Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Intensification of climate extremes through physical feedbacks and thresholds

Overview and role within climate change

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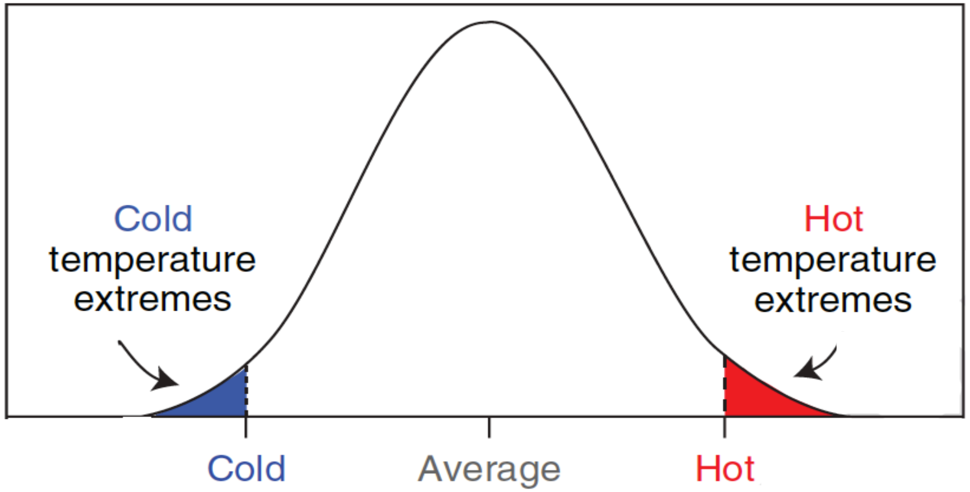
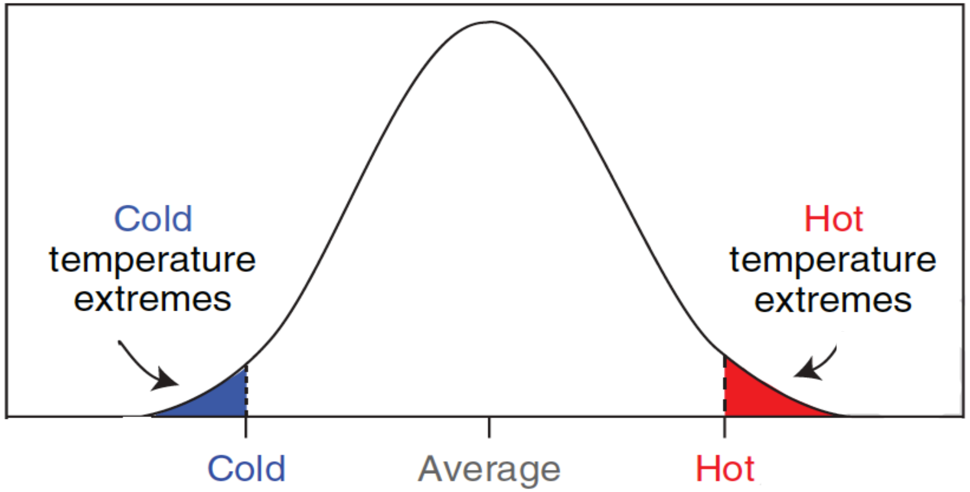
How can feedbacks & thresholds affect extremes?



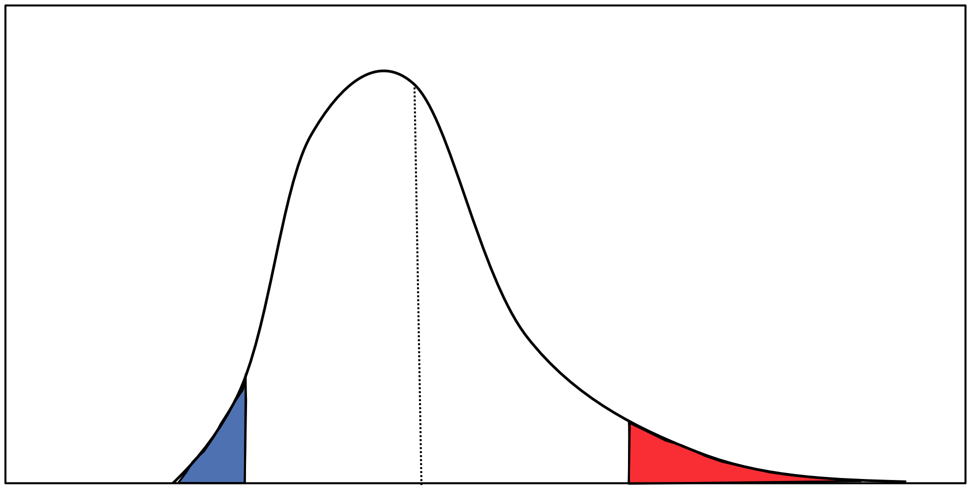
Gaussian distribution

(CCSP report 2008)

How can feedbacks & thresholds affect extremes?



Gaussian distribution



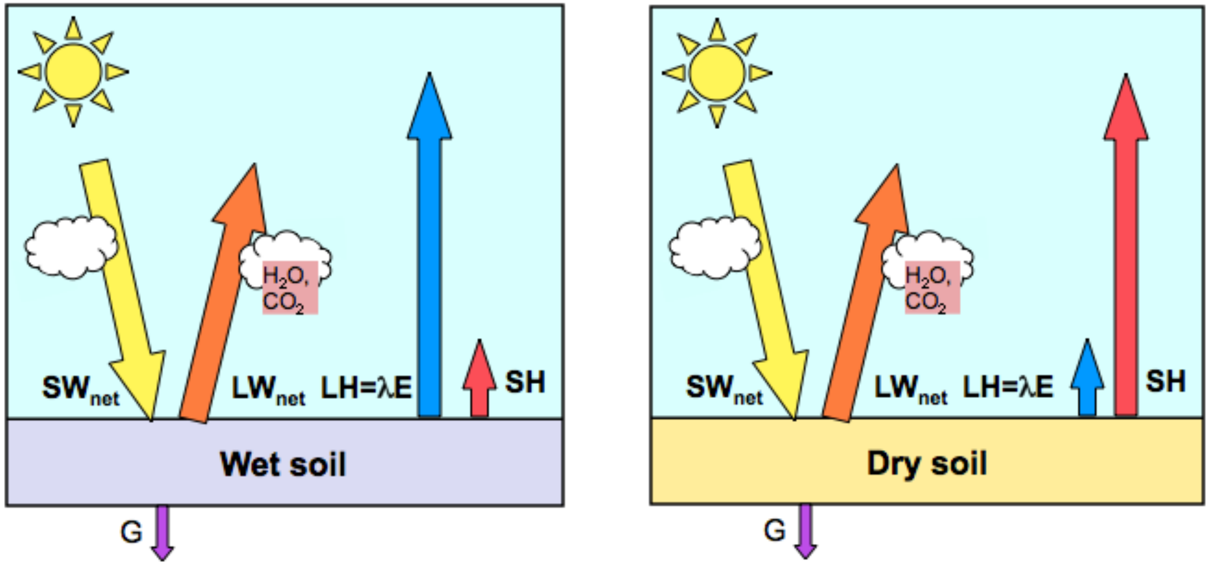
Skewed distribution

Feedbacks or thresholds tend to favor extremes at one end of the distribution, e.g. hot extremes

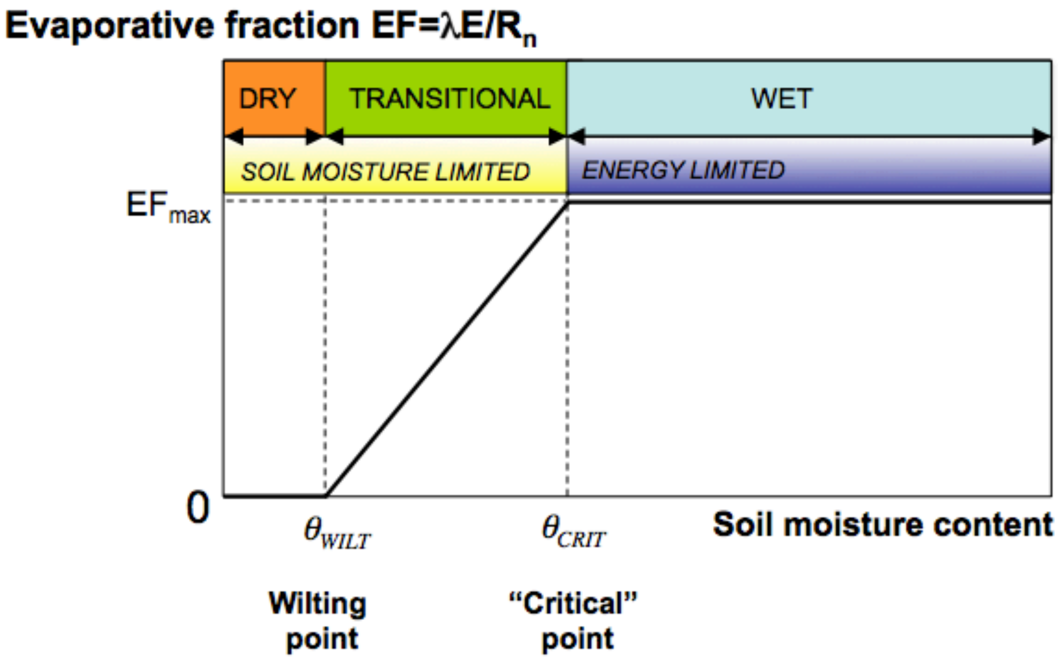
Processes leading to non-linear effects on extremes

