Assessment of 21st Century CMIP5 Projections of North American Regional Climate

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Specifically: Suzana J. Camargo, Edmund Chang Brian Colle, Rong Fu, Kerrie L. Geil, Qi Hu, Xianan Jiang, Nathaniel Johnson, Kristopher B. Karnauskas, James Kinter, Benjamin Kirtman, Sanjiv Kumar, Baird Langenbrunner, Kelly Lombardo, Lindsey N. Long, Annarita Mariotti, Joyce E. Meyerson, Kingtse C. Mo, J. David Neelin, Zaitao Pan, Richard Seager, Yolande Serra, Anji Seth, Justin Sheffield, Julienne Stroeve, Jeanne Thibeault, Shang-Ping Xie, Chunzai Wang, Bruce Wyman, and Ming Zhao

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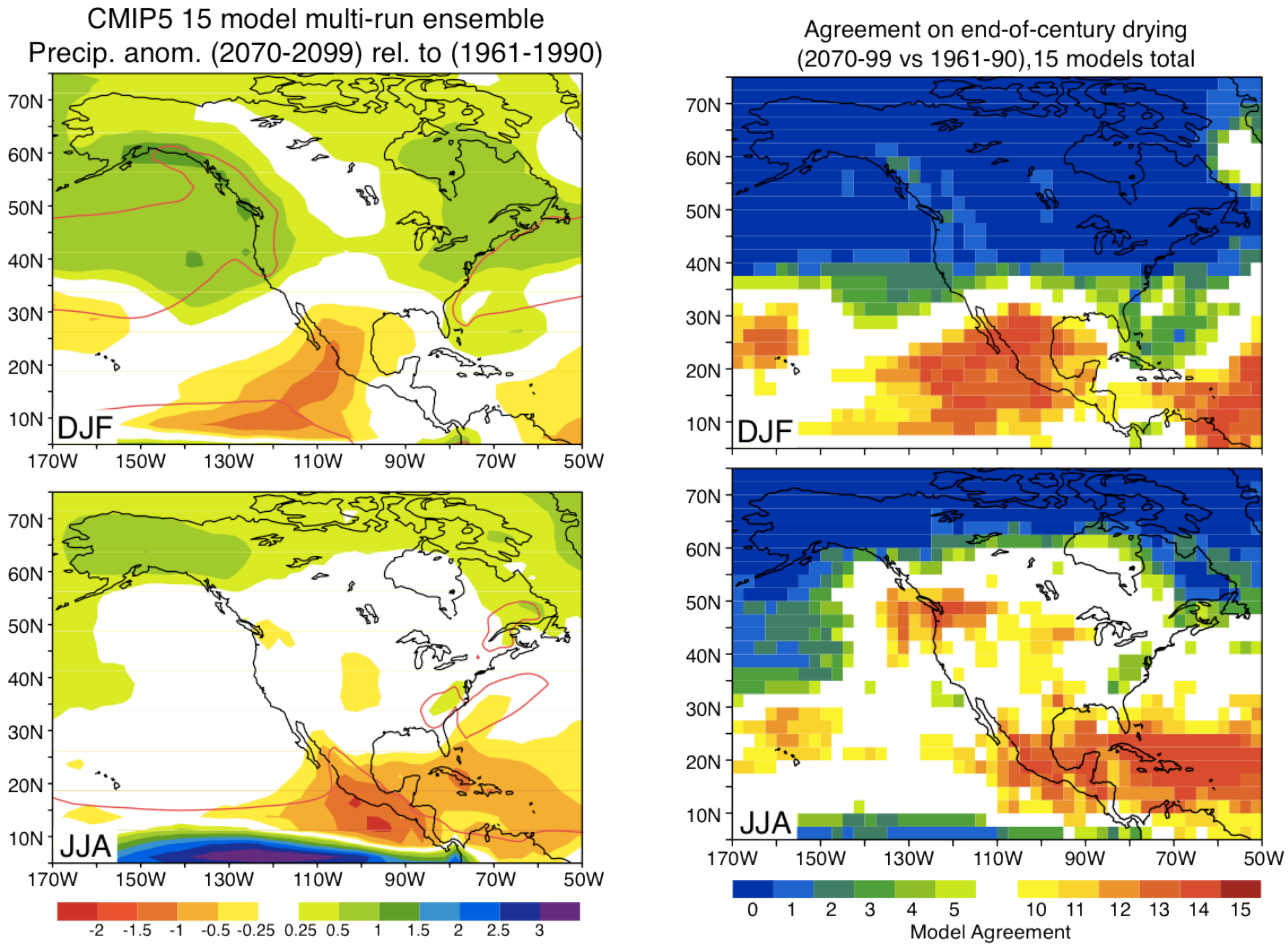
Overview of Effort

- Summary of projected 21st Century NA climate change in CMIP5 models under RCP8.5 and RCP4.5.
- The results contained herein are contributed by individual members of the CMIP5 Task Force of the NOAA MAPP program, and reflect each researcher's individual expertise.
- The number of models used in a particular analysis shown below is often limited by availability of data at the time of this study or local storage space, although we try to use as many models as possible.
- Time between data access and WG1 publication deadlines a significant issue in some cases
- More complete description of results contained within following paper:

Maloney, E. D., et al., 2012: North American climate in CMIP5 experiments: Part III: Assessment of 21st Century projections. *J. Climate*, submitted.

Multimodel Mean Precipitation Projections (RCP8.5)

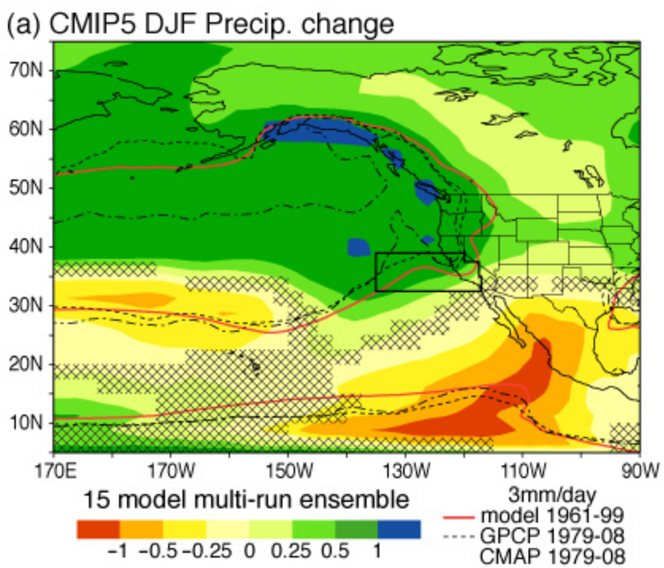


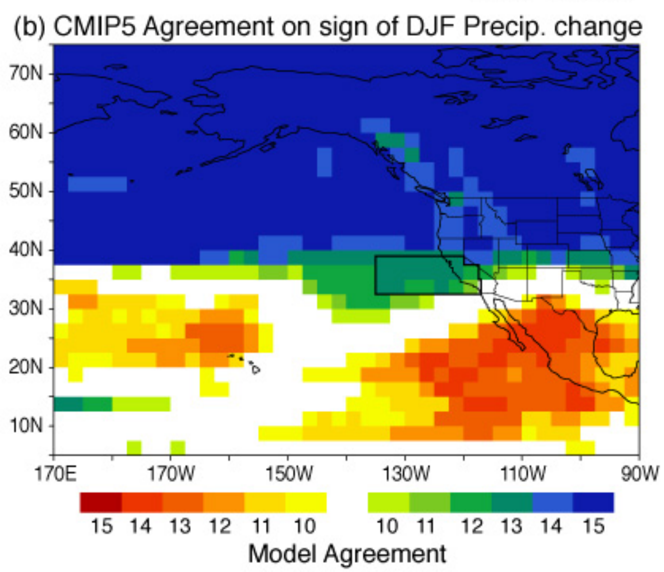
- Intermodel agreement on JJA Caribbean drying more robust than CMIP3.
- DJF West Coast precipitation increases have shifted slightly south compared to CMIP3

Contributed by David Neelin, Baird Langenbrunner, Joyce Meyerson

California precipitation change under global warming (RCP8.5, 15 models)

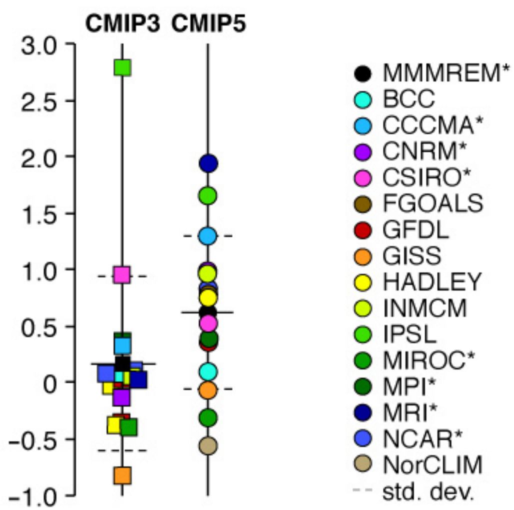
2070-99 minus 1961-90



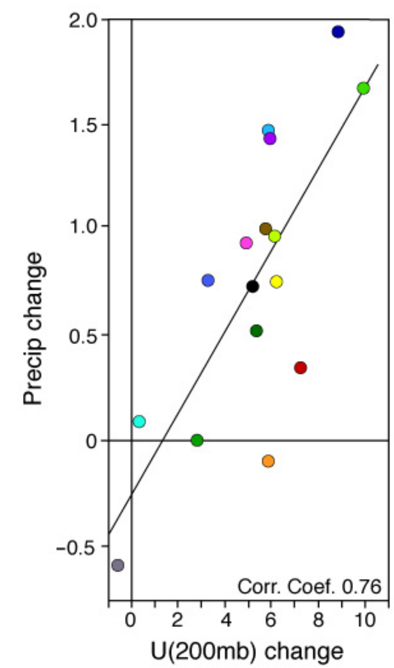


- CMIP3: uncertain precip change in CA: at boundary between increases to north & decreases in subtropics
- CMIP5: most models agree on a Precip increase for Central CA coast & storm track region approaching coast (signif.> 95%)
- The increase in related to jet extension steering storms to CA

