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Combining global-scale atmospheric heat transport and synoptic-scale extratropical cyclone characteristics to understand the role of latent heating for midlatitude storm tracks

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1. Background

Intensity and lifetime of extratropical storms, which modulate midlatitude weather, are strongly influenced by atmospheric moisture. In a warmer climate, the increased specific humidity will act to intensify individual storms.

At the same time, **increased latent energy transport reduces** the equator-to-pole temperature gradient, i.e. **baroclinicity**, which is the dominant driver of cyclone growth.

The physical drivers influencing storm tracks can have compensating effects. Therefore, we run **idealized aqua-planet simulations** with which we address the isolated role of increased latent heat release in a warmer climate.

2. Research Questions

- How do changes in latent heating compare to changes in baroclinicity concerning the future extratropical energy cycle?
- How do changes in moisture transport affect midlatitude cyclones in particular?

3. Idealized Aquaplanet Setup

This model setup is similar to Hermoso and Schemm (see QR) but symmetric on both hemispheres.

- ICON version 2.6.6
- Zonally symmetric SSTs referred to as "Qobs" distribution1
- Implemented SST fronts imitating the land-sea contrast of the Gulf Stream[2]

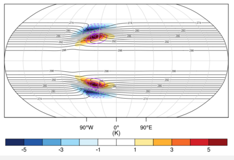

Figure 1: Initial SST anomalies (shading) and 2m-temperature response (purple).

4. First Results: Energy Flux Changes

Influence of uniform warming on downstream flow of SST front

The response of the emerging, localized storm track is dependent on the shape parameters of the SST front (e.g. location or intensity).

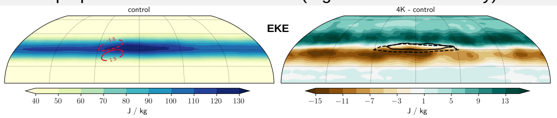

Figure 2: Vertically averaged EKE in idealized, hemispherically symmetric aquaplanet simulations (shading). Left: A localized storm track can be found downstream of an SST front (red contours). Right: Uniform warming shifts the storm track poleward and weakens it slightly, as shown by the 115 J/kg contours for control (dashed) and 4K (solid).

Poleward energy transport: the importance of moisture flux

Transient eddies significantly contribute to heat flux in the extratropics and about a third of thereof stems from latent heat transport. Changes due to warming mainly affect the moist component.

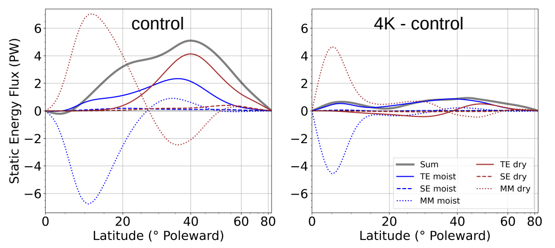

Figure 3: Climatology of zonal mean moist static energy (MSE) flux in PW. Grey depicts the atmospheric energy transport; blue and red the moist and dry parts thereof, respectively. Transient eddy (TE) fluxes (solid) are computed from deviations of monthly means, stationary eddies (SE, dashed) from zonal anomalies, and the mean meridional (MM) overturning is shown by dotted lines[3].

References

1. Neale, R. B. & Hoskins, B. J.: A standard test for AGCMs including their physical parametrizations: I: The proposal. Atmos. Sci. Letters 101, 101–107 (2001).
2. Schemm, S., Papritz, L., and Rivière, G.: Storm track response to uniform global warming downstream of an idealized sea surface temperature front, Weather Clim. Dynam., 3, 601–623 (2022).
3. Shaw, T. A., Barpanda, P., & Donohoe, A.: A Moist Static Energy Framework for Zonal-Mean Storm-Track Intensity, Journal of the Atmospheric Sciences, 75(6), 1979-1994 (2018).
4. Franzke, C. L. E., and Harnik N.: Long-Term Trends of the Atmospheric Circulation and Moist Static Energy Budget in the JRA-55 Reanalysis, J. Climate, 36, 2959–2984 (2023).

5. Outlook: Cyclone Characteristics

Analysis of cyclones tracks

Addressing the research questions: Bringing the moist static energy perspective and cyclone characteristics together using a cyclone tracking algorithm.

