# Model uncertainties in heatwave (and drought) projections

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# Plan of the talk

- Motivations
- Recent analyses of CMIP5 daily temperatures [*Cattiaux et al. 2013, Schoetter et al. 2014*]
- Quantification of the soil moisture feedback in the CNRM AGCM [*Douville et al., submitted*]
- Prospects

# Motivations (1)

- Adaptation to global warming require regional to local information about the full distribution of daily temperatures.
- Projections of daily temperatures over land do not simply show a shift of the distribution [e.g., *Hegerl et al. 2004, Schär et al. 2004*] and changes in temperature extremes do not scale as well as seasonal mean anomalies on the projected global warming [e.g., *Clark et al. 2010*].

What are the key processes that govern the frequency/intensity of hot extremes? How can we constrain the response of heatwaves in global climate projections?

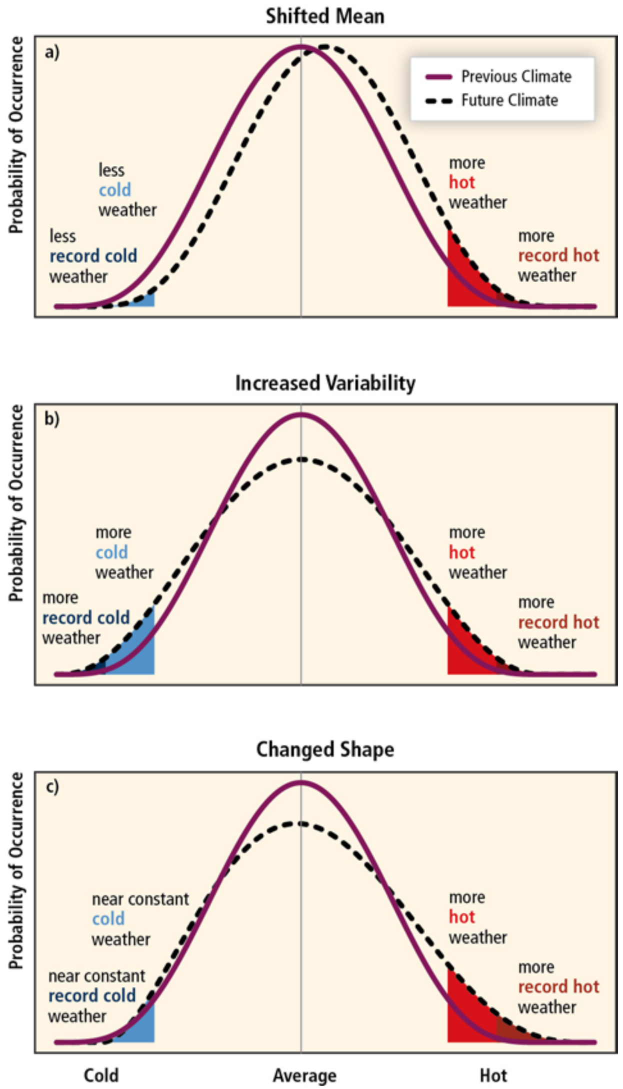
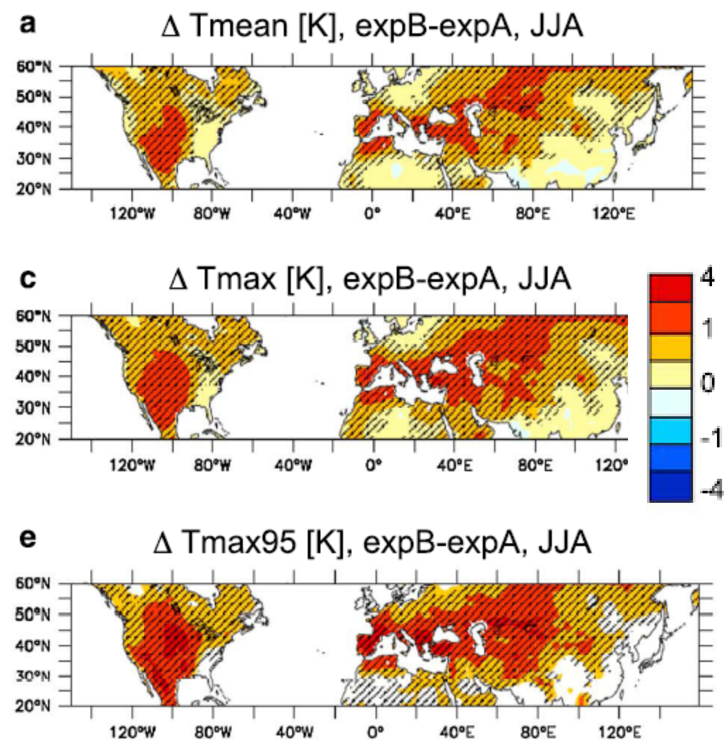



*Fig 1.2 SREX IPCC 2012*

# Motivations (2)

- Soil moisture remains a highly model-dependent quantity in land surface models [e.g., *Koster et al. 2009*]
- Soil moisture exerts a major control on the surface energy budget.
- Soil moisture changes particularly impact hot temperature projections [e.g., *Seneviratne et al. 2013*]

What is the effect of the soil moisture feedback on the pdf of $T_{max}$ and on heatwave properties? What are the possible side-effects of suppressing this feedback in a climate model?

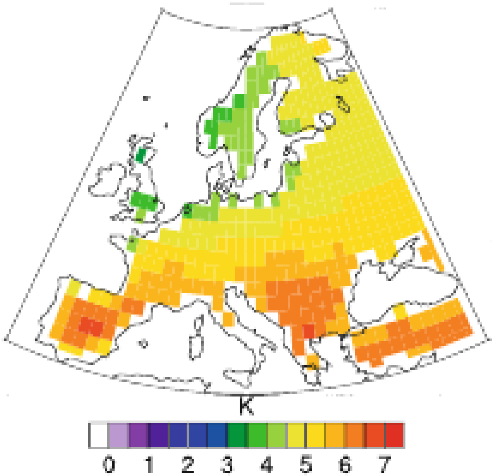



Difference of two simulations with and without soil moisture feedback over 2071–2100 for $T_{mean}$, $T_{max}$ and 95th percentile of $T_{max}$, computed as average of five AGCM experiments

