Challenges in translating climate projection for (water) adaptation planning

E.P. Maurer

IGIM CMIP meeting
College Park, MD
October 4, 2012

A well-meaning hydrologist walks into a climate change study…

Estimating Climate Impacts to Water

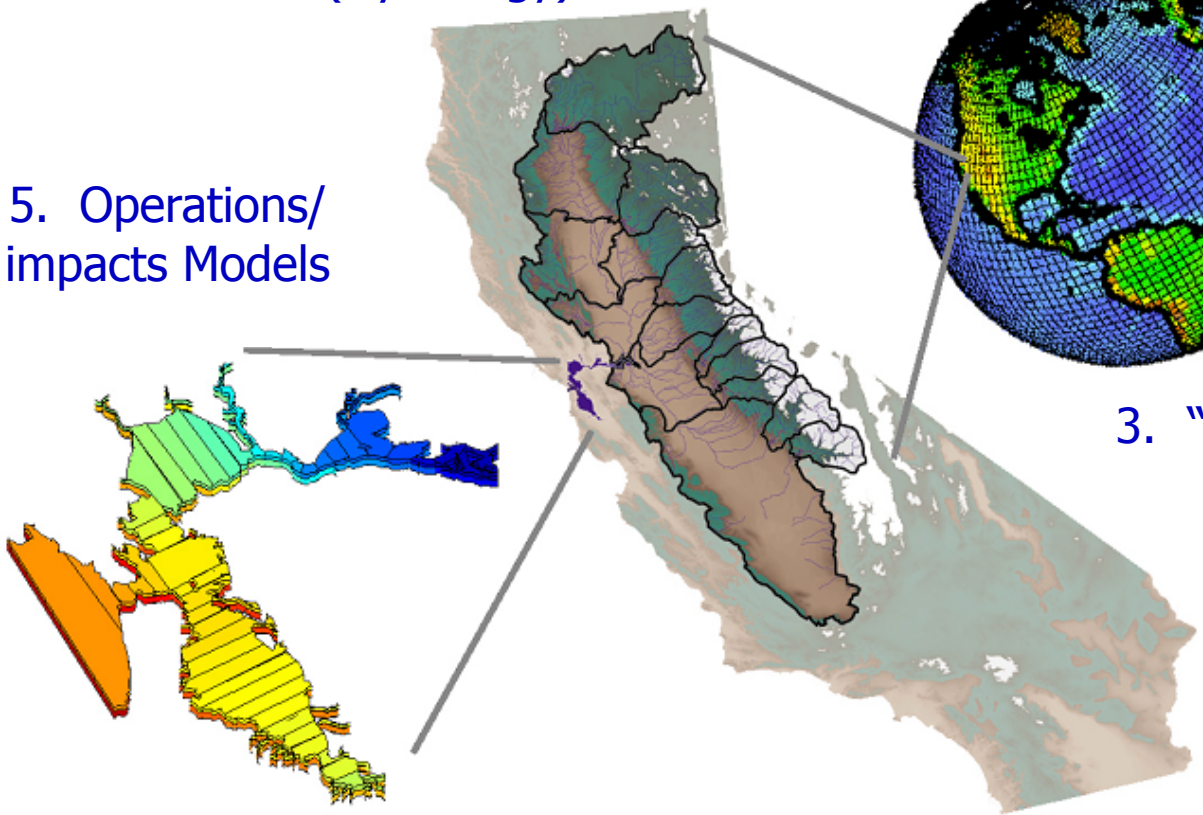
1. GHG Emissions Scenario

2. Global Climate Model

3. "Downscaling"

4. Land surface (Hydrology) Model

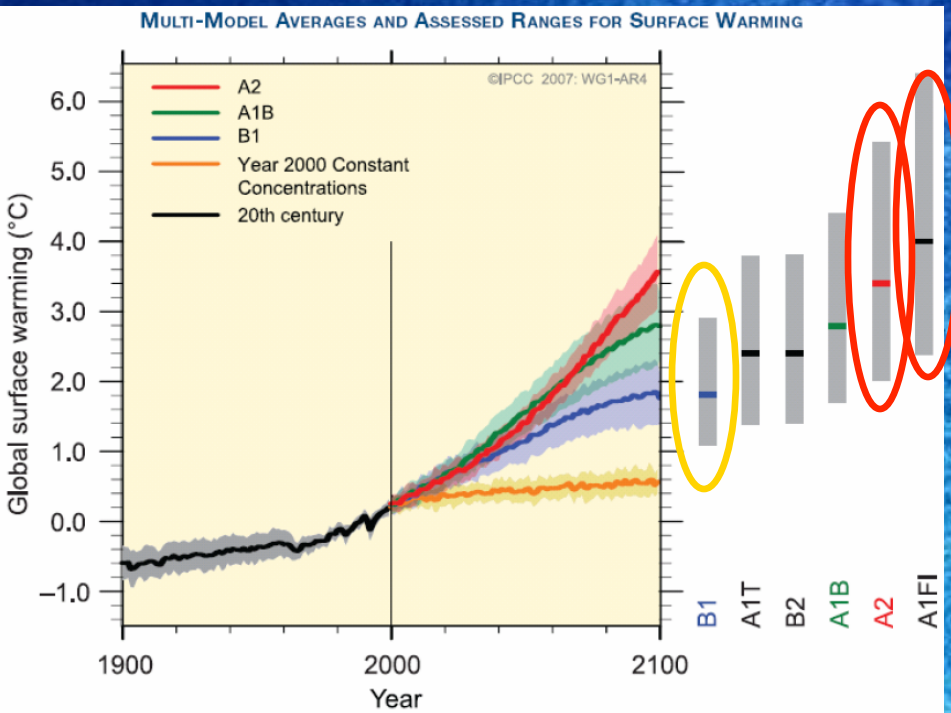
5. Operations/ impacts Models



Adapted from Cayan and Knowles, SCRIPPS/USGS, 2003

Selecting GCM runs: "Bookends"

- Brackets range of uncertainty
- Useful where impacts models are complex
- Downscale output from few GCMs



AOGCM	Equilibrium climate sensitivity (°C)
1: BCC-CM1	n.a.
2: BCCR-BCM2.0	n.a.
3: CCSM3	2.7
4: CGCM3.1 (T47)	3.4
5: CGCM3.1 (T63)	3.4
6: CNRM-CM3	n.a.
7: CSIRO-MK3.0	3.1
8: ECHAM5/MPI-OM	3.4
9: ECHO-G	3.2
10: FGOALS-g1.0	2.3
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12: GFDL-CM2.1	3.4
13: GISS-AOM	n.a.
14: GISS-EH	2.7
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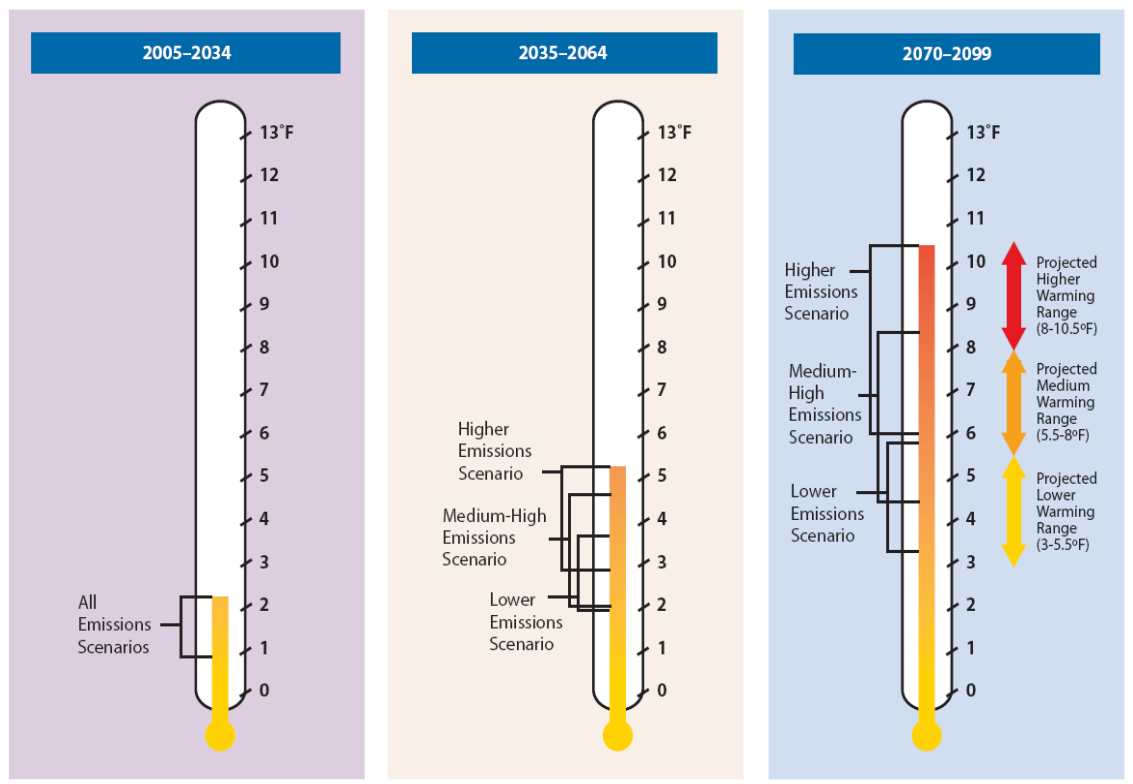
17: IPSL-CM4	4.4
18: MIROC3.2(hires)	4.3
19: MIROC3.2(medres)	4.0
20: MRI-CGCM2.3.2	3.2
21: PCM	2.1
22: UKMO-HadCM3	3.3
23: UKMO-HadGEM1	4.4

Bookend results for California

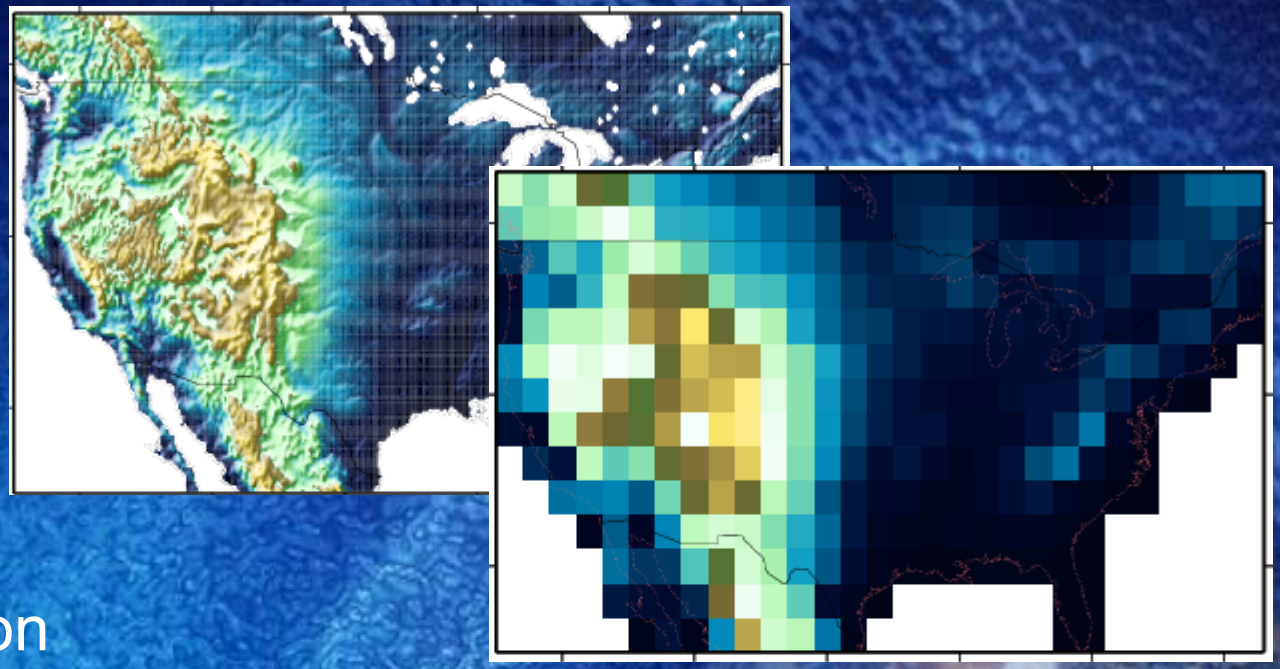
- CA average annual temperatures for 3 30-year periods
- Amount of warming depends on our GHG emissions at end of 21st century.
- Summer temperatures increases (end of 21st century) vary widely:
  - Lower: 3.5-6 °F
  - Higher: 6-10.5 °F