Sensitivity of MSE fluxes and storm tracks

Performing additional ICON simulations with adapted model setups such as different SST configurations or resolution.

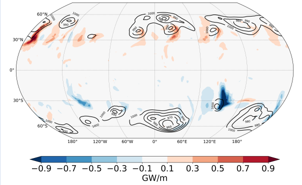

Figure 4: Vertically integrated northward moisture flux (colors) and surface pressure below 1000 hPa (contours) are presented for one exemplary model output timestep to illustrate the connection between moisture fluxes and cyclones.

Relating results to observations

Findings will be compared to ERA5 reanalysis data and CESM future climate projections.

6. Methodological Challenges

Energy budget closure

Relating meridional moist static energy flux to surface and top of atmosphere fluxes leads to a residual of 5 – 10 W/m² for ICON (slightly more in reanalysis products).

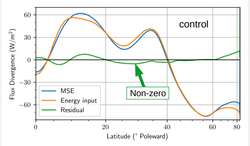

Figure 5: Climatology of the energy budget.

Defining high-frequency variability

Transient eddies are defined as deviations from a monthly mean, which is an arbitrary choice of background flow. Splitting the flow into high- and low-frequency components, however, leads to cross-terms[4].

Zonal mean framework

The framework can describe zonal mean storm tracks, yet in the real atmosphere these are not zonally symmetric.

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Supplementary Slides

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EKE

$$K'_e = (1/2)\mathbf{v}'^2$$
$$P'_e = (1/2S)\theta'^2$$

$$\frac{\partial K'_e}{\partial t} = -\nabla \cdot \left(\mathbf{v}K'_e + \mathbf{v}'_a \phi'\right) - \frac{\partial}{\partial p}\left(\omega K'_e + \omega' \phi'\right) + \omega' \frac{\partial \phi'}{\partial p} - \mathbf{v}' \cdot \left(\mathbf{v}'_3 \cdot \nabla \overline{\mathbf{v}}\right) + R_{K_e}$$

$$\frac{\partial P'_e}{\partial t} = -\nabla \cdot \left(\mathbf{v}P'_e\right) - \omega' \frac{\partial \phi'}{\partial p} - \frac{1}{S}\theta'\left(\mathbf{v}' \cdot \nabla \bar{\theta}\right) - \frac{1}{S}\frac{\partial}{\partial p}\left(\omega \frac{\theta'^2}{2}\right) + \frac{1}{S}\theta' Q' + R_{P_e}$$

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Moist static energy (MSE)

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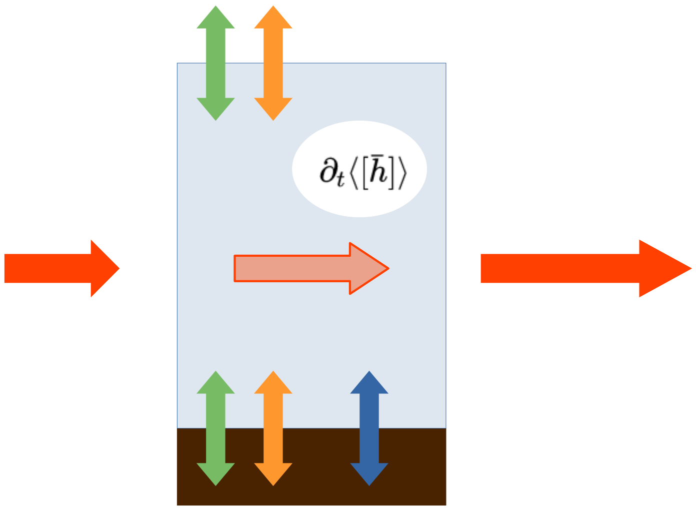
$$[\overline{vm}] = [\overline{v'm'}] + [\overline{v}][\overline{m}] + [\overline{v}^*\overline{m}^*]$$

