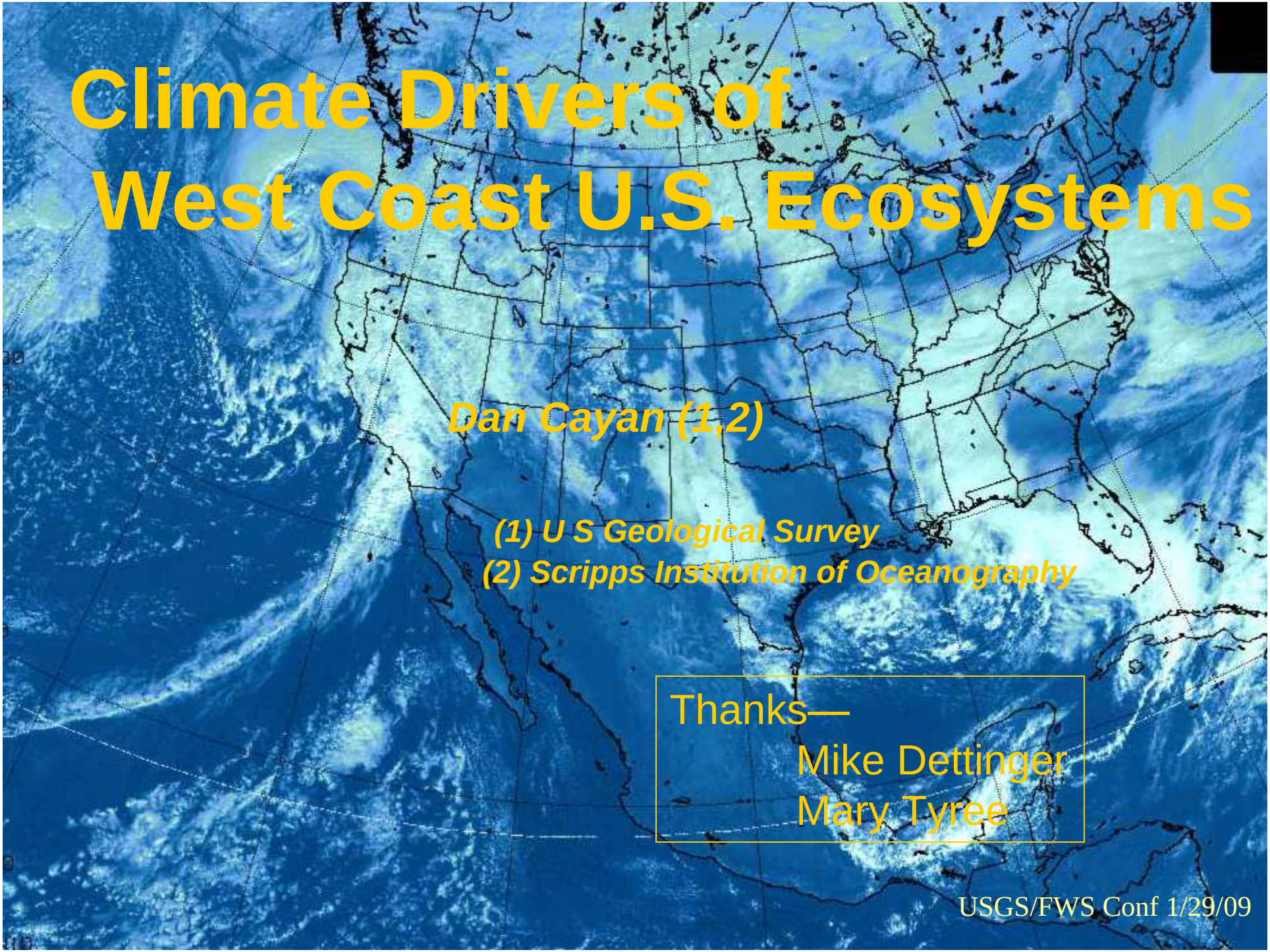


Climate Drivers of West Coast U.S. Ecosystems

Dan Cayan (1,2)

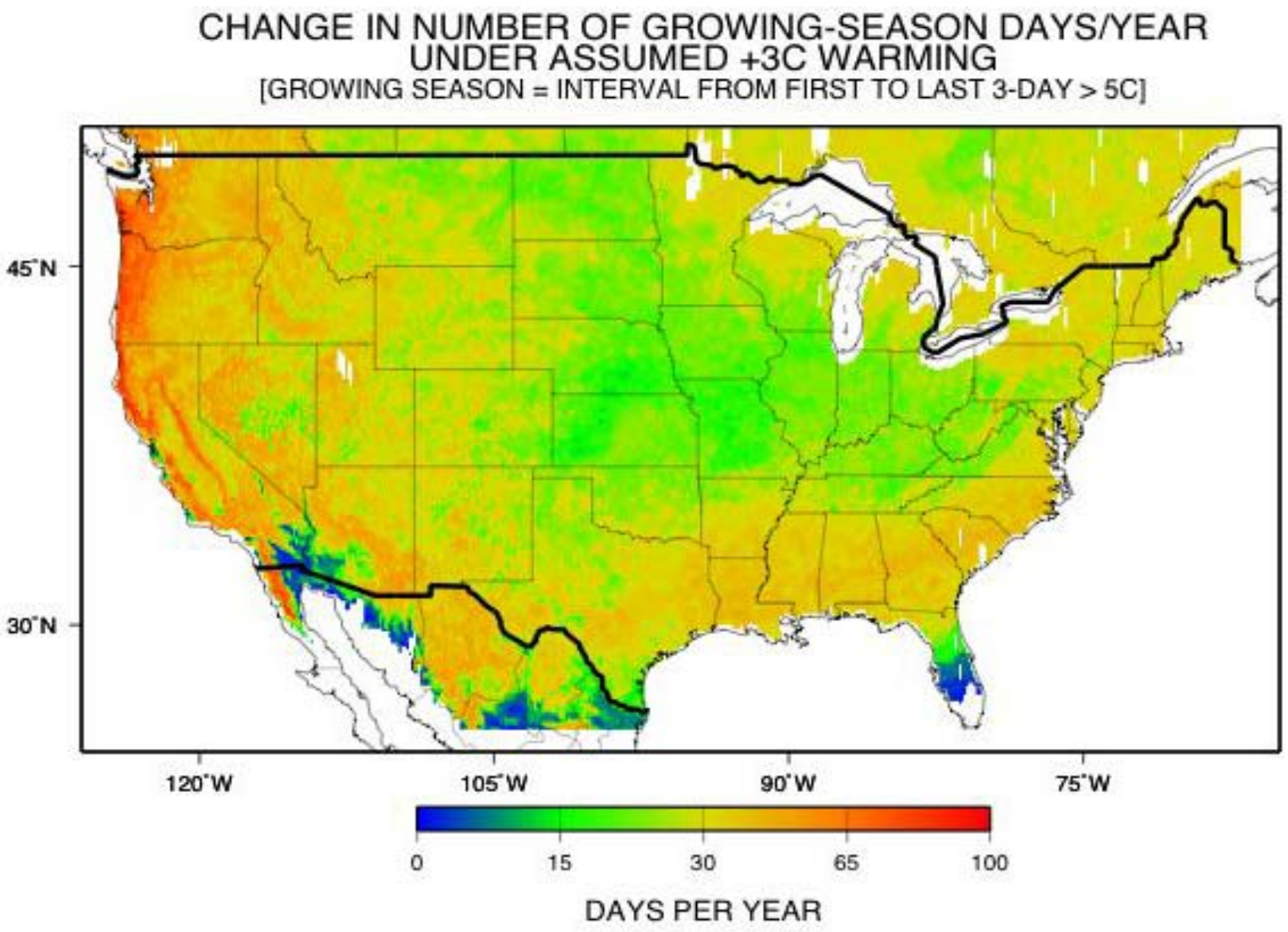
(1) U S Geological Survey
(2) Scripps Institution of Oceanography

Thanks—
Mike Dettinger
Mary Tyree

USGS/FWS Conf 1/29/09

prominent climate drivers, West Coast environment:

- Natural climate “modes"
  - ENSO
  - PDO
  - NPGO
  - Intraseasonal bursts–atmospheric rivers
- Anthropogenic changes from greenhouse gases


CHANGE IN NUMBER OF GROWING-SEASON DAYS/YEAR
UNDER ASSUMED +3C WARMING
[GROWING SEASON = INTERVAL FROM FIRST TO LAST 3-DAY > 5C]
45°N
30°N
120°W
105°W
90°W
75°W
0
15
30
65
100
DAYS PER YEAR

Warm and cool phase ENSO

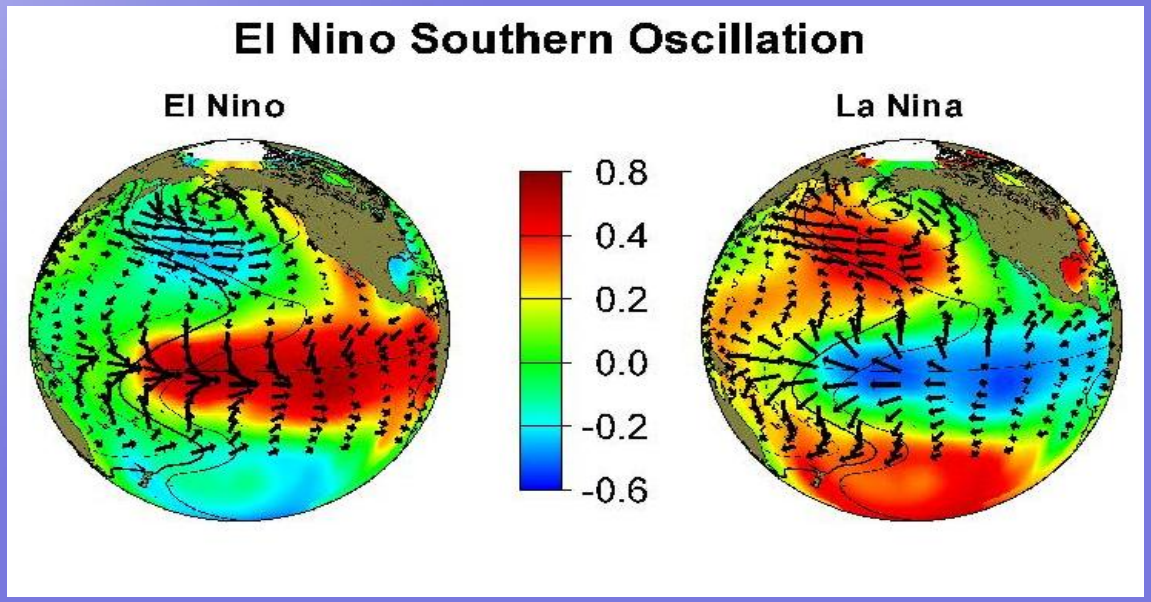
SST, SLP, and sfc wind stress anomalies

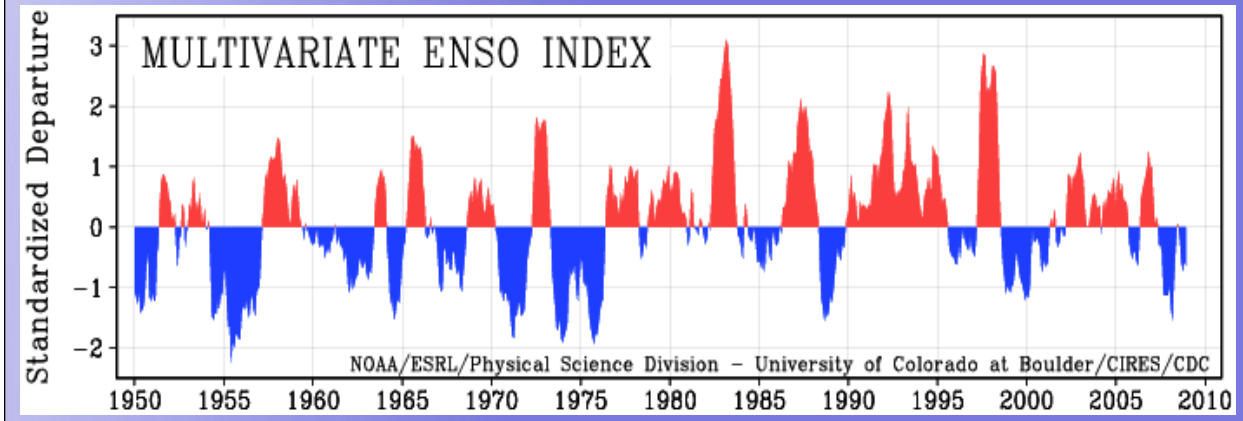
predominant interannual coupled sea-air mode

extra-tropics involved

time scale: 2-7 years

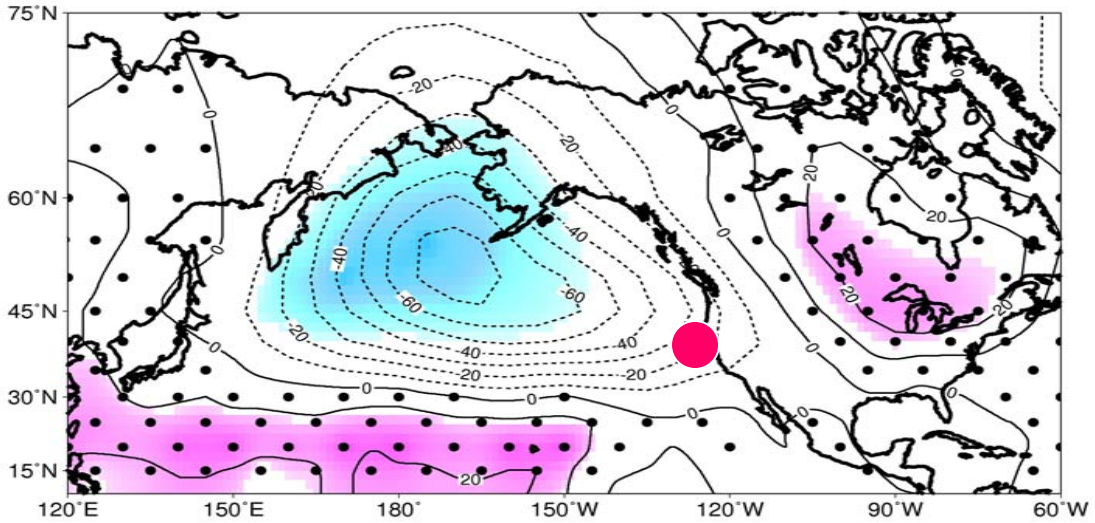
Characteristics vary considerably within different events



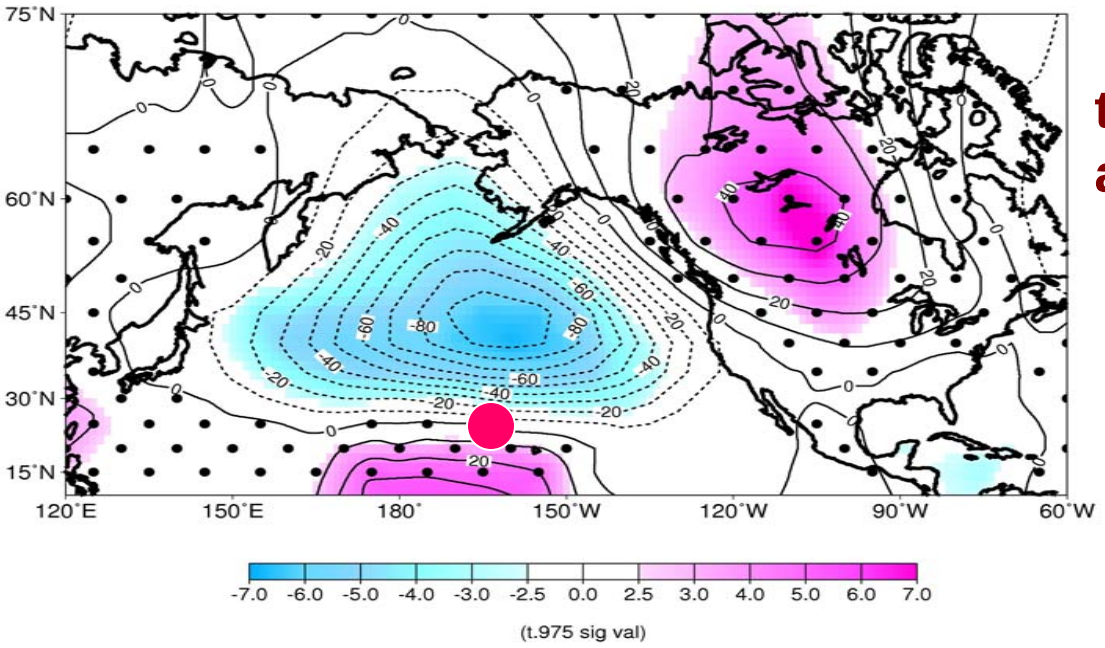


Multivariate ENSO Index
Klaus Wolter, NOAA

Composite NDJFM 700 Ht. Anoms (m)
No. California Large Low Freq Wave Energy

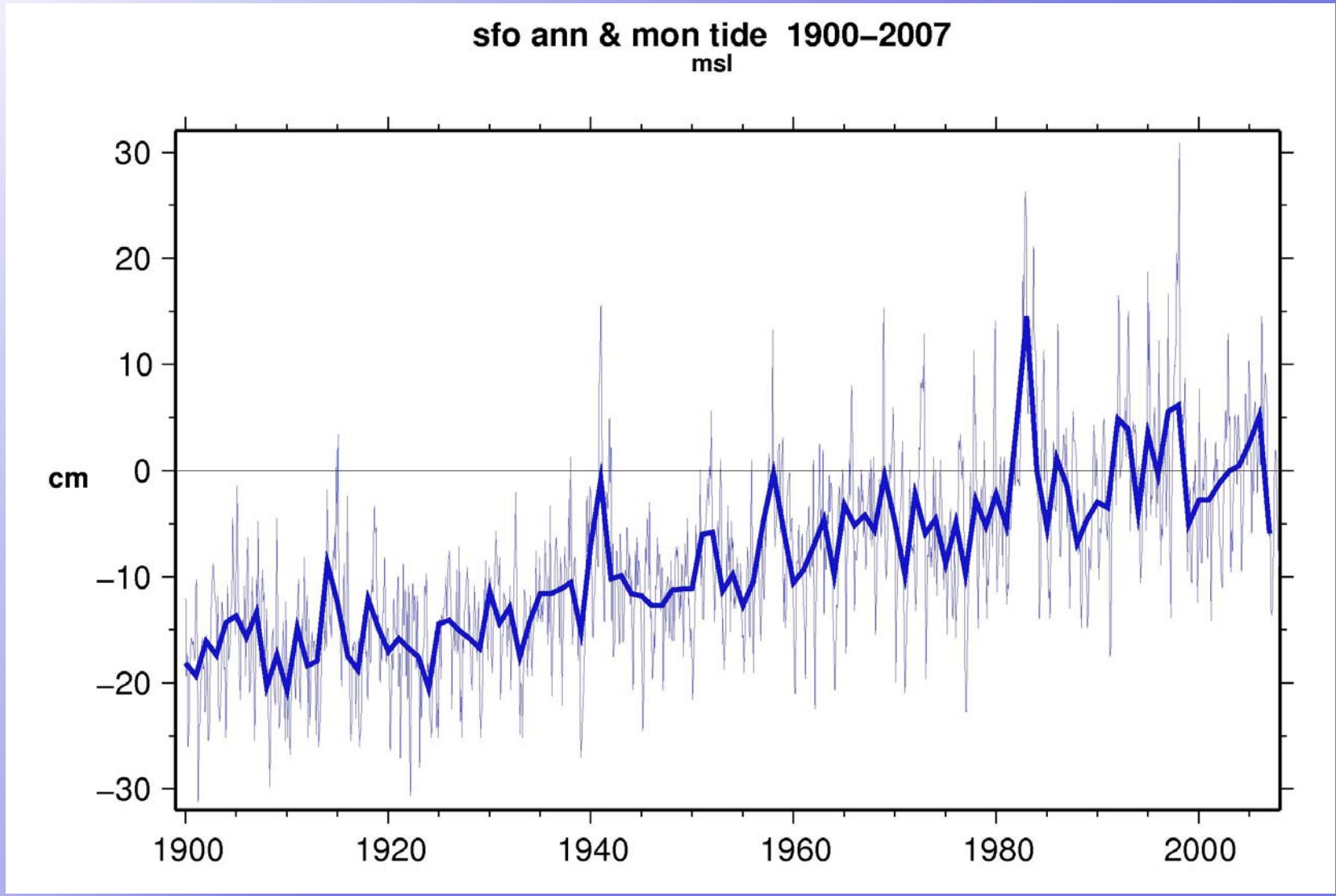


Composite NDJFM 700 Ht. Anoms (m)
Hawaii Large Low Freq Wave Energy



Atmospheric Circulation during large low frequency wave episodes is similar for No Calif and Hawaii

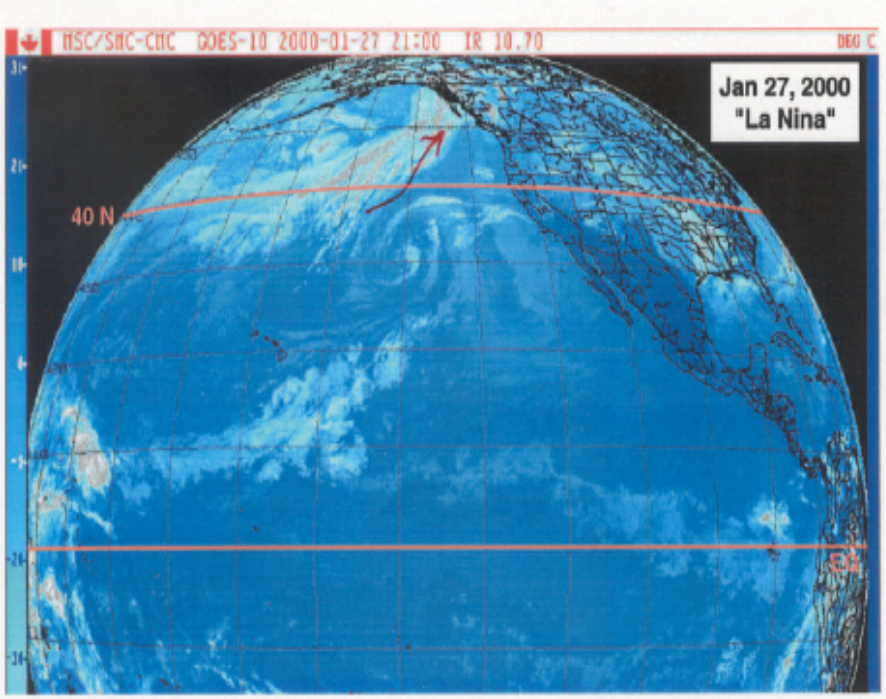
This pattern must produce long fetch, high westerlies many of the same cases that affect Hawaii also affect No Calif



