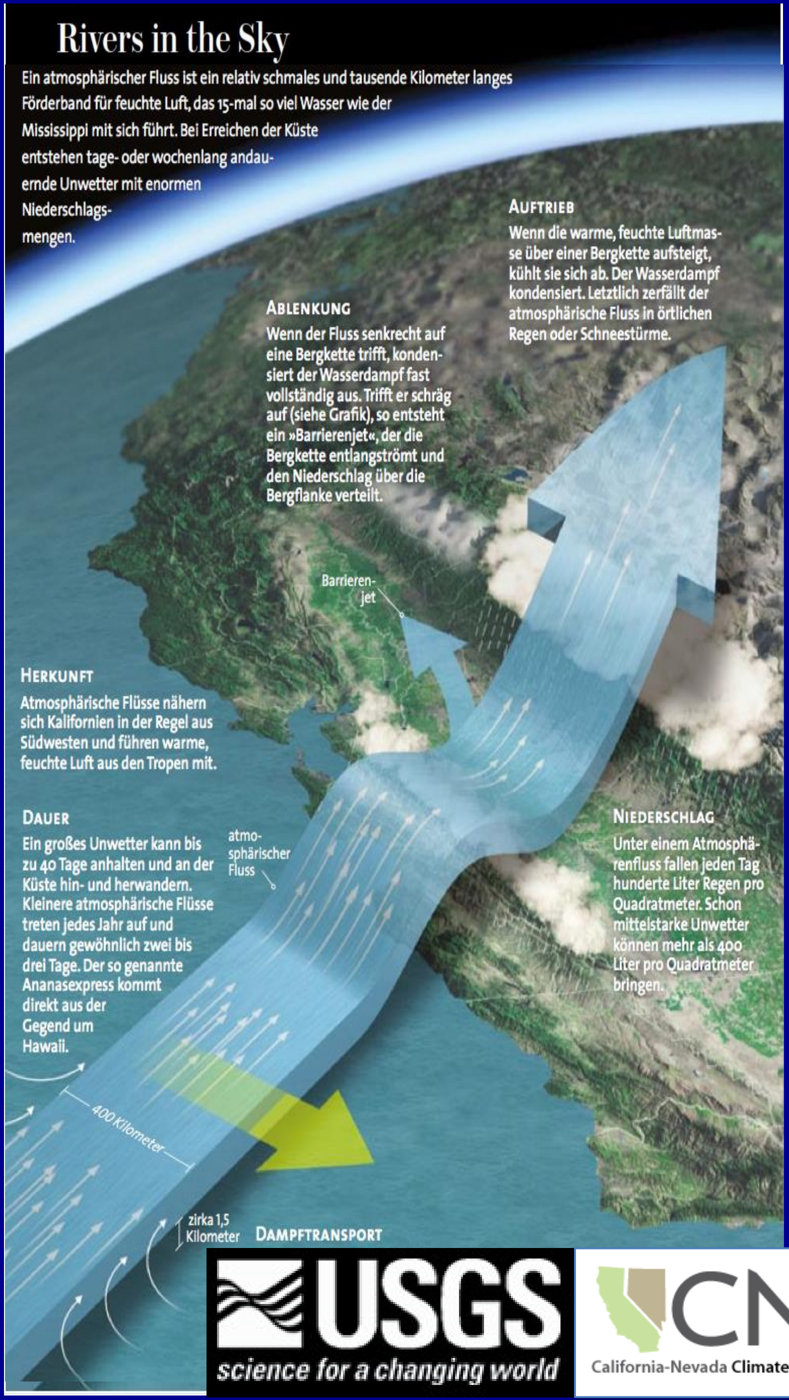


A Survey of Hydrological and Ecological Effects of Landfalling Atmospheric Rivers

Mike Dettinger, USGS/CW3E

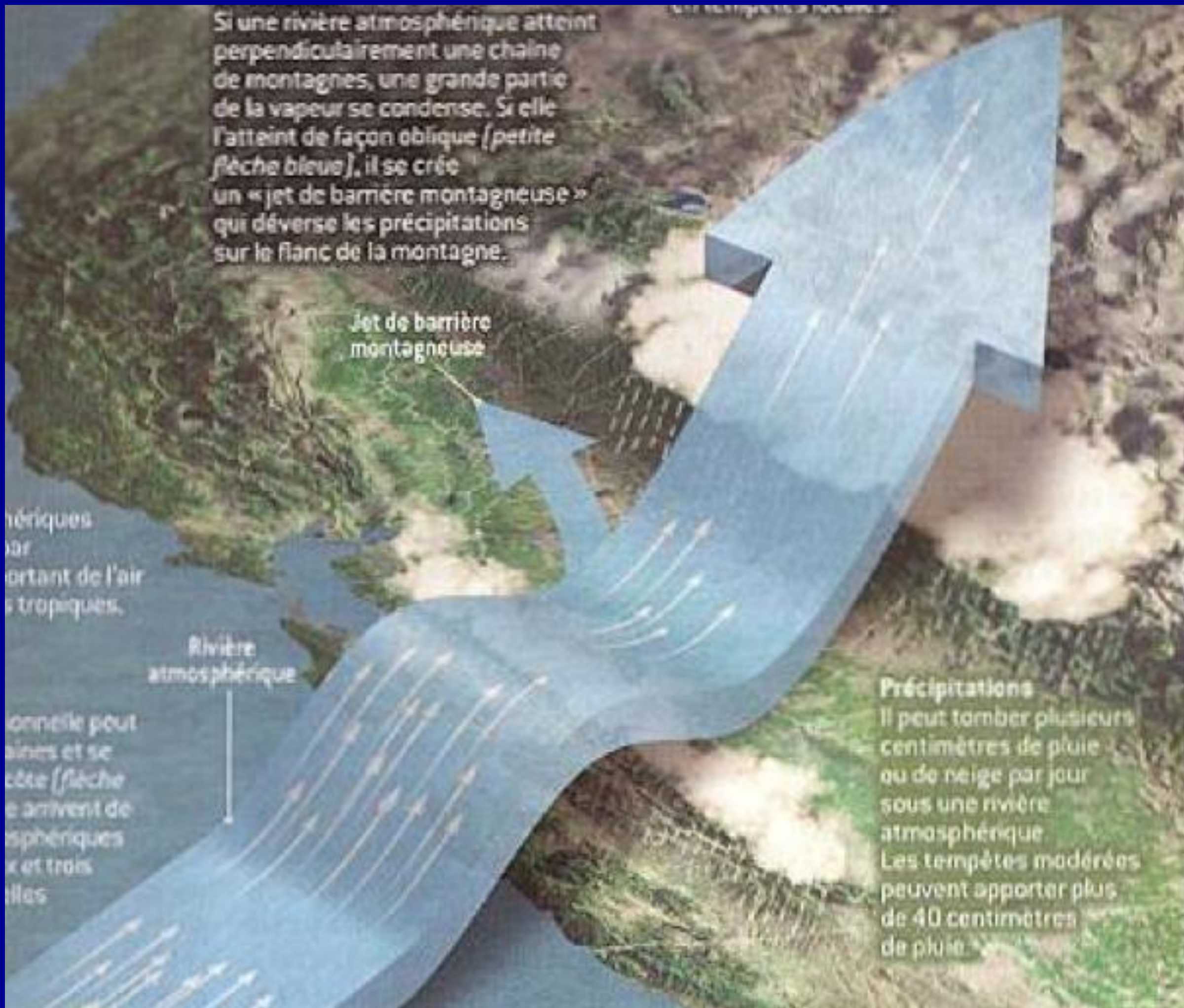
David Lavers, ECMWF

USGS science for a changing world

CNAP California-Nevada Climate Applications Program

Center for Western Weather and Water Extremes
Scripps Institution of Oceanography at UC San Diego

Outline



- **Impacts of ARs**
- **Atmospheric determinants of the impactfulness of ARs**
- **Landscape determinants of impactfulness**
- **Regional characteristics of AR impacts**

USGS science for a changing world | CNAP California-Nevada Climate Applications Program | Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at UC San Diego

Key AR impacts

- Floods
  Global survey
- Droughts
  California droughts example
- Landslides & debris flows
  Oakley et al will be talking about this
- Glacial & ice-cap mass balances
  Gorodetskaya & Mattingly have spoken about this
- Snow abundance & rain-on-snow
  Guan, GRL 2016
  Huning et al will be talking about this
- Avalanches
  Hatchett et al will be talking about this
- Erosion & geomorphic fx
- Groundwater recharge
  Mojave example
- Significant water resources
  Western US example
- Strong winds
  Small will be talking about this
- Estuarine variability
  X2 example
- Vegetation variations & wildfire
  Albano et al will be talking about this
- Fisheries
  FIRO has been discussed several times
- Oceanic fx?

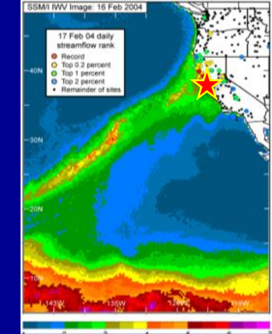
Floods *(examples from the literature)*

- **New Zealand**: Kingston et al. 2016
- **Australia/Tasmania:** Stuart, this conf
- **Hawaii (Kauai)**: Neiman et al. 2014
- **California**: e.g., Ralph et al. 2006
- **Washington**: Neiman et al. 2011
- **Tennessee**: Moore et al. 2012
- **Iowa**: Nayak et al. 2016
- **Alaska:** Jacobs, this conference
- **Canada, Brit Columbia/Alberta/Eastern Maritimes:** Assorted, this conf
- **Mexico:** Bosart et al, this conf, in press
- **Chile:** Viale, 2014
- **Greenland**: Neff et al. 2014; Mattingly, this conf
- **Western Europe**: Lavers & Villarini 2013
- **UK:** Lavers et al. 2012
- **Iberia:** Trigo et al. 2014
- **Italy:** Malguzzi et al. 2006; Lang et al. 2012
- **Greece**: Mita et al. 2014

