Downscaling global climate change projections for assessment of water resources impacts

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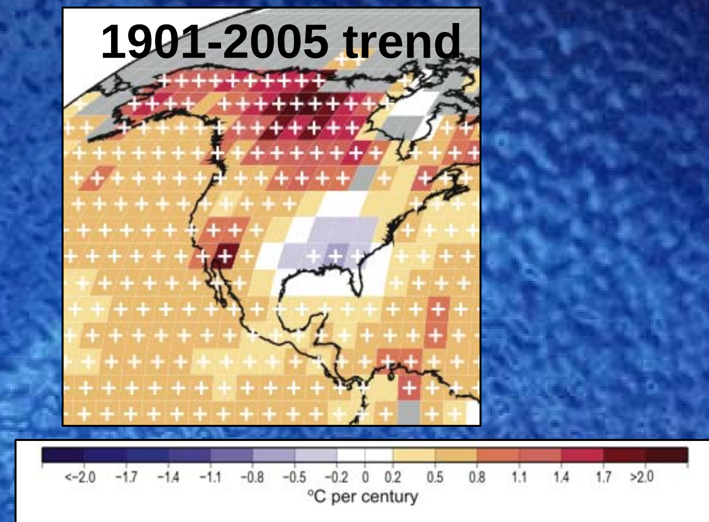
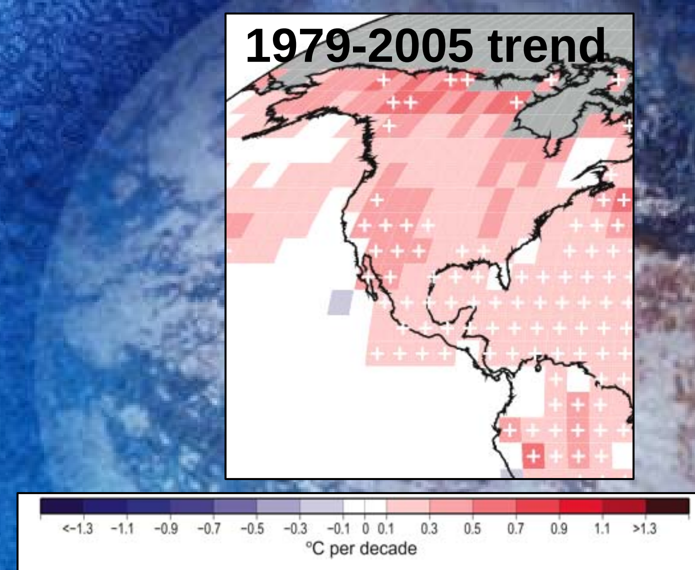
Recent Temperature Changes

- Positive trends
- Significant over wide area
- Recent trends significant across U.S. Southwest

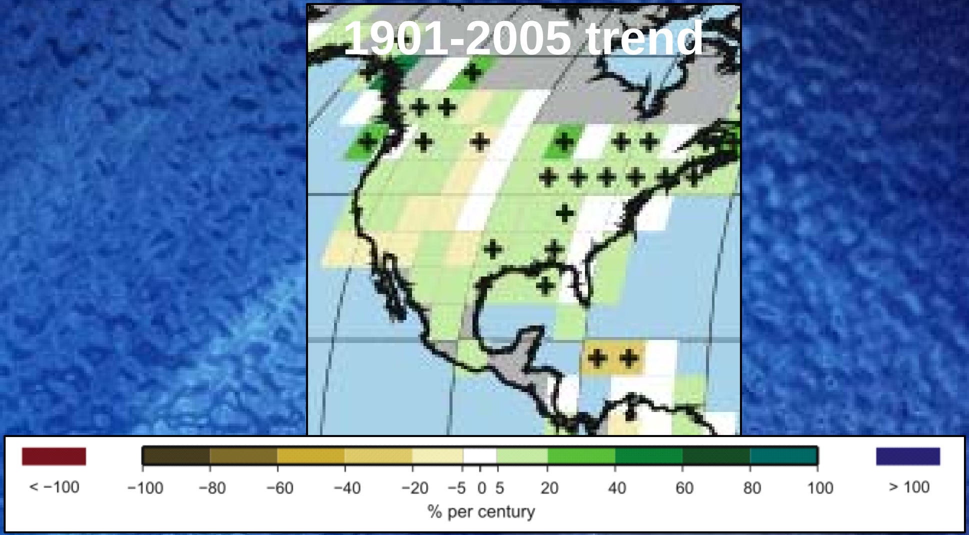


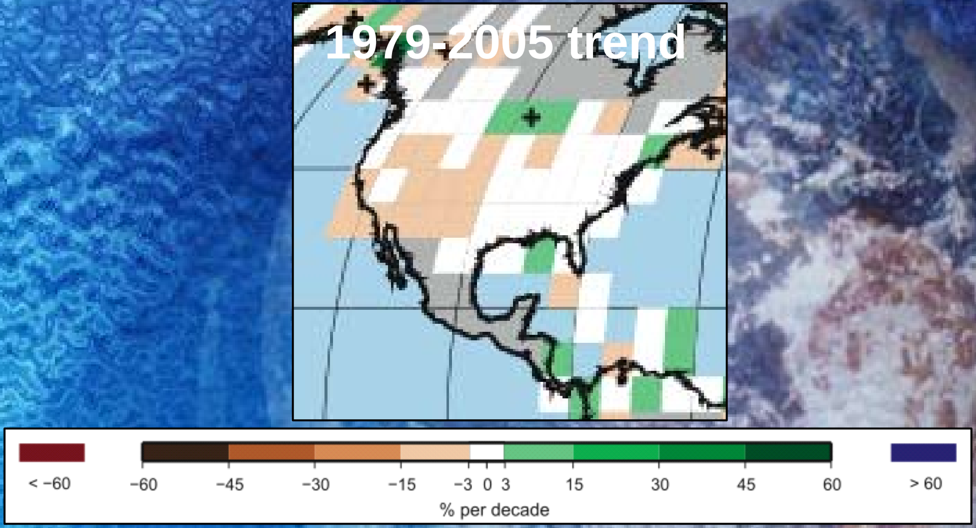


source: IPCC, 2007

Recent Precipitation Trends

- Changes generally negative in Southwest
- Natural variability is high
- Significance of trends is low