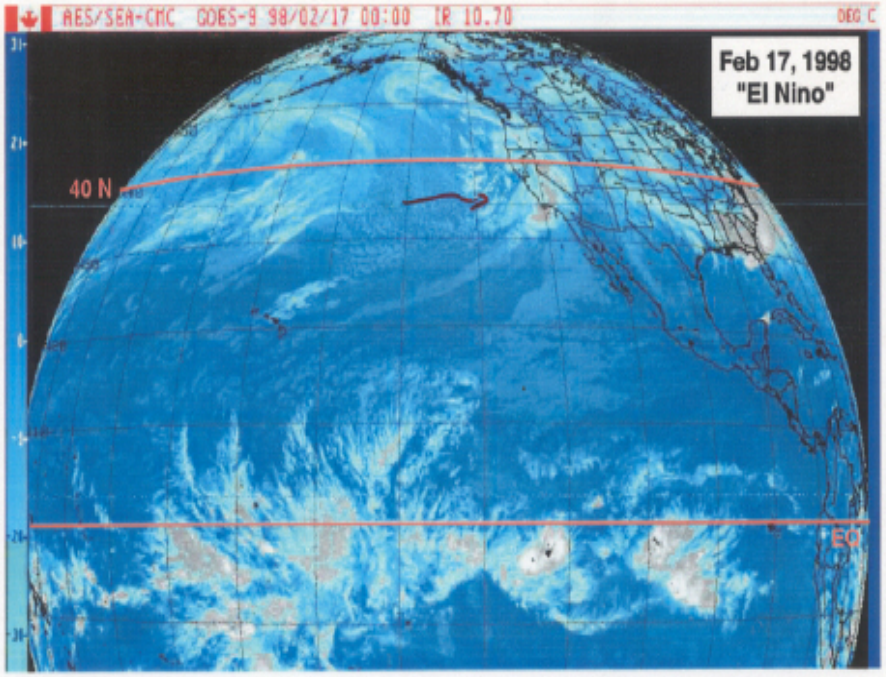
West Coast sea level has a strong El Nino signal

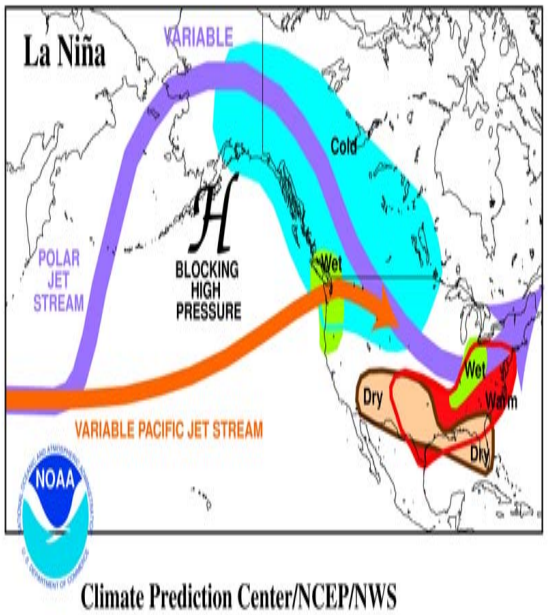
interannual peaks at San Francisco are nearly all large El Nino years

Enormous Changes In tropical Convection

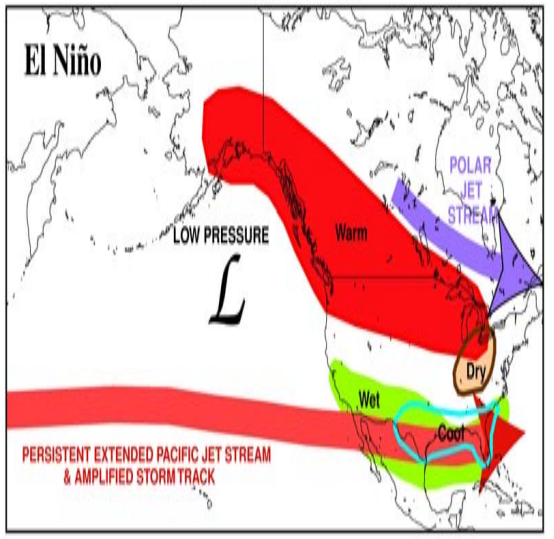


Winter N Pacific Storms are affected





TYPICAL JANUARY-MARCH WEATHER ANOMALIES AND ATMOSPHERIC CIRCULATION DURING MODERATE TO STRONG EL NIÑO & LA NIÑA



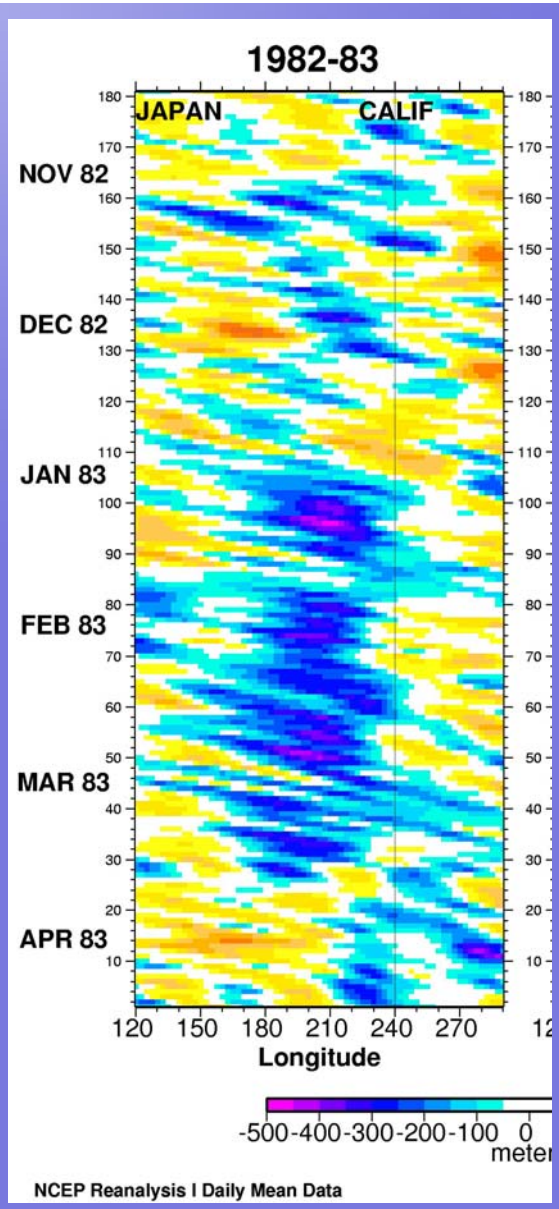
Upper level atmospheric high/low pressure features

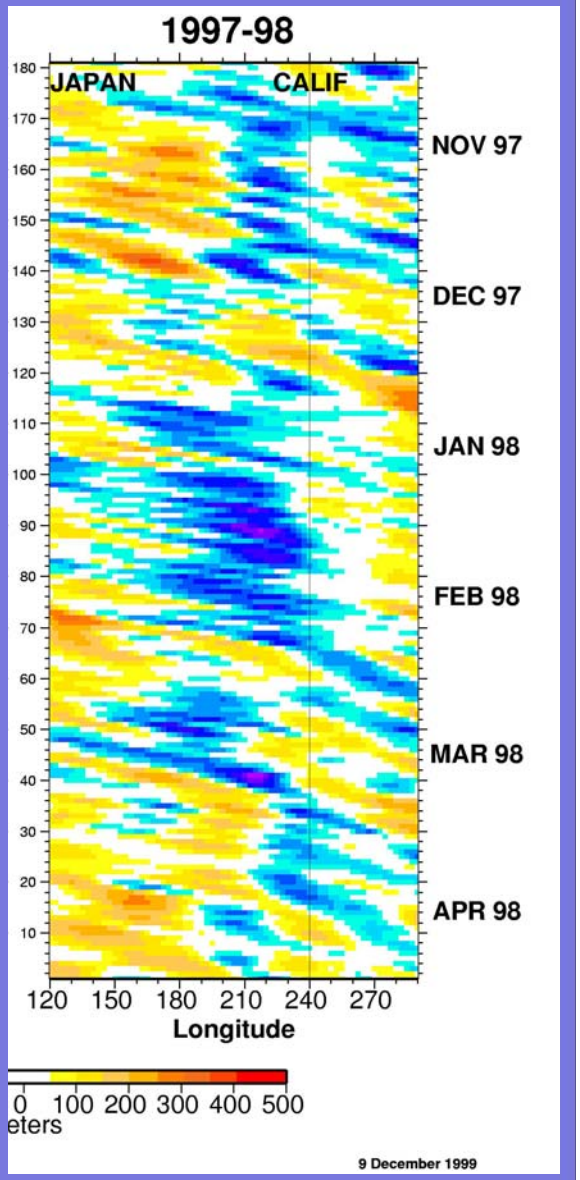
Two great El Nino's North Pacific Basin fills with winter cyclones.

Both El Nino years had persistent storminess and a long, extended storm season.

Cyclones tracked from Asia to West Coast in 5-6days; storm track was zonal and extended far south.

500mb Height Anomalies 40N

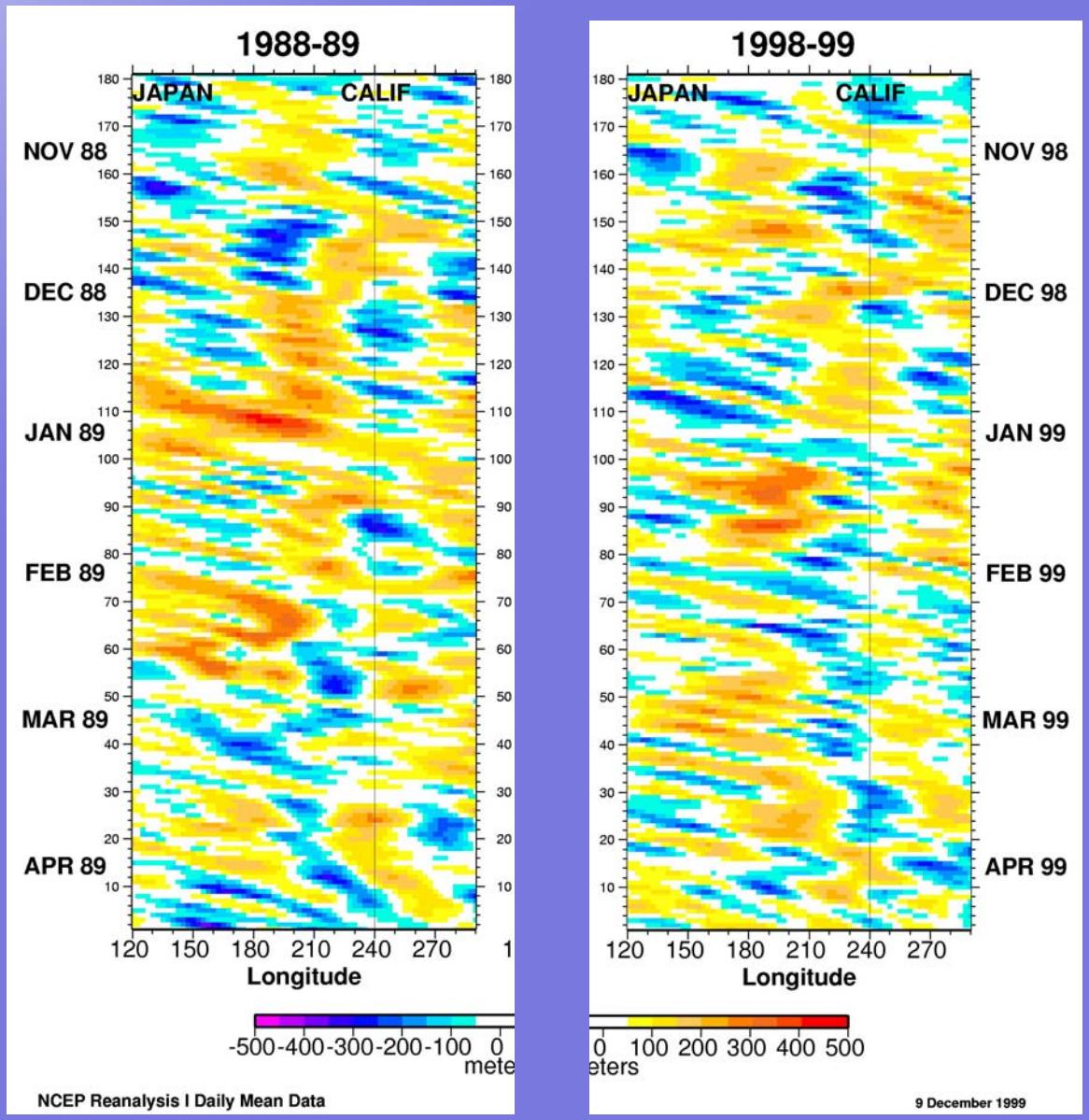




Upper level atmospheric high/low pressure features

Two La Nina years

In contrast to the El Ninos, the North Pacific Basin was much less active. Propagation speed of cyclones and anticyclones is still approx 5-6 days to traverse the basin at 40N

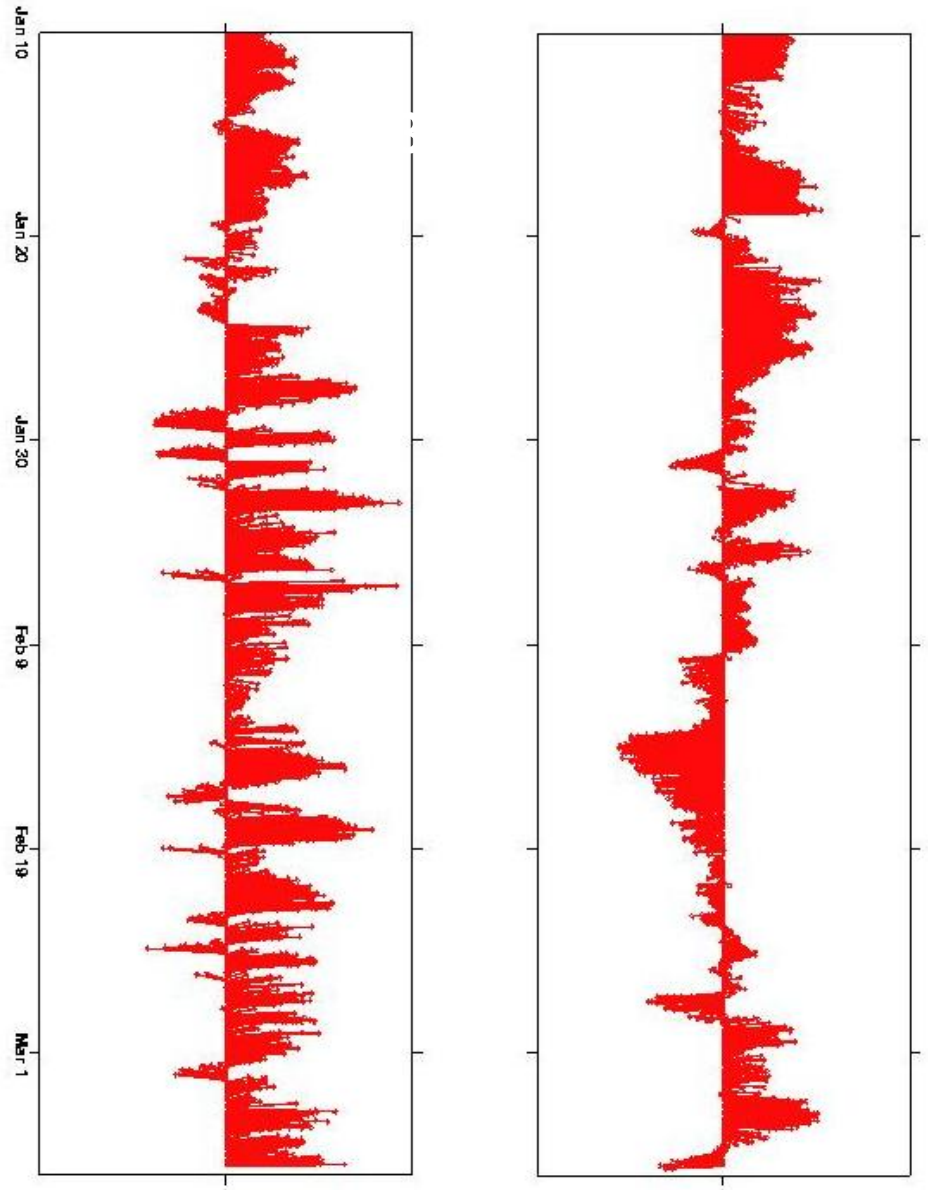


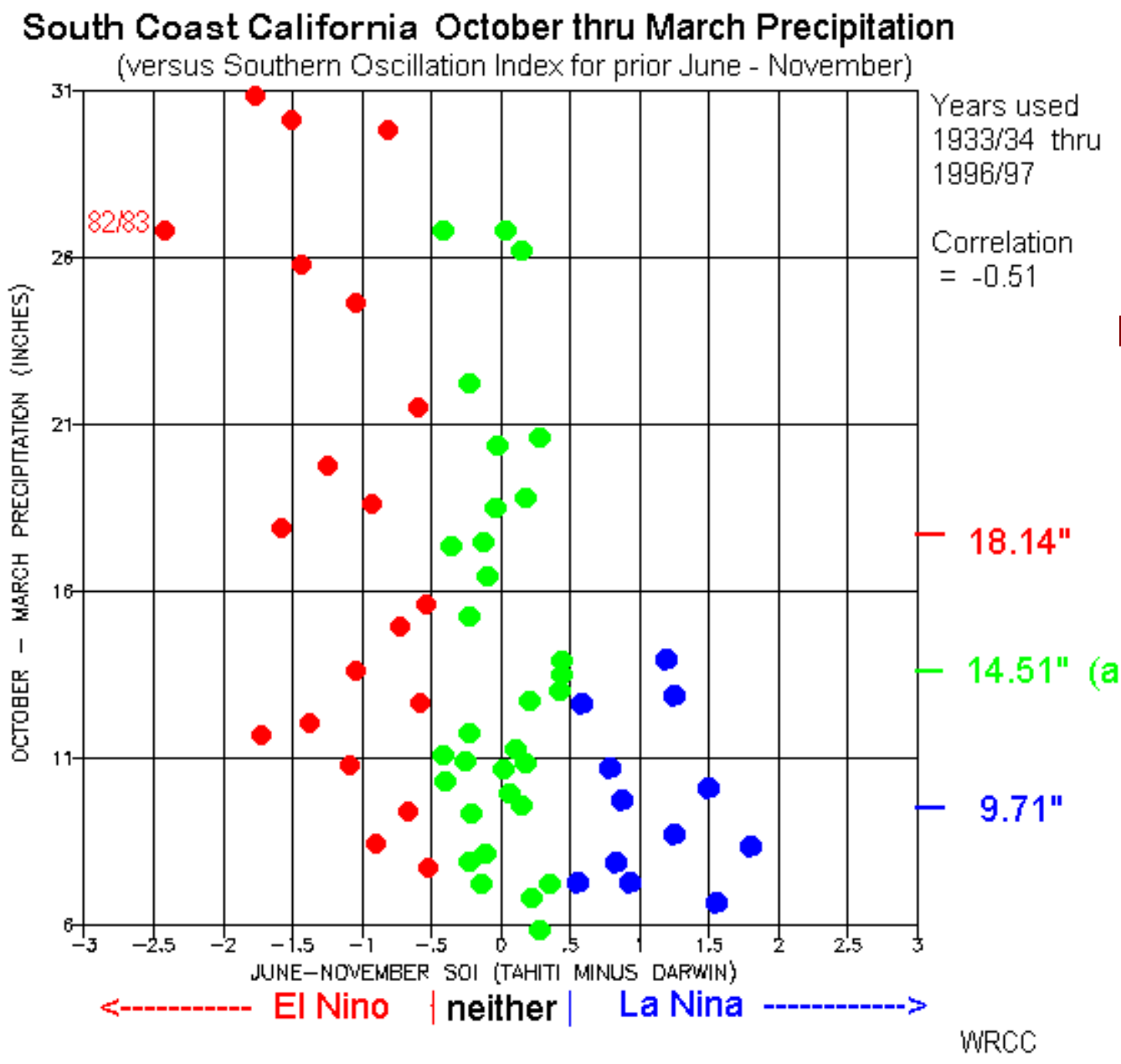
Hourly winds NOAA Buoy 46006 *41N 138W*

Jan

Offshore of The California Coast, westerly Winds were much Stronger during The 1983 El Nino Than the 1989 La Nina, which had Interludes of easterly Winds, even at Longitude 138W.