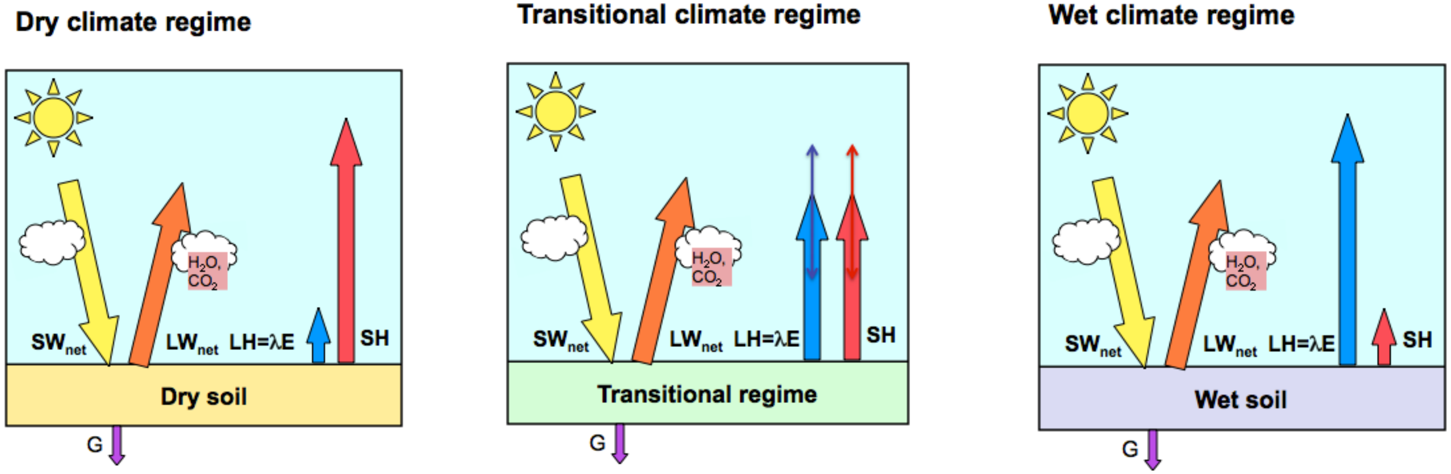
Land surface conditions typically can lead to such non-linear effects

- **snow vs non-snow covered areas**
- **dry vs humid soils**



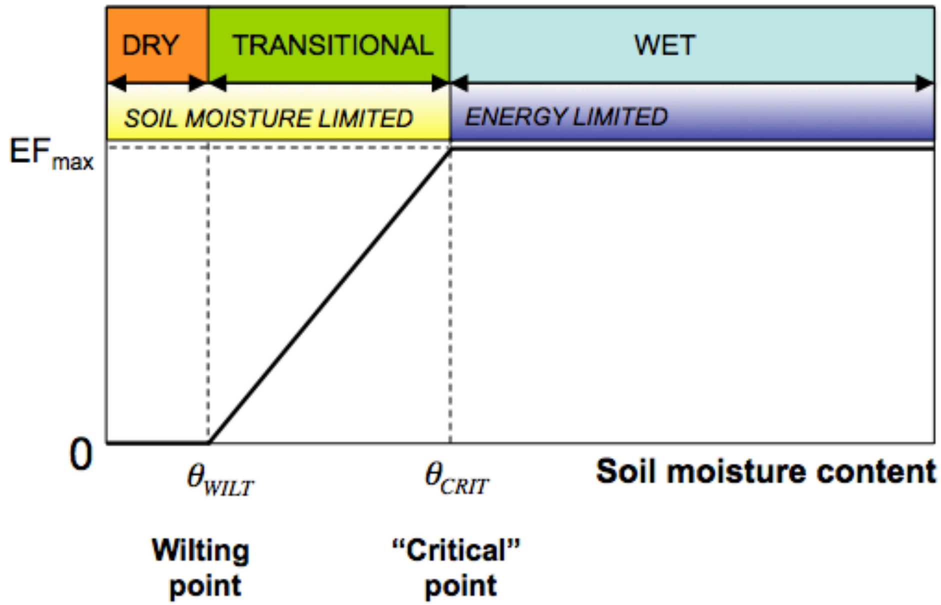
Soil moisture – temperature feedbacks

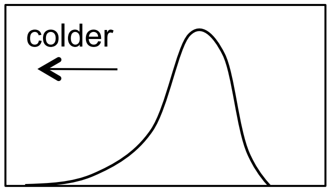


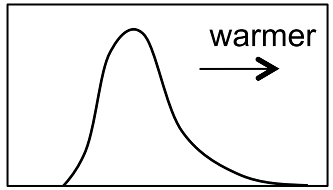


Soil moisture – temperature feedbacks

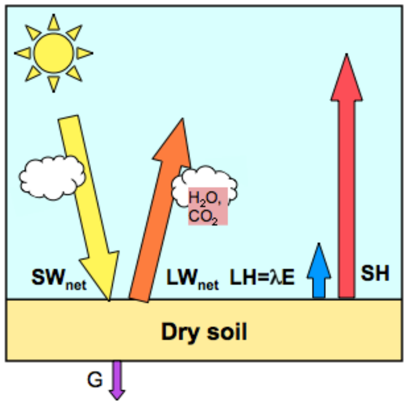
Evaporative fraction $EF=\lambda E/R_n$



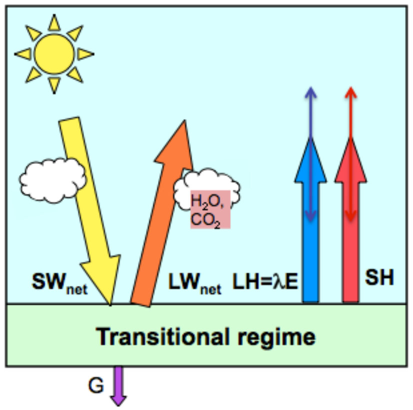




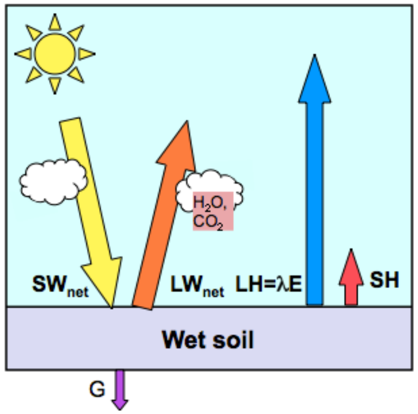
Dry climate regime



Transitional climate regime

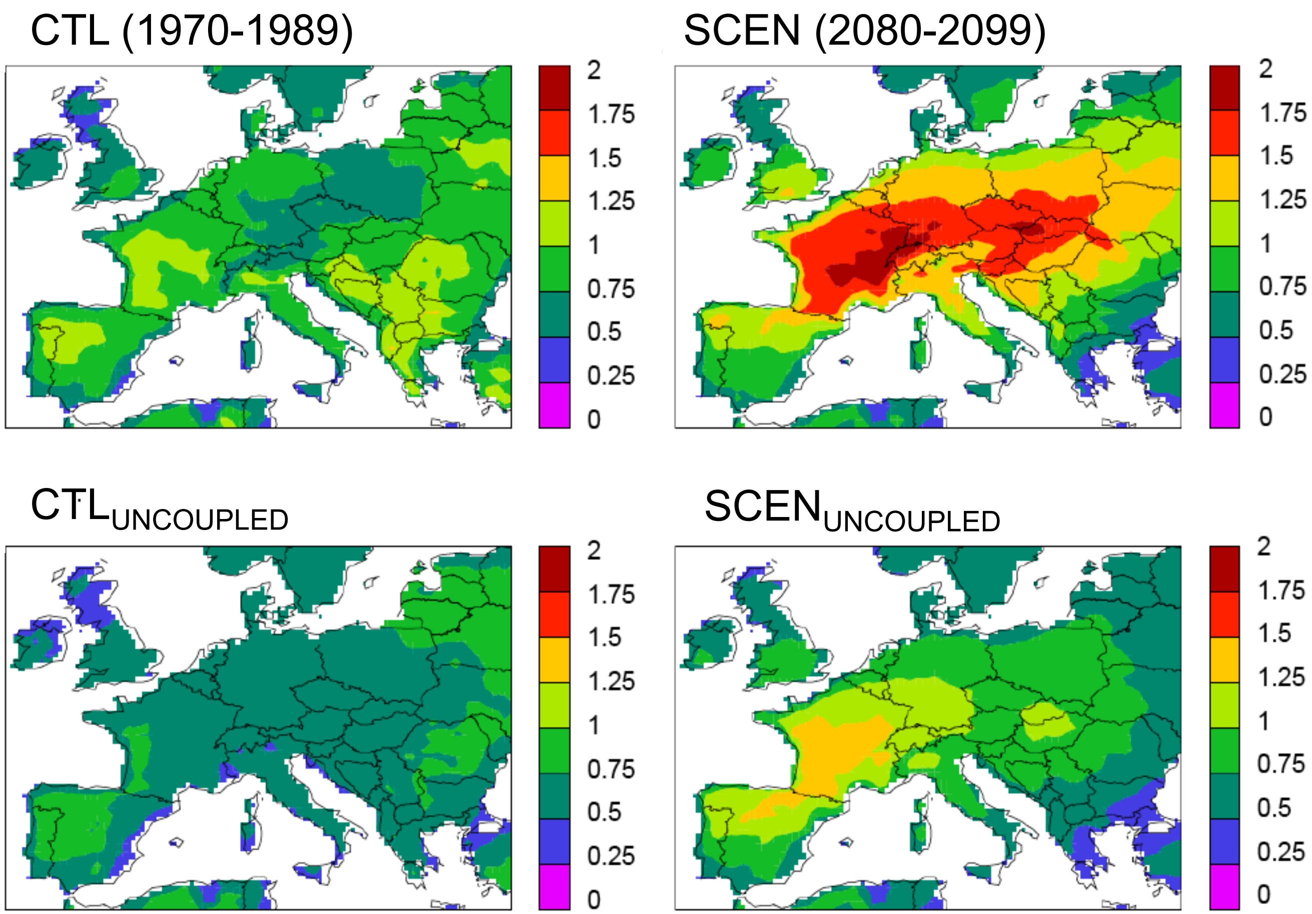


Wet climate regime



Soil moisture variability found to be a main driver for projected changes in temperature variability in Europe