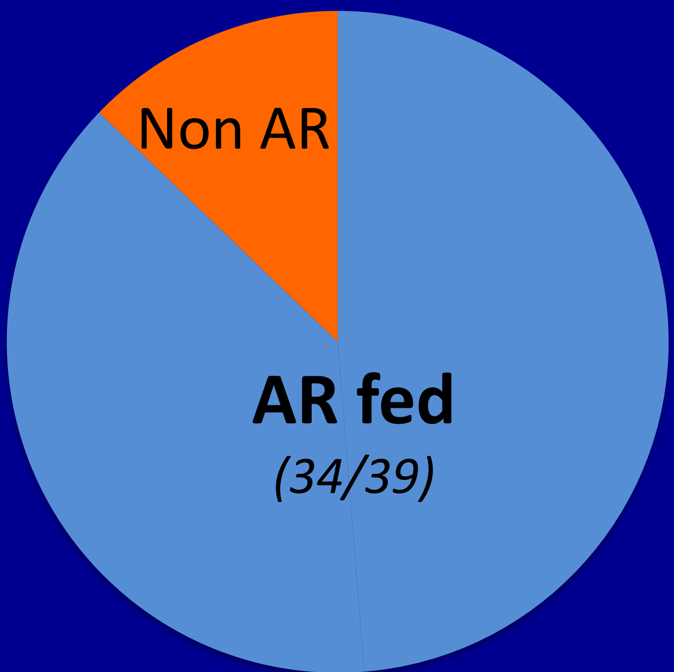
Southern California, 2014

Southern England, 2014

ARs & West Coast floods



Russian River floods, 1948-2011



ARs hit Central California ~8 days per year

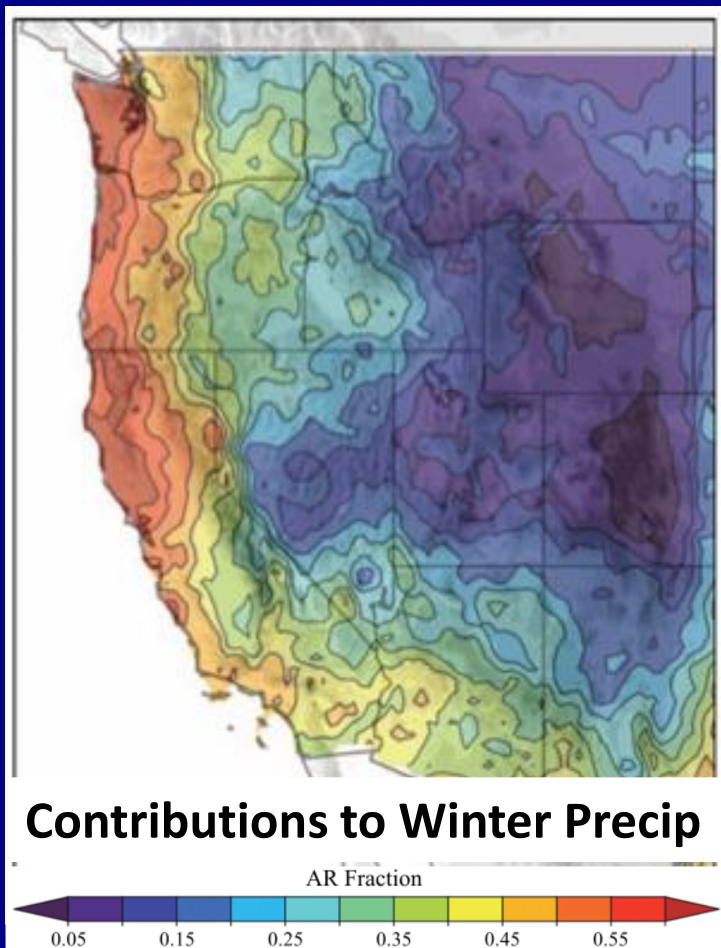
- *ALL 7 major floods of* **Russian River** *since 1997 have been atmospheric rivers (Ralph et al, GRL, 2006)*
- **On a longer time scale, among all 39 "declared" floods of the Russian River from 1948-2011…**

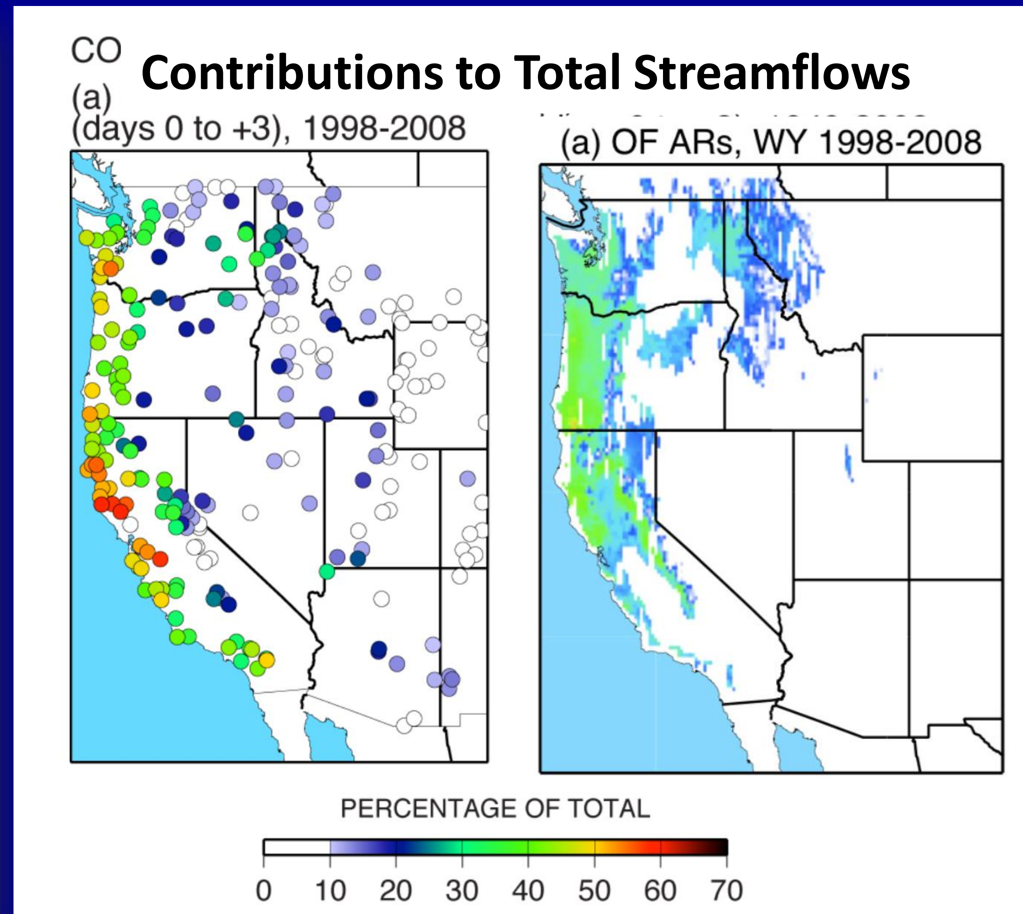
87% were caused by ARs

(Dettinger & Ingram, SciAm, 2013)

- **On lee side of Sierra Nevada, 74% of major floods of Truckee River have been caused by ARs**
- **In Washington, 46 of 48 (96%!) annual peak daily flows have been associated with ARs** *(Neiman et al, JHM, 2011)*

CONTRIBUTIONS FROM ARs TO PRECIPITATION & STREAMFLOW → Water Resources



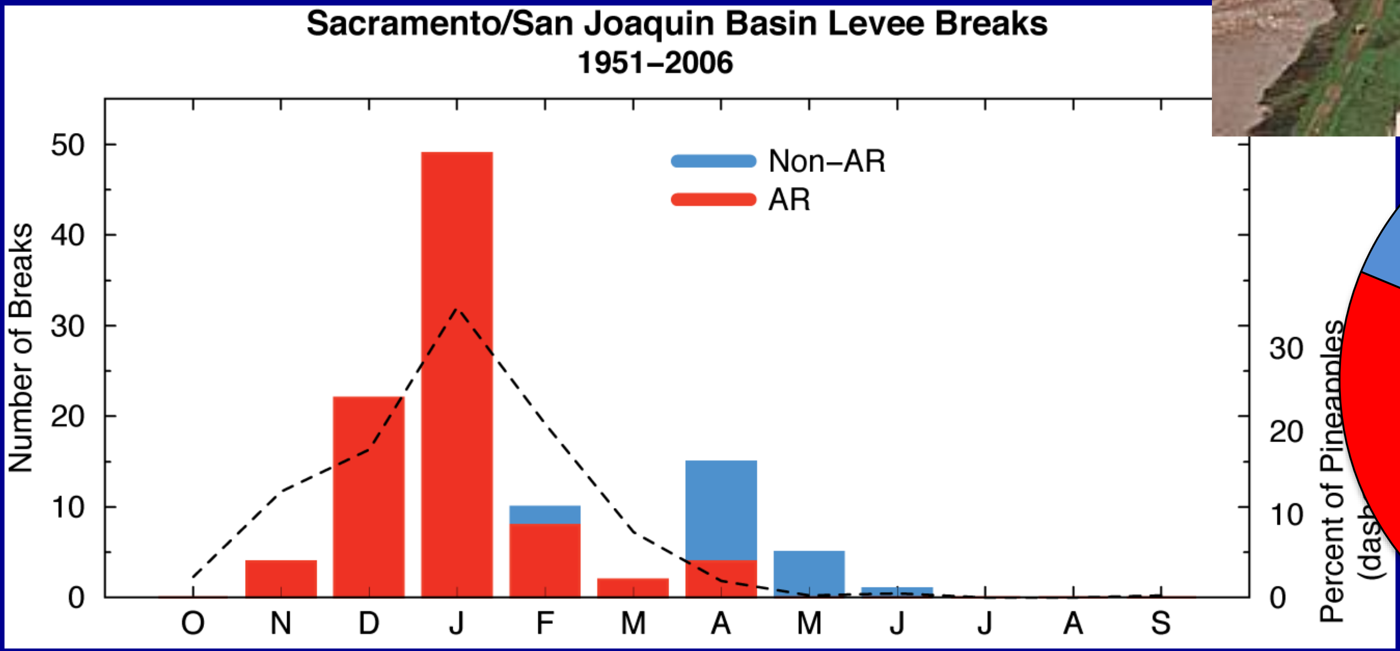


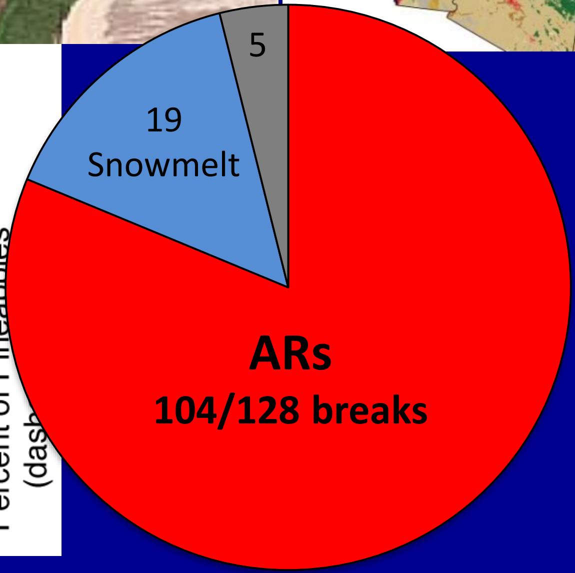
Chile: ARs contribute 15-35% of precipitation (Viale)

Rutz et al., MWR, 2014;
Dettinger et al., Water, 2011

USGS science for a changing world
CNAP California-Nevada Climate Applications Program
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Central Valley levee breaks, 1951-2006



