



Climate change, extreme precipitation, and atmospheric rivers

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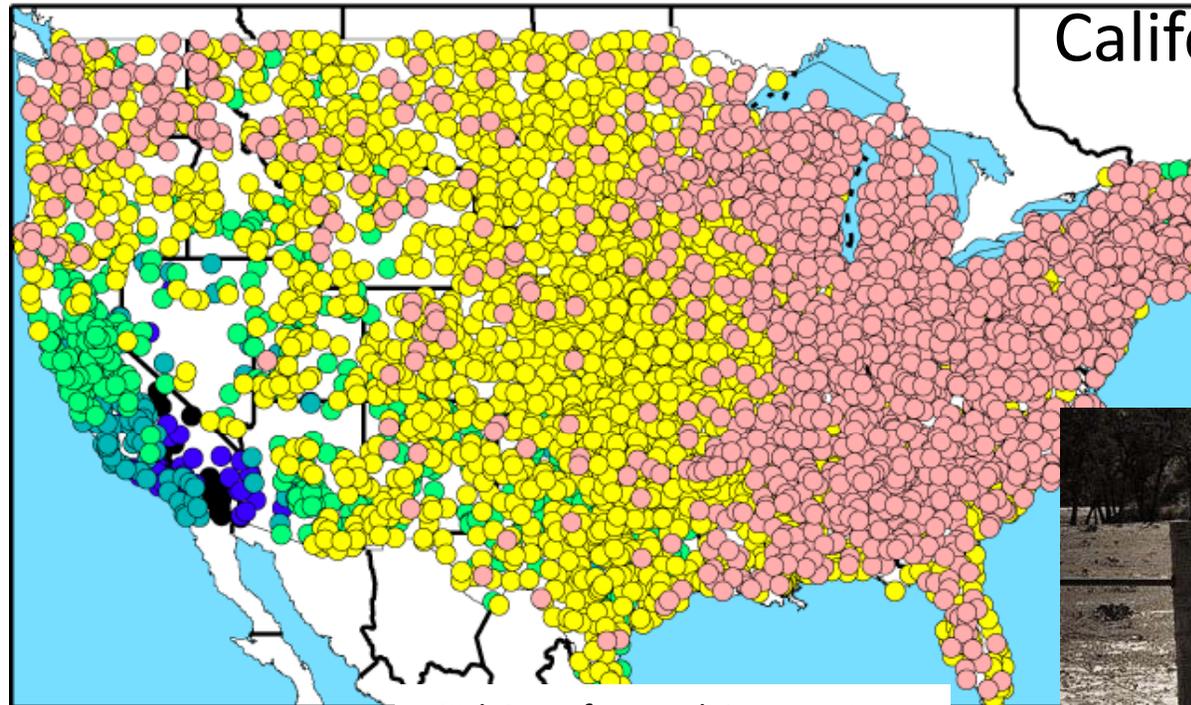
The logo for the Scripps Institution of Oceanography. It consists of the word 'SCRIPPS' in a large, bold, blue font, followed by 'INSTITUTION' in a smaller font above 'OCEANOGRAPHY' in a larger font, all in blue.

NOAA's California-Nevada Applications Program

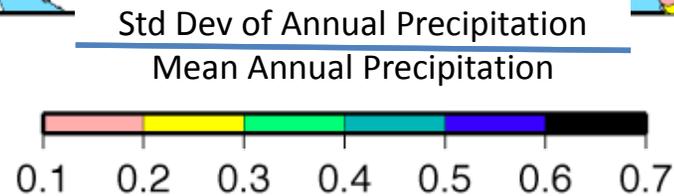
*Department of Water Resources Workshop
Climate Change, Extreme Weather, and Southern California Floods*

California's Wild Precipitation

a) COEFFICIENTS OF VARIATION OF
TOTAL PRECIPITATION, WY 1951-2008



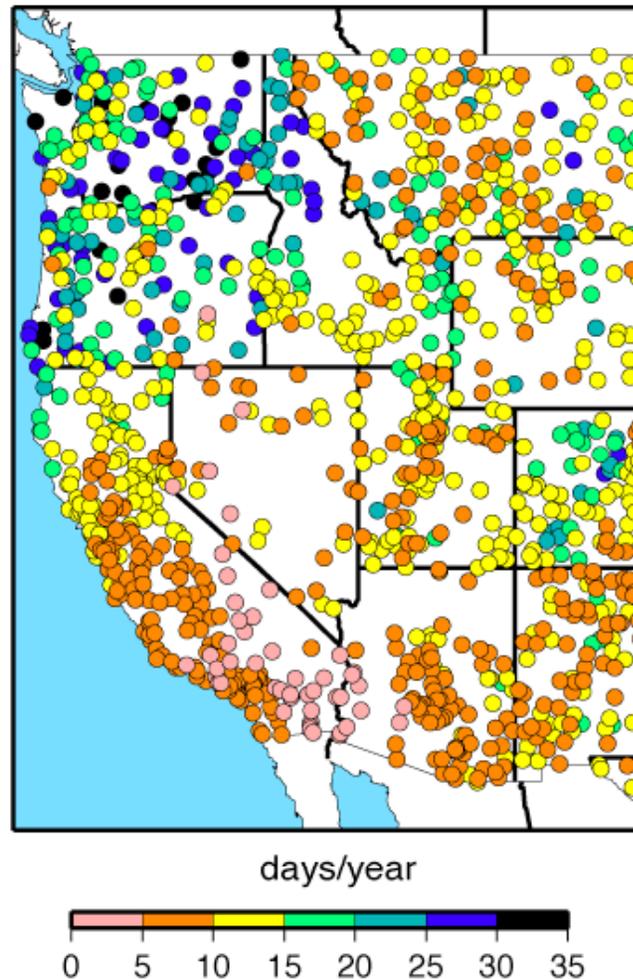
California precipitation is
uniquely variable



Dettinger et al, Water, 2011

California's Wild Precipitation

c) AVERAGE NUMBER OF DAYS/YR TO OBTAIN HALF OF TOTAL PRECIPITATION, WY 1951-2008



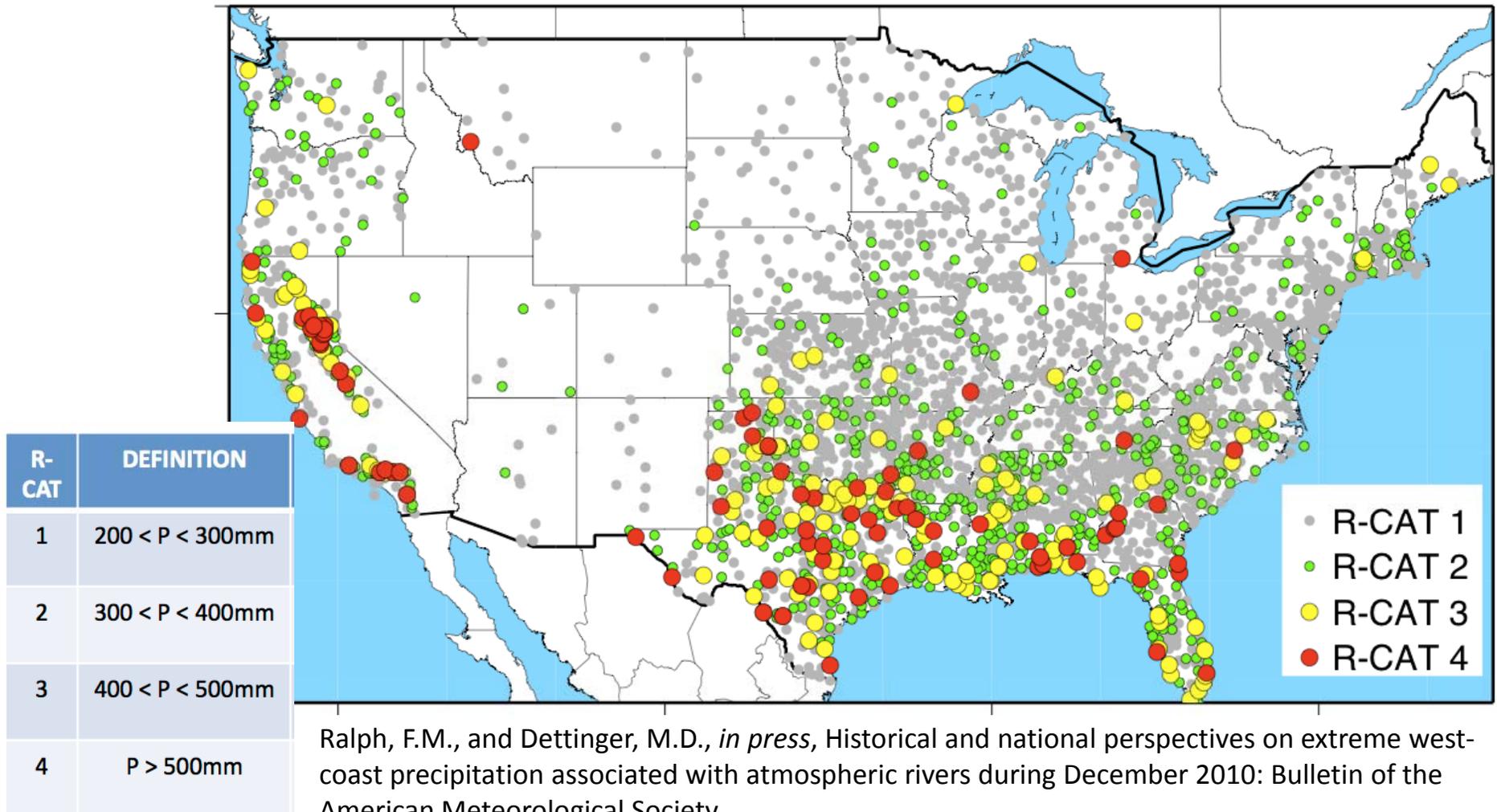
Just a few storms each year form the core of our water supplies