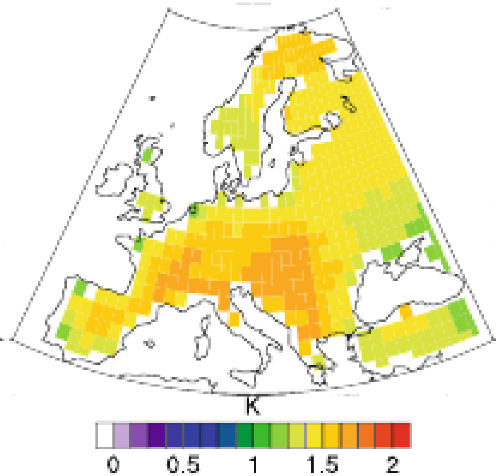
*Seneviratne et al. 2013*

# Summer mean changes in daily $T_{mean\ /\ min\ (\nabla)\ /\ max\ (\Delta)}$

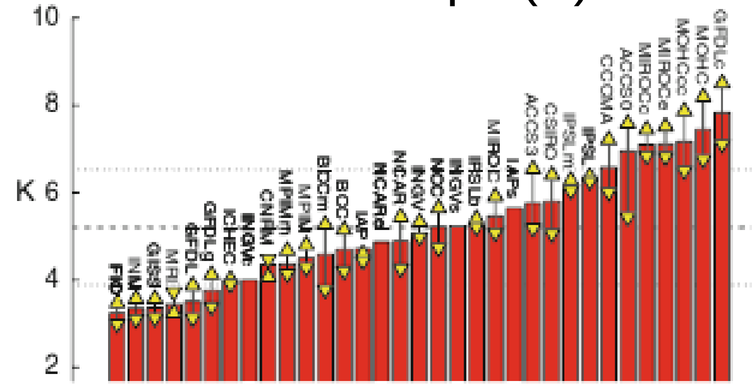
MME mean change



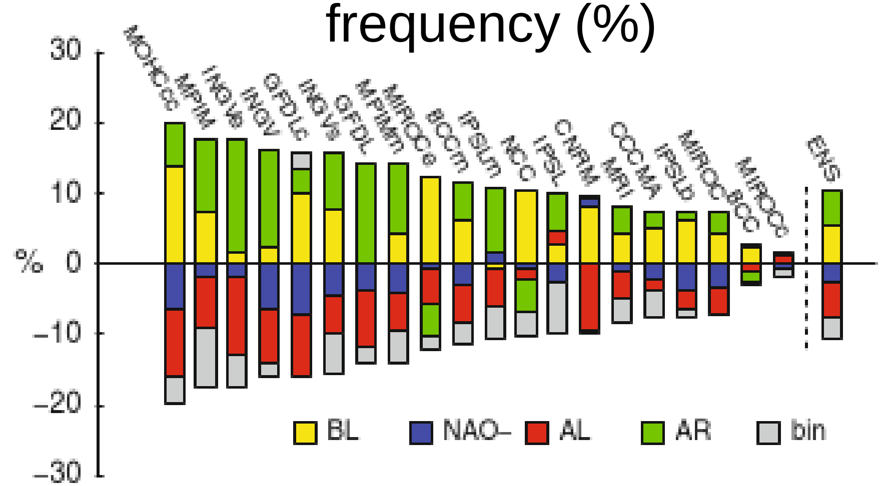

MME stdev




Temperature changes averaged over Europe (K)




Changes in NAE weather regime frequency (%)




Large spread in the projected (RCP8.5) summer mean warming despite a relative consensus on changes in large-scale circulation

*Cattiaux et al. 2013*

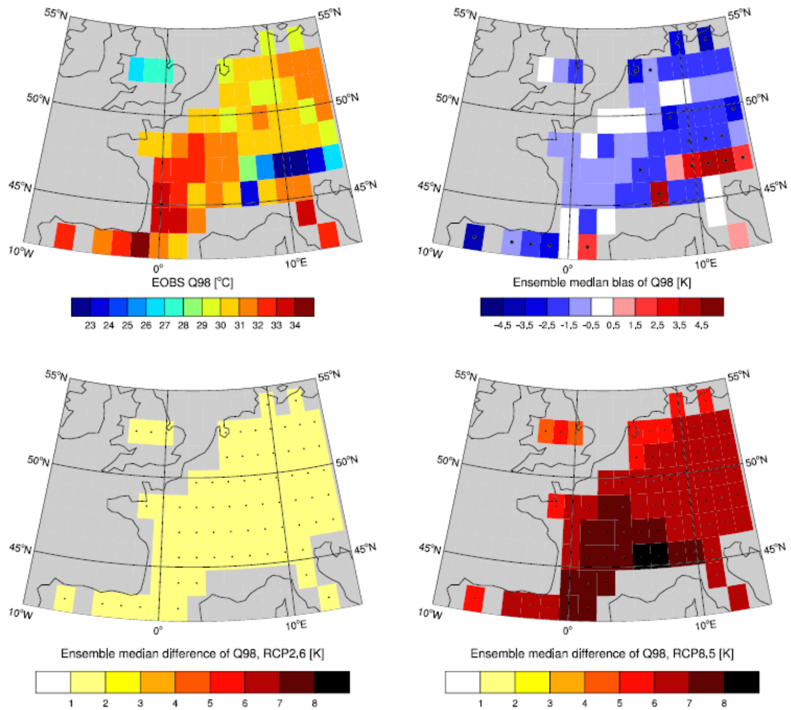
# Changes in the 98$^{th}$ percentile of summer Tmax

Present-day Q98 Tmax EOBS-V8.0

CMIP5 MME median bias

Q98 Tmax MME median response in **RCP2.6**

Q98 Tmax MME median response in **RCP8.5**




Heatwave event (HWE) definition and properties:

Tmax>Q98 for a duration (D) of at least 3 consecutive days and over an extent (E) of at least 30% of the domain

HWE intensity: I = E(Tmax-Q98|Tmax>Q98)

