Statistical Bias Correction of hydrological forcing fields from GCMs: *basic concepts*.

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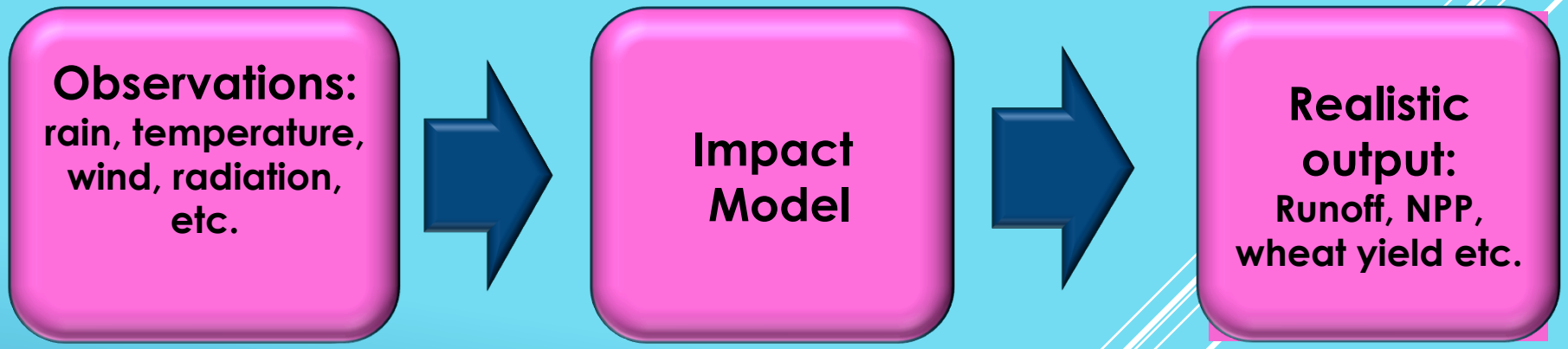
Why do we bias correct GCM output before using it to force hydrological models?



Force an impact model, that performs well when forced with observations, with unprocessed GCM output and you don't get an acceptable result…

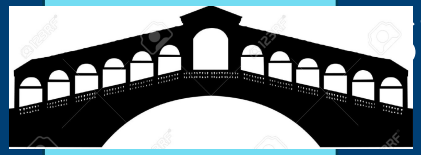
Why?

- Gridded precipitation from CGMs is not the same physical variable as the observed:
  - Temporal and spatial averaging.
  - Under-catch corrections
  - Sampling error
  - Other?

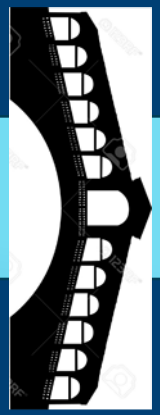
- The GCM daily temperature cycle is physically closer to the observed but there are still differences:
  - Temporal and spatial averaging
  - Ground effects
  - Evapotranspiration terms are very sensitive to temperature

SIMPLE BIAS CORRECTION METHODS

Simulated Present

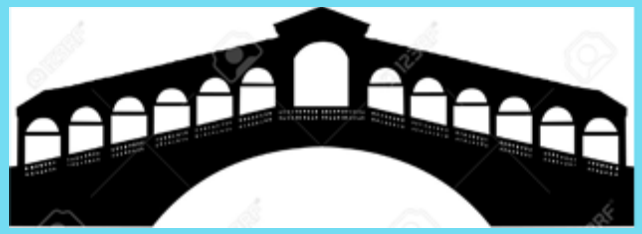


Simulated Future



Observed Present

Observed Future



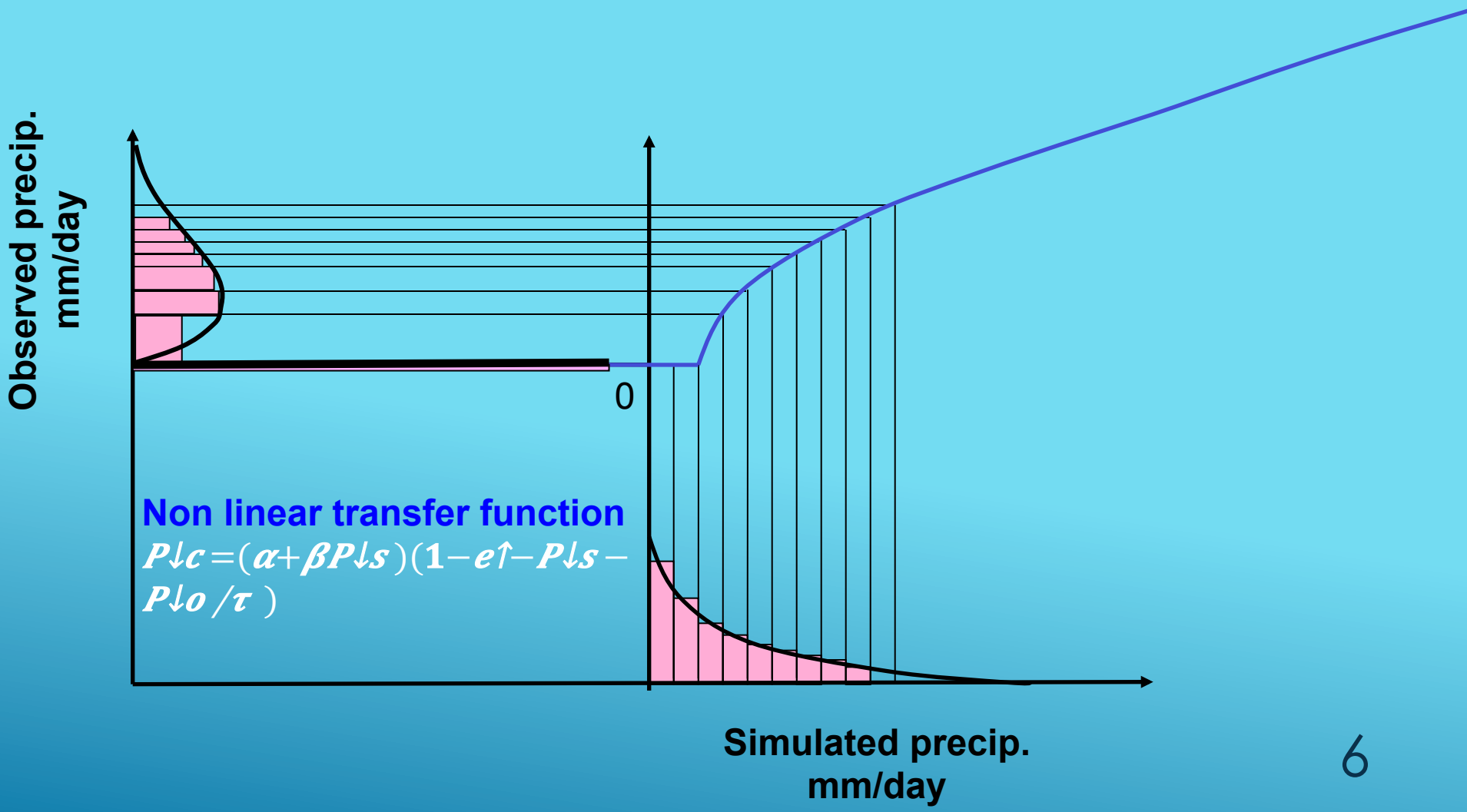
- **Additive bias correction**
  - Improves only the means and has no effect on variance, skewness etc..
  - Will not terribly mess up your projections.

- **Multiplicative bias correction.**
  - May be set to correct mean or variances but not both.
  - Will affect the simulated climate signal.
  - May have apocalyptic effects on projections

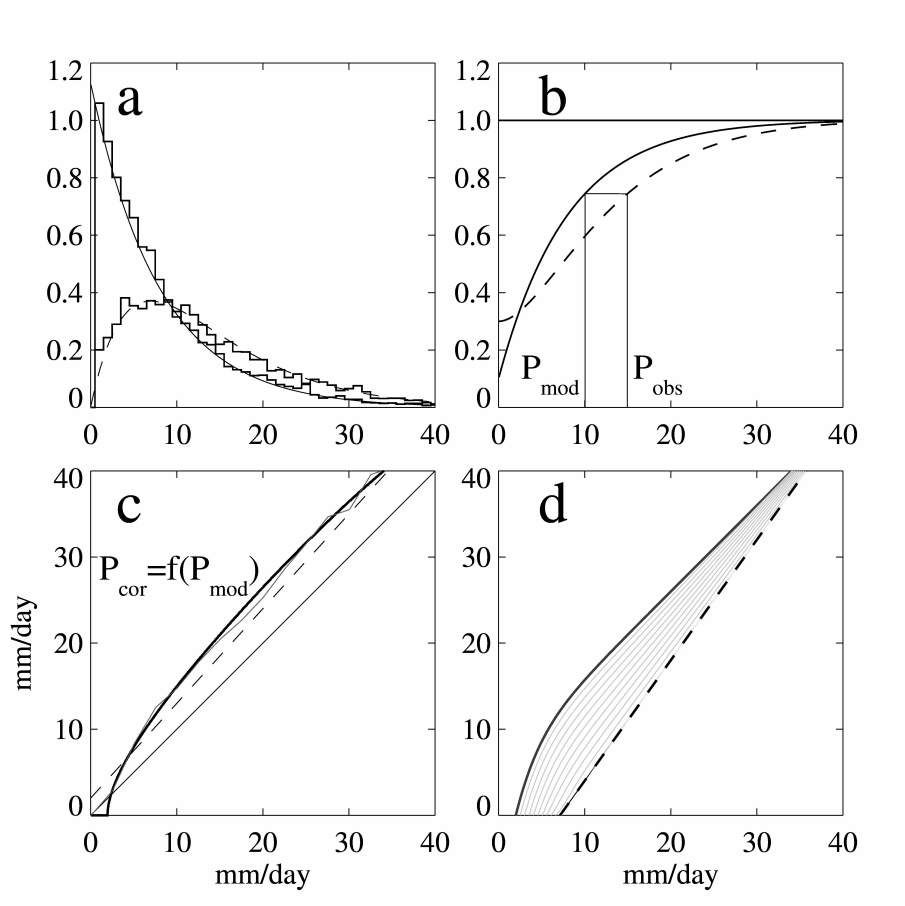
- **The 'histogram matching' or 'quantile mapping' bias correction methods potentially correct all moments of the statistical distribution.**

- **It uses all available information from both simulations and observations.**

How histogram matching works



Histogram matching methodology



a) Idealized histograms of simulated (solid line) and observed (dashed line) daily precipitation.