Dettinger et al, Water, 2011

California's storms are as big as any in the country

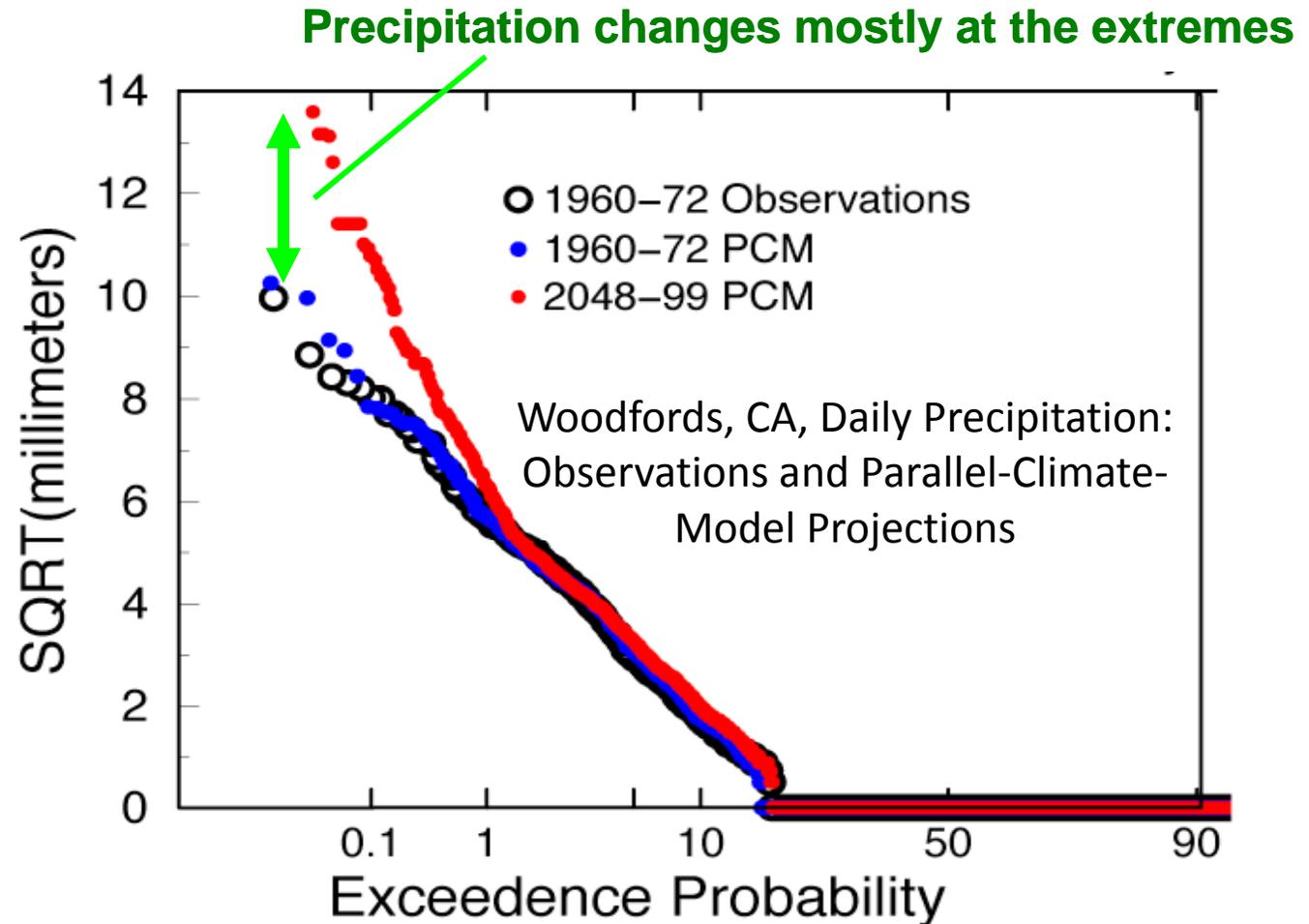
LARGEST 3-DAY PRECIPITATION TOTALS, 1950-2008



Ralph, F.M., and Dettinger, M.D., *in press*, Historical and national perspectives on extreme west-coast precipitation associated with atmospheric rivers during December 2010: Bulletin of the American Meteorological Society.

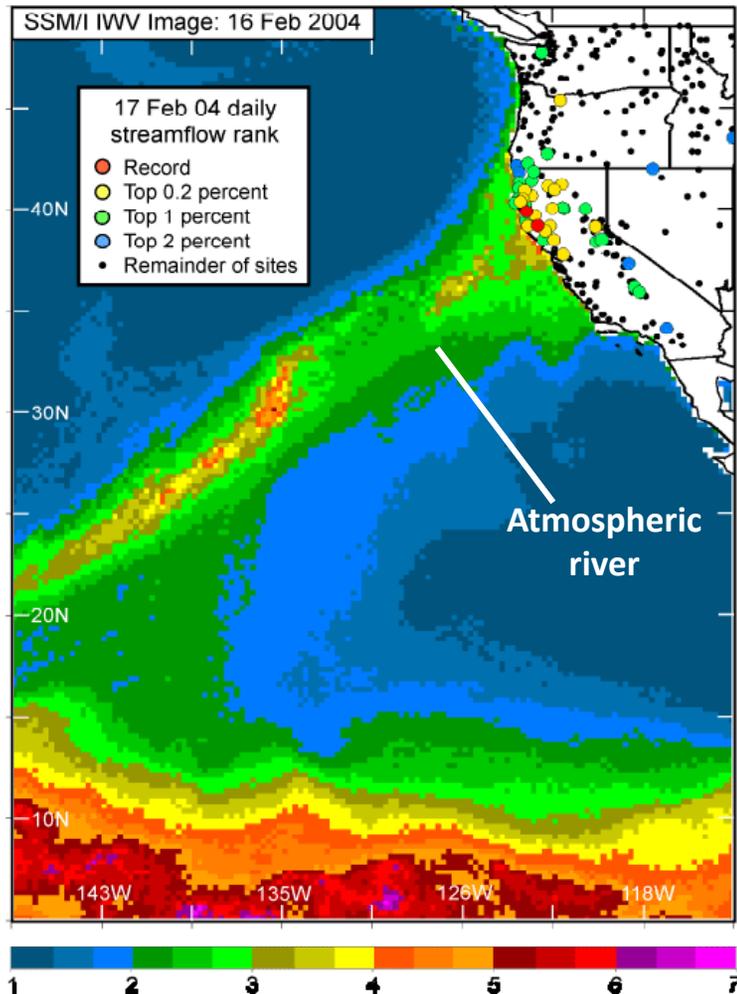
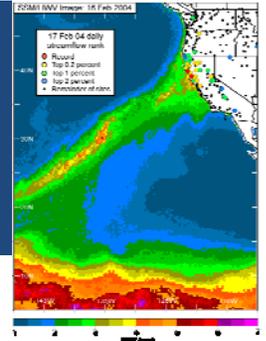
California's precipitation extremes are projected to increase with climate

Results from downscaled Parallel-Climate Model, BAU projections, which yields very small changes in AVERAGE precipitation



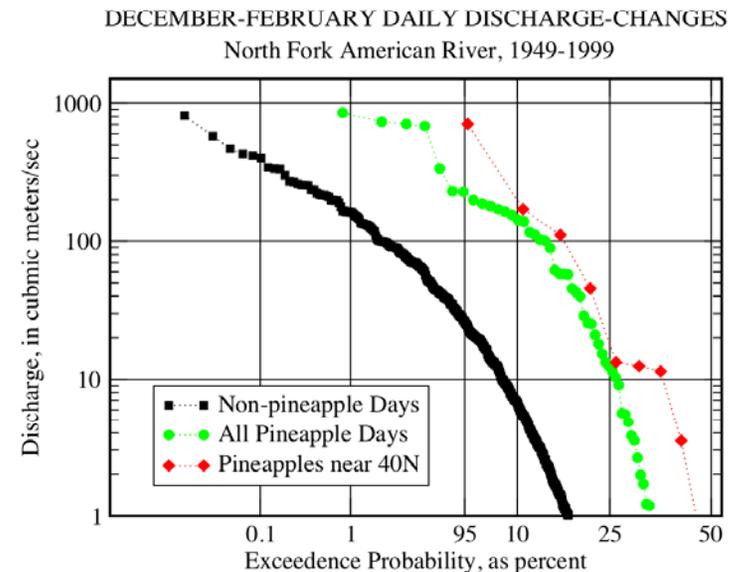
Dettinger, M.D., Cayan, D.R., Meyer, M.K., and Jeton, A.E., 2004, Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099: *Climatic Change*, 62, 283-317.

