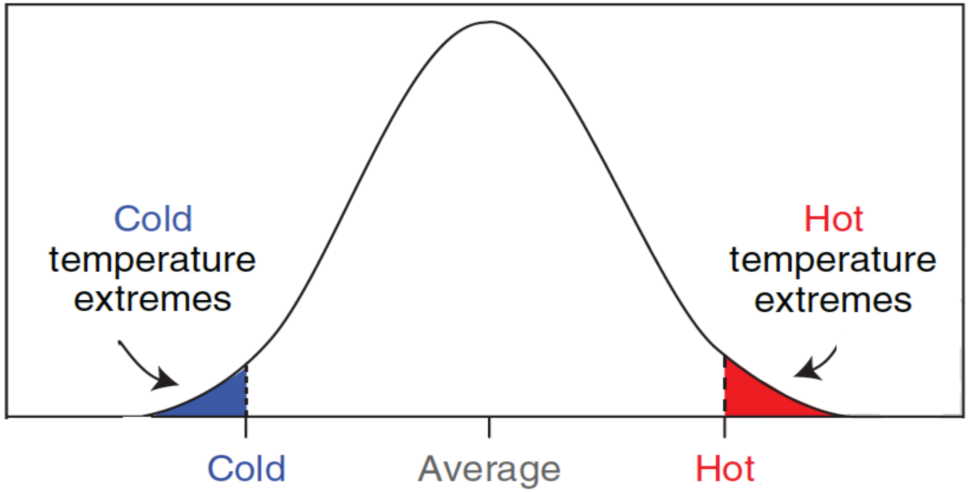
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Soil moisture: A neglected thermostat for climate extremes?

Sonia I. Seneviratne

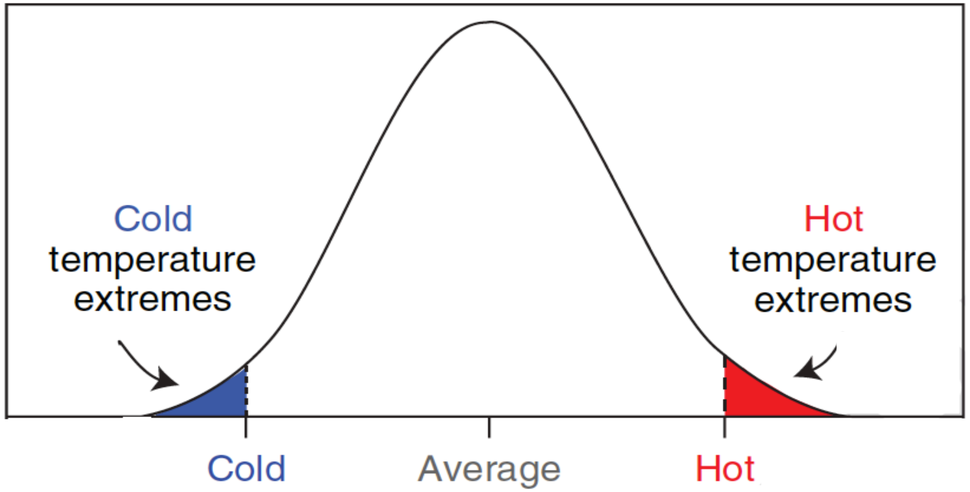
Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland
sonia.seneviratne@env.ethz.ch

How can feedbacks & thresholds affect extremes?

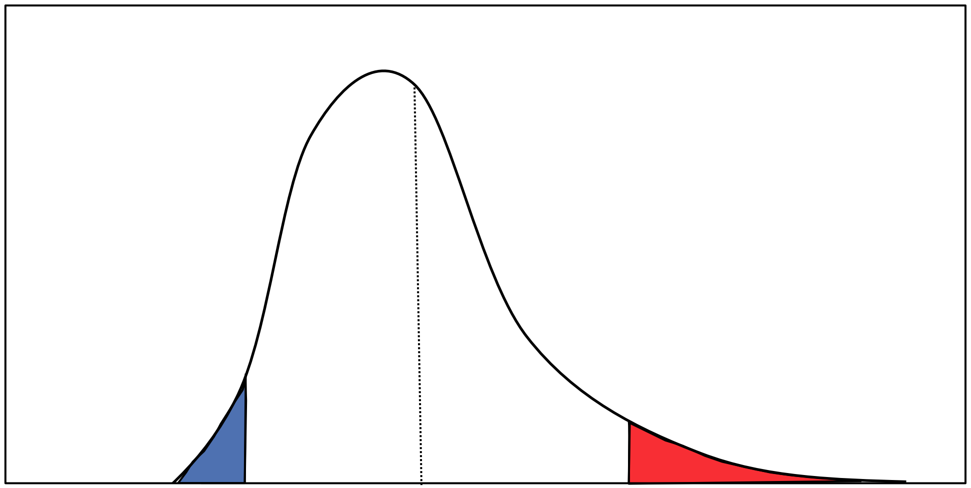


Gaussian distribution

How can feedbacks & thresholds affect extremes?



Gaussian distribution



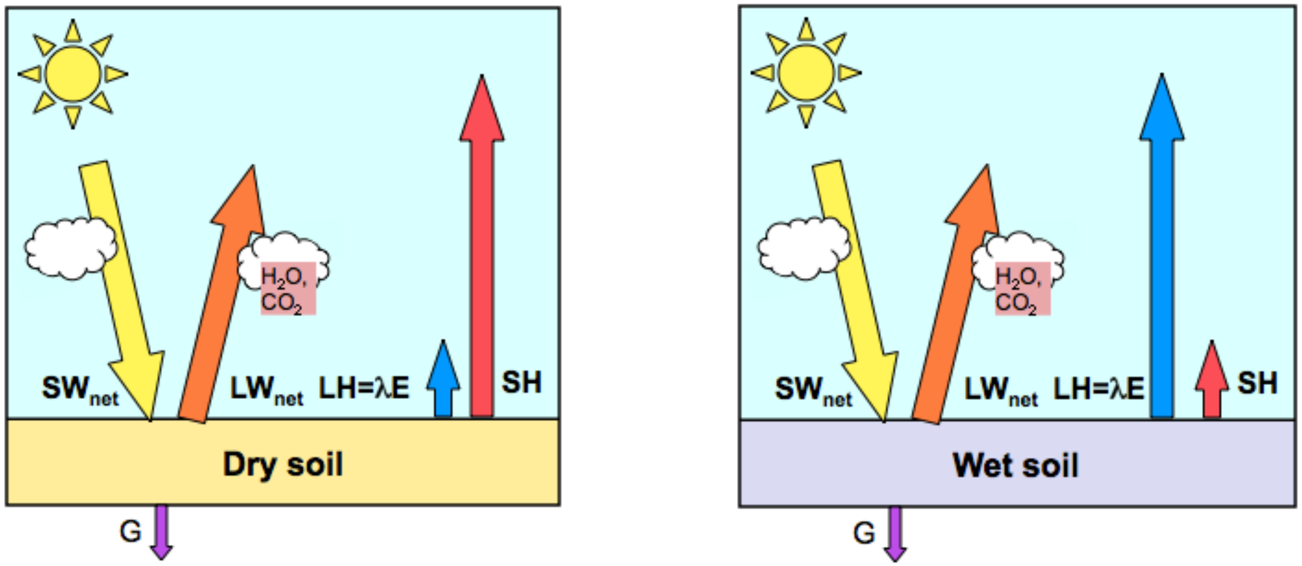
Skewed distribution

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

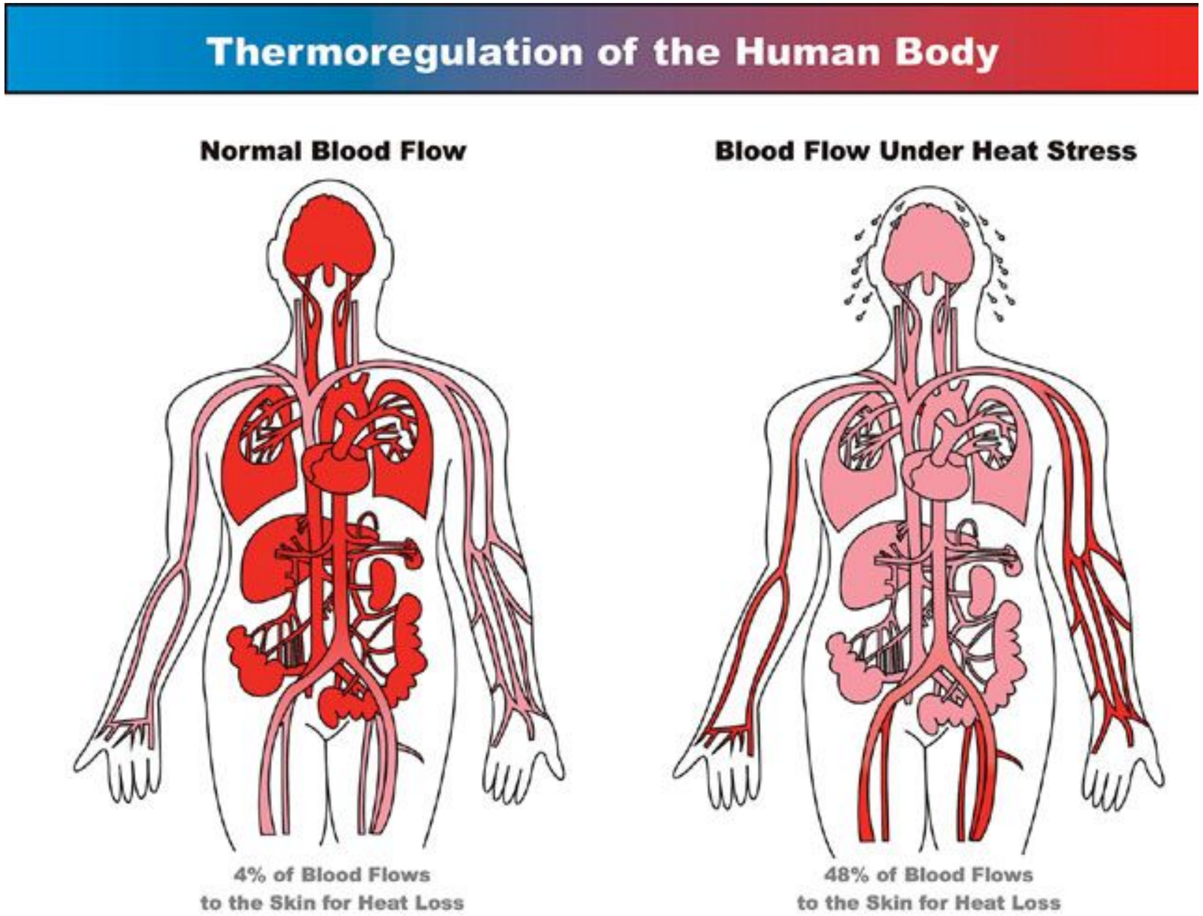
Processes leading to non-linear effects on extremes

