What regulates the annual cycle of stratospheric water vapor?

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New York University

EGU General Assembly,Vienna, April 13 2015

Dominant mode of variability: Tape Recorder

Mote et al. (1996,1998) "Atmospheric Tape Recorder"

here shown: variable total hydrogen,

2[CH4] + [H2O]

(a) HALOE
(b) first two EEOFs

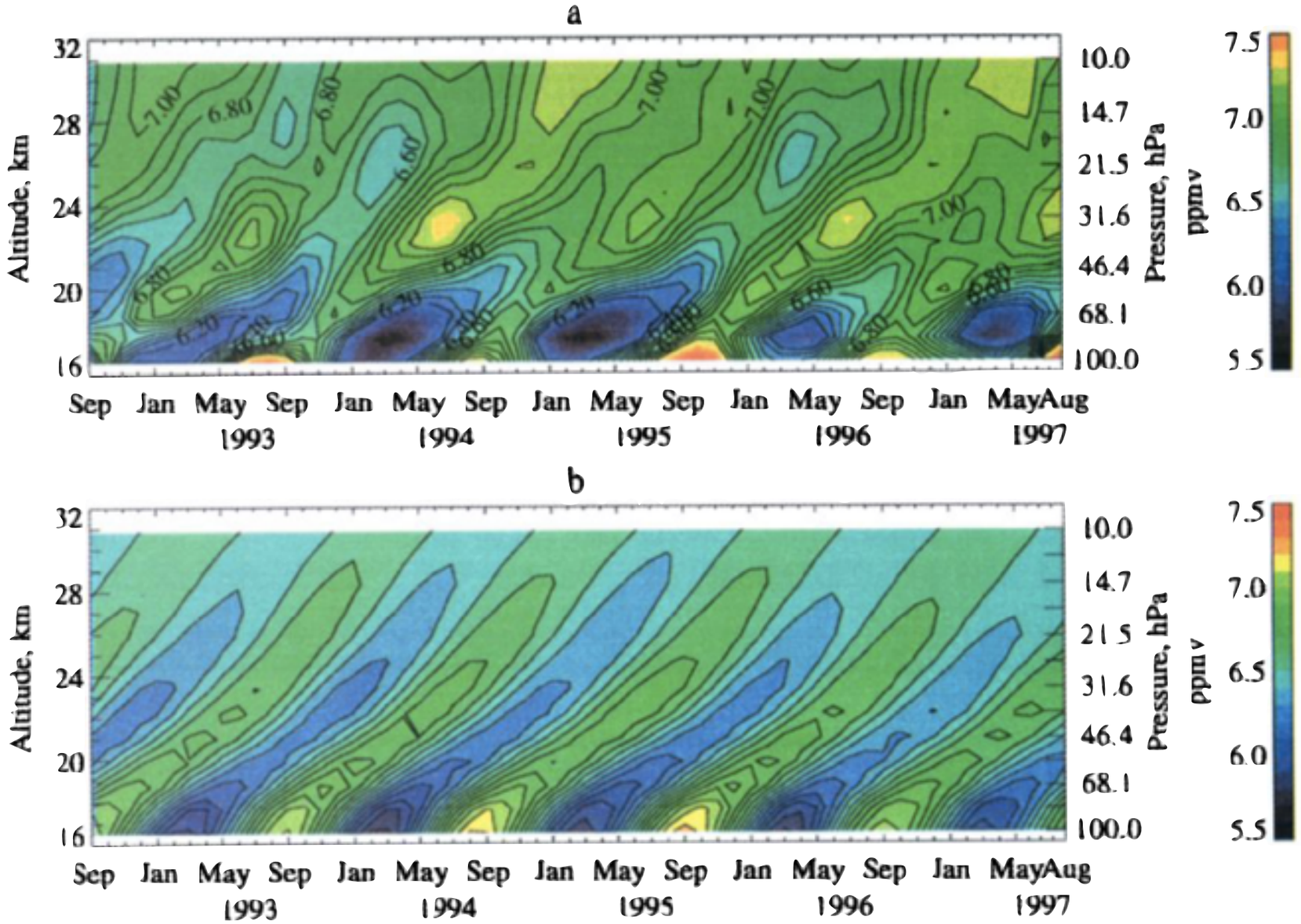

Plate 1. (top) HALOE tropical $\hat{H}$ and (bottom) its reconstruction from the first two EEOPs.

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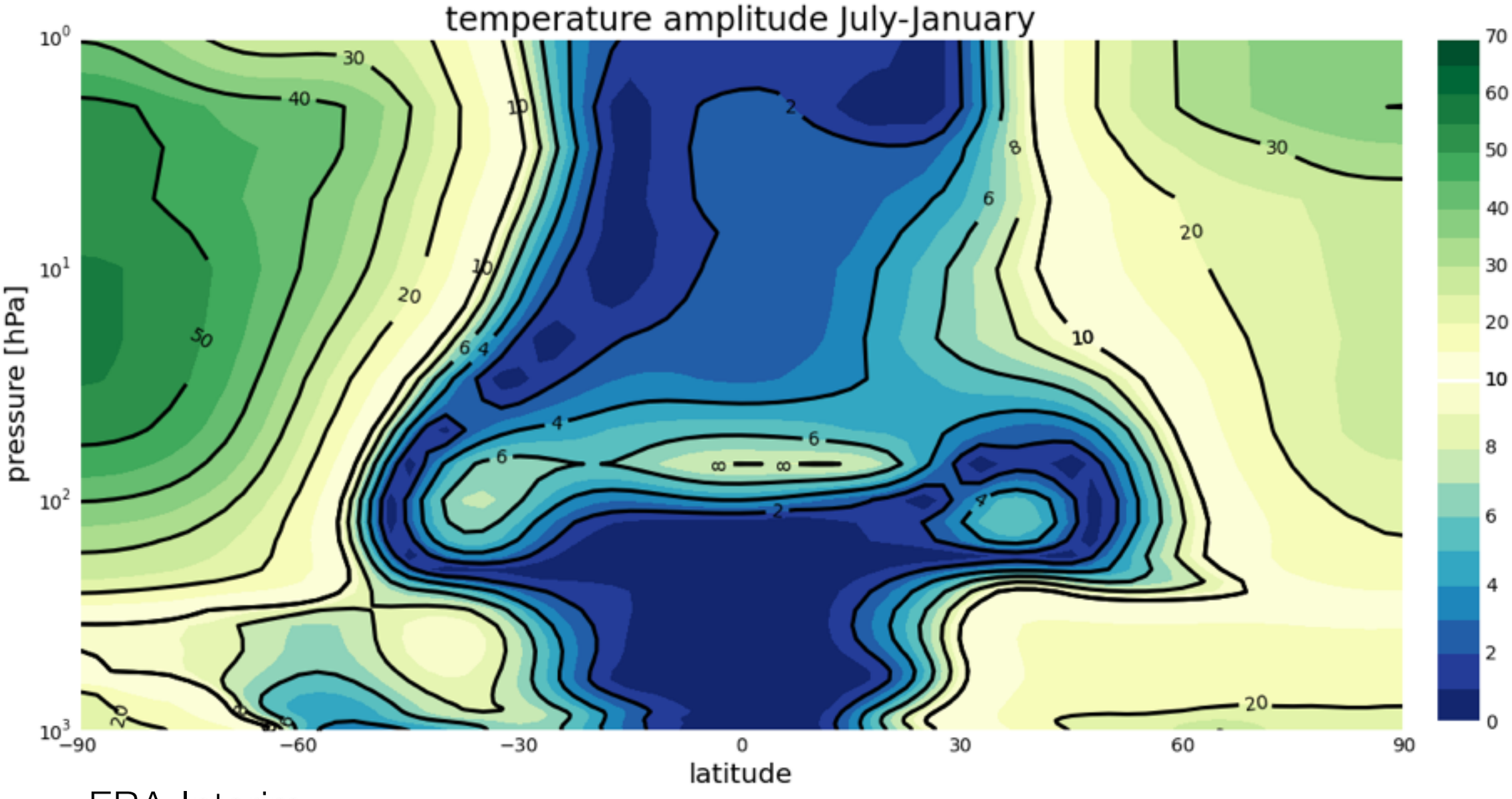
The TTL has a marked annual cycle in temperature



ERA-Interim

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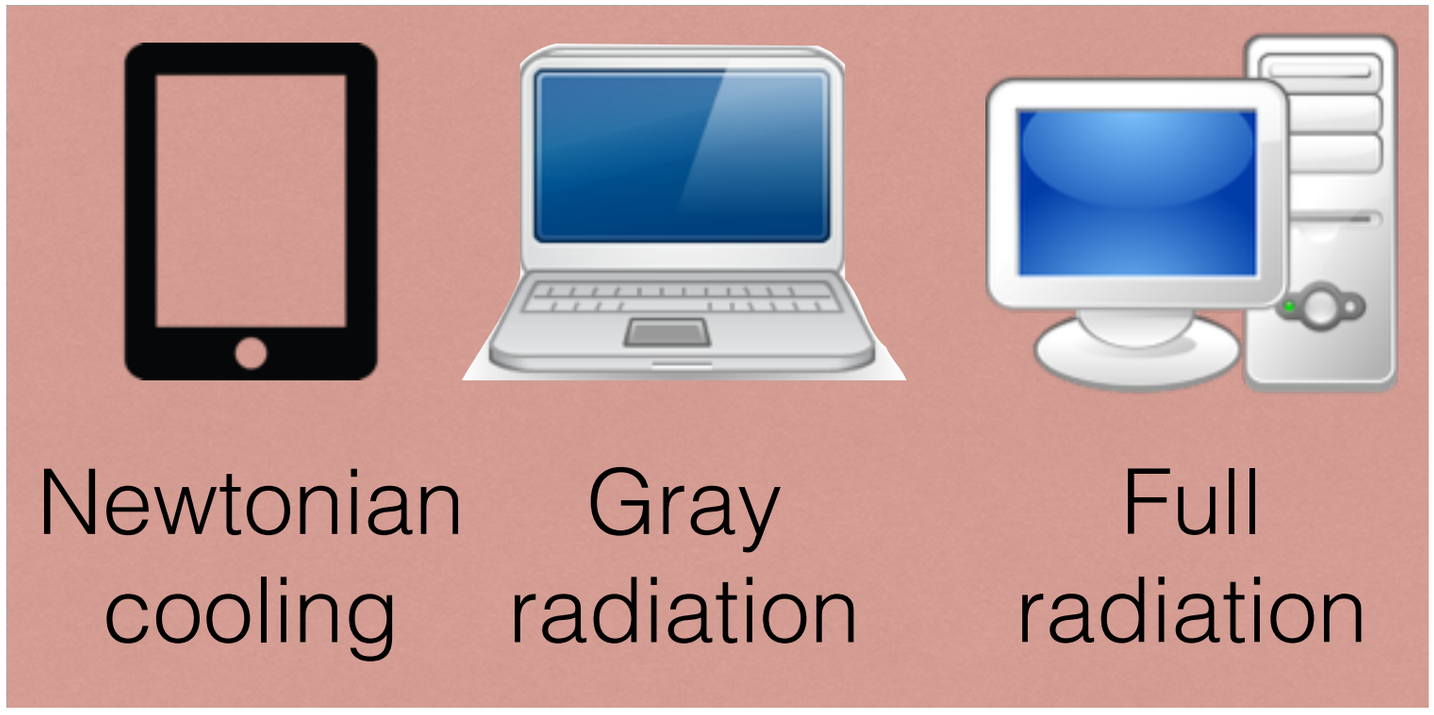
Tape Recorder - Various theories, difficult to test

- High latitude planetary waves (NH-SH differences in orographic forcing) [Yulaeva et al. 1994, Ueyama and Wallace 2010]
- Seasonal cycle in baroclinic activity (NH-SH differences in land-sea contrast) [Jucker et al. 2013]
- Tropical asymmetries (Monsoon, Warm Pool) [Kerr-Munslow and Norton 2006]
- Equatorial wave forcing [Randel et al. 2008], and mean flow wave filtering [Ortland and Alexander 2014]

GCM Hierarchy



QG | Newtonian cooling | Gray radiation | Full radiation | Full GCM, CCM

"simple" GCMs

complexity ⟶

Inspired by Held 2005

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Modeling an idealized Moist Atmosphere (MiMA)

We build a minimalistic model with:

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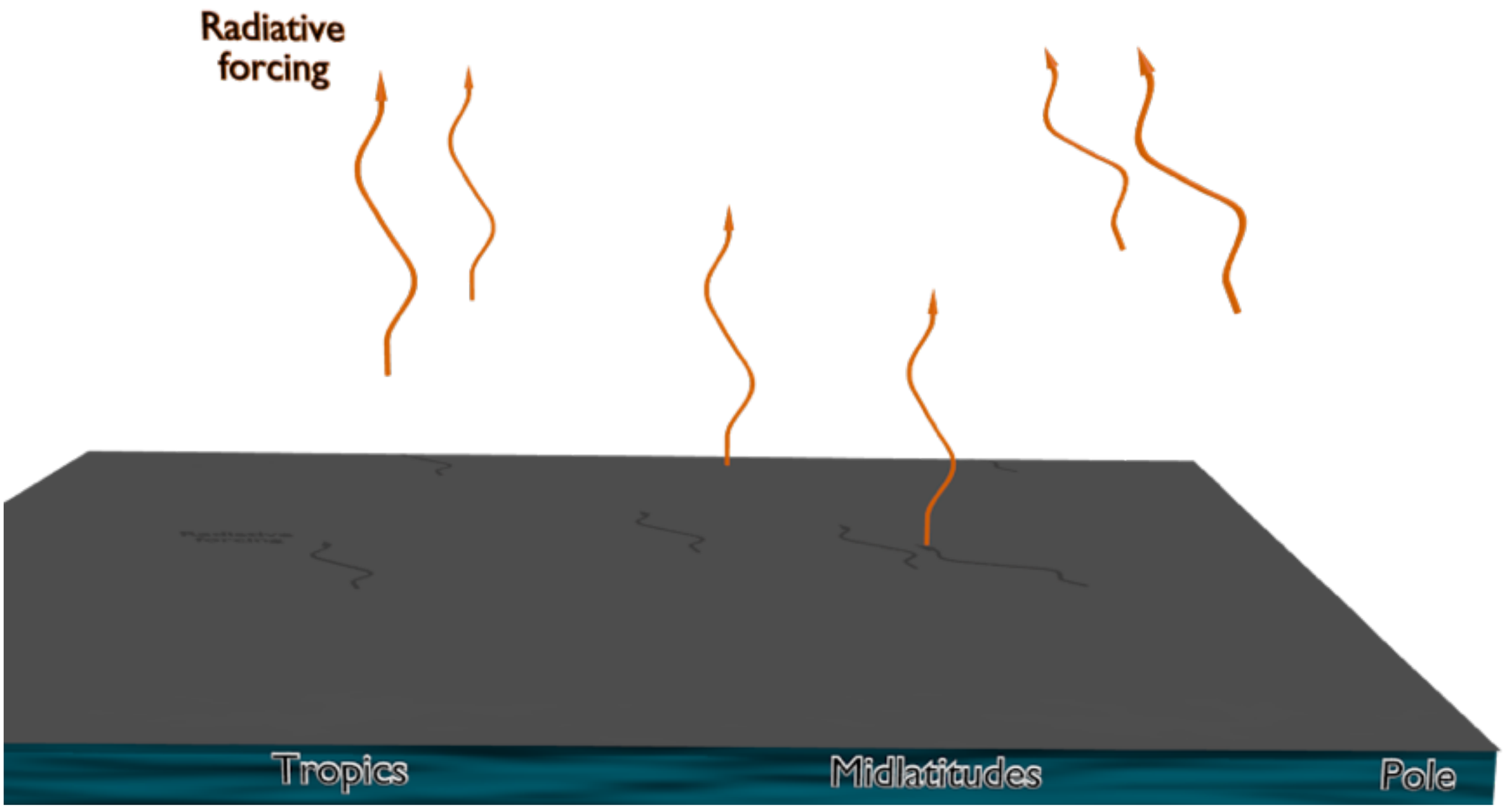
Modeling an idealized Moist Atmosphere (MiMA)



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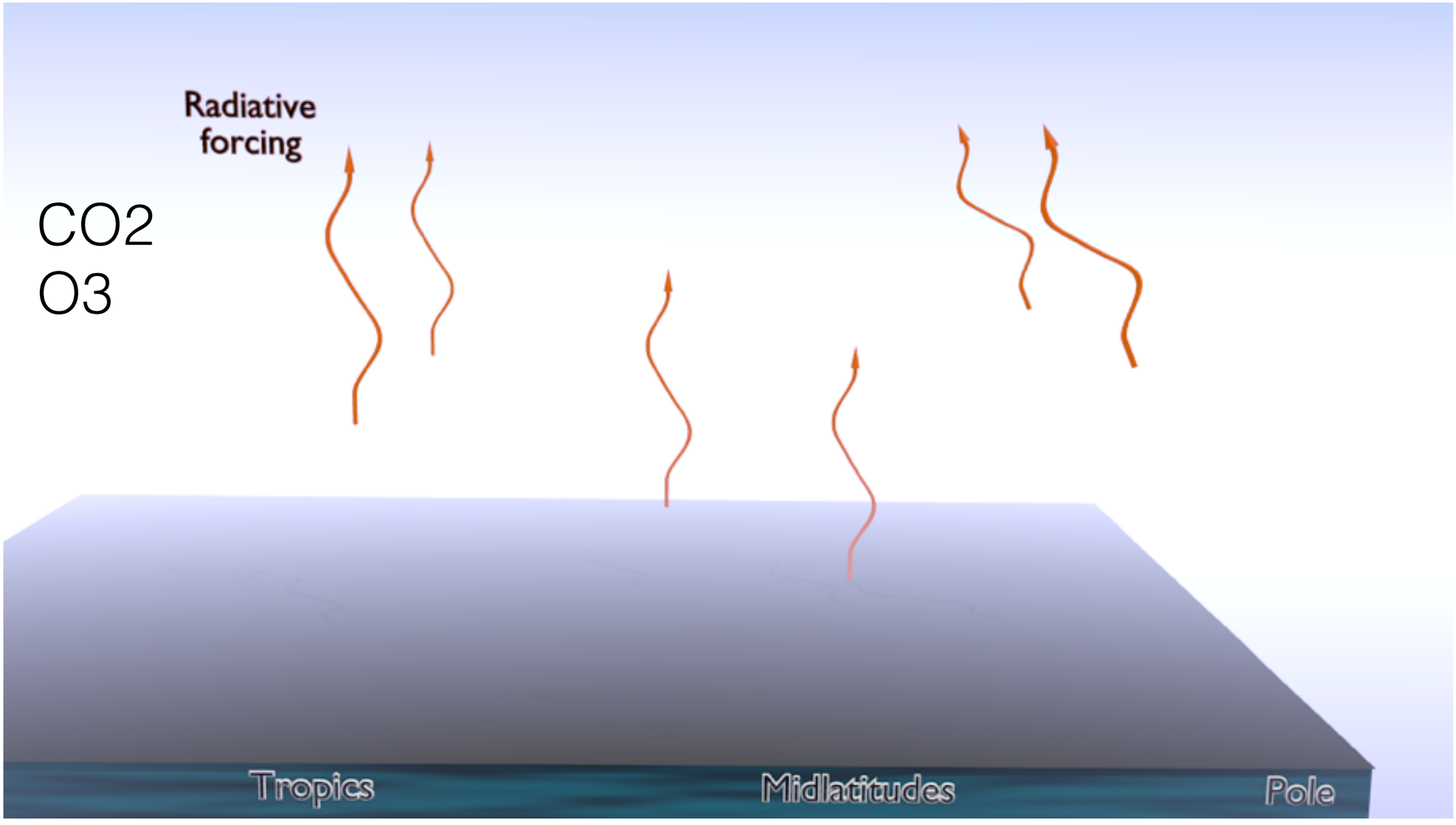
Modeling an idealized Moist Atmosphere (MiMA)



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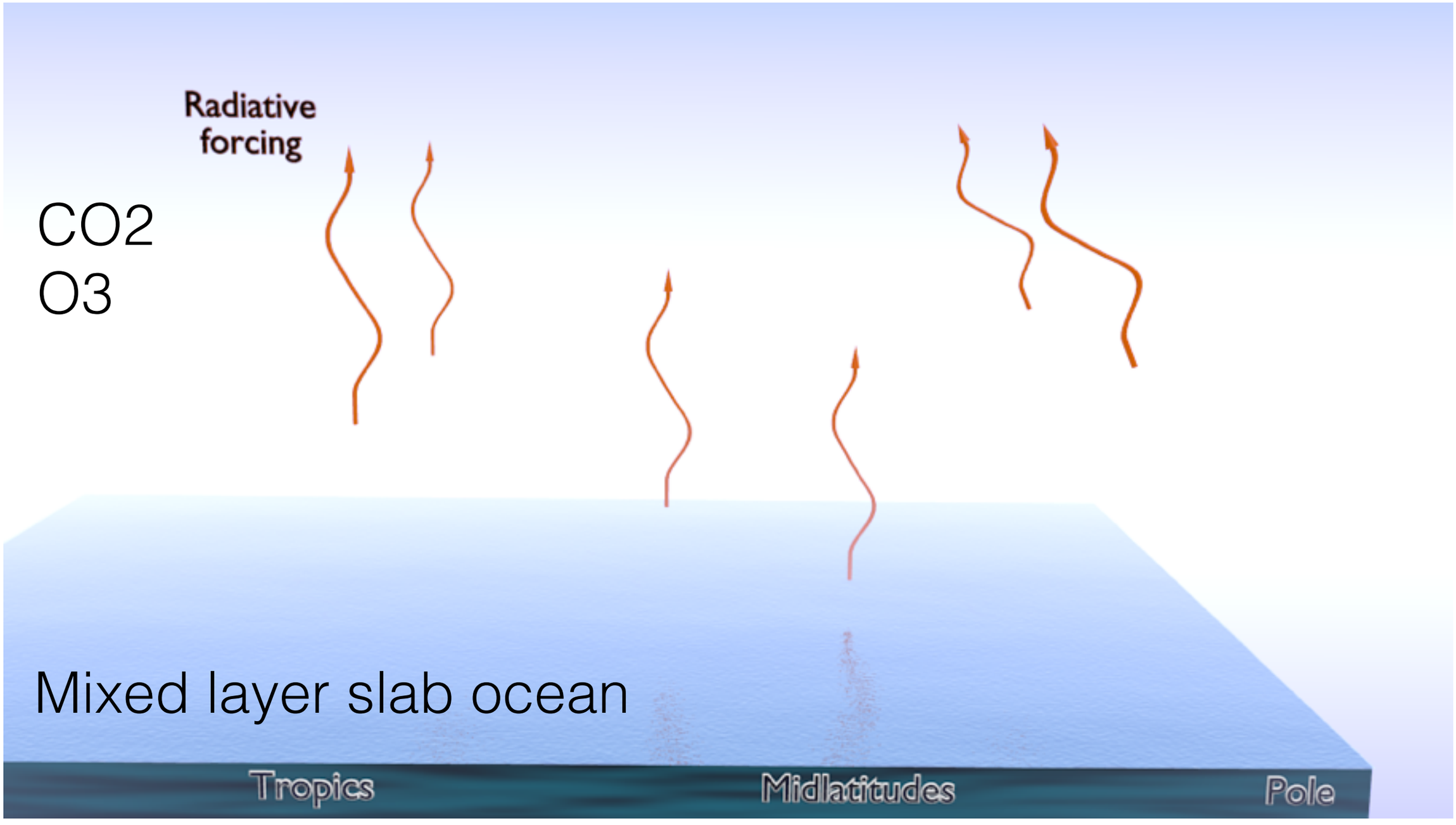