Standard deviation of summer temperature, CHRM model



Interactive simulations (reference)

Simulations with soil moisture set to climatology ("uncoupled")

(Seneviratne et al. 2006, Nature)

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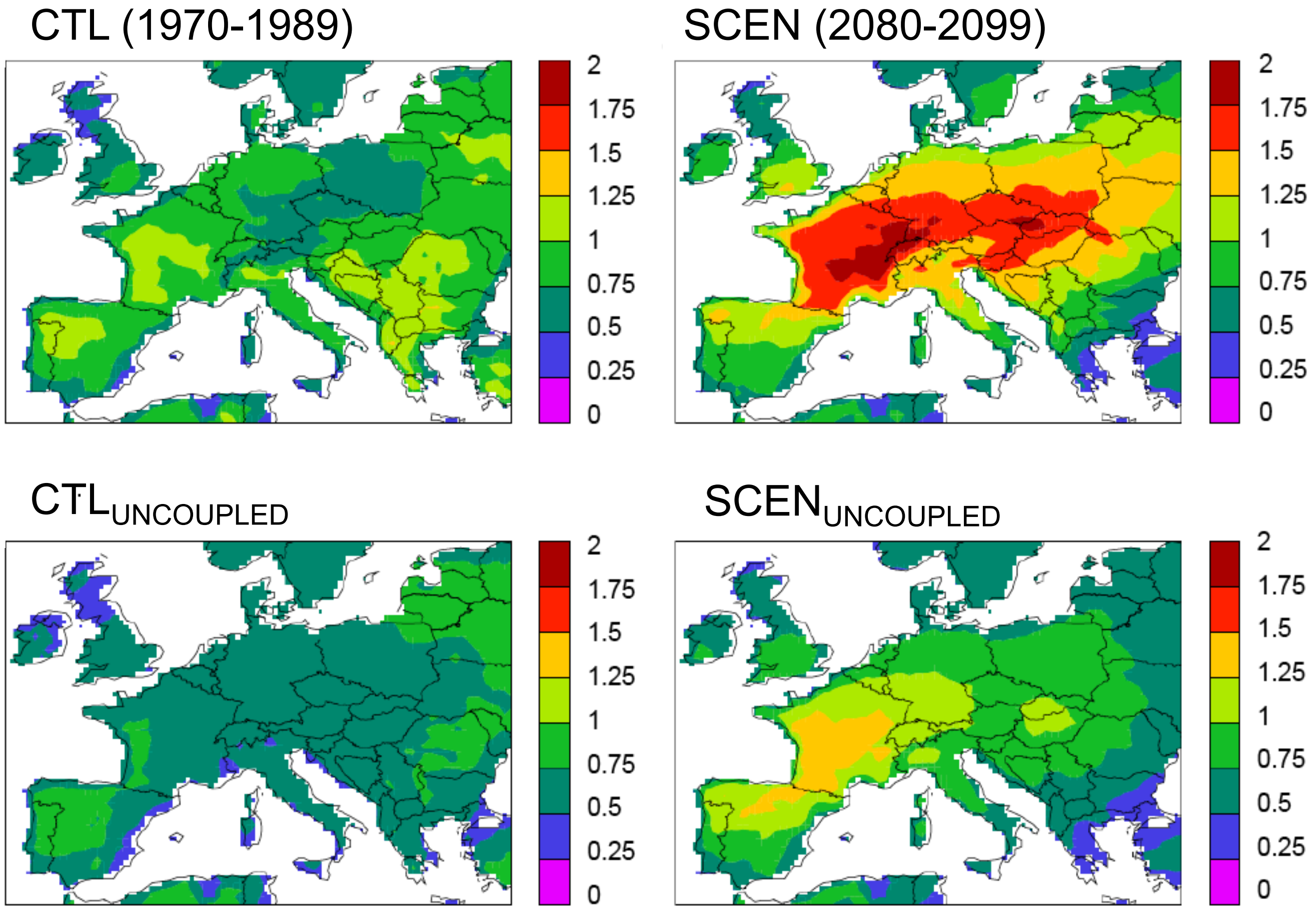
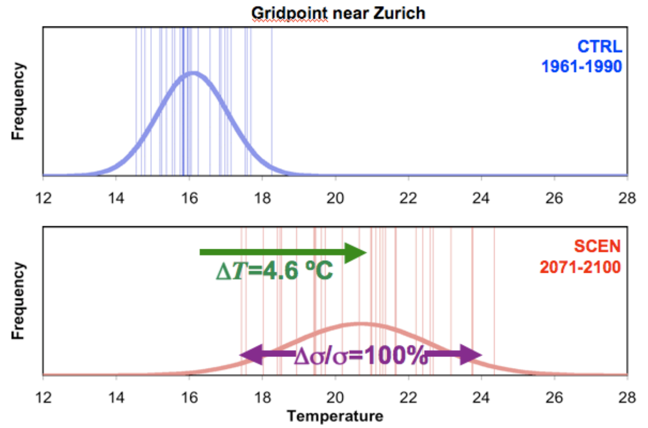


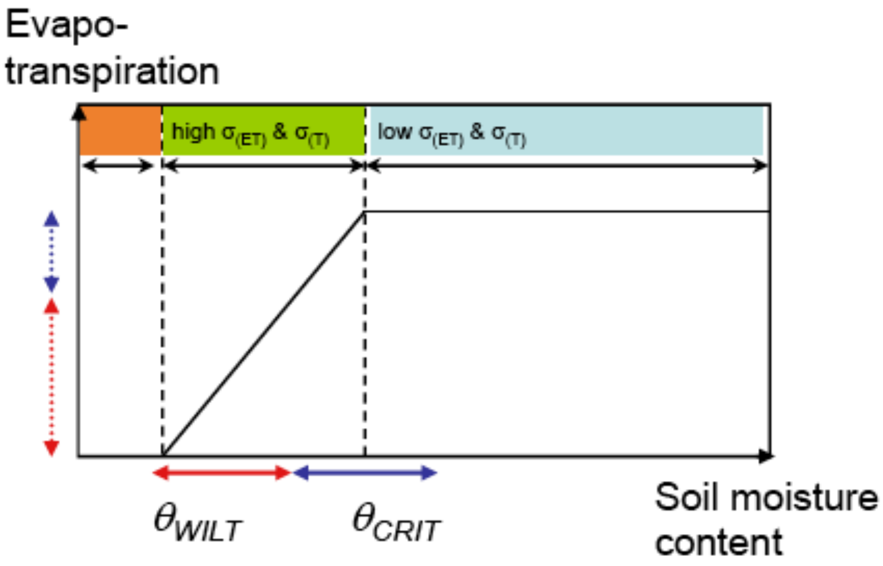


(Schär et al. 2004, Nature)

Simulations with soil moisture set to climatology ("uncoupled")

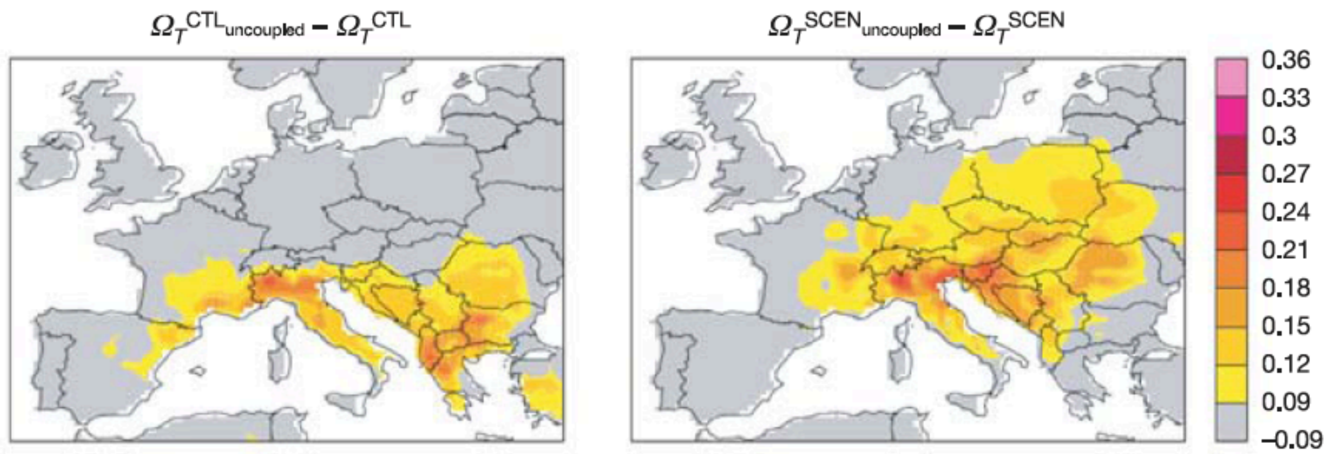
(Seneviratne et al. 2006, Nature)

Soil moisture-climate coupling and heatwaves in Europe



(Seneviratne et al. 2010, Earth-Science Reviews)

Shift in soil moisture regime is the driving mechanism for change in temperature variability



