Evaluating Climate Projection for Drought and Extreme Surface Temperatures over South-Central US

Rong Fu and Robert Dickinson

Nelun Fernando, Lei Yin, Tong Ren, Ze Yang, Adam Bowerman

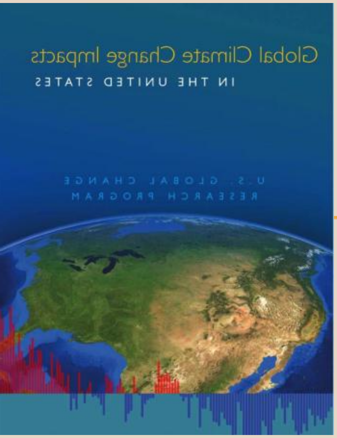
The Second Water Forum, CIESS

The University of Texas at Austin,

Oct. 22-23, 2012

Based on Fu et al. 2012, submitted to J. Climate

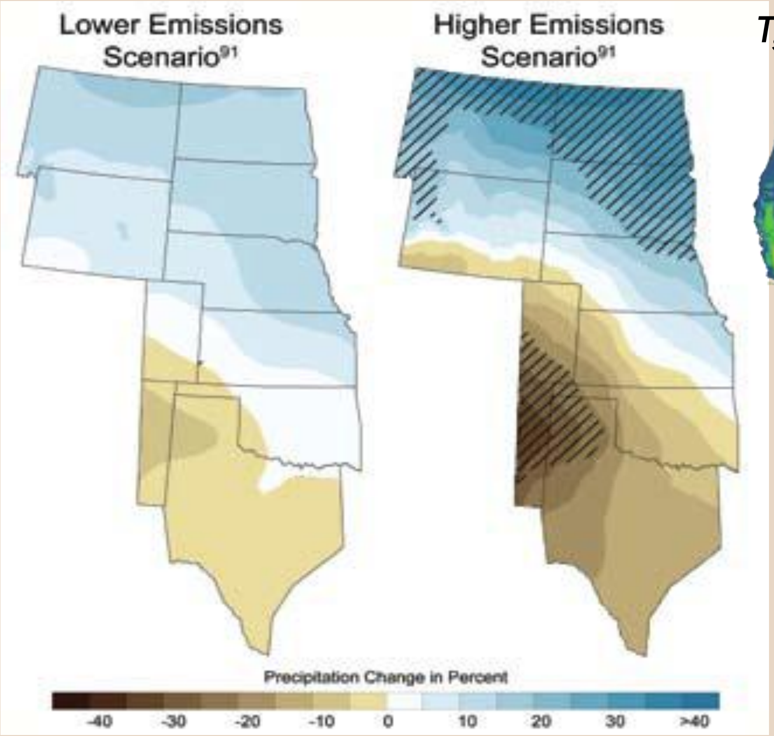
Oct, 23, 2011, Austin TX



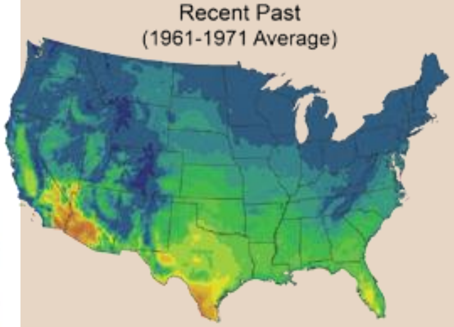
2009 Report on global climate change impacts in the United States (Karl et al)

IPCC AR4 models projected 15-30% decrease of rainfall and nearly double the number of days when T>90F.

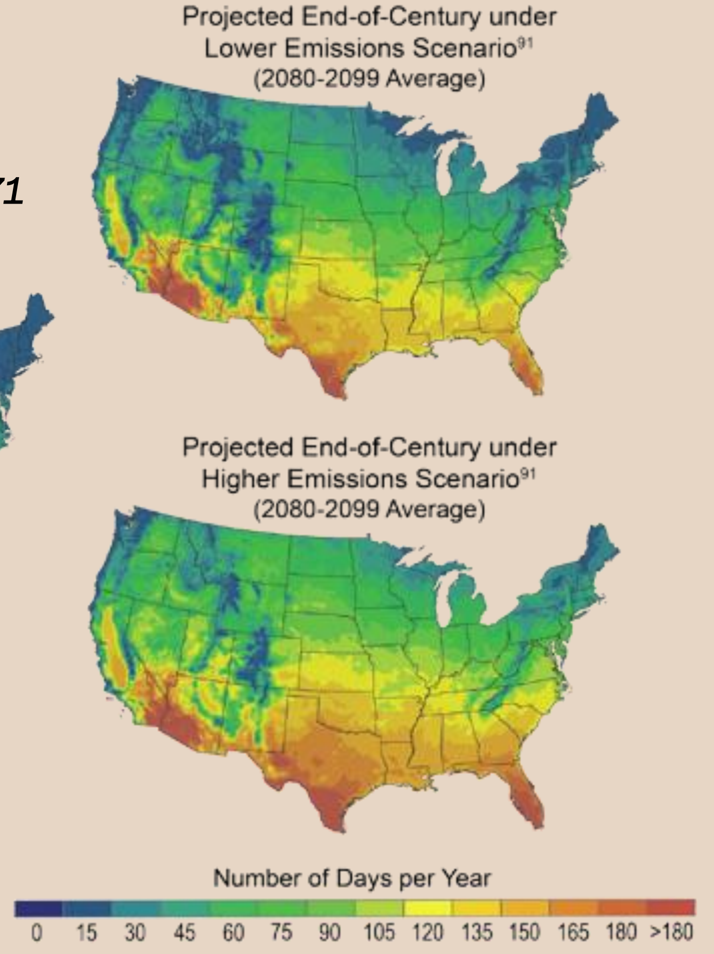
Projected Spring rainfall change by 2080s-2090S compared to that of 1971-2000



