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Dealing With a Regional Climate Model Ensemble

Melissa Bukovsky
National Center for Atmospheric Research
Boulder, CO, USA

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NARCCAP

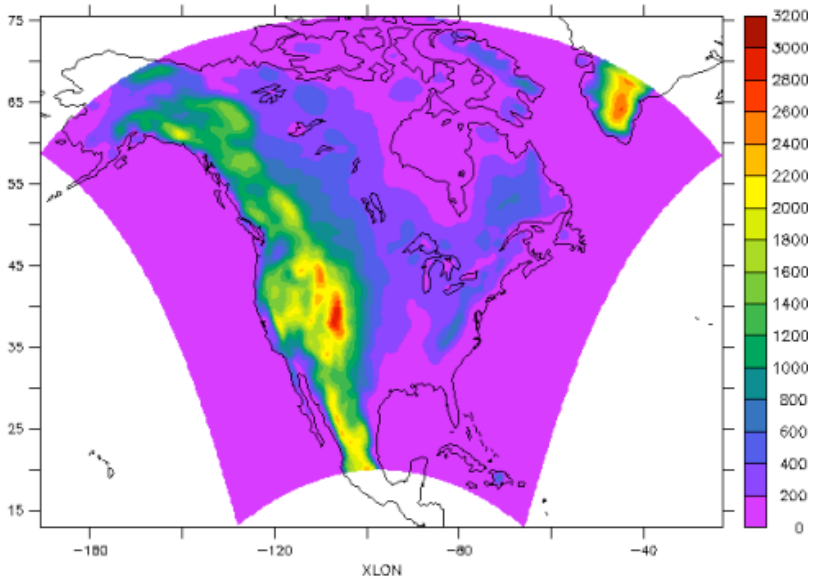
North American Regional Climate Change Assessment Program

- 6 RCMs downscaling 4 CMIP3 GCMs (with 12 combinations planned)
  - Current: 1971-2000 (1999)
  - Future: 2041-2070 (2069)

- RCMs were also used to dynamically downscale the NCEP/DOE Reanalysis 2
  - 1980-2004

- 50-km horizontal resolution over most of North America

- Plus, 2 global 50-km timeslices (GFDL and CAM).



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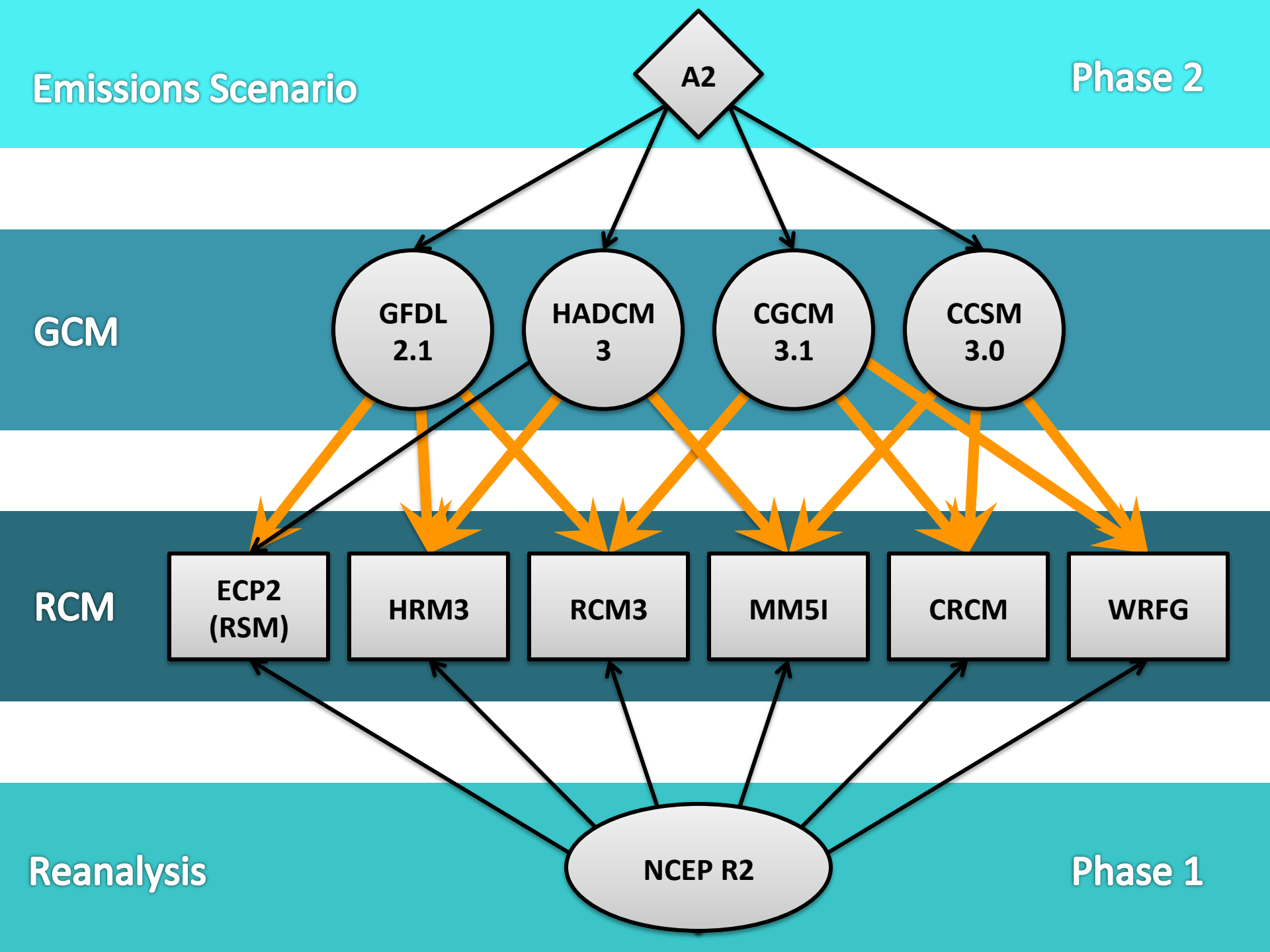
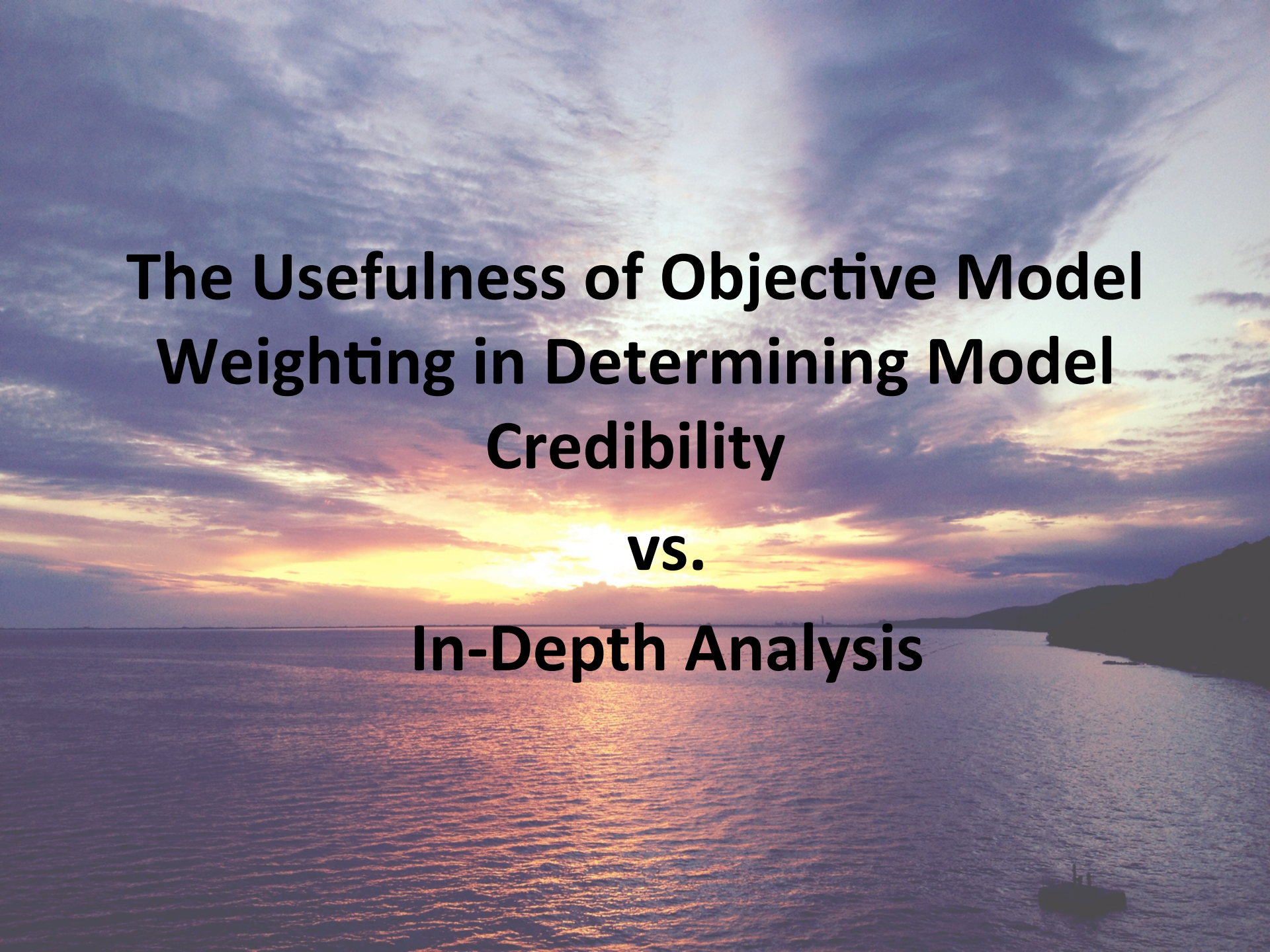

Emissions Scenario
A2
Phase 2
GCM
GFDL 2.1
HADCM 3
CGCM 3.1
CCSM 3.0
RCM
ECP2 (RSM)
HRM3
RCM3
MM5I
CRCM
WRFG
Reanalysis
NCEP R2
Phase 1

Many Projects, Much Analysis

- Analysis focus is usually on the weather in the climate simulations somewhere in North America.

- Focus today:
  - Weighting
  - North American Monsoon


The Usefulness of Objective Model Weighting in Determining Model Credibility
vs.
In-Depth Analysis

ENSEMBLES Performance Metrics

Special Issue 23 of Climate Research, 2010, Vol. 44, and included references.

- Metric f1: Large-scale circulation.
  - Test the degree to which RCMs reproduce observed weather regimes at 500-hPa in terms of their mean frequency, interannual variability, and daily chronology.
- Metric f2: Mesoscale.
  - Evaluates spatial correlation, interannual variability, and correlation between precipitation and temperature mesoscale signals.
- Metric f3: Probability density distributions.
  - Examines statistical properties of empirical PDFs of daily and monthly precipitation and daily maximum and minimum temperature.

ENSEMBLES Performance Metrics

- Metric f4: Extremes.
  - Tests an RCM's ability to reproduce 99th, 99.9th, and 99.99th percentile daily precipitation and also uses GEV theory to assess the 5-year return period in daily precipitation and maximum and minimum temperature.
- Metric f5: Temperature trends.
  - Assesses seasonal 2-m temperature trends by comparing the slope of the RCM trend to that in observations.
- Metric f6: Annual cycle.
  - Examines an RCM's ability to reproduce the annual cycle of monthly temperature and precipitation.

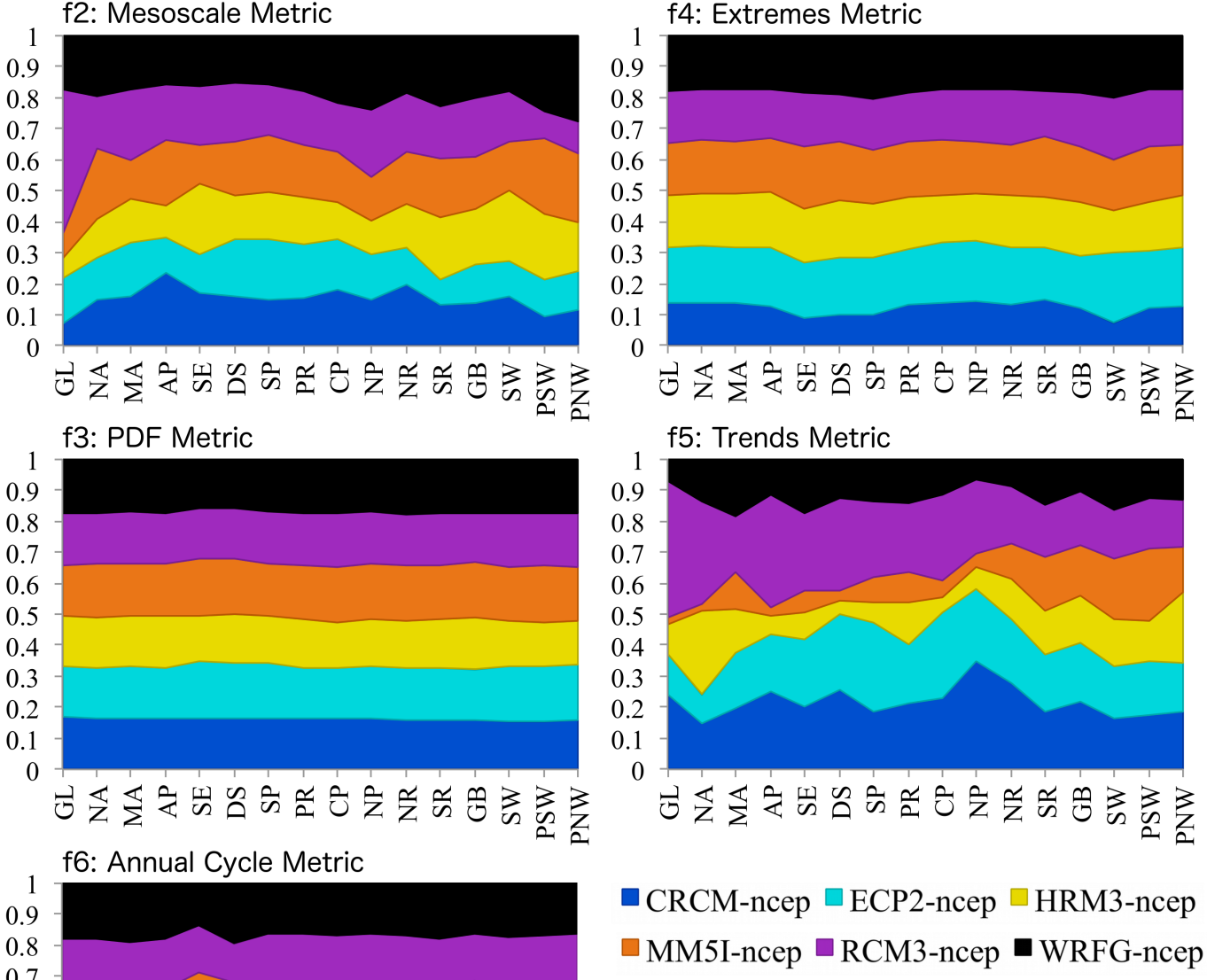
ENSEMBLES Performance Metrics

- **Final RCM weight.**
  1. All metrics are 0-1.
  2. Multiply all metrics together.
  3. Normalize again so that this value sums to 1 across RCMs (to allow application to the ensemble mean).

In the end: 1 number per simulation with many sub-components that ranges from 0-1.