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

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



Evaporation & temperature



Our body uses evaporation for cooling

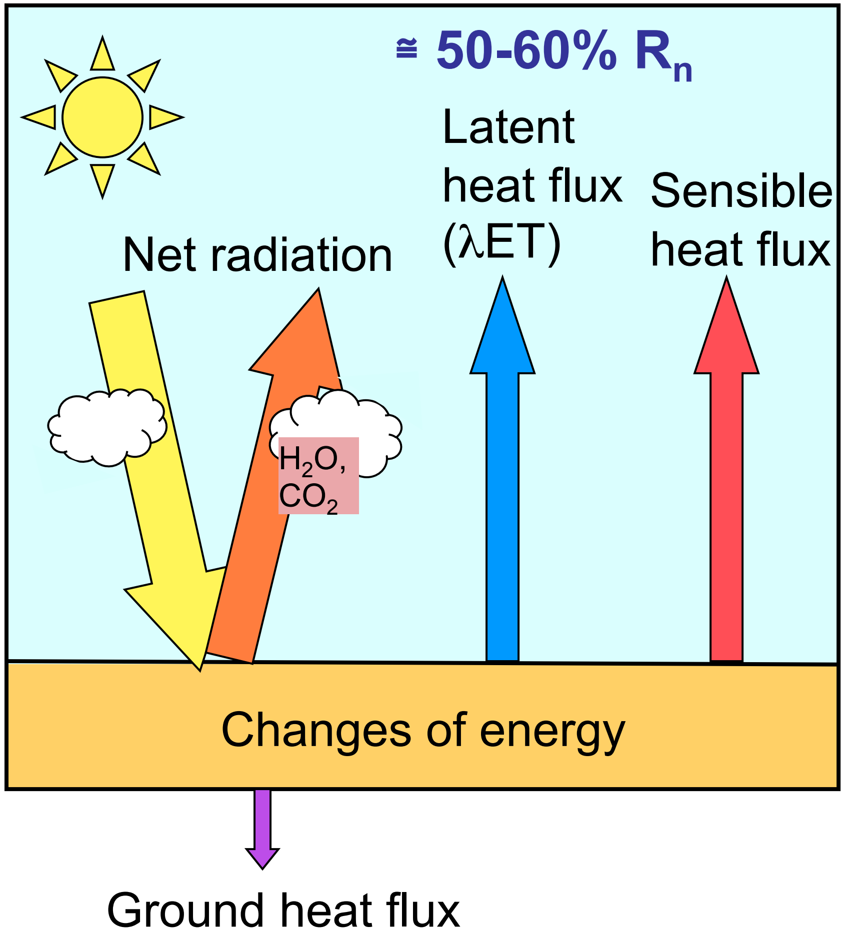
➔ Similar mechanism maintains cool temperatures on land surfaces!

Land evapotranspiration & energy balance

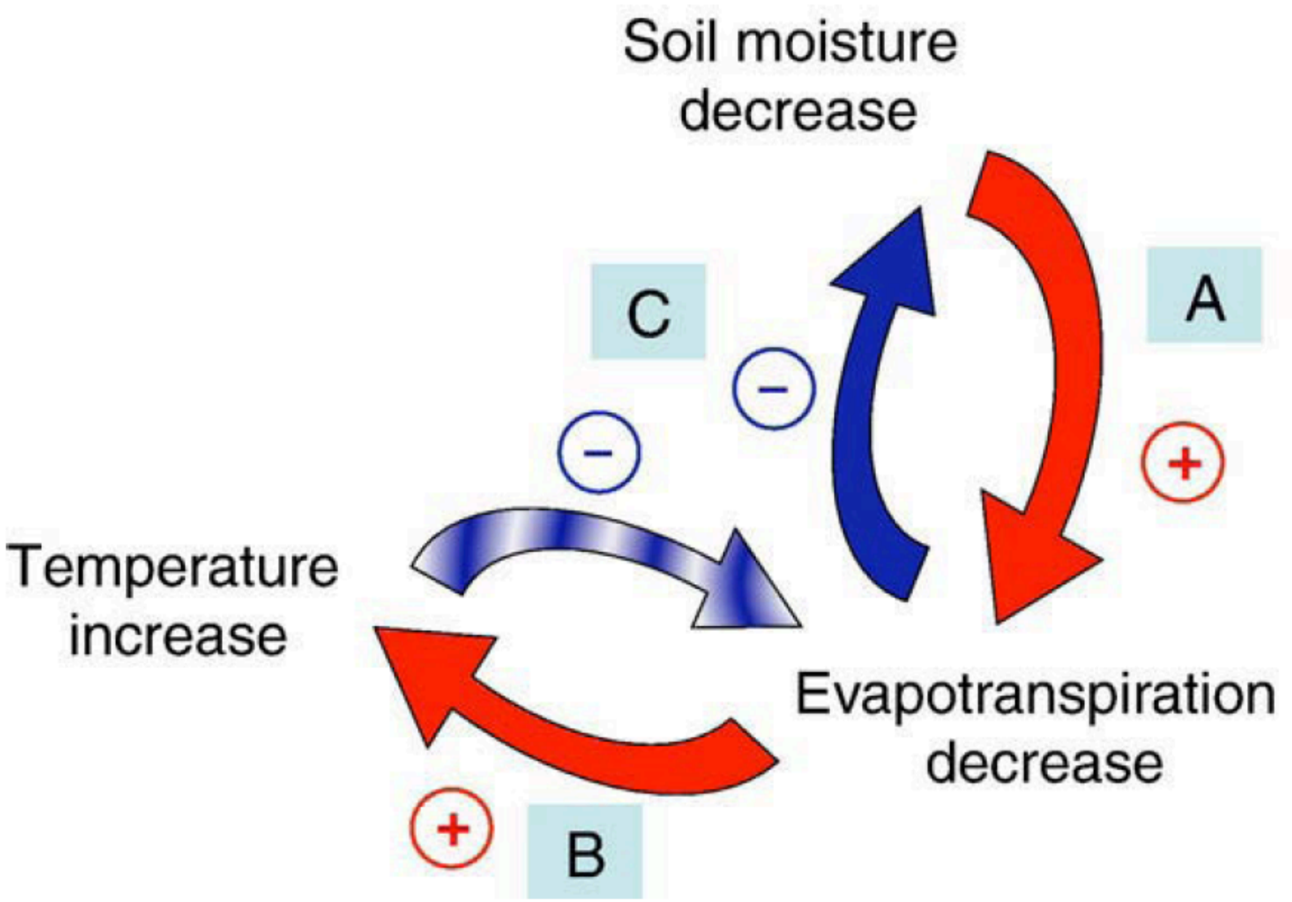
Land evapotranspiration uses up more than half of all net radiation available on land

