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CLIM XTREME Climate Change and Extreme Events

# The Most Extreme Rainfall Events over Europe

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## BACKGROUND

### RESEARCH QUESTIONS

I. What **types of uncertainties of extreme precipitation events** over central Europe occur with climate change?

II. What **specific conditions** in future climate are **linked to inter-model uncertainties** of future changes of extreme precipitation?

### DATA

**Large ensembles of 10 CMIP6 global climate models** for the 30-year historical period **1970-1999** and a simulated 30-year future period **2070-2099** with the scenario SSP370.

### METHODOLOGY

✓ **Identify future changes of daily 100-year precipitation events** over five Central European river catchments, as performed in *Ruff & Pfahl (2023)*, **and identify their uncertainties** through inter-model differences.

✓ Use **scaling diagnostic** from O`Gorman and Schneider (2009), as applied in *Pfahl et al. (2017)*, to **separate the future changes into dynamic and thermodynamic contributions** and quantify uncertainties through inter-model differences. Dynamical changes are compared to synoptic composites to **understand underlying conditions and mechanisms**.

### SCALING DIAGNOSTIC

**Aim:** decompose extreme precipitation into a dynamic (est. by vertical velocity) and thermodynamic (est. by derivative of saturation humidity) part

**Assumption:** moist-adiabatic and saturated ascent of air during extreme precipitation events

**Thermodynamic contribution:** constant $\omega_e$ (here mean over historical events of the model), evaluate changes in $q_s$

**Dynamic contribution:** constant $T_e$ and thus $q_s$ (here mean over historical events of the model), evaluate changes in $\omega_e$

**Thermodynamic contribution**

$$P_{thermo} \sim -\left\{ \omega_e \frac{dq_s}{dp}\bigg|_{\theta^*} \right\}$$

climatological $\omega_e$ (mean over hist. events of a model)

**Dynamic contribution**

$$P_{dyn} \sim -\left\{ \omega_e \frac{dq_s}{dp}\bigg|_{\theta^*} \right\}$$

climatological $T_e$ (mean over hist. events of a model)