Ma



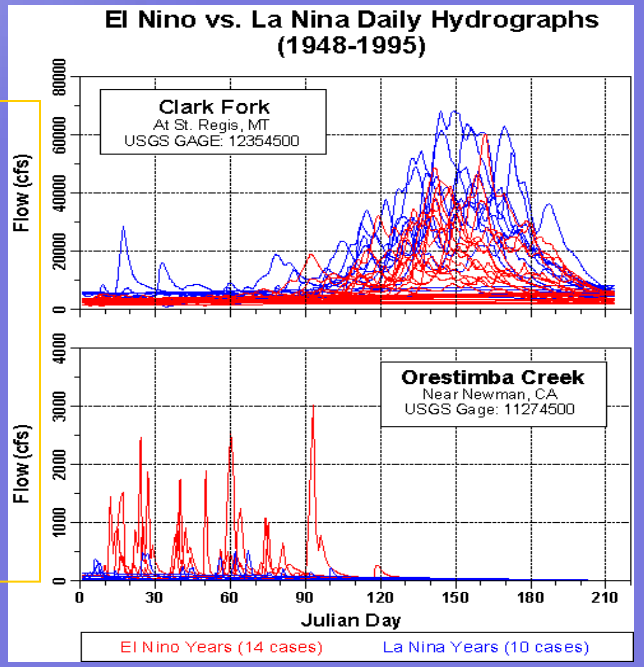


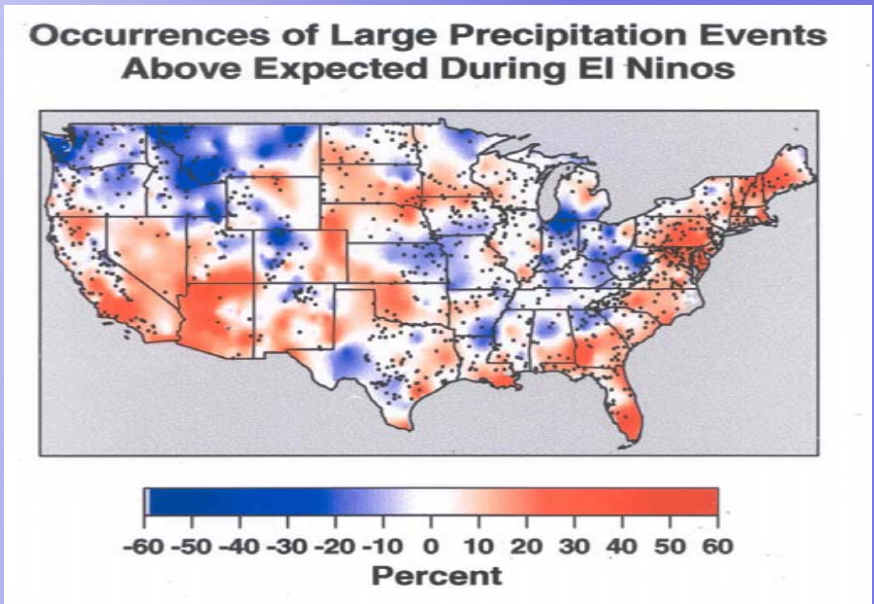
Each El Nino Is different.

Not all El Ninos produce great storm activity along the California Coast

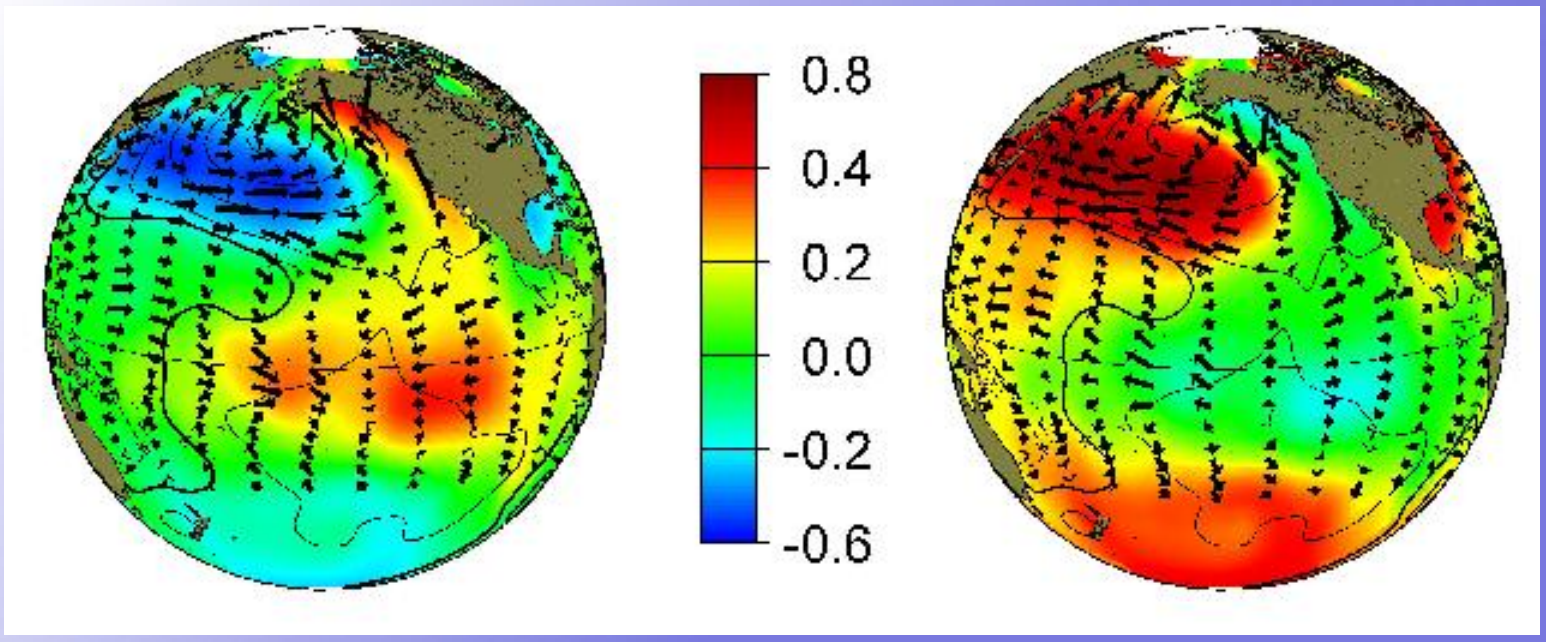
El Nino favors high streamflow in the Southwest

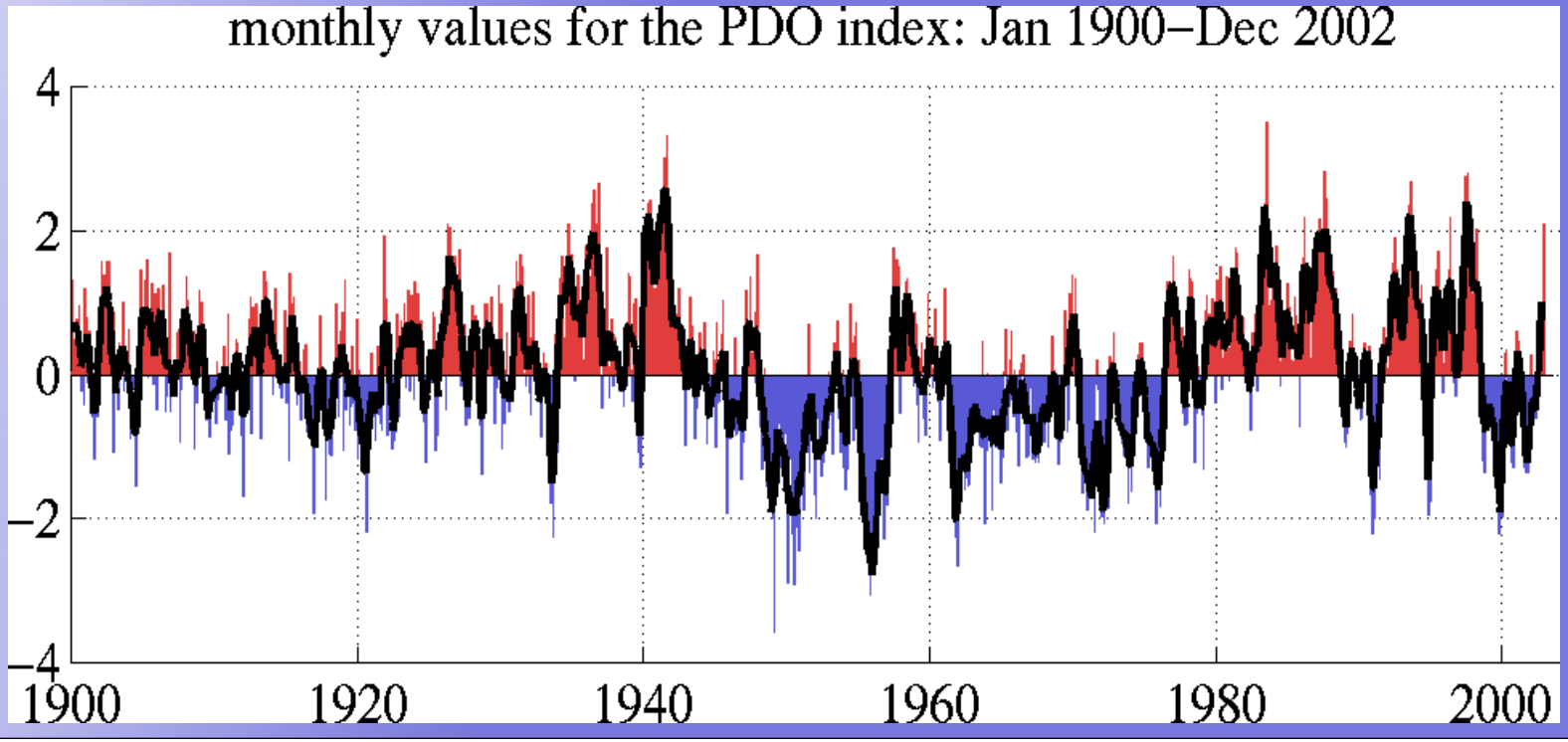
An ensemble of daily streamflow hydrographs during several El Nino(red) And La Nina (blue) years illustrates how ENSO changes the odds of flood/drought in San Diego County streams. La Nina's have rarely produced high flows, but El Ninos often do.





The change in flood Frequency is driven by a change in U.S. winter precipitation patterns during EL Nino vs. La Nina



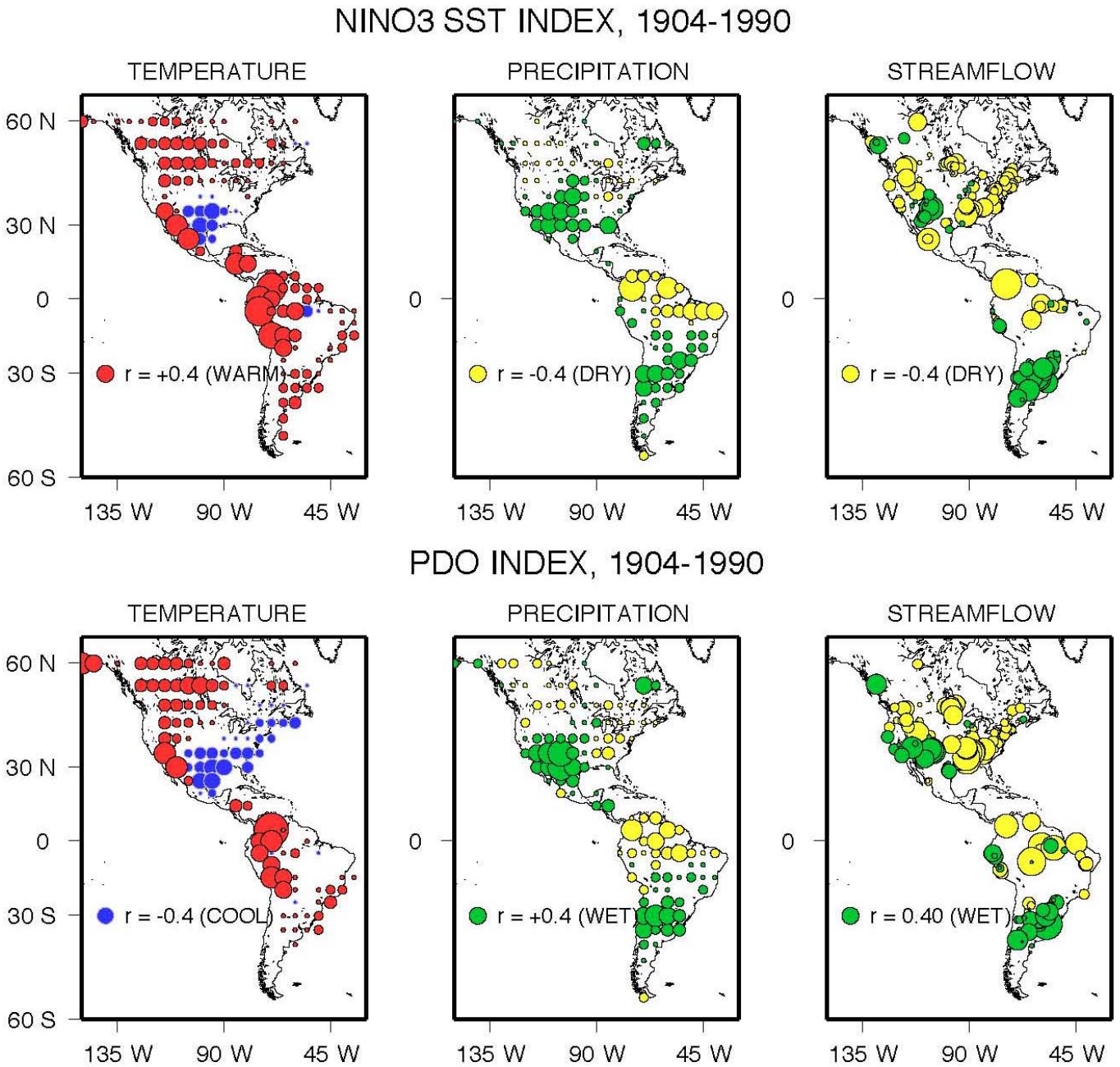


Pacific Decadal Oscillation

But Sierra Flows are Not reliably Linked to PDO or ENSO

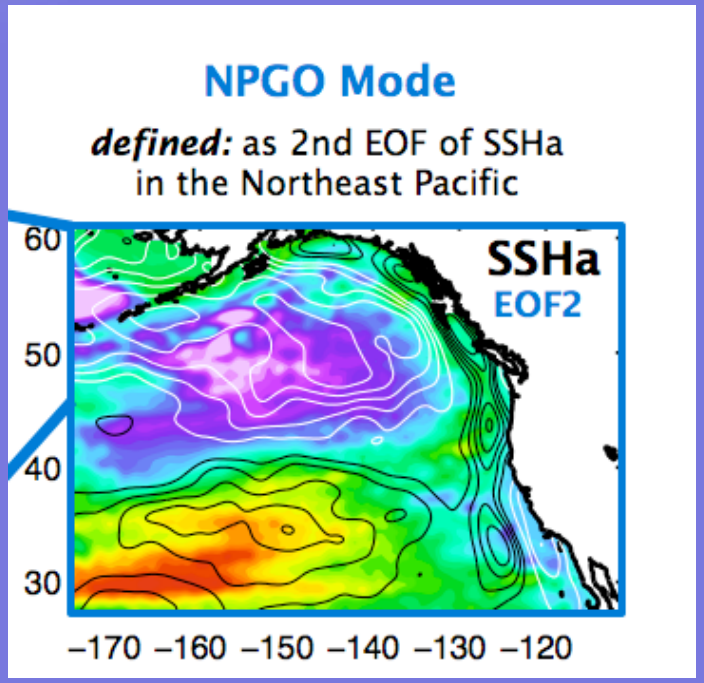
Columbia is though

Nate Mantua
Univ Wash



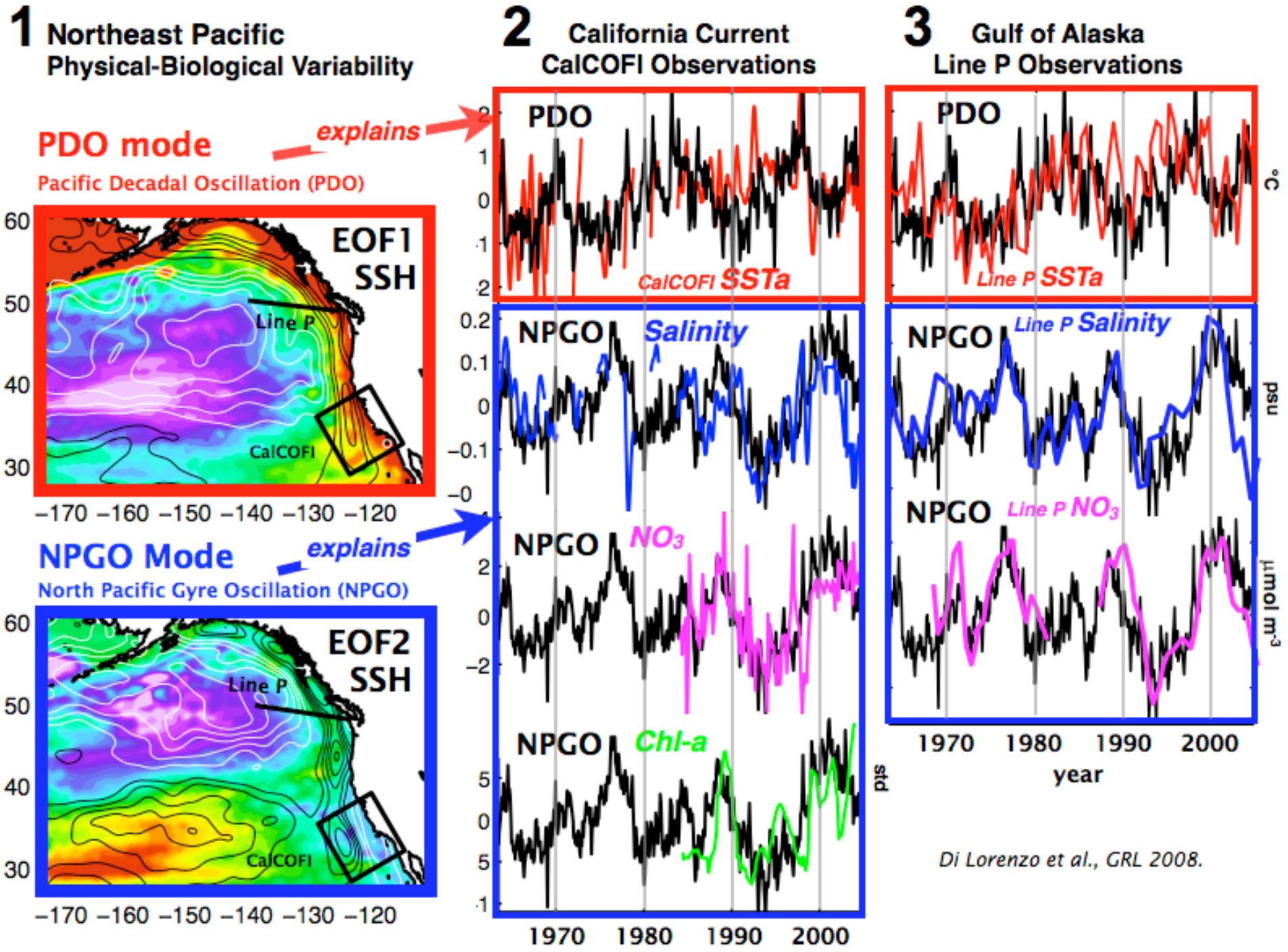
PDO, like ENSO
results in cross-
hemispheric
organization of
anomalous
temperature and
moisture

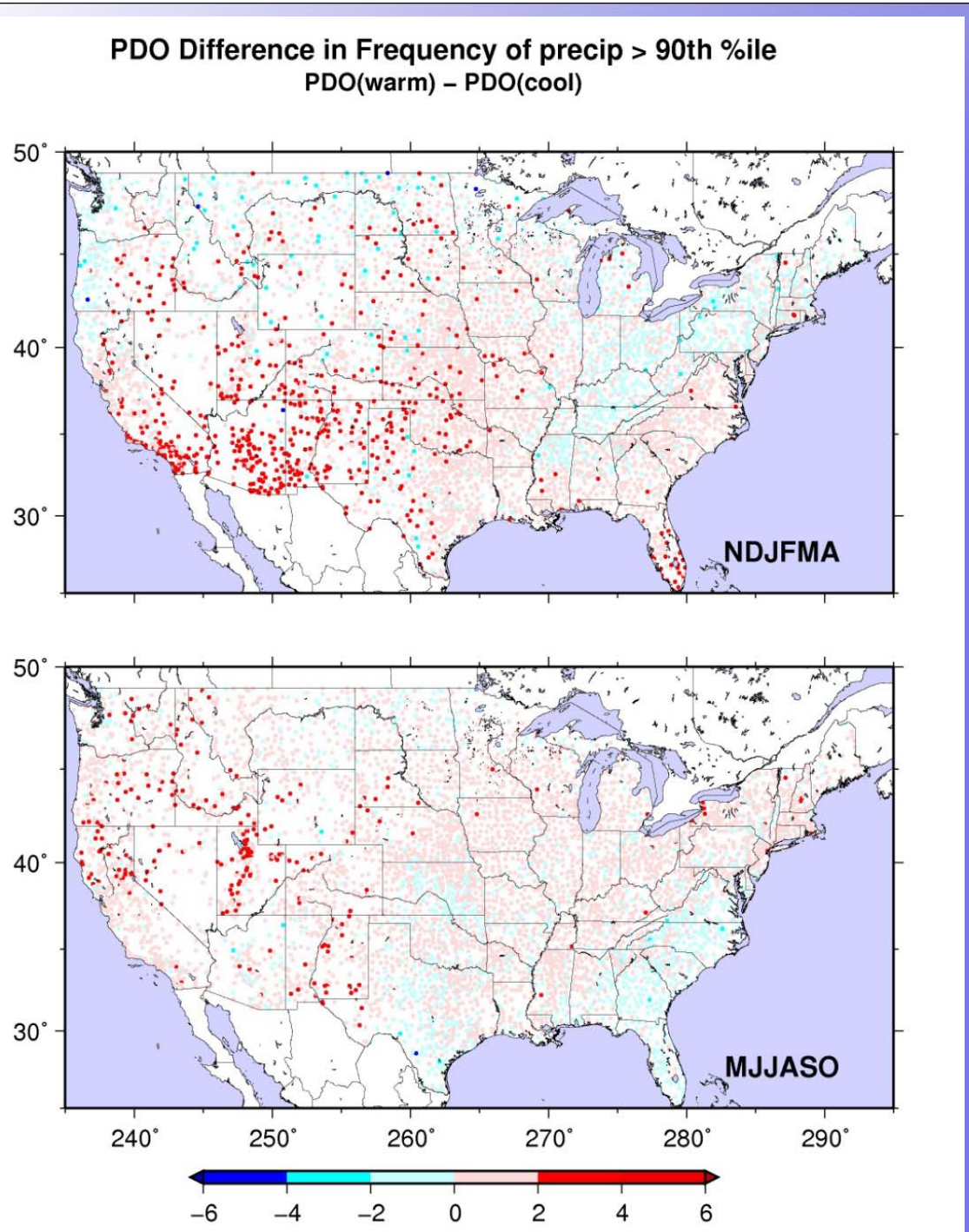
North Pacific Gyre Oscillation



Di Lorenzo E., Schneider N., Cobb K. M., Chhak, K, Franks P. J. S., Miller A. J., McWilliams J. C., Bograd S. J., Arango H., Curchister E., Powell T. M. and P. Rivere, 2008: North Pacific Gyre Oscillation links ocean climate and ecosystem change. *Geophys. Res. Lett., 35, L08607, doi:10.1029/2007GL032838.*