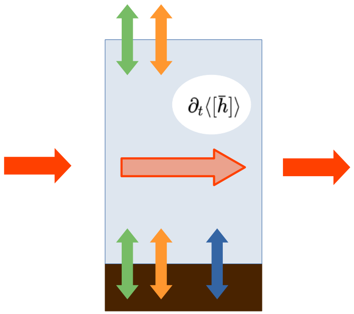
$$\langle[\overline{vm}]\rangle = \langle[\overline{v'm'}]\rangle + \langle[\overline{v}][\overline{m}]\rangle + \langle[\overline{v}^*\overline{m}^*]\rangle$$

$$\partial_y\langle[\overline{vm}]\rangle = [\overline{EIA}] - \partial_t\langle[\bar{h}]\rangle$$



v	meridional wind velocity,
$m = c_pT + Lq + \Phi$	MSE,
$h = c_pT + Lq$	thermal energy,
EIA	Energy input atmosphere from
$= \mathrm{LH} + \mathrm{SH} + \mathrm{LW}_{\mathrm{sfc}} - \mathrm{OLR} + Q_{\mathrm{SWrad}}$	radiative and surface fluxes,
$\partial_y(\cdot) \equiv \partial_\phi\{\cos\phi(\cdot)\}/(a\cos\phi)$	meridional divergence.

$$\partial_y\underbrace{\langle[\overline{v'm'}]\rangle}_{TE} = 0$$



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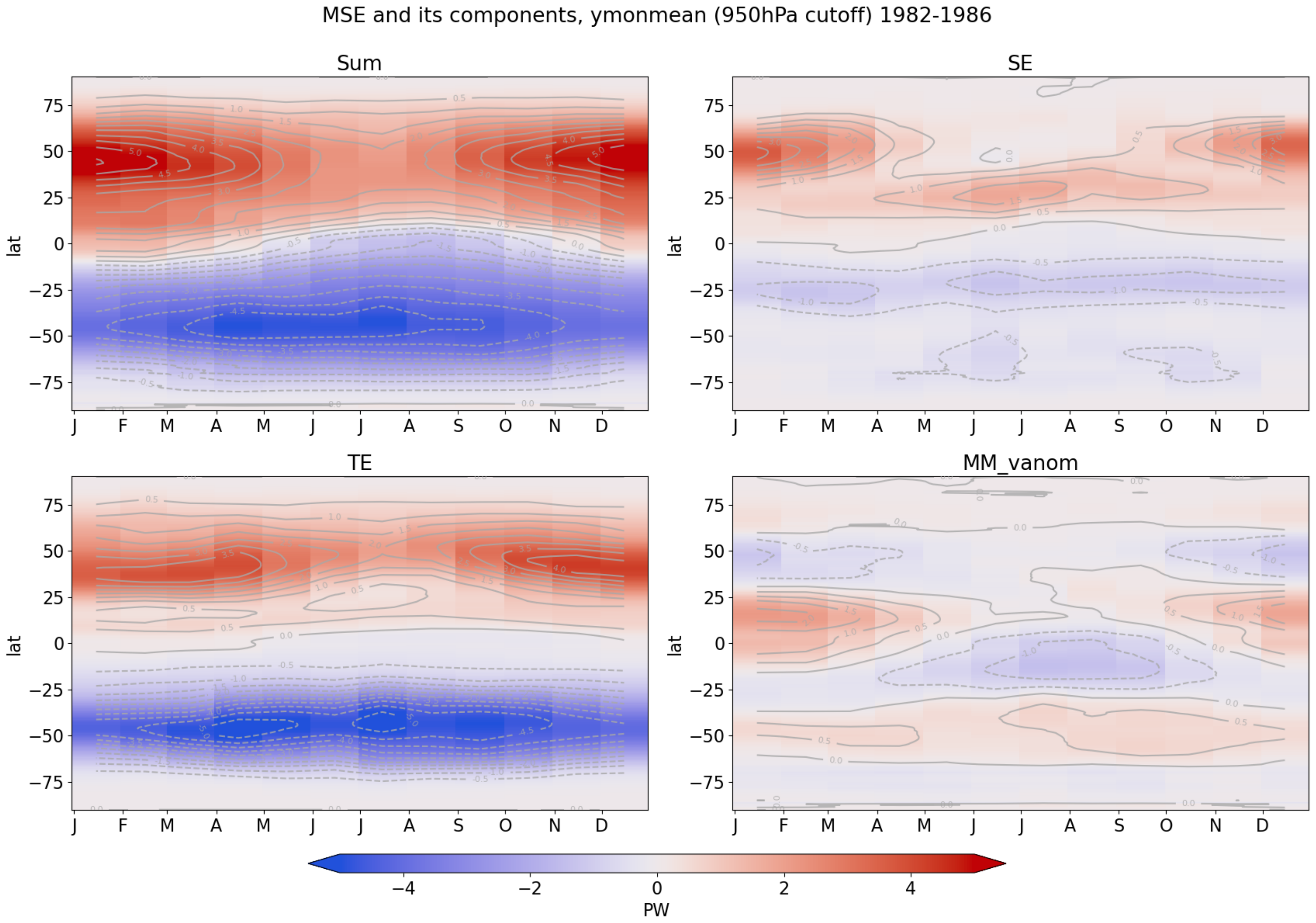
ERA5 Poleward MSE flux



