Uncertainty in hydrologic impacts of climate change: A California case study

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Photos from USGS

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Motivating Questions

- What are potential impacts of climate change on CA hydrology (what is at stake)?
- Given variability between GCMs, can we confidently detect these changes?
- How are these affected by emissions pathways (implications of our decisions and policies)?

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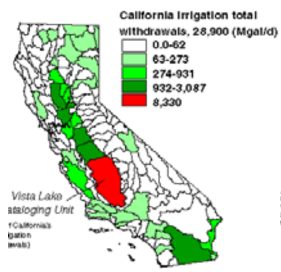
Why California?

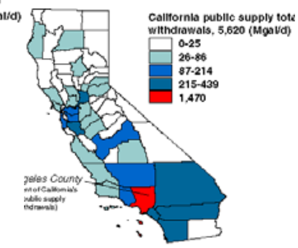
- CA hydrology is sensitive to climate variations, climate sensitive industries (agriculture, tourism), 5th largest economy in world
- Water supply in CA is limited, vulnerable to T, P changes
  - timing, location
- Changes already are being observed

Precipitation and Runoff

Irrigation Water Use



Public Water Use



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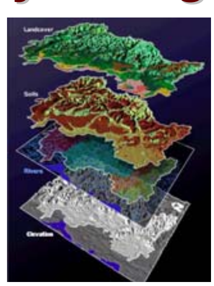
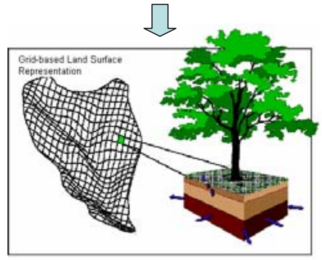
Typical Hydrologic Analysis

Observations of Temperature, Precipitation, etc.



Land Surface Parameterization



Simulation of historic hydrology

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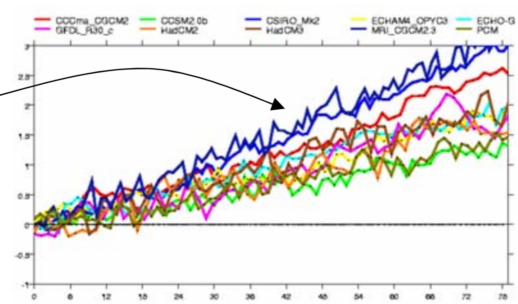
Projecting Future Climate - 1

The projected future climate depends on:

1) Global Climate Model (GCM) used:

- •Varying sensitivity to changes in atmospheric forcing (e.g. CO_2, aerosol concentrations)
- •Different parameterization of physical processes (e.g., clouds, precipitation)

Global mean air temperature by 10 GCMs identically forced with CO_2 increasing at 1%/year for 80 years



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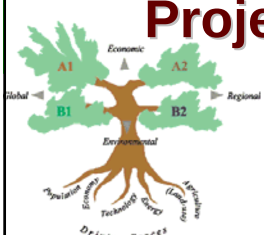
Projecting Future Climate - 2



2) How society changes in the future:

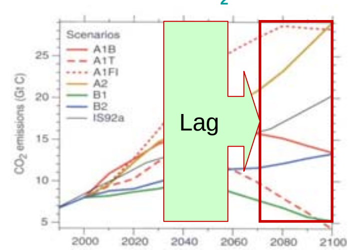
"Scenarios" of greenhouse gas emissions:

A1fi: Rapid economic growth and introduction of new, efficient technologies, technology emphasizes fossil fuels – Higher estimate

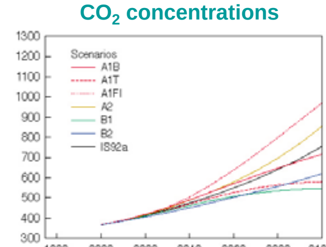
A2: Technological change and economic growth more fragmented, slower, higher population growth – Less high for 21st century

B1: Rapid change in economic structures toward service and information, with emphasis on clean, sustainable technology. Reduced material intensity and improved social equity - Lowest estimate for 21st century