Atmospheric rivers and flooding

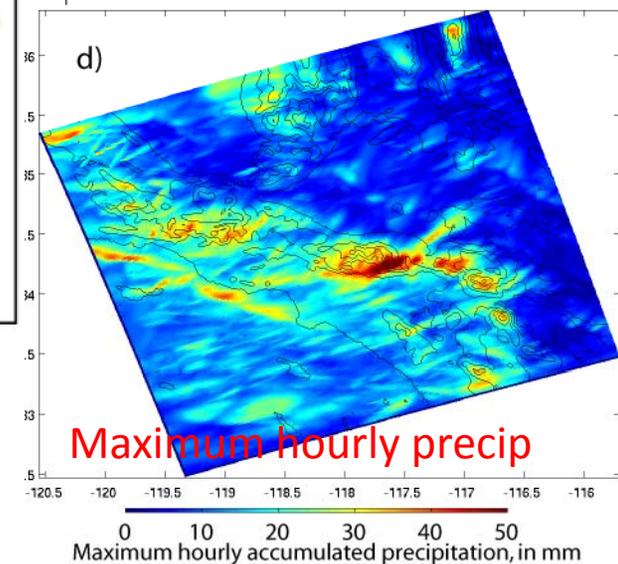
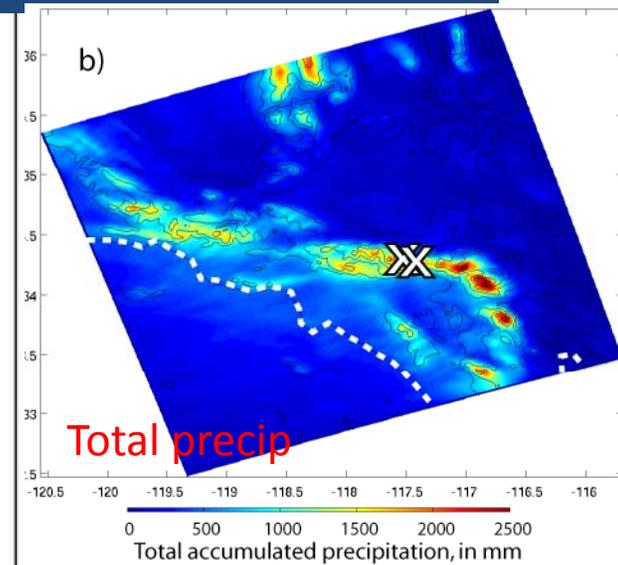
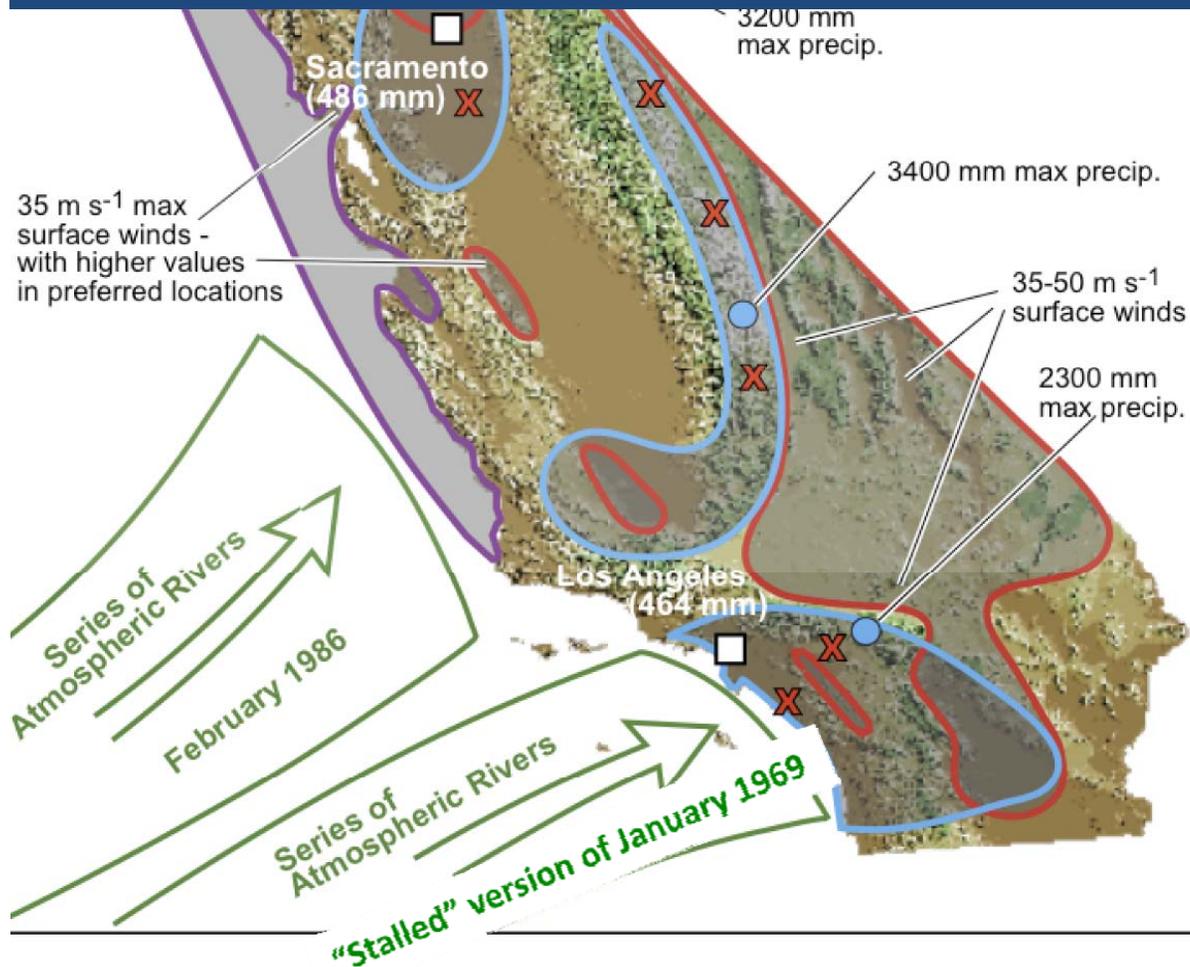


Atmospheric-total water vapor

- All major floods of Russian River since 1997 have been **atmospheric rivers (ARs)**
- The 9 largest winter floods of Carson River since 1950 have been **pineapple expresses** (just a particular AR config)
- In Washington, 46 of 48 annual peak daily flows have been associated with ARs.
- Responses of daily flows in American & Merced Rivers to PEs are typically order of magnitude larger than to other storms