Ref: Luers et al., 2006, CEC-500-2006-077
and Cayan et al., 2006, CEC-500-2005-203-SF

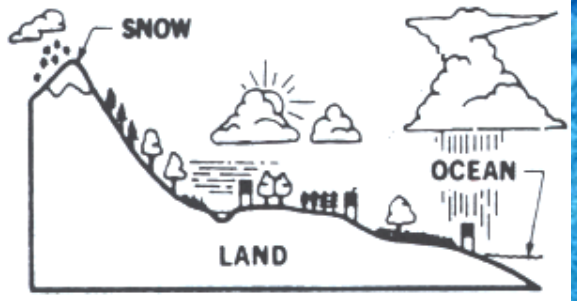
Downscaling: bringing global signals to regional scale

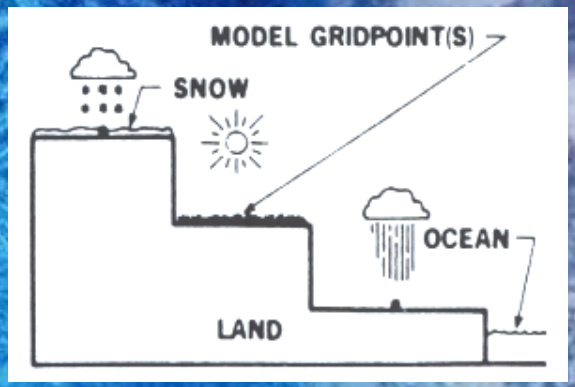
- GCM scale and processes at too coarse a scale



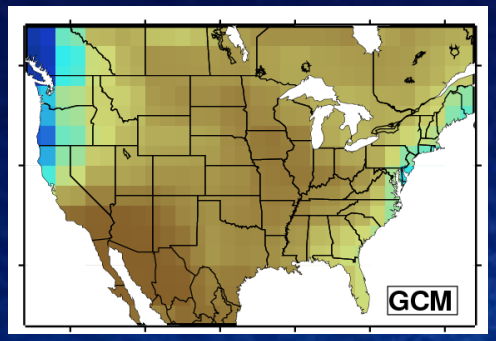
- Resolved by:
  - Bias Correction
  - Spatial Downscaling

Figure: Wilks, 1995

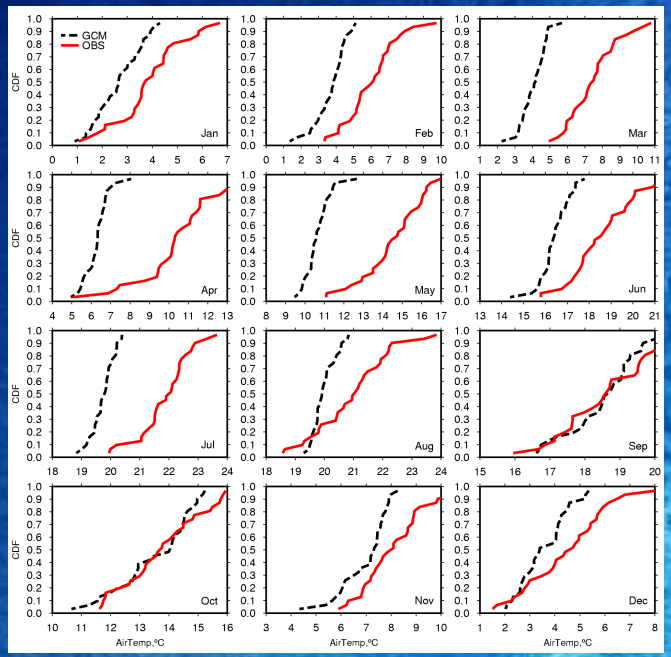




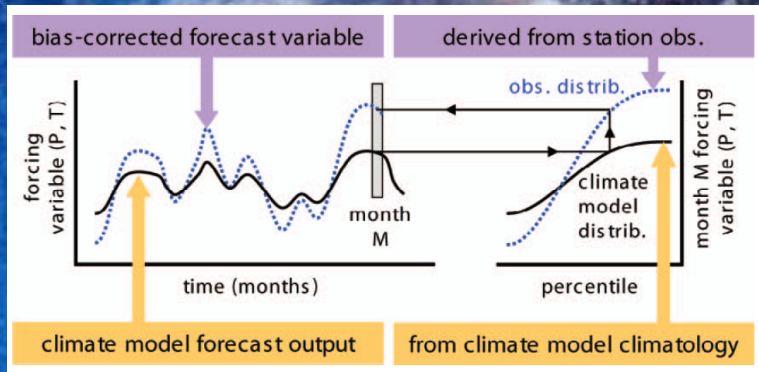
BCSD Method – "BC"



- At each grid cell for "training" period, develop monthly CDFs of P, T for
  - GCM
  - Observations (aggregated to GCM scale)
  - *Obs are from Maurer et al. [2002]*
- Use quantile mapping to ensure monthly statistics (at GCM scale) match obs
- Apply same quantile mapping to "projected" period

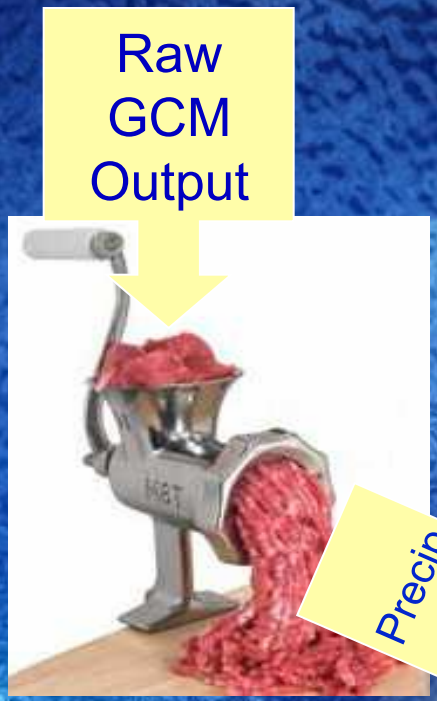


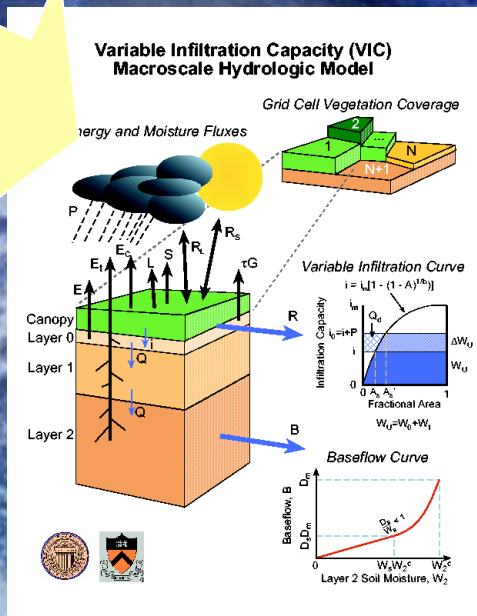
Wood et al., BAMS 2006



Downscaling for Hydrology Impact Modeling

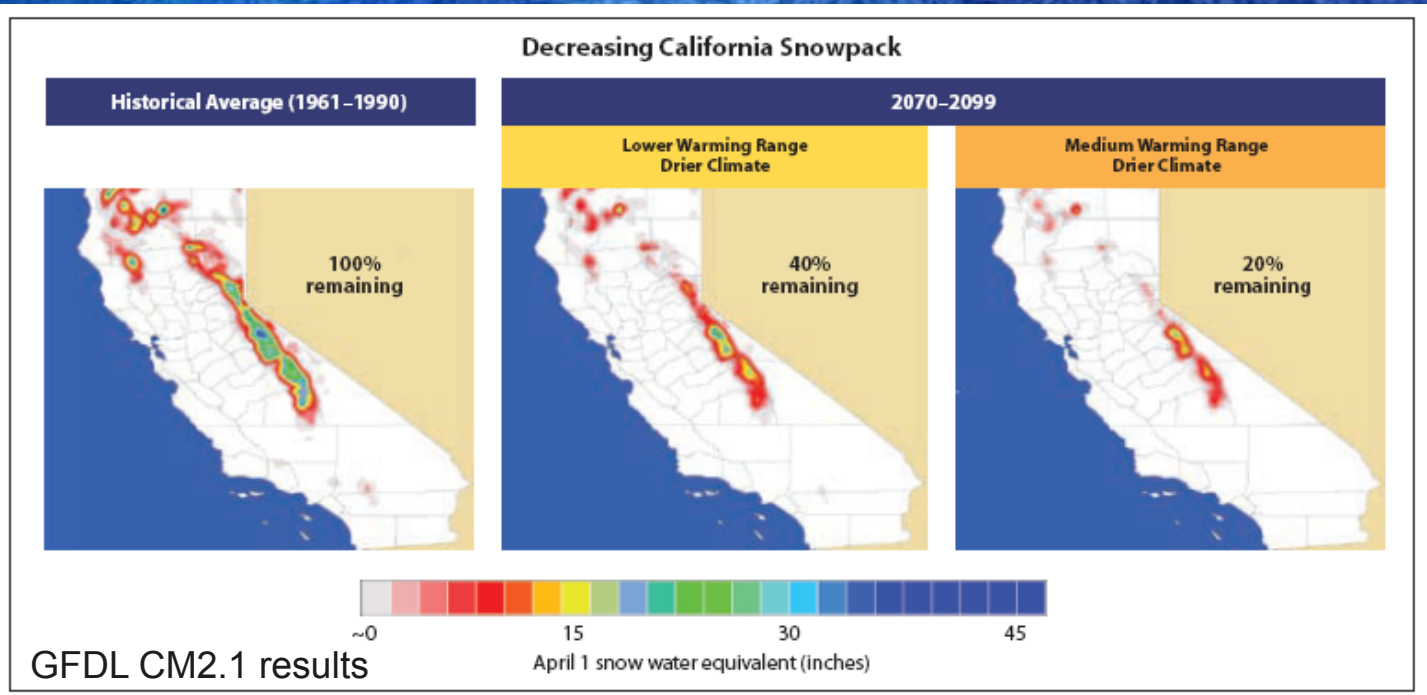
- BCSD downscaling of GCM Precip and Temp
- Use to drive VIC model
- Obtain runoff, streamflow, snow





Projected Impacts: Loss of Snow

- Snow water in reserve on April 1
- Change (Sacramento-San Joaquin basin, 2 GCMs, 2 emissions scenarios):
  - -12% to -42% (for 2035–2064) (up to 1 Lake Shasta)
  - -32% to -79% (for 2070–2099) (up to 2 Lake Shastas)