Number of days when T_s>90F during 1961-1971

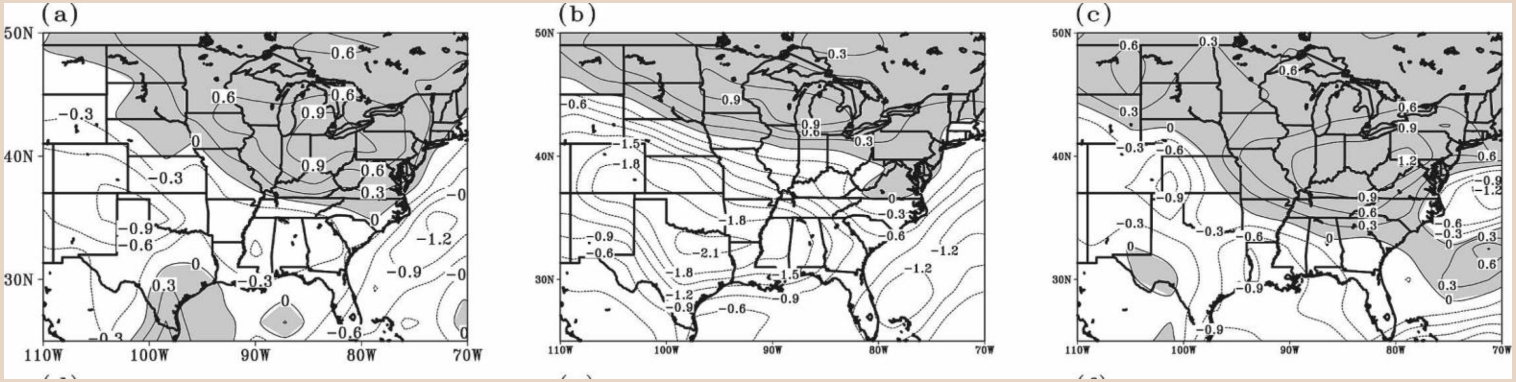


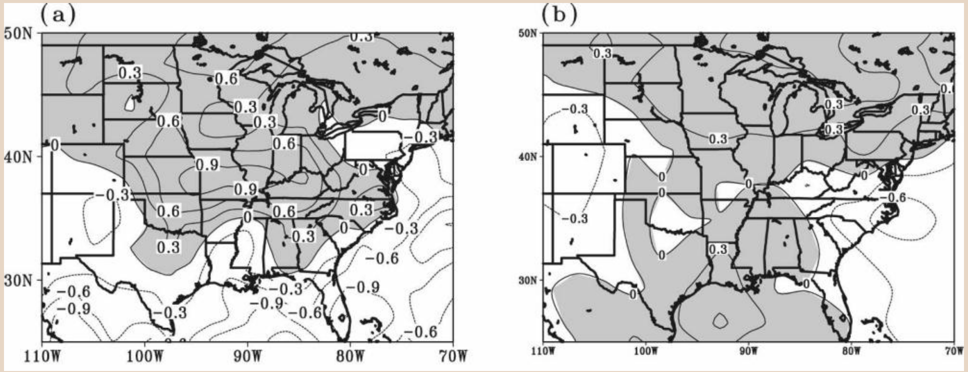
Projected number of days when T_s>90F by 2080-2099



However,

- ***Large inter-model discrepancy in projected future rainfall changes***
- ***Which projections should we believe?***





Projected rainfall change during April to June in 2079-99 relative to 1979-1999. (source: Figs 10 and 11 of Cook et al. 2008)

How can we determine creditability of the CMIP5 climate projection?

- ***Does the multi-models ensemble projection necessarily out-perform individual model projection over Texas and SC US?***

  - ***Gleckler et al. (2008), Pierce et al. (2009): An ensemble mean, especially a multi-model ensemble mean projection, can out-perform the best quality model because the former allows cancellation of offsetting errors in the individual global models.***

  - ***What should we do if majority of the models have similar biases?***

Criteria for our process-based model evaluation Metrics:

- ***Relevant to climate projection***
- ***Capture processes that control droughts over Texas***
- ***Can be compared to long-term observations***

Response to increase of the global sea surface temperature

Surface water budget and drought indices

Surface meteorological conditions

Large-scale circulation

Connection with ENSO

IPCC AR5 Models and Datasets Used for Evaluation:

Datasets:

- CPC US-Mexicao daily rainfall (Higgins et al. 1996), 1°,
- GHCN daily Tmax,Tmin (Vose et al. 1992), 2.5°
- NLADAS (Rodell et al. 2004), ET, 1/8°, 1980-2007.
- ERSSTv3b SST (Smith et al. 2008), 2.0°, 1854-2005
- NCEP reanalysis (Kalney et al 1996; Kistler et al. 2001), 2.5°, 1948-present

All the datasets and models are re-mapped to 2.5° spatial resolution

Periods:

- 1950-2005; meteorological data
- 1980-2005: surface energy/water balance.

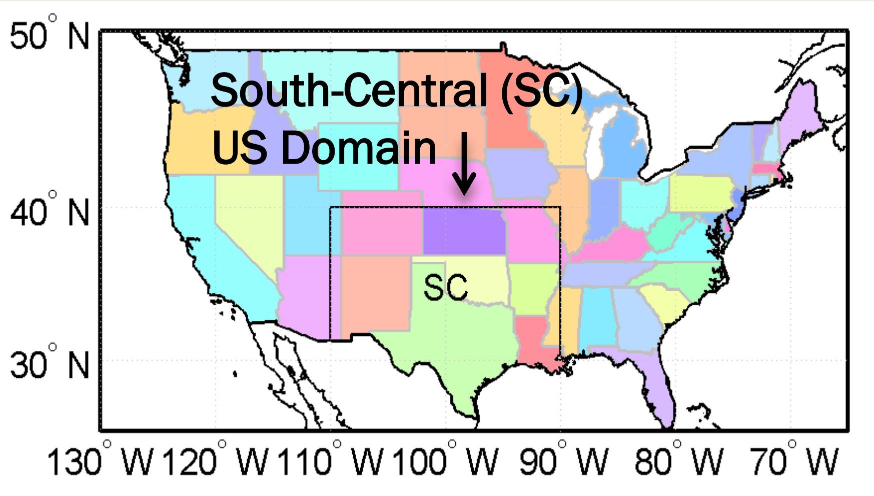
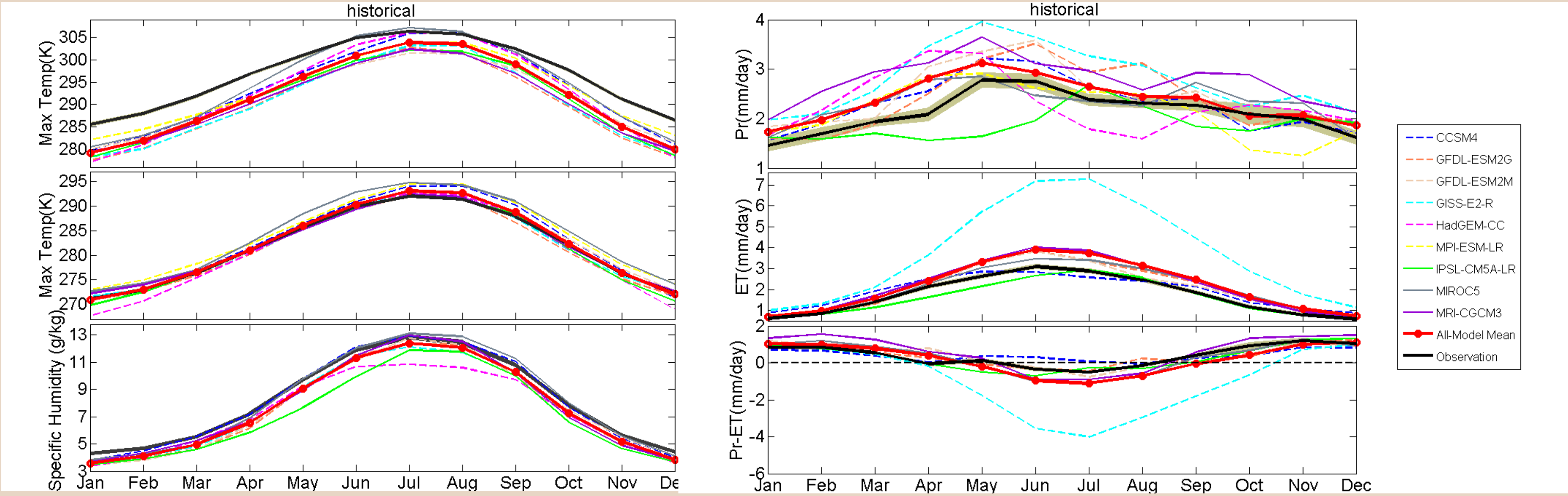


