Evaluation of CMIP5 model simulations of 20th century North American climate

Justin Sheffield and the NOAA CMIP5 Task Force

with contributions from:

Andrew Barrett, Suzana J. Camargo, Brian Colle, Rong Fu, Kerrie L. Geil, Qi Hu, Xianan Jiang, Nathaniel Johnson, Kristopher B. Karnauskas, Jim Kinter, Sanjiv Kumar, Baird Langenbrunner, Kelly Lombardo, Lindsey N. Long, Eric Maloney, Annarita Mariotti, Joyce E. Meyerson, Kingtse C. Mo, J. David Neelin, Zaitao Pan, Alfredo Ruiz-Barradas, Richard Seager, Yolande L. Serra, Anji Seth, De-Zheng Sun, Jeanne M. Thibeault, Julienne C. Stroeve, Chunzai Wang, Shang-Ping Xie, Jin-Yi Yu, Tao Zhang, Ming Zhao

Overview of NOAA CMIP5 Task Force Model Evaluations

1. **Goal is to evaluate CMIP5 20th century historical simulations for North American climate and related climate processes**

2. **Synthesis of work across a range of climate features from basic climate variables to regional climate features to inter-annual to decadal variability and trends**

3. **Work carried out by multiple Task Force PIs that includes new analysis by individual PIs and leverages from individual papers submitted to the J. Climate special issue**

4. **Each analysis uses multiple climate models/ensembles but generally a different set depending on data availability and downloading/processing effort.**

5. **Models are evaluated for their ability to reproduce observed climate features, and some analyses were able to compare directly to CMIP3 data and previous studies**

6. **Presentation today can only show a sampling of the breadth/depth of the analyses**

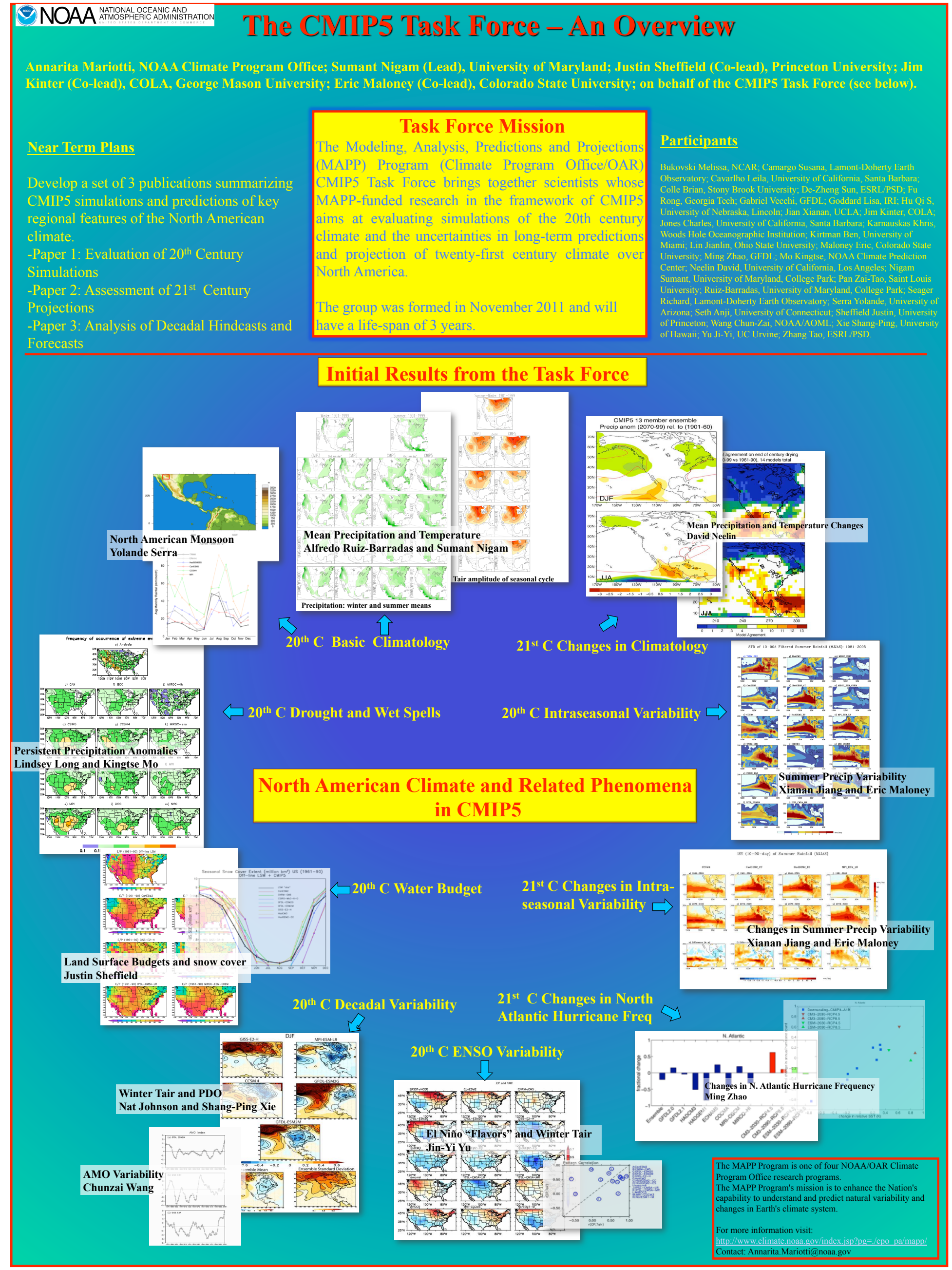
7. **More details are in two-part paper submitted to J. Climate:**

Sheffield, J., 2012a: North American Climate in CMIP5 Experiments. Part I: Evaluation of 20th Century Continental and Regional Climatology. *J. Climate*, submitted.

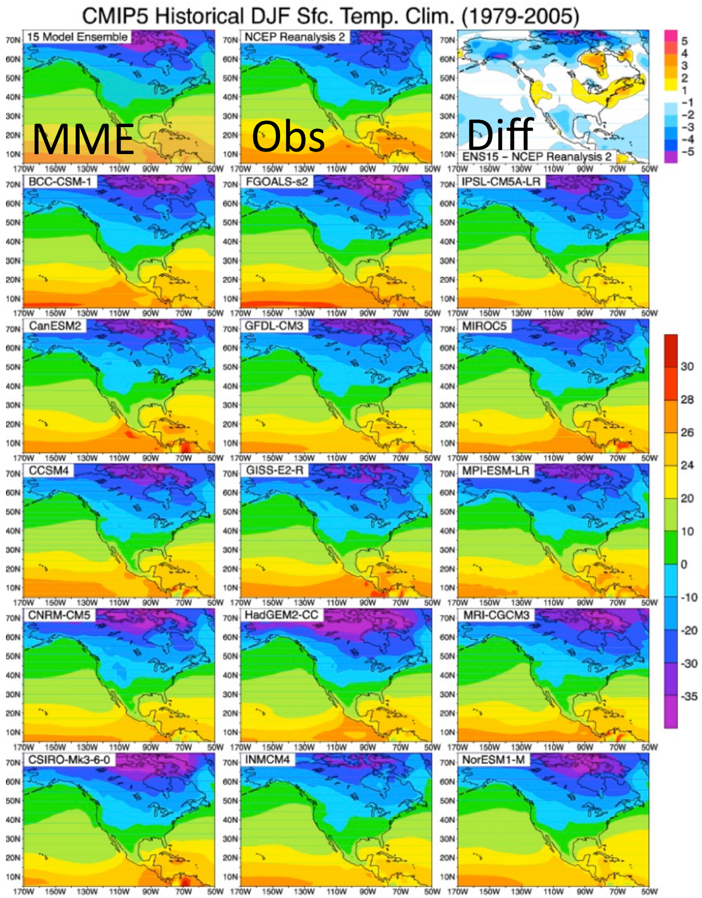
Sheffield, J., 2012b: North American Climate in CMIP5 Experiments: Part II: Evaluation of 20th Century Intra-Seasonal to Decadal Variability, *J. Climate*, submitted.

Range of features relevant to N. American climate and its impacts

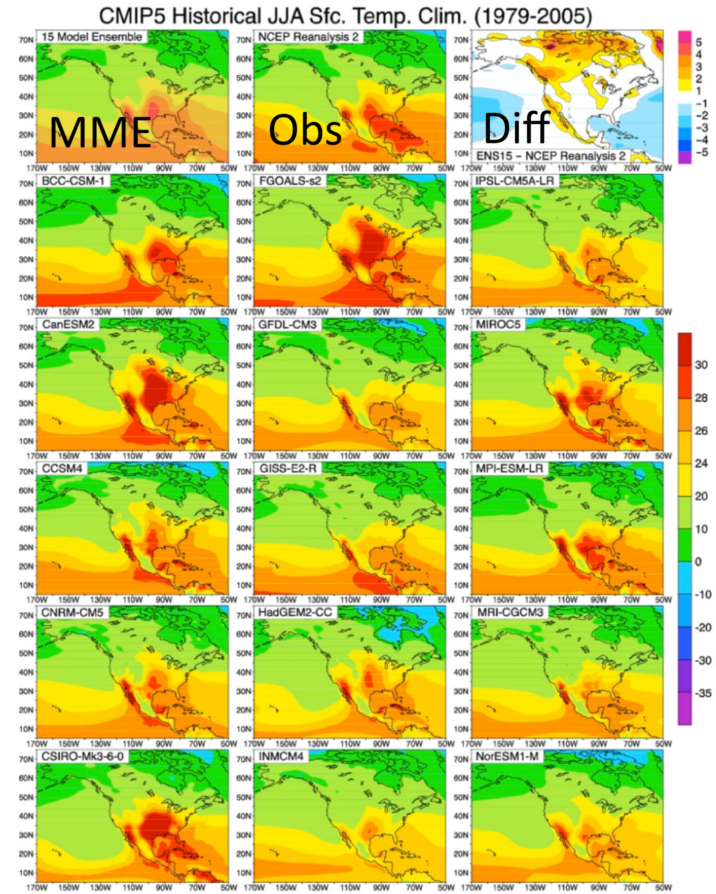
1. ***Continental climate*** (precipitation, temperature, land/atmosphere water budgets, SSTs, biophysical indicators, persistent dry/wet spells)
2. ***Regional climate*** (east coast winter storms, northeast precipitation, western water, North American monsoon, Great Plains low level jet/ drought, Arctic sea ice, south/ southeastern extremes)
3. ***East Pacific and Atlantic tropical cyclones***
4. ***Intra-seasonal variability*** (Eastern Pacific, Midsummer drought Central Am.)
5. ***Inter-annual to decadal variability and trends*** (ENSO plus teleconnections, warm/cold event asymmetry, AMO, PDO, warming hole, trends in precipitation, temp).



Seasonal Air Temperature



Surface air temperature climatology for (left) December-February and (right) June-August (1979-2005).

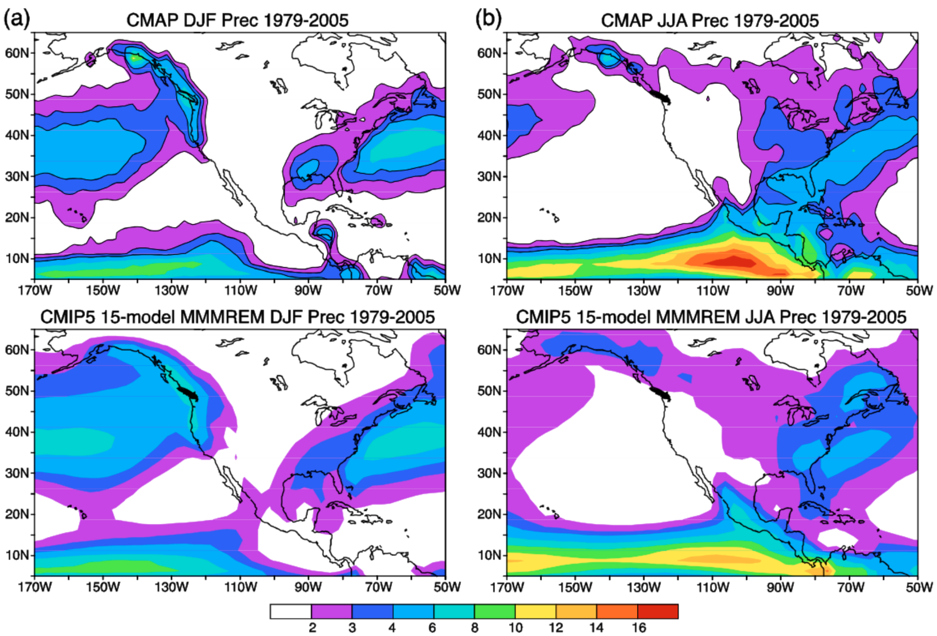


- The multi-model ensemble (MME) reproduces reasonably well the spatial distribution of temperature and is generally within 1^{o}C of observations.
- MME mean does well at representing regional features such as the southerly regions with mean summer temperatures >30^{o}C, the extension of temperatures >10^{o}C into Canadian prairies and the wintertime 0^{o}C contour.

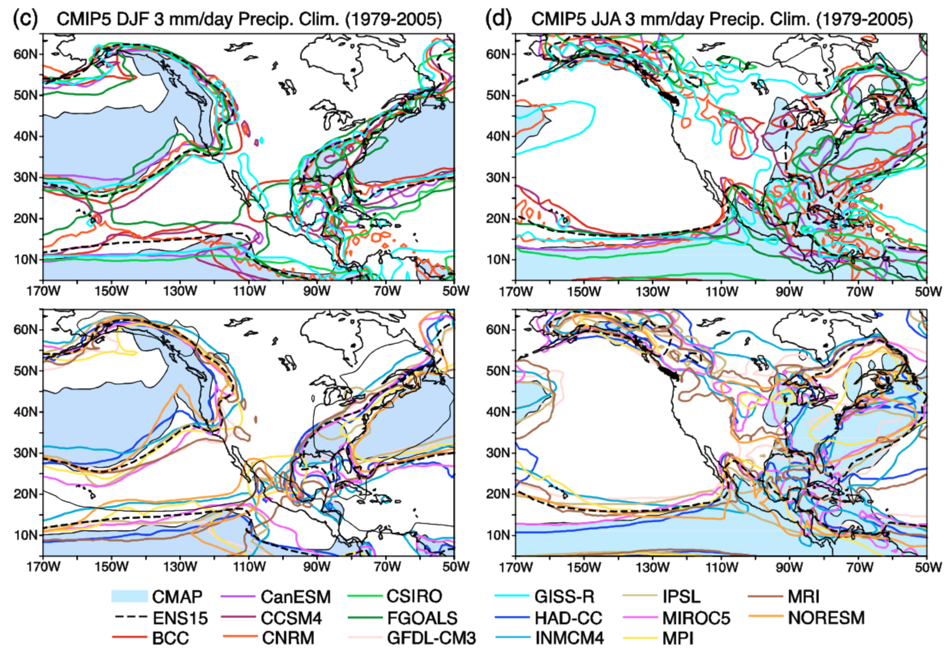
Baird Langenbrunner, Joyce E. Meyerson, J. David Neelin, UCLA

Seasonal Precipitation

Precipitation climatology for December-February and June-August (1979-2005). CMAP observations (top); CMIP5 (bottom)



Comparison of individual models to observations using the 3 mm day^{-1} contour as an index of the major precipitation features, Shading shows the regions where CMAP exceeds 3 mm day^{-1}.



