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Managing Water in the West

Introduction of West-Wide Climate Risk Assessment

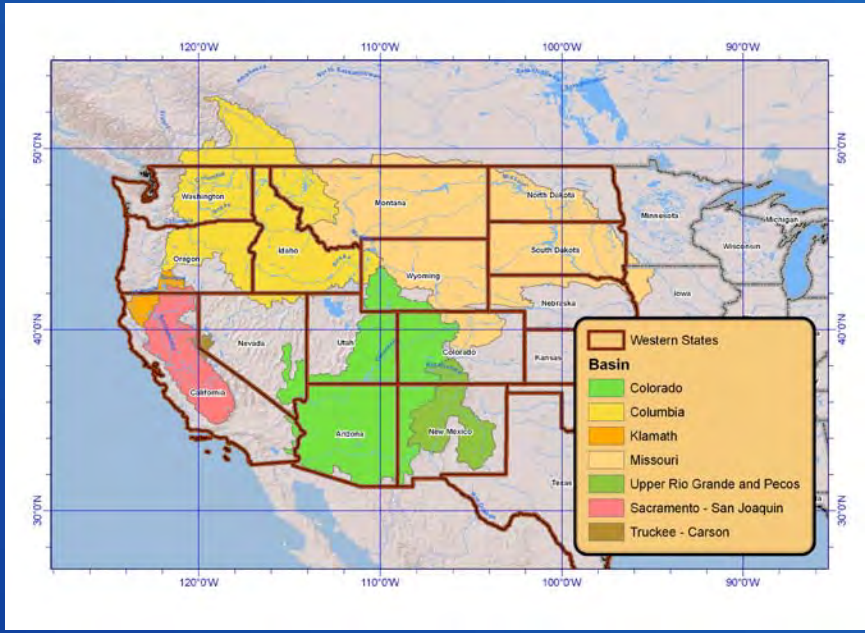
February 2, 2012, Fountain Valley, CA

Water Resources Planning and Operations Support Group
Technical Service Center, Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation

Background

- Public Law 111-11, Subtitle F (SECURE Water Act, SWA, 2009) § 9503.
- Climate change risks for water and environmental resources in "major Reclamation river basins."
- Reclamation's WaterSMART (Sustain and Manage America's Resources for Tomorrow) program
  1. Basin Studies
  2. West-Wide Climate Risk Assessments (WWCRAs)
  3. Landscape Conservation Cooperatives (LCCs)



8 major Reclamation River Basin

SECURE – Science and Engineering to Comprehensively Understand and Responsibly Enhance

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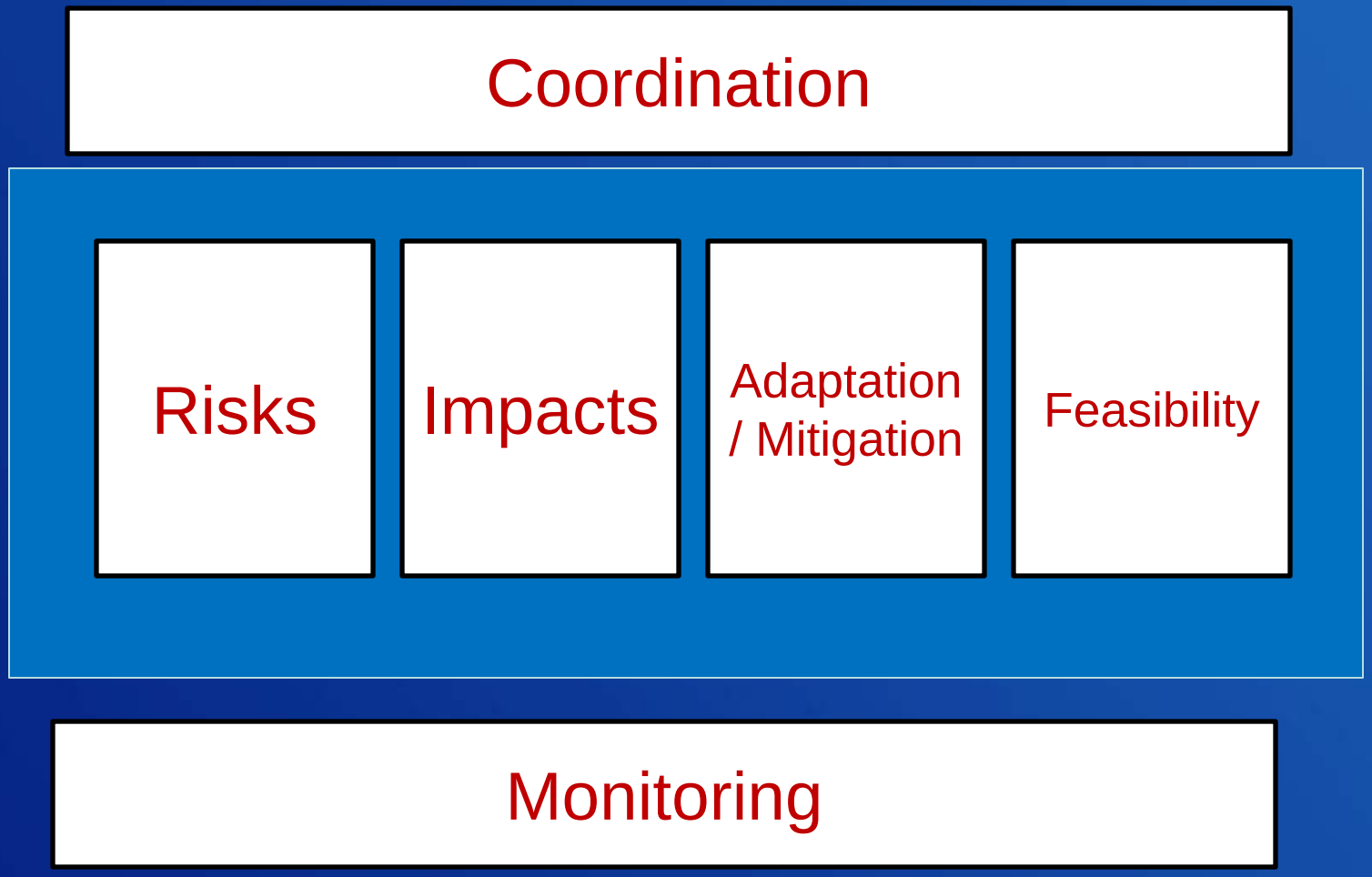
SECURE Water Act, 2009



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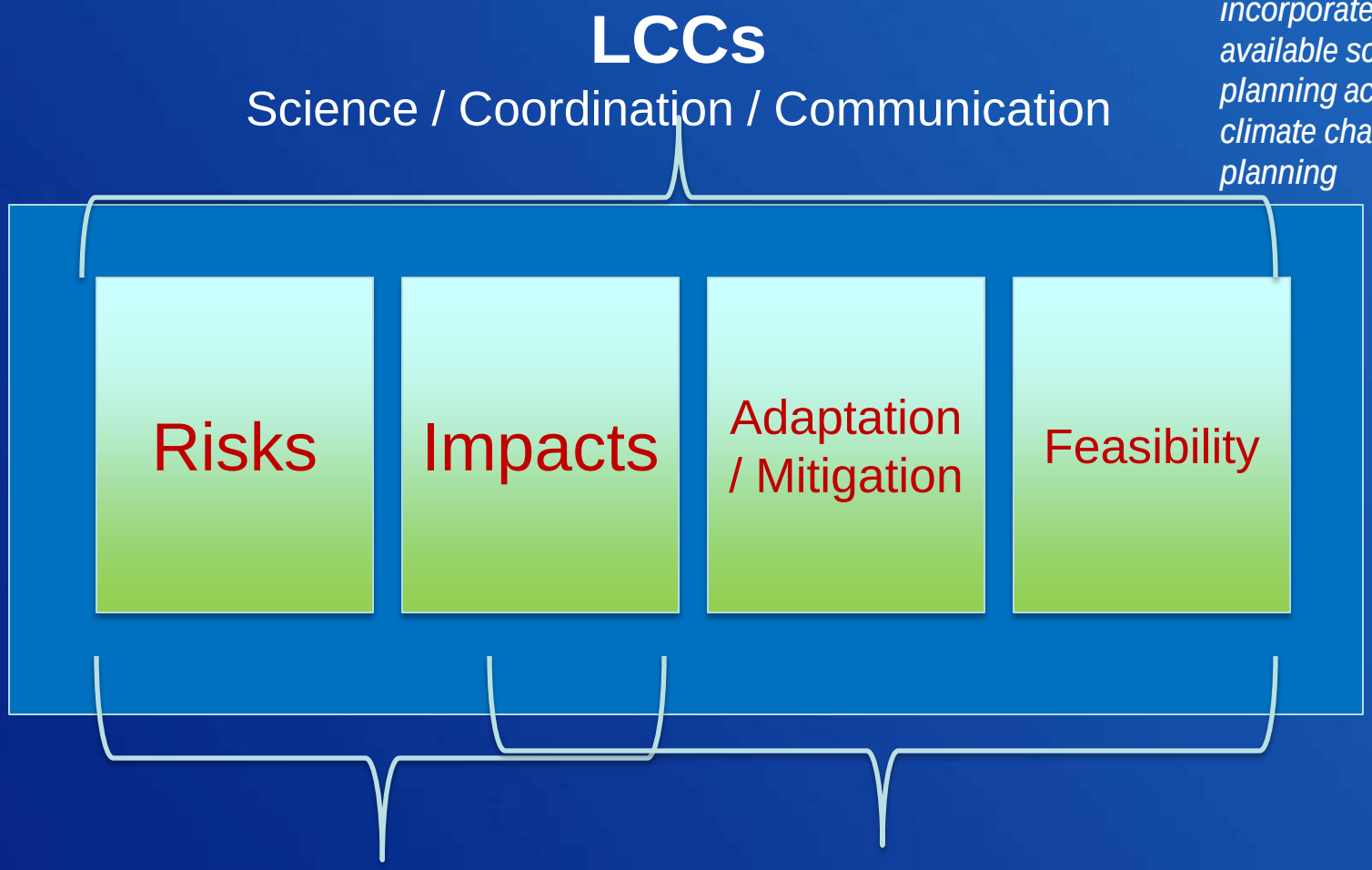
Reclamation WaterSMART Program

Comprehensive approach to incorporate the best available science into planning activities for climate change adaptation planning



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SECURE Water Act, 2009

- Risks
  - Change in snowpack
  - Groundwater recharge and discharge
  - Increases in water demand or reservoir evaporation as result of increasing temperature
- Impacts
  - Ability to deliver water
  - Hydroelectric power generation
  - Recreation at Reclamation facilities
  - Fish and wildlife habitat
  - Endangered, threatened, candidate species
  - Water quality issues
  - Flow dependent ecological resiliency
  - Flood control management

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West Wide Climate Risk Assessments

Baseline Assessments of Risks and Impacts

- Transforming General Circulation Model information into a spatial and temporal scale relevant to a planning context
- Projections of Future Water Supply
- Projections of Future Water Demand
- Simulating future operations of Reclamation facilities
  - Hydropower, flood control, … etc.
- Determining Ecosystem Responses and Resiliency

* Consistent approach across 8 major Reclamation River Basins

WWCRA Activities

CMIP3 & Updates

BCSD 2008 & Updates

With Stakeholders e.g. CO Basin Study

FY 2011 Rio Grande

FY 2010 - 2011

FY 2011 - 2012

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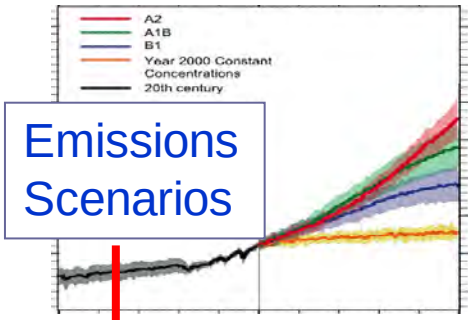
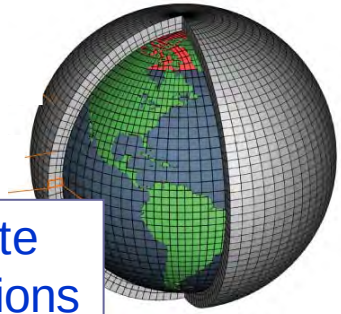
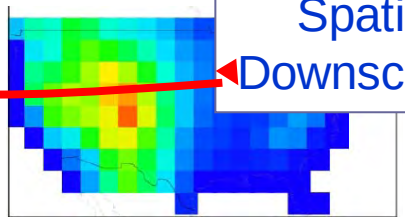
Downscaled GCM Output



Emissions Scenarios



Climate Simulations



Spatial Downscaling

- **3 emissions scenarios**
  - **A1b, A2, B1**
- **Monthly P&T 1950-2099**
- **1/8° (12 km) gridded data**

Santa Clara Univ. (Maurer)
Reclamation
LLNL

Santa Clara University
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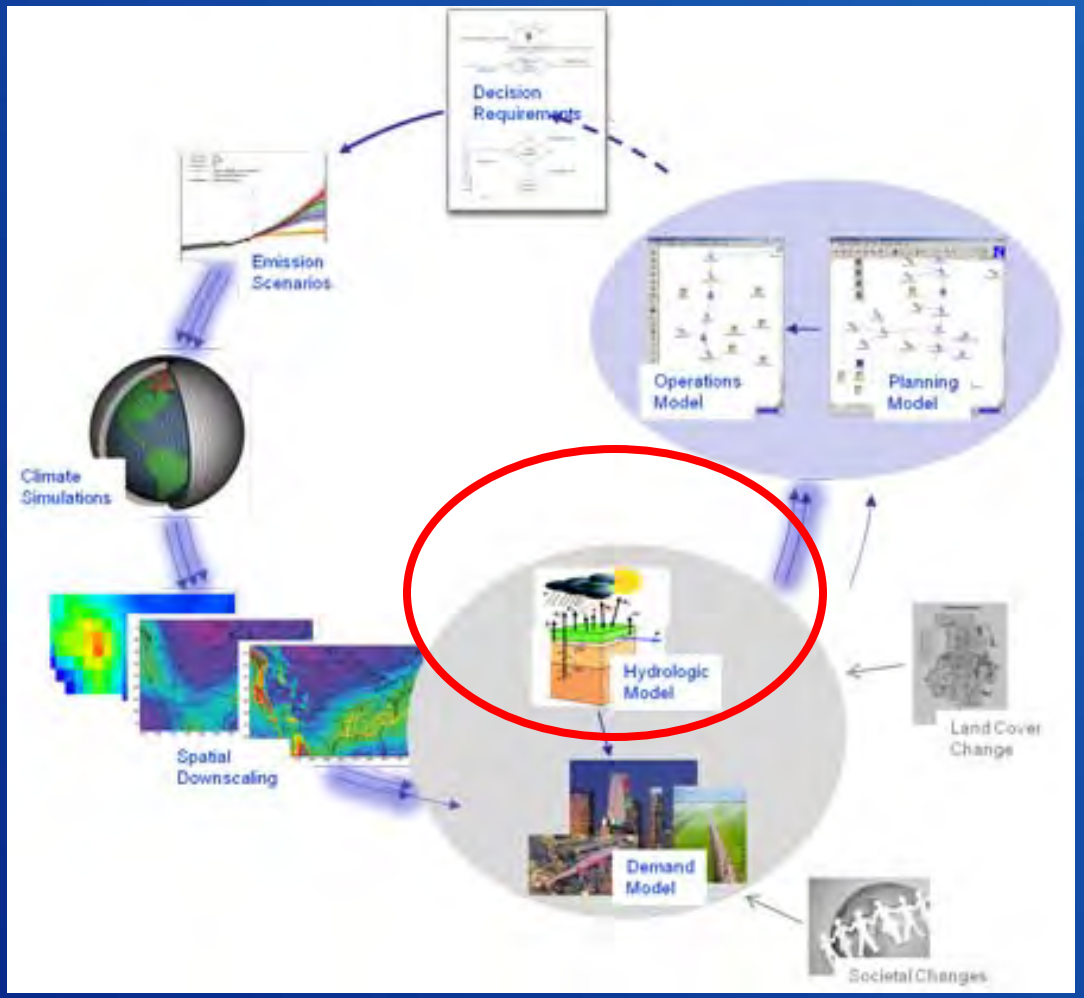
WWCRA Activities