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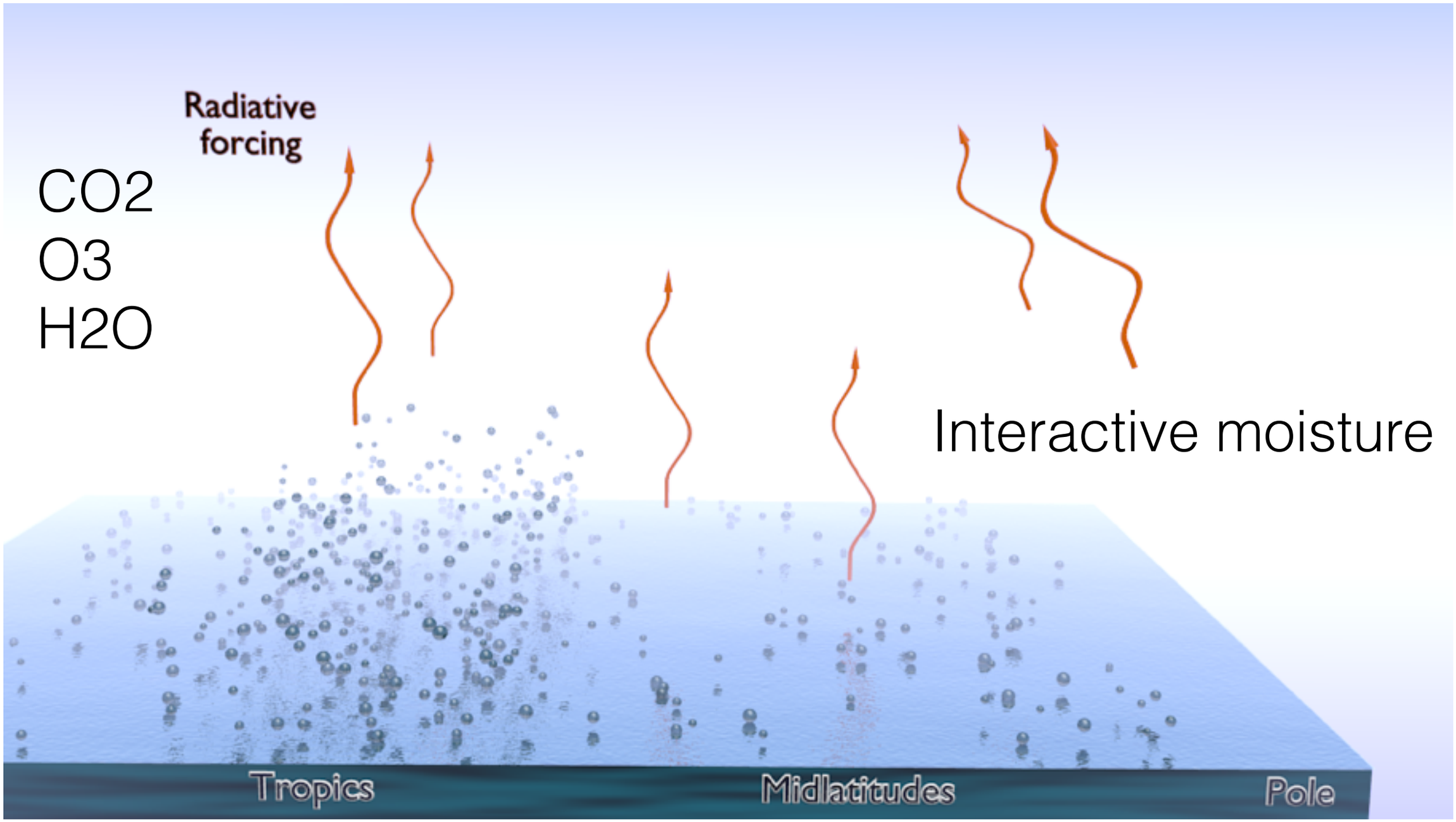
Modeling an idealized Moist Atmosphere (MiMA)



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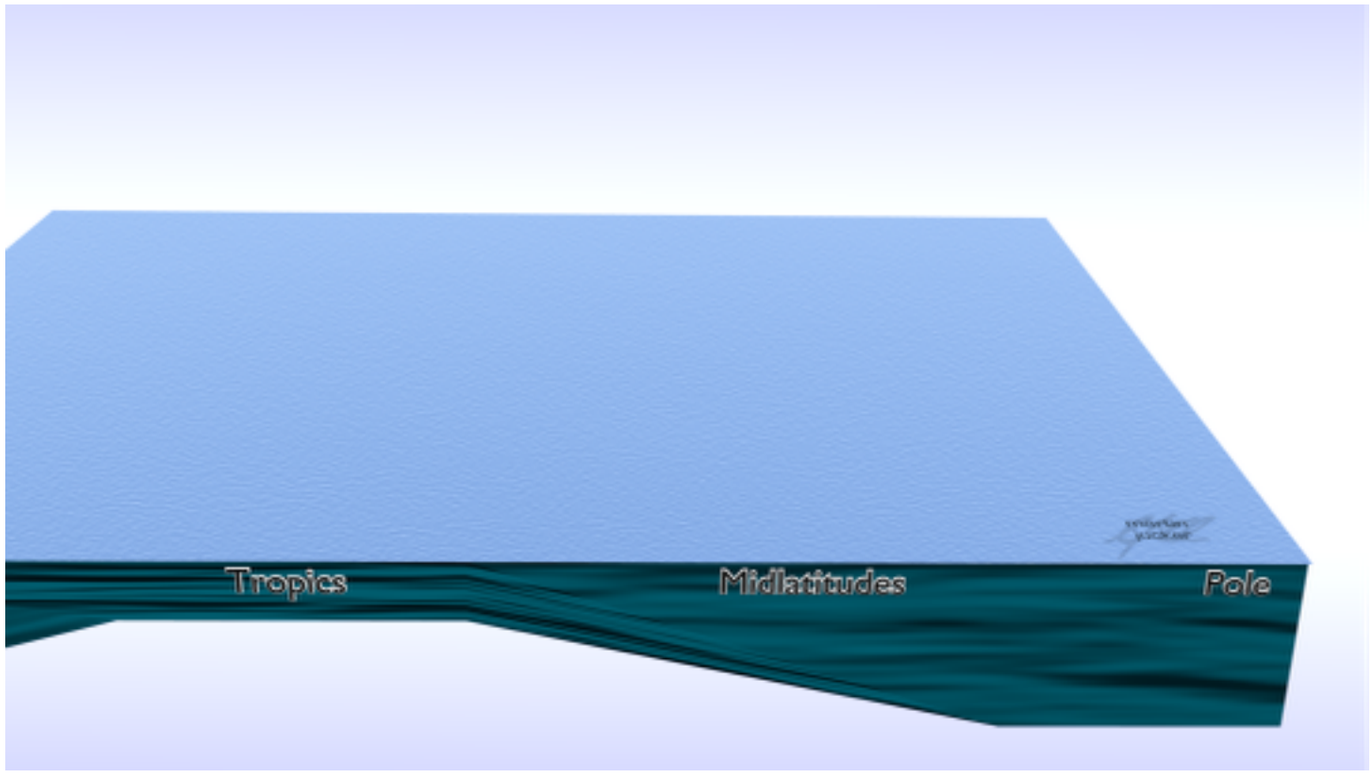
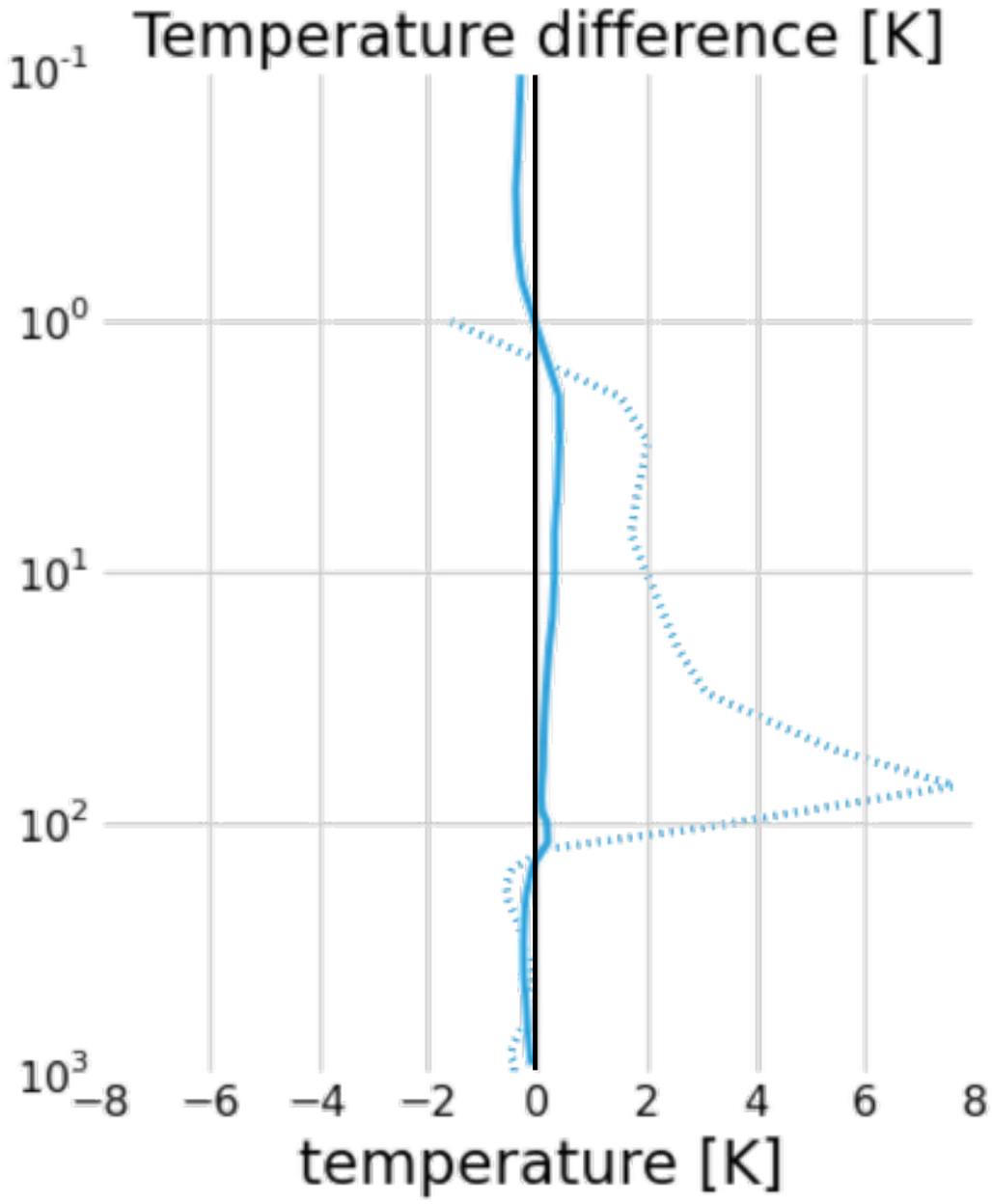
What is the minimum requirement for the tape recorder?



N-S symmetric (control)



