Newly Available High Resolution Data Dynamically Downscaled for the Colorado River Basin

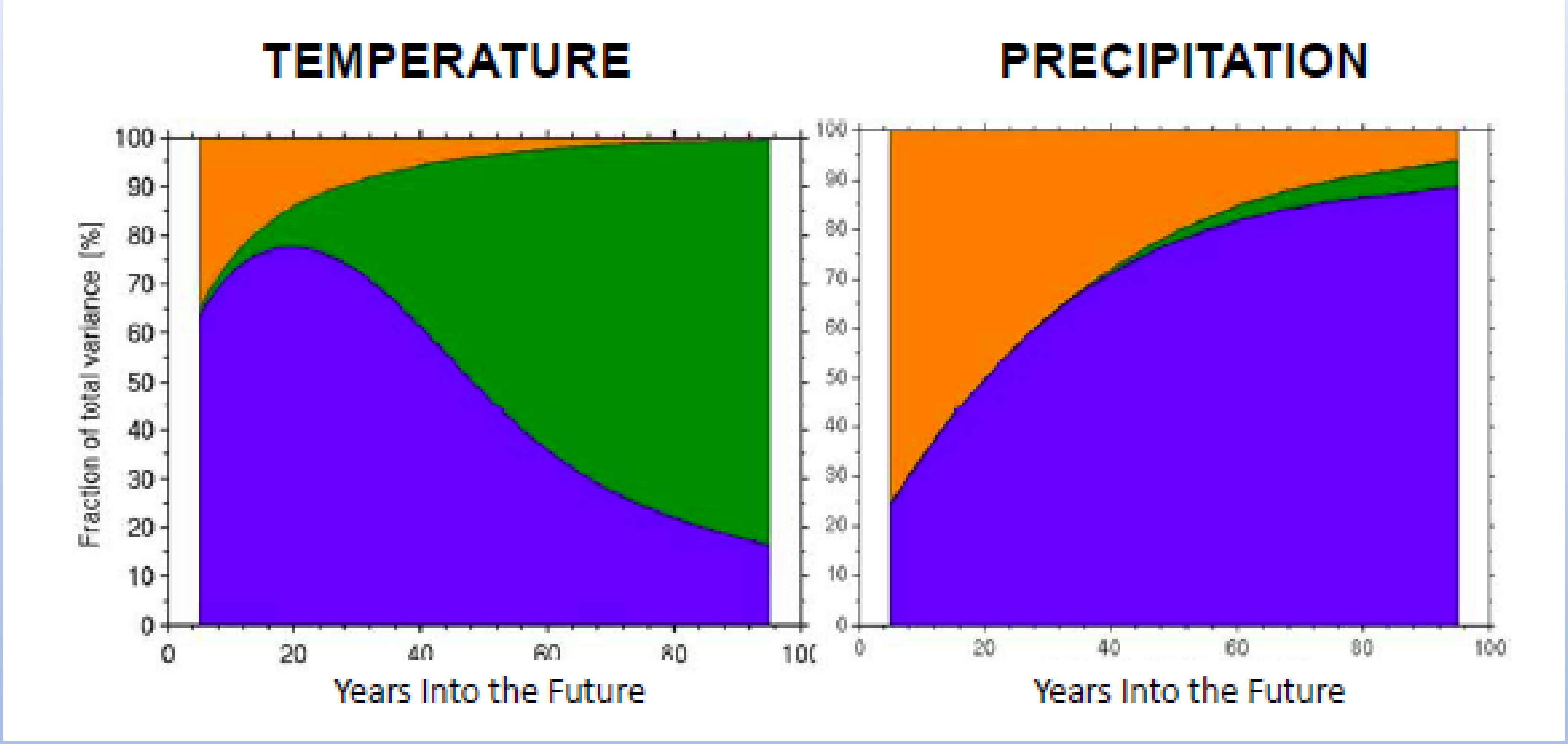
Christopher Castro

Hsin-I Chang

Department of Hydrology and Atmospheric Sciences

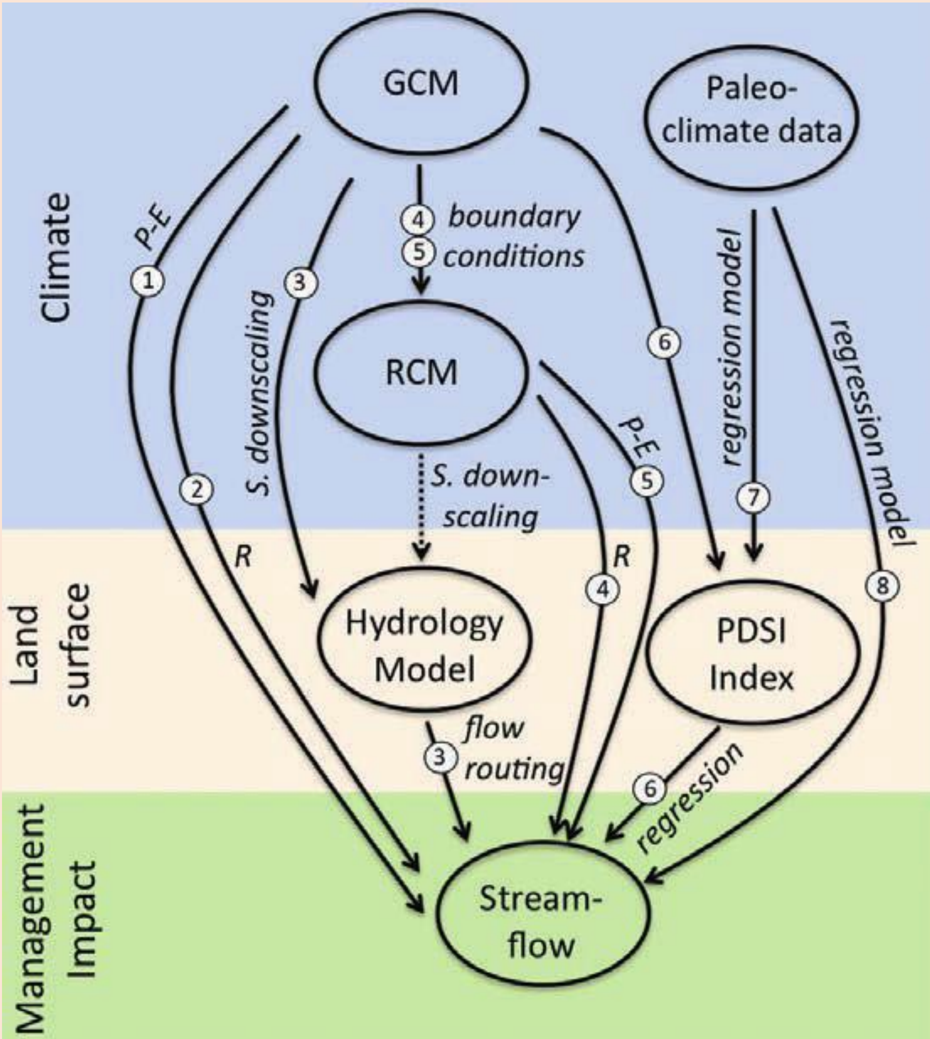
University of Arizona

Uncertainty varies over time



HUMAN SCIENTIFIC NATURAL

Understanding uncertainties in climate and streamflow projections (BAMS, 2014)



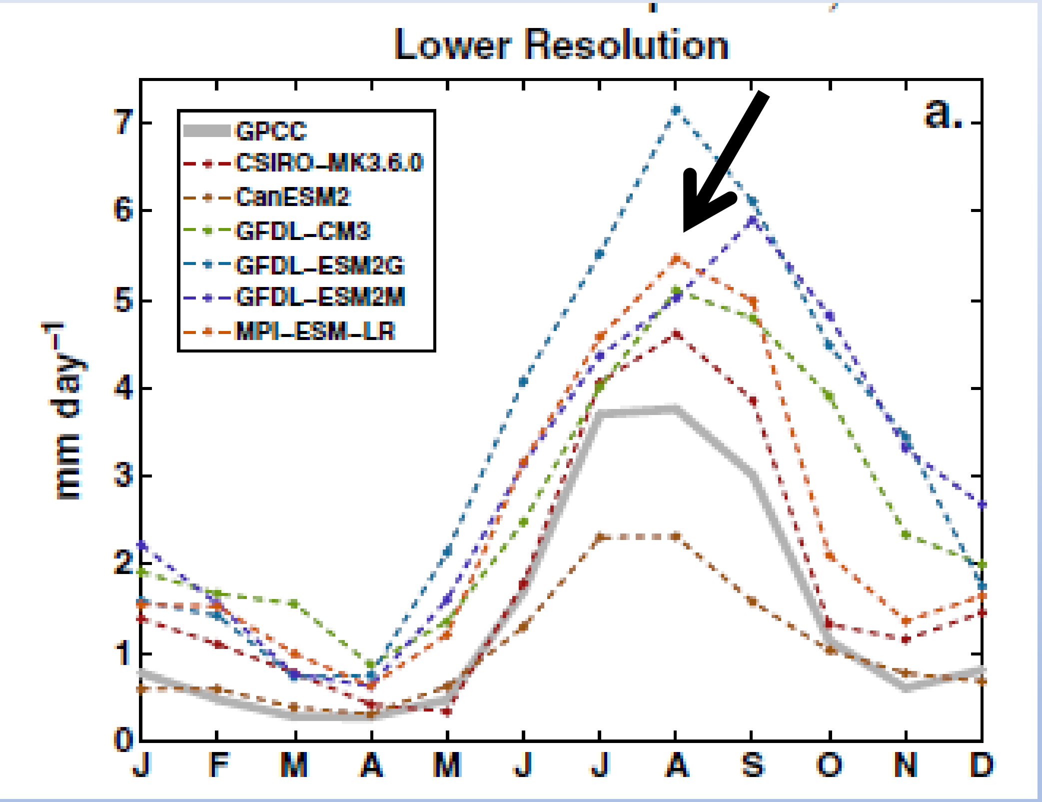
- Sources of climate projection uncertainty for Colorado River:
    1. GCM and emission scenarios used
    2. Spatial scale and topography dependency
    3. How land surface hydrology represents precipitation and temperature change
    4. Downscaling methodologies

Current global climate model (GCM) projection list

Model	Center	Atmospheric Horizontal Resolution (lon. x lat.)	Number of model levels	Reference
ACCESS1-0	Commonwealth Scientific and Industrial Research Organization/Bureau of Meteorology, Australia	1.875 x 1.25	38	Bi et al. (2012)
BCC-CSM1.1*	Beijing Climate Center, China Meteorological Administration, China	2.8 x 2.8	26	Xin et al. (2012)
CanCM4	Canadian Centre for Climate Modelling and Analysis, Canada	2.8 x 2.8	35	Chylek et al. (2011)
CanESM2*	Canadian Center for Climate Modeling and Analysis, Canada	2.8 x 2.8	35	Arora et al. (2011)
CCSM4*	National Center for Atmospheric Research, USA	1.25 x 0.94	26	Gent et al. (2011)
CESM1-CAM5-1-FV2	Community Earth System Model Contributors (NSF-DOE-NCAR)	1.4 x 1.4	26	Gent et al. (2011)
CNRM-CM5.1*	National Centre for Meteorological Research, France	1.4 x 1.4	31	Voldoire et al. (2011)
CSIRO-MK3.6*	Commonwealth Scientific and Industrial Research Organization/Queensland Climate Change Centre of Excellence, AUS	1.8 x 1.8	18	Rotstayn et al. (2010)
EC-EARTH	EC-EARTH consortium	1.125 x 1.12	62	Hazeleger et al. (2010)
FGOALS-S2.0	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	2.8 x 1.6	26	Bao et al. (2012)
GFDL-CM3*	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 x 2.0	48	Donner et al. (2011)
GFDL-ESM2G/M*	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 x 2.0	48	Donner et al. (2011)
GISS-E2-H/R*	NASA Goddard Institute for Space Studies, USA	2.5 x 2.0	40	Kim et al. (2012)
HadCM3*	Met Office Hadley Centre, UK	3.75 x 2.5	19	Collins et al. (2001)
HADGEM2-CC (Chemistry coupled)	Met Office Hadley Centre, UK	1.875 x 1.25	60	Jones et al. (2011)
HadGEM2-ES*	Met Office Hadley Centre, UK	1.875 x 1.25	60	Jones et al. (2011)
INMCM4*	Institute for Numerical Mathematics, Russia	2 x 1.5	21	Volodin et al. (2010)
IPSL-CM5A-LR*	Institut Pierre Simon Laplace, France	3.75 x 1.8	39	Dufresne et al. (2012)
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	2.5 x 1.25	39	Dufresne et al. (2012)
MIROC4h	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	0.56 x 0.56	56	Sakamoto et al. (2012)
MIROC5*	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	1.4 x 1.4	40	Watanabe et al. (2010)
MIROC-ESM*	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8 x 2.8	80	Watanabe et al. (2010)
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8 x 2.8	80	Watanabe et al. (2010)
MPI-ESM-LR*	Max Planck Institute for Meteorology, Germany	1.9 x 1.9	47	Zanchettin et al. (2012)
MRI-CGCM3*	Meteorological Research Institute, Japan	1.1 x 1.1	48	Yukimoto et al. (2011)
NorESM1-M*	Norwegian Climate Center, Norway	2.5 x 1.9	26	Zhang et al. (2012)