Table 1. Description of CMIP5 models used in this study

Model (Fig marker)	Institute (Country)	Available Ensembles	Components (Resolutions)	Calendar	Reference
CCSM4 (A)	National Center for Atmospheric Research (USA)	6	F09_g16 (0.9×1.25_gx1v6)	No leap	Gent et al., 2011
GFDL-ESM2M (B)	NOAA/Geophysical Fluid Dynamics Laboratory (USA)	1	Atm: AM2 (AM2p14, M45L24) Ocn: MOM4.1 (1.0° lat ×1.0° lon, enhanced tropical resolution: 1/3 on the equator)	No leap	John Dunne et al., 2012
GFDL-ESM2G (C)	NOAA/Geophysical Fluid Dynamics Laboratory (USA)	1	Atm: AM2 (AM2p14, M45L24) Ocn: MOM4.1 (1.0° lat ×1.0° lon, enhanced tropical resolution: 1/3 on the equator)	No leap	John Dunne et al., 2012
GISS-E2-R (D)	NASA/Goddard Institute for Space Studies (USA)	5	Atm: GISS-E2 (2.0° lat ×2.5° lon) Ocn: R	No leap	Schmidt et al., 2006
HadGEM2-CC (E)	Met Office Hadley Centre (UK)	3	Atm: HadGAM2 (N96L60) Ocn: HadGOM2 (Lat: 1.0-0.3 Lon: 1.0 L40)	360 d/y	Collins et al., 2011; Martin et al., 2011
MPI-ESM-LR (F)	Max Planck Institute for Meteorology (Germany)	3	Atm: ECHAM6 (T63L47) Ocn: MPIOM (GR15L40)	Gregorian	Raddatz et al., 2007; Marsland et al., 2003
IPSL-CM5A-LR (G)	Institut Pierre Simon Laplace (France)	5	Atm: LMDZ4 (96×95×39, 1.875° lat ×3.75° lon) Ocn: ORCA2 (2×2L31, 2.0° lat ×2.0° lon)	No leap	Marti et al., 2010
MIROC5 (H)	AORI, NIES & JAMSTEC (Japan)	4	Atm: AGCM6 (T85L40) Ocn: COCO (COCO4.5)	No leap	Watanabe et al., 2010
MRI-CGCM3	Meteorological Research Institute	3	Atm: GSMUV (TL159L48)	Gregorian	Yukimoto et al., 2011

Evaluate seasonal cycles of climatic surface conditions:

- ***Cold bias in daily maximum surface temperature (Tmax)***
- ***Wet biases in Precipitation (P), Evapotranspiration (ET), esp. during spring & summer***
- ***Large discrepancies in seasonal rainfall***

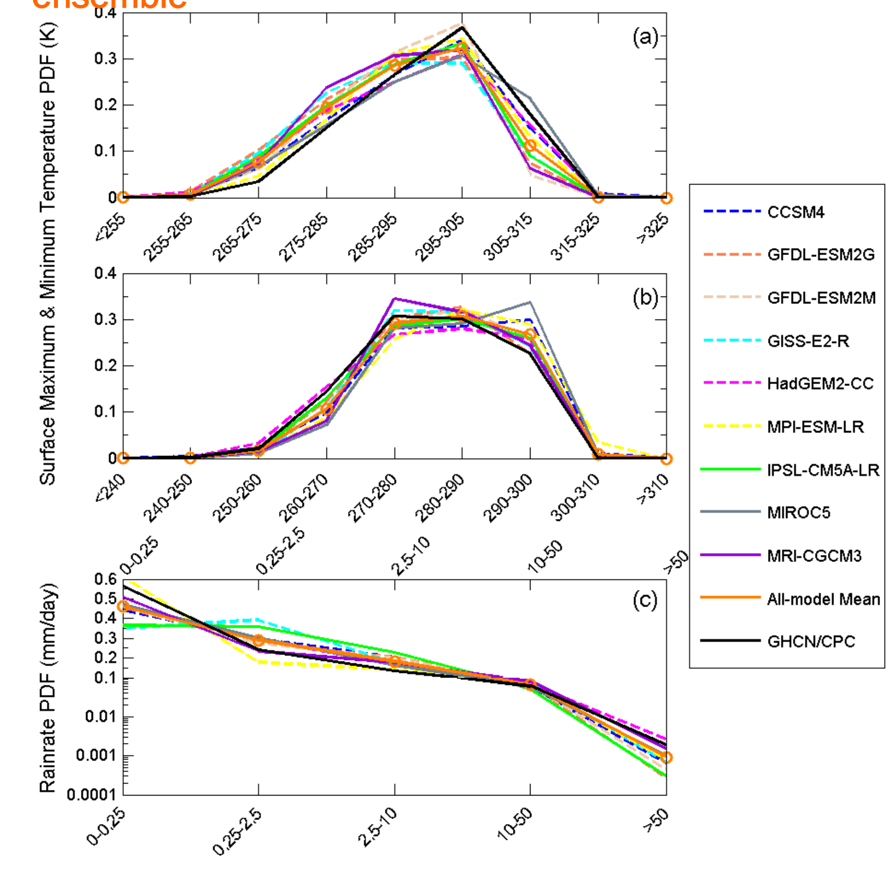


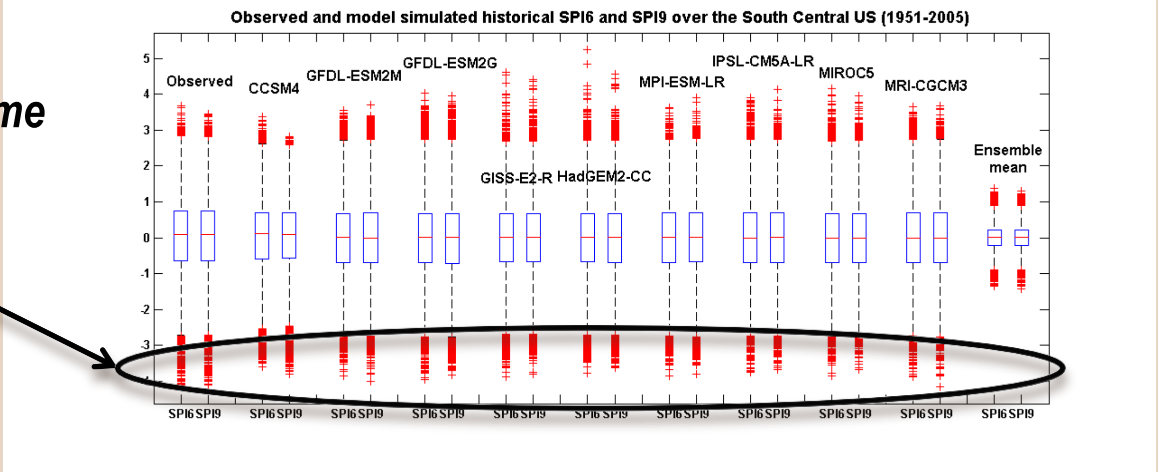
Black line: observations, Bold Red line: multi-model ensemble mean

Probability distributions of Tmax, Tmin, P and drought indices (SPI6 and SPI9)

- *Tmax: underestimate warmer Tmax and overestimate cooler Tmax*
- *Tmin: underestimate cooler Tmin, overestimate warmer Tmin (consistent with wet bias)*
- *P: underestimate non-rain and heavy rainrate, overestimate light rainrate*
- *SPI: reasonably realistic, but underestimate intensity of extreme drought.*