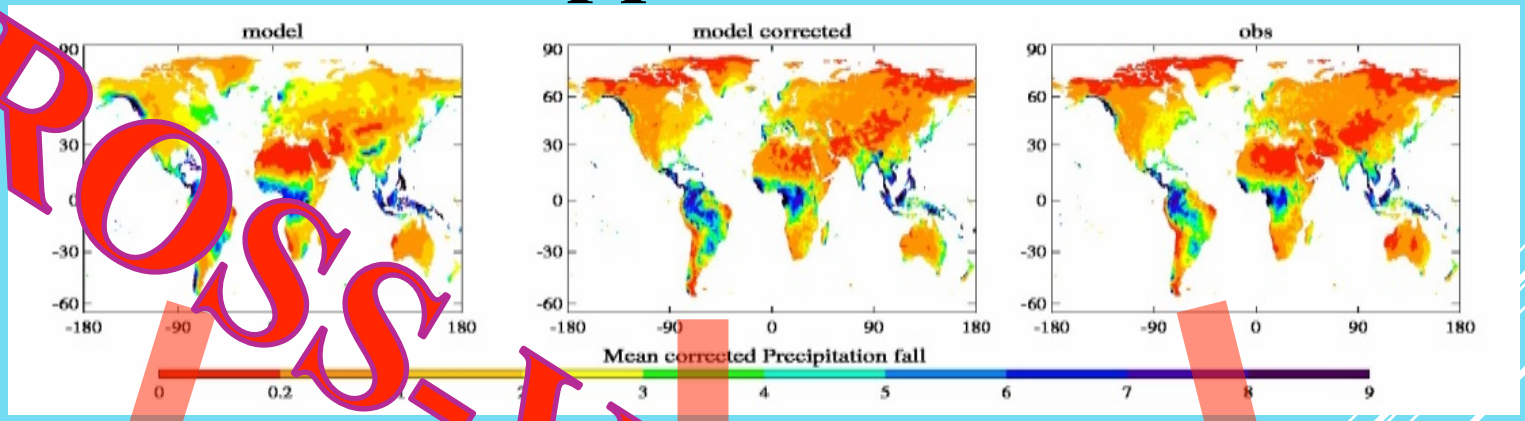
b) Cumulative distributions.

c) Transform function. Is determined by few (< 3) parameters.

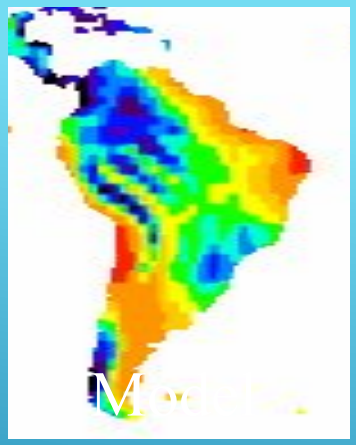
d) Transitional daily transform functions.

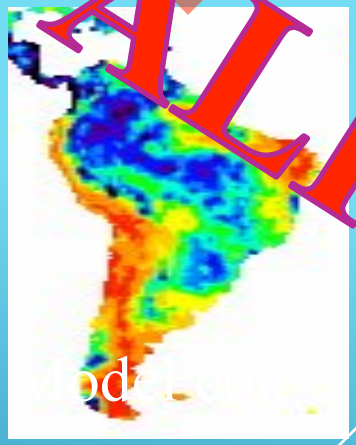
e) YOU DON'T NEED TO DO ANY OF THIS TO CALCULATE THE TF! Just plot Rank of Obs. vs Rank of Sim.

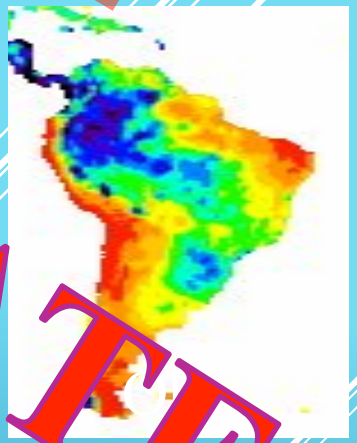
Application



CROSS-VALIDATE!!!





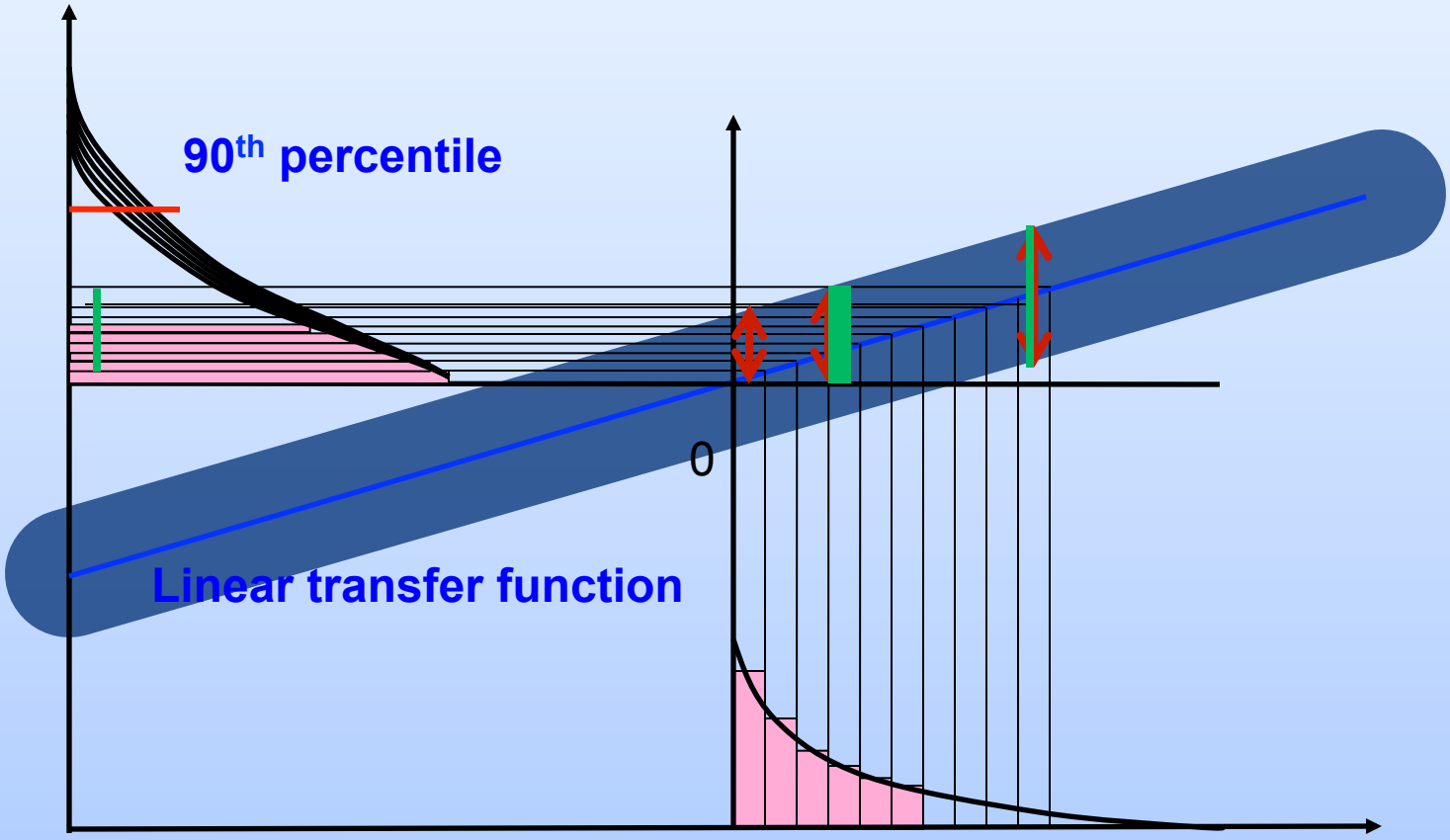


1990-2000 January precipitation over South America corrected using 1960-1970 transfer function.

Uncertainty in the bias correction (TF)

- Fits to the transform function are associated with uncertainty from different sources:
  - Standard error associated with fit (negligible).
  - Choice of fitting function. (can be made negligible, trade-off with robustness)
  - Decadal variability of fit parameters. (*This is the big one… and this is why you cross-validate!!!!!!*)

How does uncertainty in the TF affect the transformed histogram?



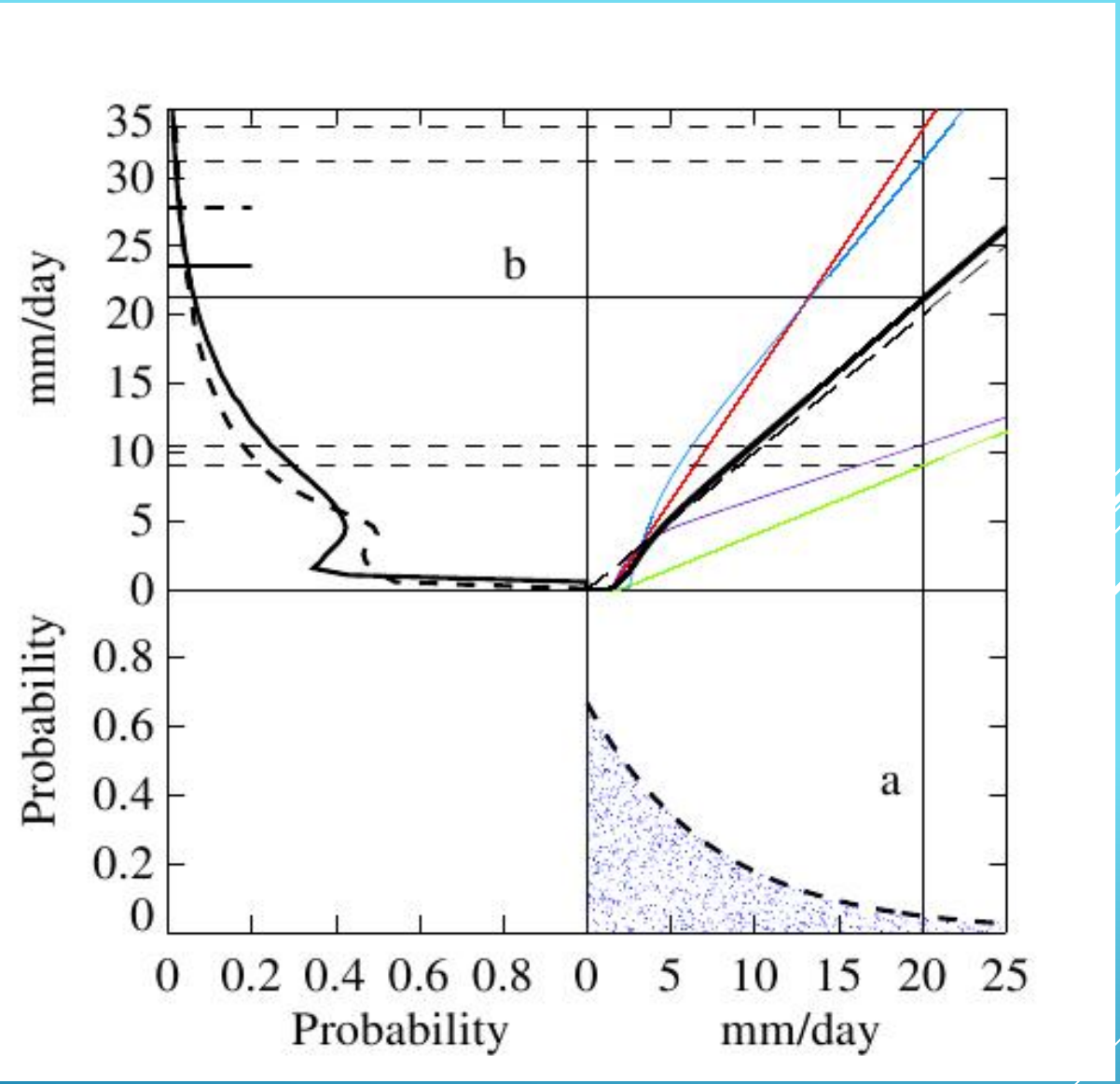
•How can we produce a horizontal mapping of the bias-correction-induced uncertainty? (*ex.: precipitation*):

•Plot the average additive correction for the 90th percentile of the local precipitation intensity distribution in mm/day.