The North Pacific Gyre Oscillation (**NPGO) is a climate pattern that emerges as the 2nd dominant mode of sea surface height variability (2nd EOF SSH) in the Northeast Pacific. The NPGO is significantly correlated with previously unexplained fluctuations of *salinity, nutrients and chlorophyll-a measured in long-term observations in the California Current (CalCOFI) and Gulf of Alaska.***

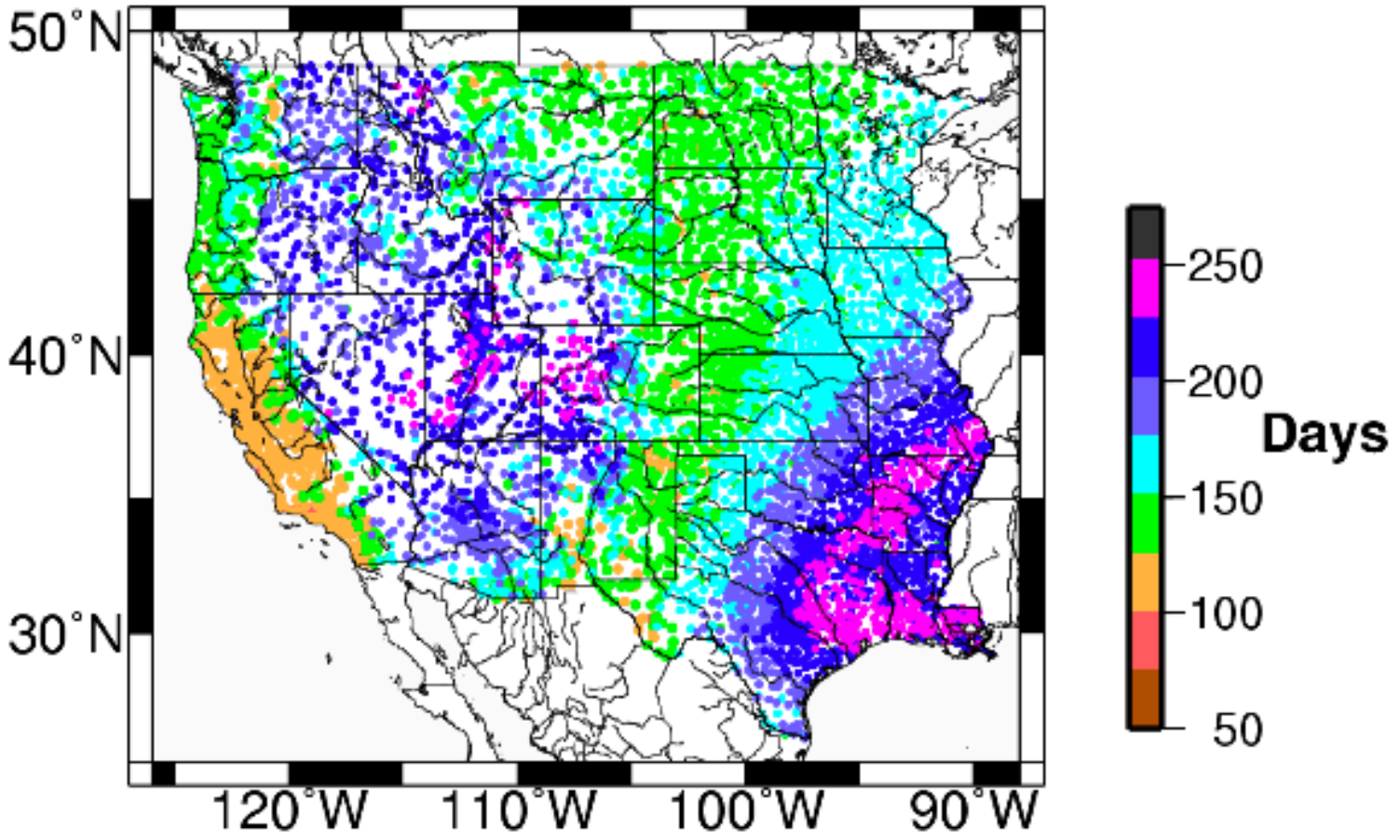

1 Northeast Pacific
Physical-Biological Variability
PDO mode
explains
Pacific Decadal Oscillation (PDO)
EOF1
SSH
Line P
CalCOFI
60
50
40
30
−170 −160 −150 −140 −130 −120
NPGO Mode
explains
North Pacific Gyre Oscillation (NPGO)
EOF2
SSH
Line P
CalCOFI
60
50
40
30
−170 −160 −150 −140 −130 −120
2 California Current
CalCOFI Observations
PDO
CalCOFI SSTa
NPGO
Salinity
NPGO
NO3
NPGO
Chl-a
std
1970 1980 1990 2000
3 Gulf of Alaska
Line P Observations
PDO
Line P SSTa
°C
NPGO
Line P Salinity
psu
NPGO
Line P NO3
µmol m-3
1970 1980 1990 2000
year
Di Lorenzo et al., GRL 2008.



heaviest precipitation has occurred more/less frequently during warm PDO phase

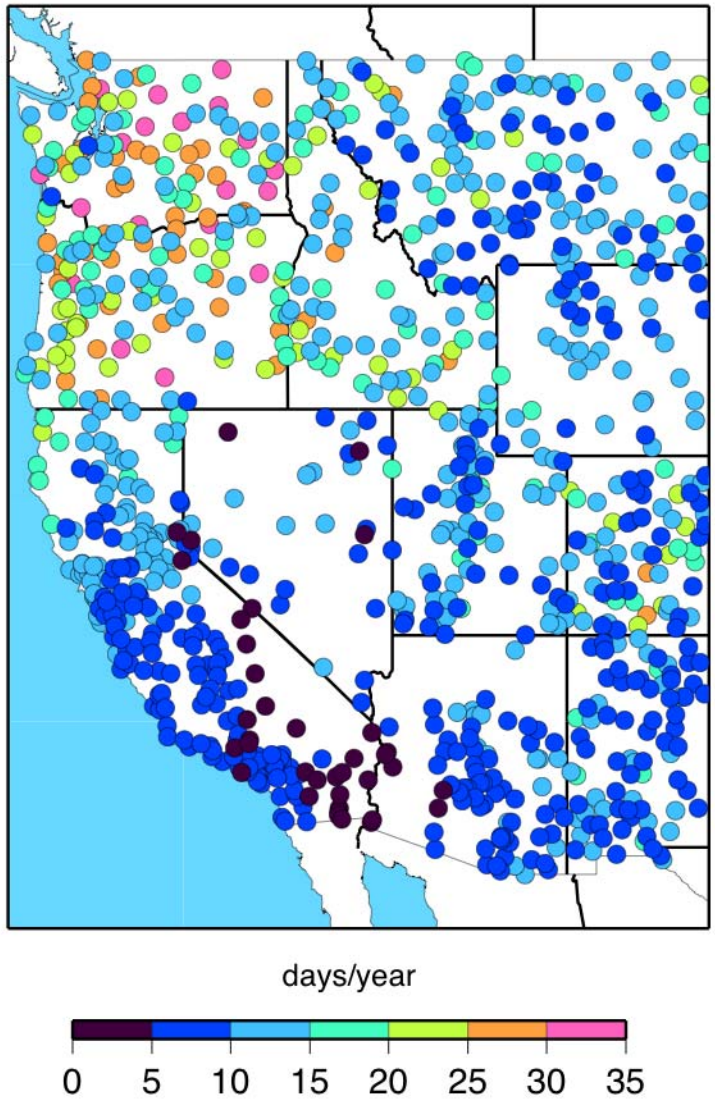
a. L67: Time (days) to accumulate 67% of annual total precip

Mean of length of record, daily CO-OP and 1st order stations



Along West Coast, particularly California, there is a short seasonal window during which the year's water supply is delivered

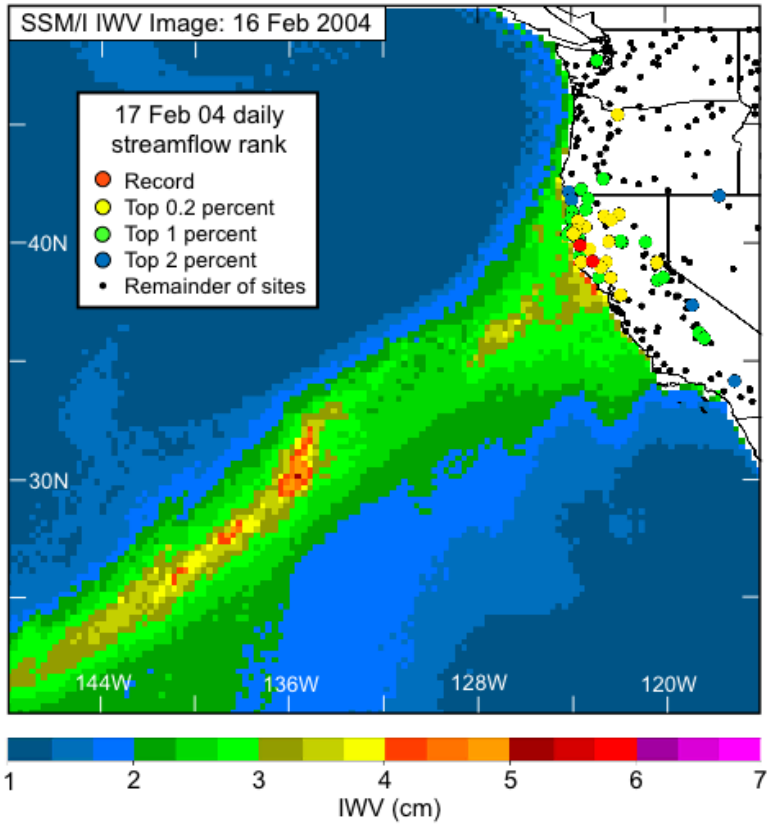
AVERAGE NUMBER OF DAYS/YR TO OBTAIN HALF OF TOTAL PRECIPITATION, WY 1951-2006



And, the number of days during which most of the year's precipitation occurs is relatively few

THE big storms in California's arsenal…

Atmospheric Rivers!

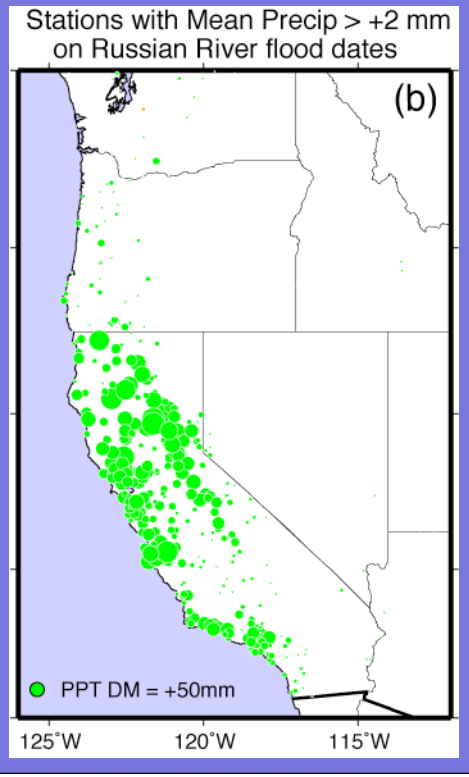


Ralph et al, GRL, 2006; Neiman et al, in press; Dettinger 2004

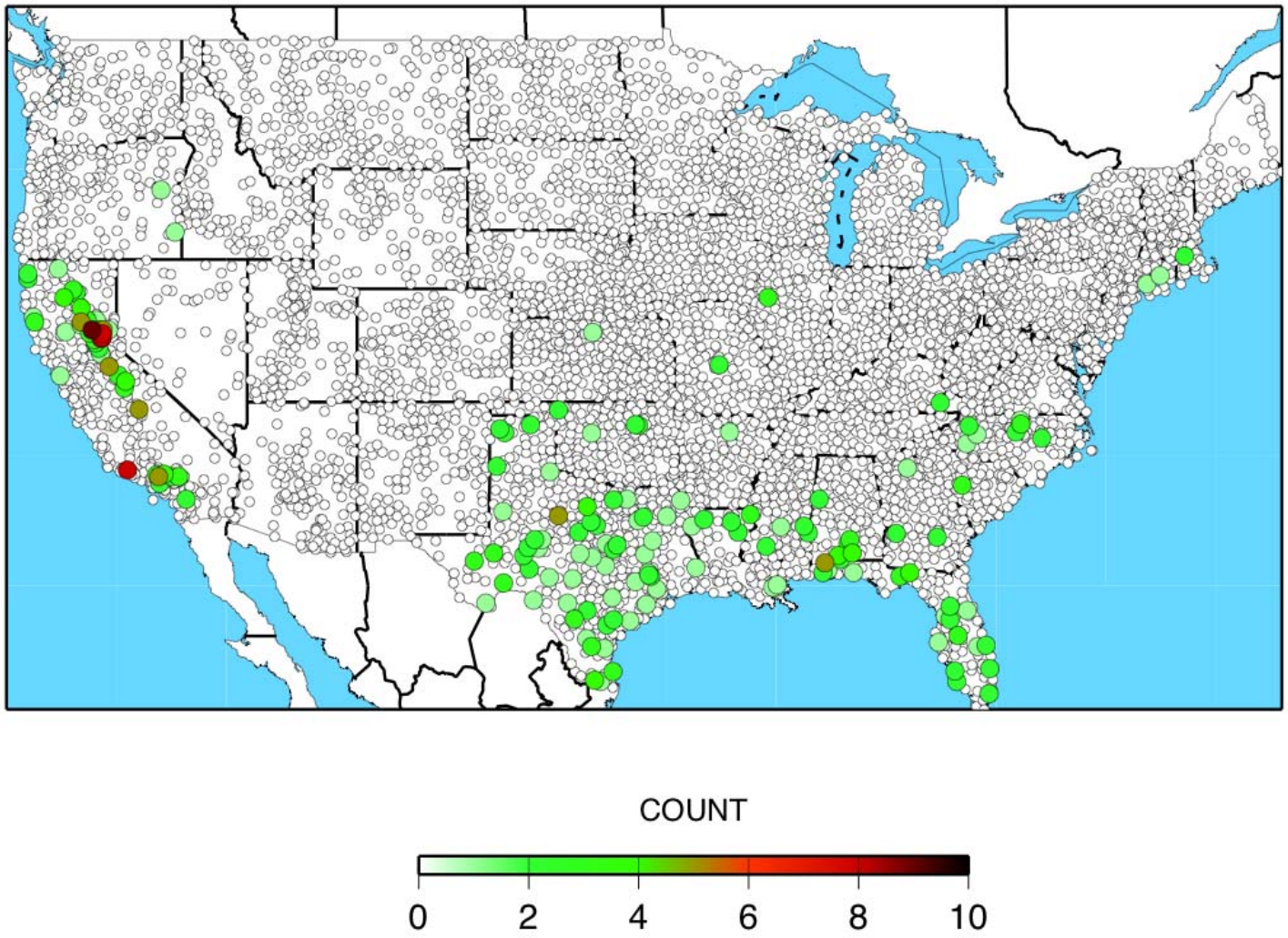
- All 7 major floods of Russian River since 1997 have been caused by atmospheric rivers

- The 9 largest winter floods of Carson River since 1950 have been atmospheric rivers (I.e., pineapple expresses)

Corresponding precip patterns tend to be restricted mostly to Pacific coast states



Number of times historically when more than 40 cm (16 inches) of precipitation have fallen in a 3-day period

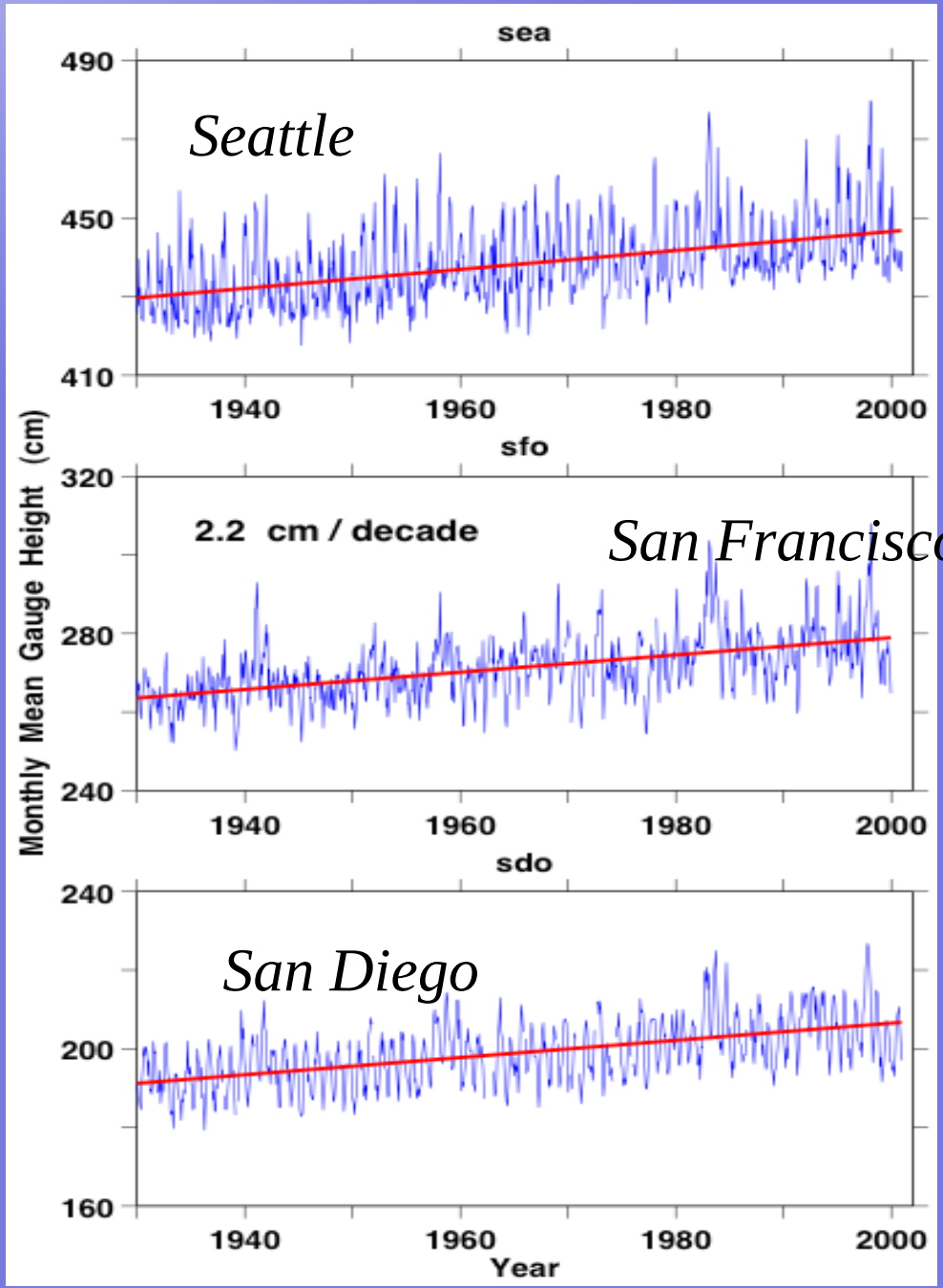


Mike Dettinger

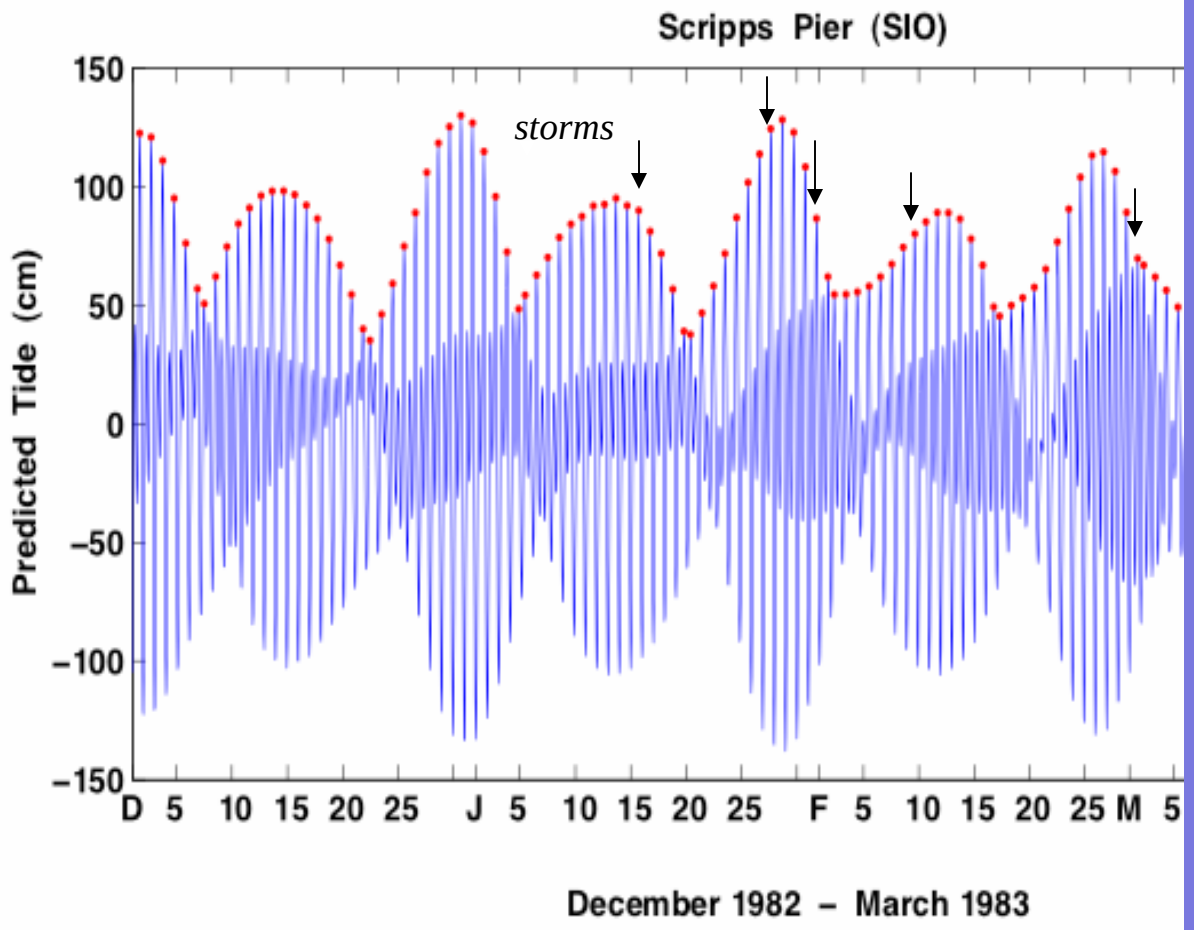
West Coast sea level consistent upward trends from Seattle to San Diego