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Objectives

- Develop future climate and hydrologic context common to all reporting basins → west-wide hydrologic analysis
- Use models to characterize future natural hydrology
- Serve the hydrologic projections online

Outline – Developing WWCRA Hydrologic Projections

- Selecting a model network – hydrology model and routing model
- Applying the model network
- Example results – future hydrologic projections
- Products – reports, online data access …

Selecting a Model Network

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Objectives

- Work with available hydrologic model applications → no model building, no refinement, use what we have "as-is"

- WWCRA – University of Washington's VIC (Variable Infiltration Capacity) applications

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model

http://www.hydro.washington.edu/Lettenmaier/Models/VIC/VIChome.html

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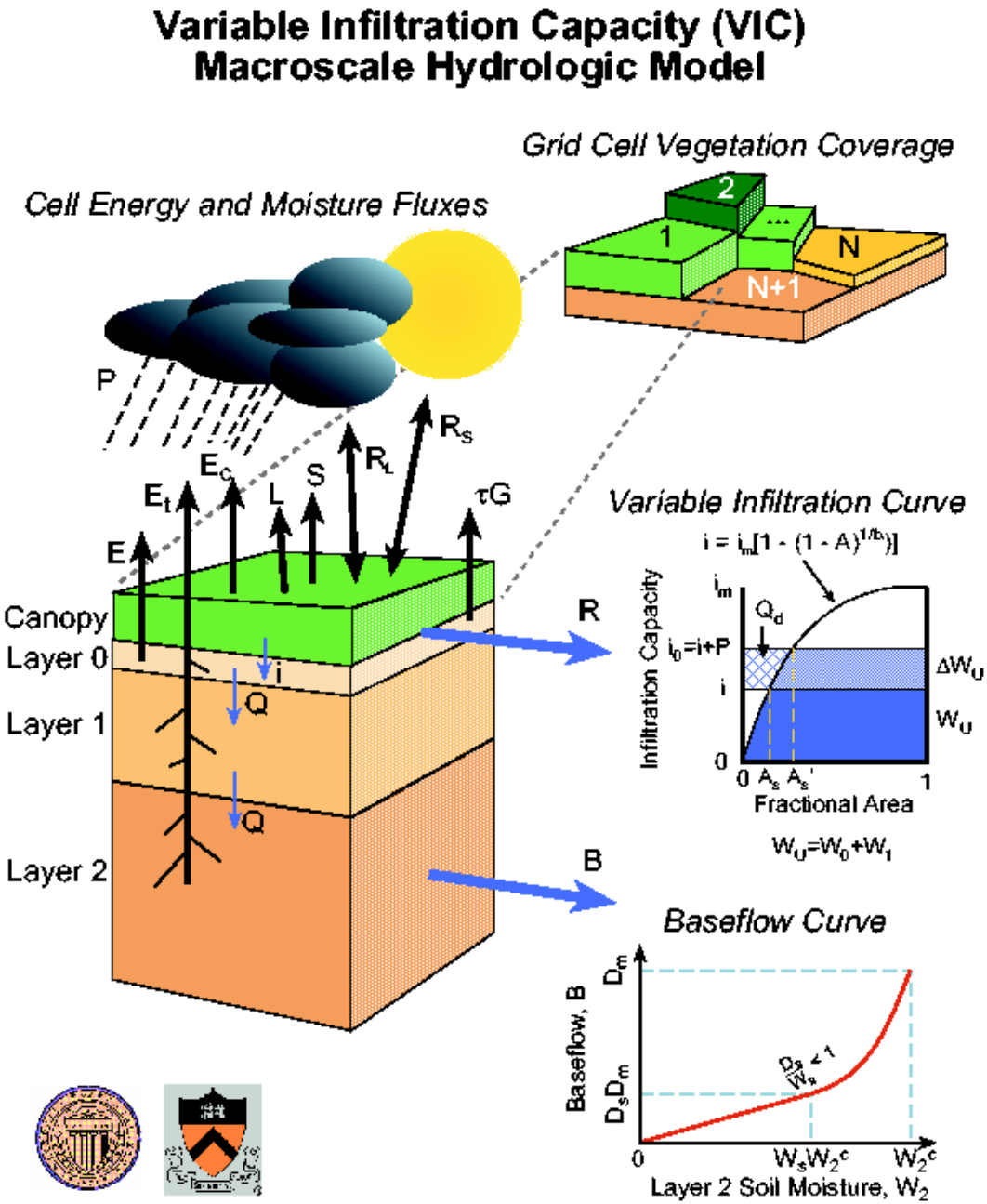
Selection: VIC apps

- Selection Drivers
  - No geographic gaps for SWA reporting basins
  - Computed PET
- Quality of these models?
  - Calibrated to reproduce monthly to annual runoff in large sub-basins.
  - These models have *biases*
- Use of these models?
  - Relative changes

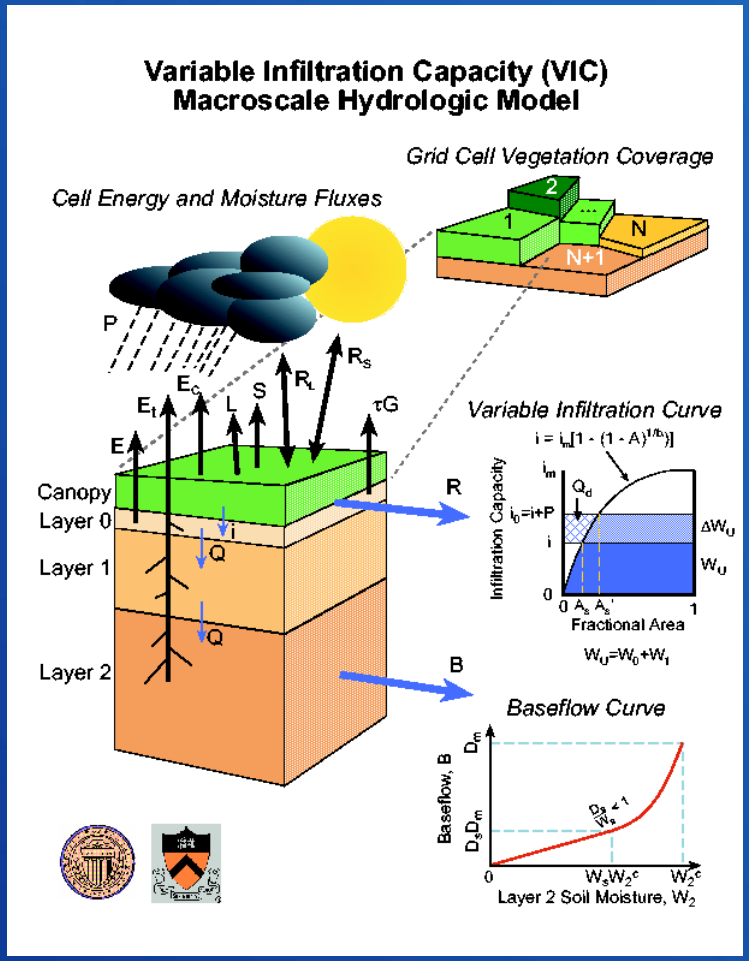
VIC Model Details

- Original Reference
  - Liang et al. 1994
- Motivated by desire to couple land surface hydrology over large areas with atmospheric models → solve water and energy balance at each time step
  - Computes PET rather than requiring input PET
  - Computes other surface energy terms (e.g., sensible heat, ground heat flux)
- Multiple vegetation classes in each cell
- Sub-grid elevation band definition (for snow)
- Sub-grid infiltration/runoff variability



VIC Model Details (cont'd)

- **Gridded macro-scale hydrology model (grid size > 1 km)**
- **VIC model version 4.0.7 (32-bit)**
- **VIC model overview, http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml**



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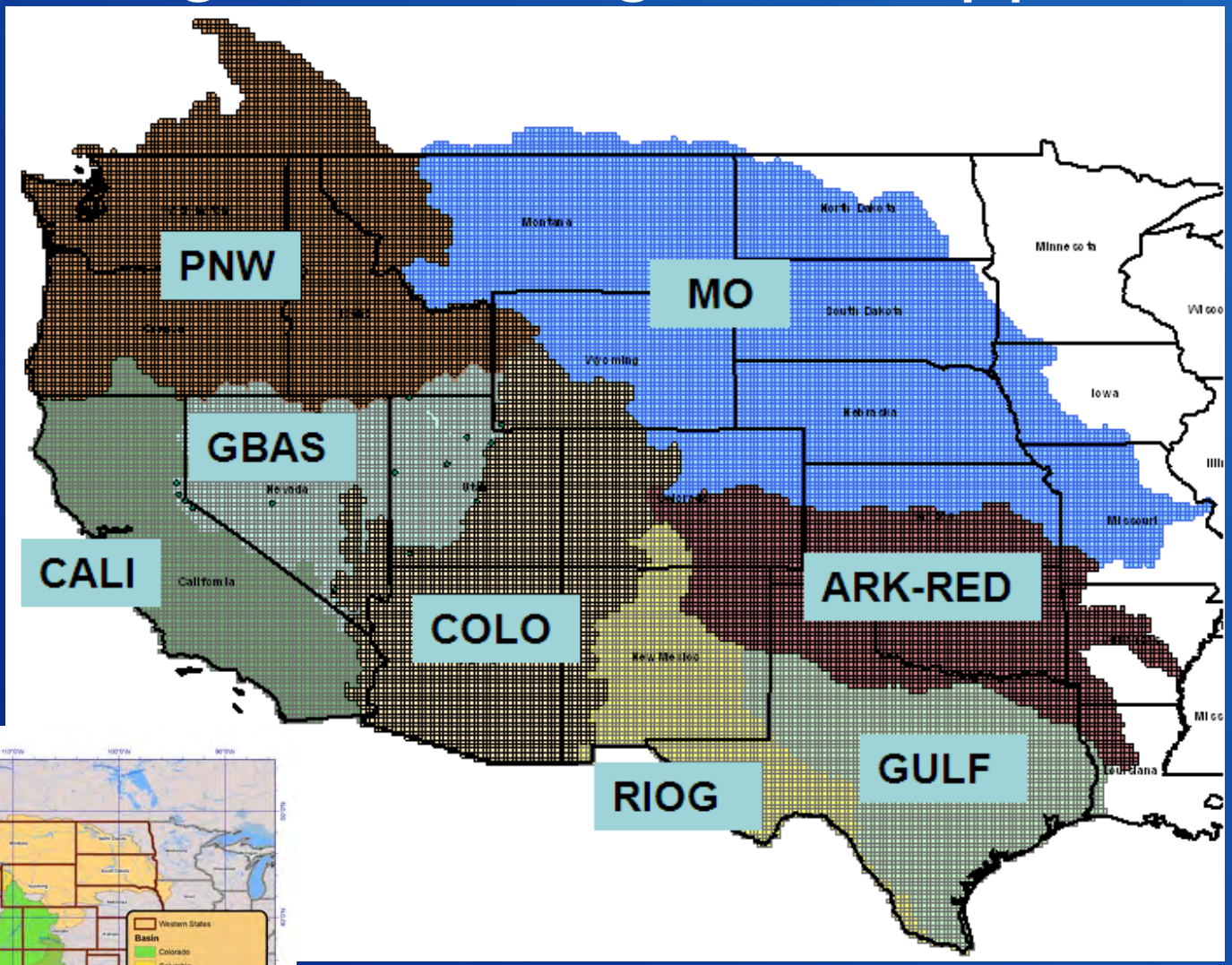
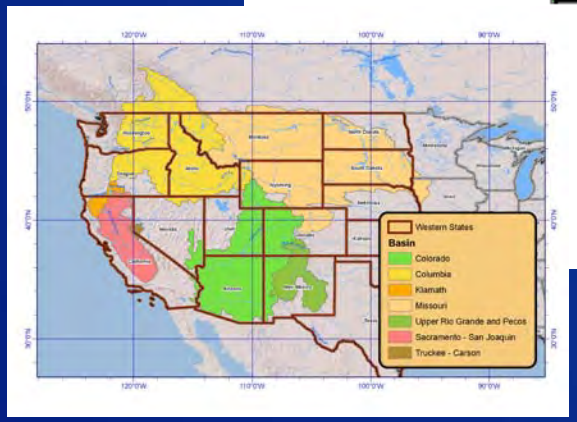
Hydrologic Modeling - VIC Applications





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Hydrologic Modeling - VIC Applications

- **Eight "calibrated" VIC models covering the 17 state Reclamation region**
- **Grid resolution, 1/8th degree (~ 12 km)**
- **Total number of grid cells, ~36,000**

Count	*VIC Application Name*	*Number of Grid Cells*	*Secure Water Act (SWA) Major Reclamation River Basins*
1	PNW	6,392	Columbia River
2	CALI	2,906	Sacramento River San Joaquin River Klamath River
3	GBAS	2,710	Truckee River
4	COLO	4,518	Colorado River
5	RIOG	2,356	Rio Grande
6	MO	9,953	Missouri River
7	ARK-RED	3,999	x
8	GULF	2,989	x
TOTAL		35,823	

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Outline

- Selecting a model network – hydrology model and routing model
- **Applying the model network**
- Example results – future hydrologic projections
- Products