Not all GCM tells the same story

Southwest/Mexico precipitation (1980-1999)

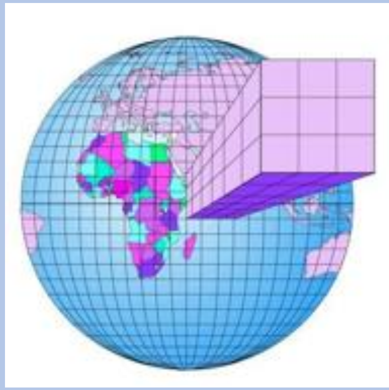


We selected GCMs that has good historic climate results for the Southwest and Mexico

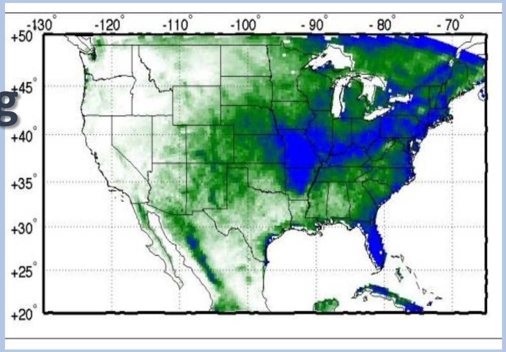
Cook and Seager (2013, *J. Geophys. Res.*)

Multi-model schematic:

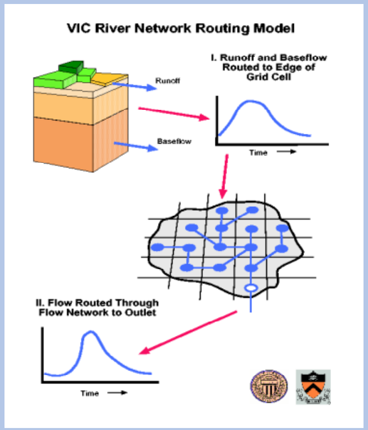
Translating IPCC climate signals to basin-scale hydroclimate projections



Dynamical downscaling



Bias correction



Global IPCC climate projections (1-2°)

Regional climate simulations (25-35 km)

Basin-scale simulations (12.5km resolution)

Statistical Downscaling


REPORT TYPE (ALL CAPS)

USE OF CLIMATE INFORMATION FOR DECISION-MAKING AND IMPACTS RESEARCH: STATE OF OUR UNDERSTANDING

SERDP Project RC-2242

MARCH 2016

Rao Kotamarthi
Environmental Science Division, Argonne National Laboratory, Argonne, IL

Linda Mearns
Regional Integrated Science Collective, National Center for Atmospheric Research, Boulder, CO

Katharine Hayhoe
Climate Science Center, Texas Tech University, Lubbock, TX

Christopher L. Castro
Department of Hydrology and Atmospheric Science, University of Arizona, Tucson, AZ

Donald Wuebbles
Department of Atmospheric Sciences, University of Illinois, Urbana, IL

Citation: Kotamarthi, R., L. Mearns, K. Hayhoe, C.L. Castro, and D. Wuebbles, 2016, Use of Climate Information for Decision-Making and Impacts Research: State of Our Understanding, prepared for the prepared for the Department of Defense, Strategic Environmental Research and Development Program, March

SERDP DOD • EPA • DOE

One of the most debated tables by the authors in writing of the DOD report…

TABLE 4 Recommendation Table on the Use of Climate Datasets based on Regional Features[a]

Scale		Statistical Downscaling Methods					Dynamic Downscaling		GCM
	Delta Correction	Empirical Quantile Mapping	Bias correction	Parametric Quantile Mapping	Constructed Analogues	Wx generator	NARCCAP, CORDEX	Convective-permitting	CMIP5
Global scale: ~3,000 km or more, weeks to months (general circulation structure, jet stream position)	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
Synoptic scale: 100–3,000 km, days to weeks (highs and lows, midlatitude cyclones, monsoons, atmospheric teleconnections)	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
Course mesoscale-α, β: 10–100 km, hours to days (katabatic winds, weather fronts, mesoscale convective systems, tropical cyclones, sea breeze circulations)	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
Fine mesoscale-γ: 1–10 km, hours to minutes (supercell thunderstorms, tornadoes, gust fronts, air mass thunderstorms, mountain-valley winds, mountain snowfall)	[red]	[red]	[red]	[red]	[red]	[red]	[yellow]	[green]	[red]

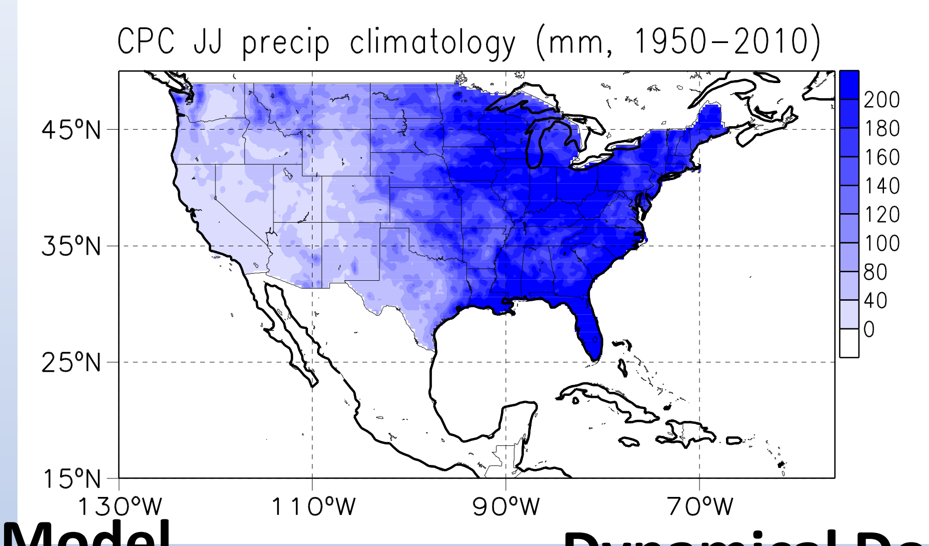
Green: good
Yellow: maybe
Red: bad

Spatial and temporal resolution suited for basin-scale hydroclimate studies

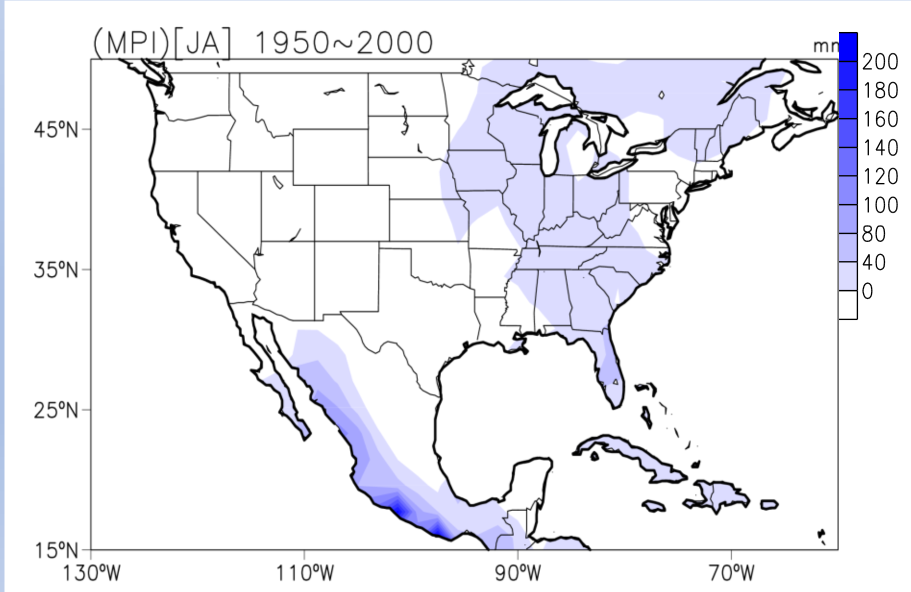
Regional Climate Modeling with Dynamical Downscaling