Scenarios of CO_2 emissions



CO_2 concentrations



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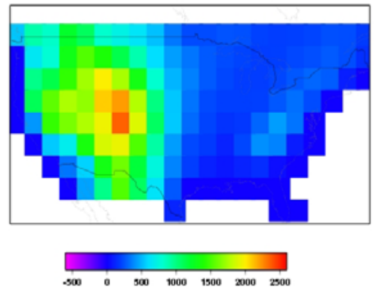
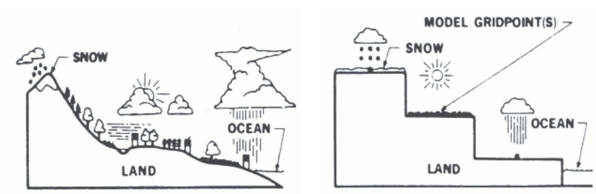
How are GCMs used for Hydrologic Impact Studies?

- The problems:
  - GCM spatial scale incompatible with hydrologic processes
    - roughly 2 – 5 degrees resolution
    - some important processes not captured
  - Though they accurately capture large-scale patterns, GCMs have biases



- Resolved by:
  - –Bias Correction
  - –Spatial Downscaling



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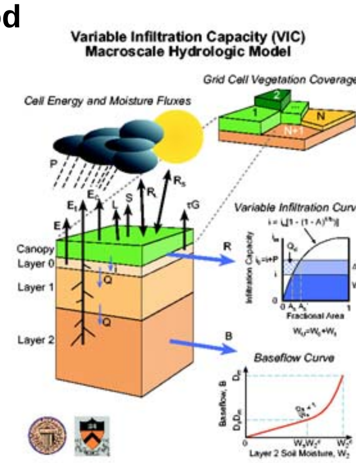
Hydrologic Model

- •**Drive a Hydrologic Model with GCM-simulated (bias-corrected, downscaled) P, T**
- •**Reproduce Q for historic period**
- •**Derive runoff, streamflow,**
- • **snow, soil moisture**

VIC Model Features:
- •Developed over 10 years
- •Energy and water budget closure at each time step
- •Multiple vegetation classes in each cell
- •Sub-grid elevation band definition (for snow)
- •Subgrid infiltration/runoff variability



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Initial Study with 2 GCMs

HadCM3 – UK Meteorological Office Hadley Centre

PCM – National Center for Atmospheric Research/Dept. of Energy Parallel Climate Model

Distinguishing Characteristics of both models:

- Both are Coupled Atmosphere-Ocean-Land models
- Neither uses flux adjustments
- Model estimates of global annual mean temperature lie within 1ºC of observed averages
- Both are state-of-the-art and well-tested, participating in international comparisons
- realistic simulation El Niño SST anomalies

HadCM3 is considered *"Medium Sensitivity"*
PCM generally *"Low Sensitivity"*

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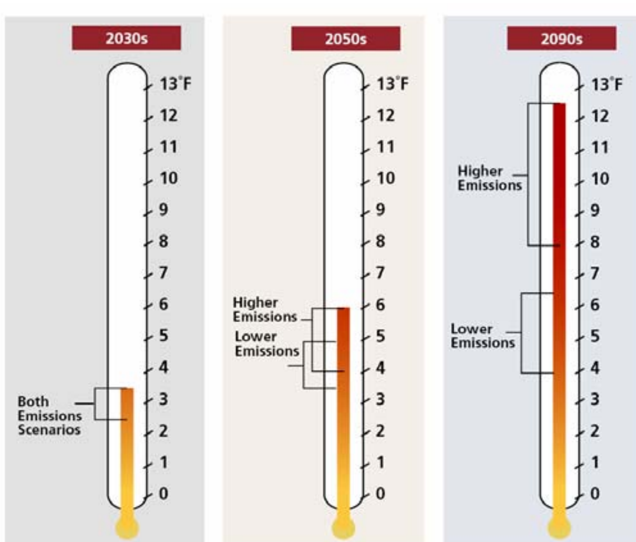
Different Warming with Different Emissions



CA average annual temperatures for 3 10-year periods

Amount of warming depends on our emissions of heat-trapping gases.