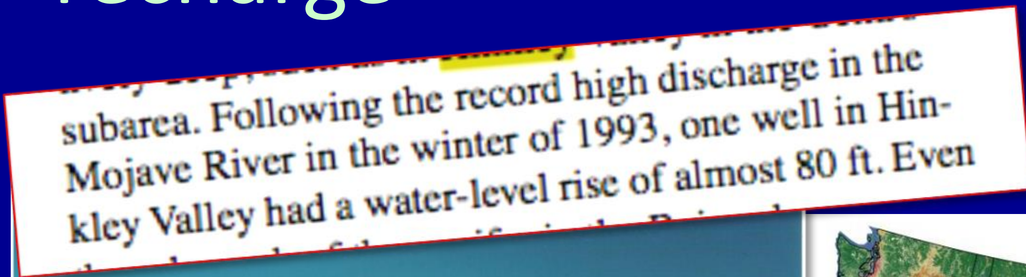


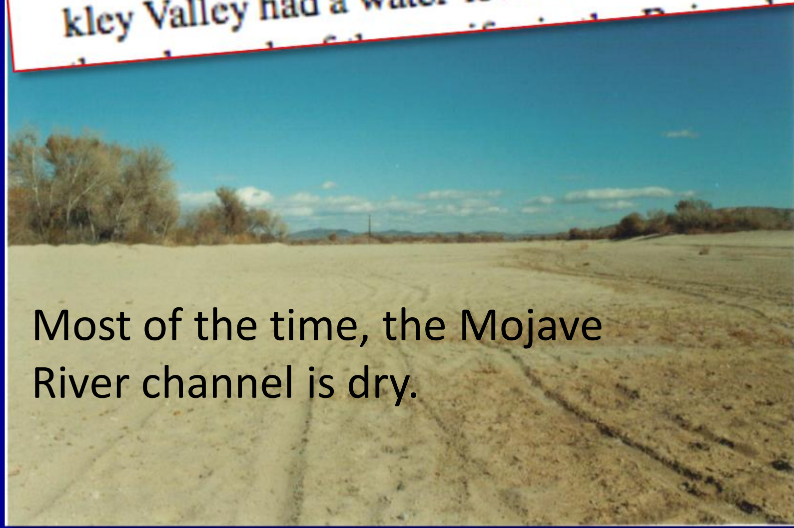
During the times of year when ARs make California landfalls, they are THE mechanism behind historical levee breaks.

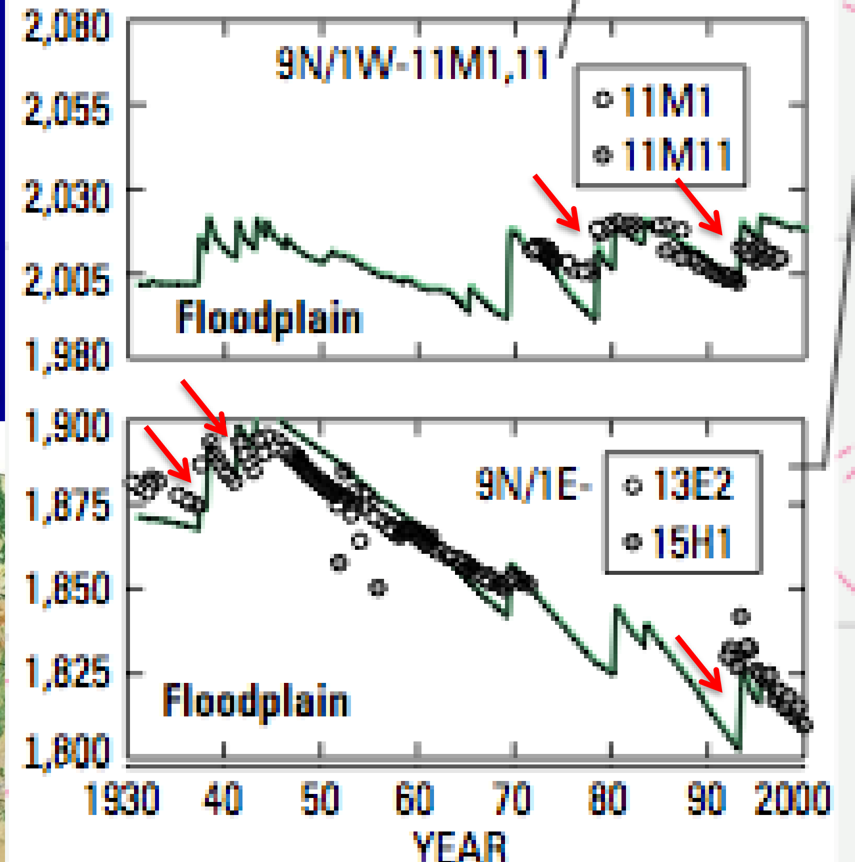
USGS science for a changing world
CNAP California-Nevada Climate Applications Program
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Florsheim & Dettinger, chapter, 2015; Florsheim & Dettinger, GRL, 2007

Mojave Desert aquifer recharge


subarea. Following the record high discharge in the Mojave River in the winter of 1993, one well in Hinkley Valley had a water-level rise of almost 80 ft. Even

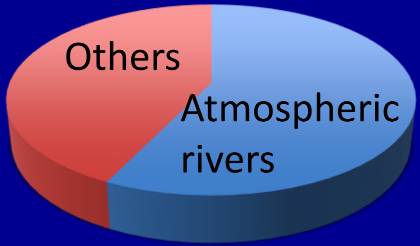

Most of the time, the Mojave River channel is dry.



Stamos et al. USGS WRIR 01-0004, 2001

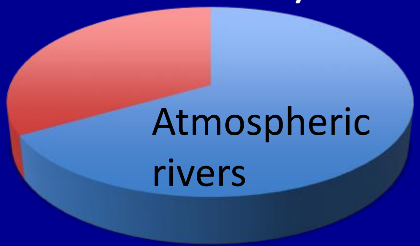
Figure 6. Gaging station 10262500, Mojave River at Barstow, January 18, 1993. (Discharge about 4,200 cubic feet per second.)