From Global scale to Regional Scale:
Monsoon vs. No Monsoon for the Southwest

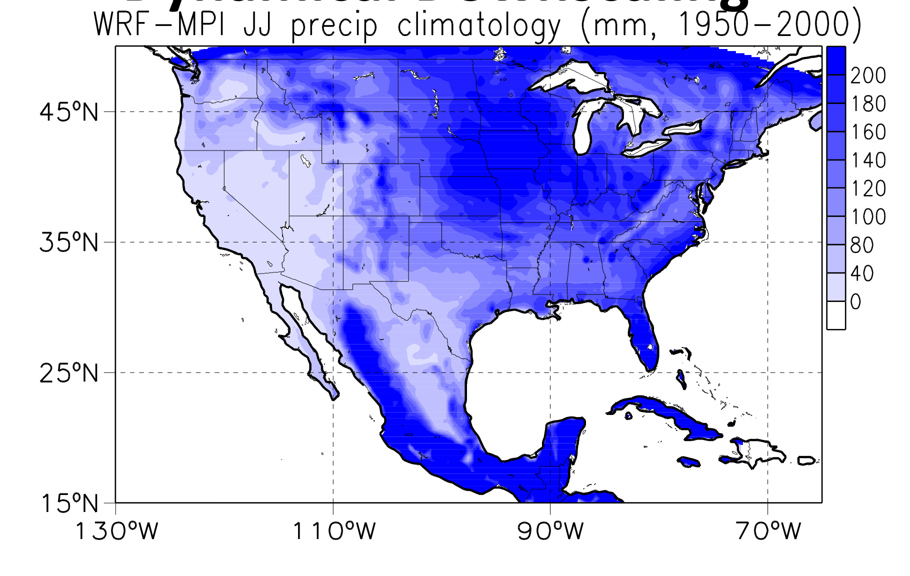
Observation



Global Climate Model

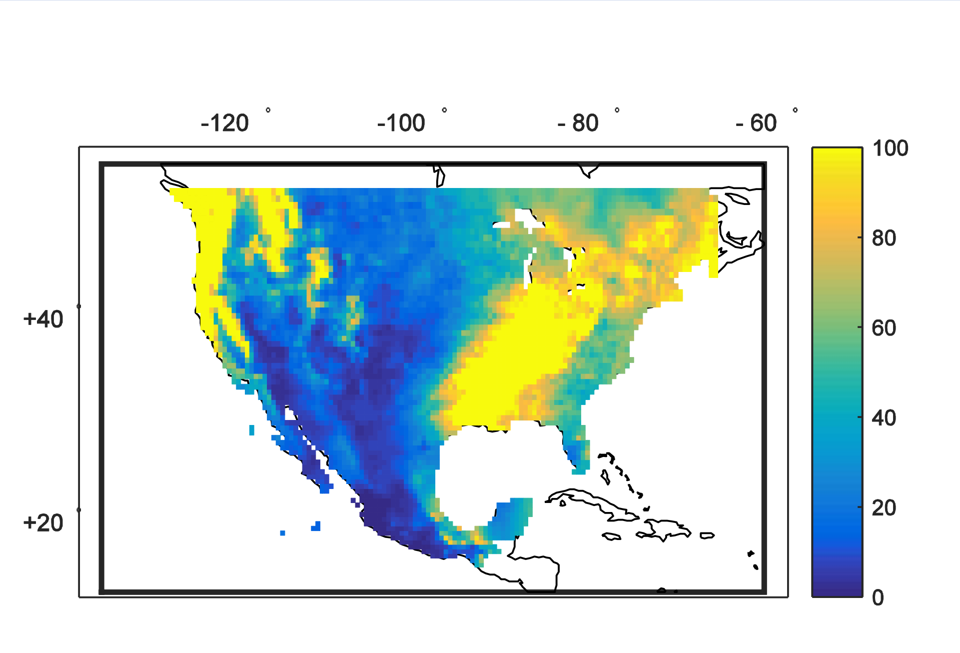


Dynamical Downscaling

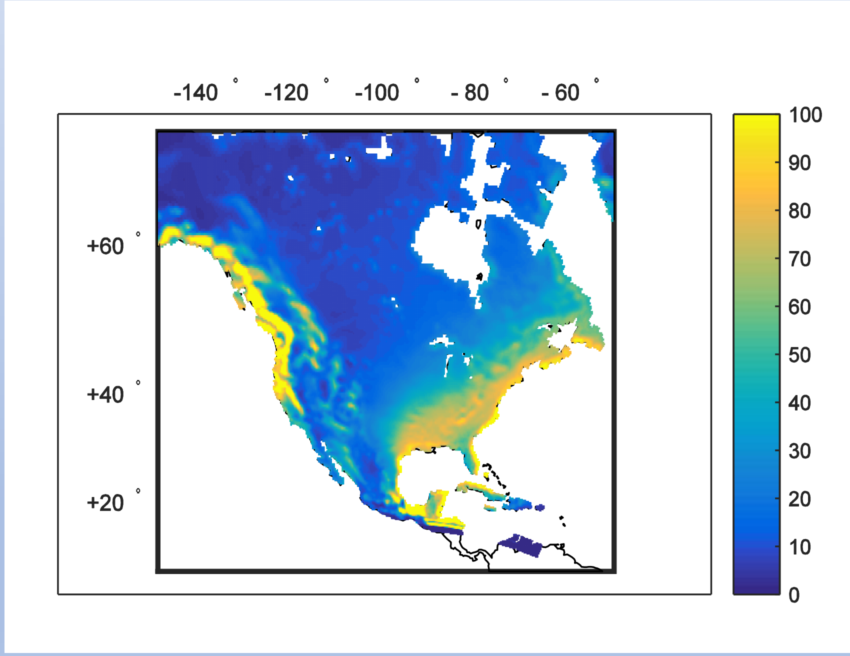


Performance of Regional Climate Model:
60-year Winter Precipitation

Observation

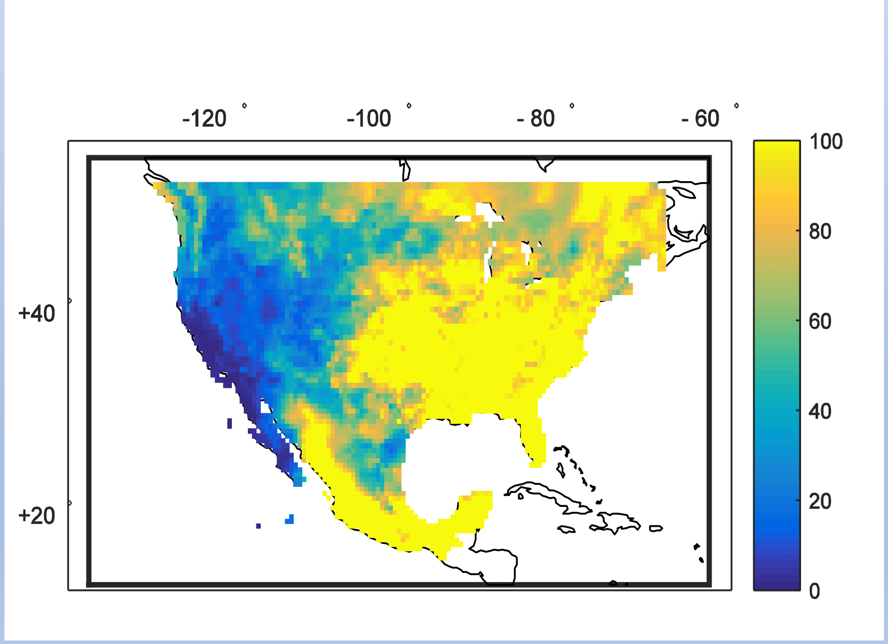


Dynamical Downscaling

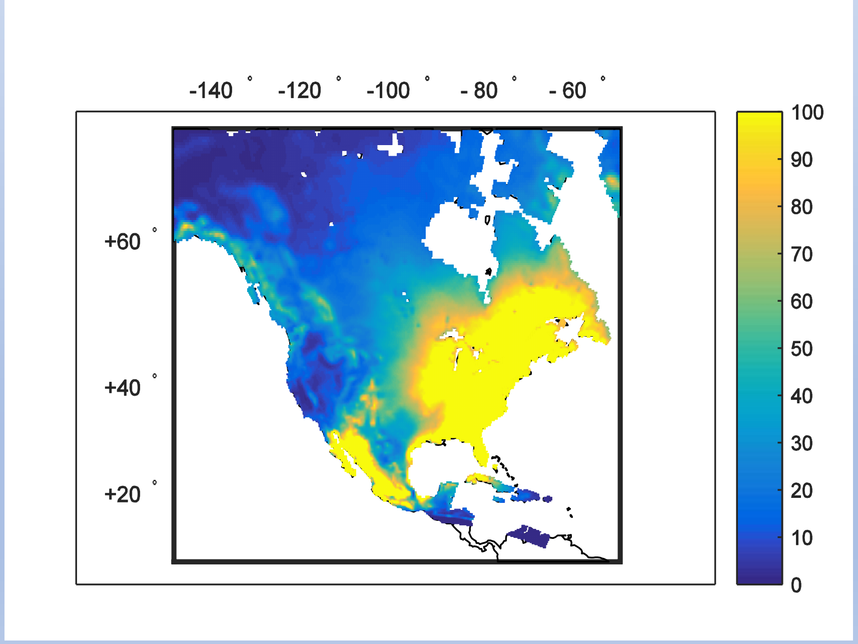


Performance of Regional Climate Modeling:
60-year Summer Precipitation

Observation



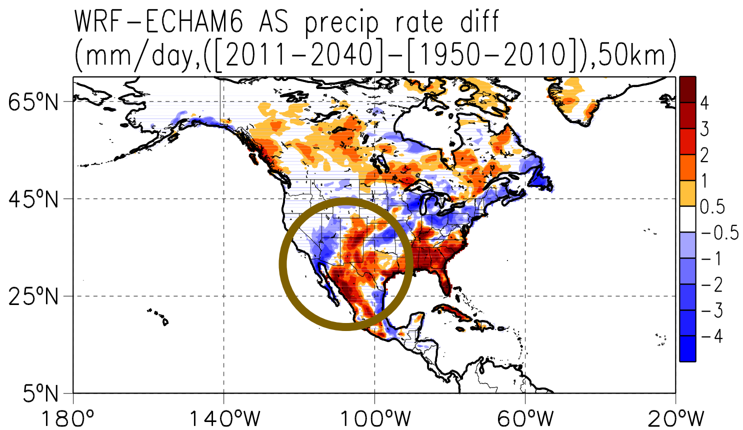
Dynamical Downscaling



Mean and extreme precipitation difference:

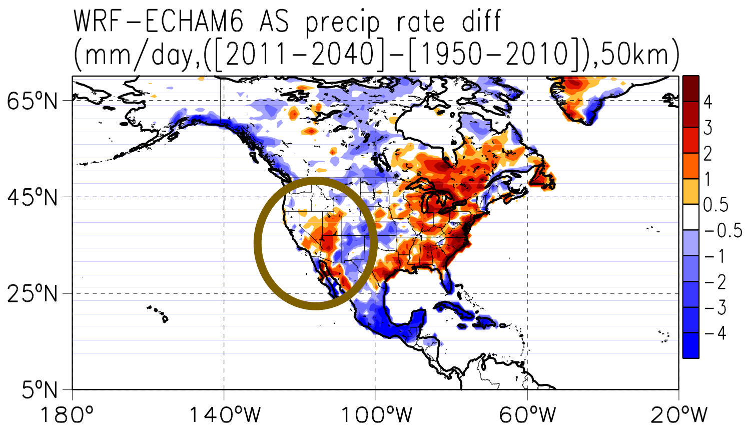
Trend of future extreme precipitation does not follow the mean precipitation ([2011-2040]-[1950-2010]).

Mean Precipitation Difference



Monsoon season:
Mean precipitation decreasing in Southwest, increasing in Mexico

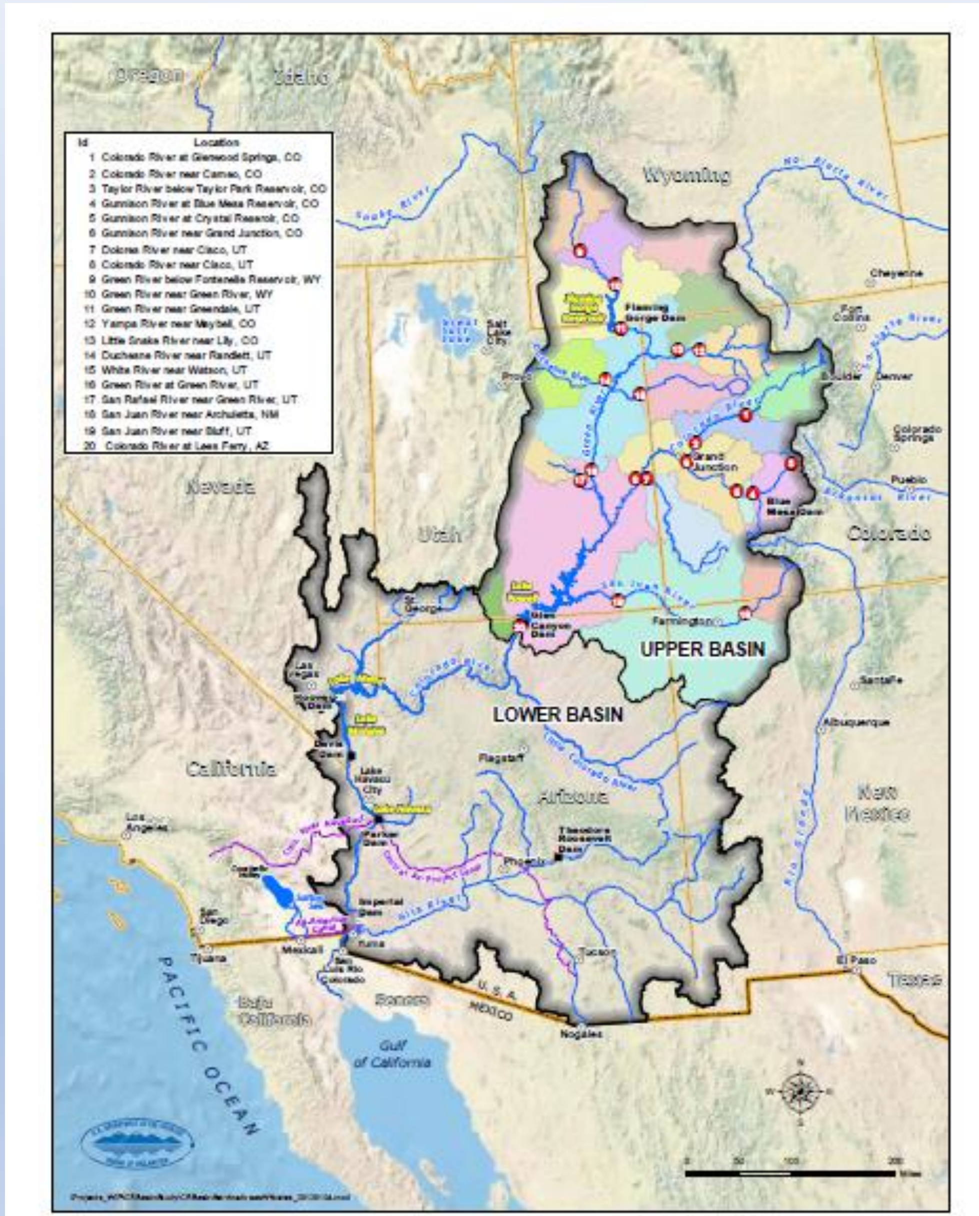
Extreme Precipitation Difference



Monsoon season:
More intense rainfall in Southwest, opposite in Mexico

Downscaled Regional Climate to Streamflow Projections over Colorado River Basins

Study Region: Upper and Lower Colorado River Basins



Harding et al. (HESSD, 2012)

Current operational streamflow projection products:
Upper Colorado River basin at Lees Ferry gauge
Full 112-Member BCSD CMIP3 Ensemble Projection