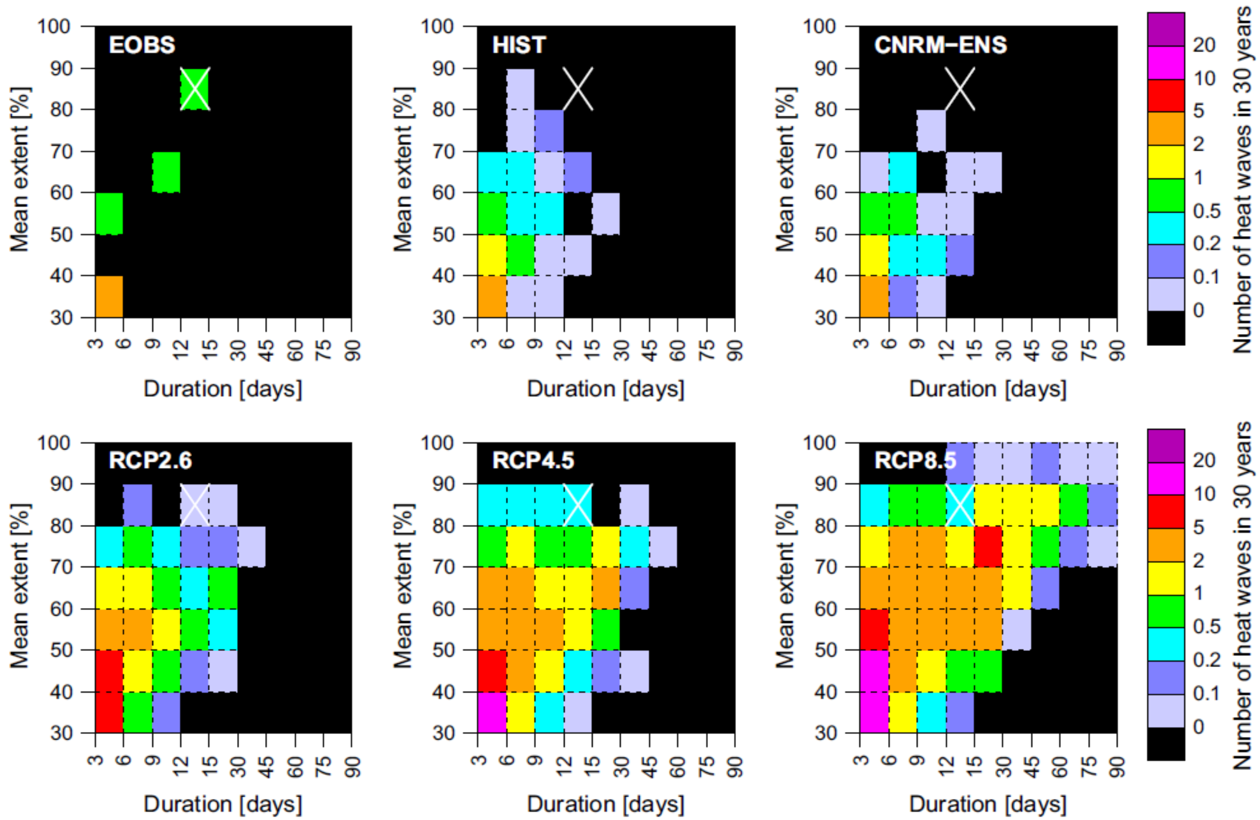
HWE severity: S = D x E x I

*Schoetter et al. 2015*

# Joint pdfs of heatwave duration and mean extent

Joint pdfs for EOBS, historical and future climate simulations (19 CMIP5 models). The *white cross* denotes the Aug 2003 heat wave.

*Schoetter et al. 2015*

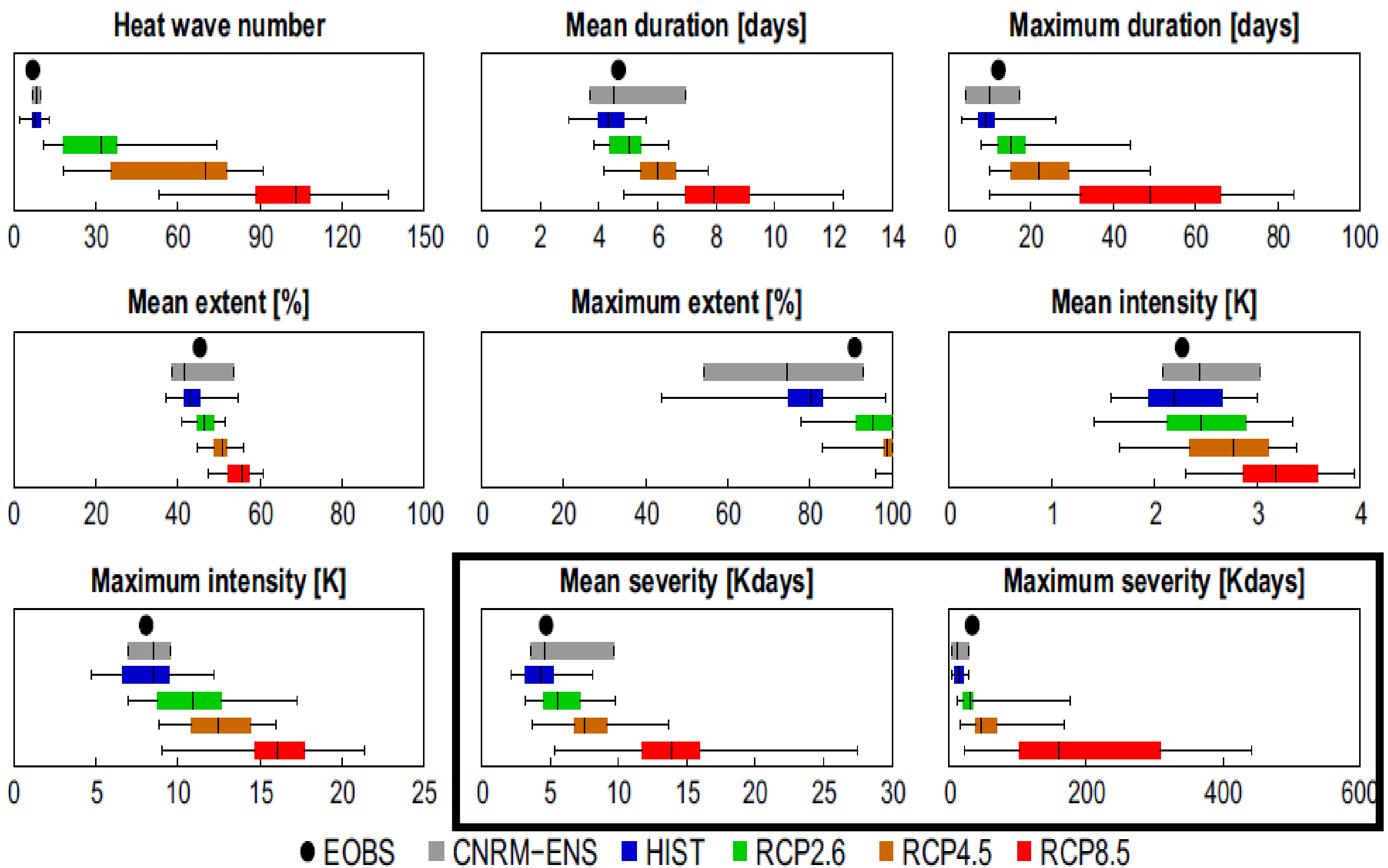



The average number of heat waves with higher or equal joint duration and mean extent than the 2003 heat wave is increasing from 0.1 (RCP2.6) to 6.1 (RCP8.5) in 30 years.

# Changes in summer heatwave properties

Box-whisker plots (median, interquartile range and full spread) for changes in mean and max properties of HWE

*Schoetter et al. 2015*




CMIP5 models show robust qualitative changes, but of very uncertain magnitude (e.g., factor 5 for changes in mean severity partly due to internal climate variability)

# Quantifying the SMF in the CNRM climate model

- The CNRM global climate model here consists of the ARPEGE-climat AGCM coupled to the SURFEX land surface model (CMIP5 version using a simple 3-layer hydrology which will be replaced by an explicit 14-layer diffusion scheme in CMIP6).
- 30-yr timeslice experiments (after spin-up) have been achieved for both present-day (P) and future (F) climate respectively.
- A simple nudging technique has been implemented to relax the deep (level 2 and 3) total soil moisture towards a monthly mean climatology without modifying the liquid/solid water ratio.
- The set of nudged (N) and reference (R) simulations allow us to partition the reference climate change into 4 contributions:

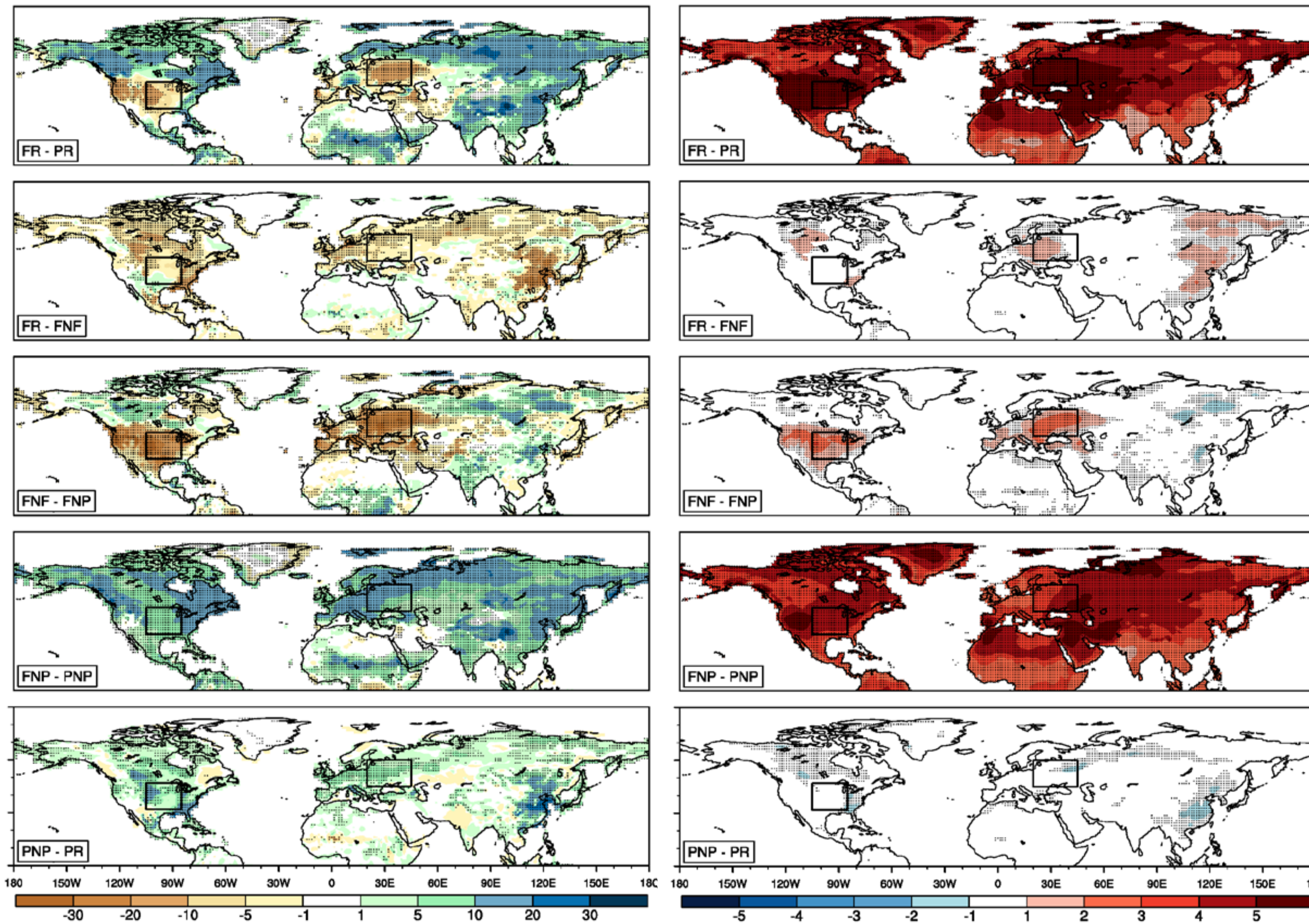
$$FR-PR=(FR-FNF)+(FNF-FNP)+(FNP-PNP)+(PNP-PR)$$

| (FR-FNF) | (FNF-FNP) | (FNP-PNP) | (PNP-PR) |
|---|---|---|---|
| Nudging in future climate (x-1) | SMF on future climate | Climate Change without SMF | Nudging in present-day climate |

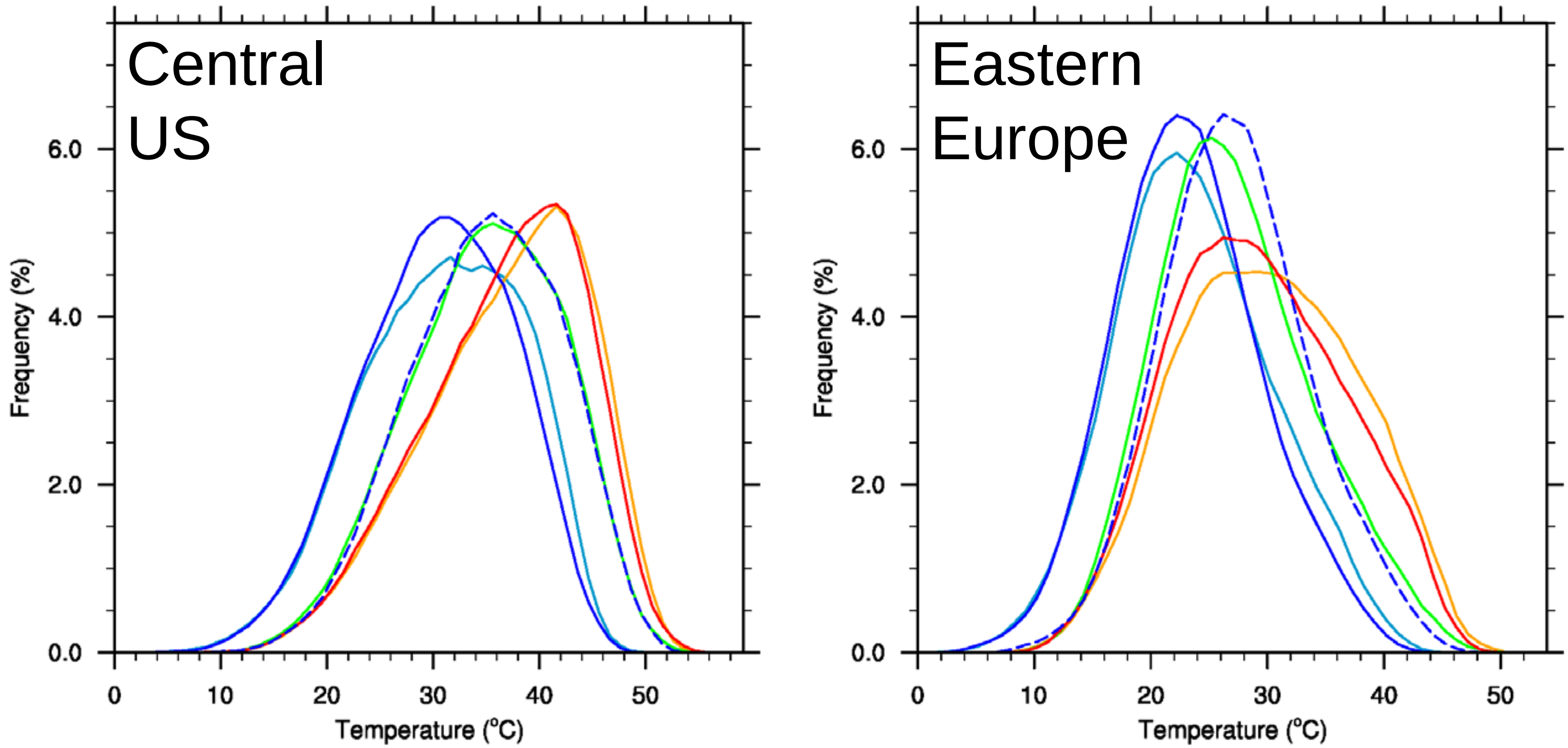
# Breakdown of summer mean climate change