Black line: observation, Orange line: multi-model ensemble



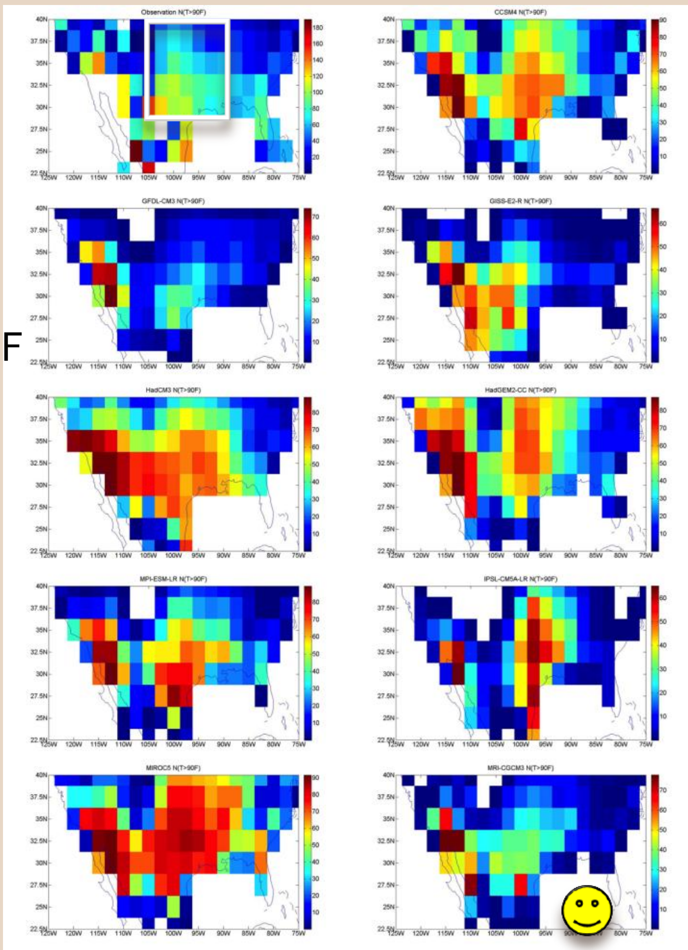


Number of days/yr when T_{max}>90F & 100F:

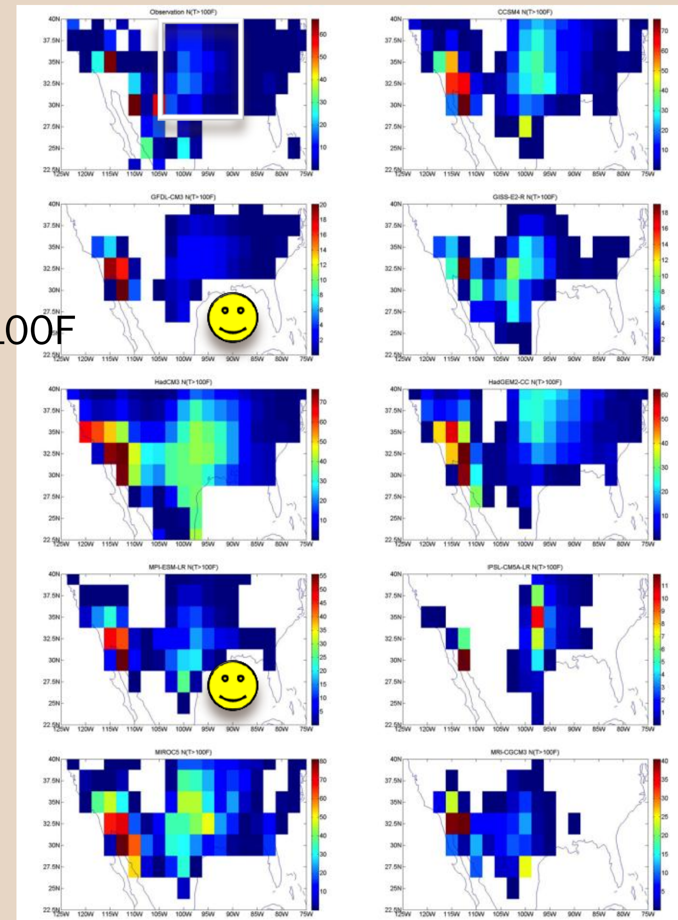
- ***Reverse the E-W gradient of extreme Tmax over Texas,***
- ***Most of models overestimate occurrence of extreme Tmax over the southeastern Great Plains,***
- ***Large inter-model discrepancies***

☺ highlight better models

Tmax>90F



Tmax>100F



Evaluation of Large-scale atmospheric circulation:

- ***Most of the models underestimate the 500hPa ridge over central US in summer and strength of jet in spring (except for CCSM4).***
- ***Probably responsible for wet and cold biases in spring and summer.***

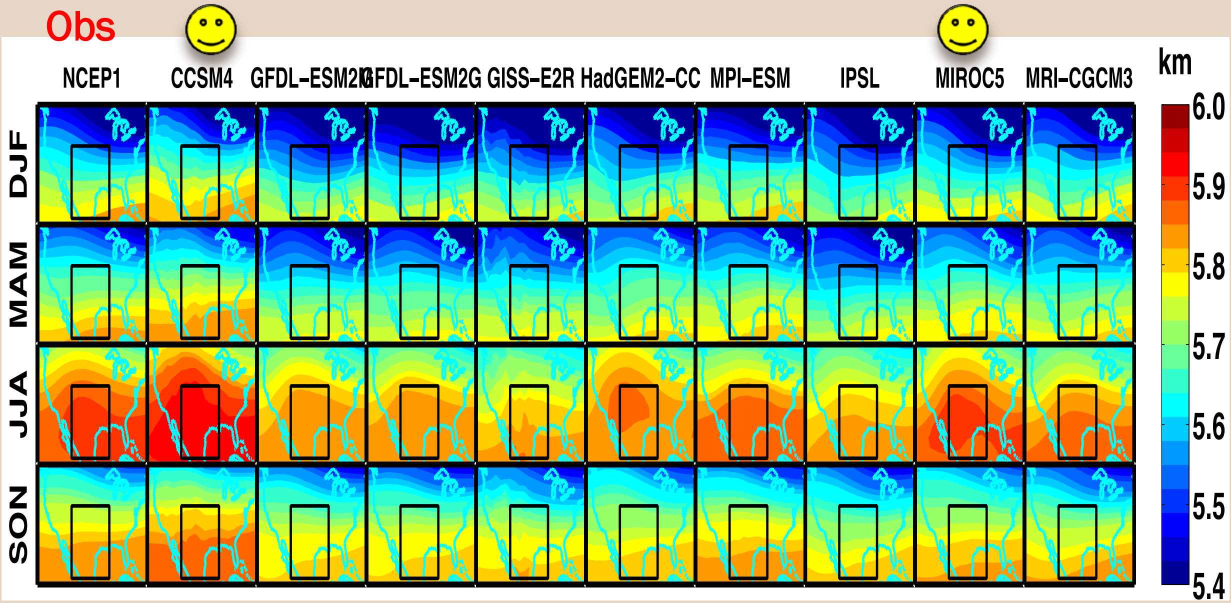
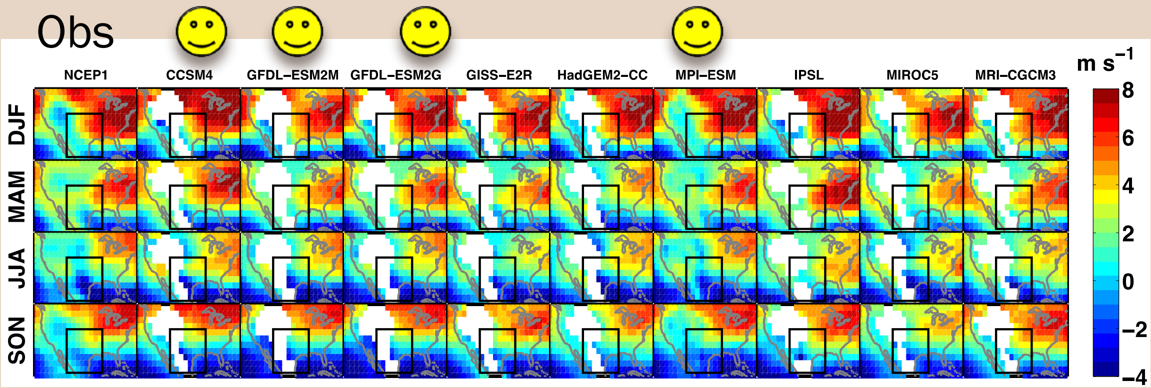


Figure 6: Comparison of the modeled Z500hPa pattern by each CMIP5 models with that of NCEP-CDAS1.