2090-2099 summer temperature increases vary widely:
Lower: 3.5-9 °F
Higher: 8.5-18 °F

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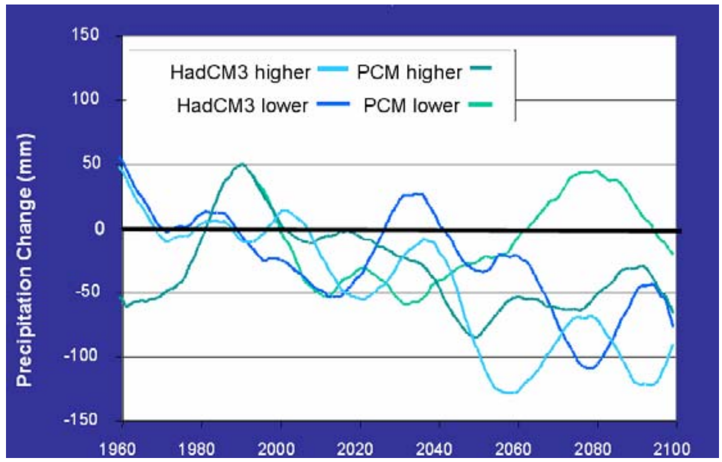
Winter Precipitation Projections

Statewide Average

Winter precipitation accounts for most of annual total

High interannual variability – less confidence in precipitation-induced changes than temperature driven impacts.



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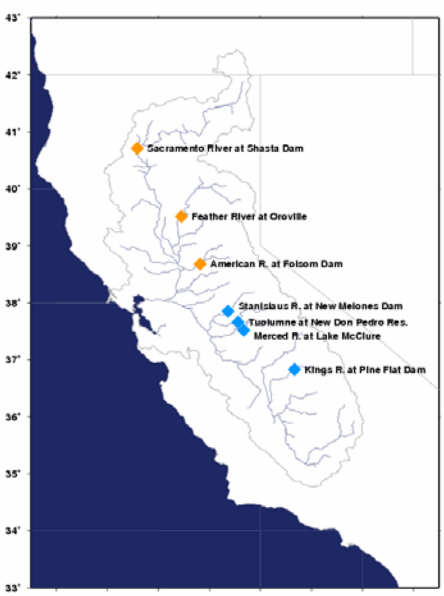
Flows for Specific Streams



Focus on Sacramento-San Joaquin Basin

Water supply feeds agriculture in Central Valley, and major urban areas.

Gauges are at the inflows to 7 major reservoirs, accounting for most of the inflow from the Sierra Nevada.

3 North gauges represent the total discharge from the Northern part

4 South gauges represent the total discharge from Southern part

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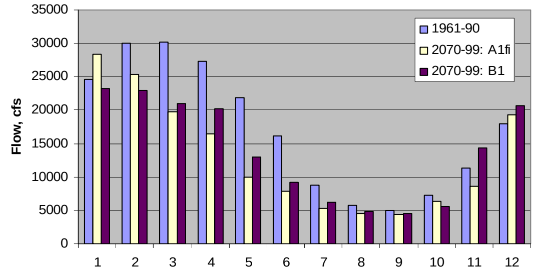
End-of-Century Streamflow: North

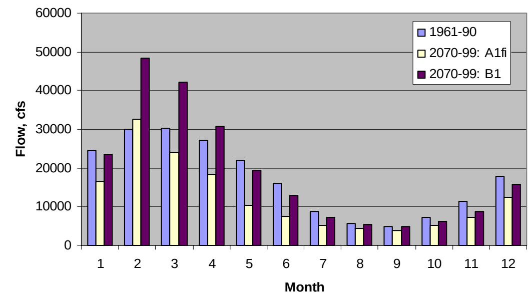
HadCM3 shows:

- 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





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Diminishing Sierra Snowpack

% Remaining, Relative to 1961-1990

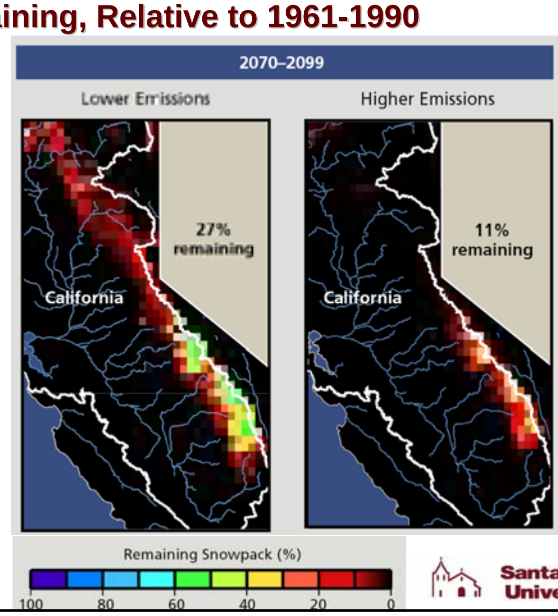
Total snow losses by the end of the century:

29–73% for the lower emissions scenario (3-7 MAF)

73–89% for higher emissions (7-9 MAF – 2 Lake Shastas)

Dramatic losses under both scenarios

Almost all snow gone by April 1 north of Yosemite under higher emissions



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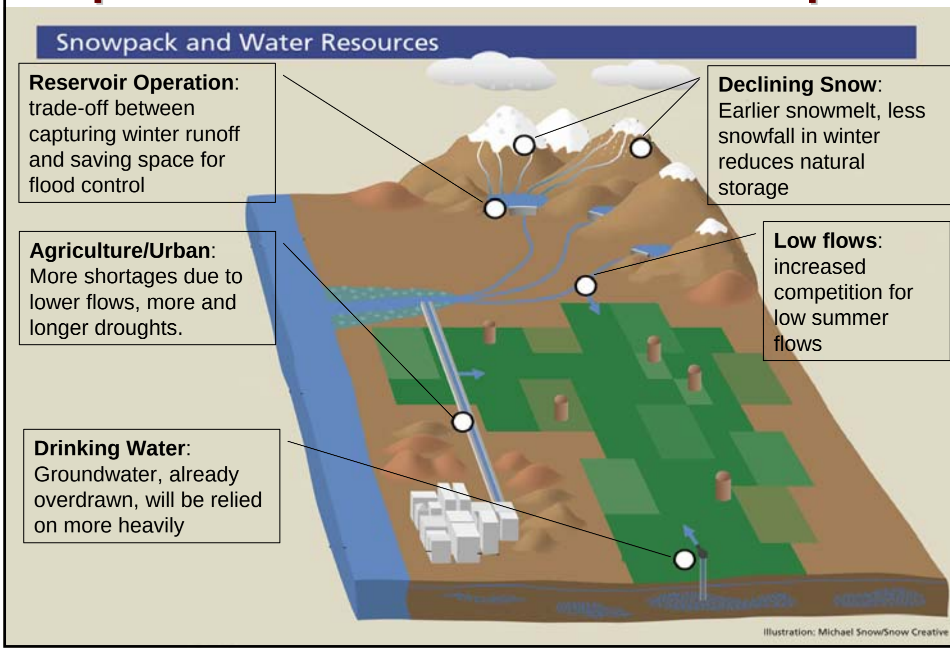
Implications of Snow and Flow Impacts



Impacts on Ski Season

Warmer temperatures result in:

- Less precipitation falling as snow in winter
- Earlier melt of accumulated snow

These combine to shorten the ski season

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Do Changes Exceed Model Uncertainty?

- Follow-up study used multi-model ensemble
- Downscaled/bias corrected 10 GCMs
- Hydrology simulations for two scenarios:
  – Control period (constant CO_2)
  – Perturbed period (1%/year increasing CO_2)
- Statistical analysis of hydrologic impacts

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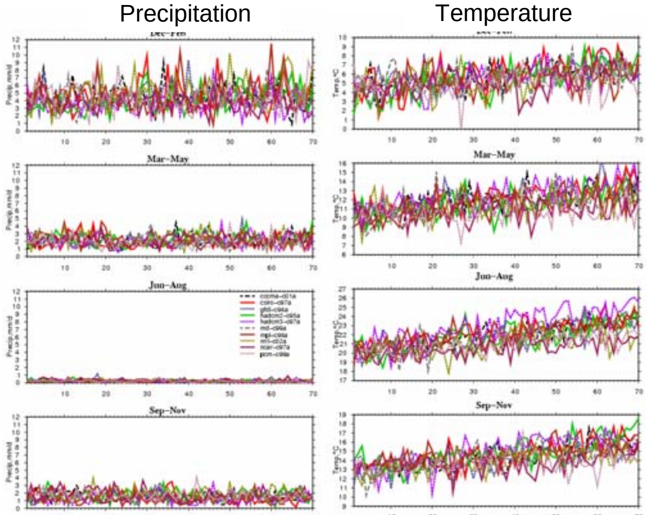
Future Climate for California

