

# US. Drought Trends

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and Environmental  
Engineering

# Outline of this talk

- 1) Droughts as a natural hazard
- 2) Characterizing droughts
- 3) Drought trends
  - a) “Traditional” soil moisture droughts in the U.S. last ~century
  - b) Flash droughts
  - c) Climate change and the 2013-14 California drought
- 4) Conclusions

# Economic losses (\$B) and loss of life in recent U.S. droughts

<u>Event</u>	<u>cost,</u> <u>CPI</u> <u>adjusted</u>	<u>deaths</u>
Western/Plains Drought/Heatwave Spring-Fall 2013	10	53
U.S. Drought/ Heatwave 2012 Southern Plains/ Southwest Drought & Heat Wave Spring-Summer 2011	30	123
Southwest/ Great Plains Drought 2009	4	0
US drought 2008	8	0
Drought/heat wave summer/fall 2007	3	0
Midwest/ Plains/ Southeast Drought Spring-Summer 2006	6	0
Midwest Drought Spring-Summer 2005	2	0
Western/ Central Drought/ Heatwave Spring-Fall 2003	6	35
U.S. Drought Spring-Fall 2002	11	0
Western/ Central/ Southeast Drought/ Heatwave Spring-Fall 2000	7	140
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U.S. Drought/ Heatwave Summer 1988	39	454

Source: NOAA Billion-dollar weather/climate disasters

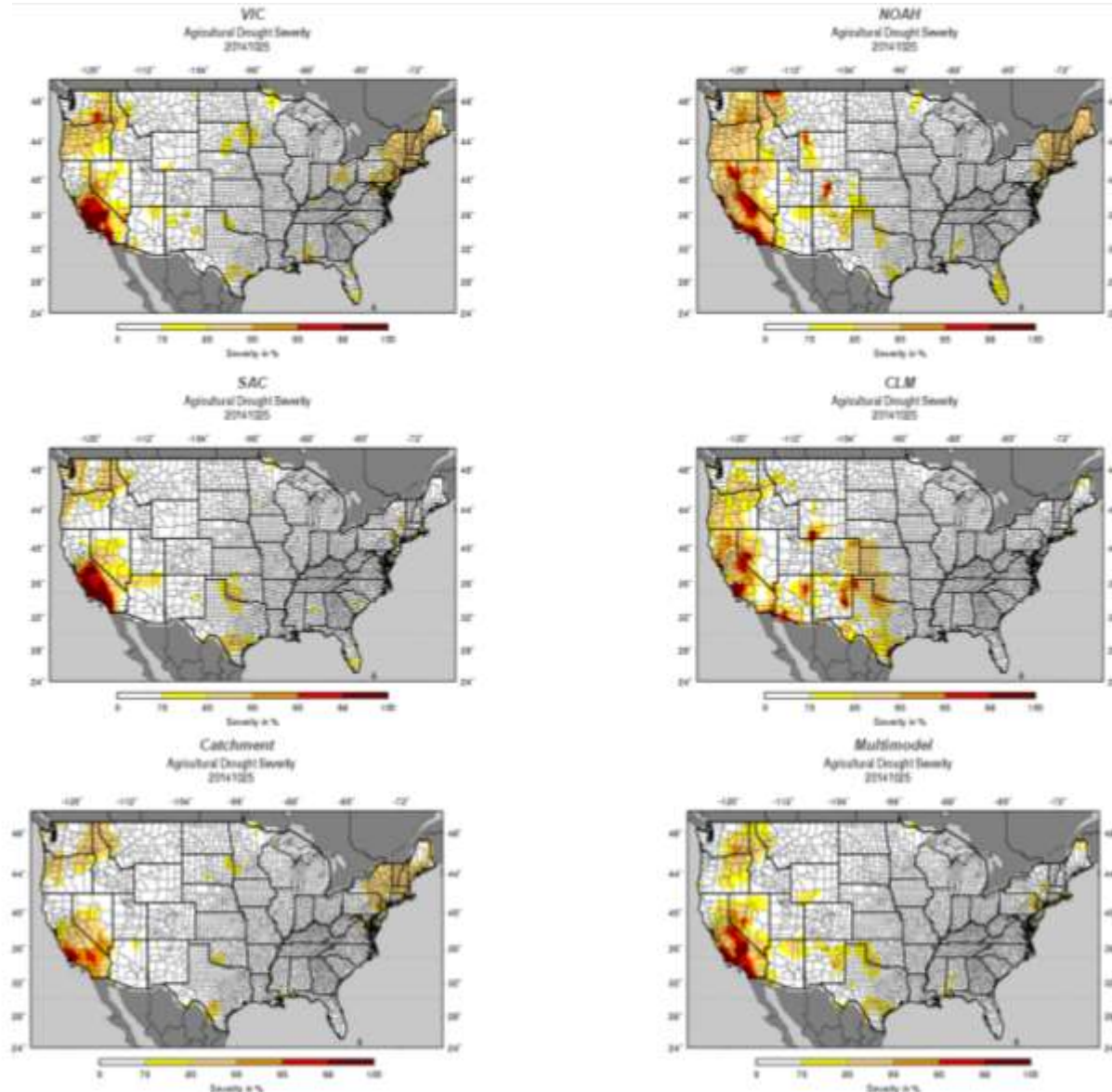
# Drought characteristics

- “creeping disaster” – most evolve slowly over time
- Typically cover large areas
- Hence losses can be large
- Definitions vary (meteorological, agricultural, hydrological)

# Drought reconstruction

- Spatially and temporally continuous dataset of hydro-climatological variables (1915-2003,  $\frac{1}{2}$  degree spatial resolution)
- Drought event identification using spatio-temporal clustering
- Severity estimated for each drought event for different durations and spatial extents
- Results used to construct Severity-Area-Duration (SAD) curves

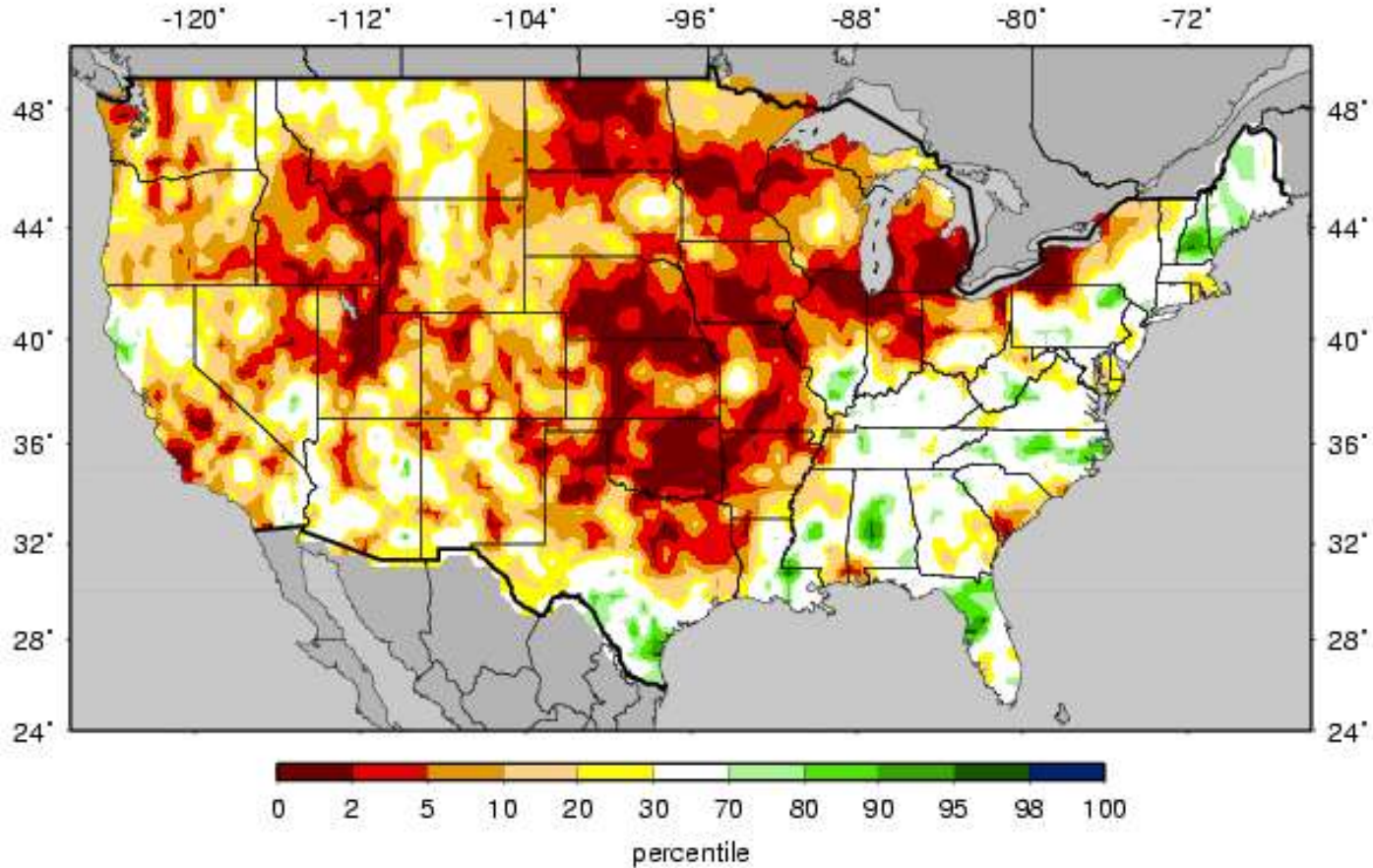
# UW Surface Water Monitor



<http://www.hydro.washington.edu/forecast/monitor/drought/index.shtml>

1934/08/01

VIC Soil Moisture Percentiles (wrt/ 1916-2004)  
19340801



VIC Snow Water Equivalent Percentiles (wrt/ 1916-2004)  
19340801 threshold = 10 mm

# Severity-Area-Duration Analysis

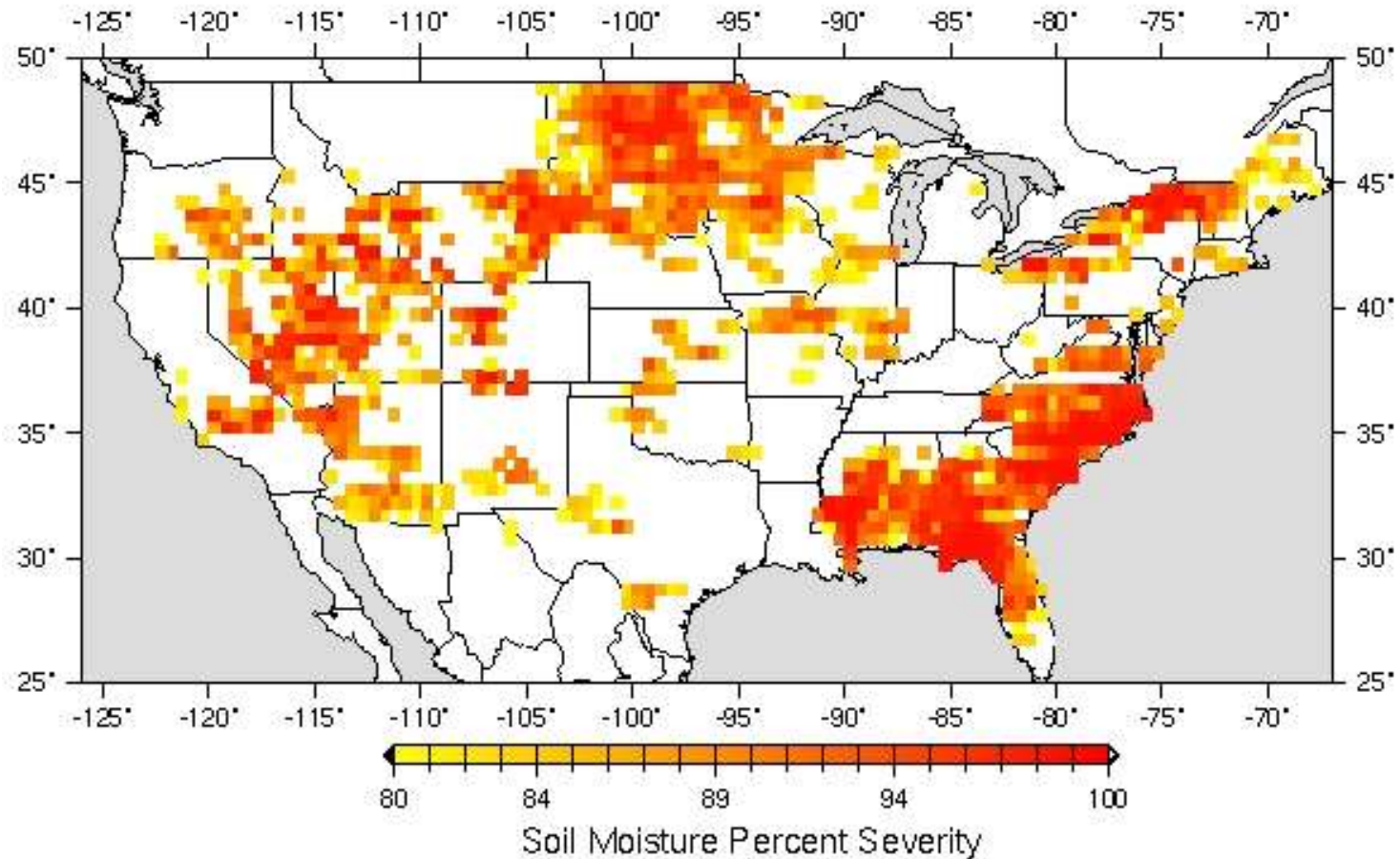
- Depth-Area-Duration technique, widely used in probable maximum precipitation analysis
- Replace depth with measure of drought severity

$$S = 1 - \frac{\sum P}{t}$$

$S$  : severity,  $\sum P$  : cumulative percentile of soil moisture (runoff),  $t$  : event duration