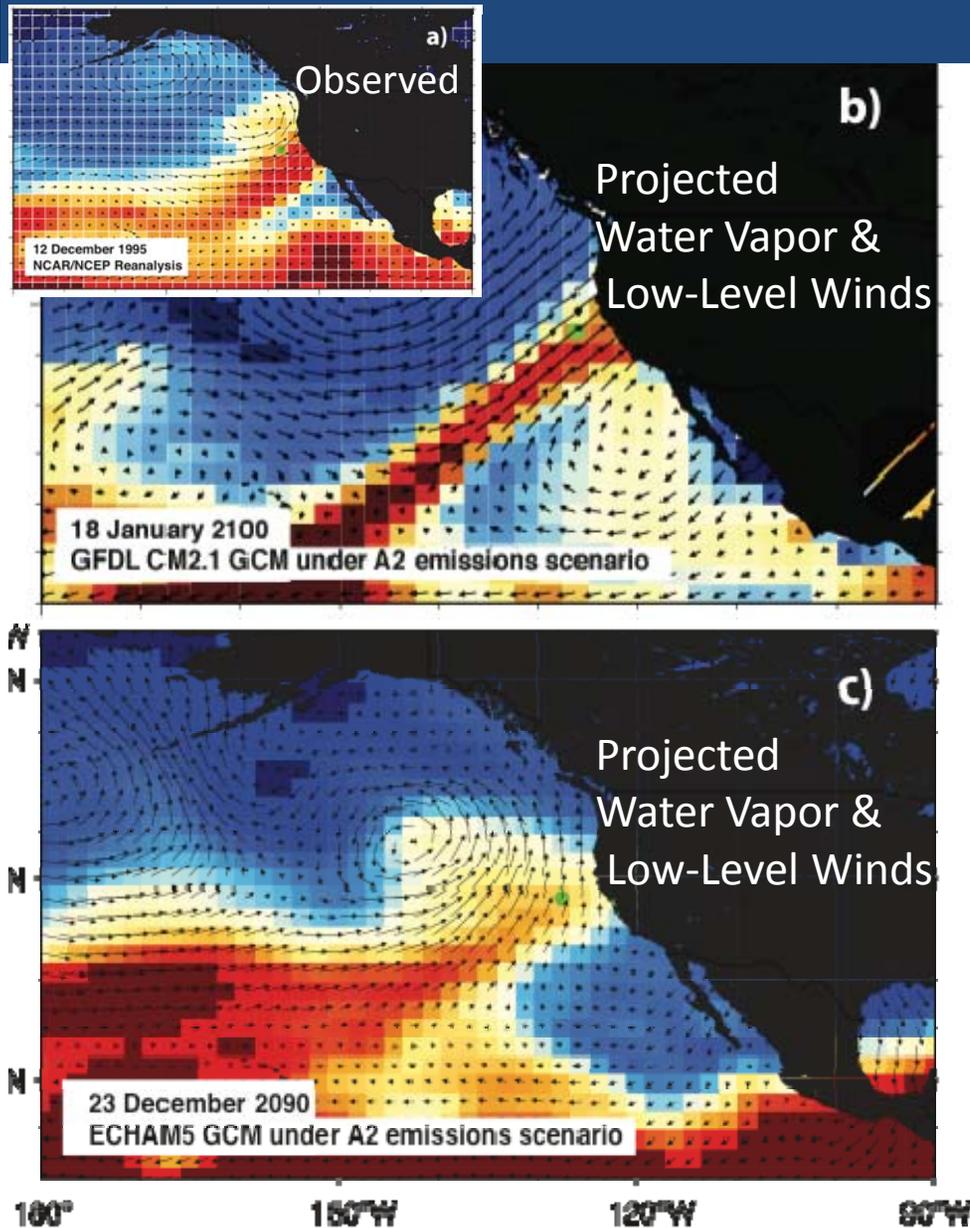


AR in AR^kStorm = Atmospheric River



...and when asked to design a really killer storm for California emergency managers, we used historical ARs strung together to do so.

Atmospheric Rivers & Climate Change

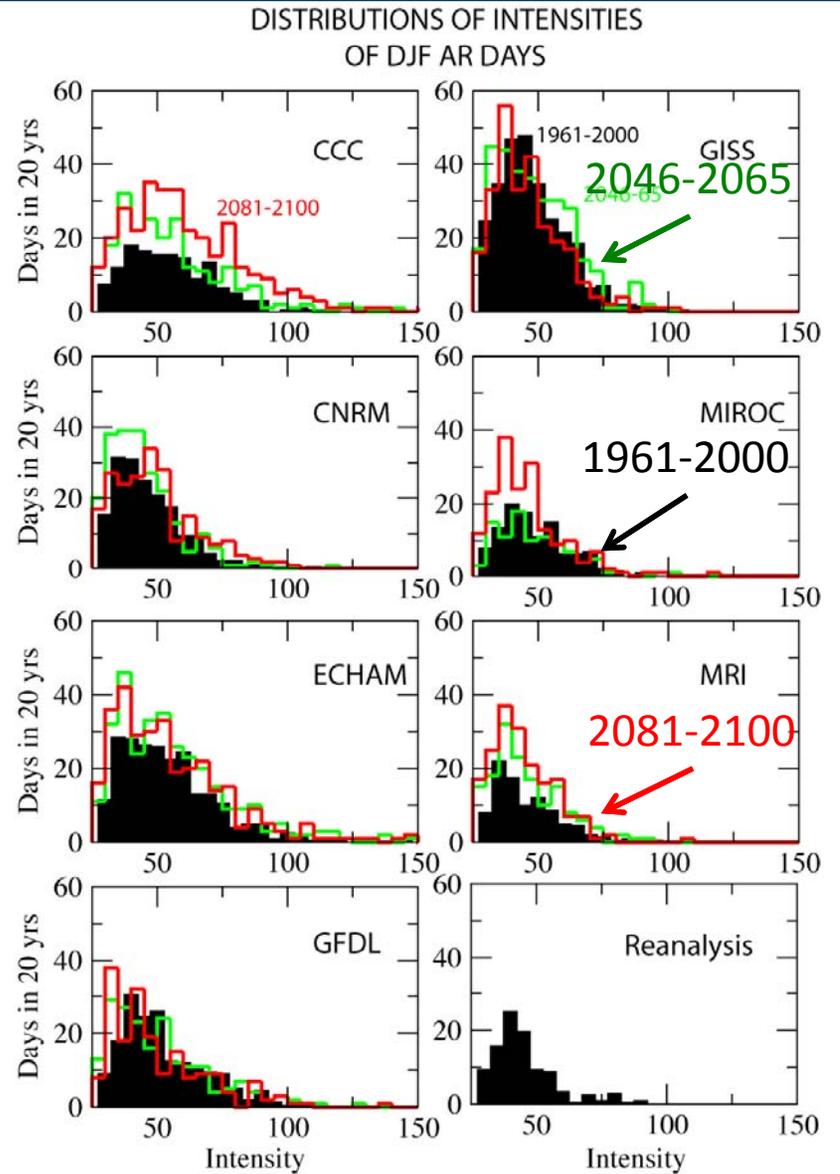
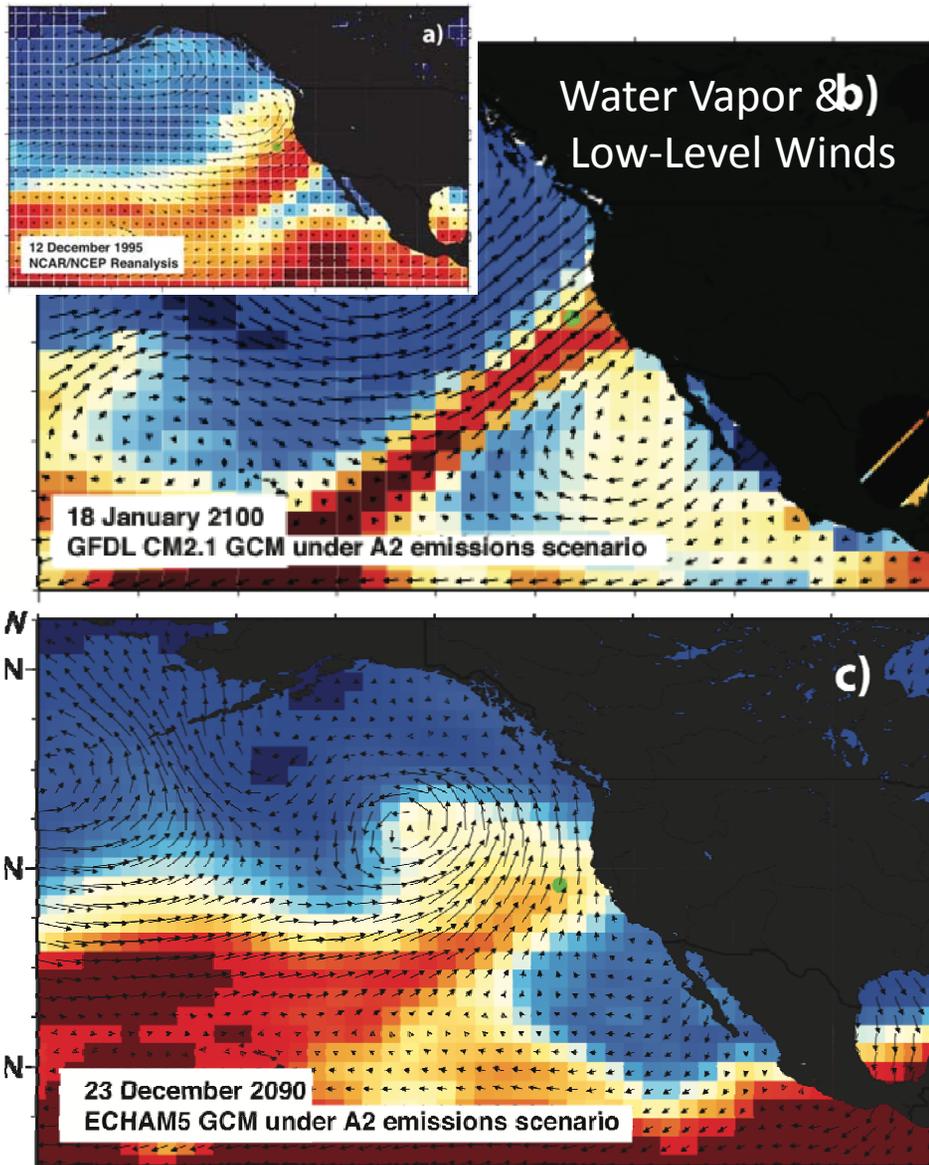


By end of 21st Century, most GCMs yield:

- More atmospheric vapor content, but weakening westerly winds
- Net increase in “intensity” of extreme AR storms
- Warmer ARs (+1.8 C) → snowline raised by about 1000 feet on average
- Lengthening of AR seasons (maybe?)