Ref: Luers et al., 2006, CEC-500-2006-077

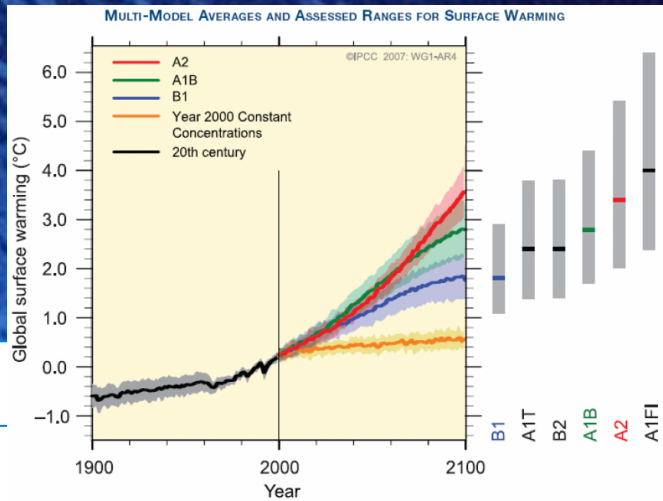
Some Agency and Organizational Responses

World Federation of Engineering Organizations (2009)	To develop and implement engineering tools, policies and practices for risk assessment and adaptation of existing and new civil infrastructure to climate change
Water Utility Climate Alliance (CAP, Denver Water, MWD, NYC DEP, SFPUC and others)	Collaborating on climate change issues affecting drinking water utilities.
Federal Climate Change and Water Working Group (Reclamation, USACE, NOAA and USGS) (2008)	Helping the water management community adapt practices as climate changes
ASCE - Committee on Adaptation to a Changing Climate (2010)	Encourage assessments of the built and natural environment to find and quantify vulnerabilities … and incorporate updated criteria into engineering practice
California Climate Action Team - Water-Energy Team (2005)	Coordinating GHG emission reduction and adaptation actions affecting energy that supports the storage, transport and delivery of water
Santa Clara Valley Water District	Climate change addressed in watershed and flood control planning

Background: Confederation Bridge in the Gulf of Saint Lawrence (http://www.cakex.org)

IPCC CMIP3 GCM Simulations

- 20th century through 2100 and beyond
- >20 GCMs
- Multiple Future Emissions Scenarios

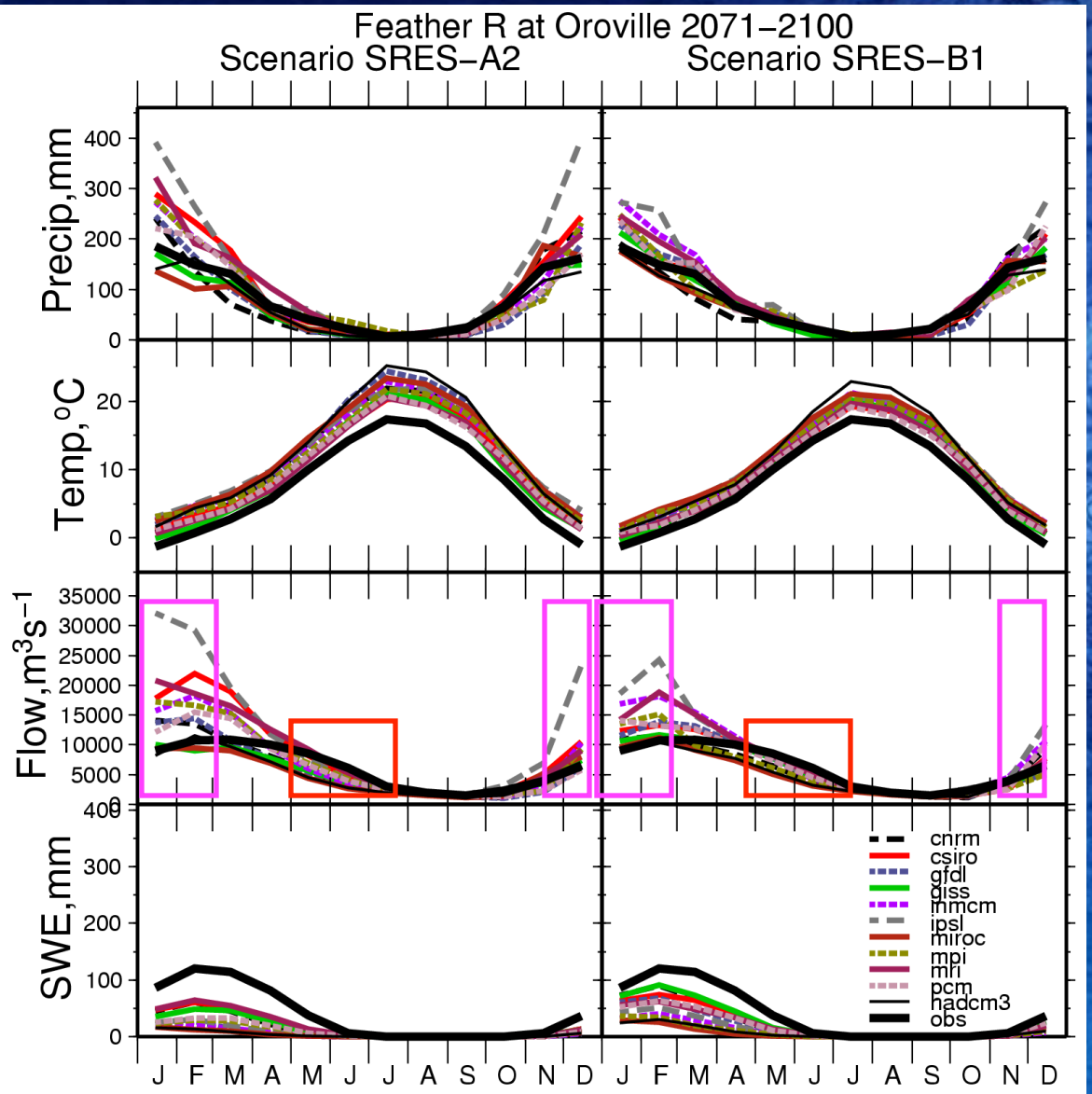


WCRP CMIP3 Multi-Model Data

1 realization multiple realizations

	PIcntrl	PDcntrl	20C3M	Commit	SRESA2	SRESA1B	SRESB1	1%to2x	1%to4x	Slabcntl	2xCO2	AMIP
BCC-CM1, China		2	4				2	1	1			4
BCCR-BCM2.0, Norway	1		1	1	1	1	1	1				
CCSM3, USA	2	1	9	5	5	7	8	1	1	1	1	1
CGCM3.1(T47), Canada	1		5	5	5	5	4	1	1	1	1	
CGCM3.1(T63), Canada	1		1			1	1	1		1	1	
CNRM-CM3, France	1		1	1	1	1	1	1	1			1
CSIRO-Mk3.0, Australia	2		3	1	1	1	1	1		1	1	
CSIRO-Mk3.5, Australia	1		1	1	1	1	1	1				
ECHAM5/MPI-OM, Germany	1		4	3	3	4	3	3	1	1	1	3
ECHO-G, Germany/Korea	1	1	5	4	3	3	3	1	1			
FGOALS-g1.0, China	3		3	3		3	3	3				3
GFDL-CM2.0, USA	1		3	1	1	1	1	1	1	1	1	
GFDL-CM2.1, USA	1		3	1	1	1	1	1	1			
GISS-AOM, USA	2		2			2	2					
GISS-EH, USA	1		5			4		1				
GISS-ER, USA	1		9	1	1	5	1	1	1	1	1	4
INGV-SXG, Italy	1		1		1	1		1	1			
INM-CM3.0, Russia	1		1	1	1	1	1	1	1	1	1	1
IPSL-CM4, France	1	1	2	1	1	1	1	1	1			6
MIROC3.2(hires), Japan	1		1			1	1	1		1	1	1
MIROC3.2(medres), Japan	1		3	1	3	3	3	3	3	1	1	3
MRI-CGCM2.3.2, Japan	1	1	5	1	5	5	5	1	1	1	1	1
PCM, USA	1	1	4	3	4	4	4	5	1			1
UKMO-HadCM3, UK	2		2	1	1	1	1	1				
UKMO-HadGEM1, UK	1		1		1	1		2	1	1	1	1

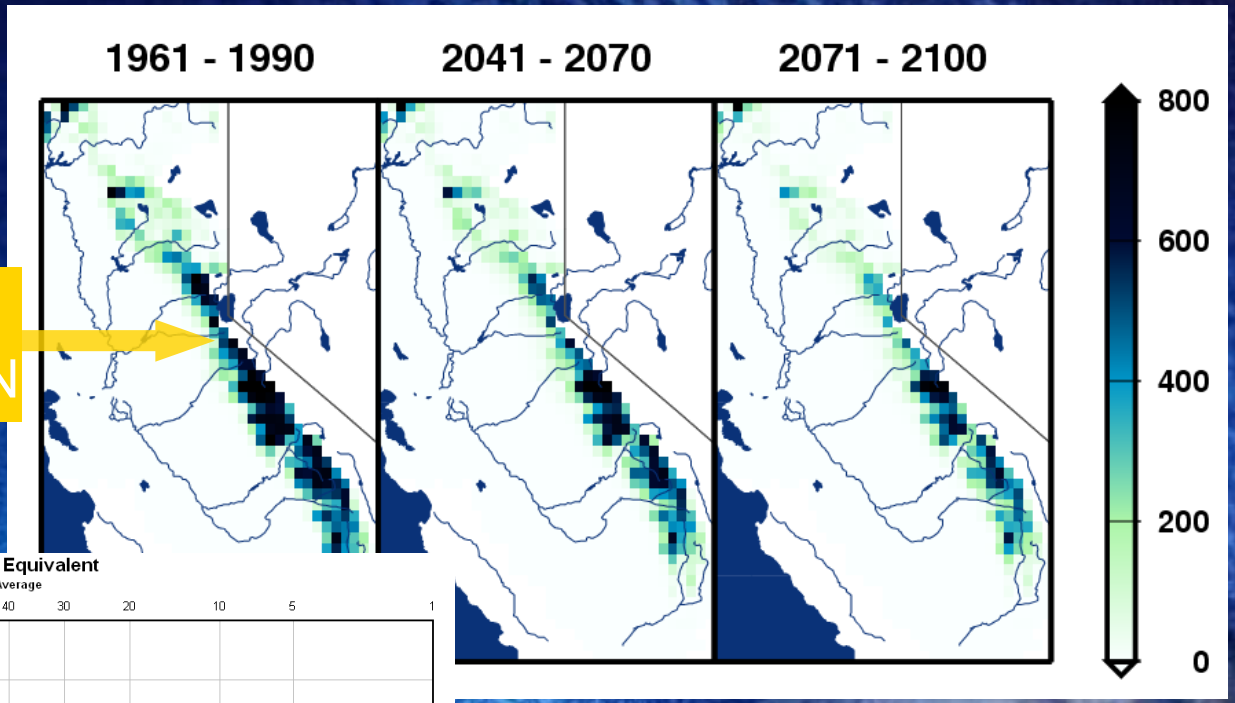
Multi-Model Ensemble Projections for Feather River