➔ Buffer for incoming energy

Land energy balance

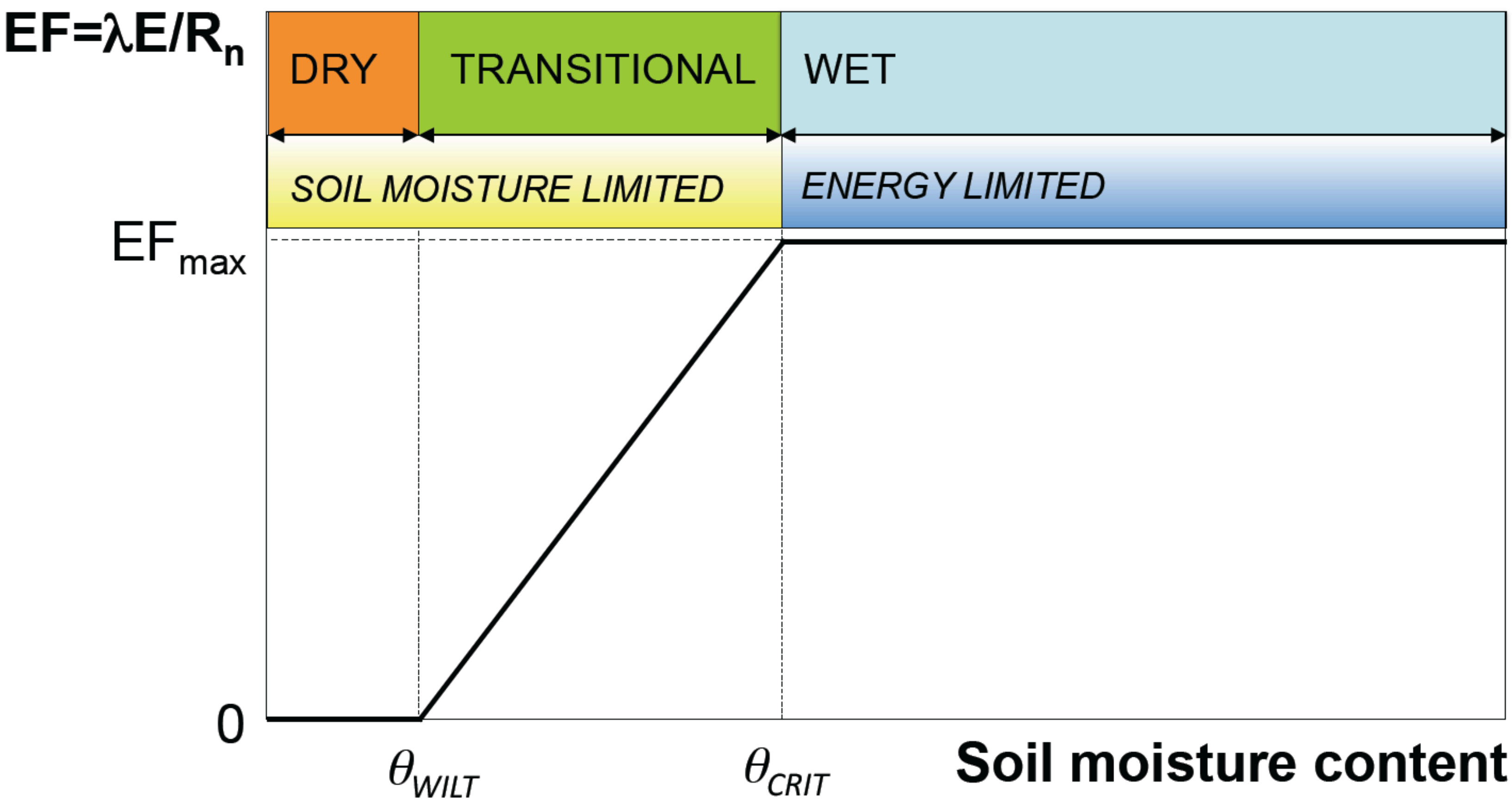


Soil moisture – temperature feedback



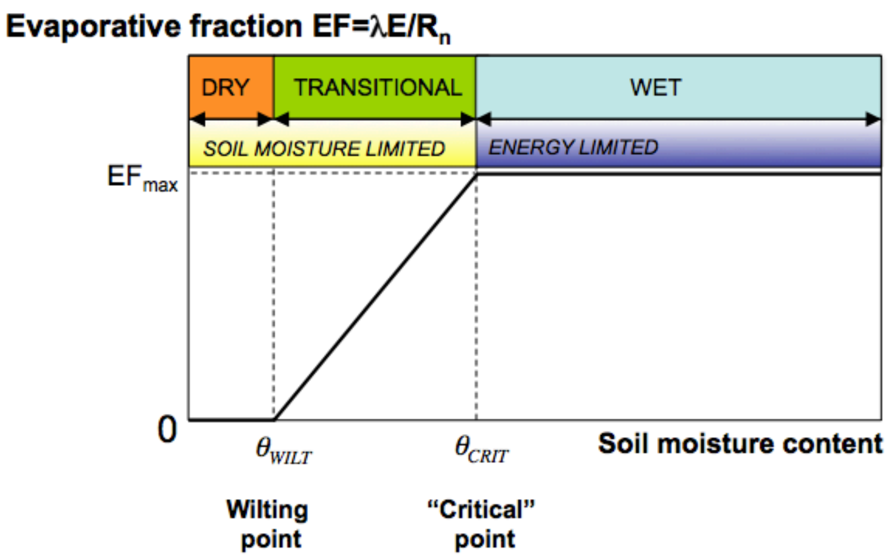
(Seneviratne et al. 2010, Earth-Science Reviews)

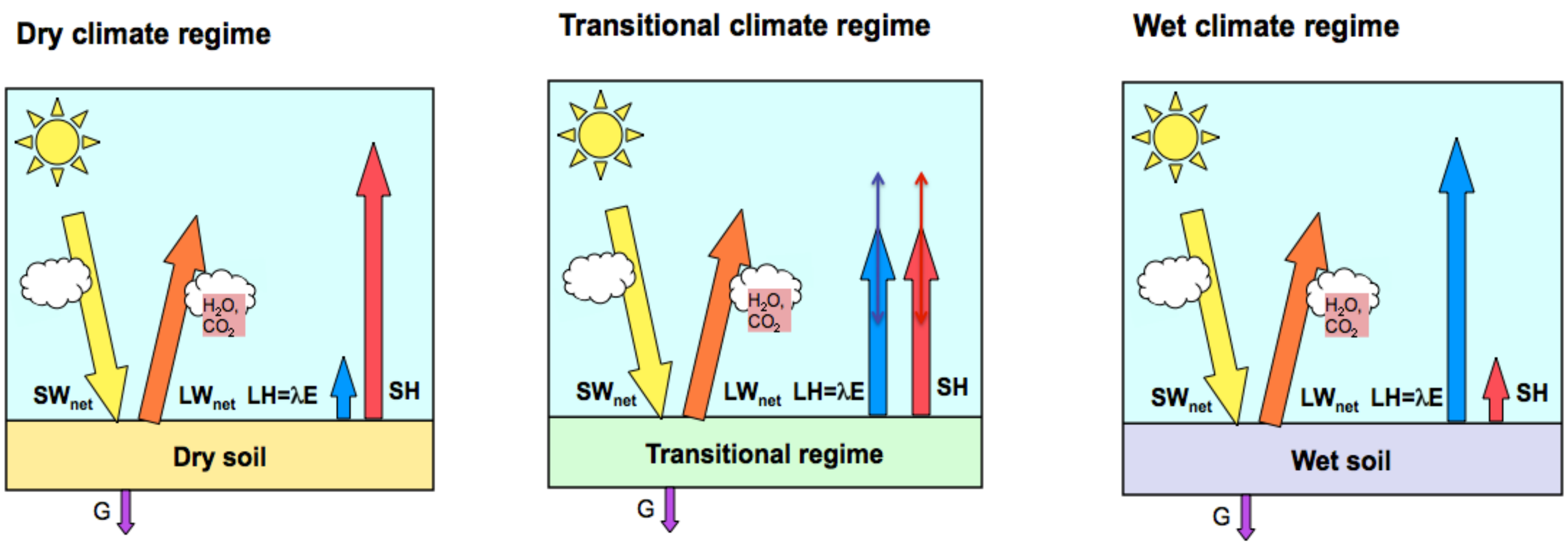
Soil moisture – evapotranspiration coupling



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

Soil moisture – temperature feedbacks



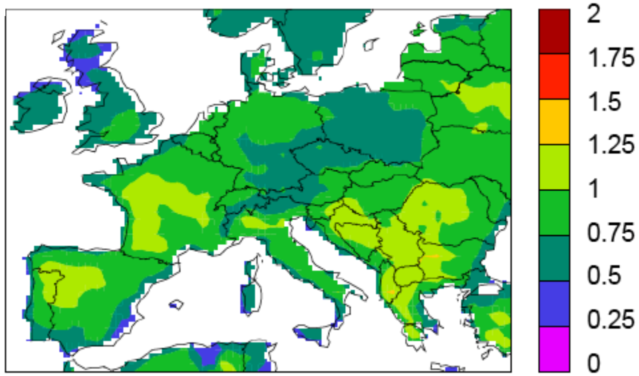


Soil moisture – temperature feedbacks

Up to 60% of summer temperature variability in transitional climate regimes due to soil moisture feedbacks

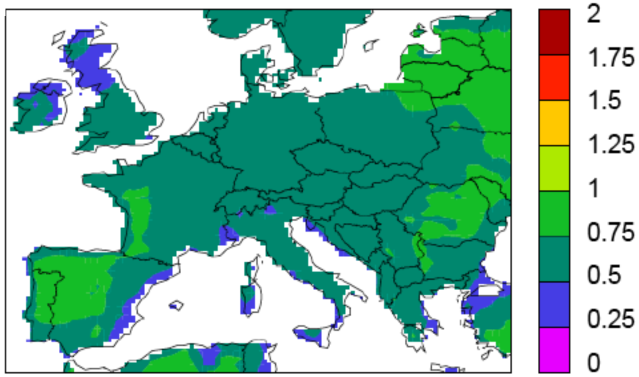
Standard deviation of summer temperature, CHRM model

CTL (1970-1989)



Interactive simulations (reference)

$CTL_{UNCOUPLED}$



Simulations with soil moisture set to climatology (“uncoupled”)

(Seneviratne et al. 2006, Nature)

