Climate Change and Downscaling

Ethan Gutmann

5 / 24 / 2018

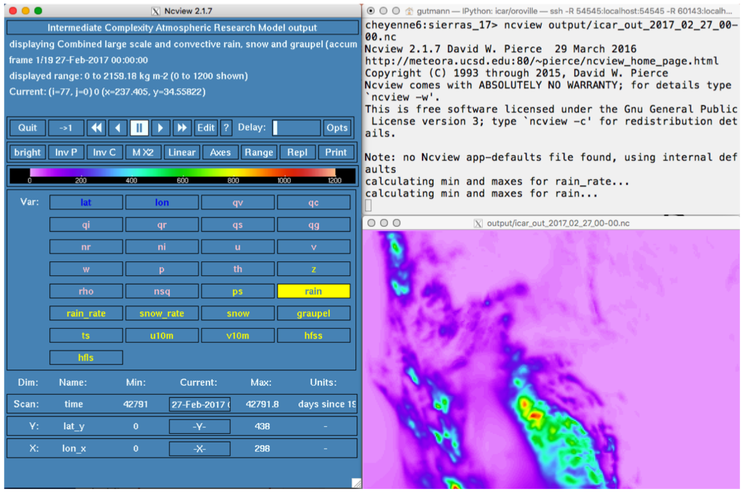
CSDMS Annual Meeting Clinic

What are you hear for?

Outline

- Lecture (sorry)
  - Outline of climate issues
  - Description of downscaling methods
  - Discussion of available data

- Interactive (whee)
  - Login to summit
  - Visualize data
  - Run your own downscaling



There is no silver bullet

Extreme events are REALLY hard

What do you need from climate models?

- Precipitation
- Temperature
- Wind?
- Humidity?
- Radiation?

Daily, Hourly? Sub-hourly?

1 event? 100 years? …10,000 years?

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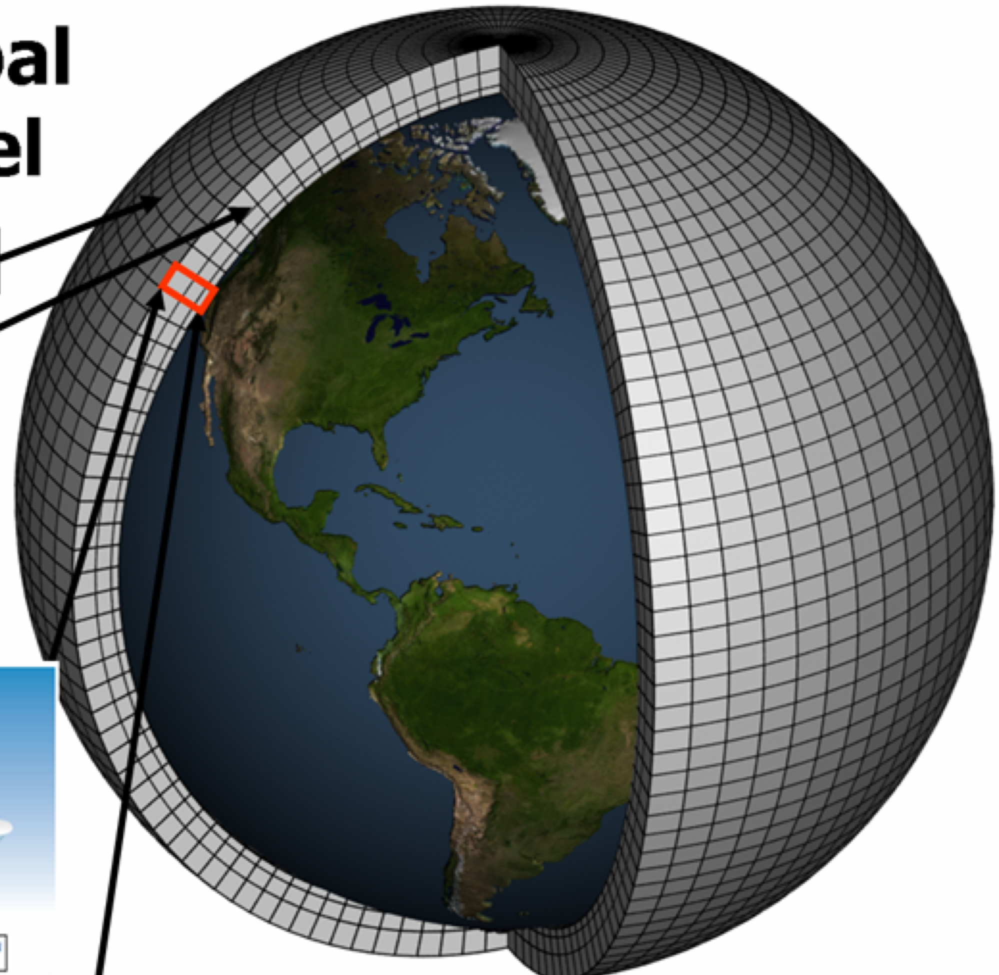
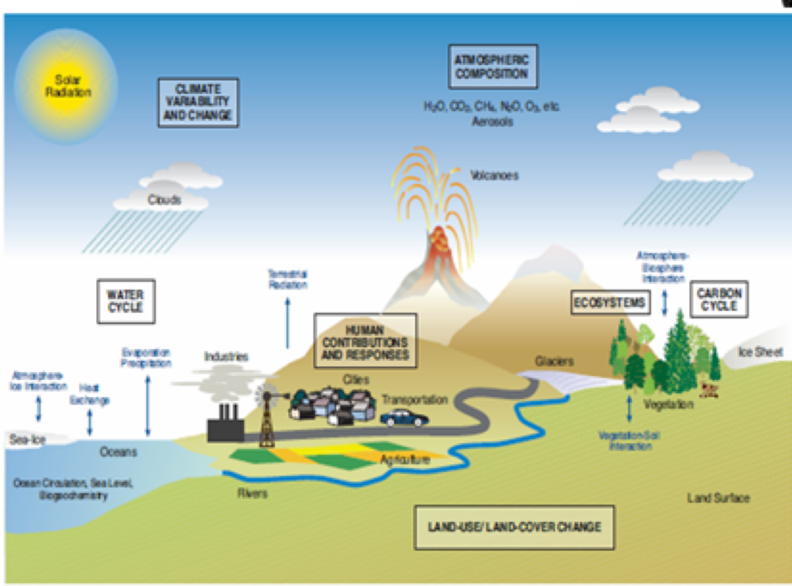
Schematic for Global Atmospheric Model

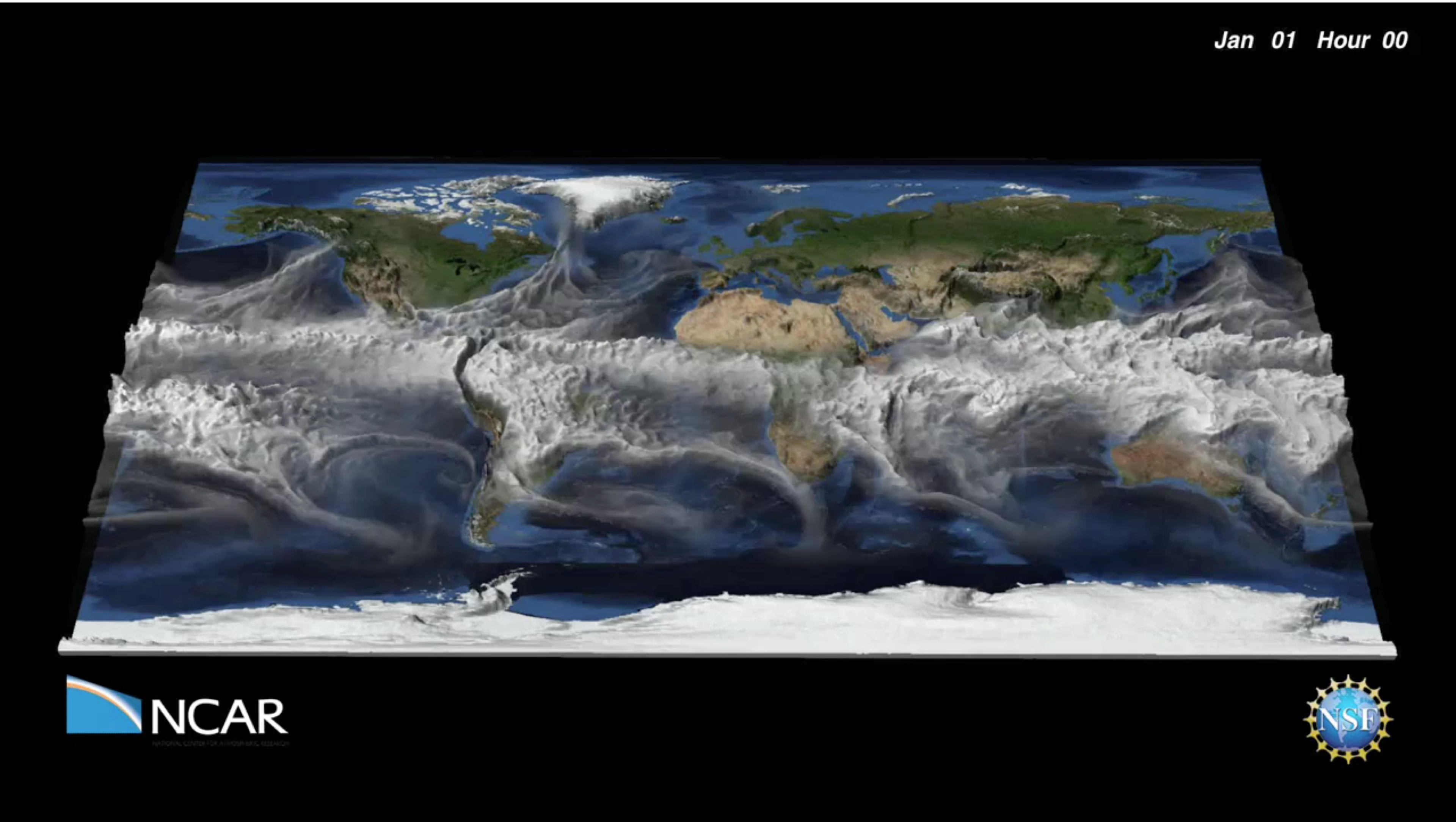
Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)



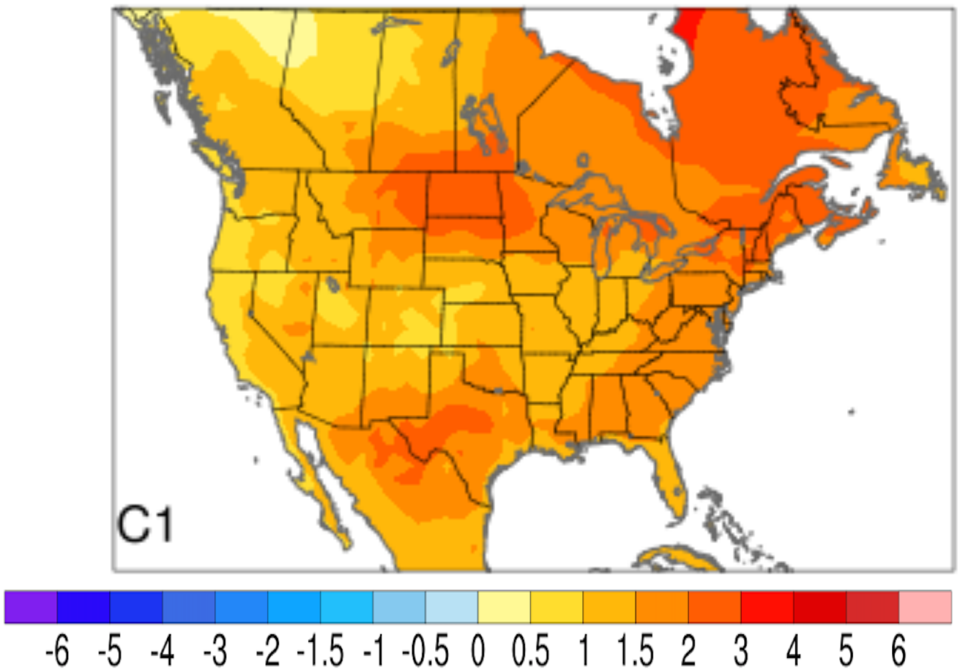


Climate Models

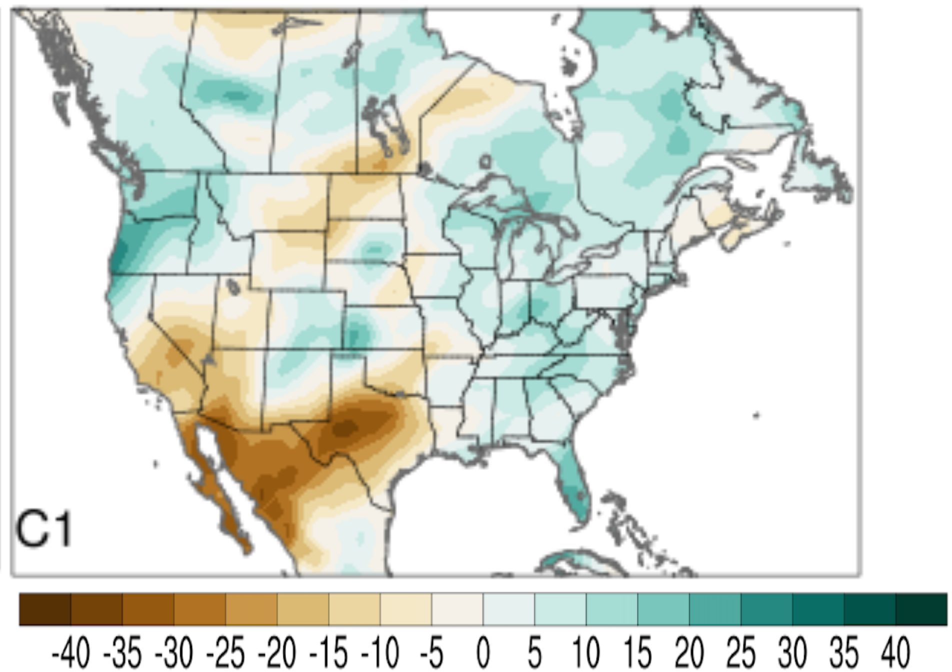


What will the future look like?

Warmer
Air Temperature
(2030s – 1990s)



Wetter and Drier…
Precipitation
(2030s – 1990s)



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What will the future look like?

Warmer
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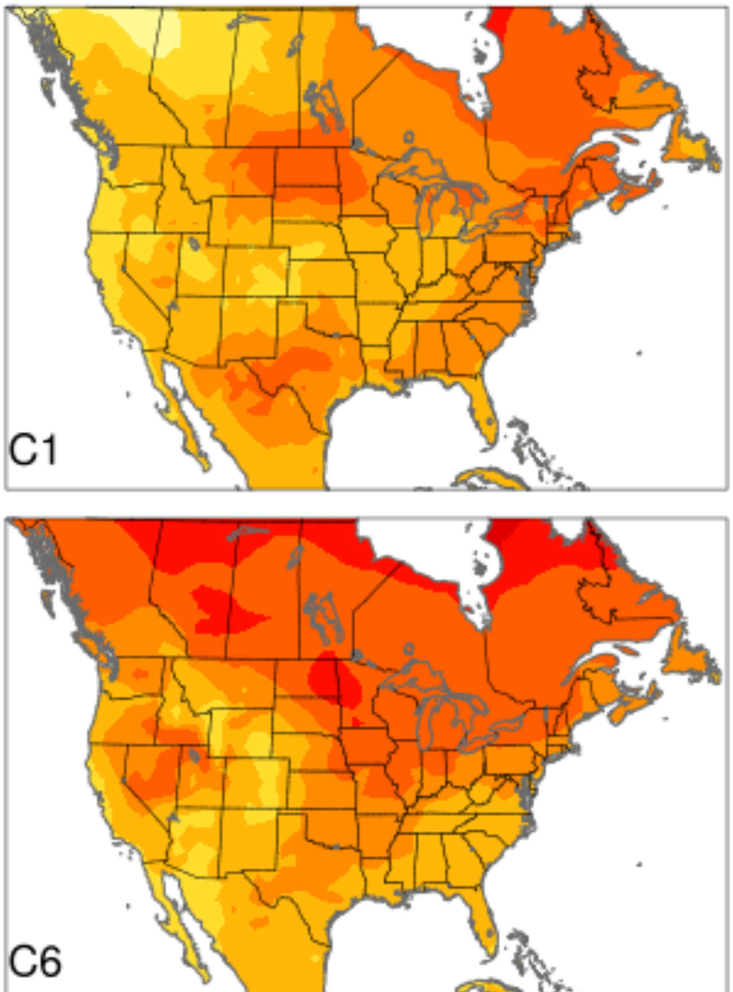
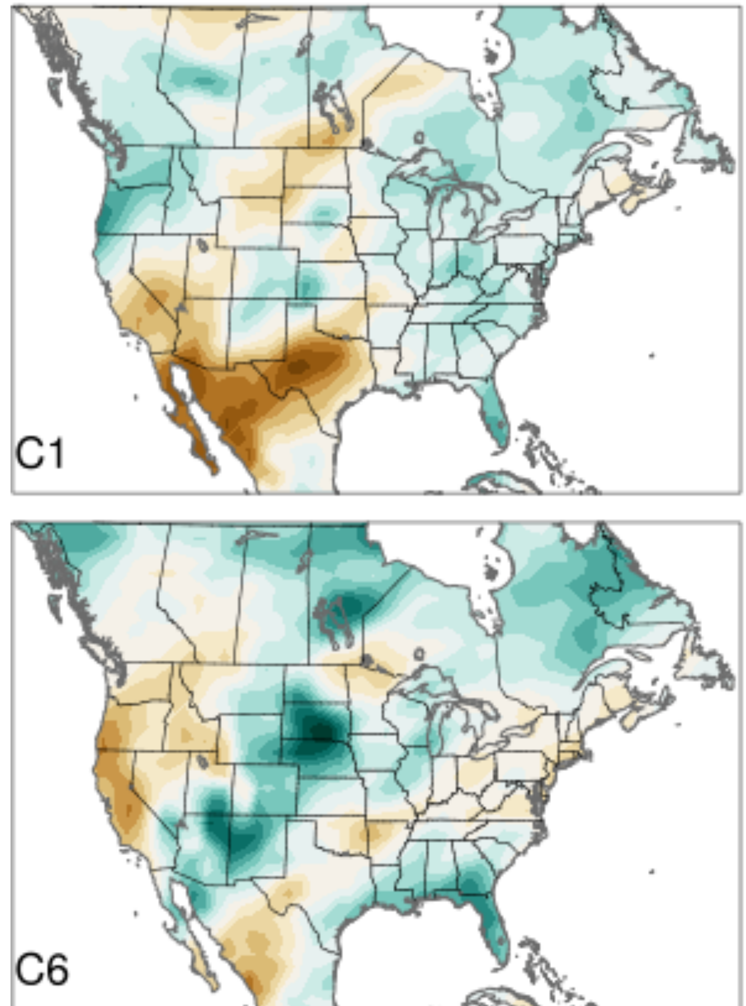