Area avg prec change
CMIP3 & CMIP5

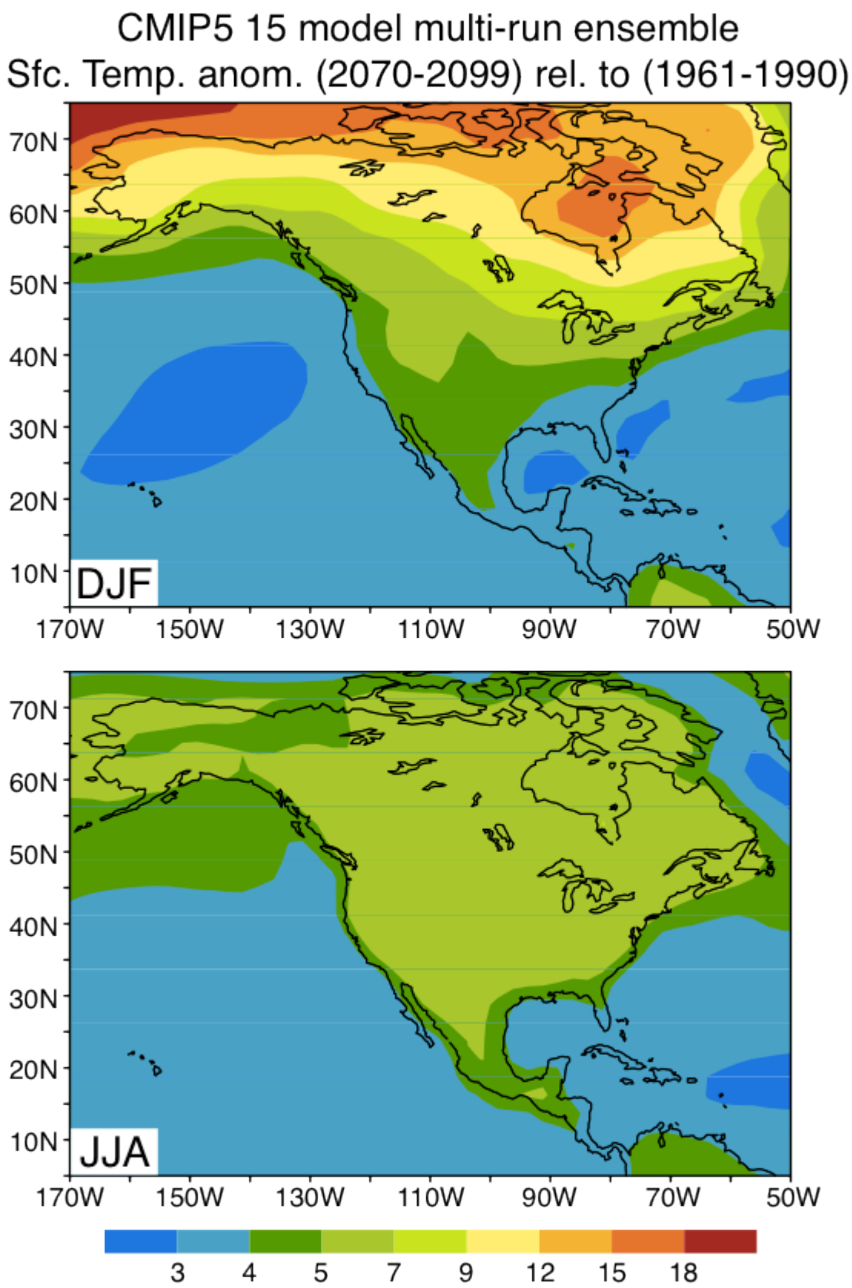


Prec vs zonal wind change



Contributed by David Neelin, Baird Langenbrunner, Joyce Meyerson

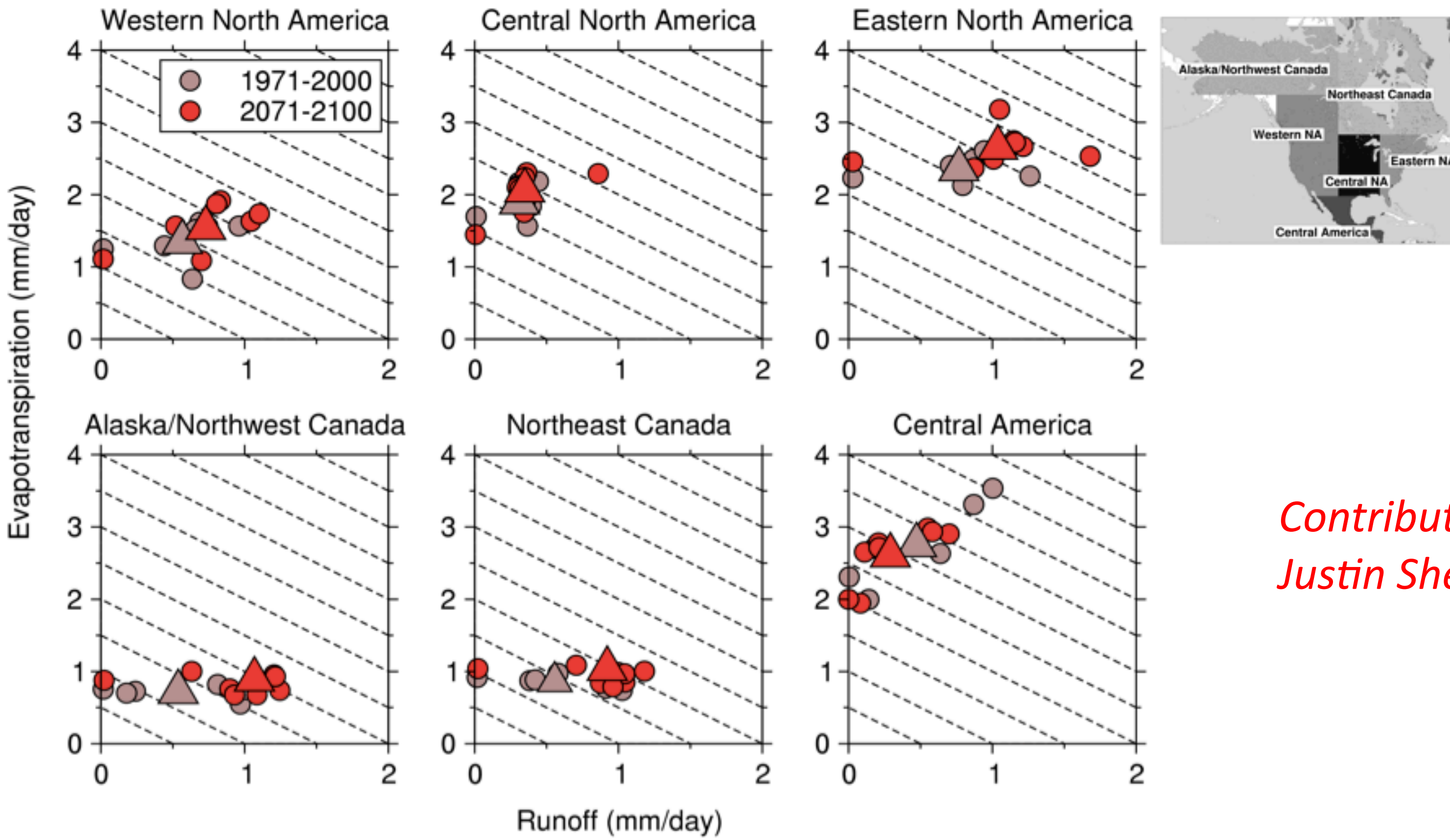
Multimodel Mean Temperature Projections (RCP8.5)



- Multimodel mean DJF temperature increases peak near 15°C in the vicinity of Hudson Bay and North Coast of Alaska
- 7°C warming across North America during boreal summer.

Contributed by David Neelin, Baird Langenbrunner, Joyce Meyerson

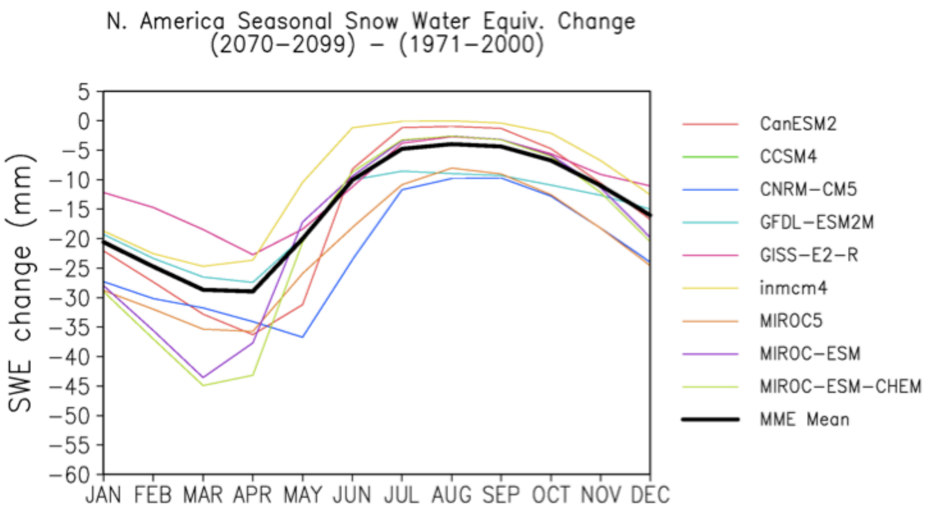
Runoff and Evaportranspiration (RCP8.5, 13 models)

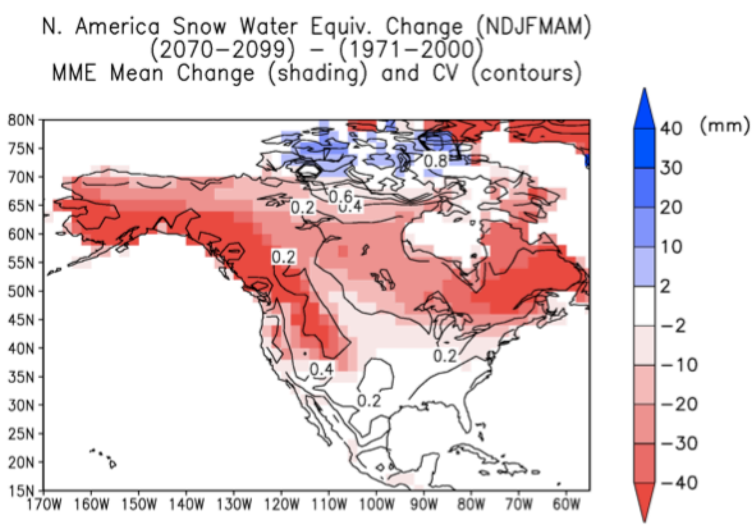


Contributed by Justin Sheffield

- Increases in annual mean precipitation in western and eastern NA. Partitioned more to evaportranspiration, although models have historical bias in this regard.
- Central U.S. changes modest
- High latitude precipitation increases partitioned more to runoff
- Central America decreases in precipitation mainly associated with decreased runoff.

Snow Water Equivalent (RCP8.5, 9 models)



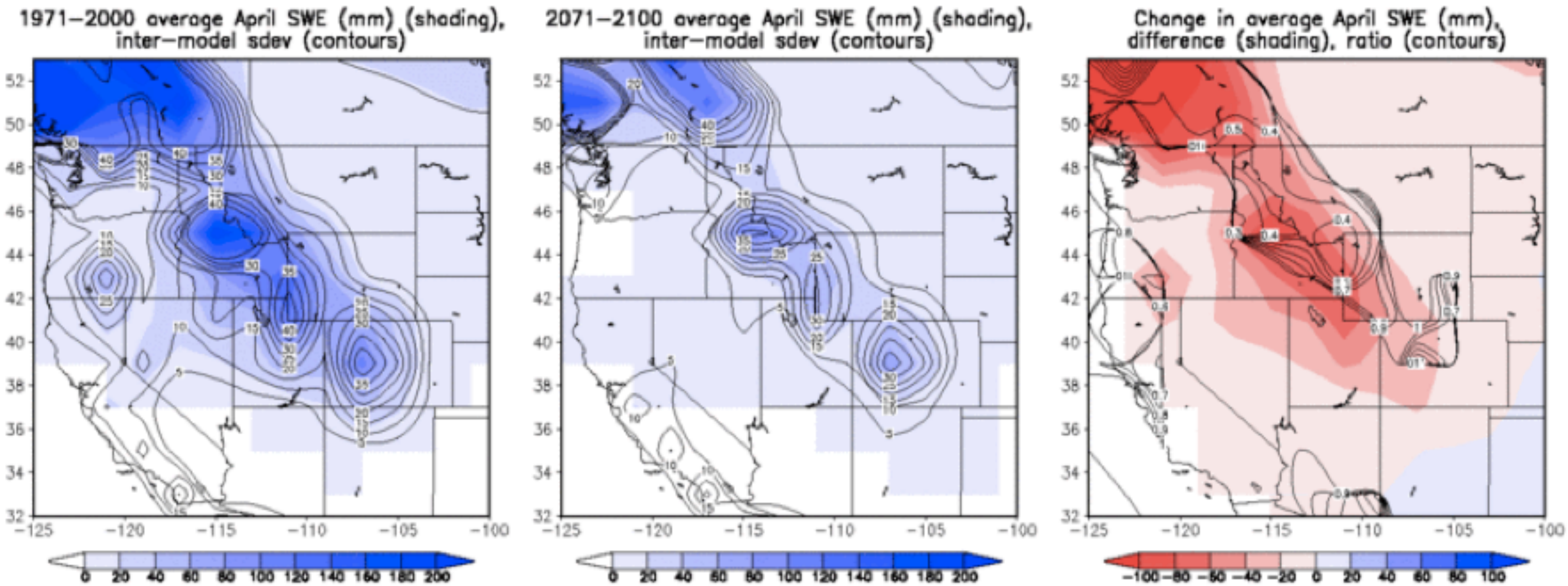


Contributed by Justin Sheffield

- MME mean decrease in SWE averaged over NA of about -30mm in the Spring (with an inter-model range of about 25mm)
- North of 70ºN, SWE is projected to increase due to increasing precipitation, which outweighs the effects of increasing temperature.
- Uncertainties in SWE associated with temperature projections, especially in transitional regions