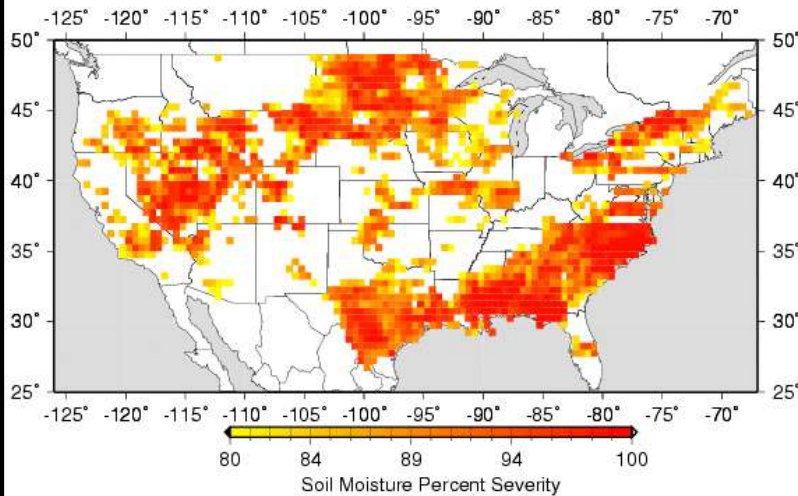
# Defining drought extent

## 01 1934 Soil Moisture-Defined Drought Extent

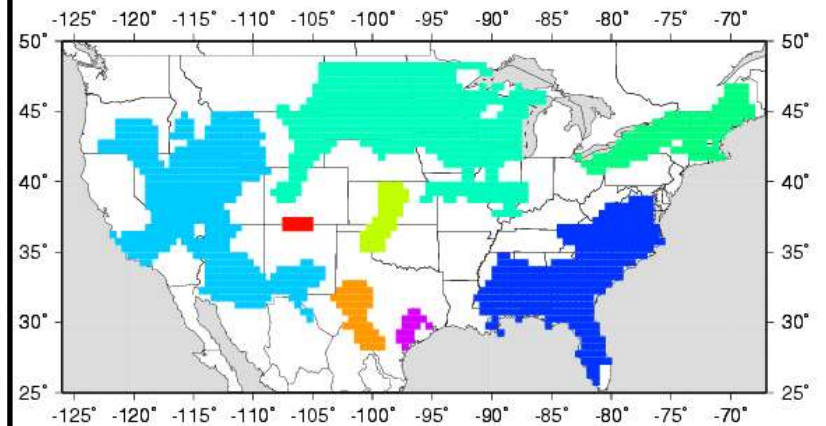
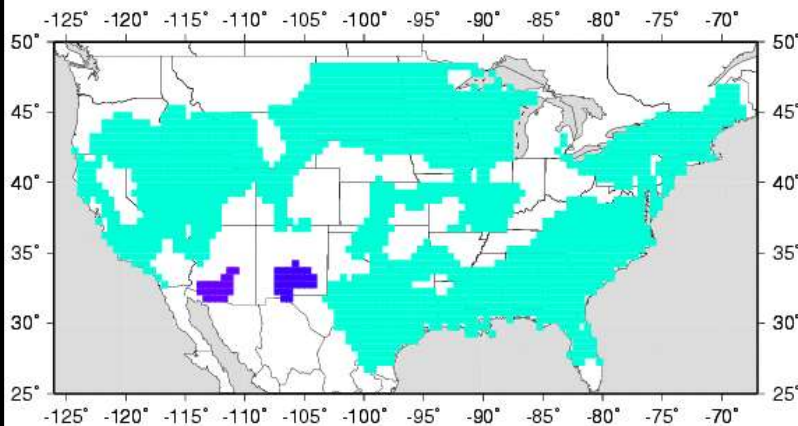
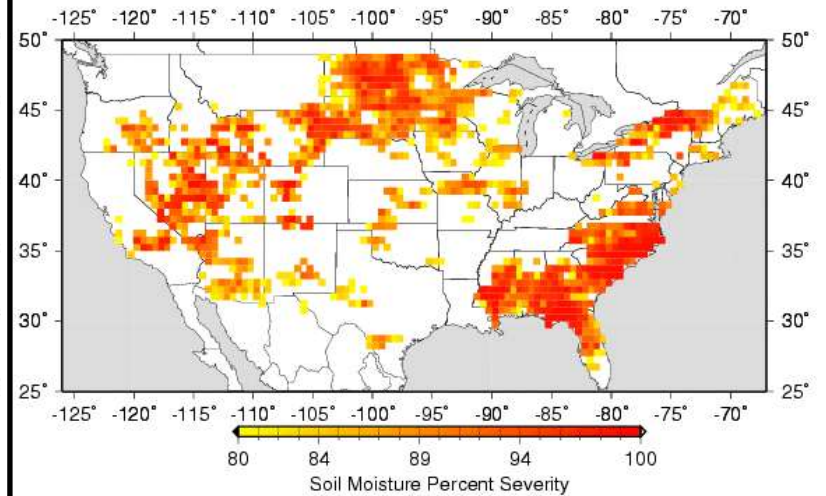


# Evolution of droughts over time

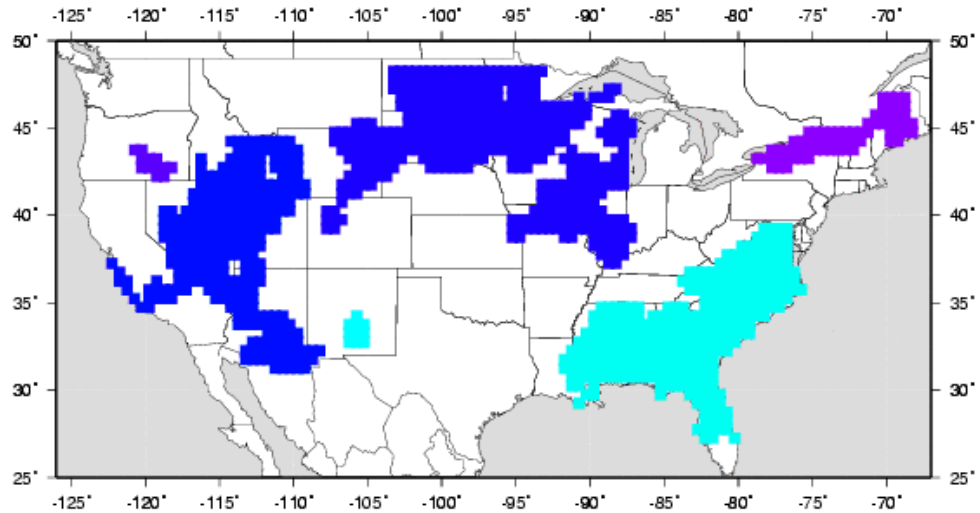
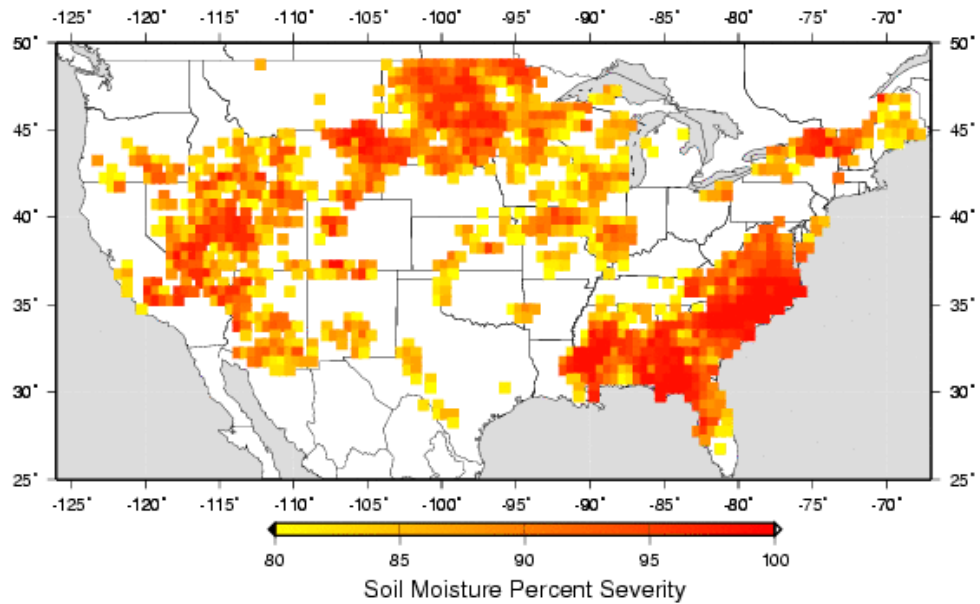
12 1933 Soil Moisture-Defined Drought Extent



01 1934 Soil Moisture-Defined Drought Extent



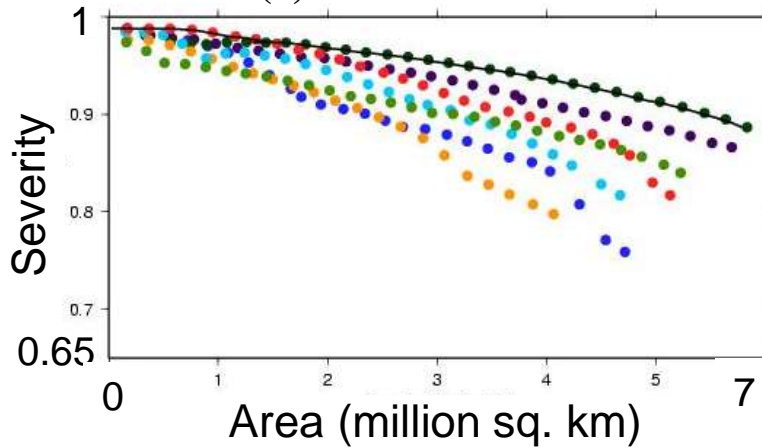
### 01 1934 Soil Moisture-Defined Drought Extent