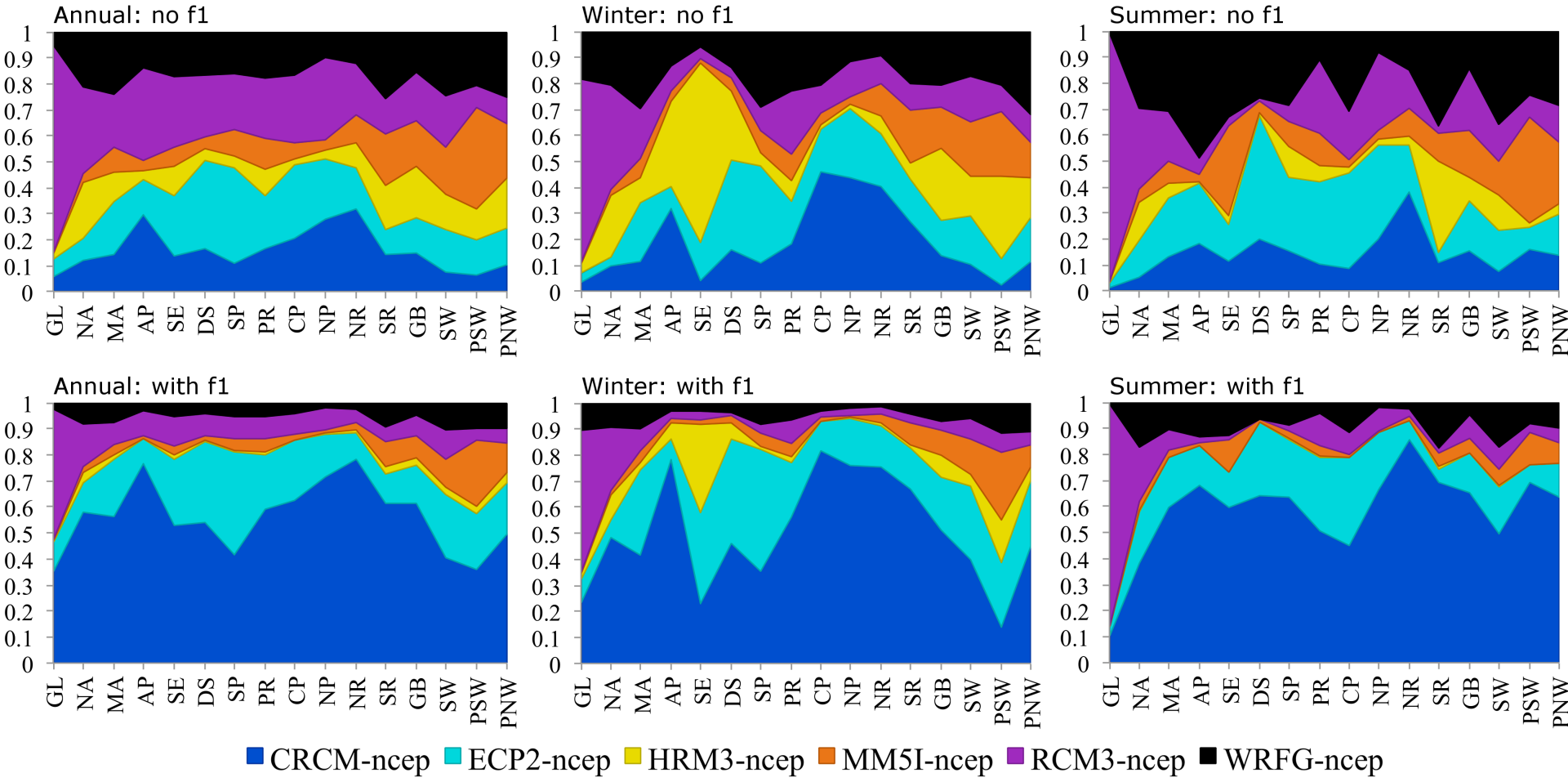
What do the weights do?

- **To the ensemble mean, not much.**
  - In some regions, it makes the ensemble mean of the historical climate worse relative to observations.
  - The large scale metric is the only one where the models show large relative differences in performance – why? I included the nudged simulations. They get almost all of the weight when the large-scale metric is used.
  - If you want to see the results/numbers for 16 different North American regions, ask me later.
- **Useful and interesting process, but they are unlikely to be useful for combining the models into something meaningful.**



Ensembles Weighting Metrics

Final Weights

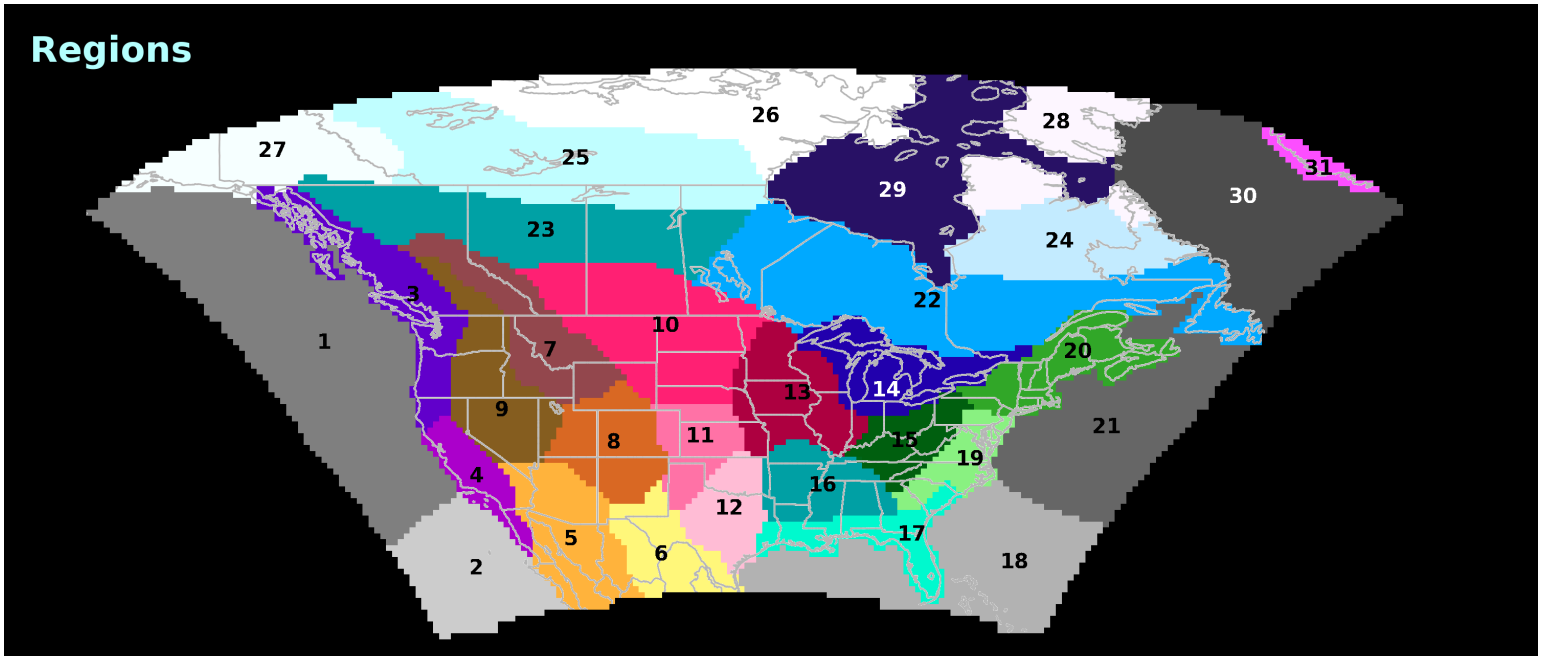


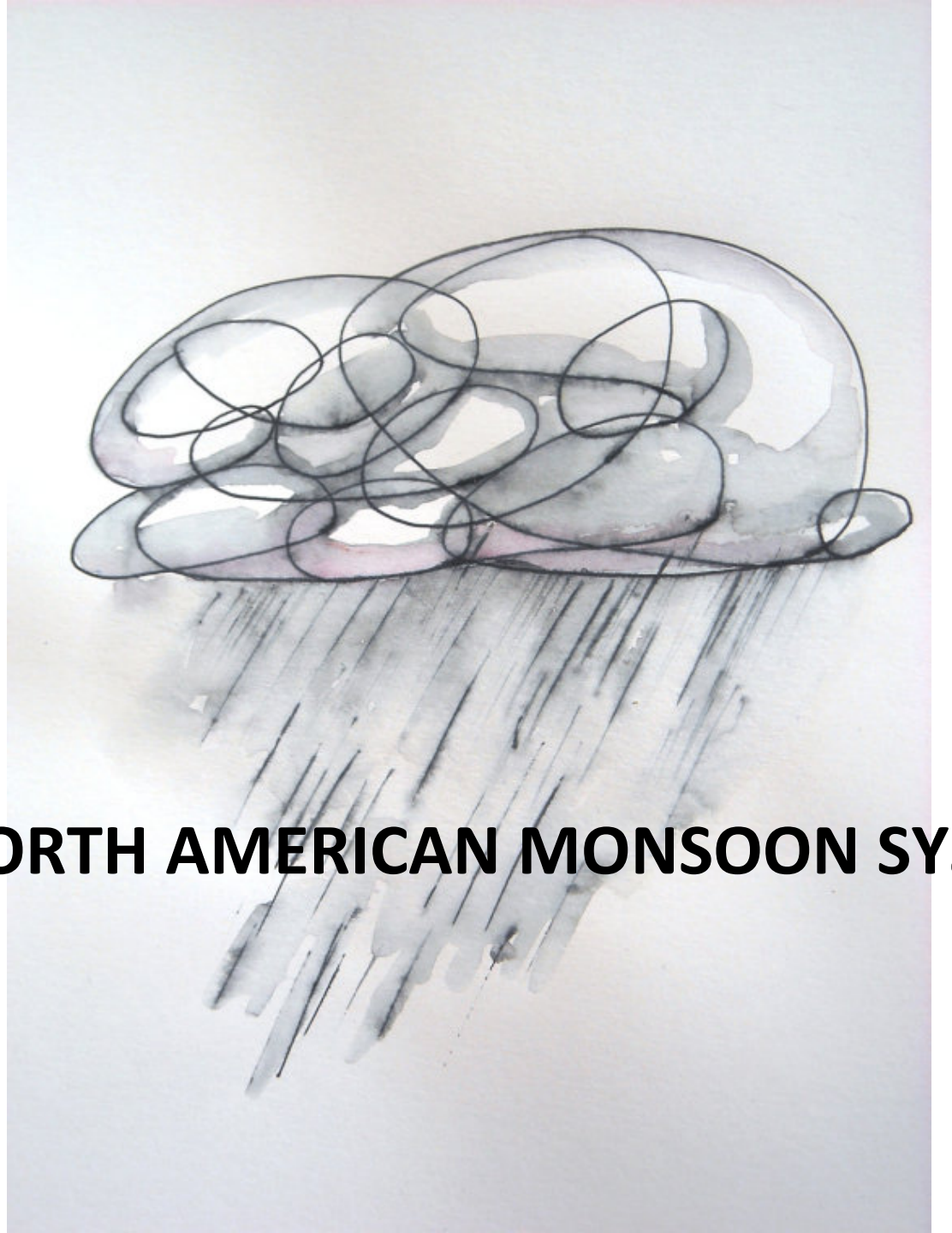
Can weights meaningfully change the ensemble mean?

1. Using a lattice design, we sample a large number of possible weight combinations (0-1) and the corresponding ensembles.
    - 92,379 ensembles.
2. Compare temperature change and precipitation change based on all 11 RCM-GCM simulations.
    - First, estimate probability density functions (PDFs) for each region, model, and season based on 30 years of climate model output.
    - Compute an ensemble PDF using the different weighting schemes.
    - Using these ensemble PDFs, we can look at expected values (mean) and the variability due to both the ensemble and the inter-annual variability.

Can weights meaningfully change the ensemble mean?

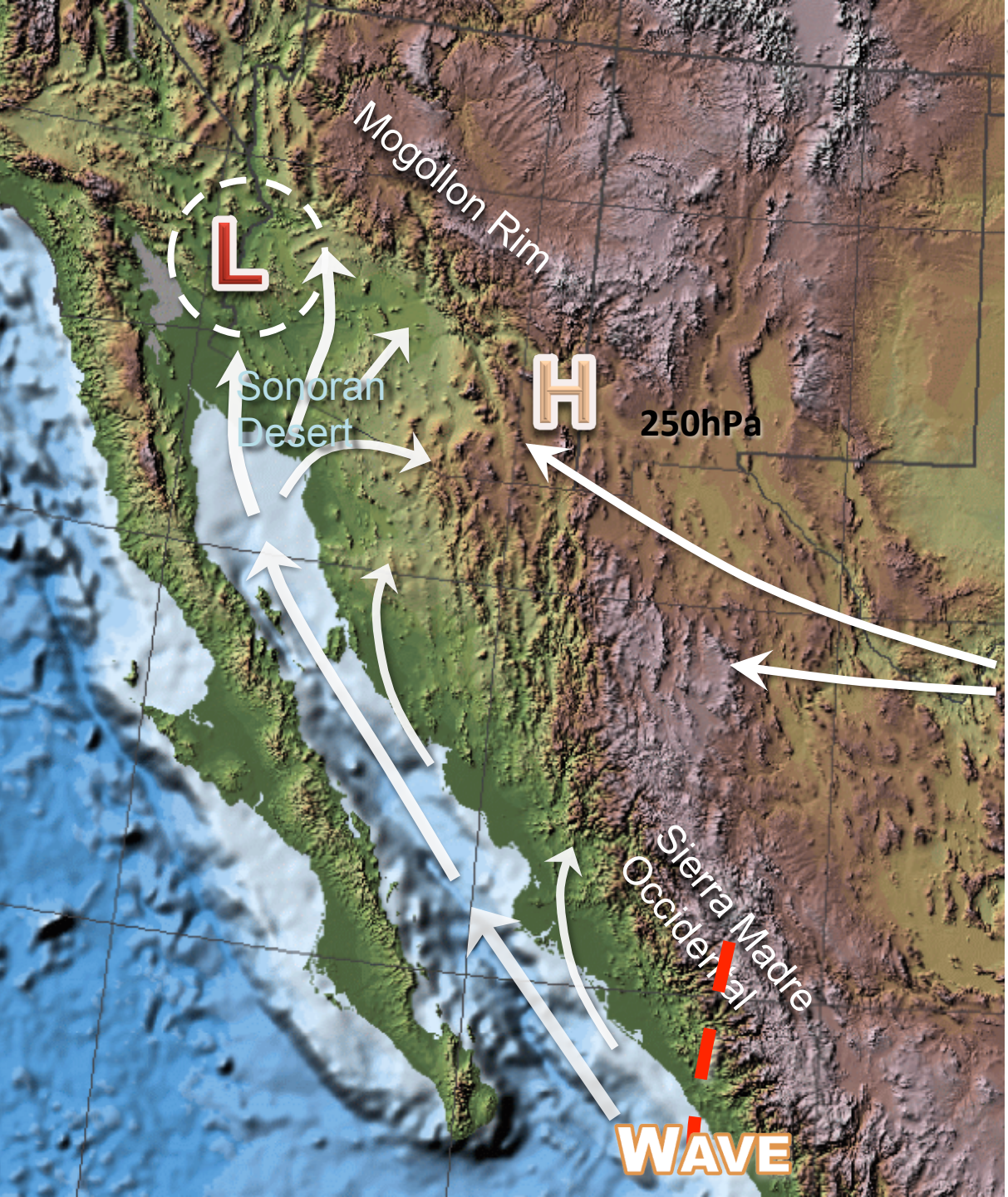
- **Unlikely**
- For weights ranging from zero to one, all the weight has to go to one or two models out of 11 for the ensemble mean to change in any significant way in almost any region in North America.





NAM 101

THE NORTH AMERICAN MONSOON SYSTEM



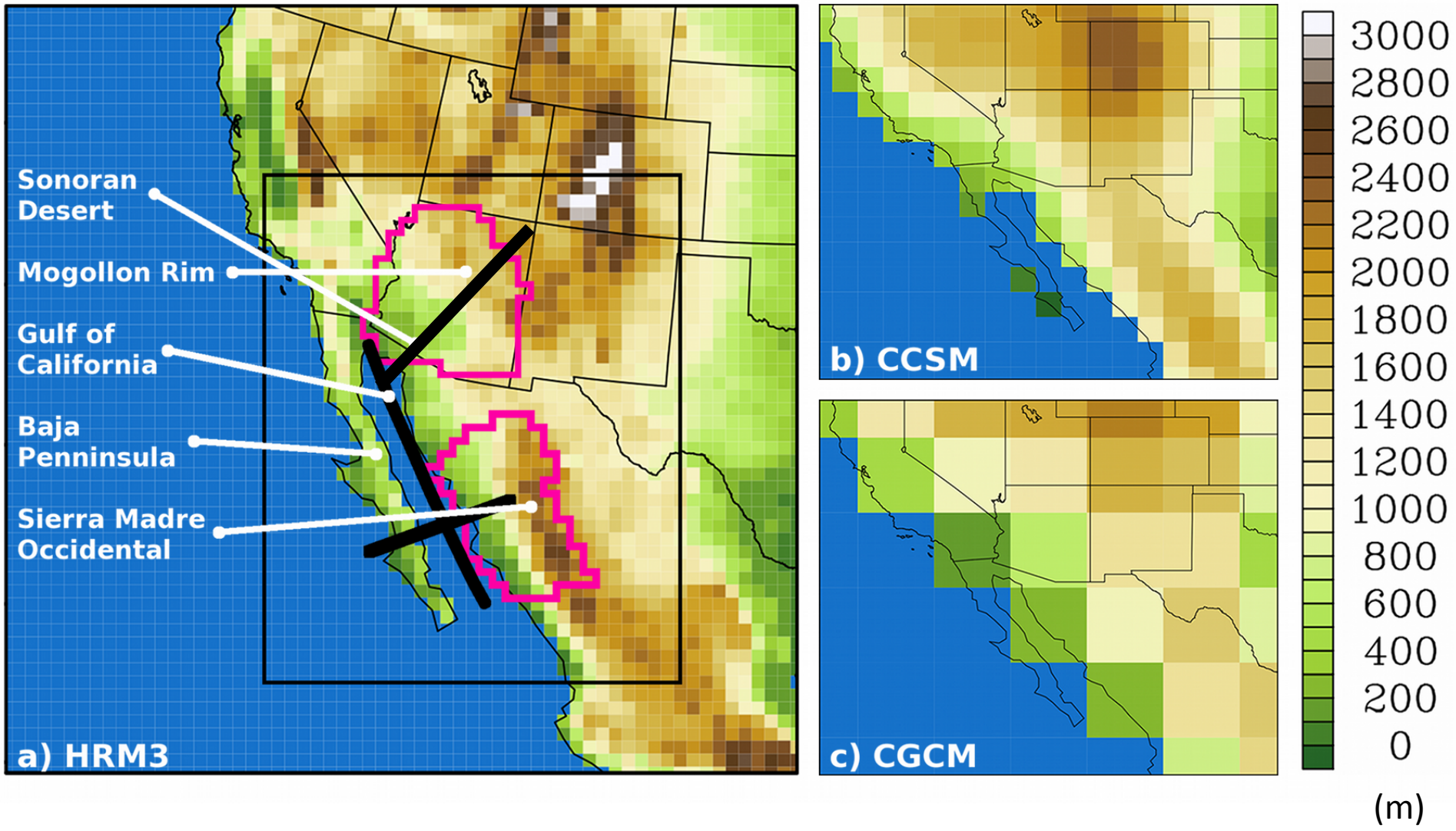
Shaded Relief - Land and Ocean
Source: U.S. Geological Survey