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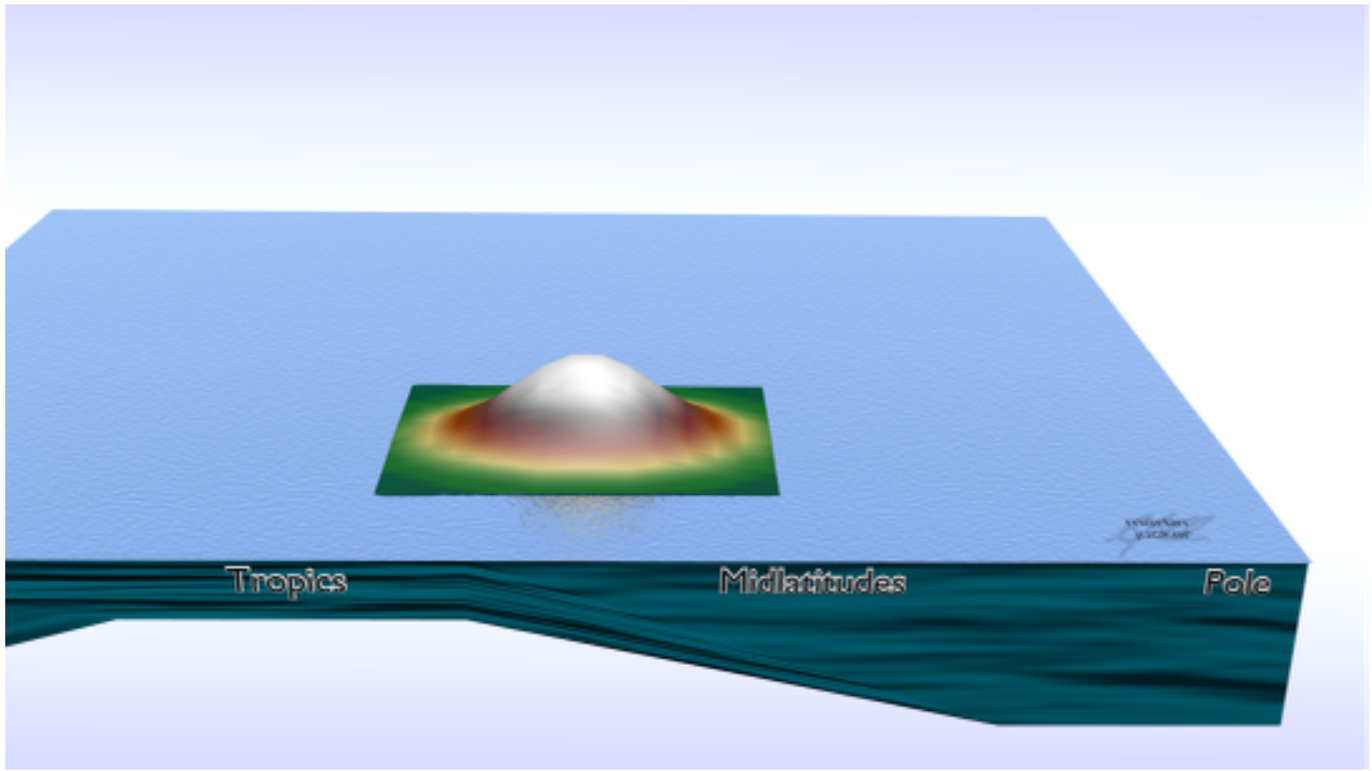
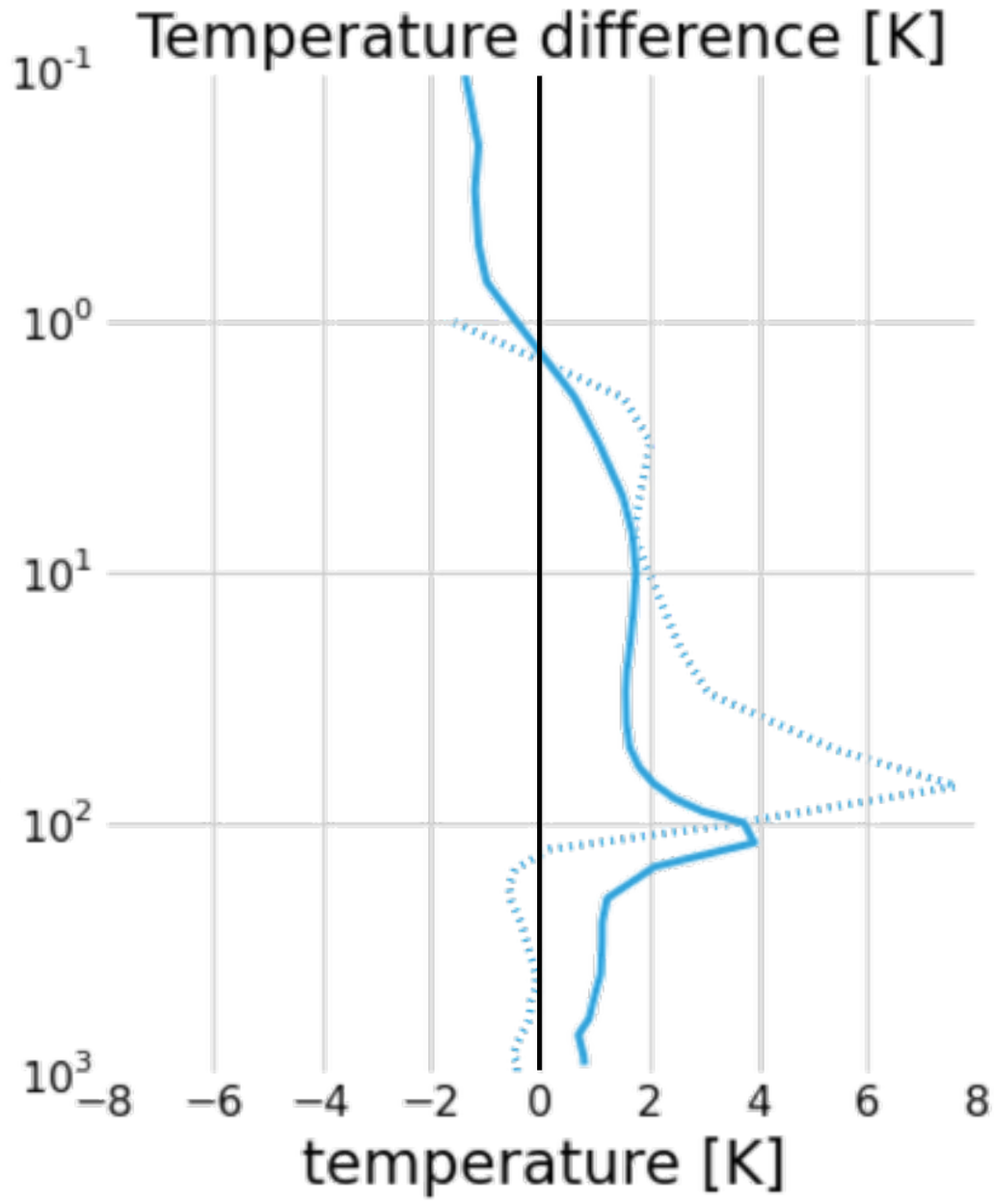


NH wave-1 topography
+ land-sea contrast, “monsoon”



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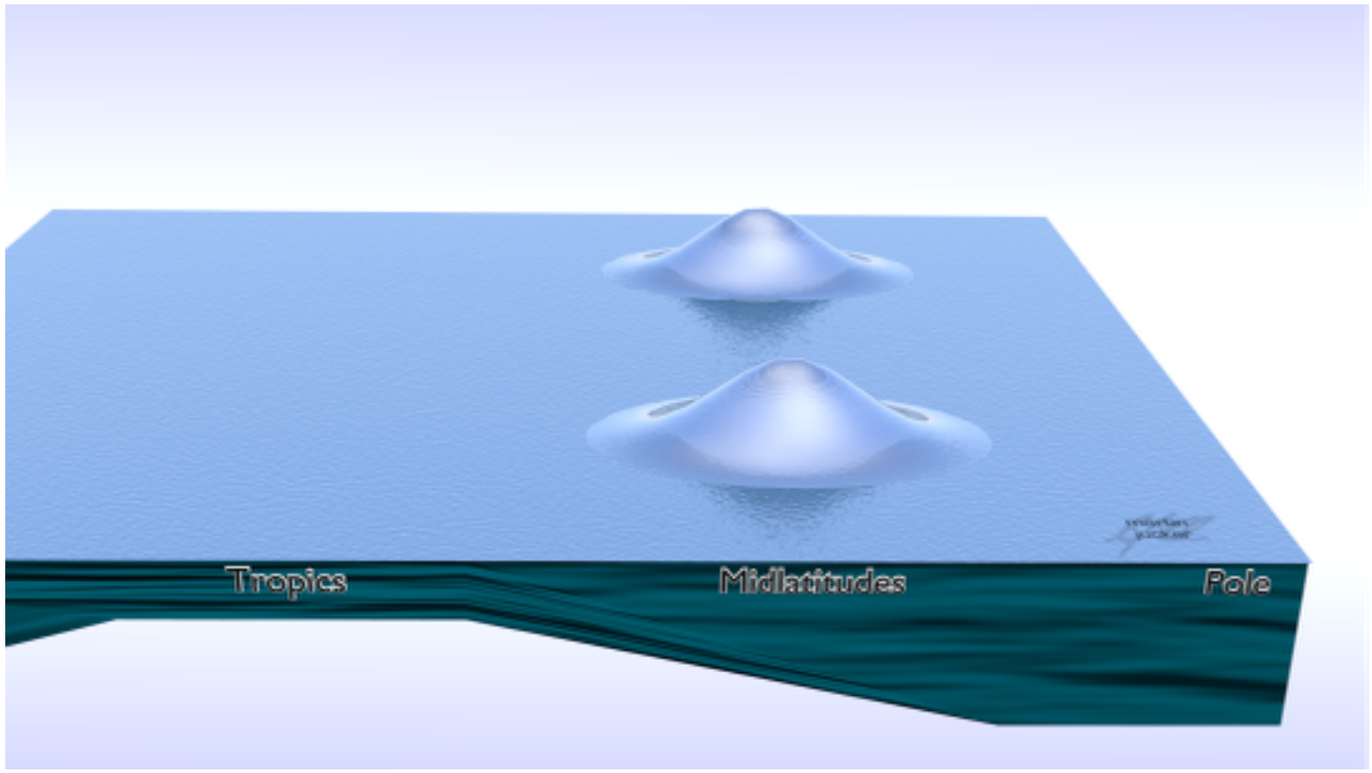
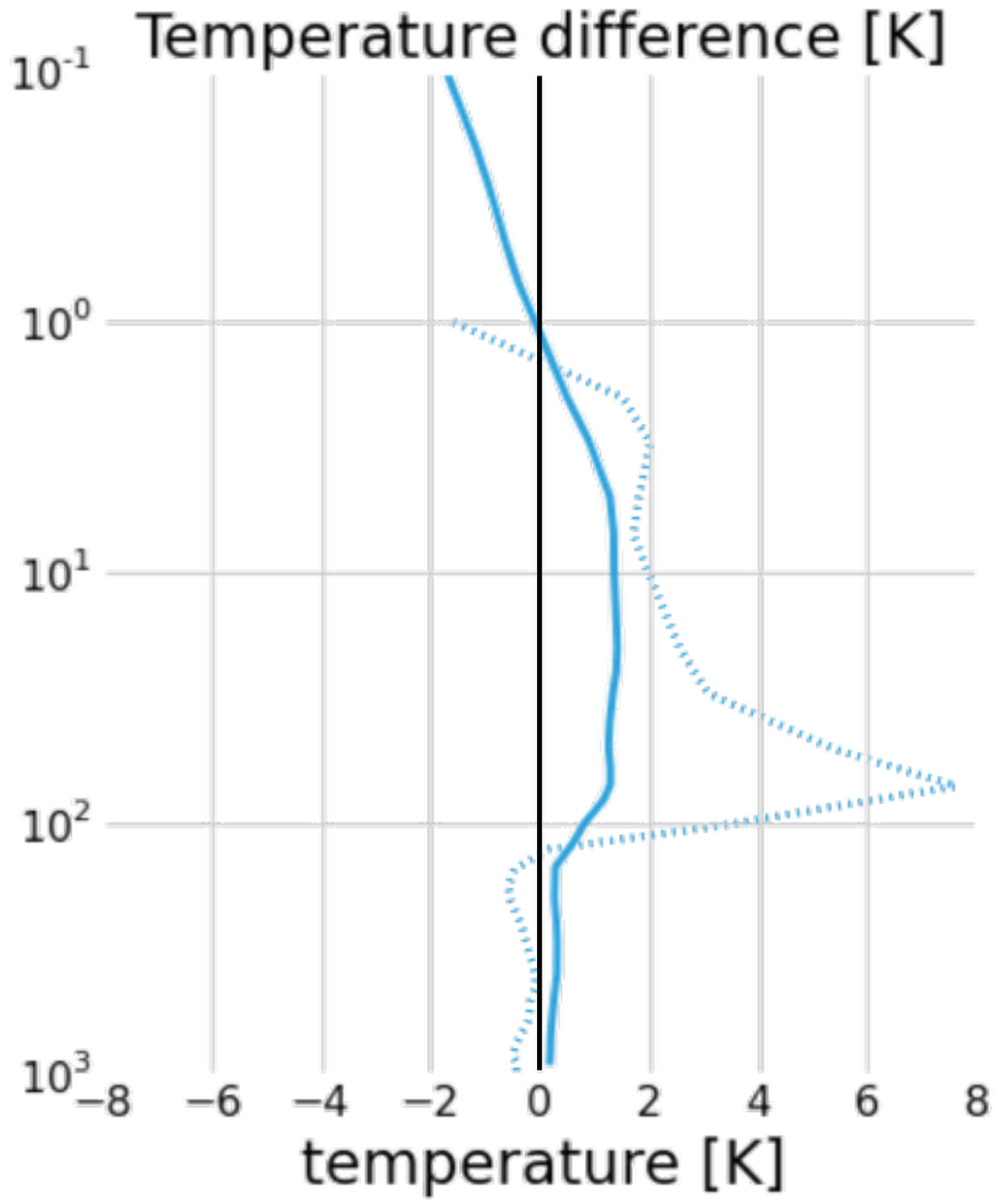