## TEMPORAL AND INTENSITY CHANGES

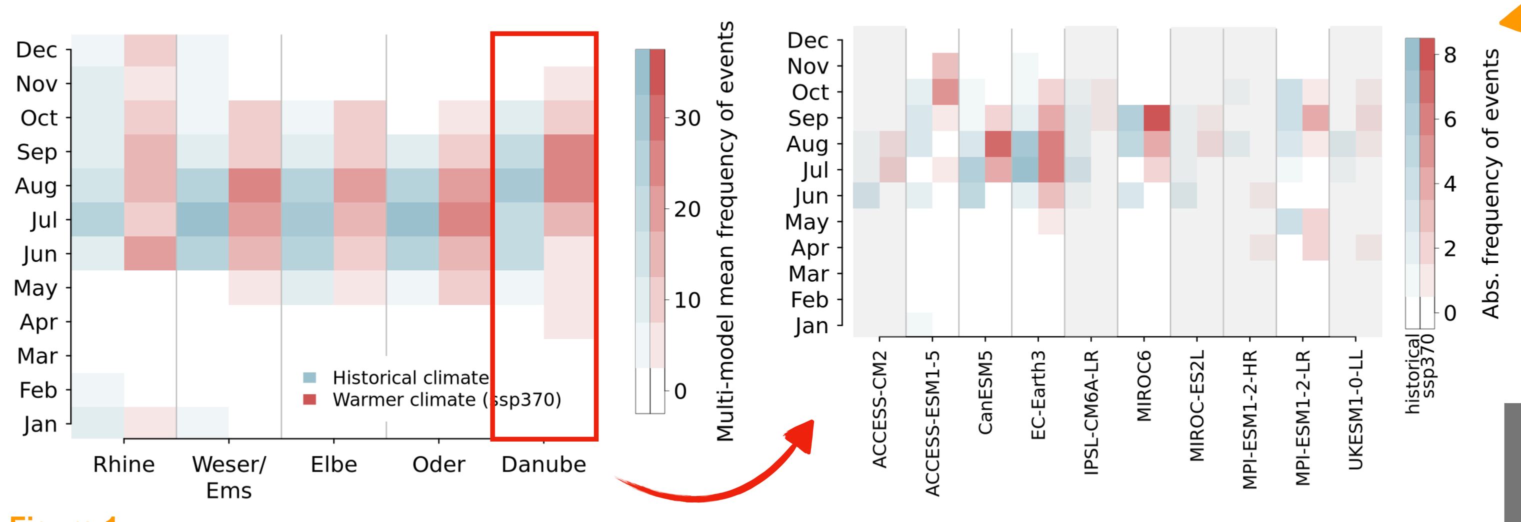


**Figure 1**
Monthly distribution of daily 100-year precipitation events in a 30-year historical and warmer climate period, **(left)** from 10 CMIP6 models and **(right)** for each model individually just for **Danube** events.

- Extreme precipitation events mainly occur **from May to Oct** for all river catchments with **a slight seasonal broadening** in a warmer future climate

- Multi-model means of extreme precipitation changes **show significant increases** (similar to Clausius-Clapeyron rate)

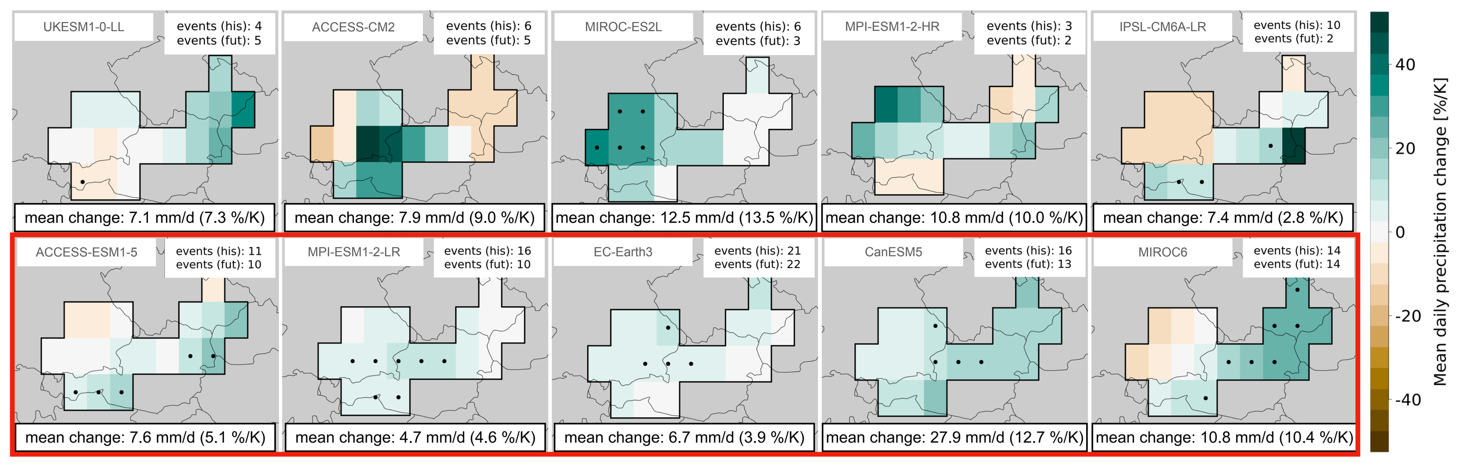


**Figure 3**
Projected changes of **daily 100-year precipitation events** over the Danube catchment for all 10 CMIP6 models. Black dots show **statistical significance** on a 95% level.