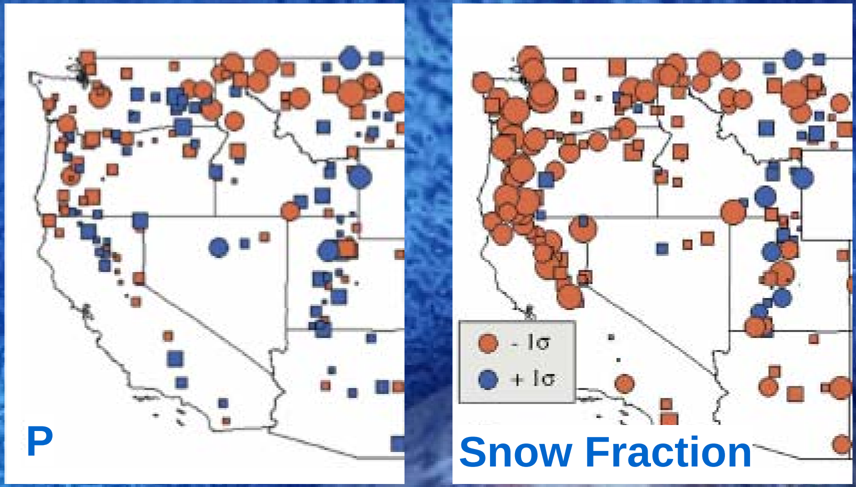




source: IPCC, 2007

More Winter Precipitation Falling as Rain

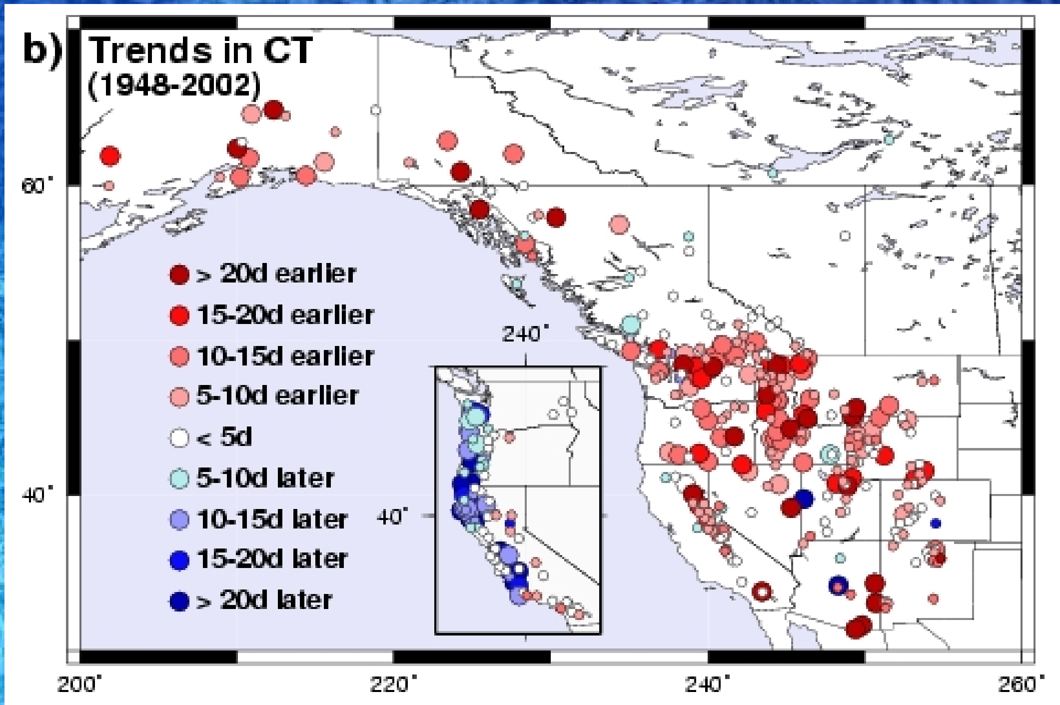
- Trends in winter precip and snow fraction (1949-2004)
- Reduced snowfall is response to warming during winter wet days (0-3°C)
- Changes of 2nd half of 20th century:
- Red indicates decreasing snow fraction
- About 10% decrease in fraction of winter precip as snow
- Low to moderate elevations (<1500 m) impacted most



Ref: Knowles et al., 2006, J. Climate 19.

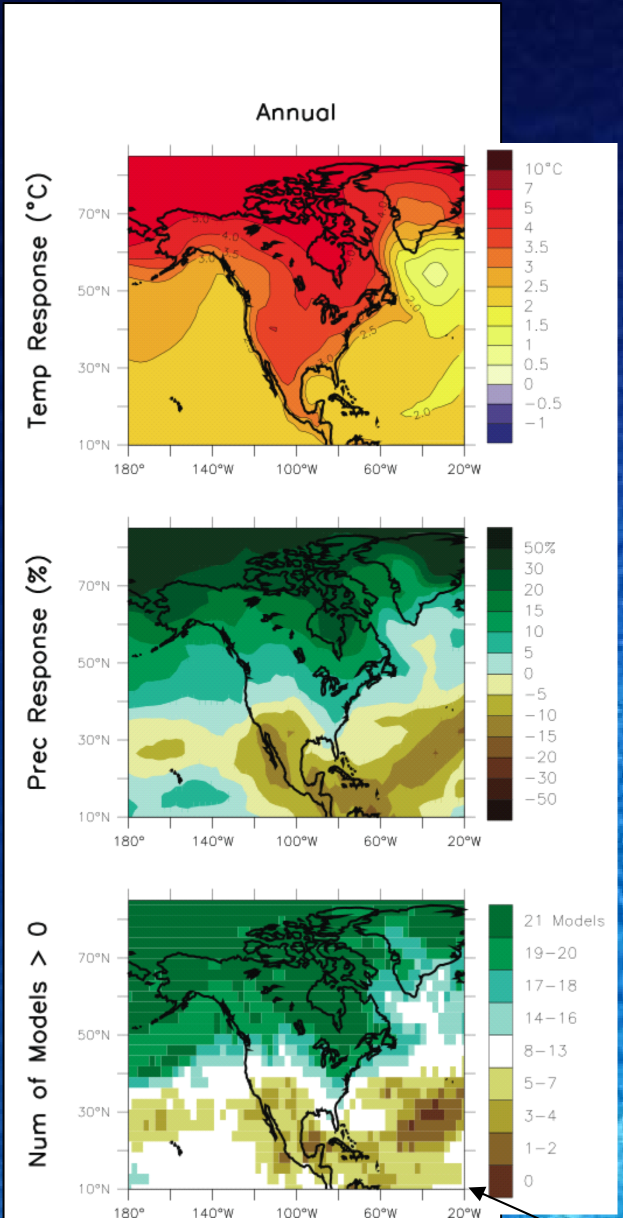
Stream flow is arriving earlier for snow-dominated rivers

- Trends correspond to a timing shift of **1 to 3 weeks** and more over the past ~50 years
- Timing shift dominated by changes in snowmelt-derived streamflow, partially attributed to warming



Ref: Stewart et al., 2005, J. Climate 19.

Looking toward the future: end of 21st century

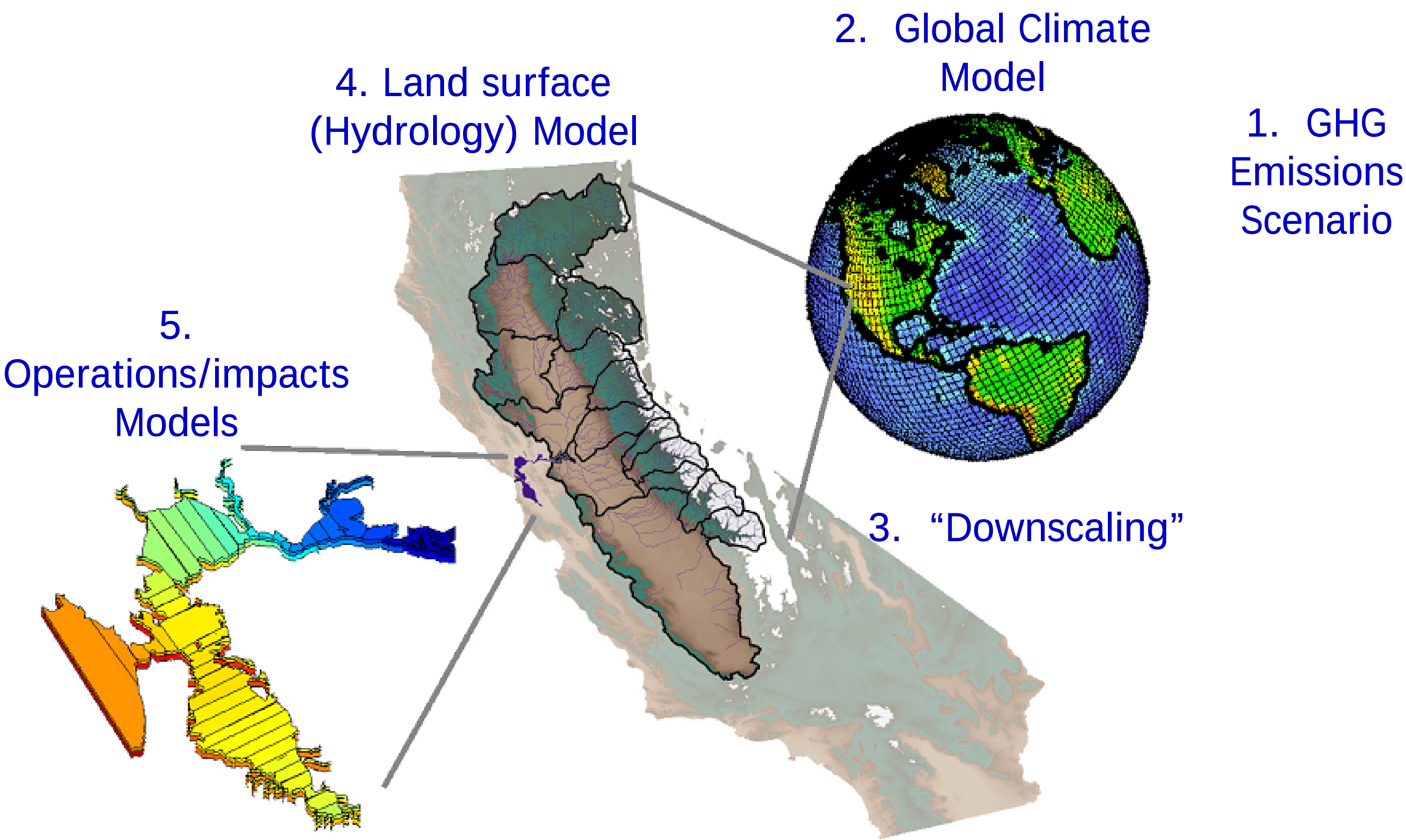


source: IPCC, 2007

number of models out of 21 that project increases in precipitation

- 21 modeled changes for A1B emissions
- 2080-2099 minus 1980-1999
- Warming is large-scale, certain
- Precipitation changes more regional, less confident
- How to make this useful on a local level?
- .