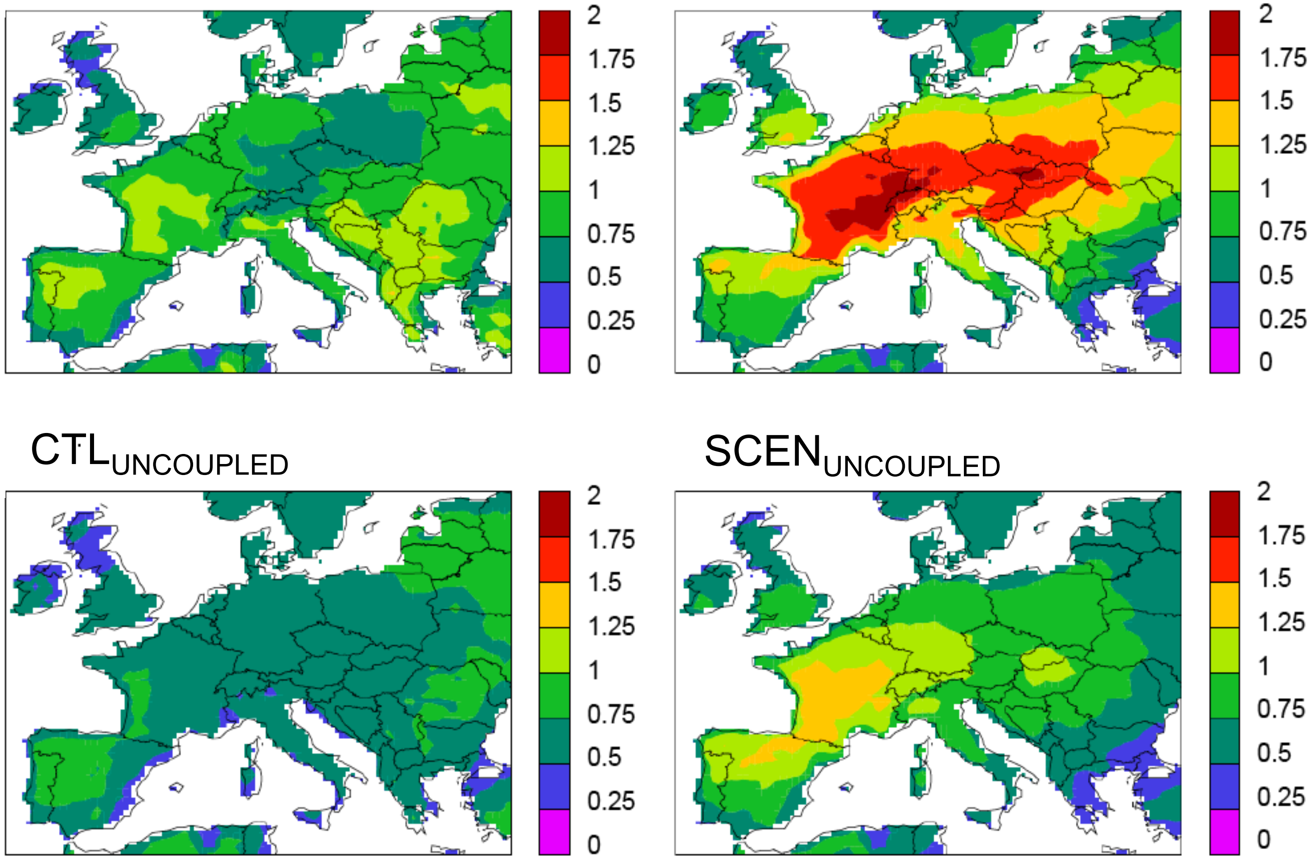
Soil moisture – temperature feedbacks

Up to 60% of summer temperature variability in transitional climate regimes due to soil moisture feedbacks

Standard deviation of summer temperature, CHRM model

CTL (1970-1989) SCEN (2080-2099)

CTL$_{UNCOUPLED}$ SCEN$_{UNCOUPLED}$



Interactive simulations (reference)

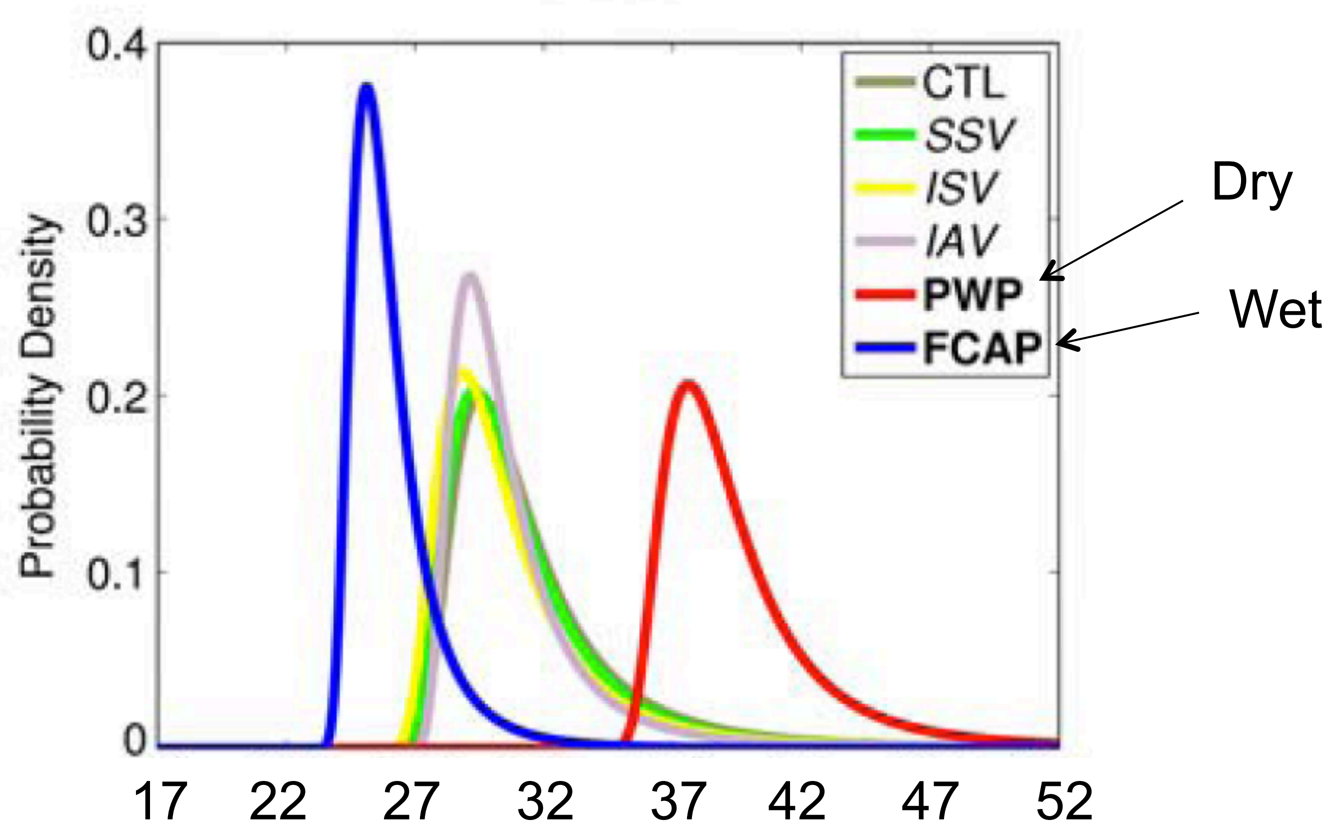
Simulations with soil moisture set to climatology (“uncoupled”)

(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)