Shaded Relief - Land and Ocean

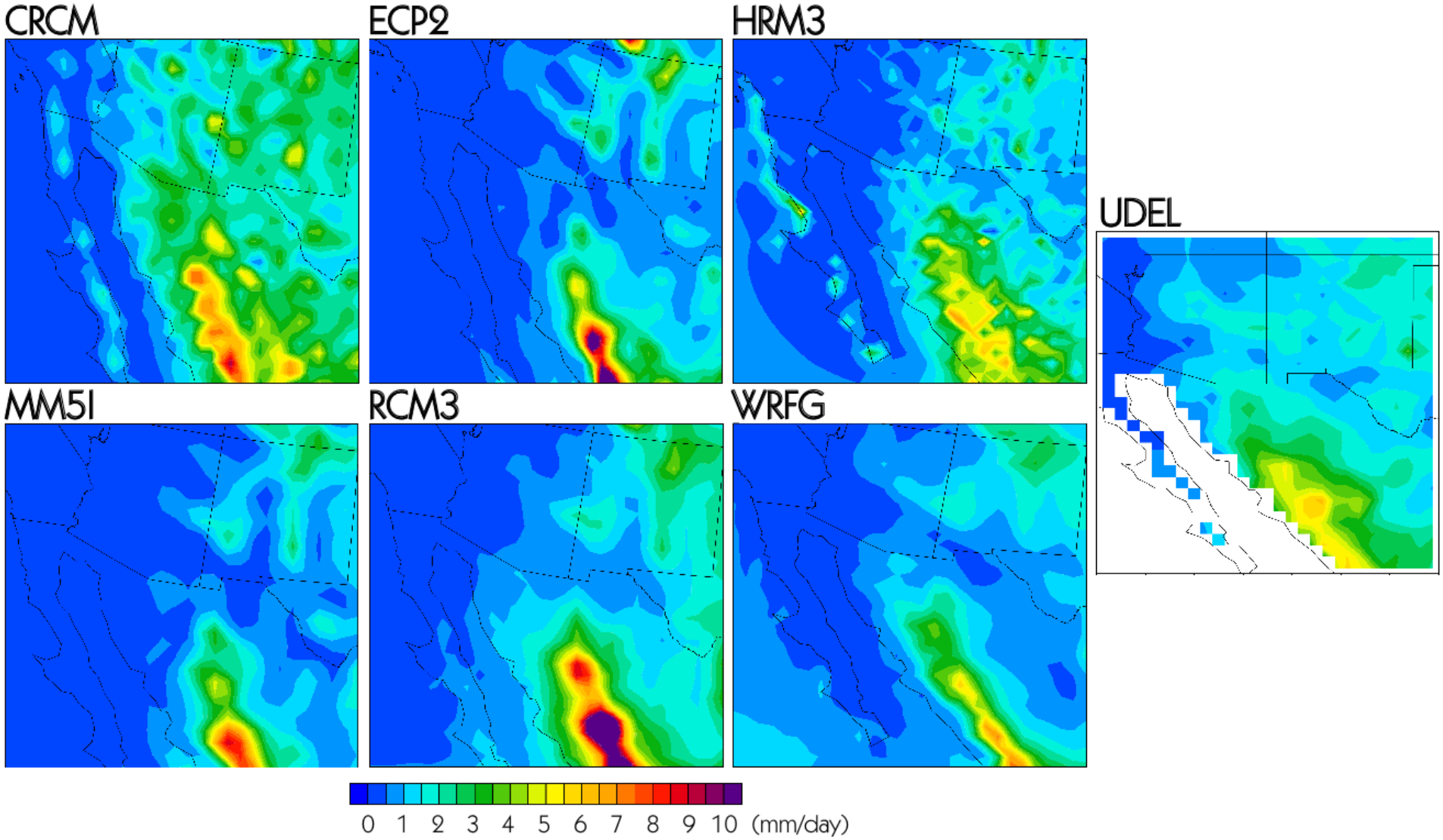
Elevation in Feet	Bathymetry in Feet
10000 - 20320	> -749
9500 - 9999	-750 to -1499
9000 - 9499	-1500 to -2999
8500 - 8999	-3000 to -5999
8000 - 8499	-6000 to -8999
7500 - 7999	-9000 to -11999
7000 - 7499	-12000 to -15999
6500 - 6999	< -16000
6000 - 6499	
5500 - 5999	
5000 - 5499	
4500 - 4999	
4000 - 4499	
3500 - 3999	
3000 - 3499	
2500 - 2999	
2000 - 2499	
1500 - 1999	
1000 - 1499	
500 - 999	
250 - 499	
1 - 249	
-282 - 0	

Bathymetric intervals only apply to ocean bodies

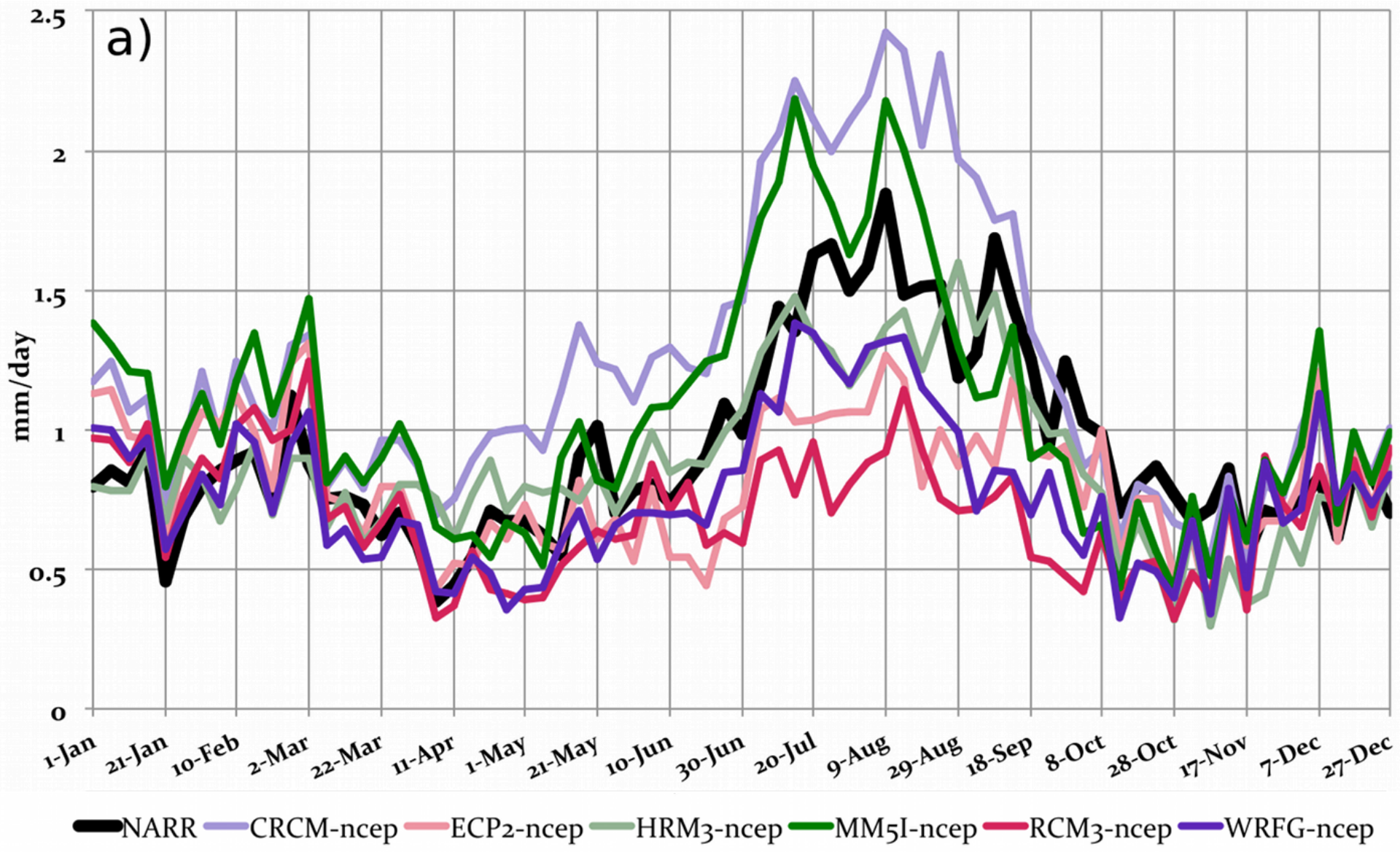
Resolution, Regions, & Cross-Sections

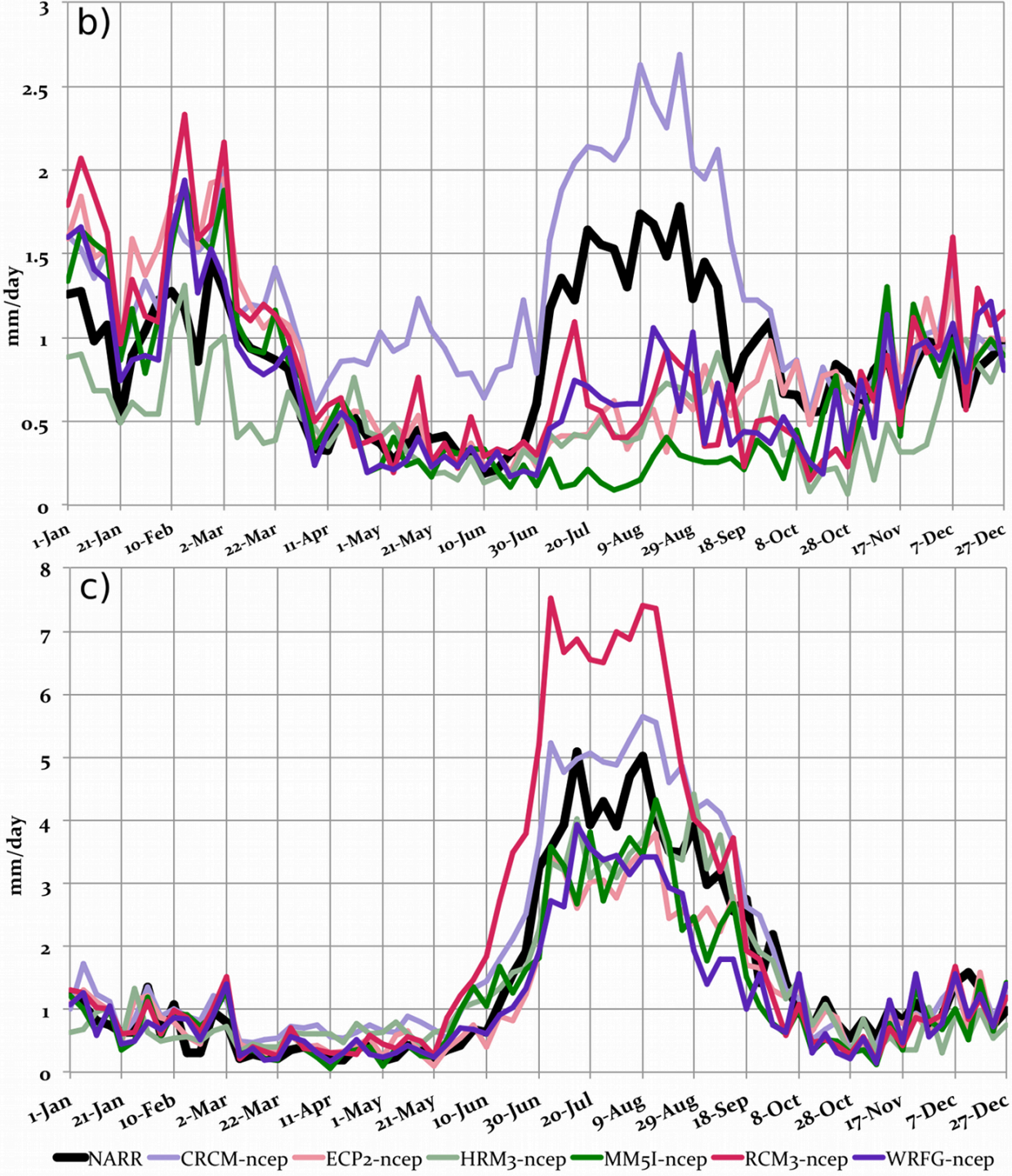


1980-2004 JJAS Average Precipitation Rate



1980-2004 5-day Average Precipitation Climatology
NCEP-Driven Simulations



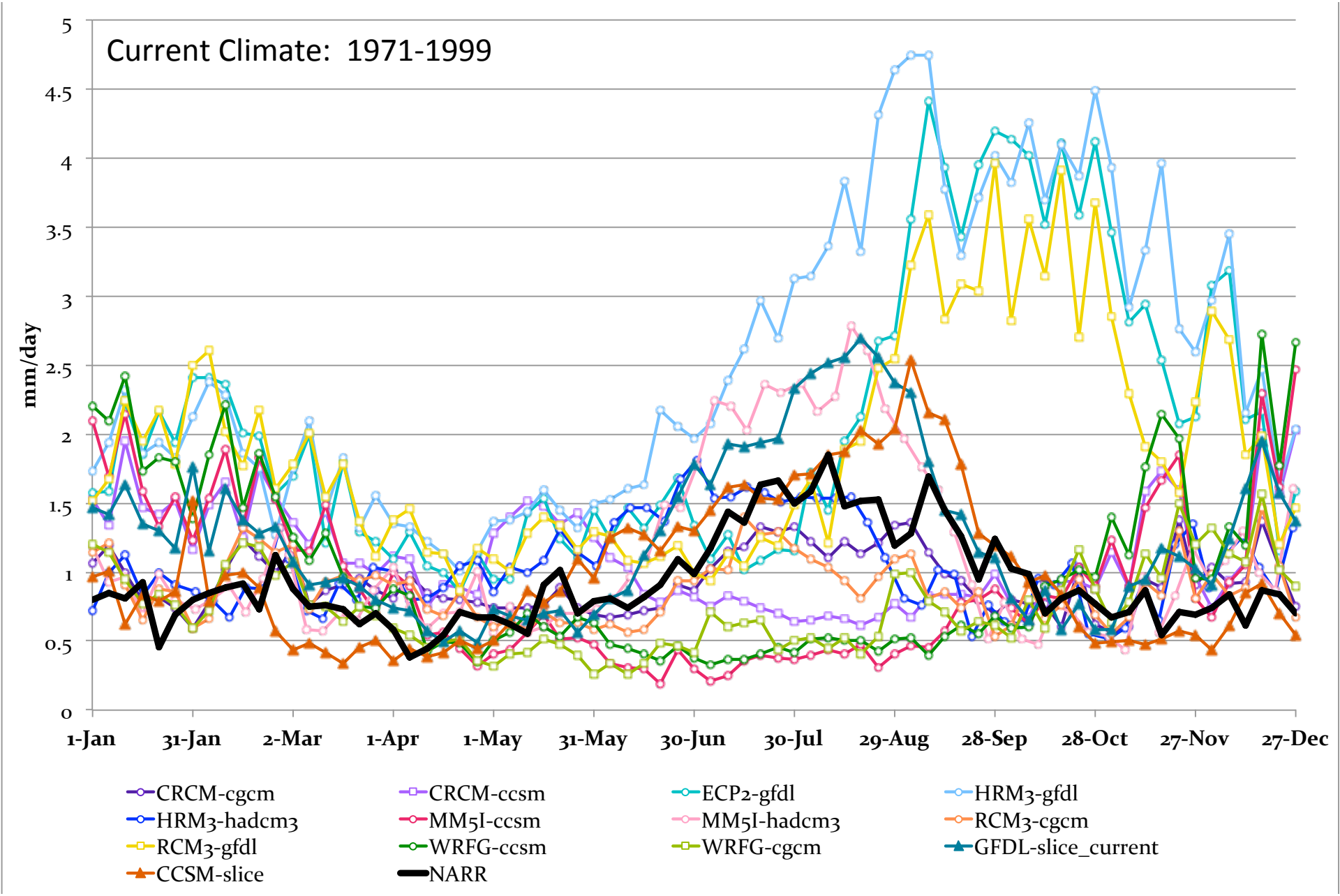


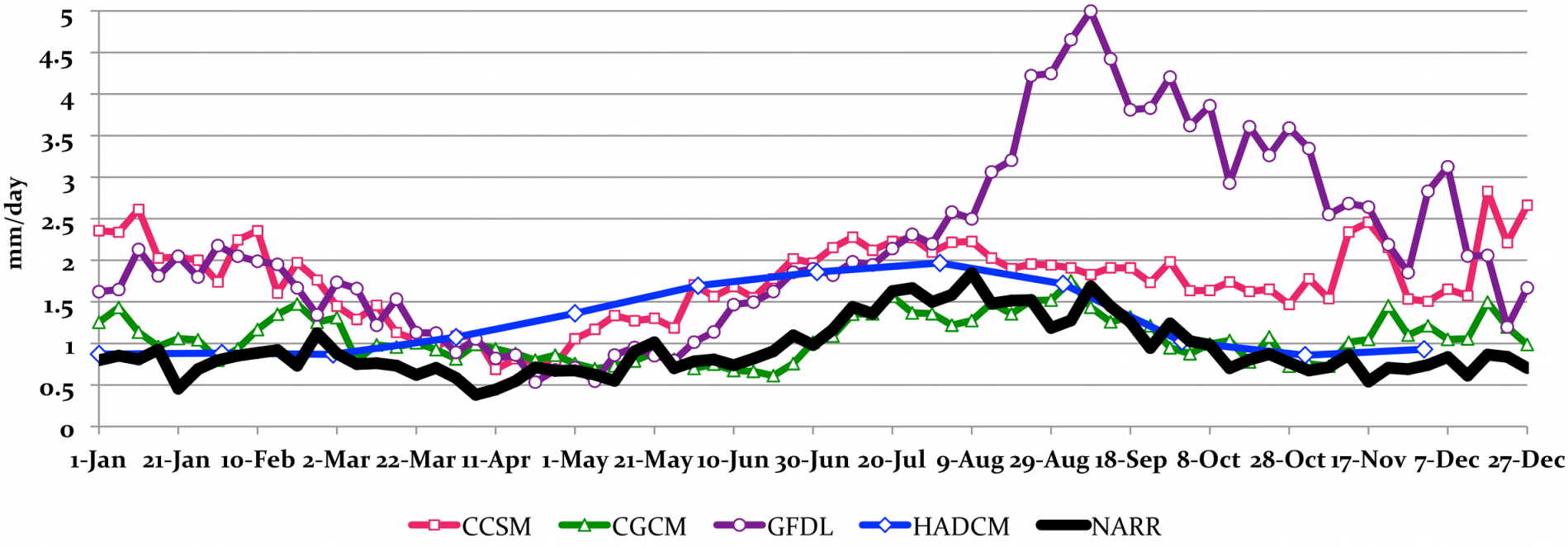
1980-2004 5-day Average Precipitation Climatologies