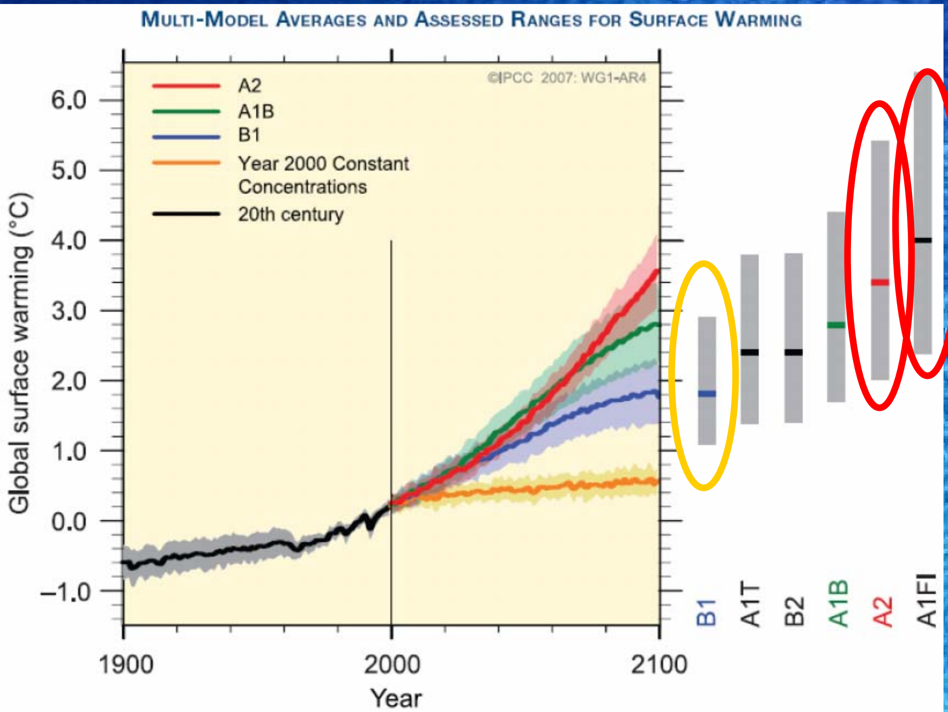
Estimating regional impacts



Adapted from Cayan and Knowles, SCRIPPS/USGS, 2003

"Bookend" Studies to Cope With Uncertainties

- Brackets range of uncertainty
- Useful where impacts models are complex

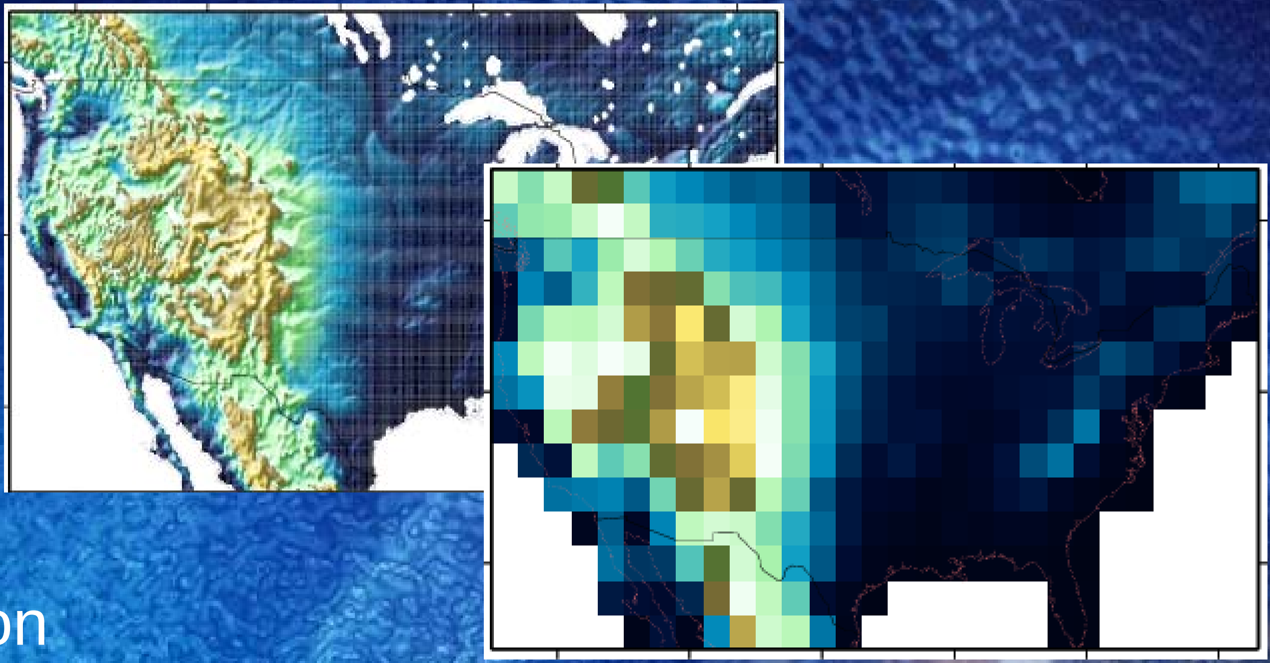


Multiple global estimates quantify uncertainty

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
11: GFDL-CM2.0	2.9
12: GFDL-CM2.1	3.4
13: GISS-AOM	n.a.
14: GISS-EH	2.7
15: GISS-ER	2.7
16: INM-CM3.0	2.1
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

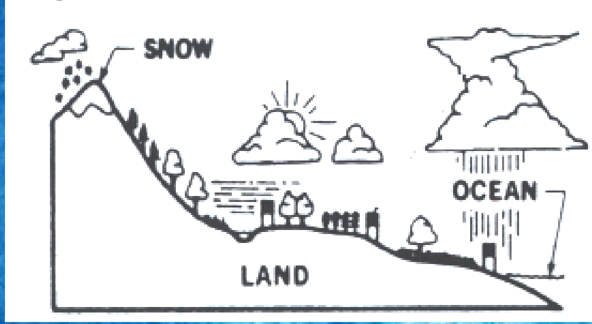
Downscaling: bringing global signals to regional scale

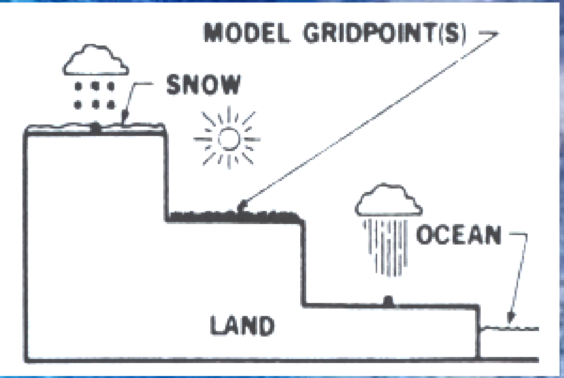
- GCM problems:
  - Scale incompatibility between GCM and impacts
  - Regional Processes not well represented