Latent heat ($W.m^{-2}$) | 2-meter daily maximum temperature (°C)

Reference anomalies
=
Nudging in future climate (x-1)
+
SMF on future climate
+
Climate change without SMF
+
Nudging in present-day climate



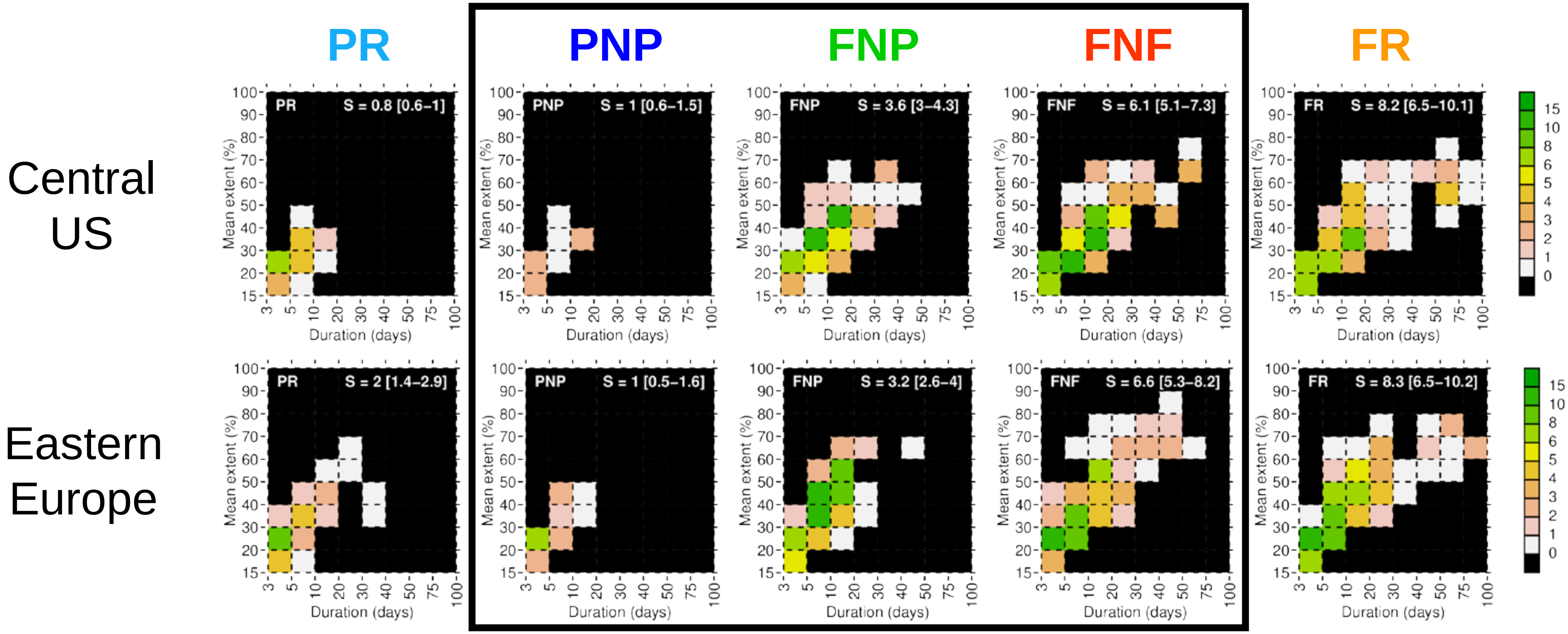
# Summer pdf of Tmax in all experiments




**FR-PR=(FR-FNF)+(FNF-FNP)+(FNP-PNP)+(PNP-PR)**

The soil moisture feedback dominates changes in the shape of the Tmax distribution in the mid-latitudes

# Joint pdf of heatwave duration and extent

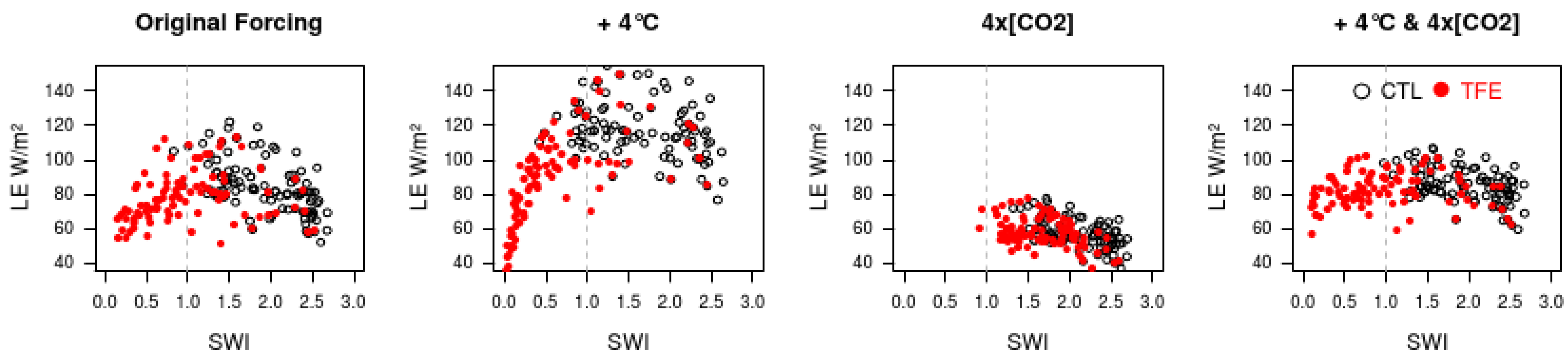



In each panel, S denotes the mean heat wave severity (normalized relative to the mean severity estimated in PNP) with the bootstrapped 5-95% confidence interval in brackets.

The soil moisture feedback explains about half of the increase in the mean severity of heatwaves over both Central US and Eastern Europe

# Constraining (extreme) temperature projections

- Although qualitatively robust, the projections of high-impact temperature extremes remain highly model-dependent.
- Recent (more or less successful) observational constraints of climate sensitivity and/or cloud feedbacks will not be sufficient for temperature extremes.
- Constraining the soil moisture feedback would be also very helpful.
- The vegetation response to both CO2 increase and climate change should be also explored.