70 year projections at 1%/year CO_2 increase

Precipitation | Temperature



Regional P, T for California

P displays no apparent trend

T shows increasing trend in all seasons and for all GCMs

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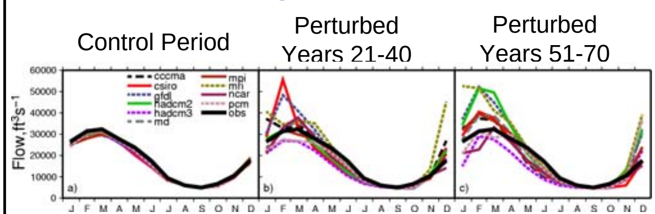
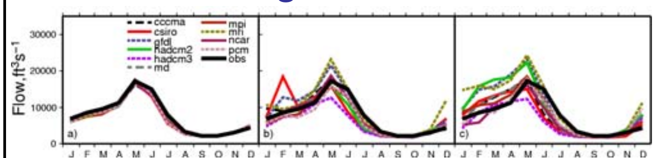
Streamflow Simulation with 10 CMIP GCM simulations

Northern Gauges



Southern Gauges



- Inter-model variation appears within first few decades, reflecting differences in GCM parameterization, resolution, CO_2 sensitivity.
- Between 30 and 60 years, uncertainty increases prior to annual peak.

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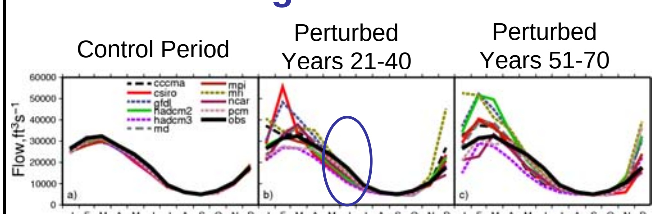
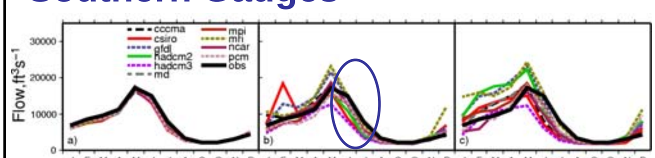
Streamflow Simulation with 10 CMIP GCM simulations

Northern Gauges



Southern Gauges



Intermodel variability between GCMs does not prevent significant detection of decreases in early summer streamflow, even by years 21-40

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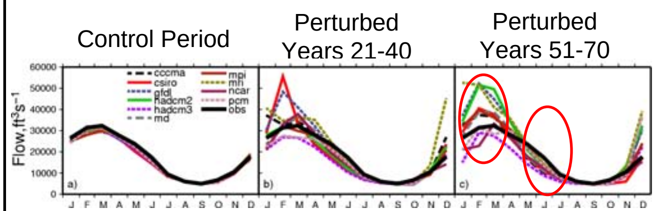
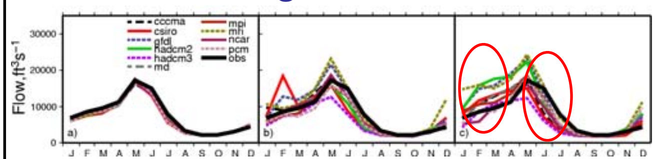
Streamflow Simulation with 10 CMIP GCM simulations

Northern Gauges



Southern Gauges



Both increases in winter streamflow and decreases in summer low flows exceed intermodel variability by years 51-70, as does the retreat of the midpoint of the annual hydrograph.

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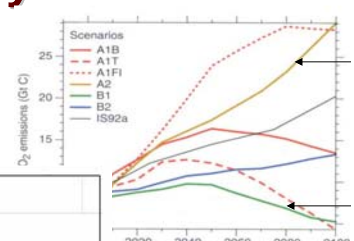
Are CA impacts under different emissions significantly different?