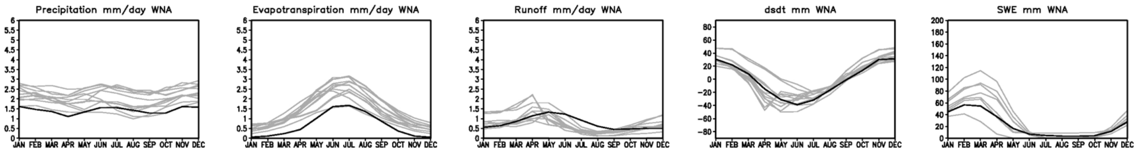
- The multi-model ensemble does reasonably well in representing the main features of precipitation over North America and the adjoining seas.
- There is large spread in individual model performance regionally however (e.g. high in continental interior; too much spread in the location of East Coast storm tracks)
- For some regions, a few outlier models provide much of the bias in the multi-model mean.

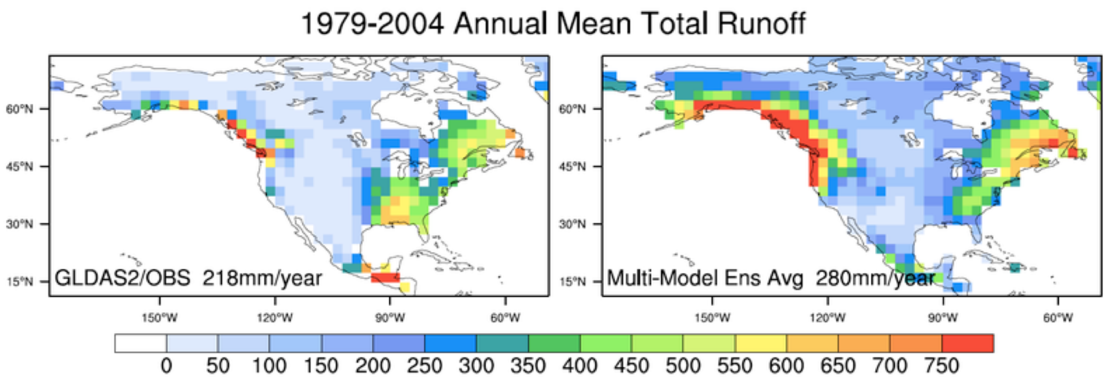
Baird Langenbrunner, Joyce E. Meyerson, J. David Neelin, UCLA

Land – Atmosphere Water Budgets

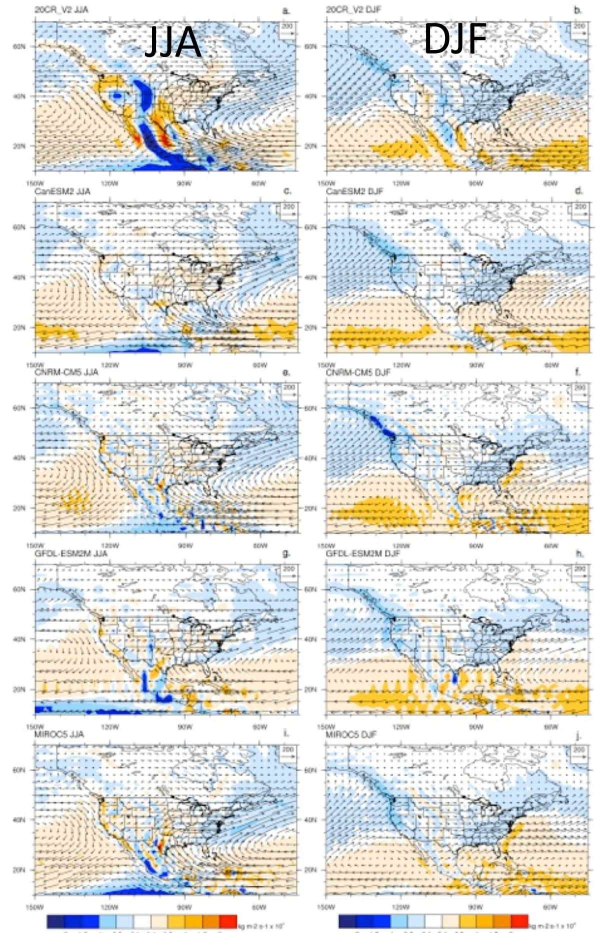
Justin Sheffield, Princeton;
Anji Seth, UConn

Mean seasonal cycle (1971-2000) of North American regional land water budget components for 12 CMIP5 models





Vertically integrated moisture transport (vectors) and its divergence (contours) for 1981-2000

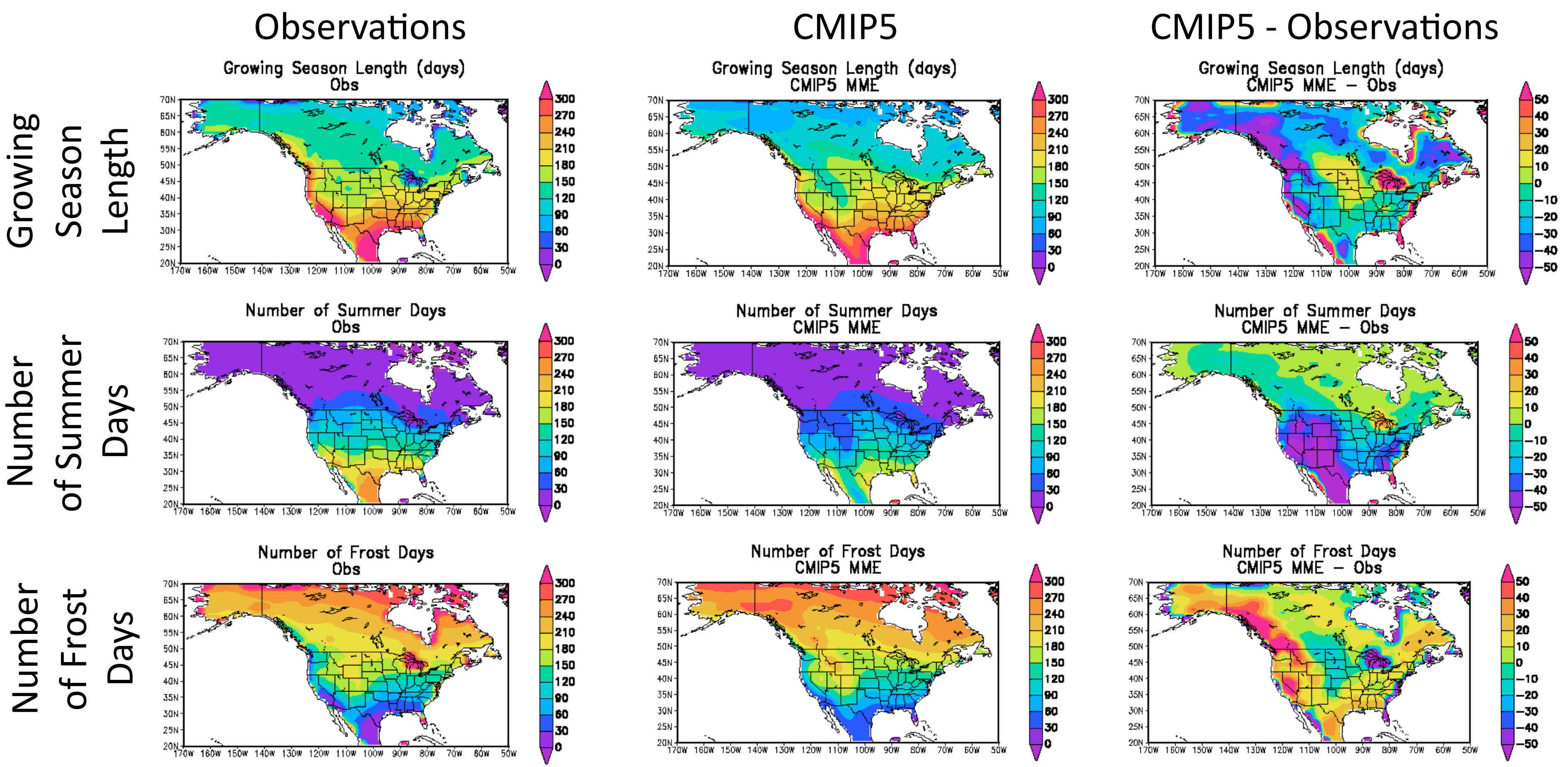


• The models have a reasonable seasonal cycle of terrestrial hydrology but the regional biases in precipitation filter down into biases in ET, runoff and snow accumulation.

• E.g. models overestimate precipitation in western regions, overestimate ET in the cooler months, underestimate runoff (and relative to model precipitation)

• Models capture main features of atmospheric moisture transport, with convergence off the east coast and divergence in the central plains and most of the west. However, they do not simulate the strong convergence over the Rockies and Mexican Plateau.

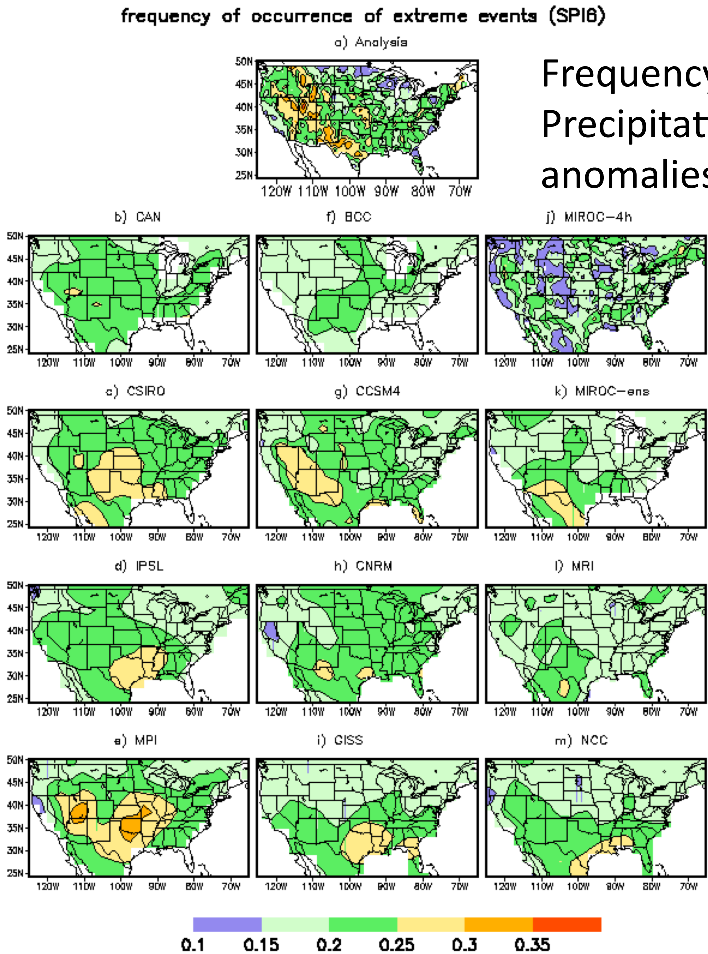
Biophysical Indicators - Temperature



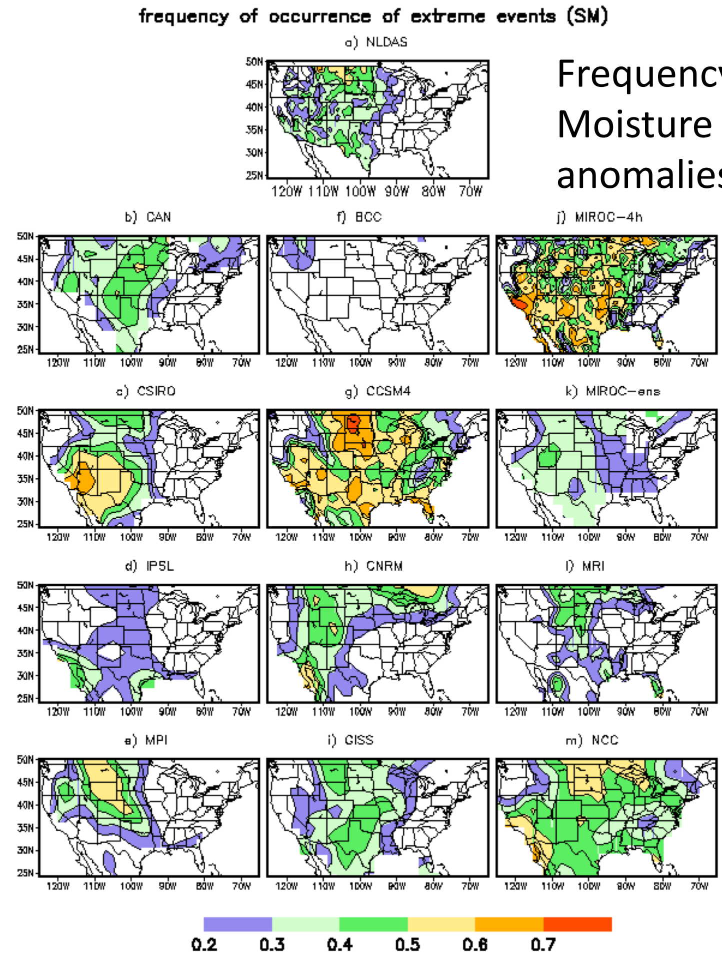
- The models do reasonably well at capturing the spatial distribution of seasonal temperature variations.
- The models' growing season is generally too long overall with the largest positive biases (up 40-50 days) in the central US and coastal regions, but is too short in western Canada.
- The frequency of summer days is too low in western regions
- The frequency of frost days is too high in the western mountains for most models.