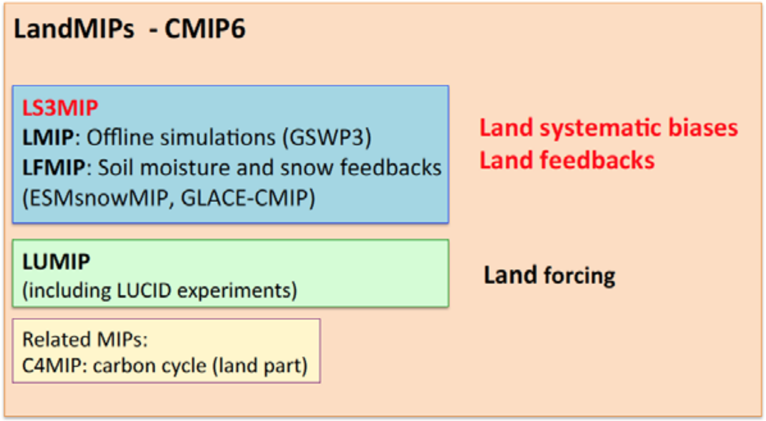



Simulated monthly latent heat (LE) vs. monthly soil wetness index (SWI) under observed and disturbed meteorological forcings for both control (black circles) and throughfall exclusion (red dots) plots at Caxiuanã. [*Joetzjer et al. 2014*]

# The LS3MIP objectives

- Intercomparison and evaluation of land surface biases in both offline (GSWP3) and online (CMIP6) LSMs
- Intercomparison of land surface responses in both offline (GSWP3) and online (CMIP6) LSMs (links with ISIMIP?)
- Quantification and Intercomparison of land surface feedbacks in global climate (AGCM and AOGCM) using simulations with prescribed soil moisture boundary conditions
- Focus on snow, soil moisture and vegetation (including direct $CO_2$ effect on plants' transpiration)

NB: Land use remains outside of LS3MIP with a dedicated parallel project (LUMIP)



# References


- Cattiaux, J., H. Douville, Y. Peings (2013) European temperatures in CMIP5: origins of present-day biases and future uncertainties. Clim. Dyn., doi:10.1007/s00382-013-1731-y
- Cattiaux, J., H. Douville, J. Najac, S. Parey, R. Schoetter, R. Vautard, P. Yiou (2015) Projected increase in the daily variability of European summer temperatures. Geophys. Res. Lett., 42, 899-907, doi:10.1002/2014GL062531
- Douville, H., J. Colin, E. Krug, J. Cattiaux (2015) Mid-latitude daily summer temperatures reshaped by soil moisture under climate change. Geophys. Res. Lett. (submitted)
- Schoetter, R., J. Cattiaux, H. Douville (2014) Changes of western European heat wave characteristics projected by the CMIP5 ensemble. Clim. Dyn., doi:10.1007/s00382-014-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# Kolmogorov-Smirnov distance between pdfs

Kolmogorov-Smirnov distance

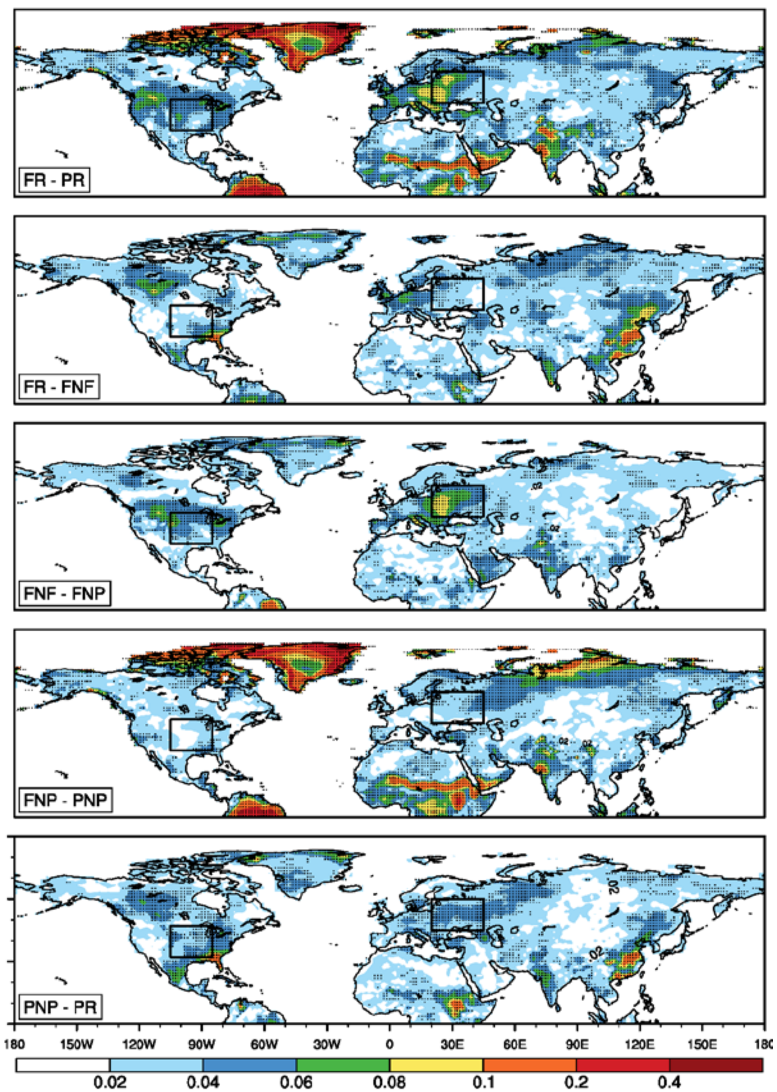
Reference distance

Nudging in future climate (x-1)

SMF on future climate

Climate change without SMF

Nudging in present-day climate




Kolmogorov–Smirnov distance between pairs of empirical distributions of daily Tmax. Stippling denotes grid cells where the distance is statistically significant at the 95% level. All distributions have been centered (i.e. the summer mean Tmax has been removed) to focus on the shape of the distribution.