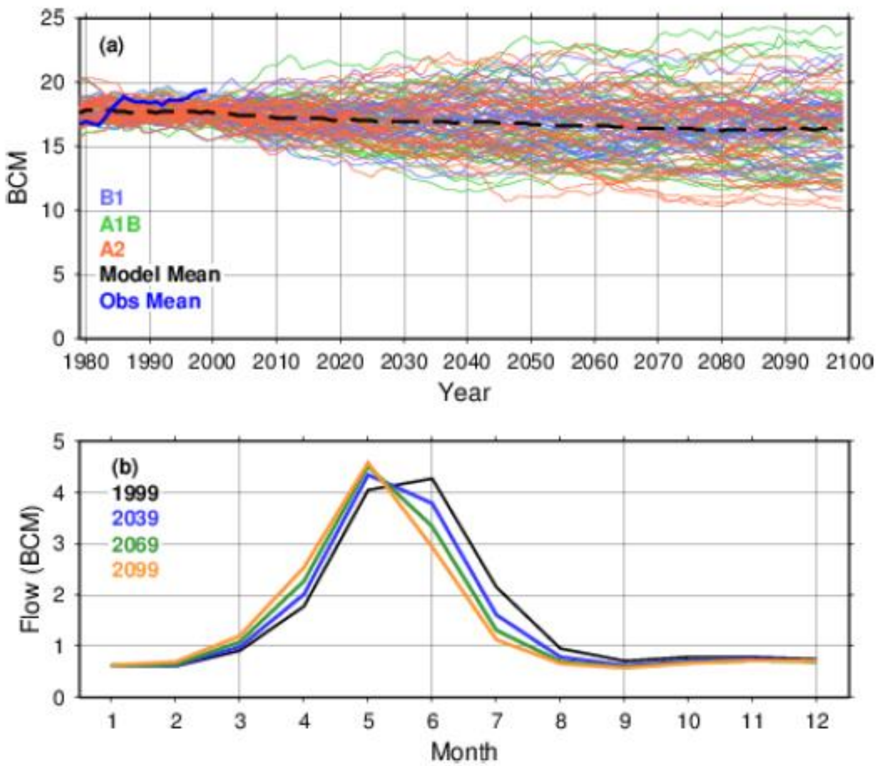


Fig. 6. (a) Simulated 30-yr average streamflows of the Colorado River at Lees Ferry AZ, 1979 through 2099. **(b)** The mean monthly average streamflows for the three future projection periods, compared with the historical 30-yr period flow ending in 1999.

<u>Assumptions</u>

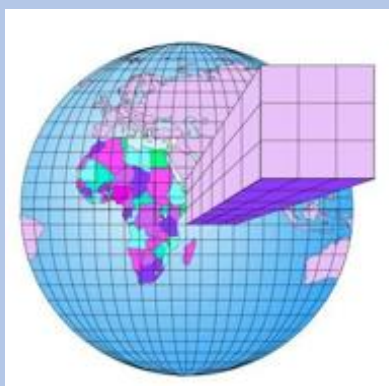
Greater reduction in uncertainty with more ensemble members, or the "bigger cloud"

Mean of the multi-model ensemble is our most confident metric because of cancellation of model error

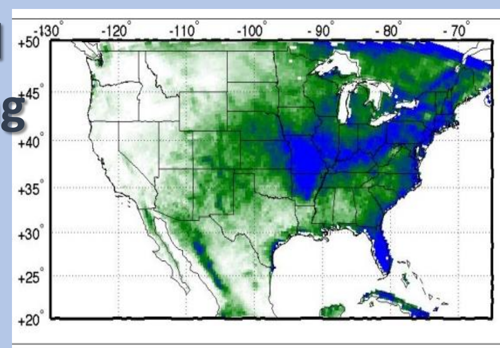
But what should Bureau of Reclamation do if dynamical downscaling would yield a different result than BCSD, but with far fewer members??

Harding et al. (2012, HESSD)

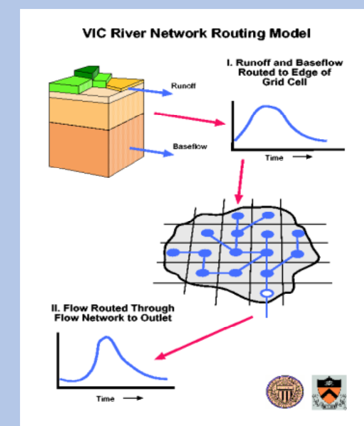
Multi-model schematic:
Translating IPCC climate signals to basin-scale hydroclimate projections



Dynamical downscaling



Bias correction



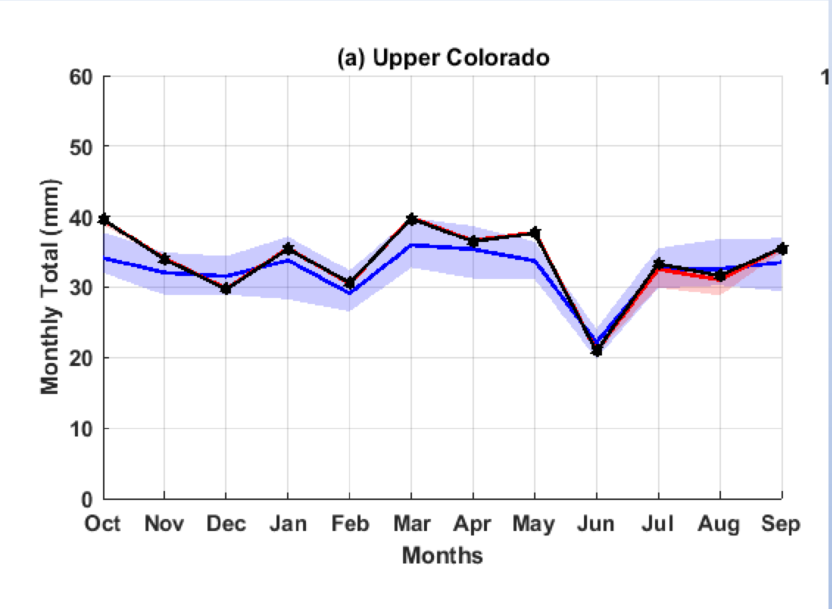
Global IPCC climate projections (1-2°)

Regional climate simulations (25-35 km)

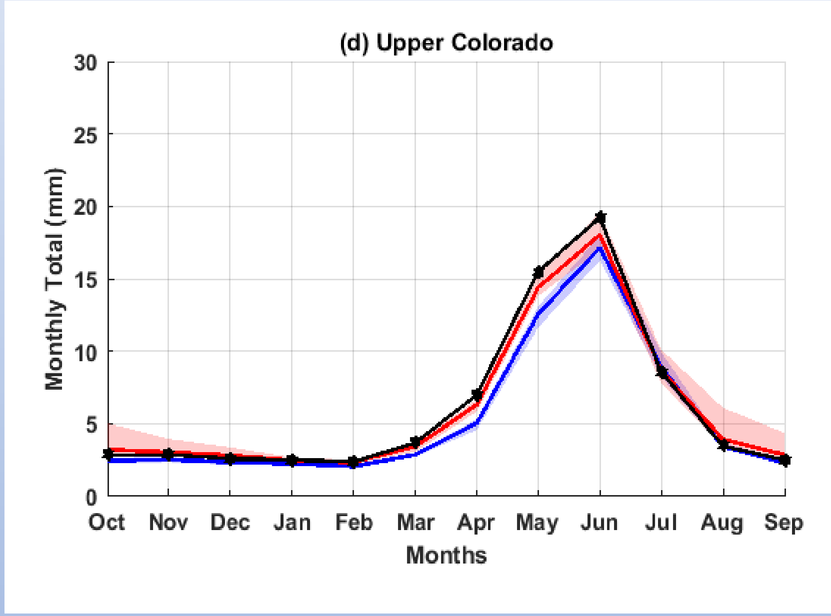
Basin-scale simulations (12.5km resolution)

Monthly precipitation and streamflow at Upper Colorado Basin (Lees Ferry): 1971-2000

Precipitation

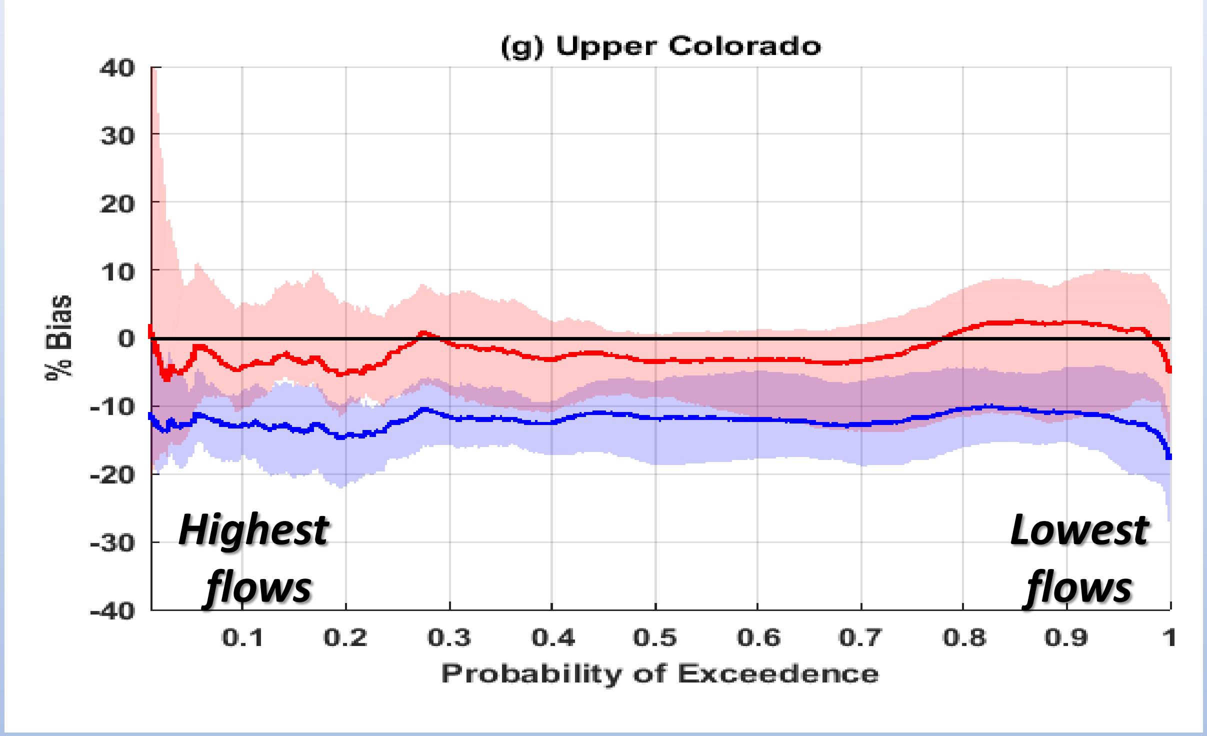


Streamflow



Blue: Statistical Downscaling
Red: Dynamical Downscaling
Black: Observation

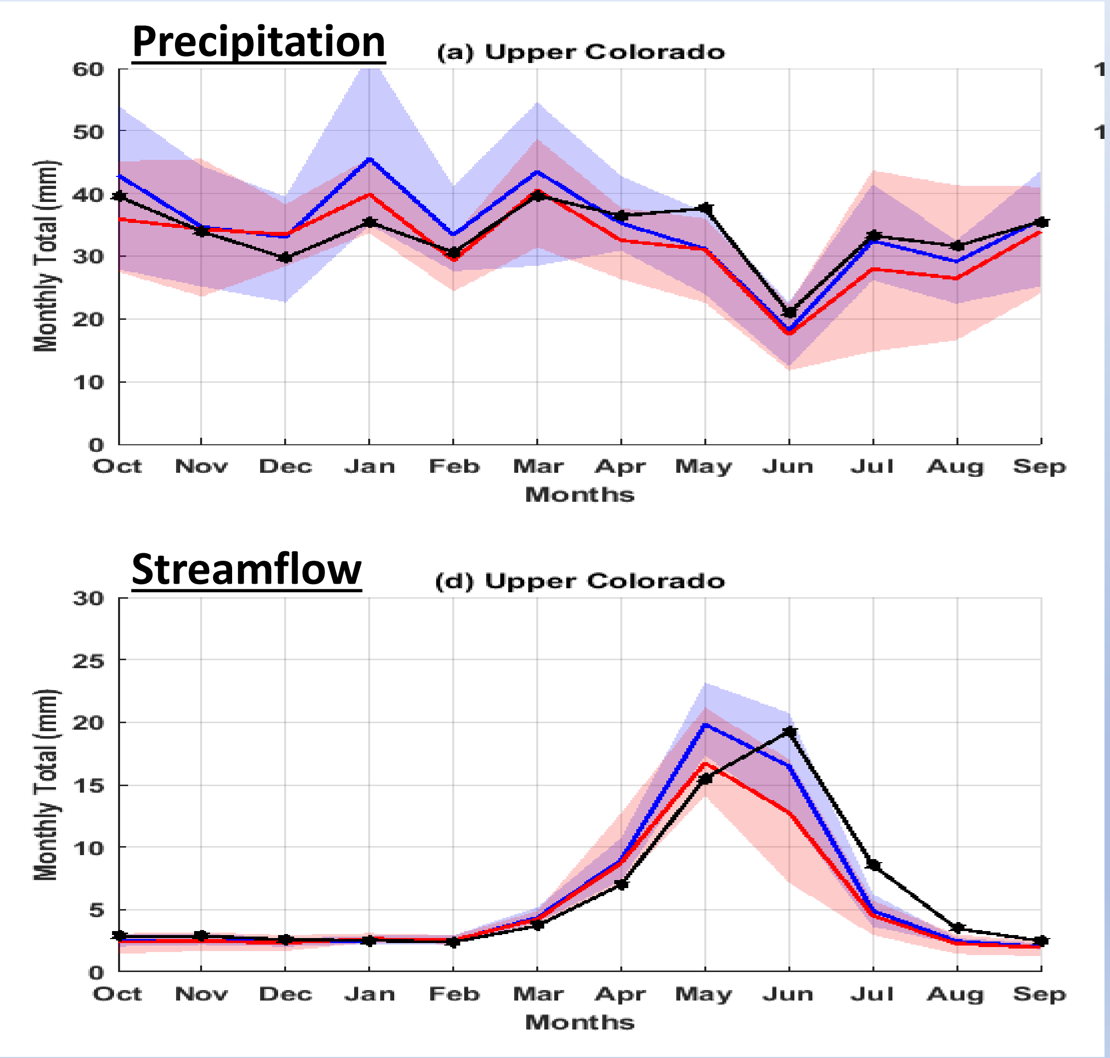
Upper Colorado Streamflow Bias at Lees Ferry: 1971-2000