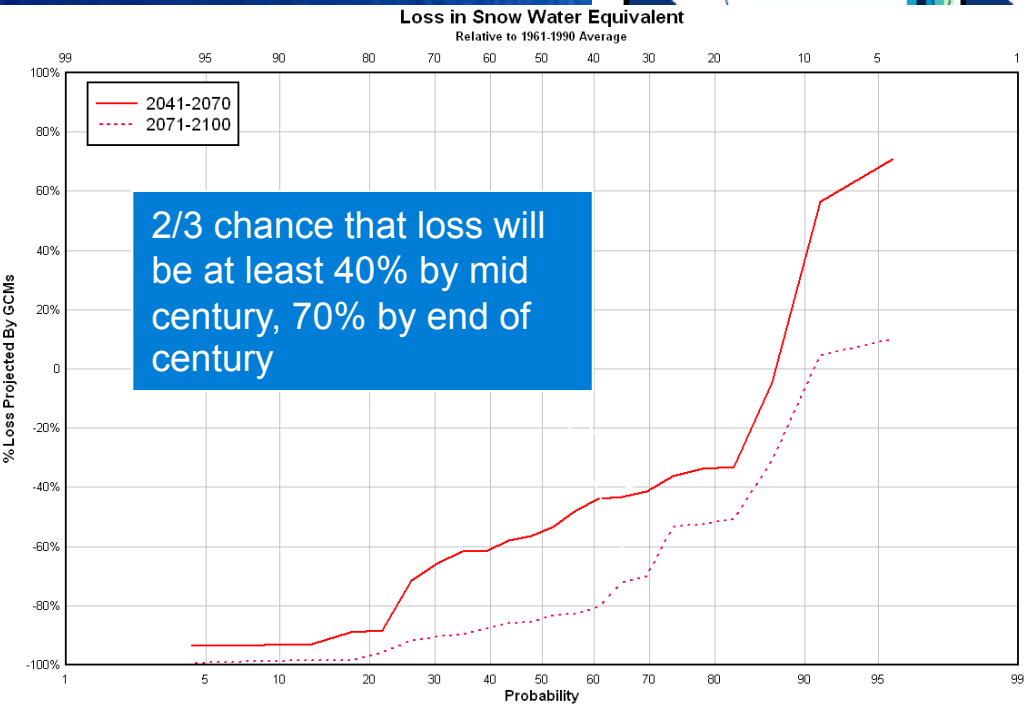


- Increase Dec-Feb Flows
  - +77% for A2
  - +55% for B1
- Decrease May-Jul
  - -30% for A2
  - -21% for B1

Impact Probabilities for Planning

Point at:
120ºW, 38ºN



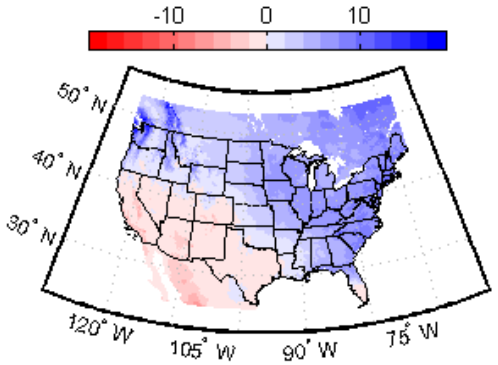


- Combine many future scenarios, models, since we don't know which path we'll follow (22 futures here)
- Choose appropriate level of risk

Demand for downscaled data

Monthly downscaled data

- PCMDI CMIP3 archive of global projections
- 16 GCMs, 3 Emissions
- 112 GCM runs
- Allows quick analysis of multi-model ensembles
- gdo4.ucllnl.org/downscaled_cmip3_projections



BCSD-CMIP3-Climate-monthly | BCCA-CMIP3-Climate-daily | BCSD-CMIP3-Hydrology-monthly

Enter specifications on three page form below. Then press 'Submit Request'. ?

Submit Request

Form Status (completed == green)

1.1 1.2 2.3 2.4 3.5 3.6 3.7 3.8

Size (%, 100 max): 1

Page 1: Products, Variables, Projections | Page 2: Temporal & Spatial Extent | Page 3: Analysis, Format, & Notification

Step 1.1: Products & Variables – monthly projections ?

Products

- 1/8 degree BCSD projections
- 1/8 degree Observed data (1950-1999)
- 2 degree Raw GCM projections
- 2 degree Bias-corrected GCM projections
- 2 degree Observed data (1950-1999)

Variables

- Precipitation Rate (mm/day)
- Ave Surface Air Temperature (deg C)

Step 1.2: Emissions Scenarios, Climate Models and Runs ?

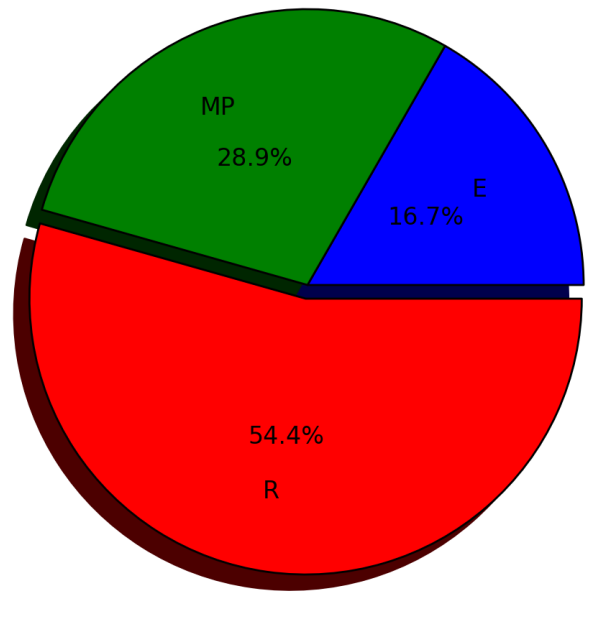
De-select all runs	None	None	None
Select all runs	All	All	All
Climate Models:	Emissions Path: A1b	Emissions Path: A2	Emissions Path: B1
bccr_bcm2_0			
cccma_cgcm3_1			
cnrm_cm3			
csiro_mk3_0			
gfdl_cm2_0			
gfdl_cm2_1			
giss_model_e_r			
inmcm3_0			
ipsl_cm4			
miroc3_2_medres			
miub_echo_g			
mpi_echam5			
mri_cgcm2_3_2a			
ncar_ccsm3_0			
ncar_pcm1			
ukmo_hadcm3			

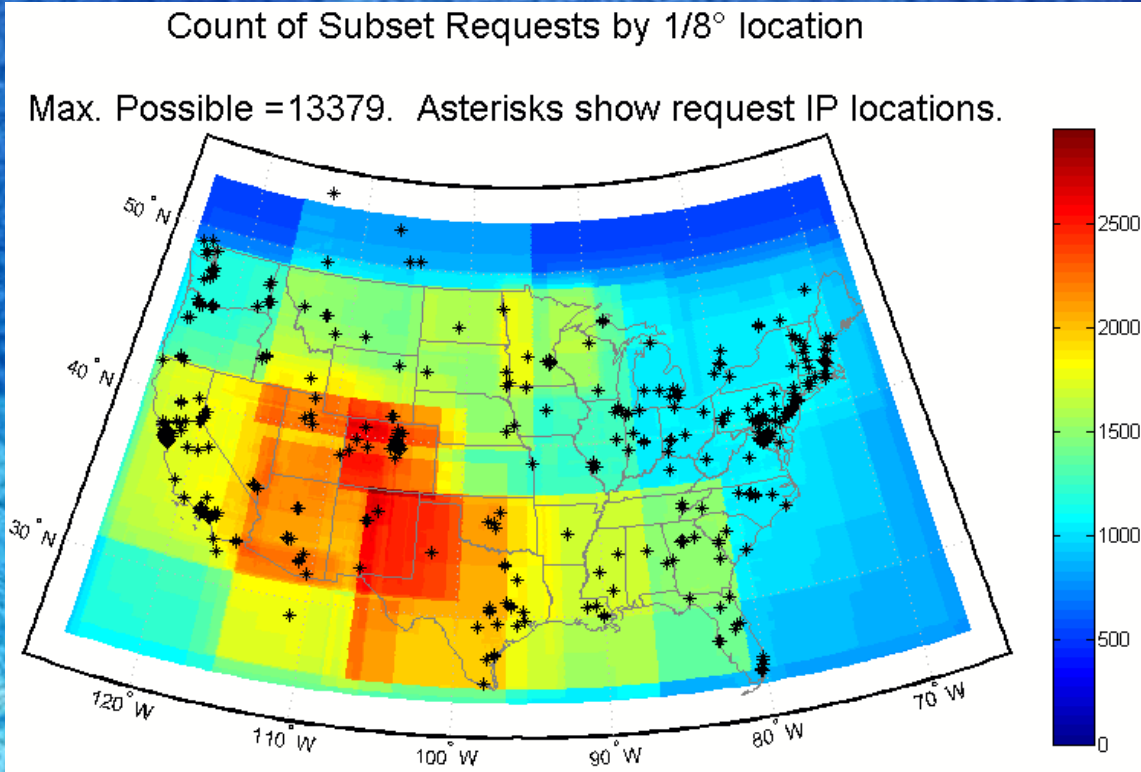
RECLAMATION USGS

Santa Clara University | CLIMATE CENTRAL | SCRIPPS INSTITUTION OF OCEANOGRAPHY

Use of U.S. Data Archive

- Thousands of users downloaded >20 TB of data
- Uses for Research (R), Management & Planning (MP), Education (E)





What is missing from downscaled data archive?

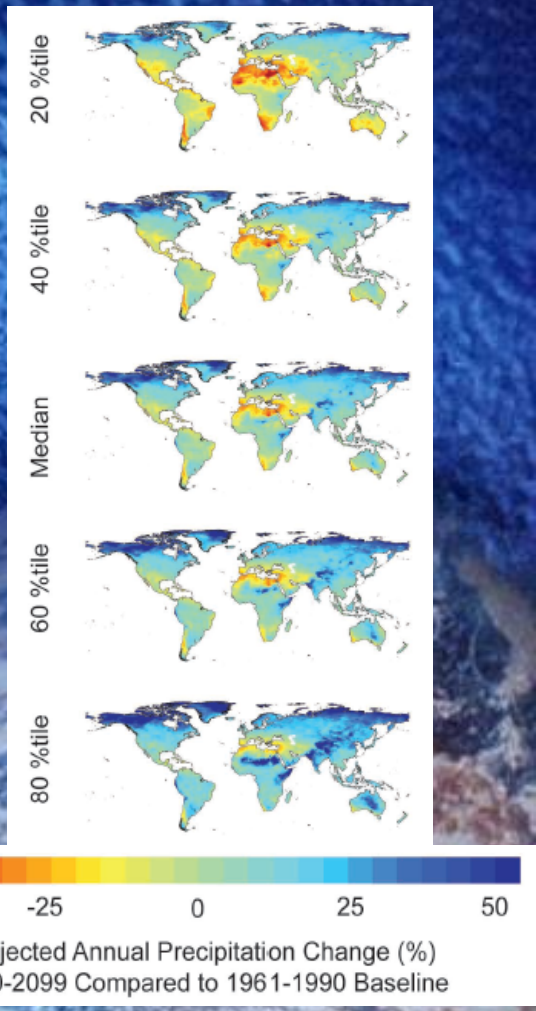
Items Requested
Daily Data
Additional Climate Variables:
Tmax/Tmin
Evapotranspitation/Potential Evapotranspiration
Surface Wind
Humidity
Solar Radiation
Surface Pressure
Cloud Cover
Derived Variables:
Runoff
Snow
Soil Moisture
Raw and intermediate data (from the downscaling process)
More resources to cope with netCDF files
Data from other downscaling methods to intercompare
Full historic data for 20th century (1900-current)
Ability to extract watersheds (not just rectangular subsets)
Expanded spatial domain

Global BCSD

- Similar to US archive, but ½-degree
- Publicly available since 2009
- Captures variability among GCMs
- www.engr.scu.edu/~emaurer/global_data/
- Data accessed by users in all 50 States and 99 countries (last 11 months only)