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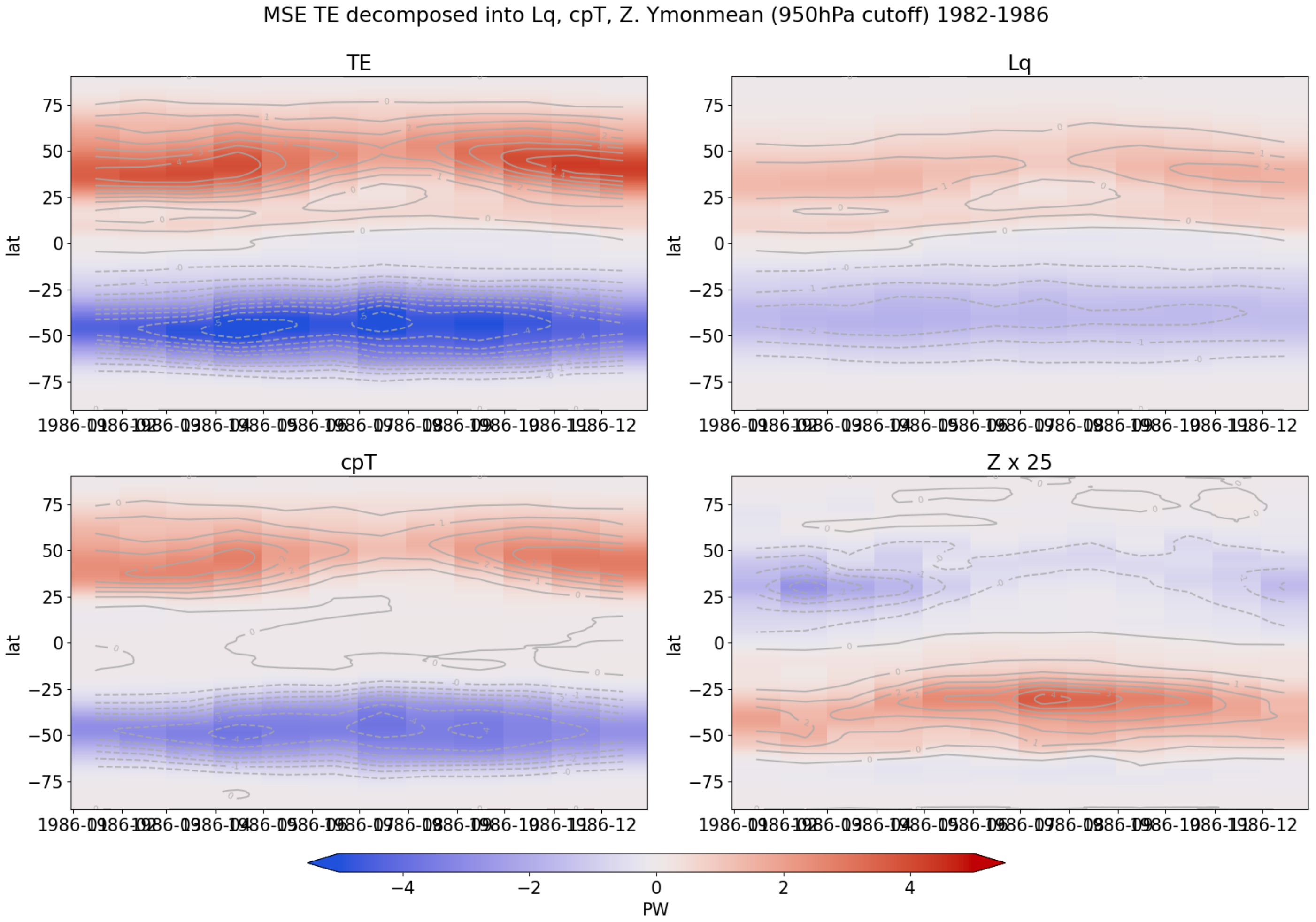