Flows > 1000 cfs for > 3 days



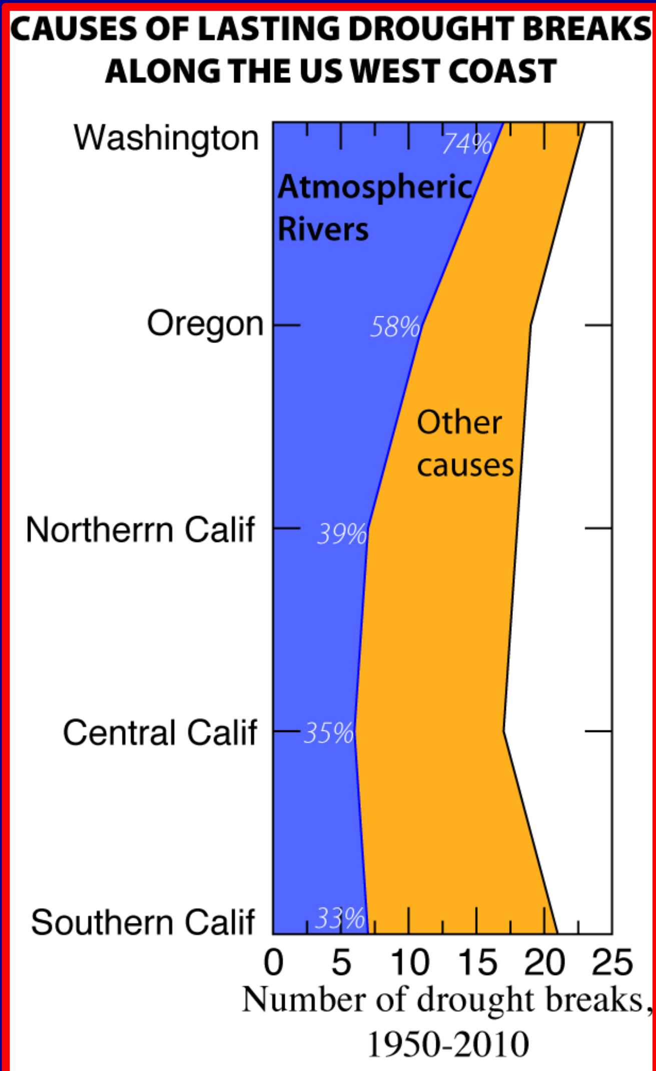
4 of 7 such episodes

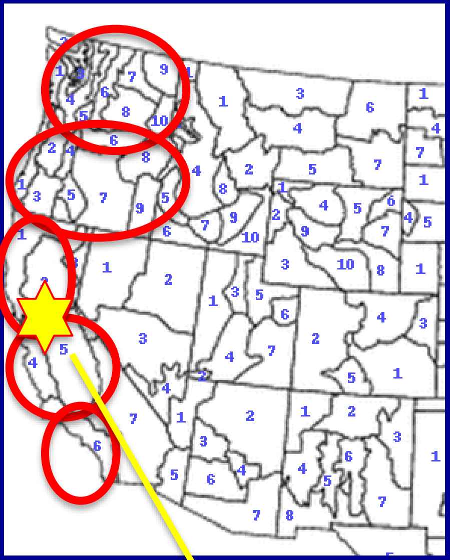
Flows > 5000 cfs for > 1 day

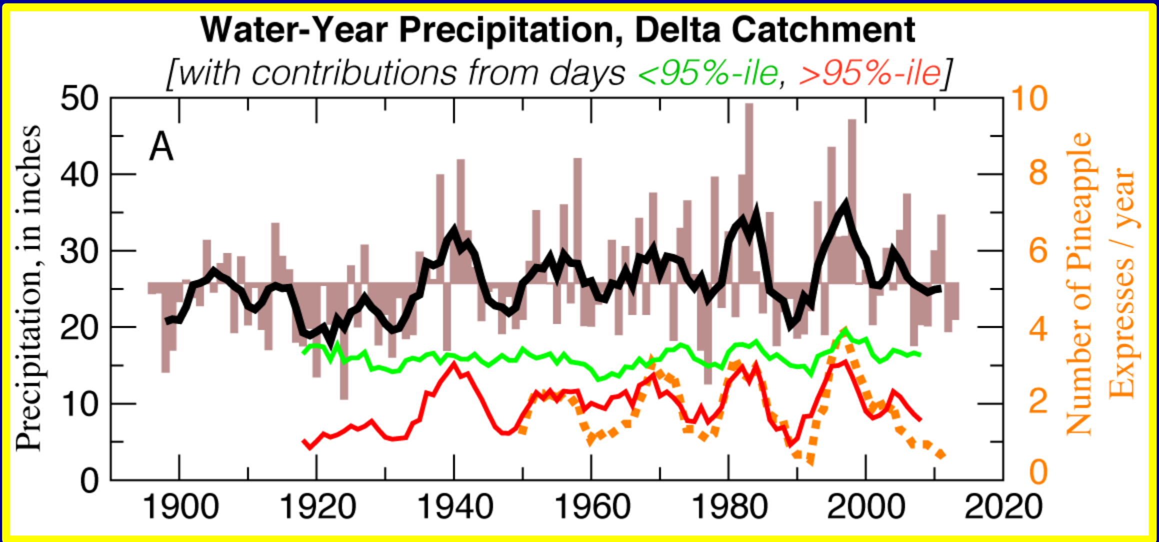


4 of 6 such episodes

AR as US West Coast drought makers & drought breakers



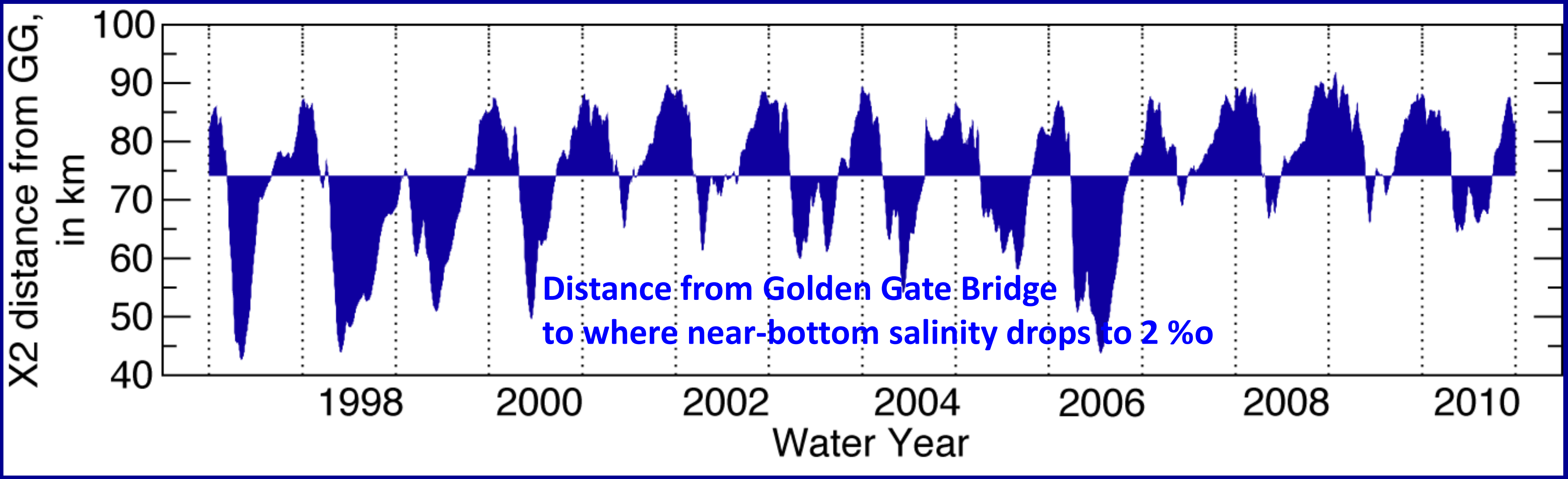


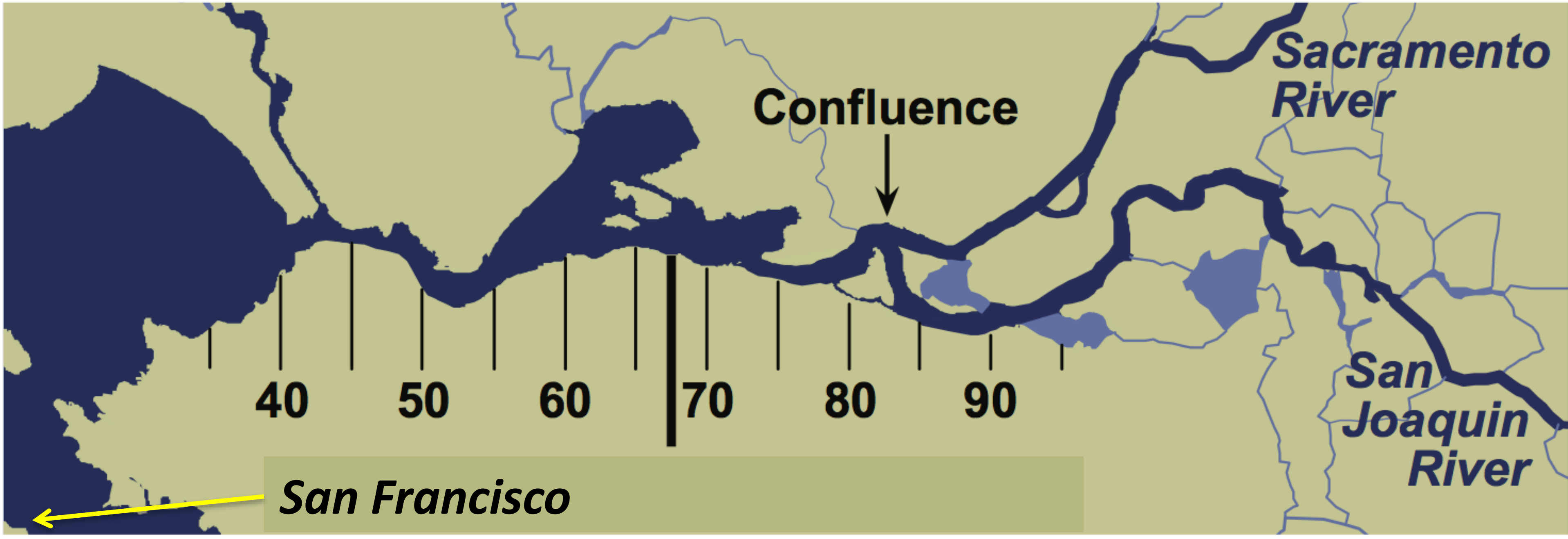


Dettinger, JHM 2013;
Dettinger, SFEWS 2016

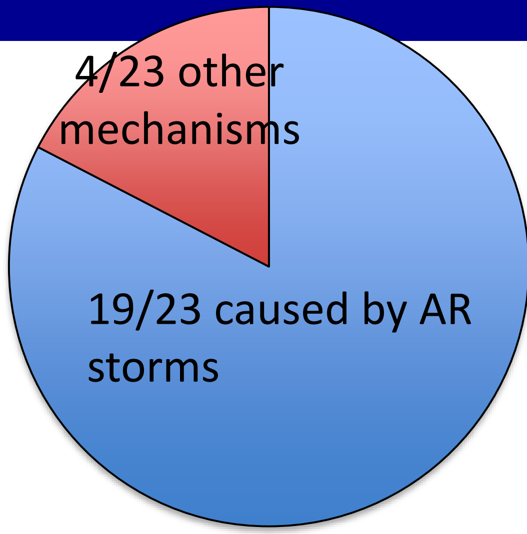
USGS science for a changing world
CNAP California-Nevada Climate Applications Program
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

tmospheric Rivers & Estuarine Health: X2

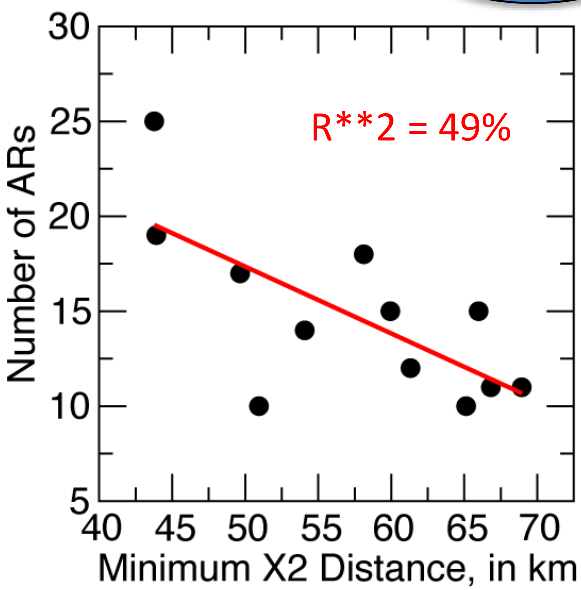


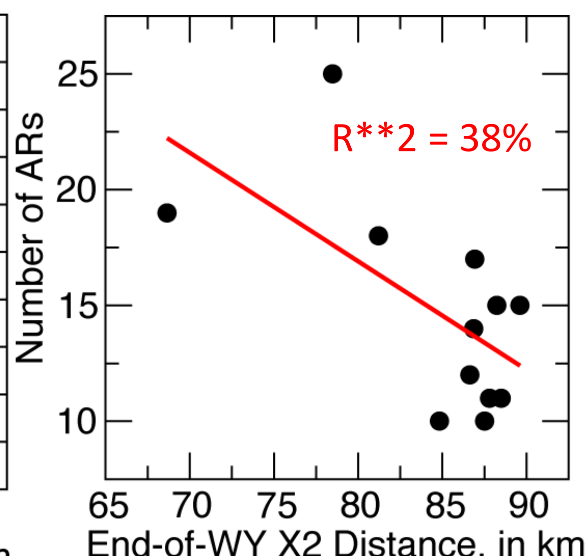


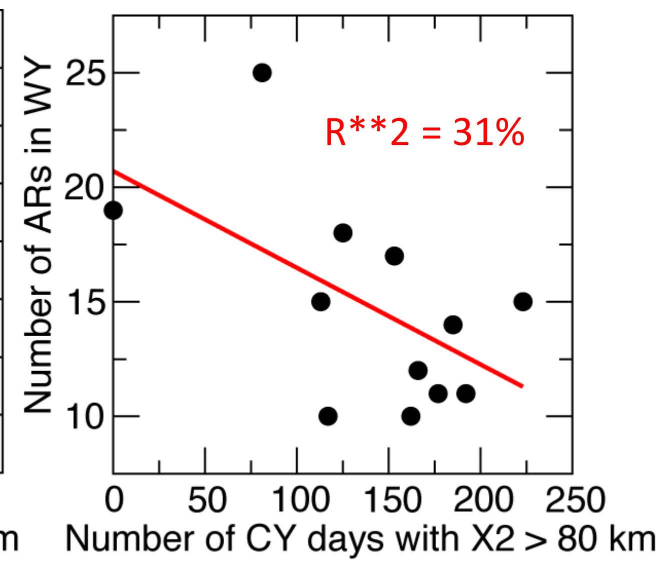
Atmospheric Rivers & X2: Distance from Golden Gate Bridge to where near-bottom salinity drops to 2 %o