Justin Sheffield, Princeton

Frequency of Persistent Wet and Dry Anomalies



Frequency of Precipitation anomalies



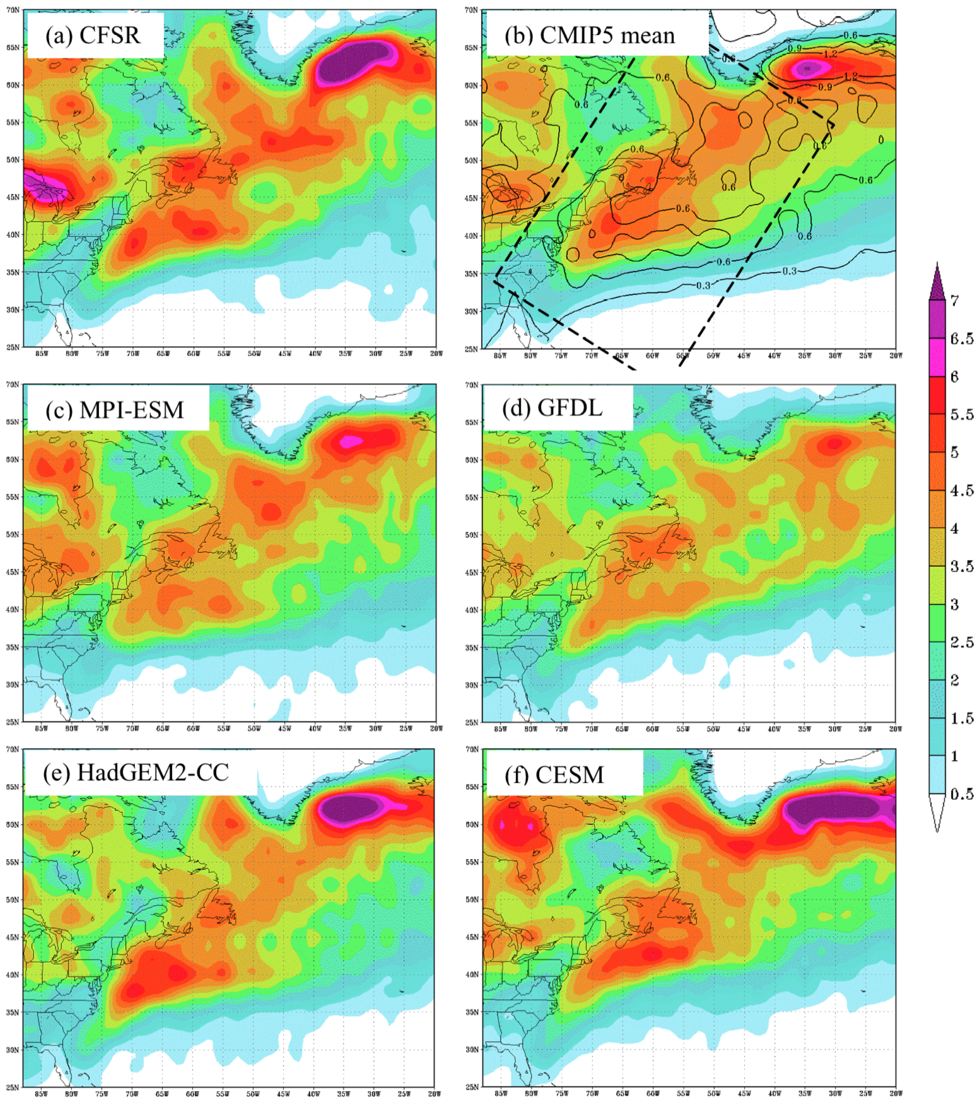
Frequency of Soil Moisture anomalies

- The models show quite different skill in simulating the frequency of persistent anomalies.
- Some models capture the east-west contrast in precipitation events – they also have a realistic precipitation climatology.
- Skill for precipitation frequencies does not imply skill for soil moisture. Models need realistic land surface model as well as being able to simulate large-scale circulation anomalies

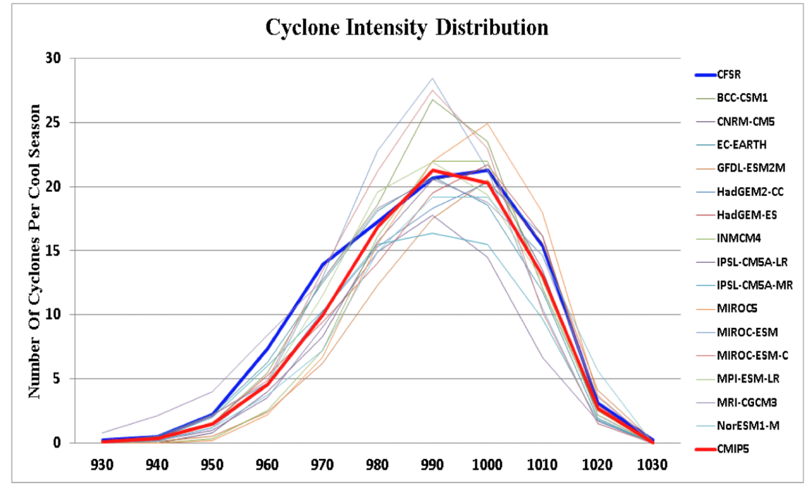
Lindsey Long, Kingste Mo, CPC

Western N. Atlantic Winter Cyclones

Frequency of cool season cyclones



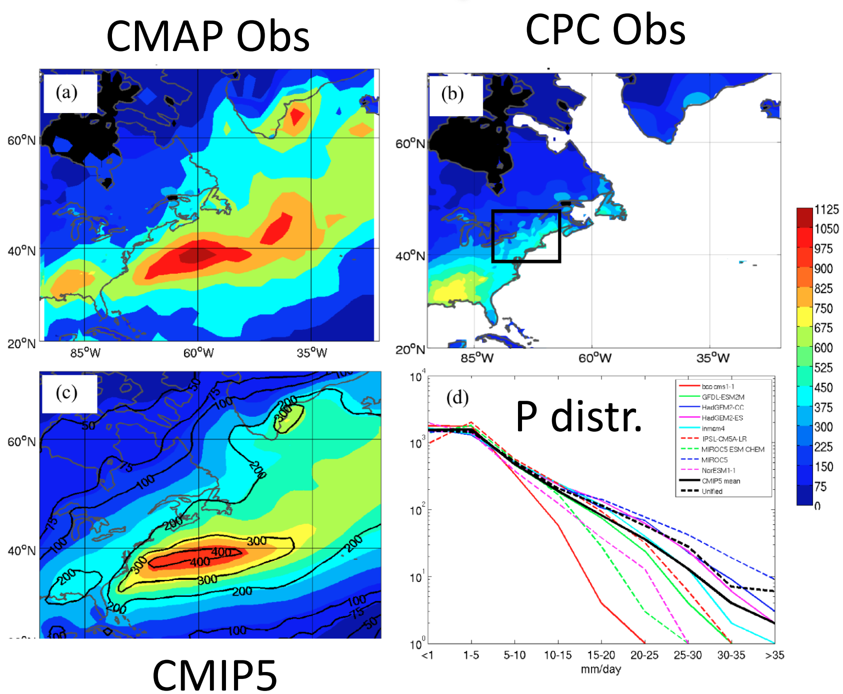
Cyclone Intensity Distribution



- The multi-model mean captures the cool season cyclone density over the western North Atlantic
- But under predicts the magnitude by 10-20%, which can be attributed partly to model resolution.
- All models tend to under predict the frequency of strong cyclones.

Brian Colle and Kelly Lombardo, SUNY

Northeast Cool Season Precipitation



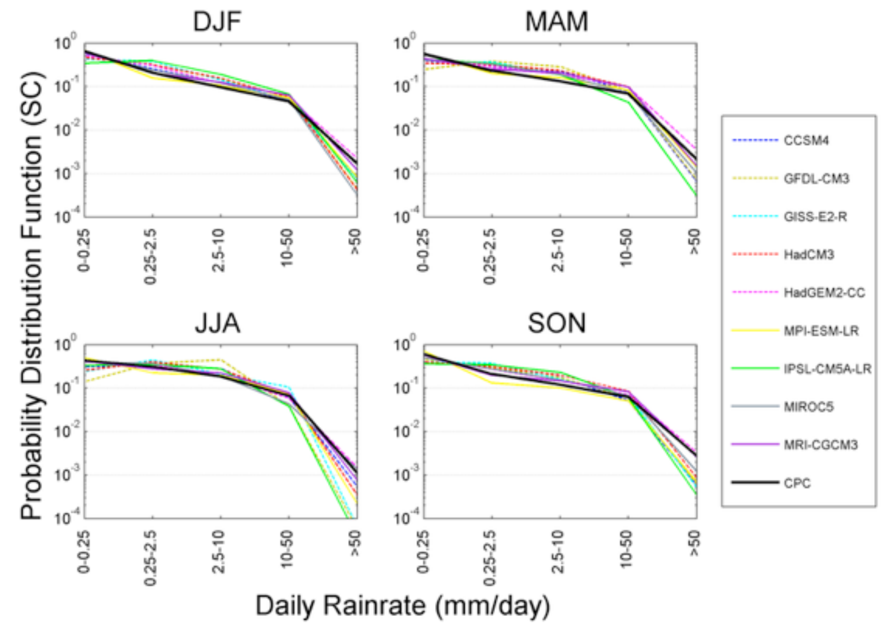
• The maximum precipitation towards the Northeast US coast associated with the storm track is realistically simulated by the models, but large spread

• But an over prediction over northern New England and southeast Canada

• Many models underestimate the frequency of heavy precipitation events

Brian Colle and Kelly Lombardo, SUNY

Southern Tier States Precipitation



• Over the southern US, most models underestimate heavy rainfall over the southern US, although a few models, in particular HadGEM2, do reasonably well.

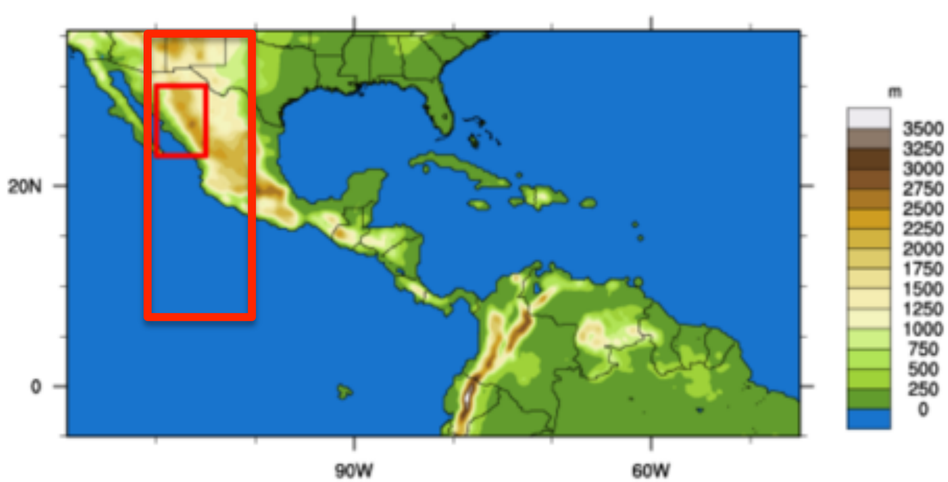
• (Not shown) models tend to underestimate the frequency of the hottest temperature maximums in summer and overestimate the frequency of cooler temperature maximums.

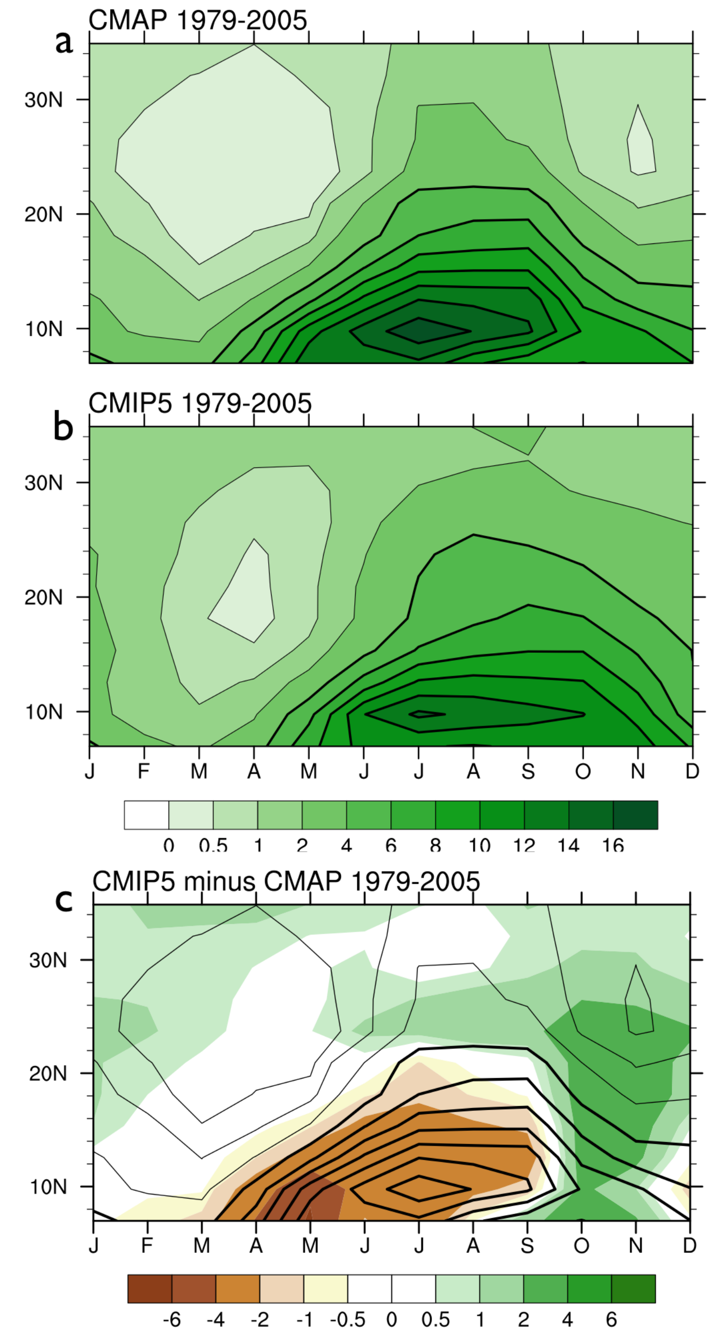
Rong Fu, UTexas Austin

Warm season rainfall in the North American Monsoon

A. Seth, University of Connecticut

- The North American Monsoon (NAM) brings rainfall to southern Mexico in May, expanding northward to the Southwest US by late June or early July.
- Monsoon rainfall accounts for roughly 50-70% of the annual totals in these regions
- The North American monsoon is generally later and underestimated in terms of precipitation for the multi-model mean.