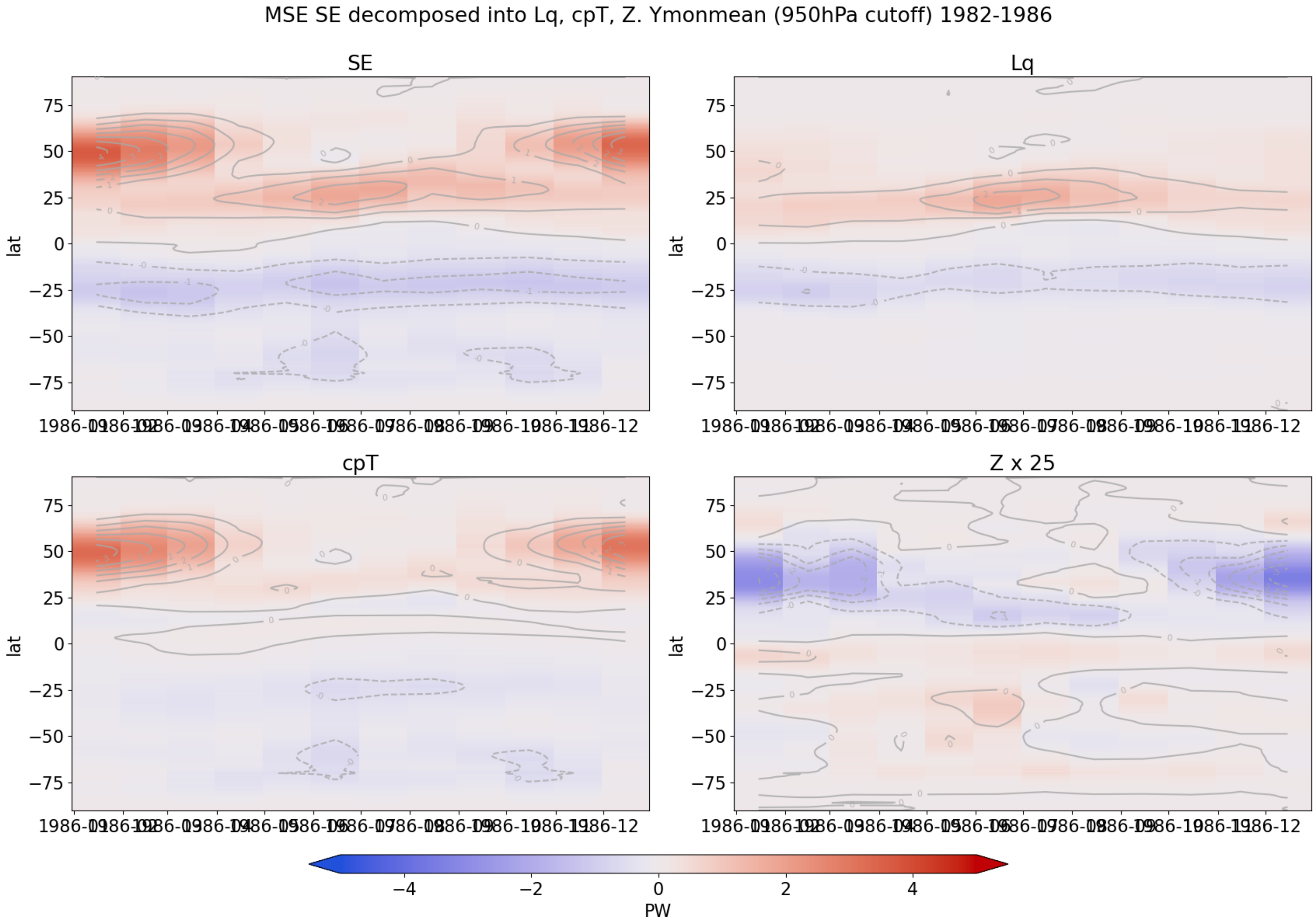
Transient eddies