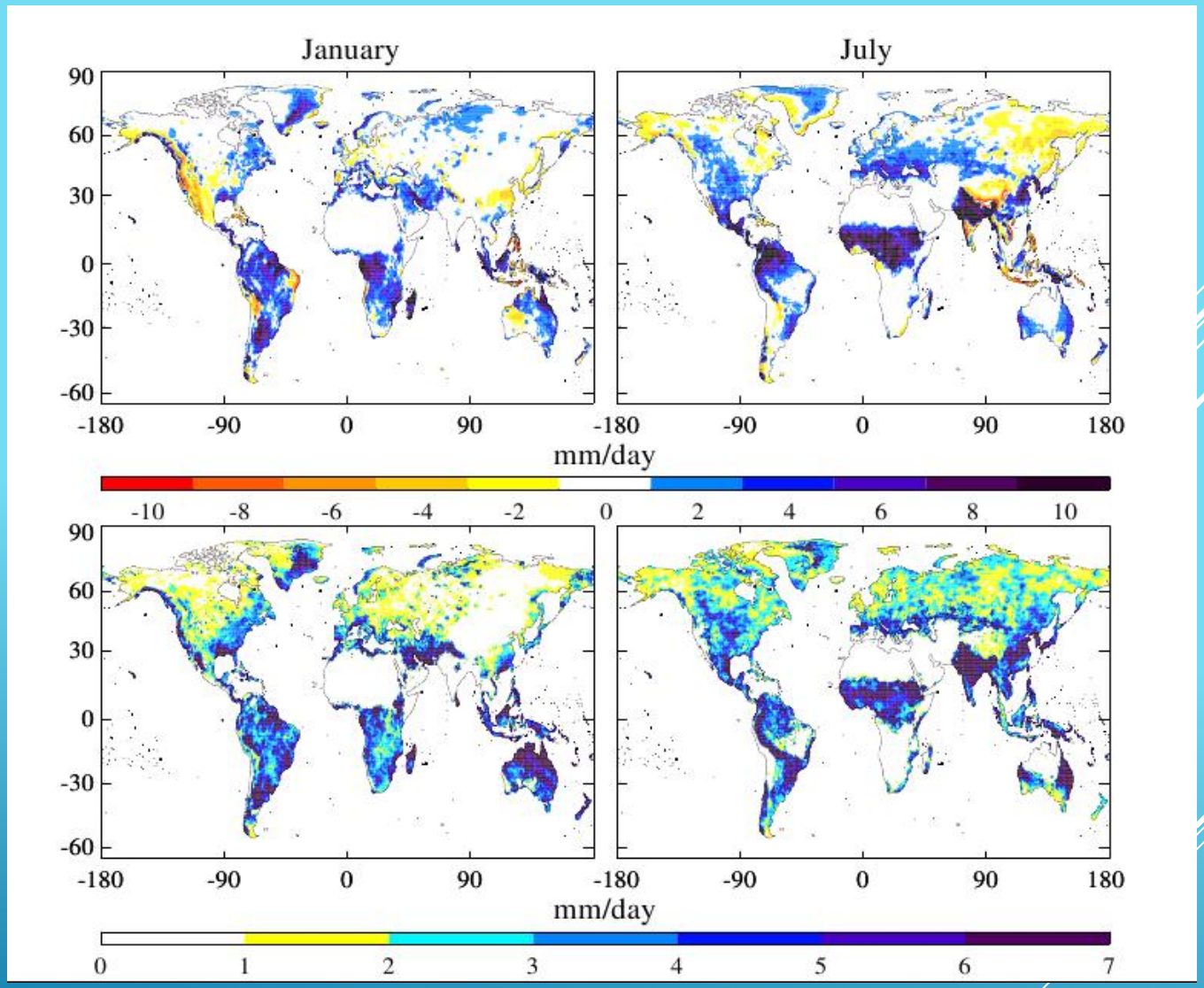
• The average is computed over the 12 separate *TFs* obtained using the 3 members of the ECHAM5 ensemble alternatively with the 4 decadal periods form 1960 to 1999.

• Plot the standard deviation across the 12 *TFs* for the same intensity percentile.

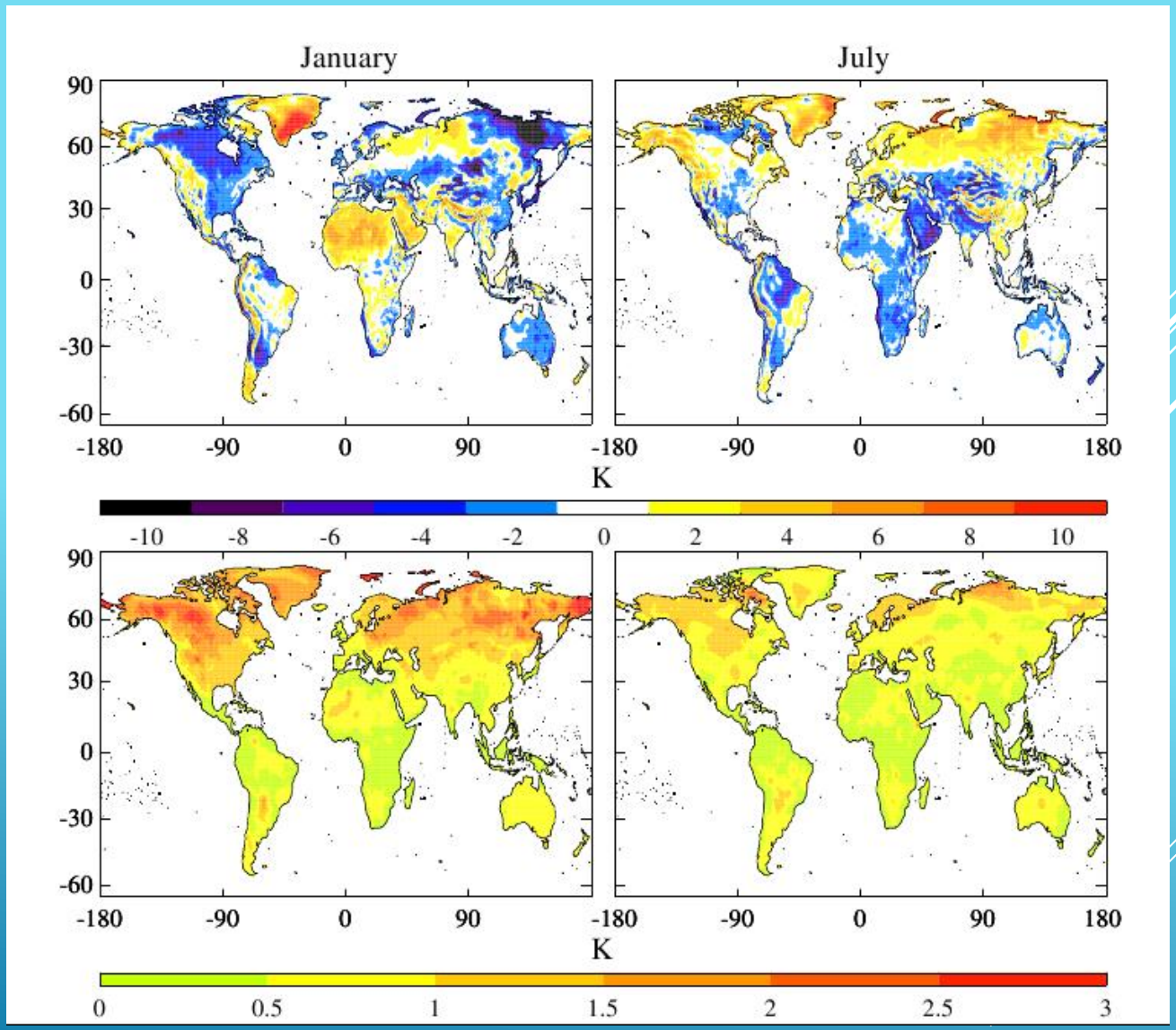
Accounting for uncertainty in the bias correction.



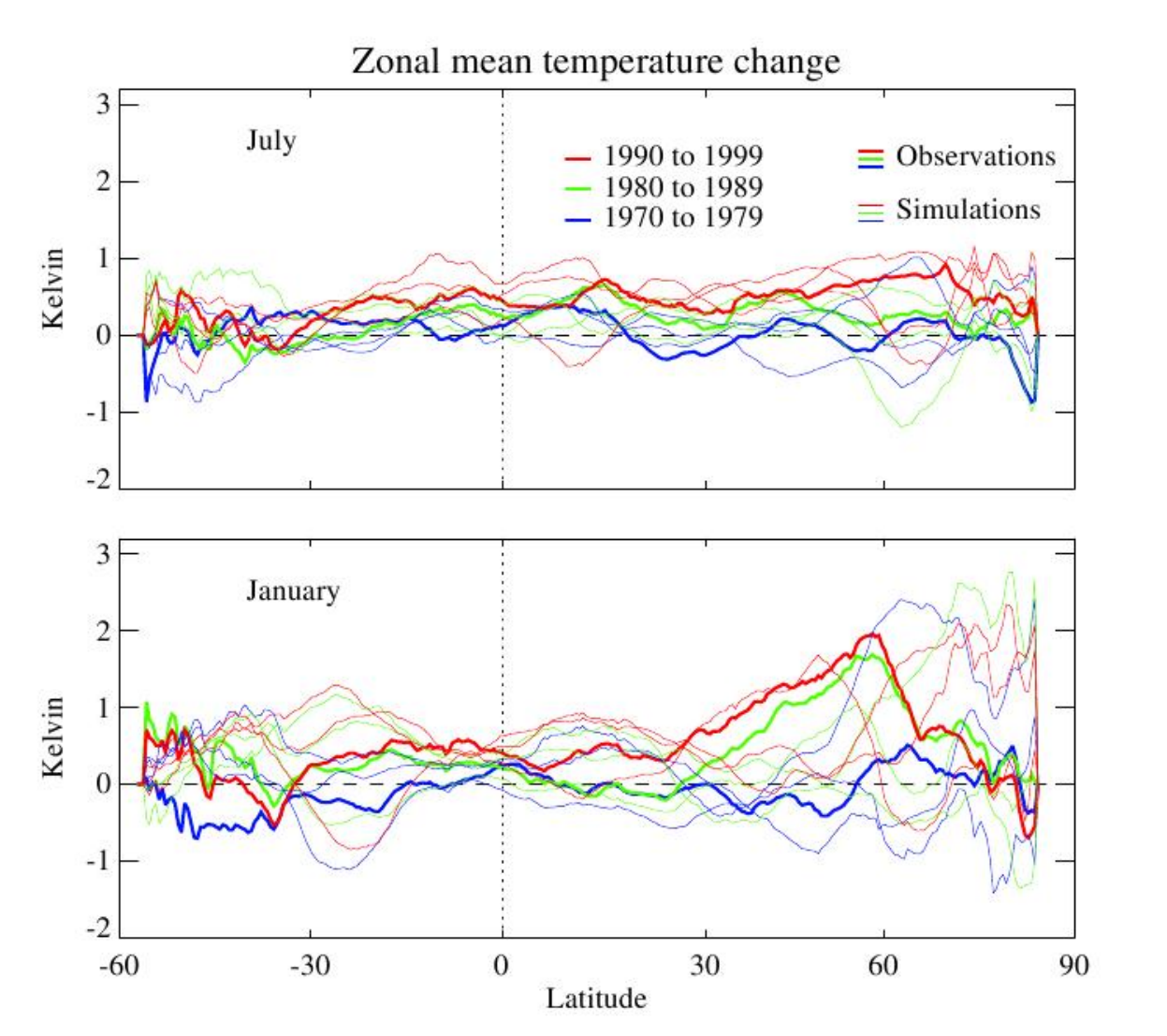
Uncertainty in the bias correction for daily precipitation.