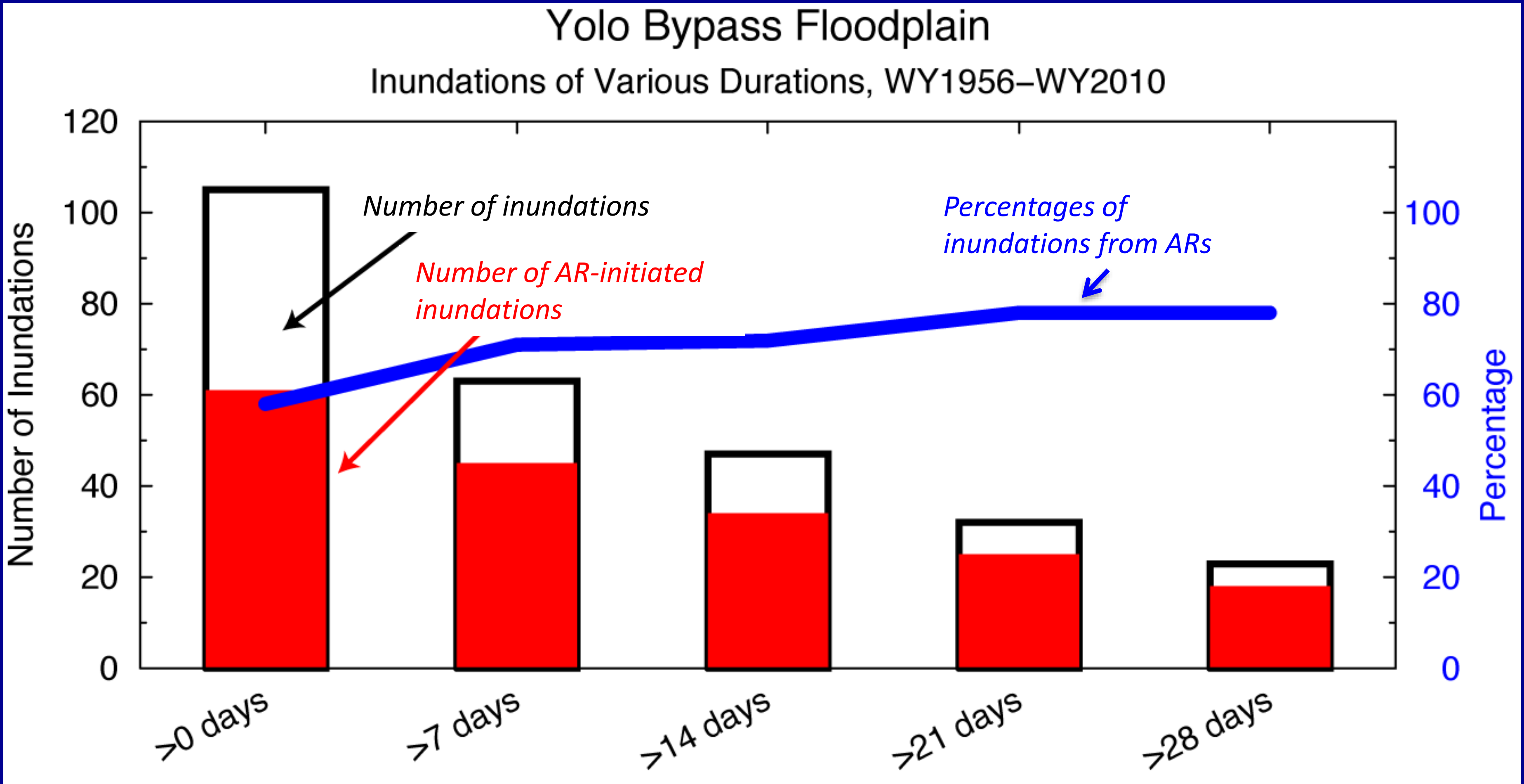
83% of largest (daily-scale, >0.85 km) X2 retreats freshening the estuary, WY1997-2010, have been due to atmospheric-river storms







Ecologically Valuable Floodplain Inundations, 55 yrs of Yolo Bypass inundations

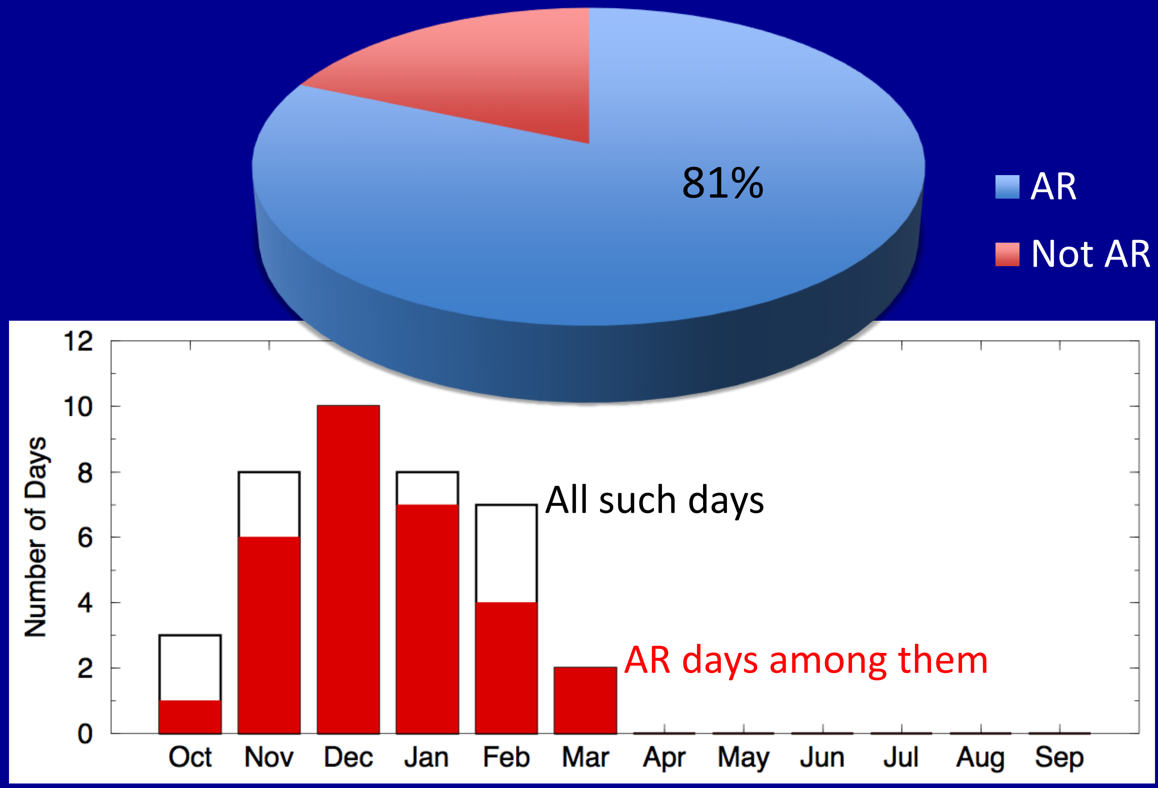


Florsheim & Dettinger, chapter, 2015

USGS science for a changing world
CNAP California-Nevada Climate Applications Program
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Warm AR storms in a snowy setting

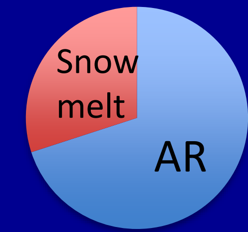
Of 38 days with Tmin > 0ºC & Precipitation > 5 cm at Tahoe City, WY1948-2010

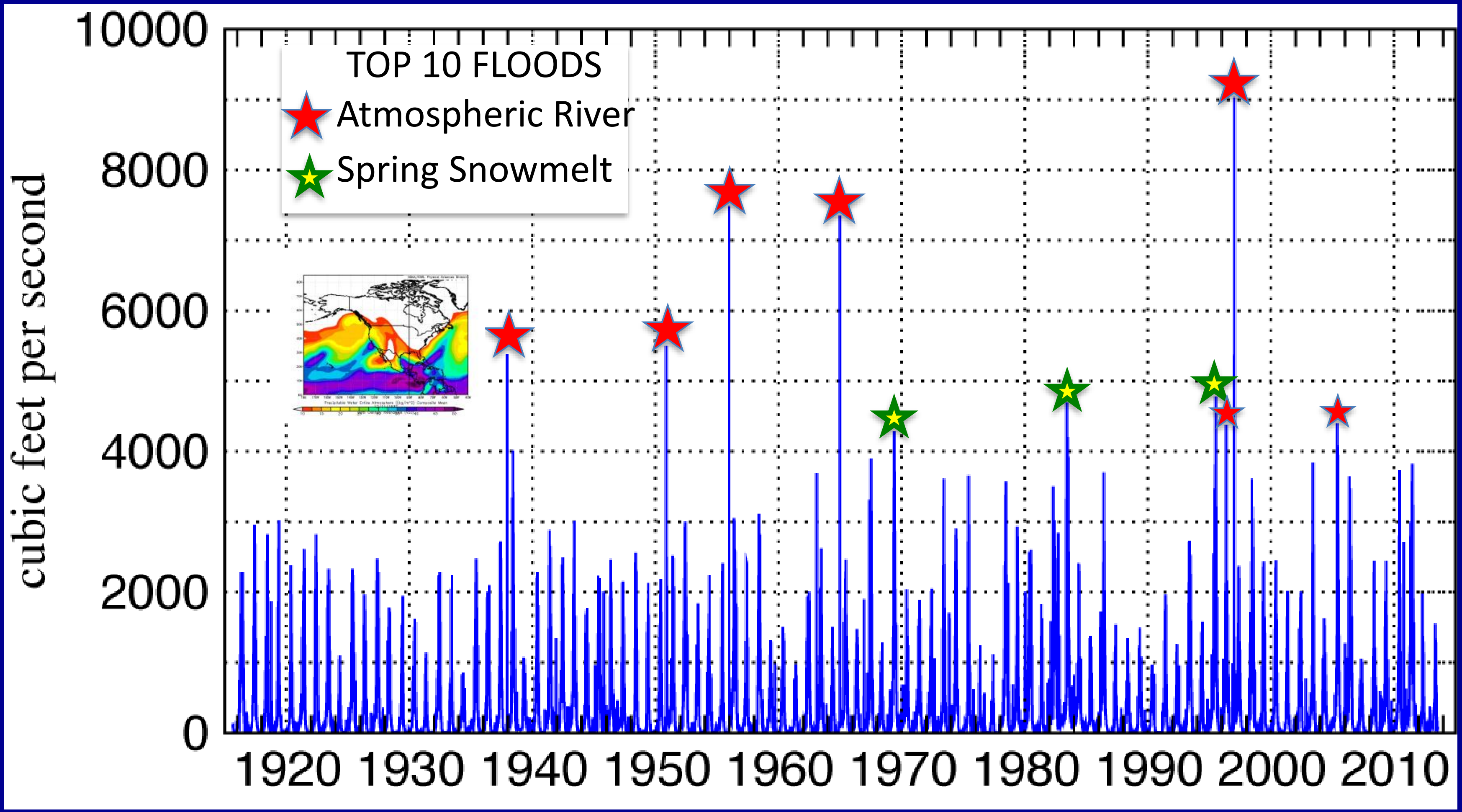


Dettinger et al, Tahoe-book chapter, in prep

USGS science for a changing world
CNAP California-Nevada Climate Applications Program
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