Historical tide gage observations of mean sea level at San Francisco
Seattle and San Diego exhibit secular increase of ~2cm/decade

This is consistent with estimates of global sea level rise



Coincidence of storms and high tides in Winter 1983 -- heavy coastal damage



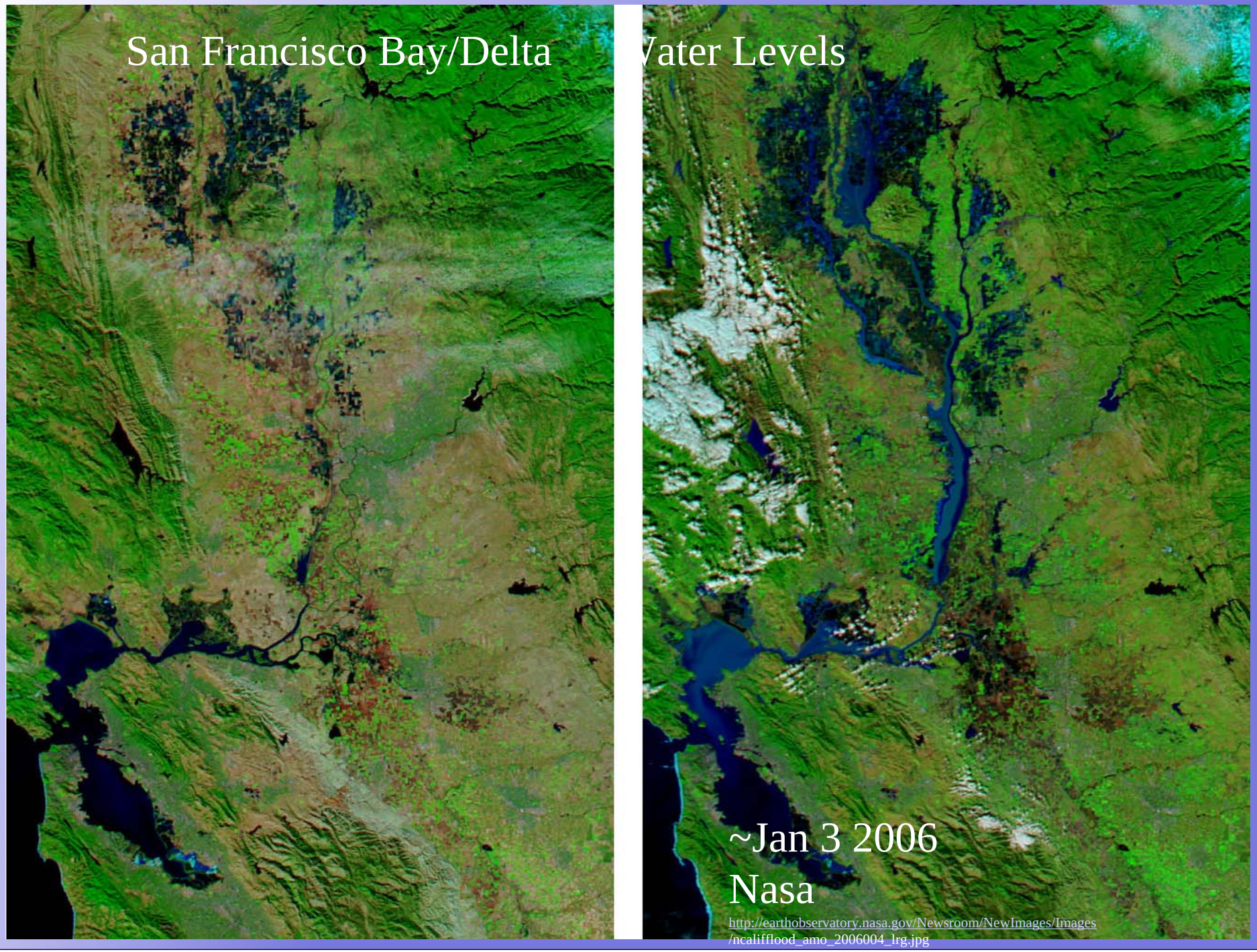
High tide levels vary by about 1 m

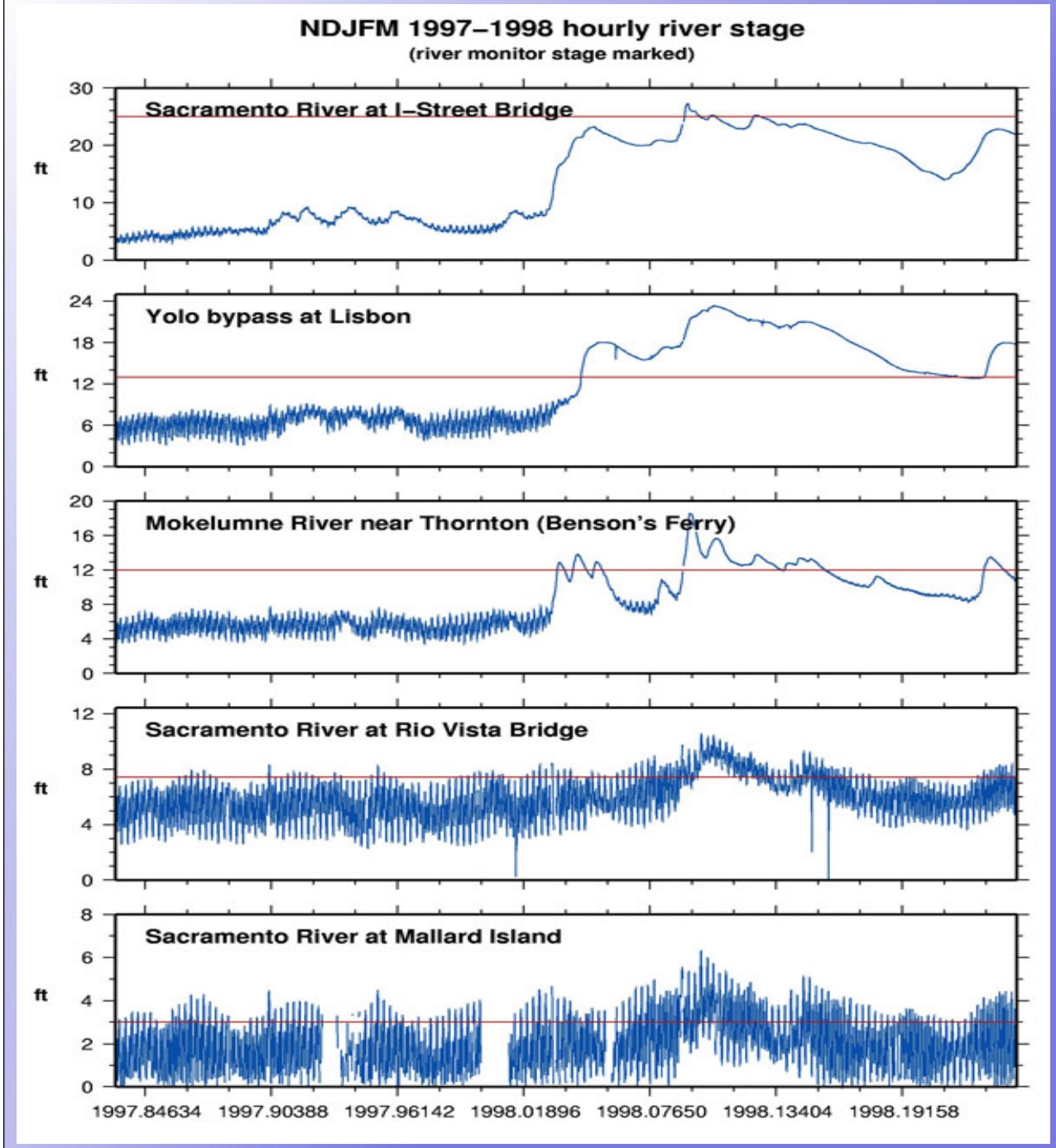
Highest storm-forced level = 28 cm

Two high tides and two low daily tides, unequal in amplitude.

Monthly tidal changes dominated by spring-neap cycle, with two periods of relatively high tides (springs) around full and new moon. One spring tide range per month is usually higher than the other on this coast.

The highest monthly tides in the winter and summer months are higher than those in the spring and fall as a result of lunar and solar declination effects.

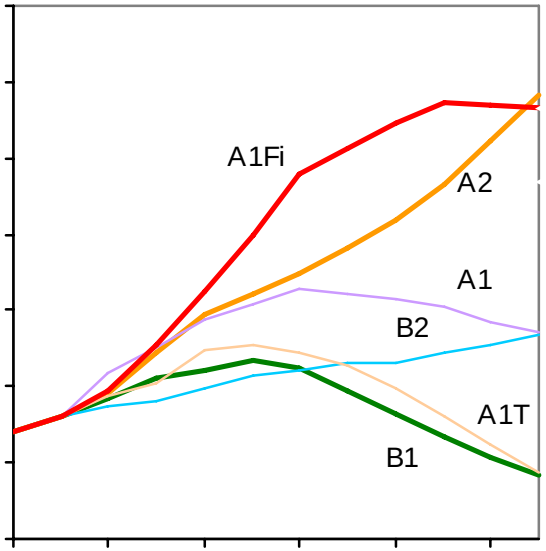

San Francisco Bay/Delta
Water Levels
~Jan 3 2006
Nasa
http://earthobservatory.nasa.gov/Newsroom/NewImages/Images/ncalifflood_amo_2006004_lrg.jpg



Winter 1997-98

competition between fresh water inflow and ocean tides

a)

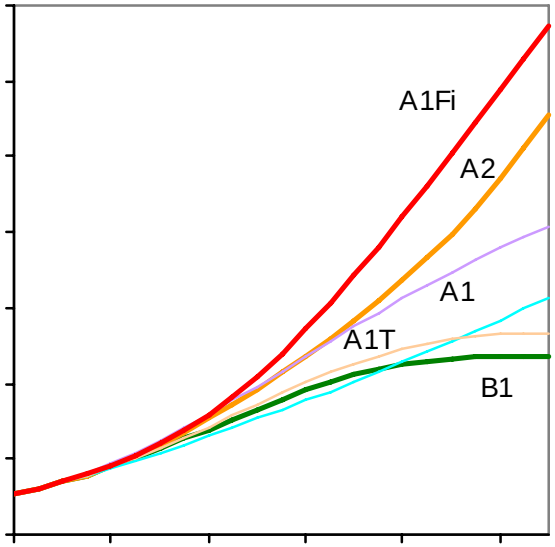


High Emissions

Medium- High Emissions

Low Emissions

b)



High Emissions

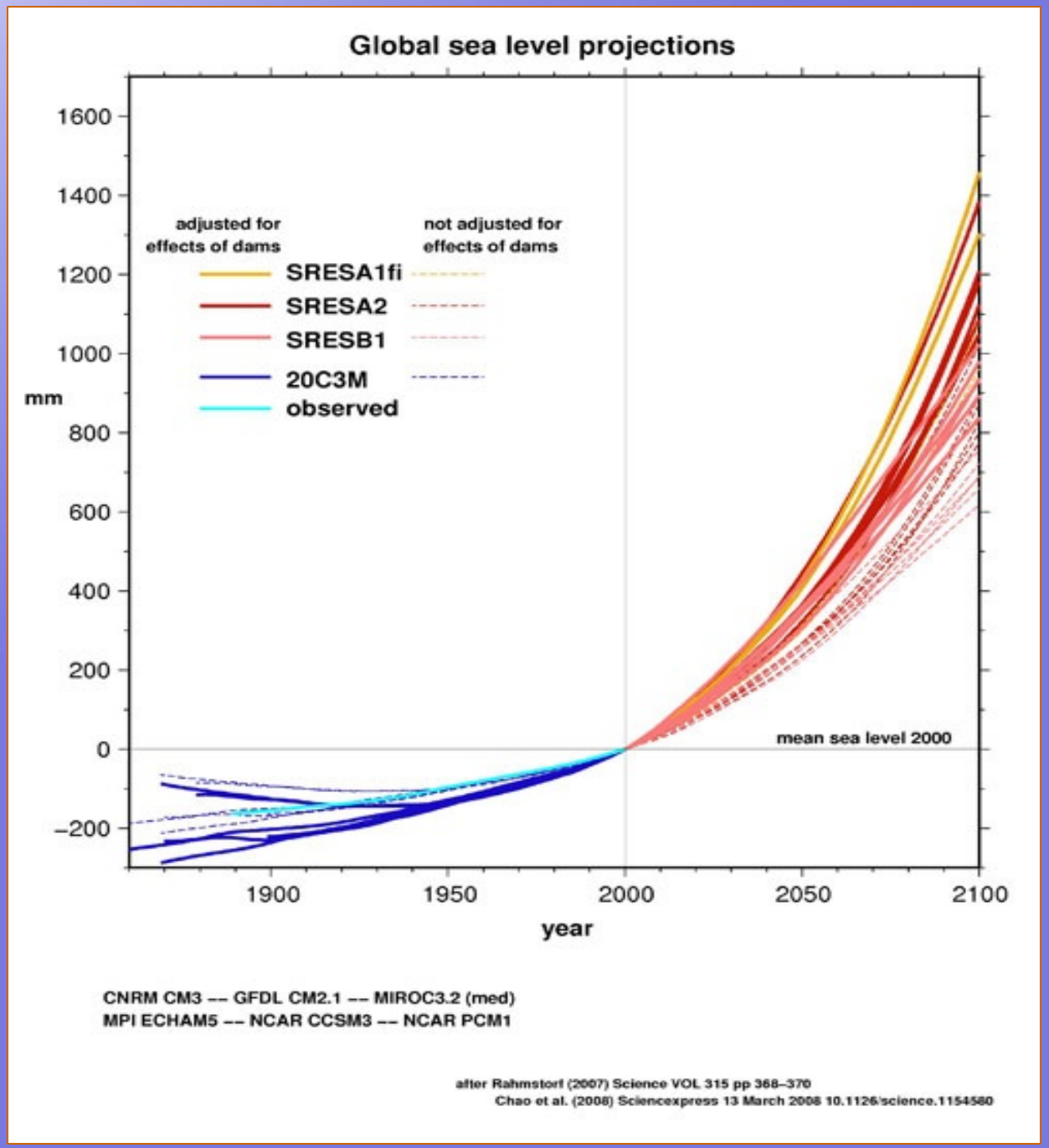
Medium- High Emissions

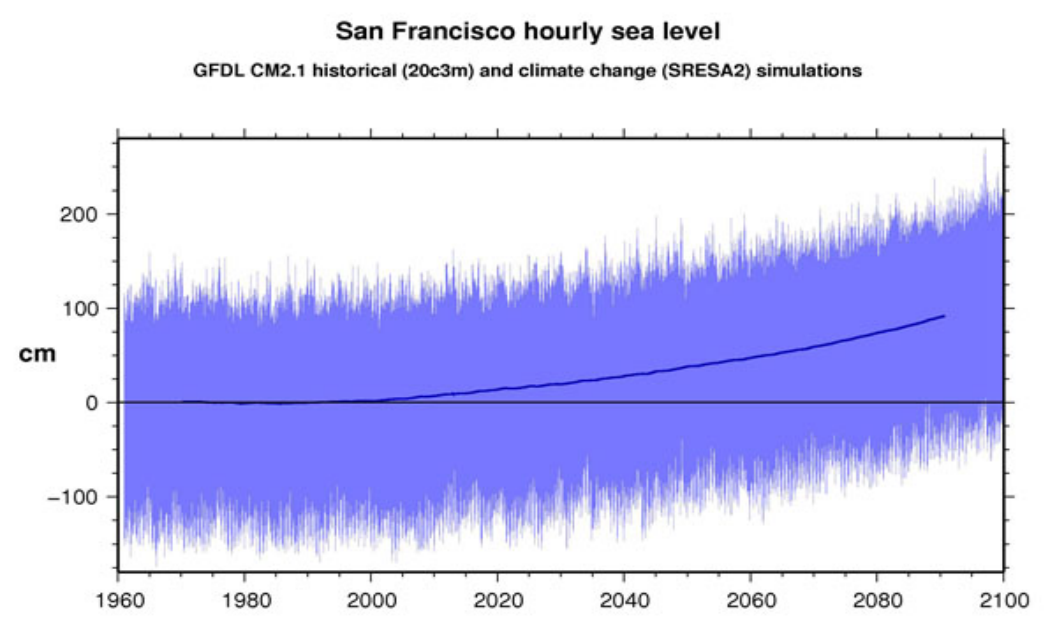
Low Emissions

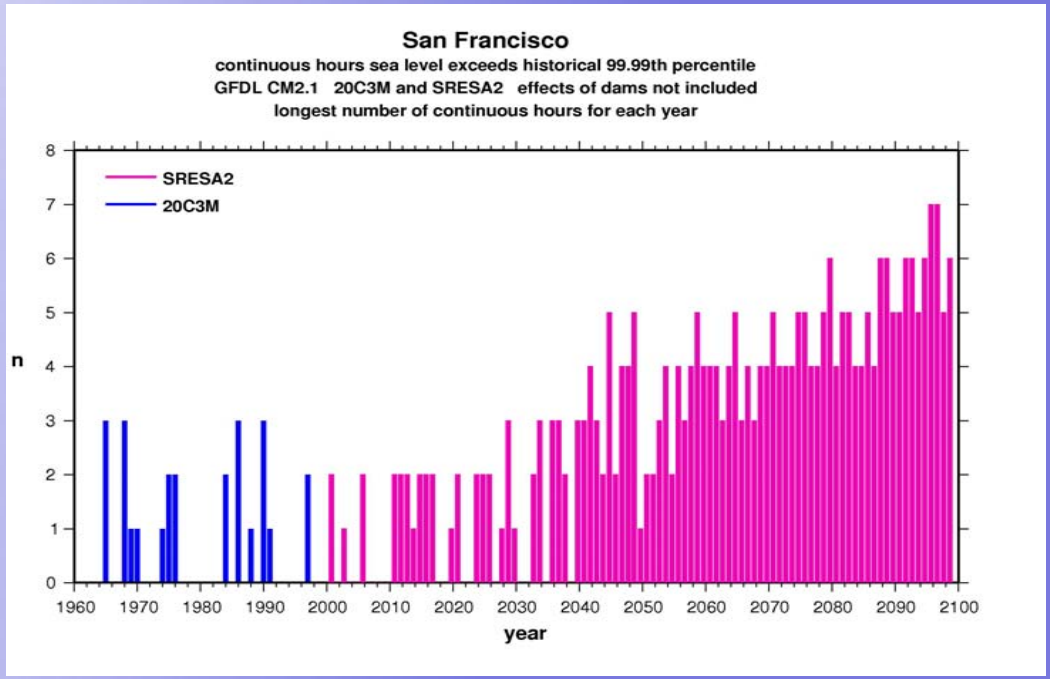
Figure 1. IPCC SRES Emission Scenarios ((Nakicenovic, N. et al.. 2000). The trajectories in Figure 1 do not exactly match those in official IPCC documents because the results we report here are based on revised emissions projections subsequently made available by IPCC; these are available at http://sres.ciesin.columbia.edu/. In addition, the authors used a new version of MAGICC available from http://www.cgd.ucar.edu/cas/wigley/magicc/index.html. The differences between Figure 1 and similar figures provided by the IPCC, however, are minor and do not affect the discussion in this paper.

Projected sea levels

from the B1 and A2 emission scenarios using the Rahmstorf (2007) scheme for each of the three models. Both the original Rahmstorf (dashed curves) and a version adjusted for the affect of reservoirs and dams (solid) are shown. Historical (blue) and projected simulations (red shades) are shown along with observed global sea level (aqua).