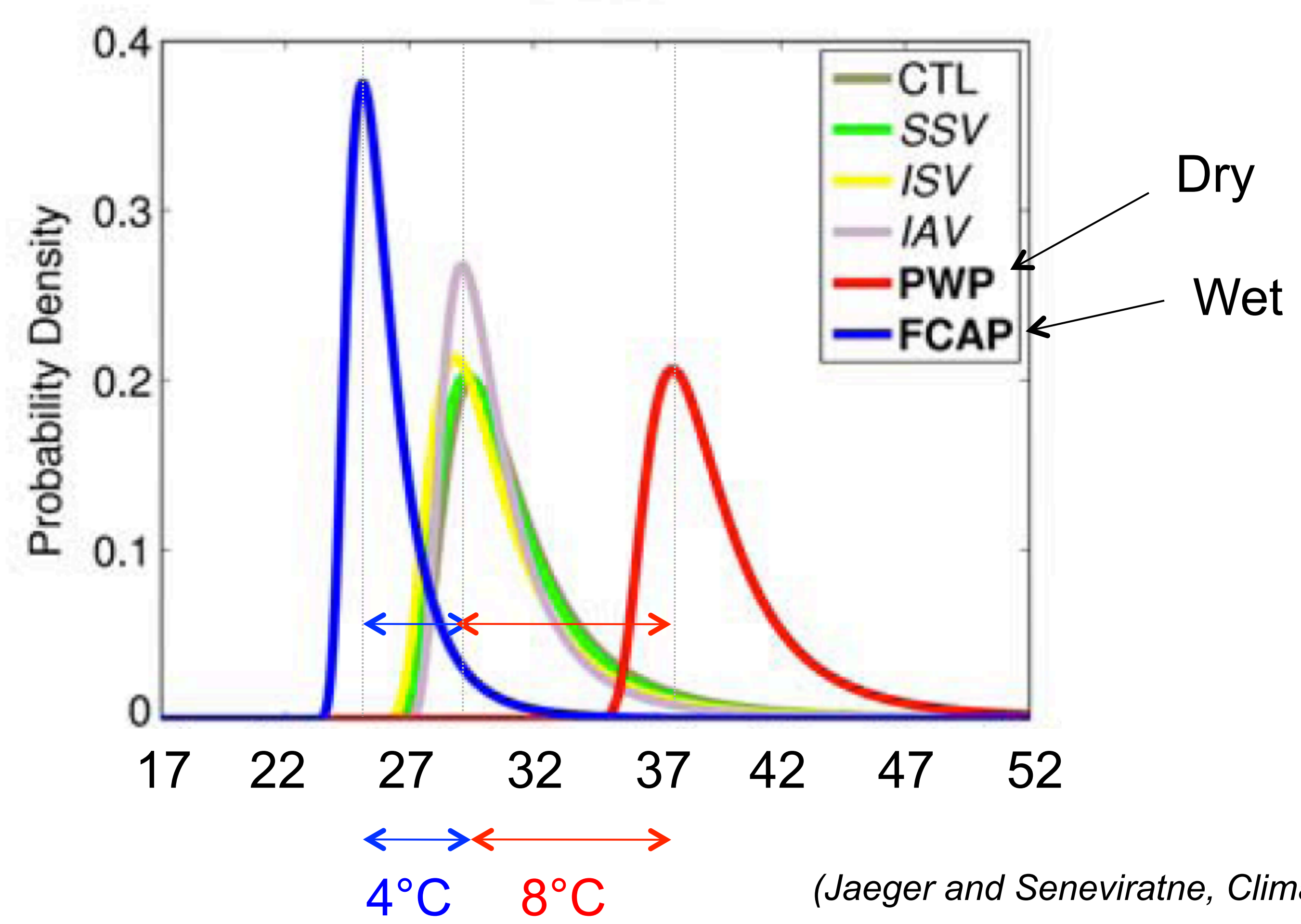


(Jaeger and Seneviratne, Climate Dynamics, 2011)

Asymmetric effects of soil moisture on extremes

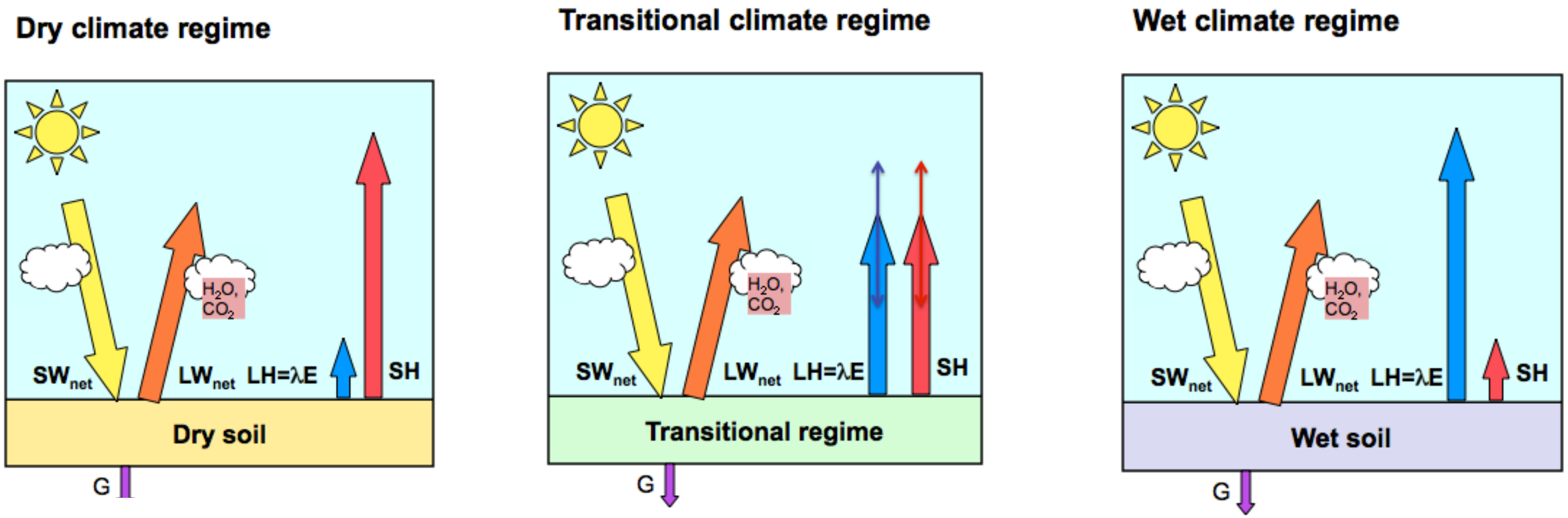
Distribution of summer Tmax block maxima

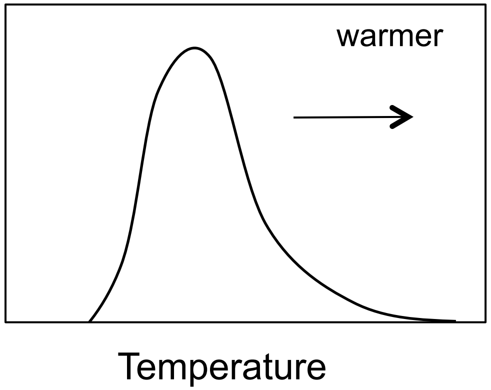
RCM simulation with COSMO/CCLM (France, 1959-2006)



(Jaeger and Seneviratne, Climate Dynamics, 2011)

Soil moisture – temperature feedbacks





Evaluation with observations

Do observations confirm…

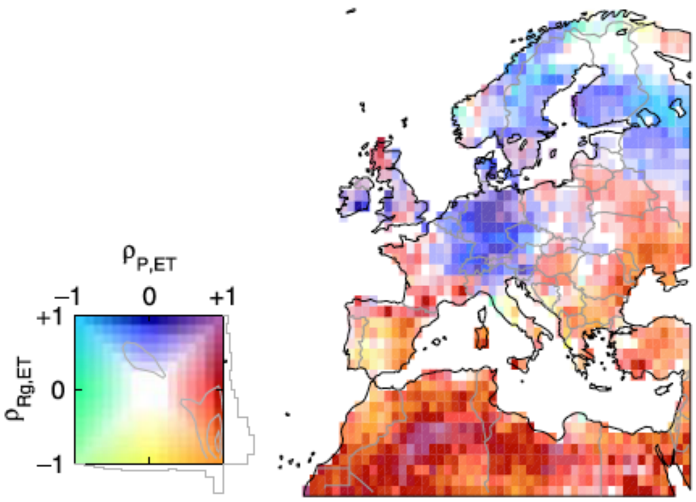
1) … the geographical location of regions of strong soil moisture-atmosphere coupling?

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

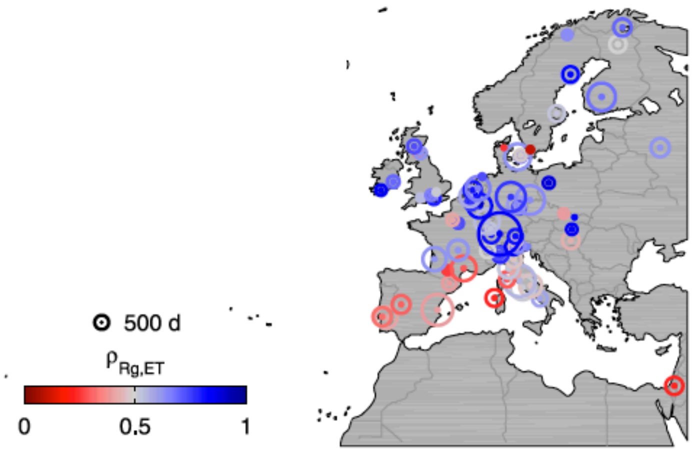
3) …that these effects may be asymmetric?

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)



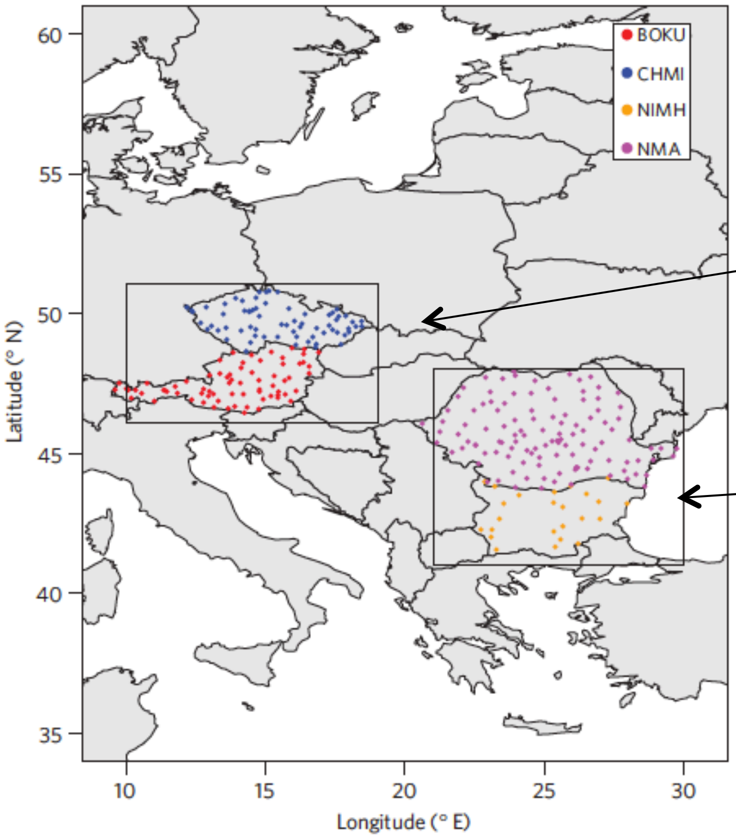
Correlation of daily evapotranspiration with radiation
(Fluxnet measurements)