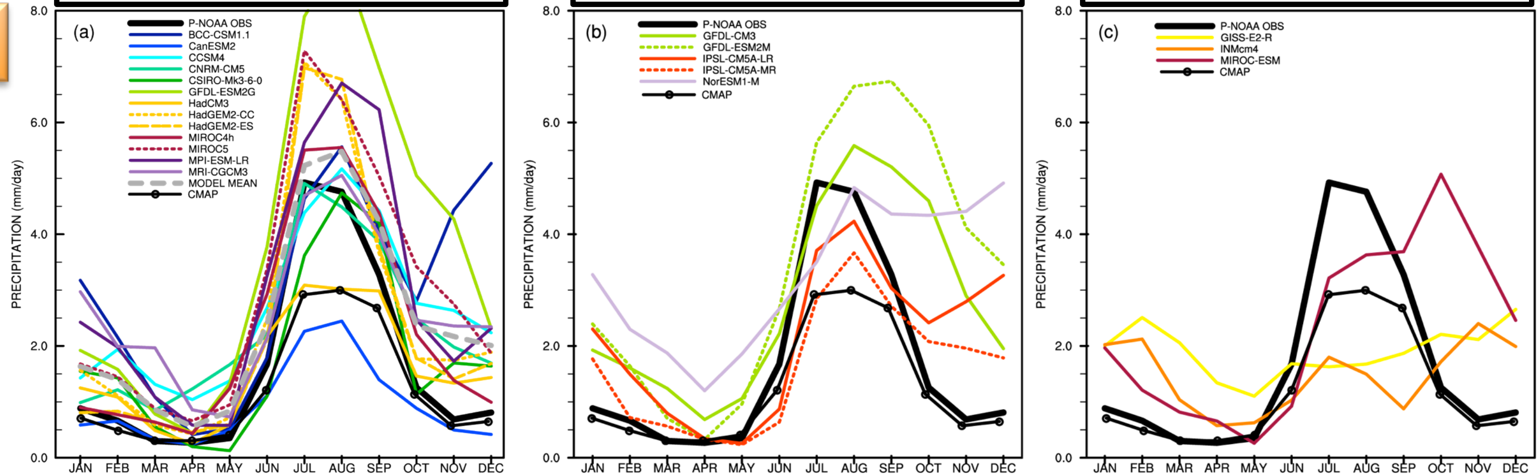


Core North American Monsoon Precipitation in CMIP5 Models

Kerrie Geil and Yolande Serra, University of Arizona

CMIP5:

Small (0 month) Phase Errors: 1979-2005	Moderate (1 month) Phase Errors: 1979-2005	Large (>1 month) Phase Errors: 1979-2005

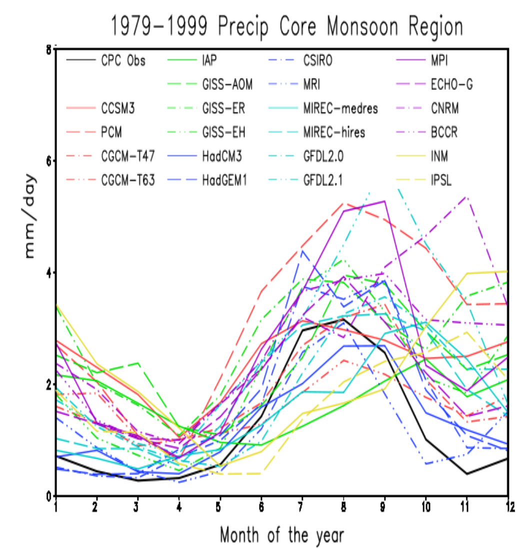


Method: Calculate monthly phase error in annual cycle w/r P-NOAA observations.

Results:

- CMIP5 shows better onset compared to CMIP3 in the core NAM region.
- CMIP5 models show difficulty ending the monsoon as was the case for CMIP3.
- Some CMIP5 models show larger positive bias in monsoon monthly maximum compared to CMIP3.

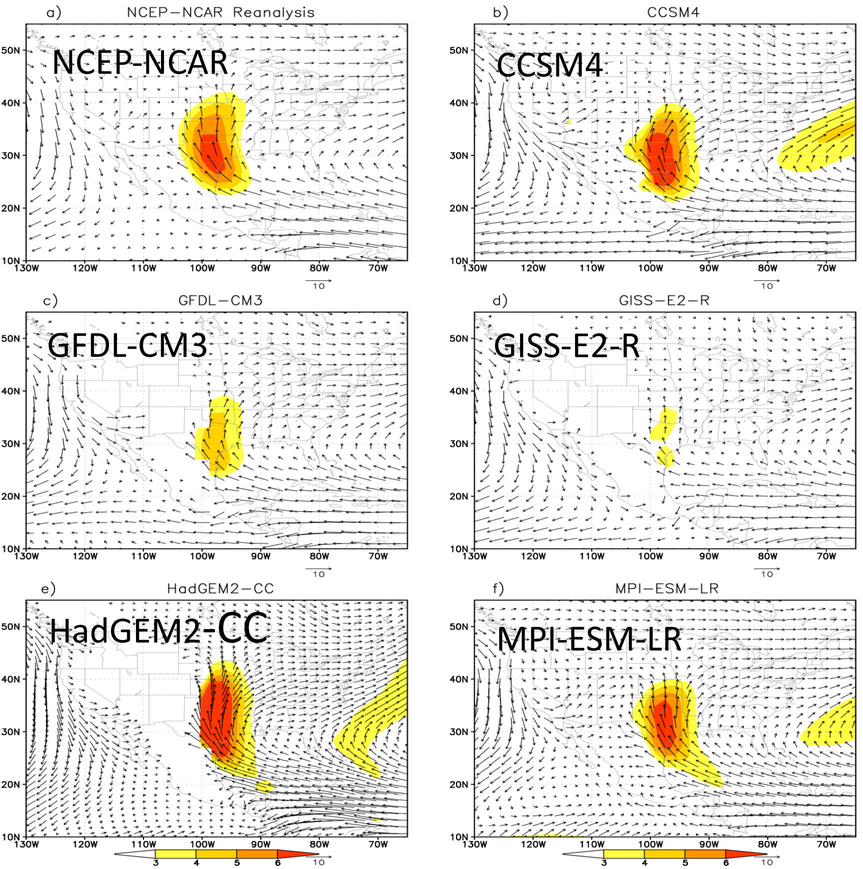
CMIP3:



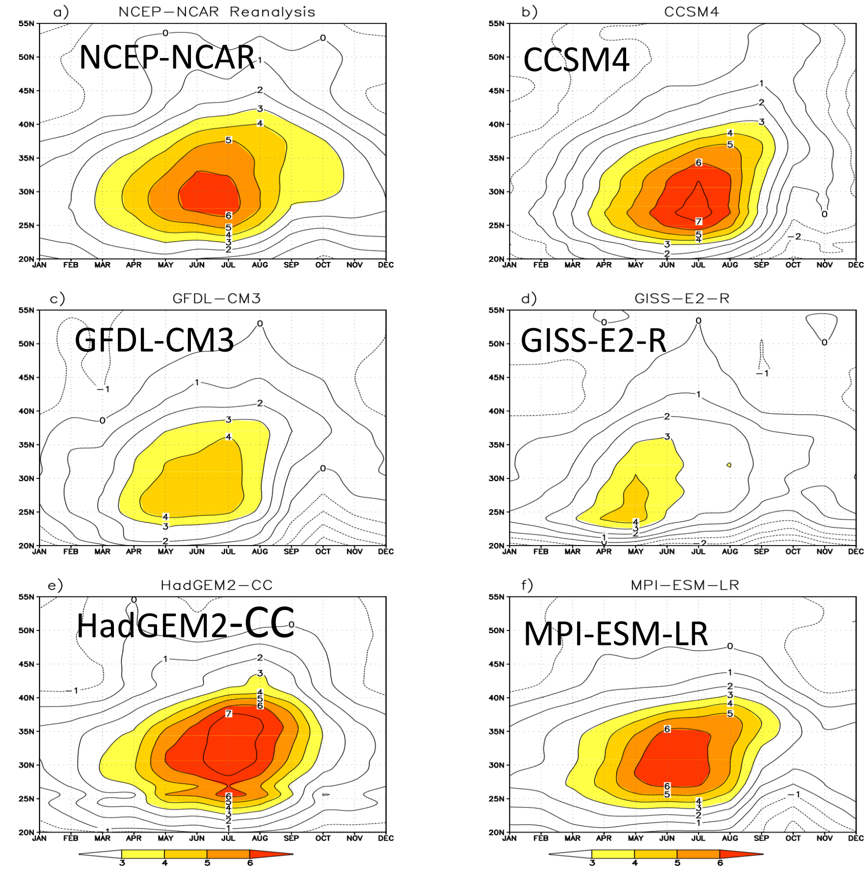
AR4 results courtesy of Lee Byerle, Lt. Col., Maxwell AFB Montgomery, AL.

US Great Plains Low Level Jet

Averaged summer 925hPa wind during 1971-2000.
Shading is > 3m/s



Long-term mean (1971-2000) monthly meridional wind averaged over 95˚-100˚W

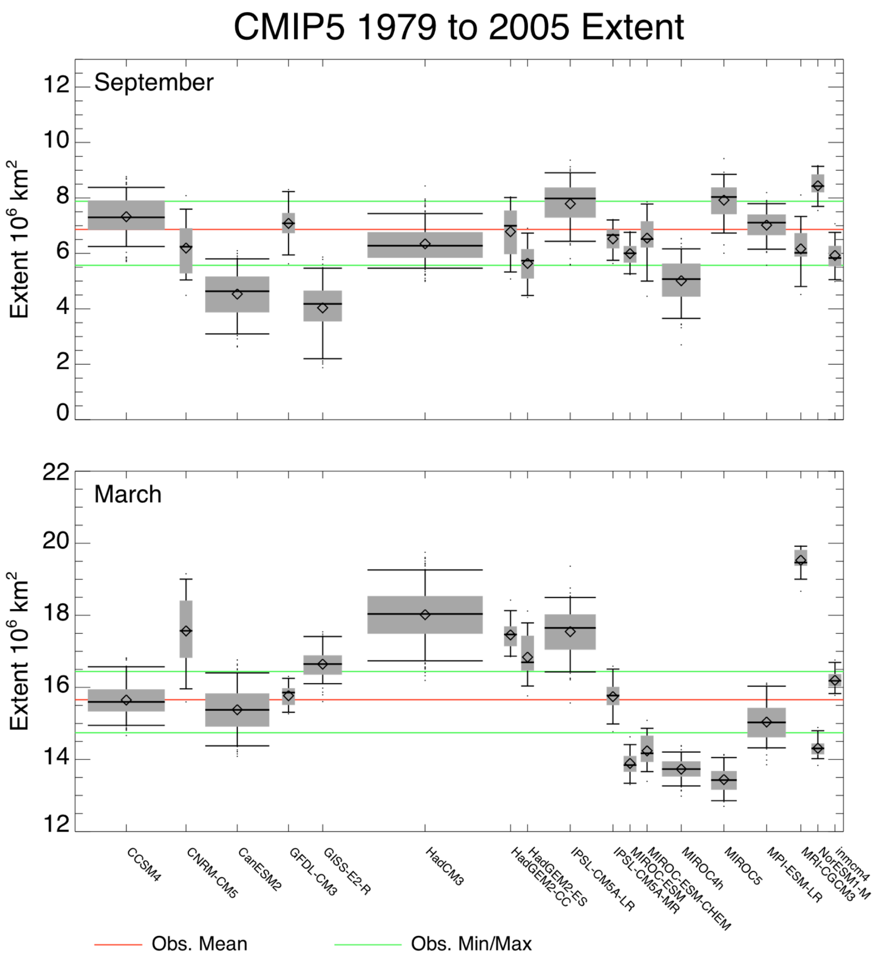


- LLJ is an important source of warm season moisture to central US: shaped mainly by orography
- Variability in the LLJ is linked to drought occurrence
- The five models evaluated capture its main features, with the accuracy of the northerly extension and intensity related to the model resolution

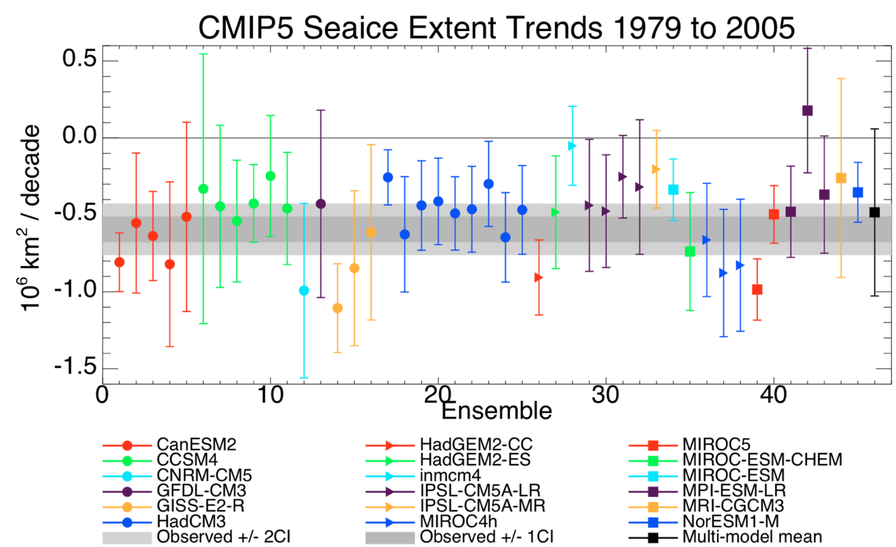
Steve Hu, U. Nebraska

Arctic Sea Ice Extent

Andrew Barrett, Julienne C Stroeve , NSIDC



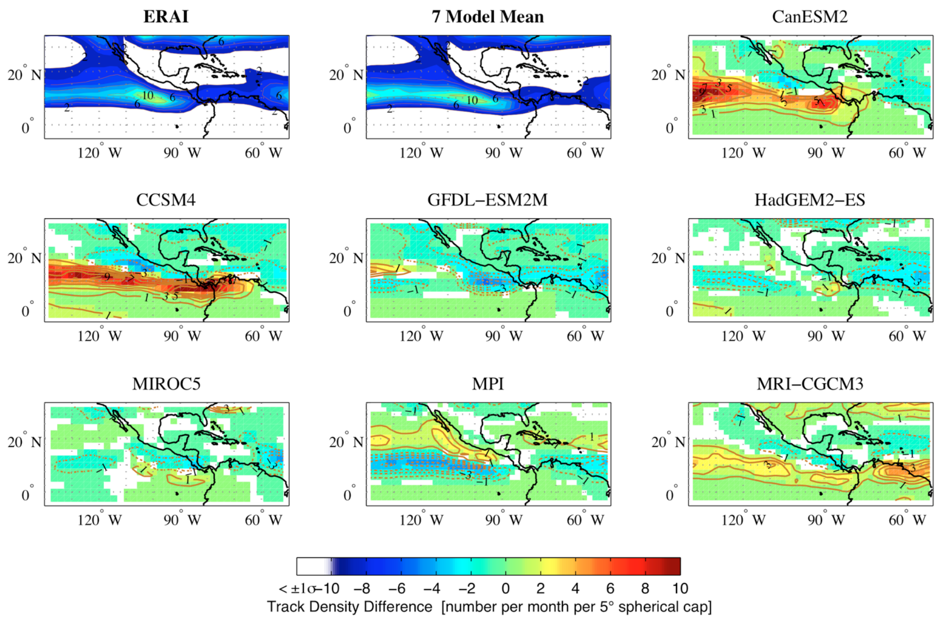
Since routine monitoring by satellites began in late October 1978, Arctic sea ice has declined in all calendar months



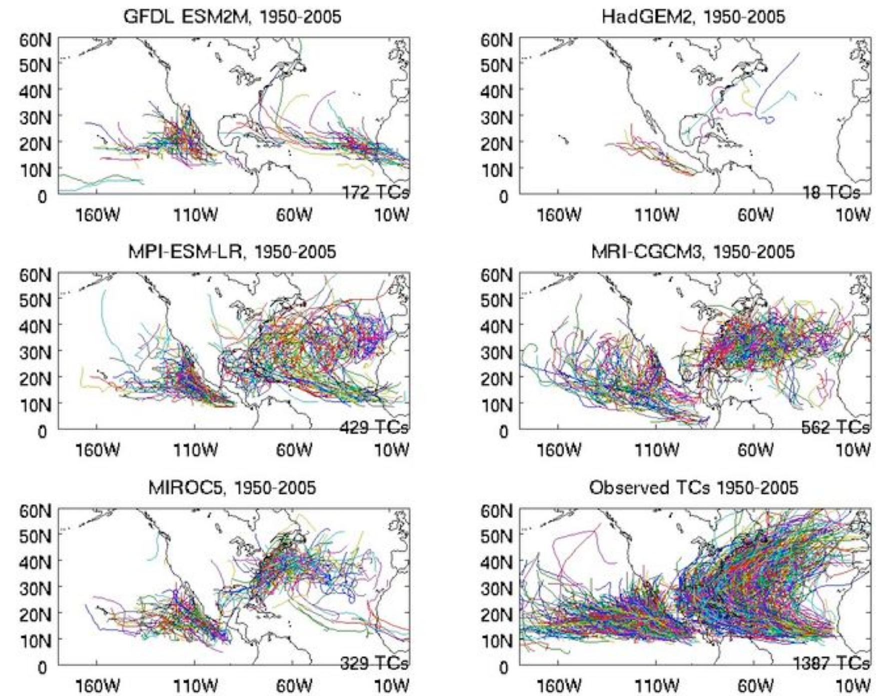
- Models tend to under predict sea ice extent in September and most fall outside of the range of observations in March.
- Related to biases in ice thickness (as seen from ICESat comparisons)
- Most models underestimate the observed rate of decline in September sea ice extent for 1979-2005. The multi-model mean trend is not statistically different from zero.