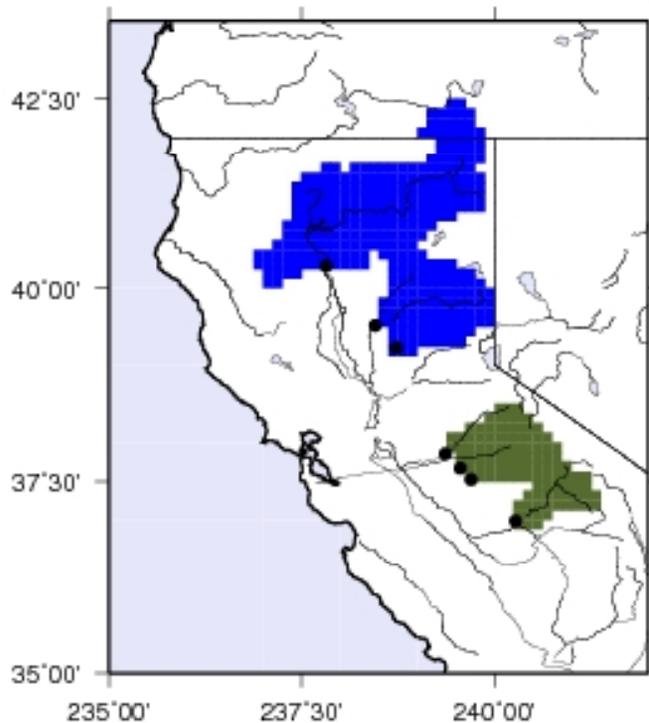
Dettinger, M.D., 2011, Climate change, atmospheric rivers and floods in California—A multimodel analysis of storm frequency and magnitude changes: Journal of American Water Resources Association, 47, 514-523.

Atmospheric Rivers & Climate Change



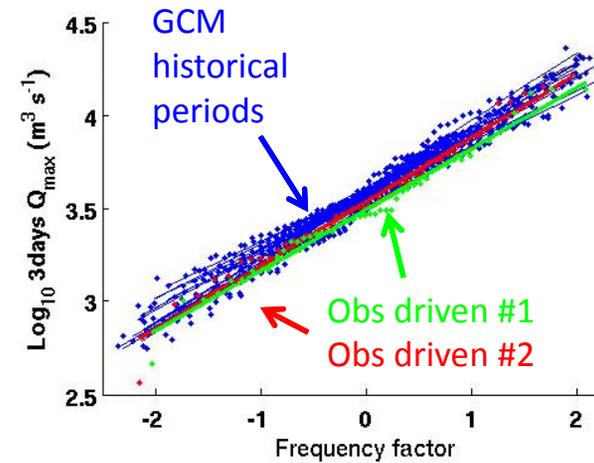
Simulated historical 3-day floods in Sierra Nevada

California flood study

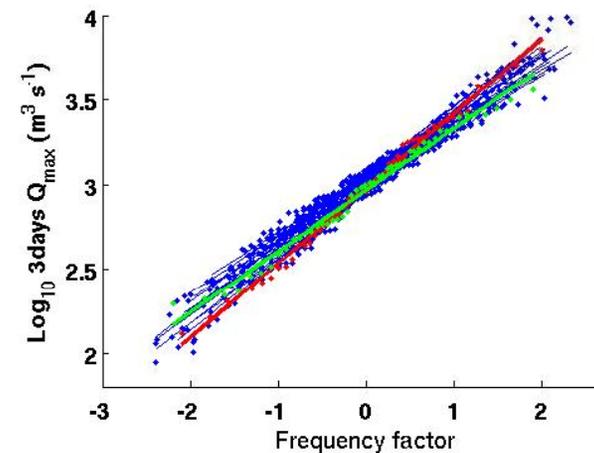


VIC macroscale hydrologic model at 1/8 degree resolution

Northern Sierra



Southern Sierra

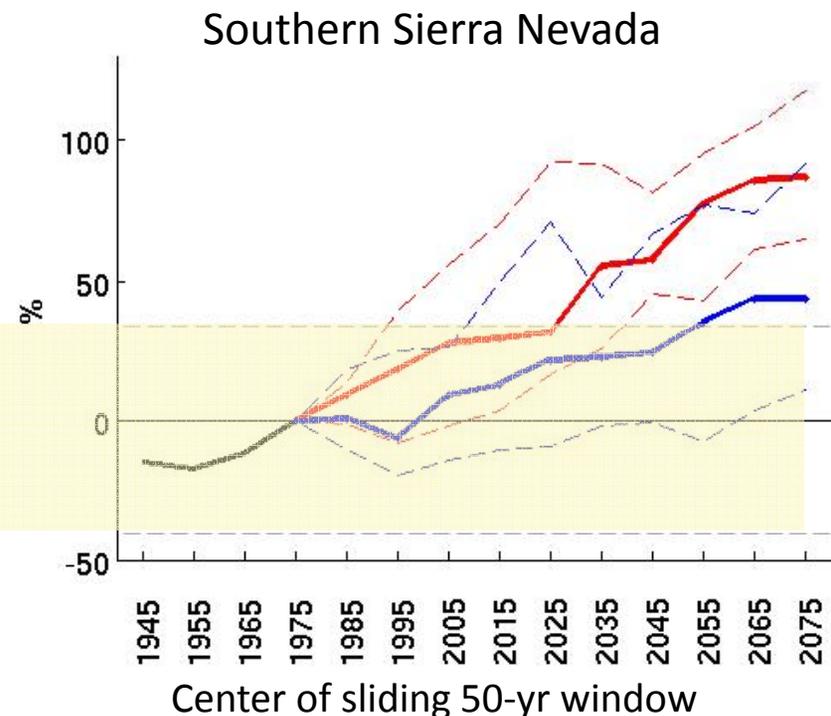
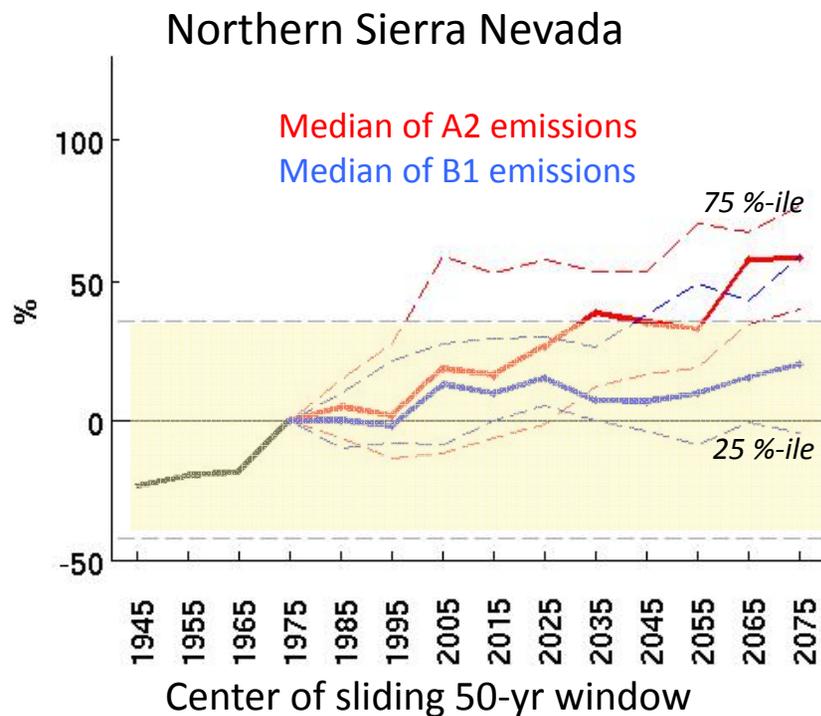


Projected 50-yr floods in Sierra Nevada



Changes from 50-yr flood estimated for 1951-2000 period

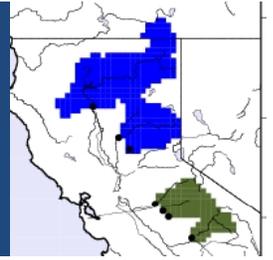
Distributions from ensemble of 16 different GCMs



From recent extensions to the analyses in: Das, T., Dettinger, M., Cayan, D., and Hidalgo, H., 2011, Potential increase in floods in California's Sierra Nevada under future climate projections: *Climatic Change*, 24 p.