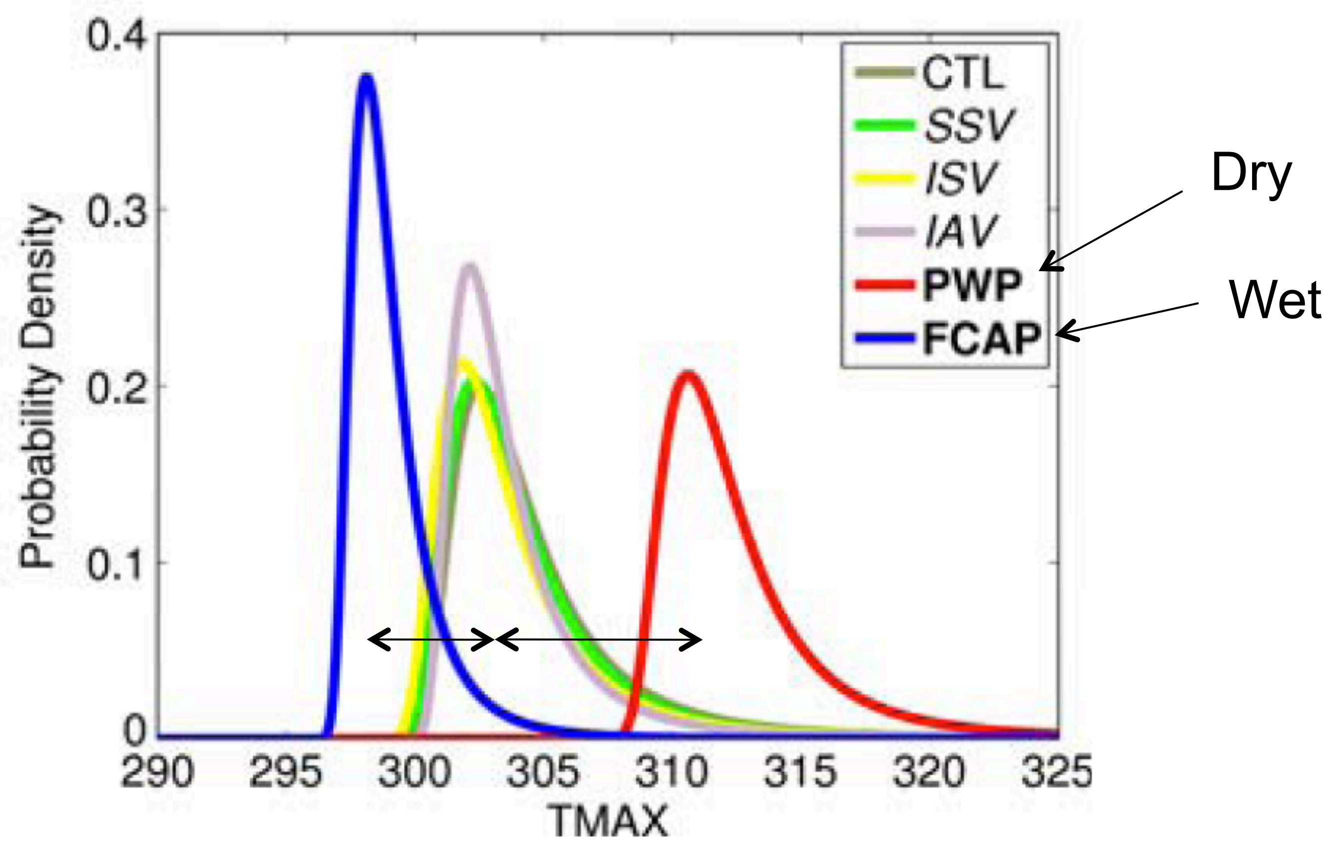
Soil moisture-temperature coupling estimated from diagnostic $\Delta\Omega$

(Seneviratne et al. 2006, Nature)

Asymmetric effects of soil moisture on extremes

Distribution of summer Tmax block maxima

RCM simulation with COSMO/CCLM (France, 1959-2006)



(Jaeger and Seneviratne, Climate Dynamics, 2011)

Evaluation with observations

Do observations confirm…

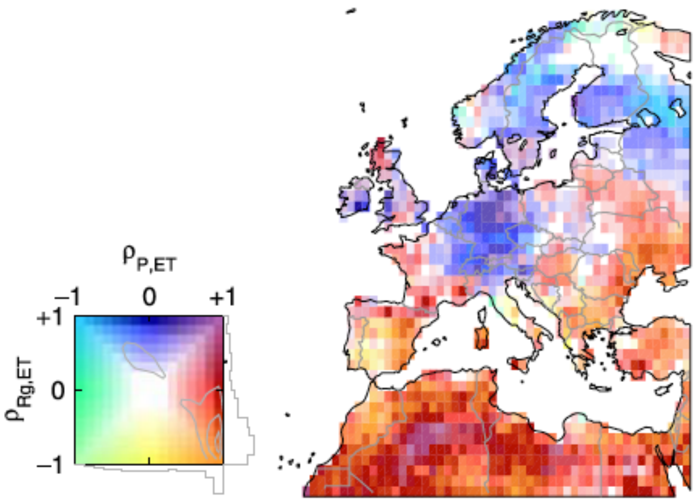
1) **… the geographical location of regions of strong soil moisture-atmosphere coupling?**

2) **… that soil moisture variability controls summer temperature variability (and the occurrence of hot extremes) in these regions?**

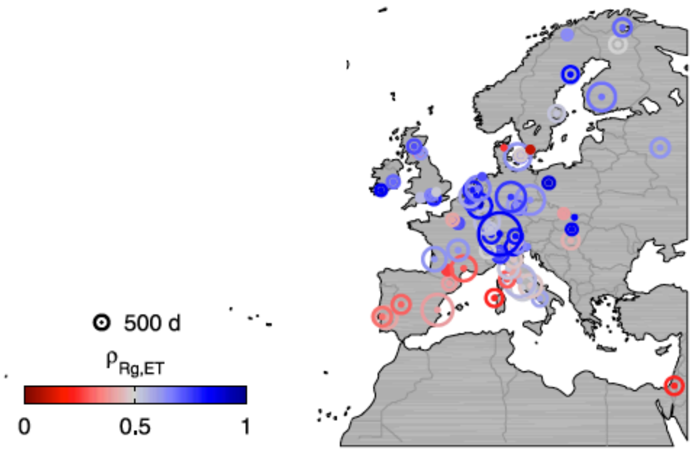
3) **…that these effects may be asymmetric?**

Regions of strong soil moisture-atmosphere coupling

Expected to be located in regions with soil moisture-limited evapotranspiration regimes



Correlation of yearly evapotranspiration with radiation and precipitation (GSWP-2 data)



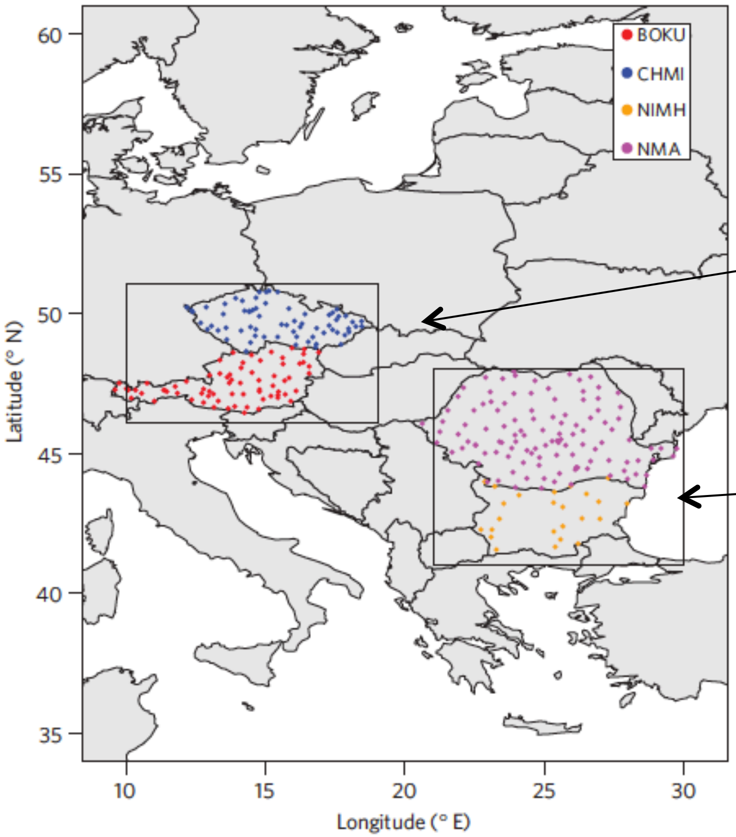
Correlation of daily evapotranspiration with radiation
(Fluxnet measurements)

(Teuling et al. 2009, GRL)

Role of soil moisture on hot extremes: Observations

Observational evidence for soil-moisture impact on hot extremes in southeastern Europe

Martin Hirschi[1,2]★, Sonia I. Seneviratne[1]★, Vesselin Alexandrov[3], Fredrik Boberg[4], Constanta Boroneant[5], Ole B. Christensen[4], Herbert Formayer[6], Boris Orlowsky[1] and Petr Stepanek[7]