Wetter
And Drier…
(2030 – 1995)

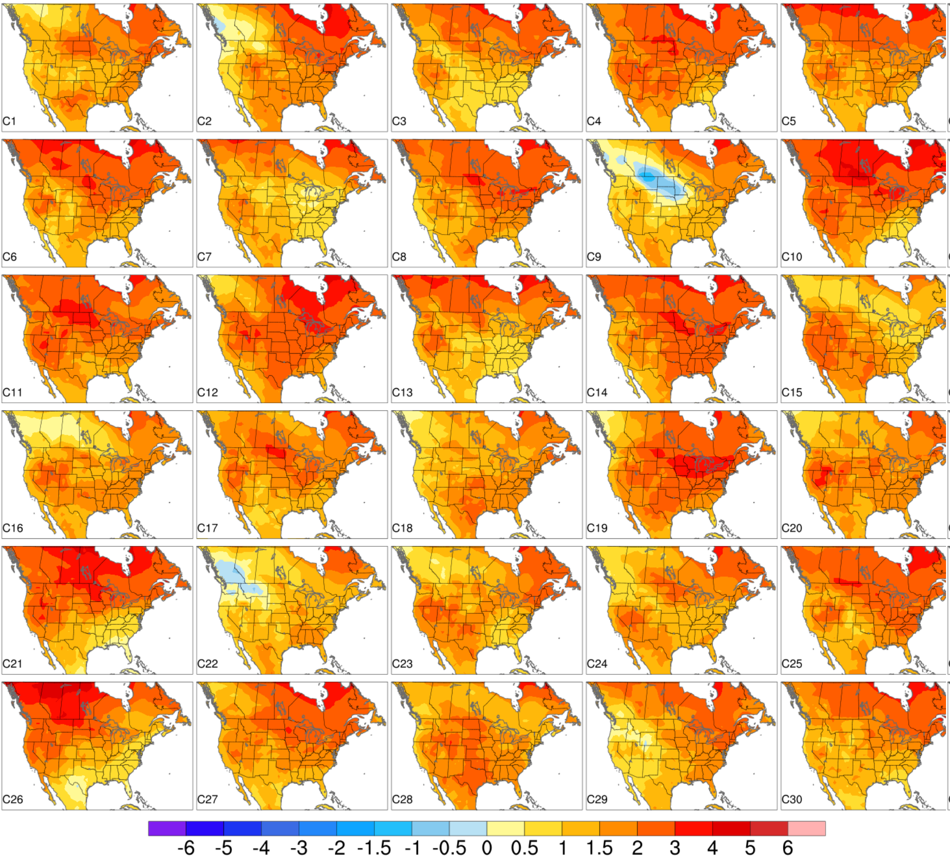


What will the future look like?

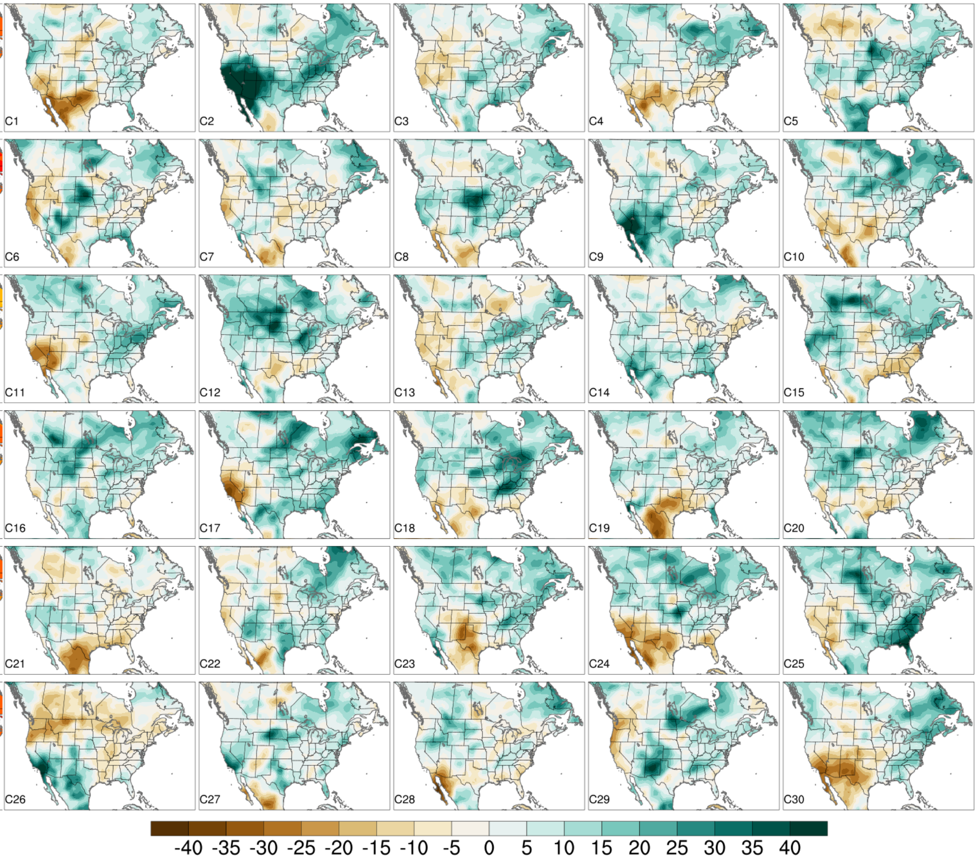
Warmer
Air Temperature
(mostly)

Wetter
And Drier…
(Sometimes?)

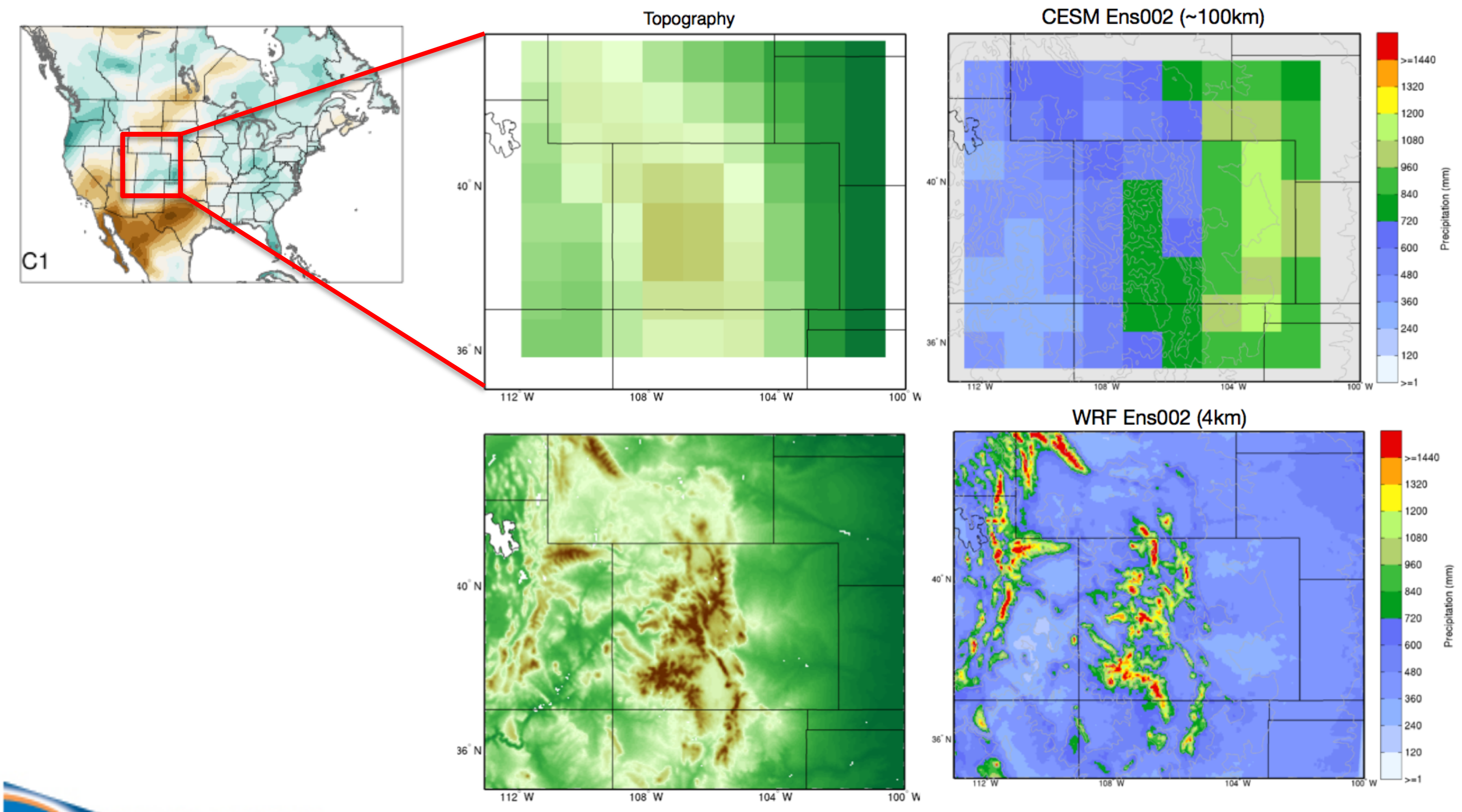
SAT ONDJFM (2025:2034 - 1990:1999)



Precip ONDJFM (2025:2034 - 1990:1999)



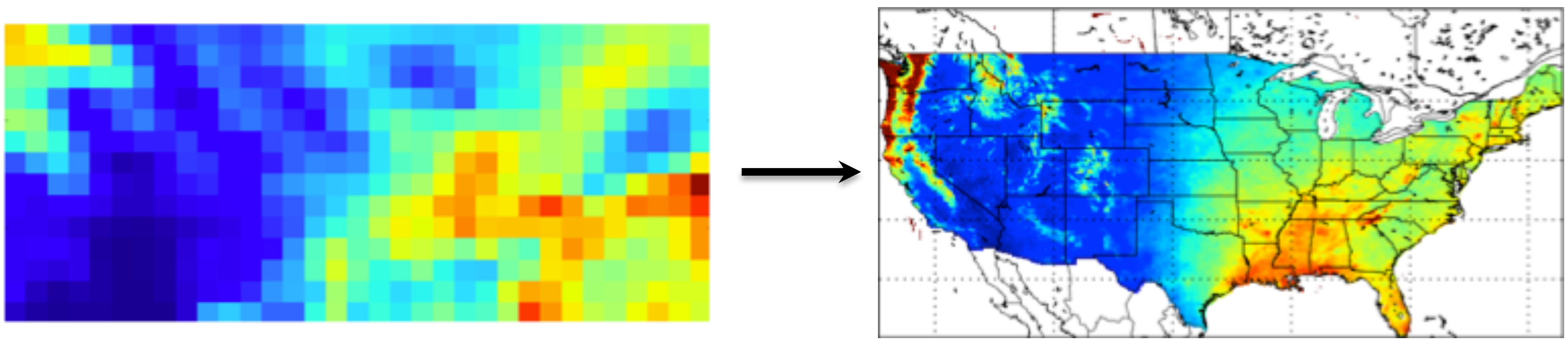
Why Downscaling?



Importance of Mountains to Water Resources

What this means for precipitation

- GCMs predict too little precipitation over mountains



- Precipitation is generated by Convective parameterization instead of orographic processes.

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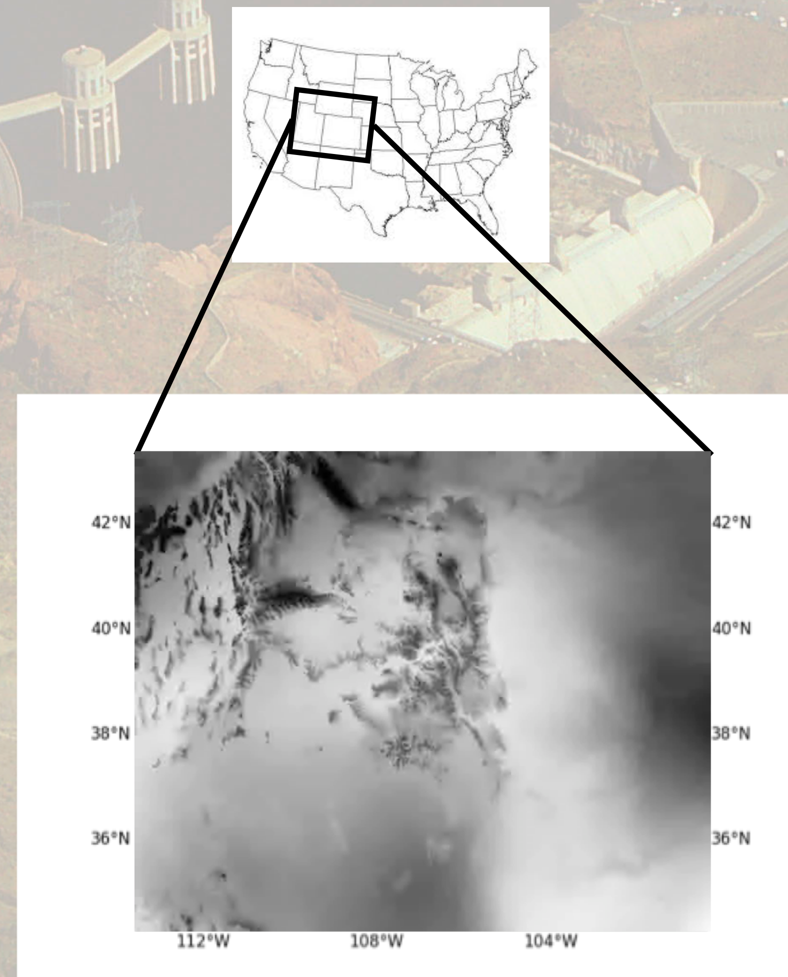
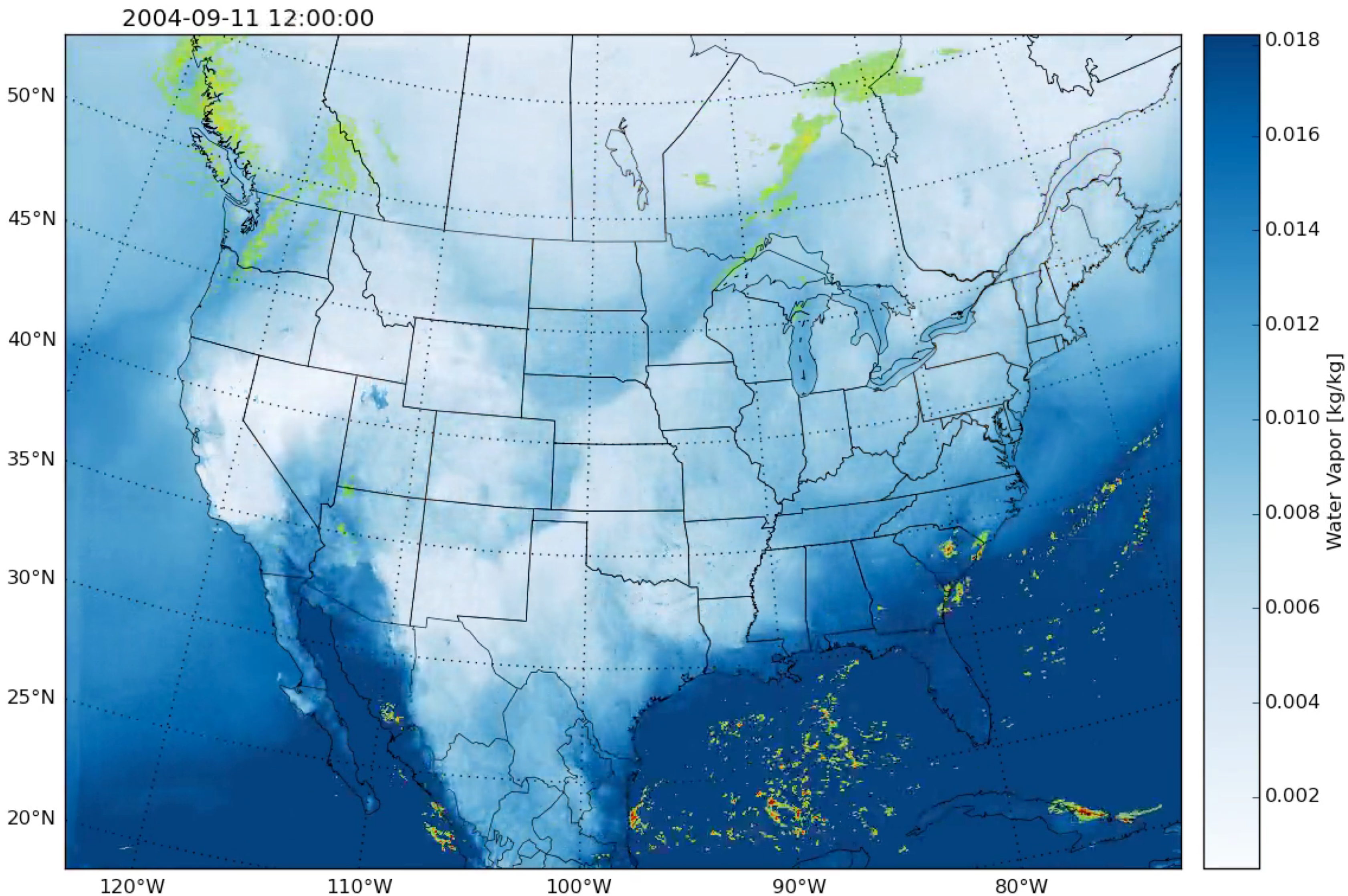
Dynamic Downscaling

- High-resolution Regional Climate Model

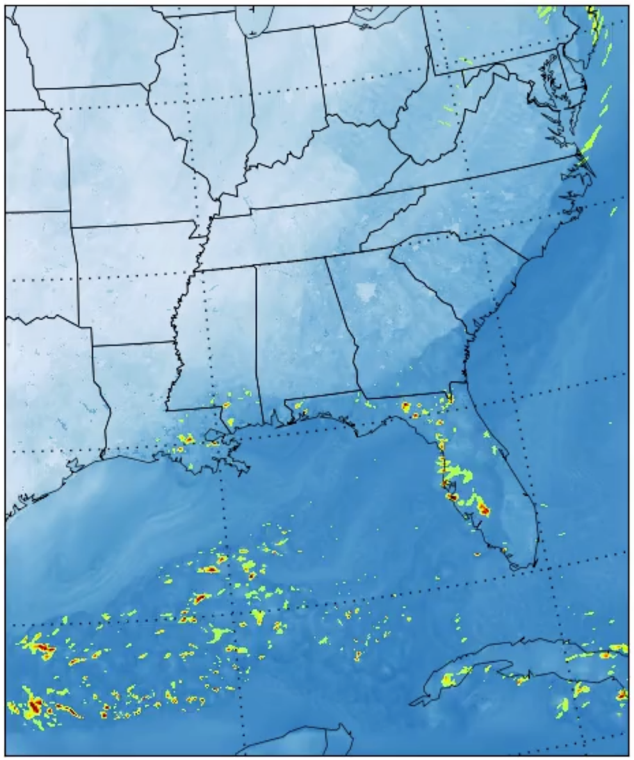




2004-09-11 12:00:00
50°N
45°N
40°N
35°N
30°N
25°N
20°N
120°W
110°W
100°W
90°W
80°W
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
Water Vapor [kg/kg]

