Analysis of Cloud Water Scaling to Surface Moisture Fluxes from Fully Coupled Terrestrial Simulations

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Motivation and goals

- Land-atmosphere (L-A) coupling is important for understanding regional climate functioning and influencing hydrometeorological extremes such as droughts and heatwaves [1], but accurate determination of L-A coupling strength is difficult due to complex feedback loops and varying background atmospheric conditions.
- The role of clouds is often ignored or simplified in previous L-A coupling studies, and the non-linear control of evapotranspiration (ET) on cloud formation and convection formation is not well understood [2].
- **The study aims to diagnose the feedback between surface moisture fluxes, boundary layer processes and cloud water under different atmospheric conditions in order to improve our understanding of the L-A coupling based on simulations with a fully coupled regional climate system model.**

Simulation data and methods

1. Simulation Data:

- Model: Regional fully-coupled Terrestrial Systems Modelling Platform [3] (**TSMP**).
- **TSMP**: coupled model system, COSMO (atmosphere) + CLM (land surface) + ParFlow (surface and subsurface hydrology).
- Setup: Dynamical downscaling of ERA5 reanalysis with SST prescribed; one-way single nest
- Time period: 1979 - 2021; analysis for warm season (JJA).

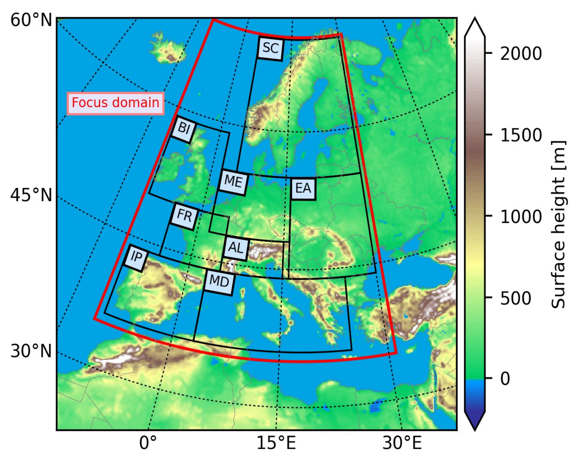

Fig. 1. Map of EURO-CORDEX (red box); Analysis focus on eight PRUDENCE regions as shown in black boxes.

2. Theoretical background:

- Moisture balance at cloud layer:

$$\frac{\Delta TQC}{\Delta t} \cong -\int_{z_s}^{z_b}\left(\rho \boldsymbol{v}\cdot\nabla q + \frac{\partial F^q}{\partial z}\right)dz$$

changes in total cloud water

TQC: total cloud water (mm);
Zs: surface terrain height (m);
v: horizontal wind speed (m/s)
Zb: cloud base height (m);
F: vertical turbulent flux (kg/m s^2);
q: specific humidity (kg/kg)

Cloud formation microphysics:

$$\frac{\partial q^c}{\partial t} \cong A_{q^c} + S_c - S_{au} - S_{ac}$$

changes in cloud water content

qc: cloud water content (kg/kg);
Aqc: advection of cloud water (kg/kg)/s;
Sc: condensation rate (kg/kg)/s;
Sau: autoconversion rate (kg/kg)/s;
Sac: accretion rate (kg/kg)/s

- The changes in cloud water are linked to a local source due to vertical turbulent transport (driven by surface ET) and a remote source due to atmospheric moisture flux dynamics (AMFD) (driven by moisture flux convergence/divergence (TCON/TDIV_HUM)).

3. Dataset classification:

- **Baseline** regime: Select cloudy days with low-level cloud cover > 10% at grid point scale;
- **Dry/Wet** regime: For cloudy days, classify calendar days at each grid point as **Dry** or **Wet** based on daily total precipitation equal to 0 mm/day or larger than 0 mm/day;
- **AMFD** regime: For cloudy days, classify calendar days at each grid point into **Low**, **Medium**, and **High** regimes by calculating the 33rd and 66th percentiles of AMFD over vertical column.