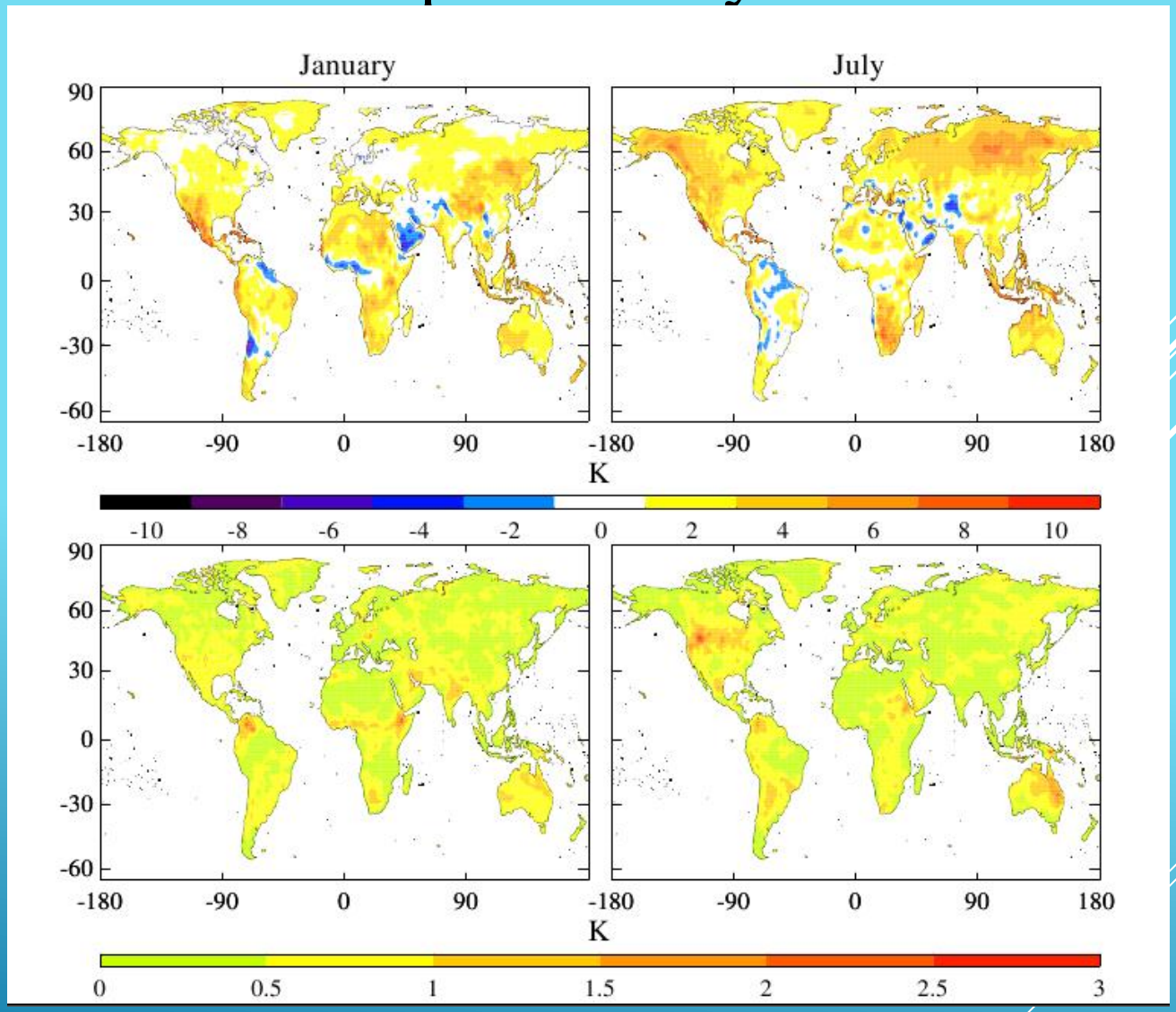
Uncertainty in the bias correction for daily temperarure.



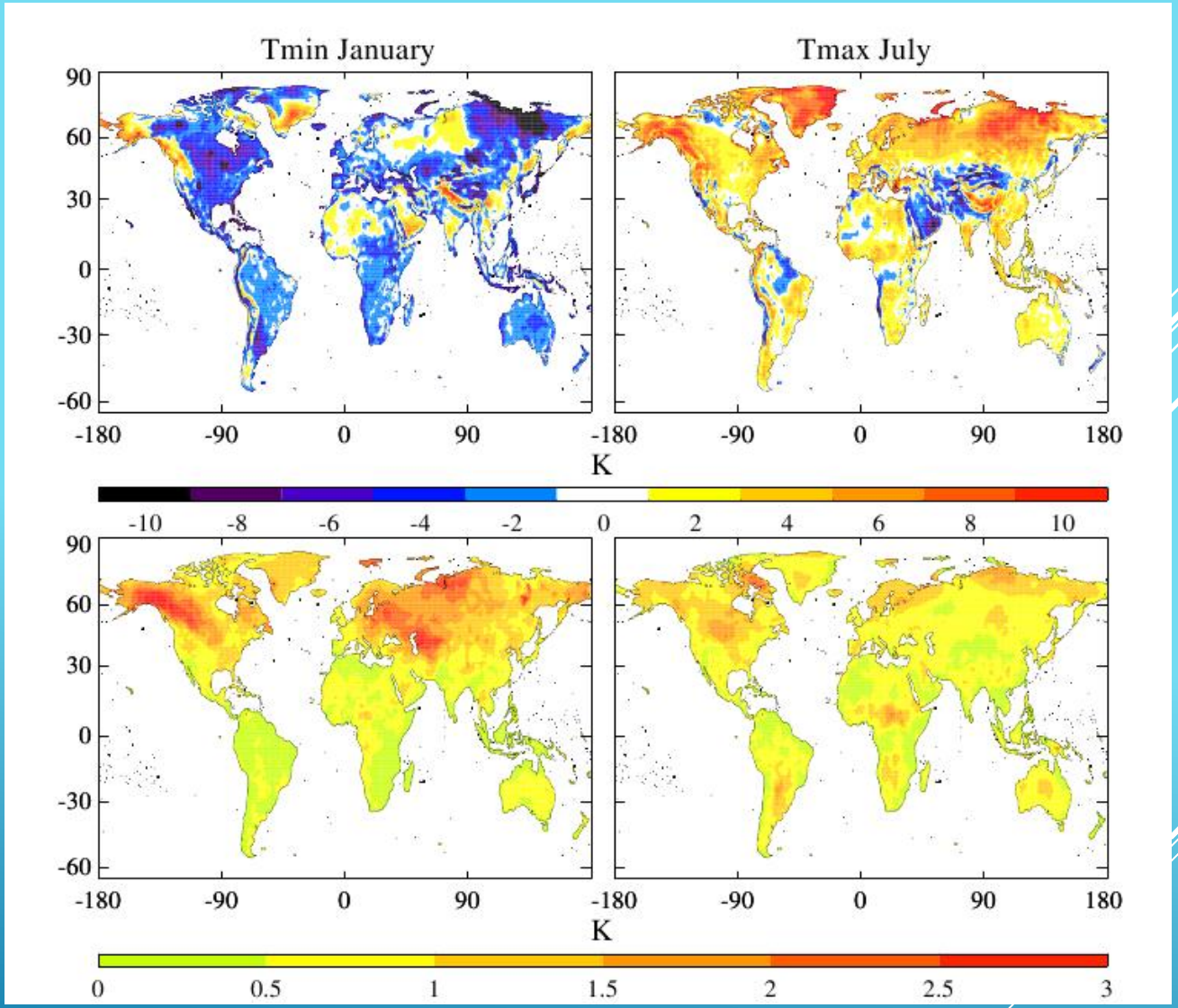
Decadal variability of zonal mean temperature.



Uncertainty in the bias correction for daily temperature cycle.



Uncertainty in the bias correction for mean daily minimum (maximum) temperatures for the month of January (July).



Conclusions and remarks

- Bias correction is an essential step in producing simulated hydrological projections.

- Statistical BC allows all the information in both observations and model to be taken in consideration.

- The validity of a new BC methodology must be established via cross-validation.

- The different choice of BC methodology is NOT an added source of uncertainty.

- Any bias correction method applied across an ensemble of simulations will drastically reduce the spread of results.

Statistical Bias Correction of hydrological forcing fields from GCMs: *Challenges*

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What are some of the remaining problems?

•Statistical bias corrections are couched in uncertainty. The difference between Bias and Error depends on the length of the simulation.