Visits from 3 Nov 2011 to 27 Sep 2012

A1B Scenario



Source: Girvetz et al, PloS, 2009

Most commonly requested items

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Daily Data
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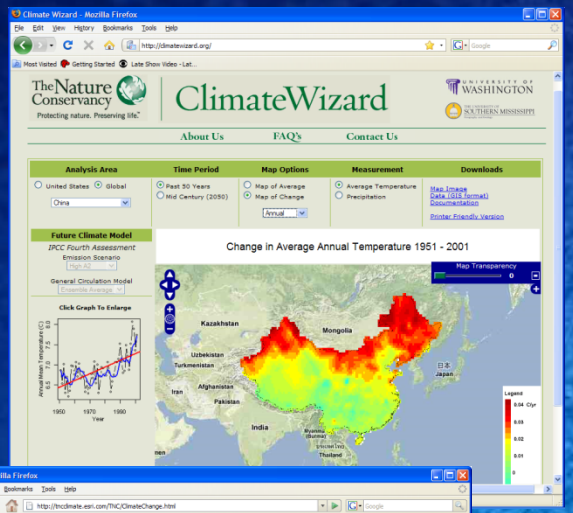
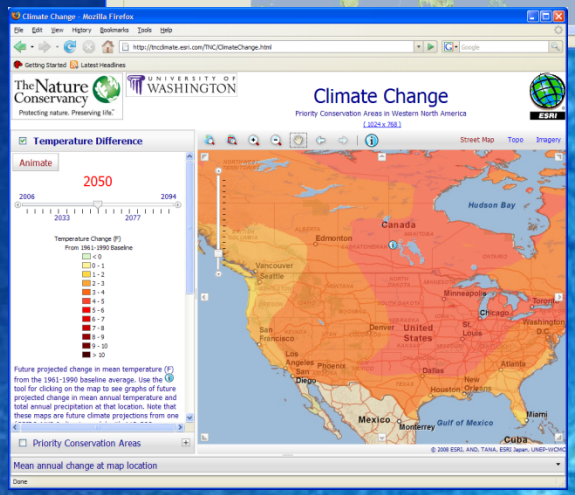
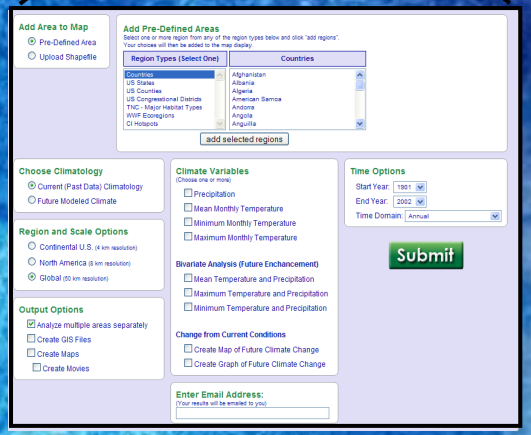
Online Analysis and Download with http://ClimateWizard.org

Level 1

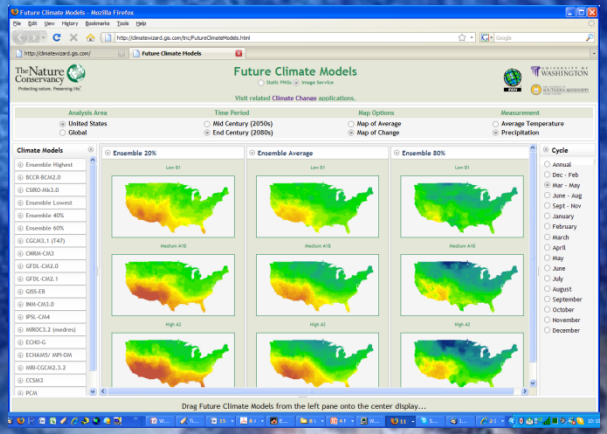




Level 2



Level 3



- Global and US data sets
- Country and US state boundaries defined
- Spatial and time series analysis
- Upload of custom shapefiles

Girvetz et al., PLoS, 2009

Too much information?

Little guidance in selection of:

- Emissions
- GCMs

Hundreds of downscaled GCM runs

- Many impacts studies cannot use all of them

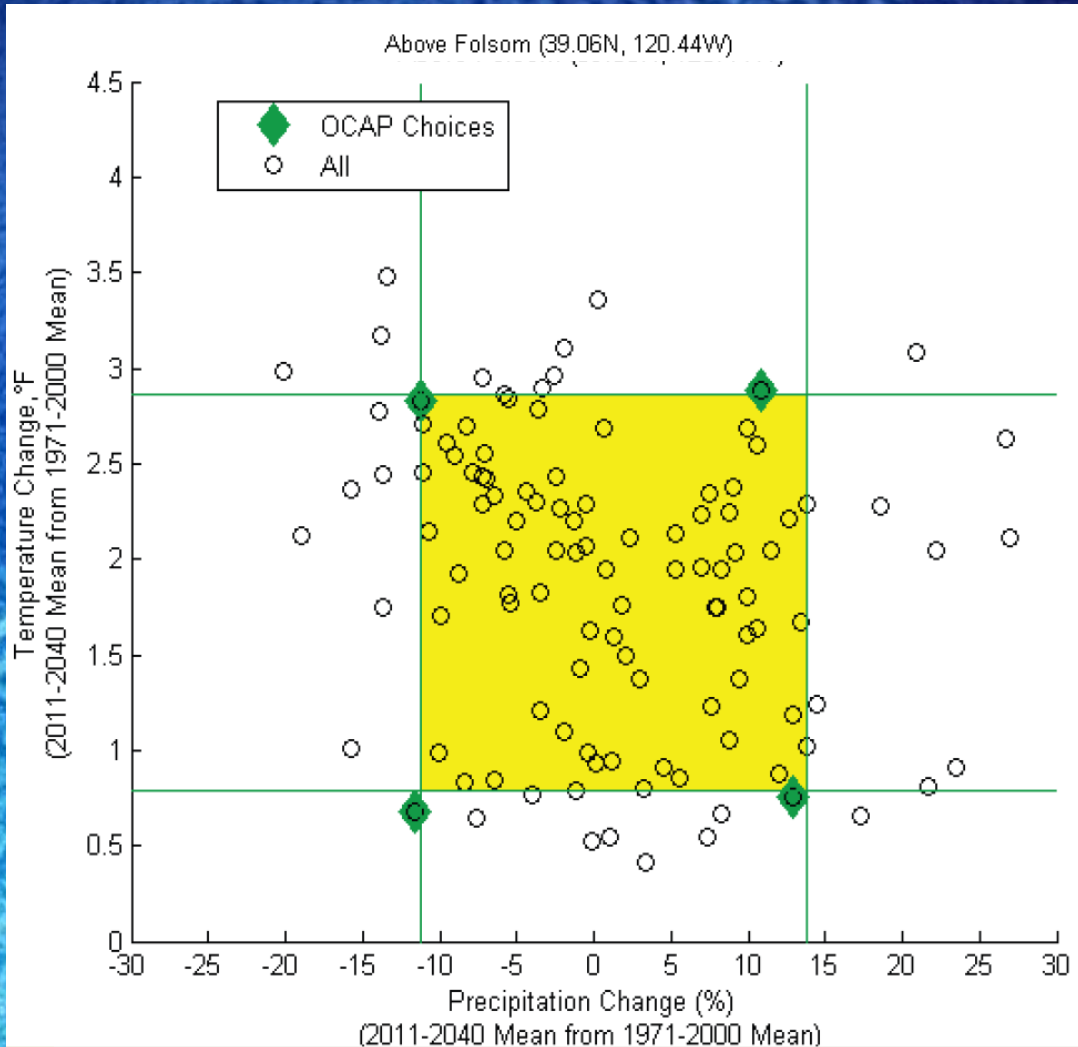
How much information is really useful?

Selecting Specific GCM Runs

Bivariate probability plot shows correlation between ΔT, Δ P

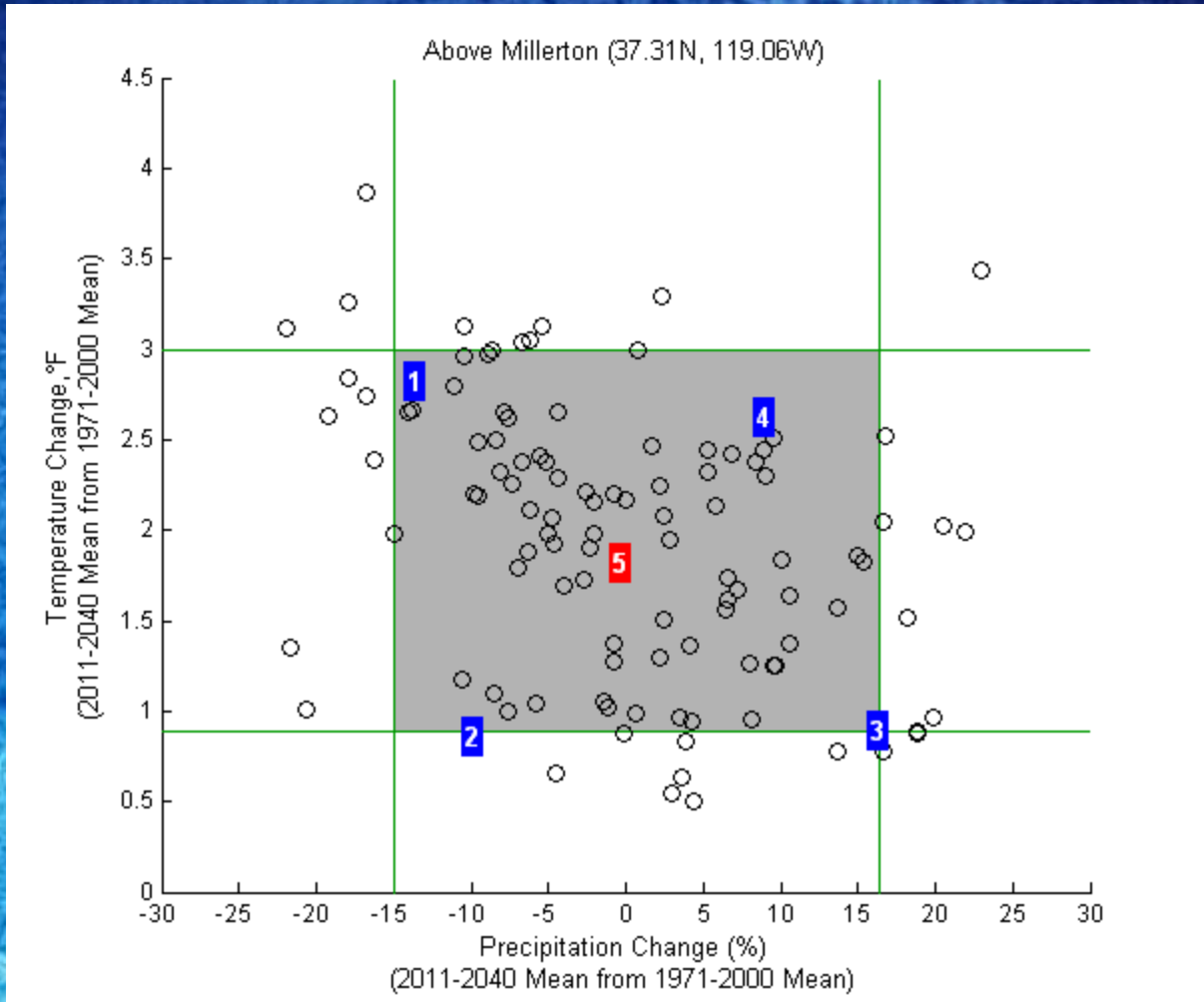
Identify Change Range: 10 to 90 %-tile ΔT, Δ P

Select bounds based on:
- risk attitude
- interest in breadth of changes
- number of simulations desired



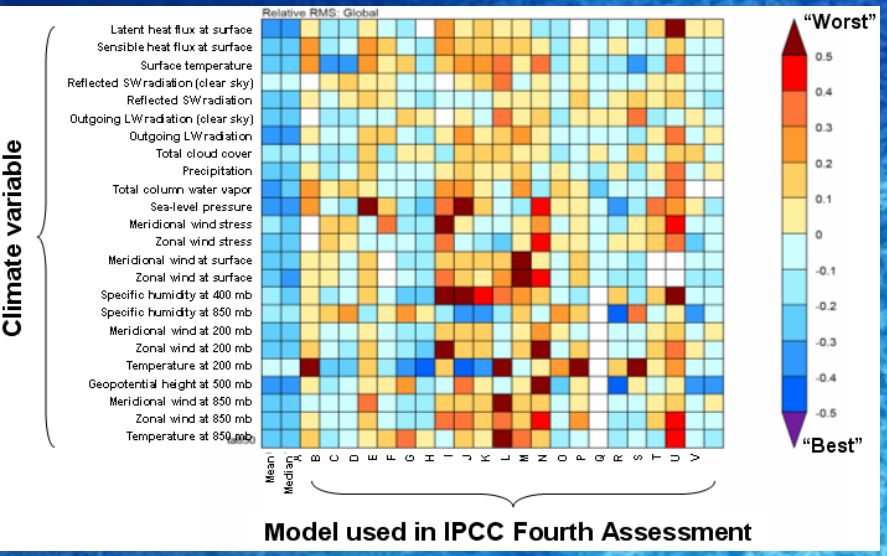
Brekke et al., 2009

Or use 5?