Stationary eddies



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Mean flow

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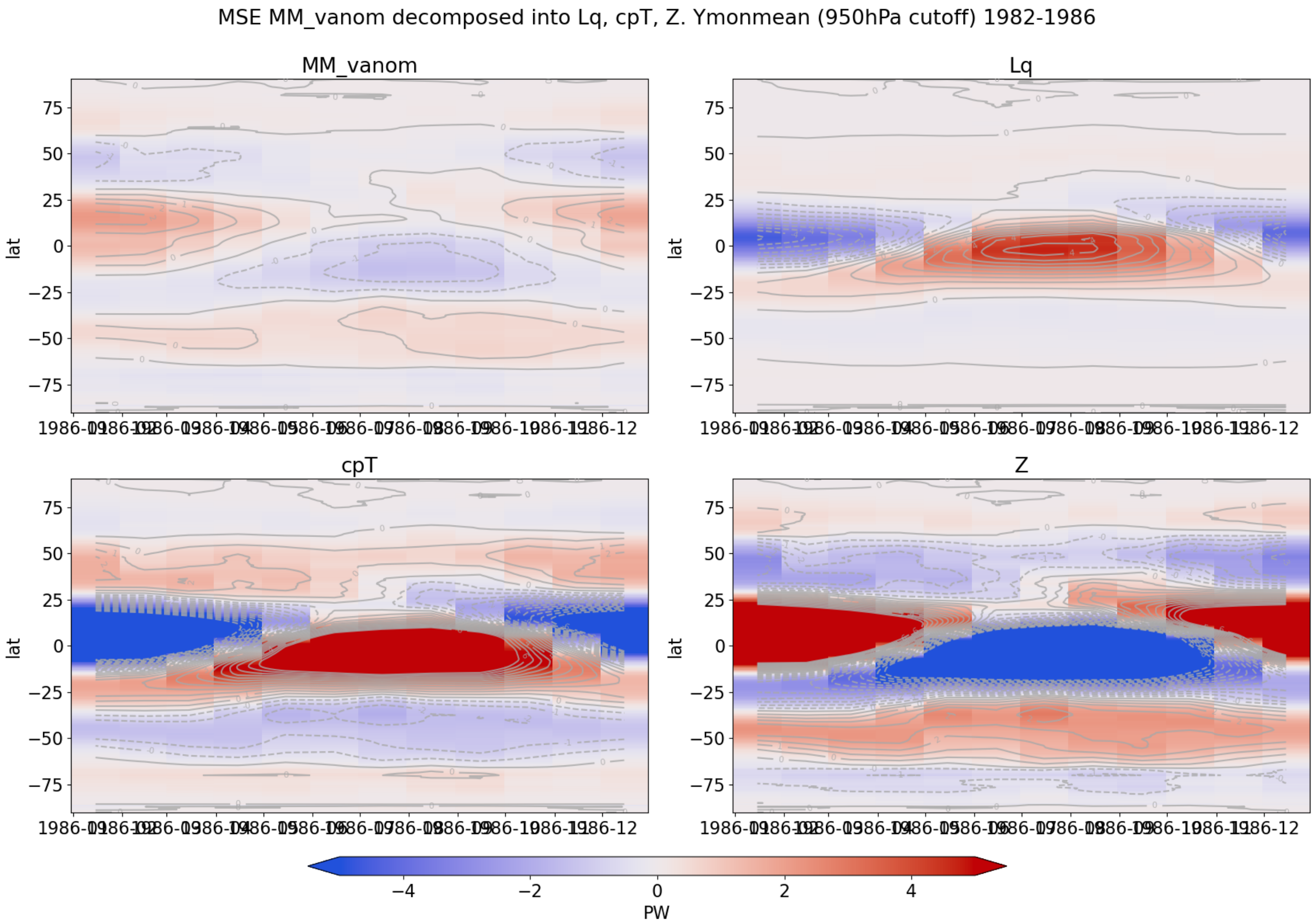