Applying the Model Network

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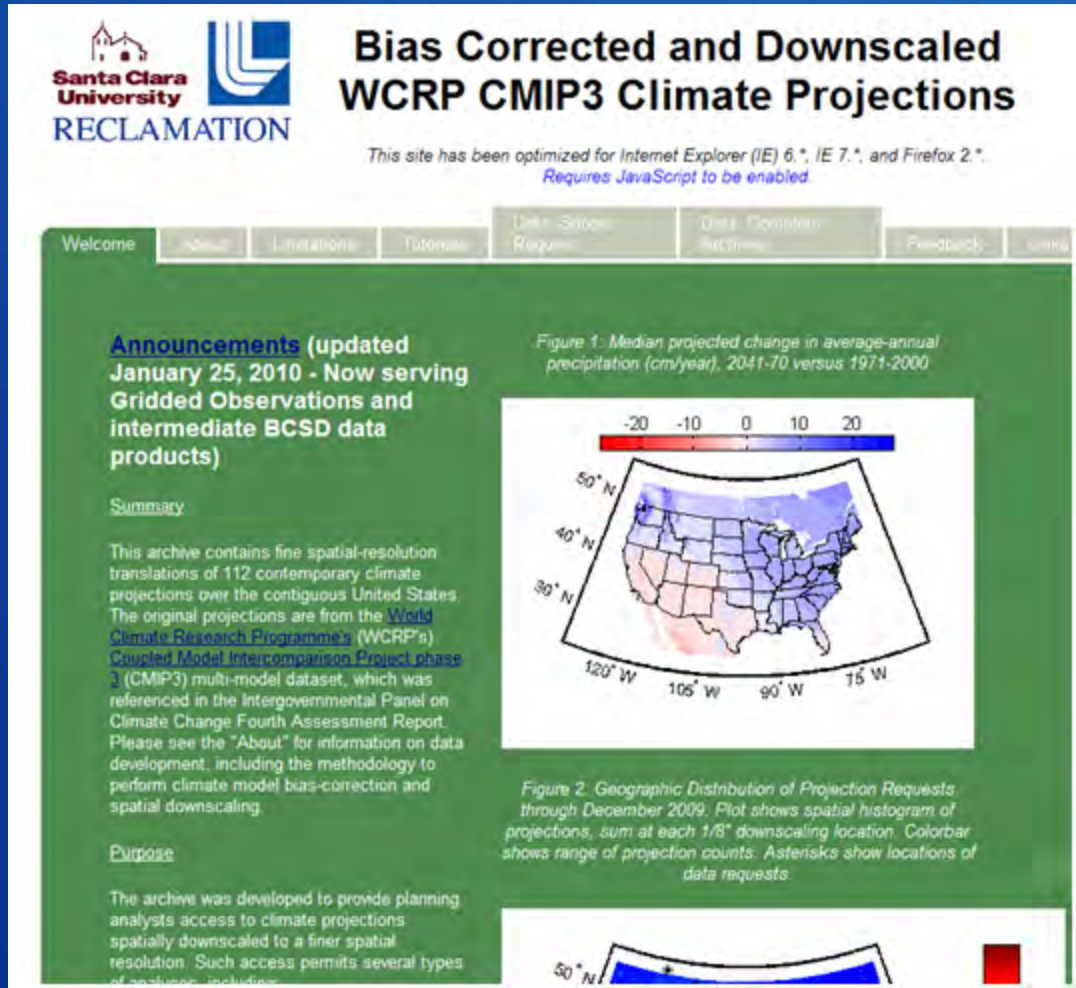
Selected Climate Projections (Bias-corrected, Spatially Downscaled)

http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/

- 112 CMIP3 Projections
  - 16 models, 3 emission scenarios, and multiple initializations for model-emissions combination
- Variables:
  - Precipitation Rate (mm/day)
  - Mean Daily Temperature (°C)
- Temporal Coverage and Resolution
  - 1950-2099, monthly
- Spatial Coverage and Resolution
  - Contiguous U.S., 1/8° (~12km x 12 km)
- Developers
  - Reclamation, Santa Clara University (Ed Maurer), LLNL



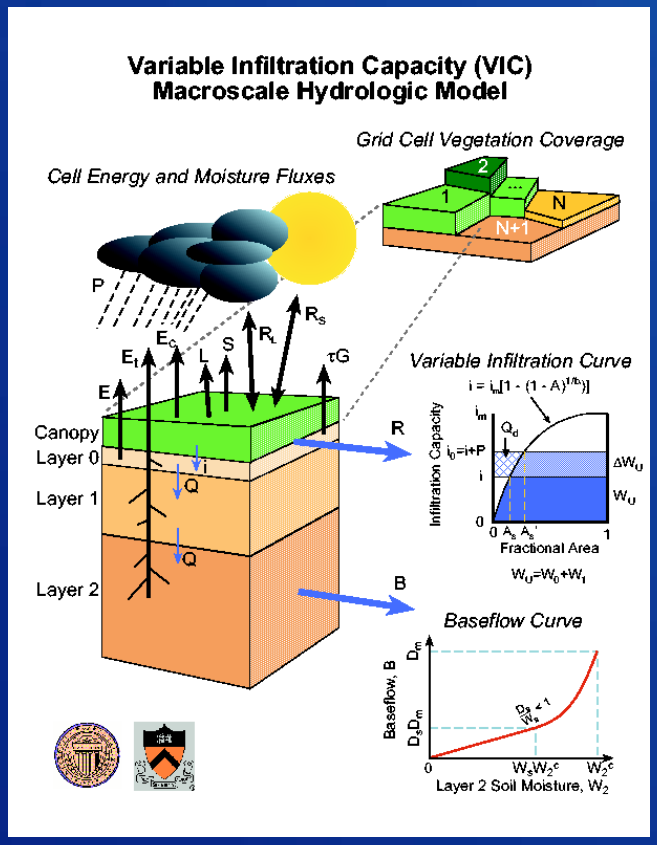
Applying VIC

- Generate weather inputs
  - follow Wood et al. 2004
  - Spatial:
    - no reconciliation necessary, VIC grids coincide with BCSD grid (1/8deg)
  - Temporal:
    - translate “monthly BCSD T and P data” into “daily Tmin, Tmax, P and wind speed” necessary for VIC simulationn
    - ~historical resampling & scaling
    - Library of historical: daily Maurer et al (2002), 1950-1999
    - Sampling rules: similarity in like month, constraint P scaling (working with UW CIG (Salathe/Hamlet), Andy Wood, and Ed Maurer on this issue)
- Simulate Runoff

Hydrologic Modeling – VIC Setup, 2 Steps

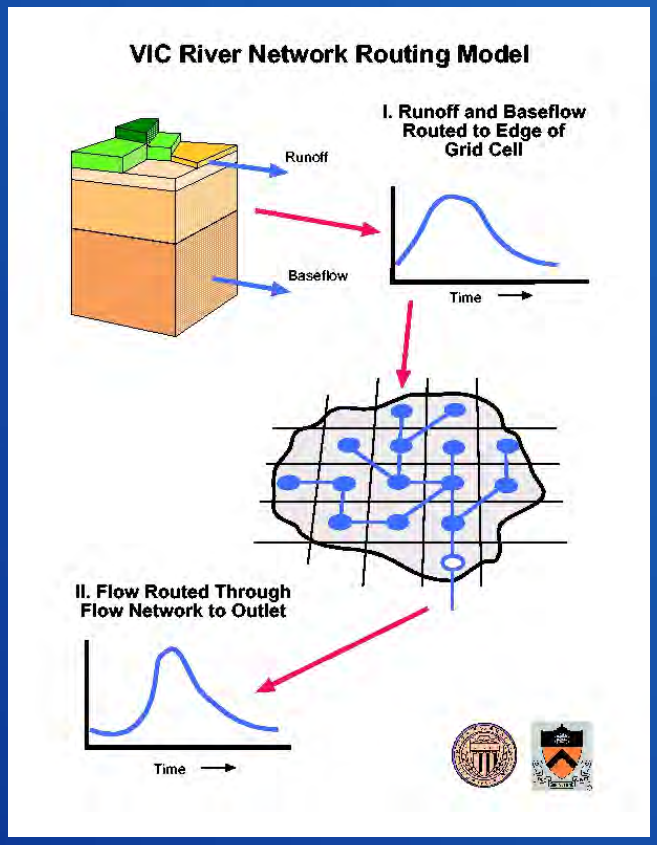
1.Land Surface Simulation

- simulate runoff (and other fluxes) at each grid cell



2. Streamflow Routing

- transport runoff from grid cell to outlet



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What's being simulated

- 112 gridded climate projections → 112 gridded hydrology projections (runoff, swe, et, pet)
- Time Period: daily 1950-2099
- ~36,000 grid cells at 1/8th degree (~12 km) spatial resolution

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Outline

- Selecting a model network – hydrology model and routing model
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Example Results – Future Hydrologic Projections

Results - Background

- Continuous simulation – gridded (~12 km x 12 km)
  - 1950-2099 (daily)
  - Mostly variables aggregated to monthly for reporting

- Reference decade, 1990s - water years, 1990-1999

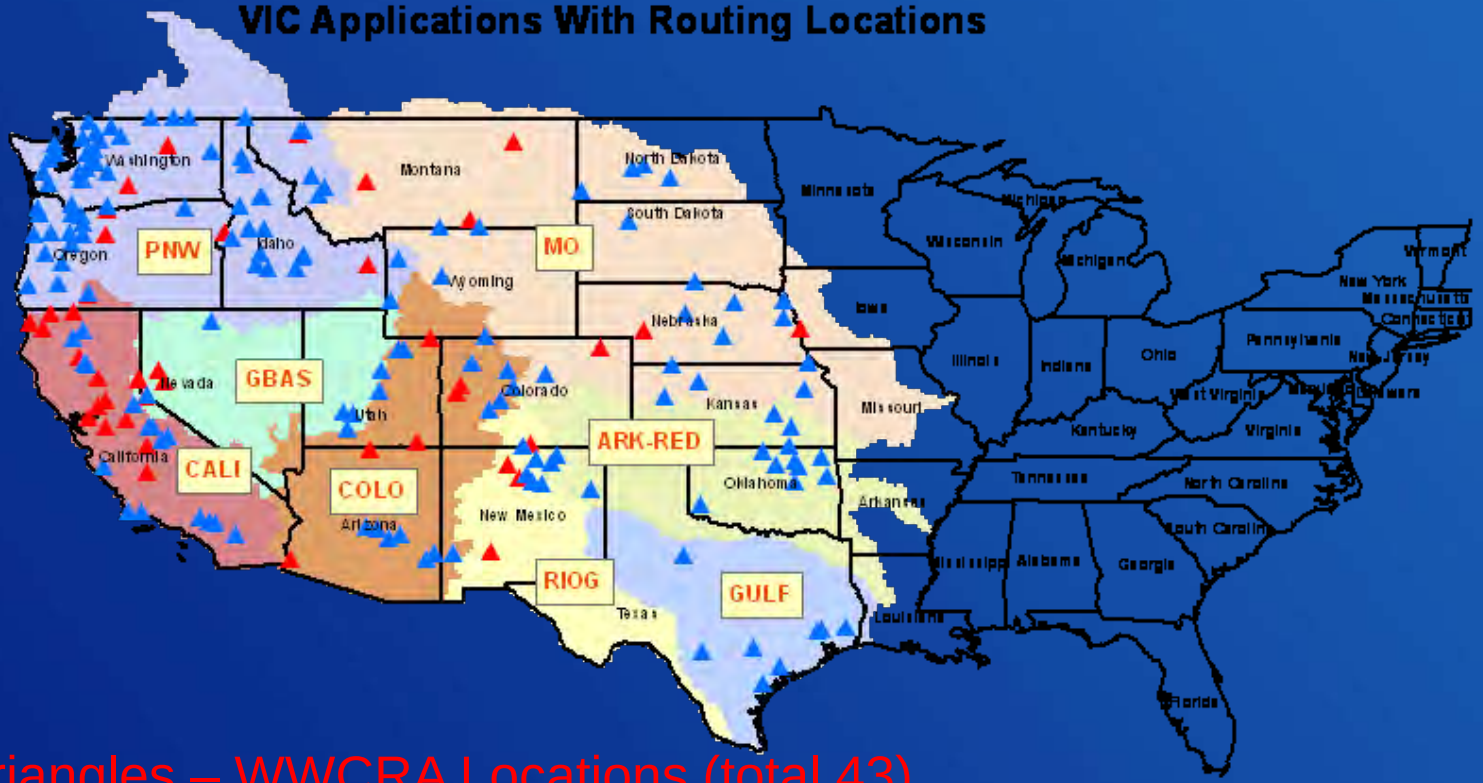
- Three future decades
  - 2020s - water years, 2020-2029
  - 2050s - water years, 2050-2059
  - 2070s - water years, 2070-2079

- Changes in future decades from the 1990s reference

Results - WWCRA

- **Precipitation and temperature trends**
- **Change in snowpack – SWE**
- **Timing of runoff**
- **For reporting**
  - **43 WWCRA locations spanning the major Reclamation basins**
  - **152 HCDN (Hydroclimate Data Network) sites spanning the western US**

VIC Applications With Routing Locations



Red triangles – WWCRA Locations (total 43)

Blue triangles – HCDN locations (total 152)

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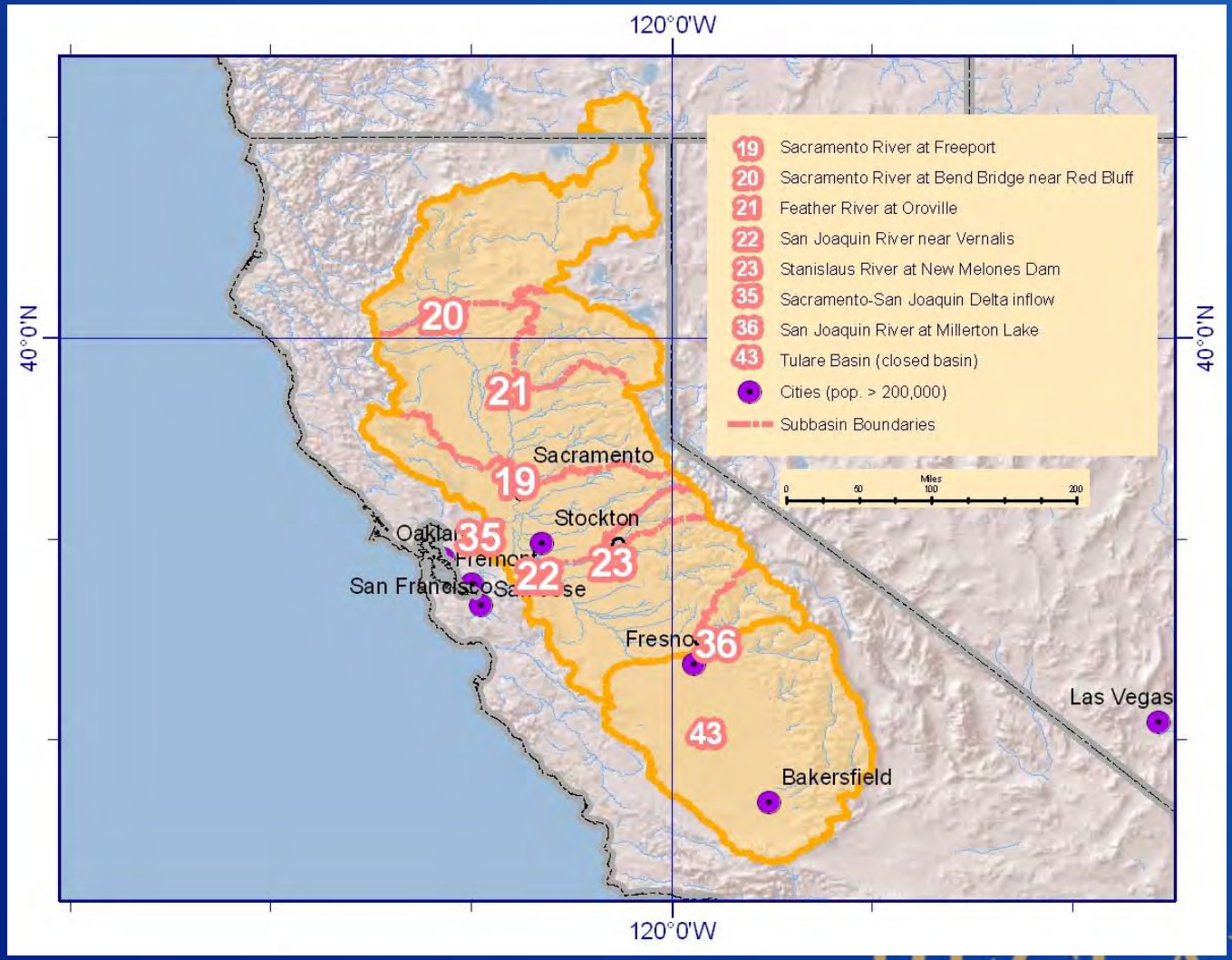
Sacramento R., San Joaquin R. and Tulare Basins