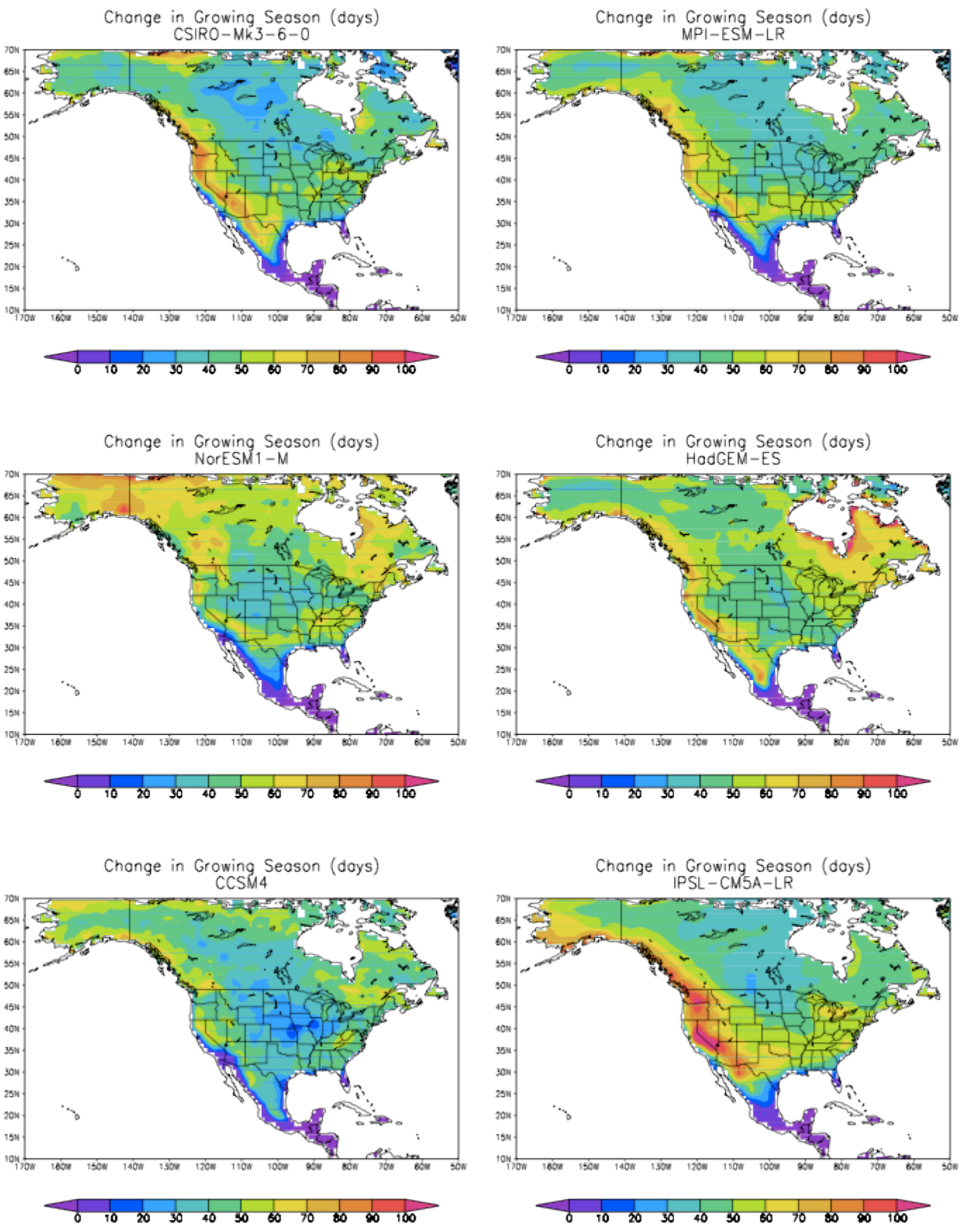
April Snow Water Equivalent (RCP8.5, 9 models)

Contributed by Justin Sheffield



- April SWE is an indicator of total snow accumulation over the winter-time and the potential water resources availability for the coming year
- All models project a decrease in April SWE of up to 100mm in the central Rockies and Canadian Rockies.
- The spatial resolution of the models is generally too coarse to discern the details of the Sierra Nevada, but the models project a decrease in April SWE over this area.
- The decrease in SWE is driven by higher temperatures that increase the ratio of rainfall to snowfall and increase melt efficiency, consistent with CMIP3

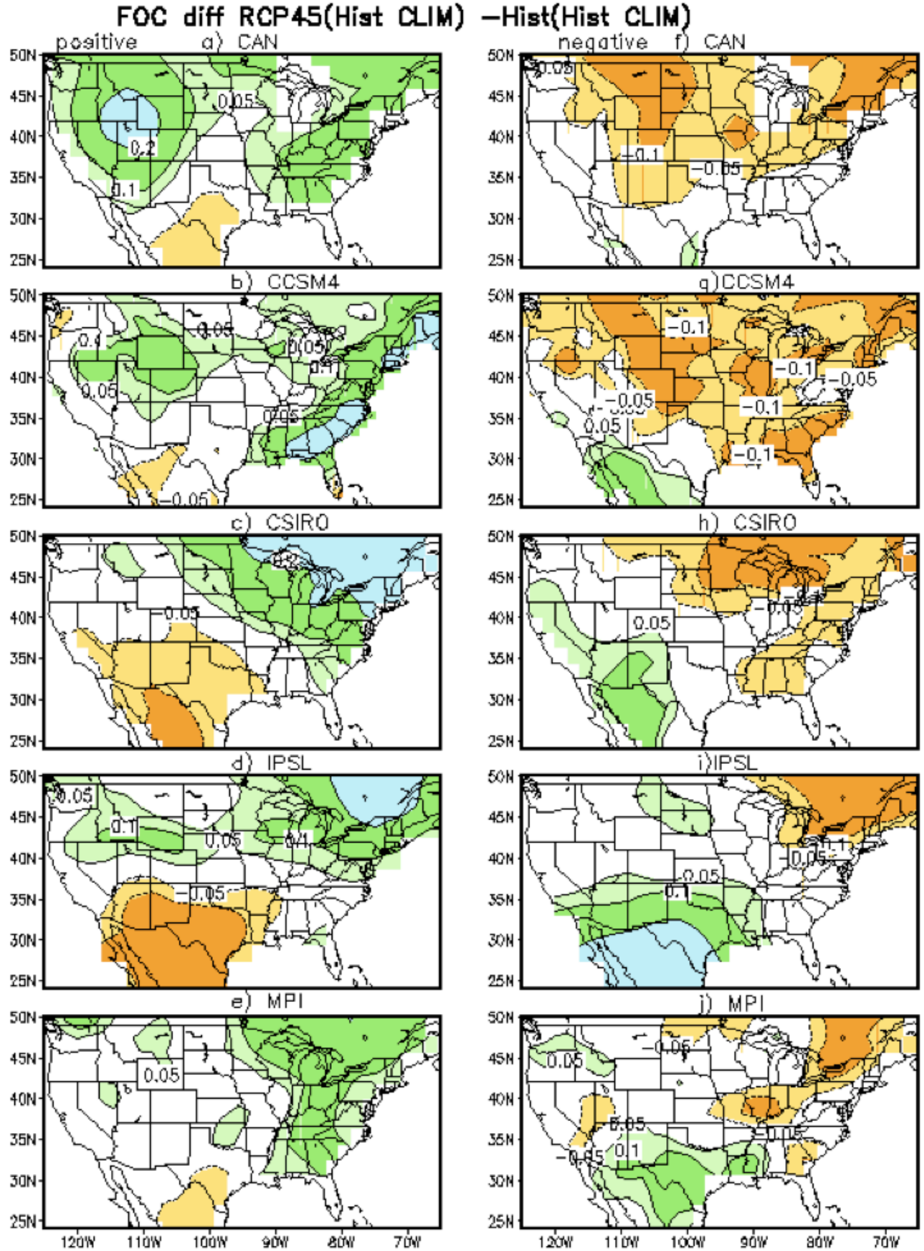
Growing Season Length (RCP8.5, 6 models)



- Growing season will increase across the NA continent by 2071-2100, although substantial variability in the magnitude of these changes exists on a regional basis, and from model to model.
- Largest changes over the W. US and N. Mexico, where increases of 2 months or more are projected. Same regions are characterized by some of the largest negative biases in historical simulations
- C. US and Canada, increases of about 3-6 weeks are projected
- Earlier last Spring freezes strongest factor

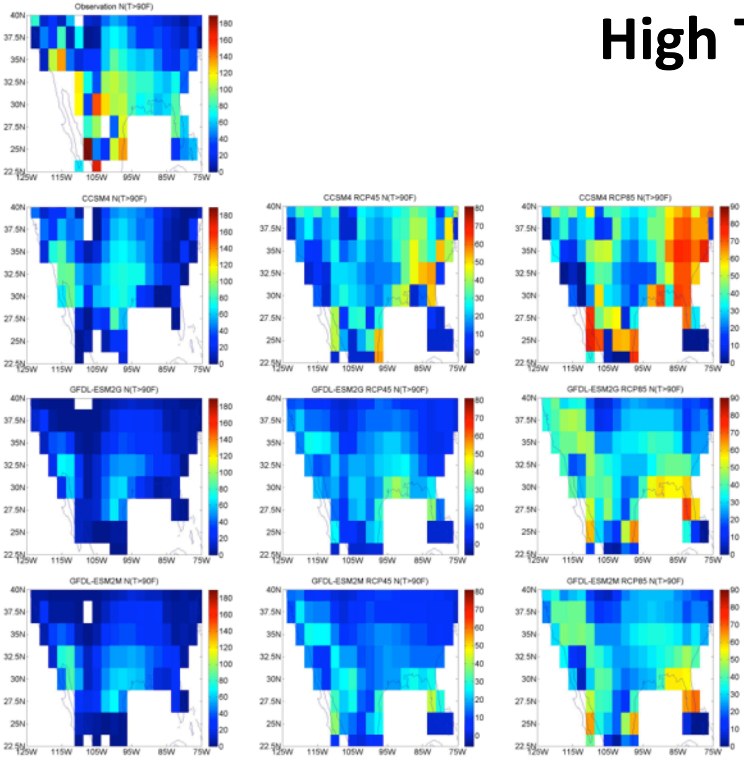
Contributed by Justin Sheffield

Frequency of Occurrence of Extended Wet and Dry Periods (RCP4.5)



- Events defined on the basis of precipitation anomalies above certain threshold for 9 months
- Increases in negative (dry) events in Mexico and the southwest, and an increase in positive (wet) events in the eastern United States at end of 21st Century The CAN and IPSL, and MPI and CCSM4 to a lesser extent, also show increases in positive events in the northwest and northern Great Plains.
- It should be noted that model ability to simulate the correct distribution of extreme precipitation event occurrence in the current climate is limited (Sheffield et al. 2012).

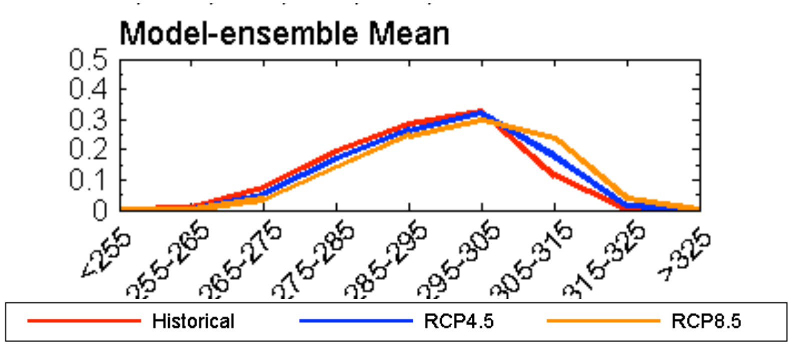
Contributed by Lindsey Long and Kingtse Mo



High Temperature Extremes (8 models)