AZ (top)

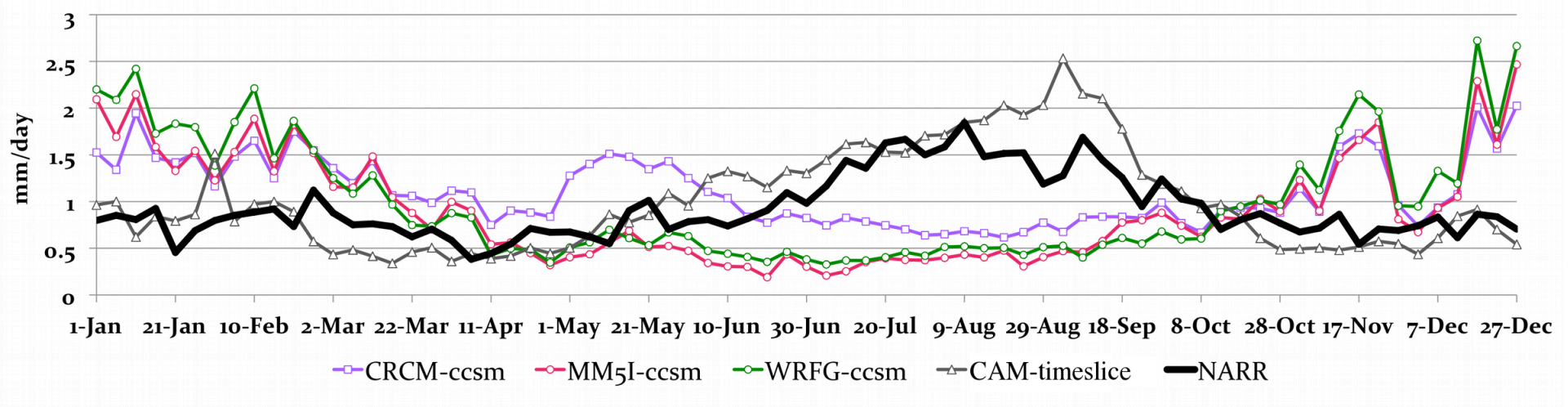
Mexico (bottom)

GCM-driven 5-day Average Precipitation Climatology



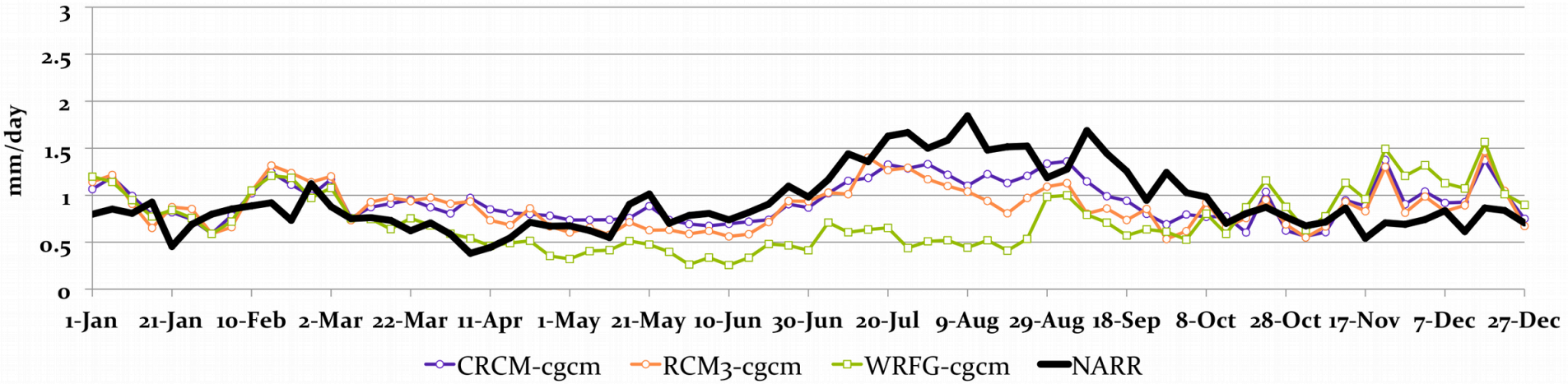


5-day or Monthly Average GCM Precipitation Climatology



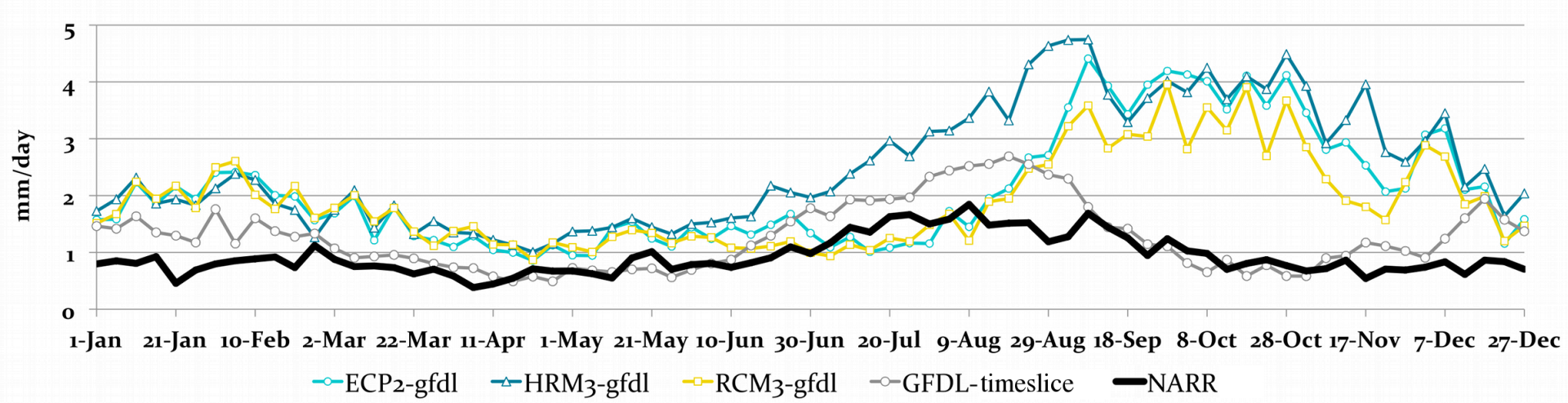
- **CCSM-driven Simulations**

  - CCSM has low specific humidity bias over east Atlantic, Gulf of Mexico, and Caribbean.
  - SSTs over Gulf of Mexico are too cold.
  - Monsoon high is too strong and about 800-km southwest of where it should be.
  - Little-to-no tropical easterly wave activity.



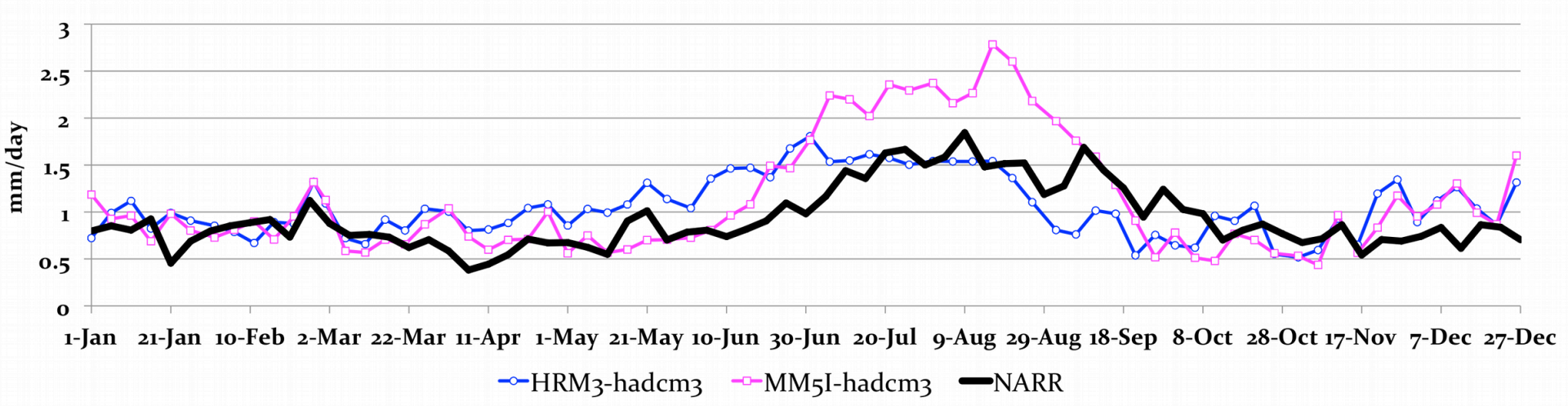
- **CGCM-driven Simulations**

  - Even stronger low specific humidity bias over east Atlantic, Gulf of Mexico, and Caribbean.
  - Monsoon high is not too strong, but it is still about 800-km southwest of where it should be.
  - Tropical easterly waves exist!
  - RCM3 has high intensity bias to precipitation.
  - CRCM and CGCM are related.

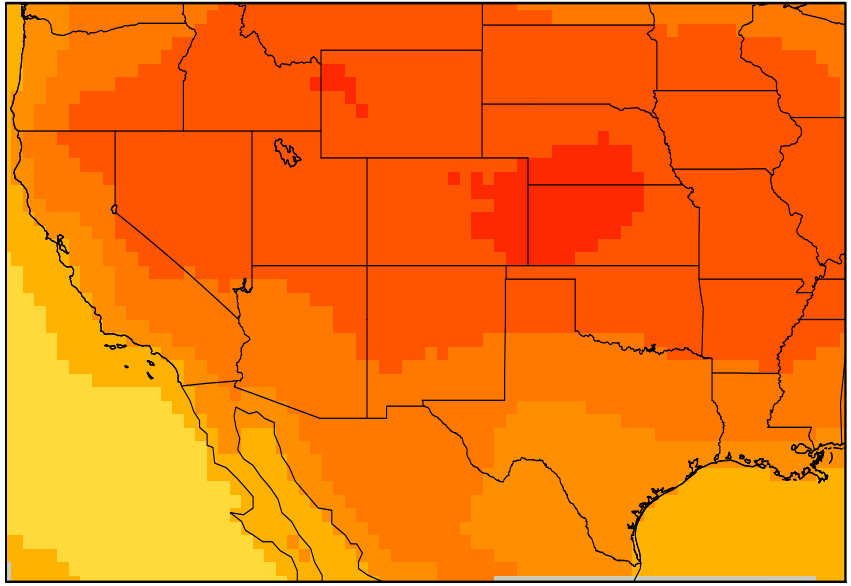


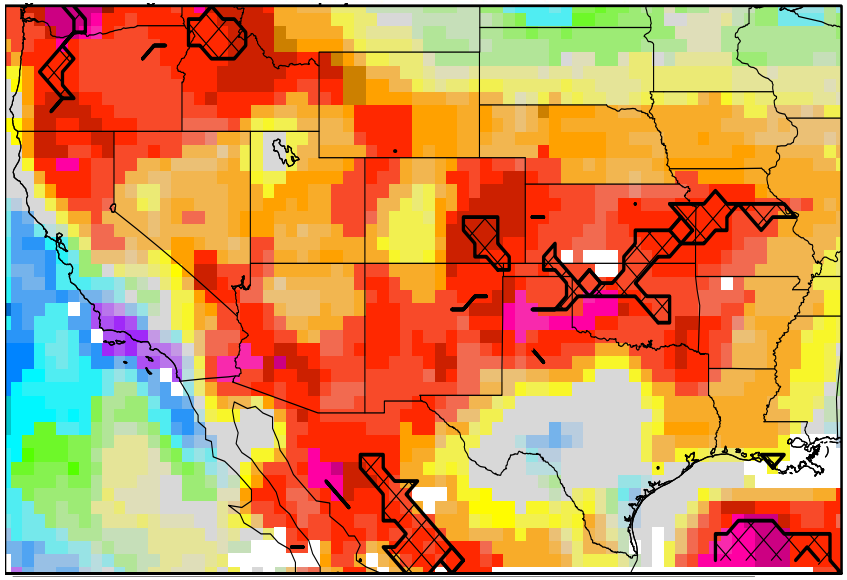
- **GFDL-driven Simulations**

  - The never-ending monsoon.
  - Large-scale low pressure southwest of the region develops due to excessive precipitation that forms in an ITCZ that doesn't propagate south in Autumn. Fuels extended season.



- **HRM3-driven Simulations**
  - Early onset, but not nearly as bad as the others. No significant, inherited GCM bias.