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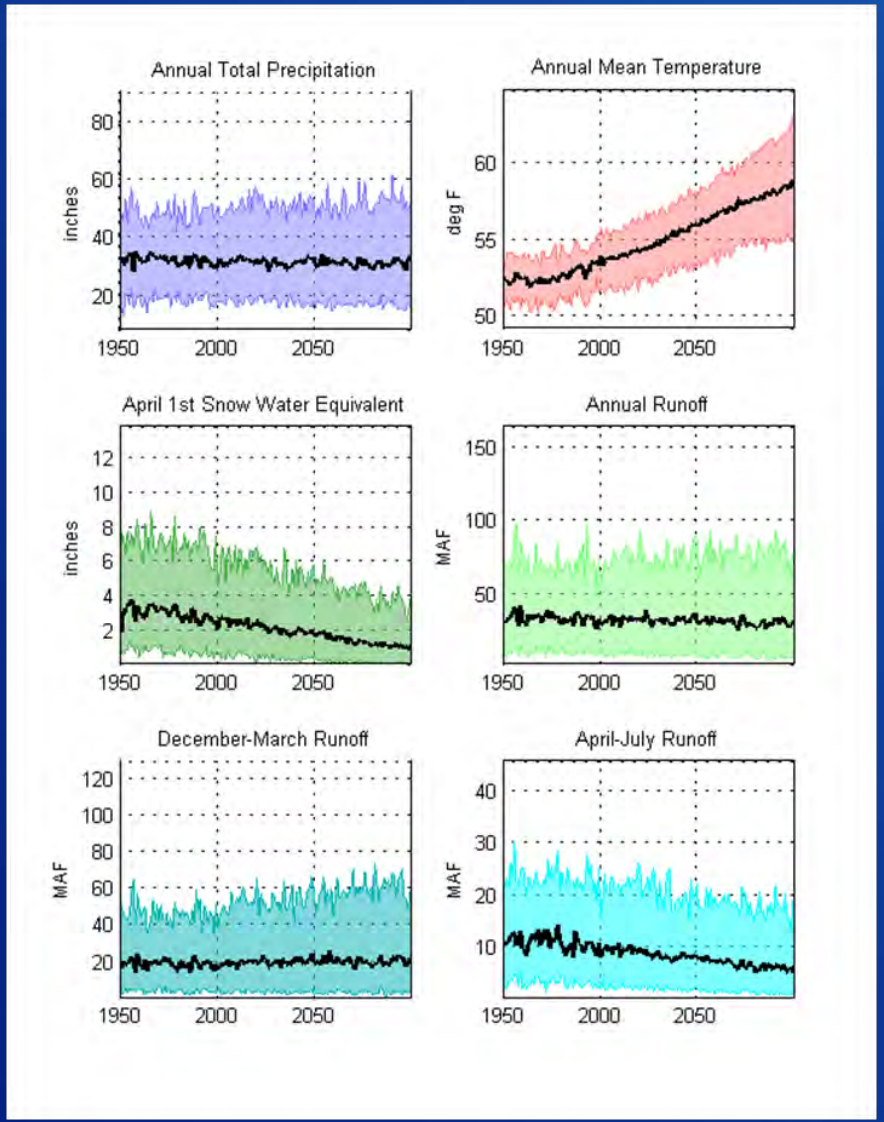
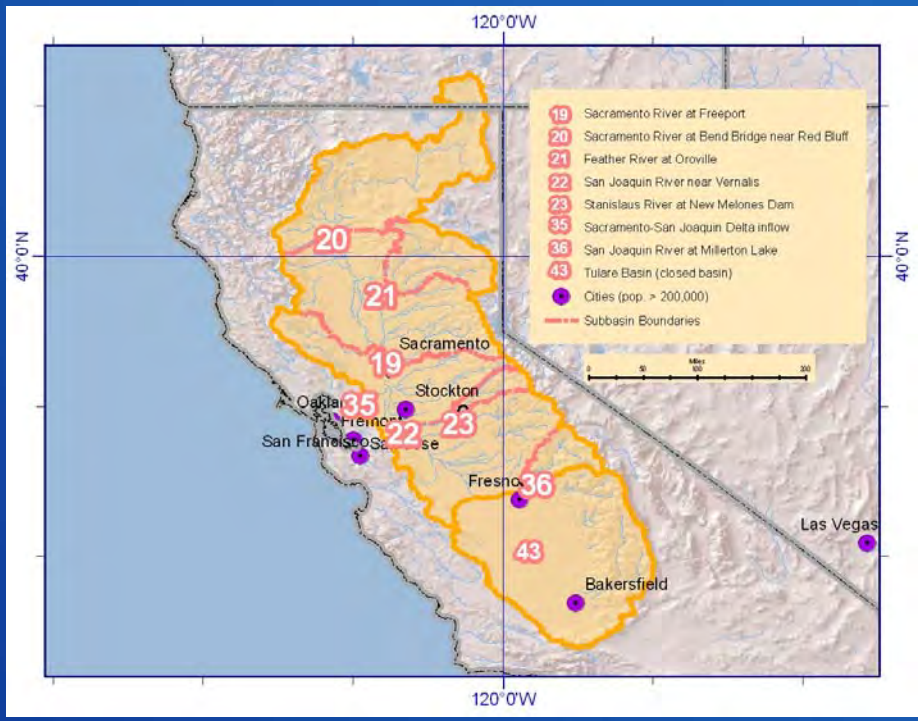
Sacramento and San Joaquin Rivers at the Delta – Location 35





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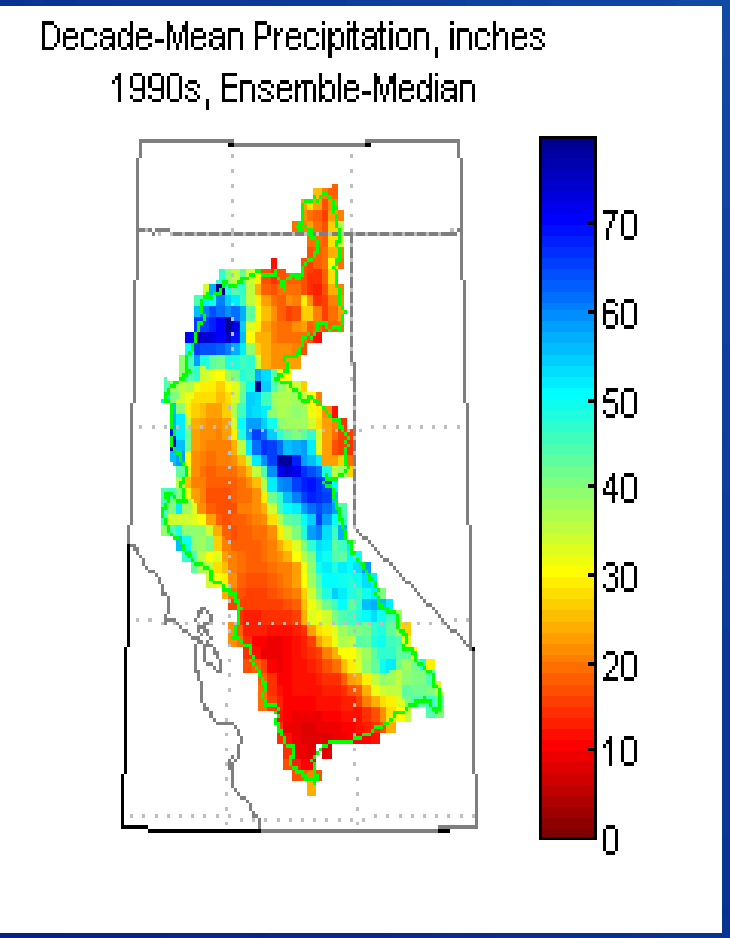
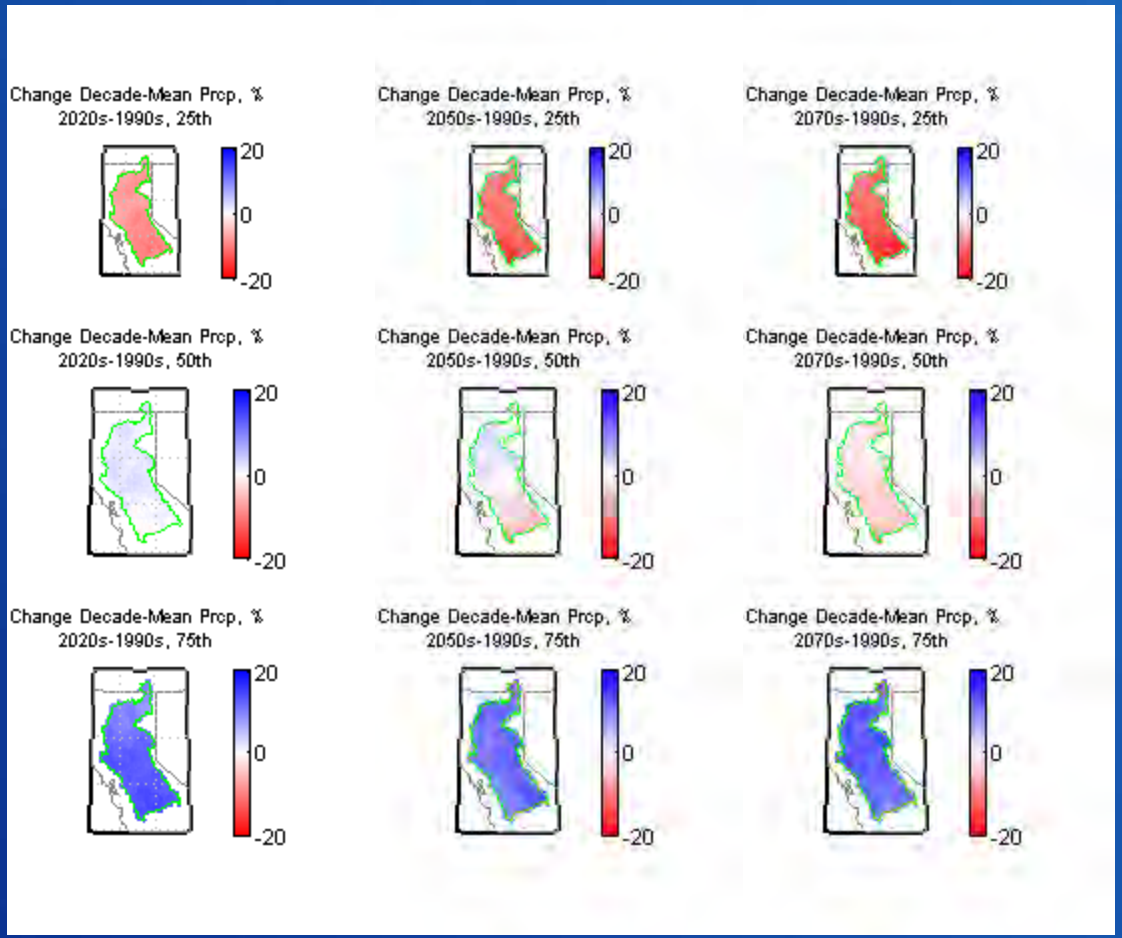
Sacramento and San Joaquin Rivers at the Delta – Precipitation





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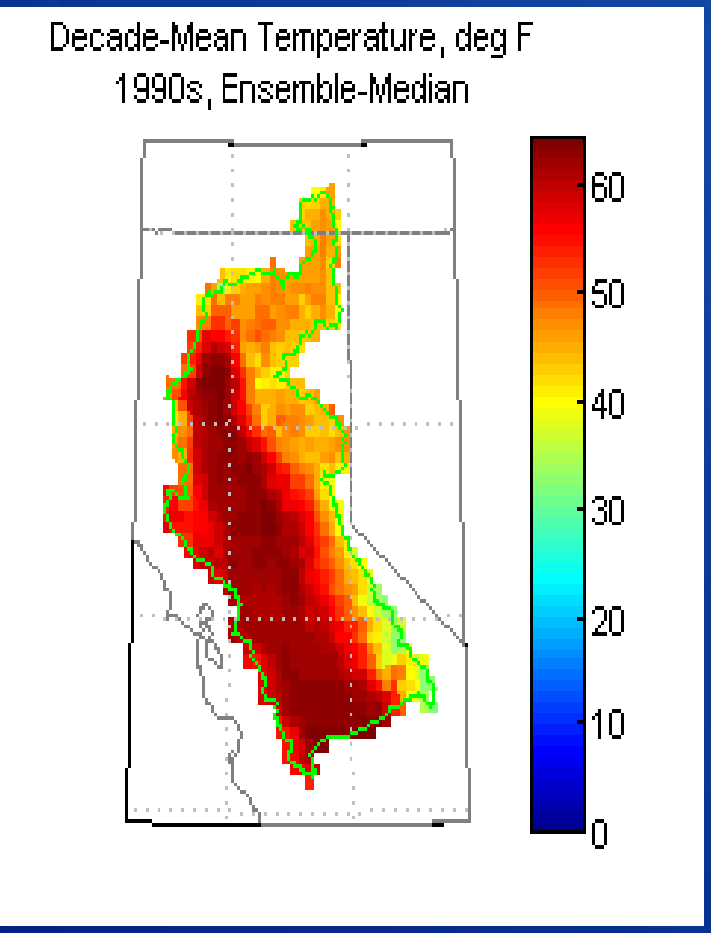
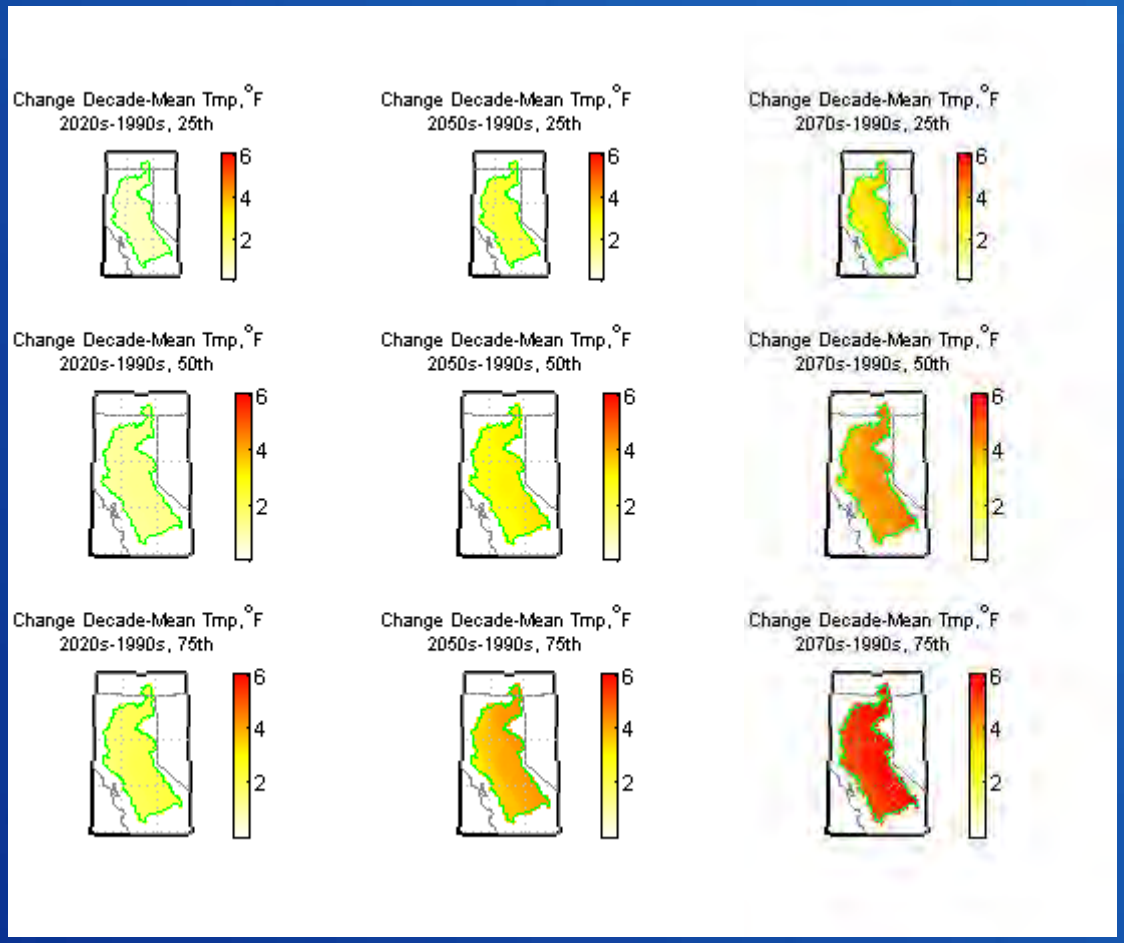
Sacramento and San Joaquin Rivers at the Delta – Temperature