(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

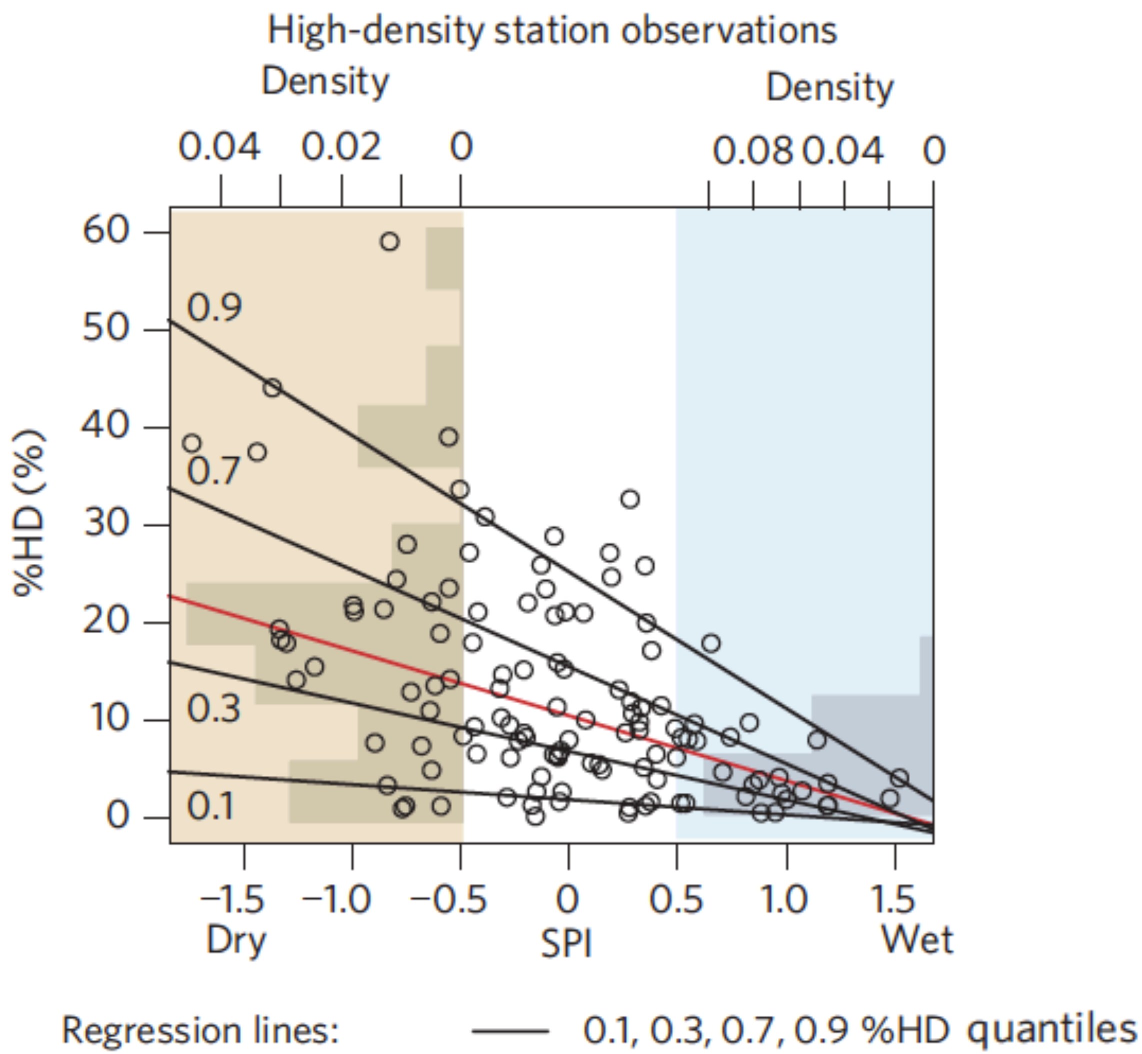
Soil moisture-limited evapotranspiration regime

(Hirschi et al. 2011, Nature Geoscience)

Role of soil moisture on hot extremes: Observations

Analysis in Southeastern Europe

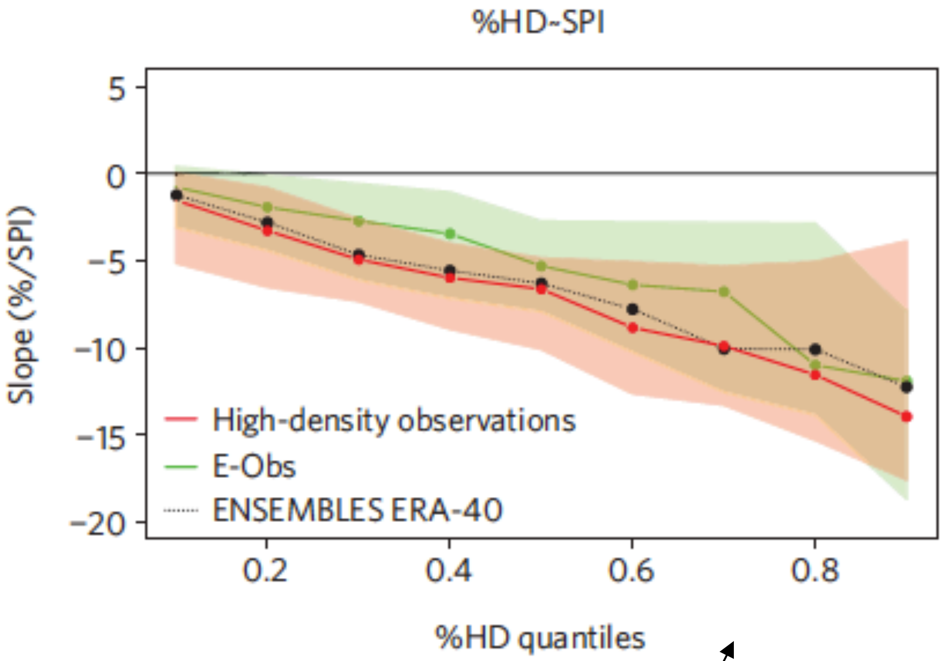
Quantile regression of percentage of hot days (%HD) with 6-month standardized precipitation index (SPI)



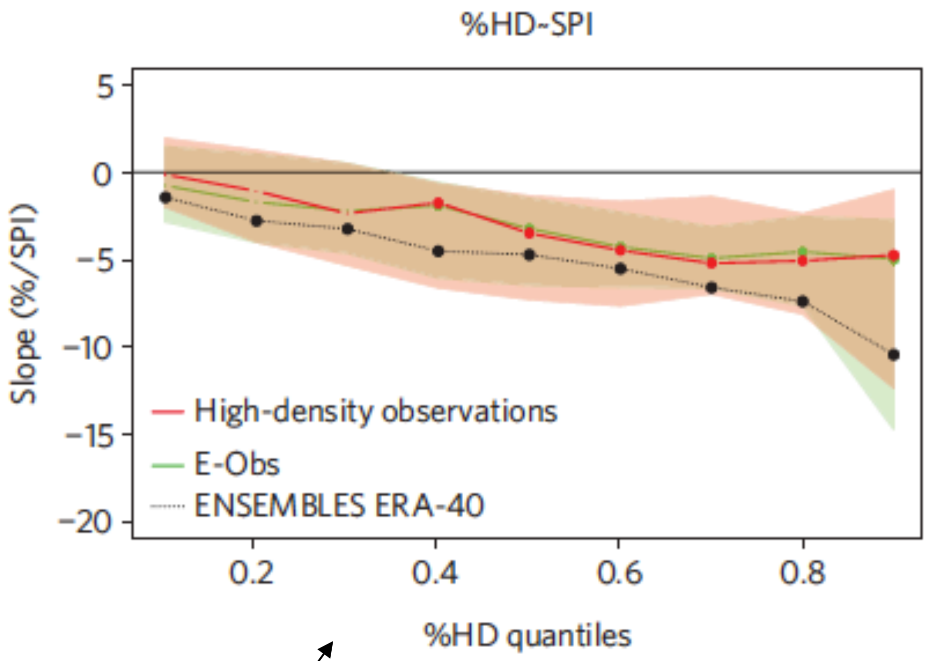
(Hirschi et al. 2011, Nature Geoscience)