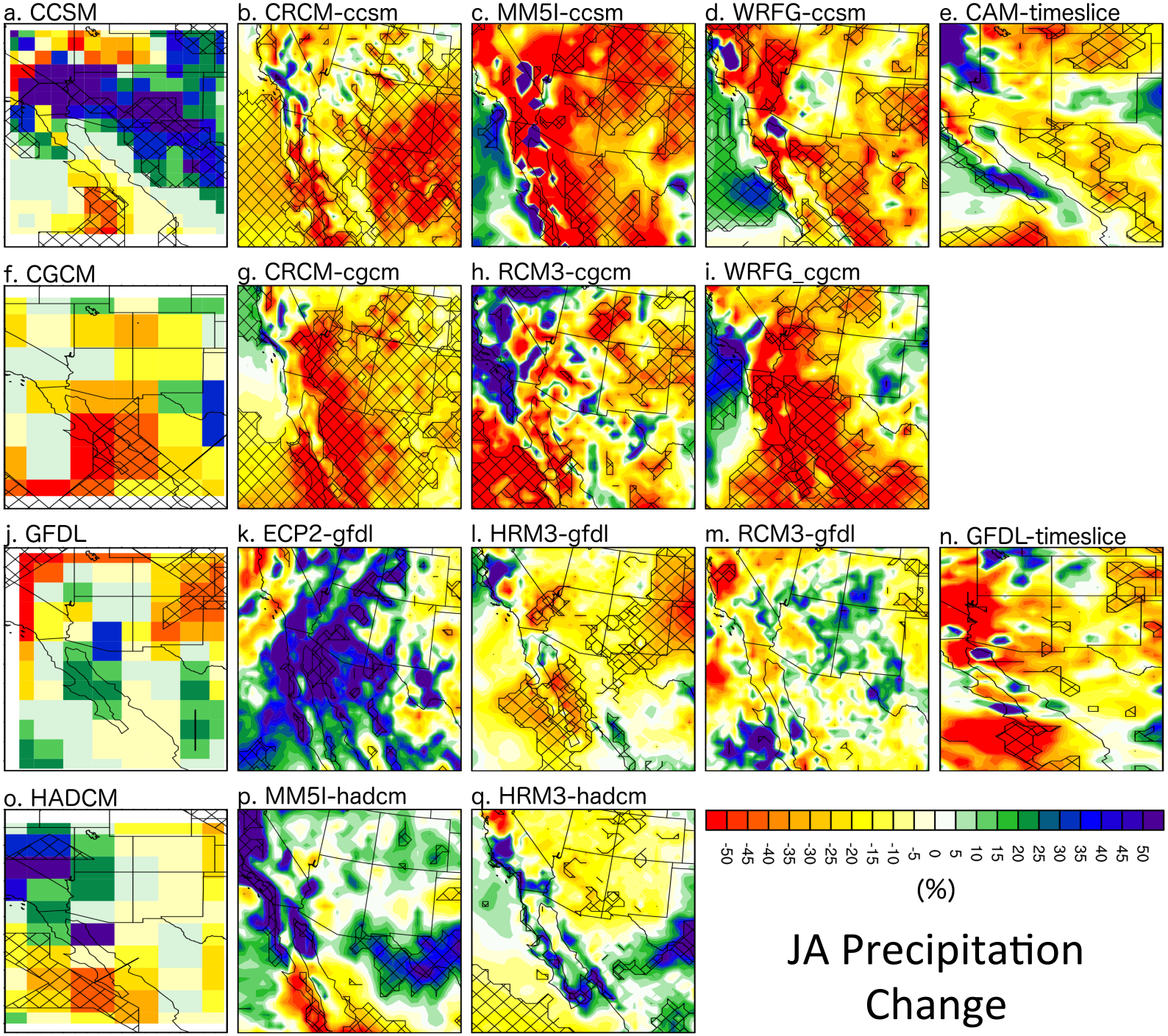




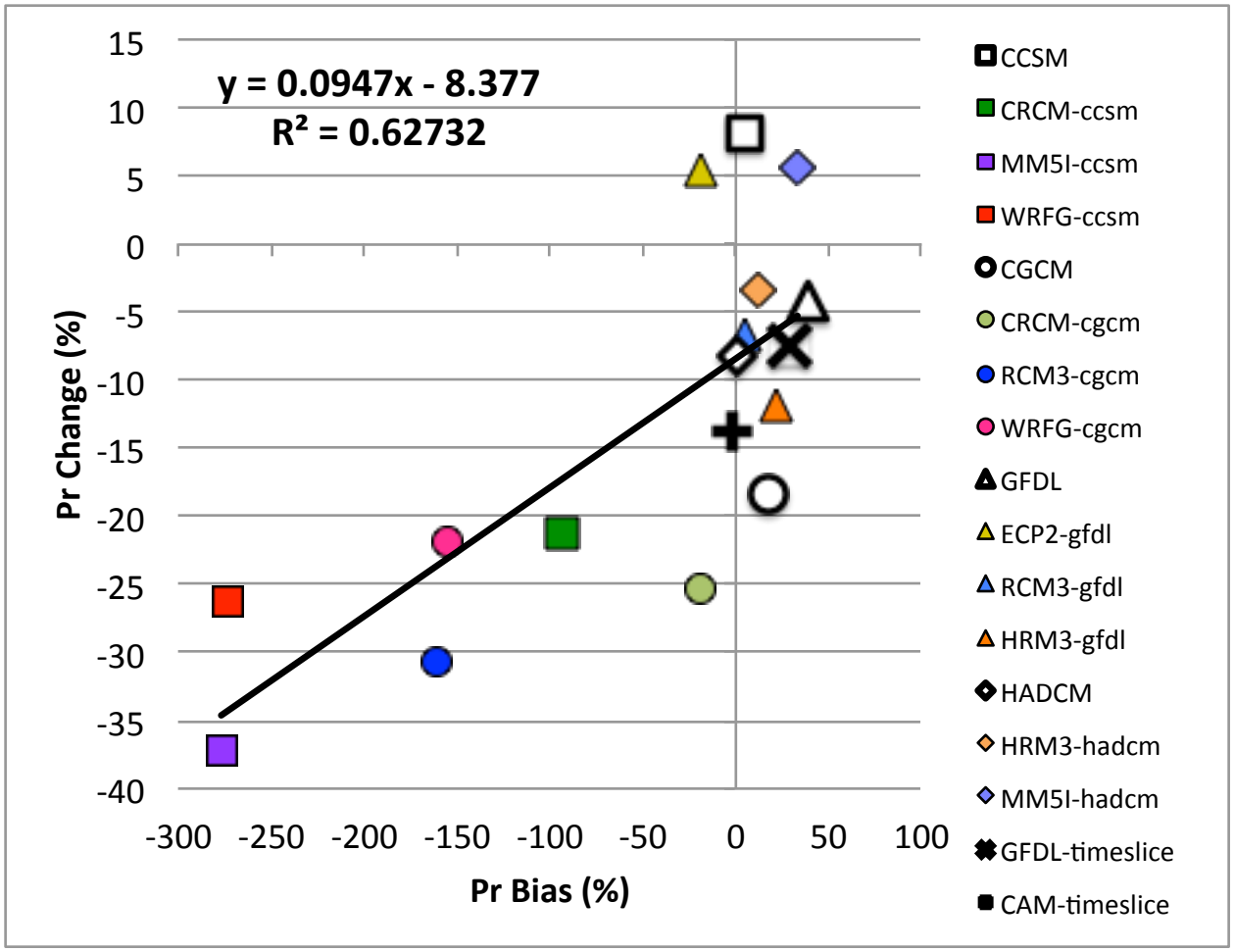
July-August 2041-69 – 1971-99 NARCCAP 13-Model Ensemble Mean Change

2-m Temperature (top) Precipitation (bottom)

For Precip) : Vertical color scale indicates model agreement on the sign of change. Hatching indicates where more than 50% of the models show change that is significant at the 0.10 level *and* where more than 75% of the models agree on the sign of change.


a. CCSM
b. CRCM-ccsm
c. MM5I-ccsm
d. WRFG-ccsm
e. CAM-timeslice
f. CGCM
g. CRCM-cgcm
h. RCM3-cgcm
i. WRFG_cgcm
j. GFDL
k. ECP2-gfdl
l. HRM3-gfdl
m. RCM3-gfdl
n. GFDL-timeslice
o. HADCM
p. MM5I-hadcm
q. HRM3-hadcm
-50 -45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50
(%)
JA Precipitation Change

Precipitation Change vs. Bias

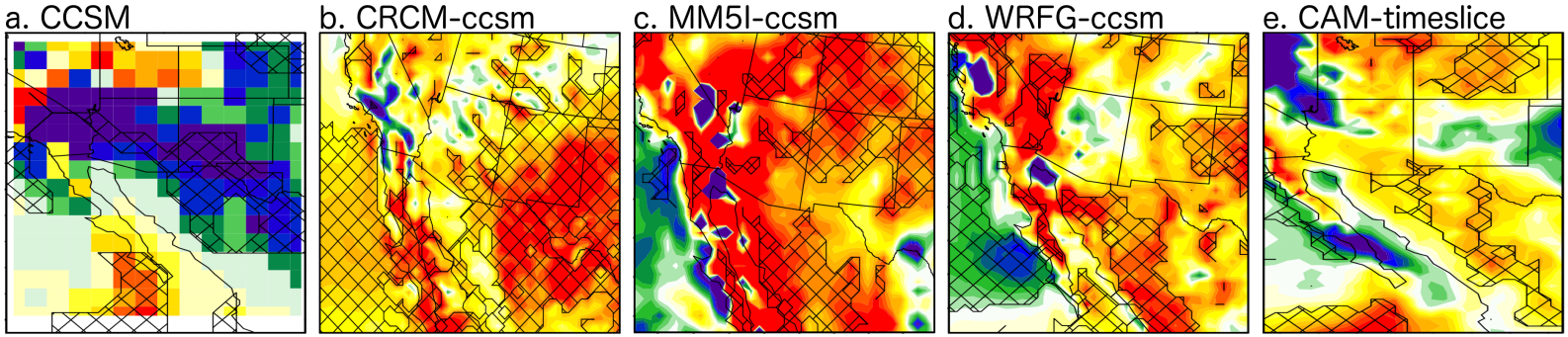


Simulations with the greatest dry bias also have greatest decreases in precipitation frequency at all intensities and the greatest decrease in precipitation intensity.

*Full region, land-only. Linear fit does not include driving GCMs.

2041-2069 : 1971-1999, July-August

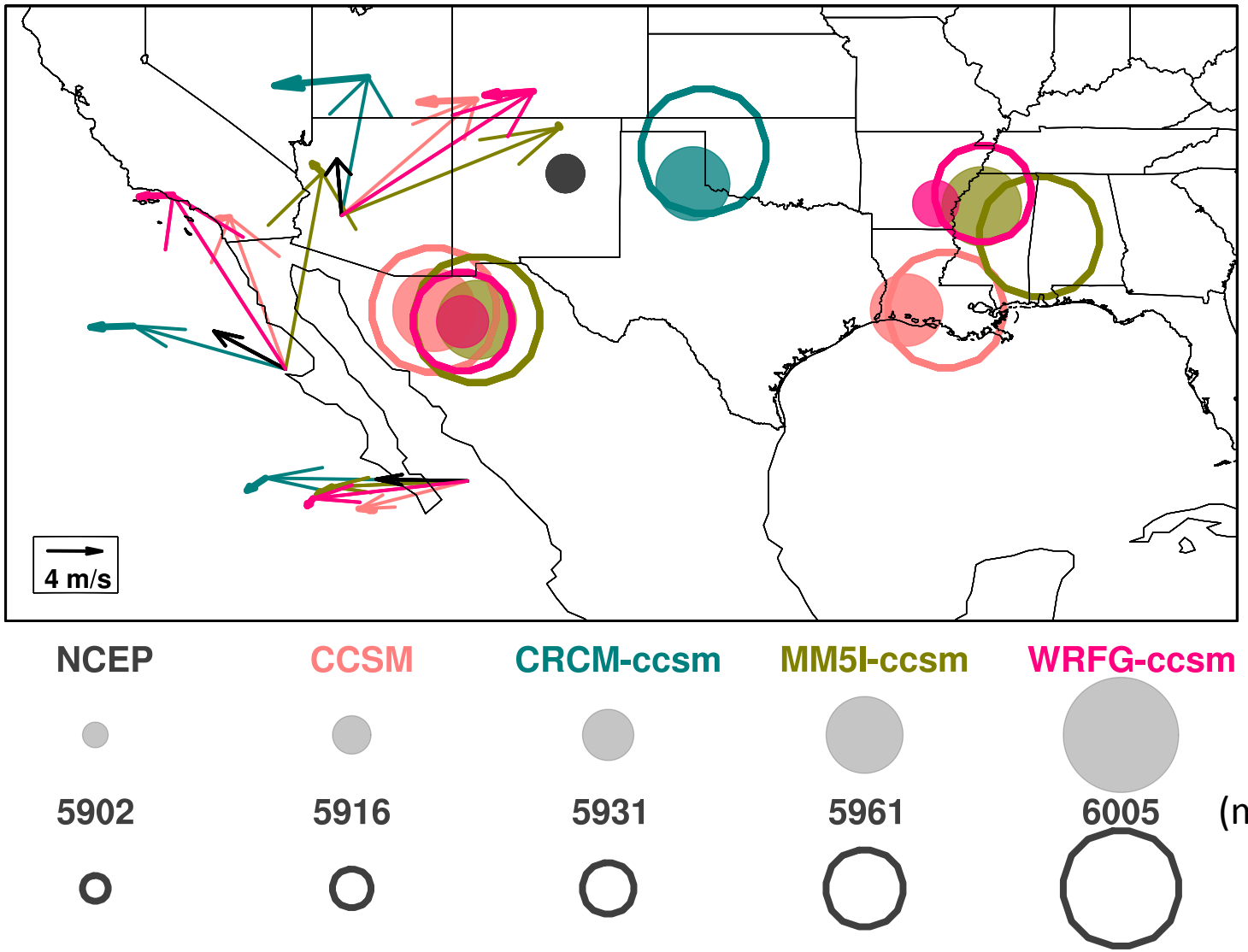
3h Precip. Rate Frequency Distribution Change (%) by Percentiles

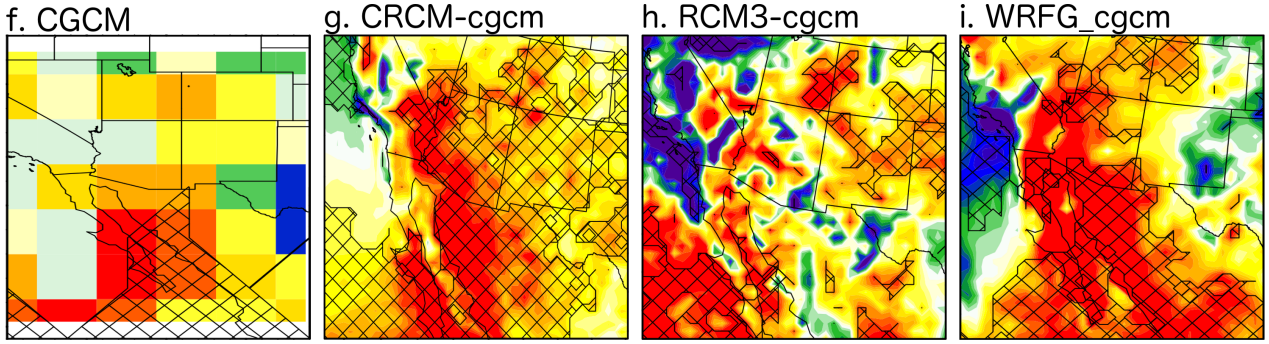


- Monsoon high strengthens. It was already too strong.
- Pattern of synoptic-to-large-scale change resembles El Niño. El Niño = dry monsoon.
  - CCSM has an ENSO cycle that is too frequent and too week.
  - Moves to a more El Niño-like state in the future. This change is not deemed credible.
- MM5I change is stronger due to model "drift". Among other problems that become stronger.
- CCSM change due to model physics response.

CCSM-driven

500-mb Changes

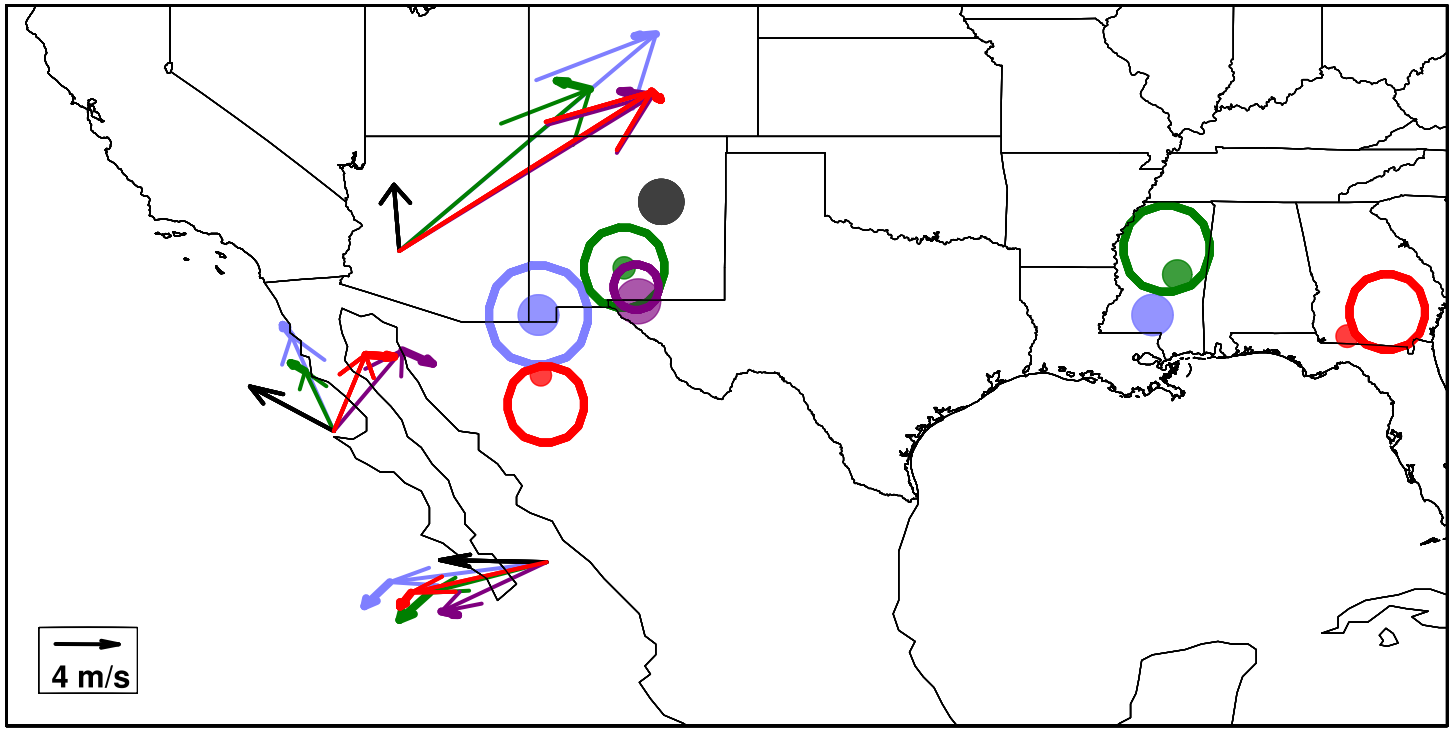




- Drying associated with a circulation change that suggests fewer and/or weaker tropical easterly waves. The CGCM has them, so this is plausible.
- Decrease in precipitation may still be overdone.
  - Model has too little atmospheric moisture to start, by 6-8 g/kg in the PBL. This decreases.
  - CIN: July-August average: 483 J/kg increases to 578 J/kg. (Obs. < 100 J/kg)
  - Applying the changes to unbiased starting conditions may not produce as much of a decrease.
- RCM3 increase is smaller because of precipitation intensity bias.