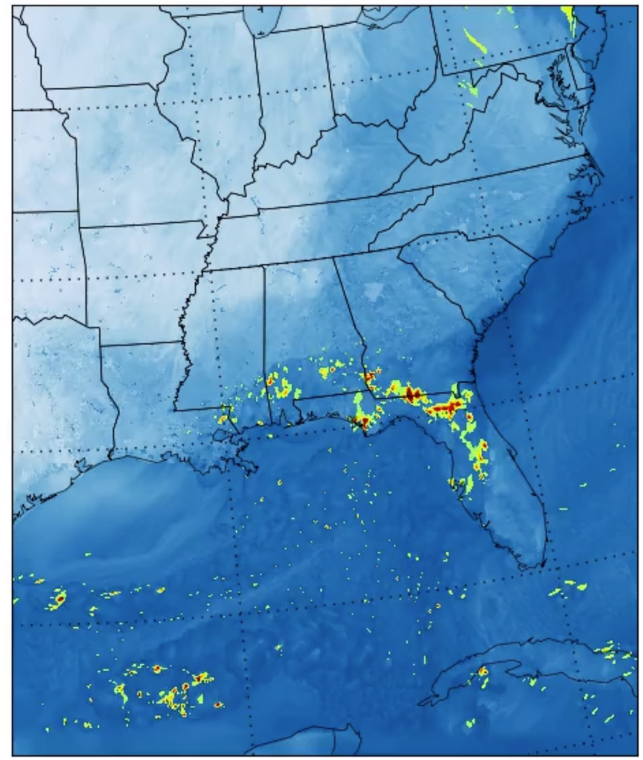
Hurricane Ivan

Hurricane Ivan (2005)
Current climate



Hurricane Ivan (Future)
warmer atmosphere

2004-09-10 00:00:00

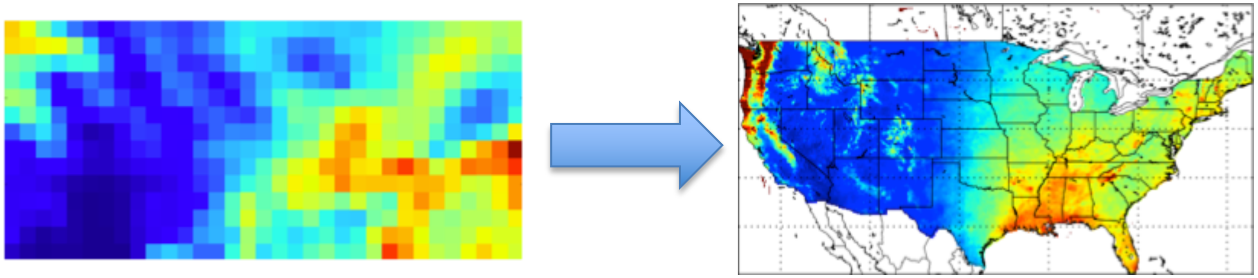


Changes in Hurricanes from a 13 Year Convection Permitting Pseudo-Global Warming Simulation,
Gutmann et al. 2018, (Journal of Climate)

Corresponding Author: Ethan Gutmann, gutmann@ucar.edu

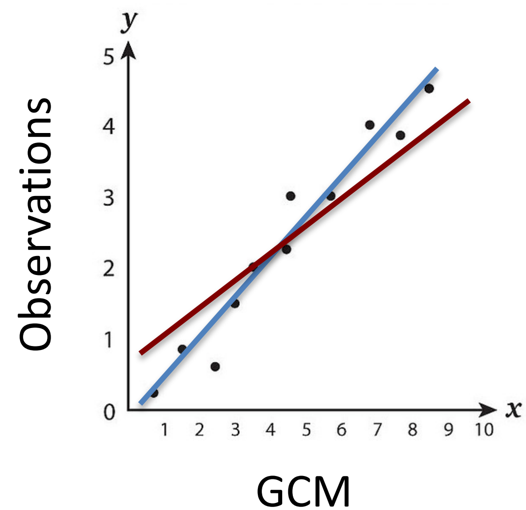
Analysis funded by Det Norske Veritas (DNV) and CONUS simulation by NSF under NCAR Water System Program

Statistical Downscaling



- onary
  tionships

- tionally cheap

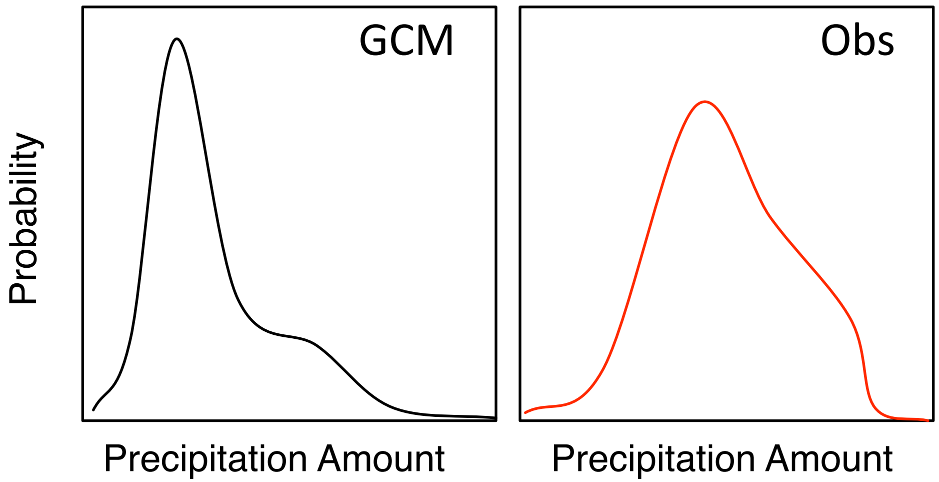


Precipitation Rescaling

Quantile Mapping

- Used in BCSD at a monthly timestep, low resolution

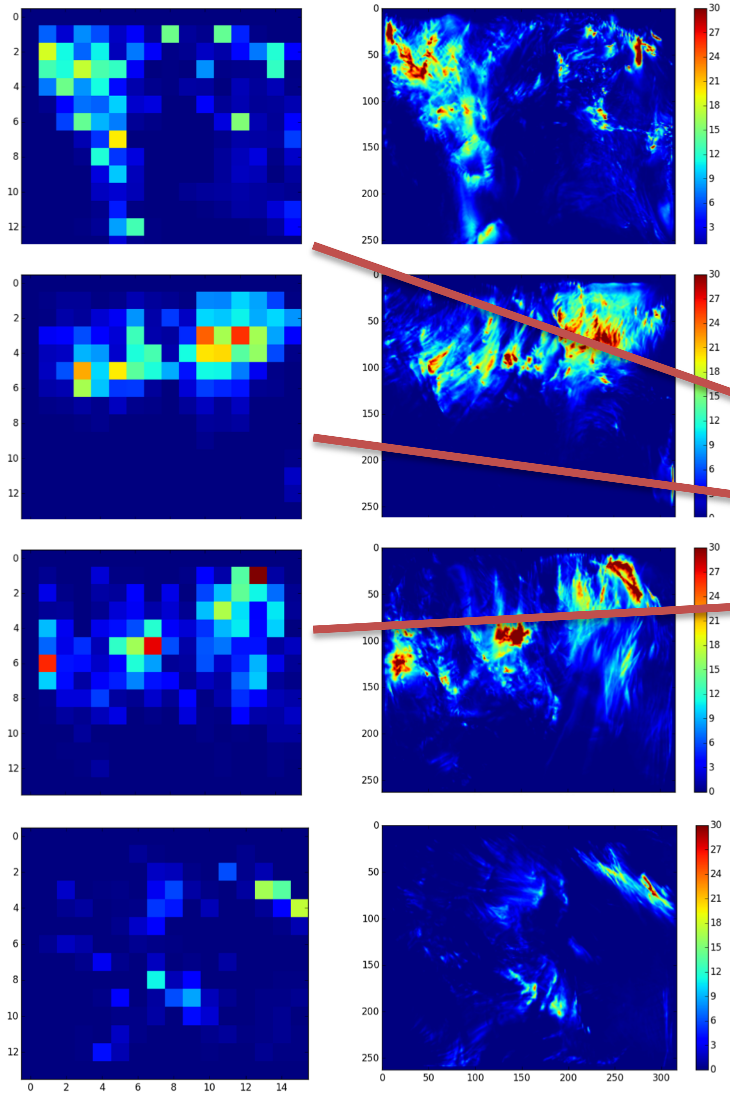
  Wood et al (2004)
  Thrasher et al (2013)



- Used in AR with a fit instead of a direct mapping, daily timestep high-resolution

  Stoner et al (2012)

Precipitation Analogs

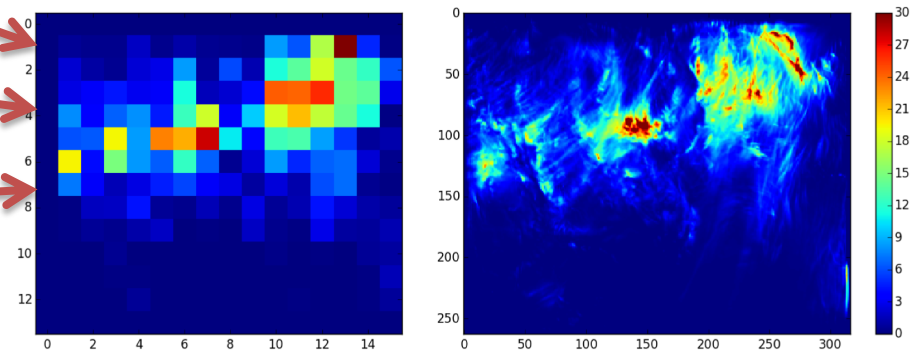


Constructed Analogs

Maurer and Hidalgo (2008)

Low-resolution Precipitation

Downscaled Precipitation



Multivariate Adapted Constructed Analogs (MACA)

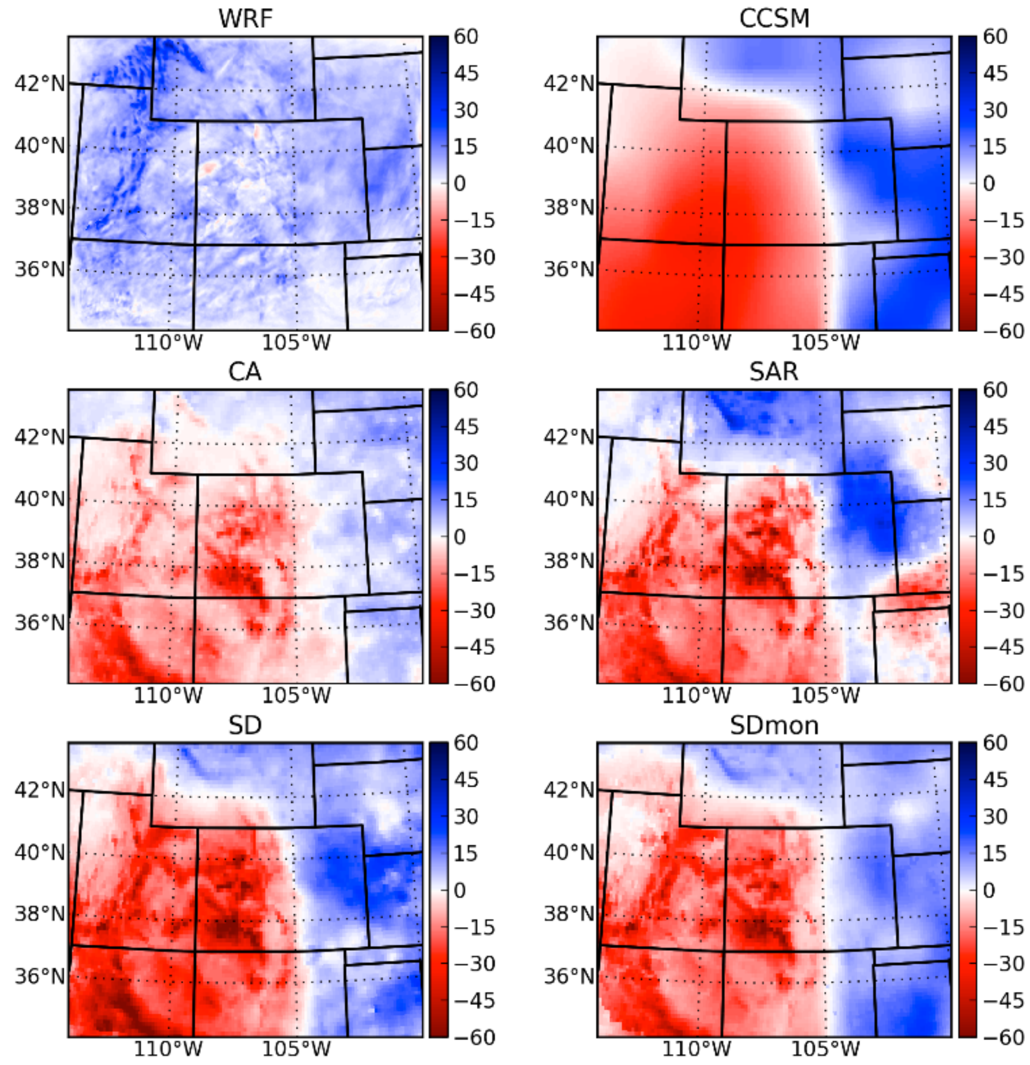
Abatzoglou and Brown (2012)

LOcalized Constructed Analogs (LOCA)

Pierce and Cayan (2015)

Representation of Climate Change

- Problems with historical fidelity aside…
- How do different methods represent climate change.
- Statistical methods are almost identical.
- Dynamical simulation is very different.



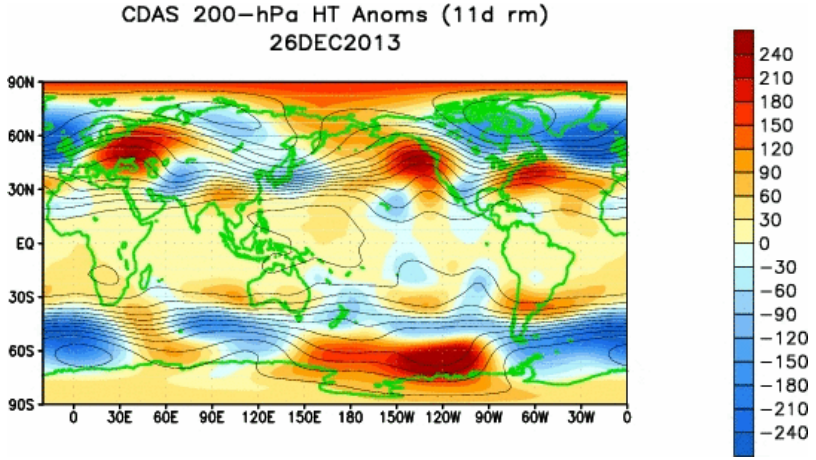
A False dichotomy of downscaling options

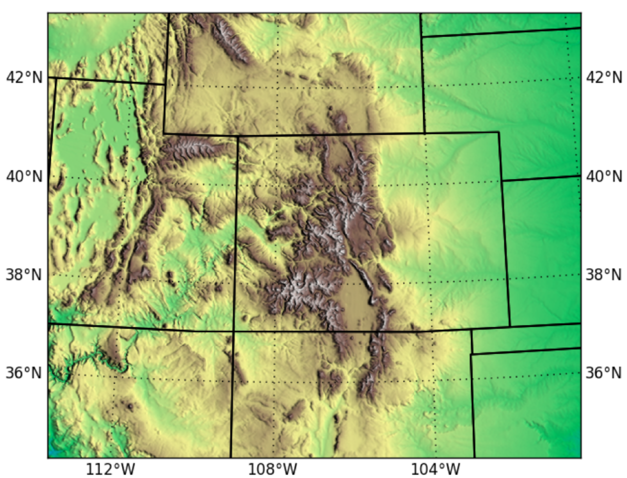
increasing physical representation

- Statistical downscaling based on rescaling GCM outputs
  - BCSD, BCCA, AR

- Dynamical downscaling using state-of-the-art RCMs

Circulation Based Example





- Rely on circulation fields
  - Pressure, temperature, wind, humidity, convective potential
- More confidence in GCM outputs
- More confidence in stationary relationships
- Compute regression on similar/analog days from the past
- Sub-domain reminder (on left)

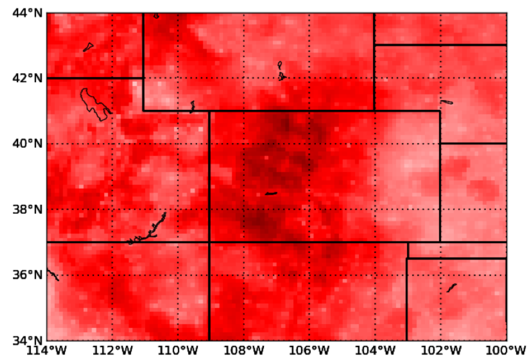
Circulation Based Example

- Training data:
  - GEFS circulation
  - Maurer Precip

- Applying to GCM circulation (normalized)

Precipitable Water

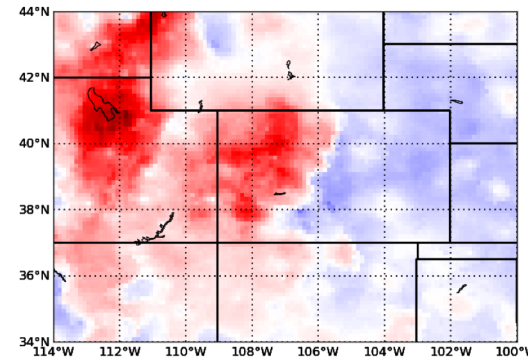
Positively correlated everywhere



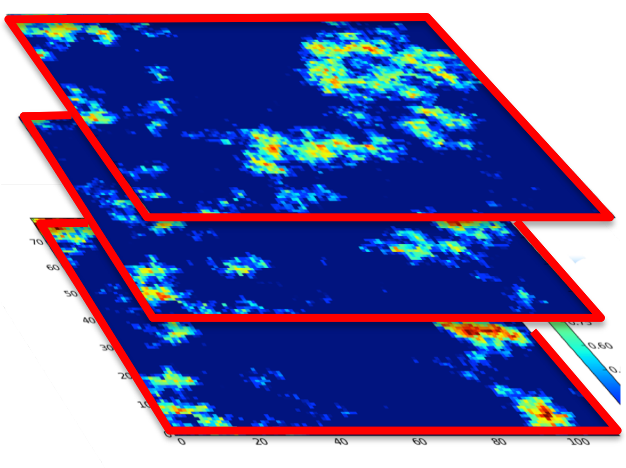
Zonal wind correlation

Positively correlated on West slopes

Negatively correlated on East slopes



Stochastic sampling



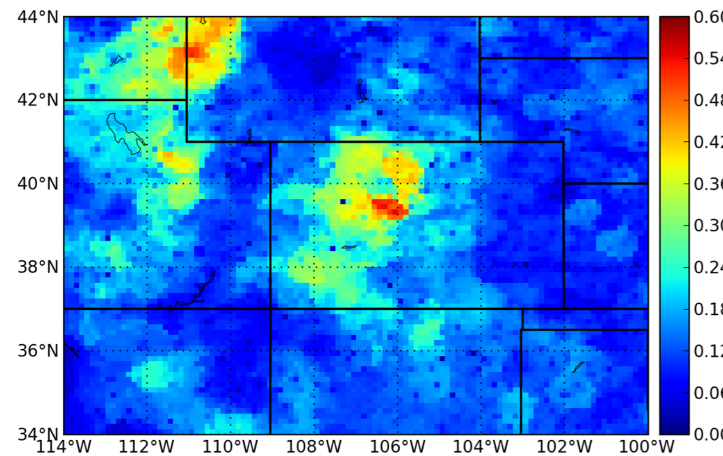
Time=6

...