- Resolved by:
  - Bias Correction
  - Spatial Downscaling

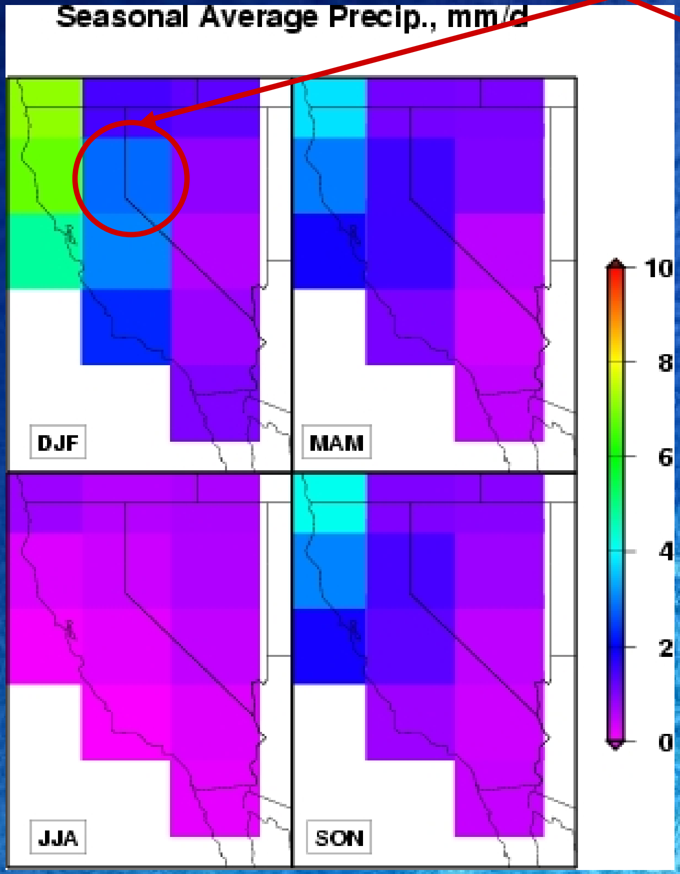
Figure: Wilks, 1995



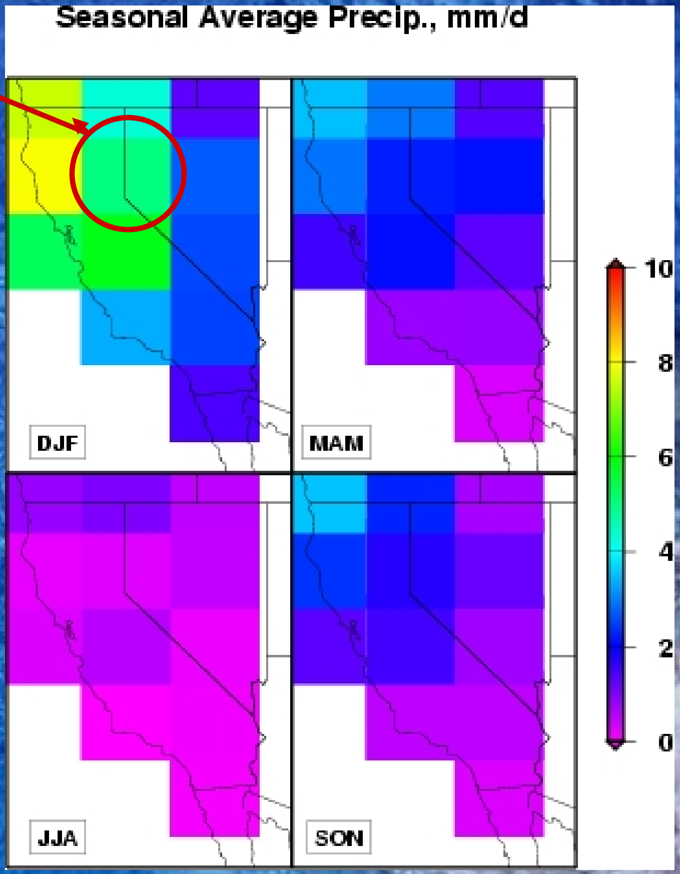


Biases in GCM Simulations

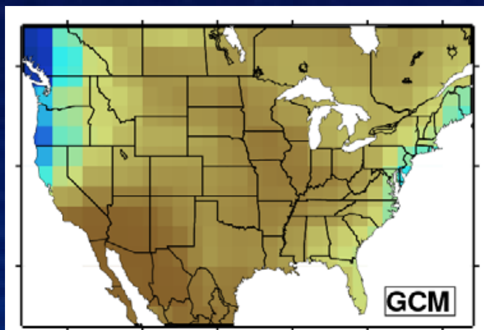
Observed Data
aggregated to GCM resolution



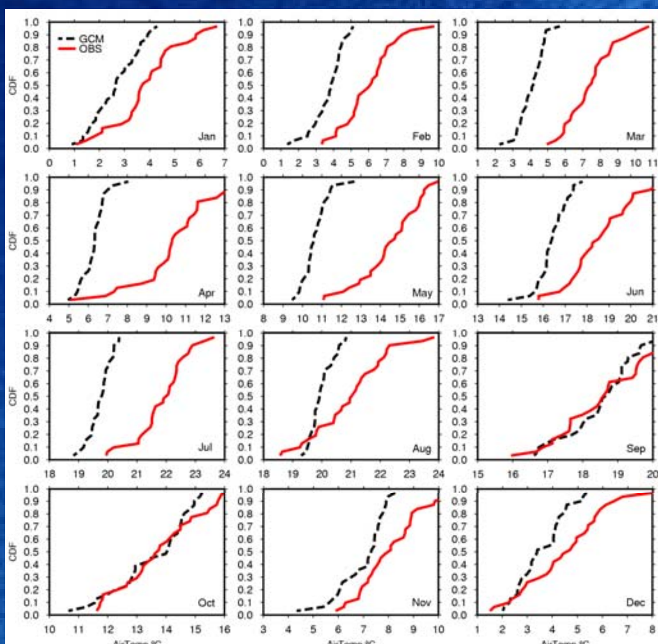
Raw **GCM output**
for same period as observations



BCSD Method – “BC”

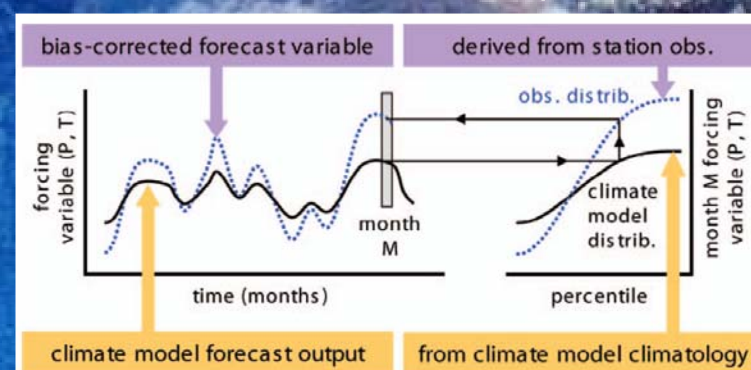


- At each grid cell for “training” period, develop monthly CDFs of P, T for
  - GCM
  - Observations (aggregated to GCM scale)
  - *Obs are from Maurer et al. [2002]*