Blue: Statistical Downscaling
Red: Dynamical Downscaling
Black: Observation

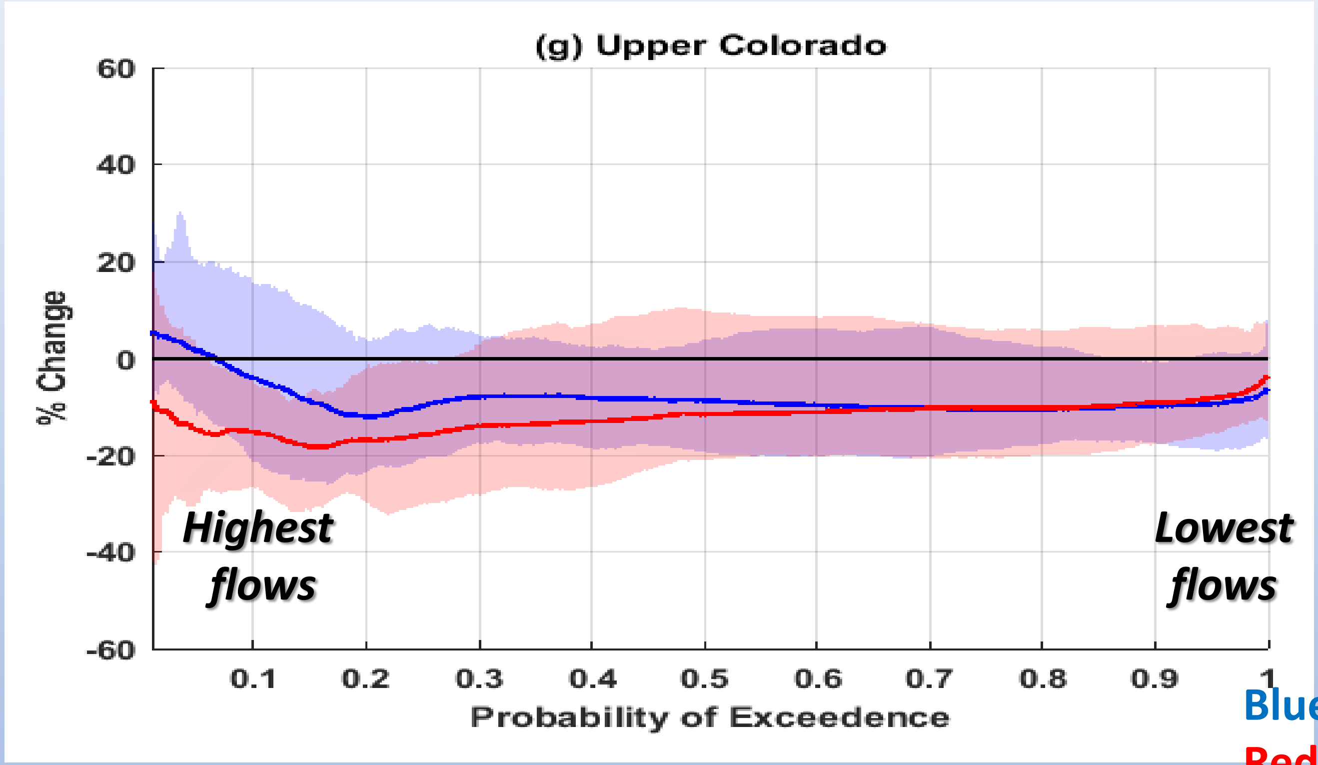
Dynamical downscaling leads to reduced bias in representation of historical streamflow, generally independent of high and low flows. The regional modeling component is main reason why, not choice of bias correction technique.

Upper Colorado River Monthly Precipitation and Streamflow: (2041-2070) minus (1971-2000)



Blue: Statistical Downscaling
Red: Dynamical Downscaling
Black: Observation

Upper Colorado River Streamflow Percentage Change: (2041-2070) minus (1971-2000)

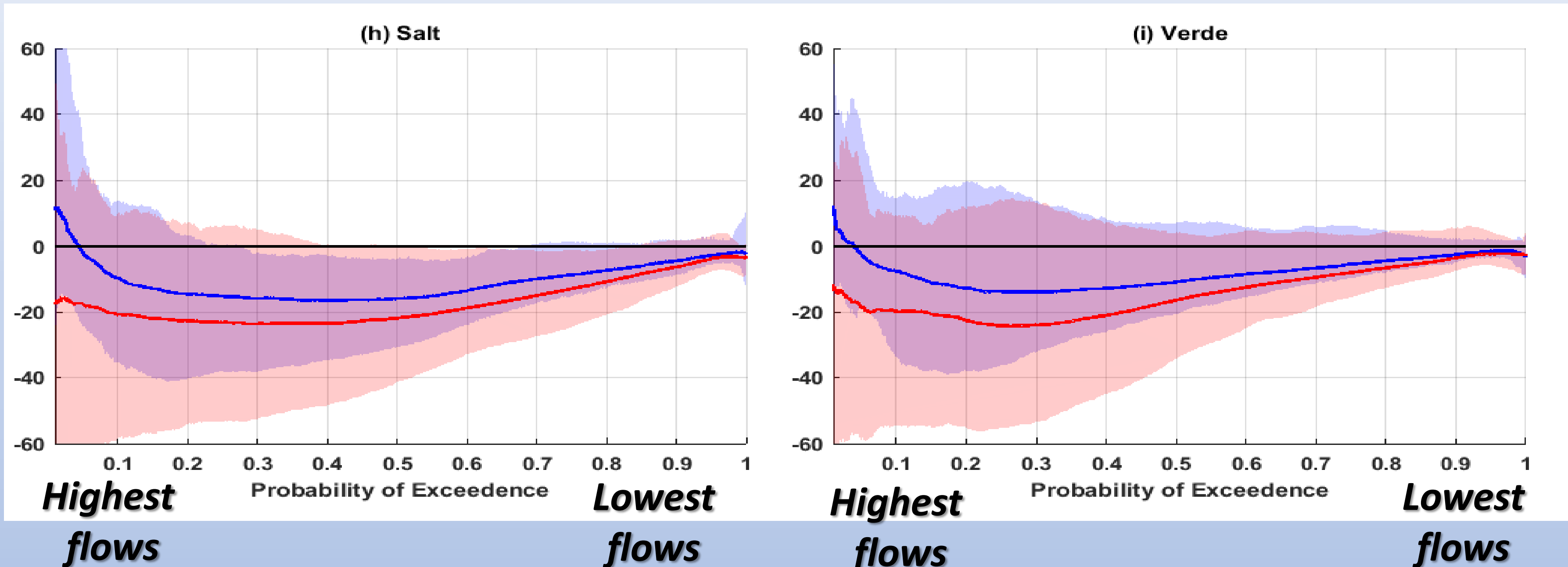


Blue: Statistical Downscaling
Red: Dynamical Downscaling
Black: Observation

Greatest difference between a statistically vs. dynamically downscaled stream flow projection occurs for highest flows.

On order of 10-20% lower streamflow during peak flows with dynamical downscaling!

Salt and Verde Basin Streamflow Percentage Change: (2041-2070) minus (1971-2000)



The potential decreases on the smaller rivers that are the lifeblood of the SRP system may be even more dramatic than for the Upper Basin!

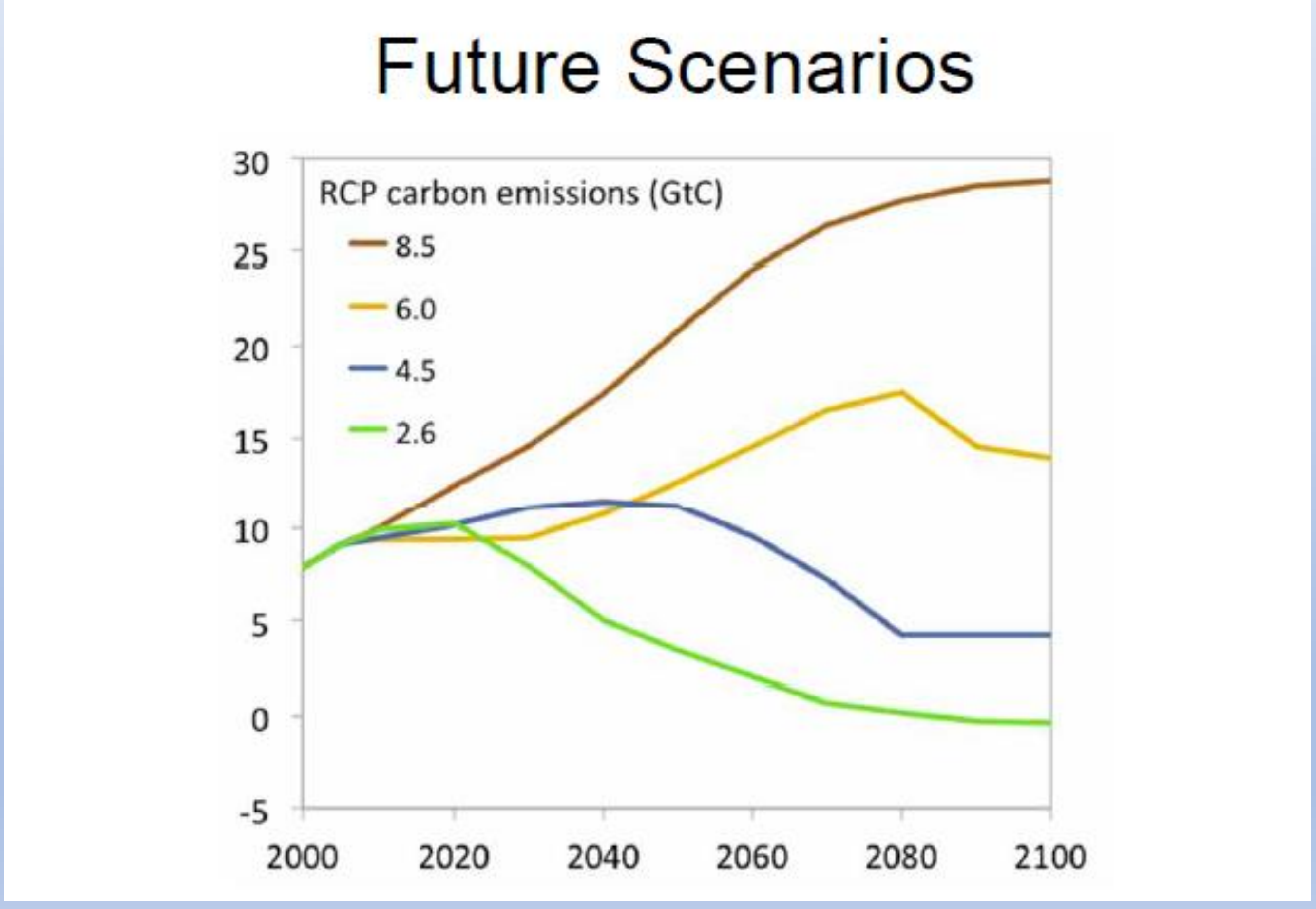
Blue: Statistical Downscaling
Red: Dynamical Downscaling
Black: Observation

Summary for Upper Colorado Basin Streamflow

- Dynamically downscaled streamflow has comparatively less bias in the historical period.
- Both statistical and dynamical downscaling show a shift of the hydrograph to an earlier period of peak flow.
- Dynamical downscaling projects lower peak streamflow than statistical downscaling, on the order of 10-20% additional decline in the mid 21st century.
- The range of simulated streamflow with dynamical downscaling is outside the range of statistical downscaling ensembles with BCSD challenging the paradigm of the cloud of points.