Evapotranspiration-cloud water dynamics coupling

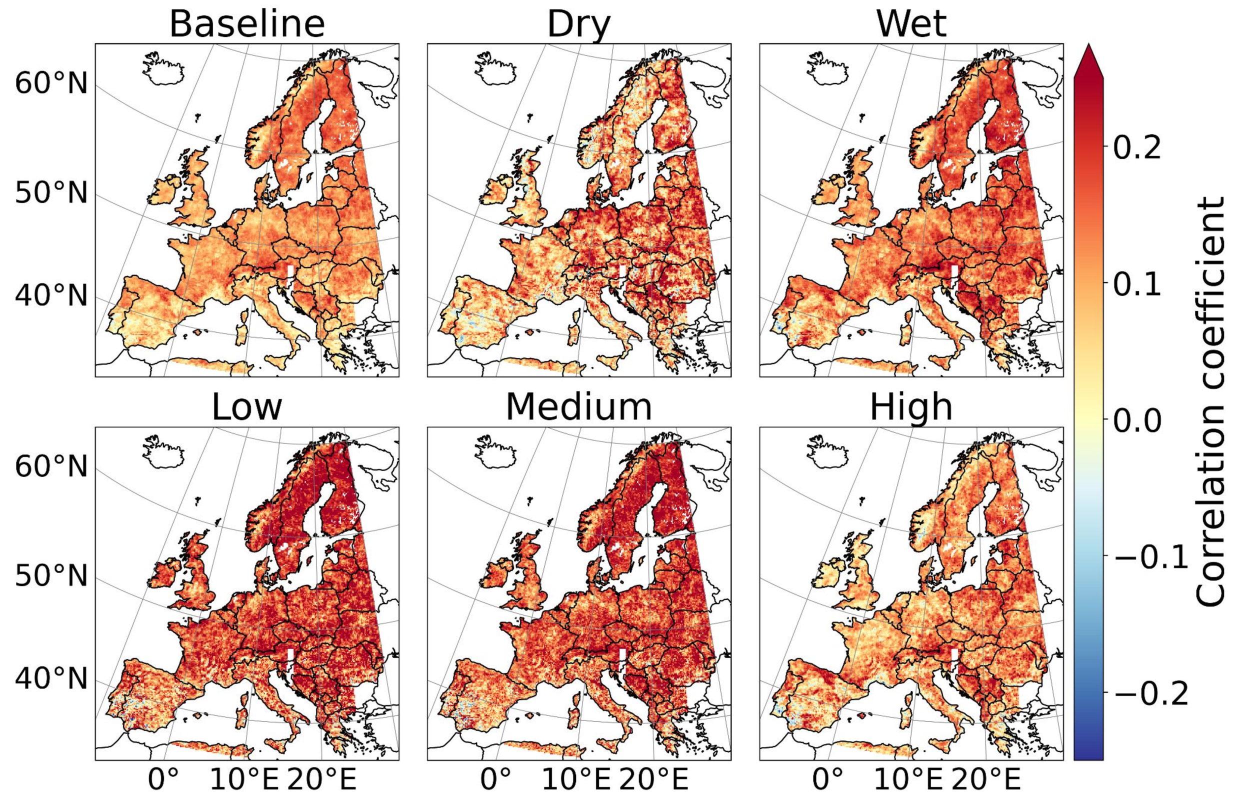

Fig. 2. Maps of Pearson correlation coefficients between ET and cloud water dynamics (ΔTQC/Δt) anomalies in JJA.

- The coupling strength is identified by the magnitude of Pearson correlation coefficient.
- ET positively coupled to cloud water dynamics (ΔTQC/Δt) as higher ET leads to more increase in cloud water.
- Strong coupling regions consistently located in northeast and south Europe over atmospheric regimes.
- Decreasing correlation coefficients from **High** to **Low** AMFD highlights the role of advection in masking local coupling.