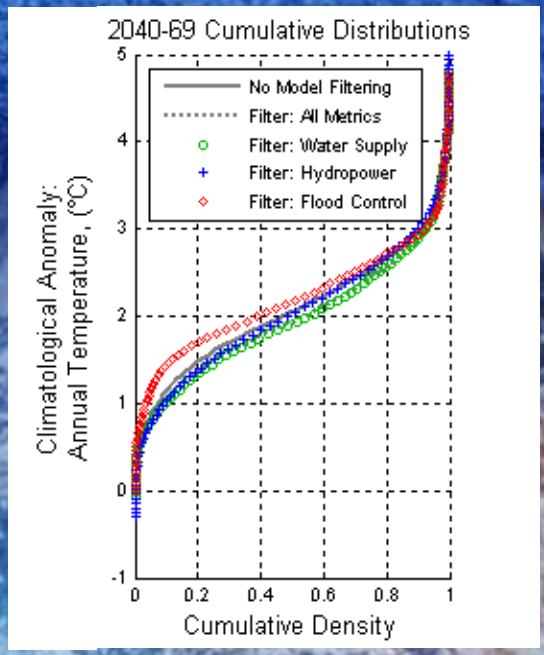

Above Millerton (37.31N, 119.06W)
Temperature Change, °F
(2011-2040 Mean from 1971-2000 Mean)
Precipitation Change (%)
(2011-2040 Mean from 1971-2000 Mean)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
1
2
3
4
5

Selecting GCMs for Impact Studies

- Ensemble mean provides better skill
- Little advantage to weighting GCMs according to skill
- Most important to have "*ensembles of runs with enough realizations to reduce the effects of natural internal climate variability*" [Pierce et al., 2009]
- Maybe 10-14 GCMs is enough?



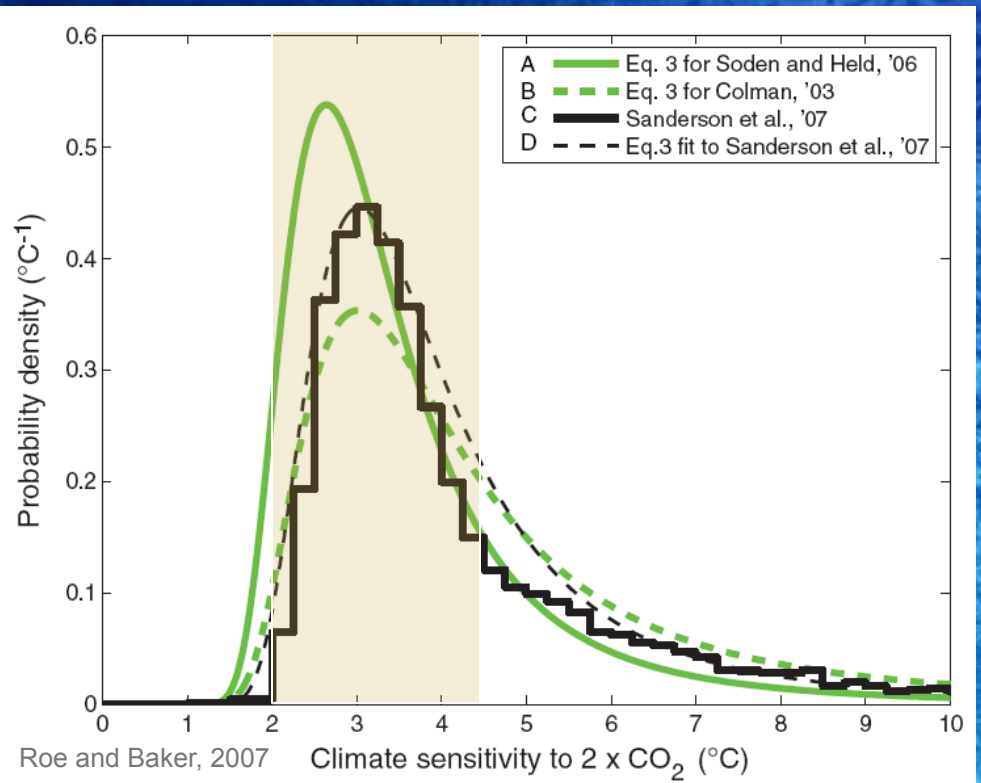
Gleckler, Taylor, and Doutriaux, Journal of Geophysical Research (2008)
as adapted by B. Santer



Brekke et al., 2008

Do CMIP GCM runs capture important uncertainties?

- Perturbed physics ensembles
- Is planning for the higher probability outcomes appropriate?



Roe and Baker, 2007

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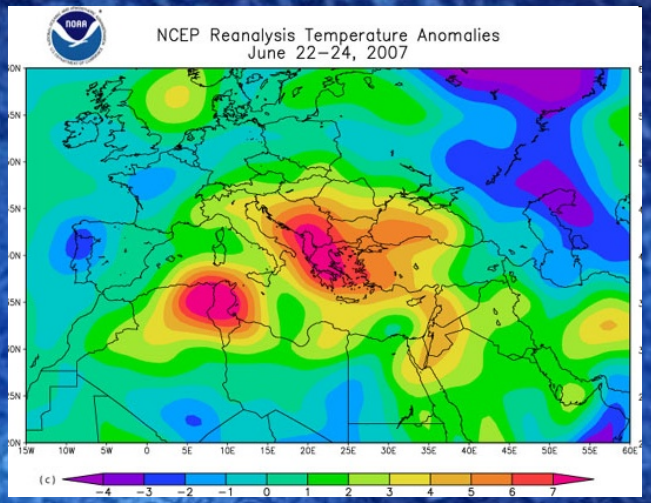
Downscaling for Extreme Events

- Some impacts due to changes at short time scales
  - Heat waves
  - Flood events
- Daily GCM output limited for CMIP3, more plentiful for CMIP5
- Downscaling adapted for modeling extremes



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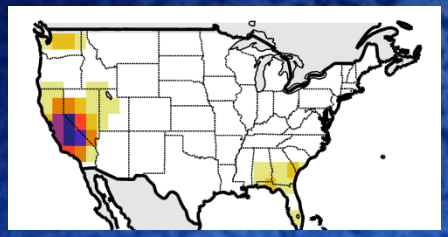
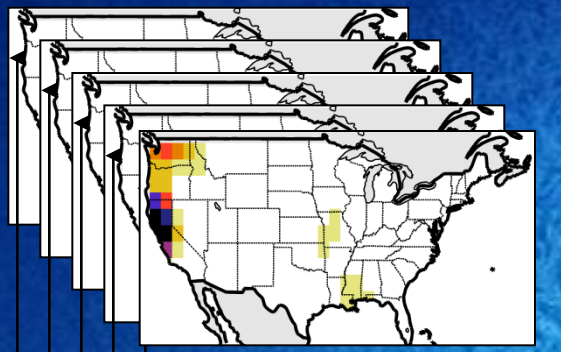
Raw and intermediate data (from the downscaling process)
More resources to cope with netCDF files
Data from other downscaling methods to intercompare
Full historic data for 20th century (1900-current)
Ability to extract watersheds (not just rectangular subsets)
Expanded spatial domain

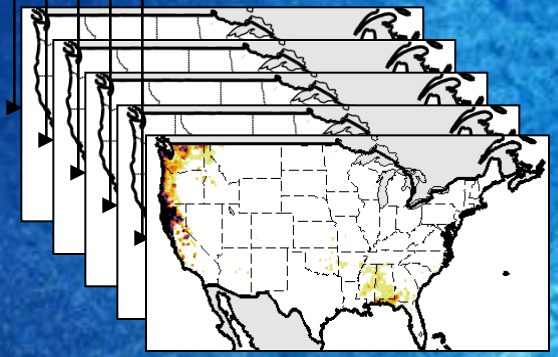
Constructed Analogues



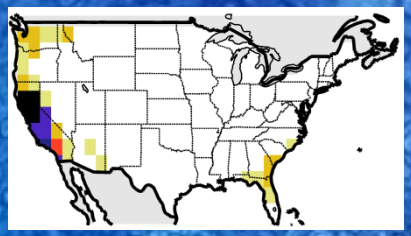
Given daily GCM anomaly

Library of previously observed anomaly patterns:

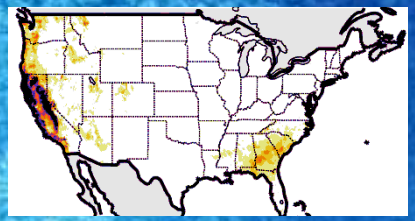




Coarse resolution analogue:



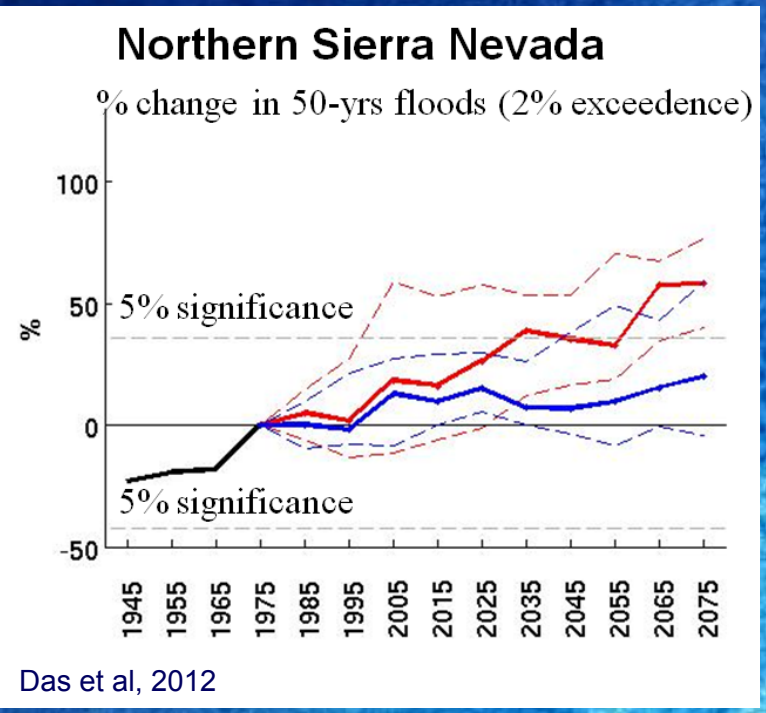
Analogue is linear combination of best 30 observed