The soil moisture feedback dominates changes in the shape of Tmax distribution in the mid-latitudes

# Changes in daily Tmax variance and skewness

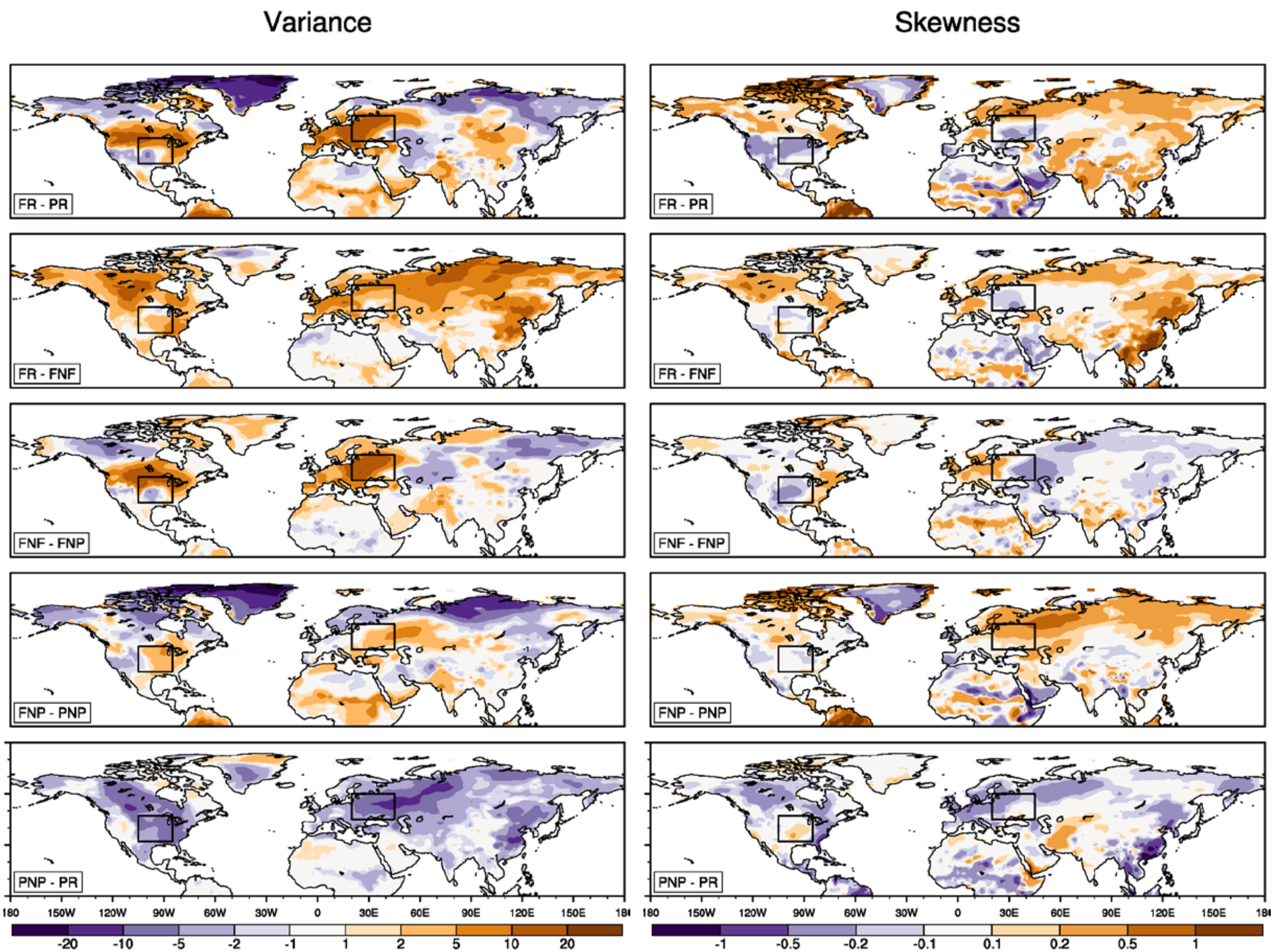
Reference anomalies

Nudging in future climate (x-1)