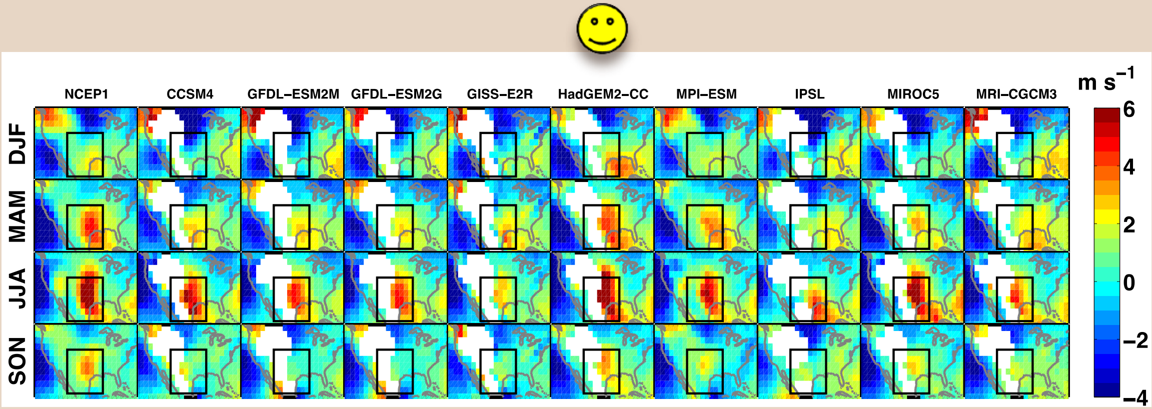
*Circles highlight better models

- 1/2 models underestimate lower tropospheric westerly winds (U850) in spring and summer.
- ***Underestimate lower tropospheric southerly winds (V850) in spring***

U850 hPa



V850 hPa



Correlation between SC US rainfall anomalies and Nino3 and Nino4 indices:

About a half of the models

- ***underestimate correlation with ENSO in winter***
- ***overestimate ENSO connection in spring, summer and fall***
- ***Because of errors in ENSO teleconnection pattern (not shown)***

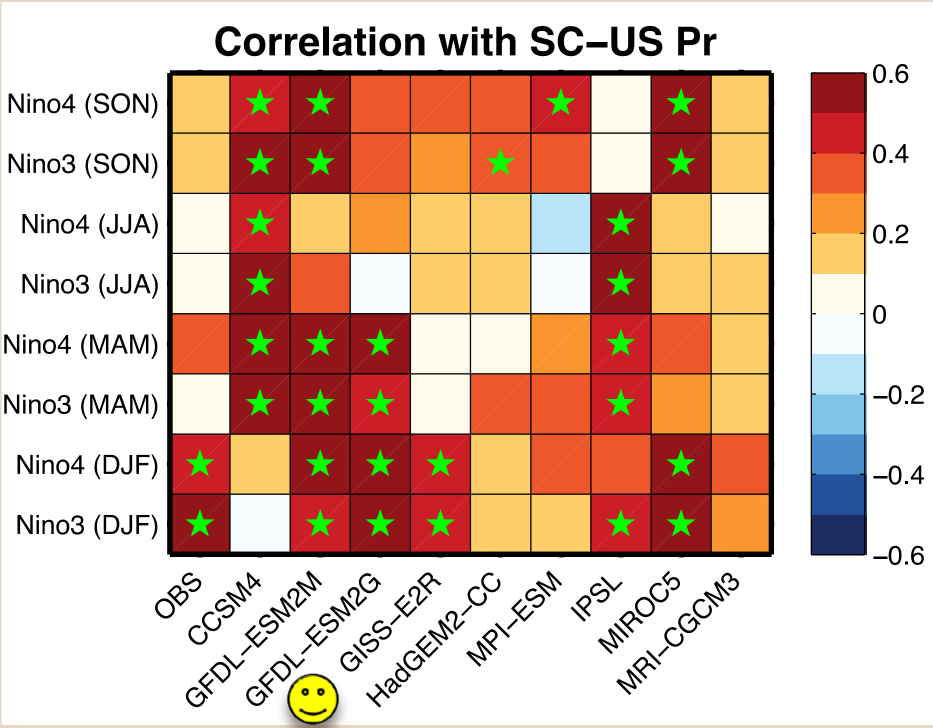
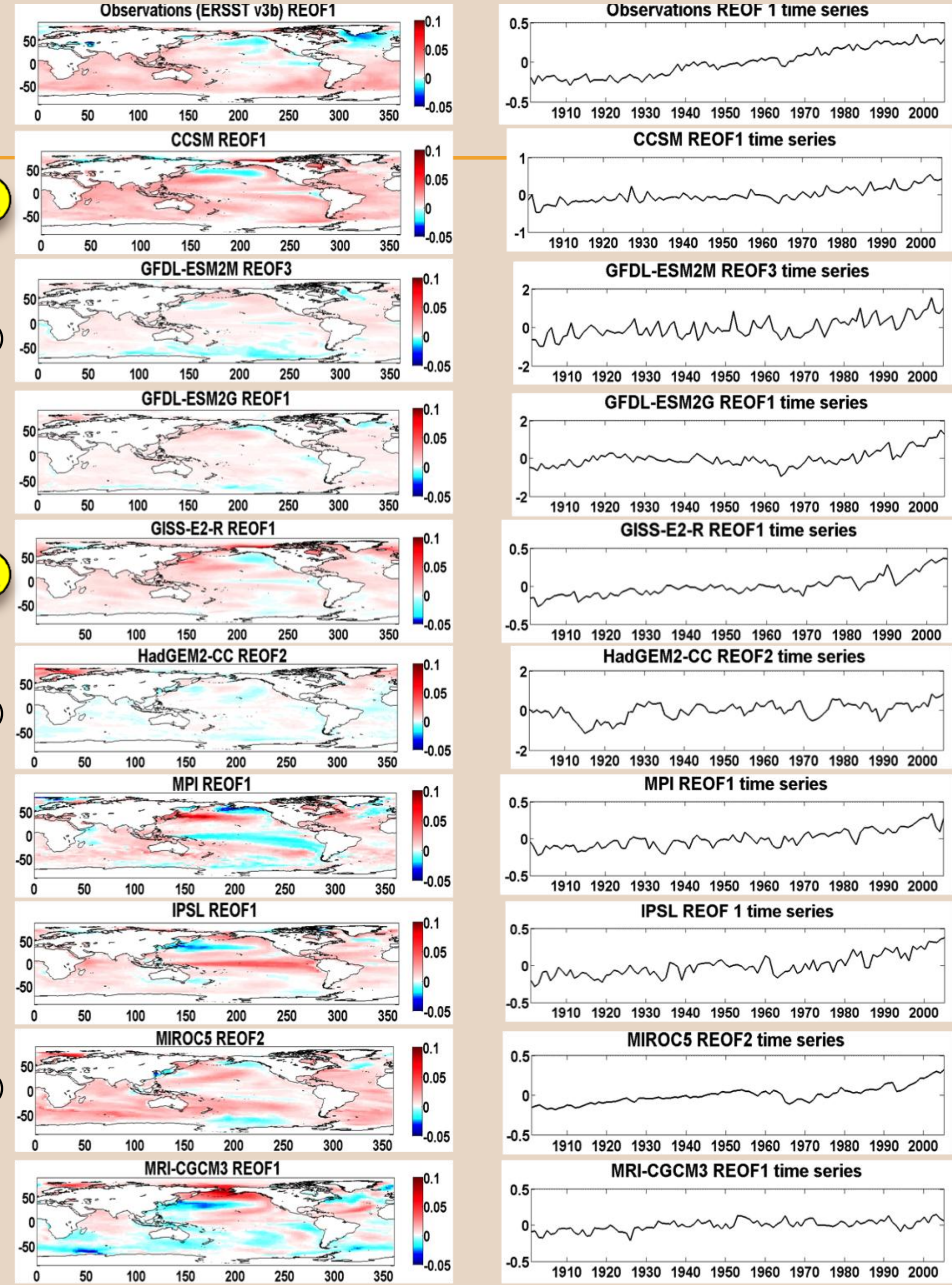


Figure 9: Correlations between Niño4, Niñ3 and SC US rainfall. “Star” indicates significant correlation coefficient at 95% confidence level using student t-test.