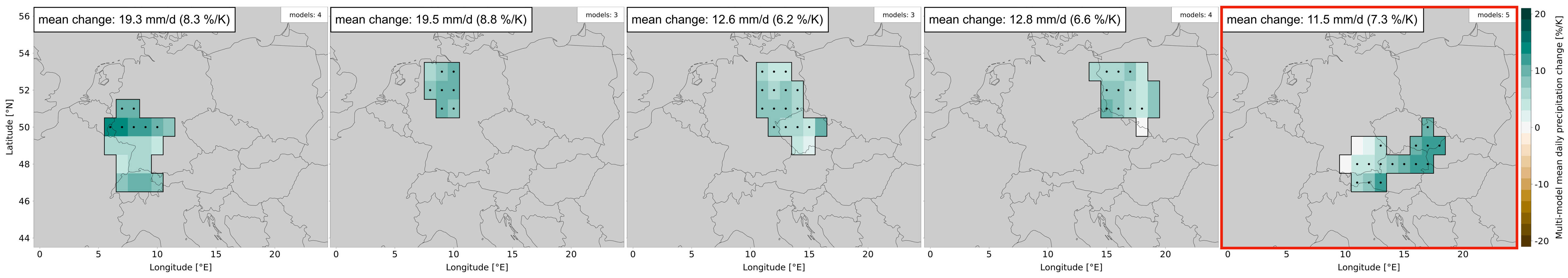


**Figure 2**
Projected changes of **daily 100-year precipitation events** over Central European river catchments from **robust models** (at least 10 events per climate period), shown as relative changes normalised by the global warming rate. Black dots show **agreement of the sign of the precipitation change** in at least 80% of the models.

- **Individual models** show a **larger spread** of area-averaged **increase** in future extreme precipitation (similar for all river catchment)

- Partly **distinct differences between spatial patterns** due to low event numbers, high event-to-event variability and differences in physical mechanisms between models