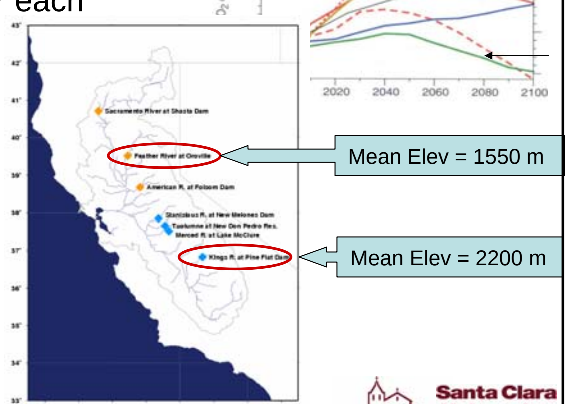
•New experiment using 11 GCMs, most recent generation

•2 Emissions scenarios for each GCM:

-A2
-B1

•Same bias correction, downscaling, hydrologic modeling





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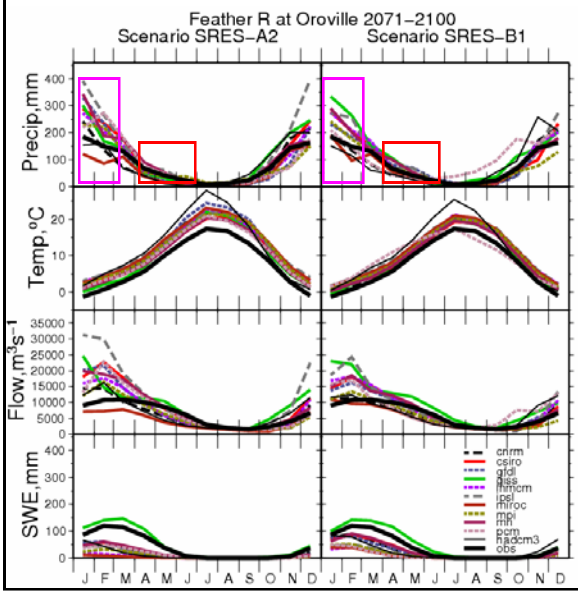
Feather River at Oroville Dam: P



- P: Increase Jan-Feb
  - +27% for A2
  - +16% for B1
- P: Decrease Apr-Jun
  - -29% for A2
  - -10% for B1

A2 Changes are high confidence (> 95%)
B1 changes are lower confidence (most <90%)

Confidence that A2 and B1 differ: 80-90% for Apr-May, low otherwise

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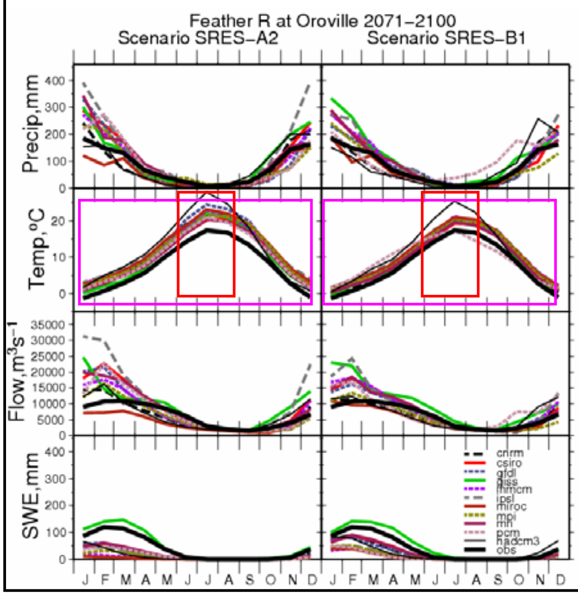
Feather River at Oroville Dam: T



- Annual Avg. T Increase
  - +3.7ºC for A2
  - +2.3ºC for B1
  - Highly significantly different
- Summer T Increase
  - +5.1ºC for A2
  - +3.1ºC for B1
  - Highly significantly different

All T changes are high confidence (> 90%)