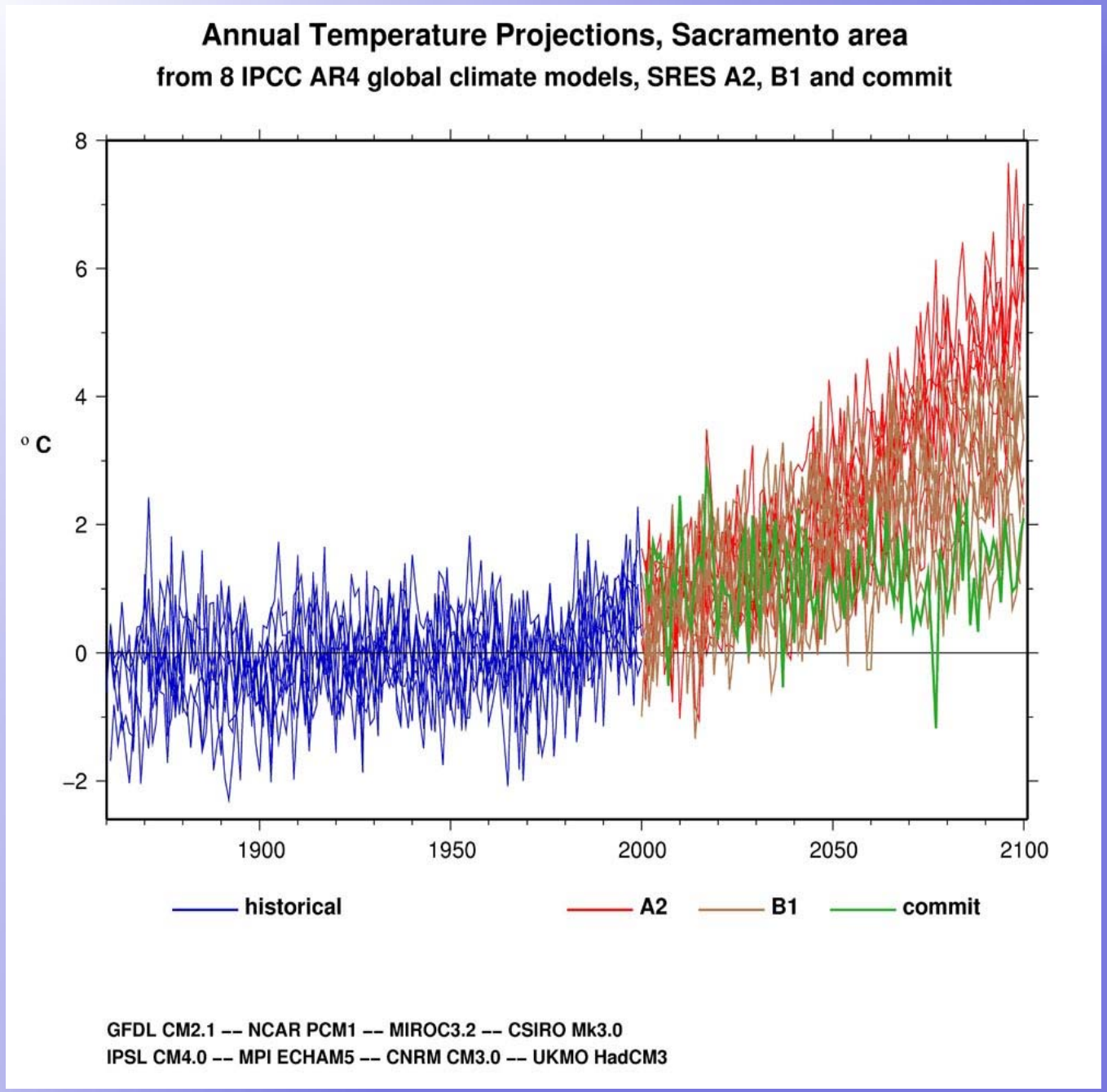




Projected sea level San Francisco

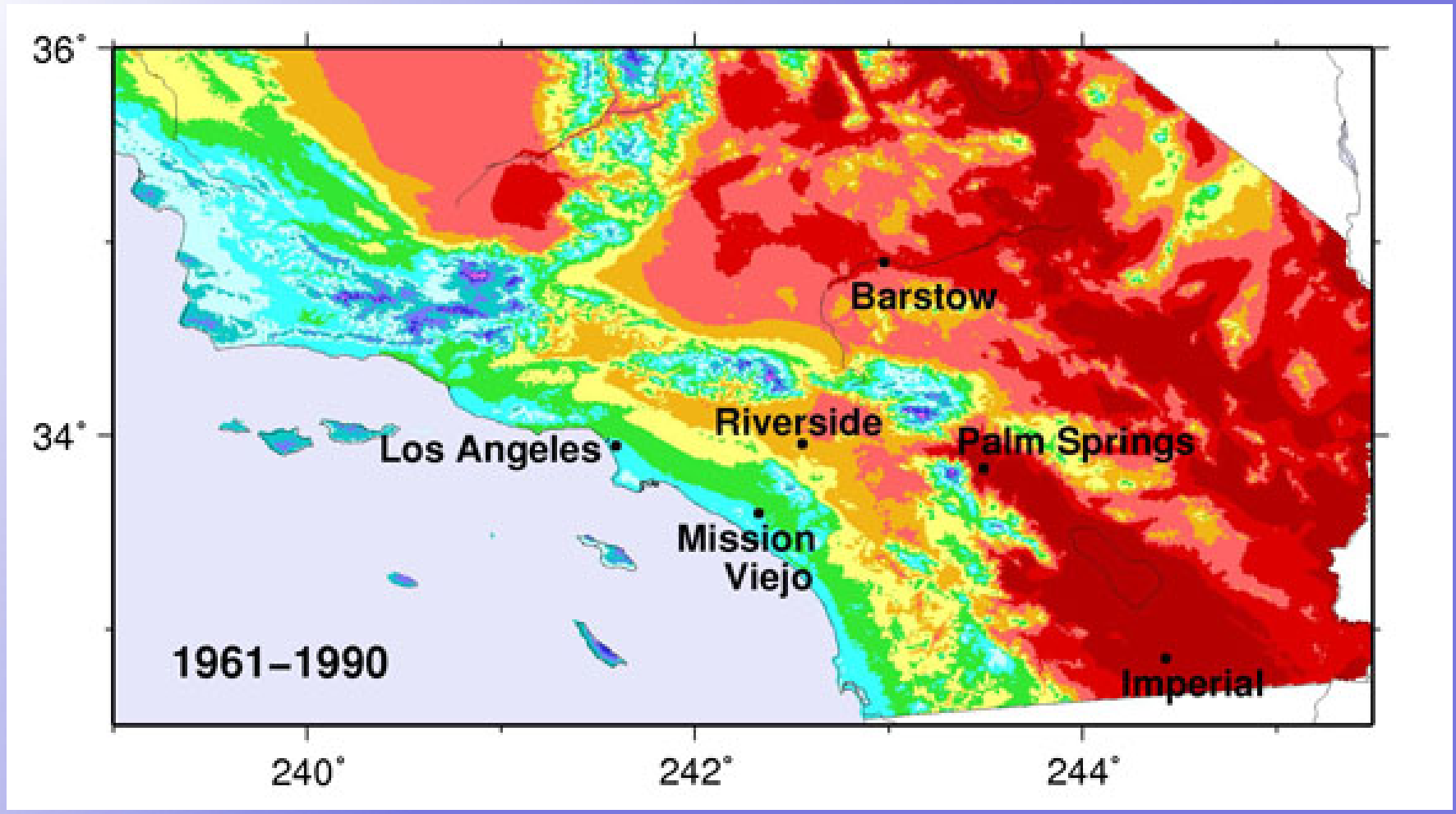
Under projected global warming, such as in the GFDL A2 simulation sea level rises considerably by 2100, in this scenario by approximately 0.9m.

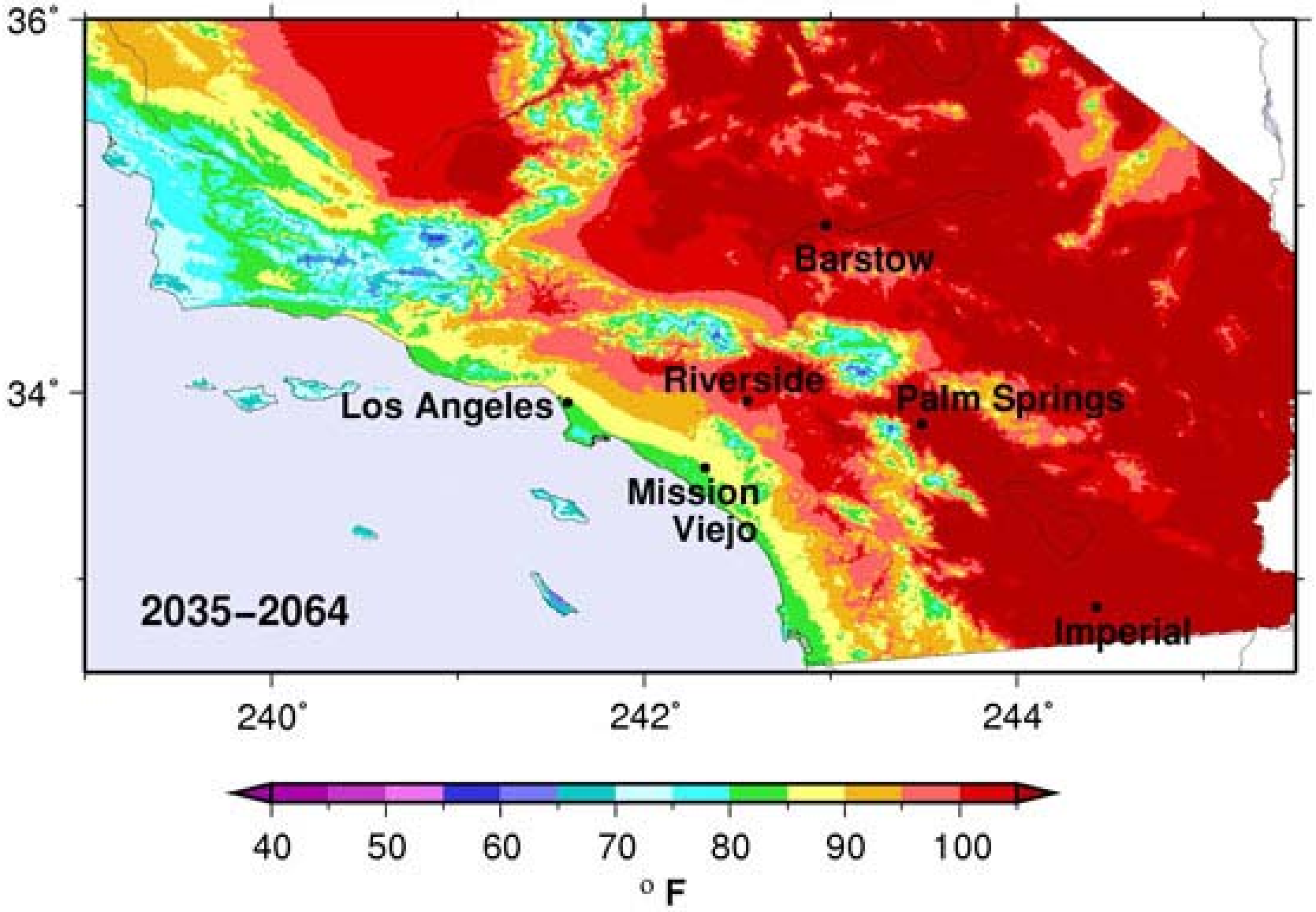
At San Francisco high sea level events, exceeding high threshhold occur increasingly often and persist for longer durations.



regional and global surface temperatures rise markedly

This impacts Sea level rise


36°
34°
240°
242°
244°
Barstow
Riverside
Palm Springs
Los Angeles
Mission
Viejo
Imperial
1961–1990



GFDL A2 1km downscaled to 1km
Hugo Hidalgo Tapash Das Mike Dettinger

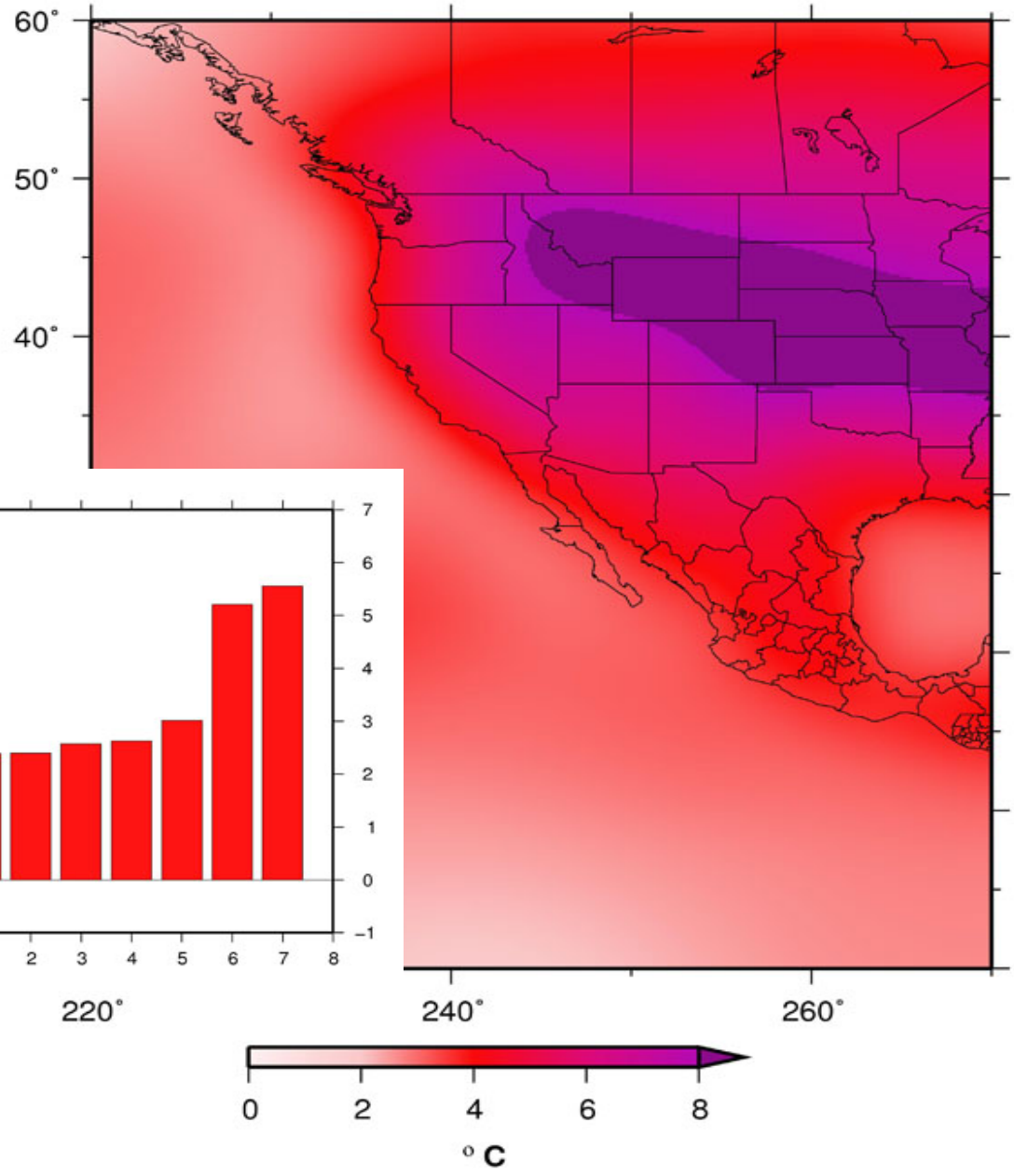
Climate models project 1.5-2.C ocean surface warming by end–of-century.

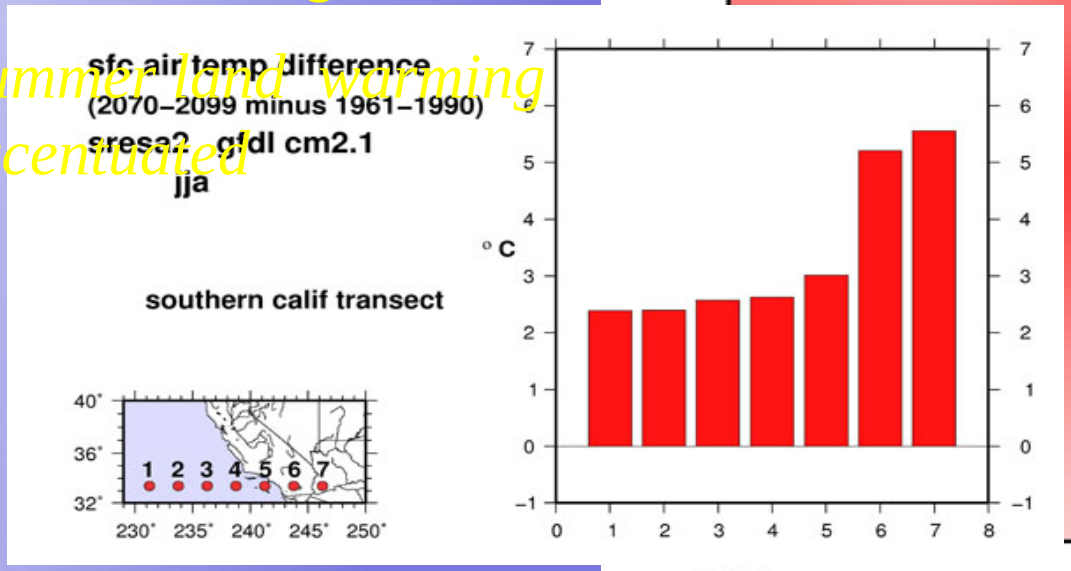
Greater warming on land than oceans would amplify California coast-interior thermal gradient.

Summer land warming is accentuated

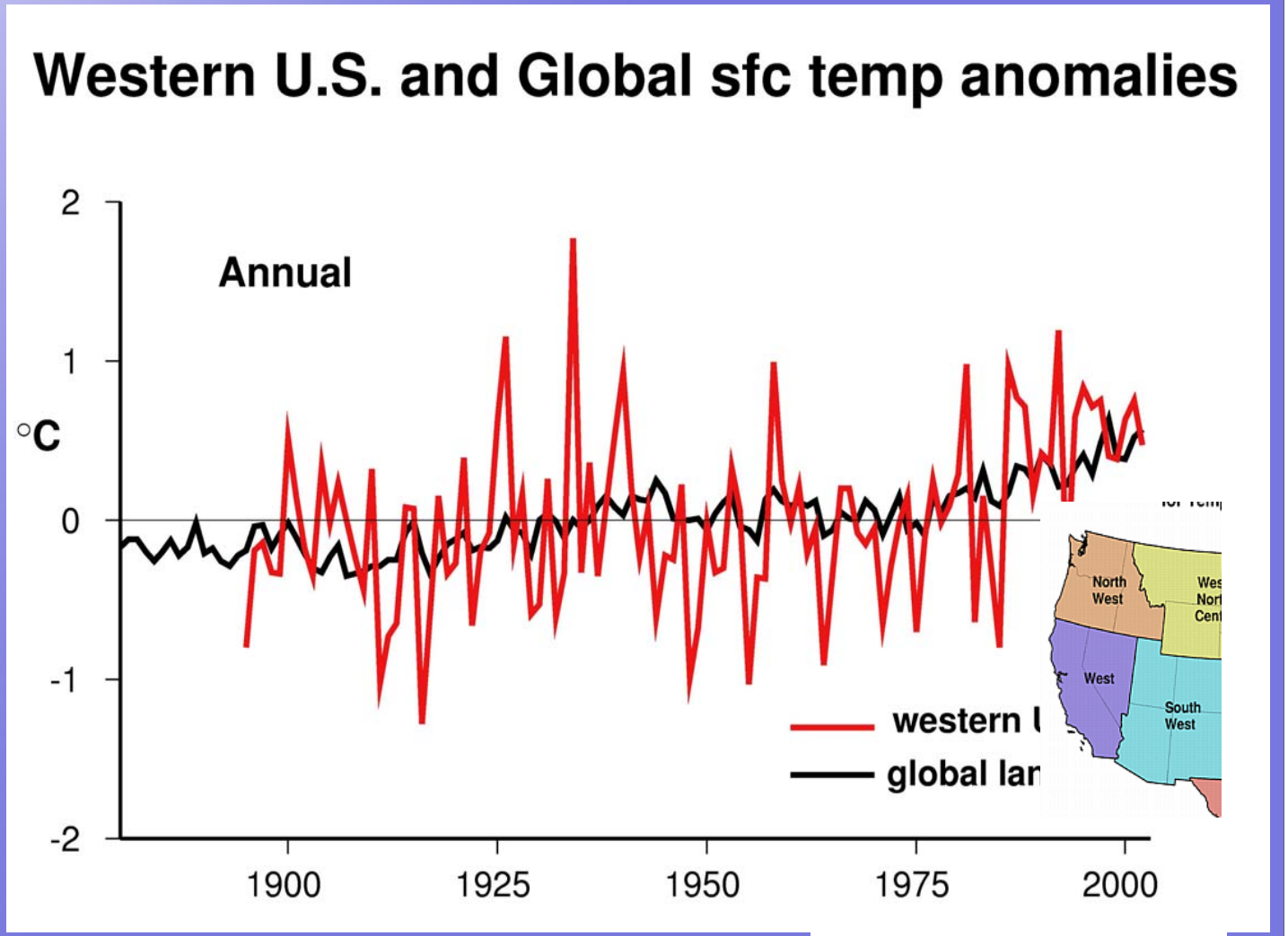
GFDL CM2.1 is a medium-high sensitivity model. Other models produce less (or more) warming

GFDL CM2.1 Jun-Aug air temp change
2070-2099 *minus* 1961-1990





During recent history, temperature changes in west U.S. have tracked those in global temperature

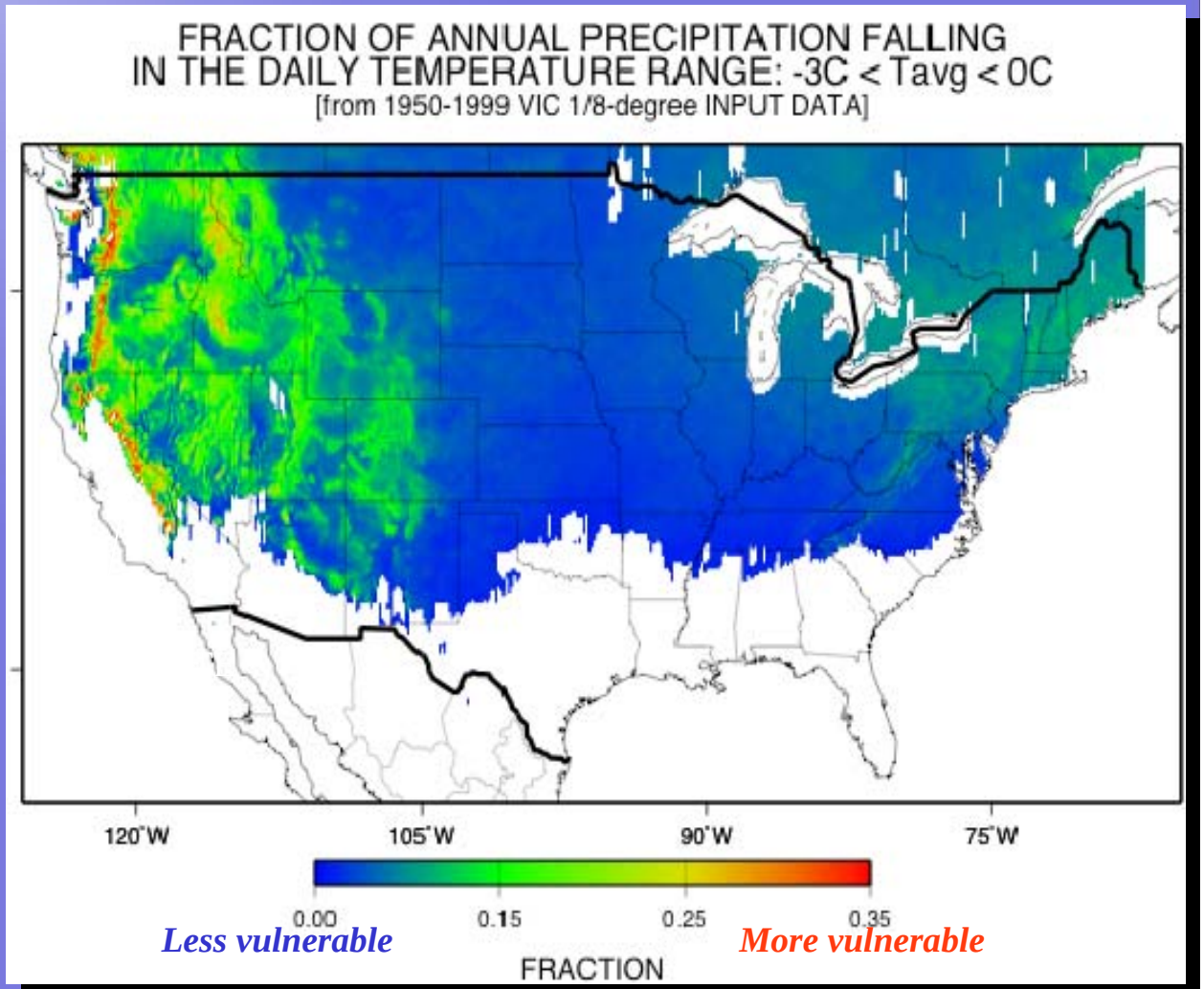


Global land data from the Global Historical Climatology Network (GHCN; Version 2) and global SST data from the UK MOHSST and NCEP OI SST (Version 2) anoms based on 1880-2002 mean

Western U.S. data from the time bias corrected NCDC statewide-regional-national dataset (Climate Division data) anoms based on 1895-2002 mean

SENSITIVITY TO A +3ºC WARMING…

What fraction of each year's precipitation historically fell on days with average temperatures just below freezing?