98-yr of daily Streamflows of the Merced River, Sierra Nevada, CA





USGS science for a changing world

CNAP California-Nevada Climate Applications Program

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

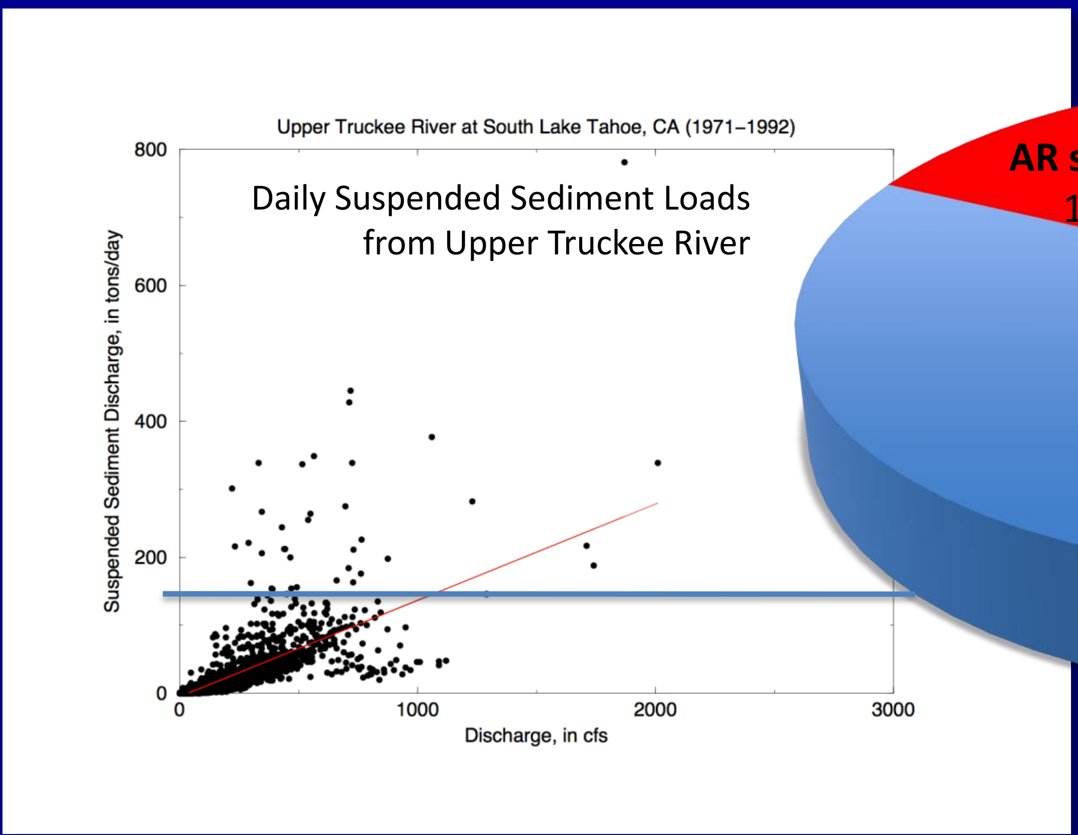
7 / 10 top floods have been due to atmospheric rivers

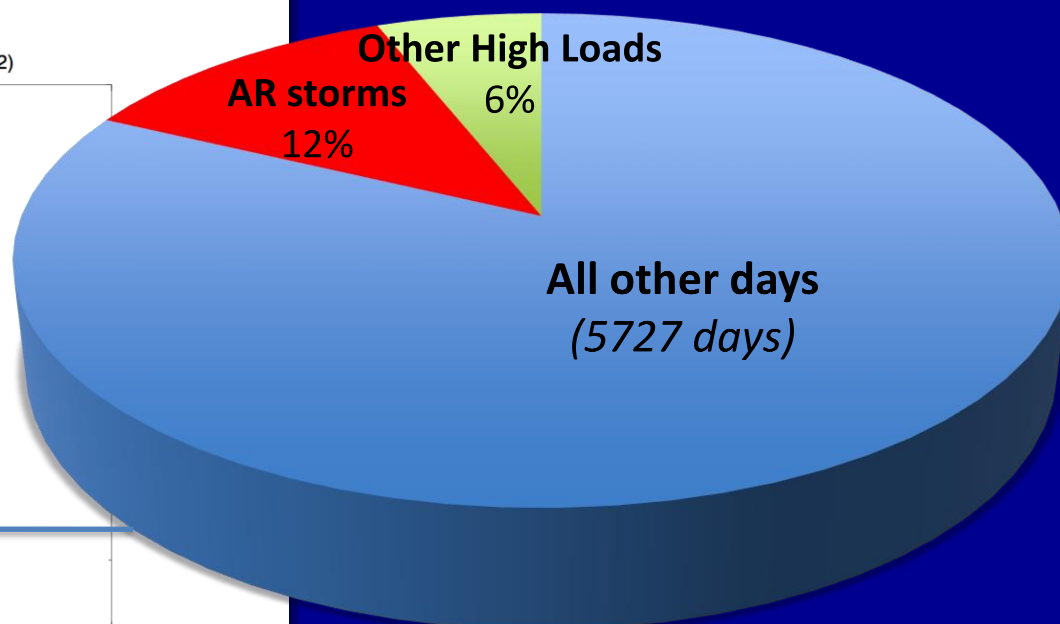
Lake Tahoe: ARs & sediment transport

Upper Truckee River at South Lake Tahoe, 1971-1992

- 12% of all sediments from UTR into Lake Tahoe were delivered on 0.6% (36) of the days.

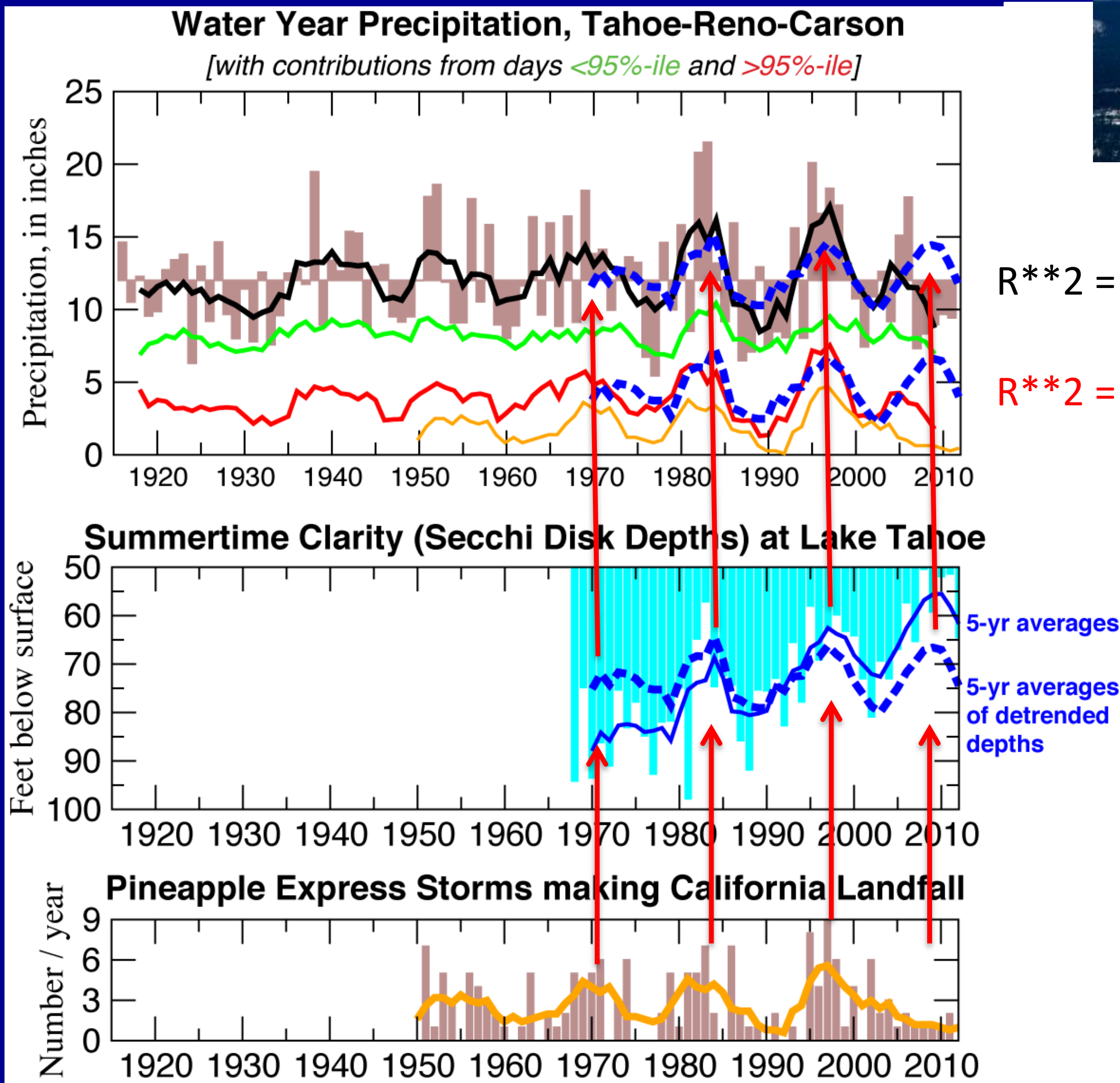
- Total sediment transports by 36 high-load vs other days, and by AR high-load vs other high-load days





Dettinger et al, Tahoe-book chapter, in prep

WINTER ARs & SUMMER TAHOE CLARITY



R**2 = 67%

R**2 = 58%

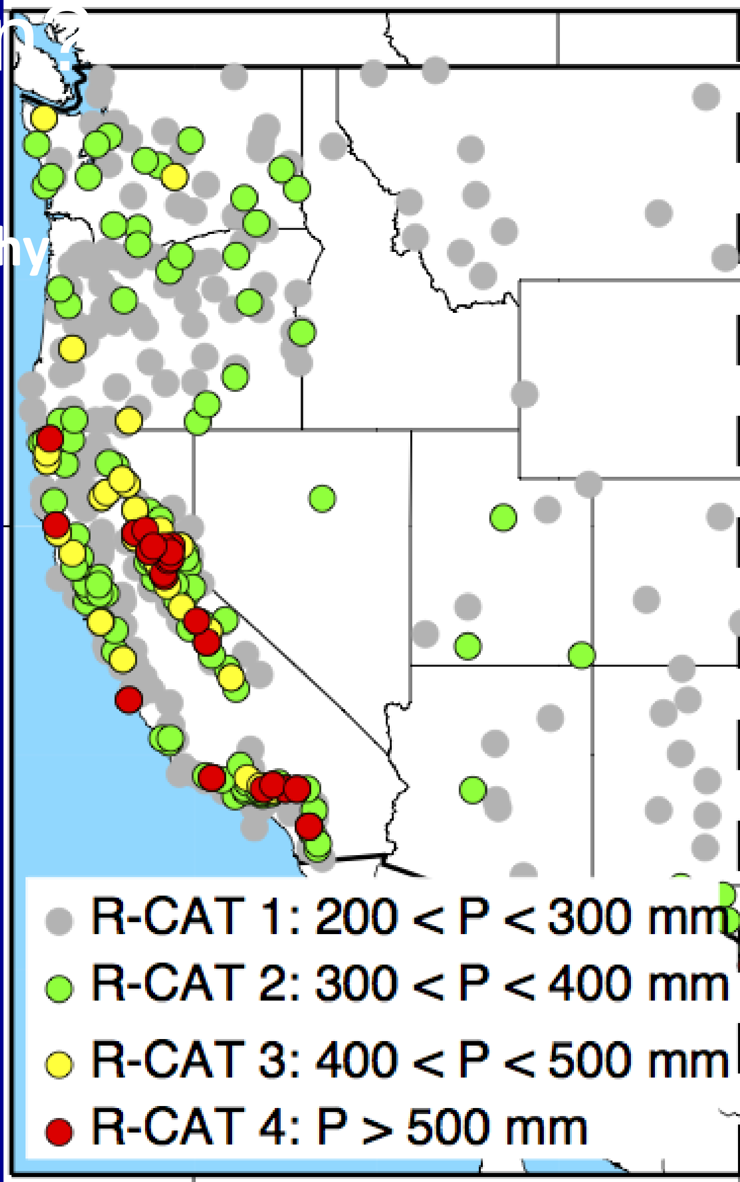
of clarity variance explained

Immediate impact of AR is a clarity increase; at annual level (including following summer), more ARs means less clarity.