Radiation-limited evapotranspiration regime

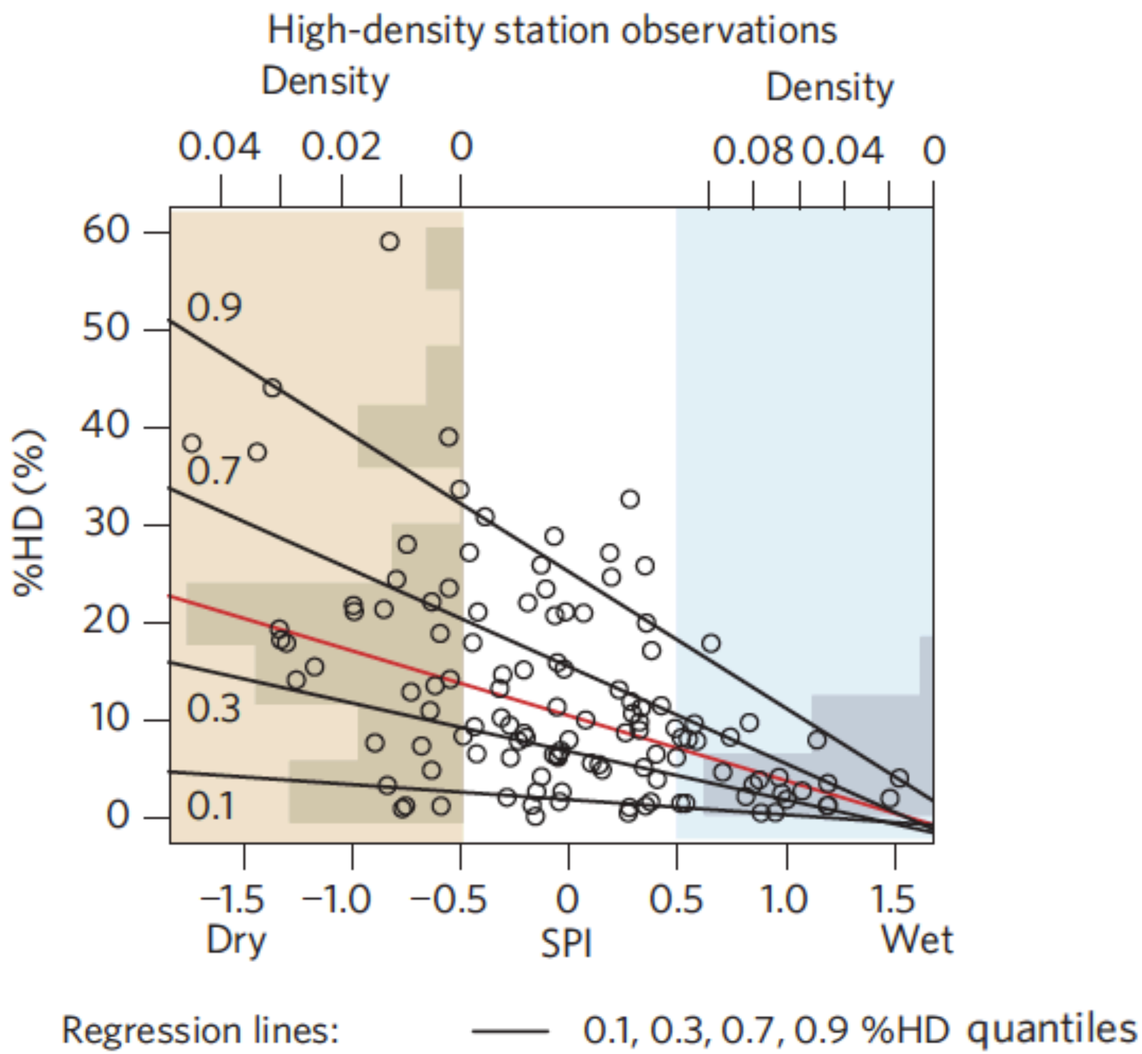
Soil moisture-limited evapotranspiration regime

(Hirschi et al. 2011, Nature Geoscience)

Role of soil moisture on hot extremes: Observations

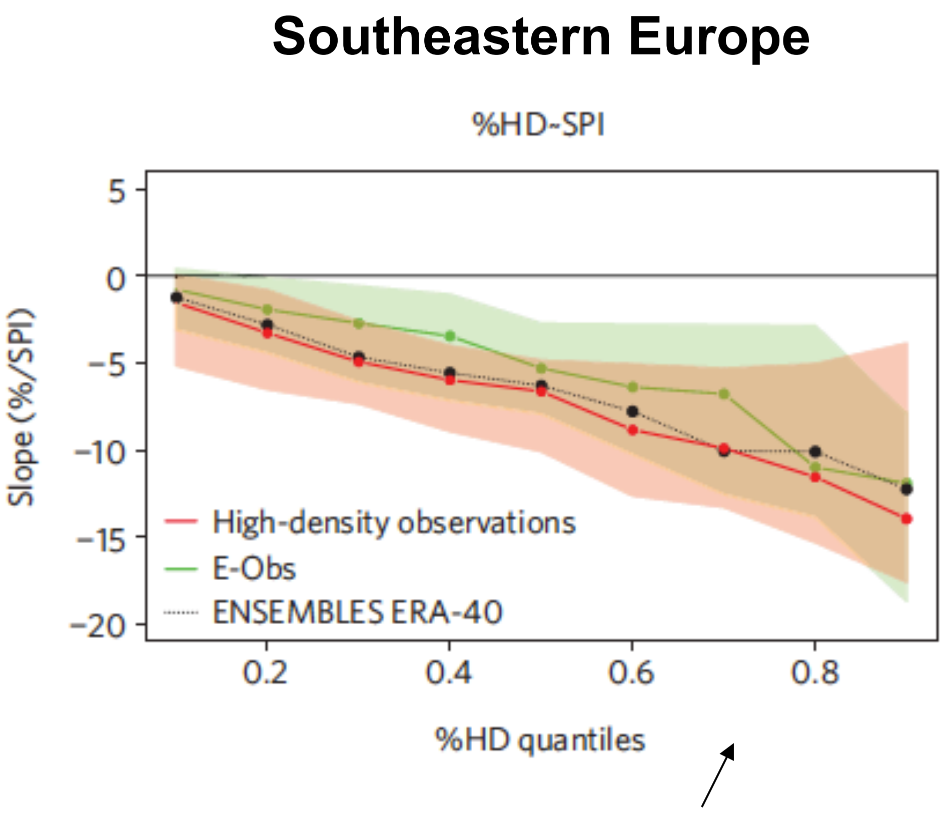
Analysis in Southeastern Europe

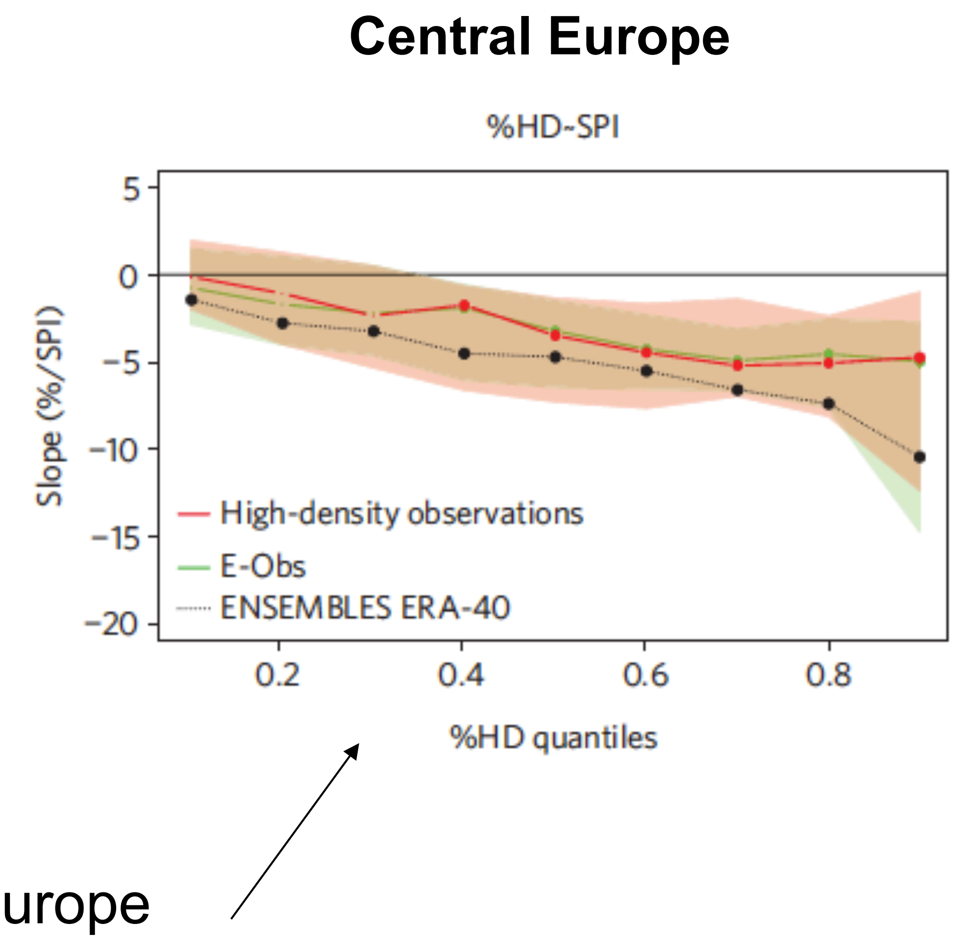
Quantile regression of percentage of hot days (%HD) with 6-month standardized precipitation index (SPI)



(Hirschi et al. 2011, Nature Geoscience)