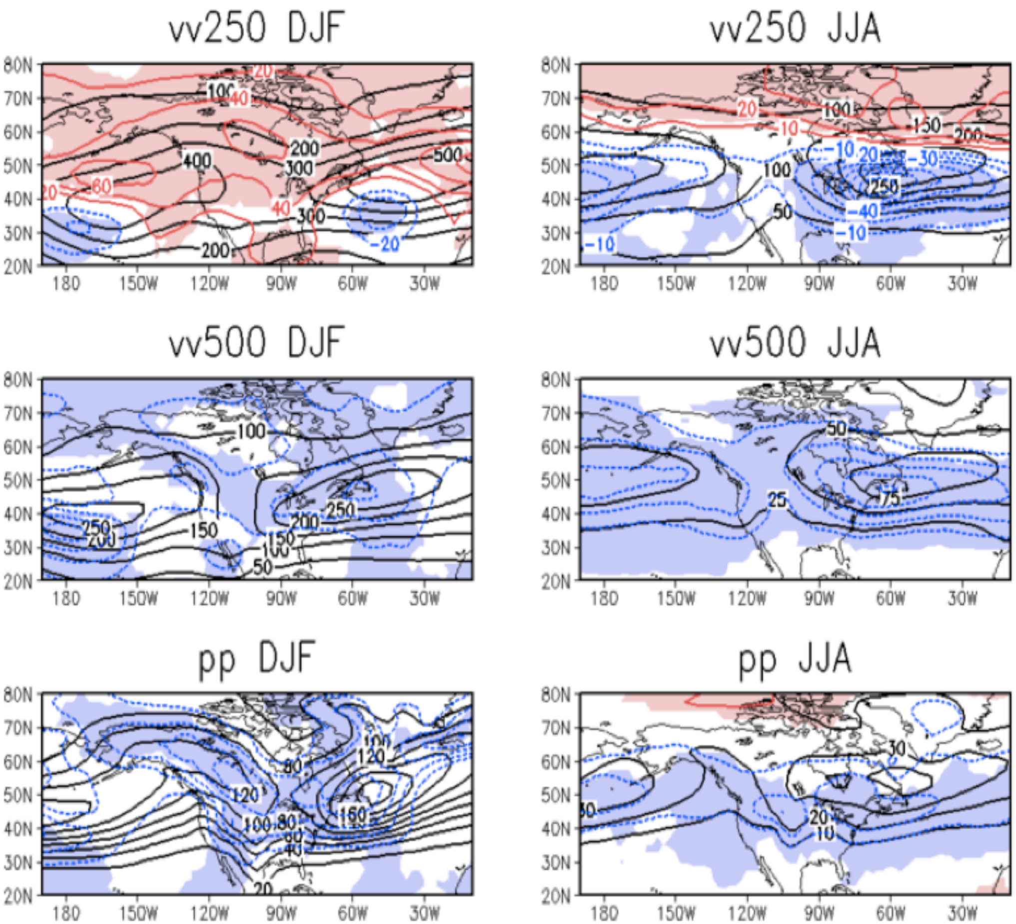
- Largest increases in 90 degree days at 2071-2100 are projected to occur for RCP4.5 in the Midwest and northeast US, where ND>90F is projected to increase by 50% to 100% by the late 21st century.
- An increase of ND>90F by 10%-50% is also projected over the Southwest and South Central U.S., where ND>90F is climatologically high during the 20th century.
- Models that underestimate climatological ND>90F tend to project a weaker increase of ND>90F (e.g., MPI, IPSL, MRI), whereas models that overestimate climatological ND>90F tend to project a stronger increase of ND>90F (e.g., HadGEM2, MIROC5).
- Spatial pattern of increasing ND>90F is generally similar under RCP8.5 to that projected under RCP4.5, but with 10-30% greater magnitude.

Relative occurrences of Tmax:



Contributed by Rong Fu

Storm Track Activity (RCP8.5, 16 models)



- Statistics based on variance of synoptic-scale meridional wind
- At 250 hPa, the models project a strengthening of the storm track (ST) on its poleward flank at late 21st Century, and a slight weakening on its equatorward flank during NH winter. In summer, the models project a significant decrease in upper tropospheric ST activity south of the ST peak, and weak increase over the high latitudes.
- In the mid and lower troposphere, storm track activity generally weakens during both seasons.

Contributed by Edmund Chang

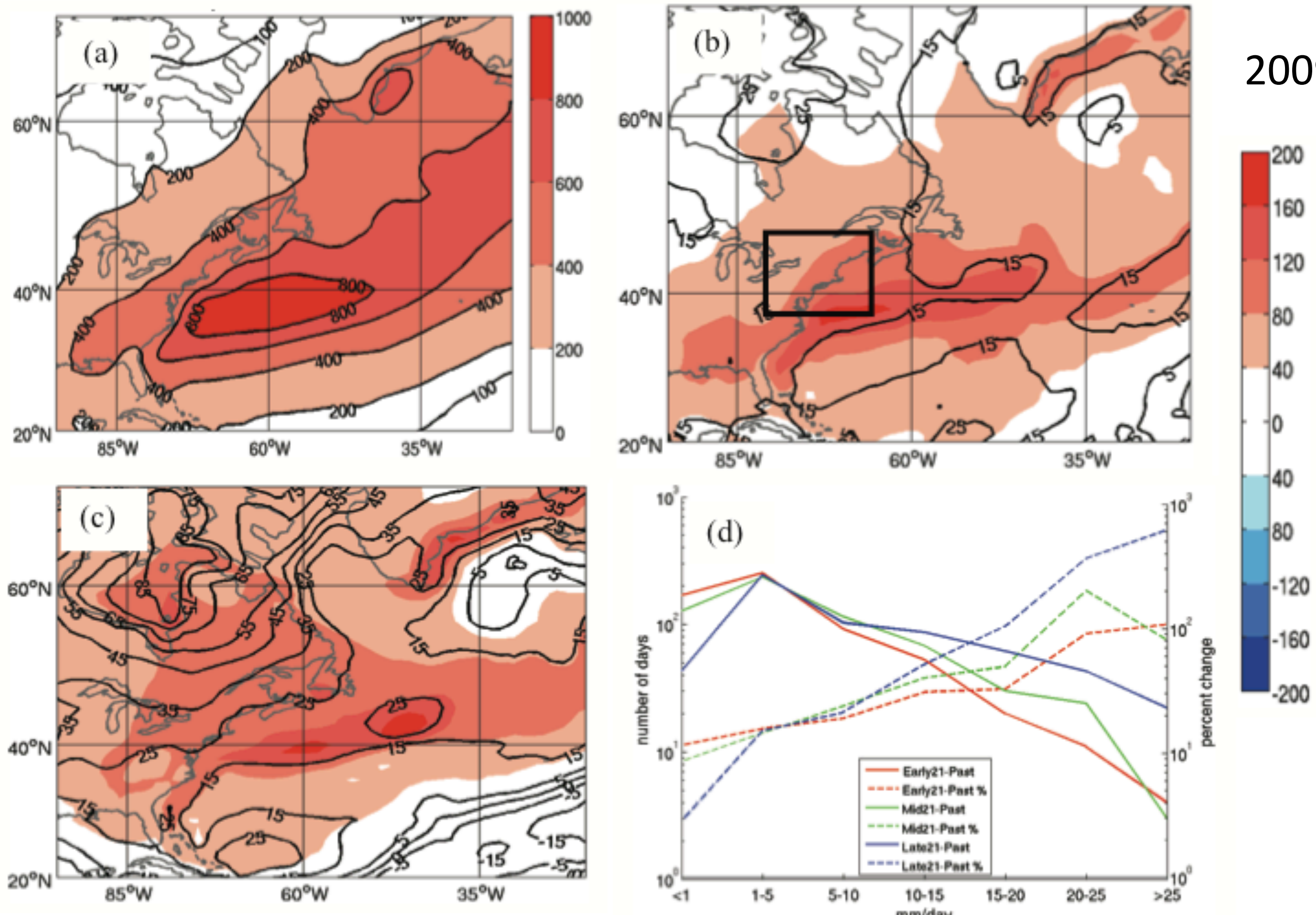
East Coast Nov.-March Precipitation Change (RCP8.5, 9 models)

Contributed by Brian Colle and Kelly Lombardo

Historical

2009-2038

2069-2098

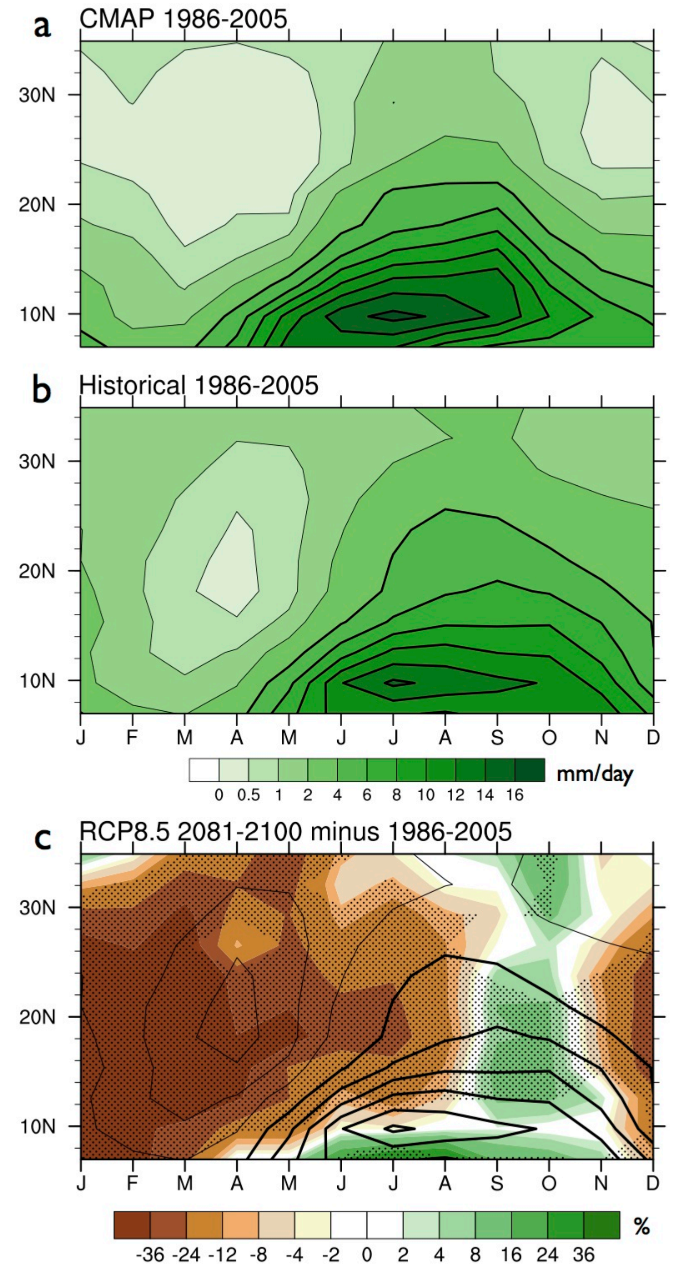


- Over the Northeast U.S., the mean precipitation increases 25-35% by the later 21st century.
- The largest change of 50-85% (40-100 mm/season) is around eastern Canada.
- Number of relatively heavy precipitation events (> 20 mm/day) over the Northeast U.S. doubles early 21st, and increases by 5-6 times by the later 21st century.

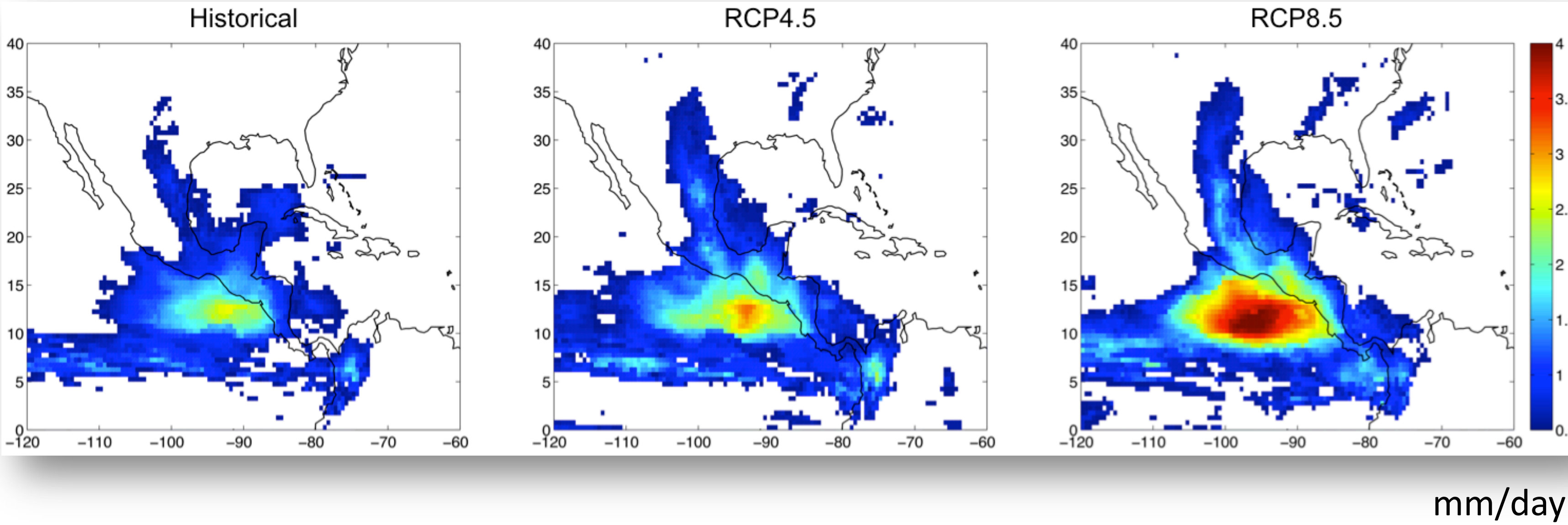
Redistribution of warm season rainfall in the North American Monsoon (RCP8.5, 13 models)

Contributed by Anji Seth

- The CMIP5 historical experiment MME captures a northward migration of precipitation in the North American monsoon region (longitudes 102.5° to 115°W) during the warm season as seen in the observed estimate from CMAP
- The models' precipitation (b) begins later and is weaker than the observed estimate (a).
- Model projections from RCP8.5 are consistent with the CMIP3 results and demonstrate reduced precipitation between 10°-25°N through the cold season extending into June and July, and increased precipitation in September and October.
- However, timing of NA monsoon precipitation exhibits projected changes in the same sense as historical biases.