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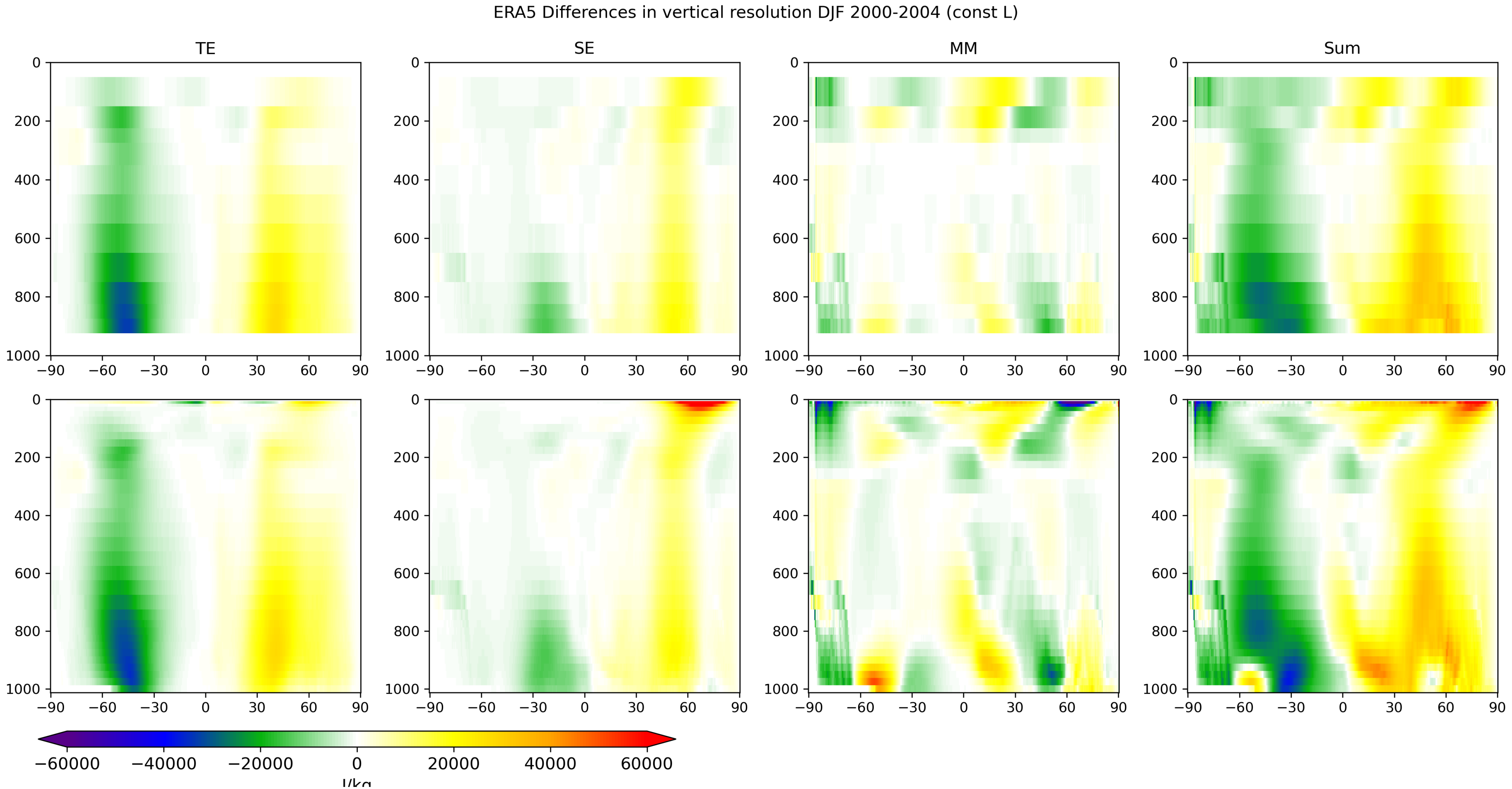
ERA5 vertical cross sections



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