## SCALING ANALYSIS & ATMOSPHERIC DYNAMICS

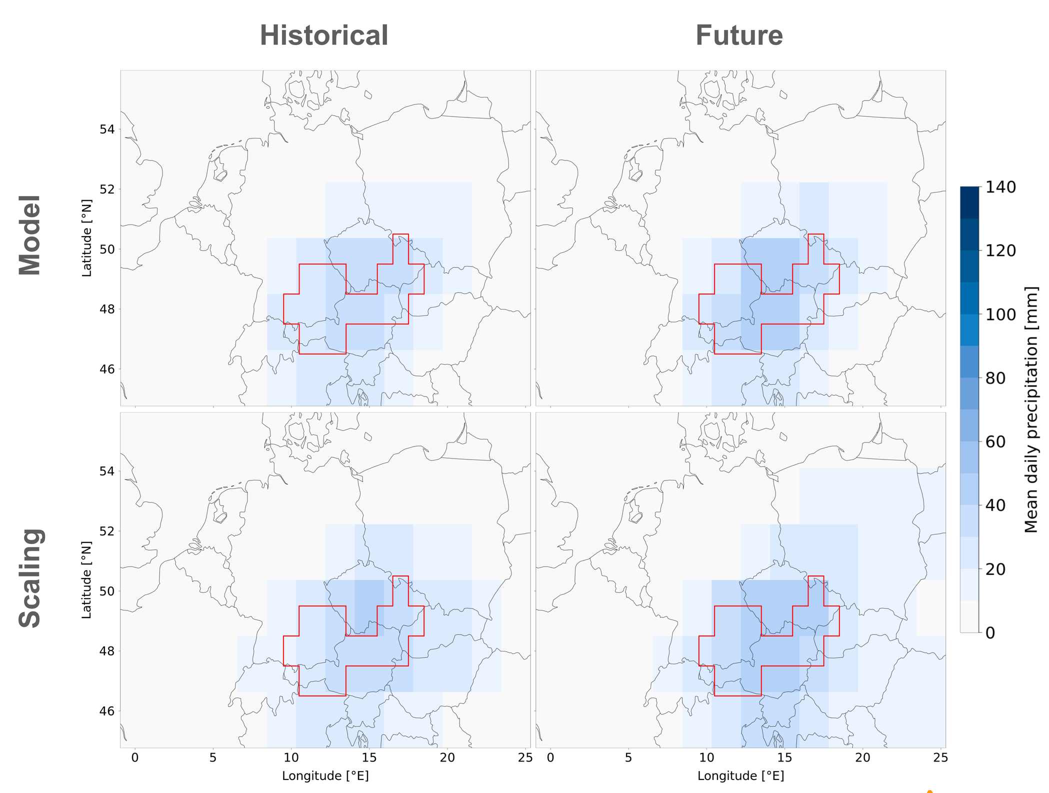


**Figure 4**
Composite of **daily 100-year precipitation events** over the Danube catchment from the MPI-ESM1-2-LR for **(left)** the historical climate, **(mid)** a warmer climate and **(right)** its **projected changes** from **(upper row)** the original model data and **(lower row)** the scaling relation.

- **Test suitability of the diagnostic** through comparison of extreme event composites
- **Scaling relation reproduces events and projected changes** (for Danube) **very well**

- Comparison of separated dynamical changes and **synoptic composites** during extreme events **for MPI-ESM1-2-LR**
- **Increase of vertical velocity** as **expected from positive dynamical change**
- **Synoptic situation** in a warmer period **is similar** to the historical, but with **slightly weaker** upper-level **cut-off low** and **surface cyclone**
- As expected, the **atmospheric water vapour content increases**, …

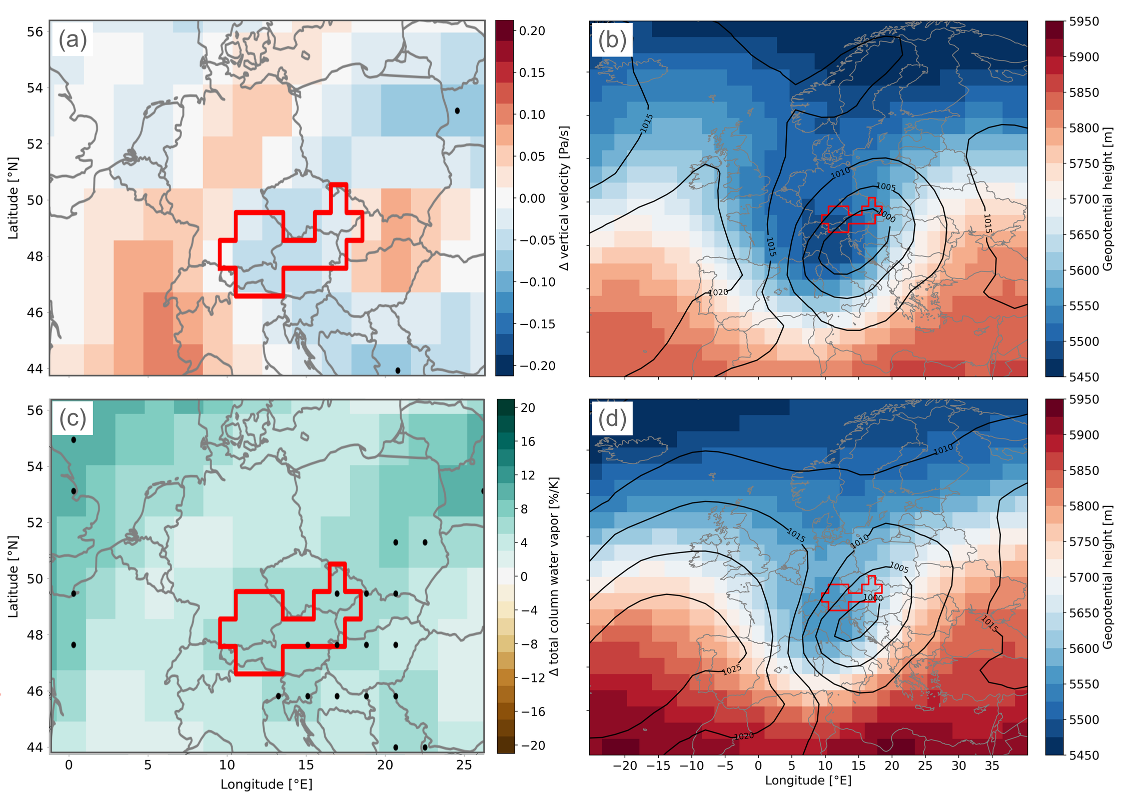


**Figure 6**
Projected changes of the **(a) vertical velocity** at 700 hPa and **(c) total column water vapour** and composites of the **geopotential height** at 500 hPa and **sea level pressure** (contours) during extreme events in **(b)** the historical and **(d)** a warmer climate period, all for Danube events of the **MPI-ESM1-2-LR**.