Role of soil moisture on hot extremes: Observations





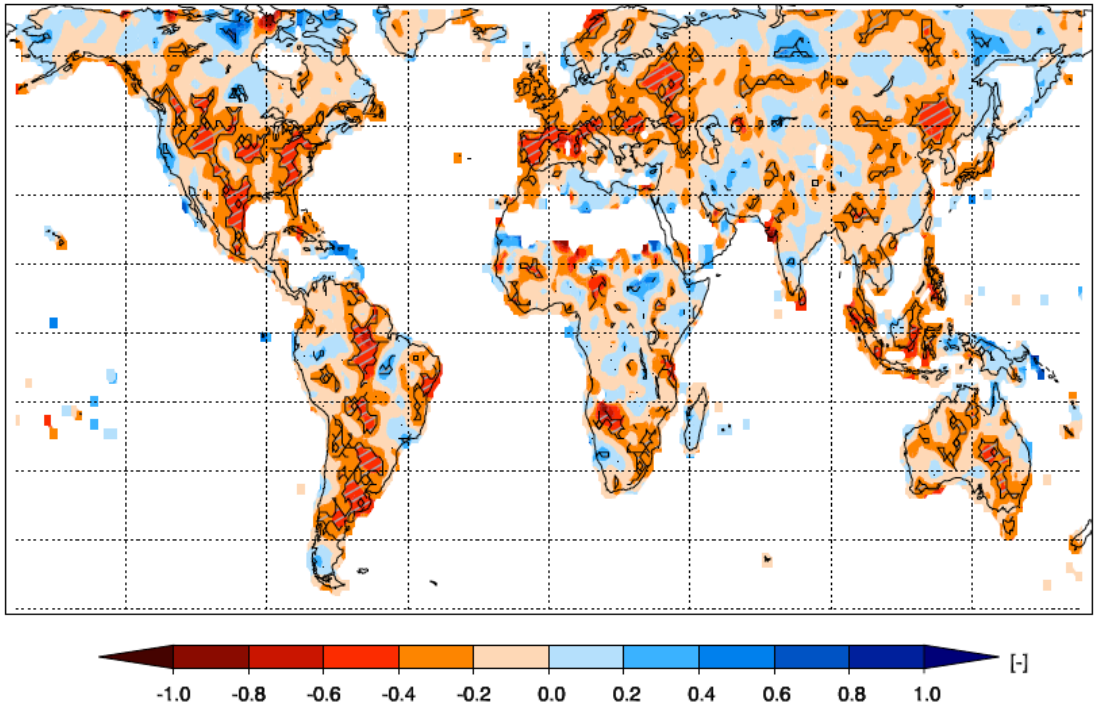
Substantially stronger effect in SE Europe

RCMs from ENSEMBLES perform fairly well
(but slight overestimation in C. Europe)

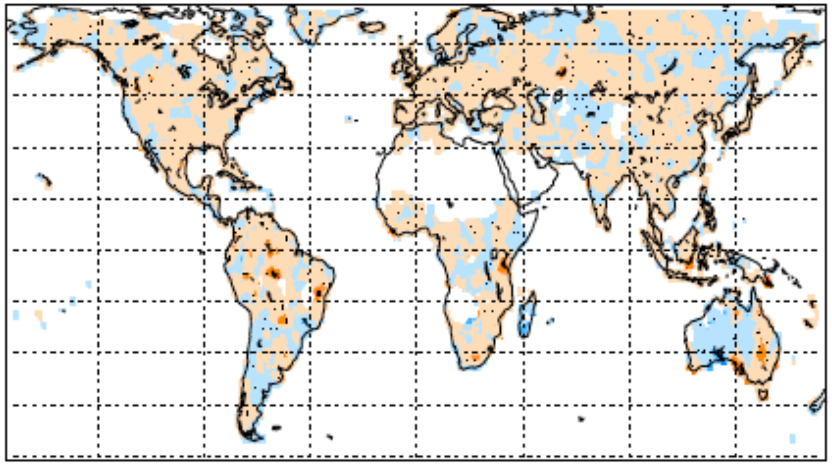
(Hirschi et al. 2011, Nature Geoscience)

Global analysis

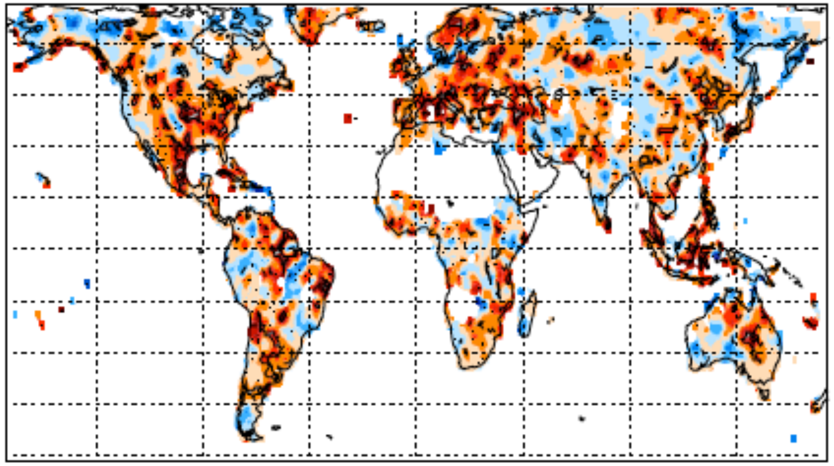
Correlation of #HD and preceding 3-mth SPI



10th percentile regression slope



90th percentile regression slope



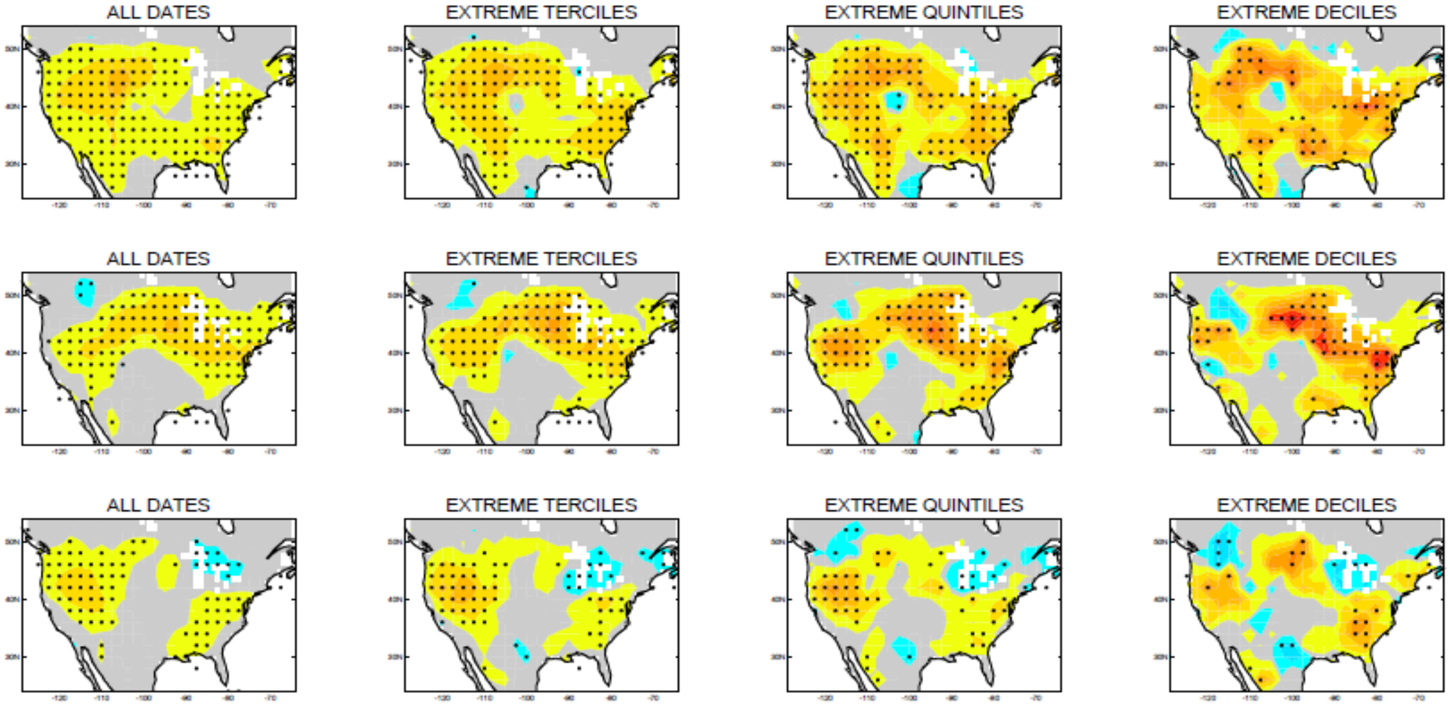
T°: ERA-interim
Precip: CRU

Analysis for regional hottest month

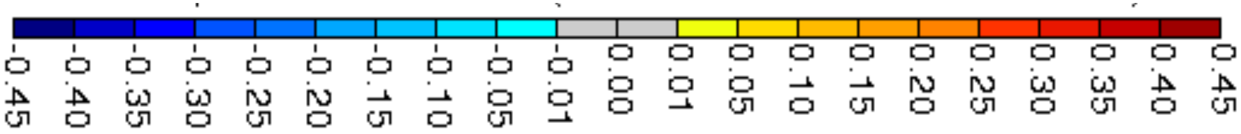
(Mueller and Seneviratne, in prep)

Temperature forecasts: Increase in skill due to land initialization (JJA) (conditioned on strength of local initial soil moisture anomaly)

	all points	Extreme terciles	Extreme quintiles	Extreme deciles
16-30 days				
31-45 days				
46-60 days				