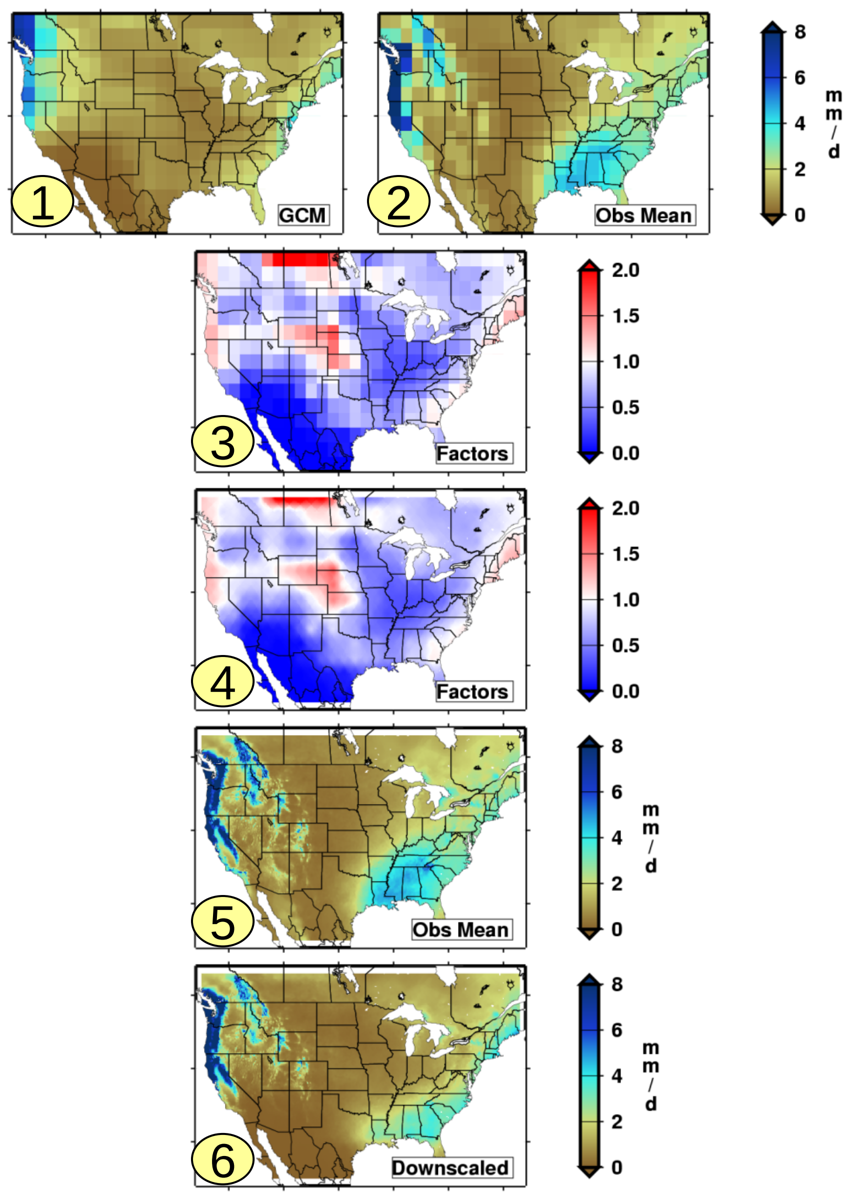


- Use quantile mapping to ensure monthly statistics (at GCM scale) match
- Apply same quantile mapping to “projected” period

Wood et al., BAMS 2006



BCSD Method – "SD"



- Use bias-corrected monthly GCM output (1)
- Aggregate obs to GCM scale (2)
- Calculate P,T factors relative to coarse-scale climatology

  (3) = (1)/(2) (P)   (3) = (1) - (2) (T)
- Interpolate factors to 1/8° grid (4)
- Apply to fine-scale climatology

  (6) = (4)*(5) (P)   (6) = (4)+(5) (T)

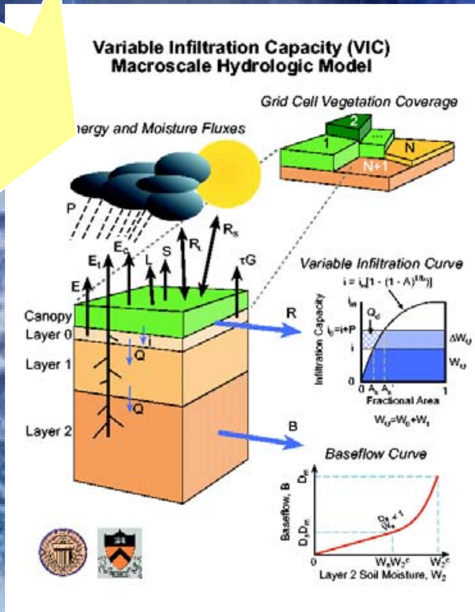
Daily Values from rescaled historical values

Generating Regional Hydrologic Impacts

- Downscaling of GCM Precip and Temp
- Use to drive hydrology model
- Obtain runoff, streamflow, snow

Raw GCM Output

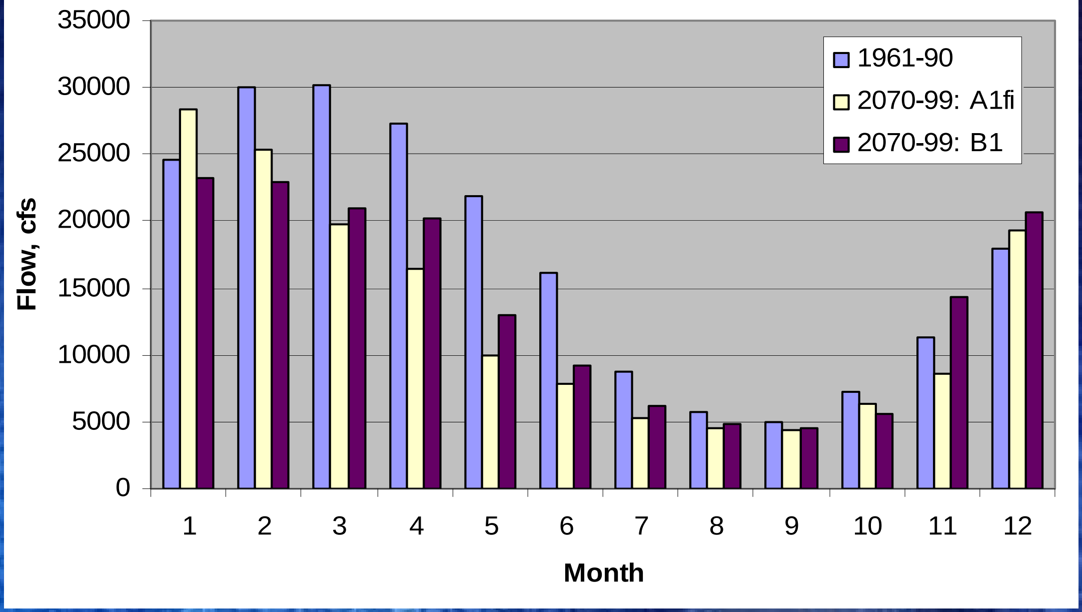
Precip, Temp



Bracketing Streamflow Impacts: North CA

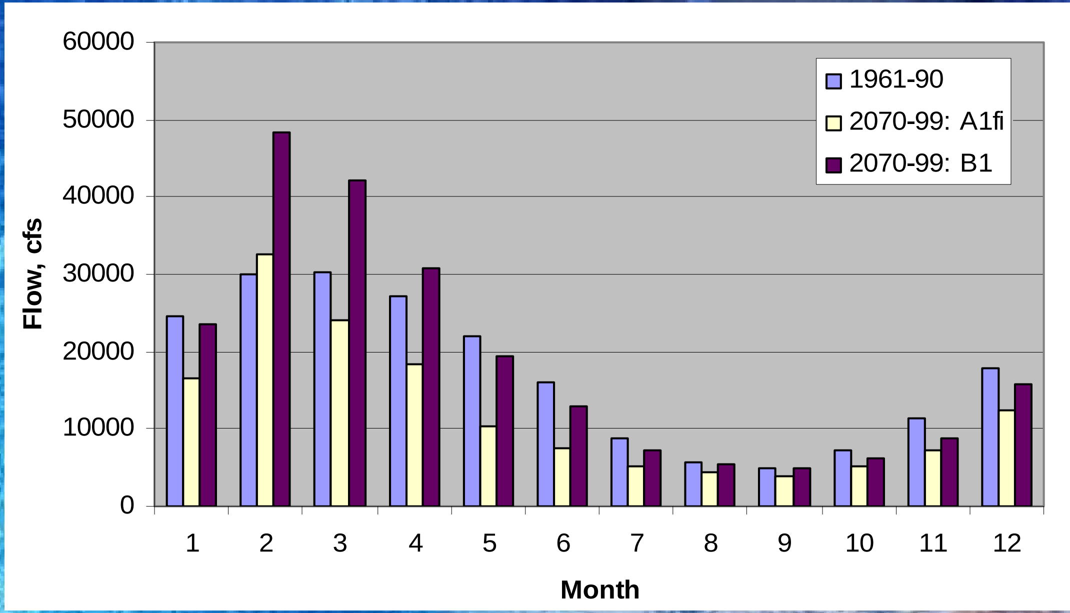
HadCM3 shows:

- Annual flow drops 20-24%
- April-July flow drops 34-47%
- Shift in center of hydrograph 23-32 days earlier
- smaller changes with lower emissions B1



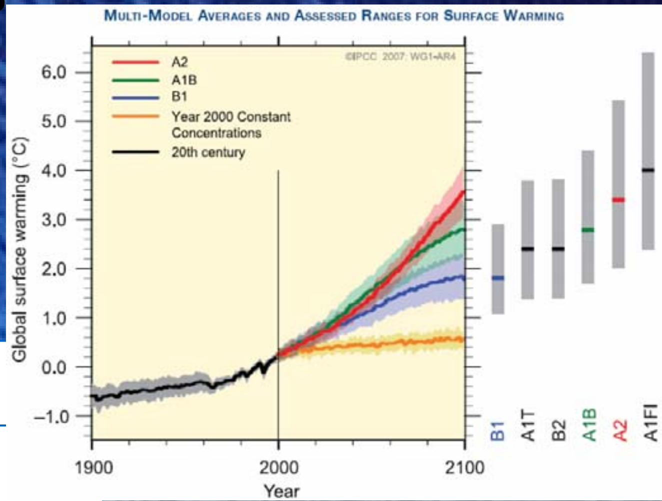
PCM shows:

- Annual flow +9% to -29%
- April-July flow drops 6-45%
- Shift in center of hydrograph 3-11 days earlier
- difference between emissions pathways more pronounced than for HadCM3



GCM Simulations:
models and emissions

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

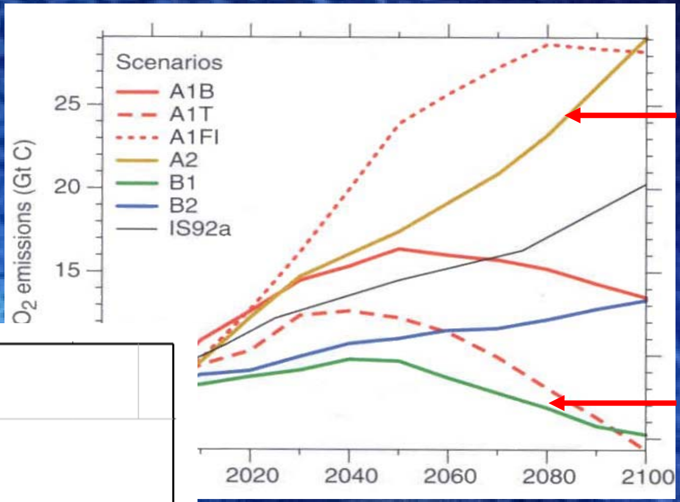


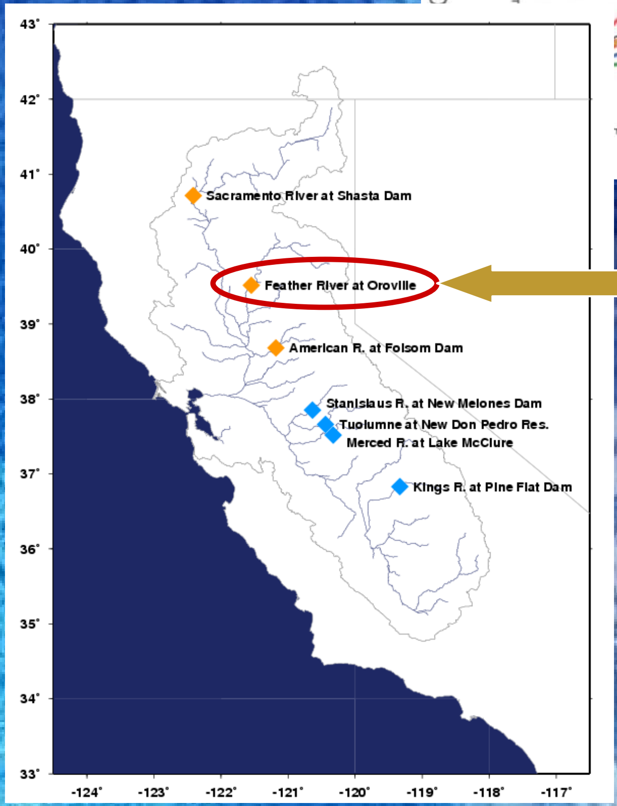
1 realization | multiple realizations

	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

Comparing Impacts to Variability

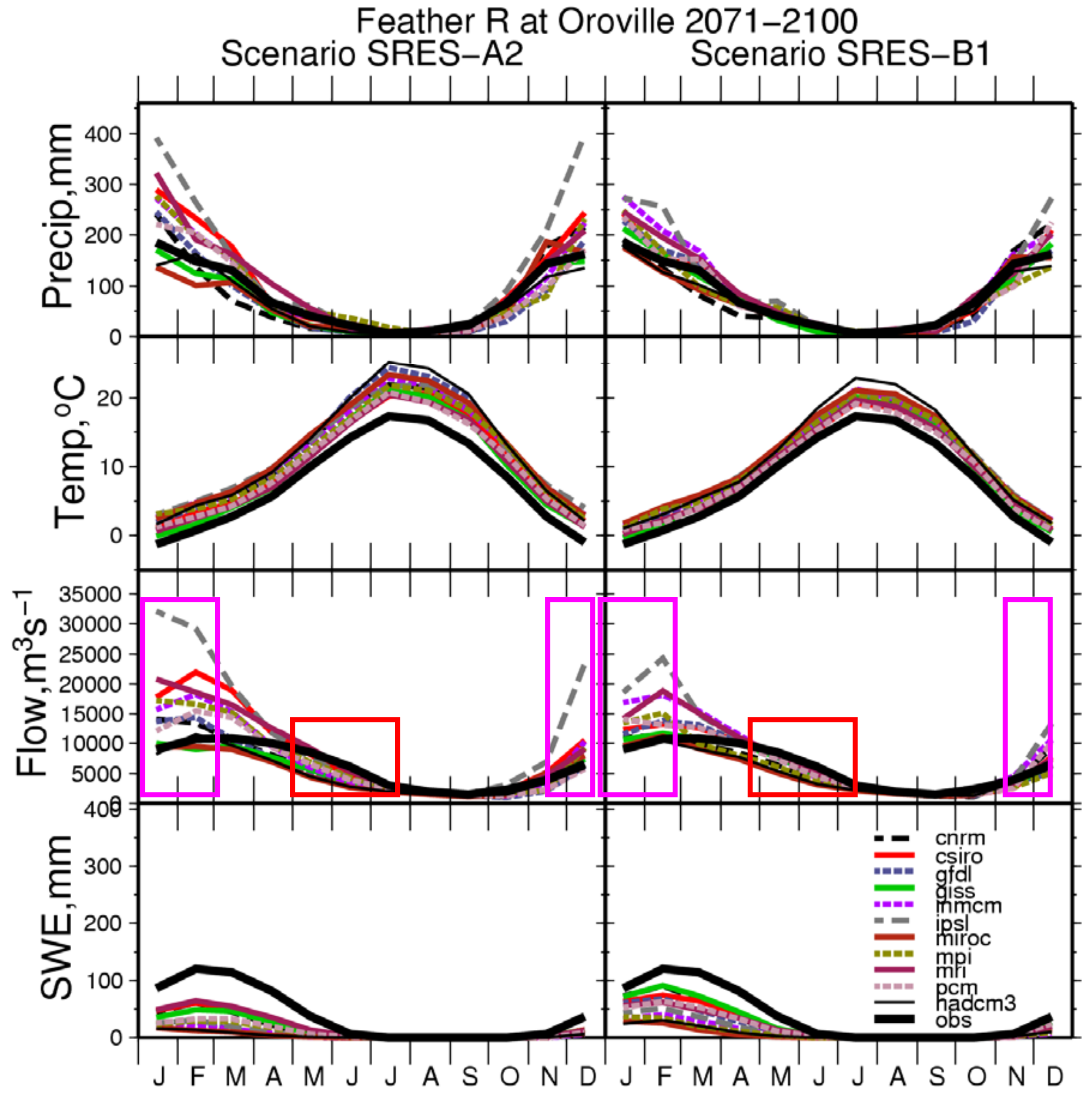
- 11 GCMs, most recent generation (IPCC AR4)
- 2 Emissions scenarios for each GCM:
  - -A2
  - -B1
- Same bias correction, downscaling, hydrologic modeling