Evapotranspiration-cloud water dynamics scaling

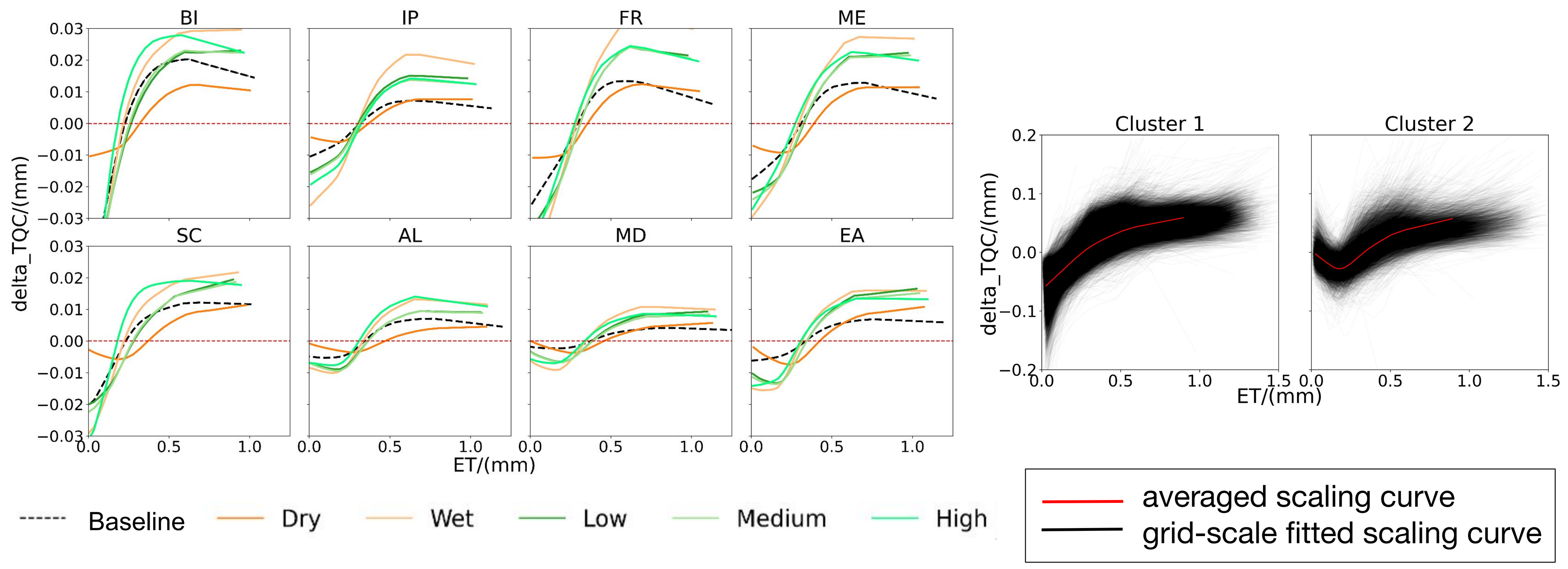

Fig. 3. **Left**: Scaling curves fitted by binned average and loose regression between ET and ΔTQC/Δt. The red dashed line indicates zero ΔTQC/Δt; **Right**: Two types of scaling curves calculated using K-means clustering algorithm.