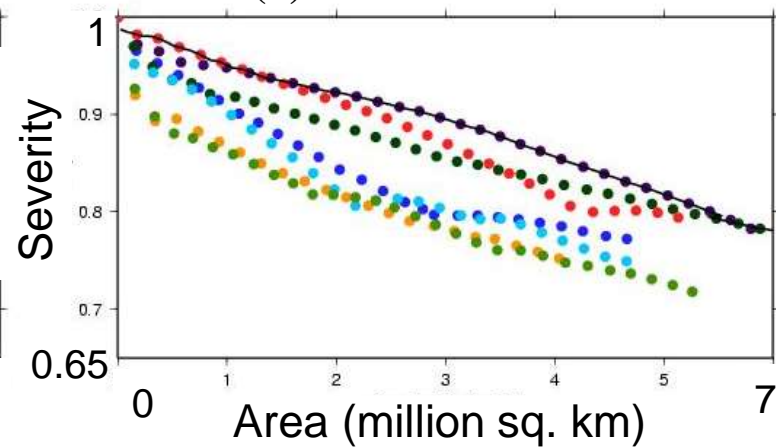
from Andreadis et al., 2005

# Soil Moisture S-A-D Curves

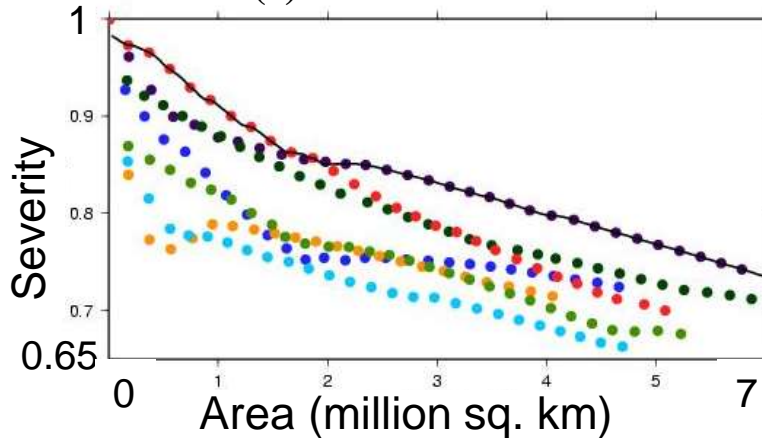
(a) 3 Month Duration



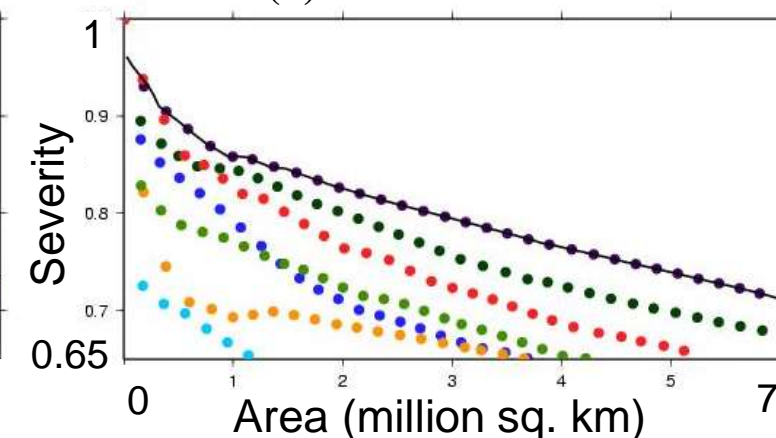
(b) 12 Month Duration



(c) 24 Month Duration



(d) 48 Month Duration



1928-32

1932-38

1950-57

1960-67

1975-79

1987-93

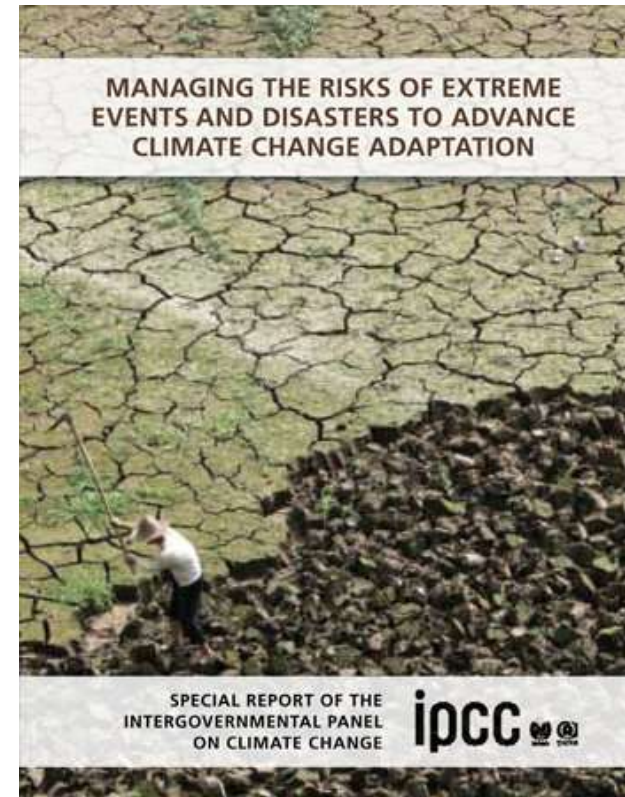
1998-03

# IPCC SRES (2012) report on the increase (or not) of drought

*“... there is medium confidence that since the 1950s some regions of the world have experienced trends toward more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, central North America and northwestern Australia.*

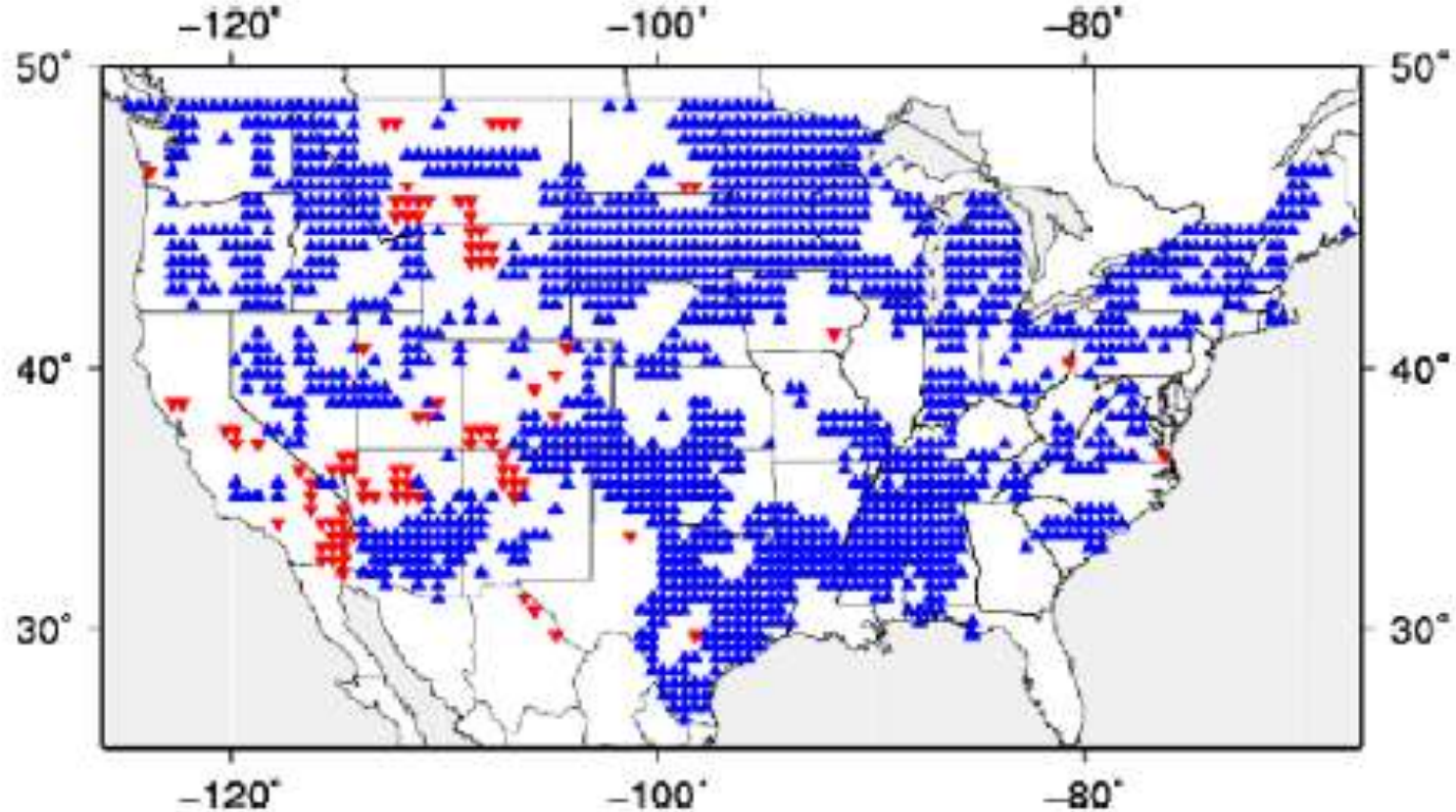
*There is medium confidence that anthropogenic influence has contributed to some changes in the drought patterns observed in the second half of the 20<sup>th</sup> century, based on its attributed impact on precipitation and temperature changes.*

*However there is low confidence in the attribution of changes in droughts at the level of single regions due to inconsistent or insufficient evidence”*



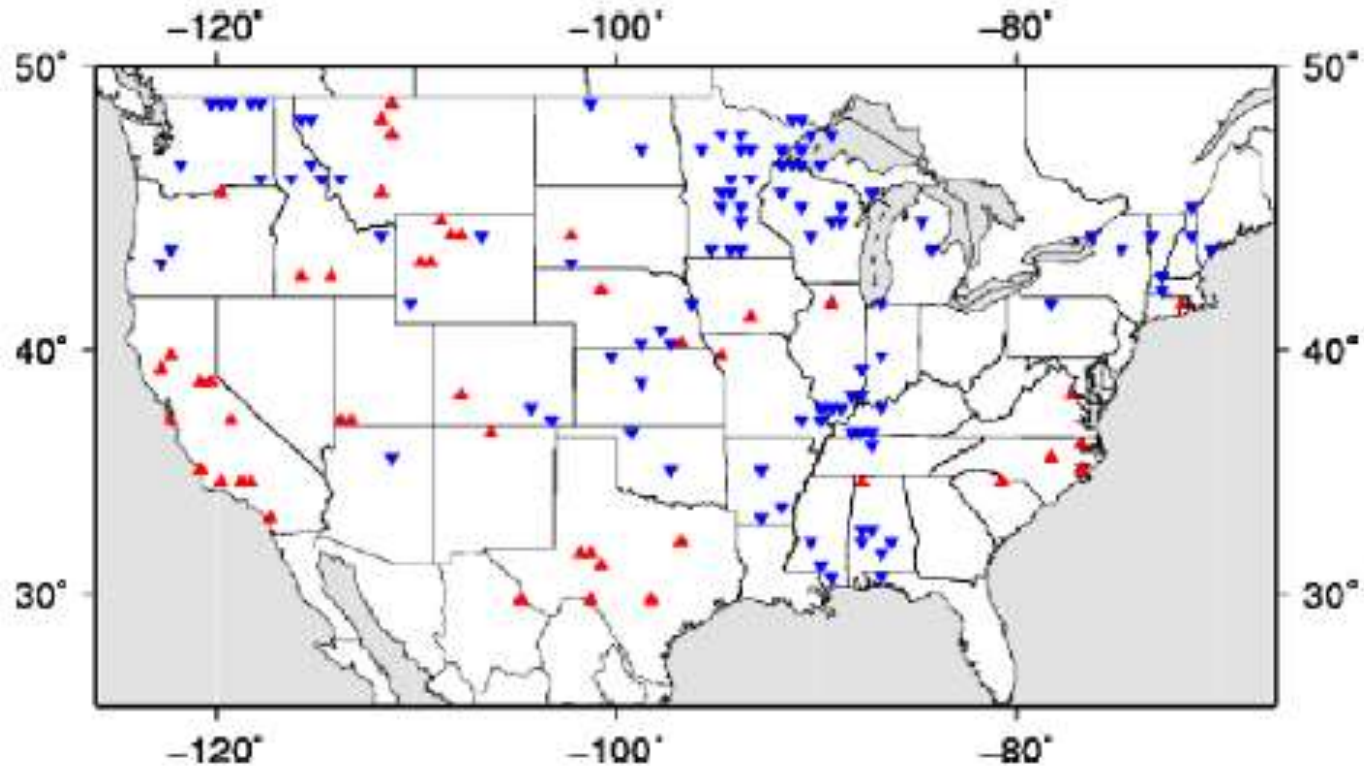
Uncertainty driven by multiple indices, models, datasets, time periods ...