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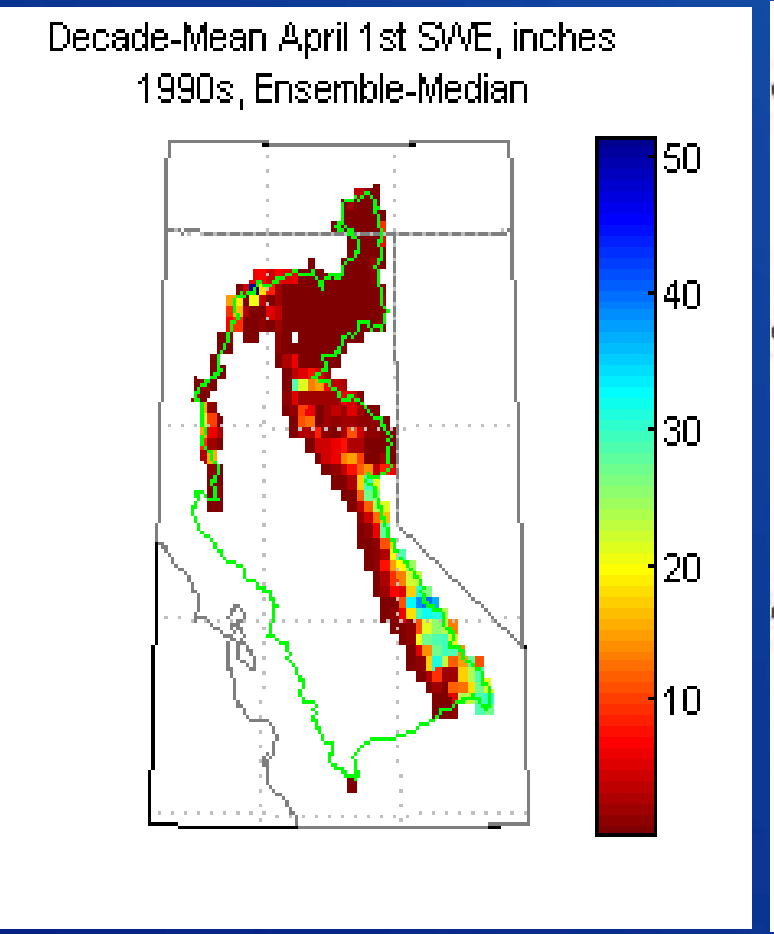
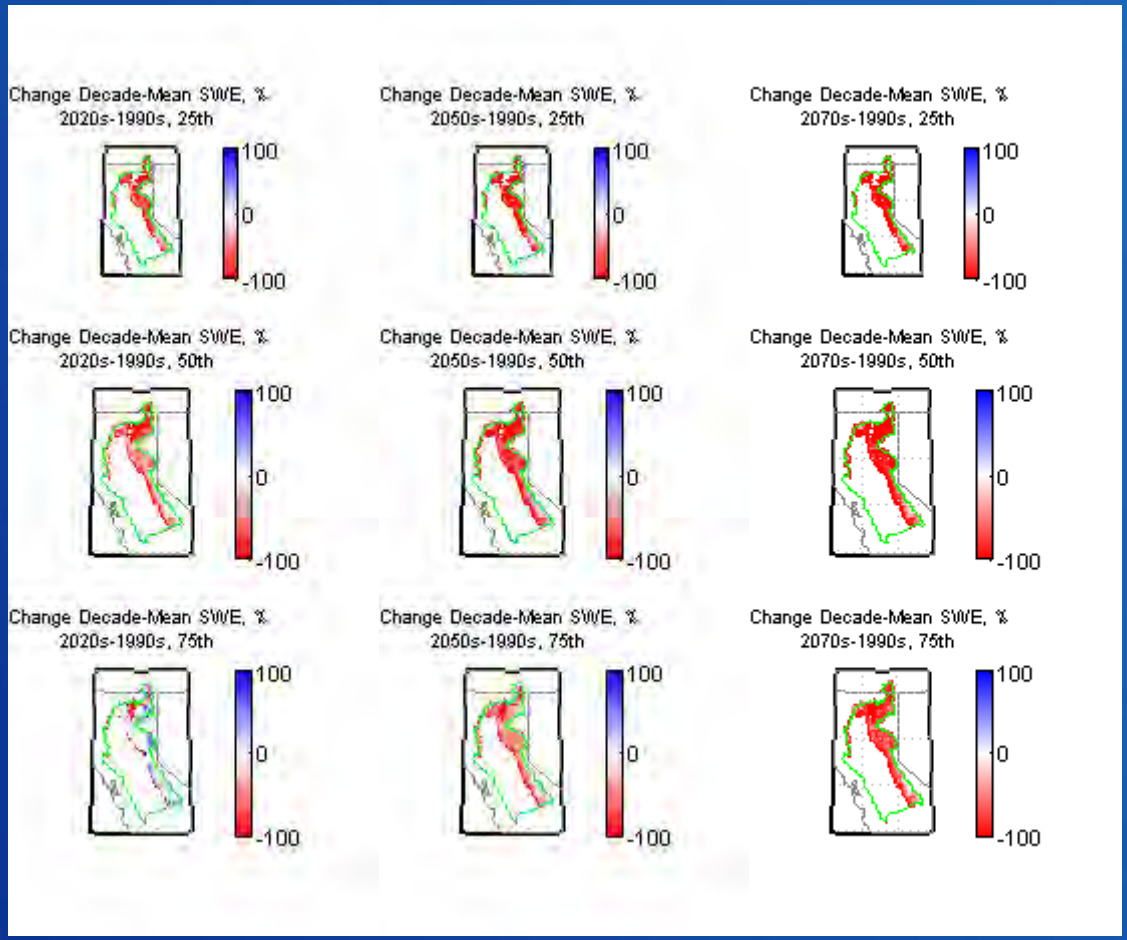
Sacramento and San Joaquin Rivers at the Delta – SWE





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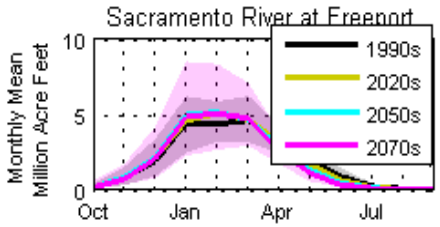
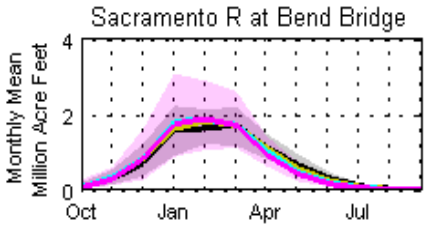
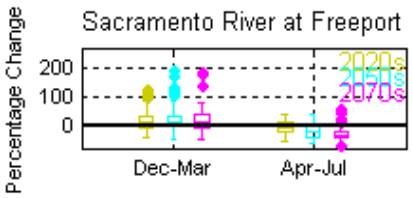
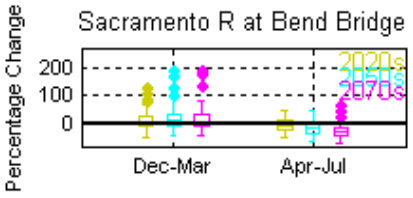
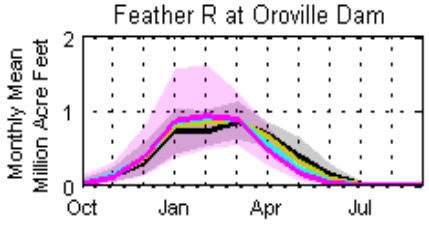
Streamflow Impacts