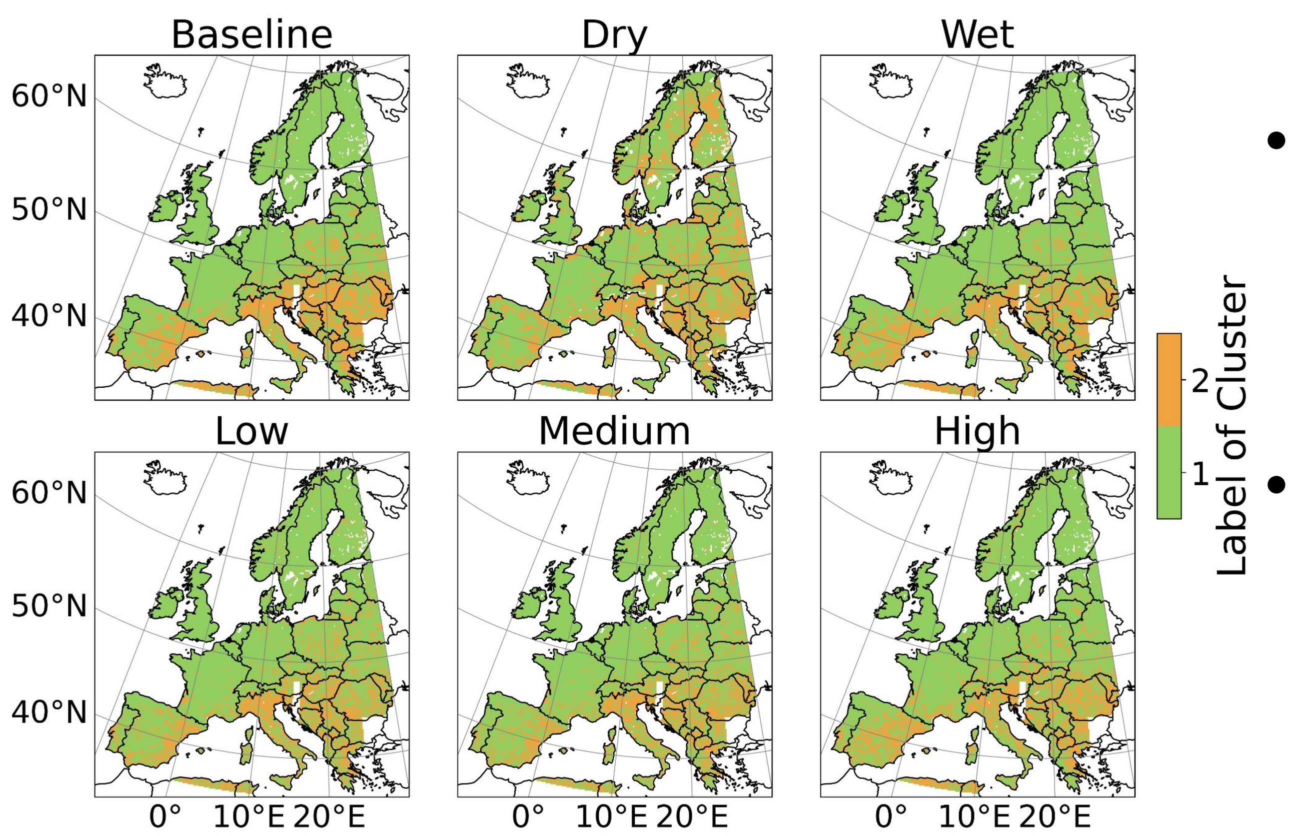

Fig. 4. Spatial distribution of the two types of scaling curves.

- Two types of positive scaling relationships can be identified: Cluster 1 represents a 'logarithmic' scaling; Cluster 2 represents a 'hook' scaling.
- The local **Dry/Wet** conditions determine the type of scaling between ET and ΔTQC/Δt globally as the hook scaling favors the water-limited region in the southern Europe.