Bottom line:

Projected floods in Sierra Nevada

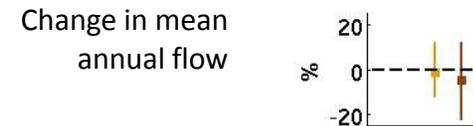


16 GCMs, A2 emissions

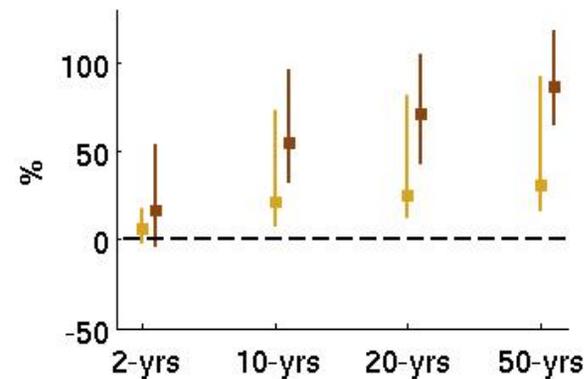
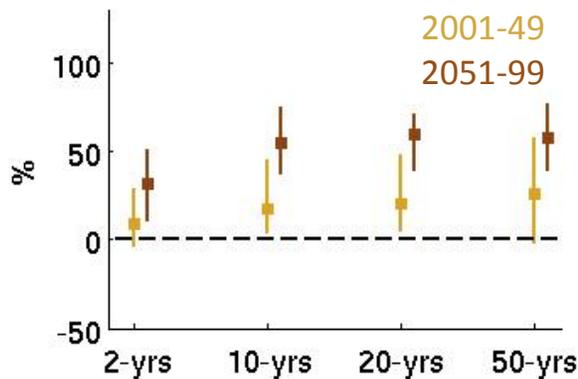
Northern Sierra Nevada



Southern Sierra Nevada

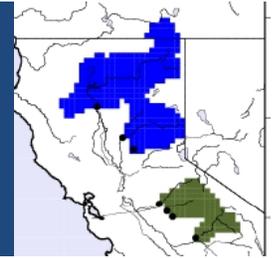


Change in flood flows with various return periods



Perhaps most notably, EVEN IN PROJECTIONS WITH DRIER OVERALL CONDITIONS, FLOODS ARE PROJECTED TO INCREASE.

Projected storm sizes & frequencies in Sierra Nevada

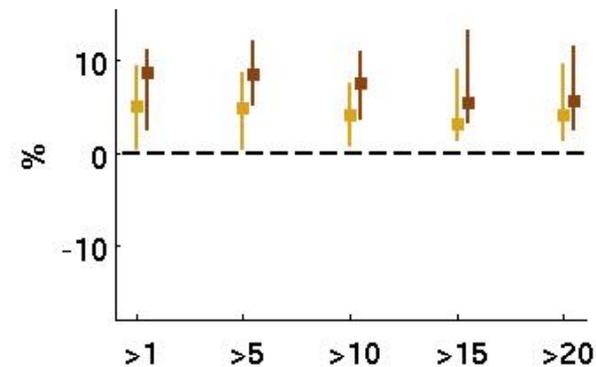
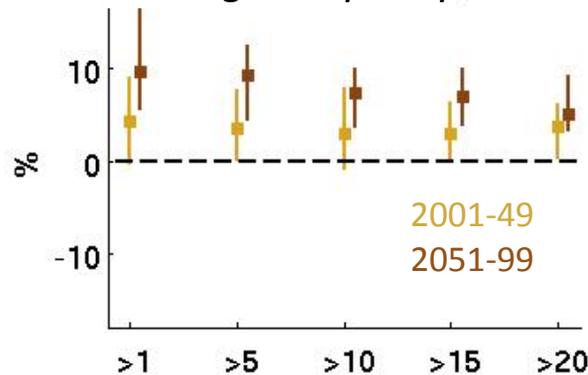


16 GCMs, A2 emissions

Northern Sierra Nevada

Southern Sierra Nevada

Changes in precip contributions above thresholds



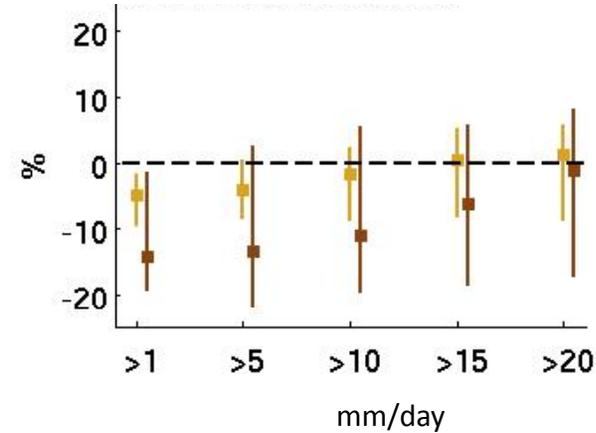
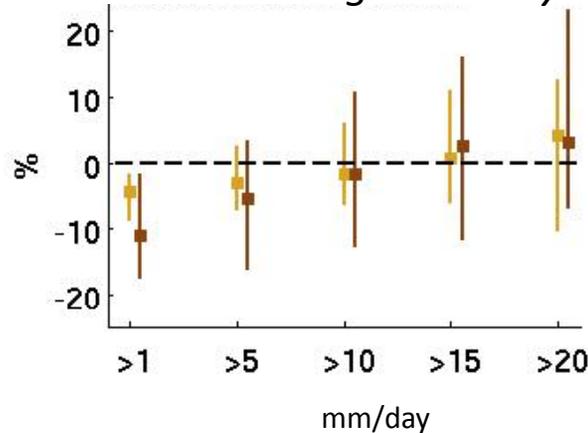
*NSN:
Larger
storms*

*SSN:
Larger
storms*

*Mixed wet
days*

Changes in #days above thresholds

*Fewer wet
days*



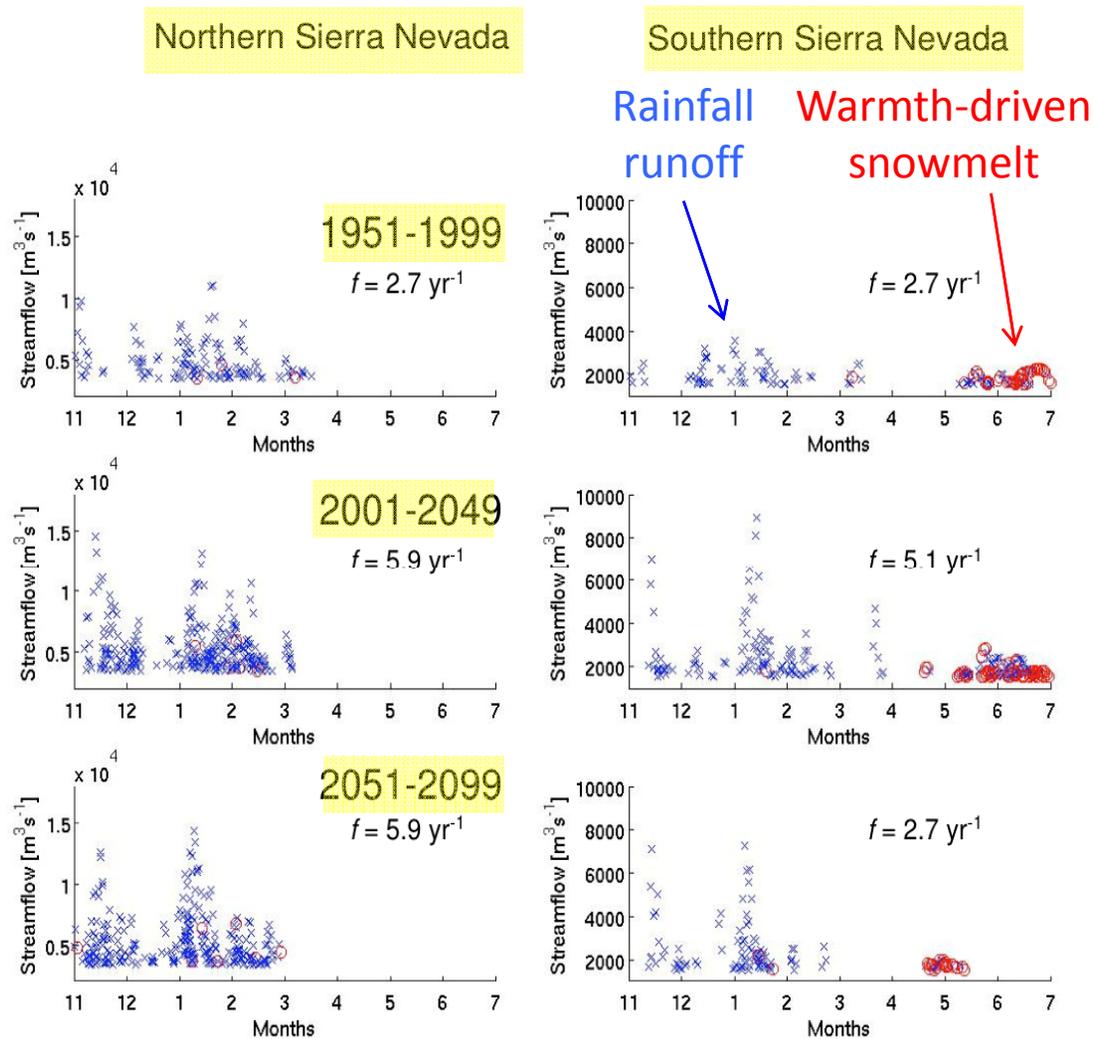


Fig. 5 Floods in Californian Northern Sierra Nevada (Left) and Southern Sierra Nevada (Right). Panels on first row shows floods using observed meteorology driven VIC simulated streamflows from the period 1951-1999. Second and third row panels show floods using downscaled CNRM CM3 driven VIC simulated streamflows from periods 1951-1999, 2001-2049 and 2051-2099. Numbers (f) in each panels indicate frequency of the floods per year on average. In the figure, "X" symbols are precipitation-driven floods and red circles are snowmelt driven floods. Flood is defined if streamflow in a given day for the period November through July is larger than 99 percentile value computed from the time period 1951-1999.