Leading REOF of global SST variance during 1900-2005:

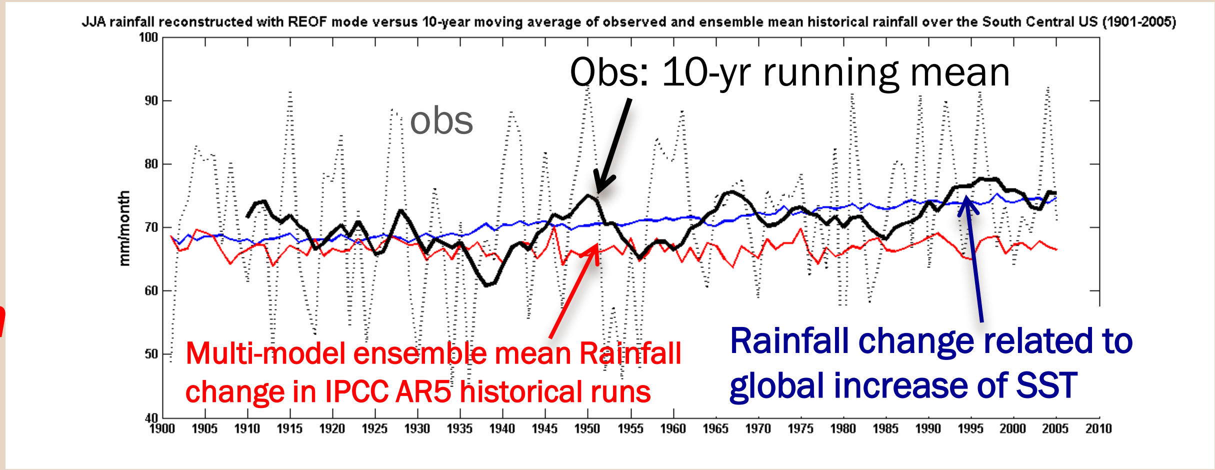
- ***Observation shows the global increase of sea surface temperature (SST) as the leading mode for SST variance (Schubert et al. 2008).***
- ***Few models realistically capture this global increase of SST mode (CCSM4 and MPI)***



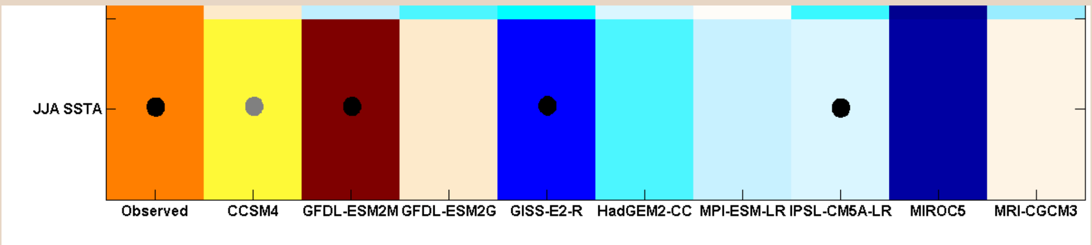
☹: Fail to capture the warming mode

Modeled response of summer rainfall over SC US to the increasing global SST mode:

- ***Most of the models underestimate the change of summer rainfall over SC US associated with global increase of SST over th period of 1900-2005.***



- ***Only CCSM4 captures the observed relationship between the increase of global SST mode and increase of summer rainfall over SC US.***



Ranking the models using our process-based metrics:

CCSM4 overall ranks the best, especially in SC US rainfall response to increase of global SST.