Dettinger et al, Tahoe-book chapter, in prep

What determines intensity, storm/seaonal totals, distribution & impacts of AR precipitation?

- **Number of landfalls per year**
- **Vapor transport onshore & cross-topography**
  Wind speed & vapor content in low level jet
- **Dynamic, convective & orographic uplift**
- **Duration of AR passage overhead**
  Mesoscale frontal waves
- **Altitude of AR core**
  Sierra Nevada spillover (Backes et al, JHM, 2015)
- **Temperature of AR**
  Snowline altitude
- **Closeness to saturation**
  How much uplift before precipitation begins
- **Stability of atmosphere**
  How readily is AR lifted by orography
- **Presence/absence of resulting barrier jet**



Land conditions that determine AR impacts

- **Topographic slopes and orientations**
  Neiman example
- **Rain shadowing**
  Anderson example
- **Elevation and temperatures**

Particularly regarding AR storms

- **Antecedent soil moisture or snow cover conditions**
  Ralph example
- **Bedrock and soils**
- **Land uses**
- **Drainage patterns and geometries**
- **Vegetation types and densities**

Not so specific to AR storms

USGS science for a changing world
CNAP California-Nevada Climate Applications Program
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Conclusions

- ARs frequently lead to floods for GOOD and ill.
- Its time for us to start paying more attention to impacts & benefits from ARs besides (in addition) to the damaging impacts of floods.

USGS science for a changing world

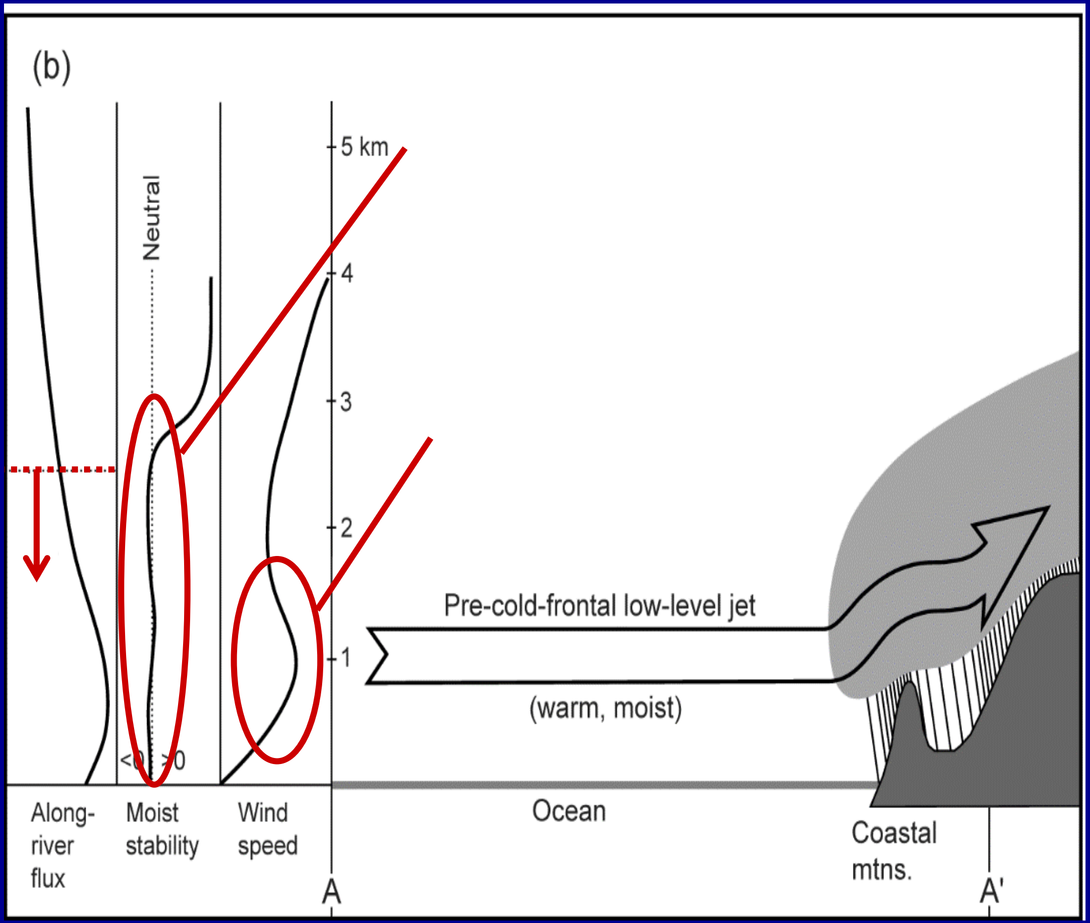
CNAP California-Nevada Climate Applications Program

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

AR impacts

- Floods
- Droughts
- Landslides & debris flows
- Glacial & ice-cap mass balances
- Snow abundance & rain-on-snow
- Avalanches
- Erosion & geomorphic fx
- Groundwater recharge
- Water resources
- Strong winds
- Estuarine variability
- Vegetation variations & wildfire
- Fisheries
- Oceanic fx?

Why do landfalling ARs yield heavy rain?

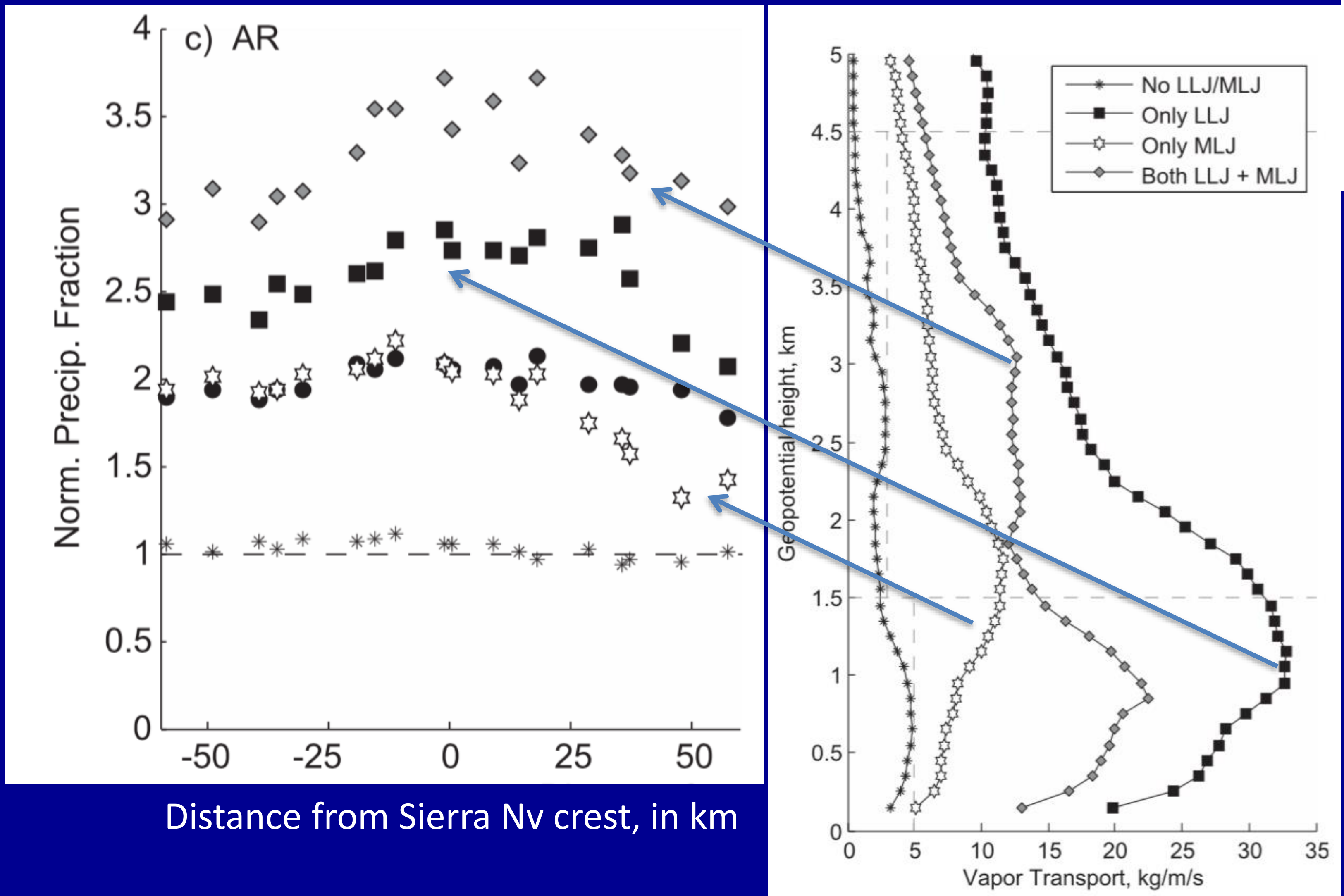


- Composite sounding located 500 km off CA coast in pre-cold-frontal LowLevel Jet (atmospheric river)
- LL Jet directed toward coast and situated at 1-2 km MSL, wind speeds 15 to 20 m/s
- Most (75%) of pre-cold-frontal along-river moisture flux is below 2.5 km MSL
- Vapor transport ~ 10-20 Mississippis
- Moist neutral stratification below 2.8 km MSL, hence no resistance to orographic lifting
- **Overlapping set of conditions very conducive to orographic rain enhancement in coastal mtns & Sierra Nevada**

USGS science for a changing world | CNAP California-Nevada Climate Applications Program | Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at UC San Diego