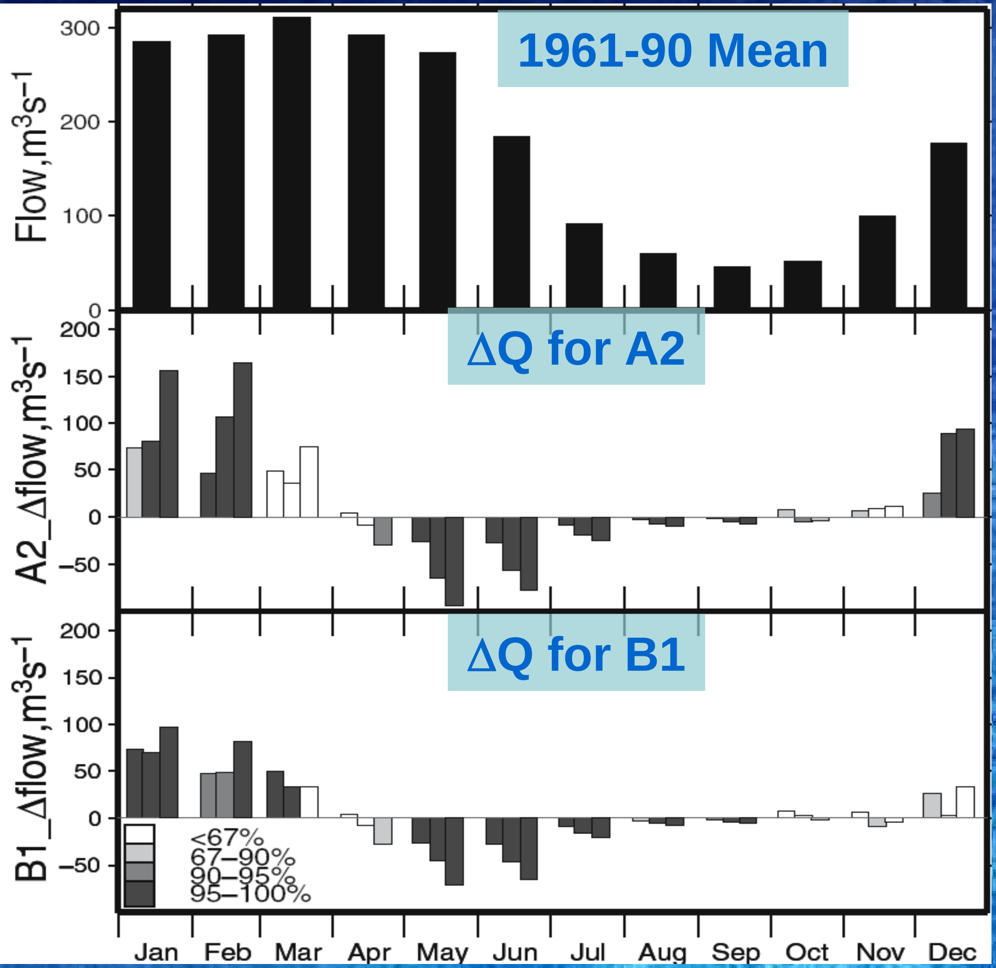
Feather R.

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

Feather River at Oroville Dam



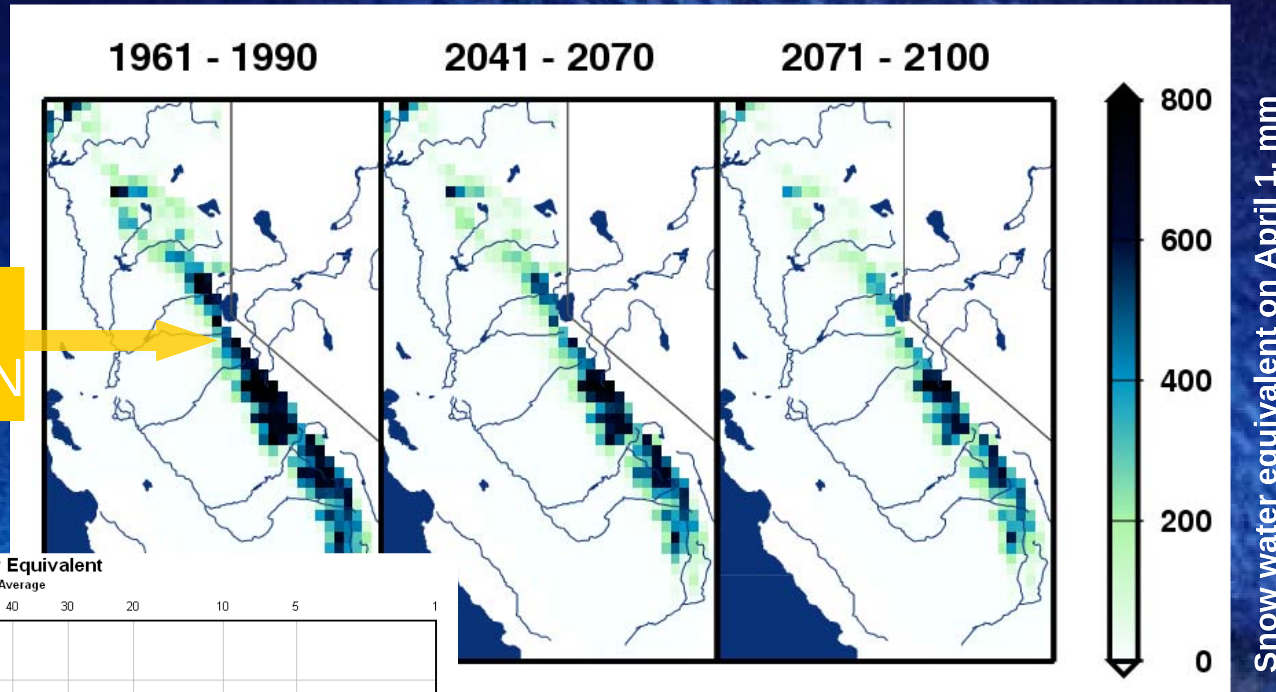
All increases in winter and decreases in spring-early summer flows are high confidence (>95%)

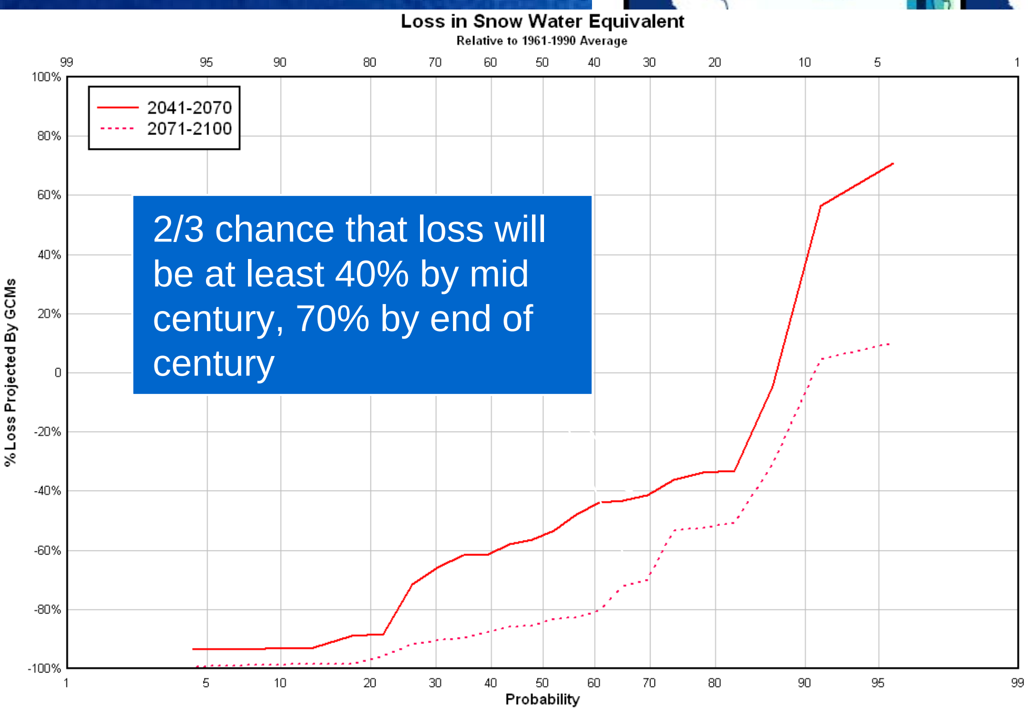
Only May-August are differences in flow (A2 vs. B1) statistically different at >70%

Anticipating an Uncertain Future

- Many long-term impacts are significant, models agree in some respects
- Differences between scenarios in next 50 years is small relative to other uncertainties
- Combine GCMs and emissions scenarios into "ensemble" of futures.
- Allows planning with risk analysis