Role of soil moisture on hot extremes: Observations

Southeastern Europe



Central Europe



Substantially stronger effect in SE Europe

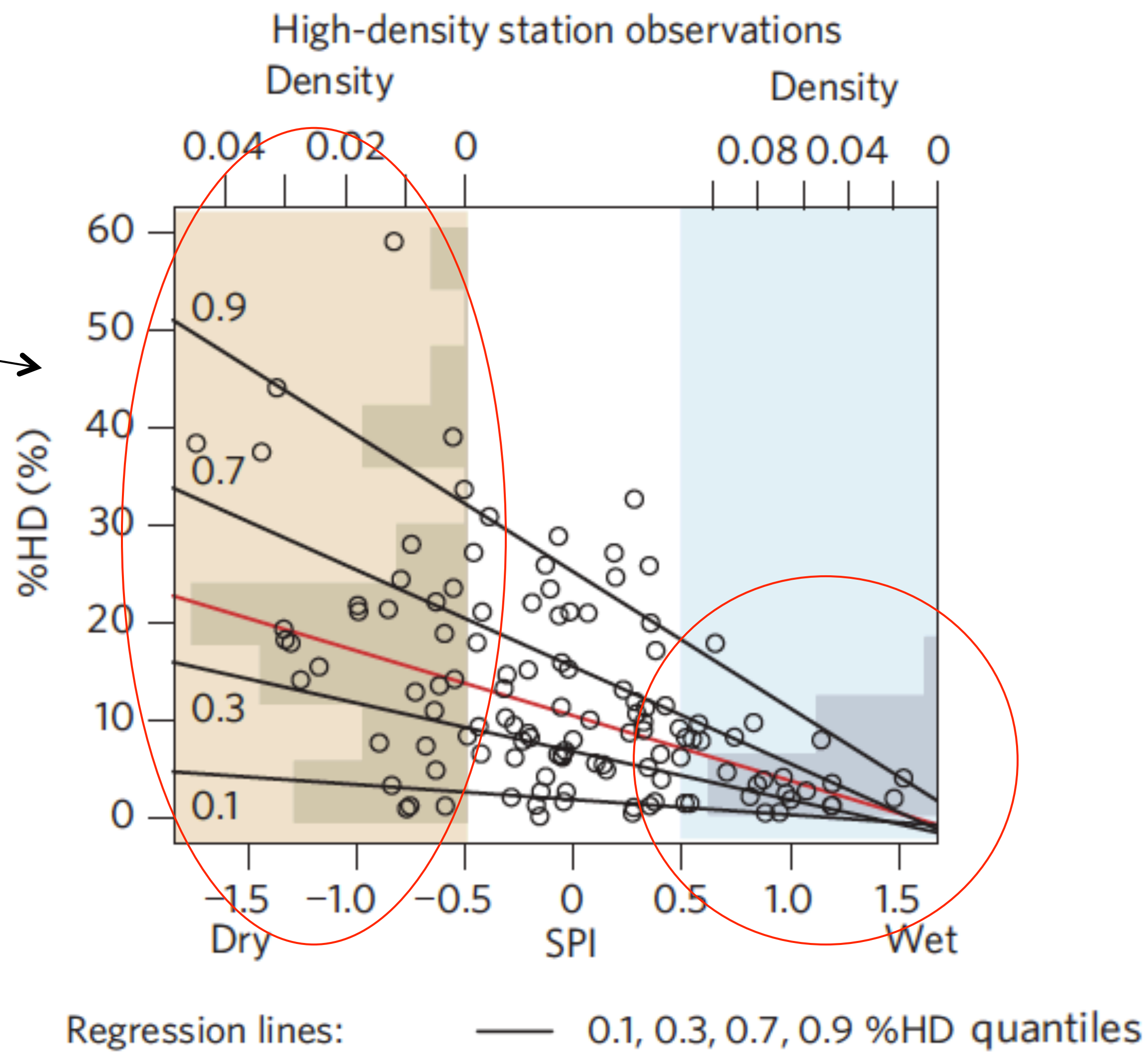
RCMs from ENSEMBLES perform fairly well
(but slight overestimation in C. Europe)

(Hirschi et al. 2011, Nature Geoscience)

Role of soil moisture on hot extremes: Observations

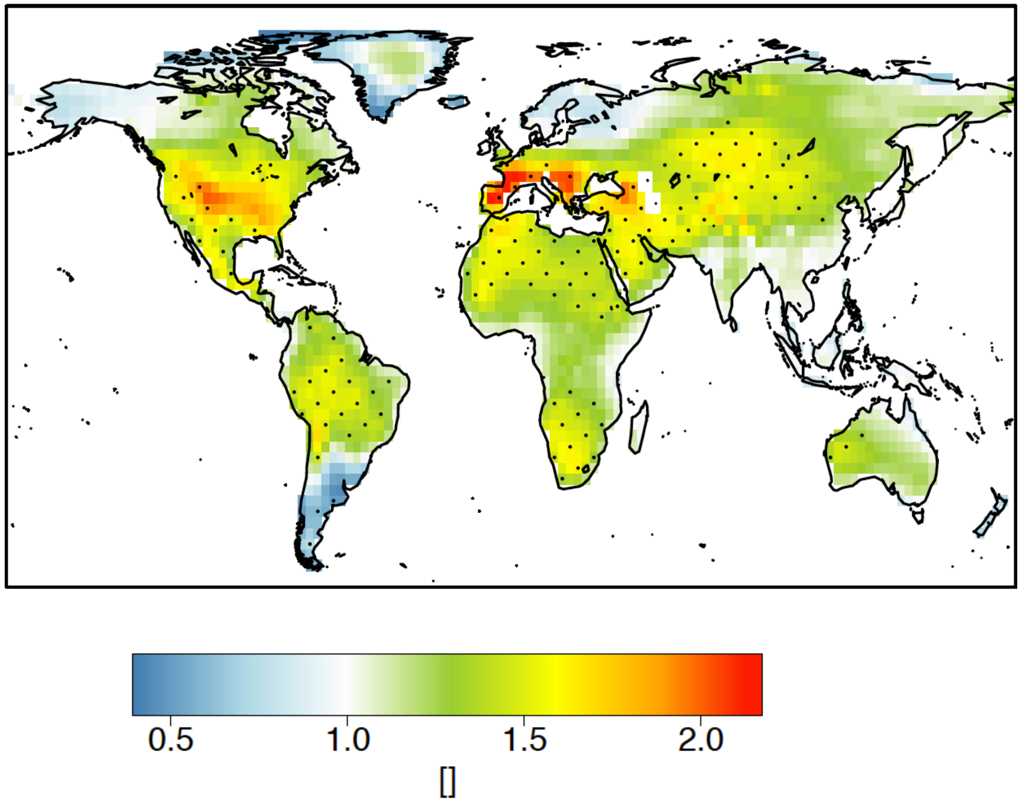
Possibly more skill for prediction of hot extremes after wet vs dry conditions:

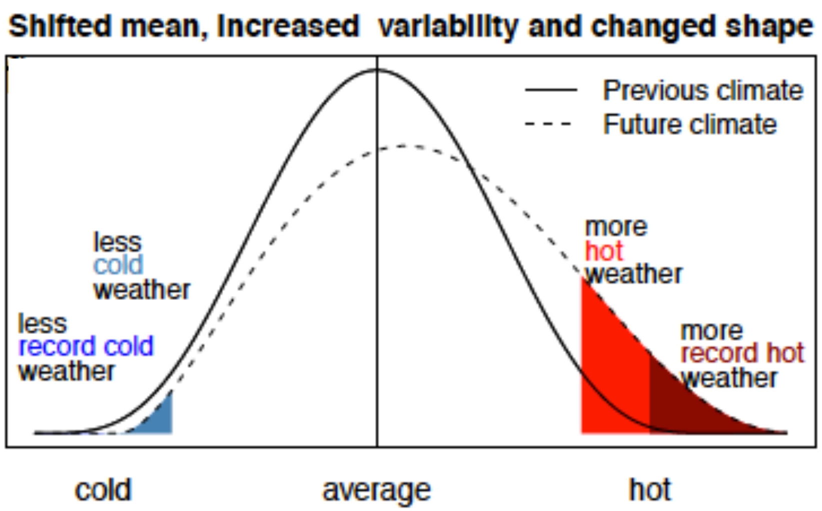
Dry soil necessary but not sufficient condition



(Hirschi et al. 2011, Nature Geoscience)

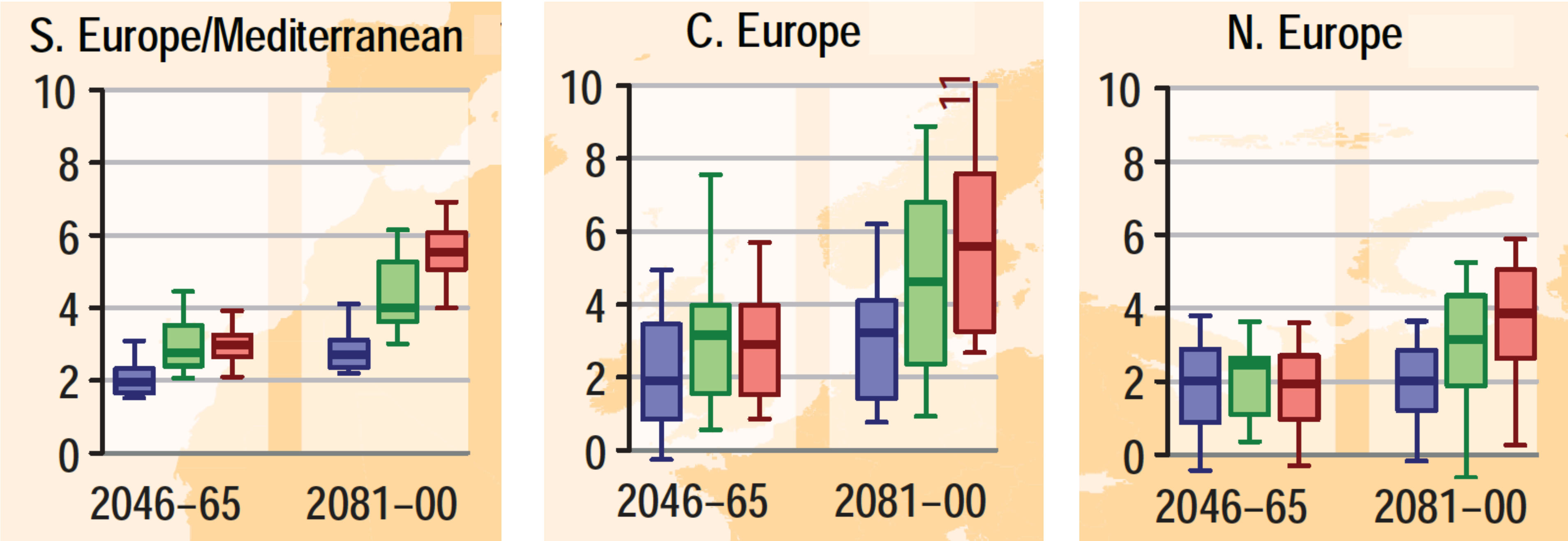
Scaling of changes in 90th percentile of summer (JJA) Tmax with median change in global annual mean Tmax