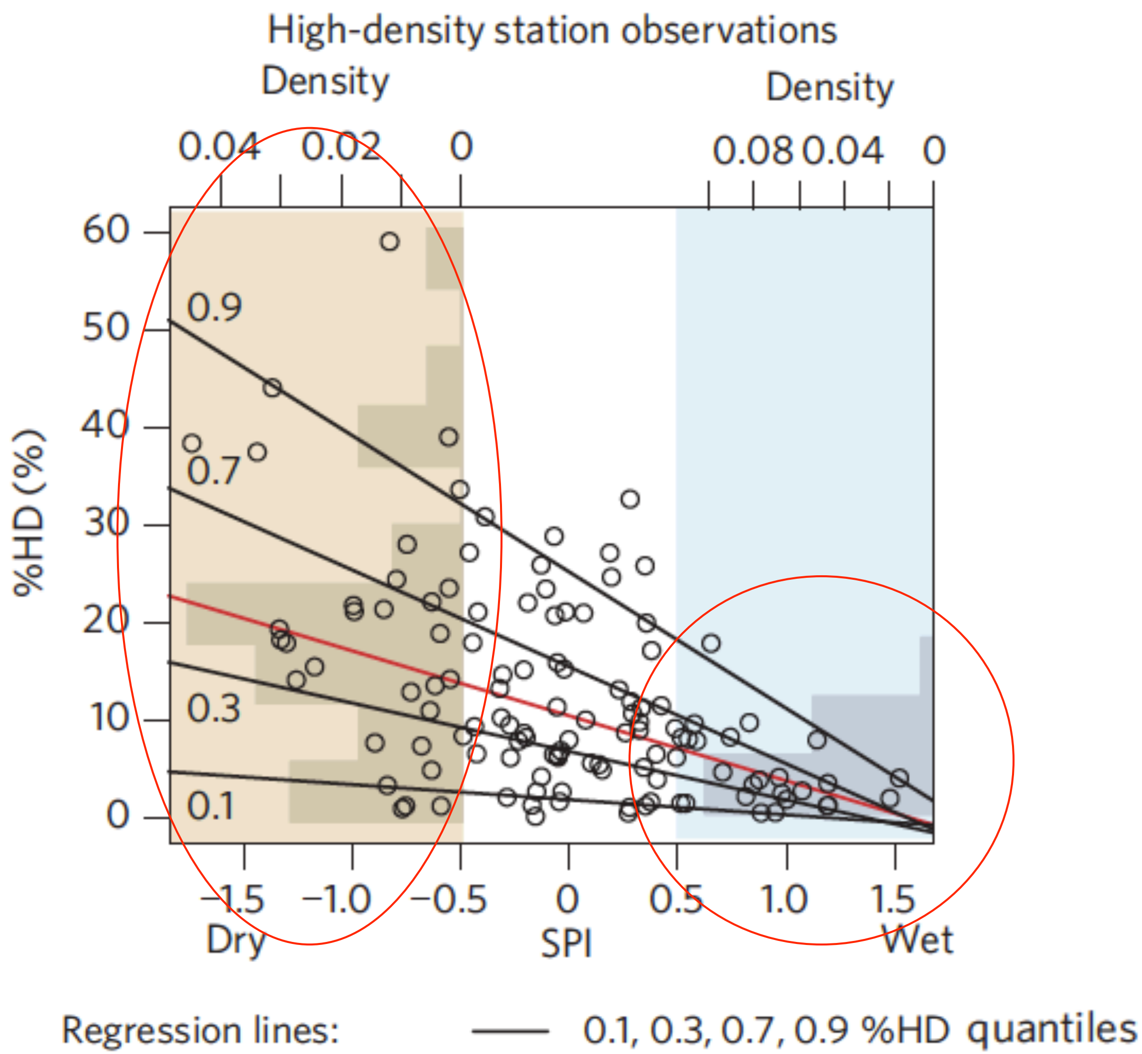
Forecast skill: r^2 with land ICs vs r^2 w/o land ICs



(Koster et al. 2010, GRL)

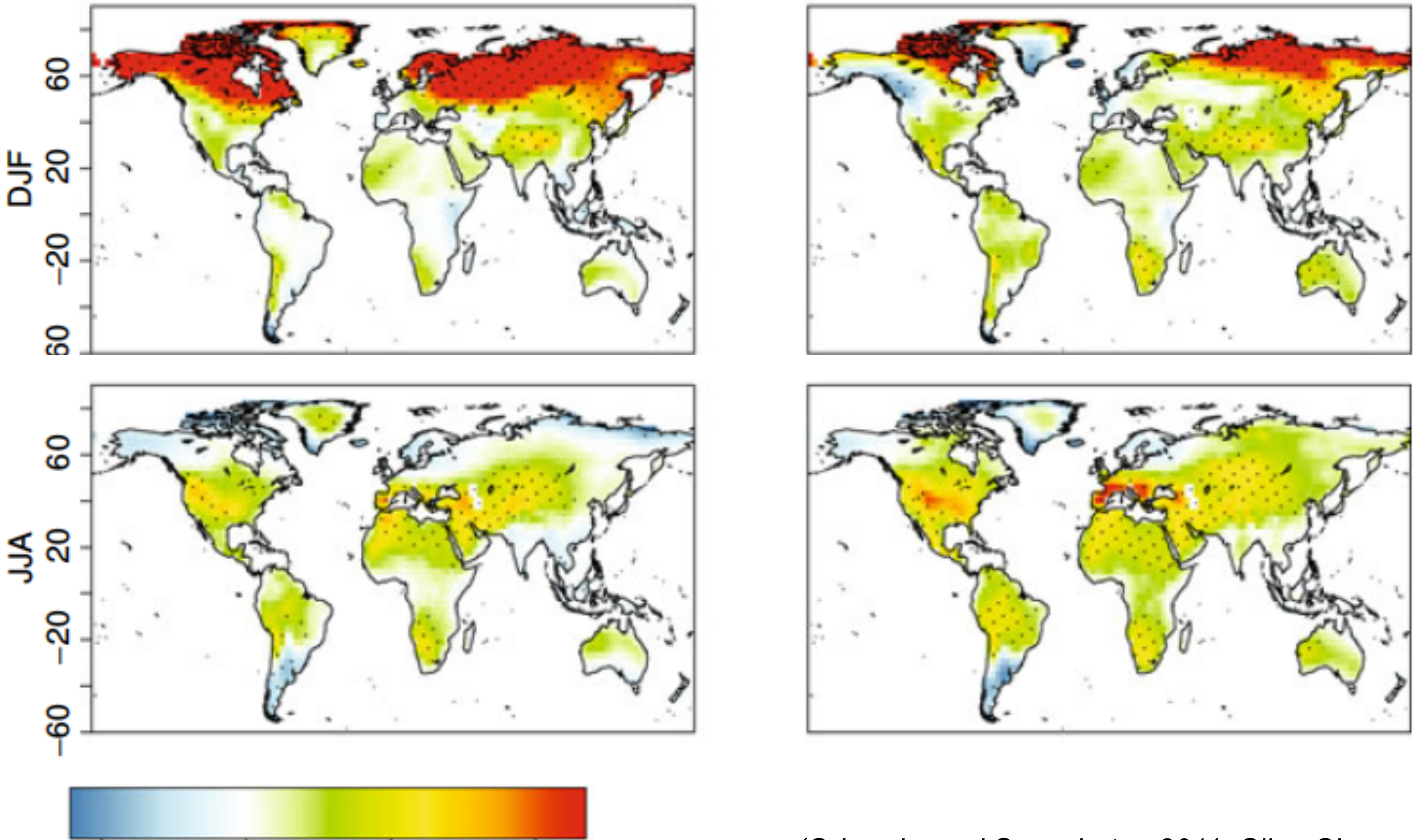
Role of soil moisture on hot extremes: Observations

Possibly more skill for hot extremes after wet vs dry conditions (dry soil necessary but not sufficient condition)



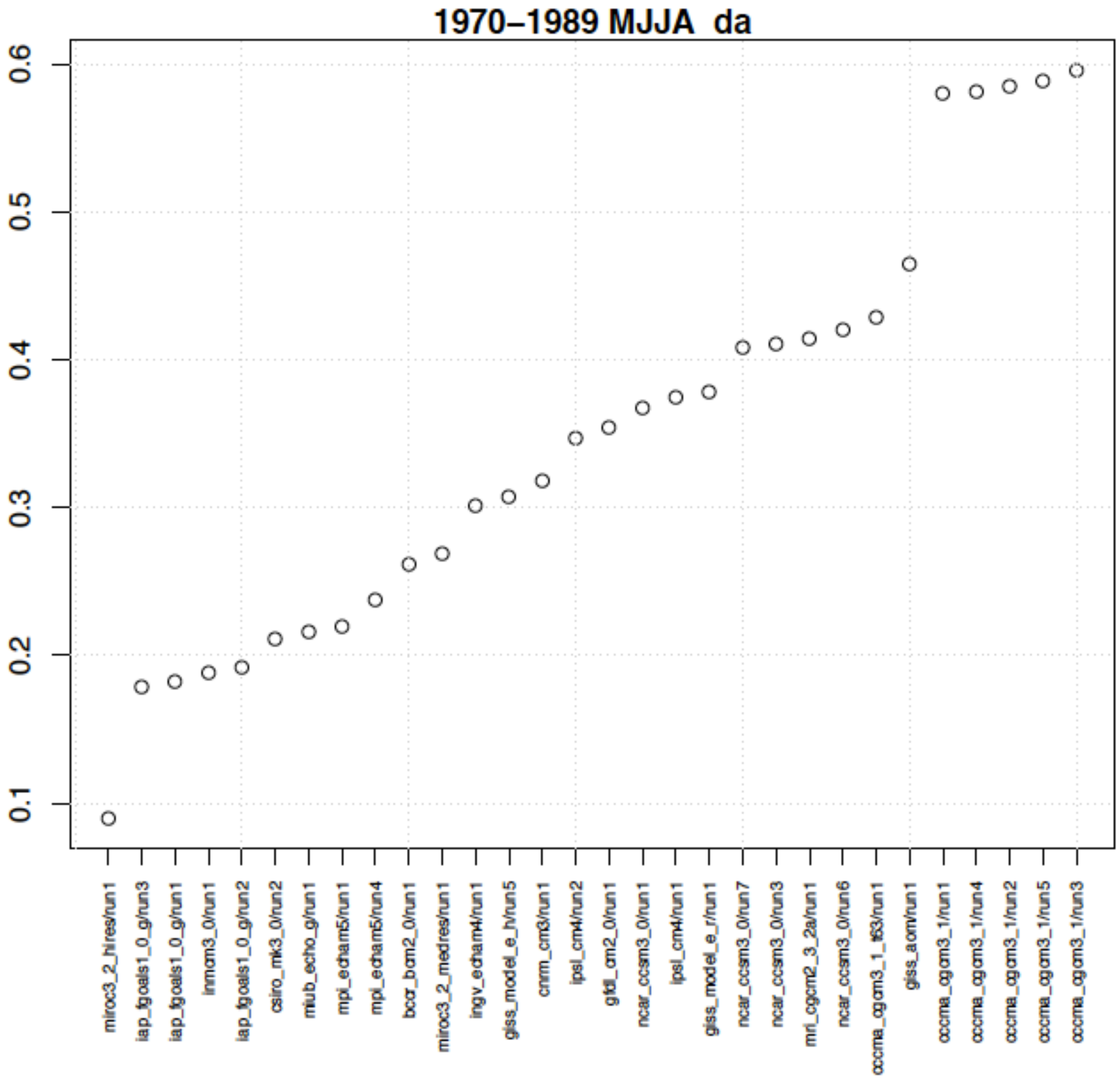
(Hirschi et al. 2011, Nature Geoscience)