•**Suggested solution**: Analysis of transfer function spread.
(Piani et al., 2010b, Chen et al. 2012)…. ***Not really a solution…***

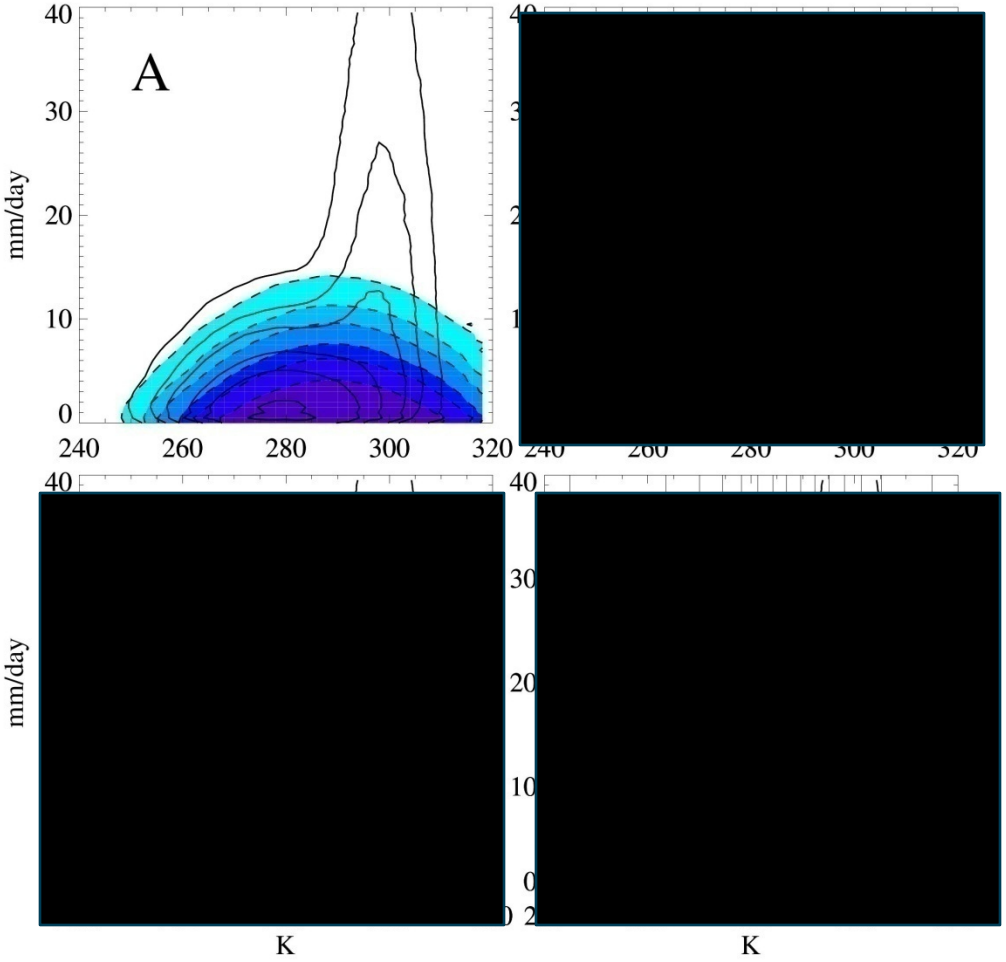
•So far we have corrected temperature and precipitation separately. No improvements are made in the representation of the dynamical relations between the two variables.

•**Suggested solution**: undertake full 2D statistical bias correction.
(Piani and Haerter, 2012, Montroull et al. 2015)… ***Difficult….***

•Corrections are not independent on time scale: if you correct the daily variance you do not correct the monthly variance.

•**Suggested solution**: the cascade statistical bias correction.
(*Haerter and Piani, 2012, Hearter and al. 2015*)

2D statistical bias correction of temperature and precipitation (2D histogram matching).



A) Idealized 2D histograms of simulated (colored contours) and observed (solid contours) daily precipitation and temperature.

B) Like **A**, but the simulations have been independently corrected with a linear Transfer Function.

C) Like **B**, but the simulations have been independently corrected with a perfect Transfer Function.

D) Like **B**, but the simulations have been corrected with a 2D linear Transfer Function.

Application 2D statistical bias correction

Simulations: Max Planck Institute for Meteorology regional climate model (REMO)

Observations: station data (Kempten, Schleswig).

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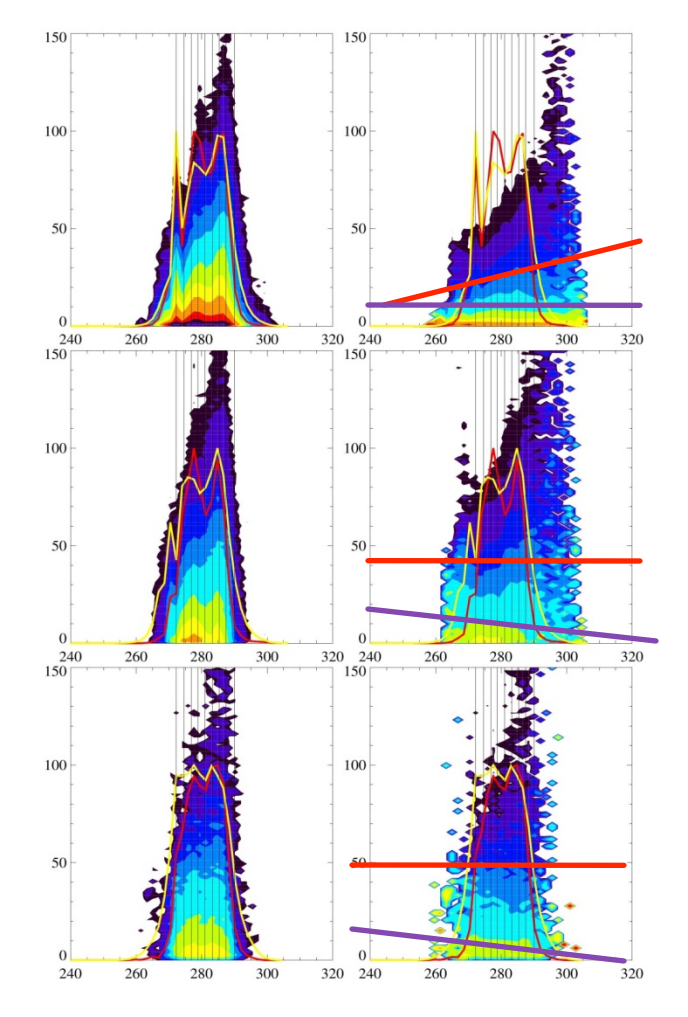
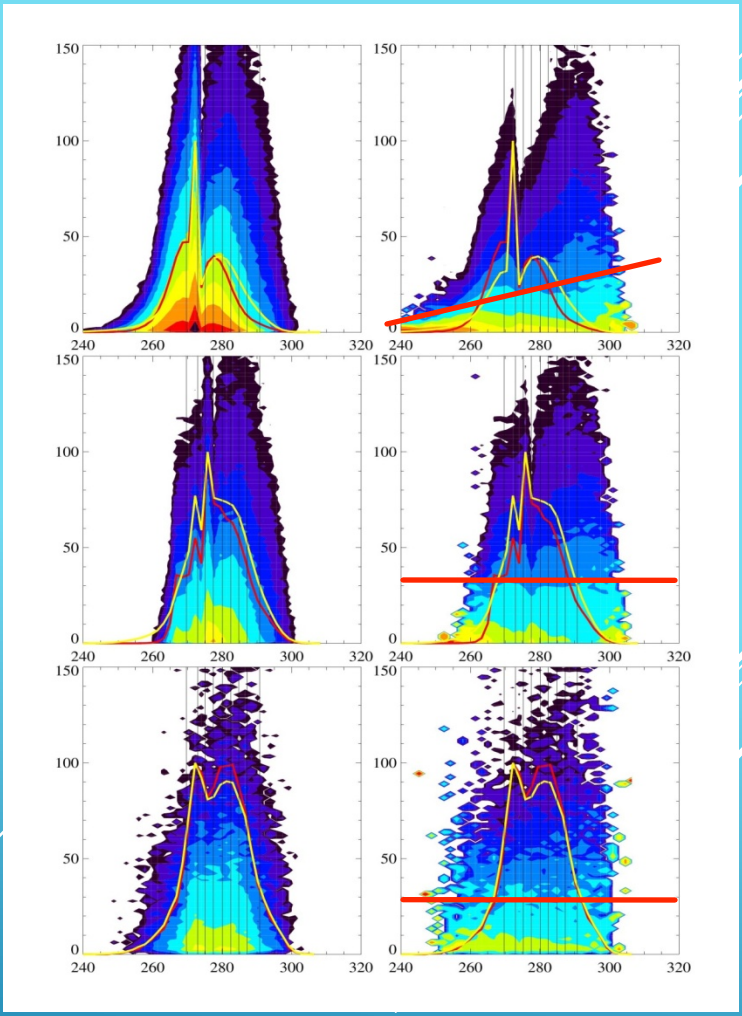




Copulas

- **Definition of 2D Copula**

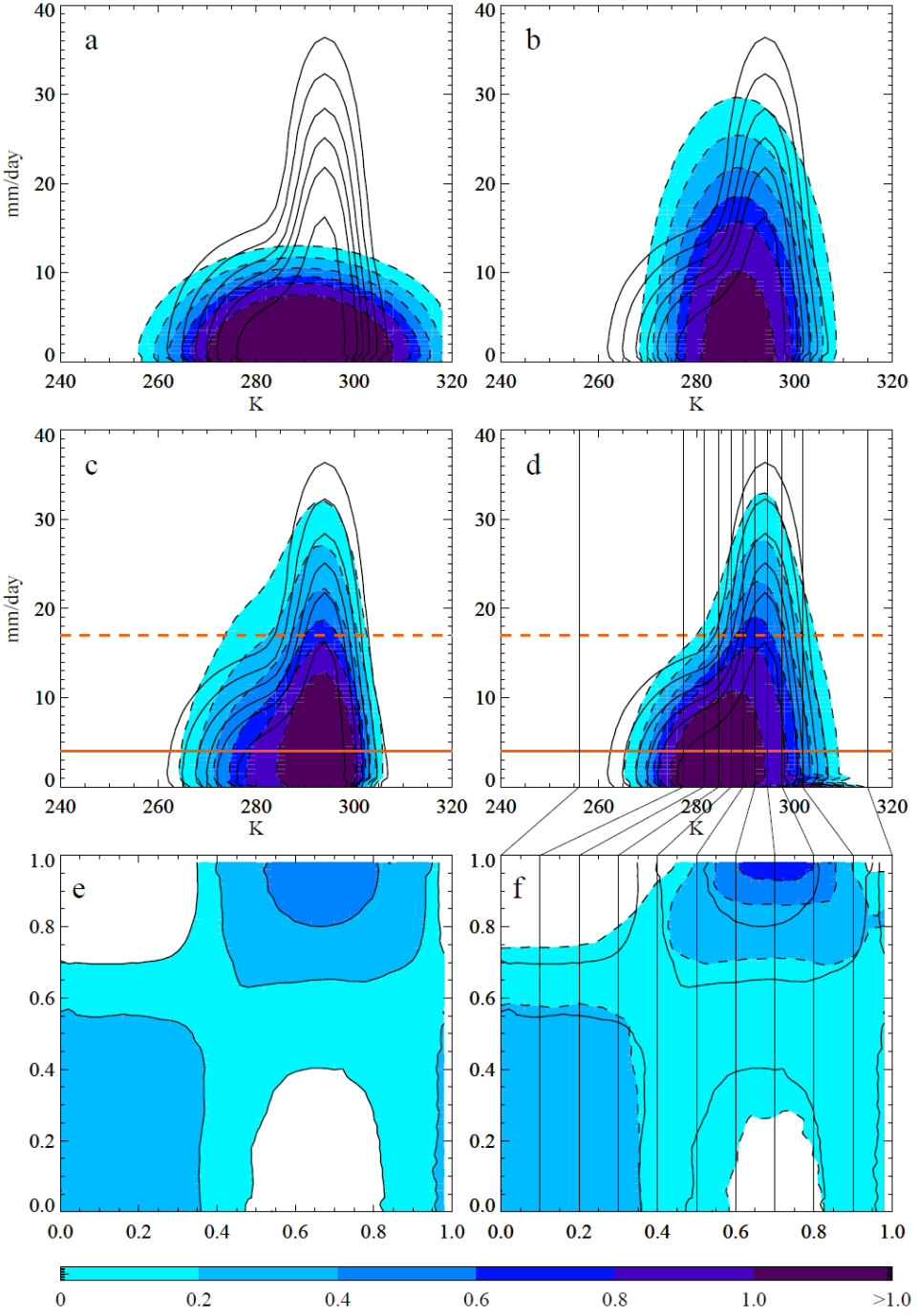
C: $[0,1]^2 \rightarrow [0,1]^2$ is a *2*D **copula** if *C* is a joint cumulative distribution function of a *2*D random vector on the unit square with uniform marginals.