Confidence that A2 and B1 differ: >90% for all months except Mar-Apr

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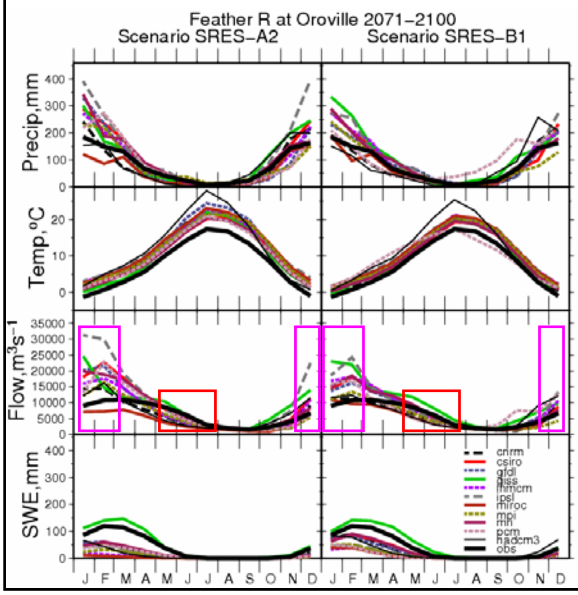
Feather River at Oroville Dam: Q



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

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

Confidence that A2 and B1 differ for these flows: 60-80%

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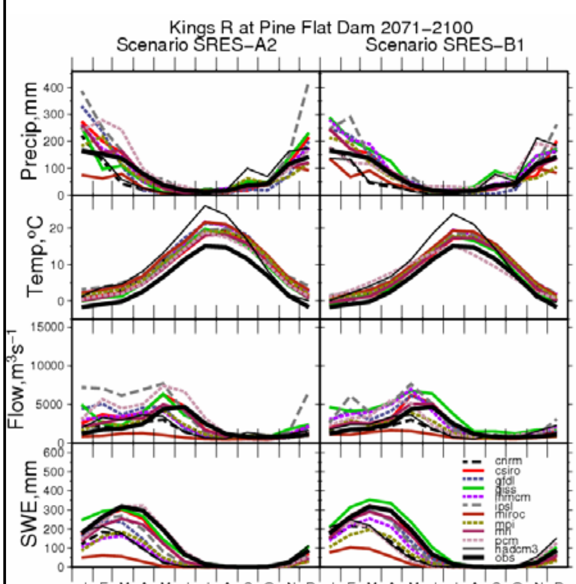
King River at Pine Flat Dam



T changes similar to North:

- •Smaller increase in Jan-Feb P
  - •A2: +20%
  - •B1: +13%
- •Larger decrease in Apr-Jun P
  - •A2: -42%
  - •B1: -21%
  - Highly significantly different
- •Q changes are more dramatic
  - Jan-Feb:
    - •A2: +110%
    - •B1: +72%
  - Jun-Aug:
    - •A2: -43%
    - •B1: -33%

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Snow Accumulation and Runoff Timing

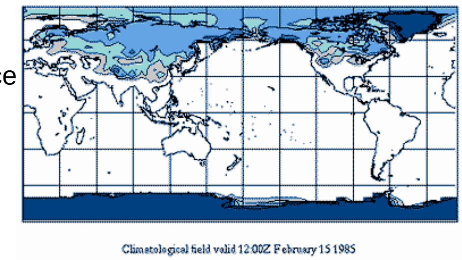

Image from: Canadian Cryospheric Information Network

- April 1 Snow Pack – All high confidence
  Feather River
  - A2: -69%
  - B1: -59%

  King River
  - A2: -40%
  - B1: -32%
- Change in Date to Annual Flow Centroid
  Feather River
  - A2: -27 days
  - B1: -23 days

  Kings River
  - A2: -40 days
  - B1: -29 days

  } Highly significantly different

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Summary

- We (and our children) can confidently expect to experience:
  - increased winter streamflow
  - decreased spring/early summer flow
  - decreased snow pack
  - earlier arrival of water
- Our emissions pathway affects with high significance at least:
  - increase in temperature
  - decline in spring/summer flows
  - timing shift in annual hydrograph for higher elevation basins

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Thank You!

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