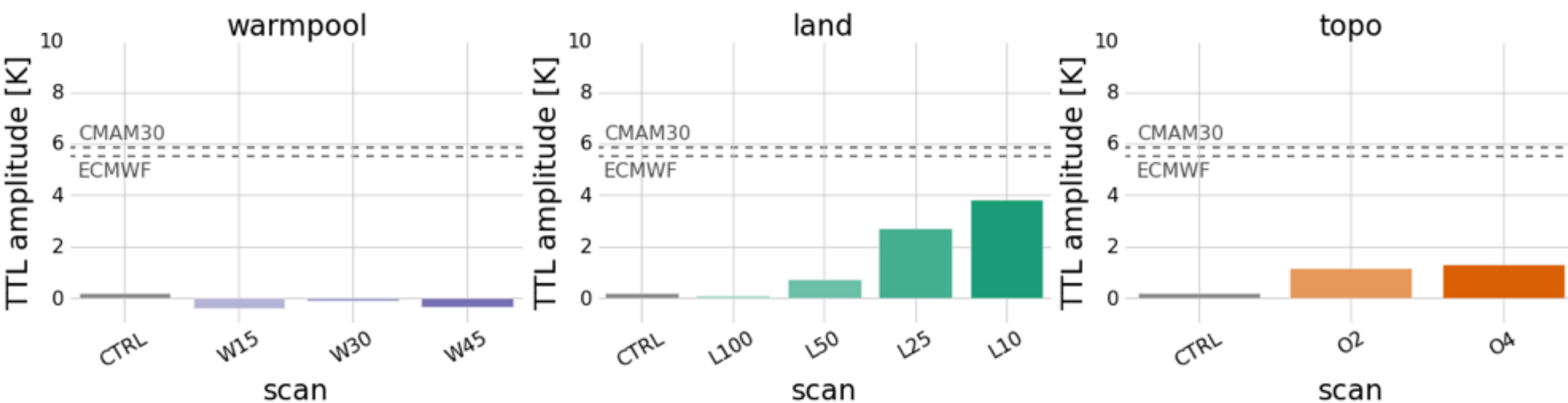
Seasonal Cycle of TTL Temperature



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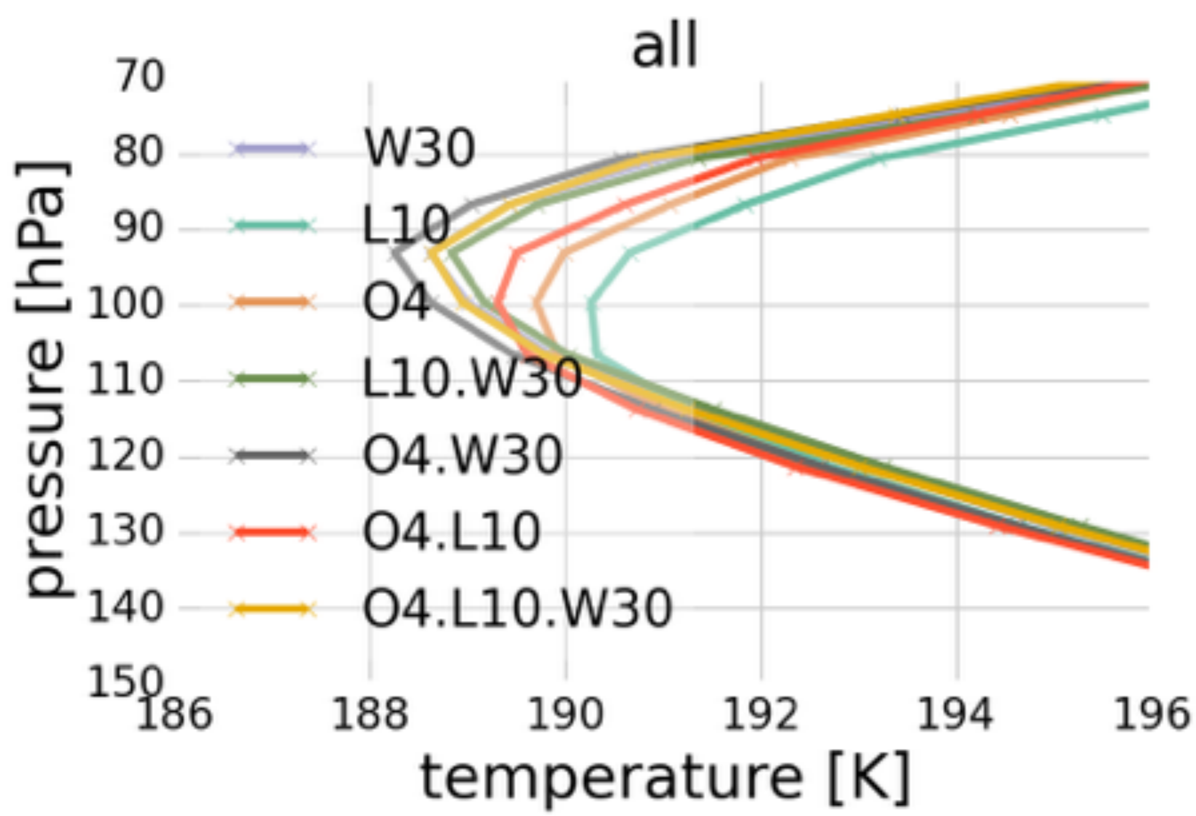
Nonlinearity of Results TTL seasonal cycle



Nonlinearity of Results