CGCM-driven

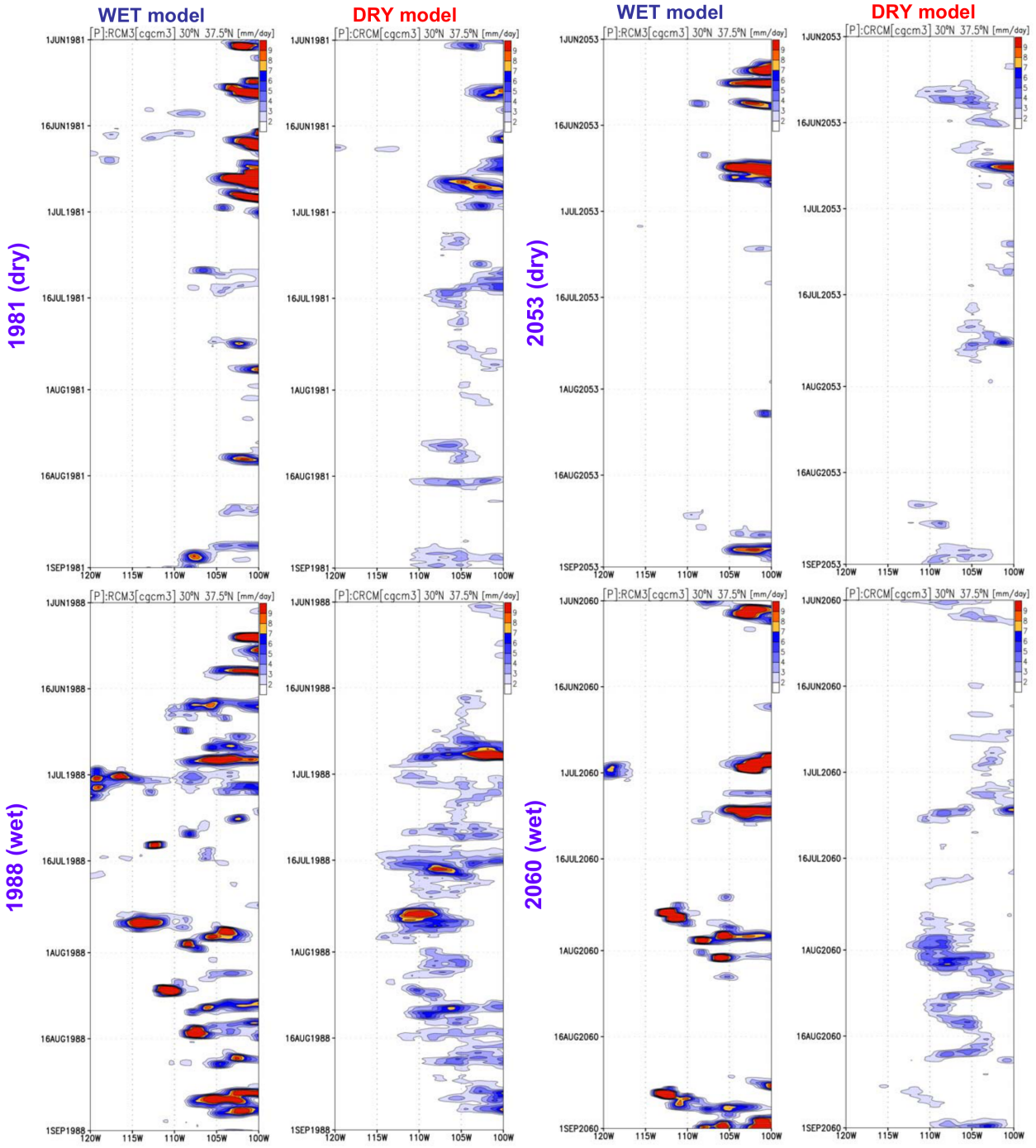
500-mb Changes

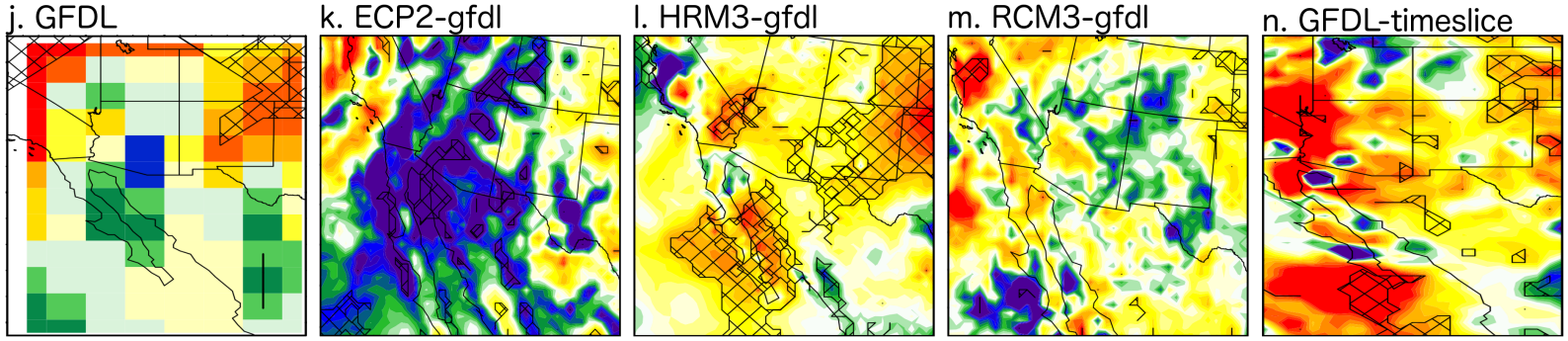


NCEP CGCM CRCM-cgcm RCM3-cgcm WRFG-cgcm

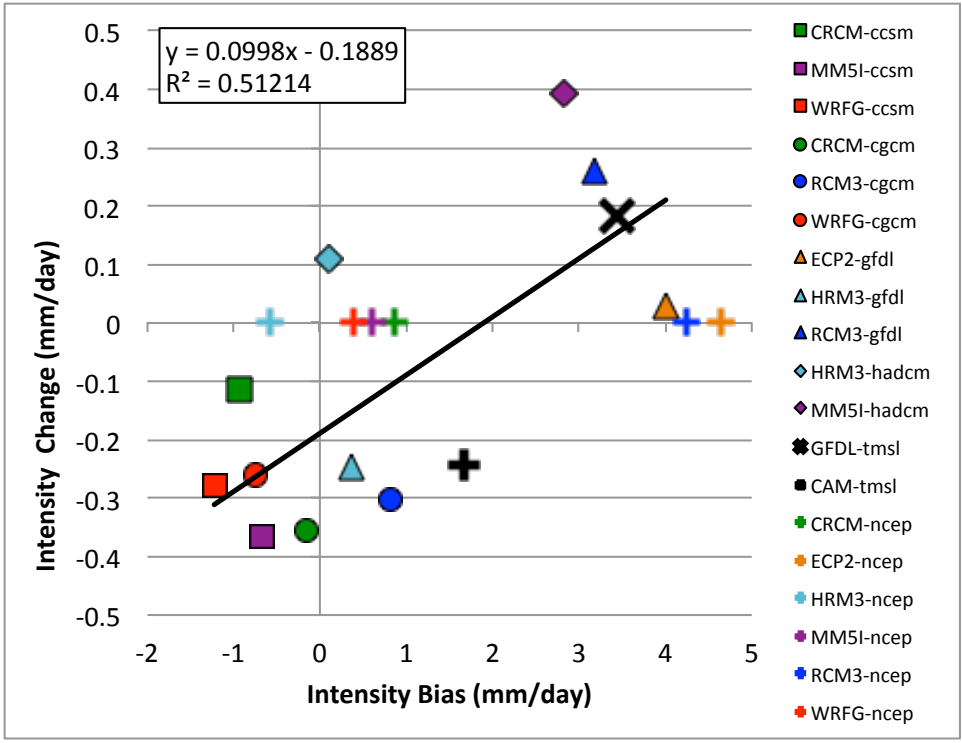
5902 5916 5931 5961 6005 (m)

*Note: no zg for RCM3, dot size = NCEP, location from winds!


WET model
DRY model
WET model
DRY model
1981 (dry)
2053 (dry)
1988 (wet)
2060 (wet)
[P]:RCM3[cgcm3] 30°N 37.5°N [mm/day]
[P]:CRCM[cgcm3] 30°N 37.5°N [mm/day]
1JUN1981
16JUN1981
1JUL1981
16JUL1981
1AUG1981
16AUG1981
1SEP1981
1JUN1988
16JUN1988
1JUL1988
16JUL1988
1AUG1988
16AUG1988
1SEP1988
1JUN2053
16JUN2053
1JUL2053
16JUL2053
1AUG2053
16AUG2053
1SEP2053
1JUN2060
16JUN2060
1JUL2060
16JUL2060
1AUG2060
16AUG2060
1SEP2060
120W
115W
110W
105W
100W

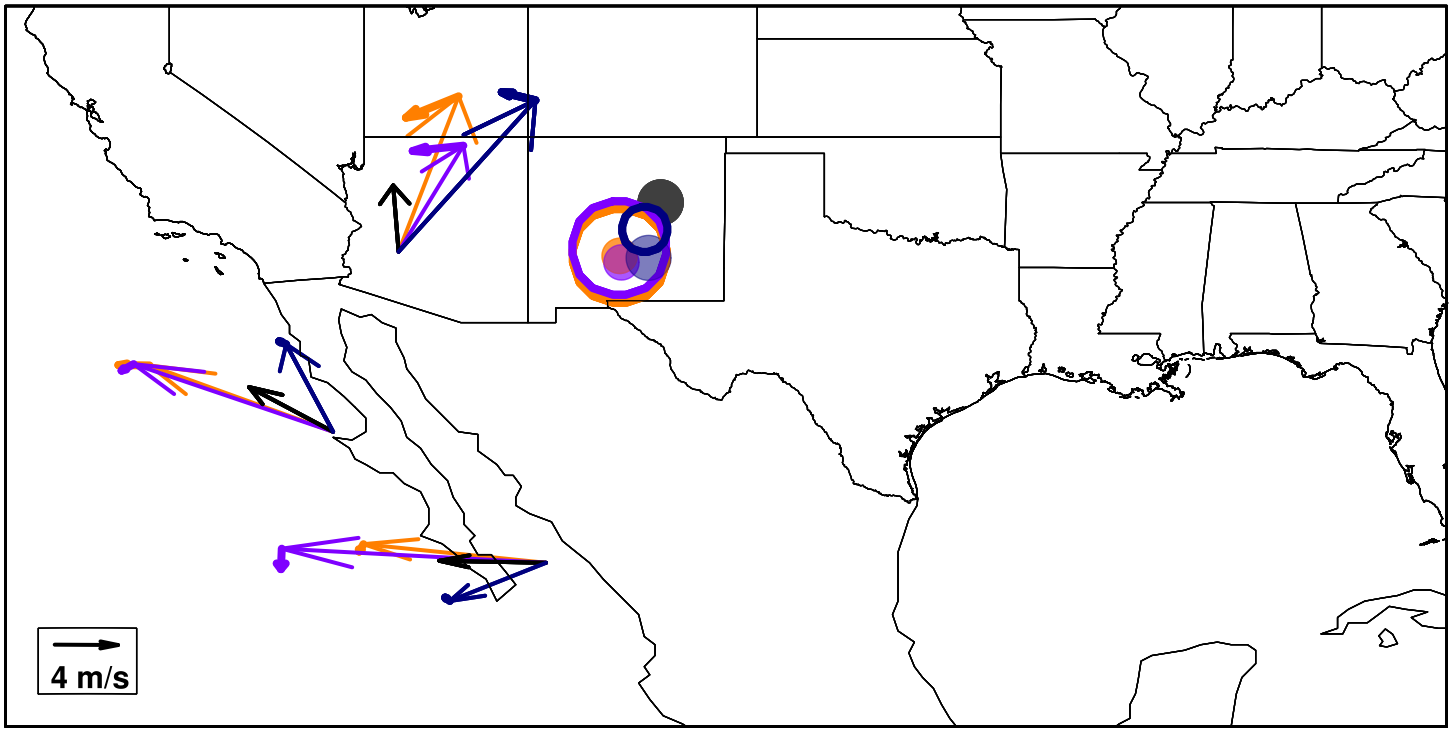


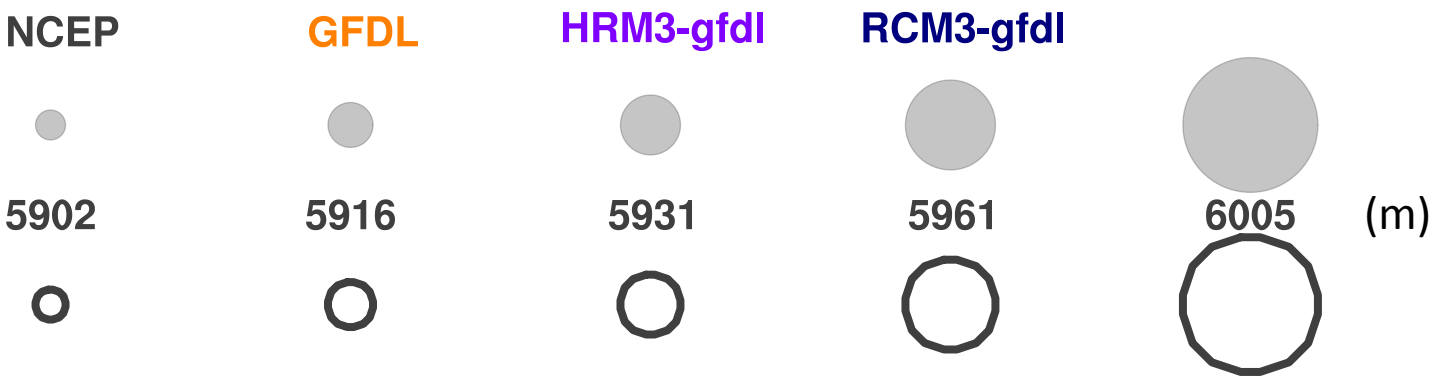
- Unknown effect of “never-ending monsoon” on the core of monsoon season. Problem starts to appear in August.
- HRM3 is the only one with a GoC LLJ. With strengthening monsoon high and decrease in southerly flow in future, small decreases are warranted.
- ECP2 and RCM3 have high intensity precipitation problem.



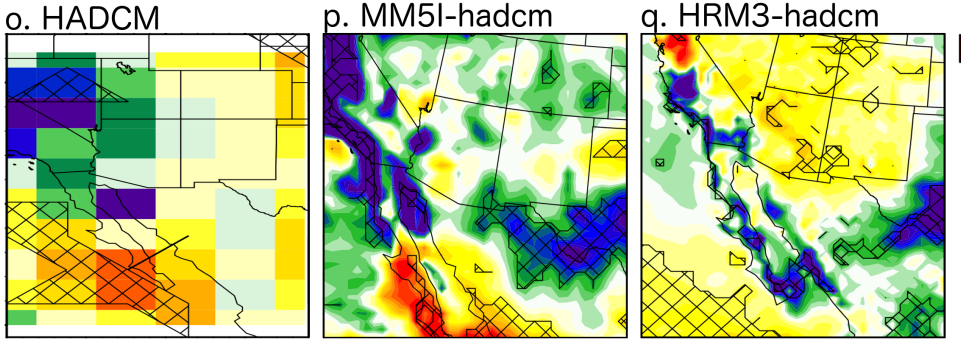
GFDL-driven

500-mb Changes





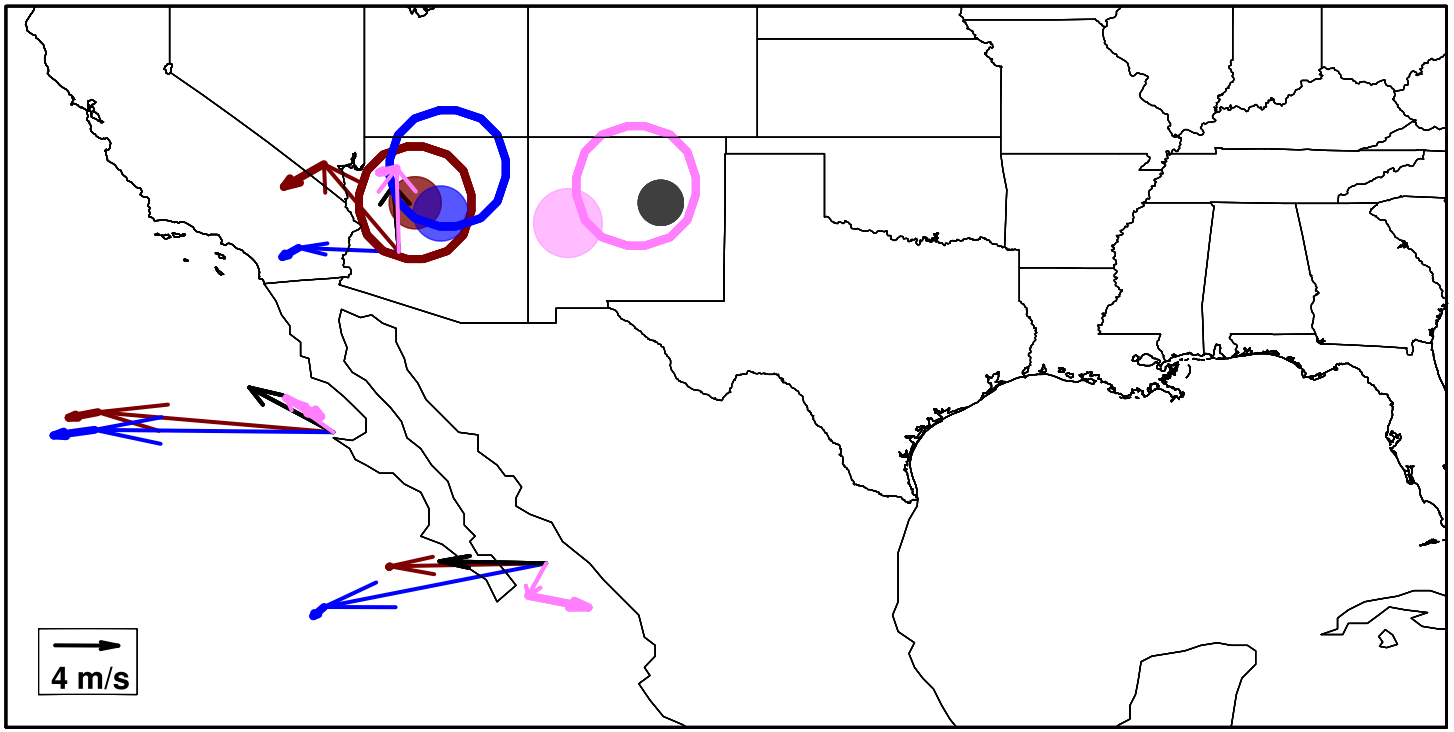
*Note: no zg for RCM3, dot size = NCEP, location from winds!