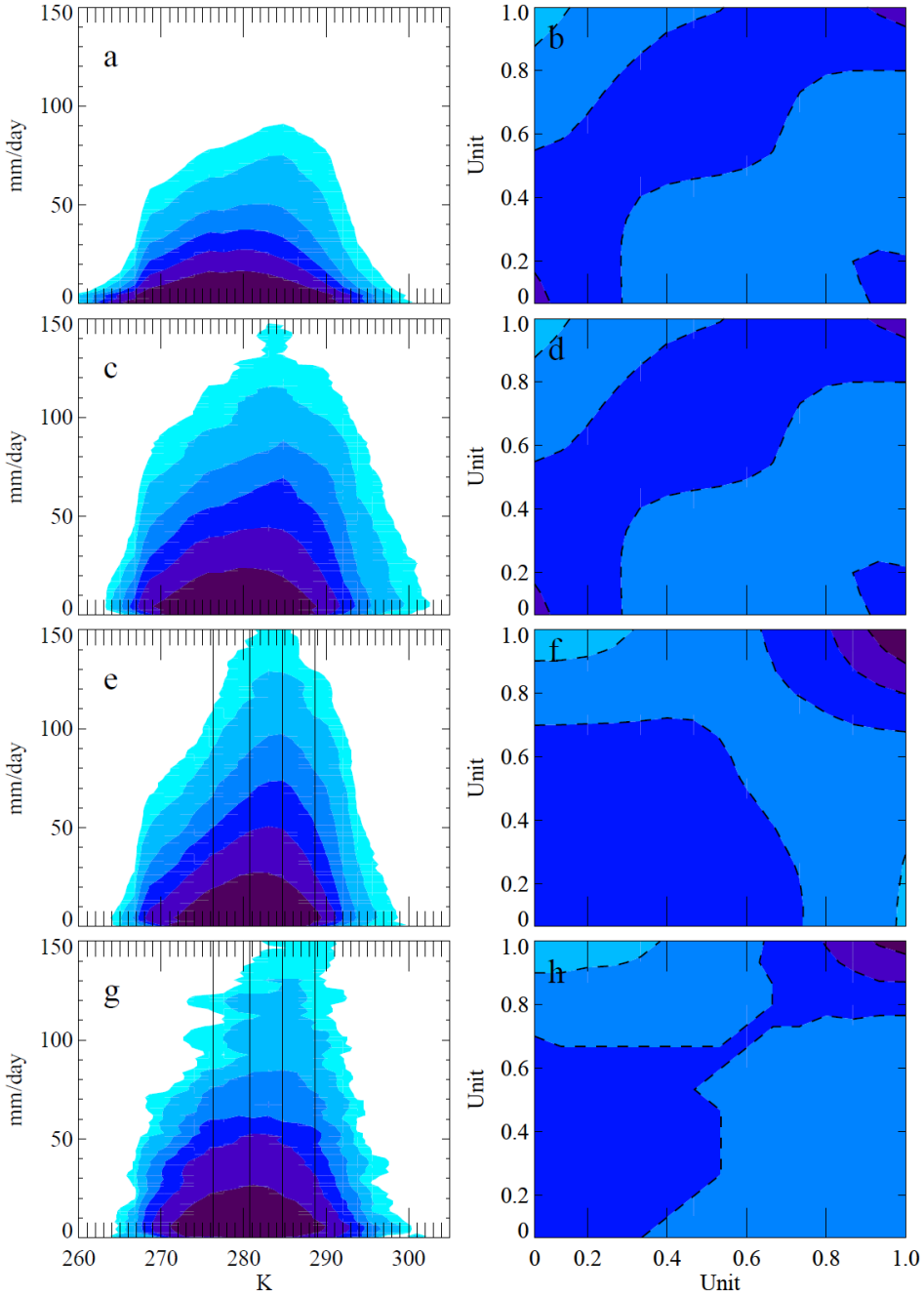
- **Definition of 2D Copula probability density function**
- *Cpdf*: $[0,1]^2 \rightarrow [0,1]$ is a *2D* **copula probability density function** if *Cpdf* is a joint PDF of a *2*D random vector on the unit square with uniform marginals.

- **Marginal** is the resulting PDF for one of the variables after integrating over the other….

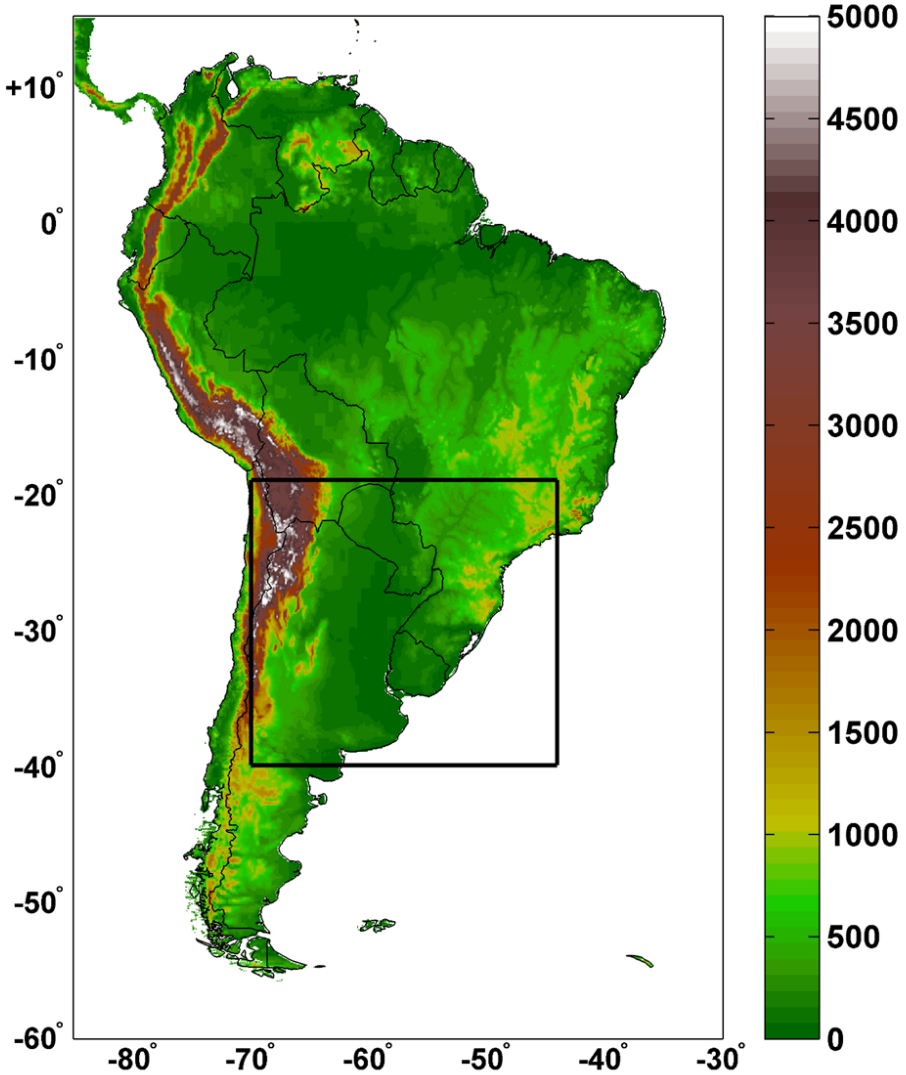
Why Copulas?

- Copulas are a comprehensive graphic representation of the statistical link between two variables unobscured by the particular shape of the distributions of the individual variables (marginals).
- The calculation of a CPDFs is difficult to explain to a human but extremely easy to code.
- For example, given a data set of 100 measurements of daily precipitation and temperature, simply substitute every pair (P,T) with their rankings, i.e. (0.94,0.52) if it was the 94^{TH} driest day and the 52^{nd} coldest.
- That's it. Then just plot the 2D PDF of the rankings.


a
b
c
d
e
f
mm/day
K
0
10
20
30
40
240
260
280
300
320
0.0
0.2
0.4
0.6
0.8
1.0
>1.0

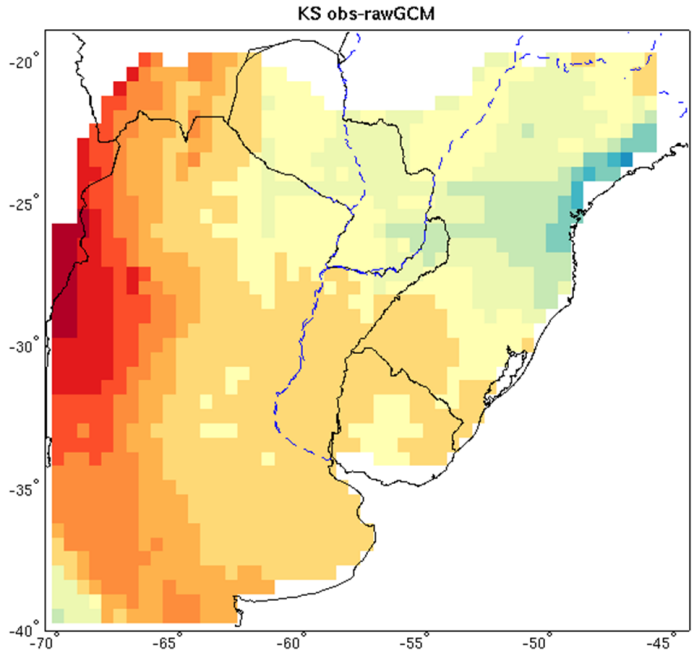

a
b
c
d
e
f
g
h
mm/day
Unit
150
100
50
0
1.0
0.8
0.6
0.4
0.2
260
270
280
290
300
K
0.2
0.4
0.6
0.8
1.0