Tropical Disturbances, Storms and Cyclones

Storm track density (top) and mean strength (bottom) for ERA Interim and seven CMIP5 models



Tracks of tropical cyclone-like storms in the CMIP5 historical runs in the period 1950-2005

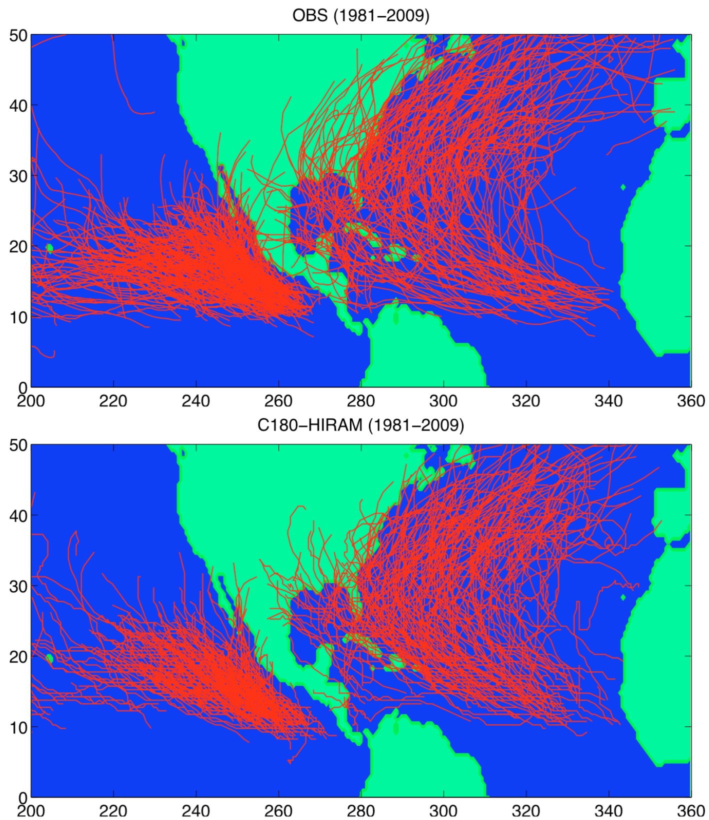


- When all tropical disturbances and storms are considered (left), the set of models examined does a reasonable job of depicting the density and location of activity but with much scatter
- When only tropical cyclones are analyzed (right), all models severely under predict the number of TCs, especially in the peak hurricane season
- These biases have implications for simulated precipitation over the southeastern US which can receive up to 20% of annual and 30% of warm season precipitation from TCs (Kam et al., 2012) and contribute significantly to heavy precipitation (Knight and Davis, 2009).

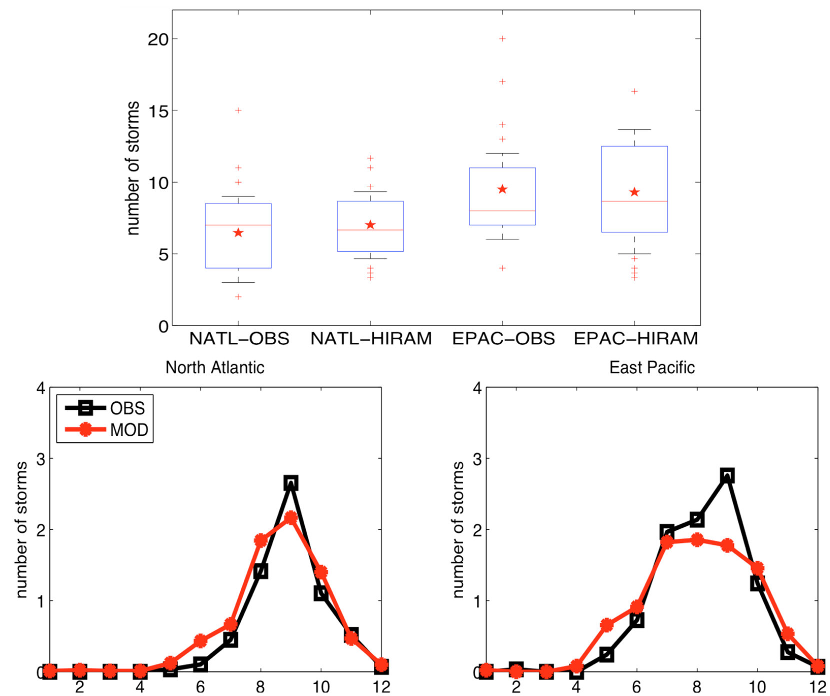
Yolande Serra, UA; Suzana Camargo, LDEO

High-Resolution Modeling of Tropical Cyclones

Observed (upper panel) and C180HIRAM simulated (lower panel) hurricane tracks for the N. Atlantic and E. Pacific for 1981-2008



Upper panel: observed and C180HIRAM simulated annual hurricane count statistics. Lower panels: Observed and model simulated seasonal cycle (number of hurricanes per month) for the N. Atlantic and E. Pacific.



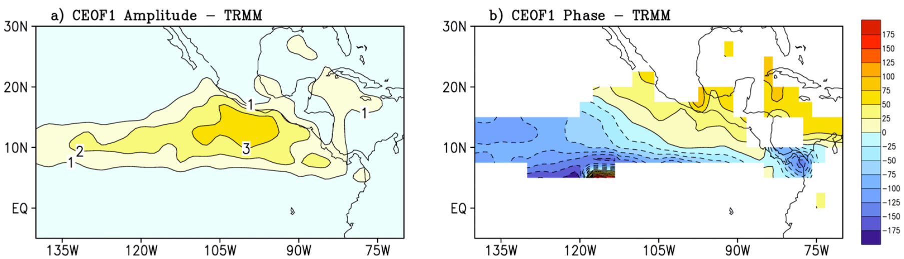
• Experiments with the higher resolution GFDL model, indicate that 25-50km resolution models can do a good job at replicating TC frequency and variability

• although they still cannot simulate the most intense storms.

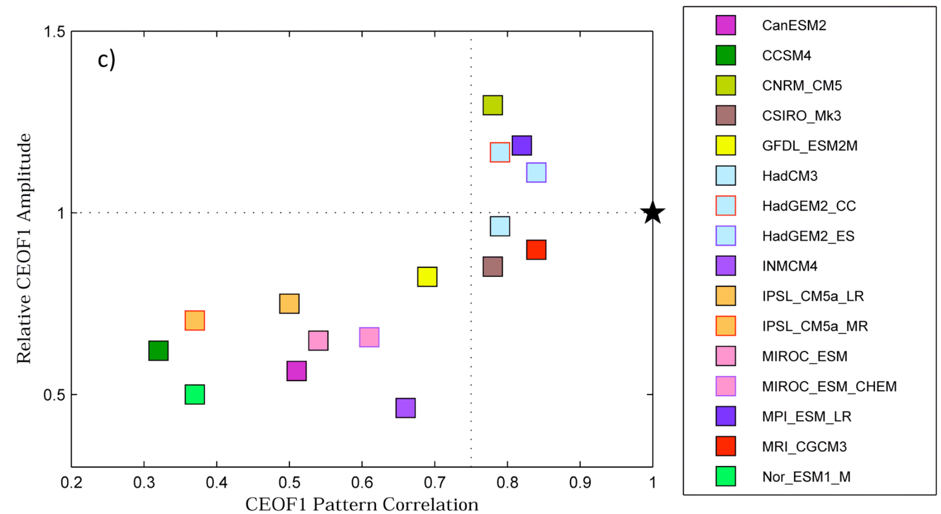
Ming Zhao , GFDL

Eastern North Pacific Intraseasonal Variability

Intraseasonal variability (ISV) over the eastern north Pacific (ENP) exerts pronounced influences on regional weather and climate



Spatial distribution of amplitude (a) and phase (b) of the first leading complex EOF (CEOF1) mode based on 30-90-day band-pass filtered TRMM rainfall during boreal summer (June-September) over the eastern Pacific.



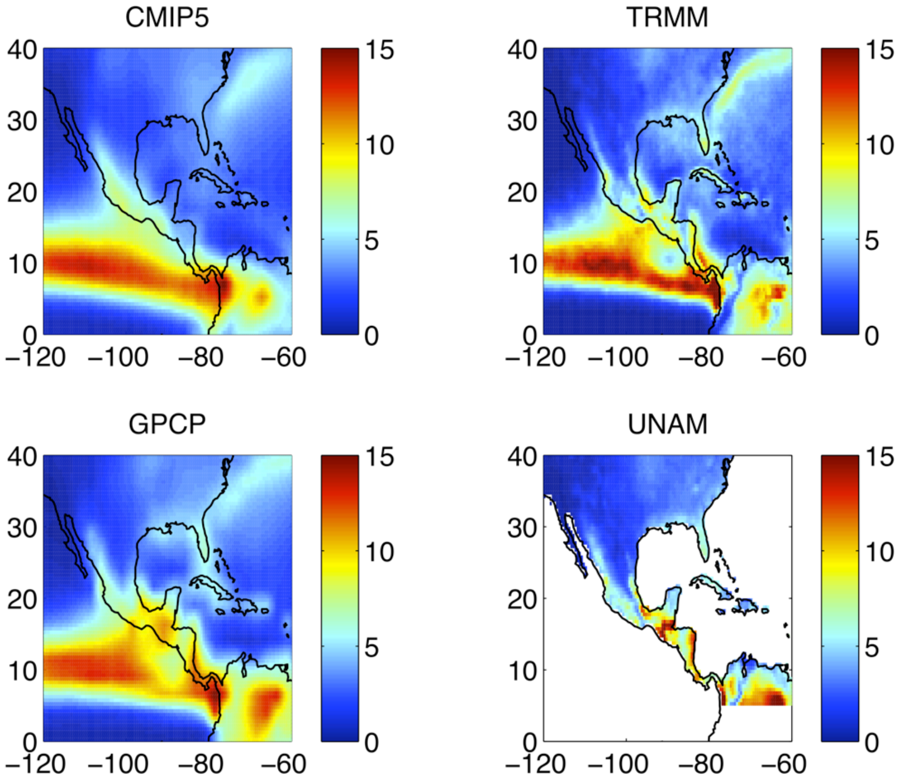
X-axis: Pattern correlation coefficients of the CEOF1 mode between TRMM observations and CMIP5 GCM simulations.
Y-axis: Relative amplitudes of CEOF1 in model simulations to their observed counterparts.

- Only seven out of the 16 models capture the spatial pattern of the leading ENP ISV mode
- But several of these exhibit biases in simulating ISV amplitude.
- It is indicated that model fidelity in representing ENP ISV is closely associated with ability to simulate a realistic summer mean low-level circulation. The presence of westerly or weak mean easterly winds over the ENP could be conducive for more realistic simulations of the ISV.

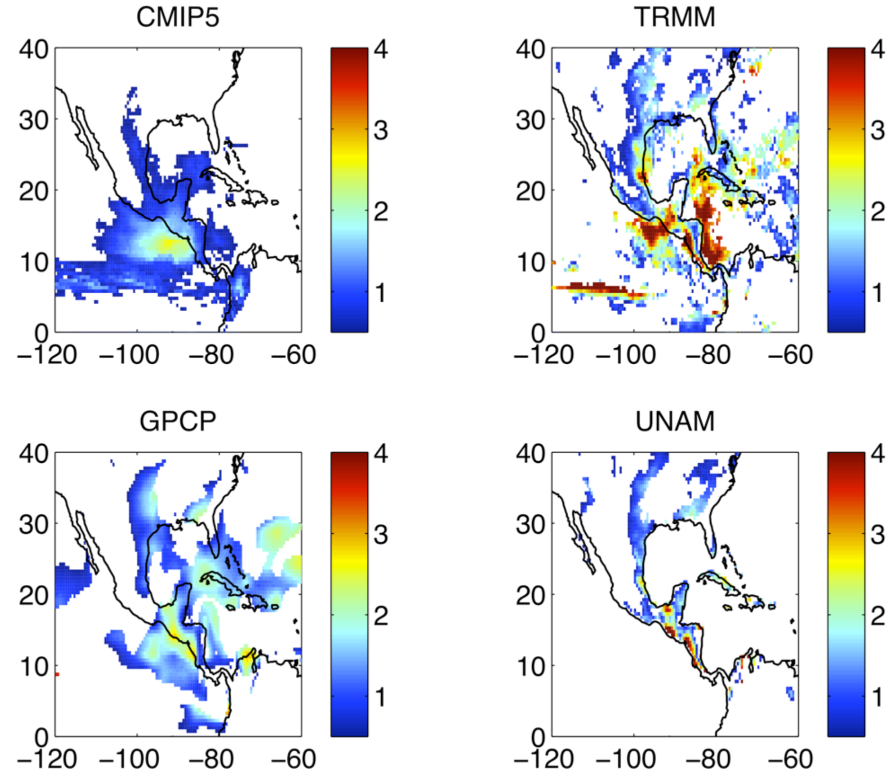
Jiang X., E. Maloney, F. Li, and D. Waliser

The Midsummer Drought in Central America

CMIP5 MMM and observed summertime (June-September) precipitation (mm/day)



CMIP5 MMM and observed and MSD strength (mm/day)

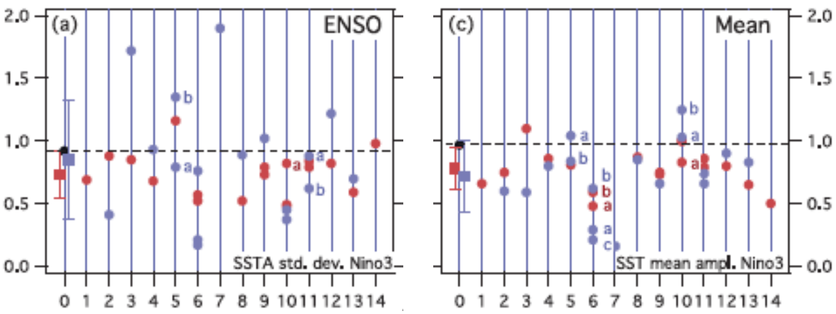


- The rainy season in Central America and southern Mexico spans roughly May through October.
- For most of the region, the precipitation climatology features maxima in June and September and a period of reduced rainfall during July-August known as the midsummer drought (MSD).
- The MSD is regular enough to be known colloquially and plays an important role in farming practices.
- CMIP5 models reasonably well simulate the observed historical MSD, both in spatial structure and amplitude.