# Reconstructed U.S. soil moisture trends, 1915-2003



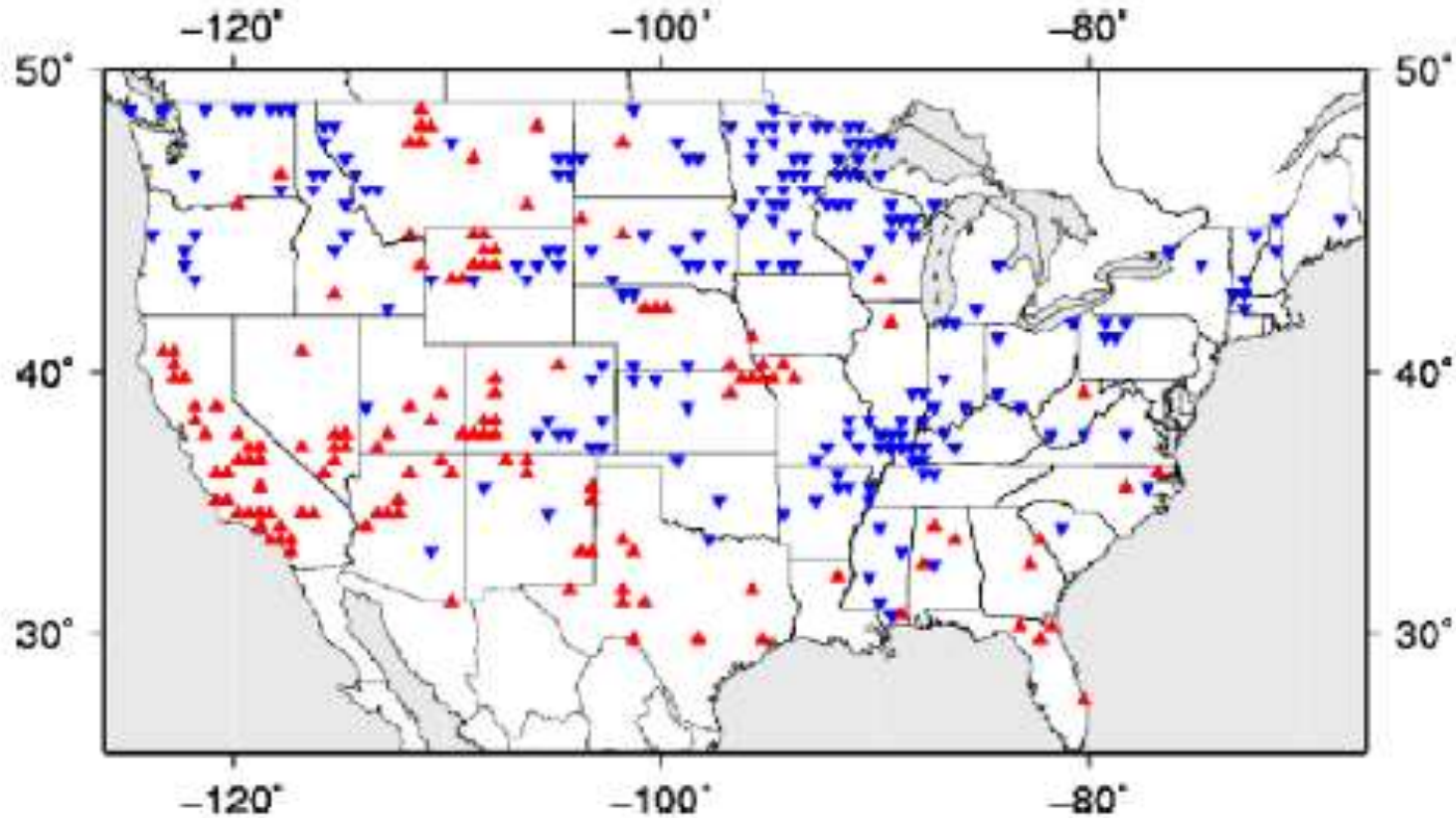
**Figure 1.** Annual trends in model soil moisture. Blue triangles show upward trends, while downward trends are shown as red inverted triangles.

# Trends in U.S. drought duration, 2915-2003



**Figure 3.** Trends in drought duration. Blue inverted triangles show downward trends, and red triangles show upward trends.

# Trends in U.S. drought severity, 1915-2003



**Figure 4.** Trends in drought severity. Upward trends are shown as red triangles, while downward trend as blue inverted triangles.

from Andreadis and Lettenmaier, GRL 2006

# Soil moisture trends in China, 1950-2006

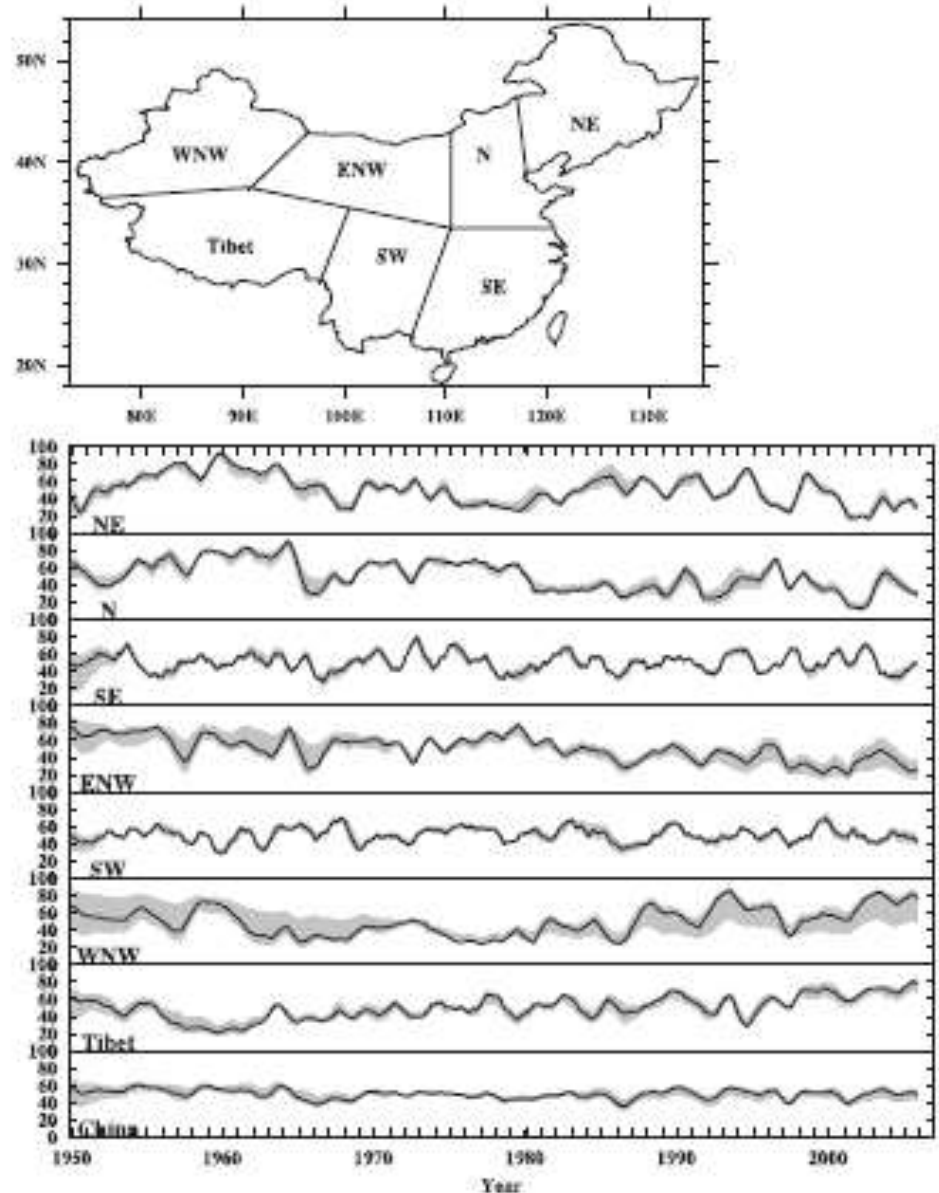


FIG. 1. (top) Location of regions ("China" refers to the entire domain); (bottom) 13-month moving averages of soil moisture percentiles from the ensemble median (dark lines) and range of individual models (gray shading) for the seven regions and China.

# Flash Drought over the United States

Kingtse Mo

Climate Prediction Center

NWS/NOAA

# What is flash drought?

Most obvious from satellite applications (ESI-  
Evaporative Stress Index)

- Heat Waves– High temperature
- Causes Evaporation ET to increase
- Rapid drop in soil moisture SM

# Type 1 flash drought

- Temperature driven events
- High  $T_{air}$  => **increased ET** => decreased SM
- When SM anom < 30% (20%) – D0(D1) - **agricultural drought**

# Type 2 flash drought

1. Precipitation driven
2. Lack of P =>
3. Decrease of SM
4. decrease of ET=>
5. Increase of sensible heat
6. Increase of Tair

Different from Type 1 drought

# Questions:

- Does flash droughts have preferred regions to occur?
- Do they have trends?
- What are physical mechanisms responsible for flash drought?

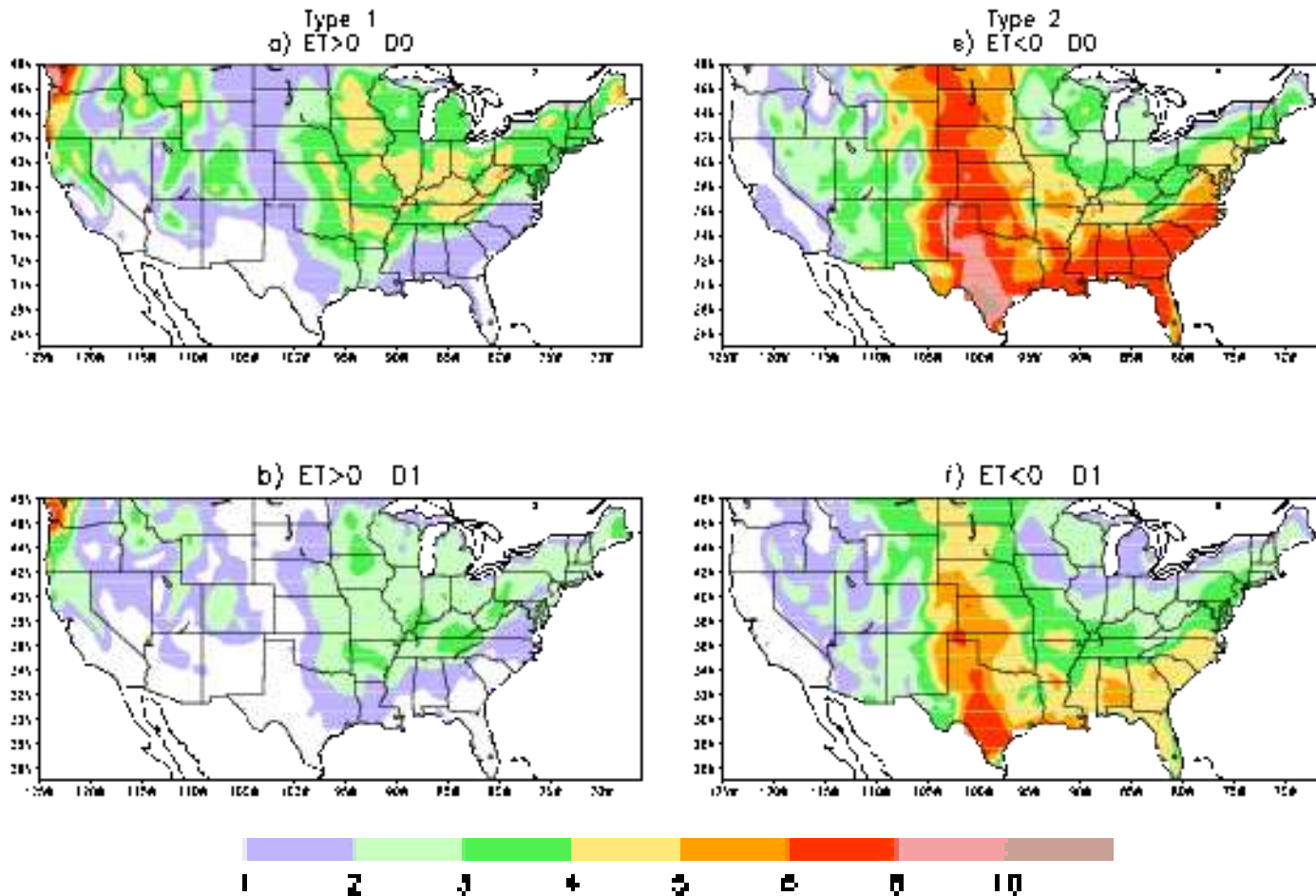
# Data

- **Pentad data:** 5 day means from UW SWM
- **Observations:** Tair , Precipitation (UW)
- **Surface variables:** total soil moisture, (SM) and ET from the VIC, Noah, Catchment and SAC LSMs for 1916-2013, spatial resolution 0.5 degrees lat-long

# Criteria for flash drought

- Common criteria for Type 1 and Type 2
- For each pentad and each grid cell:
- High Tair:  $T_{air\ anom} > 1$  std of  $T_{surf}$  of that pentad
- Drop of SM anom:  $SM(T) - SM(T-1) < 0$
- Agricultural drought:  $SM(T)$  , 30% (D0) 20% (D1)
- ET anom: Type 1:  $ET\ anom > 0$
- Type 2:  $ET\ anom < 0$
- That pentad is defined as **onset**

# Frequency of occurrence (multimodel ensemble mean)



- Select events according to criteria listed on the previous slide
- Add all events  $N$  for each grid point
- $FOC = N / \text{total number of pentads} * 100$