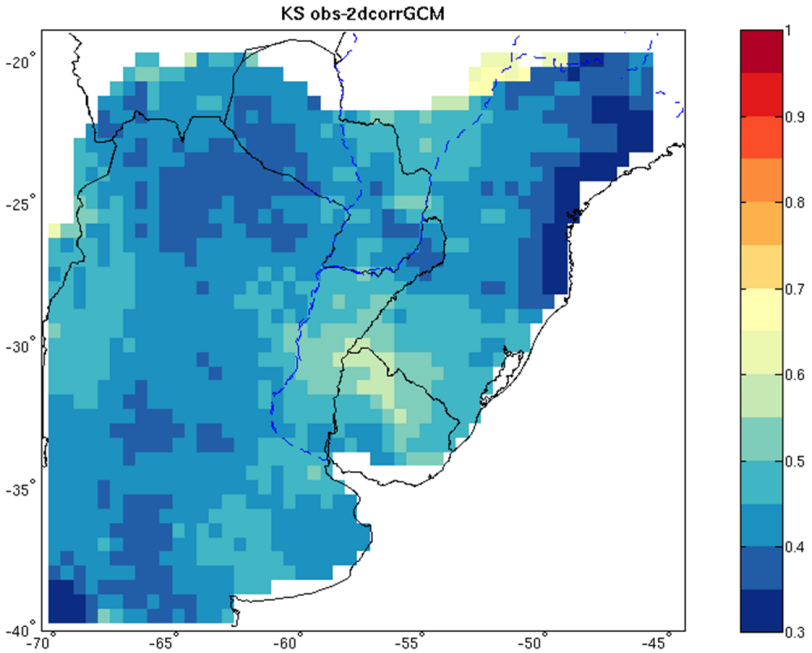
La Plata basin



Two Dimensional Kolmogorov-Smirnov statistic

-measuring the statistical differences between temperature and precipitation copulas before and after correction. Remember this is a cross-validation.



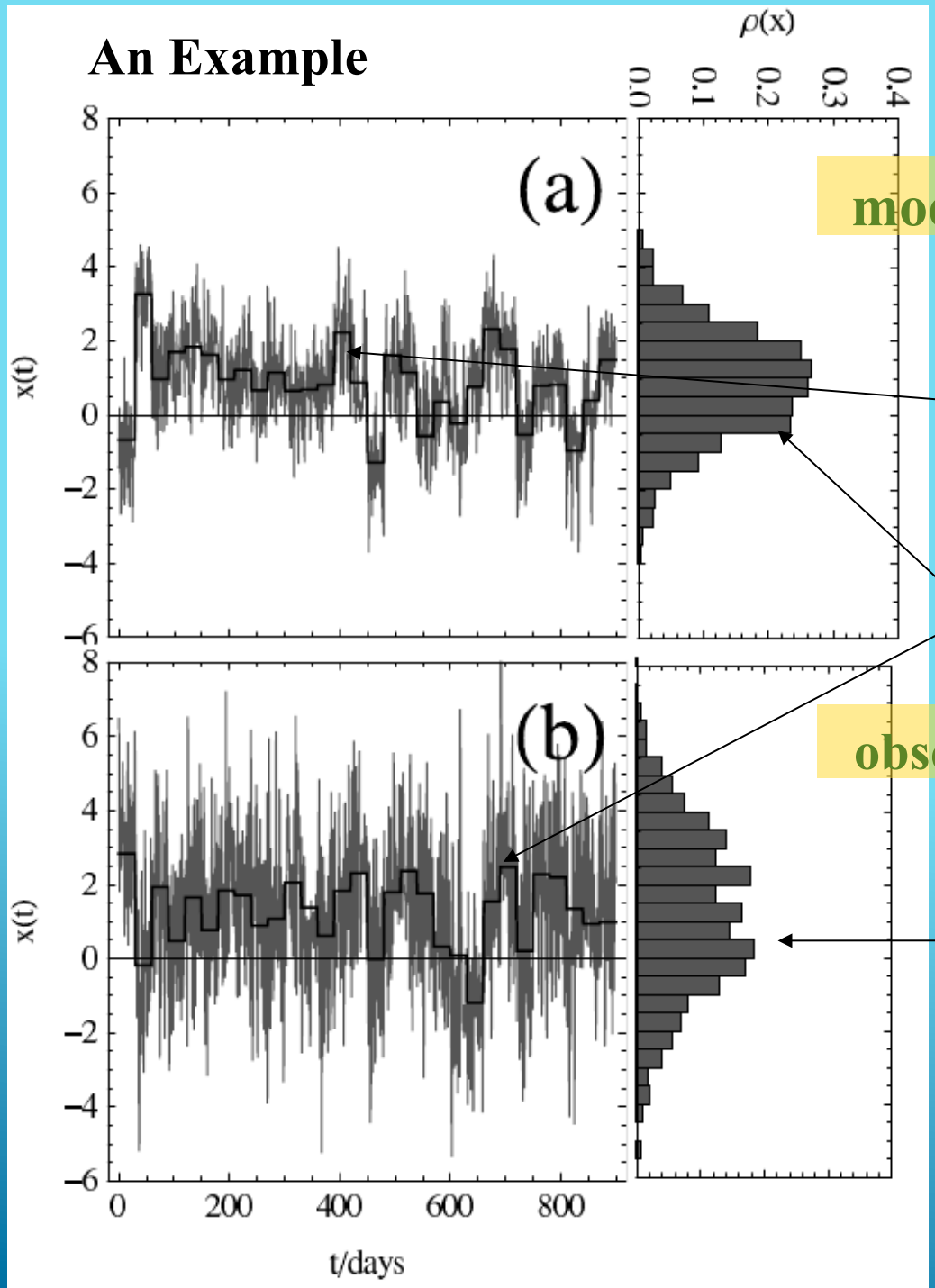


From Montroull et al. 2014

Bias Corrections are dependent on time scale.

i.e. if you correct the daily variance you do not correct the monthly variance…..

An Example



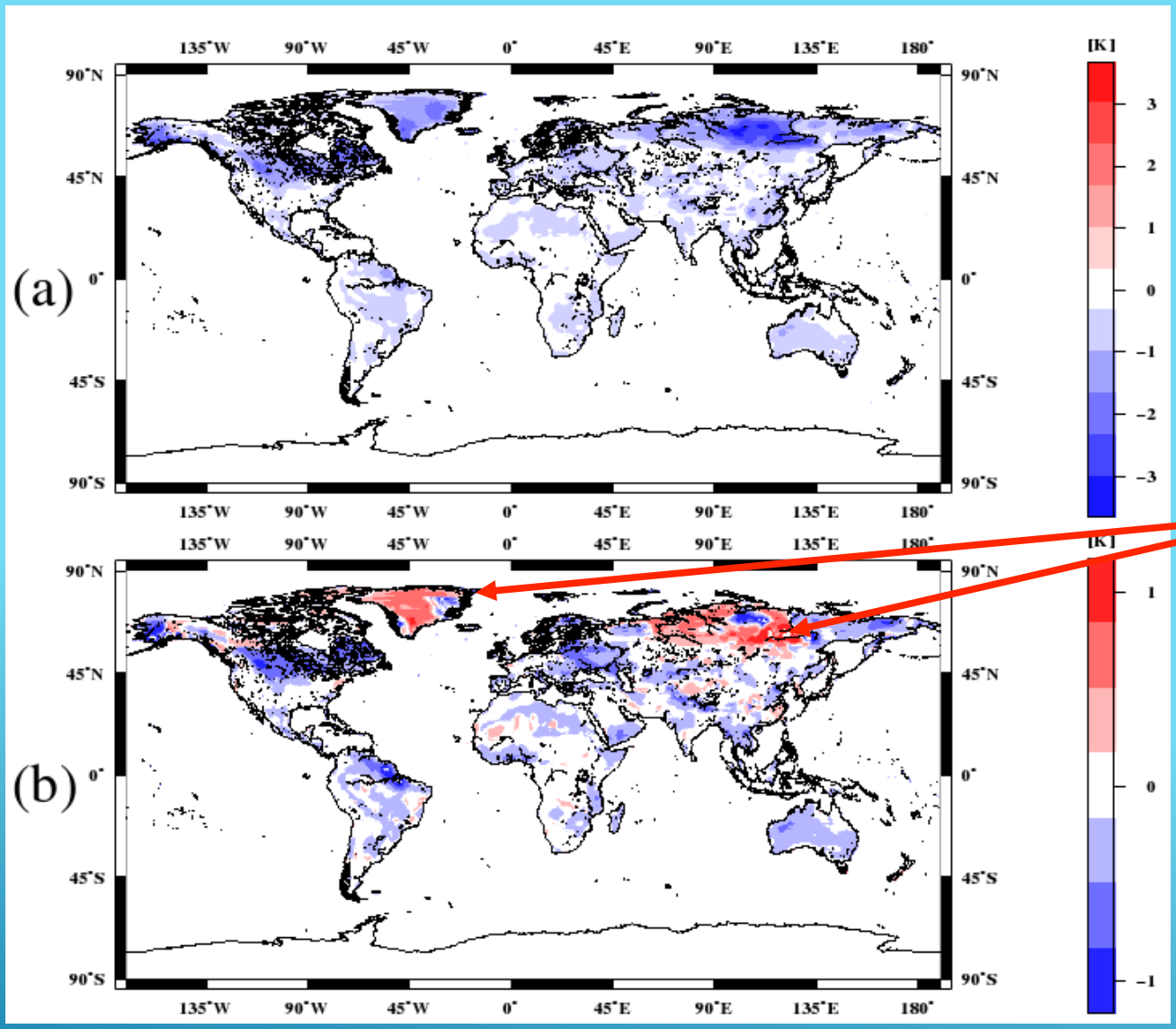
modeled

observed

Identical distribution function of the monthly means

Different distribution functions of daily data

Improvement of Variance through standard bias correction



daily

Results have worsened!

monthly

$$\Delta SD(T) = |SD(T_{mod,cor}) - SD(T_{obs})| - |SD(T_{mod,org}) - SD(T_{obs})|$$

Cascade bias correction method (Haerter et al.)