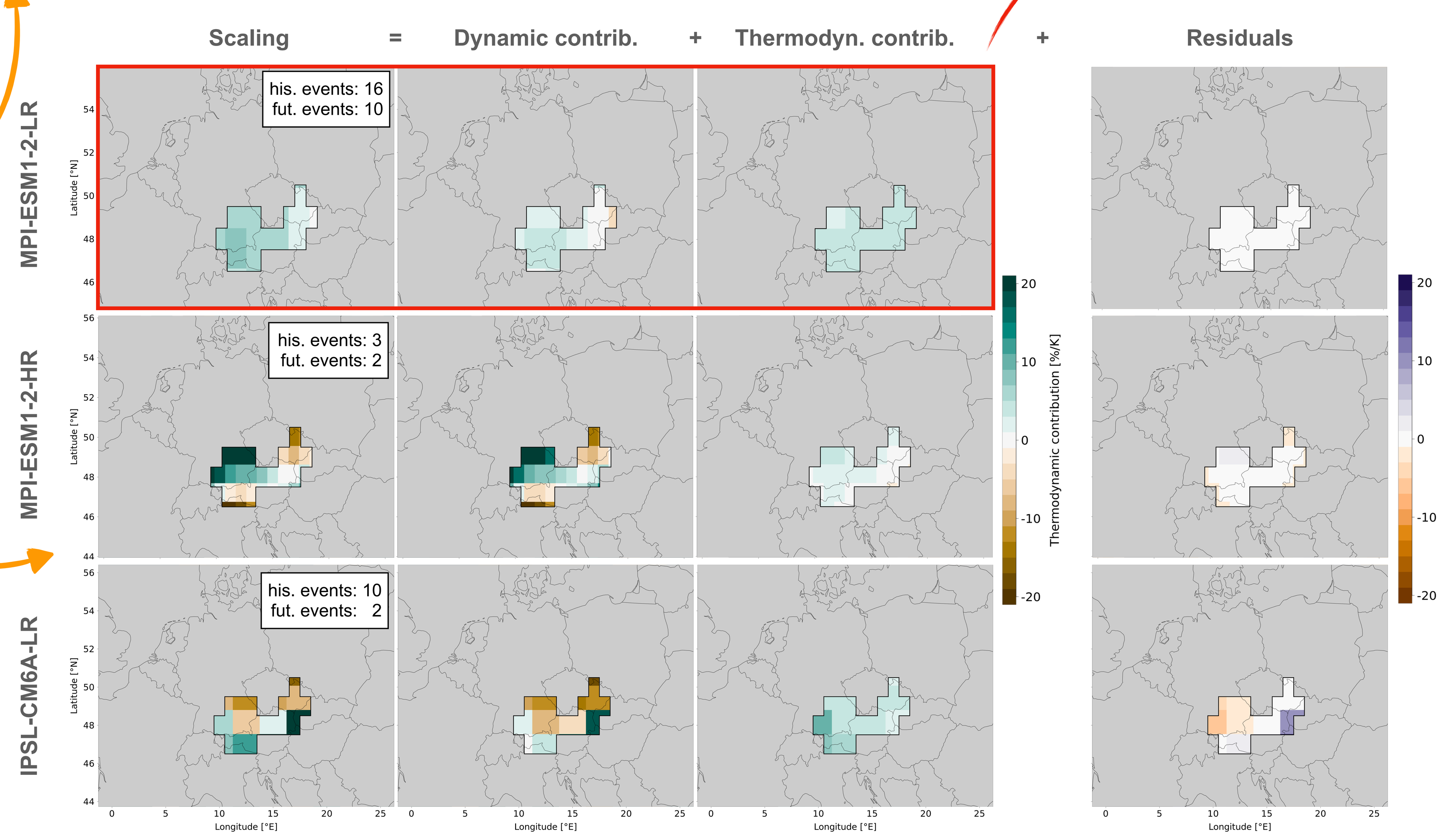


**Figure 5**
**(1. column)** scaling diagnostic of **projected changes** of daily 100-year precipitation events over the Danube catchment and the resulting **(2. column)** dynamic and **(3. column)** thermodynamic contributions and **(4. column)** the residuals for the **(upper row) MPI-ESM1-2-LR**, **(middle row)** MPI-ESM1-2-HR and **(lower row)** IPSL-CM6A-LR models.

- MPI-ESM1-2-LR: **similar contributions**, slightly more variable in dynamic than thermodynamic contribution
- MPI-ESM1-2-HR & IPSL-CM6A-LR: rather homogeneous **increase in** atmospheric **water vapour capacity** with **locally modified precipitation intensity** by dynamical processes
- **More models have to be analysed** in order to evaluate the inter-model variance correctly, as **MPI-ESM1-2-HR & IPSL-CM6A-LR** are **not** considered **robust** (due to event number)

- … **but is not distributed equally** over vertical levels
- Lower tropos-phere: slight **moisture increase**, especially over western parts, **potentially decreasing vertical stability** over this area

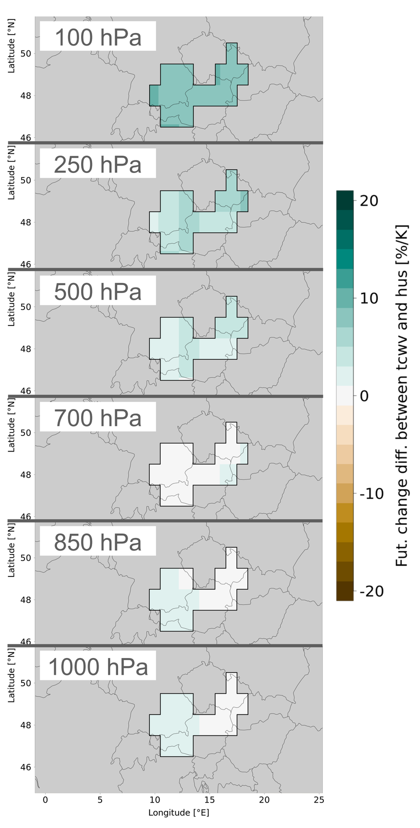


**Figure 7**
**Difference** between the **projected relative changes** of **specific humidity** at six vertical levels and the projected changes of **total column water vapour**, for Danube events of the **MPI-ESM1-2-LR**.

## CONCLUSION

- **No seasonal change but significant intensification** of 100-year precipitation events over Central Europe **in all individual global climate models**
- Answer to RQ 1: **uncertain intensification rates and spatial patterns** among climate models due to different event numbers and model physics
- Answer to RQ 2: uncertainties arise from **different dynamic contributions** among the climate models that can **not simply be explained by an altered synoptic circulation** but rather in combination with a **decreased vertical stability**

### References

- O'Gorman, P. A. and Schneider, T. (2009). The physical basis for increases in precipitation extremes in simulations of 21st-century climate change. *Proc. Natl. Acad. Sci. USA*, 106, 14773-14777.
- Pfahl, S., O'Gorman, P. A. and Fischer, E. M. (2017). Understanding the regional pattern of projected future changes in extreme precipitation. *Nature Clim. Change*, 7, 423-427.
- Ruff, F. and Pfahl, S. (2023). What distinguishes 100-year precipitation extremes over central European river catchments from more moderate extreme events?. *Weather Clim. Dynam.*, 4, 427-447.