Quantile phase diagnosis between ET and AMFD

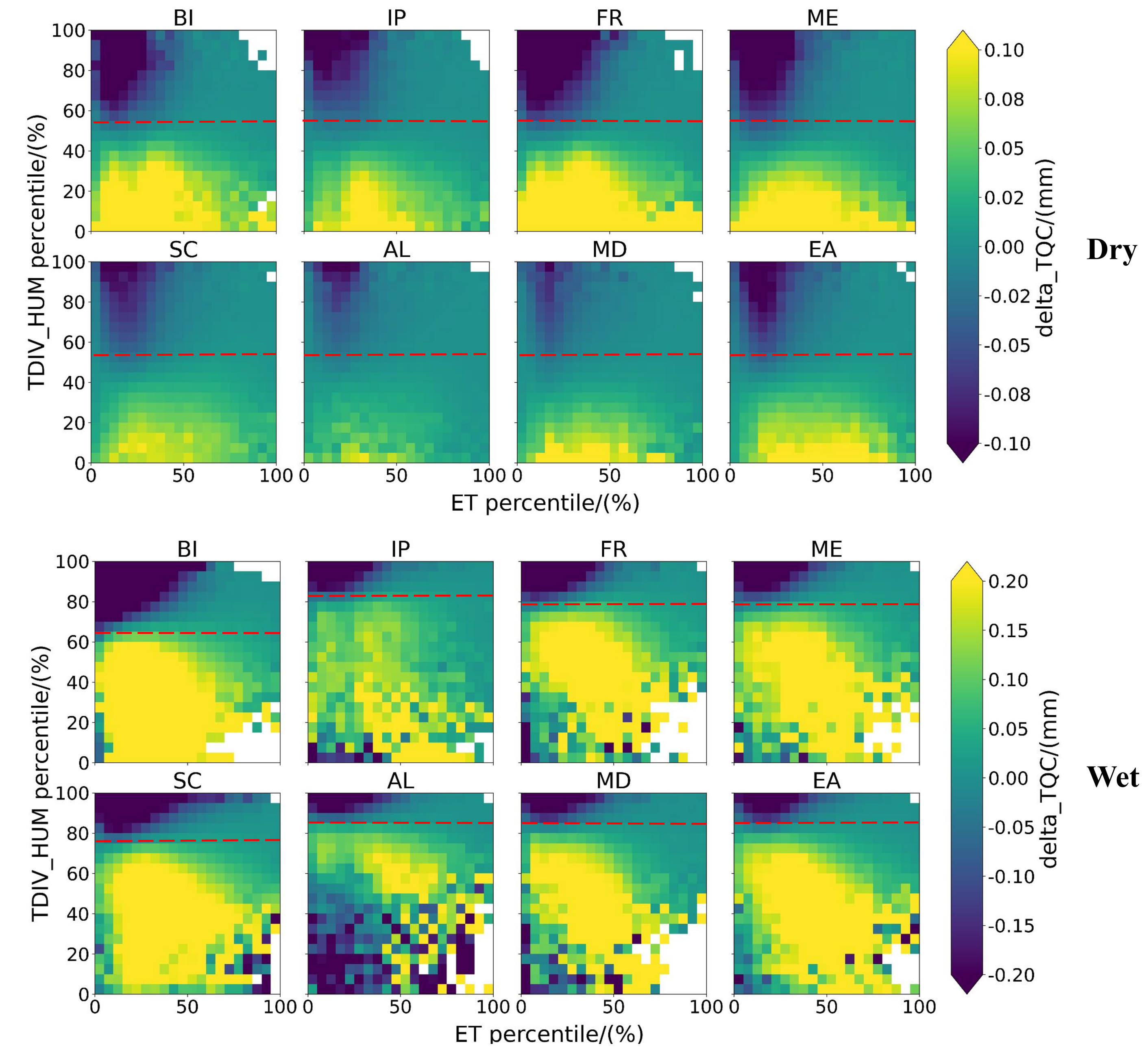

Fig. 5. Quantile phase plots by calculating the mean of ΔTQC/Δt in each 10 percentile bin of ET and AMFD. A low percentile of TDIV_HUM represents strong convergence while a high percentile represents large divergence. The red dashed line indicates the percentile with zero AMFD.

- TCON_HUM contributes positively to the increase in ΔTQC/Δt, while strong TDIV_HUM can lead to a significant TQC depletion, which may mask the positive control of ET on ΔTQC/Δt when ET is in the low percentile range.
- ET-ΔTQC/Δt scaling varies locally with the type of AMFD such that the hook scaling occurs under TDIV_HUM, whereas the monotonically increasing scaling occurs under TCON_HUM.

Conclusions

- Predominantly positive ET-ΔTQC/Δt coupling and scaling relationships highlight the role of surface moisture flux in affecting cloud moisture dynamics.
- AMFD can reduce the strength of the local L-A moisture flux coupling by enhancing remote moisture advection, while both local dry/wet conditions and AMFD strength can determine the type (cluster 1 or 2) of the ET-ΔTQC/Δt scaling relationship.
- Coupling hotspots between surface moisture flux and cloud moisture in Europe are mostly located in water-limited regions of Eastern Europe and the Mediterranean region.

References

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