NH wave-2 topography



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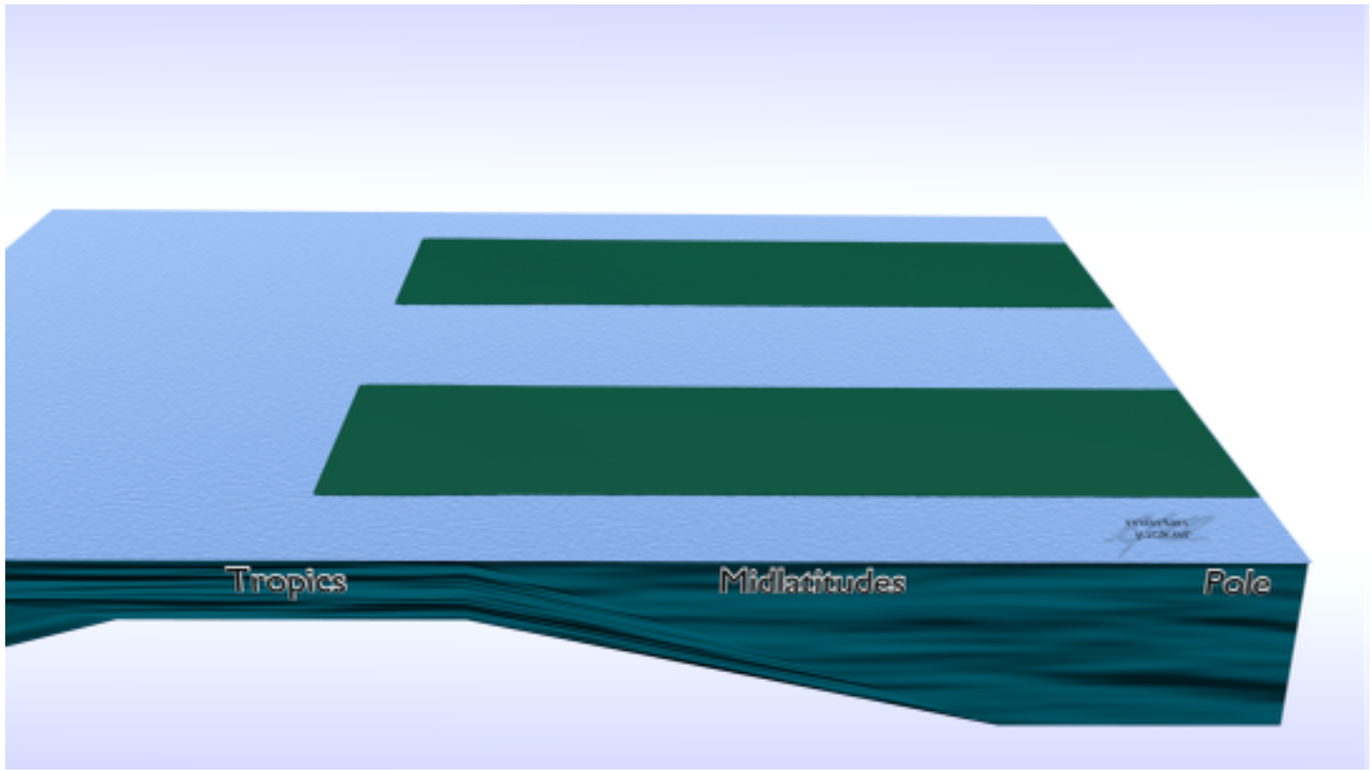

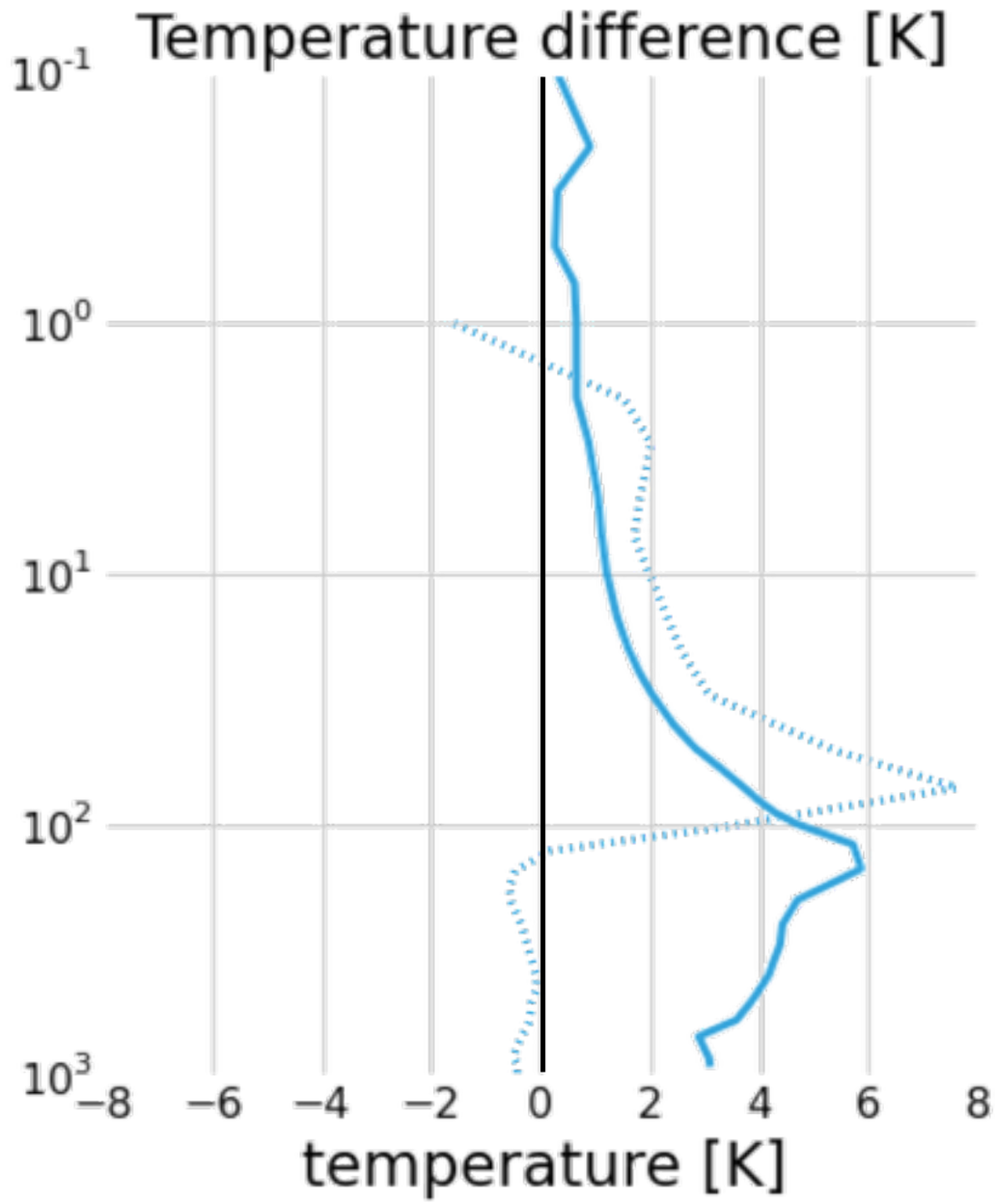

NH wave-2 land-sea contrast

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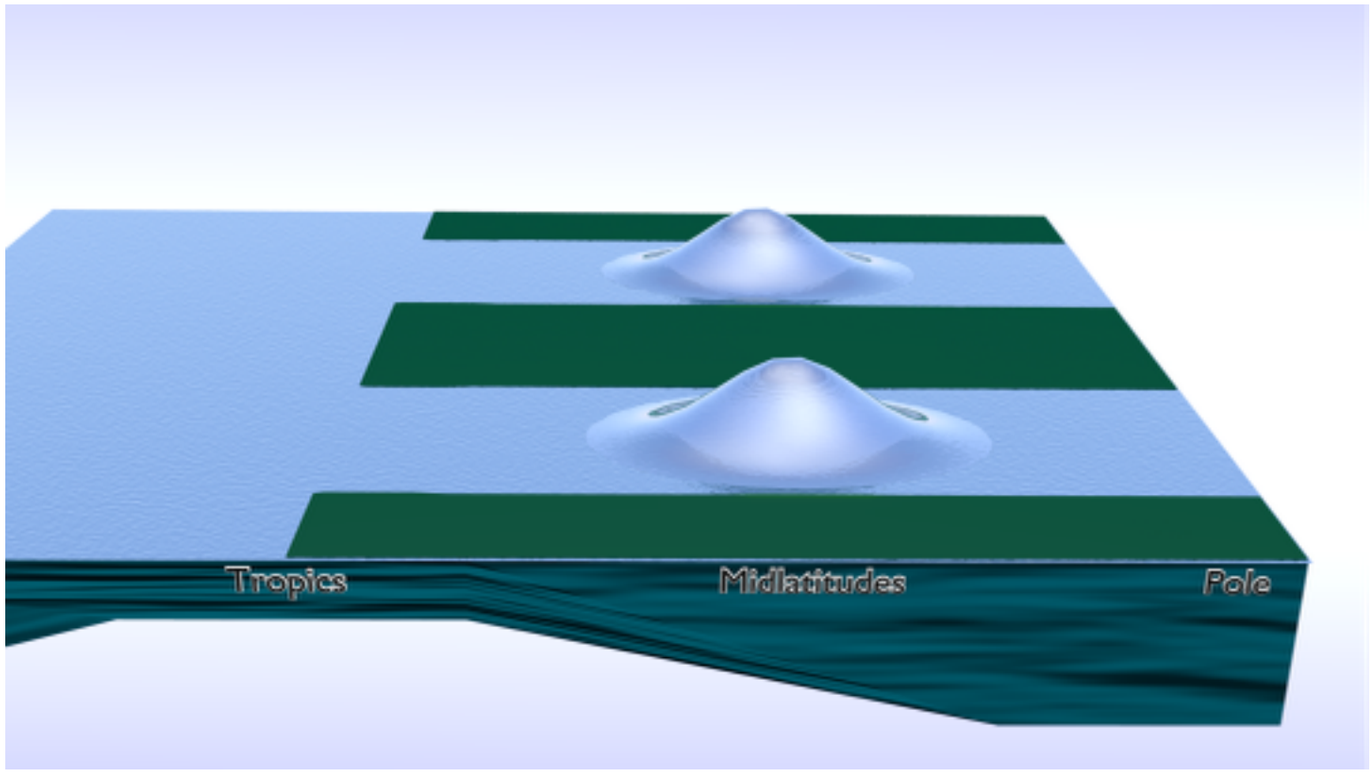
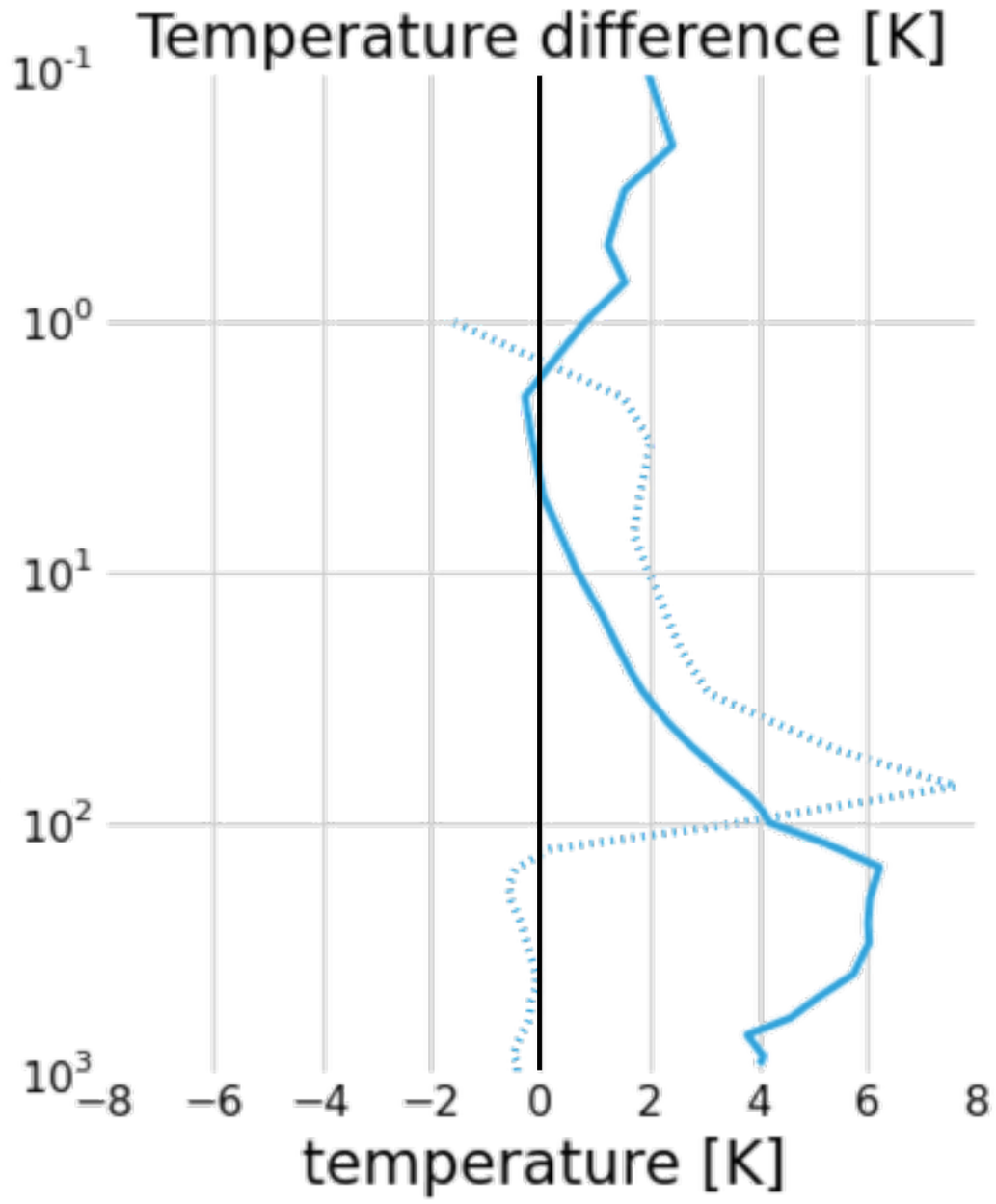