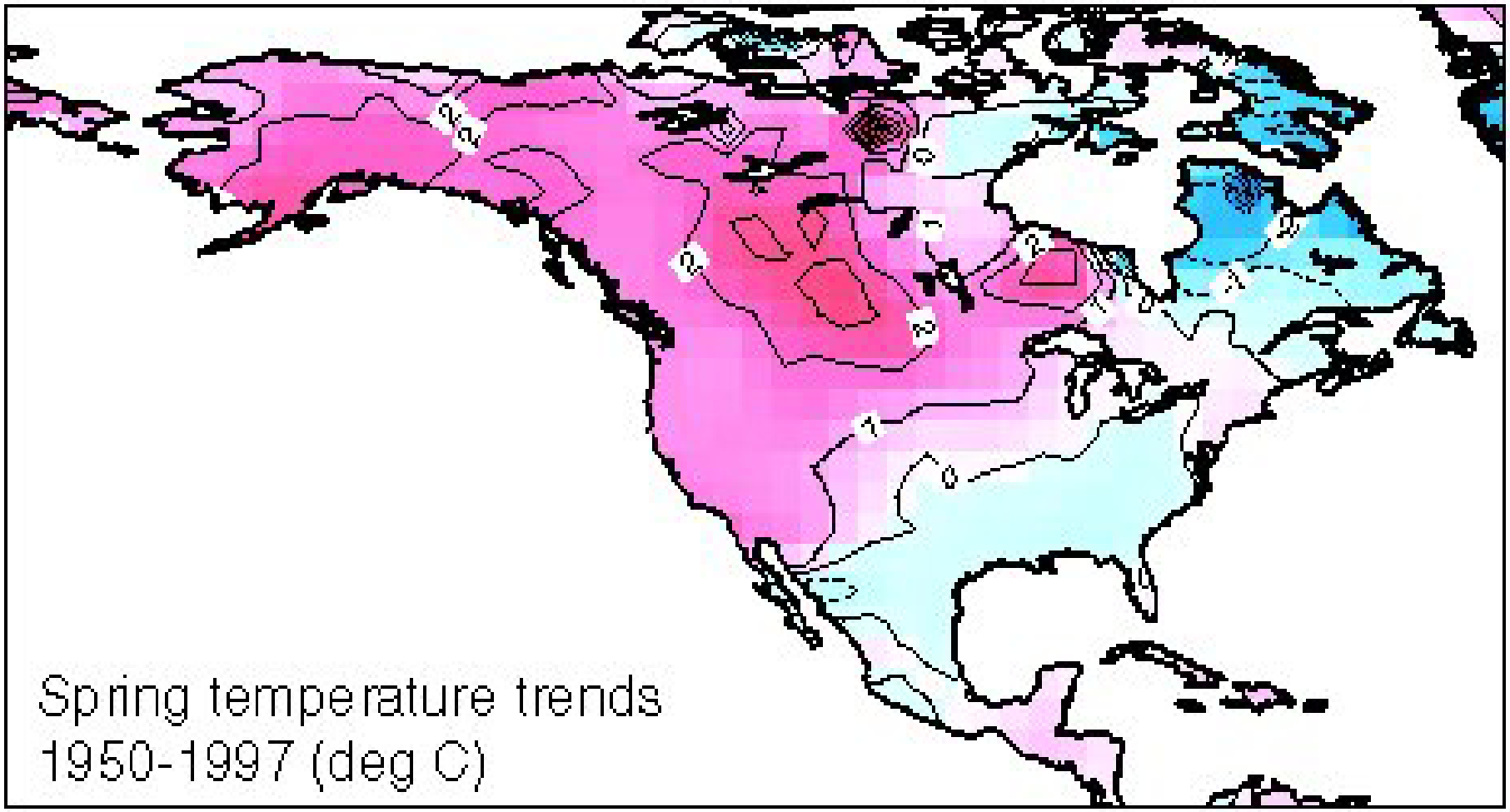


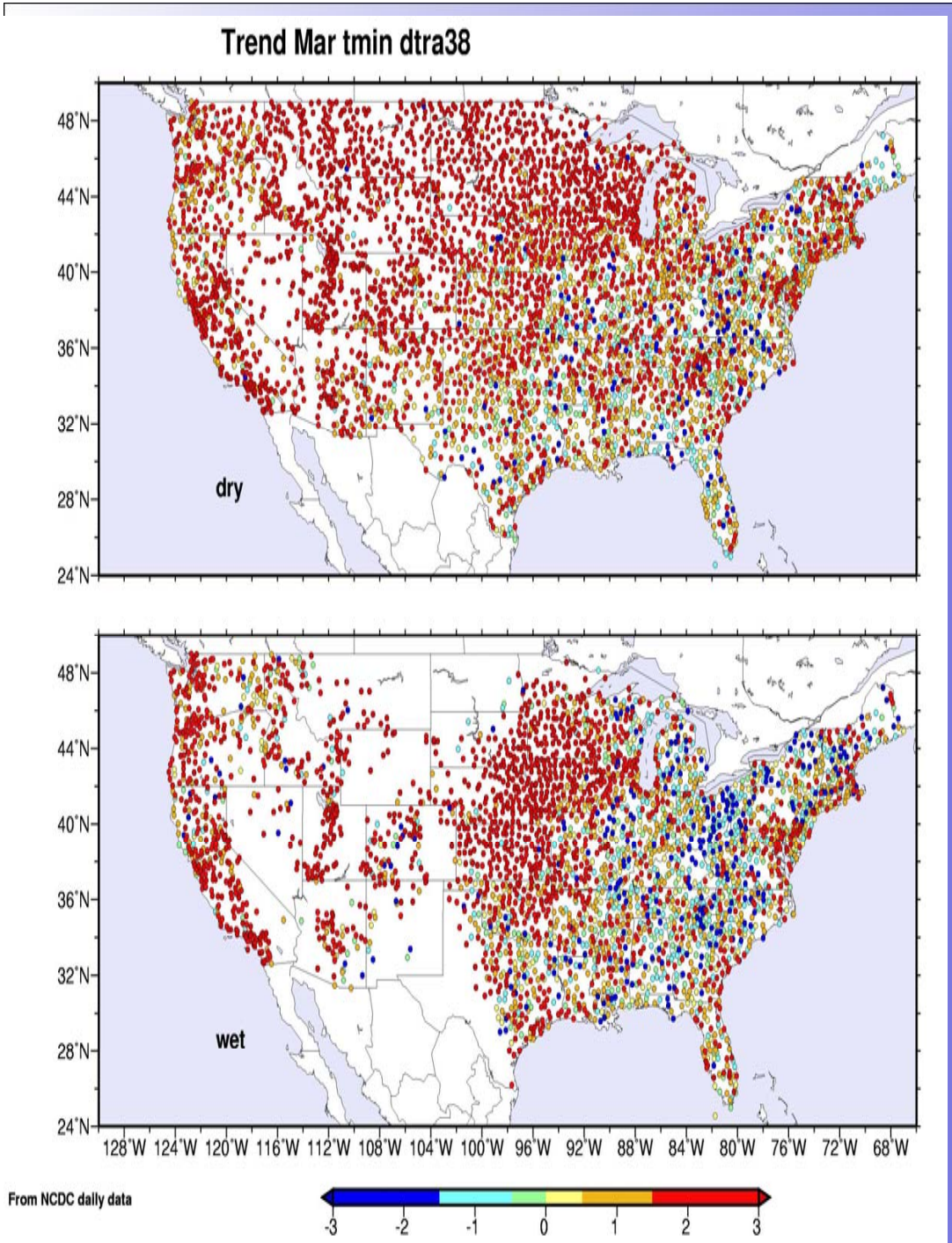
"Rain vs Snow"

Computed by Mike Dettinger from gridded historical US weather data (from Bates et al, in rev)

Very broad winter and spring warming 1950-1997

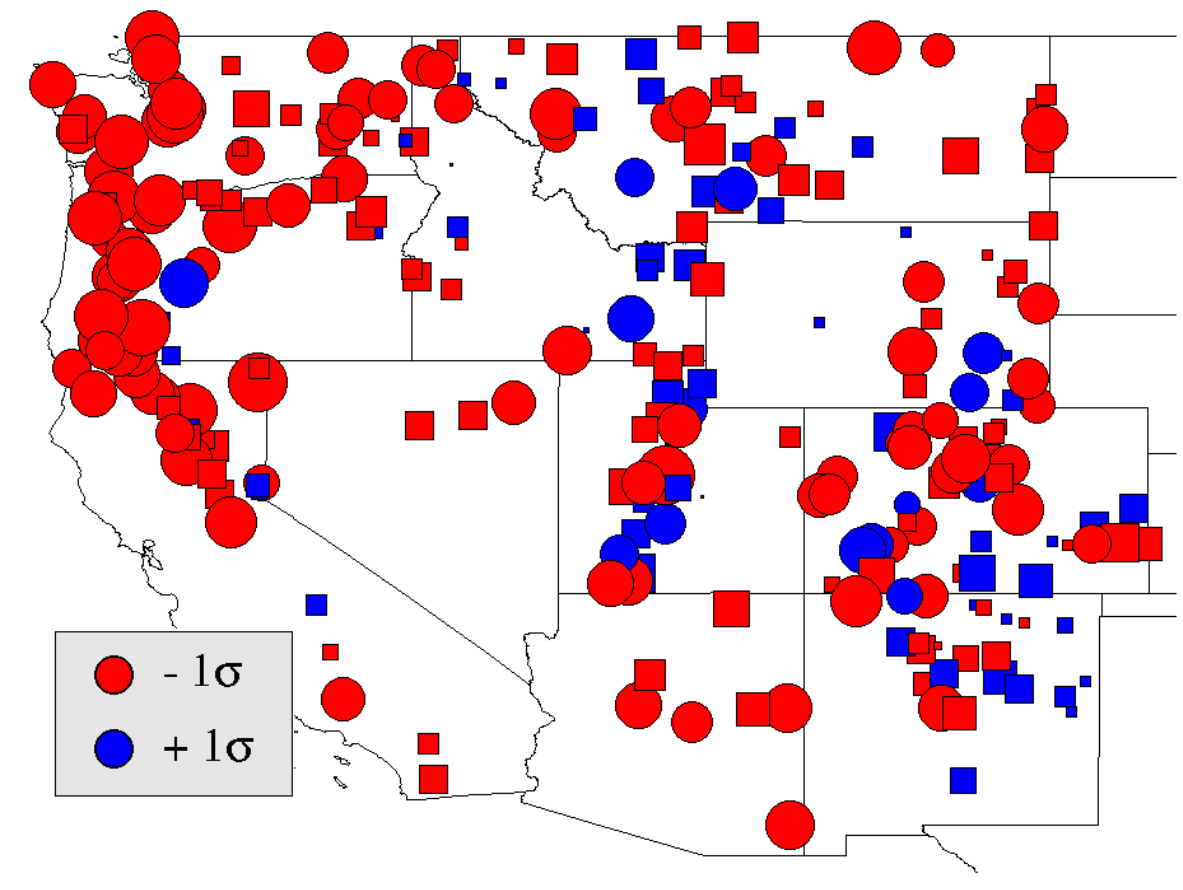
California warmed 0.5-1.5C



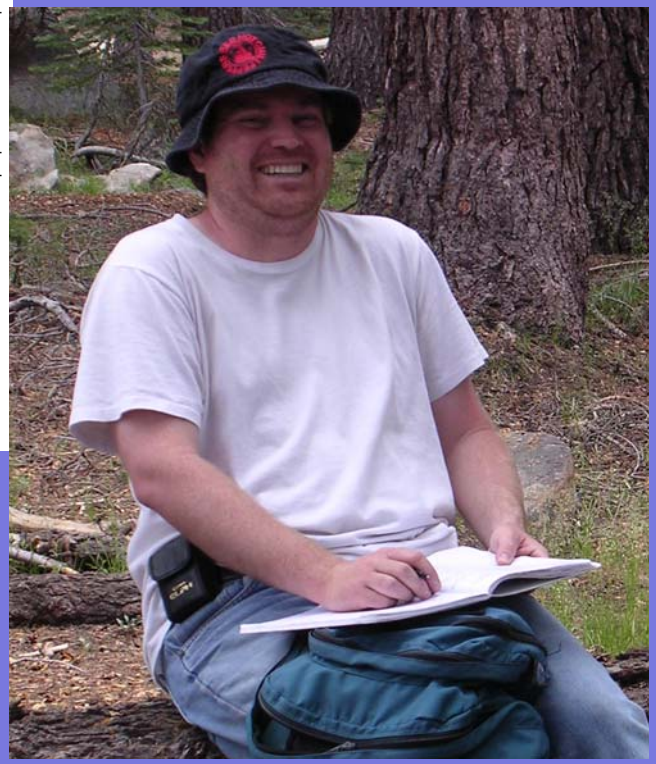


Dry & Wet days have warmed 1950-2000

less snow, more rain
earlier snowmelt

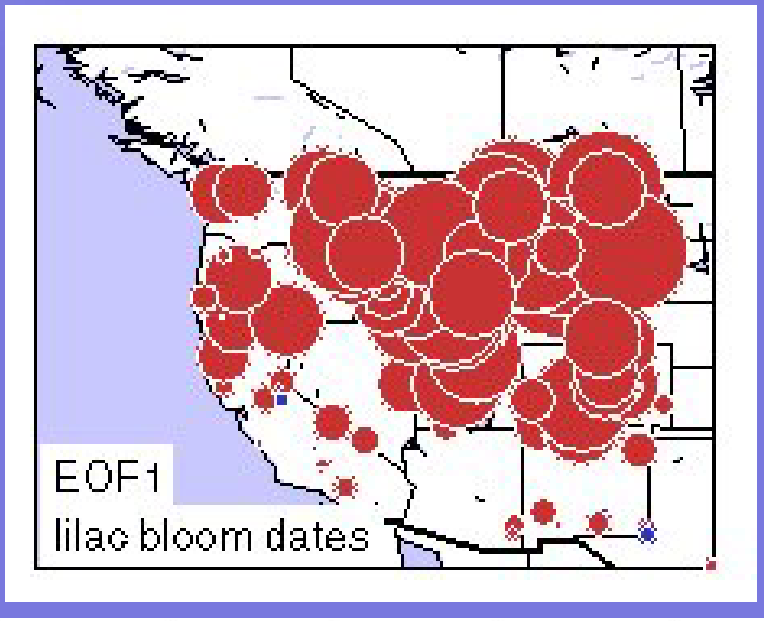


More Rain
Less Snow
WY 1949-2004

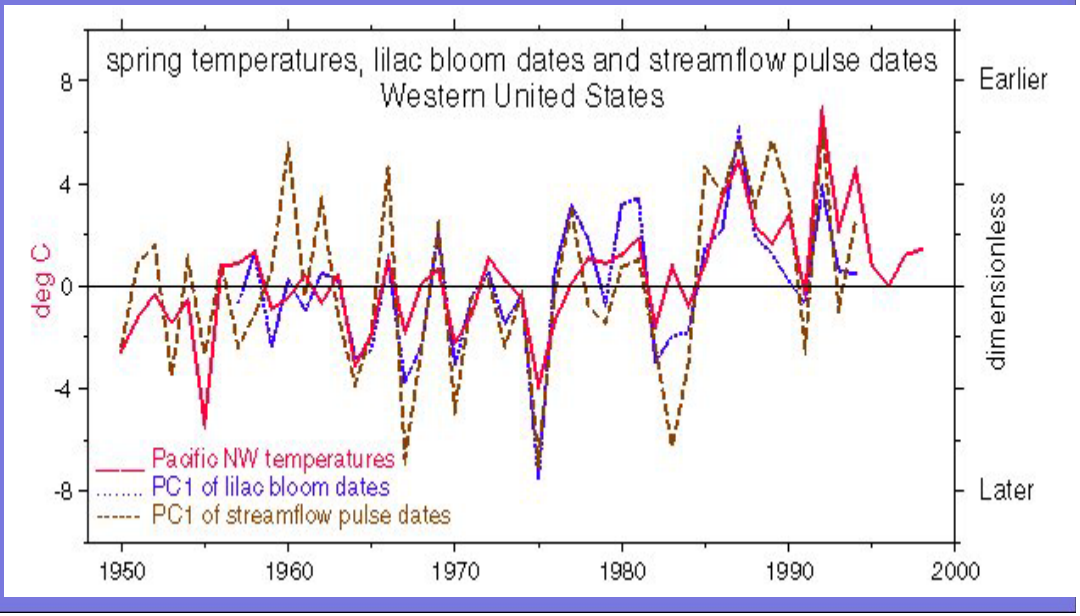


Noah Knowles et al. 2006
in press J. Climate

Winter (Nov-Mar) SFE/P trends at western US weather stations: symbol area is proportional to study-period changes, measured in standard deviations as indicated; circles indicate high trend significance ($p<0.05$), squares indicate lower trend significance ($p>0.05$).



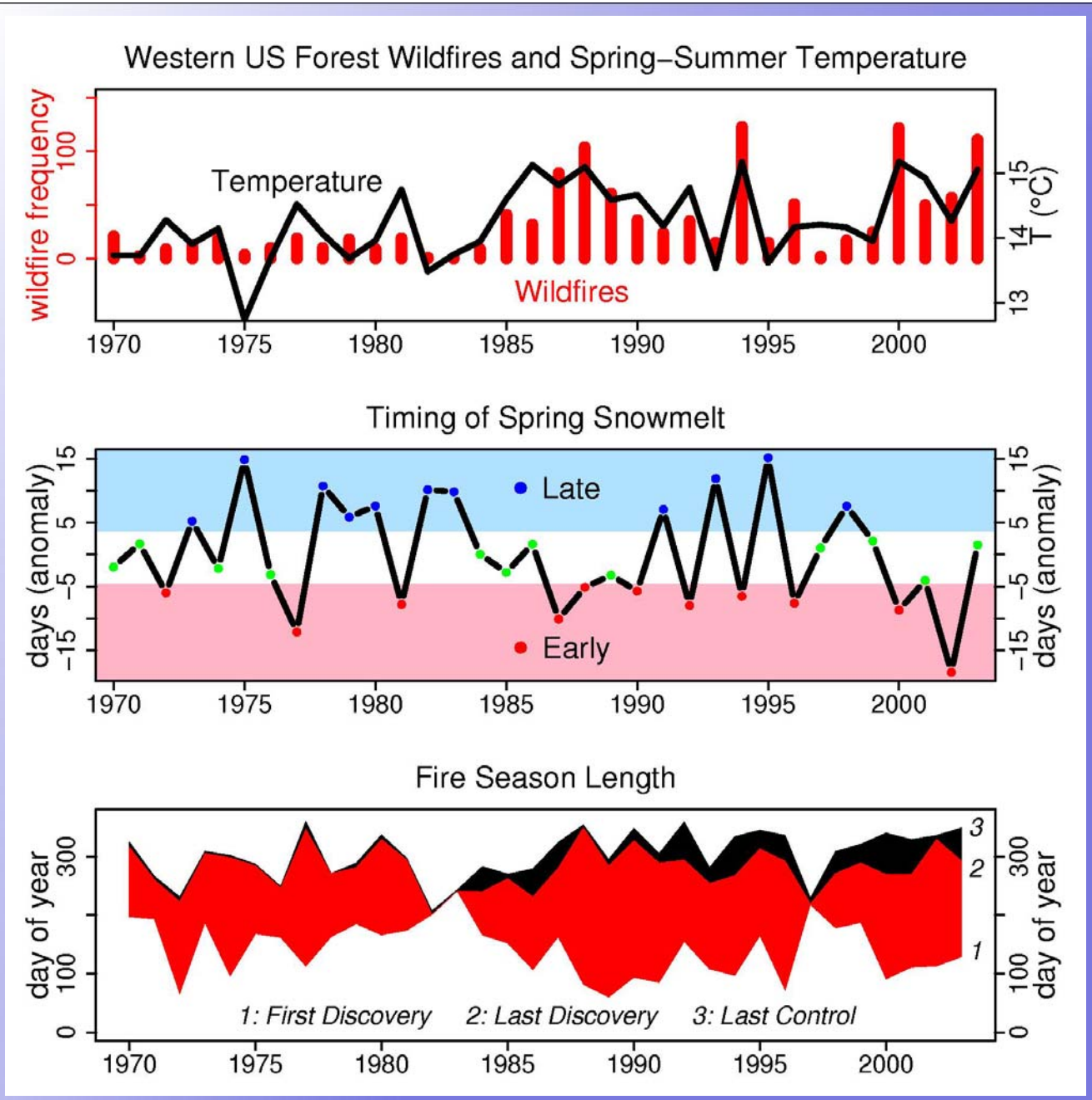
Plant bloom timing advanced by 1 wk at cooperative observer sites in the western United States 1957-1994