The Midsummer Drought (RCP4.5 and RCP8.5)

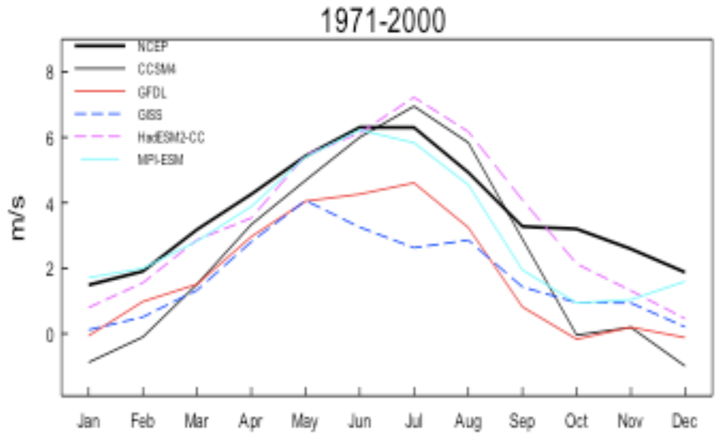


Contributed by Kristopher Karnauskas and Richard Seager

- 23, 17, and 20 models for historical, RCP4.5, and RCP8.5
- CMIP5 models reasonably well simulate the observed historical MSD, both in spatial structure and amplitude.
- CMIP5 models predict a robust CO_2-driven strengthening of the MSD.
- The stronger MSD is a result of early and mid summer rainfall being reduced relative to the late summer peak

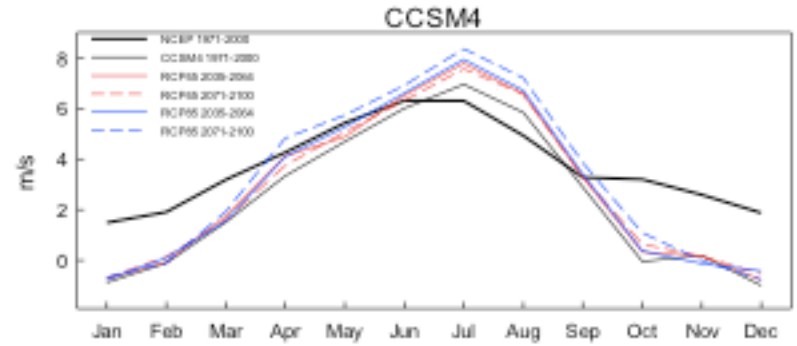
Karnauskas, K.B., A. Giannini, R. Seager, and A.J. Busalacchi (2012) A simple mechanism for the climatological midsummer drought along the Pacific coast of Central America. *Atmósfera*, accepted.
Sheffield, J., and coauthors (2012) North American Climate in CMIP5 Experiments: Part II: Evaluation of 20th Century Intra-Seasonal to Decadal Varaibility. *J. Climate*, submitted.
Maloney, E., and coauthors (2012) North American Climate in CMIP5 Experiments: Part III: Assessment of 21st Century Projections. *J. Climate*, submitted.
Karnauskas, K.B. and R. Seager (2012) The American Midsummer Drought in CMIP5: Multi-Model Evaluation and Projections. Abstract submitted to 2012 AGU Fall Meeting.

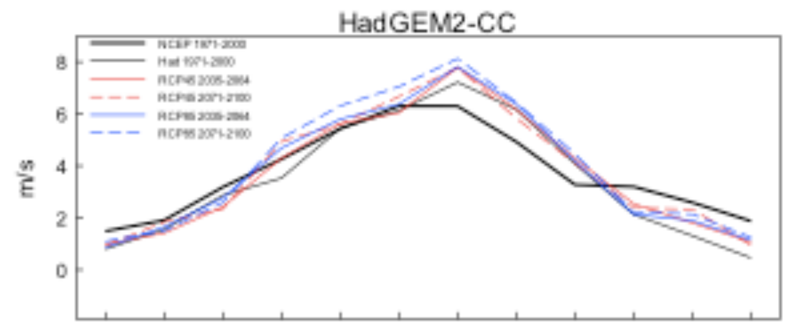
Great Plains Low Level Jet Strength (RCP8.5 and RCP4.5, 5 models)

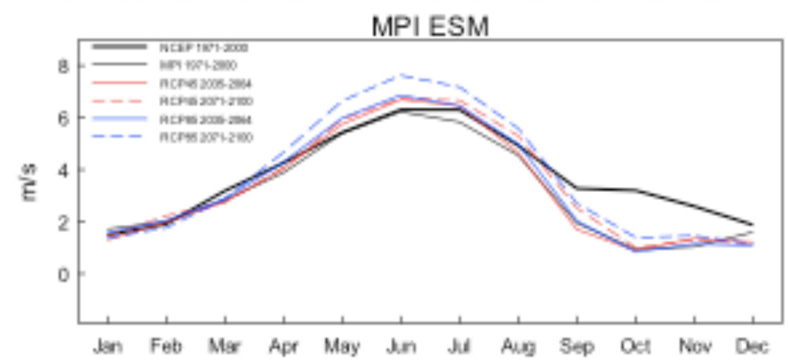


Contributed by Steve Hu

- Jet defined on basis of 925 hPa meridional wind averaged over 27.5-32.5N and 95-100W
- 3 models of those examined have success in simulating the strength of the Great Plains LLJ in current climate
- In these models, projections generally indicate a strengthening of the LLJ by about 15-25% by 2071-2100 in RCP8.5.
- Does not correspond to increased GP precip

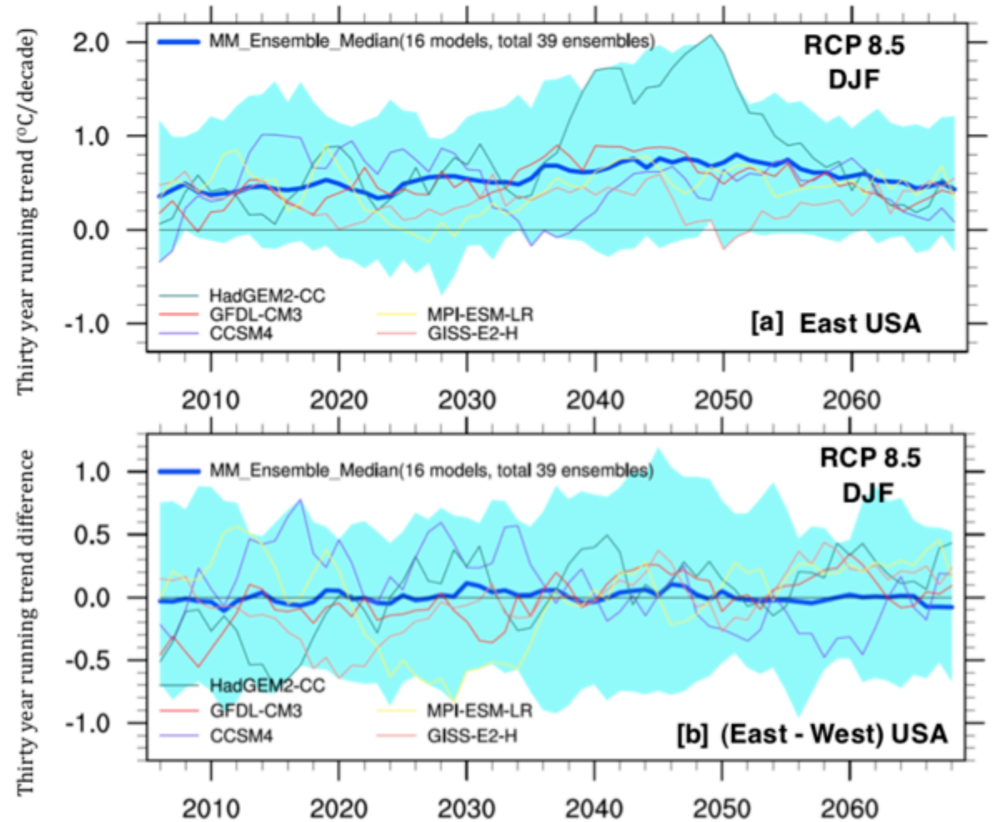






Eastern U.S. Warming Hole (RCP8.5, 16 models/39 Ensemble Members)

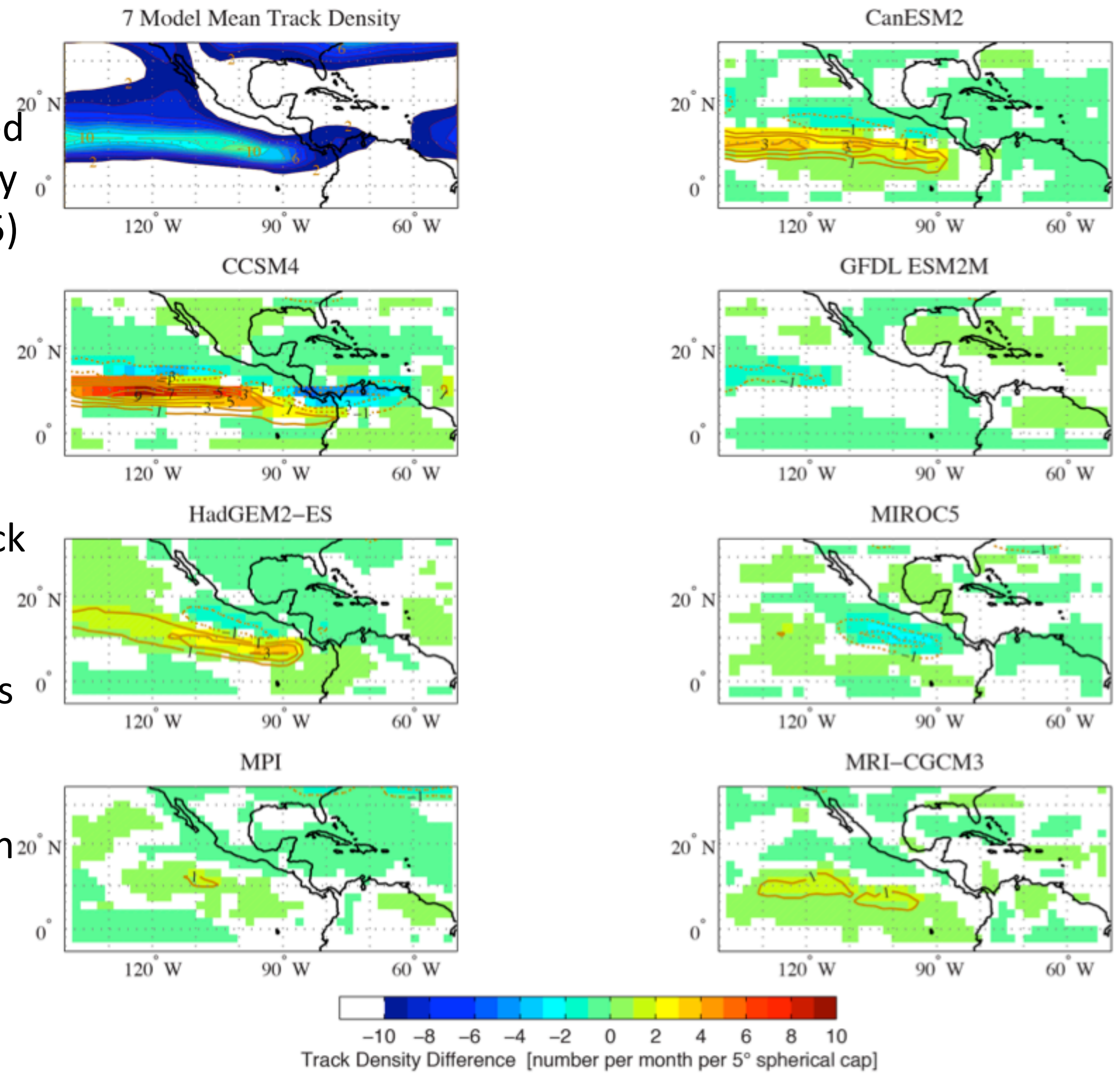
- CMIP5 multi-model mean time series had limited skill at reproducing the historical warming hole, the 95% uncertainty range of historical CMIP5 simulations does bracket the observed negative temperature trend in the eastern U.S.
- In projections, for the east – west temperature trend difference, the uncertainty range is equally distributed above and below the zero line. Similar for JJA.
- The multi-model median curve in varies between ±0.1°C.
- Hence, the chance of relatively slower warming in the eastern U.S. compared to western U.S. is the same as the opposite in RCP8.5 (and also RCP4.5)