(Orlowsky and Seneviratne 2012, Clim. Change)

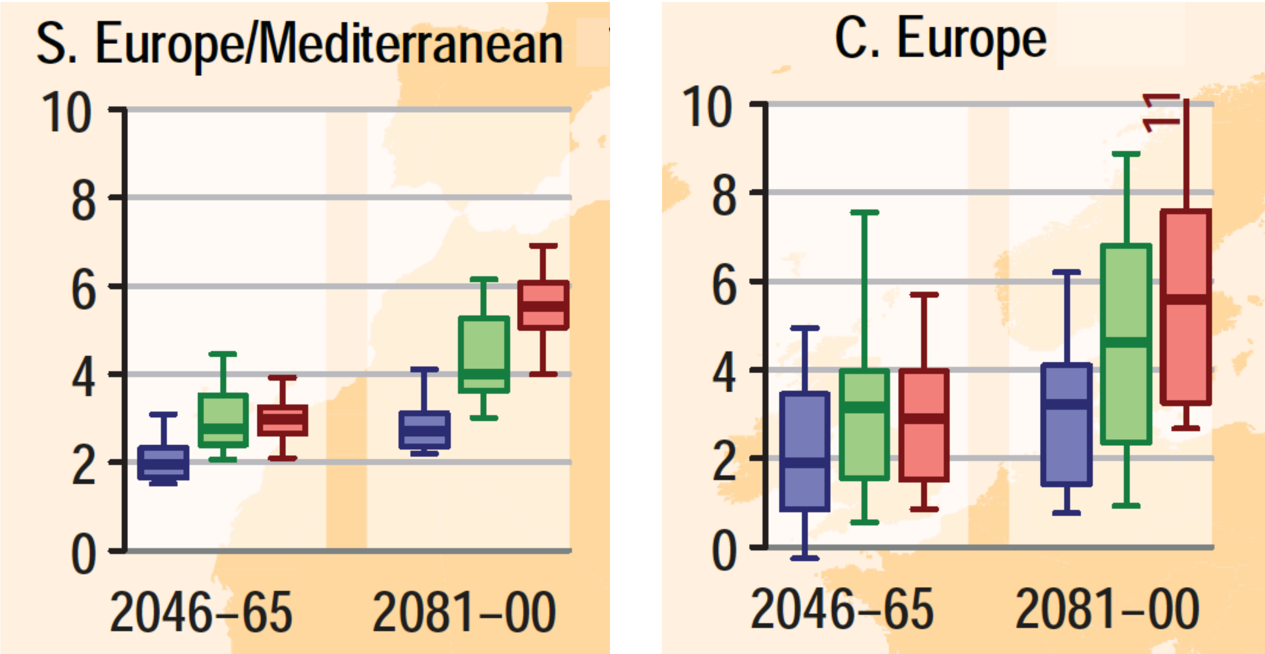
Projected changes in 20-year return values of annual maximum Tmax
(vs late 20th century, 1981-2000)

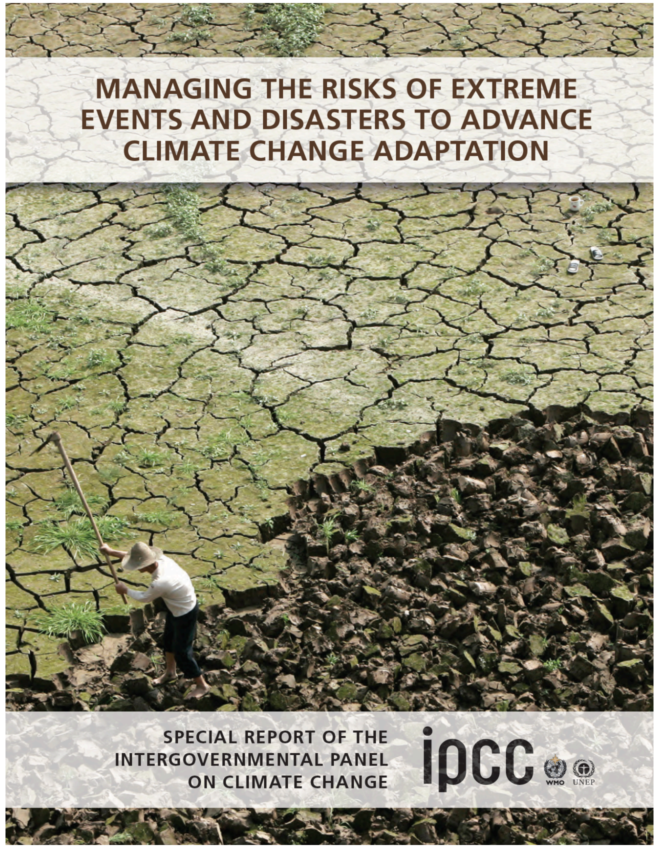


(IPCC SREX 2012; Chapter 3)

Projected changes in 20-year return values of annual maximum Tmax

(vs late 20th century, 1981-2000)

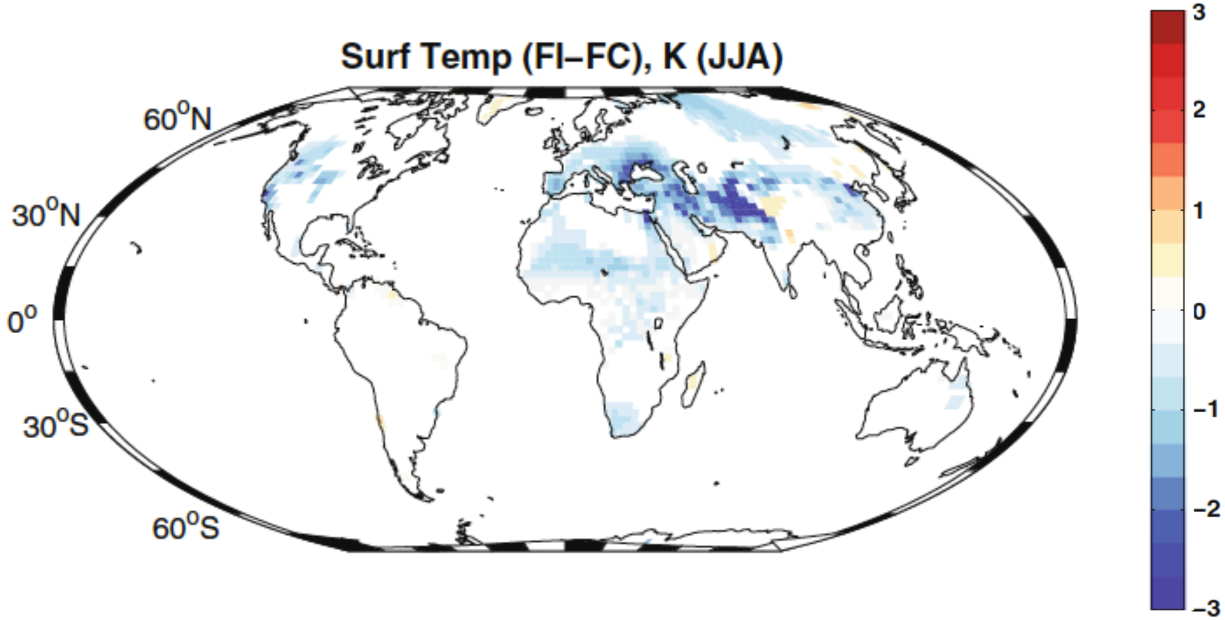




http://www.ipcc.ch/

(IPCC SREX 2012; Chapter 3)

Using soil moisture for reduction of impacts?



(Cook et al. 2011, Clim. Dyn)

Irrigation could partly offset some impacts of increasing soil moisture limitation: Not considered in current IPCC scenarios

GLACE-CMIP5: Coordinated multi-model experiment (ECHAM6, IPSL, CESM, GFDL, EC-Earth) quantifying impact of soil moisture feedbacks for projections

Summary and conclusions (1/2)

Soil moisture: A neglected thermostat for climate extremes?

Thermostat:

- Yes: Important regulating mechanisms associated with soil moisture-temperature feedbacks, in particular relevant for hot extremes

Neglected:

- Yes, until recently:
    - Limited coverage of measurements, but new GCOS essential climate variable (2010)
    - Soil moisture initialization is not yet used in operational seasonal forecasts, but first implementations are being developed (e.g. ECMWF)

Summary and conclusions (2/2)

Feedbacks and thresholds linked to soil moisture are critical for the occurrence of hot extremes in both present and future climate

- **Buffer for hot extremes**
- **Mechanisms and impacts confirmed by observations**
- **Relevant for seasonal predictability and climate-change projections**
- **Can also serve for adaptation**