Time=2

Time=1

Realistic Wet Day Fraction



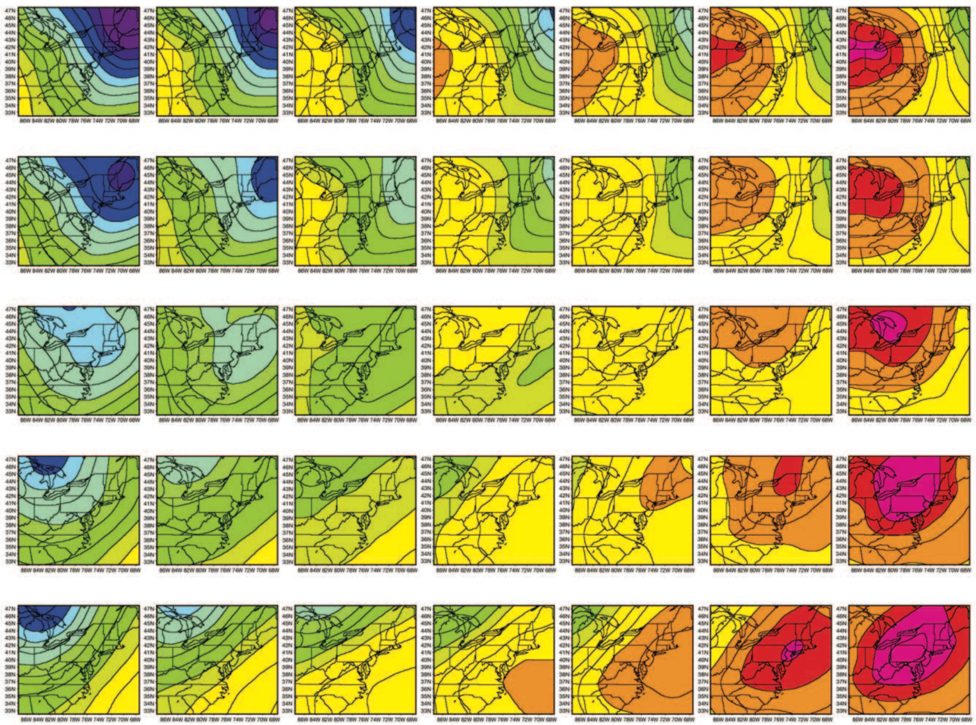
Classifying Weather Types: Self Organized Maps

- Exploit the natural variability of the model and in the natural system to cluster data

  Hewitson and Crane (2002)

- Can be difficult to match SOMs with GCM states

January SLP SOMs



See also:

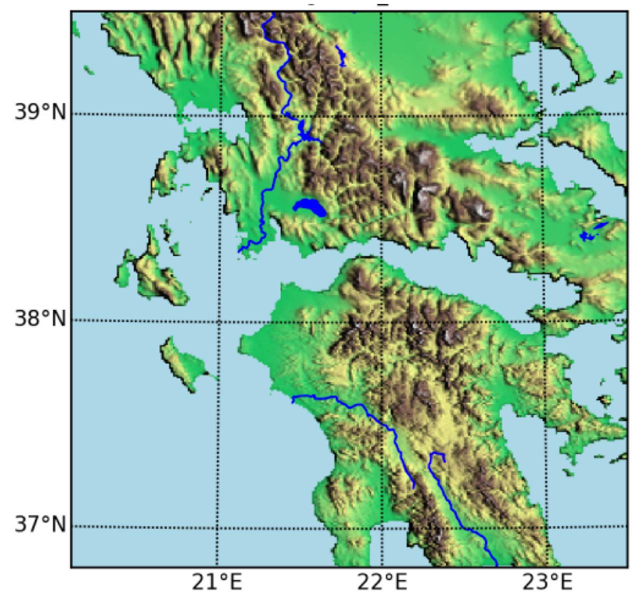
Bardossy and Plate, (1991),

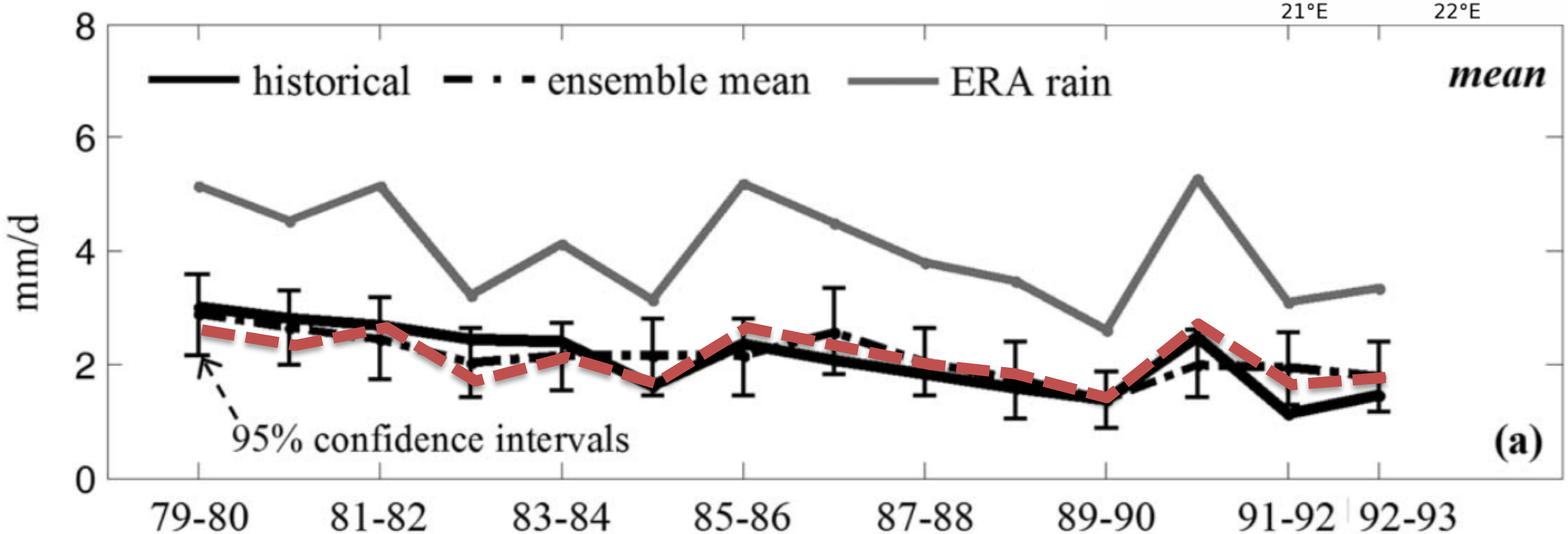
Hughs and Guttorp (1995),

Wetterhall et al., (2009)

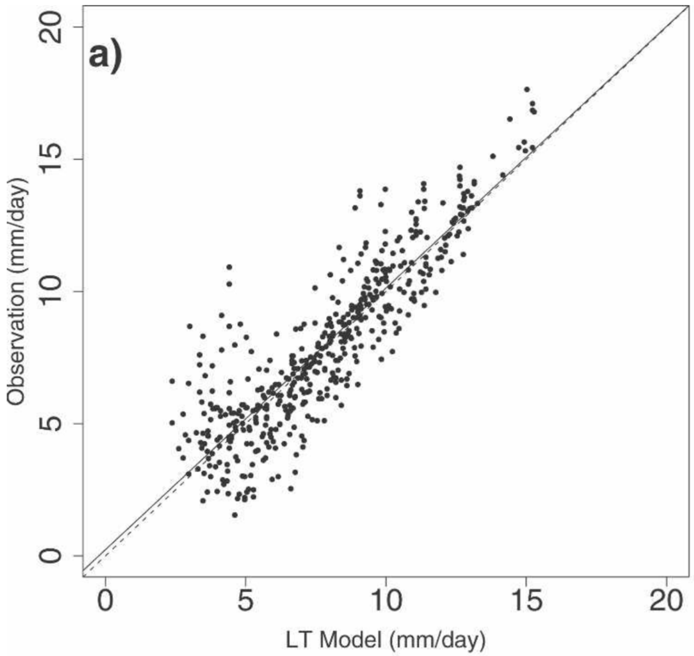
Potential Problems

- Statistics of GCM atmospheric variables may not match statistics of real world
  - e.g. dominant SOM, covariance between Q and U
- Often difficult to match observed precipitation

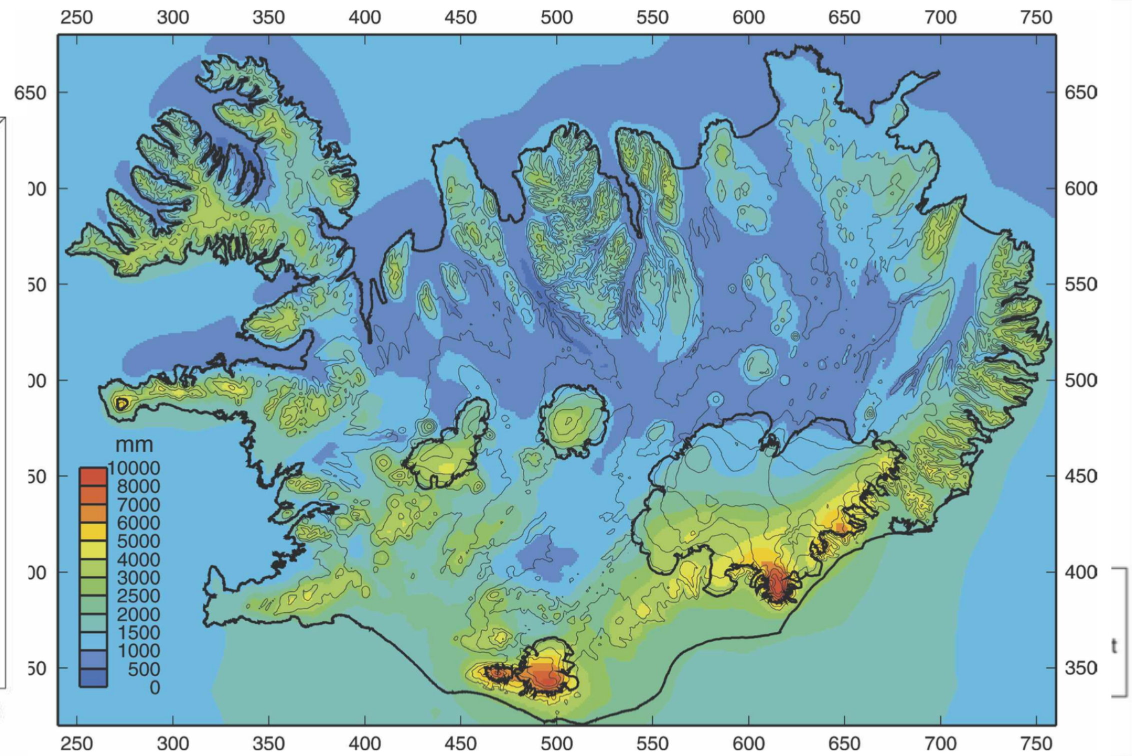




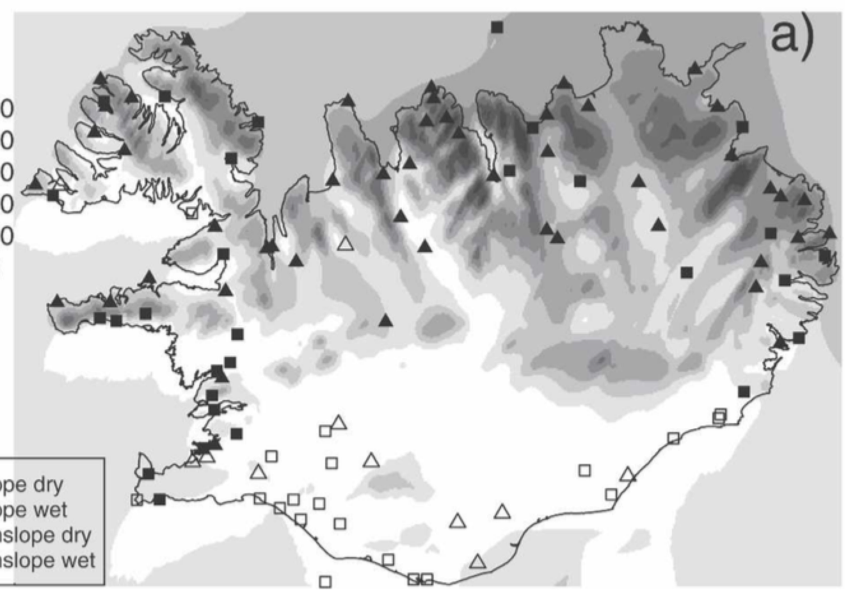
Langousis and Vassilios (2014)



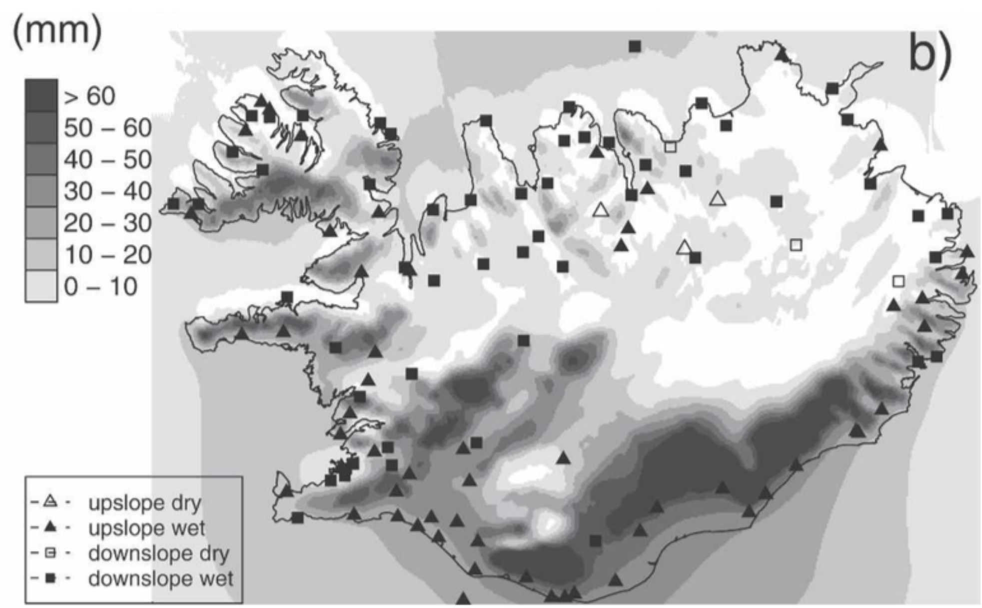
a)
Observation (mm/day)
LT Model (mm/day)
0
5
10
15
20



mm
10000
8000
7000
6000
5000
4000
3000
2500
2000
1500
1000
500
0
250
300
350
400
450
500
550
600
650
700
750



a)



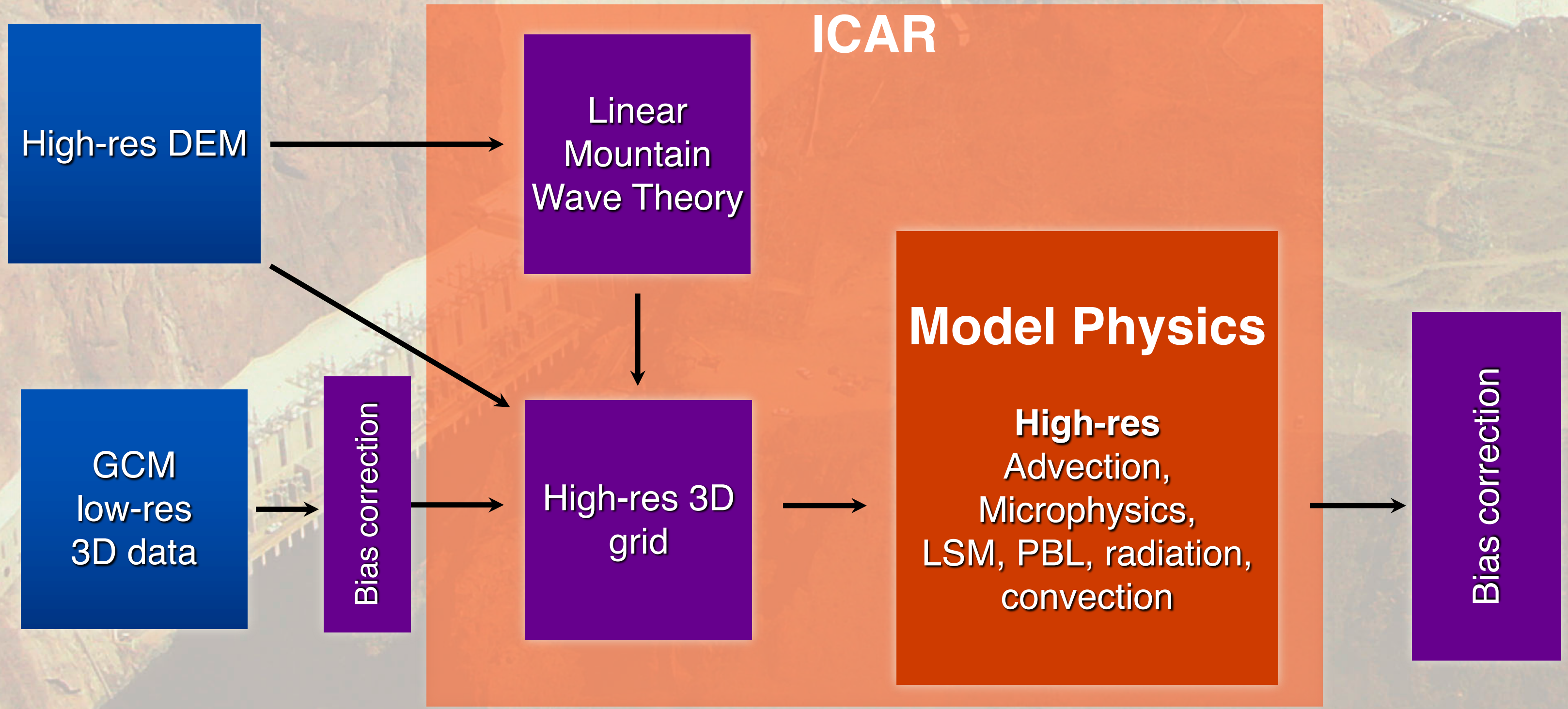
b)
(mm)
> 60
50 – 60
40 – 50
30 – 40
20 – 30
10 – 20
0 – 10
upslope dry
upslope wet
downslope dry
downslope wet