- Least biased BC.
- Increase in mid-to-upper level continental flow in future in HADCM and HRM3-hadcm over 4-corners region. Increase in strength of easterlies further south.
- MM5I departs from driver due to “drift”/warming bias. Future changes less realistic as a result.

HADCM-driven

500-mb Changes



NCEP HADCM3 HRM3-hadcm3 MM5I-hadcm3

Discussion

- Can you trust projections for precipitation change from models that don't rain during monsoon season?

- Model agreement doesn't really mean anything at face value.
  - What should the ensemble mean from the "credible" simulations look like? Which are credible?

- Yet another example of how difficult it is to determine model credibility.
  - What biases are important?

- Added value? Sometimes added garbage.

Discussion

- Unbiased boundary conditions are important!
  - Good argument for the continued improvement of GCMs/ESMs.
  - Good argument for careful selection of boundary conditions.
    - Not easy or straightforward, especially for large regions.
- Performance of RCMs also clearly effect the projections.
  - e.g. Gulf of California LLJ and precipitation intensity.

Discussion

- NARCCAP's experimental design is important in determining GCM vs. RCM effects.
  - Also gives the ability to suggest additional simulations that would be useful (e.g. holes in the matrix that would be interesting to fill).

Discussion

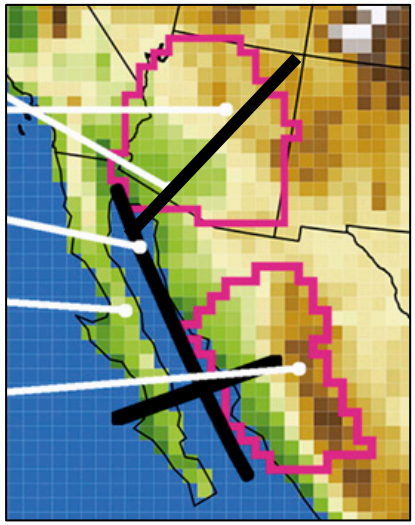
- Don’t waste your time with broad-based objective weighting metrics.
  - Regional, process-specific metrics may work.

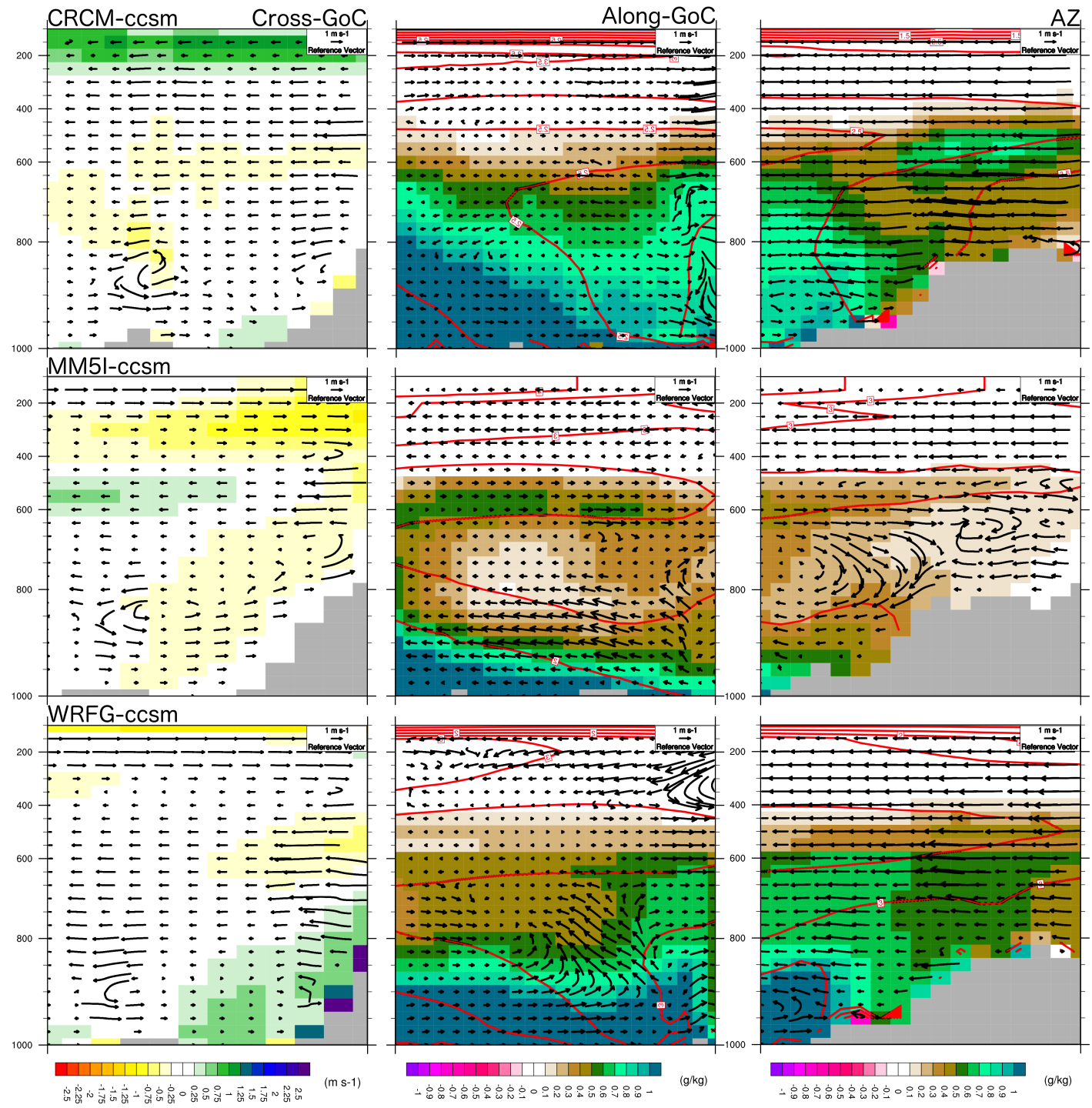
- Higher resolution isn’t necessarily better.
  - False confidence.


The End
bukovsky@ucar.edu

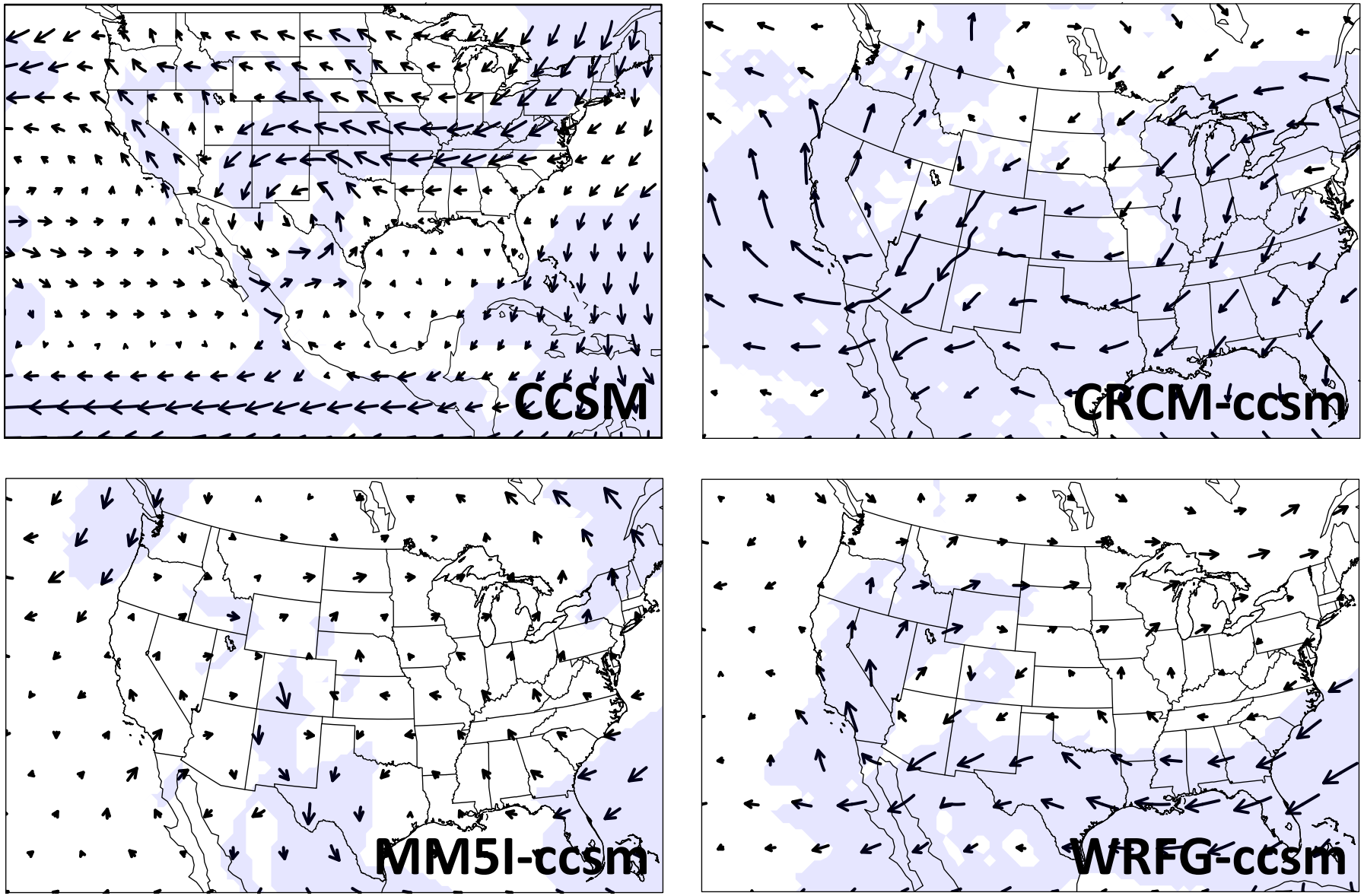
Vertical Cross-Sections

- Left: Across GoC, color = change in winds perpendicular to slice.
- Middle: Along GoC, color = change in specific humidity.
- Right: AZ, color = change in specific humidity.





700-mb Wind Difference

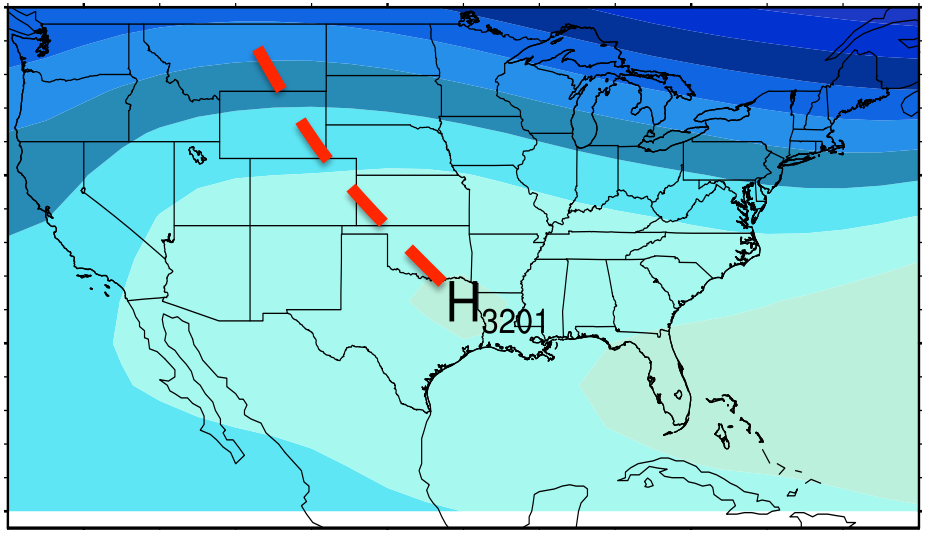


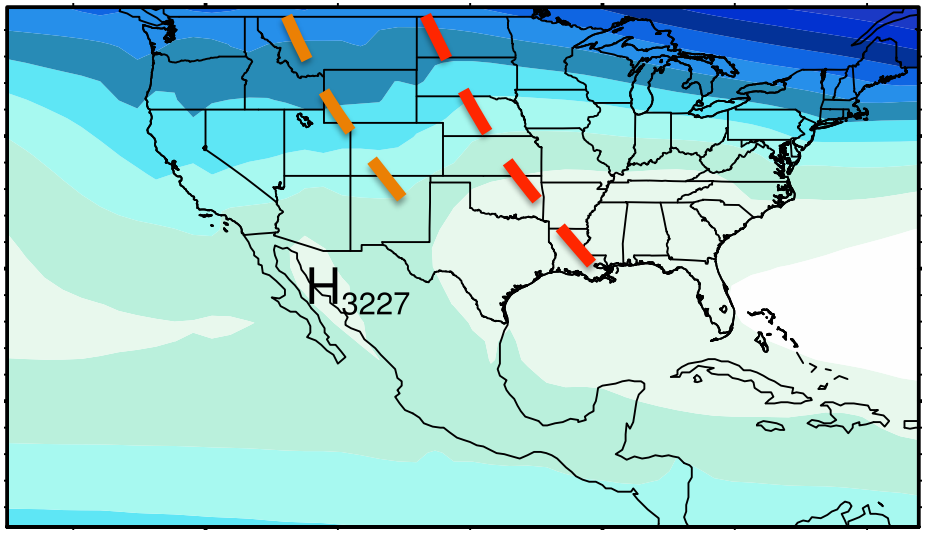
700-mb Geopotential Height

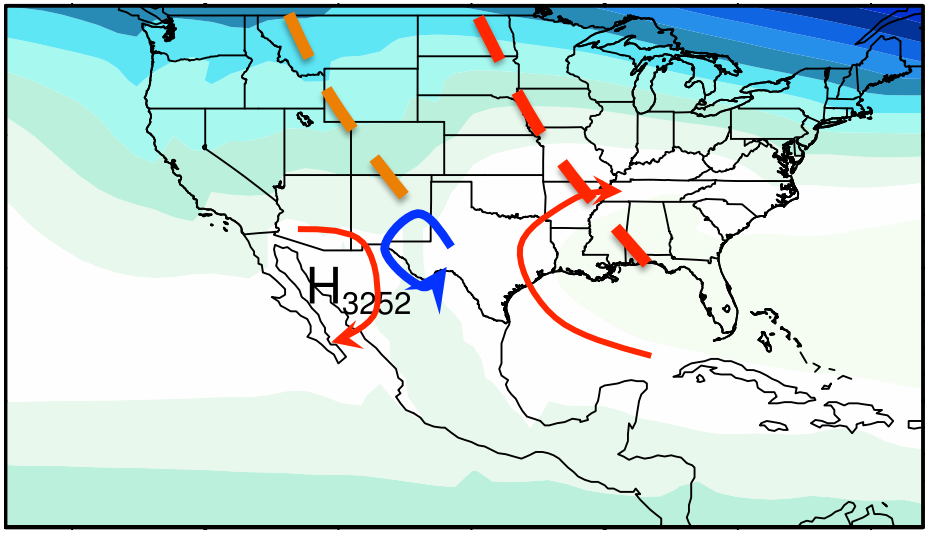
NCEP (left)

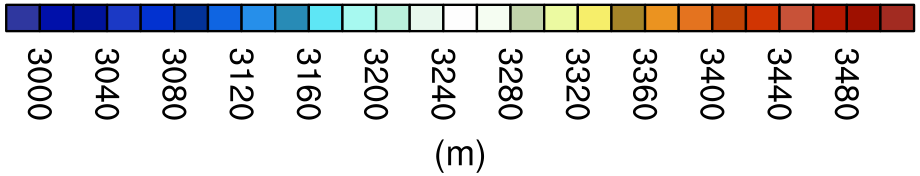
CCSM-current (bottom left)

CCSM-future (bottom right)