Impact Probabilities for Planning



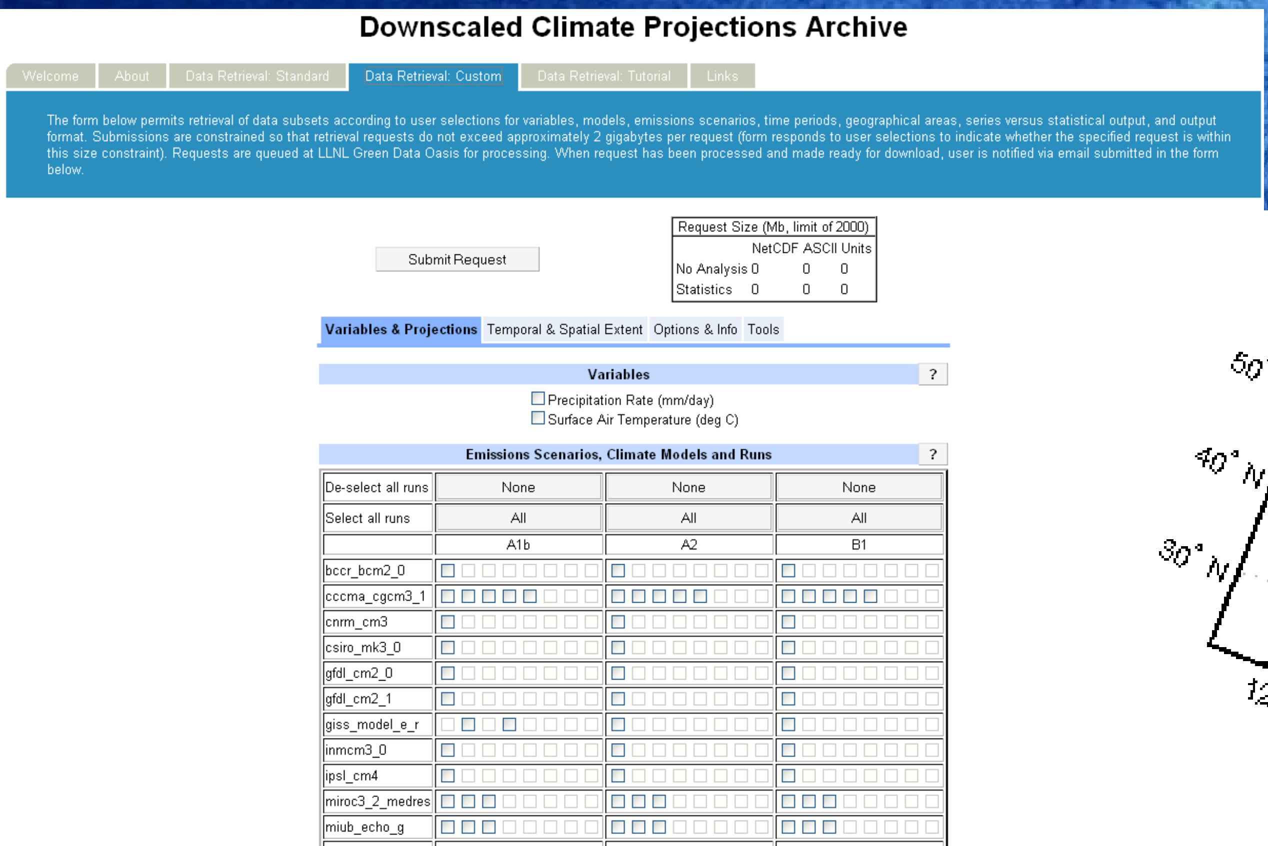


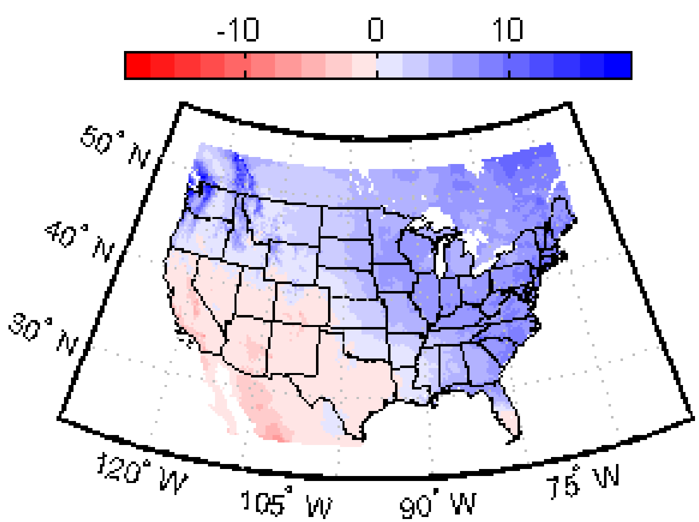
- Combine many future scenarios, models, since we don't know which path we'll follow (22 futures here)
- Choose appropriate level of risk

Facilitating Regional Impacts

using multi-model ensembles to capture uncertainty

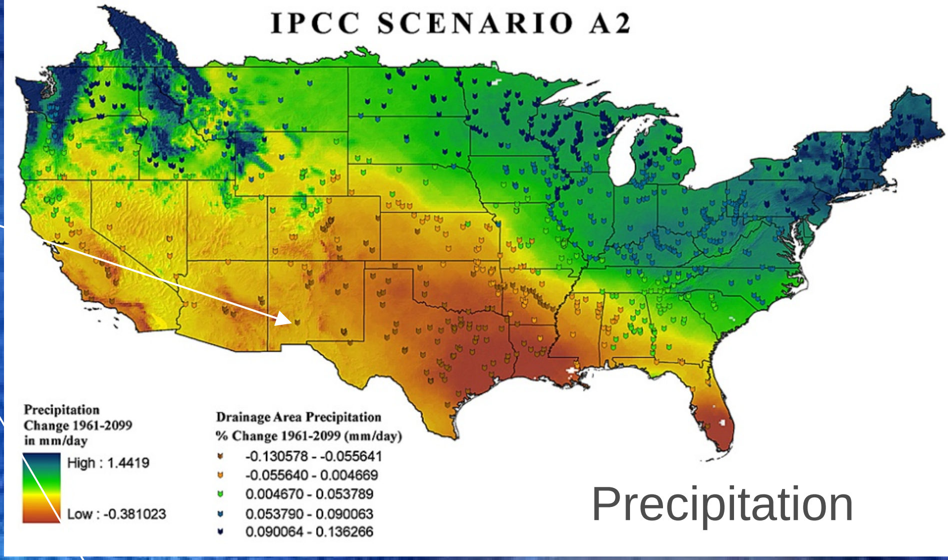
- PCMDI CMIP3 archive of global projections
- New archive of 112 downscaled GCM runs
- gdo4.ucllnl.org/downscaled_cmip3_projections

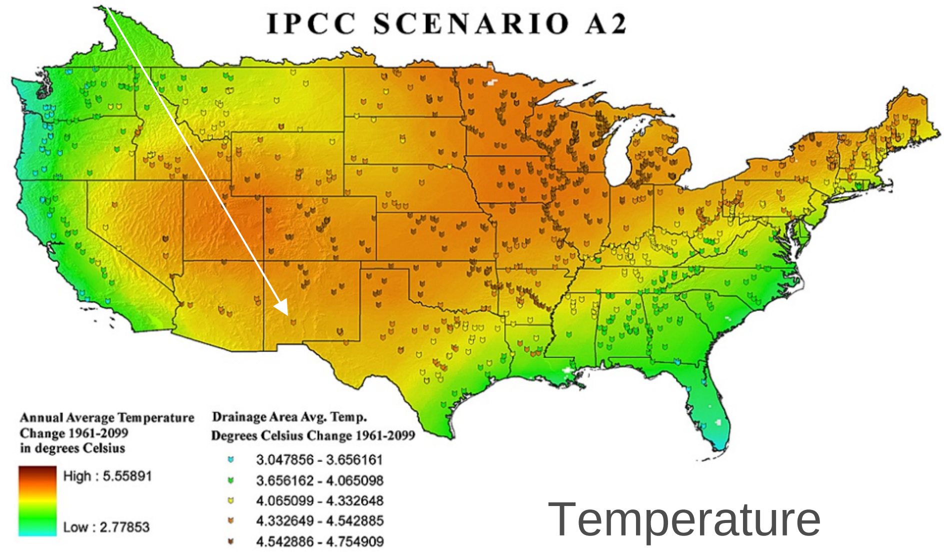




Example Using Archive

- Elephant Butte Dam
  - From 16 GCMs
  - A2 changes
    - $\Delta T = +8.2°F$
    - $\Delta P = -8.3\%$
  - B1 changes
    - $\Delta T = +4.5°F$
    - $\Delta P = -1.3\%$
  - Standard Deviation
    - $\sigma_p \approx 11.4\%$
    - $\sigma_T \approx 1.6°F$





Thanks!