Intermediate Complexity Atmospheric Research model (ICAR)

Quasi-dynamical Downscaling

Identify the key physics and develop a simple model

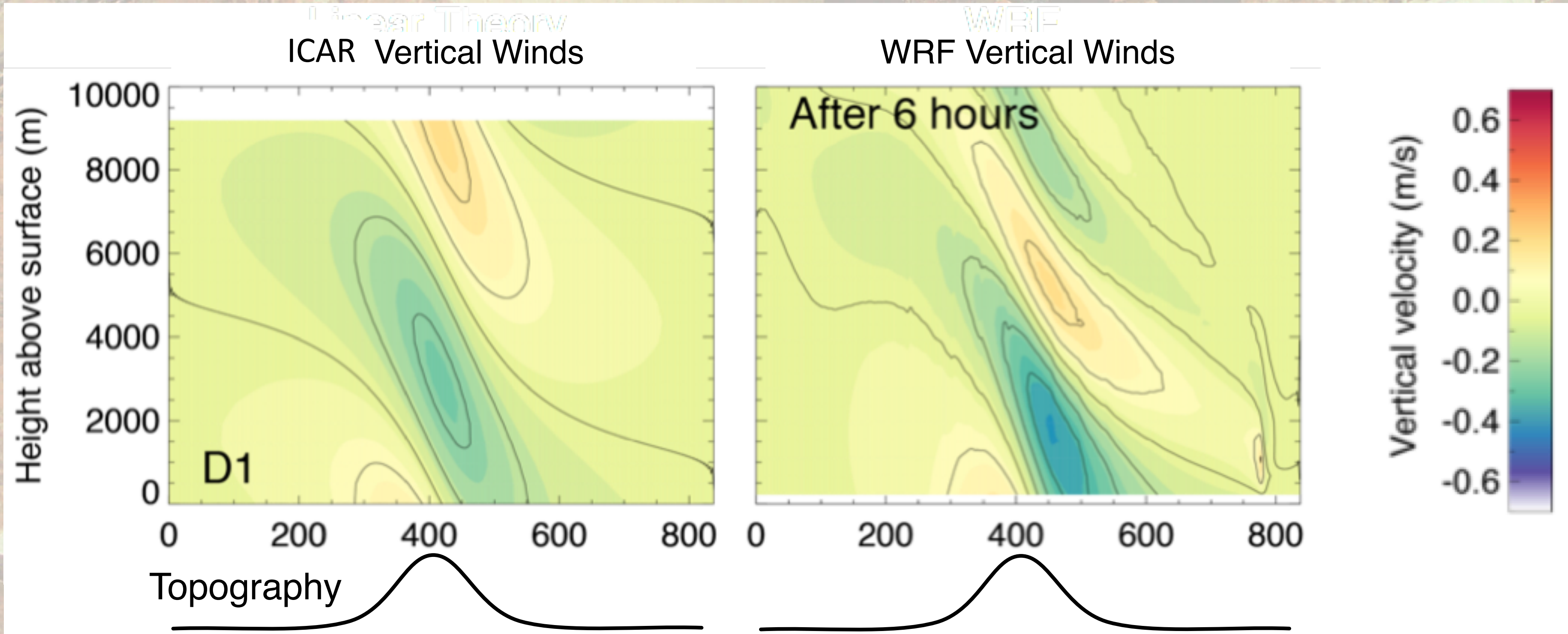
GOAL: >90% of the information for <1% of the cost



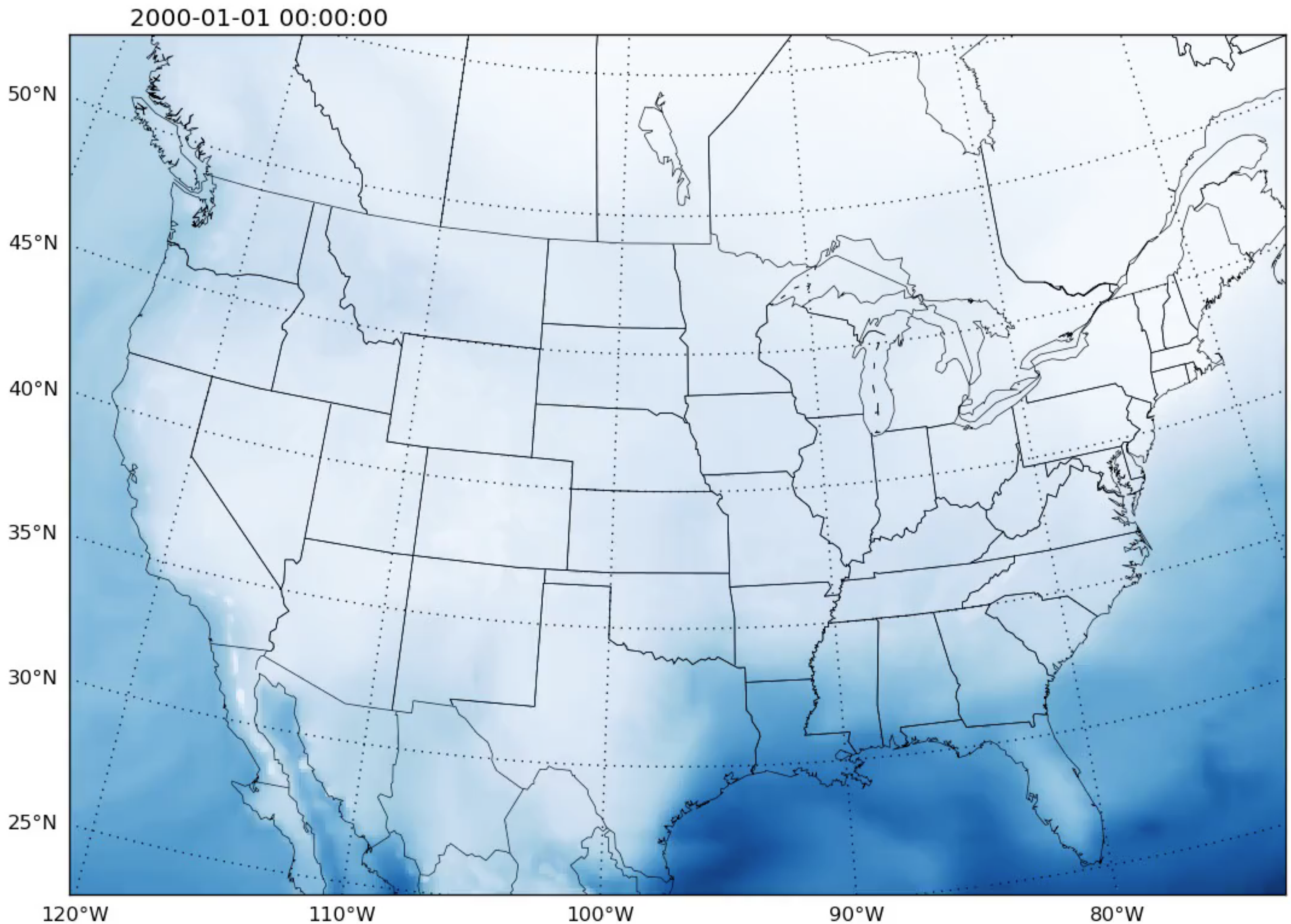
ICAR Dynamics

$$\hat{u}(k,l) = \frac{-m(\sigma k - ilf)i\hat{\eta}}{k^2 + l^2} \qquad \hat{v}(k,l) = \frac{-m(\sigma l + ikf)i\hat{\eta}}{k^2 + l^2}, \qquad \hat{w}(k,l) = i\sigma\,\hat{\eta}$$

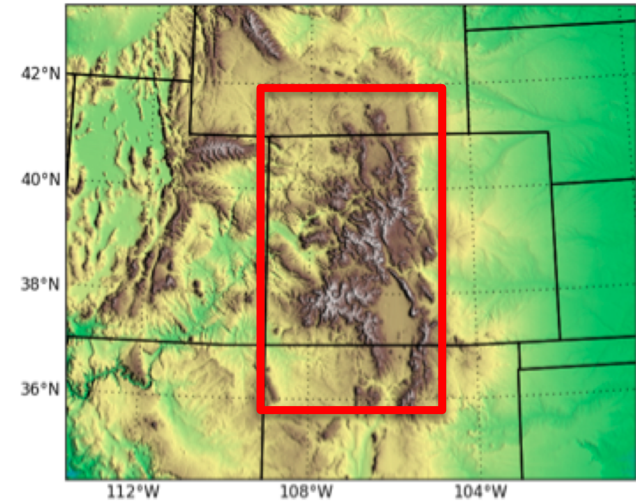
$$\hat{\eta}(k,l) = \hat{h}e^{imz}, \qquad m^2 = \frac{N^2 - \sigma^2}{\sigma^2 - f^2}(k^2 + l^2), \qquad \sigma = Uk + Vl$$



ICAR simulation



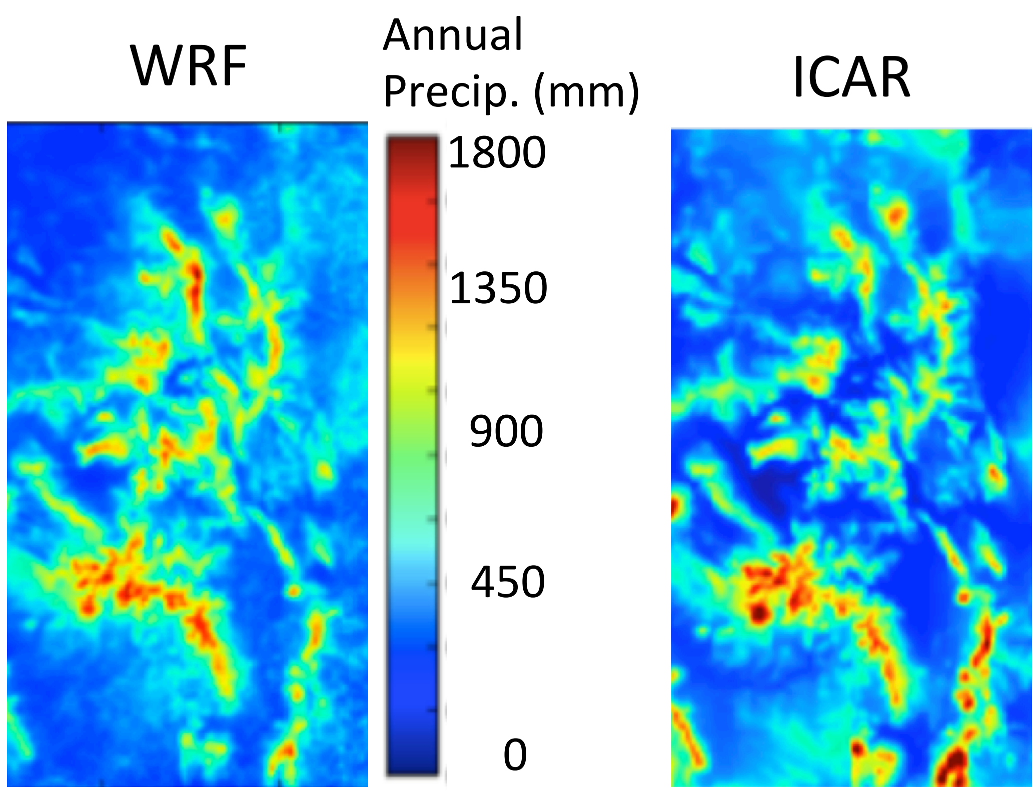
ICAR Precipitation Real Simulation



WRF and ICAR have very similar precipitation distributions.

ICAR requires 1-0.1% of the computational effort of WRF.

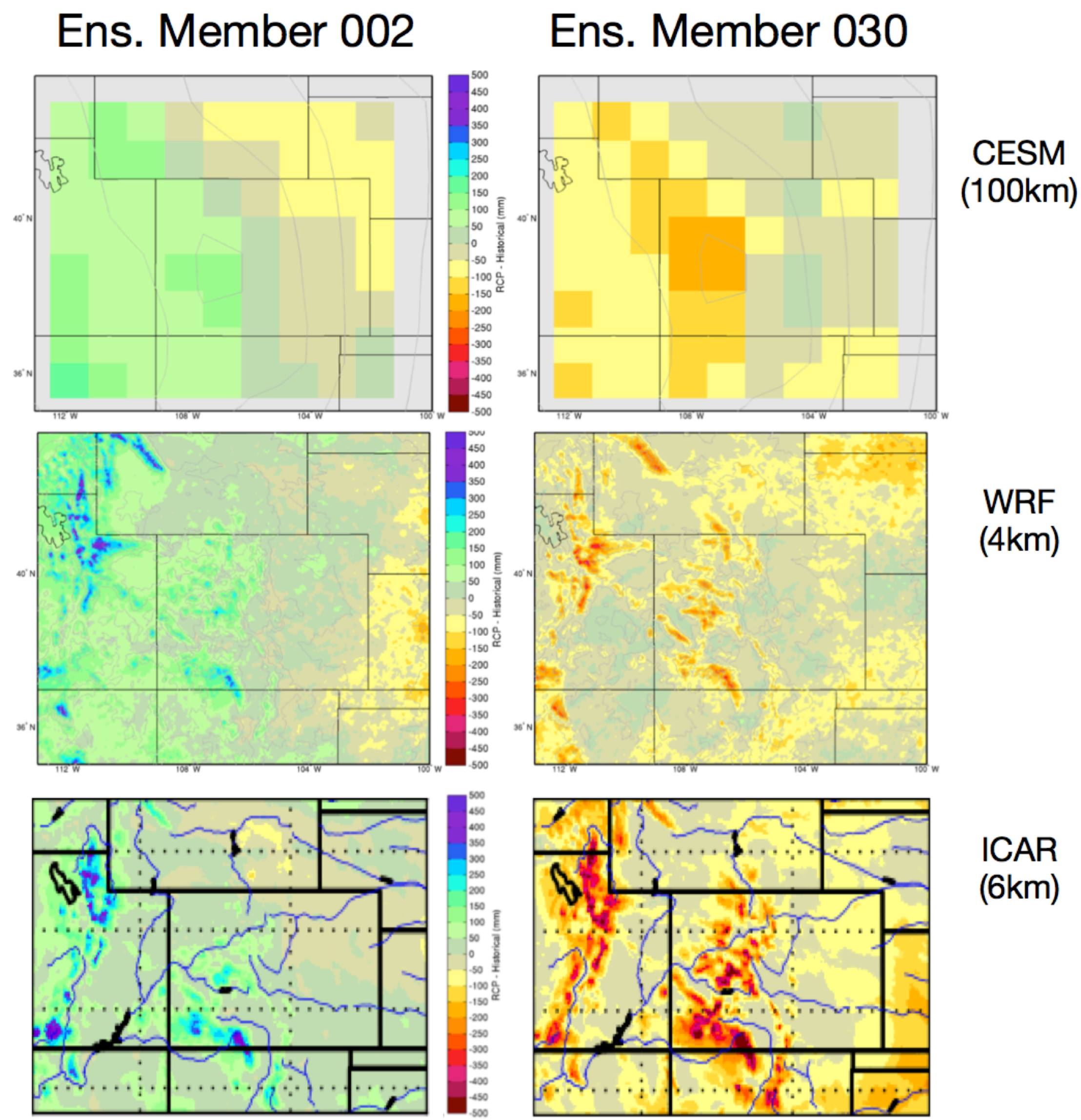
This enables a pseudo-dynamical downscaling for a wide variety of GCM / scenario combinations



(pre-bias correction)

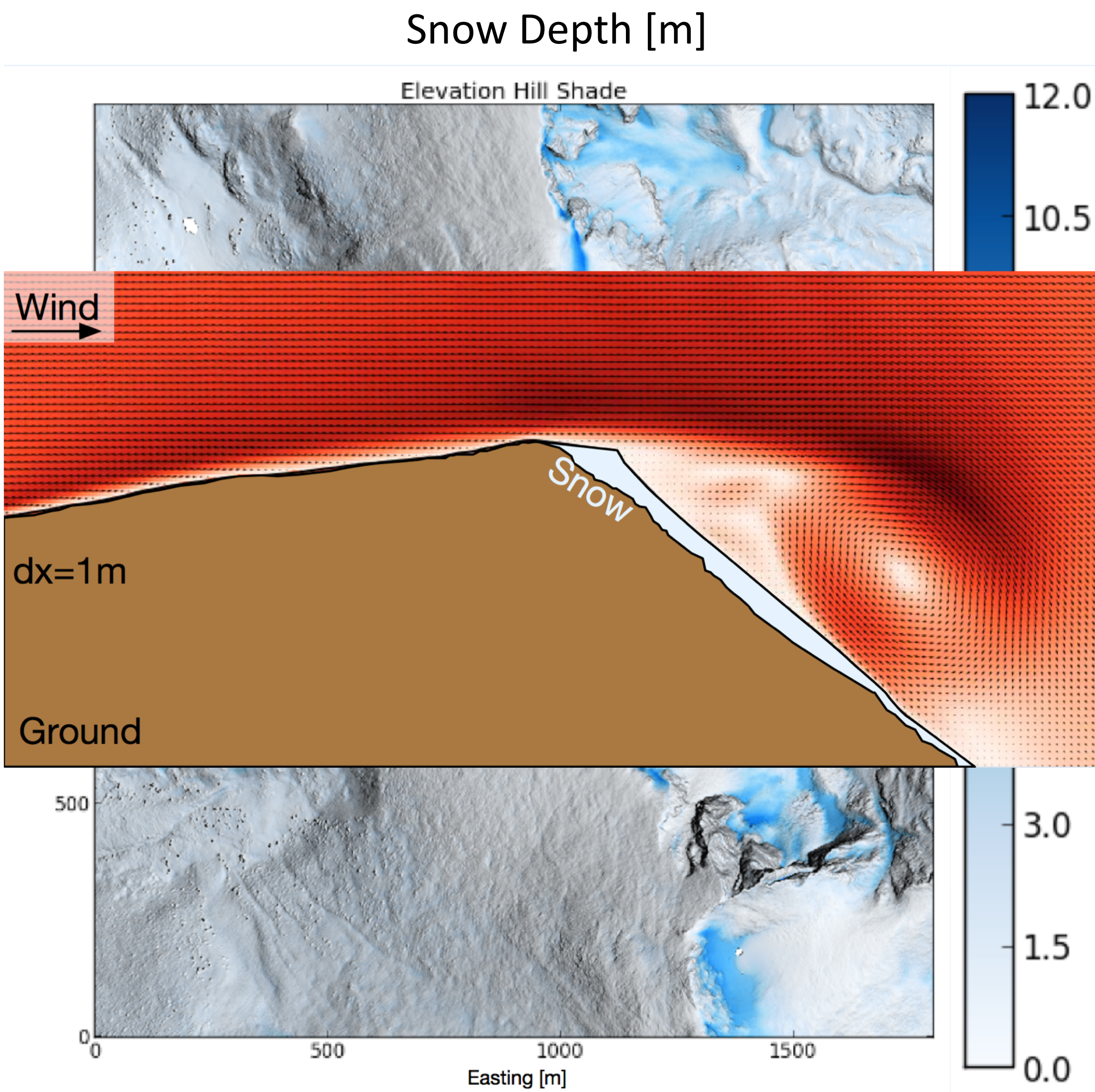
Change in Climate

- Can we know?
- Need to understand variability
- Prefer physically intuitive options
- Are methods that "match" WRF better?
- Can we develop metrics in current climate
  - Interannual variability?
  - Interdecadal?