Kris Karnauskas, WHOI; Richard Seager, LDEO

ENSO Frequency/Amplitude and Teleconnections

ENSO and mean tropical Pacific metrics for pre-industrial control simulations - CMIP3 (blue) and CMIP5 (red)

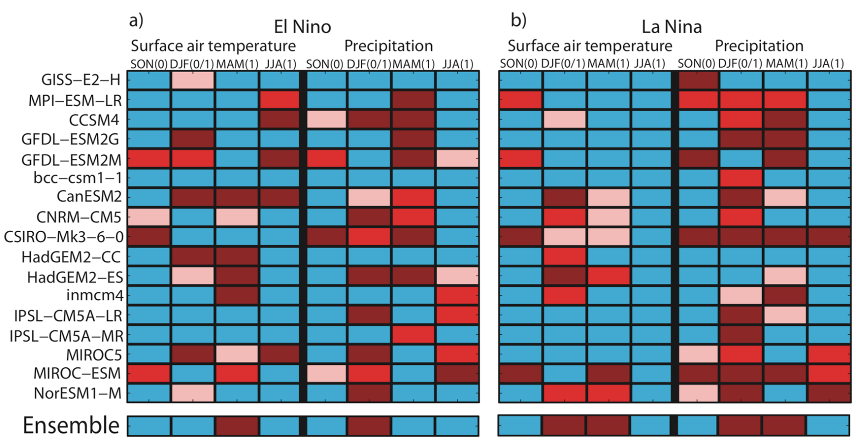


• The CMIP5 multi-model ensemble mean reproduces the frequency and mean amplitude of ENSO events

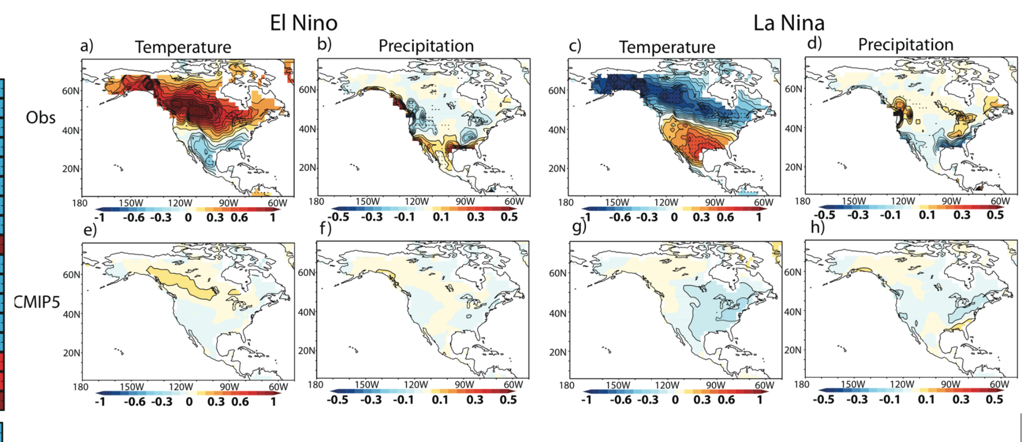
• But does not appear to have improved significantly since CMIP3 (Guilyardi et al., 2012).

• The models do not fully reproduce the phase-locking of ENSO to the seasonal cycle, a deficiency noted in CMIP3 models as well (Guilyardi et al. 2009).

Comparison of ENSO-related SAT and precipitation composite patterns between CMIP5 models and observations.



Wintertime composites of ENSO-related SAT and precipitation anomalies in observations and the CMIP5 ensemble.



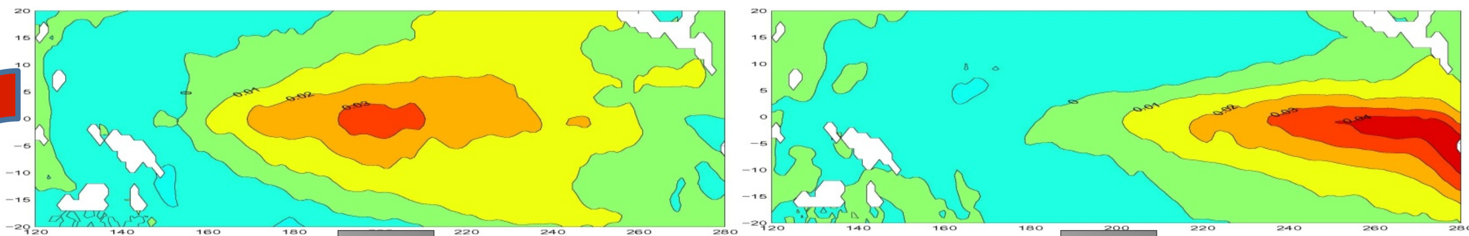
• CMIP5 surface air temperature and precipitation ENSO composites show a wide range in model fidelity to the observed relationships, with the largest discrepancies occurring during winter and spring.

• Again the situation has not changed since CMIP3 (Joseph and Nigam, 2006; Mo, 2010)

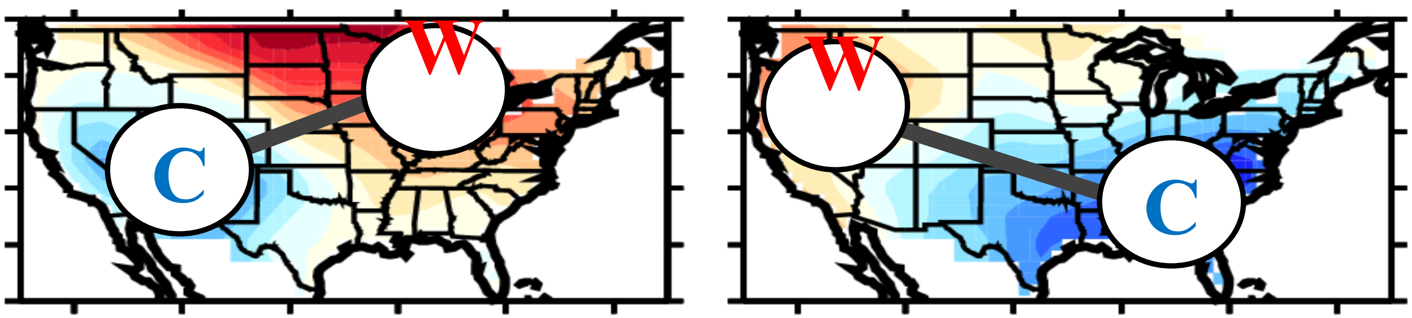
Two Types of ENSO in CMIP5 Models and Their Different Impacts on US Winter Climate

(PI: Jin-Yi Yu; University of California-Irvine; NOAA MAPP-CMIP5 Task Force)

Central-Pacific ENSO | **Eastern-Pacific ENSO**



SST



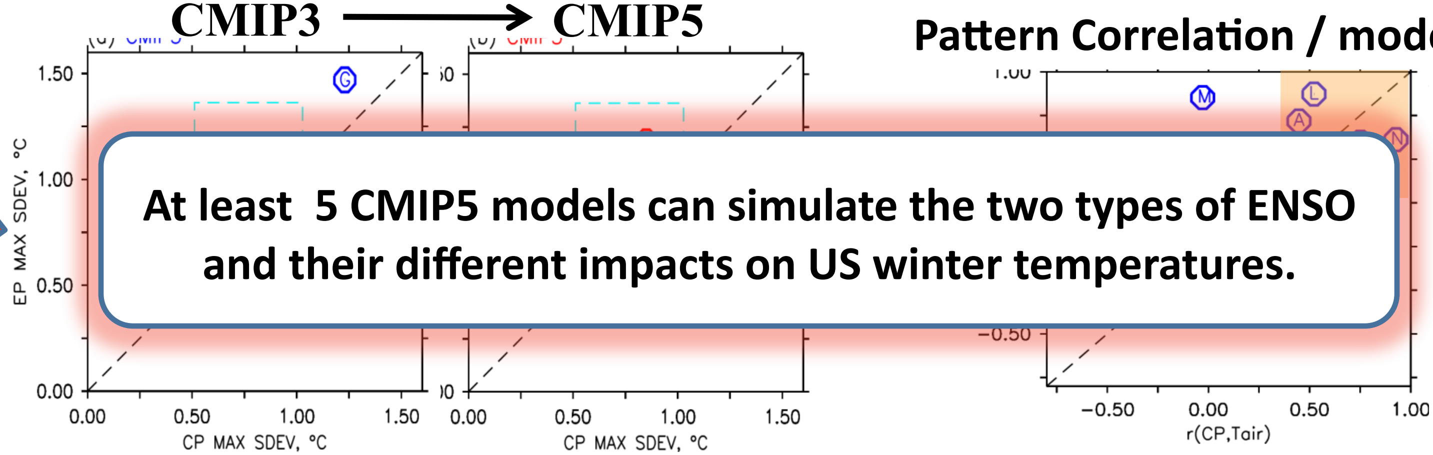
Winter (JFM) Surface Air temperature

CMIP5 Simulation of the Two Types of ENSO

CMIP3 → CMIP5

CMIP5 Simulation of the Different Impacts

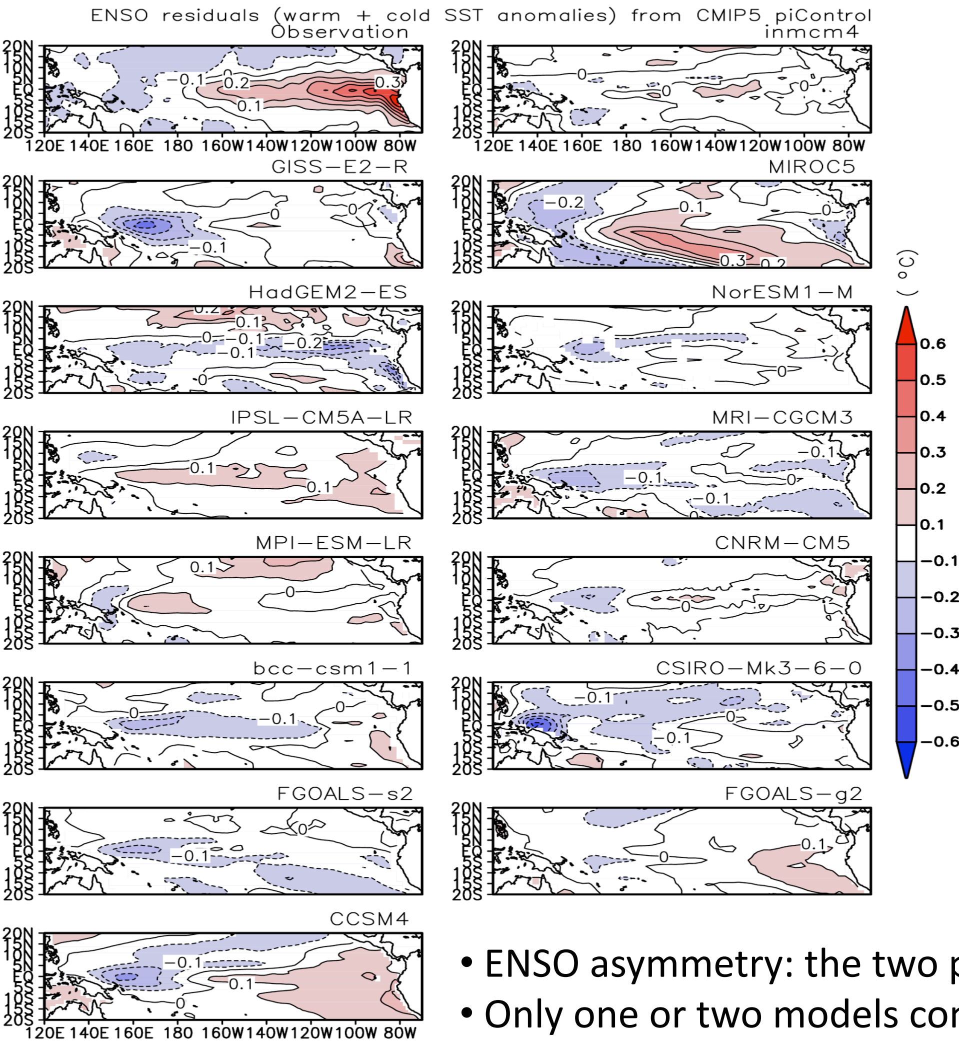
Pattern Correlation / model & Ob



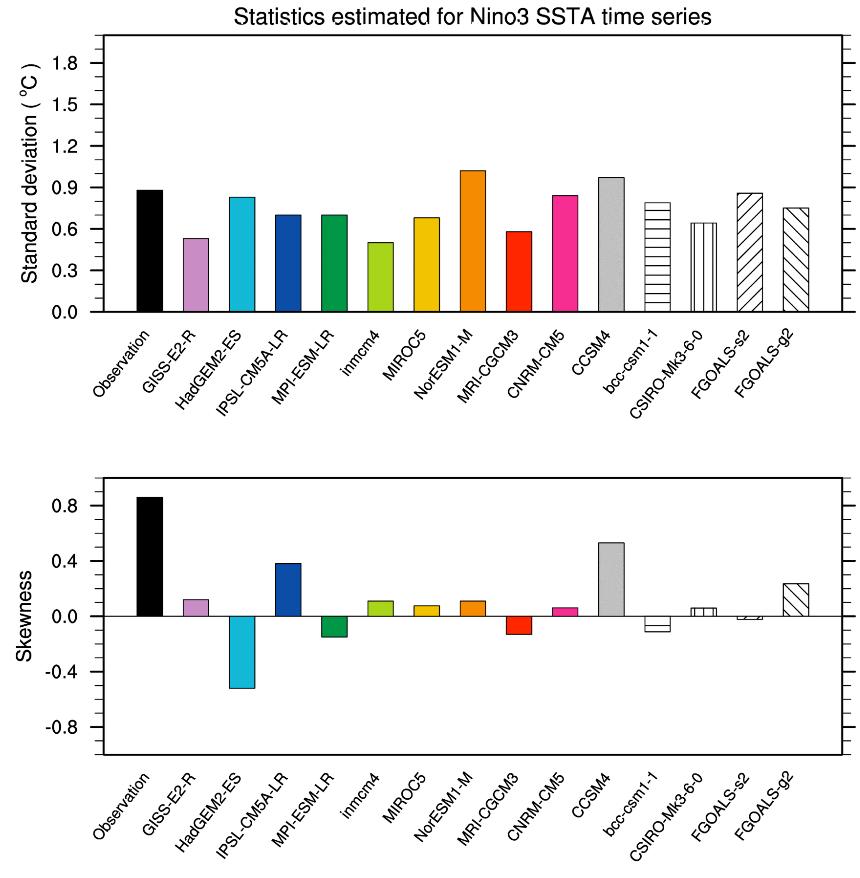
At least 5 CMIP5 models can simulate the two types of ENSO and their different impacts on US winter temperatures.