Response to increase of the global sea surface temperature

Surface conditions

Surface water budget and drought indices

Large-scale circulation

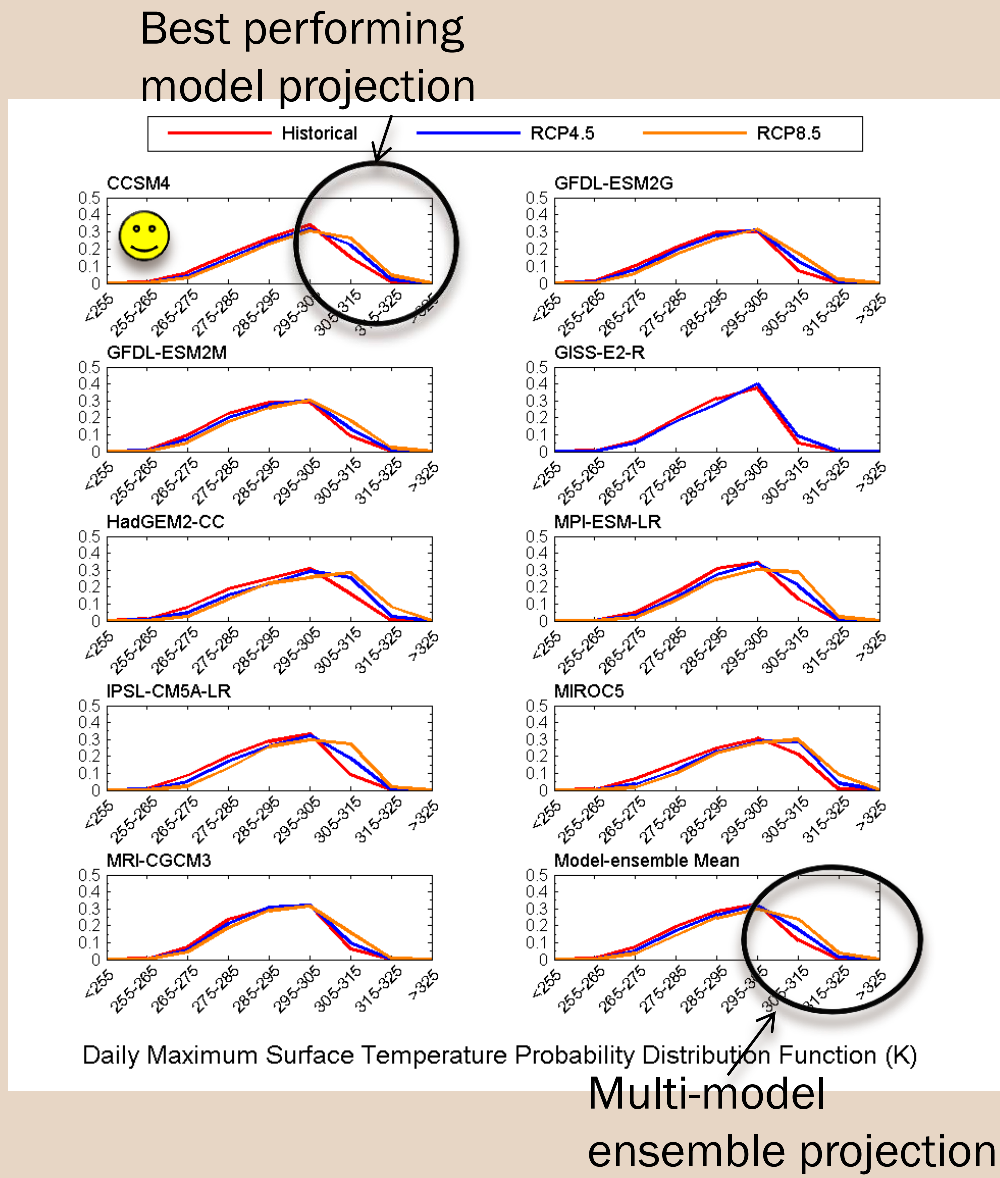
Connection with ENSO

Table 2: Ranking of model performance for SC US regional climate change

Variables	**Models** CCSM4	GFDL-ESM2G	GFDL-ESM2M	GISS-E2-R	HadGEM2	MPI	IPSL	MIROC5	MRI
				Tier-1: Forced variability or change					
				Correlation with global SST warming:					
a_{GW}	1	3	1	3	2	3	3	3	3
GW_{SST}	2	1	3	1	3	2	2	3	2
Subtotal	1.5	2	2	2	2.5	2.5	2.5	3	2.5
				Seasonal cycle:					
Tmax	1	2	2	2	1	2	3	1	2
Tmin	2	1	1	1	3	1	3	2	1
q	1	1	2	1	3	1	3	1	1
Subtotal	1.3	1.3	1.7	1.3	2.3	1.3	3	1.3	1.3
PD_{Tmax}	3	3	3	3	3	3	3	3	2
PD_{RR}	2	2	2	2	2	2	2	2	1
P	1	3	3	2	3	1	2	2	3
ET	3	2	2	3	2	2	2	2	2
SPI6	2	2	2	2	2	2	2	2	2
SPI9	2	2	2	2	2	2	2	2	2
Subtotal	2.2	2.3	2.3	2.3	2.3	2	2.2	2.2	2
Z500	2	3	3	3	2	2	3	2	3
U850	1	2	2	2	2	1	1	2	2
V850	2	2	2	2	1	2	2	2	2
Subtotal	1.7	2.3	2.3	23	1.7	1.7	2	2	2.3
				Tier-2: natural variability					
$r_{p,Niño3}$	3	2	2	1	3	3	3	2	3
SZ500, Niño3	2	2	2	3	3	3	3	3	3
$r_{p,Niño4}$	3	2	2	1	3	3	3	2	3
SZ500, Niño4	2	2	2	3	3	3	3	2	3
Subtotal	2.5	2	2	2	3	3	3	2.3	3

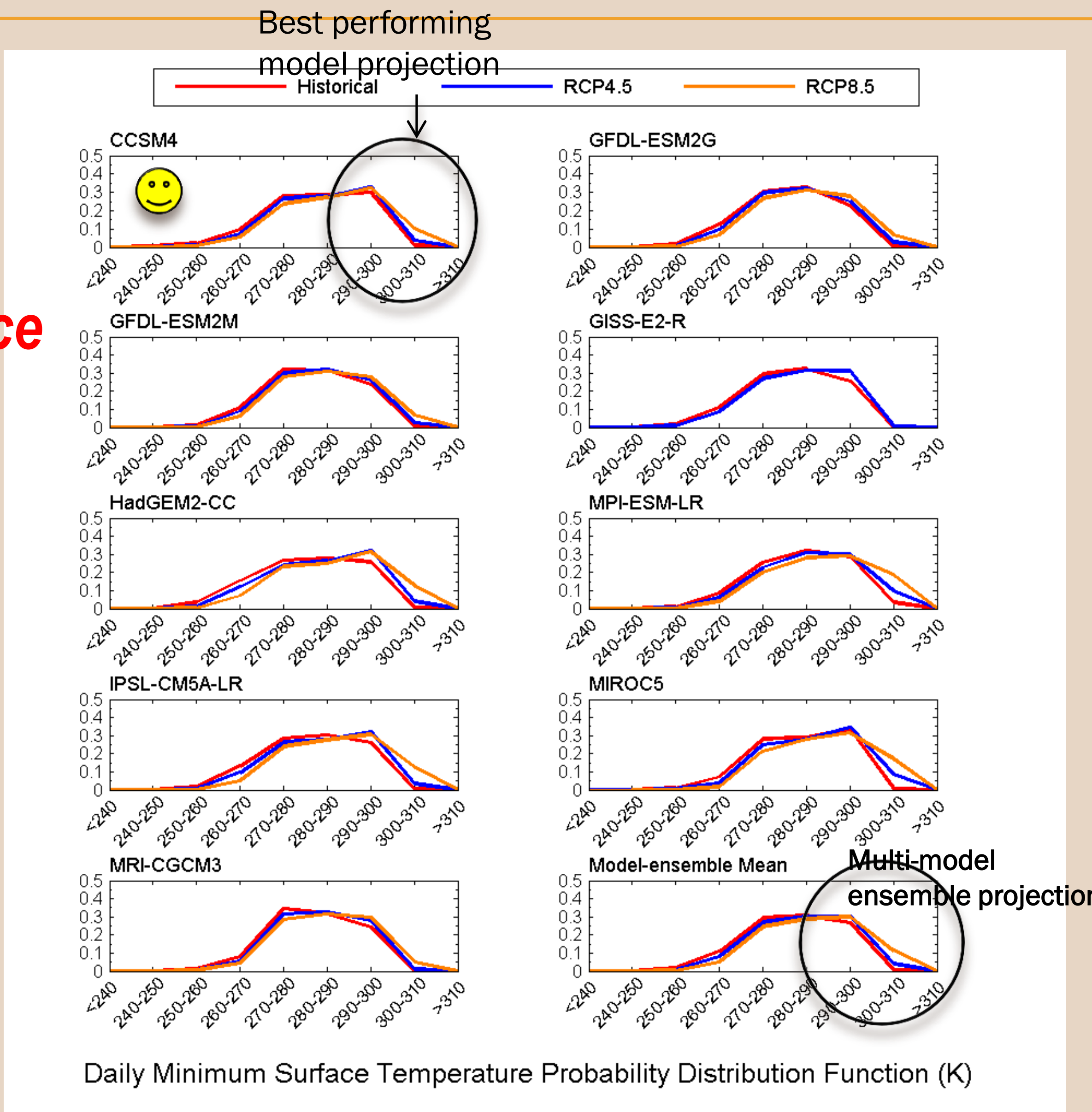
Projected change of Tmax during 2073-2099 relative to 1979-2005:

- ***Models consistently project a disproportional increase of occurrence of high Tmax (>90F - 108F) by***
  - ***25-50% under low emission (but unlikely RCP4.5) scenario (CO_2 reaches 650 ppm by 2100)***
  - ***50-100% under high emission (business as usual, RCP8.5) scenario (CO_2 reaches 1350ppm by 2100)***
- ***Recall that these models tend to underestimate Tmax.***