NH wave-2 topography
+ land-sea contrast, off



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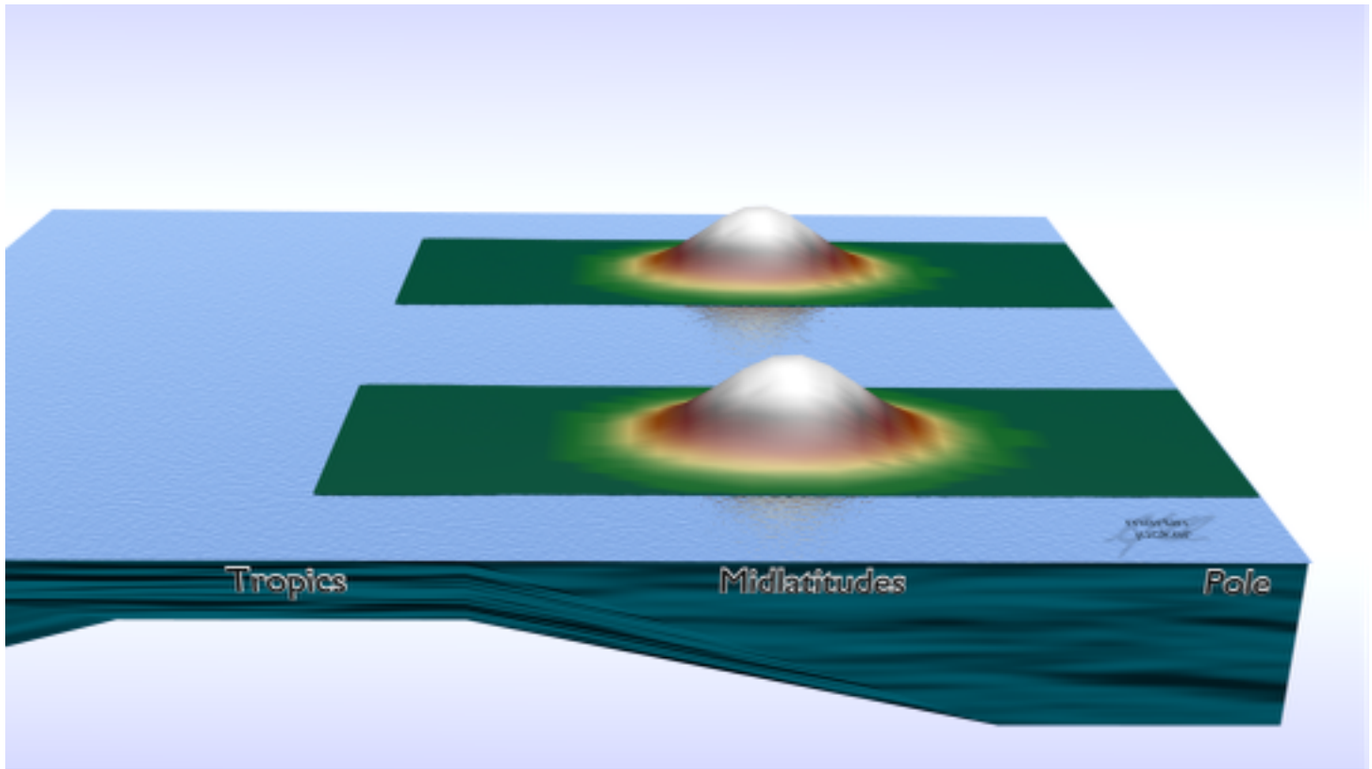
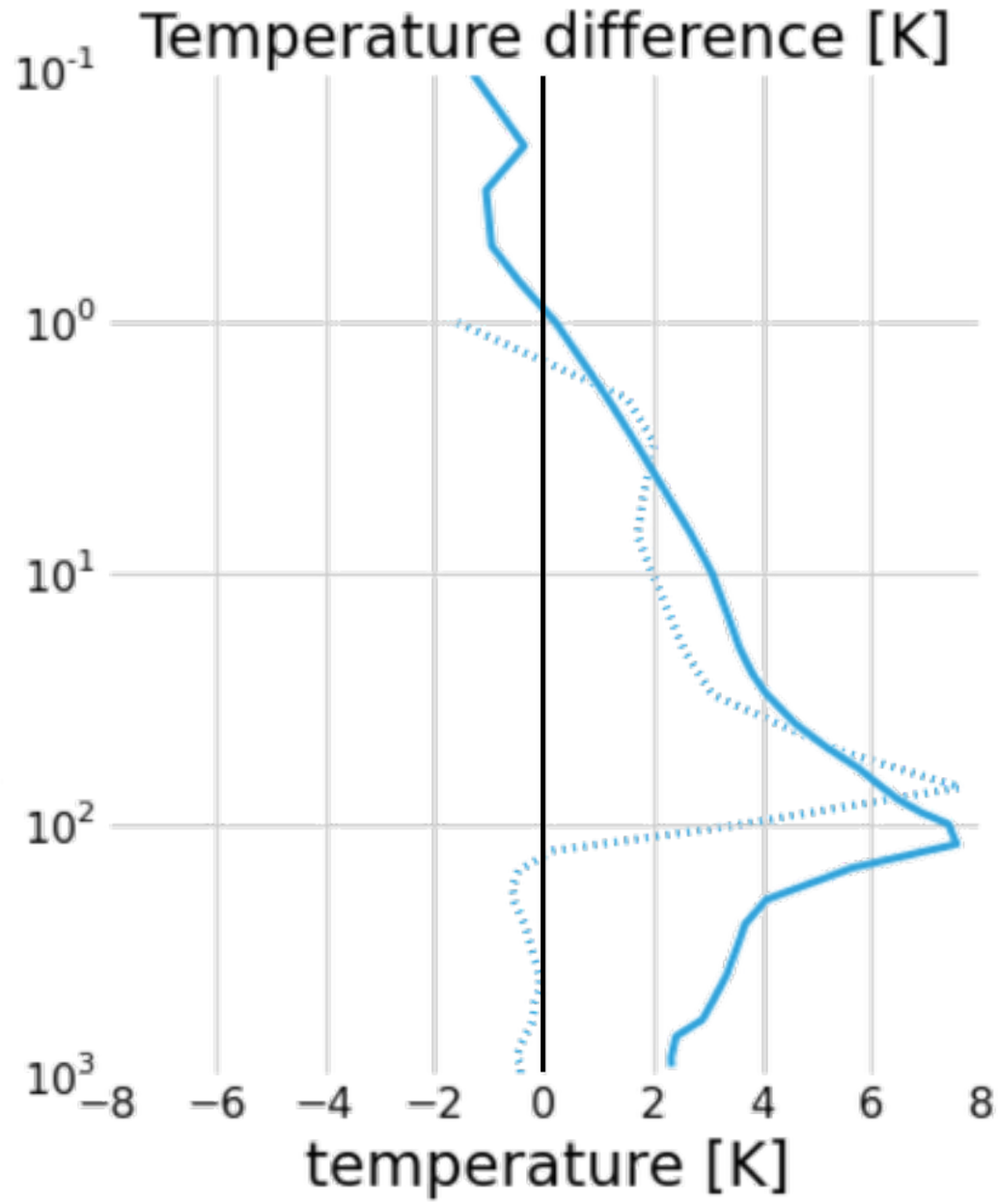


NH wave-2 topography
+ land-sea contrast, on



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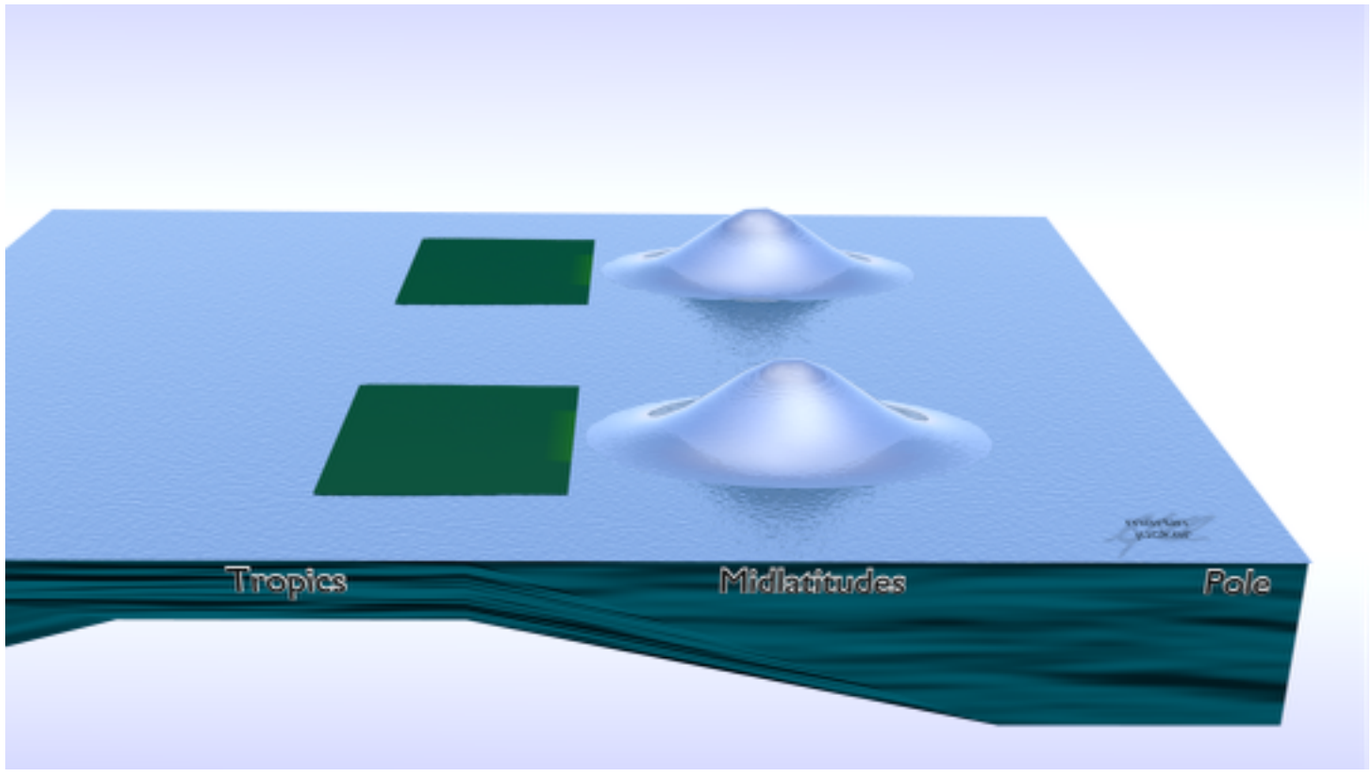
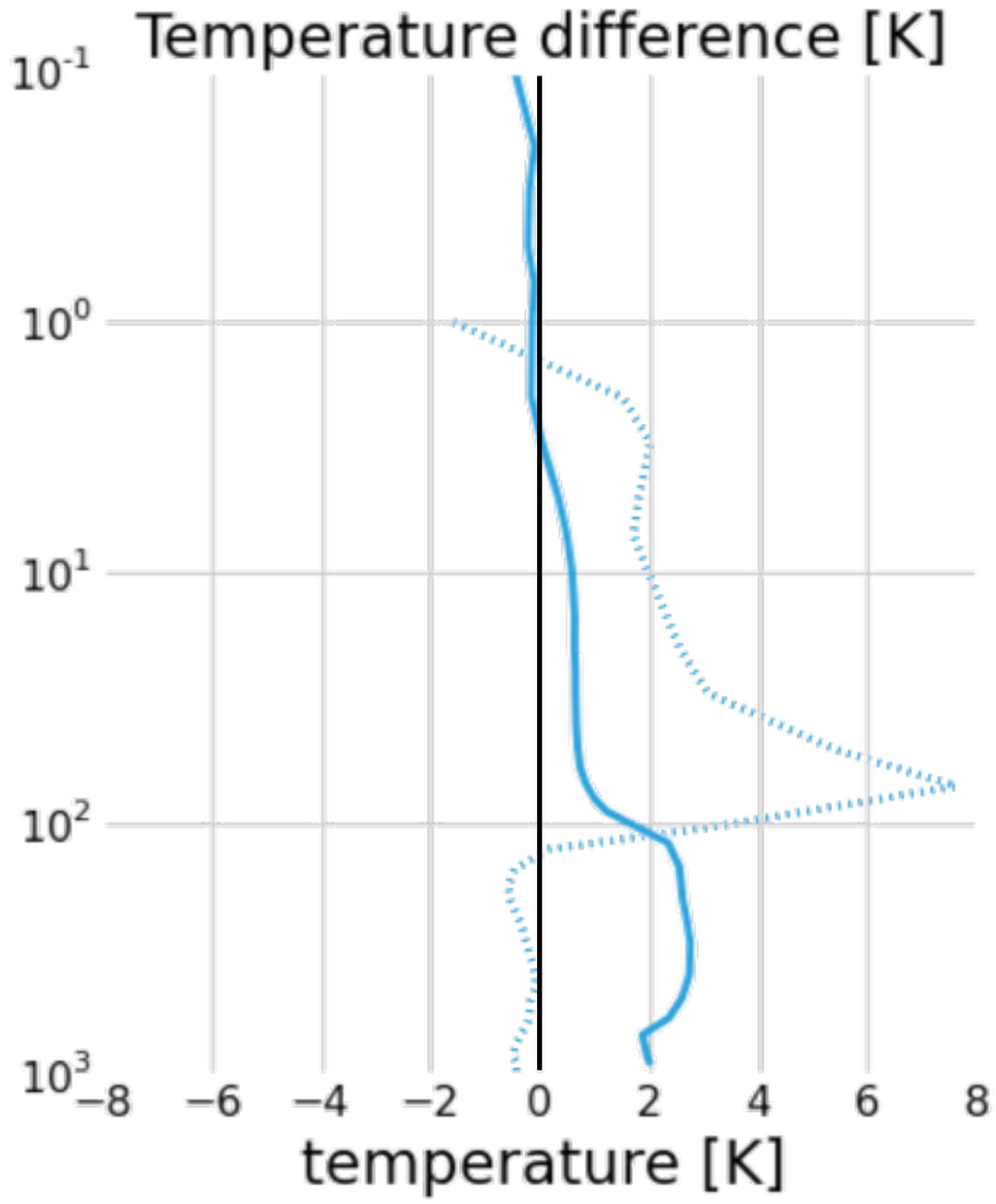