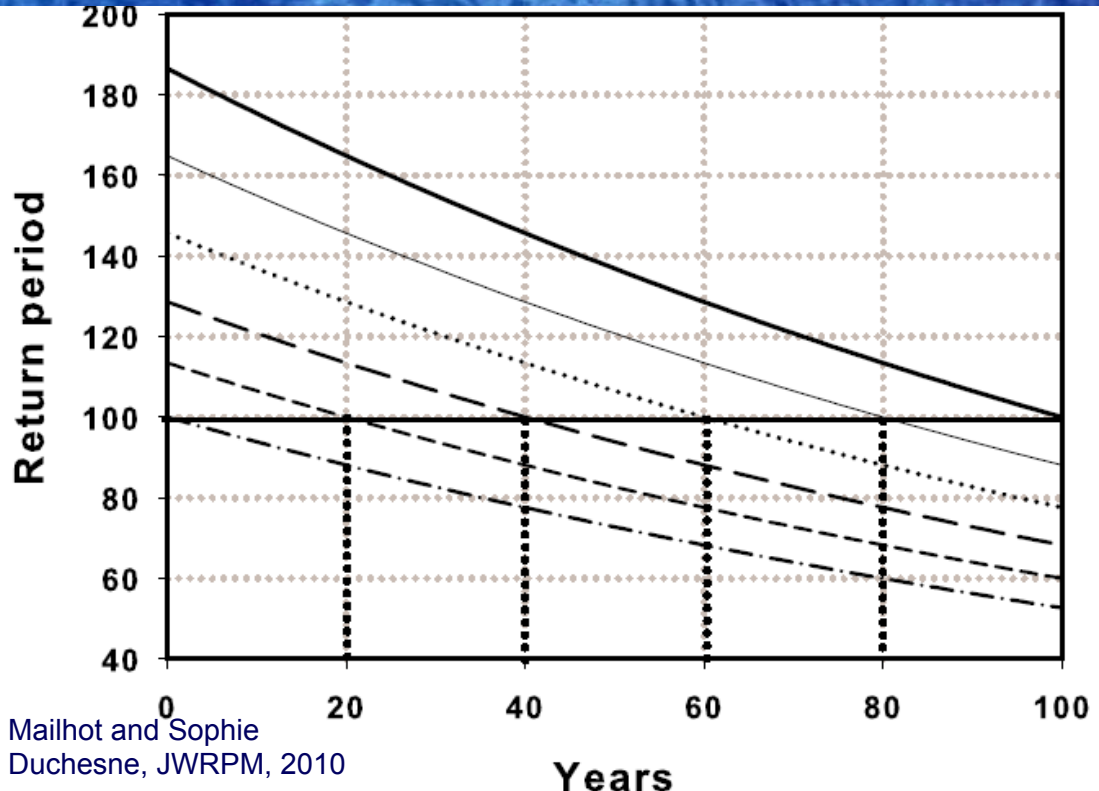
Apply analogue to fine-resolution climatology

Sustainable Design in a Dynamic Environment

- Declining return periods for extreme events
- A solution: Overdesign for present



Das et al, 2012

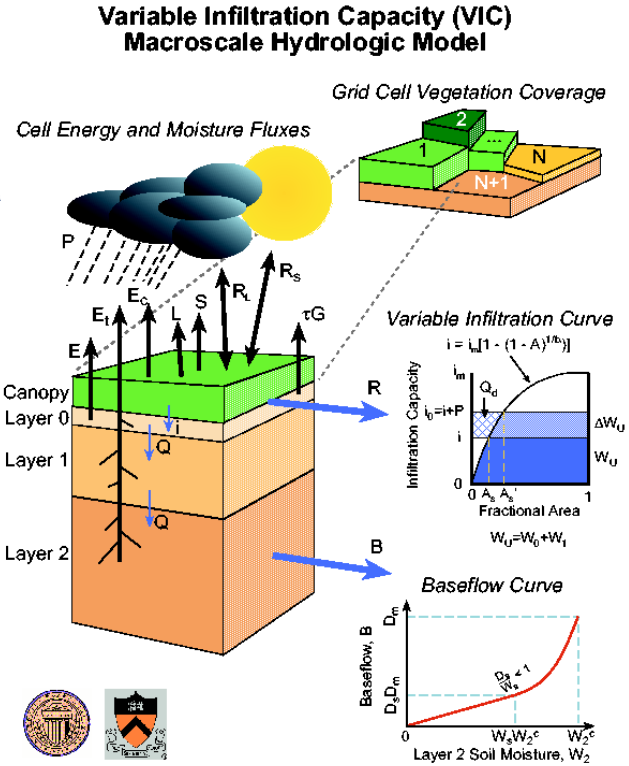


Mailhot and Sophie Duchesne, JWRPM, 2010

What is missing from downscaled data original archive?

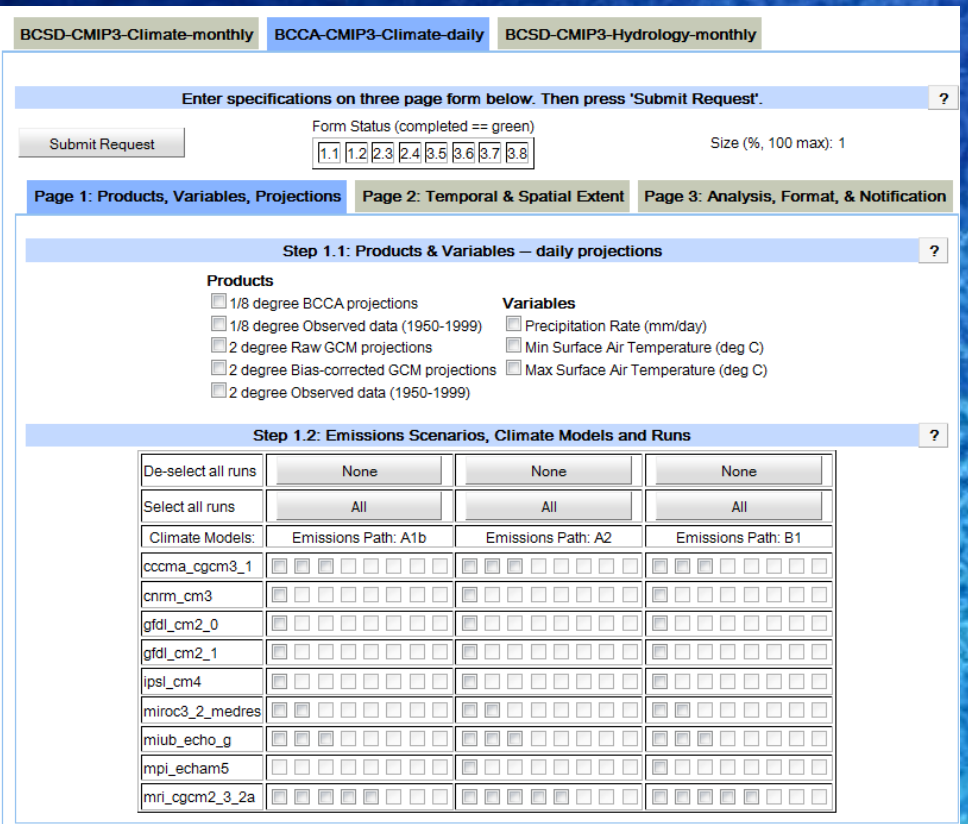
Items Requested
Daily Data
Additional Climate Variables:
Tmax/Tmin
Evapotranspitation/Potential Evapotranspiratic
Surface Wind
Humidity
Solar Radiation
Surface Pressure
Cloud Cover
Derived Variables:
Runoff
Snow
Soil Moisture
Raw and intermediate data (from the downscaling pro
More resources to cope with netCDF files
Data from other downscaling methods to intercompar
Full historic data for 20th century (1900-current)
Ability to extract watersheds (not just rectangular sub
Expanded spatial domain

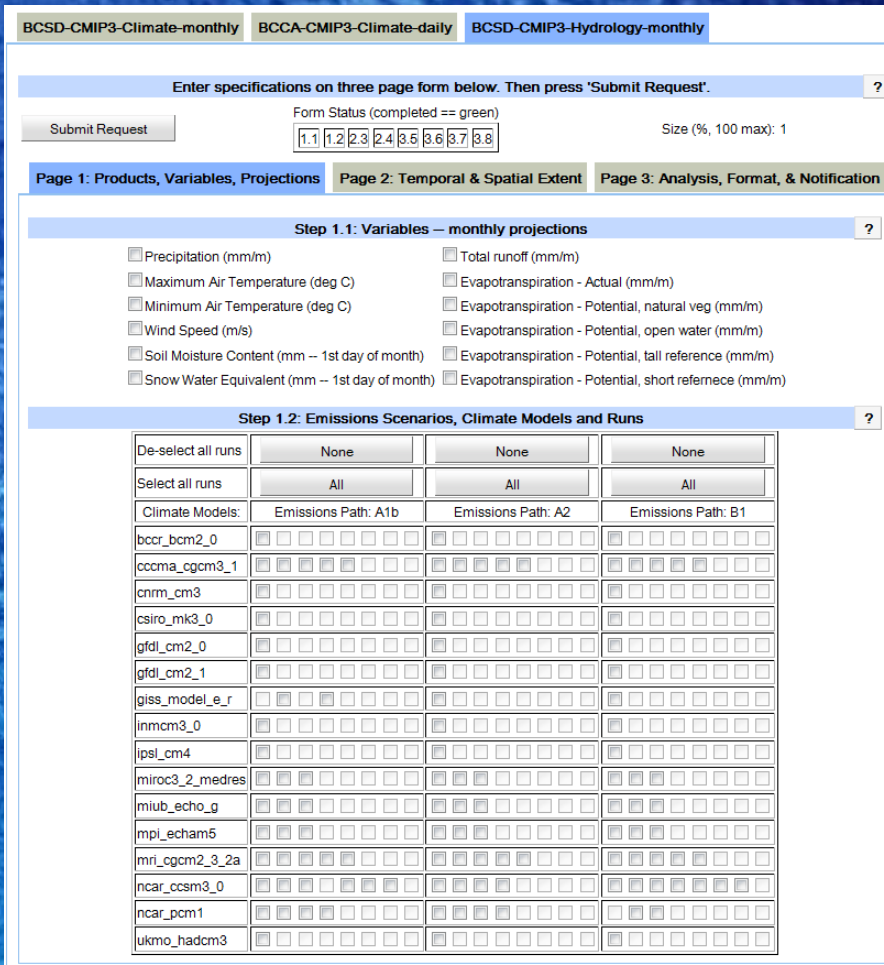
Downscaled data run through VIC model, now available



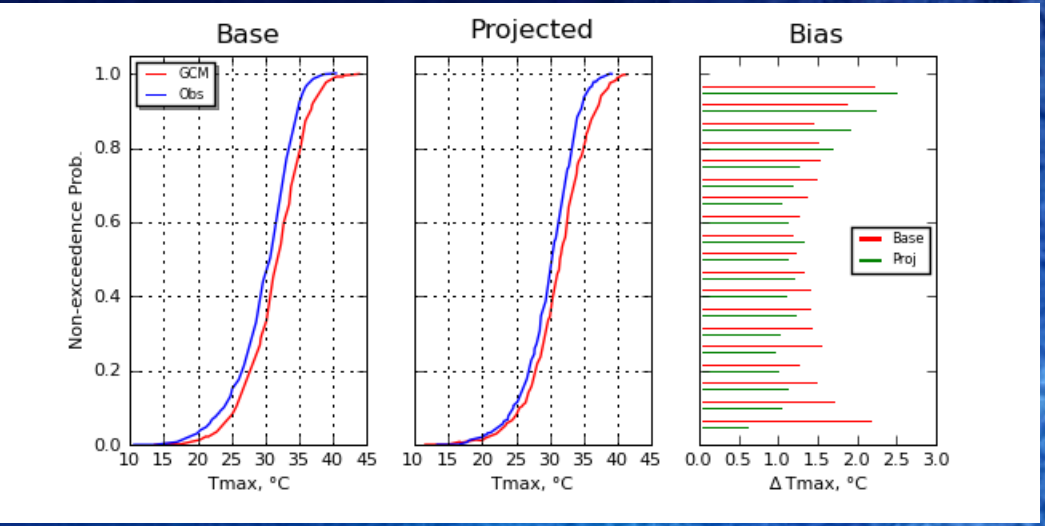
Archive expansion (still CMIP3)