Contributed by Sanjiv Kumar and Zaitao Pan

East Pacific Storm Tracking (RCP4.5, 7 models)

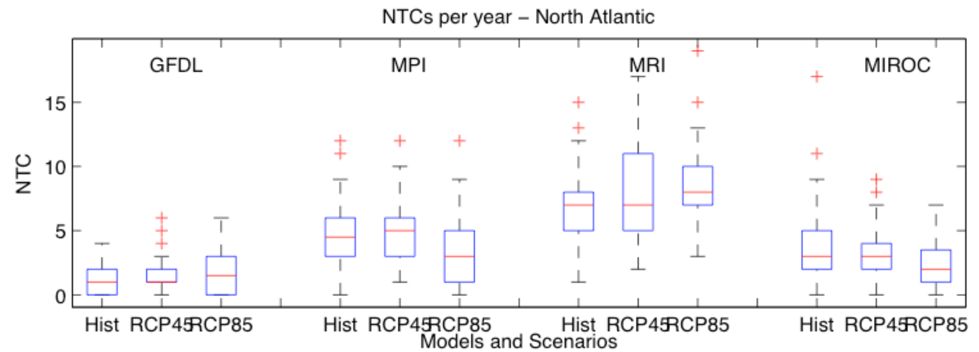
- Tropical storm track statistics calculated from 6-hourly 850 hPa relative vorticity following the method of Hodges (1995) for May-Nov 2070-2100 relative to historical.
- Several of these CMIP5 models (CanESM2, CCSM4, HadGEM2-ES, MIROC5 and MRI-CGCM3) indicate a southward shift of the main storm track as well as an increase in track density for the future projections, consistent with results found using CMIP3 models (Bengtsson et al. 2006; Colbert et al. 2012).
- This southward shift is also observed in the pattern of mean precipitation change seen in the JJA analysis

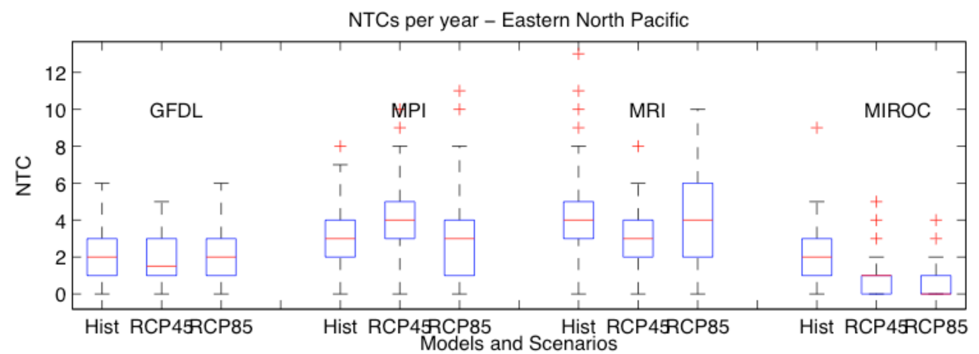


Contributed by Yolande Serra and Kerrie Geil

Explicit Tropical Cyclone Tracking (RCP4.5 and RCP8.5, 4 models)

- Directly tracking TCs in CMIP5 models using 6-hourly low-level vorticity, surface winds, surface pressure, and atmospheric temperature, explicitly screening for warm core structure and resolution-dependent threshold that are sustained for 2 days
- All models underestimate historical TC numbers
- For the North Atlantic, the MRI model exhibits a significant increase in Atlantic TC numbers in RCP8.5 relative to the historical period, whereas the MIROC5 model exhibits a significant decrease in Atlantic TC numbers in both RCP4.5 and RCP8.5.
- For the East Pacific, results are also mixed, with significant increases in TC numbers in future climate in the MPI model in the RCP4.5 scenario, and significant decreases in the MIROC5 model.

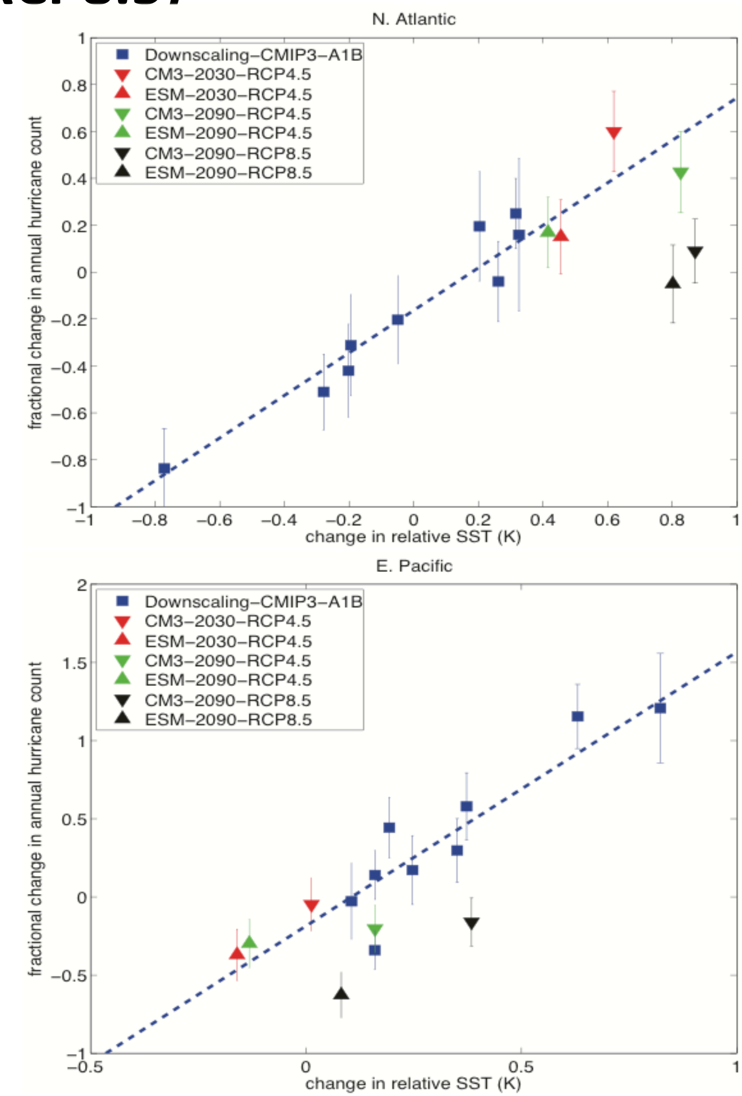




Contributed by Suzanna Camargo

Global Simulations with GFDL HiRAM Model (RCP4.5 and RCP8.5)

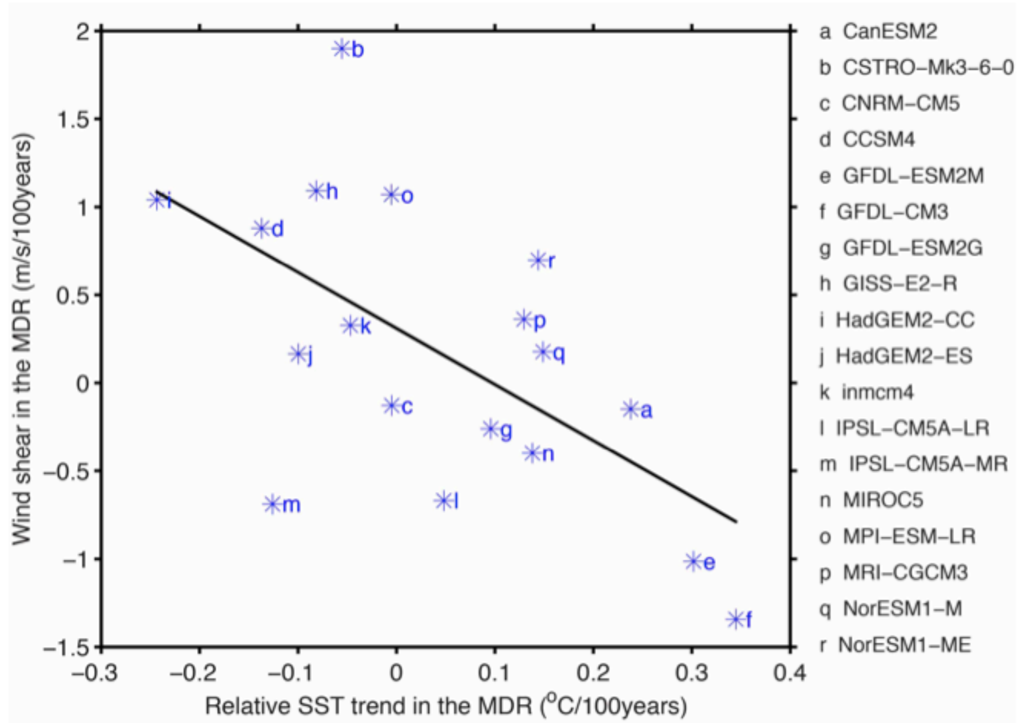
- Forced by CMIP3 and CMIP5 model projected SSTs and sea ice concentrations
- The GFDL C180HIRAM simulations with CMIP3 model forcing produce a large inter-model spread (standard deviation of fractional changes ~ 0.35) in the N. Atlantic hurricane frequency response to warming
- Two GFDL CMIP5 models tend to produce an increase especially in the near decade (2026-2035), and in the CM3 projections for RCP4.5. However, for RCP8.5, both the CM3 and ESM produce insignificant change at the late 21st century.
- Results roughly scale with local SST relative to the tropical mean, except in RCP8.5 at late 21[st] Century, where direct impact of high greenhouse gas concentrations may stifle hurricane activity.



Contributed by Ming Zhao and Bruce Wyman

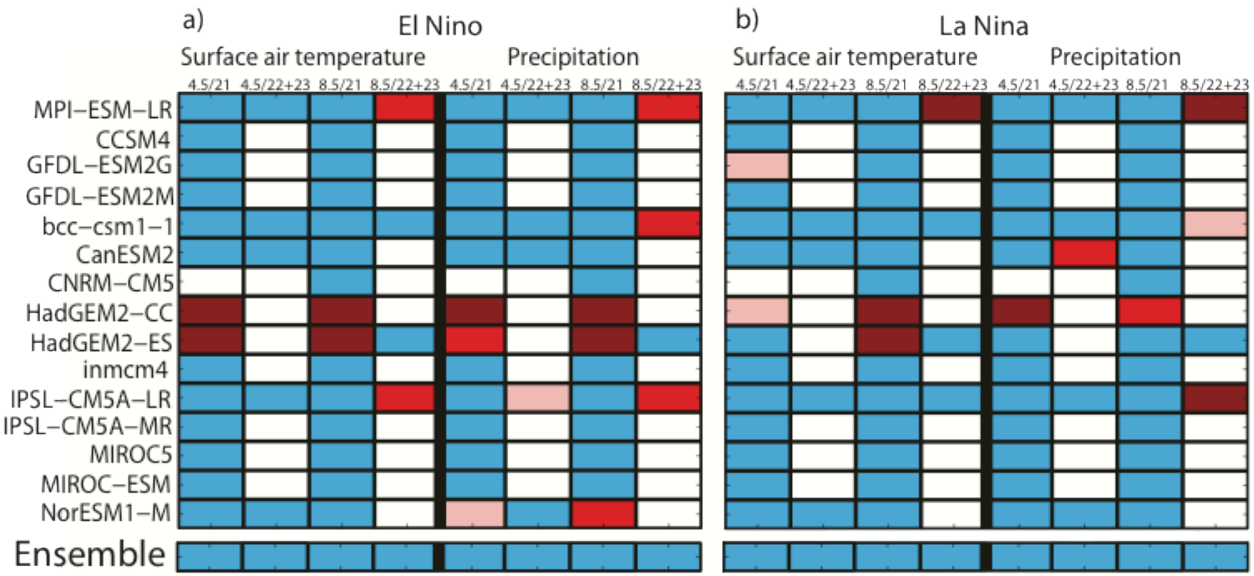
Change in Atlantic Vertical Shear vs. Relative SST (RCP4.5, 18 models)

- Main development region (85°W-15°W, 10°N-20°N) during JJASON, trend over 21st Century
- Individual models show different responses of the MDR relative SST and vertical shear trends, and hence suggest inconsistent changes in tropical cyclone activity.
- The linear fit of all shows that the vertical shear trend decreases with the MDR relative SST trend.
- This is consistent with a recent modeling study (Lee et al. 2011), showing that a slower warming in the tropical North Atlantic compared with the tropical Indo-Pacific Oceans increases the vertical shear and static stability in the MDR for Atlantic hurricanes.