Downscaling & simulating the flood consequences of climate-change projections is beginning to show that:

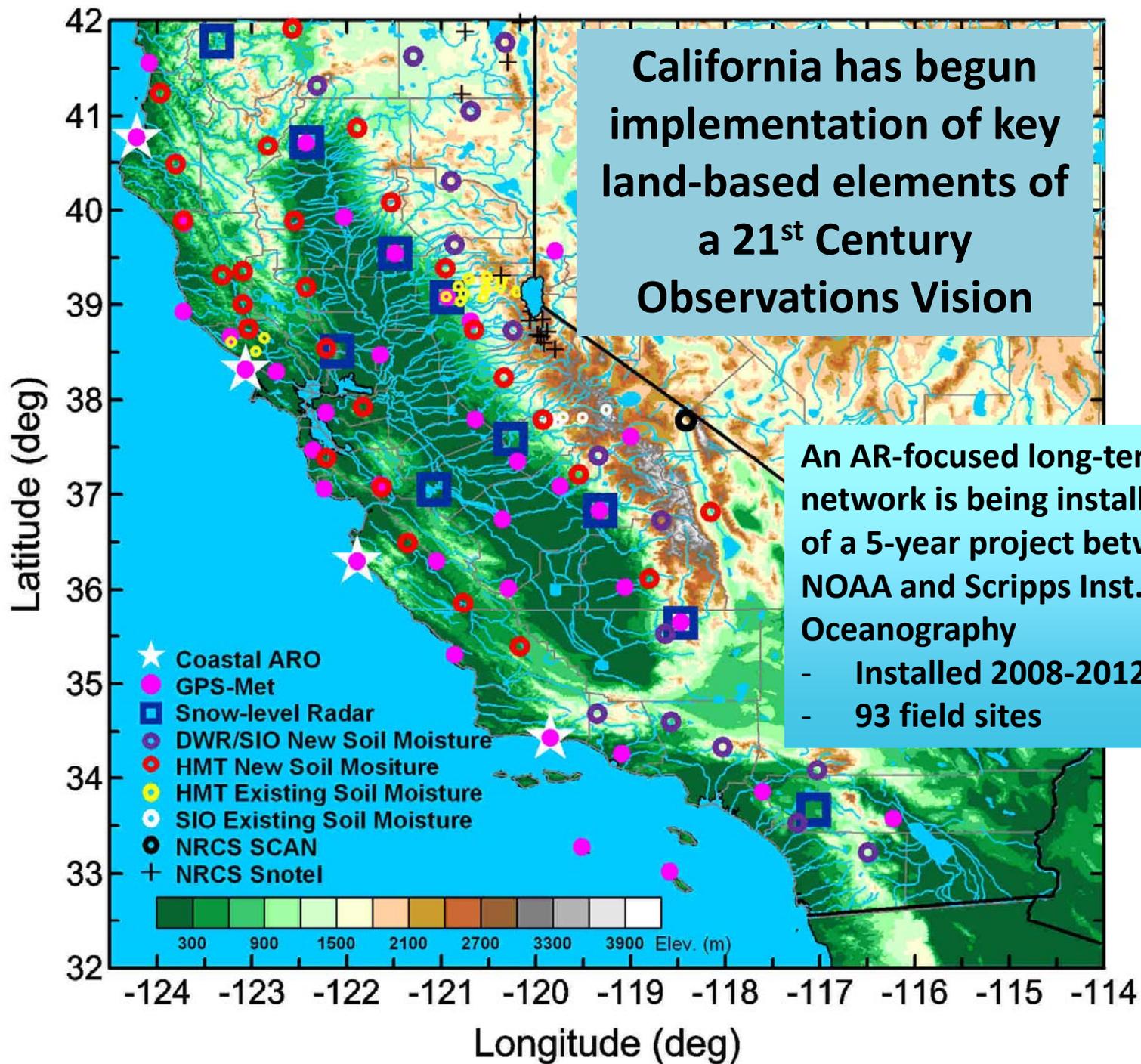
- Wintertime flood flows increase in both frequency & magnitudes in both Northern & Southern Sierra
- Spring-snowmelt high flows from Southern Sierra expected to decline
- Causes of these changes are mixes of larger/more storms, higher snowlines & even wetter soils, depending on river considered

From: Das, T., Dettinger, M., Cayan, D., and Hidalgo, H., 2011, Potential increase in floods in California's Sierra Nevada under future climate projections: Climatic Change, 24 p., doi:10.1007/s10584-011-0298-z

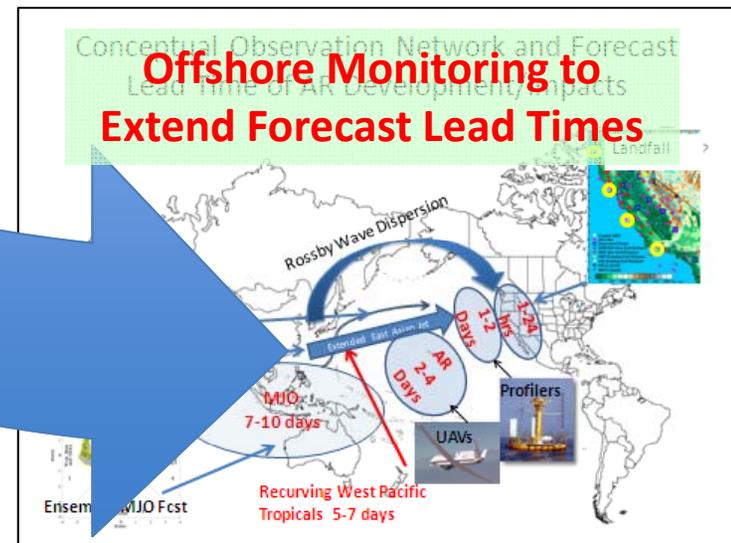
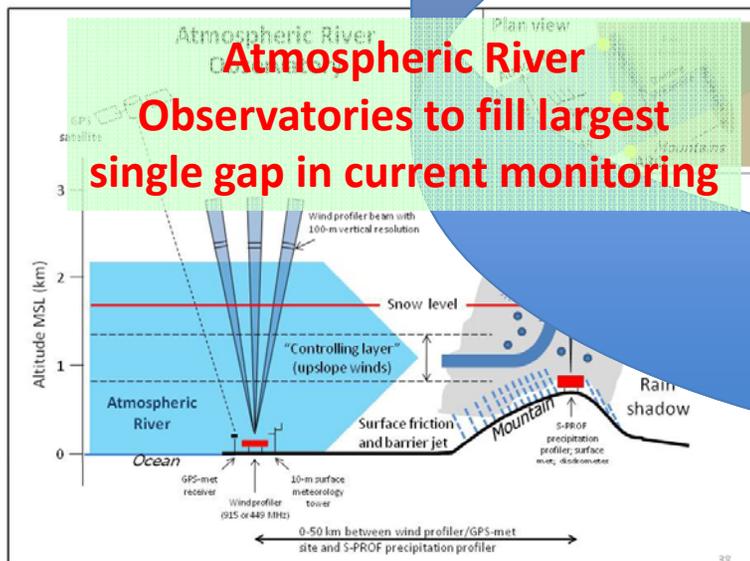
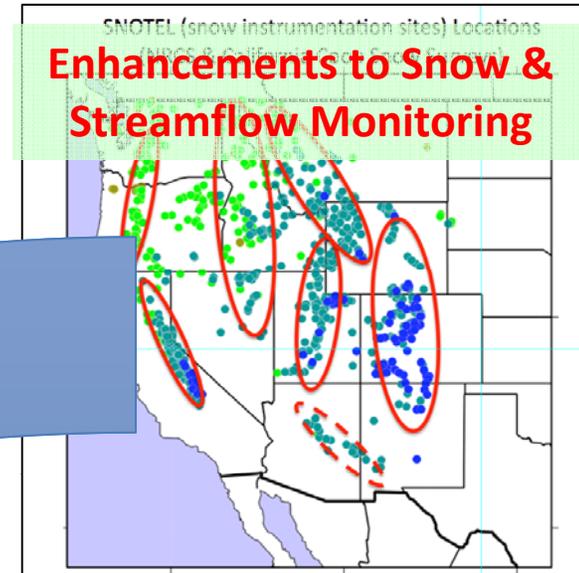
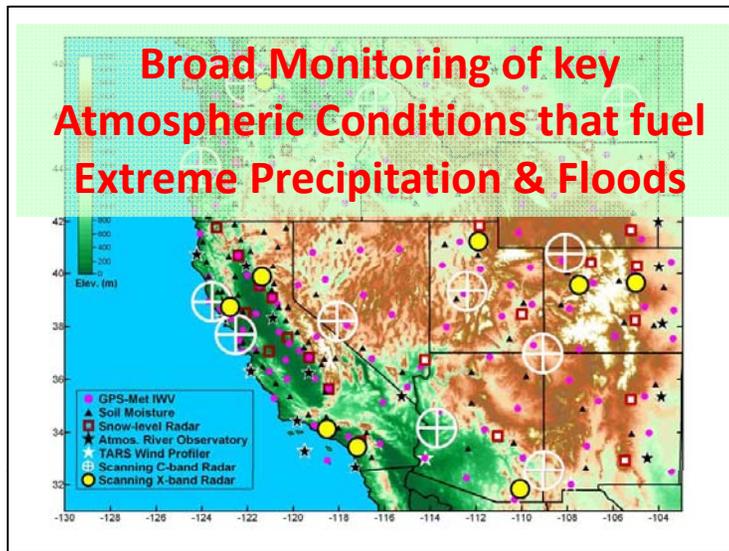
Conclusions