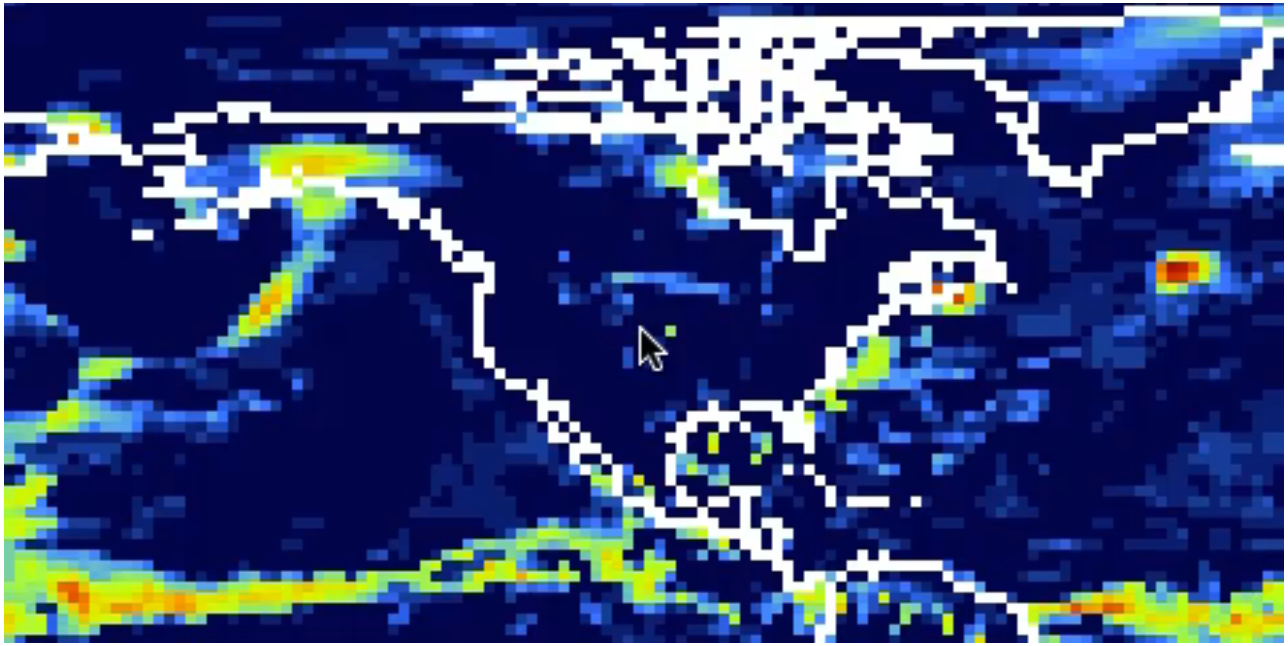






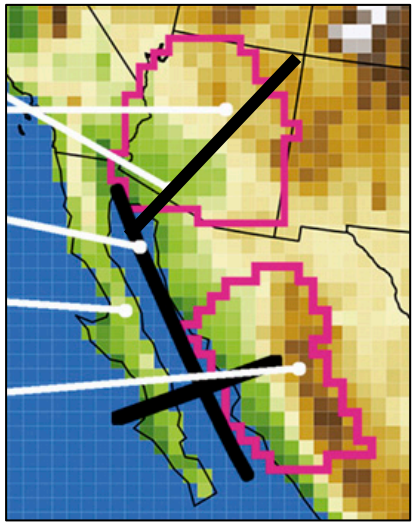


Start: July 4, 2051 12Z, 6h pr

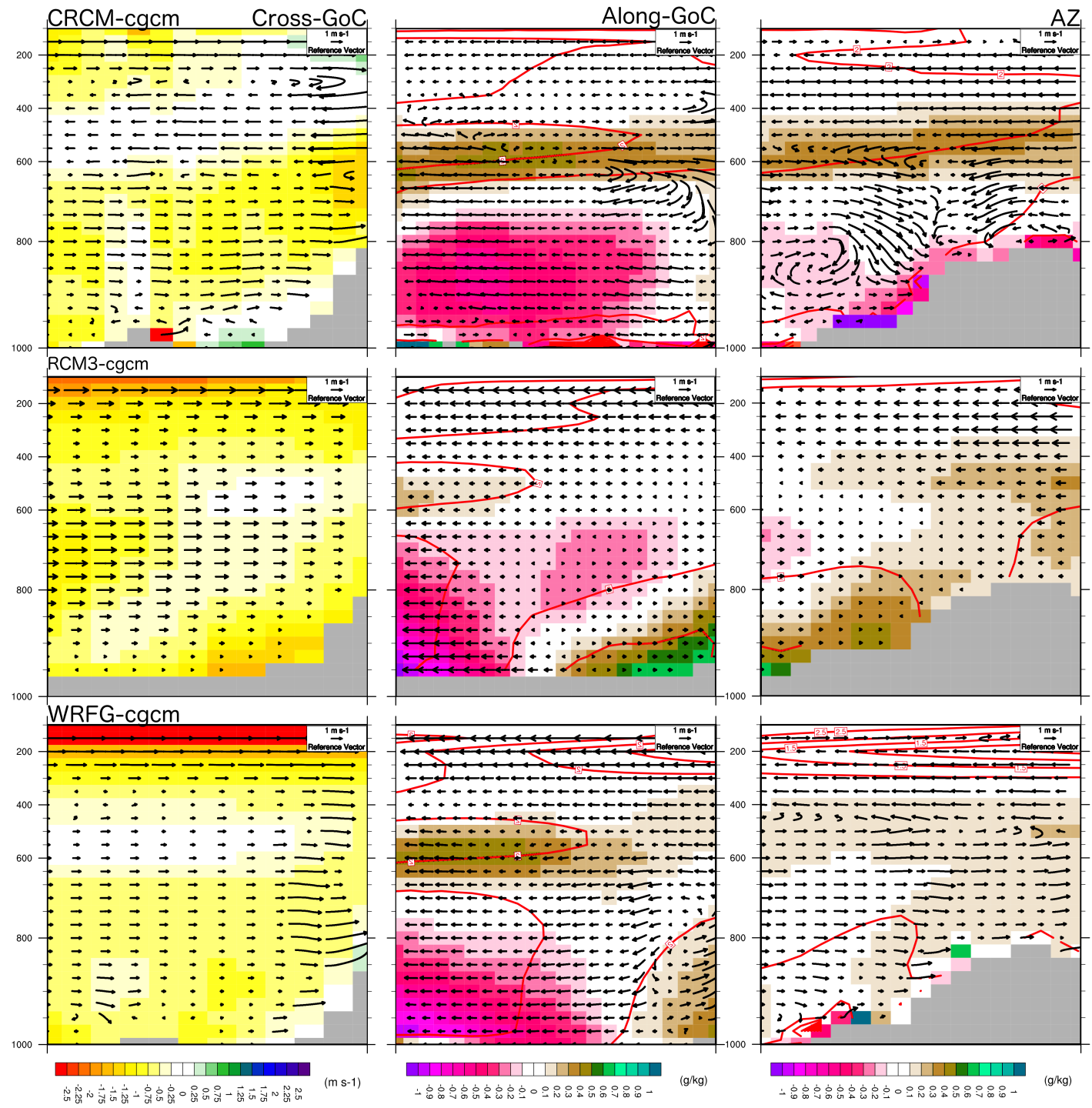


Vertical Cross-Sections

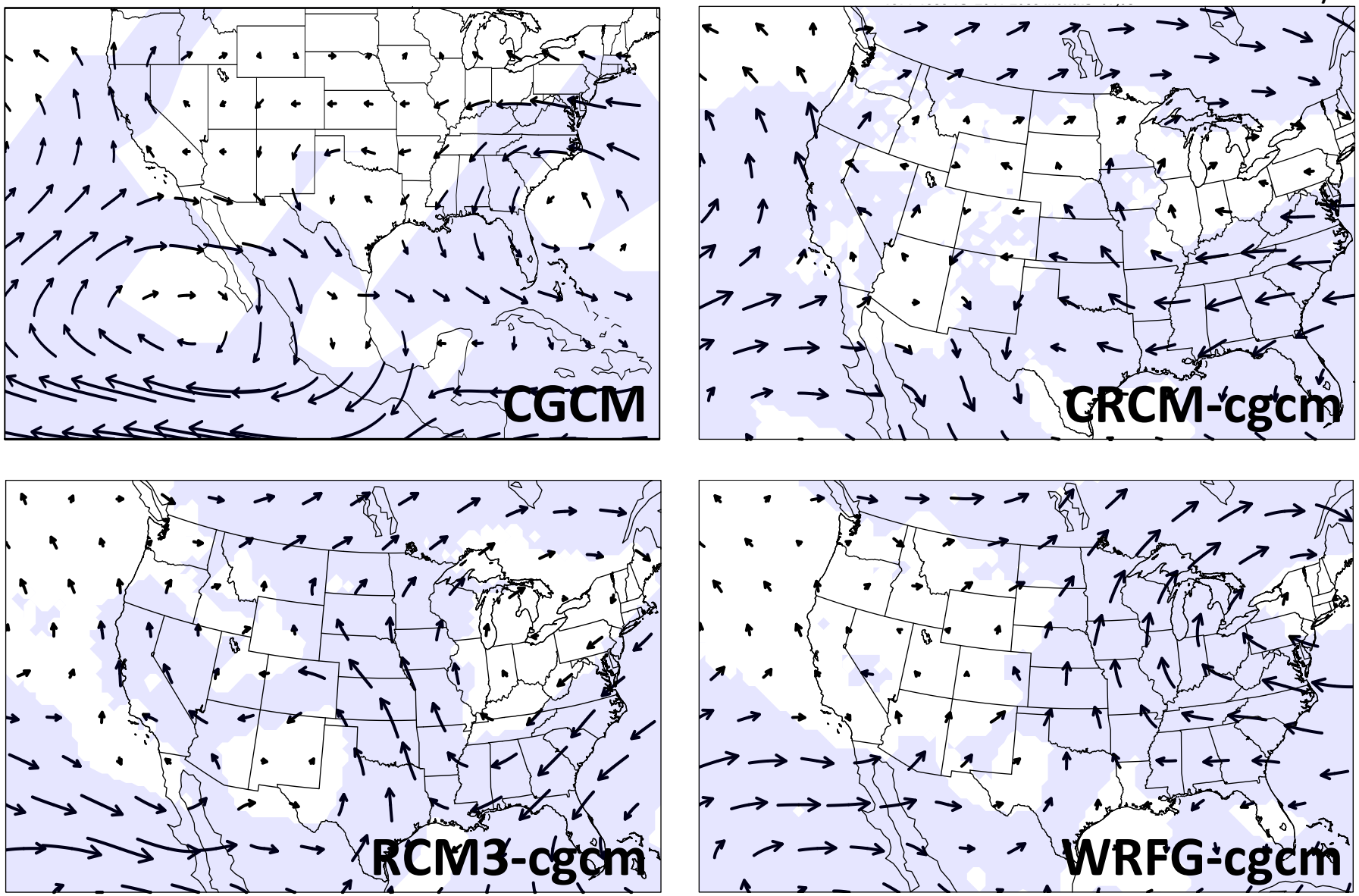
- Left: Across GoC, color = change in winds perpendicular to slice.
- Middle: Along GoC, color = change in specific humidity.
- Right: AZ, color = change in specific humidity.



***Note: No vertical wind in RCM3.**

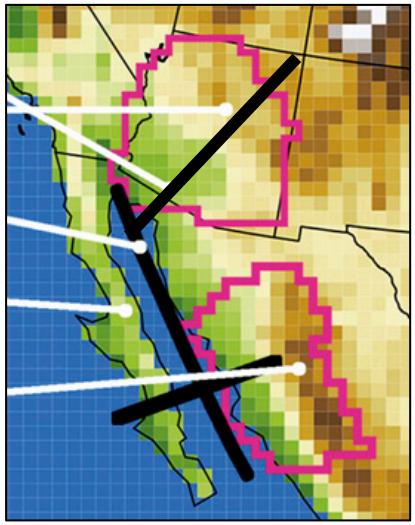


700-mb Wind Difference

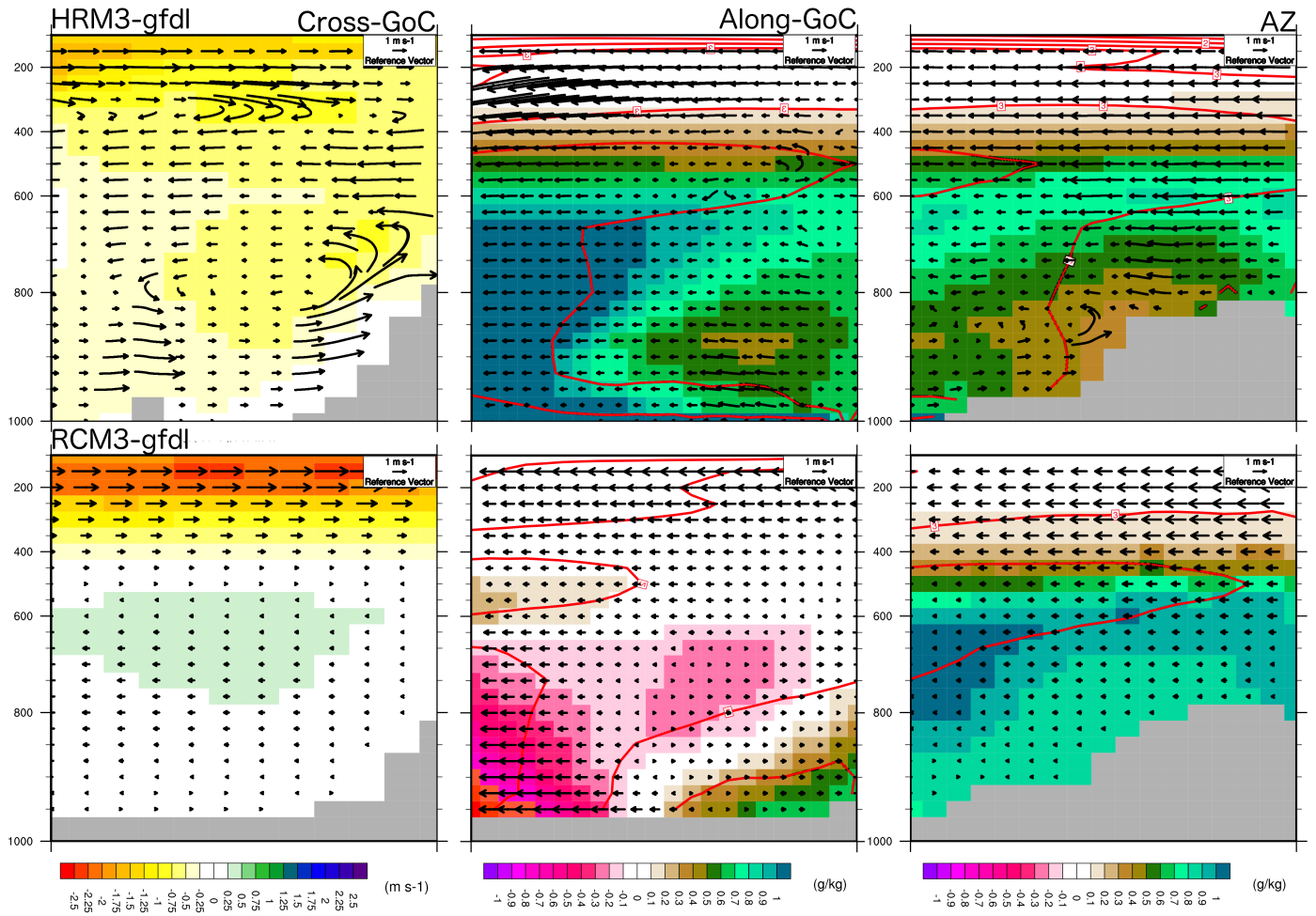


Vertical Cross-Sections

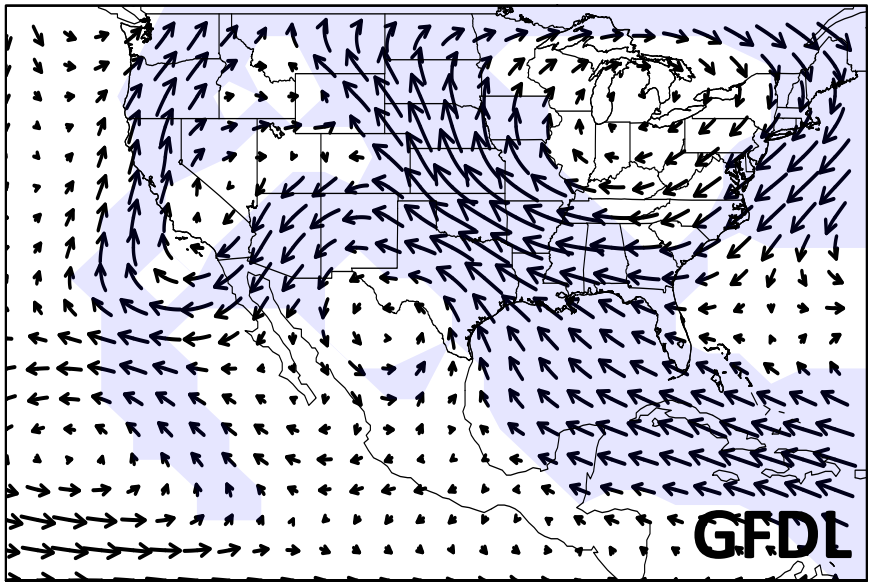
- Left: Across GoC, color = change in winds perpendicular to slice.
- Middle: Along GoC, color = change in specific humidity.
- Right: AZ, color = change in specific humidity.



***Note: No vertical wind in RCM3.**



700-mb Wind Difference



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m/s