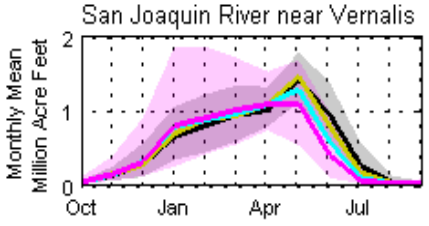


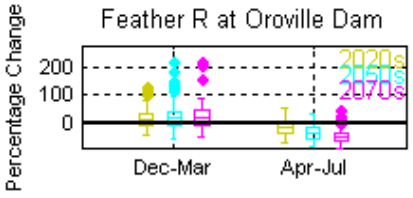


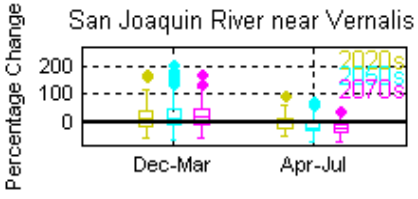


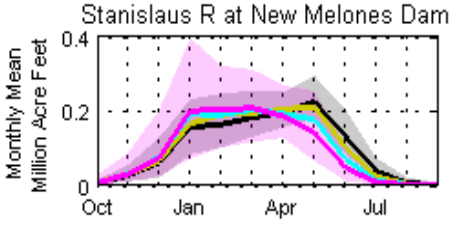


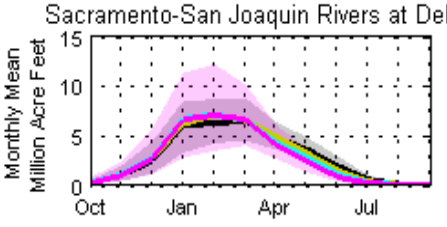


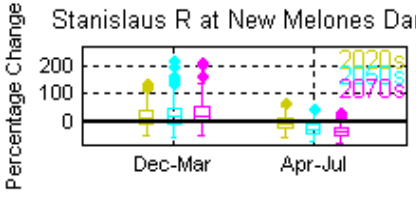


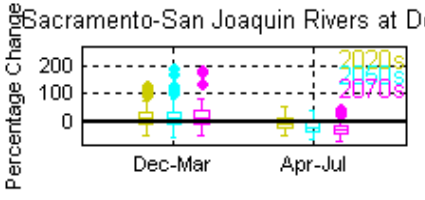


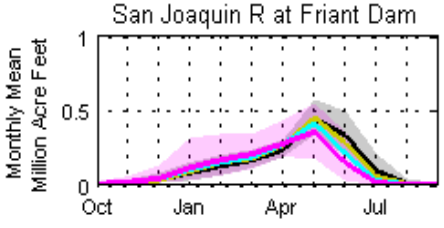


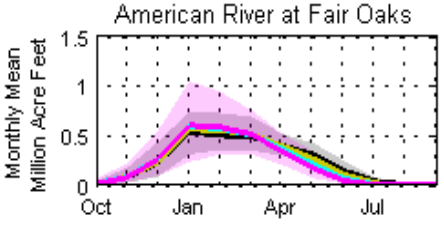


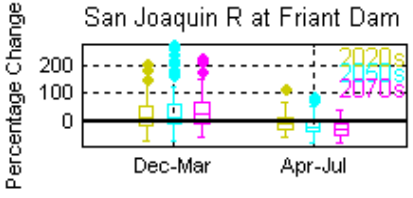


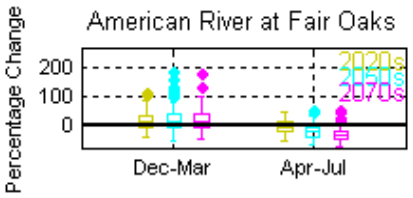


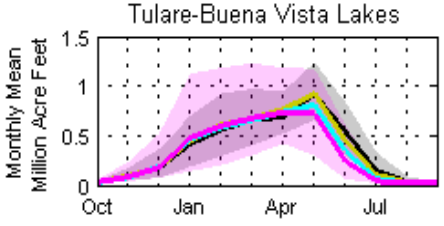


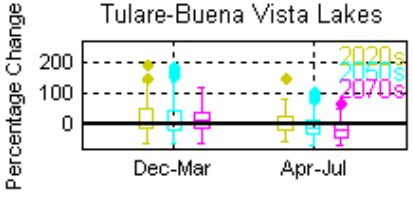




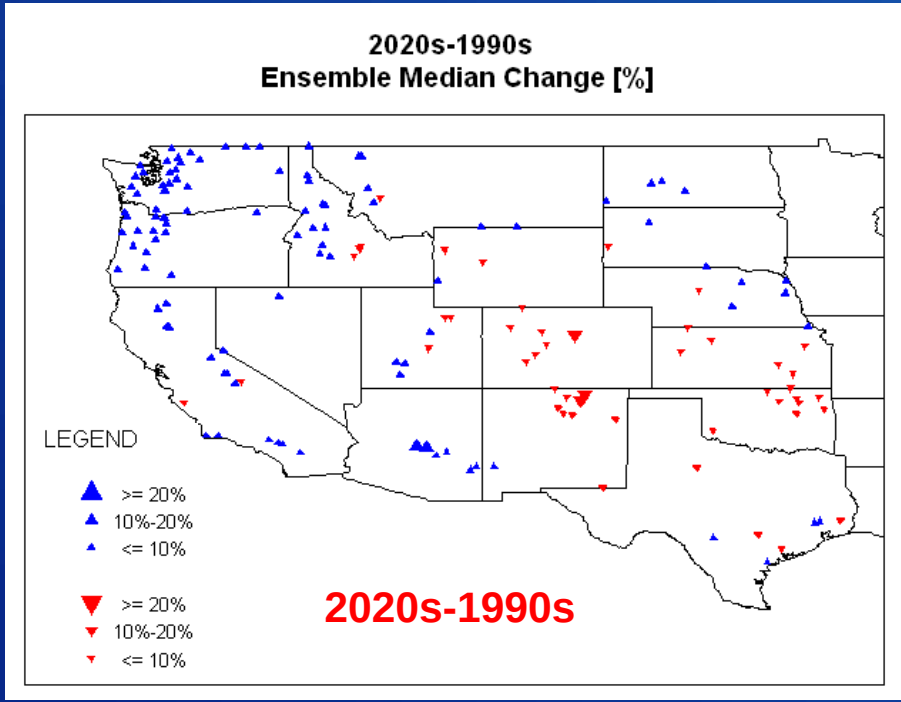


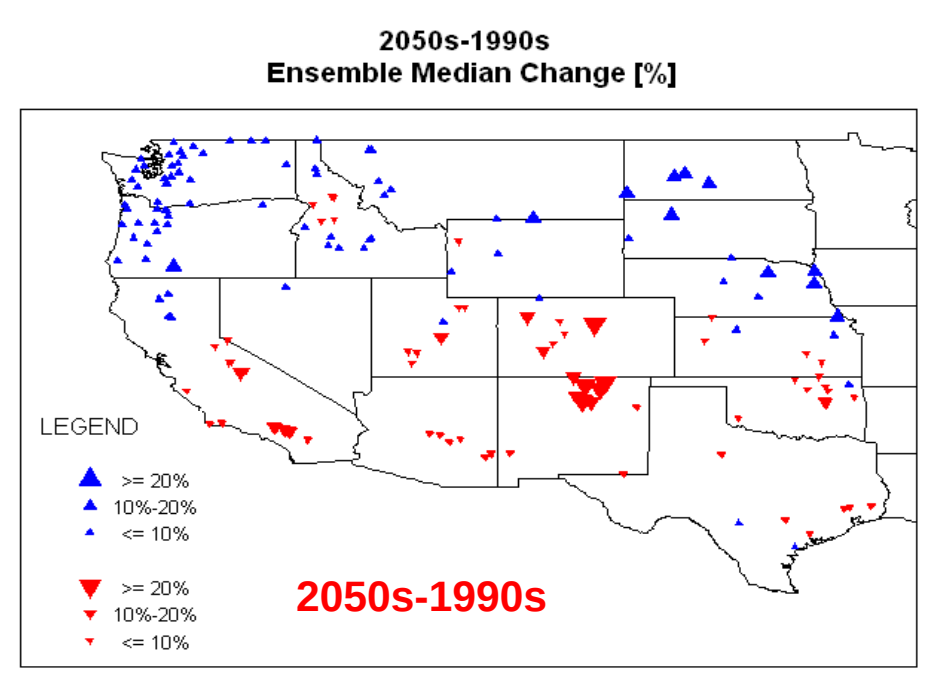






West-Wide Streamflow Impacts - HCDN





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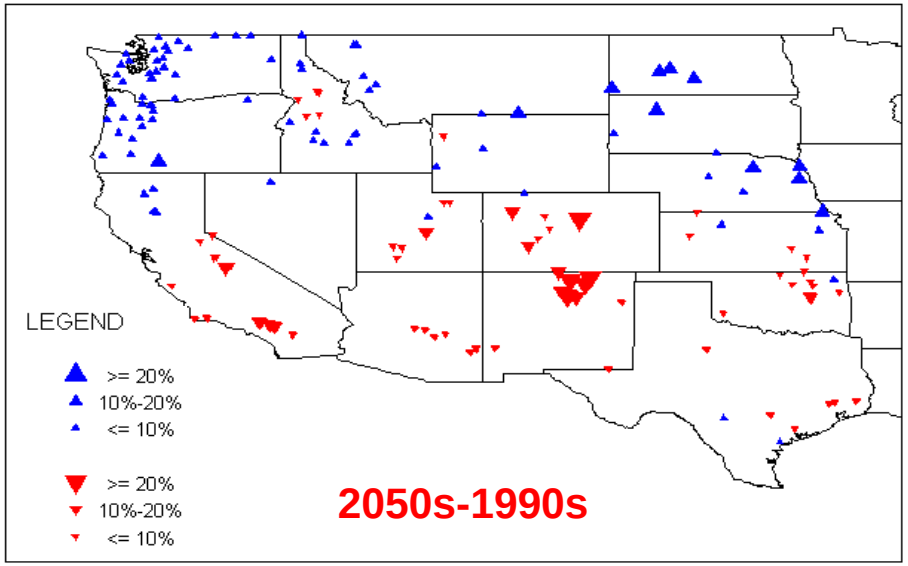
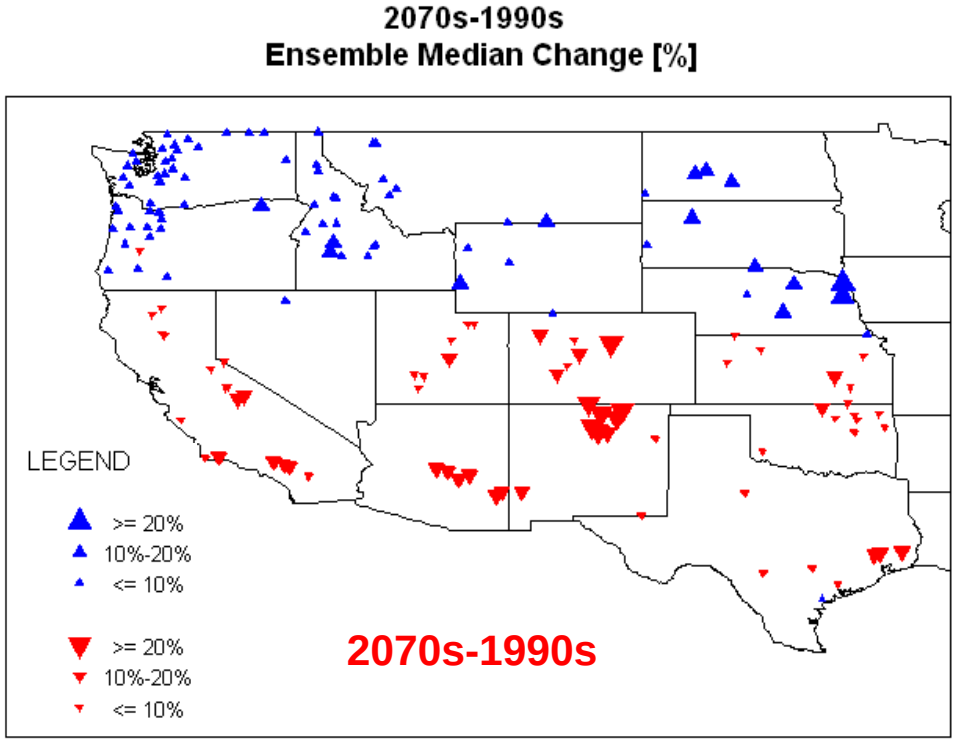
West-Wide Streamflow Impacts - HCDN





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Results – West-Wide Summary

- Precipitation is expected to increase from the 1990s level during the 2020s and 2050s, but declines nominally during the 2070s.(though the early to middle 21st century increases could be artifacts of the BCSD climate projections development leading to slightly wetter projections).
- Temperature shows a persistent increasing trend from the 1990s level.
- April 1st SWE shows a persistent decreasing trend from the 1990s level.
- Annual runoff shows some increase for the 2020s decade from the 1990s level, but shows decline moving forward to the 2050s and 2070s decade from the 1990s reference, suggesting that although precipitation changes are projected to remain positive through the 2050s, temperature changes begin to offset these precipitation increases leading to net loss in the water balance through increased evapotranspiration losses.
- Winter season (December-March) runoff shows an increasing trend.
- Spring-summer season (April-July) runoff shows a decreasing trend.

Outline

- Selecting a model network – hydrology model and routing model
- Applying the model network
- Example results – future hydrologic projections
- **Products – reporting, online data access**

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Reporting

http://www.usbr.gov/climate

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Managing Water in the West

Technical Memorandum No. 86-68210-2011-01

West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections

U.S. Department of the Interior
Bureau of Reclamation

March 2011

Technical Report

RECLAMATION
Managing Water in the West

SECURE Water Act
Section 9503(c) – Reclamation
Climate Change and Water
2011

U.S. Department of the Interior
Policy and Administration
Bureau of Reclamation
Denver, Colorado

April 2011

Report to Congress

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Online Data Access Gridded Hydroclimate

- **Co-hosted with the current CMIP-3 archive at LLNL**

  http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections

- **American Geophysical Union (AGU) Eos Article describing the online gridded hydroclimate archive**

  Gangopadhyay, S., T. Pruitt, L. Brekke, and D. Raff (2011), Hydrologic projections for the western United States, Eos Trans. AGU, 92(48), 441, doi:10.1029/2011EO480001.

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Online Data Access

Bias Corrected and Downscale

gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

RECLAMATION USGS

Santa Clara University CLIMATE CENTRAL SCRIPPS INSTITUTION OF OCEANOGRAPHY

Bias Corrected and Downscaled WCRP CMIP3 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.

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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.

Archive content is based on global climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report. Please see the "About" page for information on projection development, including the methodology to perform climate model bias-correction and spatial downscaling.

Purpose

The archive is meant to provide access to climate and hydrologic projections at spatial and temporal scales more relevant to some of the watershed and basin-scale decisions facing water managers and planners dealing with climate change. Such access permits several types of analyses, including:

- assessment of local to regional climate projection uncertainty.
- assessment of potential climate change impacts on natural and social systems (e.g., watershed hydrology, ecosystems, water and energy demands).
- risk-based exploration of planning and policy responses framed by potential climate changes exemplified by these

Figure 1: BCSD CMIP3 Monthly Climate Analysis example - Median projected change in average-annual precipitation (cm/year), 2041-70 versus 1971-2000.

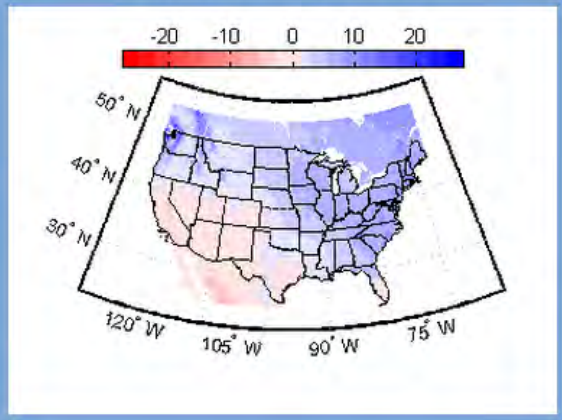

Figure 2. BCCA CMIP3 Daily Climate Analysis example -

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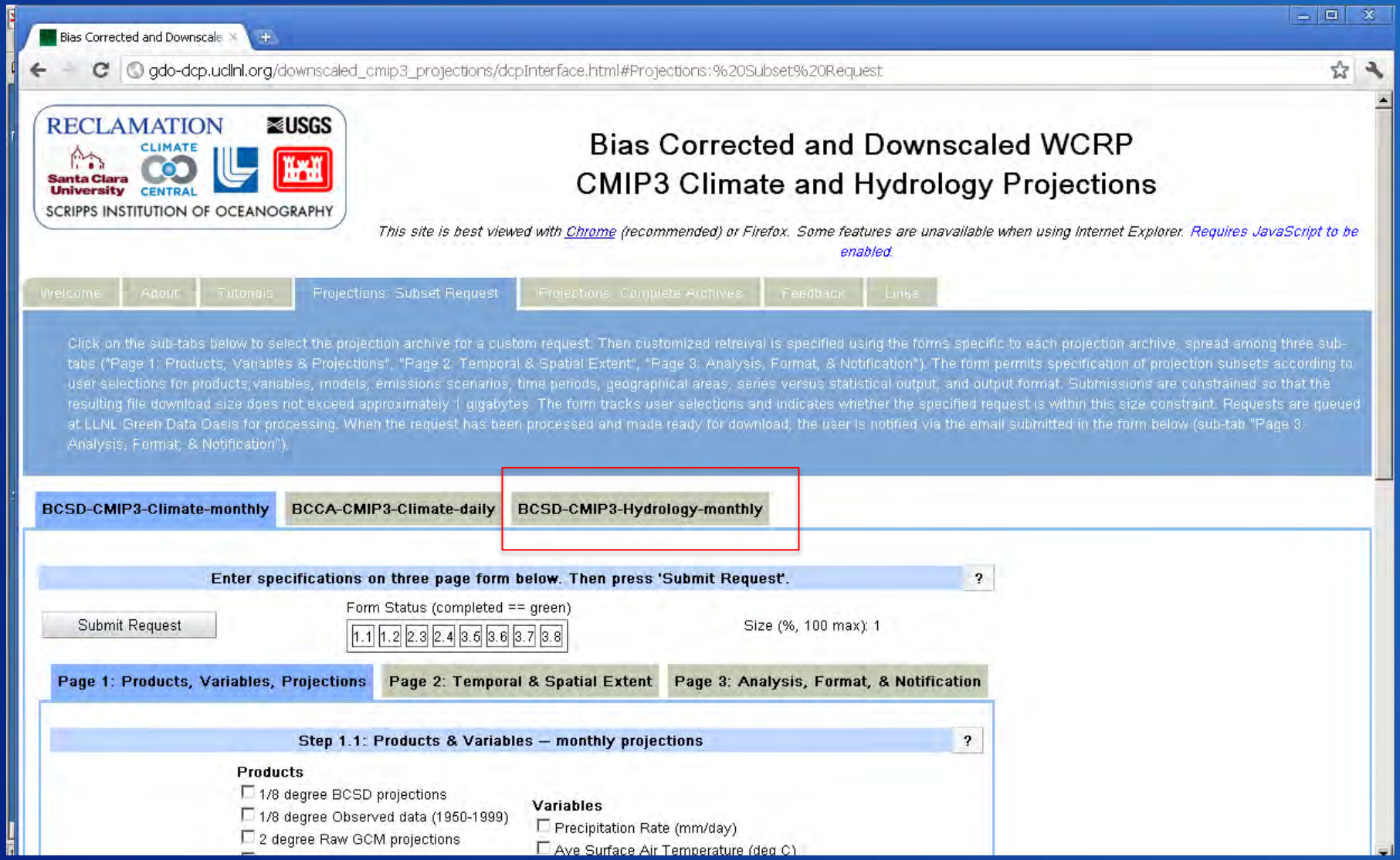
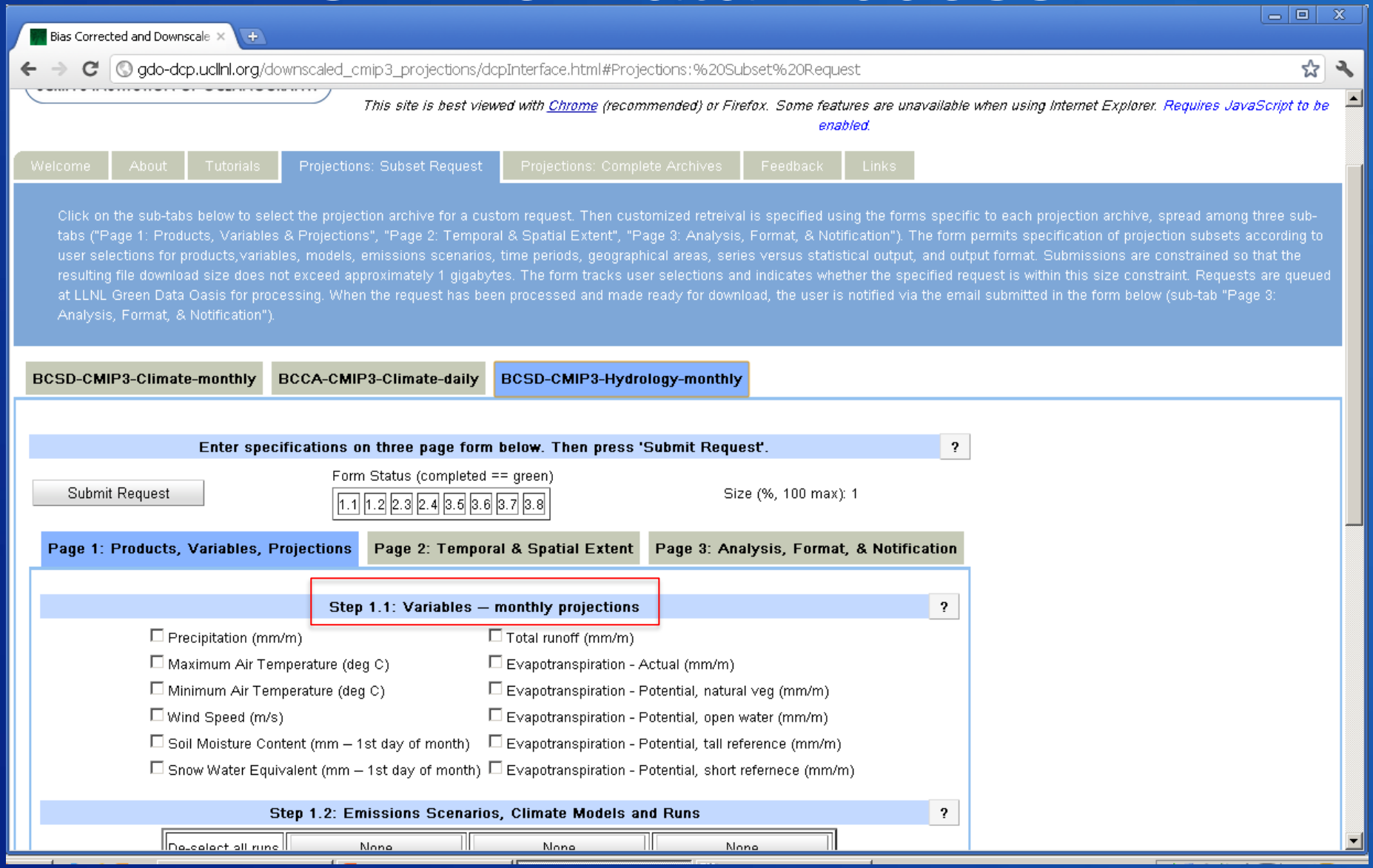
Online Data Access