Ensembles of projections of 21st Century climates & hydrology in California suggest:

- More years with lots of ARs, fewer with few
- Overall average AR intensities don't change much but occasional much stronger than historical ARs
- Increased flood risks in northern & southern Sierra, combination of snowline changes & storm intensities
- Increased flash flood risks in southern California?
- Modern observational tools offer better insights & forecasts of these events

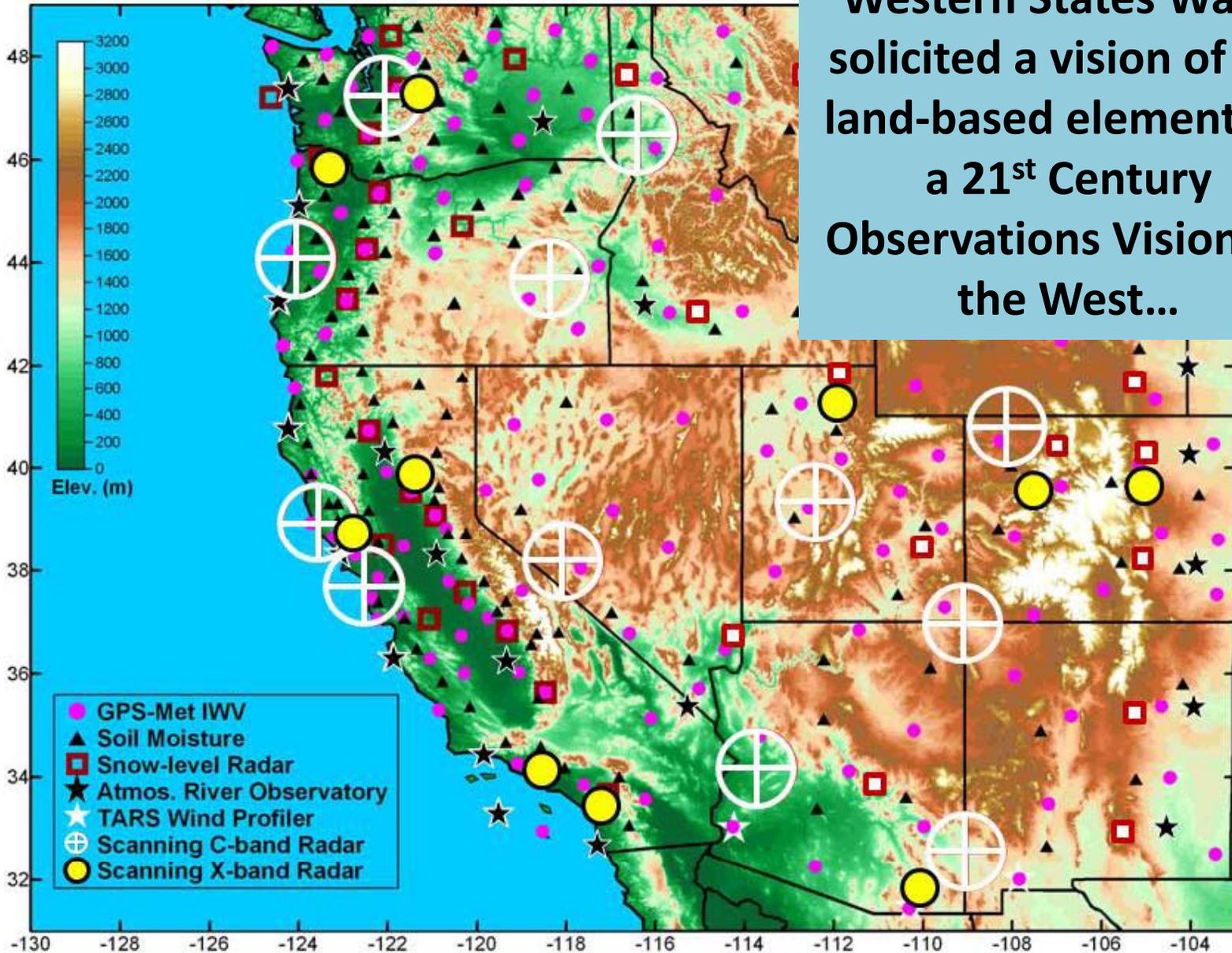


Elements of a 21st Century Monitoring Strategy for the Western US as a whole



Ralph et al., 2011, A vision of future observations for western US extreme precipitation events and flooding: White paper to Western States Water Council, 74 p.

**Western States Water
solicited a vision of key
land-based elements of
a 21st Century
Observations Vision for
the West...**



Ralph et al., 2011, A vision of future observations for western US extreme precipitation events and flooding: White paper to Western States Water Council, 74 p.

Heavy Precipitation and Flooding

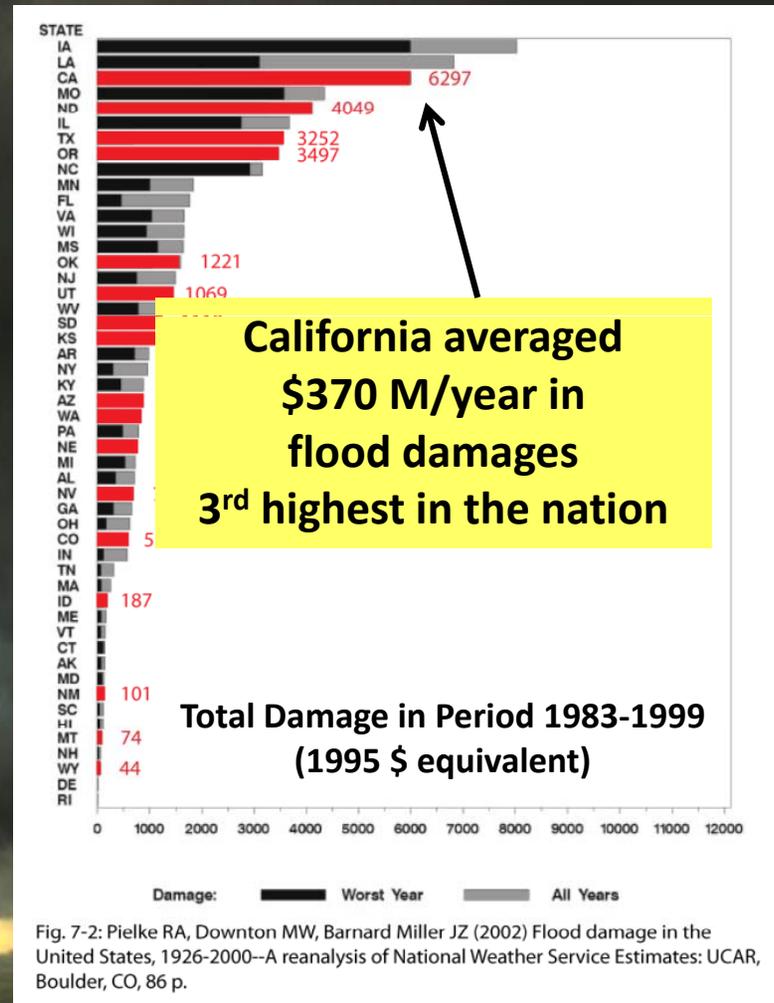


Fig. 7-2: Pielke RA, Downton MW, Barnard Miller JZ (2002) Flood damage in the United States, 1926-2000--A reanalysis of National Weather Service Estimates: UCAR, Boulder, CO, 86 p.