Contributed by Chunzai Wang

ENSO Teleconnections (RCP4.5 and RCP8.5, 15 models)

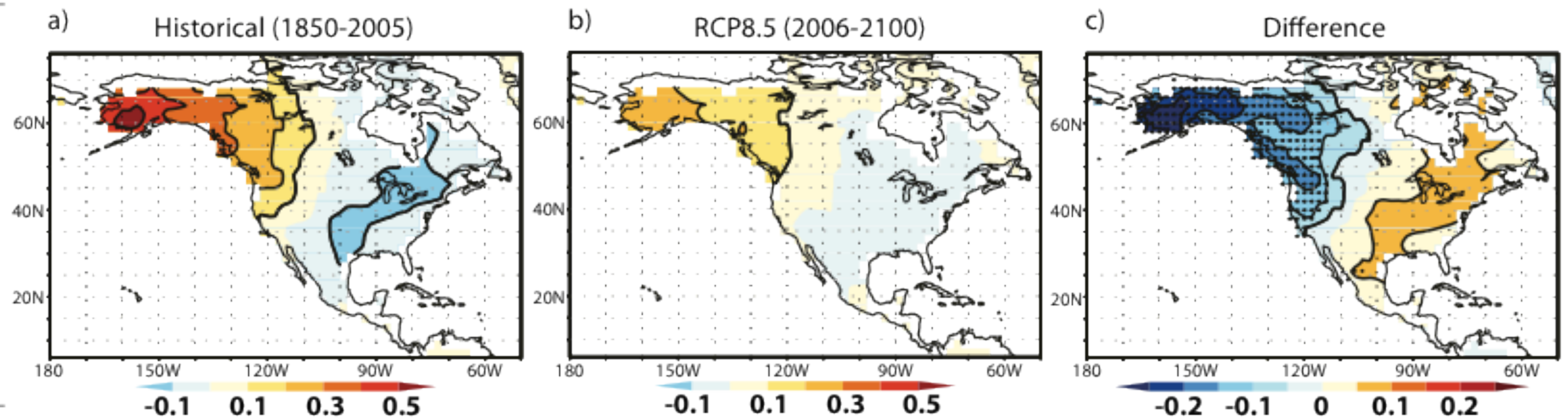


Light, medium, and dark red correspond with 90%, 95%, and 99% significance levels, respectively, blue corresponds with statistically insignificant (α_{global} > 0.1) changes, and white indicates no available data.

- CMIP5 model performance in accurately simulating ENSO teleconnections in current climate is relatively poor
- We do not distinguish different types of ENSO episodes, such as CP from EP El Niño episodes, but rather consider a single broad class of ENSO events identified by the Niño3.4 SST index.
- Some models project significant changes in ENSO-related SAT and precipitation patterns, but most do not indicate significant changes in the 21st-23rd centuries. Moreover, because pattern changes vary from model to model, these changes are not robust in the ensemble mean.

Contributed by Nat Johnson and Shang-Ping Xie

Pacific Decadal Oscillation Patterns (RCP4.5 and RCP8.5, 15 models)



- CMIP5 models have success in reproducing the PDO temperature teleconnection pattern, but mixed success at capturing the teleconnection pattern in precipitation.
- SAT and precipitation pattern changes for individual models are generally not significant, but some robust changes are apparent in the ensemble mean. The most notable change is found in spring (MAM) in the 21st century in RCP8.5 in temperature.
- Models produce a clear weakening of the PDO-related SAT variability in the warmer climate, with largest weakening over western NA.
- PDO-related North Pacific SST variability does not show a similar weakening. This finding suggests that increased ocean stratification, which increases the SST response to a given a wind forcing, and/or the decrease in mean temperature gradients may be responsible for the weakened PDO response

Contributed by Nat Johnson and Shang-Ping Xie

Areas of Model Disagreement

- Mean precipitation changes across the southern U.S.
- Annual mean precipitation changes in the NA monsoon region
- Snow water equivalent changes on a regional basis, especially in transitional regions
- Diurnal temperature range (DTR) in SE U.S.
- Growing season and frost days in the Western U.S.
- Seasonal mean Atlantic TC activity
- Intraseasonal variability in the Caribbean and Gulf of Mexico
- Changes in ENSO teleconnection to NA.
- Others……

Model Bias Affects Confidence of Projections in Some Areas

Examples:

- NA monsoon precipitation that exhibits projected changes in the same sense as historical biases.
- Evapotranspiration and runoff
- Growing season length is projected to increase most strongly over along the West Coast, where models tend to display large negative biases in historical runs.
- Models have substantial difficulties in simulating the historical distribution of persistent drought and wet spells, which produces less confidence in the pattern of extreme precipitation event changes in future climate.
- South-Central U.S. precipitation and temperature
- ENSO teleconnections

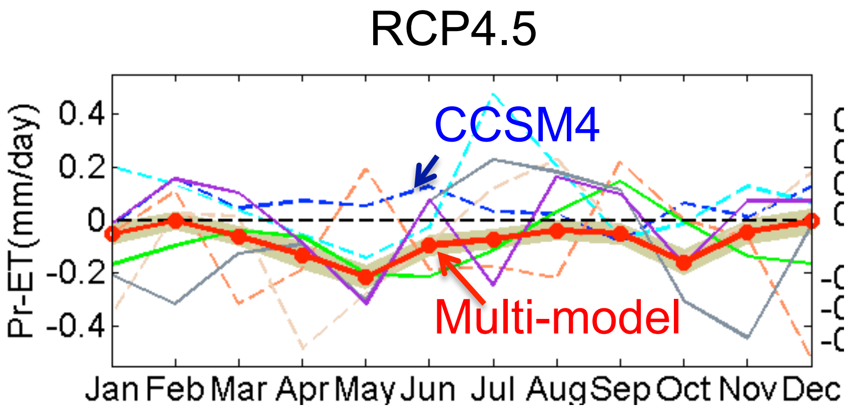
Comparison with CMIP3 Projections

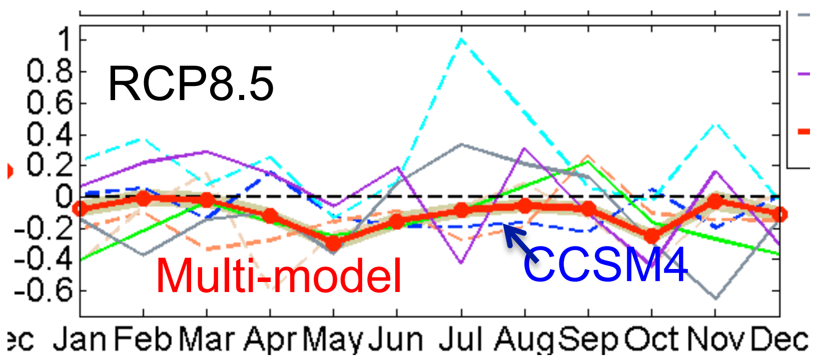
- Projections for N. America are generally consistent with those for CMIP3, although we have more confidence in projections in a few areas (e.g. Drying over the Caribbean, increased precipitation for Central California).
- Some of these analyses are novel and have no CMIP3 analogue
- It should be noted however that we have only scratched the surface in our analysis and that much more can be done, including detailed comparison to CMIP3.


Thanks

South Central U.S. Precipitation Minus Evaporation Changes (RCP4.5 and RCP8.5, 9 Models)

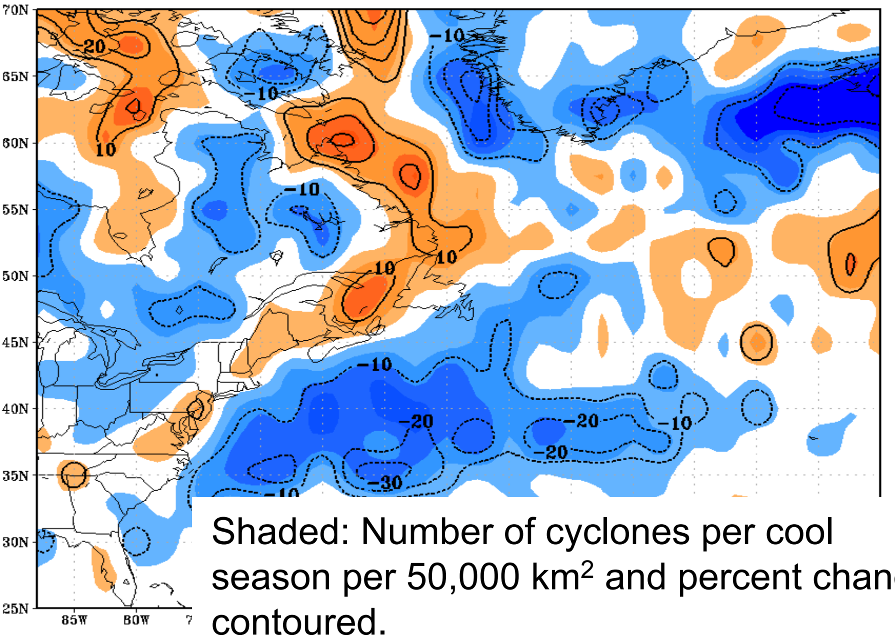
- Model evaluation shows that most of the CMIP5 models show wet and cold biases, and hence results should be interpreted with care
- Whether the South Central U.S. will become drier is ambiguous under the RCP4.5 scenario due to disagreement between multi-model ensemble mean and "best performing" model projections.
- Under the RCP8.5 scenario, the projected drying is more robust. Mainly due to rapid increases in evapotranspiration



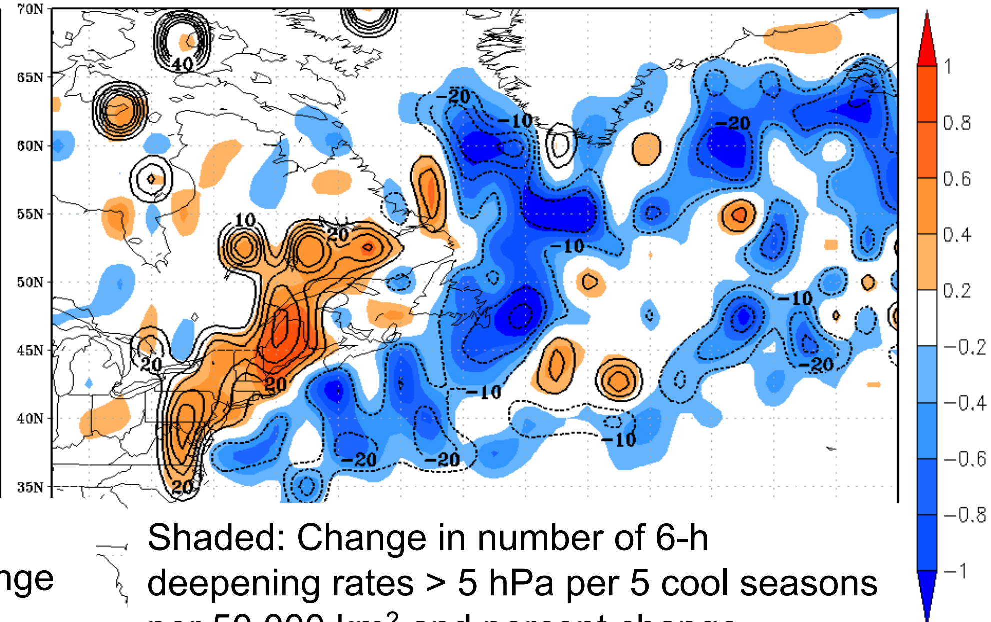


Contributed by Rong Fu

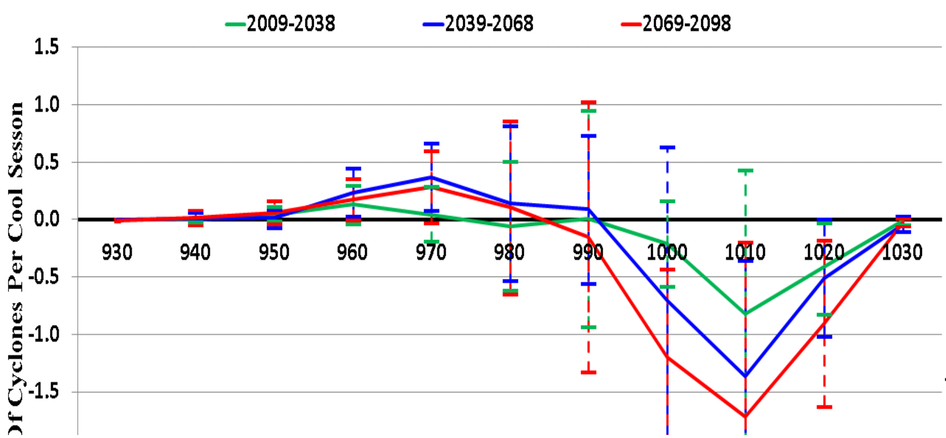
Difference in Cyclone Track Density, Max Intensity, and 6-h Deepening Rates Between 2039-2068 and 1979-2004 for 7 "Best" CMIP5 Models (Colle et al. 2012)