# Occurrence of flash drought

- They do have preferred regions

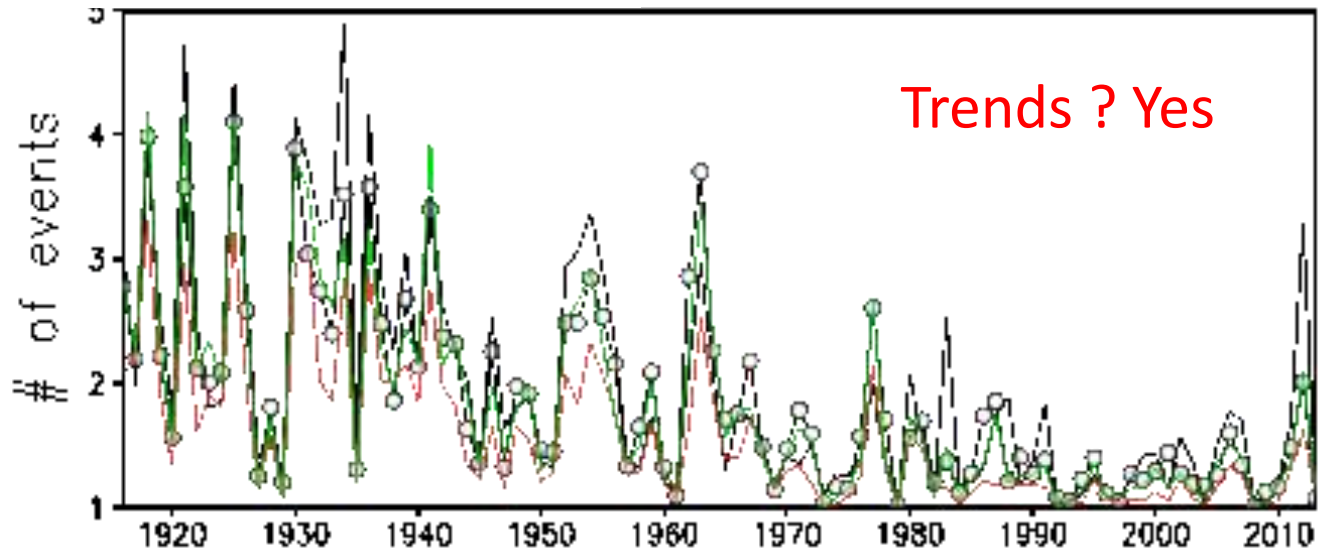
## Type 1 flash drought

- More prevalent over vegetation-dense areas: the Pacific Northwest and the Northeast quadrants including the North Central, the Ohio Basin and the Northeast
- Don't occur often : only 4-5%

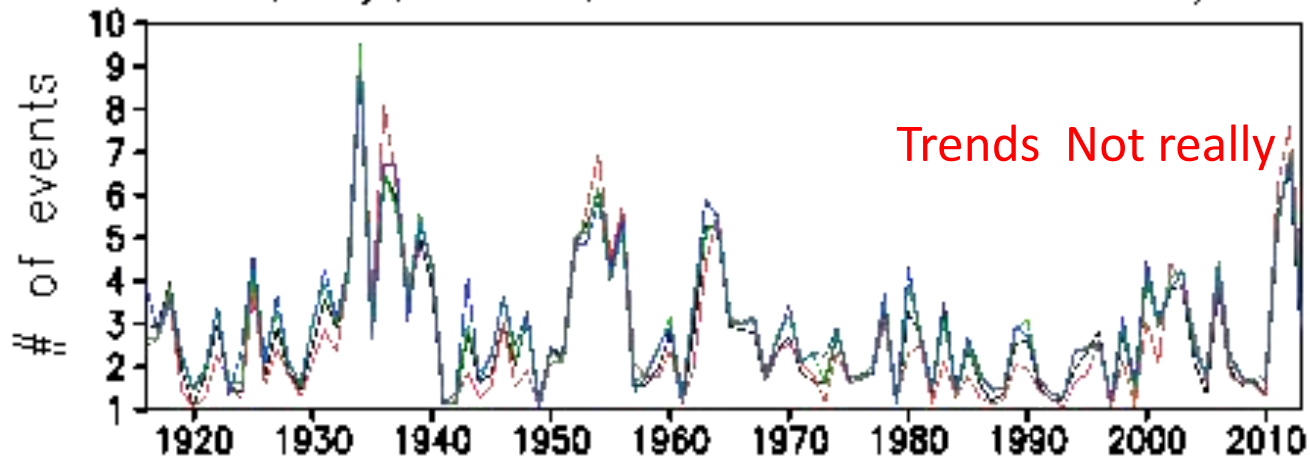
## Type 2 flash drought

- Occurs more often about 6-8%
- Most prevalent along a path from the Southern Great Plains across the South to the Southeast

# Type 1 events/yr (34–42N, 85–100W)



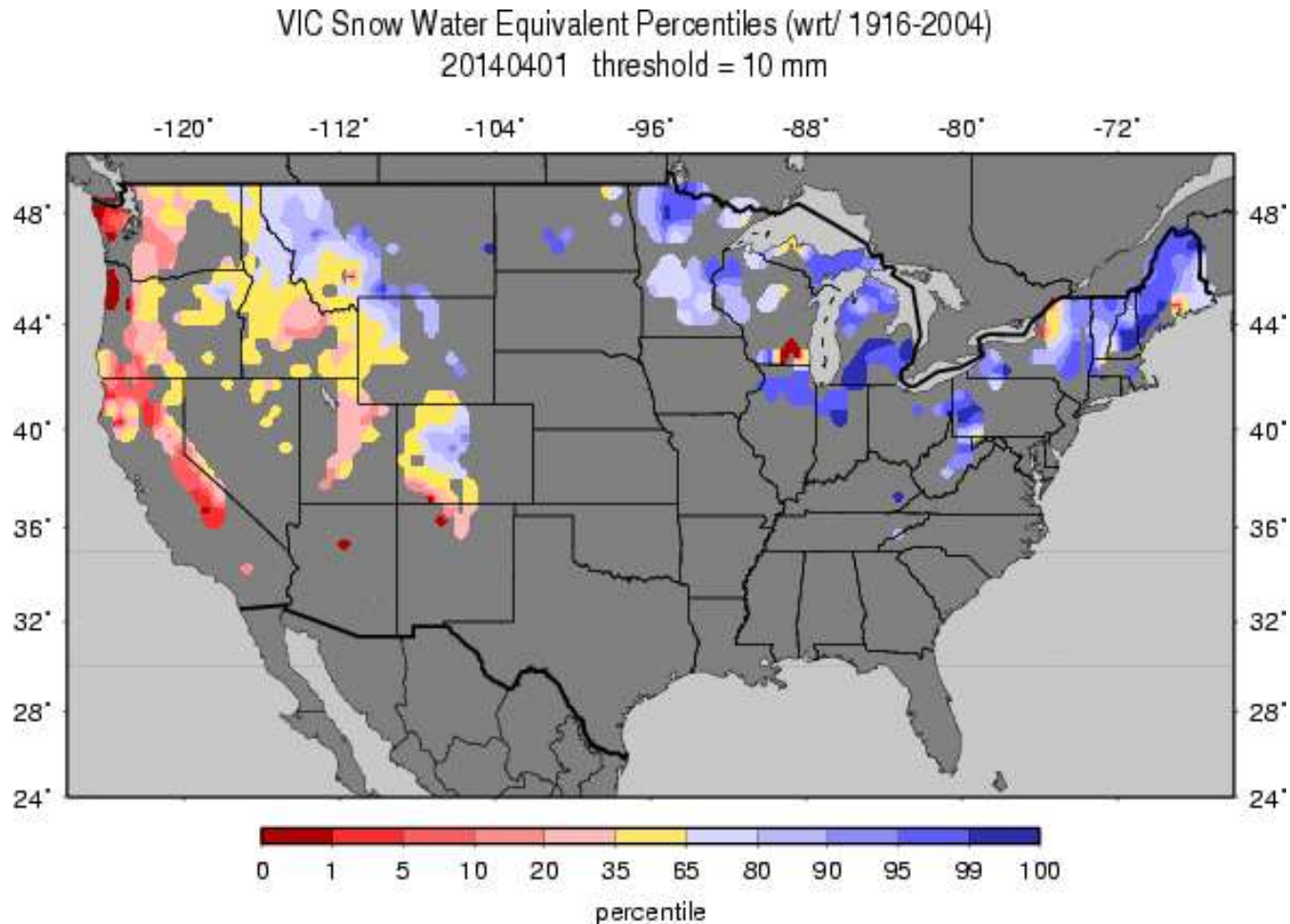
# d) Type 2 (32–42N, 100–105W)



The number of D0-D4 events each year averaged over a box

The 2013-14 California drought –  
is climate change implicated?

# California drought in 2013-2014



**Snowpack 4/1/2014 simulated by the VIC (Variable Infiltration Capacity) model**  
(University of Washington Surface Water Monitor for the Continental U.S.,  
<http://www.hydro.washington.edu/forecast/monitor>)

# California drought in 2013-2014

U.S.

**The New York Times**

## *Severe Drought Has U.S. West Fearing Worst*

By ADAM NAGOURNEY and IAN LOVETT FEB. 1, 2014

The logo for CNN U.S. features the letters "CNN" in a white, stylized font with a red outline, followed by "U.S." in a white, sans-serif font. The entire logo is set against a solid red rectangular background.

## **West's drought leads to rising prices, shrinking lakes**

By Paul Vercammen, CNN

updated 10:17 AM EDT, Fri August 1, 2014

**San Jose Mercury News**

## **California's drought linked to greenhouse gases, climate change in Stanford study**

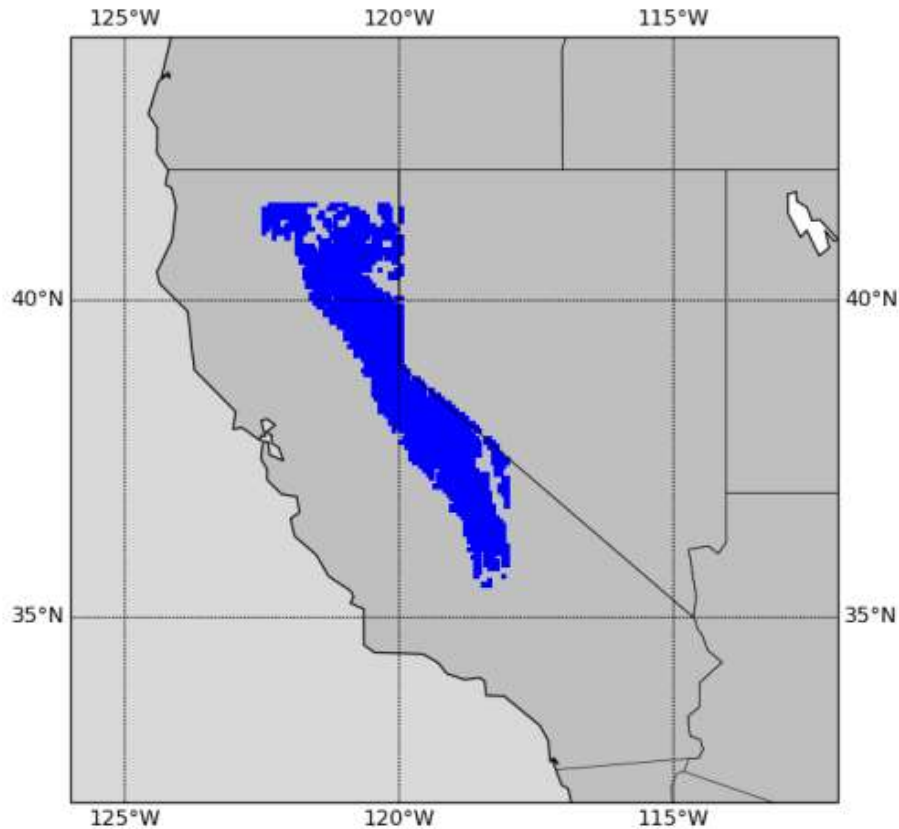
# California drought in 2013-2014

- Did climate change cause this extreme drought event?

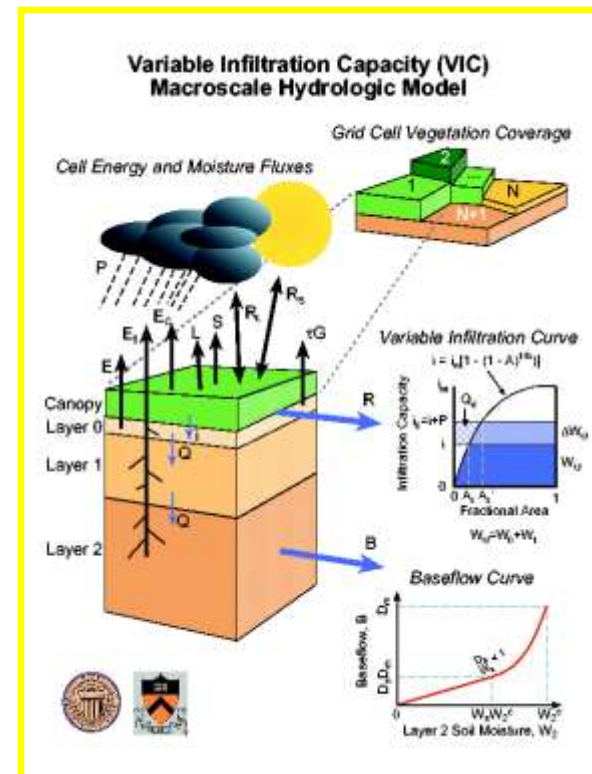
VS.