Online Data Access



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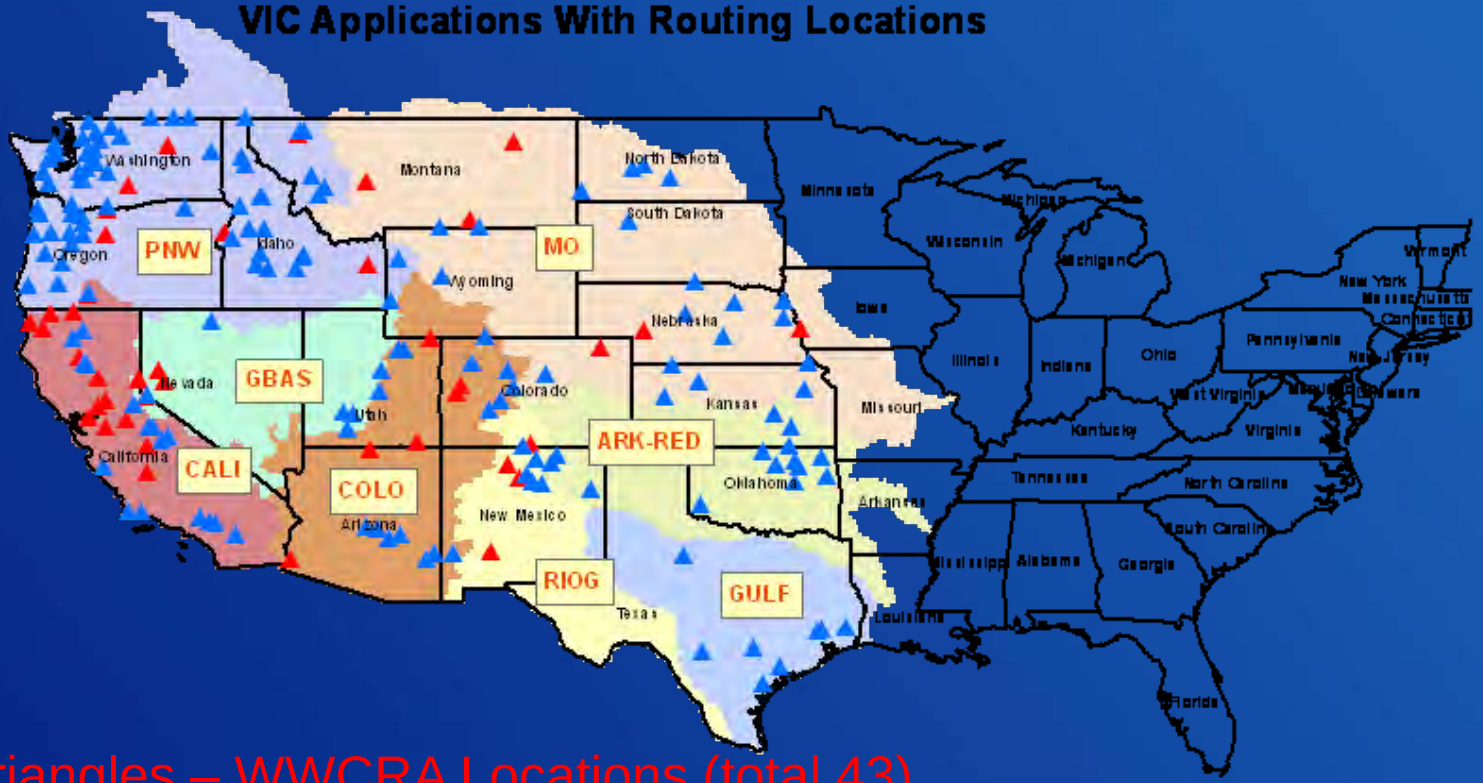
VIC Applications With Routing Locations



Red triangles – WWCRA Locations (total 43)

Blue triangles – HCDN locations (total 152)

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Online Data Access

Daily and Monthly Streamflow Projections

Jan 1, 1950 – Dec 31, 2099

195 locations West-Wide

http://gis.usbr.gov/streamflow_projections/

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Ongoing Activities

- Runoff Projections to Operations Model Hydrology
- Maintaining the online projections archive
  - updated hydrology models
  - new projections (e.g. CMIP-5)
- Demands
  - agricultural demands
  - open water (reservoir) evaporation
- Ecosystem Response

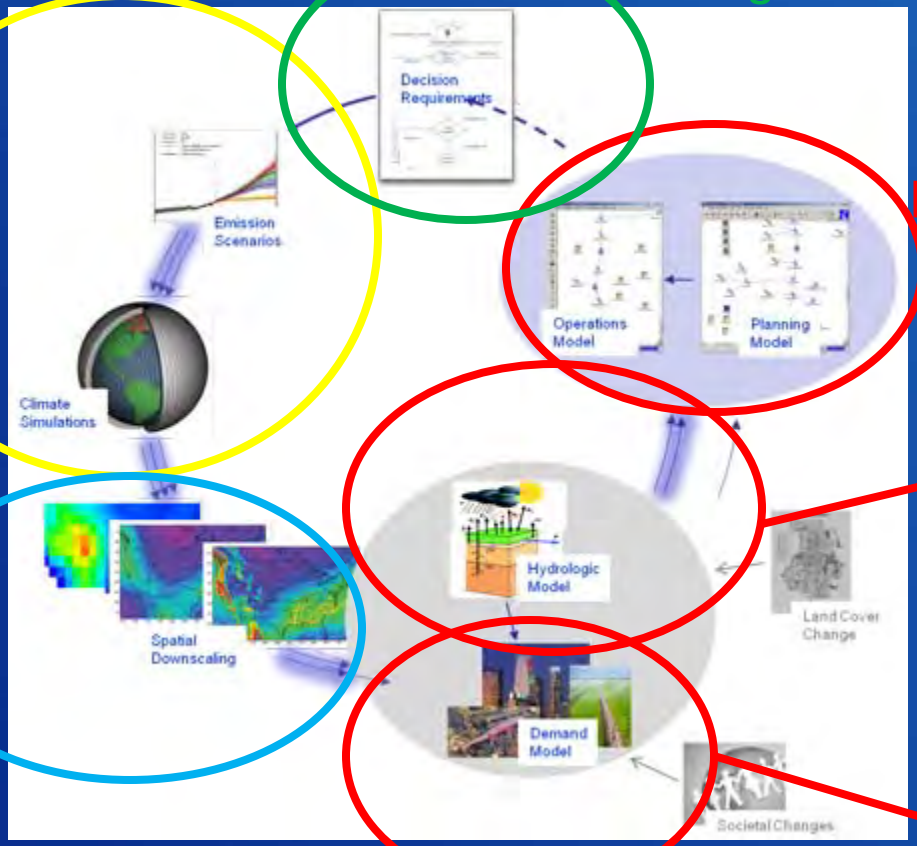
- Ongoing SWA Reporting Requirements (next report 2016)

WWCRA Activities

http://www.usbr.gov/WaterSMART/wcra/index.html

With Stakeholders
e.g. CO Basin Study

CMIP3 &
Updates



FY 2011 Rio Grande

FY 2010 - 2011

BCSD 2008 &
Updates

FY 2011 - 2012

Next Report in 2016

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Bias Correction and Spatial Downscaling

EXTRAS

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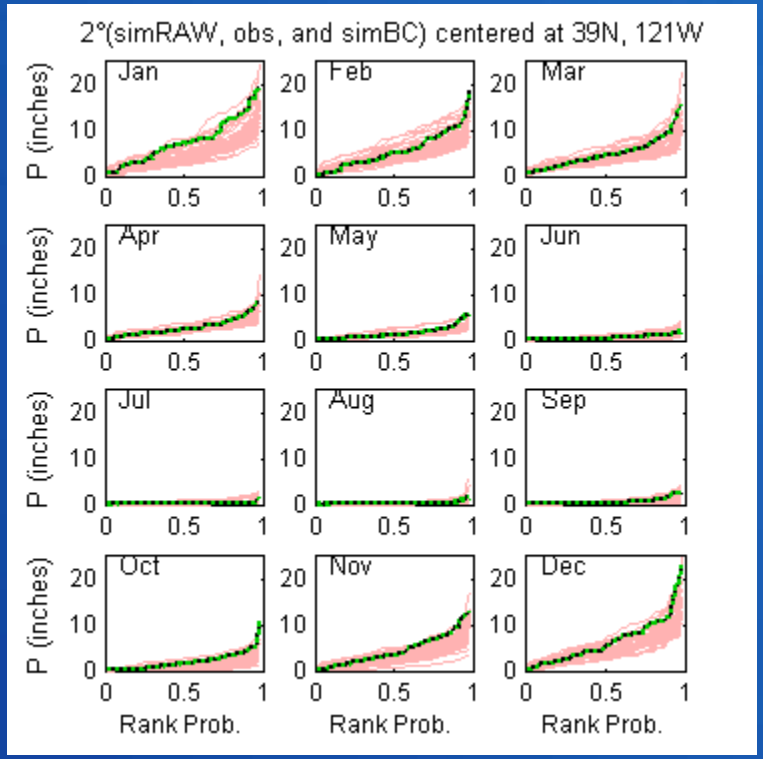
BCSD: Bias Correction part 1

- Historical Evaluation Period
  - 1950-99 (longer period provides better assessment of bias)
- Adopt common grid
  - Interpolate GCM output
  - aggregate station observations
- Assess bias at each grid cell for each month
  - 50 modeled vs observed values
  - Two CDFs, GCM and OBS
  - → **Quantile Map**



Example: location NE of Folsom Lake, CA (black = obs, red = GCMs' raw data, green = GCMs' bias-corrected data)

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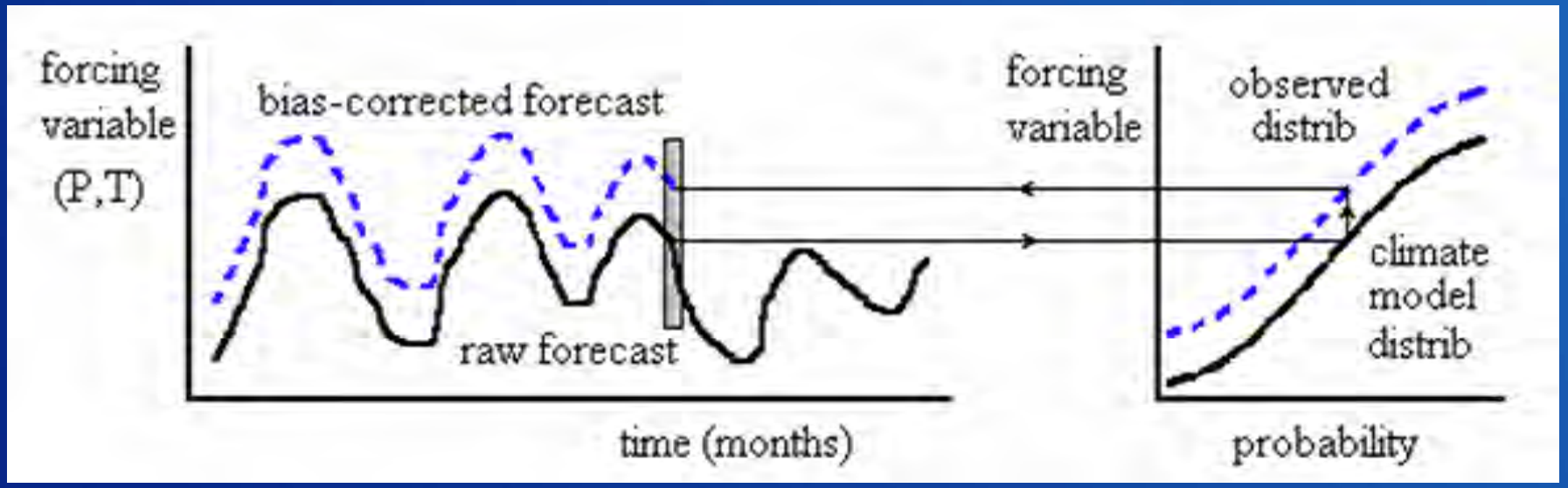
BCSD: Bias Correction part 2

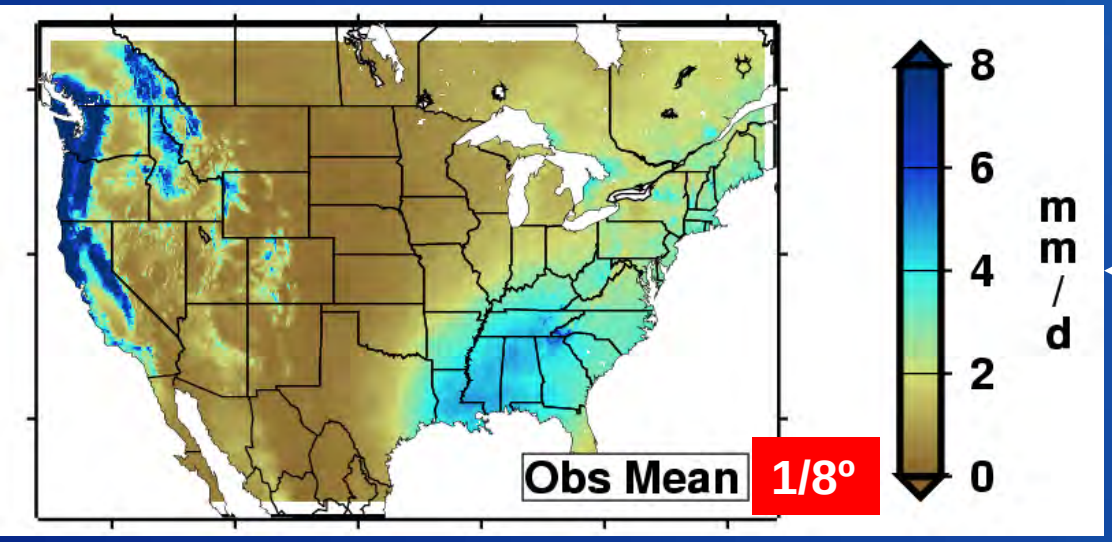
- Progress through GCM projection time-series, by time step and grid point…