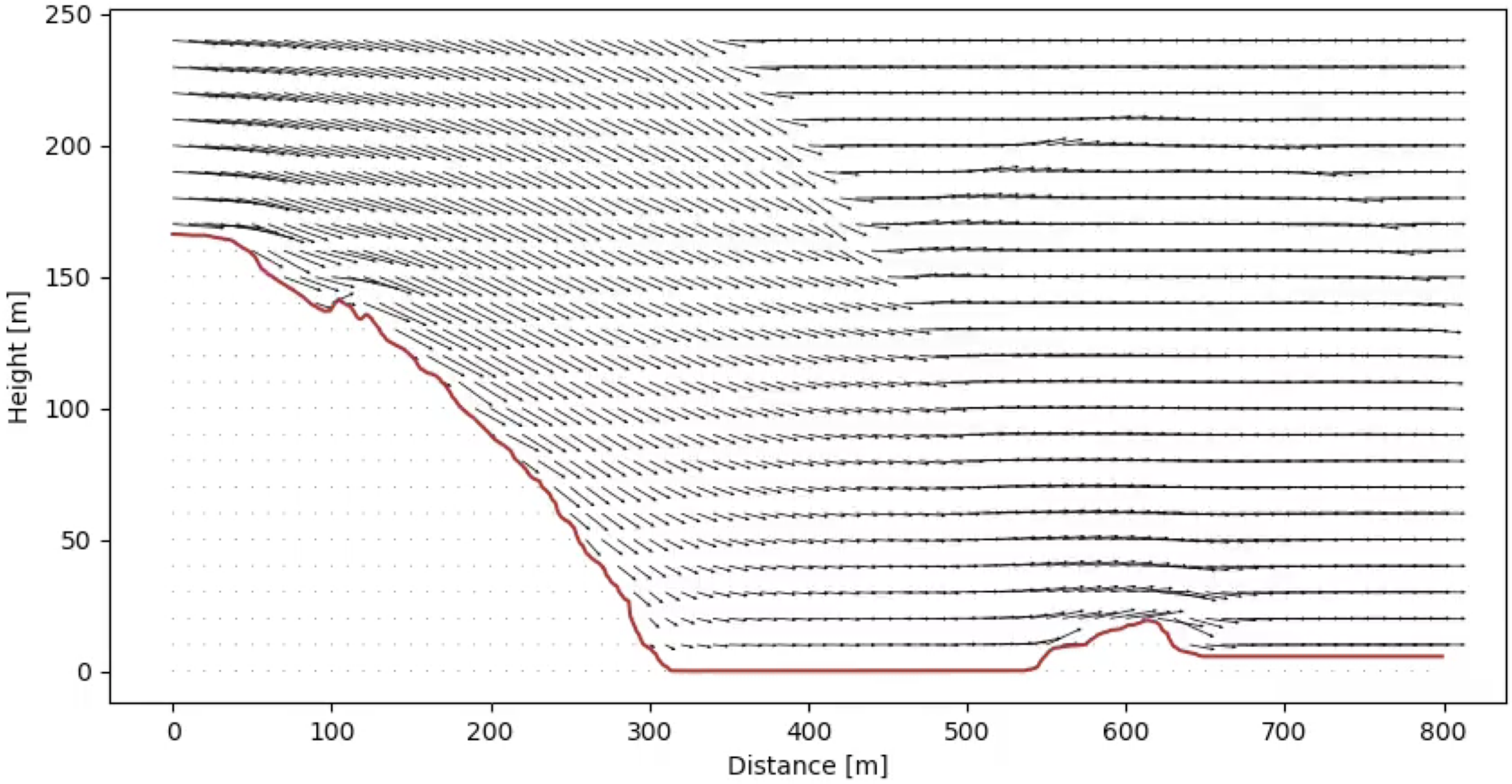


Extreme Downscaling

- Wind patterns dominate snow processes
- Investigating New modeling techniques to enable meter scale CFD wind model for snow
- Using Lattice Boltzmann method to represent complex boundaries accurately



Simulation over Complex Terrain



Dynamical vs. Statistical Downscaling

Statistical

Pros

- Computationally tractable
- Large high-resolution datasets available
- Consistent with observations

Cons

- May not represent climate change signal correctly
- Statistical nature often introduces artifacts
- Input data requirements

Dynamical

Pros

- No stationarity assumptions
- Physically consistent across variables
- Representation of physical processes

Cons

- Computationally demanding
- Available datasets are limited low-resolution
- Introduces need for additional ensembles
- …may not represent climate change signal correctly

Data Access

- Raw (non-downscaled) CMIP5 data:
  - Lawrence Livermore CMIP5 Data Portal
  - GCM data stumbling blocks
    - Noleap calendars
    - Rotated pole projections
    - Seemingly arbitrary vertical coordinates

- Downscaled data
  - Lawrence Livermore GDO
  - USGS geodata portal
  - CORDEX

RECLAMATION USGS

Santa Clara University CLIMATE CENTRAL

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections

This site is best viewed with Chrome (recommended) or Firefox. Some features are unavailable when using Internet Explorer. Requires JavaScript to be enabled.

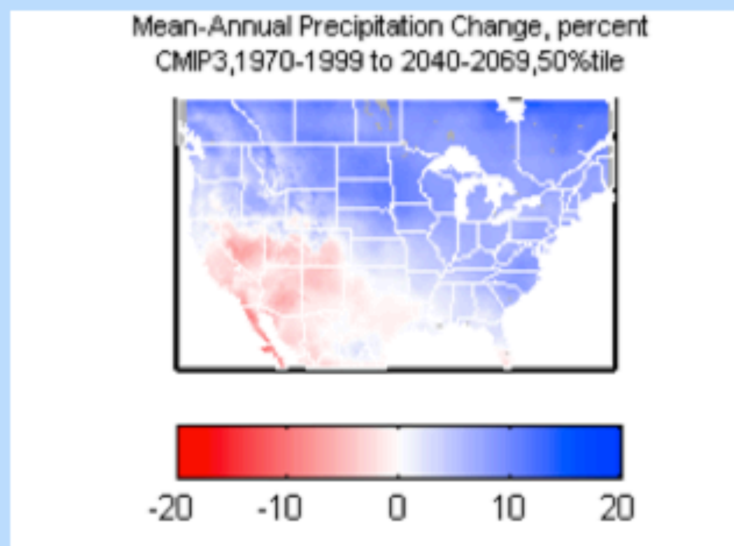
Welcome | **About** | **Tutorials** | **Projections: Subset Request** | **Projections: Complete Archives** | **Feedback** | **Links**

Downscaled CMIP5 climate projections' documentation and release notes available here.

Summary

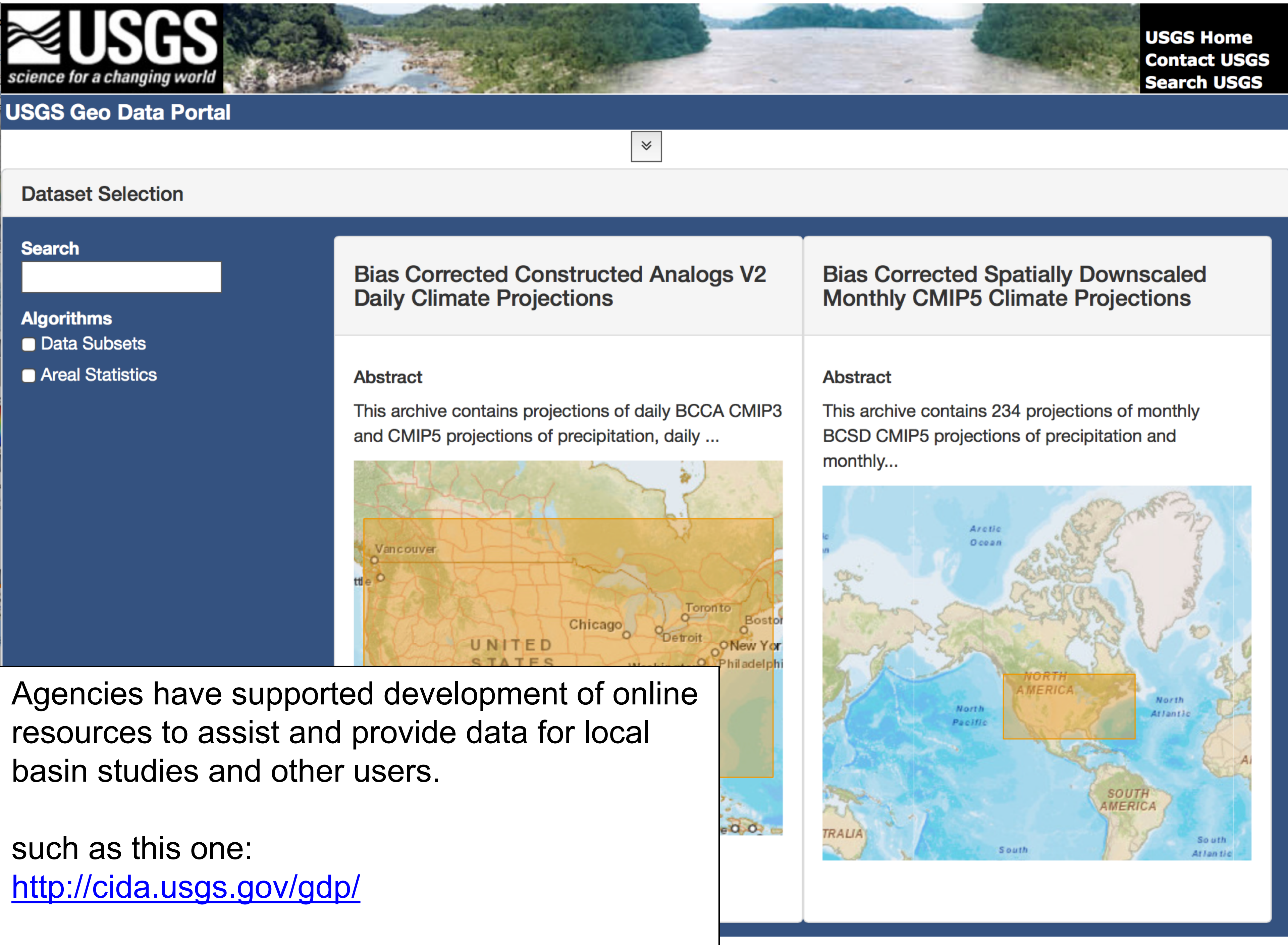
This archive contains fine spatial resolution translations of climate projections over the contiguous United States (U.S.) developed using two downscaling techniques (monthly BCSD Figure 1, and daily BCCA Figure 2), and hydrologic projections over the western U.S. (roughly the western U.S. Figure 3) corresponding to the monthly BCSD climate projections.

Figure 1. Central Tendency Changes in Mean-Annual Precipitation over the contiguous U.S. from 1970-1999 to 2040-2069 for BCSD3, BCSD5, and Difference.



Agencies have supported development of online resources to assist and provide data for local basin studies and other users.

such as this one:
http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/



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such as this one:
http://cida.usgs.gov/gdp/

https://rda.ucar.edu/datasets/ds612.0/

UCAR NCAR | Closures/Emergencies | Locations/Directions | Find People

Hello gutmann@ucar.edu (RDA) / gutmann (UCAS) dashboard sign out

NCAR UCAR Research Data Archive
Computational & Information Systems Lab

weather • data • climate

Go to Dataset: nnn.n

Home | Find Data | Ancillary Services | About/Contact | Data Citation | Web Services | For Staff

High Resolution WRF Simulations of the Current and Future Climate of North America

ds612.0 | DOI: 10.5065/D6V40SXP

For assistance, contact Chi-Fan Shih (303-497-1833).

Description | Data Access | Documentation

Help with this page: RDA dataset description page video tour

Abstract: The dataset is from a high resolution climate change simulation that permits convection and resolves mesoscale orography at 4 km grid spacing over much of North America using the Weather Research and Forecasting (WRF) model. Two 13 years simulations were performed, consisting of a retrospective simulation (October 2000 to September 2013) with initial and boundary conditions from ERA-Interim and a future climate sensitivity simulation with initial and boundary conditions derived from reanalysis and modified by adding the CMIP5 ensemble mean of the high emission scenario climate change.

Temporal Range: 2000-10-01 00:00 +0000 to 2013-09-30 23:00 +0000 (Entire dataset)
Period details by dataset product

Variables:

Air Temperature	Canopy Characteristics	Evapotranspiration	Geopotential Height
Land Surface Temperature	Longwave Radiation	Outgoing Longwave Radiation	Planetary Boundary Layer Height
Sea Surface Temperature	Shortwave Radiation	Skin Temperature	Snow Water Equivalent
Snow/Ice Temperature	Soil Moisture/Water Content	Soil Temperature	Surface Pressure
Surface Winds	Total Precipitable Water	Vertical Wind Velocity/Speed	Water Vapor

Variables by dataset product

Vertical Levels: See the detailed metadata for level information

Data Types: Grid

Spatial Coverage: Longitude Range: Westernmost=138.852W Easternmost=58.735W
Latitude Range: Southernmost=18.12N Northernmost=57.336N
Detailed coverage information

Data Contributors: UCAR/NCAR/RAP

How to Cite This Dataset: RIS BibTeX

Rasmussen, R., and C. Liu. 2017. *High Resolution WRF Simulations of the Current and Future Climate of North America.* Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D6V40SXP. Accessed† dd mmm yyyy.

†Please fill in the "Accessed" date with the day, month, and year (e.g. - 5 Aug 2011) you last accessed the data from the RDA.

Bibliographic citation shown in Federation of Earth Science Information Partners (ESIP) style

Get a customized data citation

https://na-cordex.org

WCRP CORDEX

NA-CORDEX

HOME

The North American CORDEX Program

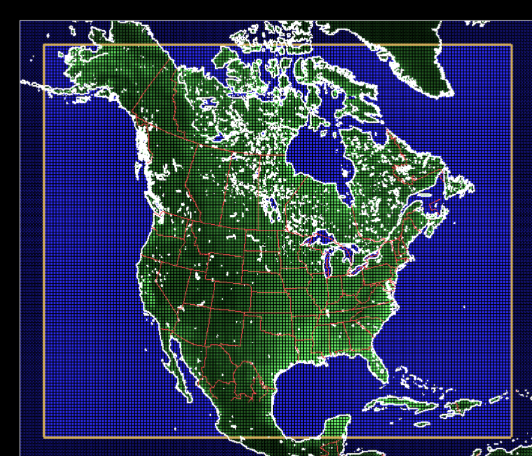
Regional climate change scenario data and guidance for North America, for use in impacts, decision-making, and climate science.

The NA-CORDEX data archive contains output from regional climate models (RCMs) run over a domain covering most of North America using boundary conditions from global climate model (GCM) simulations in the CMIP5 archive. These simulations run from 1950-2100 with a spatial resolution of 0.22°/25km or 0.44°/50km. Data is available for impacts-relevant variables at daily and longer frequencies in CF-compliant netCDF format.

SIMULATION MATRIX

	CRCM5 (UQAM)	CRCM5 (OURANOS)	RCA4	RegCM4	WRF	CanRCM4	HIRHAM5	RCP	ECS (°C)
ERA-Int	0.44° 0.22° 0.11°	0.44°	0.44°	50km 25km	50km 25km	0.44° 0.22°	0.44°		
HadGEM2-ES								4.5	4.6
				50km 25km	50km* 25km*			8.5	
CanESM2	0.44°		0.44°			0.44° 0.22°		4.5	3.7
	0.44° 0.22°	0.22°†	0.44°			0.44° 0.22°		8.5	
MPI-ESM-LR	0.44°							4.5	3.6
	0.22° 0.44°	0.22°†		50km* 25km*	50km 25km			8.5	
MPI-ESM-MR								4.5	3.4
	0.44° 0.22°							8.5	
EC-EARTH‡			0.44°					2.6	~3.3
			0.44°				0.44°	4.5	
			0.44°				0.44°	8.5	
GFDL-ESM2M								4.5	2.4
		0.22°†		50km 25km	50km* 25km*			8.5	
Access	PoC	PoC	ESGF	PoC	PoC	CCCma	ESGF		
Institution	UQAM	OURANOS	SMHI	Iowa State *NCAR	U Arizona *NCAR	CCCma	DMI		
Modeler	K. Winger	S. Biner	G. Nikulin	R. Arritt *M. Bukovsky	H-I Chang *M. Bukovsky	J. Scinocca	O. Christensen		

DOMAIN MAP



CORDEX-NA simulation domain, 0.44°/50km resolution

Downscaling Comments

- Higher-resolution does not mean more information
- Training data
  - If measurements are wrong/missing, what are you downscaling to?
- Changes in the mean
  - Is precipitation represented correctly in the physics?
    - Mountains? Convection? Monsoons? Atmospheric Rivers?
  - Is air temperature?
    - Where is the coast in the model? Snowpack? Cold air pools?
- Changes in extremes
  - Statistical methods often extrapolating past anything they are trained on
- Evaluate different methods
  - All are wrong, but some are useful

A Dose of Humility

- There is a tendency to think
  - model agreement = model accuracy
- We all know this isn't true
  - though we like to believe it anyway
- Then how do you evaluate downscaling methods?