ENSO Warm/Cold Events Asymmetry

The sum of the composite SST anomalies between the two phases of ENSO



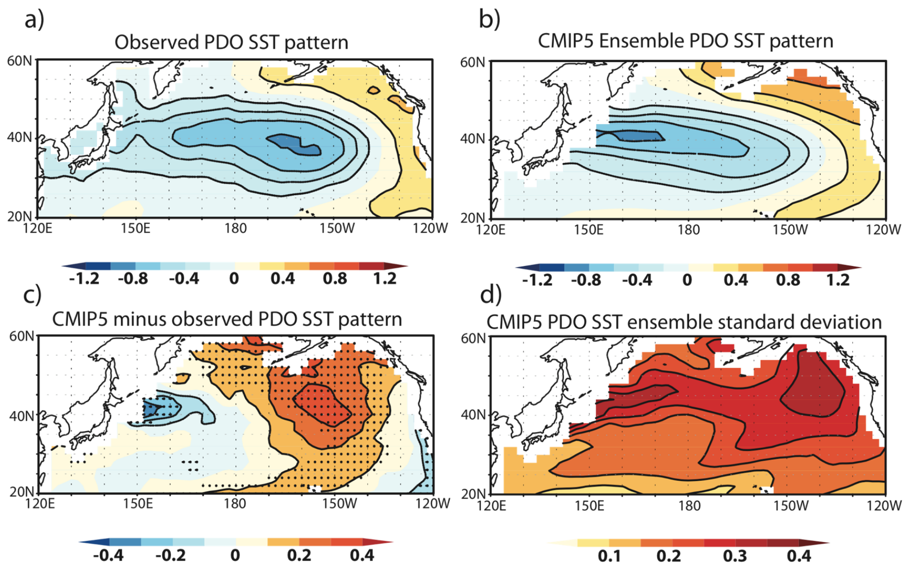
Standard deviation (upper) and skewness (bottom) of the interannual variability in Niño-3 SST.



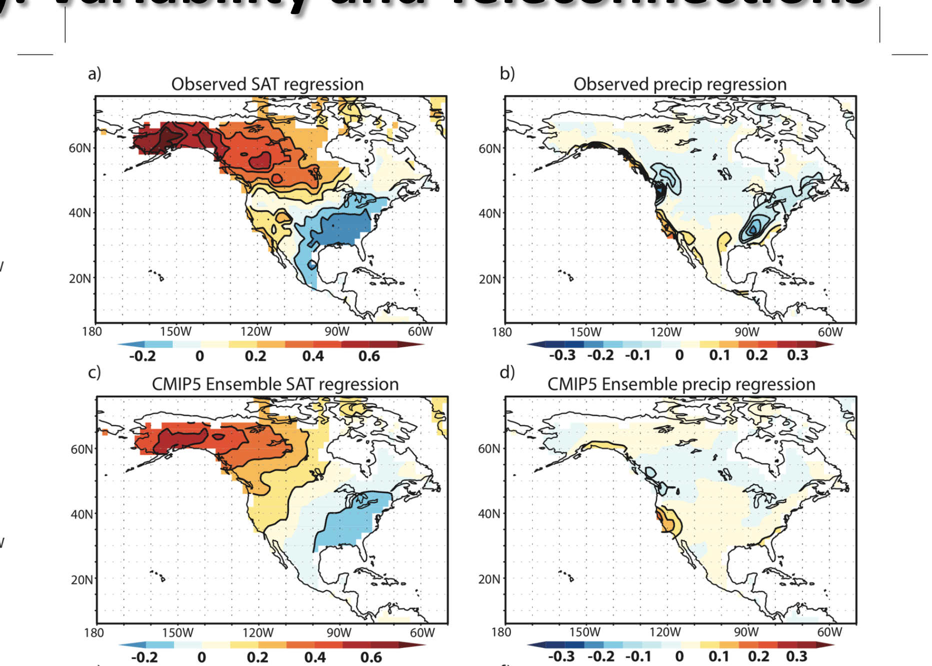
- ENSO asymmetry: the two phases of ENSO are not mirror images of each other
- Only one or two models come close to representing the skewness in ENSO phases
- This is independent of model ability to represent variability in ENSO
- This bias has implications for simulating tropical decadal variability

Tao Zhang and De-Zheng Sun, U Colorado

Pacific Decadal Oscillation (PDO): Variability and Teleconnections



PDO SST patterns in observations and CMIP5 models. Linear regression of SST upon the PDO index in (a) observations and (b) the CMIP5 ensemble, and (c) the CMIP5 minus observed PDO regression.



December-February PDO SAT and precipitation regression patterns over North America

• As in the CMIP3 models, the CMIP5 models reproduce the basic PDO horseshoe SST pattern. The most notable difference is the westward shift of the North Pacific center of action in models with respect to observations.

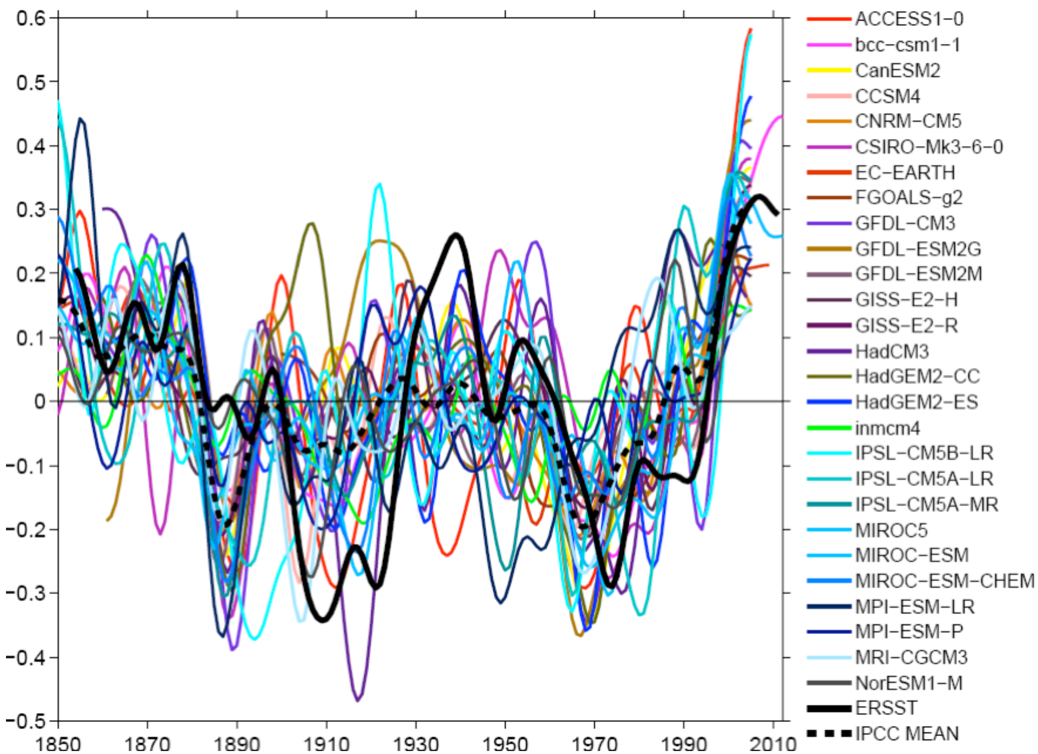
• Overall, the CMIP5 models perform well in capturing the PDO influence on North American temperature and on West Coast precipitation in winter.

• The largest deficiencies appear to lie in the representation of the wintertime precipitation signature over the eastern North America.

Nat Johnson, Shang-Ping Xie, U. Hawaii

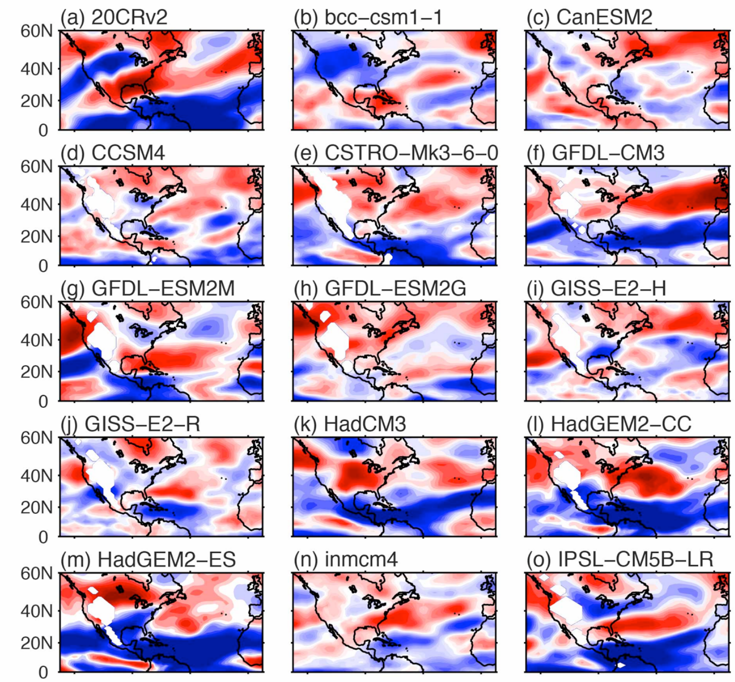
Atlantic Multidecadal Oscillation:

Variability and Connectivity with Vertical Wind Shear



The AMO index defined as the detrended North Atlantic SST during the Atlantic hurricane season of June to November (JJASON) from the equator to 60°N, 75°W-5°W with the 11-year running mean

Regressions of the JJASON AMO on vertical wind shear.



- Tropospheric vertical wind shear in the MDR is important for development of Atlantic hurricanes, with a small (large) wind shear favoring (disfavoring) hurricane activity.
- About 10/20 models can reproduce this

- Models show a large spread of uncertainty, but better than CMIP3 simulations.
- All models display a warming in the last two decades.
- Models underestimate the cooling (1900-25) and the subsequent warming (1925-40).

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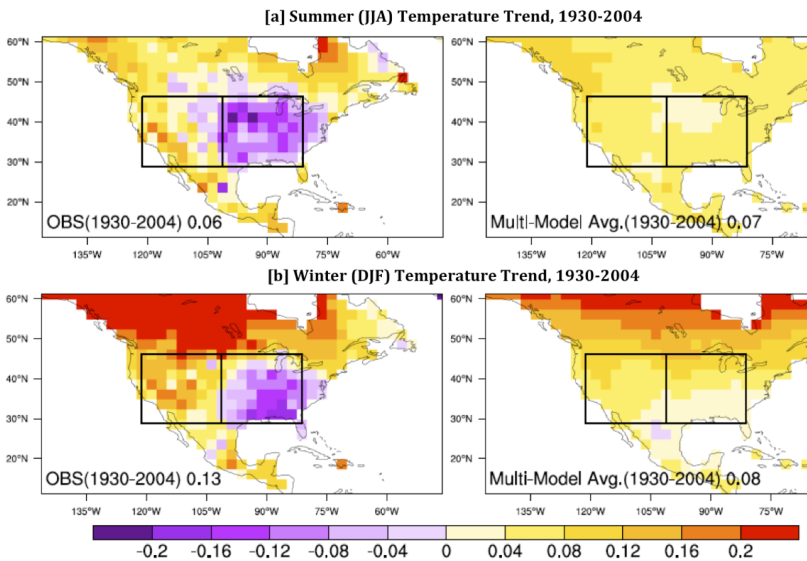
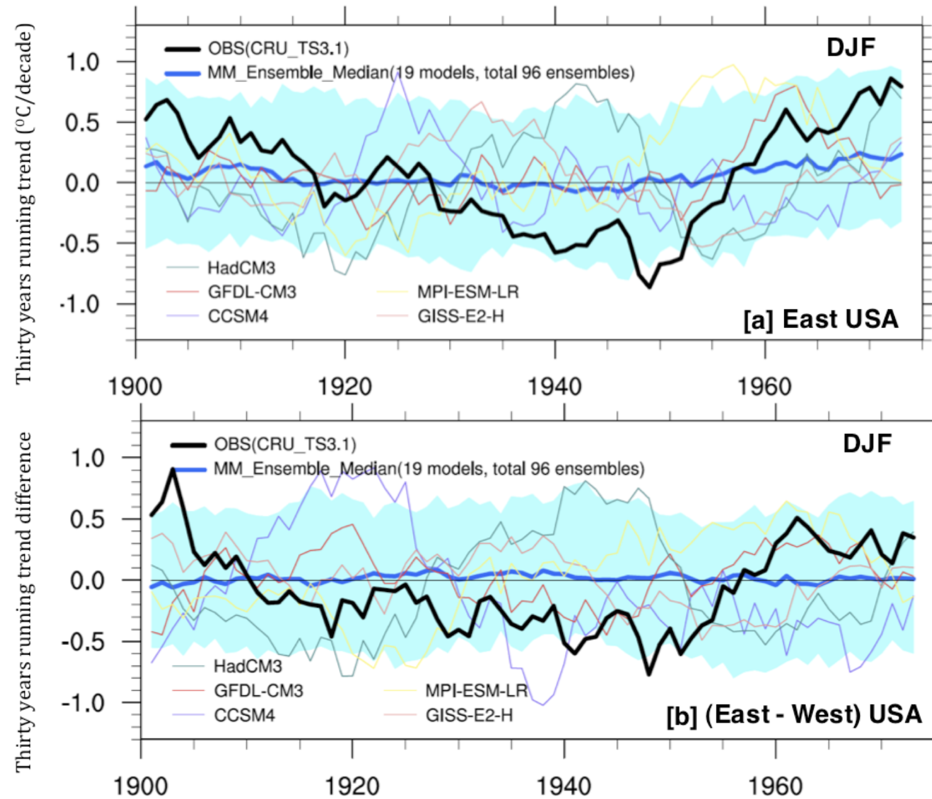
Southeastern US Warming Hole

A feature of US temperature change during the 20th century is the so-called "warming hole (WH)" observed in the southeastern US (Pan et al, 2004).