Scaling $\Delta Tmax_{local,seas}/\Delta Tmax_{global}$ for 10% (left) and 90%ile (right)



(Orlowsky and Seneviratne 2011, Clim. Change, publ. online)

Realism of land-atmosphere coupling in IPCC AR4 runs



Spatial correlation of corr(SH,LH) between AR4 models and Fluxnet observations

➔ Large variations in performance

➔ Could be used as constraint for projections

(Seneviratne et al., in prep)

Conclusions

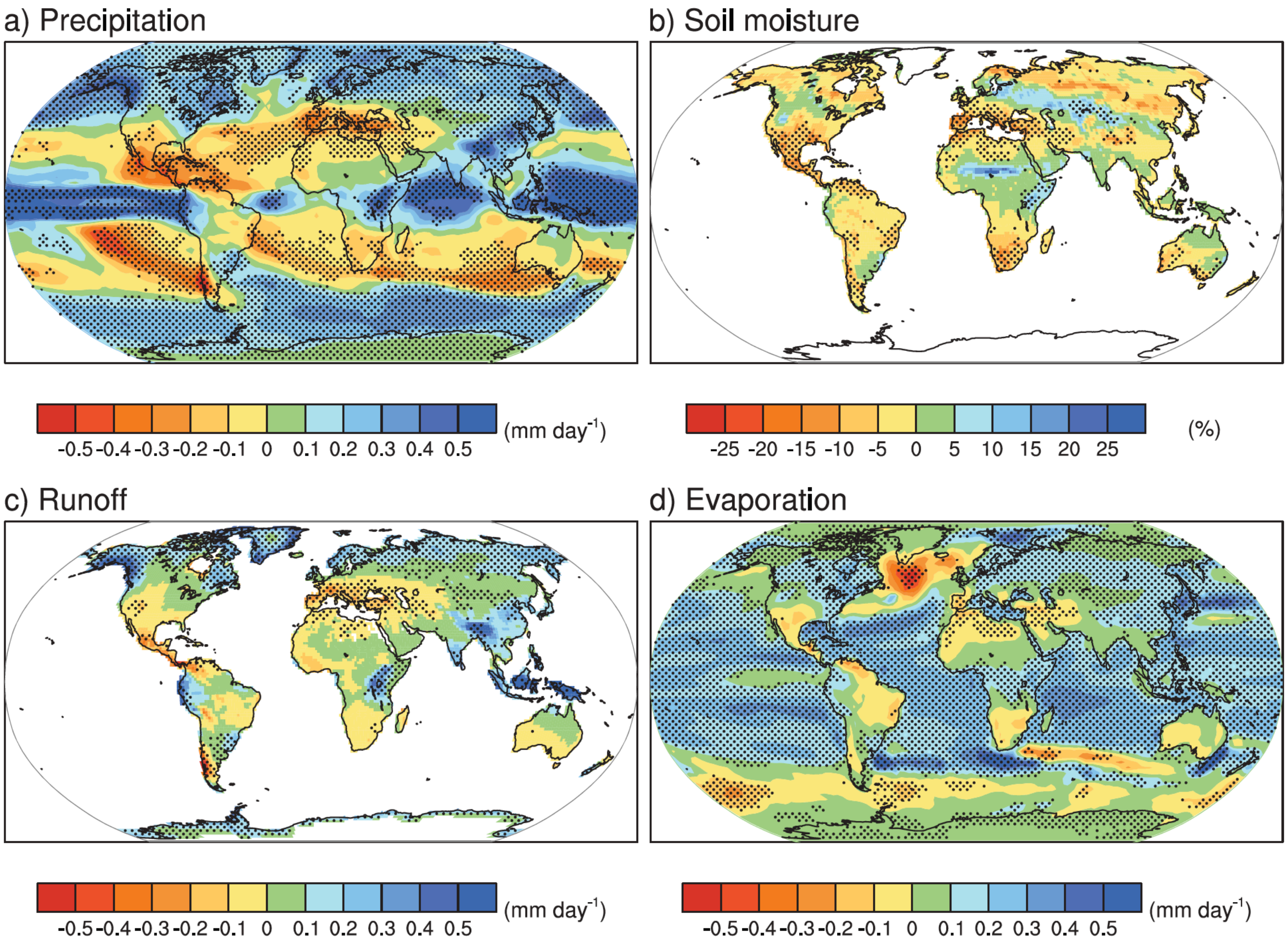
- **Feedbacks and thresholds linked to soil moisture can be critical for the occurrence of hot extremes in both present and future climate**
  - **Impact climate-change projections**
  - **Relevant for predictability**
  - **Mechanisms and relevance confirmed by observations**

- **Other interactions can similarly affect extremes, e.g. feedbacks between snow and air temperature**

- **Mechanisms affecting the shape of distributions are particularly important for the analysis of extreme events**

[redacted]

Changes in hydrological cycle



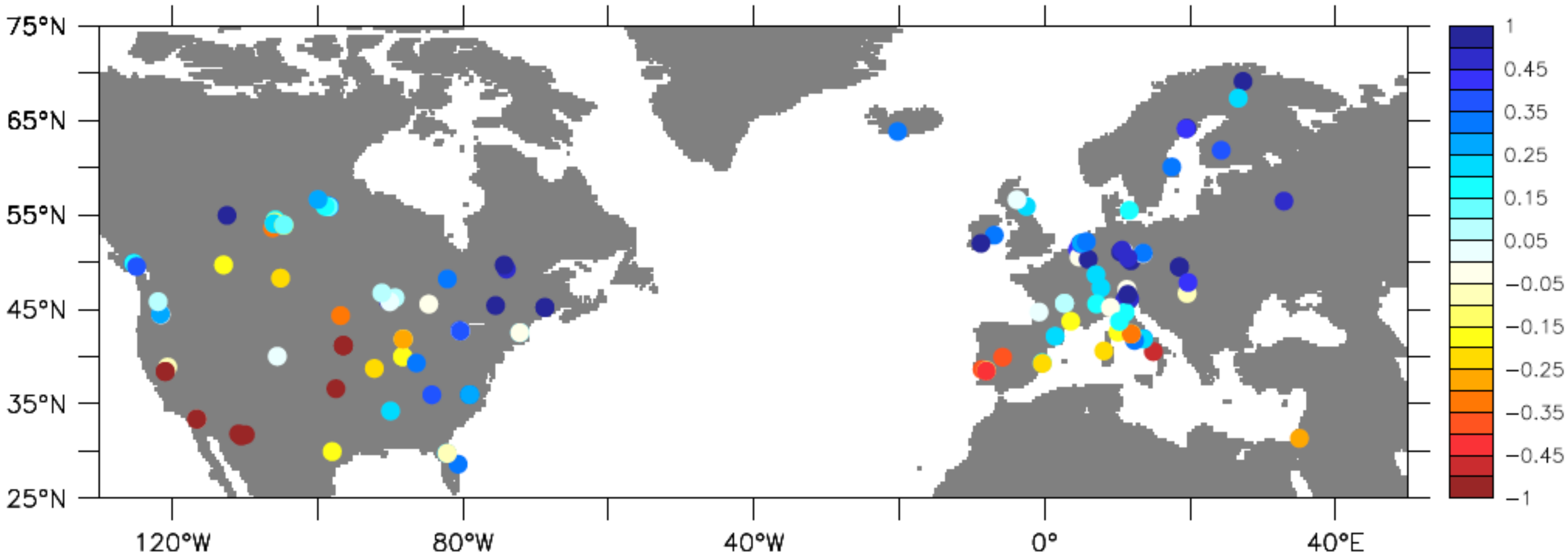
(IPCC 2007)

Realism of land-atmosphere coupling in IPCC AR4 runs

Observational diagnostic of soil moisture-temperature coupling based on Fluxnet measurements

⇒ Relationship between sensible heat flux and latent heat flux (measured with similar instrumentation): $\rho_{(LH, SH)}$

$\rho_{(LH, SH)}$, MJJAS, Fluxnet sites with at least 3 years of data (161 sites)



(Seneviratne et al., in prep)