Alternative Approach(es)

- Delta change takes historical weather and perturbs (sensitivity test)

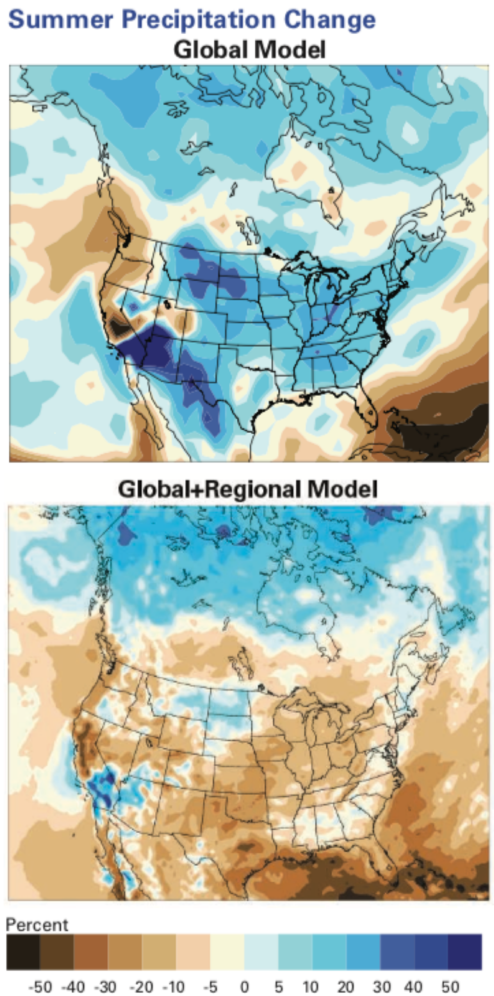
  +/-20% precip

  +2 - +6°C

- Pseudo-Global Warming (PGW) dynamical downscaling vs directly downscaling
  - Caution on individual extreme events and chaos

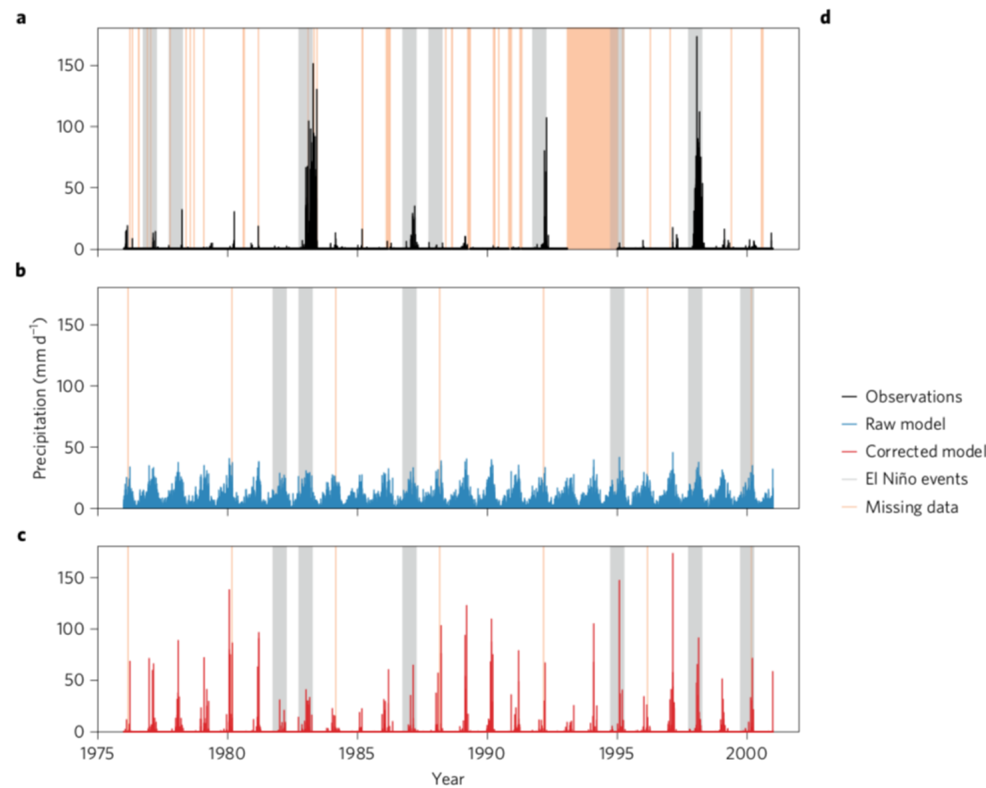
- Start with the question, can you learn something about expected changes in weather that can inform your work without downscaling/modeling?

Cautionary tales



Kerr et al 2011 *Science*

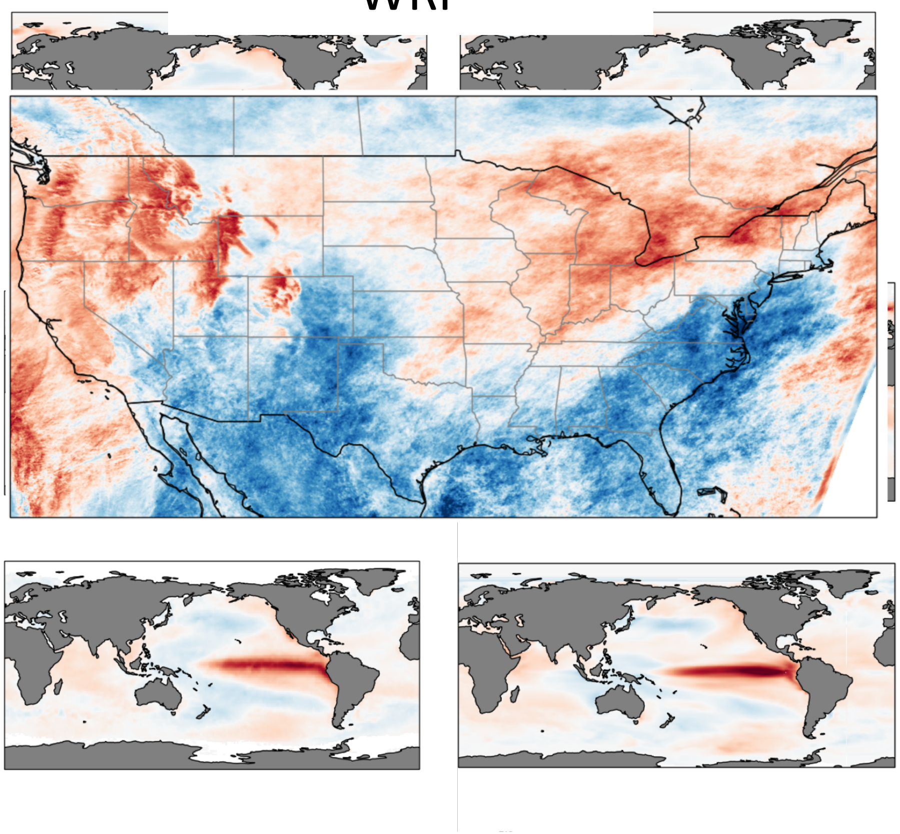
Statistical methods don't add physical processes
RCMs can completely change the signal
If GCM circulation is wrong, what good is downscaling?



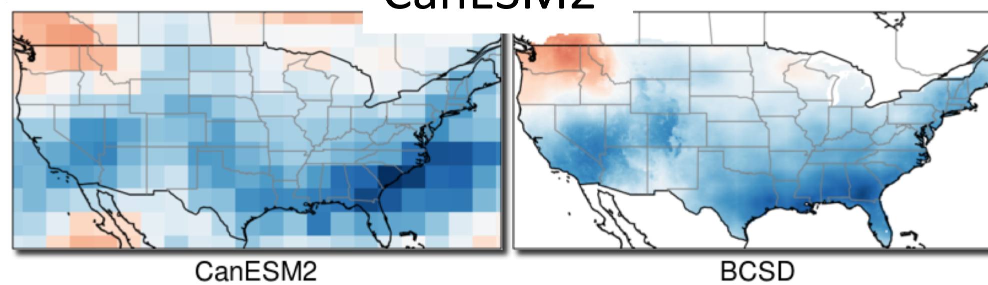
Maraun et al (2017) *Nature Climate Change*

Evaluating Downscaling Methods Variability and Regional Precipitation

WRF

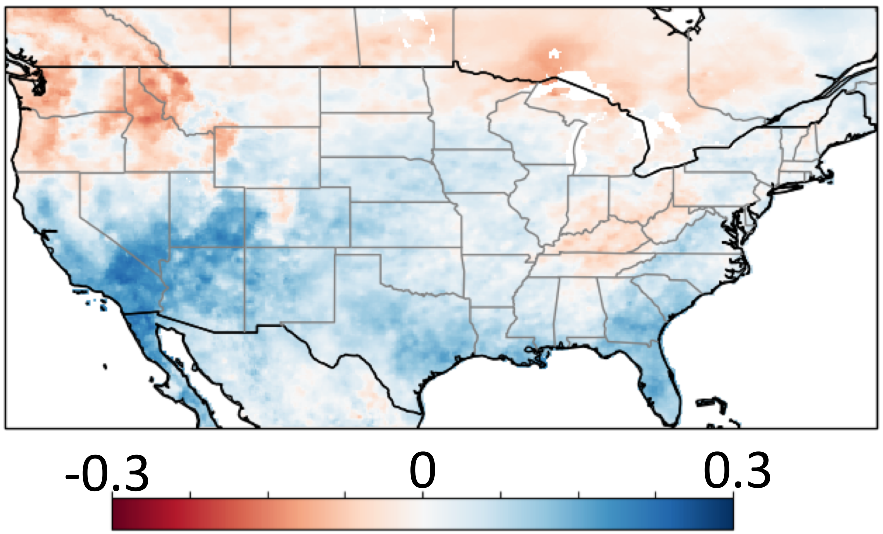


CanESM2



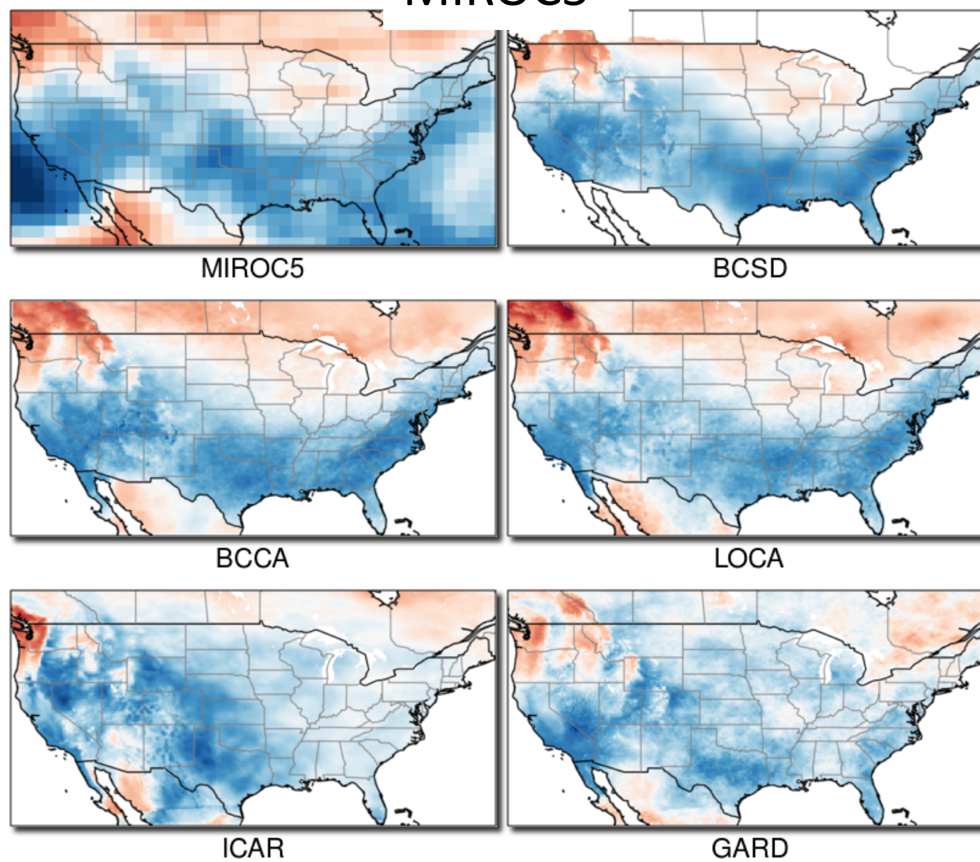
Variability and Regional Precipitation

Observed
ENSO - Precipitation

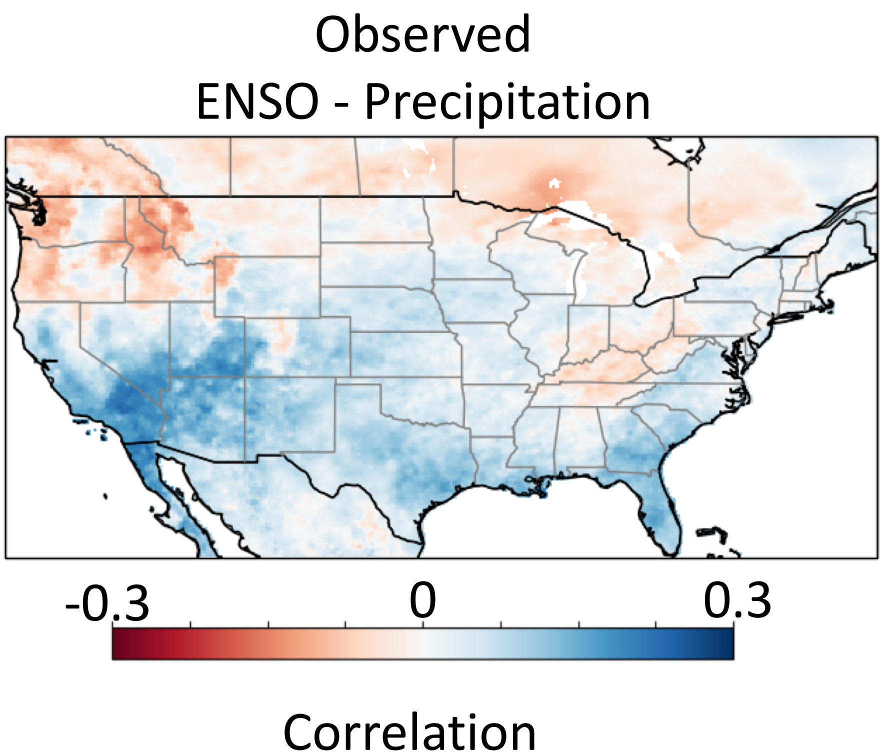


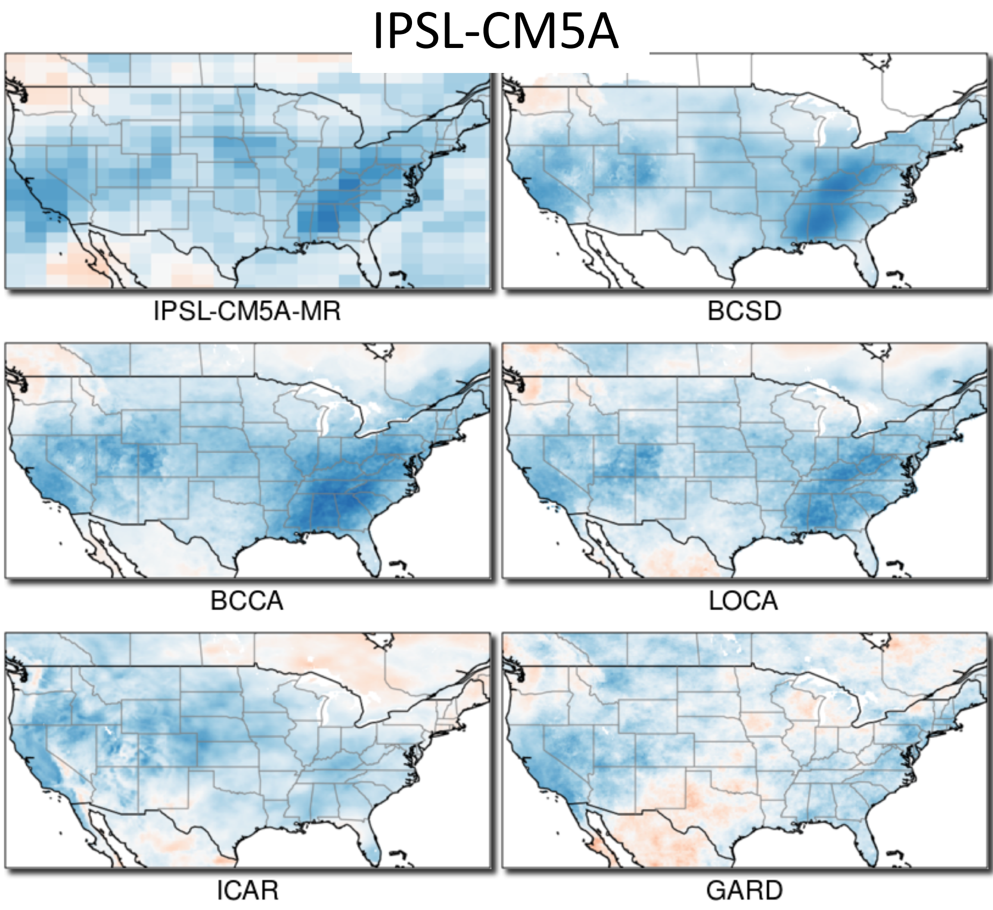
Correlation

MIROC5



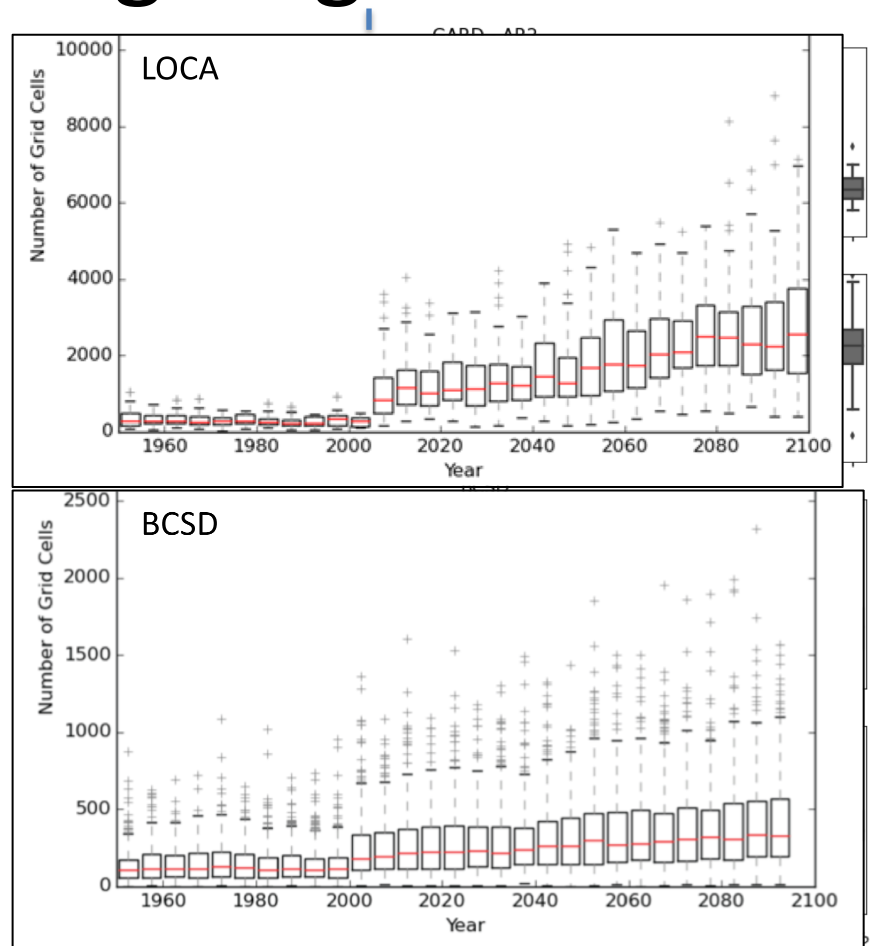
Variability and Regional Precipitation





Evaluating Downscaling Methods Expected Change Signals

- Testing the number of grid cells which have their most extreme precip in a 5yr period
- MOS: Frequency of extreme events increases sharply in 2005 (LOCA)
- Perfect-prog: Frequencies don't change in the future (En-GARD)