- Daily downscaled data
- Hydrology model output



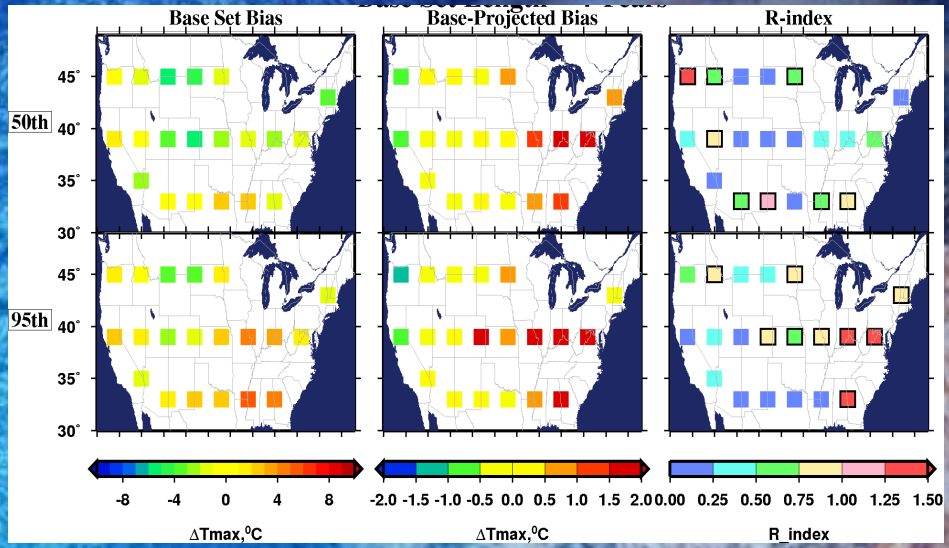


Is bias correction effective?



Biases vary in time, space, at quantiles

- On average, bias correction works
- But for small ensembles maybe not

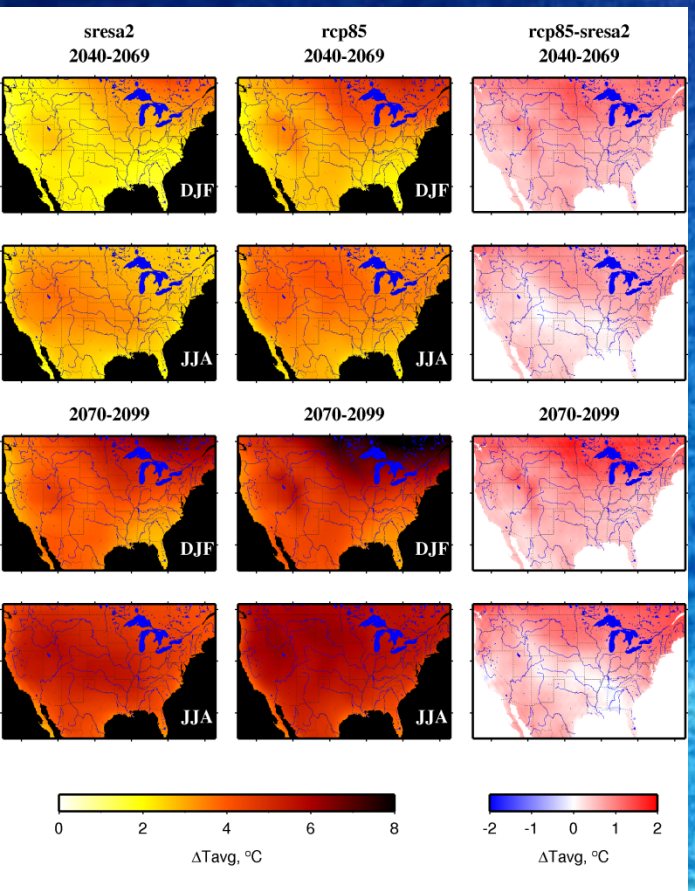


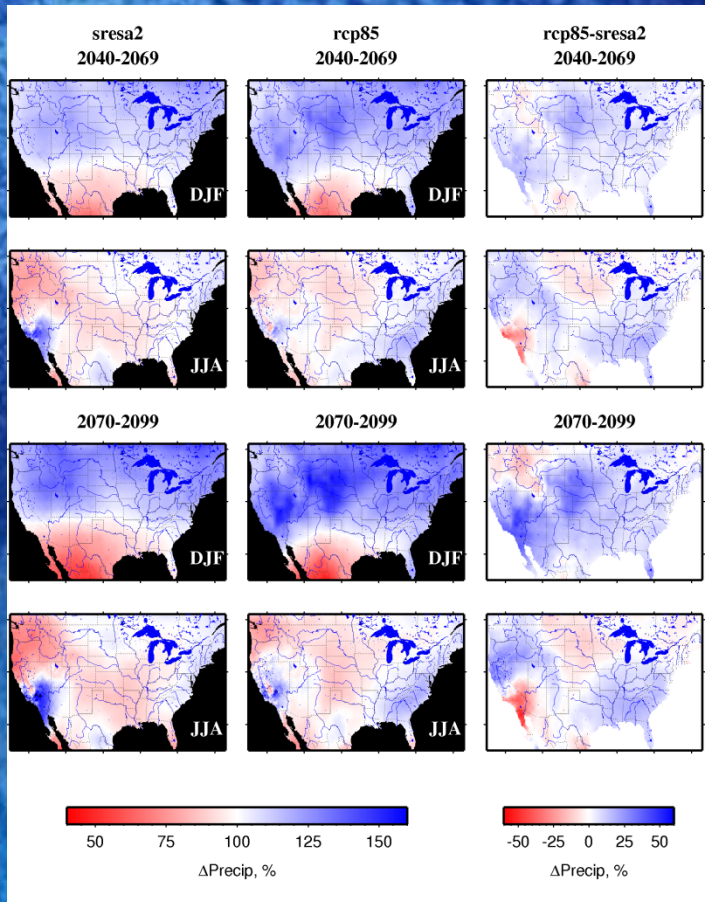
CMIP5 additions to archive

- Monthly downscaling of Tmax, Tmin, Precip for:
  - 84 historical GCM runs
  - 237 projections (total for 4 RCPs)
- Daily downscaling with two techniques:
  - 46 historical runs
  - 147 projections (total for 4 RCPs)
- Hydrology model output for 100 runs

Does CMIP3 or CMIP5 choice matter?

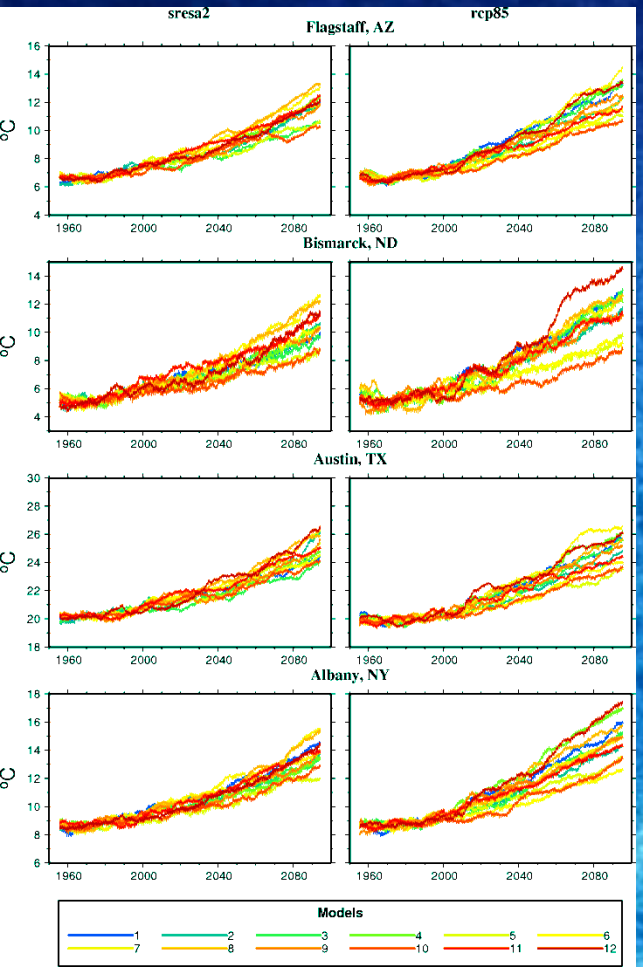
- Ensemble average changes comparable
- RCP8.5 and SRES A2 comparable

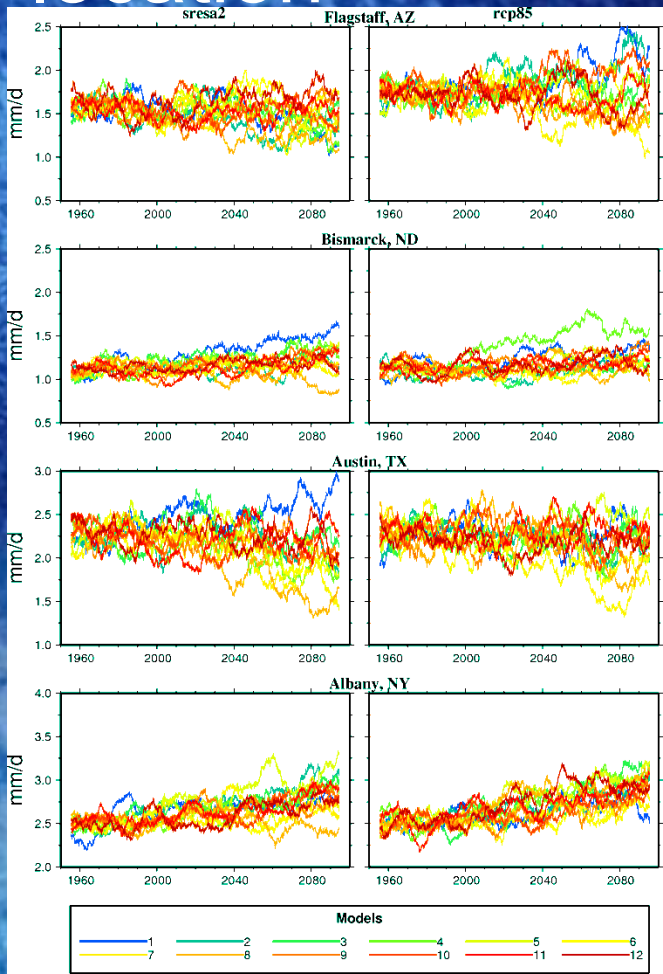




Model Spread

- Differences in model spread between CMIP3 and CMIP5 varies by location





Information overload overload

- If 112 GCM projections wasn't too much, is 500?
- Have we progressed in providing policymakers with information for…
  - Selecting concentration pathways
  - Assembling an ensemble of GCMs
  - Using appropriate downscaling
  - Interpreting results
- Can we (conditionally) recommend anything?


Thanks!