- Was it simply a result of natural variability?

# Methodology - Study area and period



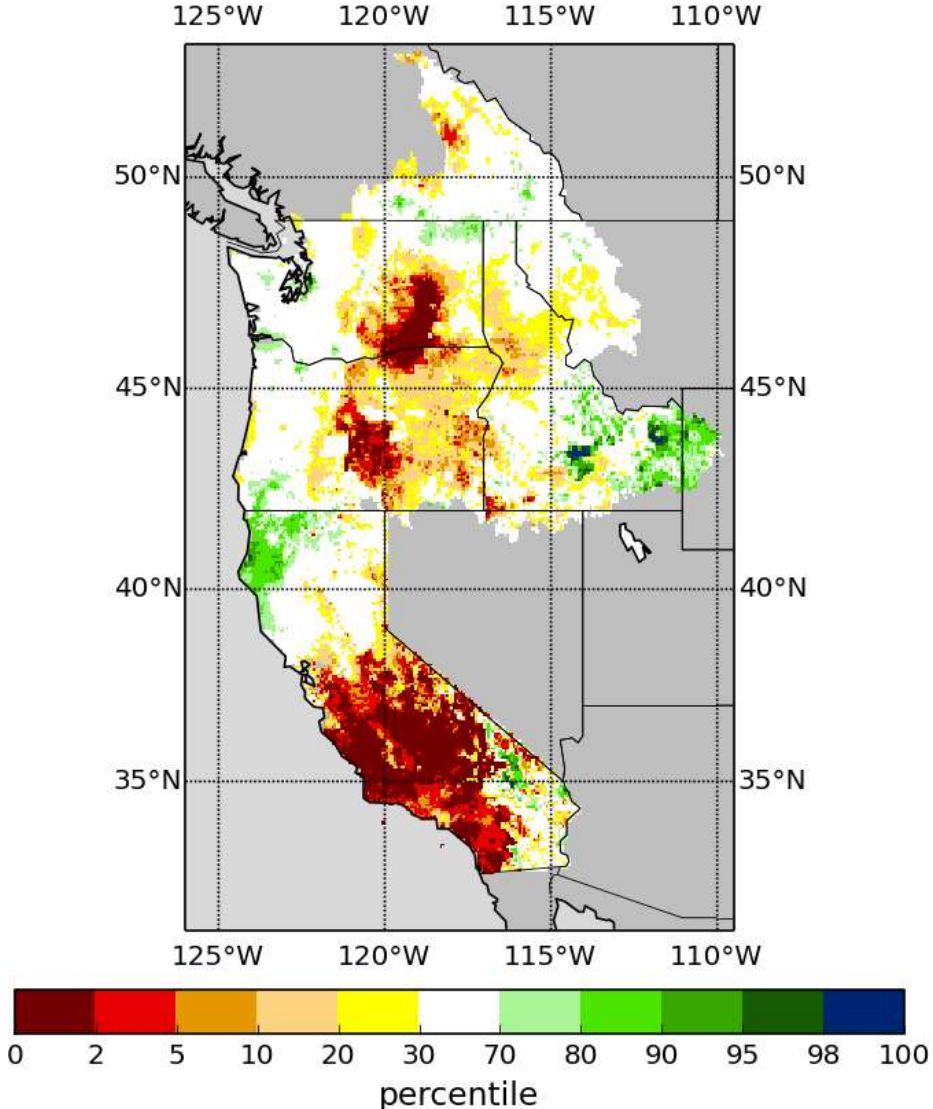
- **Sierra Nevada mountain range**  
- Long-term Apr 1 SWE > 10 mm
- **1920-2014**



# UW Drought Monitoring System for the West Coast Region

## Total Moisture Percentile

2014-10-25



# Methodology - Data

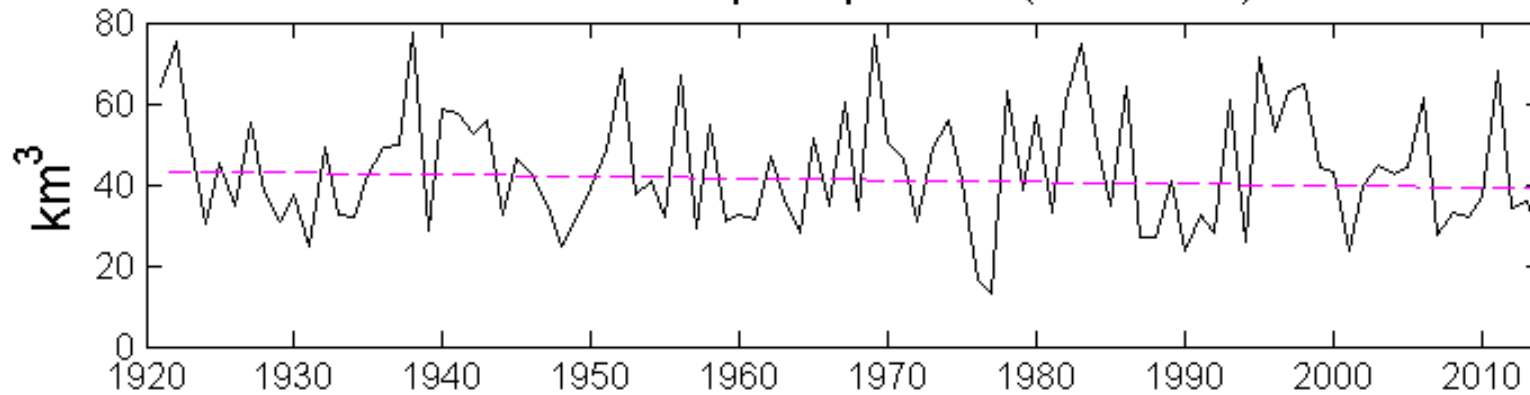
- Daily precipitation (P)
- Daily temperature (T) 1920-2014