Summer and winter temperature trend (1930-2004), unit: degree C/decade



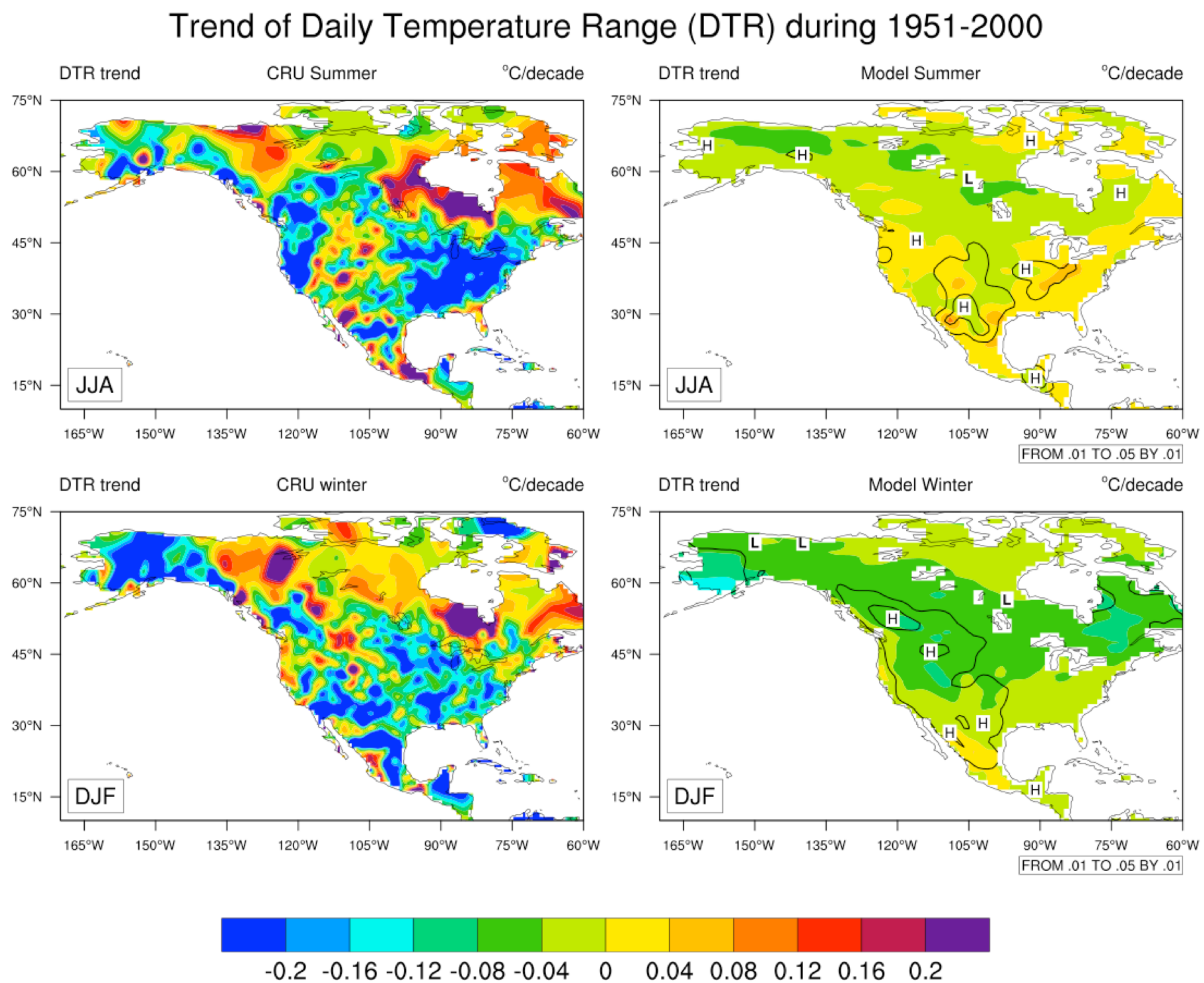
(a) 30 years running trend in East USA (30N to 47N, and 260E to 280E) DJF temperature trend (b) 30 year running trend difference between East and West USA

- The observed warming hole is replicated only by some models indicating that it is driven partly by decadal variability, rather than a forced climate signal or land surface feedback.
- The observed warming hole in the eastern US is closely associated with the multi-decadal oscillation in North Atlantic (65-70 years cycle; Kumar et al., 2012).

Zaitao Pan, Saint Louis University; Zanjiv Kumar, COLA

Trends in Diurnal Temperature Range (DTR)

Comparison of observed (left) and model simulated linear trends in daily temperature range (Tmax - Tmin) during 1951-2000 period.



- In summer, the models capture a cooling trend in central U.S., roughly corresponding to the WH region, although the position is shifted to the west and the magnitude is lower.
- In winter the models largely reproduce the broad decrease in DTR as observed, but again with lower magnitude.
- They fail to capture the increasing trends in high latitudes

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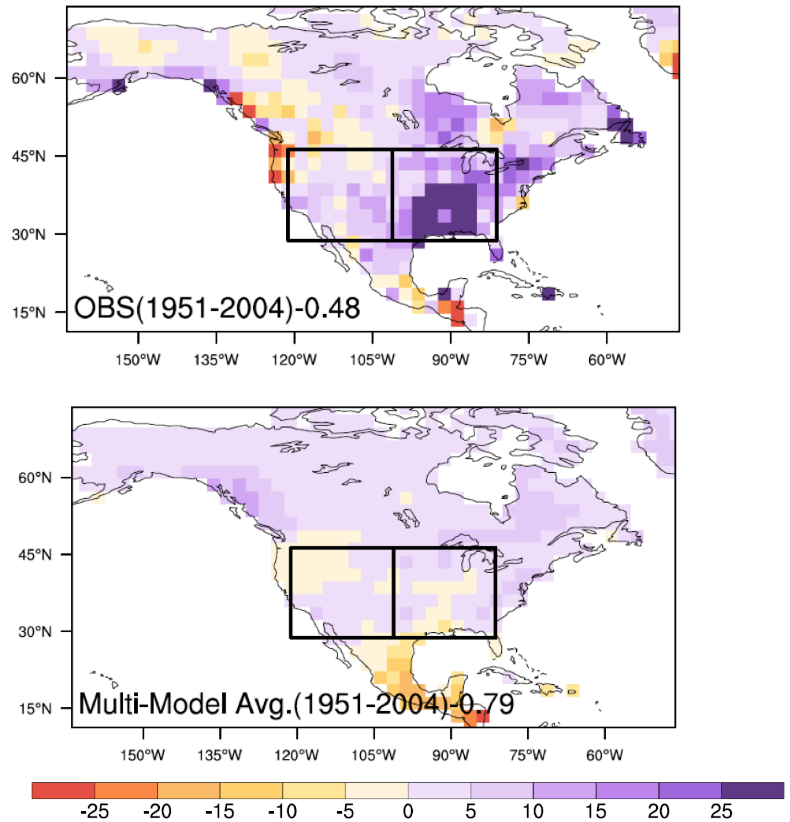
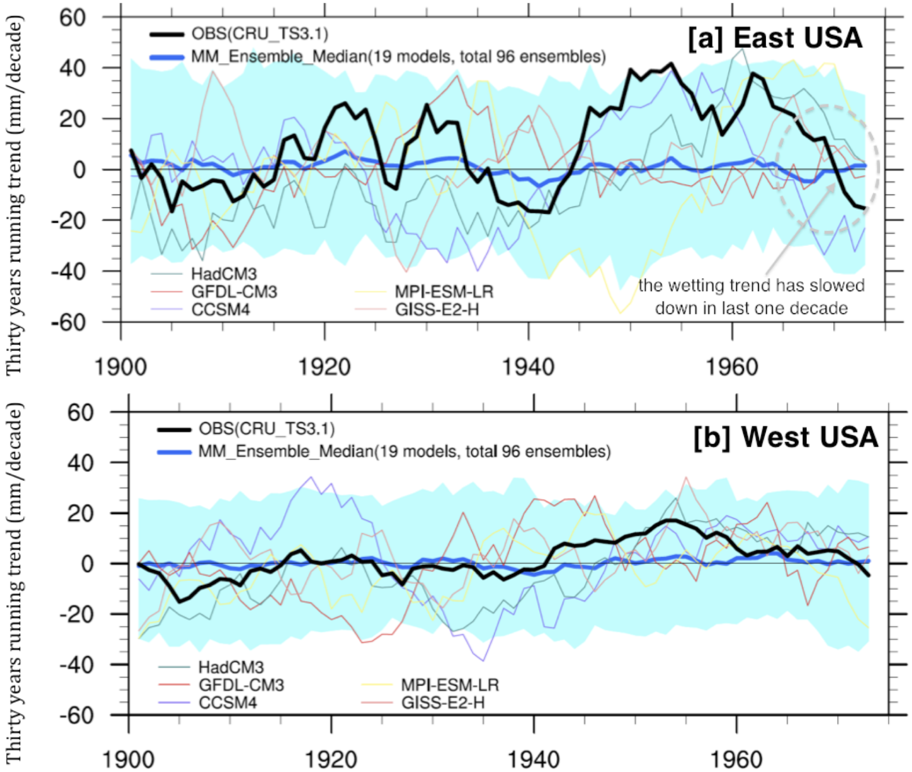
Trends in Precipitation 1951-2004

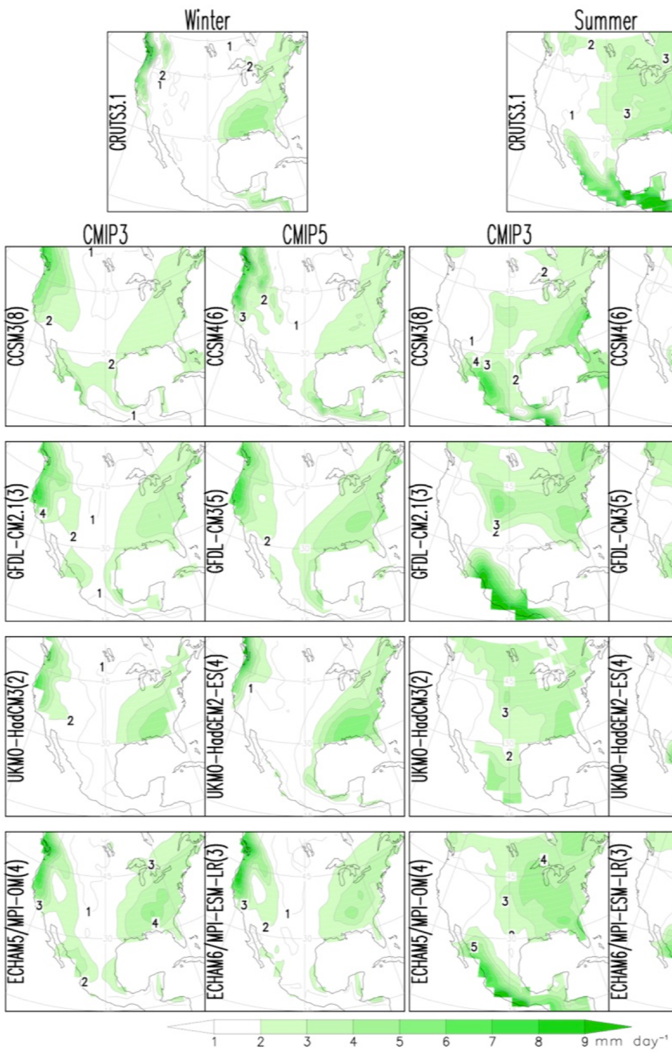




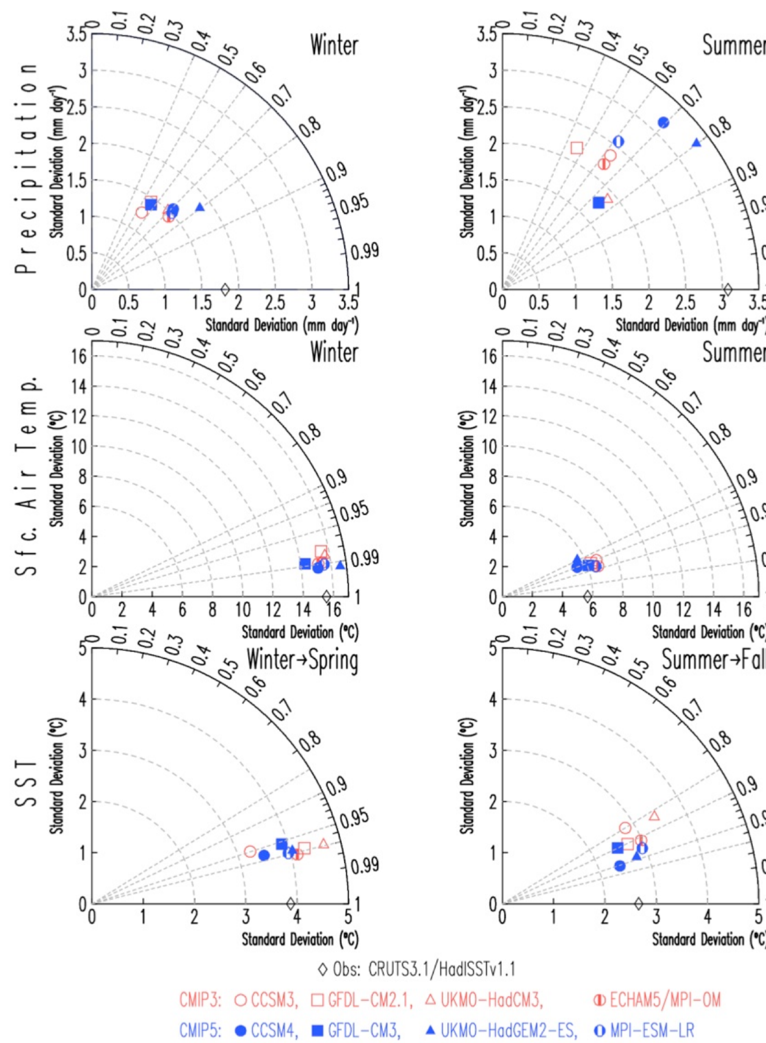
- Precipitation has generally increased over North America in the last half of the 20th century.
- The MME fails to reproduce observed increases, but rather shows a robust drying signal in the southern US and Mexico.
- The failure is in part because of high uncertainty among CMIP5 models in the sign and magnitude of regional precipitation changes.
- The drying signal in the models is symptomatic of CMIP3 models also (IPCC, 2007) and is likely driven by the inadequate connection between increasing precipitation and global SST warming

Zanjiv Kumar, COLA

CMIP5 versus CMIP3 for similar models



Seasonal precipitation climatologies for obs (top row) and 4 CMIP5/CMIP3 models



Taylor plots of precipitation (top), air temperature (middle) and SSTs (bottom) for four CMIP5/CMIP3 models

CMIP3 versus CMIP5: Have the models improved?

• Overall, the performance of the CMIP5 models in representing observed climate features has not improved dramatically

• Some variables like SST/Tas were already reproduced well by CMIP3

• PDO variability remains reasonable in CMIP5 models; AMO variability appears to have improved slightly with CMIP5

• CMIP5/CMIP3 can capture the frequency and mean amplitude of ENSO events but seasonal timing is still a problem for CMIP5.

• Weaker models are now comparable to stronger models for EP/CP ENSO

• There are some models that have improved for certain features (e.g. the timing of the NAM, the maximum precipitation over the Pacific Northwest in winter, the WHWP in the warm part of the year, spatial variability of precipitation)

• But others that have become worse (e.g. the summer minus winter difference in surface air temperature, or the cold tongue along the equatorial Pacific SST in winter, higher NAM precipitation bias).

Conclusions

- Overall, the models do well in capturing the broad scale climate of N. America and some regional features

- Resolution can explain many of the biases (e.g. GPLLJ, western North Atlantic wintertime cyclone frequency, orographic precipitation features, surface hydrology, tropical cyclones, …)

- Regional climate features provide a difficult test of coarse resolution models

- Model performance for basic climate variables has not improved dramatically since CMIP3 (But… we have only analyzed a handful of models - mostly for equivalent CMIP3/CMIP5 models).

- There are several outstanding issues: e.g. too much precipitation westward of the 100°W in summer; ENSO features and teleconnections; drying signal in the south; underestimation of extreme temperatures and heavy rainfall.

- The results have implications for the robustness of future projections of climate and its associated impacts.