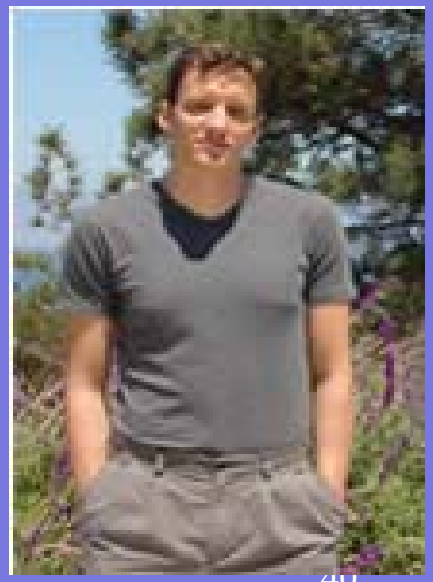
Cayan et al., 2001; Bull Am Met Soc

since 1985 the number of large wildfires in western U.S. increased by 4X

Anthony Westerling et al. Science August 2006



Large wildfire threat is aggravated by warmer springs and summers

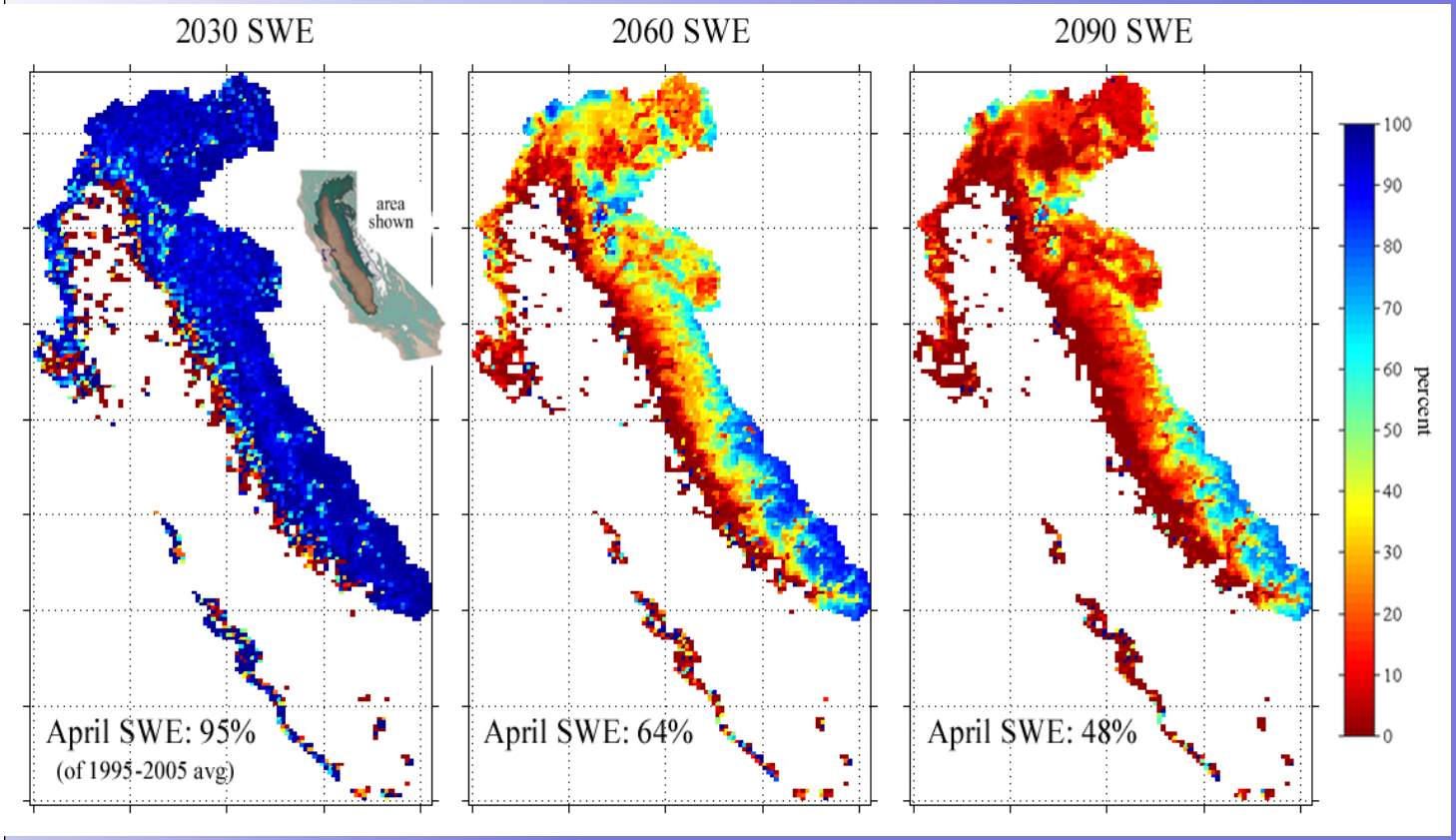


Anthony Westerling et al. *Science* August 2006

How much snowpack will be lost?

Douglas Alden
Scripps Institution of Oceanography
Installing met station
Lee Vining, CA

We face significant losses of spring snowpack

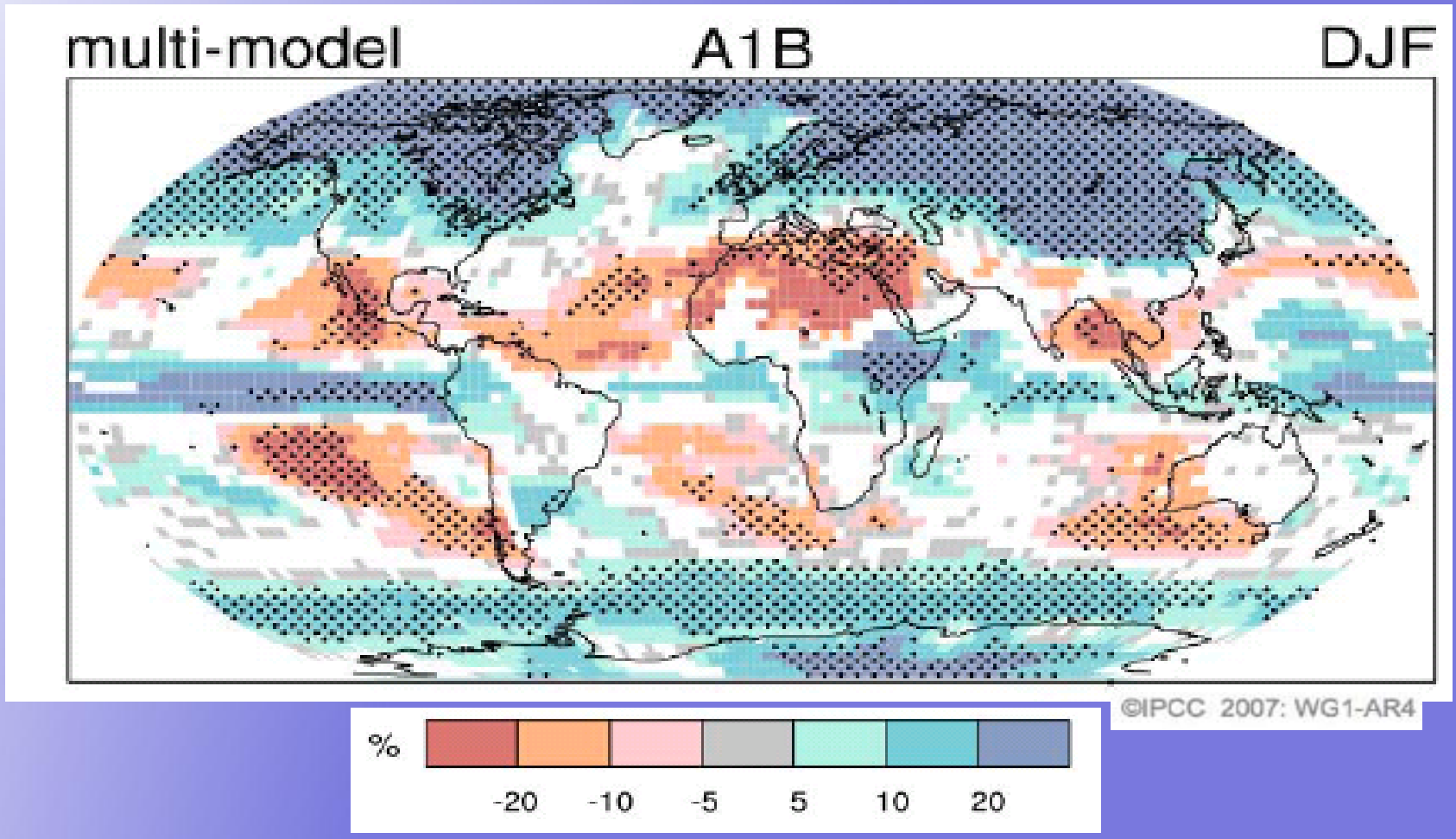


- **Less snow, more rain**
- **Particularly at lower elevations**
- **Earlier run-off**
- **More floods**
- **Less stored water**

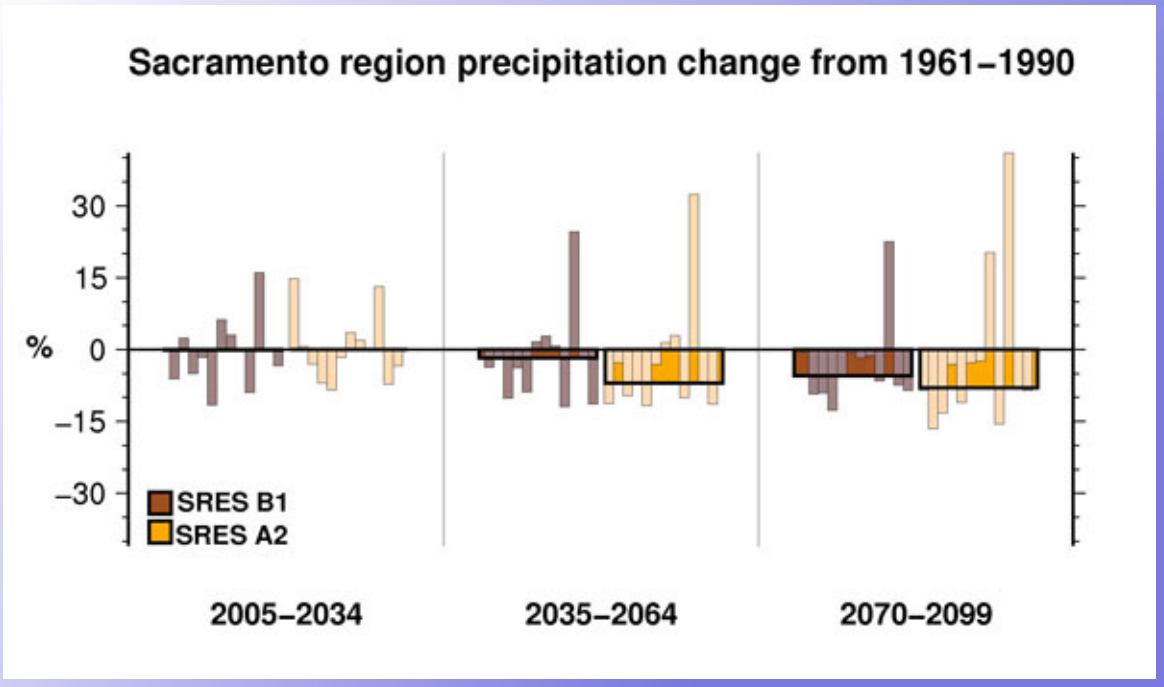
By the end of the century California could lose half of its late spring snow pack due to climate warming. This simulation by Noah Knowles is guided by temperature changes from PCM's Business-as-usual climate simulation. (a middle of the road emissions scenario)

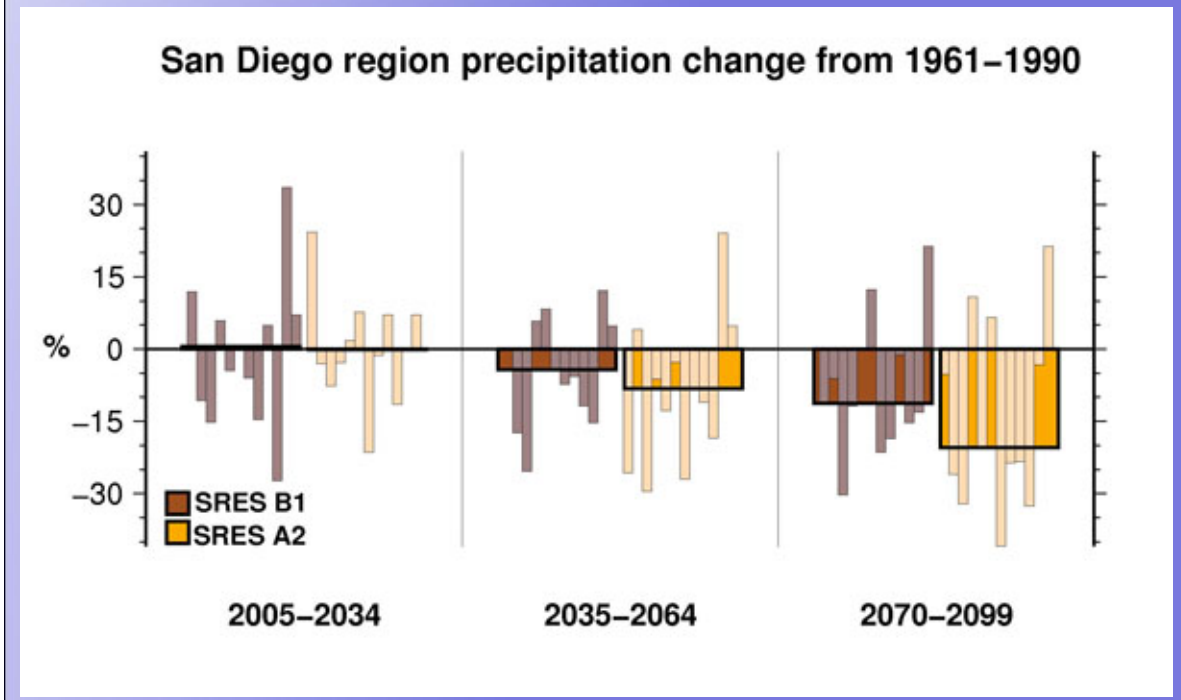
Knowles and Cayan 2001

Projected patterns of precipitation changes 2090-2099 versus 1980-1999



Globally, dry regions become drier?





12 AR4 GCMs, 2 emissions s scenarios--- an uneven consensus toward lower California precipitation

SUMMARY:

Climate warming is already occurring , projections suggest much more, along with greater impacts

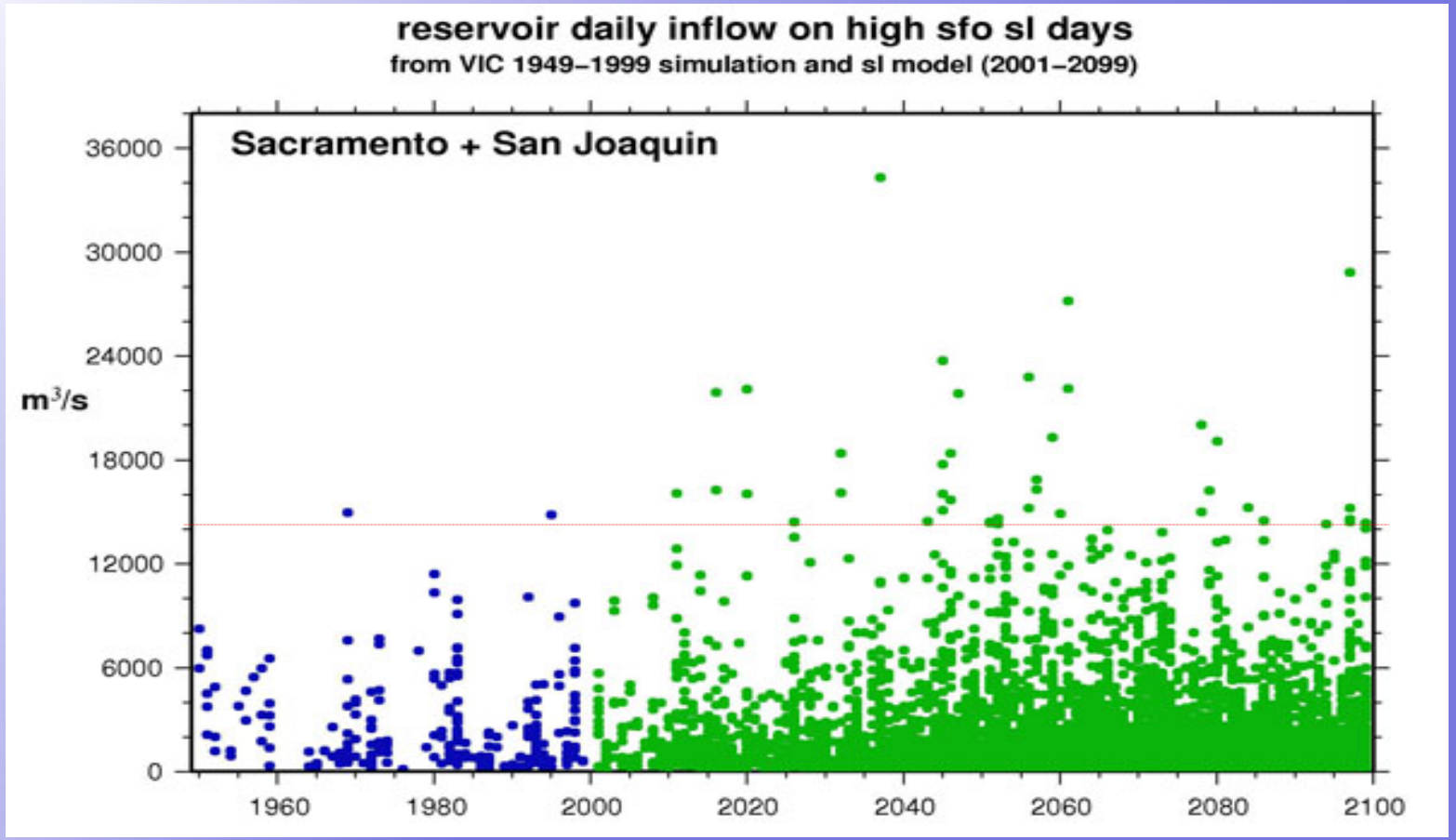
Weather, short period climate (e.g. ENSO, PDO, NPGO, ARs) and tides will continue to accentuate water level-related impacts.

Although some model simulations yield drier conditions in California over the next century, large storms continue to occur at about historical recurrence intervals.

Duration and amplitude of sea level extremes increases

In future decades, Sierra floods would be more active as larger portions of mountain catchments are likely to produce rainfall runoff instead of snowpack.

Events having high open coast sea levels and large fresh water flows into Delta and Bay increase considerably.

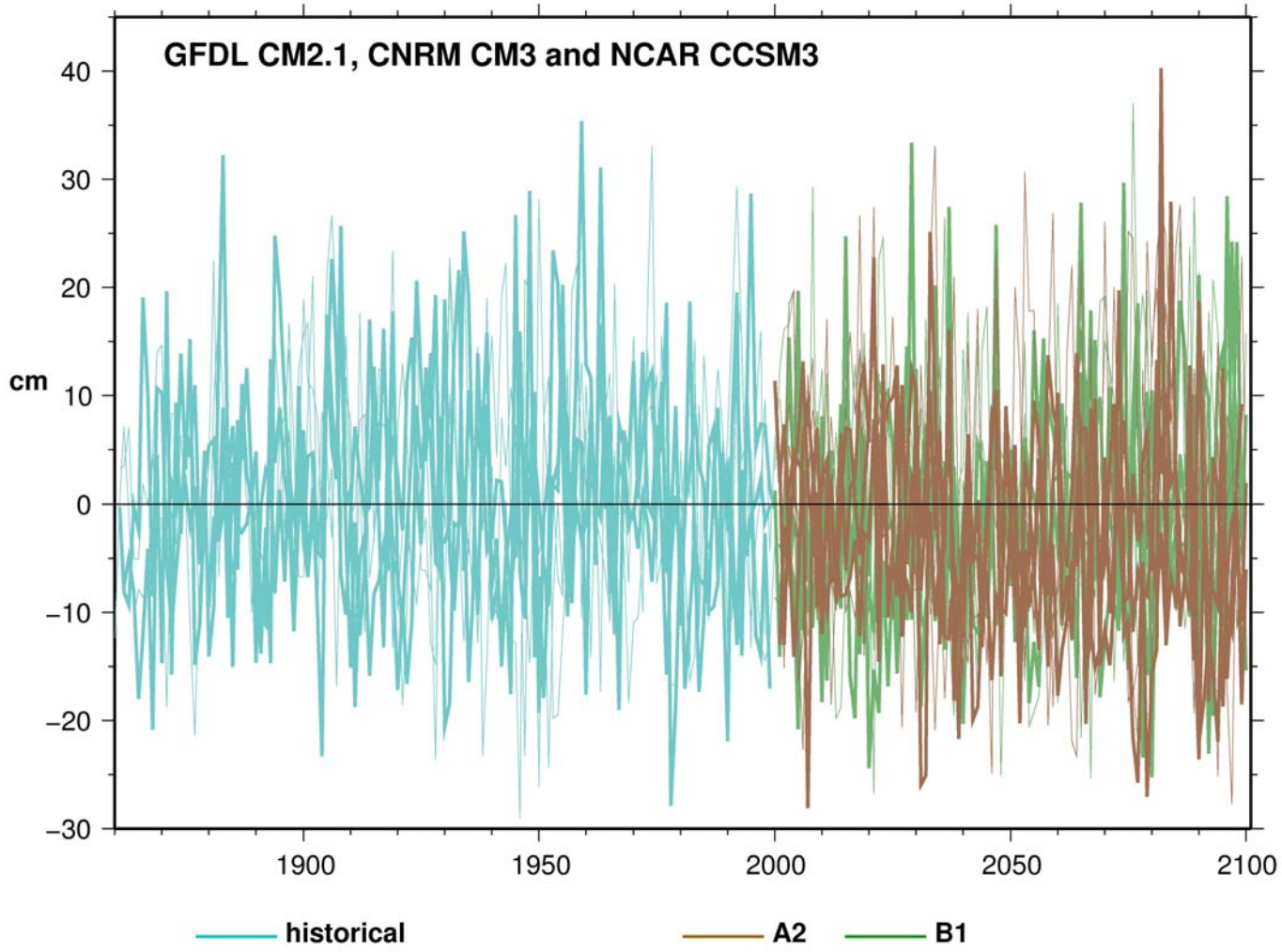


Sacramento+San Joaquin Flows during High San Francisco Sea Levels
simulated by Bay watershed model driven by GFDL A2 simul

marked increase in number and intensity

Annual Precipitation Projections, San Diego area

from IPCC AR4 global climate models, SRESA2 and B1



Swarm members:
MPI ECHAM5 –– NCAR PCM1 –– MIROC3.2