Ralph et al. (2004, 2005) MWR

ROLE OF ELEVATION OF AR CORE



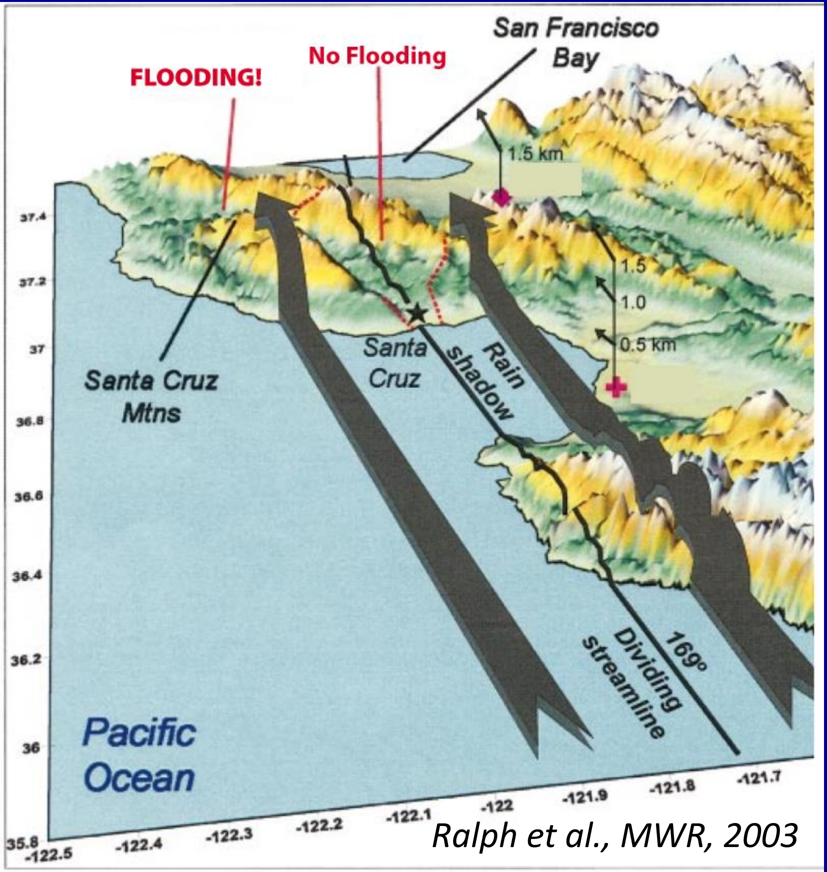
Distance from Sierra Nv crest, in km

USGS science for a changing world | CNAP California-Nevada Climate Applications Program | Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at UC San Diego

Backes et al, JHM, 2015

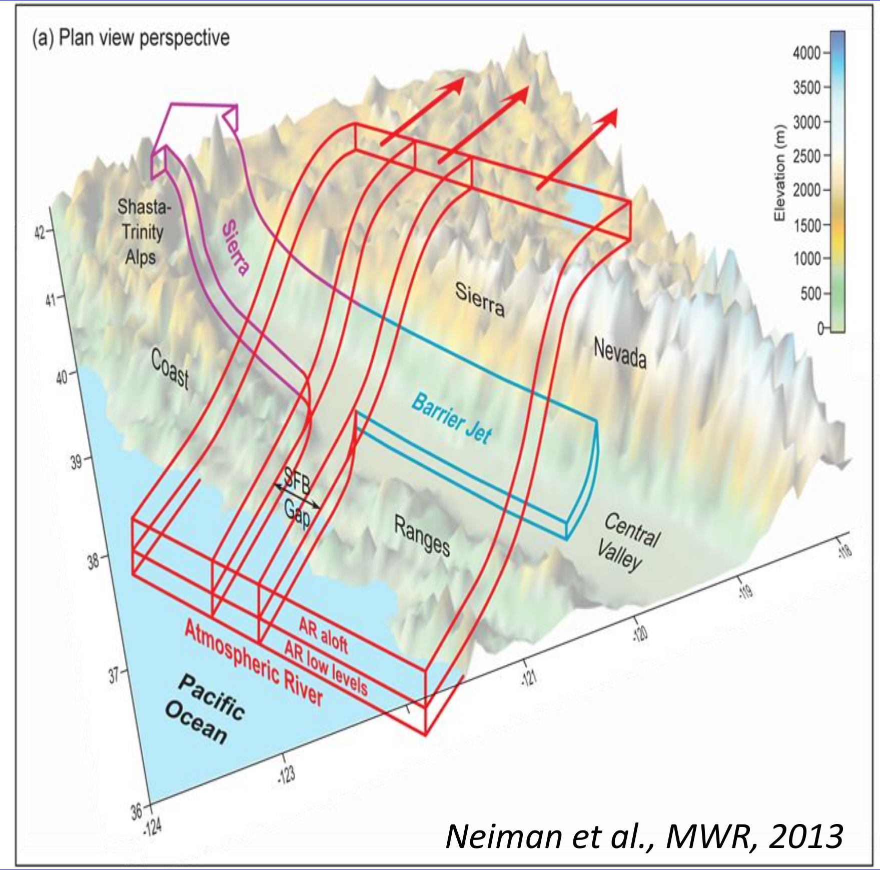
Things get complicated around mountains

High-resolution rain shadowing



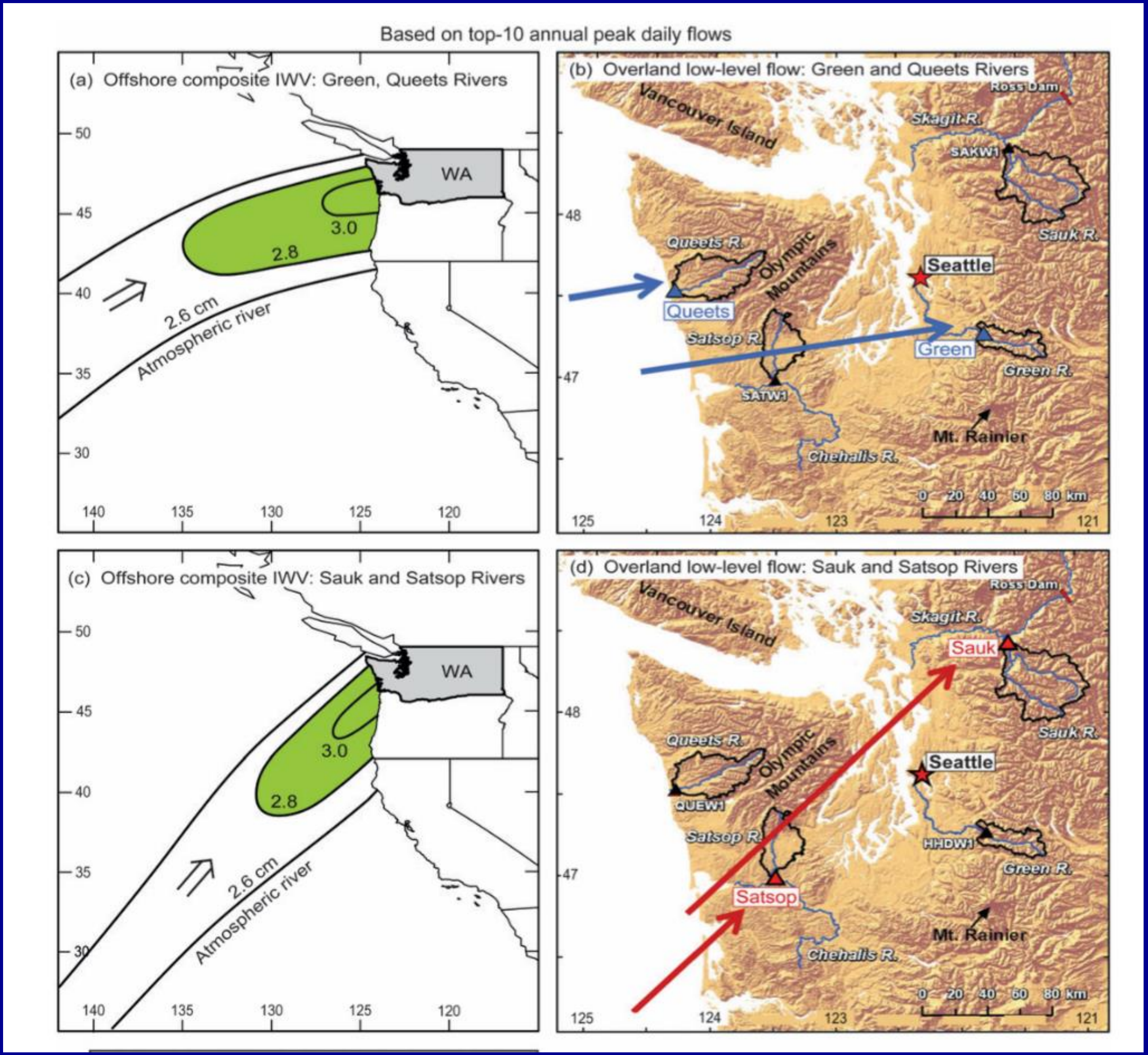
Ralph et al., MWR, 2003

Mountain Barrier Jets



Neiman et al., MWR, 2013

Orientations of Catchments (relative to AR approach) Matters to Precipitation Intensities & Locations



Neiman et al, JHM 2011

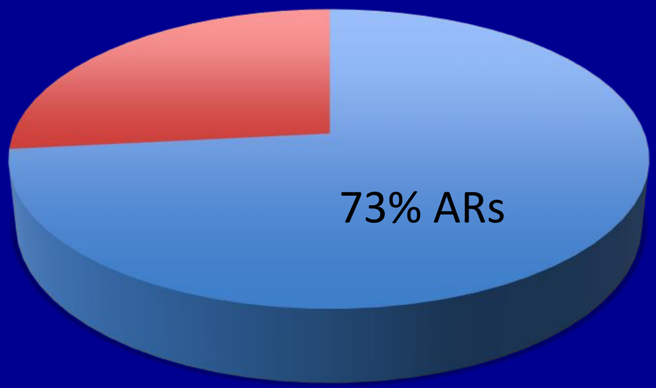
Key AR impacts

- Floods
  Global survey
- Droughts
  California droughts example
- Landslides & debris flows
  Oakley et al will be talking about this
- Glacial & ice-cap mass balances
  Gorodetskaya & Mattingly have spoken about this
- Snow abundance & rain-on-snow
  Guan example
  Huning et al will be talking about this
- Avalanches
  Hatchett et al will be talking about this
- Erosion & geomorphic fx
- Groundwater recharge
  Mojave example
- Significant water resources
  Western US example
- Strong winds
  Small will be talking about this
- Estuarine variability
  X2 example
- Vegetation variations & wildfire
  Albano et al will be talking about this
- Fisheries
  FIRO has been discussed several times
- Oceanic fx?

Sudden changes in Lake Tahoe clarity

Largest Measurement-to-Measurement Changes in Lake Clarity, WY1968-2011 (>10 m!)

Of 15 occasions with largest msmt-msmt **CLARITY INCREASES**, ALL 15 were preceded by stormy conditions, and…



11/15 were preceded by ARs.

Dettinger et al, Tahoe-book chapter, in prep