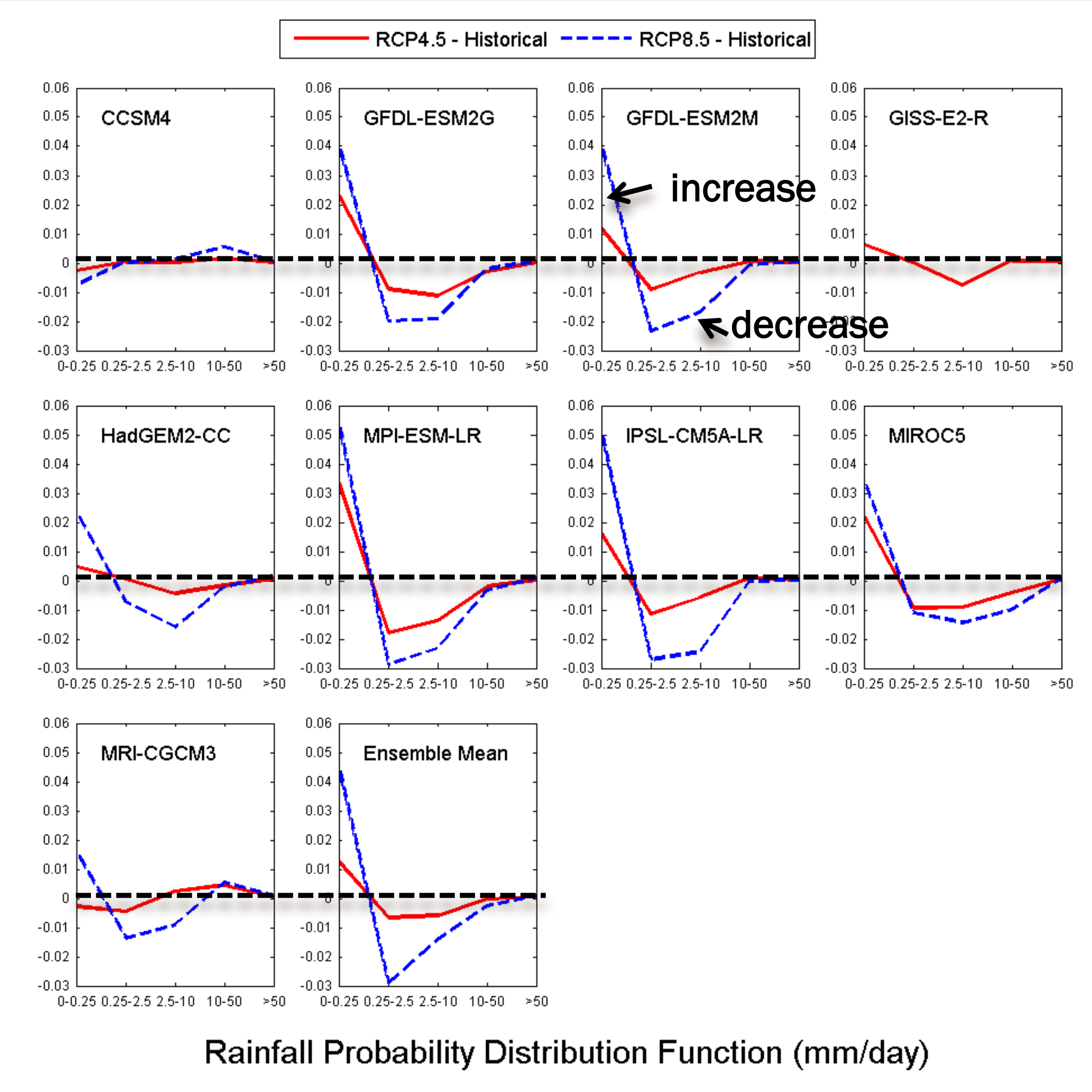
Projected change of Tmin in 2073-2099 relative to 1979-2005.

- ***Models consistently project a strong increase of occurrence of Tmin≥80F several folds under the high emission (RCP8.5) scenario.***



Projected change of rainrate in 2073-2099 relative to 1979-2005.

- ***Increase of non-rainy days and low rainrate and decrease of medium rainrate.***



Projected change of surface net water flux in 2073-2099 relative to 1979-2005:

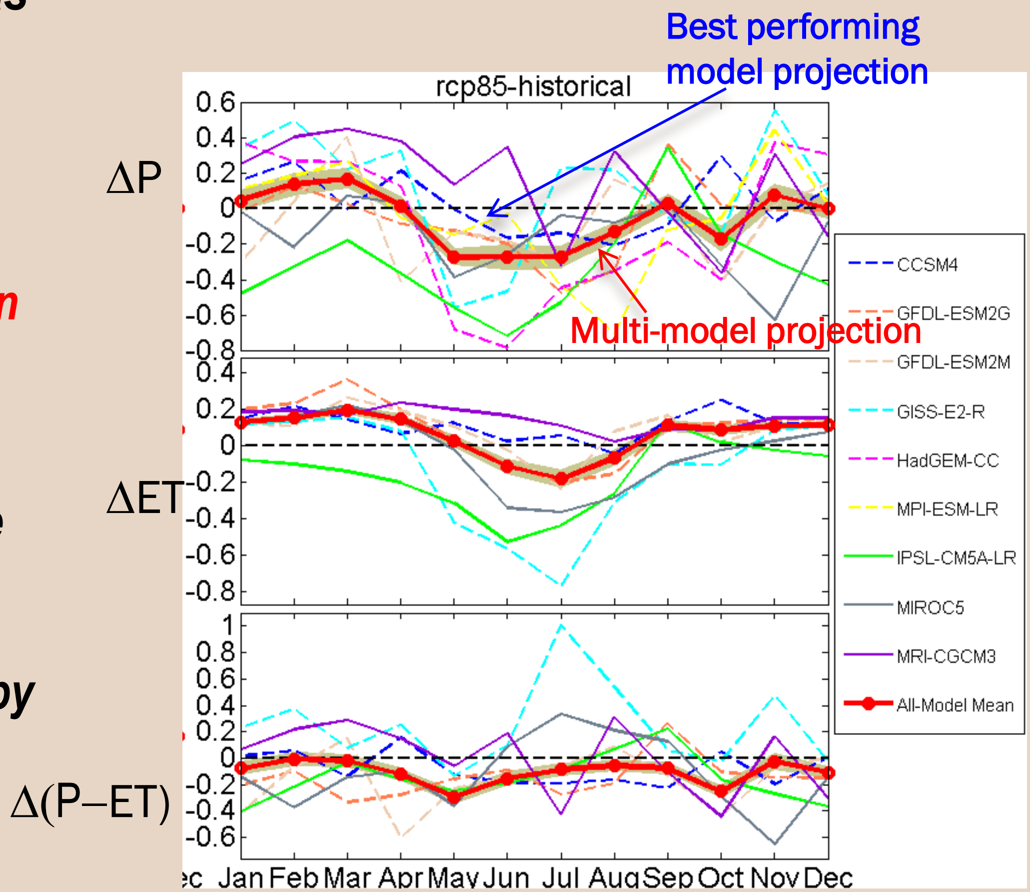
Under the high emission (business as usual, RCP8.5) scenario:

- ***Both multi-models and best performing model project net drying, by ~20% of P-ET in spring and summer, despite differences in details.***

- ***Increase of rainfall (P) and ET during winter and spring, decrease of rainfall and ET in summer.***

- ***Net drying in spring is dominated by increase of ET, whereas drying in summer is dominated by decrease of P.***

- ***Outliners in projections tends to be the worst performing models.***



Conclusions:

The 9 climate models that participated in the IPCC AR5 we evaluated

- *share common wet and cold biases, due to underestimate mid-tropospheric ridge in summer, the upper-level jet strength and westerly low-level winds in spring. Most of the models cannot adequately capture the changes of SC US rainfall with ENSO and the increase of global SST.*
- *consistently project ~20% decrease of net P-ET (dry) in spring-summer by 2073-2099 relative to 1979-2005, under the "business as usual" emission scenario (RCP8.5), despite differences in details.*