Supplemental slides

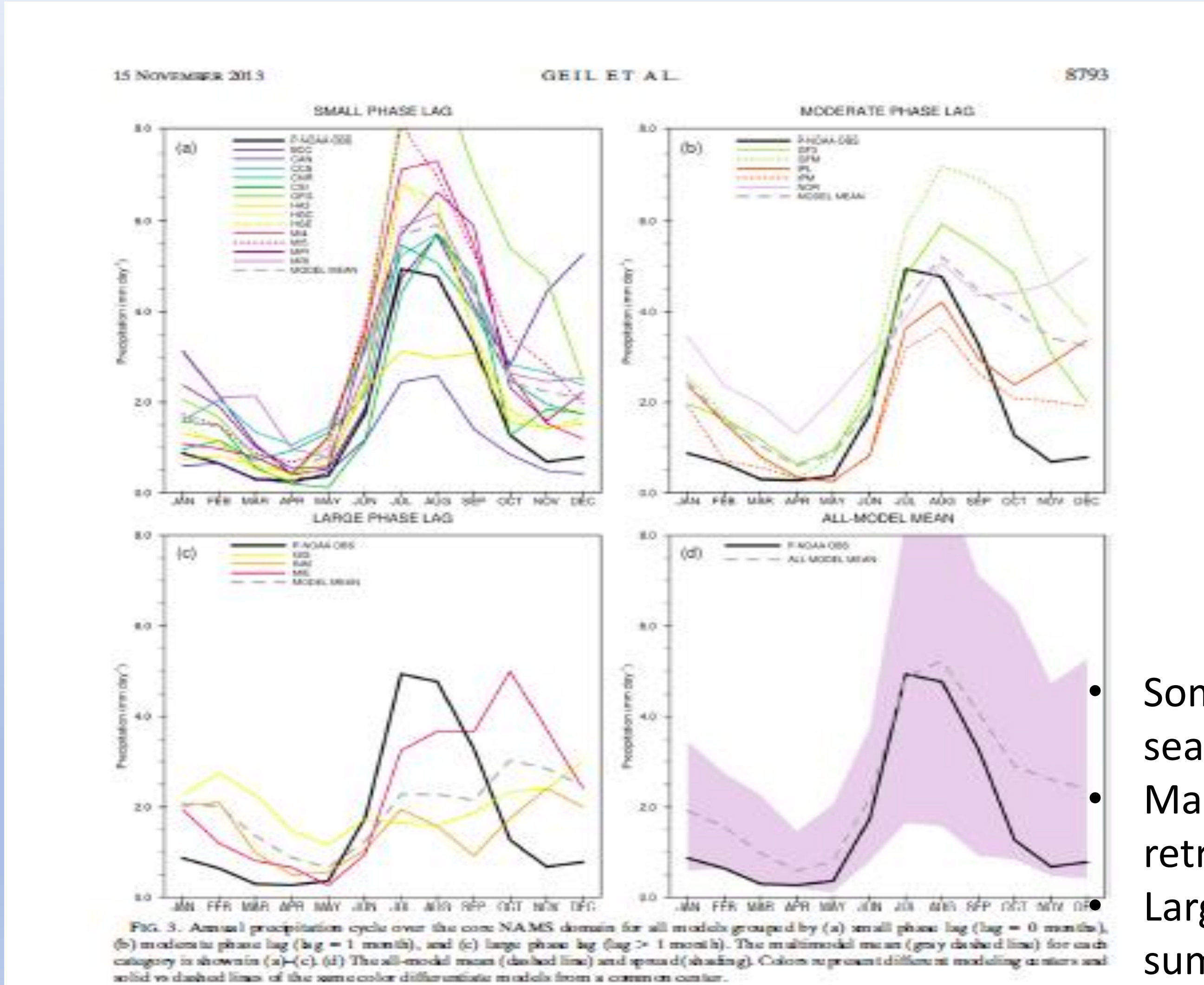
Climate projection products under different greenhouse gas emission scenarios:



Why are projections uncertain?

- **HUMAN** — We don't know what future emissions from human activities will be
- **SCIENTIFIC** — We don't know how sensitive the planet is, and our ability to simulate the climate system is limited and incomplete, particularly at the local to regional scale
- **NATURAL** — Continuous natural variations in climate make it difficult to predict conditions over shorter time scales

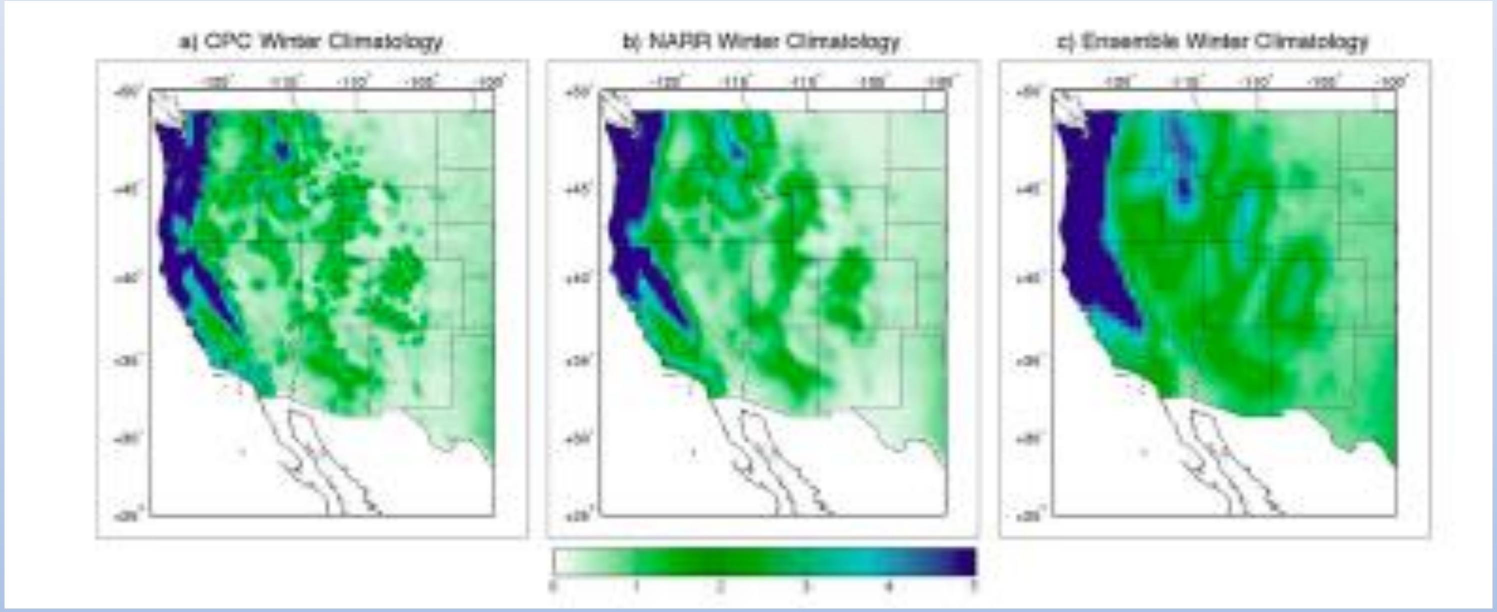
Improved North American monsoon precipitation in CMIP5 models: SW only



- Some has lagged peak monsoon season
- Many don’t capture the monsoon retreat
- Large spread in model results from summer to early fall

Geil et al (2013, *J. Climate*)

NARCCAP (CMIP3) Winter precipitation (1979-1999):



Observation **NARR** **Multi-Model Ensemble Mean**

Dominguez et al. (2012, *JGR*)

Snowfall performance

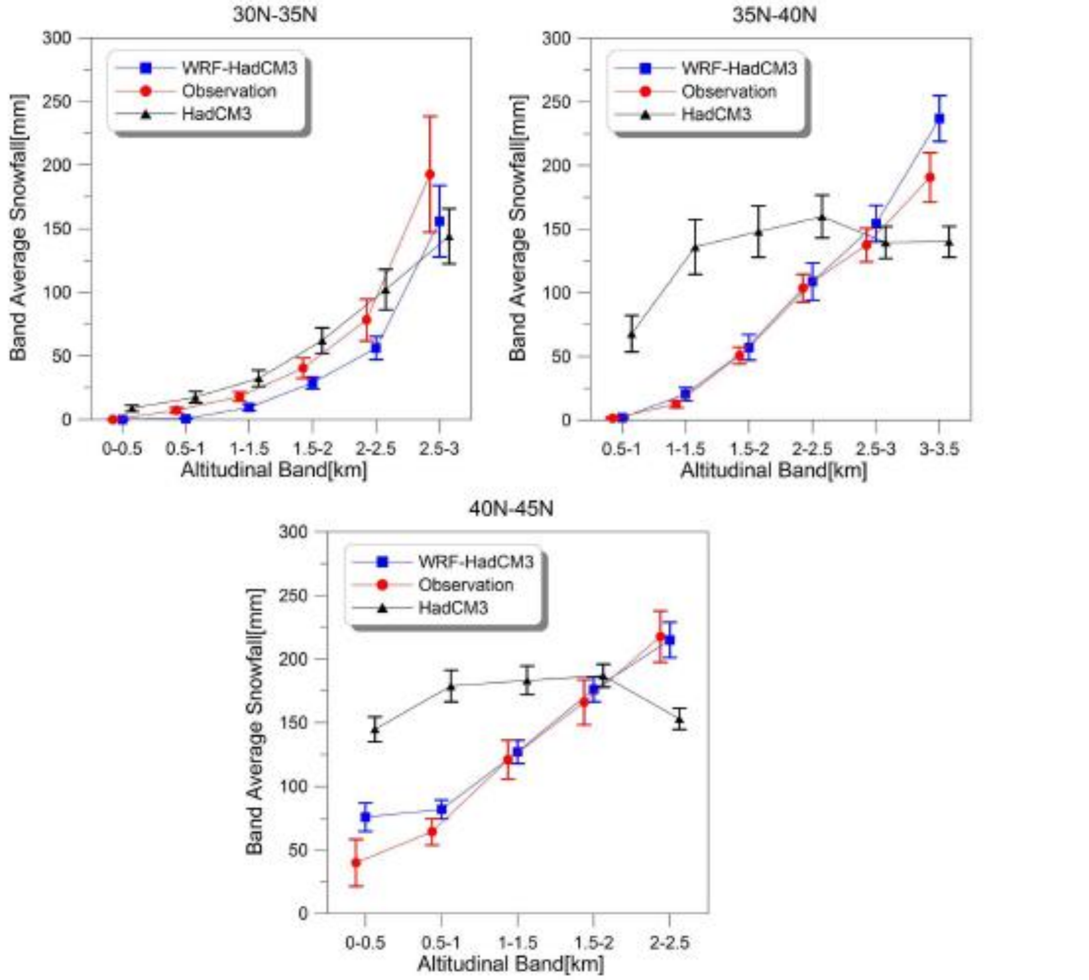


Figure 4. Comparison of model-derived snowfall for the period 1981–2005 winter (December–March) to observed snowfall for three different latitudinal bands and seven altitudinal bands. Each period is averaged in space, and shows total snowfall for the winter (December–March) season.