- Snow water equivalent (SWE)
- Runoff

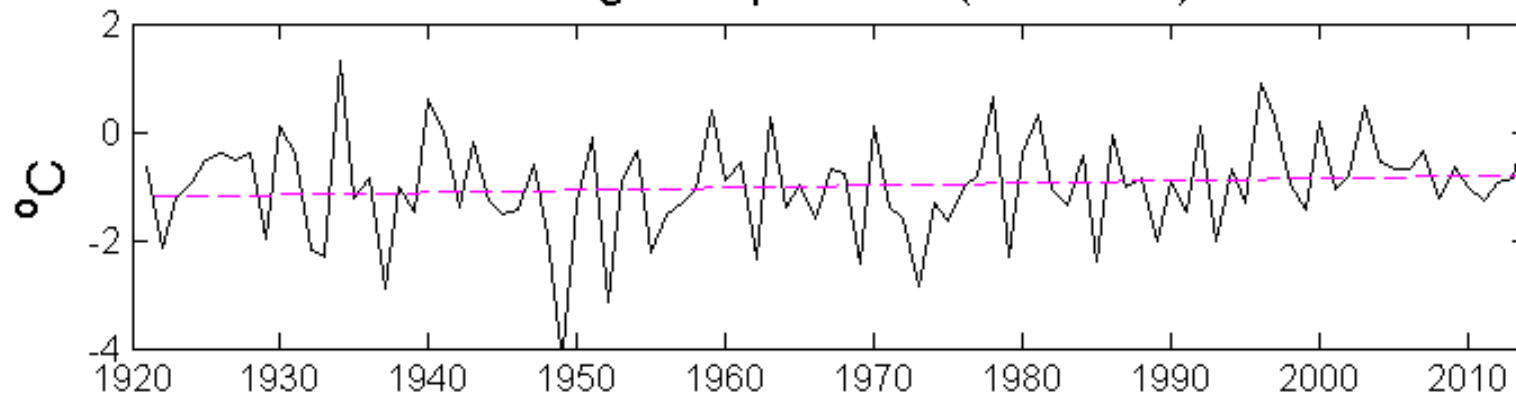
# Trend analysis

## Accumulated precipitation (Nov-Mar)



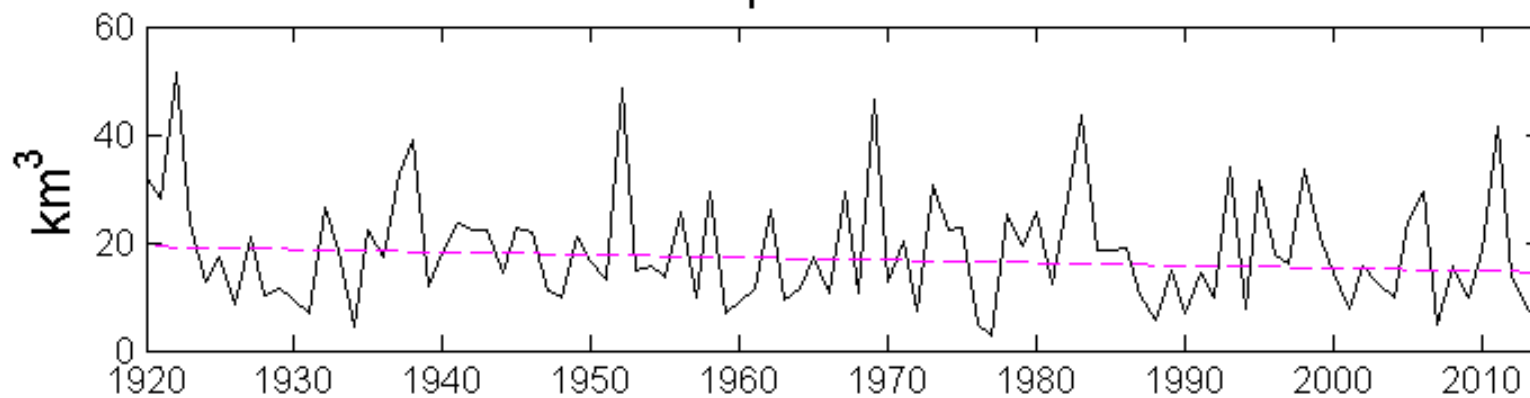
**No trend**

## Average temperature (Nov-Mar)



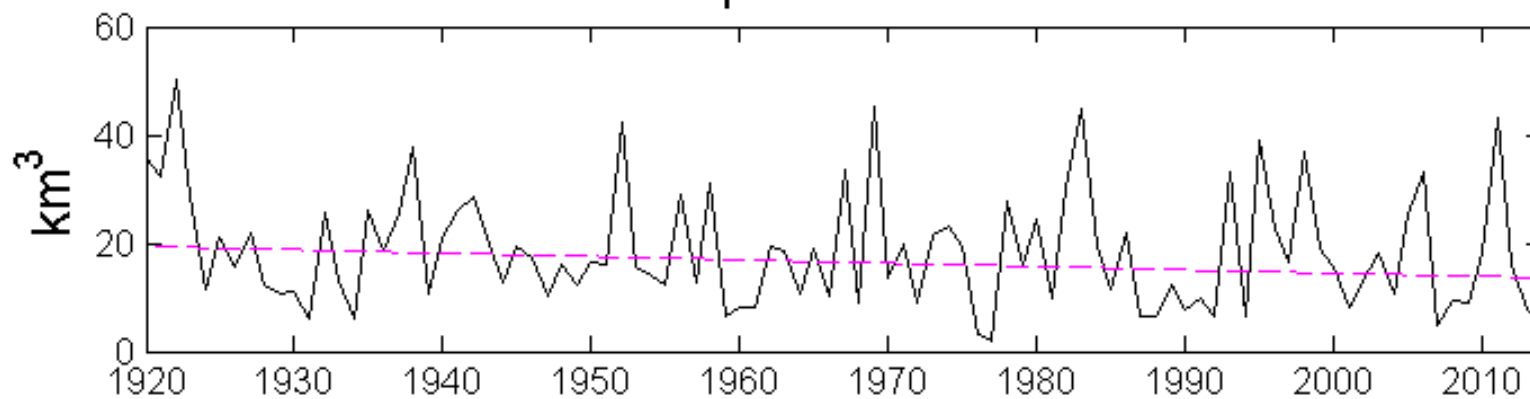
**Increasing trend**

Apr 1 SWE



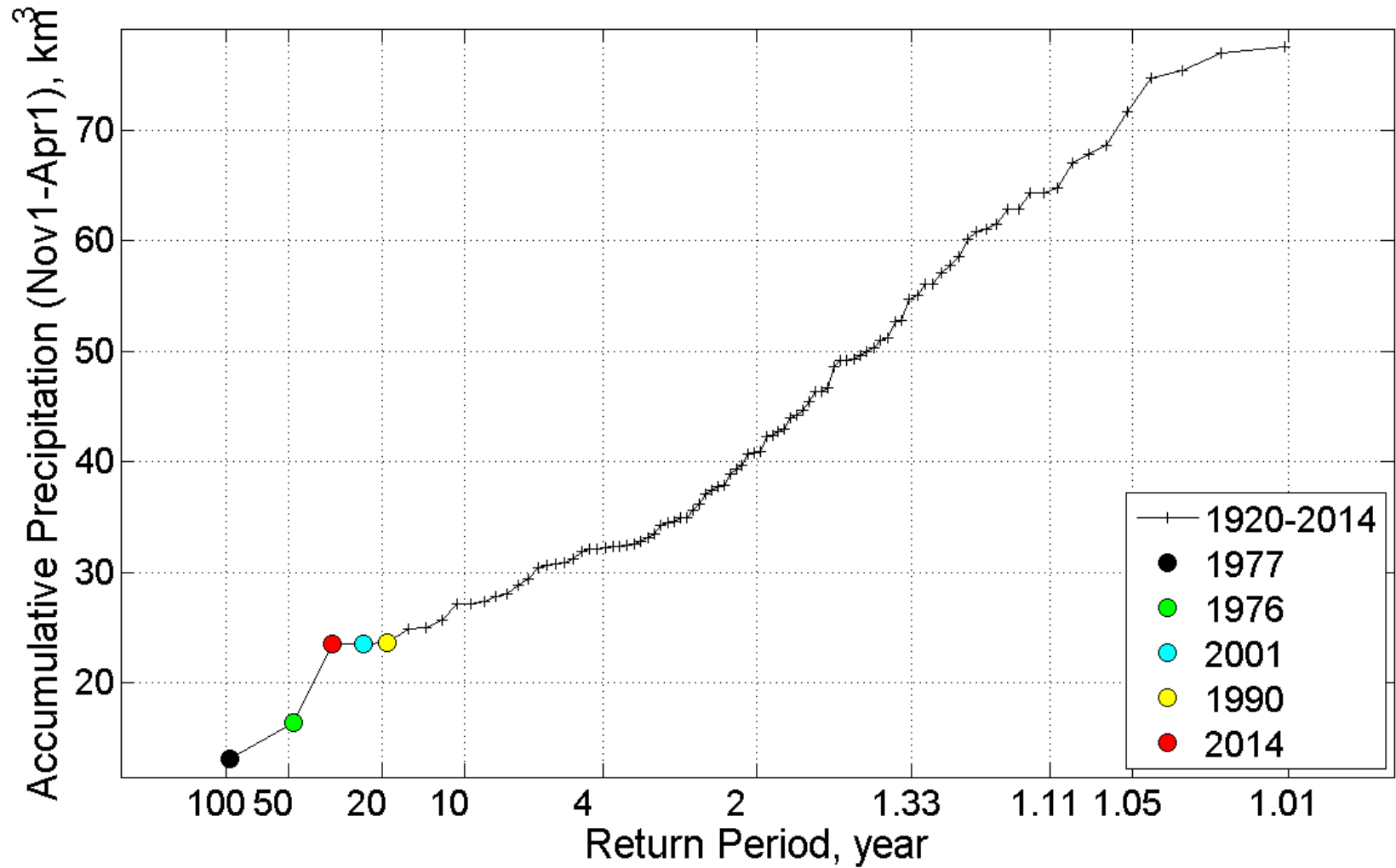
**Decreasing trend**

Apr-Jul runoff

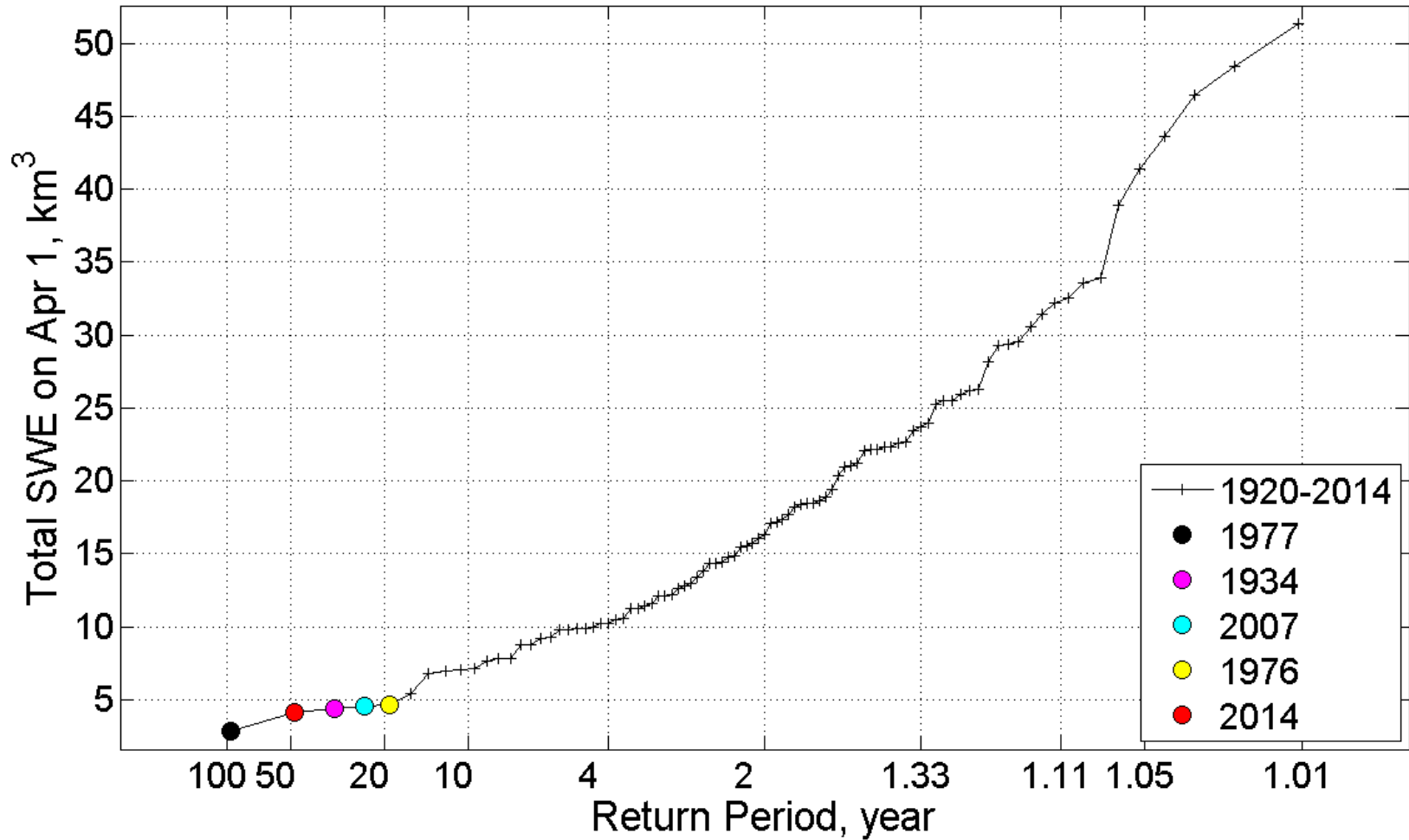