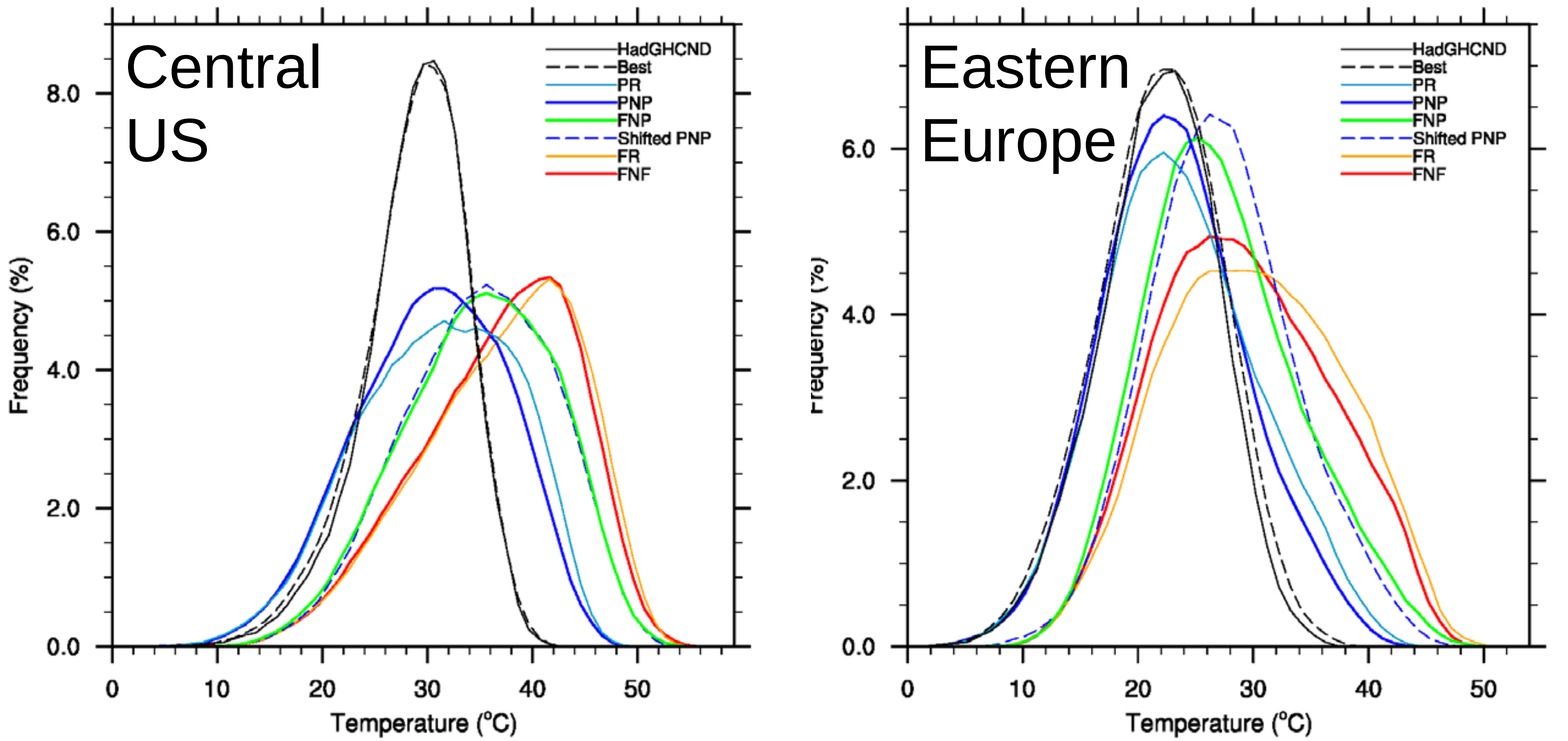
SMF on future climate

Climate change without SMF

Nudging in present-day climate



# Summer pdf of Tmax in all experiments

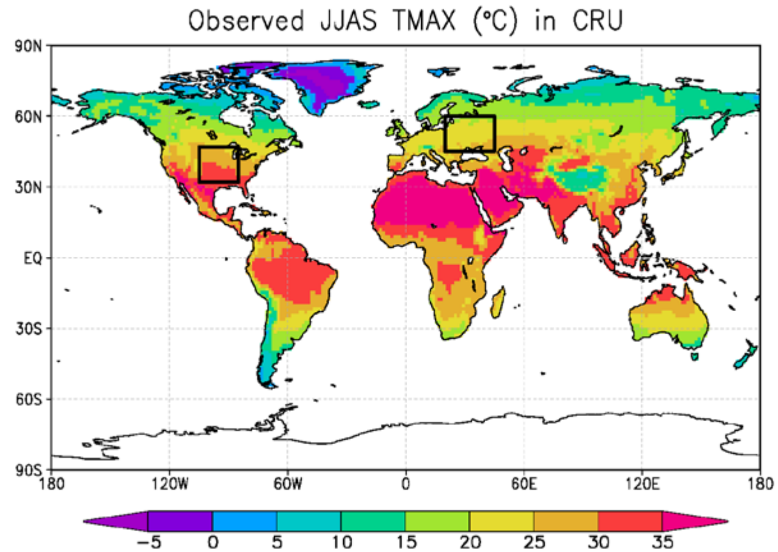


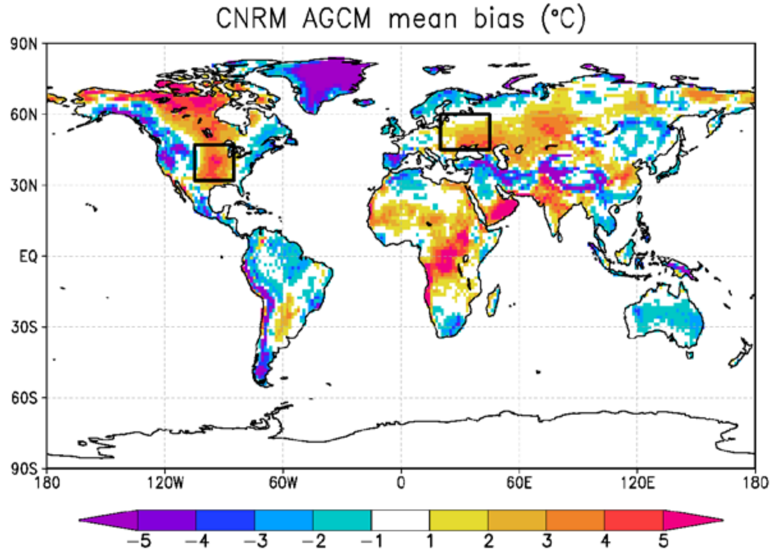

FR-PR=(FR-FNF)+(FNF-FNP)+(FNP-PNP)+(PNP-PR)

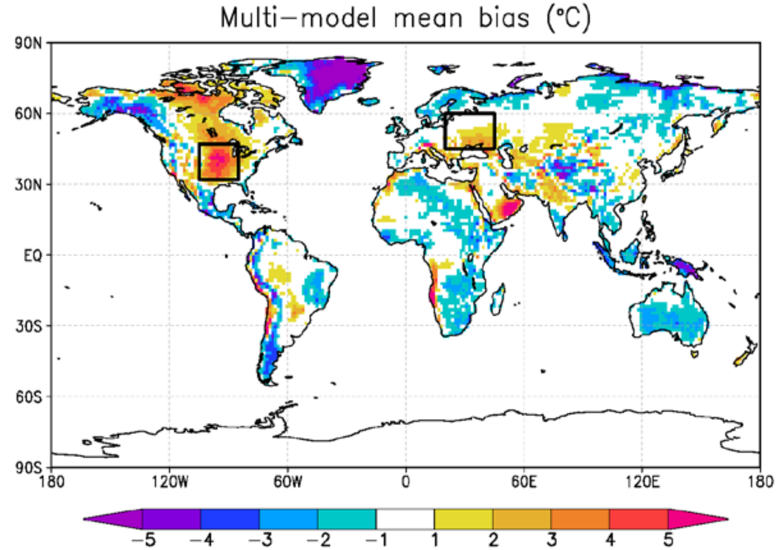
| (FR-FNF) | (FNF-FNP) | (FNP-PNP) | (PNP-PR) |
|---|---|---|---|
| Nudging in future climate (x-1) | SMF on future climate | Climate Change without SMF | Nudging in present-day climate |

# Warm mid-latitude bias in CMIP5 AGCMs

Global distribution of summer mean temperature biases (K) in ARPEGE-Climat and in an ensemble of 15 **AGCMs** (as part of CMIP5) averaged over the same 1979-2008 period.

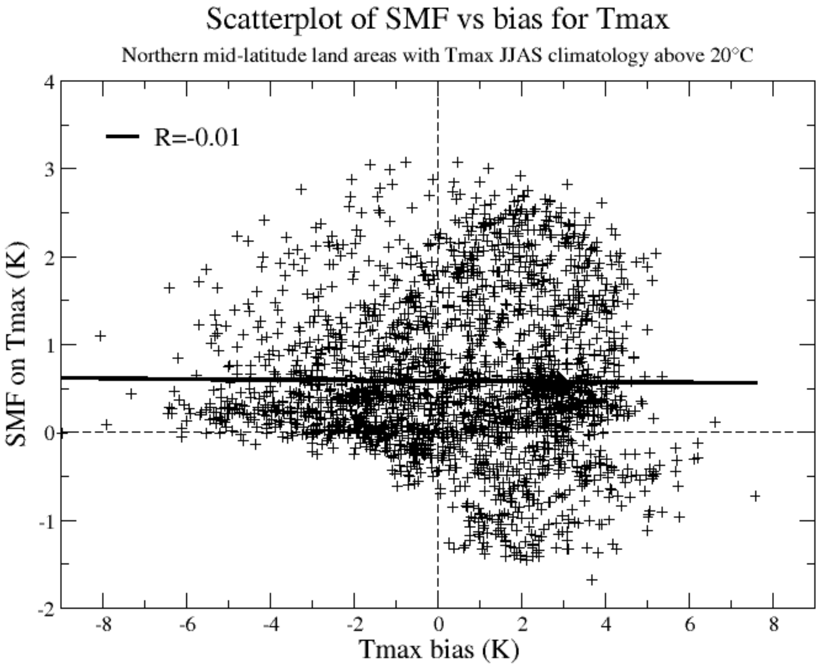


# (Lack of) relationship between SMF and biases

Scatterplot of the SMF on summer mean Tmax (estimated as the difference between FNF and FNP) versus the summer mean Tmax bias (estimated as the difference between PR and CRU_TS3.21 observations) in the temperate northern extratropics (land areas between 30°N and 75°N with summer mean Tmax > 20°C).




There is no clear relationship between Tmax biases and the SMF contribution to changes in Tmax anomalies.