NH wave-2 topography
+ land-sea contrast, subtropics



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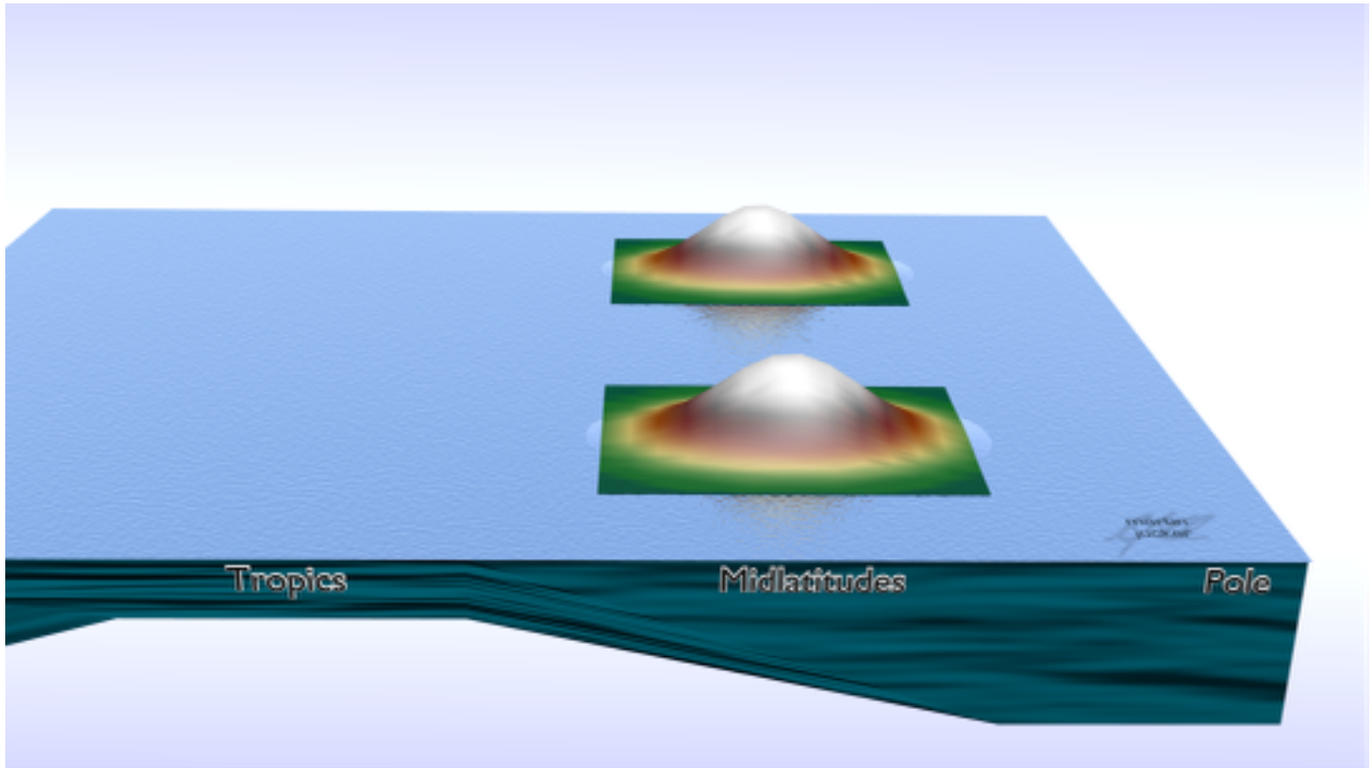
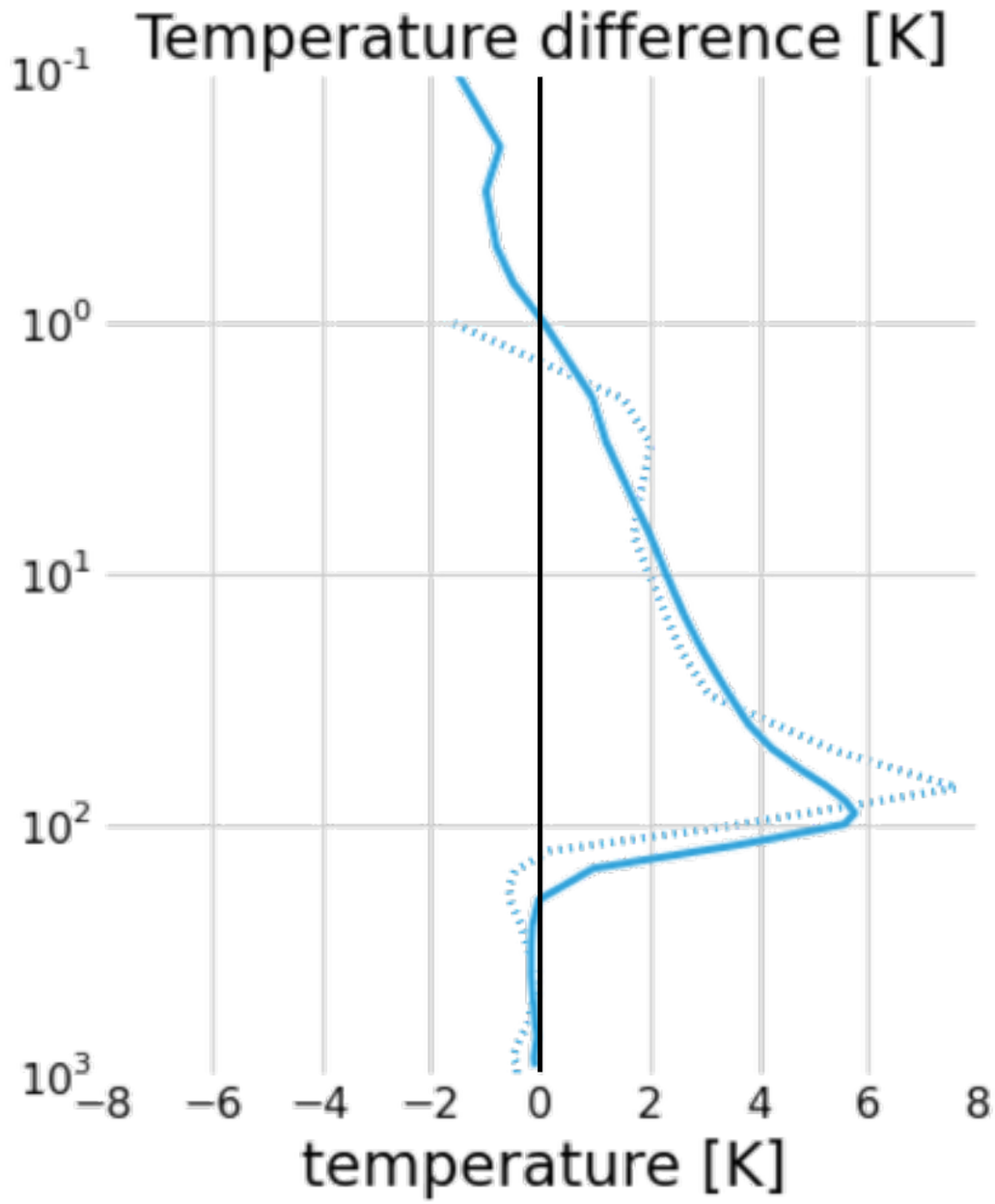


NH wave-2 topography
+ land-sea contrast, midlats



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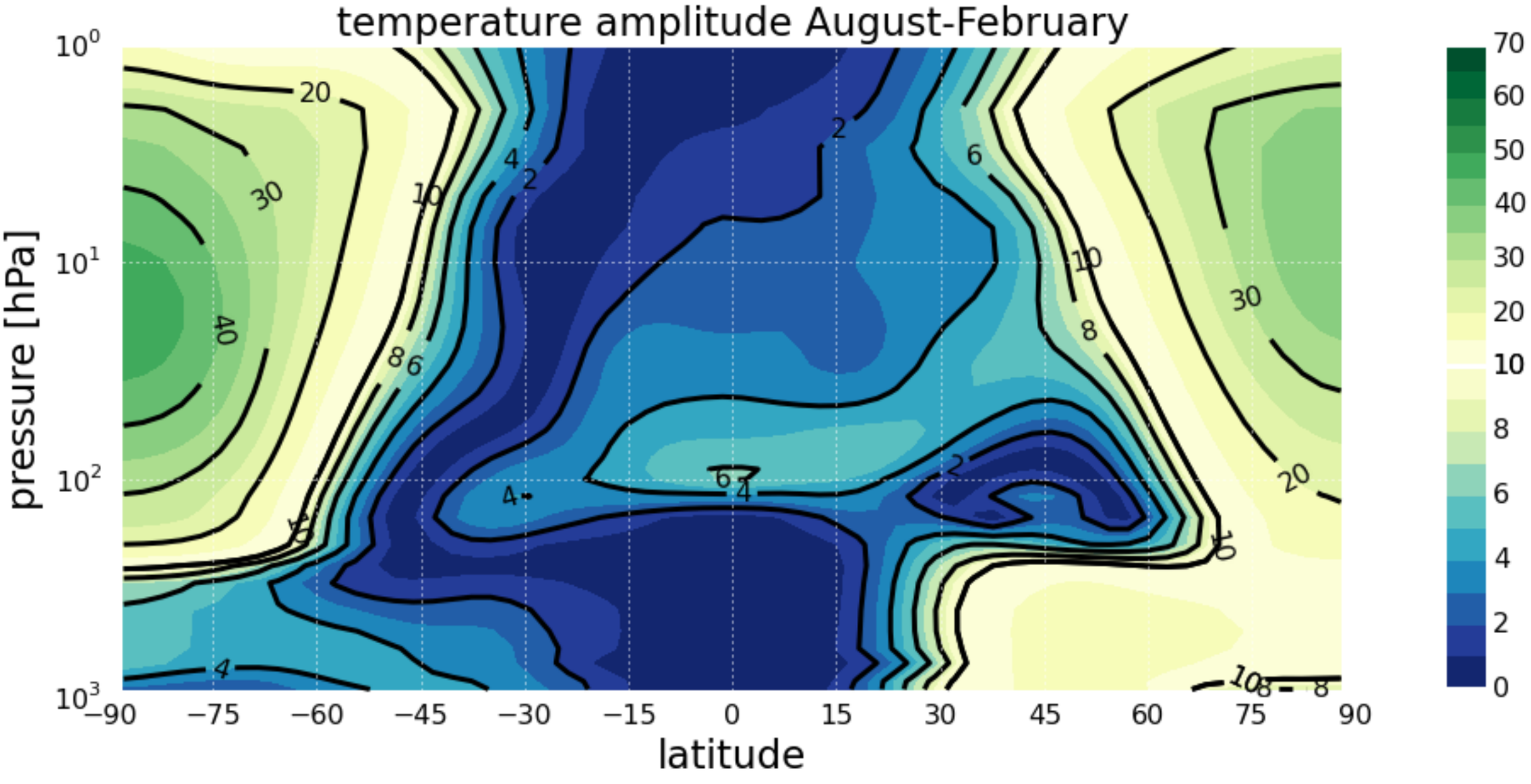
Midlatitude asymmetry in topography and land-sea is key