1. produce relative fluctuations

$$T'_{i,j} \equiv T_{i,j} - \bar{T}_j$$

Temperature at day i of month j

Mean of month j

Transfer function for daily fluctuations

$$T'^{cor}_{l,k} = f_{daily}(T'_{l,k})$$

2. produce bias correction to daily relative fluctuations

3. produce bias correction to monthly mean fluctuations

$$\bar{T}^{cor}_{l} = f_{monthly}(\bar{T}_l)$$

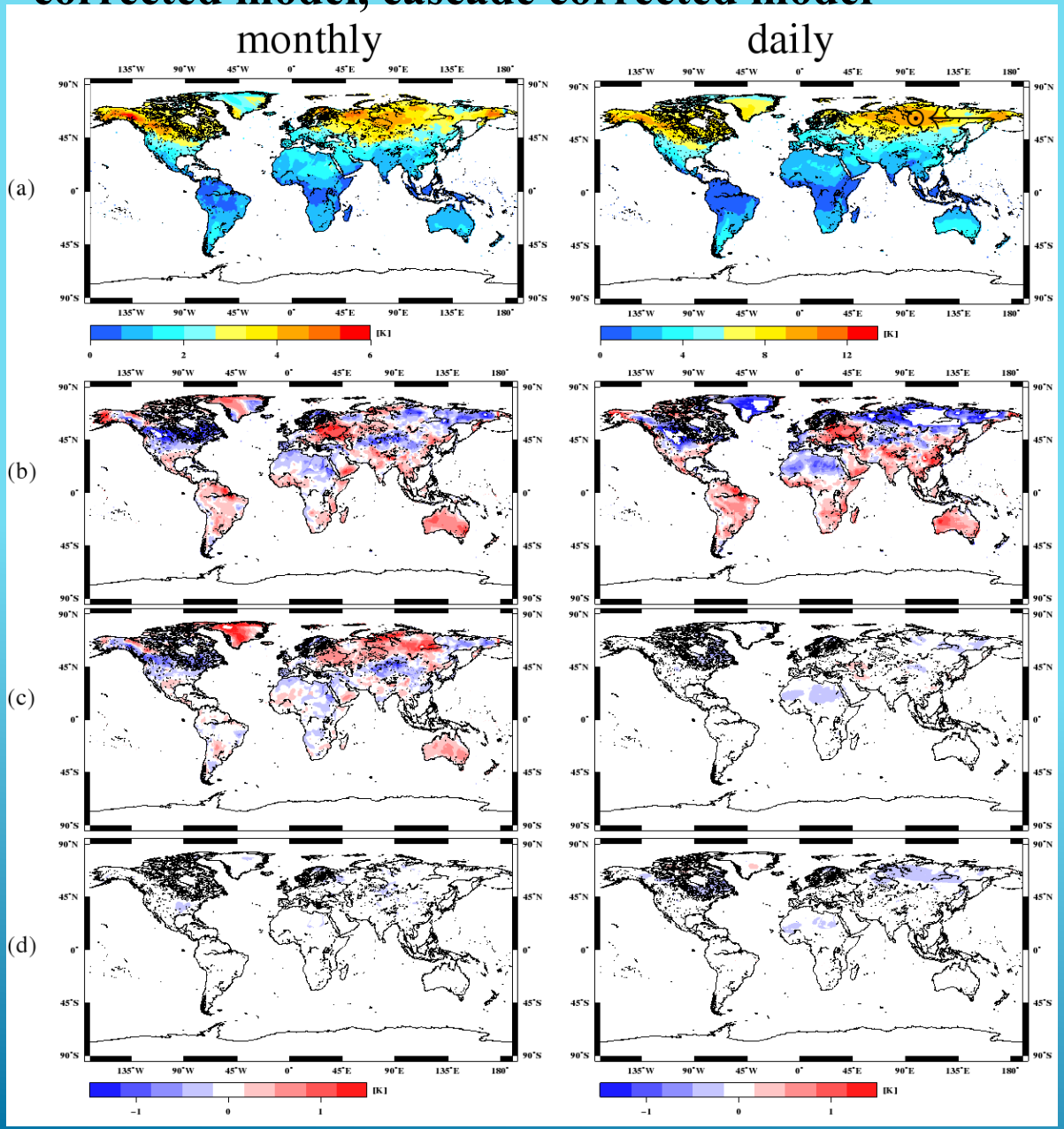
$$T^{cor}_{l,k} = \bar{T}^{cor}_{l} + T'^{cor}_{l,k}$$

Corrected monthly

Corrected daily

4. re-assemble the bias corrected time series

Standard deviation of WFD, difference to model, standard corrected model, cascade corrected model



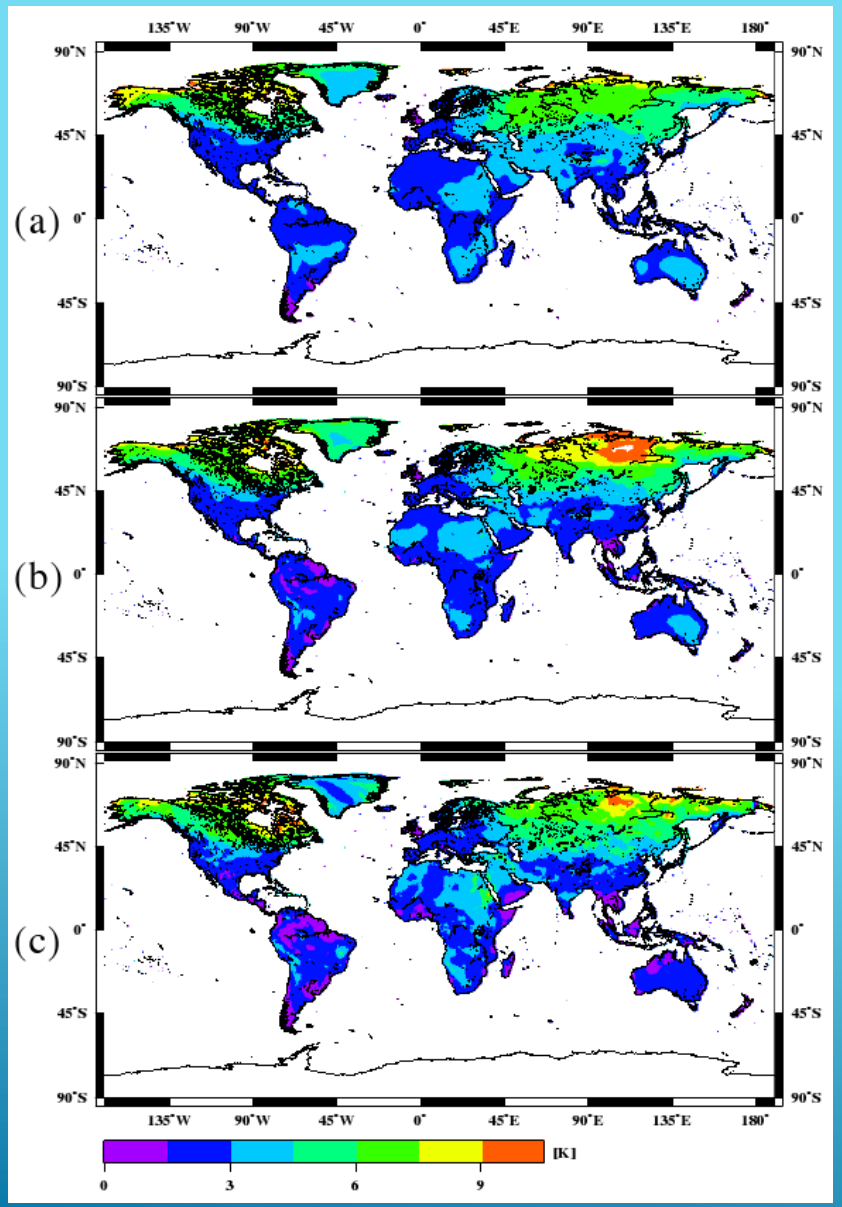
WFD

uncorrected model

Standard corrected model

Cascade corrected model

The big question: How do the different methods impact on the climate change signal?

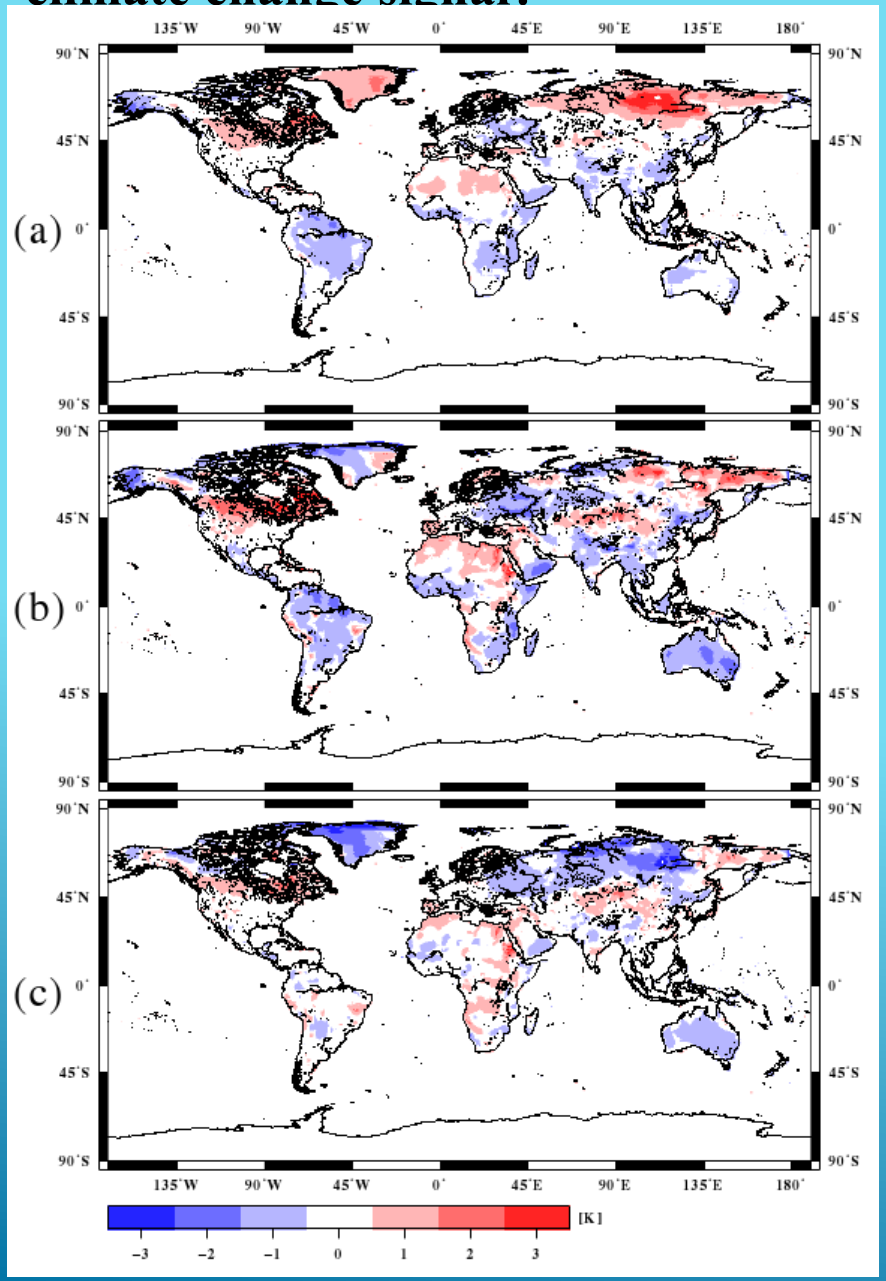


No bias correction

Standard bias correction

Cascade bias correction

The big question: How do the different methods impact on the climate change signal?



Change with standard BC

Change with cascade BC

Cascade-standard

Conclusions and remarks

- Statistical Bias Corrections perform transformations to entire PDF, hence, **mixing of timescales.**

- **Cascade bias correction** which **keeps timescales separate.**

- 2D Bias equalizations effectively reproduces the structure of the observed Copula.

- 2D Bias correction has very high observational requirements which limit its applicability to gridded output.