Figs: A. Wood, CBRFC

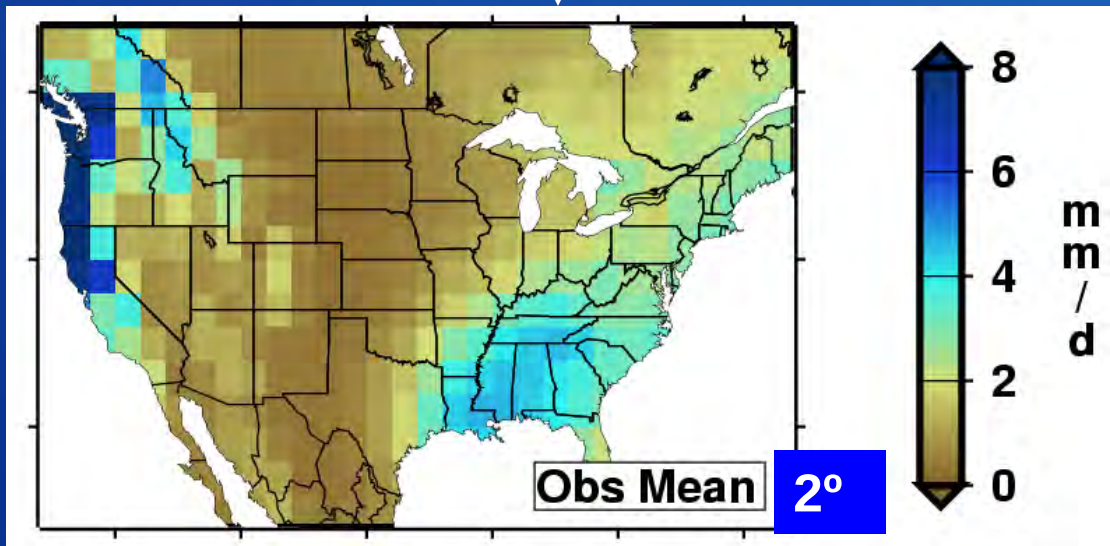
BCSD: Spatial Downscaling

1. Get reference historical pattern

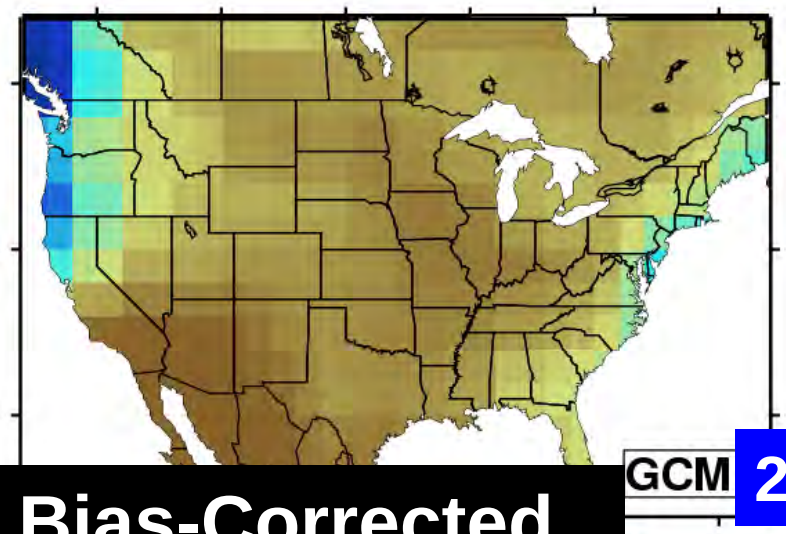


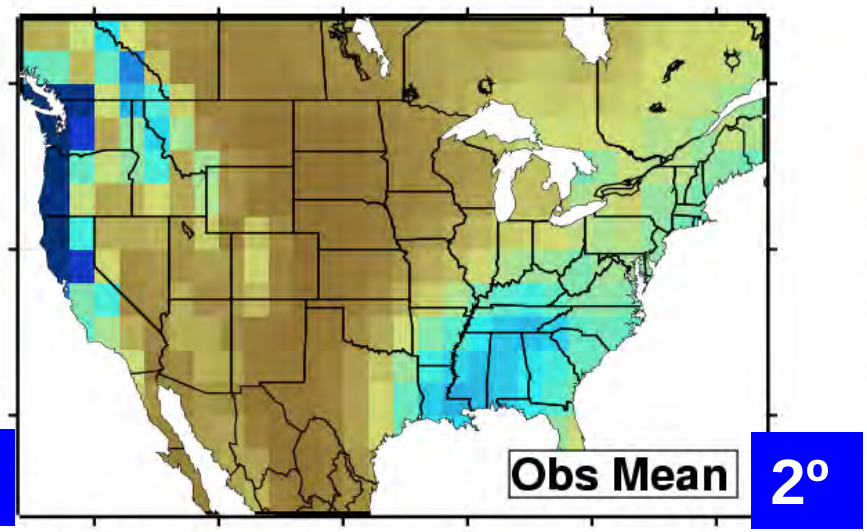
Subjective, e.g., 1950-1999 month mean conditions (OBS, from Maurer et al. 2002)

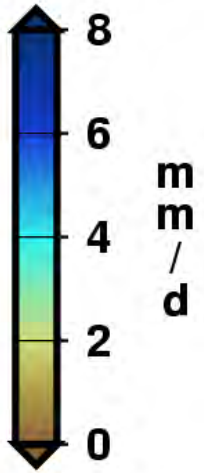
Aggregate pattern to 2º grid, same resolution used in bias-correction



BCSD: Spatial Downscaling
2. Compute Factors







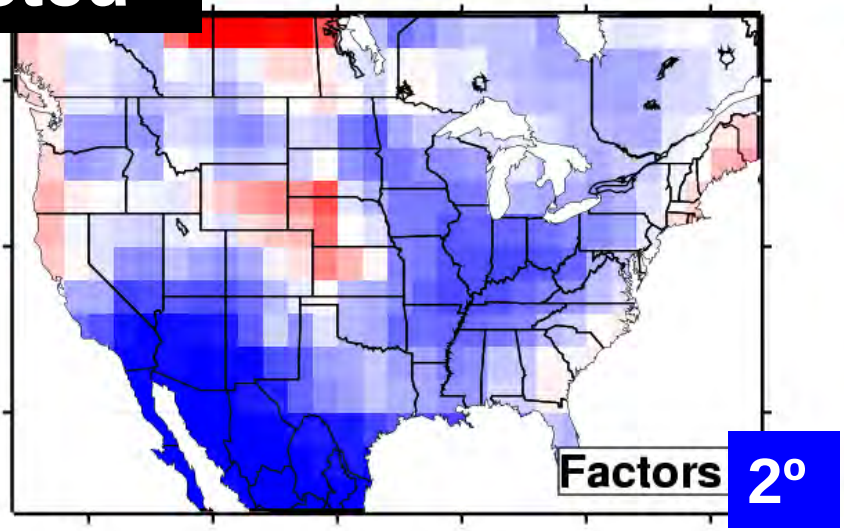
Bias-Corrected

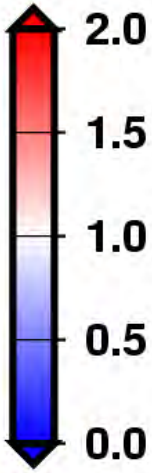
T Factors:

GCM – Obs

P Factors:

GCM / Obs





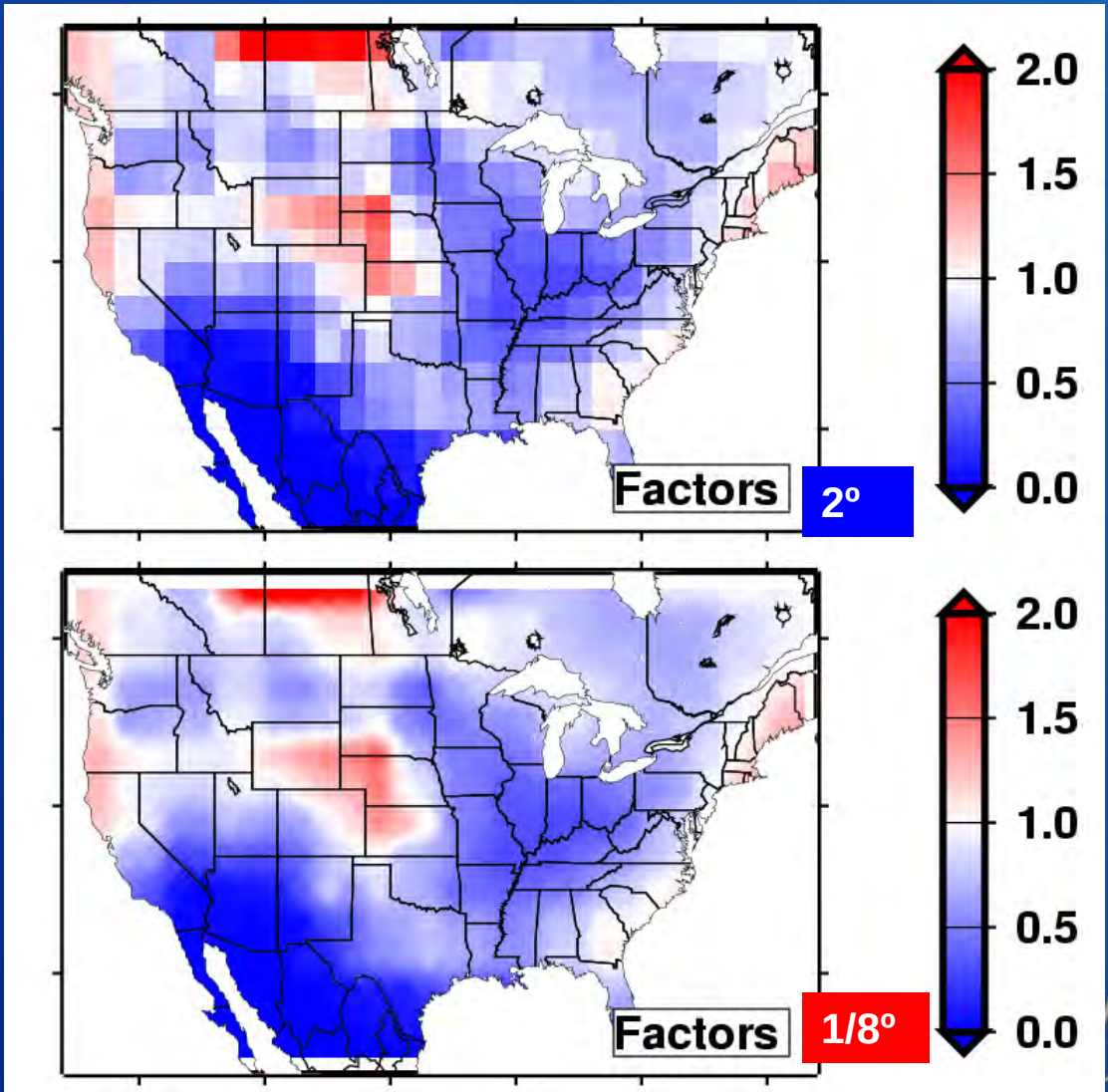
Do for <u>one</u> time step and full spatial-domain, then proceed to next time step…

Example is January 2040 from the projection from model “miub echo g”, path “A2”, run 2

BCSD: Spatial Downscaling

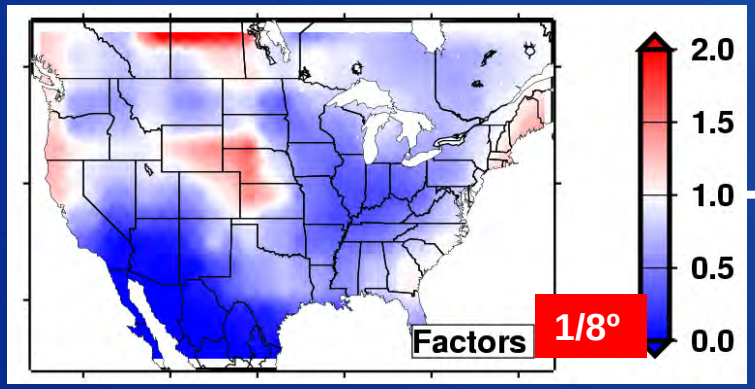
3. Disaggregate Factors

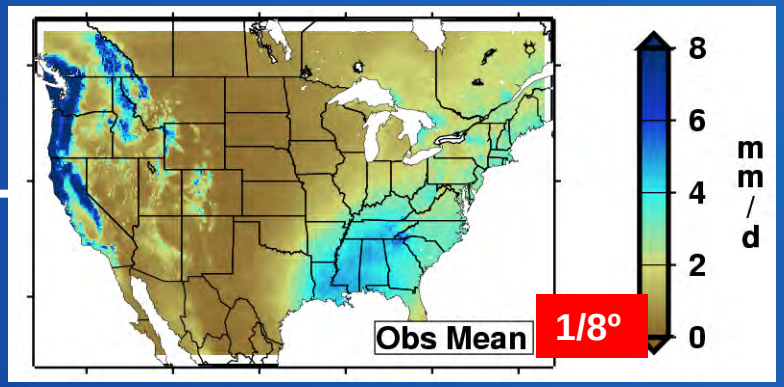
Two-way interpolation scheme, using SYMAP algorithm (Shepard, 1984)

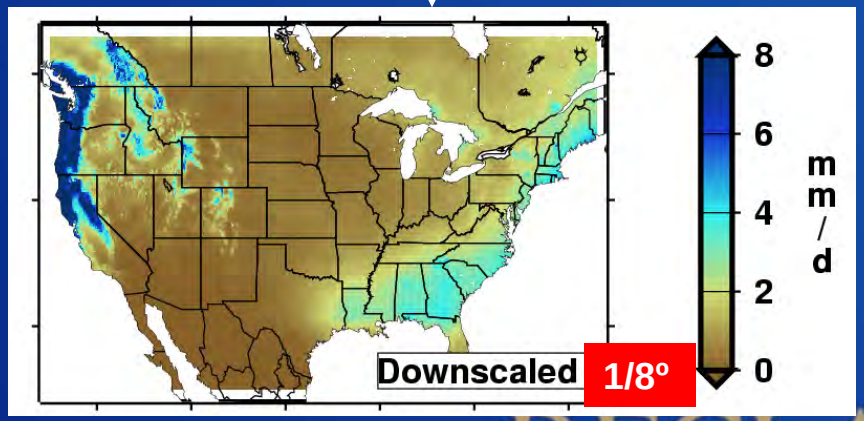


BCSD: Spatial Downscaling

4. Merge Factors and Historical Pattern







T Merge:

Obs Mean **+** Factors

P Merge:

Obs Mean **x** Factors

This time step has been downscaled… move on to next time step.

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BCSD Uncertainties

- Bias-Correction:
  - Reasonable to regrid GCM output from native to 2°?
  - Reasonable to assume constant bias into the future?
  - Reasonable to independently bias-correct T and P?
- Spatial Downscaling
  - Significance of assuming “stationarity” in relation between large-scale circulation and local surface climate?
    - Will spatial datum pattern be relevant in the future?
    - Recent findings… (Wood et al. 2004, Salathe et al. 2007)
  - Reasonable to interpolate “Factors”? (2° to 1/8°)