Wi et al.. 2012

NARCCAP (CMIP3) July/Aug Precipitation for Southwest

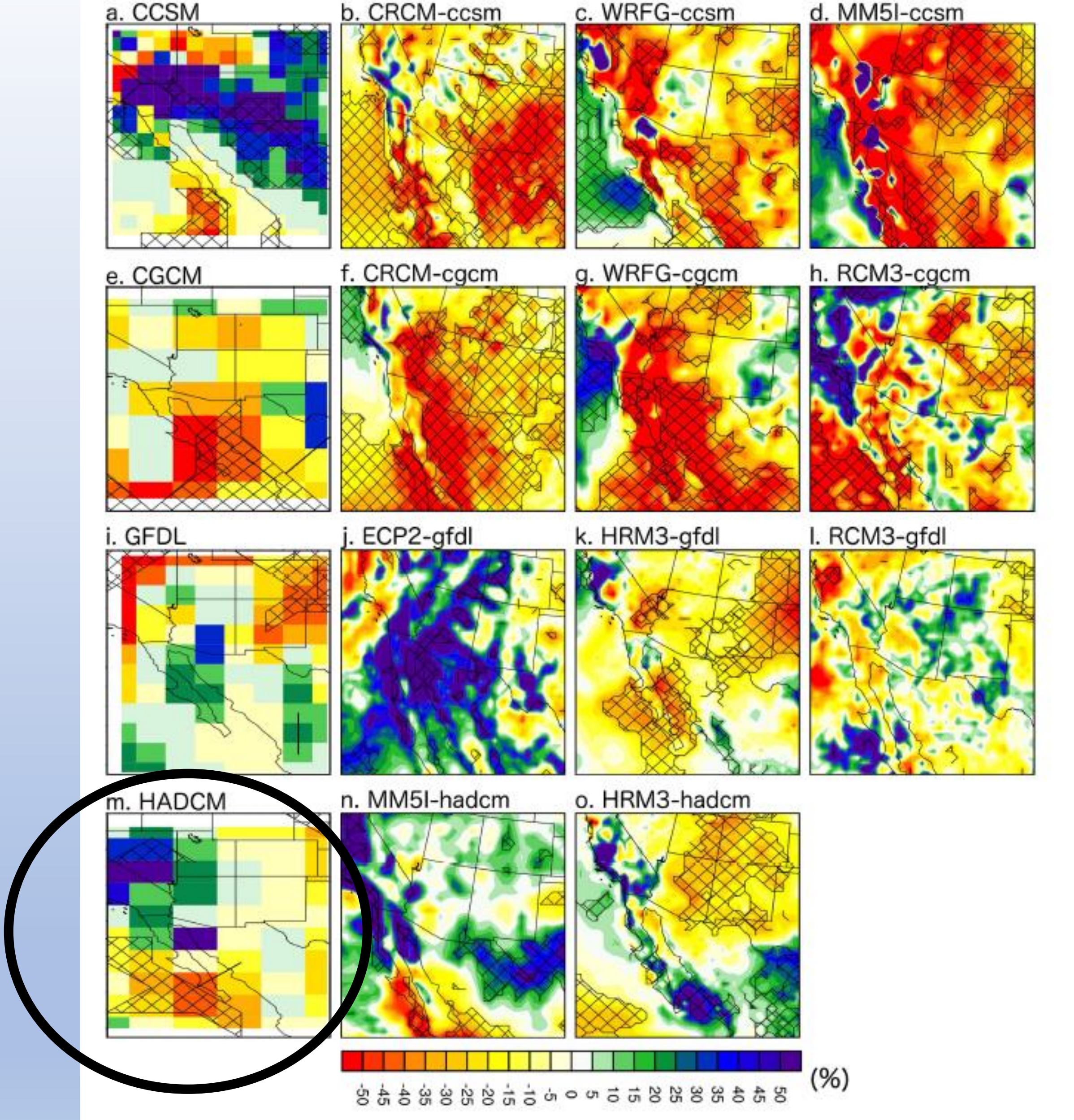


Figure 3: JA average precipitation change (%) from the baseline period. Hatching indicates where the change is statistically significant at the 0.1 level.

Sometimes, driving GCM is not the problem

Bukovsky et al. (2014, *J. Climate*)

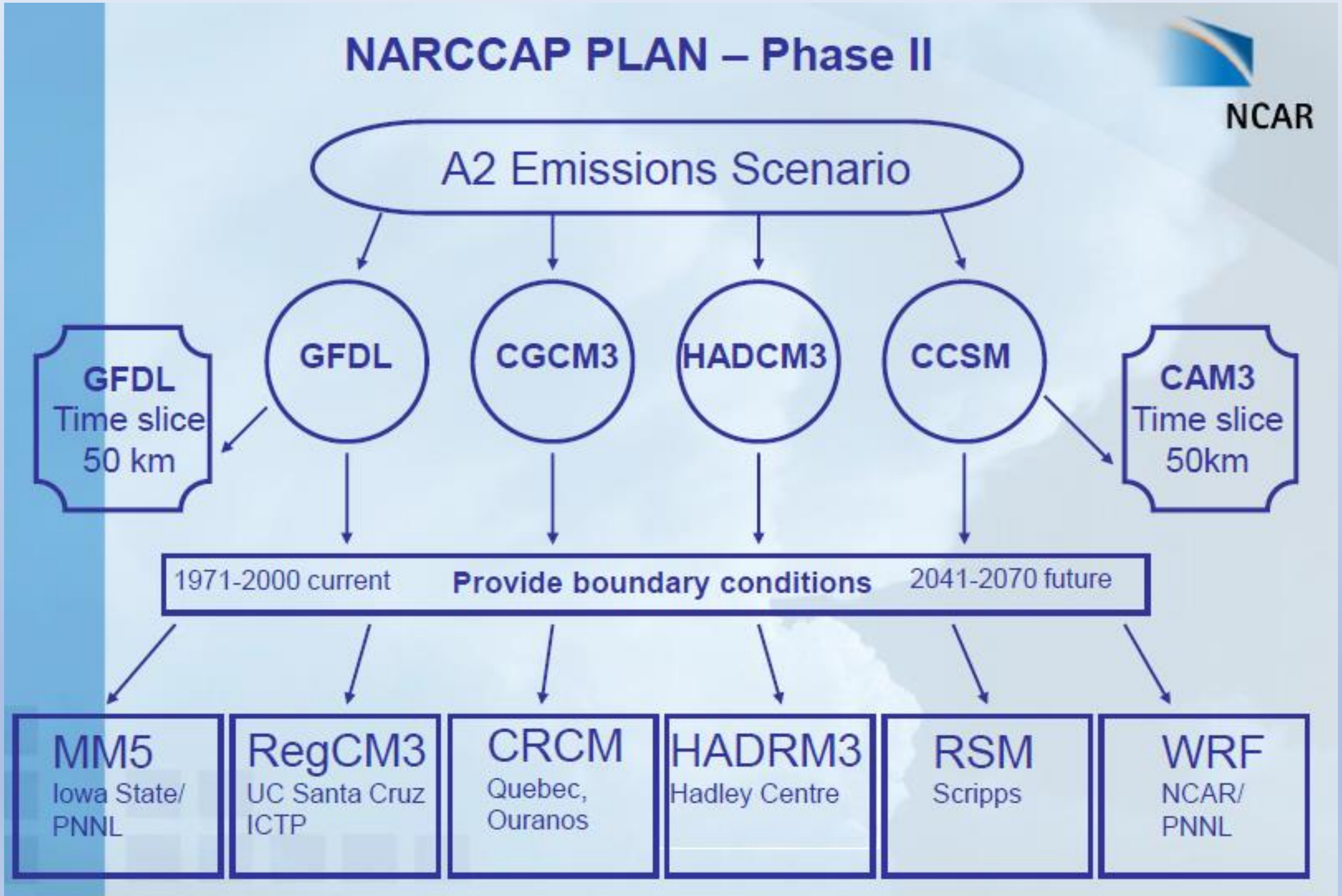
Statistical or Dynamical Downscaling
Which is “right’’ way to go?

	Statistical Downscaling	Dynamical Downscaling
Pros	Simple and inexpensive Many realizations Relatively easy to apply	Represents physical processes Lots of variables available Characterize extremes
Cons	Stationarity problem Underestimates extremes No physical process basis	Lesser scenario simulations Computationally expensive Requires training, experience

Reduce statistical uncertainty

Reduce physical process uncertainty

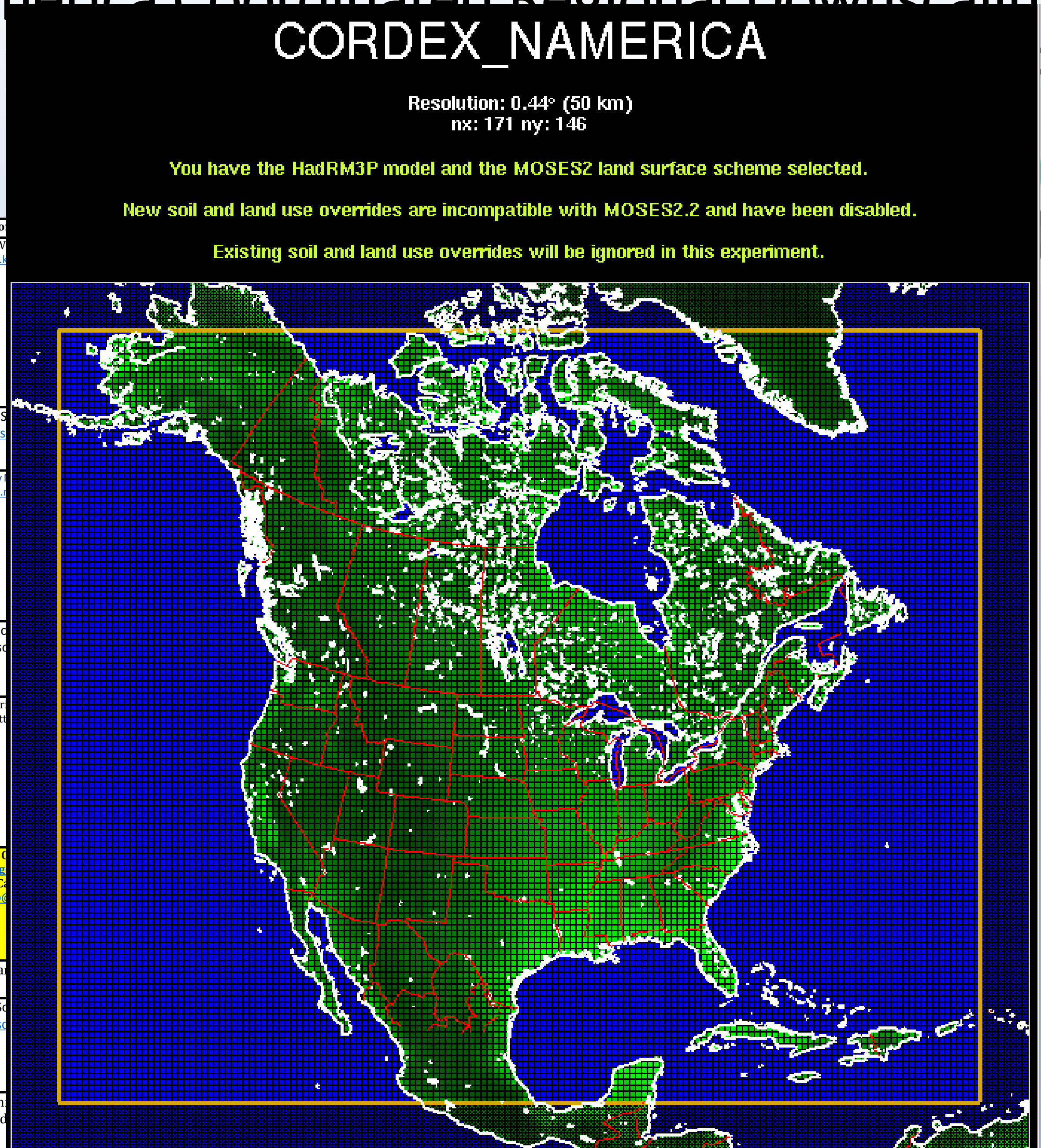
North American Regional Climate Assessment Program (NARCCAP, dynamically downscaling IPCC CMIP3 products)