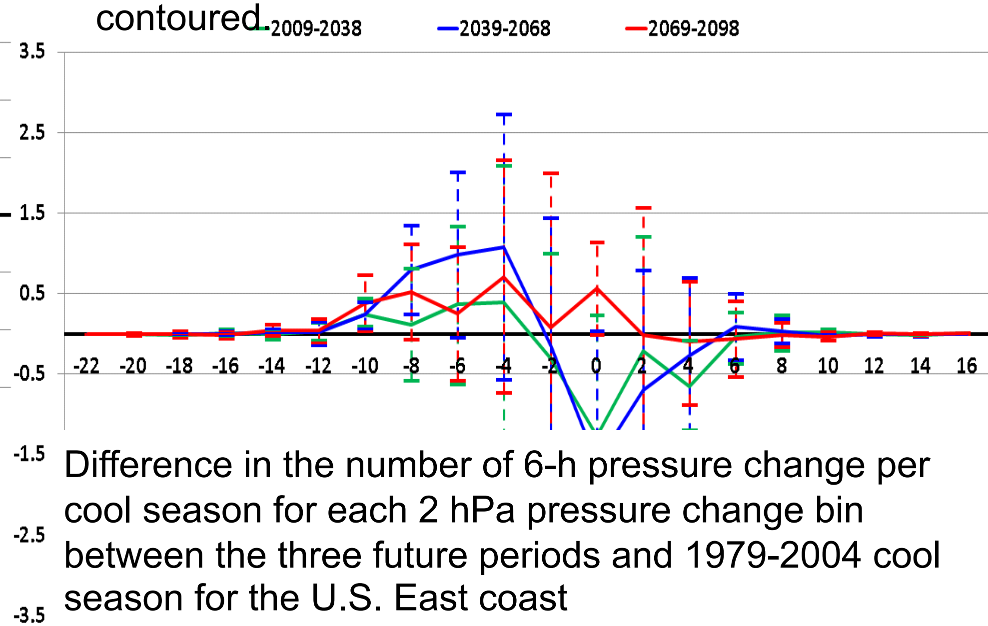
Shaded: Number of cyclones per cool season per 50,000 km² and percent change contoured.



Shaded: Change in number of 6-h deepening rates > 5 hPa per 5 cool seasons per 50,000 km² and percent change contoured.

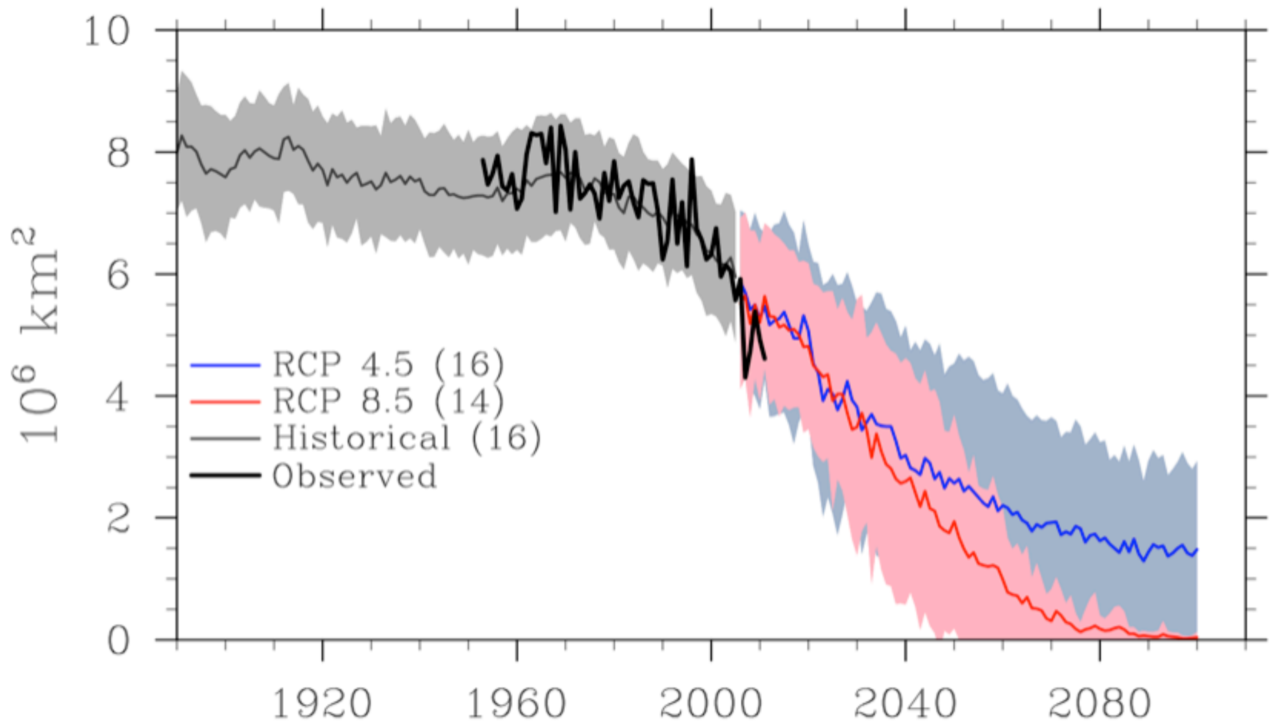


Difference in the number of cyclones per cool season reaching their maximum intensity for each 10 hPa bin between the three future periods and 1979-2004 cool season for the U.S. East coast



Difference in the number of 6-h pressure change per cool season for each 2 hPa pressure change bin between the three future periods and 1979-2004 cool season for the U.S. East coast

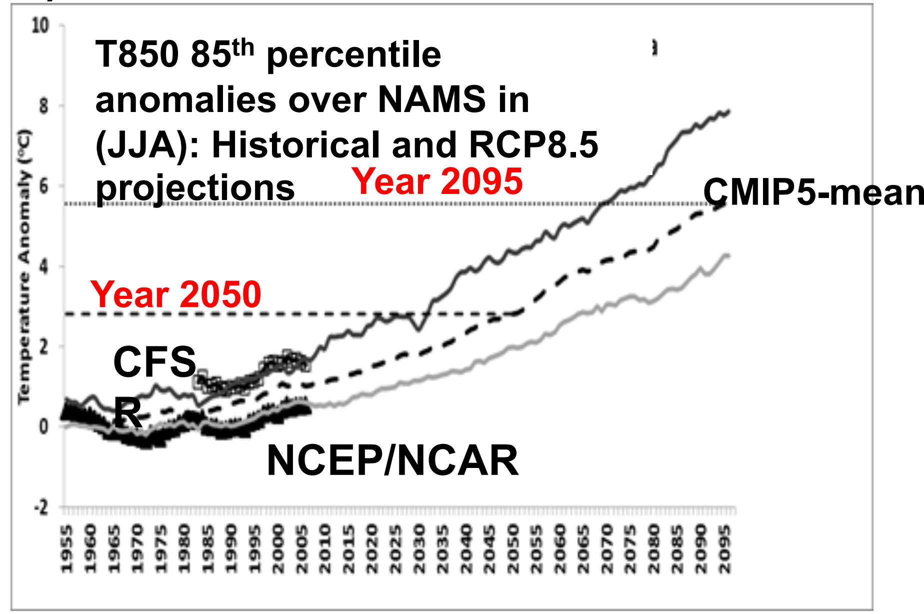
September Sea Ice (RCP8.5 and RCP4.5)



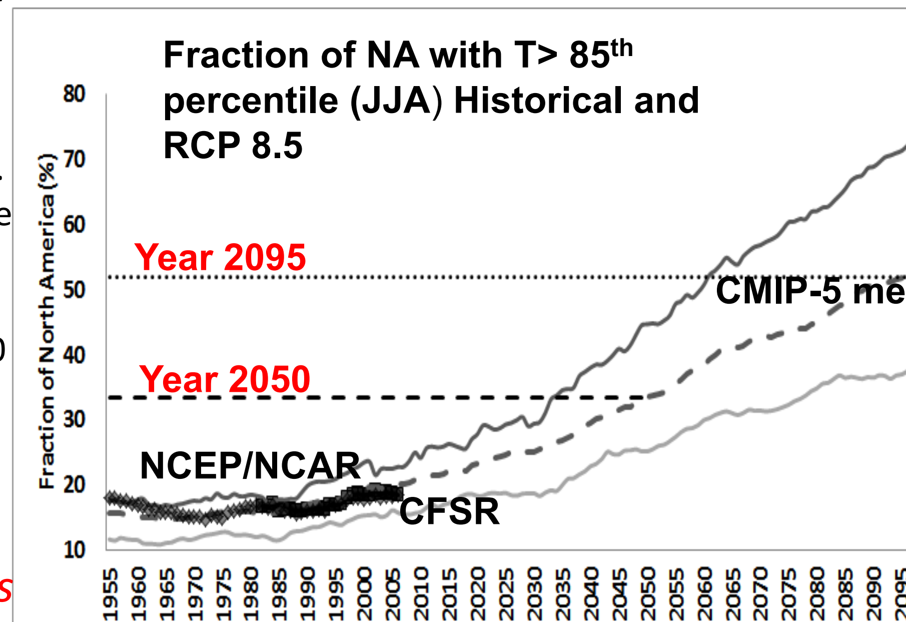
Contributed by Julienne Strove

- 16 models for RCP4.5 and 14 models for RCP8.5
- Under RCP4.5, the multi-model ensemble mean does not reach ice free-conditions by 2100, though the -1σ bound reaches nearly ice-free conditions (less than 1x10^6 km^2) around 2050.
- In contrast, the multi-model mean ice extent drops below 1x10^6 km^2 around 2060 for the RCP8.5 emission scenario, with the -1σ bound showing completely ice-free conditions by 2050.

CMIP5 Simulations of Low-Level Tropospheric Temperature and Moisture over North American Monsoon Region (RCP8.5)



- Changes in the low-troposphere (850hPa) temperature (T850) and specific humidity (Q850) over the North American Monsoon (NAMS using the NCEP/NCAR and CFSR reanalyses and CMIP5 simulations for two scenarios: "historical" (1951-2005) and "RCP8.5" (2006-2095).
- Trends in the magnitude and area of the 85th percentiles were distinctly examined over NAMS regions during the peak of the monsoon season.
- A modest increase in T850 and Q850 have occurred over the NAMS, and historical trends agree relatively well with models.
- The RCP8.5 ensemble mean projects an increase in the T850 85th percentile of about 2.8°C by 2050 and 5.5°C by 2095 over the North American monsoon relative to 1955. The area of North America with T850 ≥ the 85th percentile is projected to increase from 15% in 1955 to ~33% by 2050 and ~50% by 2095. This progressive warming is associated with an increase in the 85th percentile of Q850 of about 3g kg^{-1} in NAMS by 2095.



Contributed by Leila Carvalho and Charles Jones