Practical

- Data on Blanca / Summit
- Temporary logins provided
- Code available (and pre-compiled)
- Input and Outputs available

A note on data files

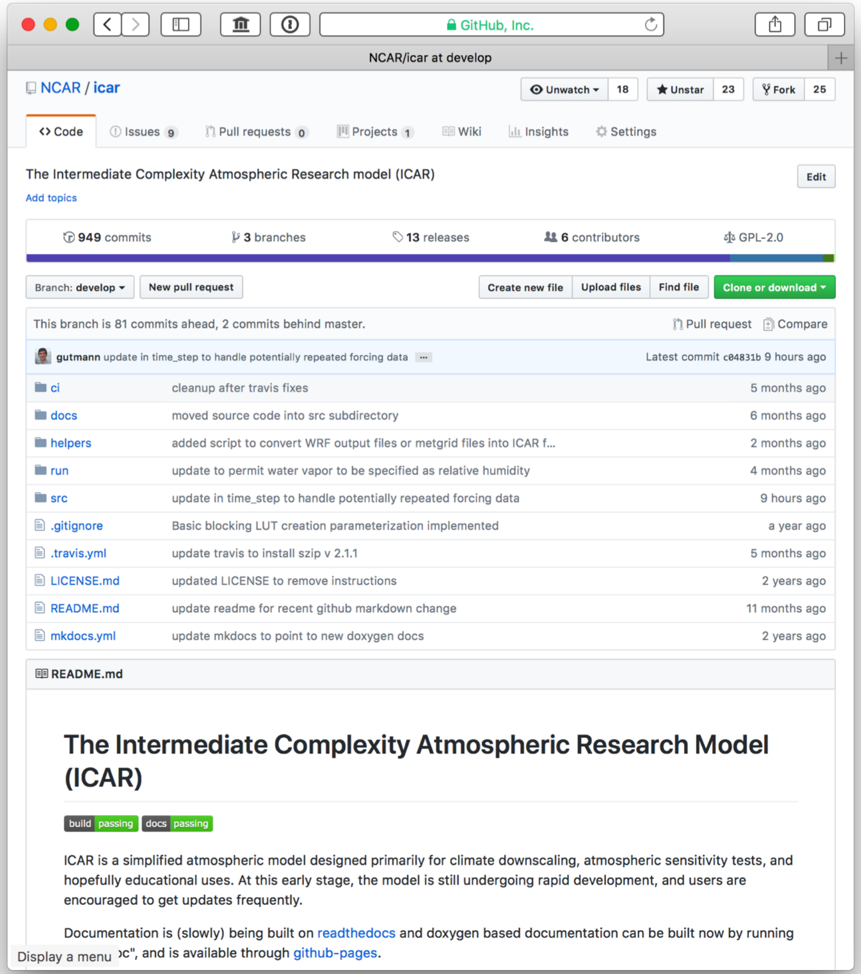
- All data are in gridded NetCDF files
- NetCDF (Network Common Data Format)
  - self-describing machine independent binary format
- Most are CF Compliant (Climate and Forecast)
  - Metadata standard
  - Defines variable attributes, coordinate conventions

En-GARD and ICAR source code available

- Code is available
  - ICAR: Gutmann et al (2016) JHM
  - En-GARD: Gutmann et al (in prep)
  - Documentation online, but feel free to get in touch

Funding provided by

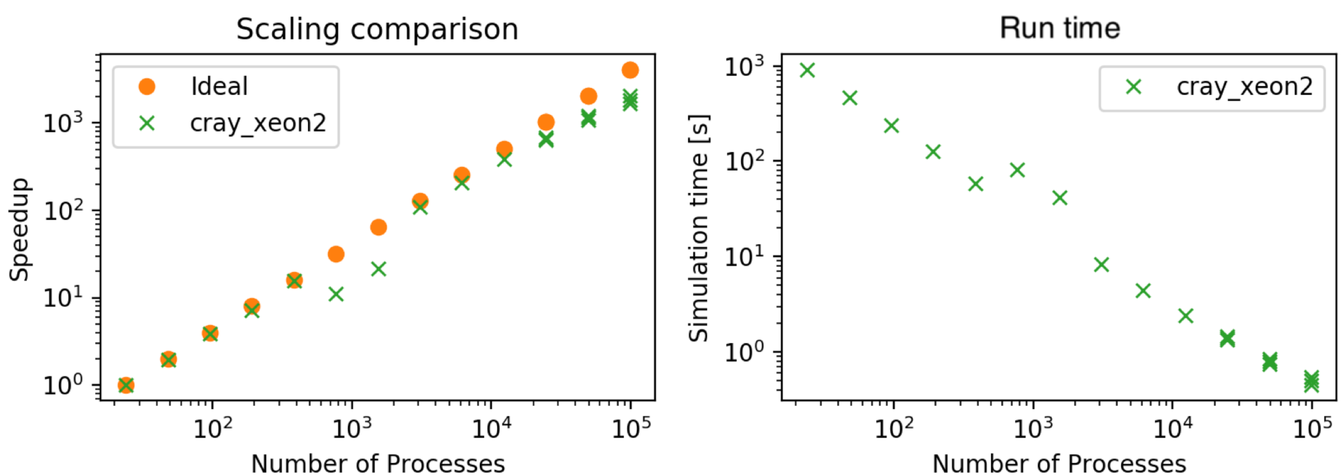
- USACE Climate Resilience and Preparedness Program
- US Bureau of Reclamation
- NASA AIST
- NCAR Water System Program (NSF)



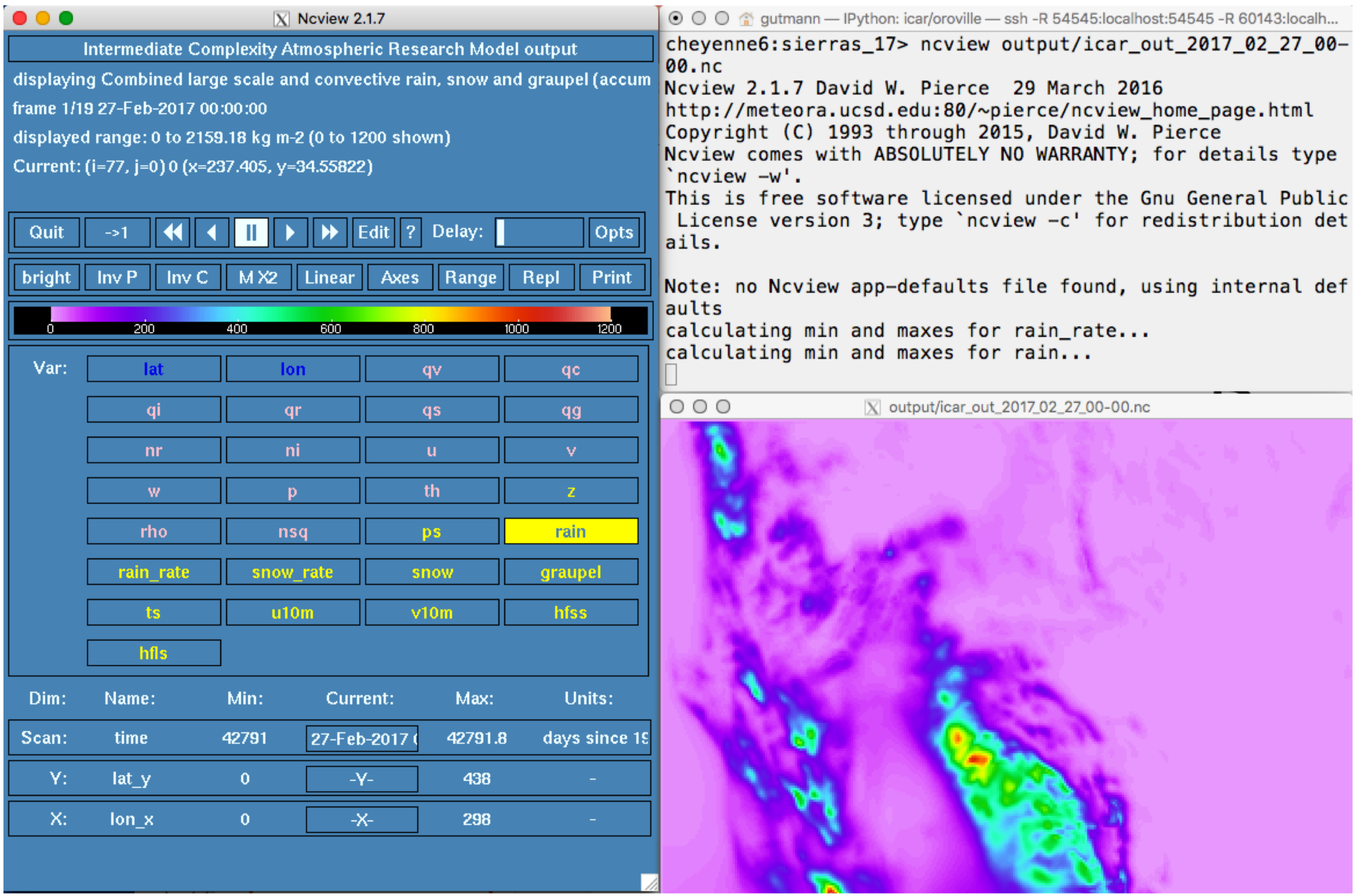
ICAR

- Data available :
  - /scratch/summit/gutmann/icar/sierras/output
- Visualize with your favorite viewer
  - Python, IDL, Matlab, …
  - ncview, panoply,...
- Example Input files available one level up

- Comp
  - Cu
    pa
    co



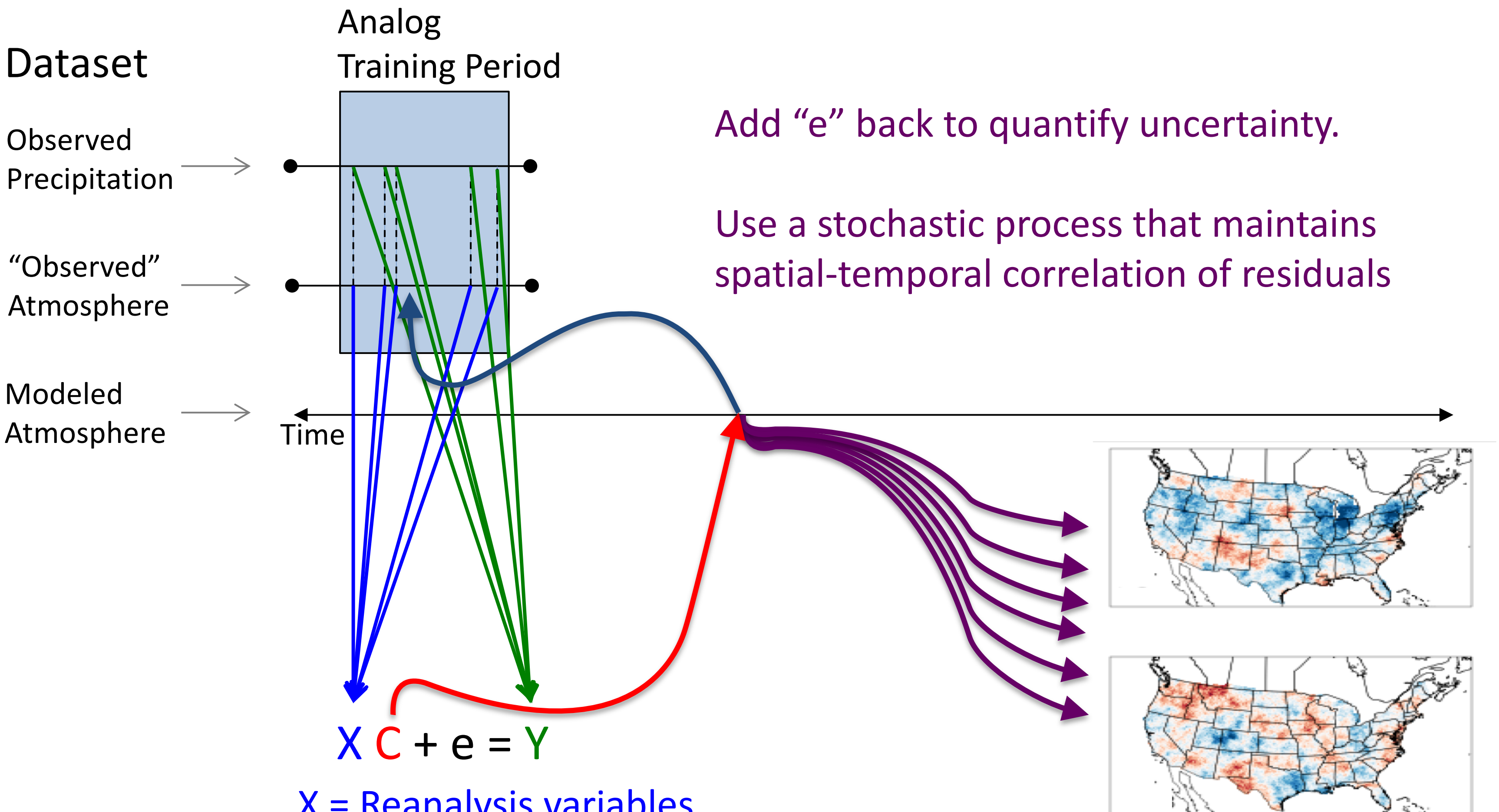
Demo



Ncview 2.1.7
Intermediate Complexity Atmospheric Research Model output
displaying Combined large scale and convective rain, snow and graupel (accum
frame 1/19 27-Feb-2017 00:00:00
displayed range: 0 to 2159.18 kg m-2 (0 to 1200 shown)
Current: (i=77, j=0) 0 (x=237.405, y=34.55822)
Quit
->1
Edit
?
Delay:
Opts
bright
Inv P
Inv C
M X2
Linear
Axes
Range
Repl
Print
0
200
400
600
800
1000
1200
Var:
lat
lon
qv
qc
qi
qr
qs
qg
nr
ni
u
v
w
p
th
z
rho
nsq
ps
rain
rain_rate
snow_rate
snow
graupel
ts
u10m
v10m
hfss
hfls
Dim: Name: Min: Current: Max: Units:
Scan: time 42791 27-Feb-2017 42791.8 days since 19
Y: lat_y 0 -Y- 438 -
X: lon_x 0 -X- 298 -
gutmann — IPython: icar/oroville — ssh -R 54545:localhost:54545 -R 60143:localh...
cheyenne6:sierras_17> ncview output/icar_out_2017_02_27_00-00.nc
Ncview 2.1.7 David W. Pierce 29 March 2016
http://meteora.ucsd.edu:80/~pierce/ncview_home_page.html
Copyright (C) 1993 through 2015, David W. Pierce
Ncview comes with ABSOLUTELY NO WARRANTY; for details type `ncview -w'.
This is free software licensed under the Gnu General Public License version 3; type `ncview -c' for redistribution details.
Note: no Ncview app-defaults file found, using internal defaults
calculating min and maxes for rain_rate...
calculating min and maxes for rain...
output/icar_out_2017_02_27_00-00.nc

En-GARD: Ensemble Generalized Analog Regression Downscaling

http://github.com/NCAR/gard



Add “e” back to quantify uncertainty.

Use a stochastic process that maintains spatial-temporal correlation of residuals

X C + e = Y

X = Reanalysis variables

C = Regression coefficients

e = error term

Y = Observed variable (e.g. precipitation)

Residuals of regression, Spread in analogs, …

Gutmann et al (in prep)
Clark and Hay (2004)

En-GARD Exercise

- Input data available :
  - /scratch/summit/gutmann/gard/colorado

  Training
    - ERAi (+ WRF 50km)
    - Obs (Maurer 02)

  GCM :
    - CCSM4 (+ WRF 50km)
- Things to test:
  - Variable selection
  - Algorithm selection
  - Parameter selection

Demo

```
ssh -Y user0060@tlogin1.rc.colorado.edu
ssh -Y scompile
sinteractive --nodes=1 --ntasks=24

module load intel
module load netcdf mkl ncview

cd /projects/${USER}
cp -r /scratch/summit/gutmann/gard/colorado/ ./
cd colorado

export OMP_NUM_THREADS=24
./gard downscale_options.txt

export PATH="/projects/gutmann/anaconda3/bin:$PATH"
./post_proc_gard.py
```

En-GARD Exercise Suggestions

- Start with basic simulation
  - Does your output match that provided?

  ./gard downscaling_options.nml

  ./post_proc.py
- Modify one parameter

  Change T2 variable to Q2 in namelist

  Change pure_analog=true to false **and** analog_regression from false to true
  - How do individual days change?
  - How does climatology (e.g. time average) change?
  - How does the future change signal change?
- Modify more parameters…

En-GARD Report back

- What did you change
- How did that effect the simulations?

WRF Tutorial

http://www2.mmm.ucar.edu/wrf/OnLineTutorial/index.htm

WRF ARW OnLineTutorial

Home | Introduction | Compilation | Basics | Case Studies | Graphics | Tools | Data

Welcome to the WRF ARW Online Tutorial

Users

- This tutorial has been designed to take you through the **WRF ARW** programs, step by step. Simply follow the ▶ at the bottom of each page to continue.
- Some of the links on these pages are mouse-over's, specifically in the namelist pages. Example.
  If these do not work, please enable Java on your computer.
  If the mouse-over links stop working, please refresh your screen.
- We recommend that you work through this tutorial before you try to run **WRF ARW** on your own.
- If you plan on attending one of our biannual tutorials in Boulder, we recommend that you work through this online tutorial before attending the tutorial.
- The most current WRF release is version 3.8.1. Please refer to WRF Model 3.8.1 Updates for more information on new Physics, Nudging, Adaptive Time Stepping, Dynamics, Initialization, and Software options since Version 2.

Look out for the following signs indicating:

- References
- Tips / Hints
- Recommendations
- Things did not go as planned - what now?