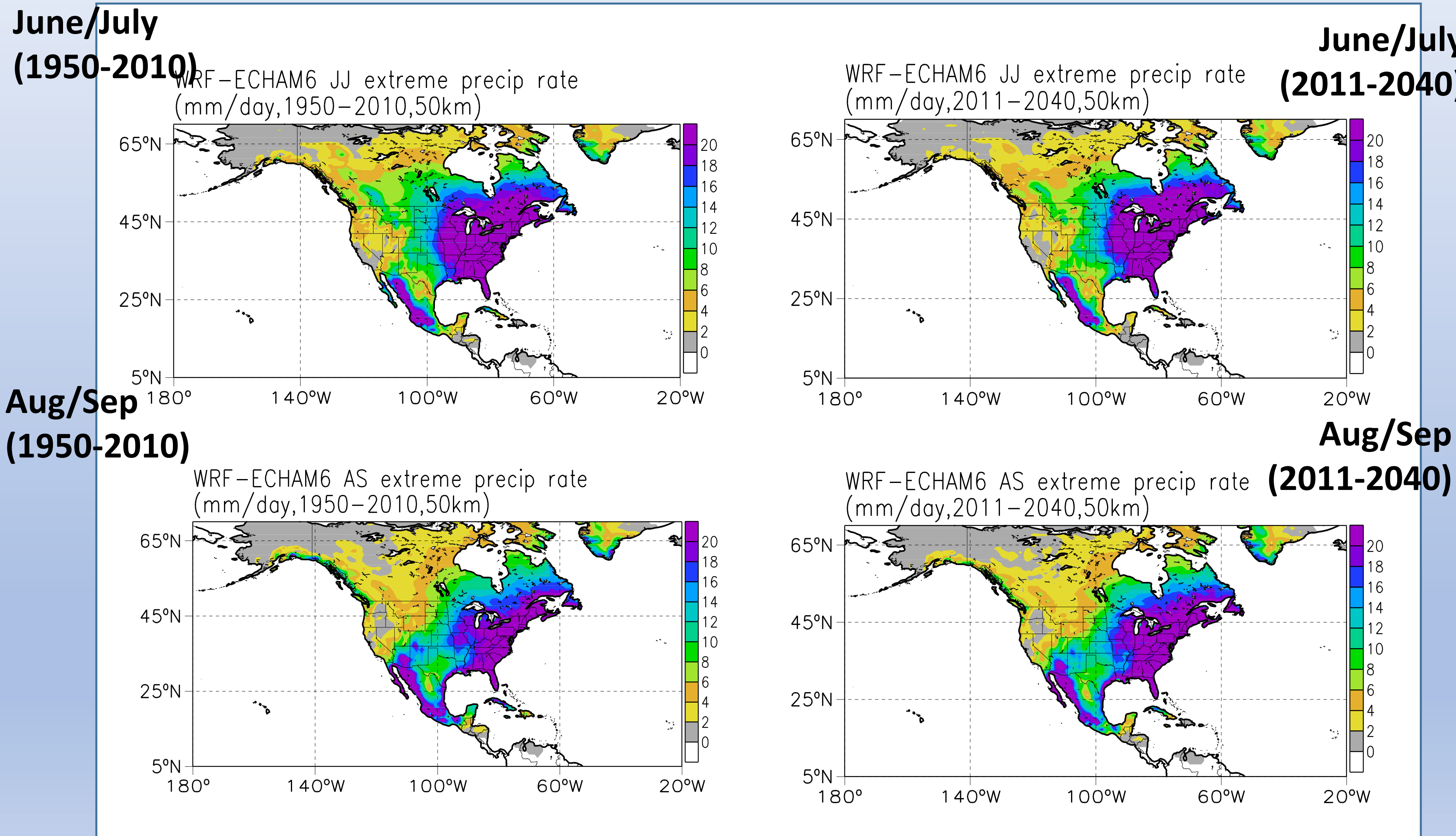
Courtesy Dr. Linda Mearns, National Center for Atmospheric Research

North Am… g Experiment (NA COR… P5 products)

	Point o
1)	Katja W winger.k
2)	Kevin S kevin.s e
3)	Grigory grigory.
4)	Ph. Luc plp@sc
5)	Ray Arri rwarritt u
6)	**Hsin-I C** **hchang** **Chris Ca** **castro@**
7)	Wilfra
8)	John Sc John.sc
9)	Ole Ch obc@d



Extreme precipitation rate (top 10%):
June/July vs Aug/Sep (WRF-CMIP5)



Summary for Regional Climate Modeling:

- Value added using dynamical downscaling technique: Precipitation distribution better represented in WRF regional climate model, as compared to raw IPCC global climate datasets.
- Performance in seasonal mean climatology: WRF simulations using IPCC climate projections have reasonable 20th century precipitation climatology for both summer and winter seasons.
- Regional climatology from different generation of IPCC projections: improvements in mean precipitation climatology are found in downscaled WRF-CMIP5 simulations, as compared to the WRF-CMIP3 runs.

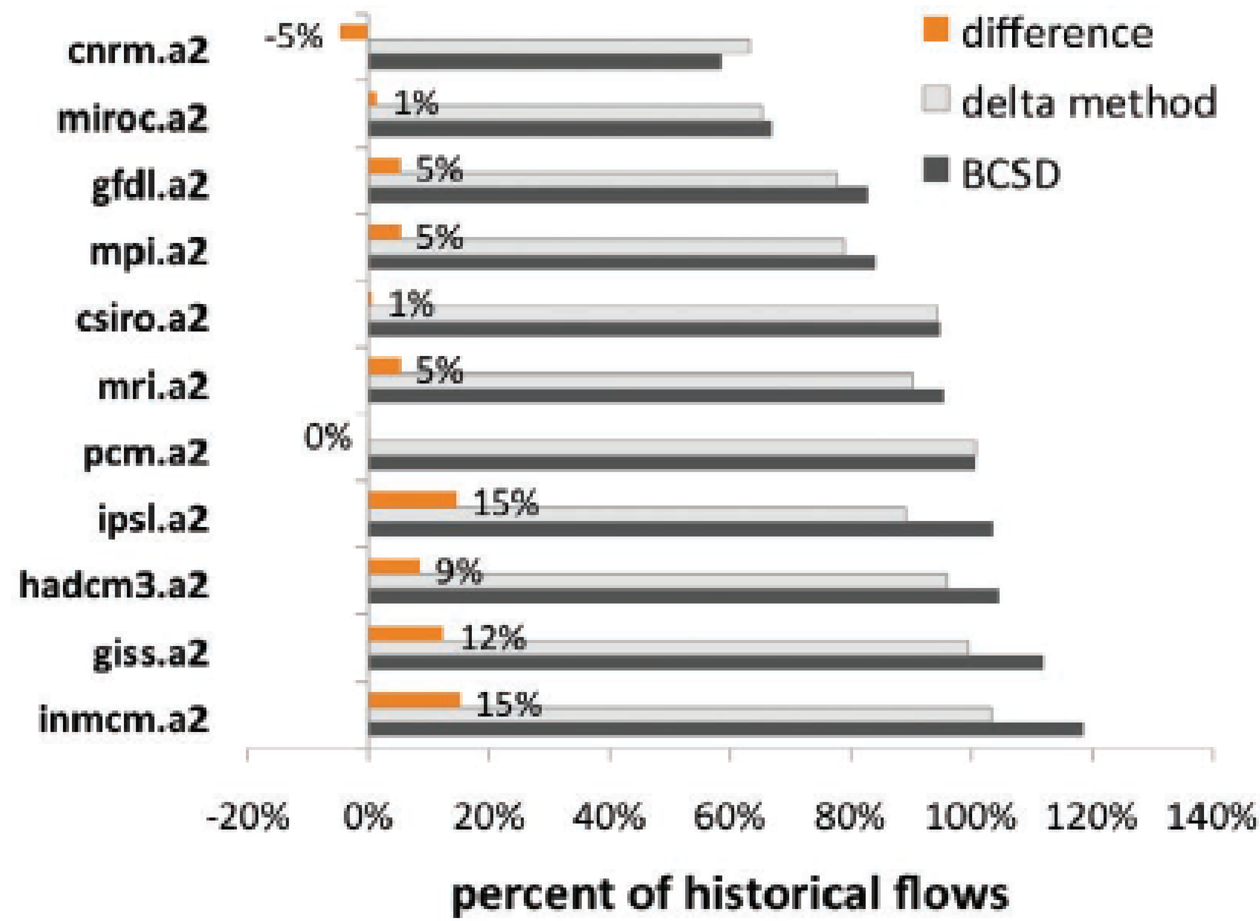
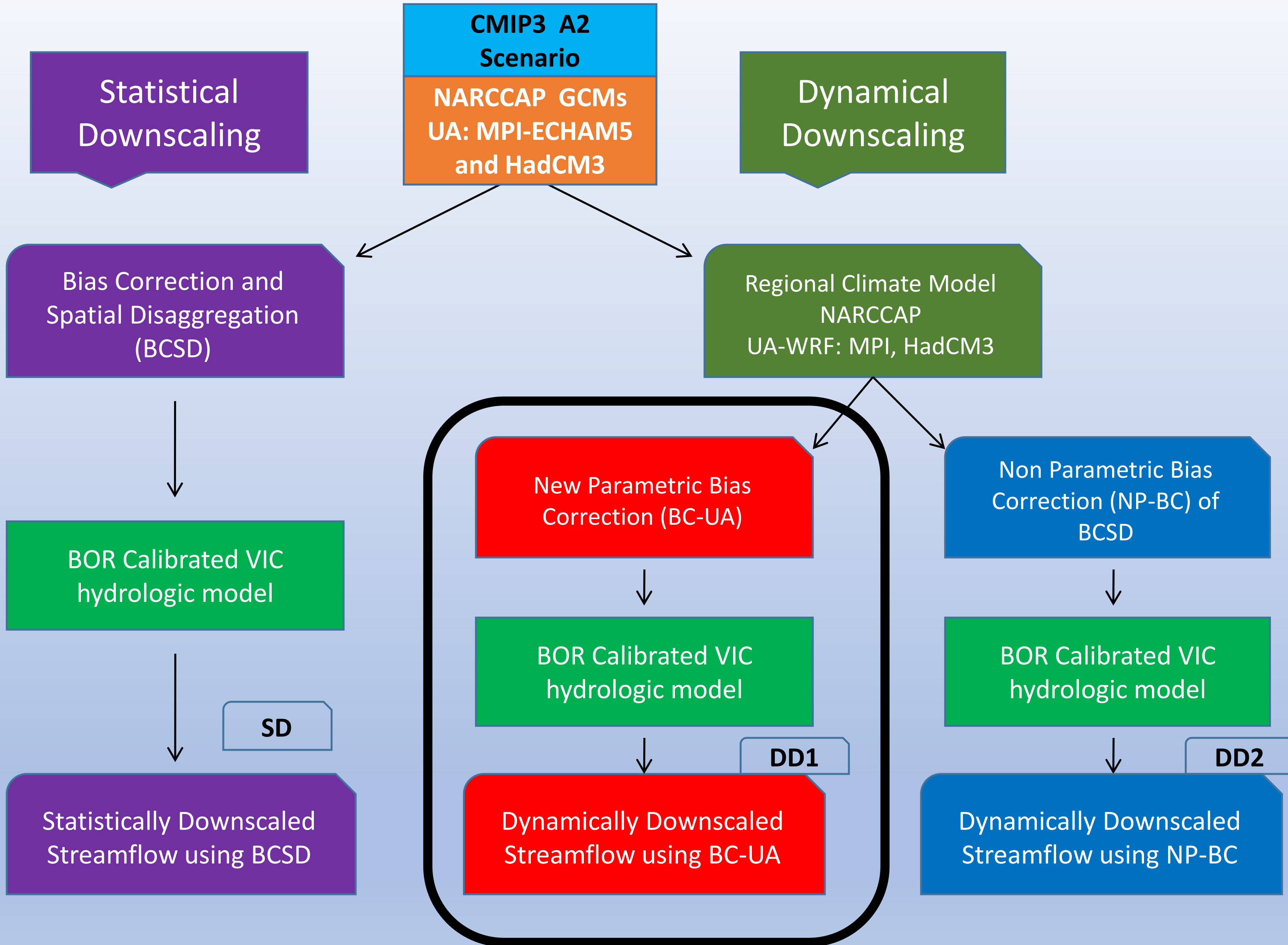


Fig. 6. Comparison of BCSD downscaling from C&L with a delta-method downscaling approach for Lees Ferry in the 2040–69 future period for A2 emission scenarios. On average, the BCSD approach has a decline in streamflow of 7% (average values of 93%), whereas with the delta method, declines are 13% (average values of 87%). Differences are the BCSD approach minus the delta-method approach.

Vano et al. (2014, BAMS)



CMIP3 A2 Scenario
NARCCAP GCMs
UA: MPI-ECHAM5 and HadCM3
Statistical Downscaling
Dynamical Downscaling
Bias Correction and Spatial Disaggregation (BCSD)
Regional Climate Model NARCCAP UA-WRF: MPI, HadCM3
New Parametric Bias Correction (BC-UA)
Non Parametric Bias Correction (NP-BC) of BCSD
BOR Calibrated VIC hydrologic model
BOR Calibrated VIC hydrologic model
BOR Calibrated VIC hydrologic model
SD
DD1
DD2
Statistically Downscaled Streamflow using BCSD
Dynamically Downscaled Streamflow using BC-UA
Dynamically Downscaled Streamflow using NP-BC