model

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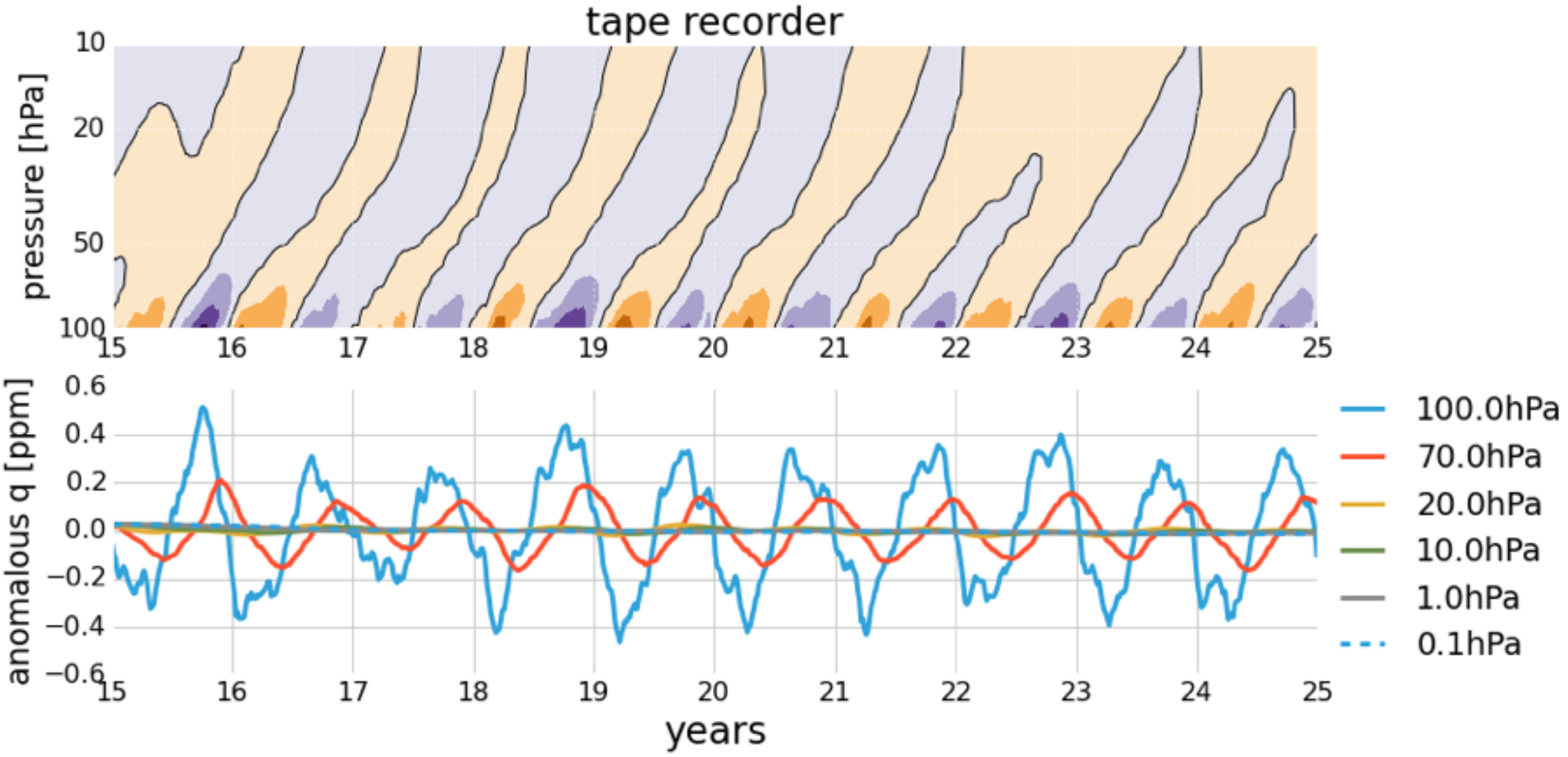
Midlatitude asymmetry in topography and land-sea is key



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Wave analysis: mean upwelling from Eliassen-Palm flux divergence

- ‘downward control’, split into wave contributions

$$f^* \bar{v}^* \approx -\frac{\nabla \cdot \mathbf{F}}{a \cos\varphi} = -\frac{\sum_k \nabla \cdot \mathbf{F}_k}{a \cos\phi}$$

- mass conservation, average over tropics

$$\langle \overline{w}^*_m \rangle (z) = \frac{\cos\phi_0}{\rho_0 \int_{-\phi_0}^{\phi_0} a \cos\phi \mathrm{d}\phi} \int_z^\infty \rho_0 \left[\overline{v}^*(\phi_0) - \overline{v}^*(-\phi_0) \right] \mathrm{d}z'$$

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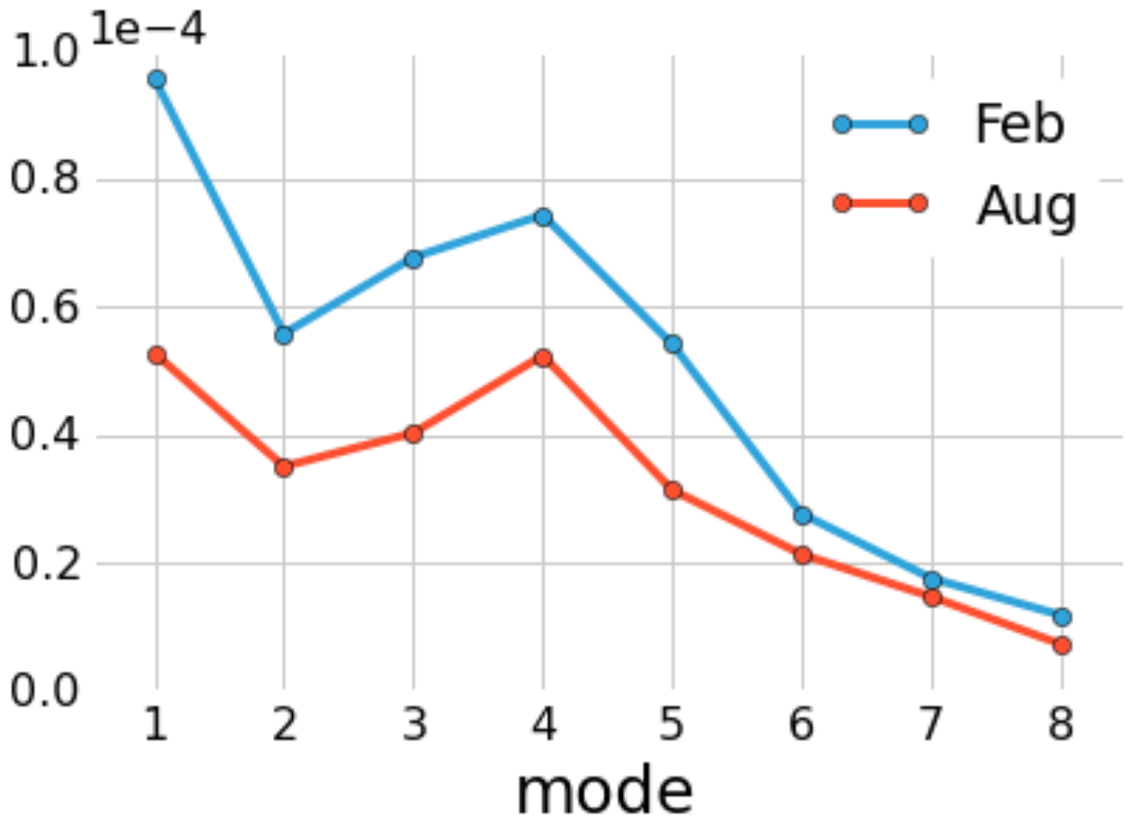
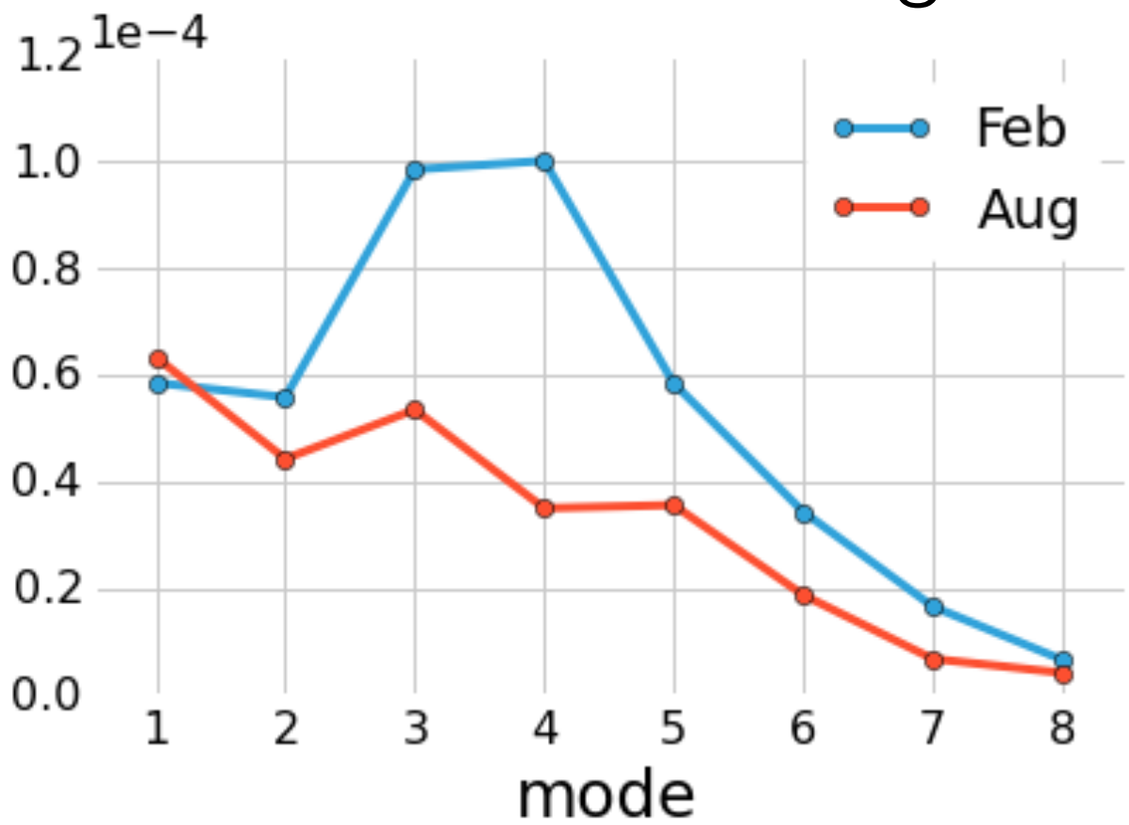
Wave analysis: mean upwelling
Monsoon ~ k=1-5; Midlats ~ k=3,4

‘Monsoon’



Midlatitude forcing



Kim *et al.* (CSU) find k=3 single largest driver of annual cycle in TTL [personal correspondence]

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Conclusions

MiMA:

- High latitude planetary waves (NH-SH differences in orographic forcing) [Yulaeva et al. 1994, Ueyama and Wallace 2010] **yes**
- Seasonal cycle in baroclinic activity (NH-SH differences in land-sea contrast) [Jucker et al. 2013] **yes**
- Tropical asymmetries (Monsoon, Warm Pool) [Kerr-Munslow and Norton 2006] **yes, but**
- Equatorial wave forcing [Randel et al. 2008], and mean flow wave filtering [Ortland and Alexander 2014] **?**

Conclusions

- Main TTL annual cycle drivers:
  - North-South differences in planetary waves and baroclinicity (topography + land) [as in Jucker et al 2013]
  - waves k=3,4
- **Underway:** Radiative forcing impact
  - Tropical stratospheric water vapor radiative forcing has impact on polar vortex strength [as in Jucker et al 2014]

Jucker, Fueglistaler, Vallis (2013): JAS 70, 3341-3358
Jucker, Fueglistaler, Vallis (2014): JGR 119, 11,054-11,064
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