**Decreasing trend**

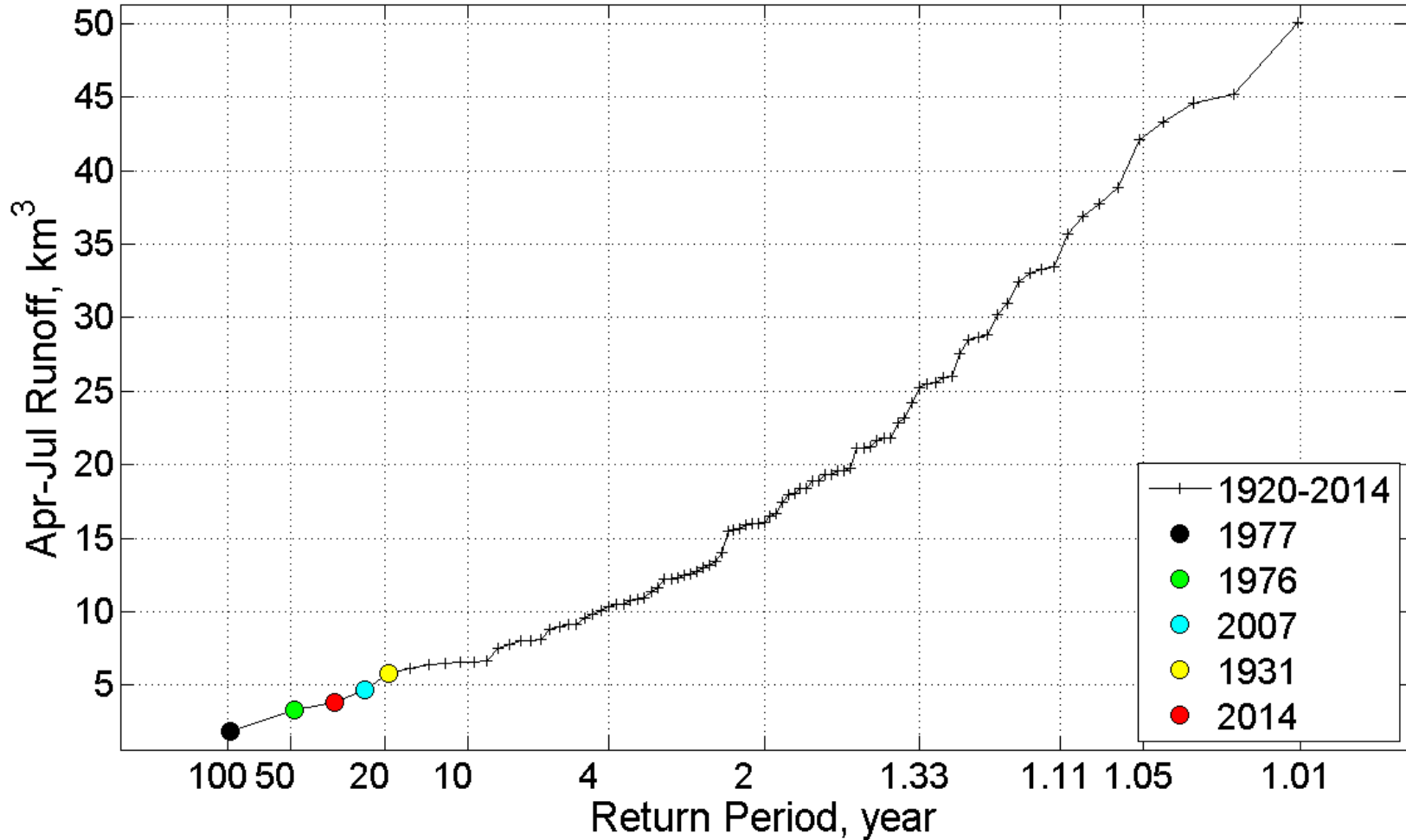
# Winter precipitation



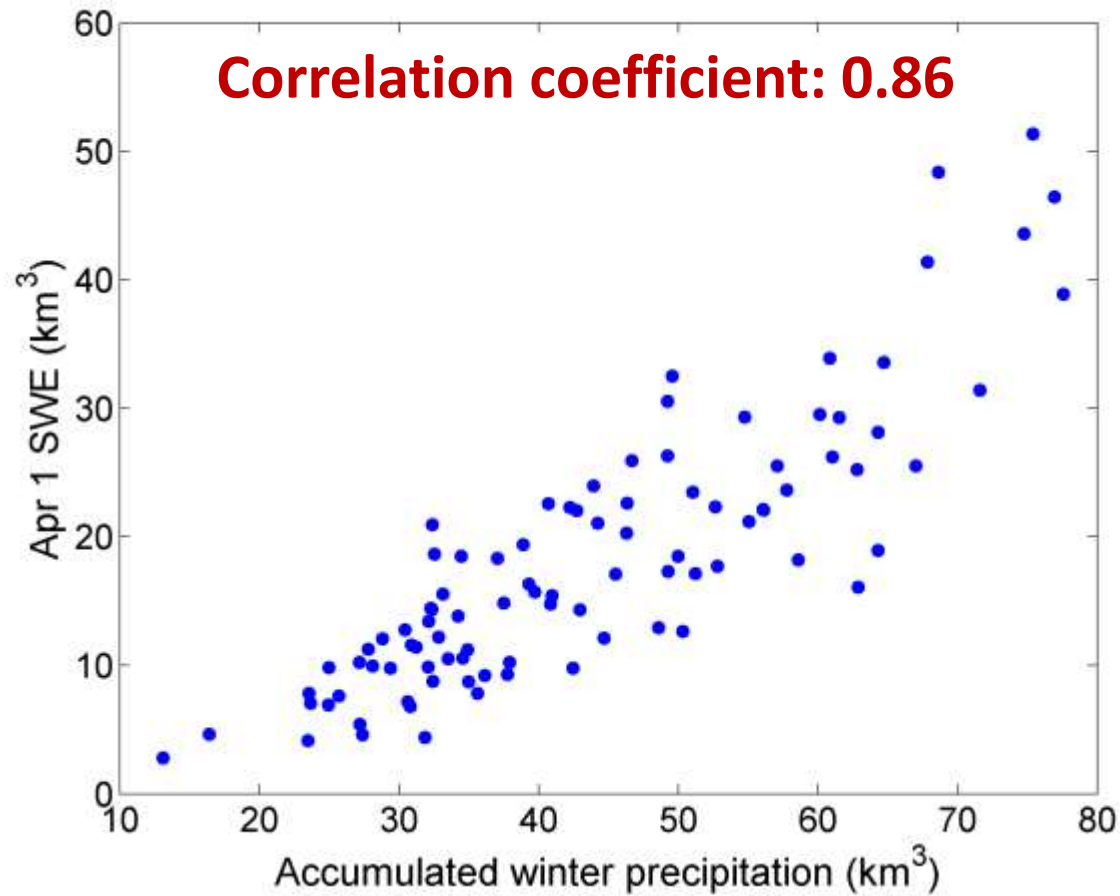
# Apr 1 SWE



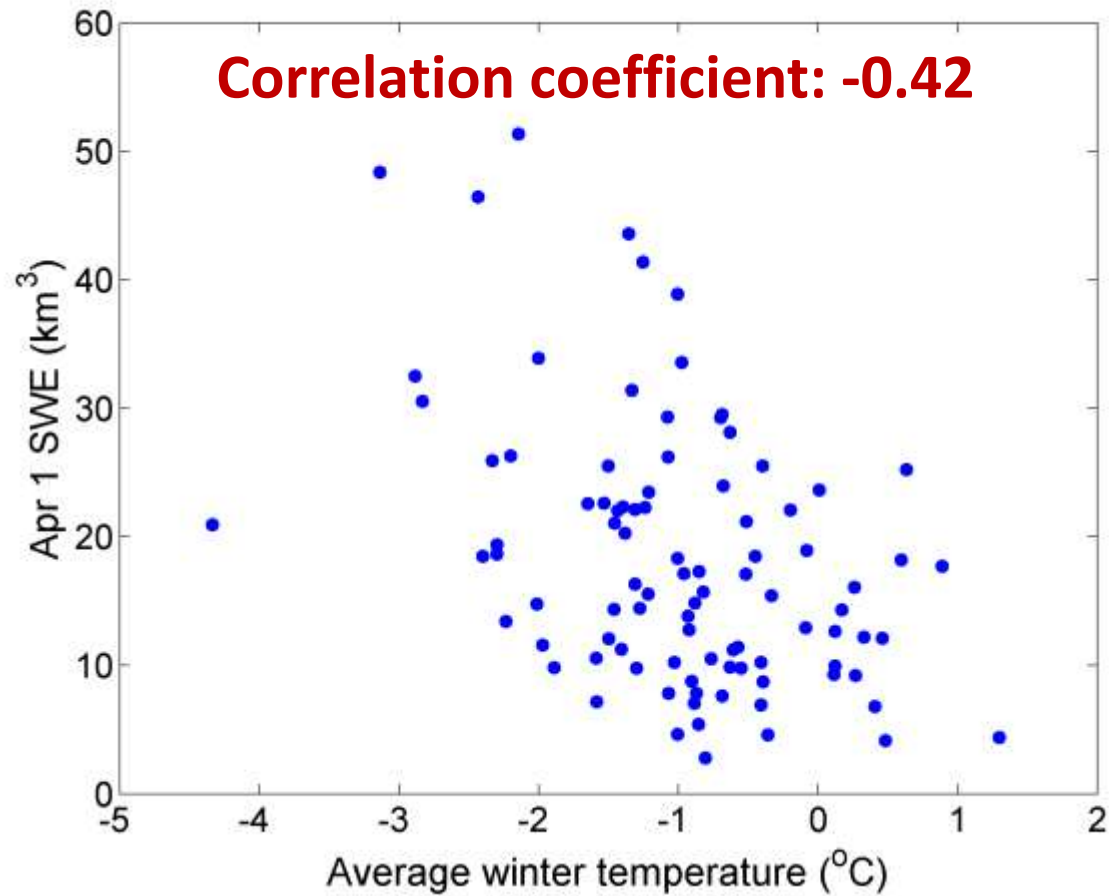
# Spring runoff



# SWE-winter P historical correlation

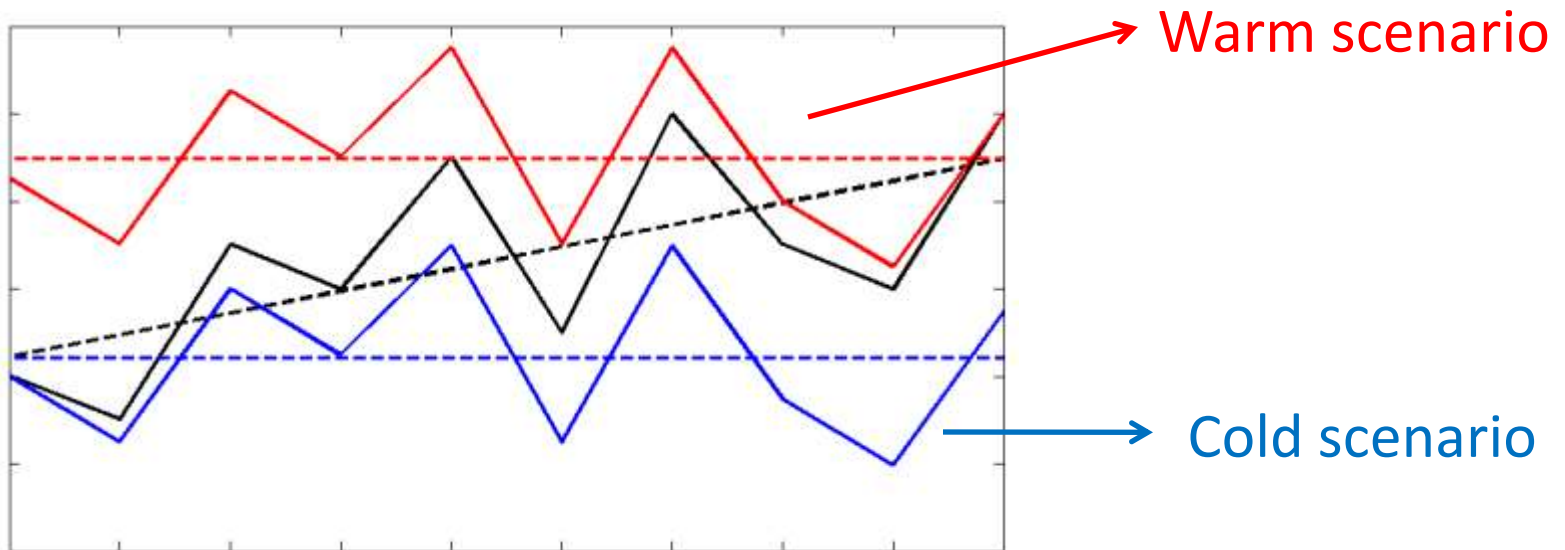


# SWE-winter T historical correlation

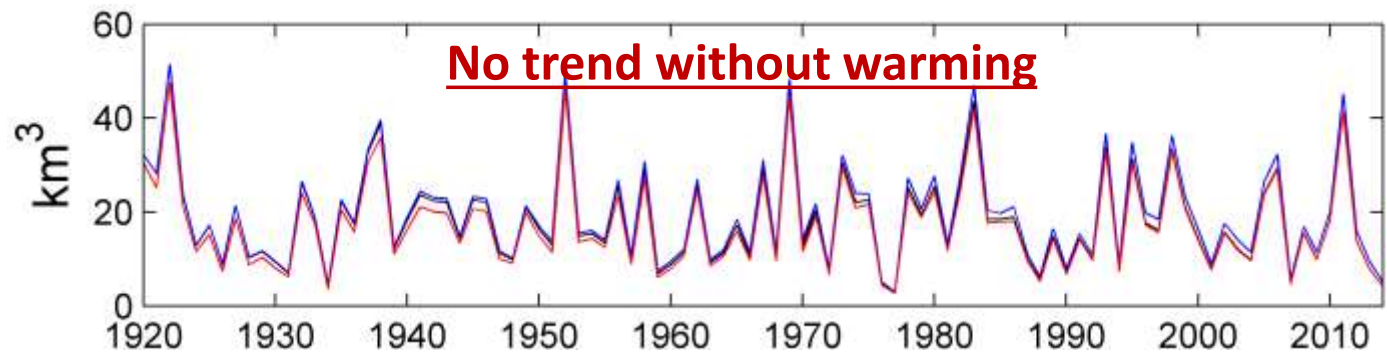


## Detrended-T scenarios

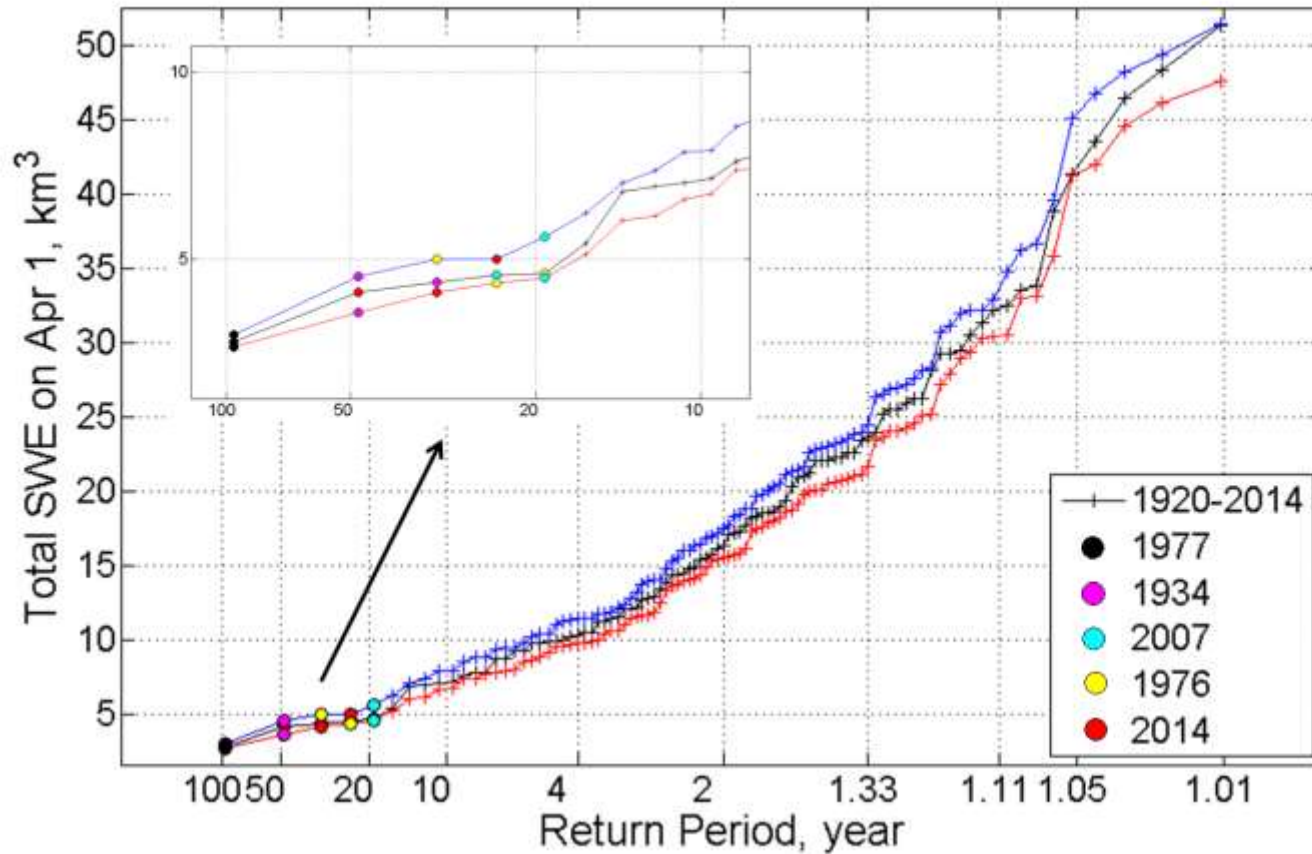
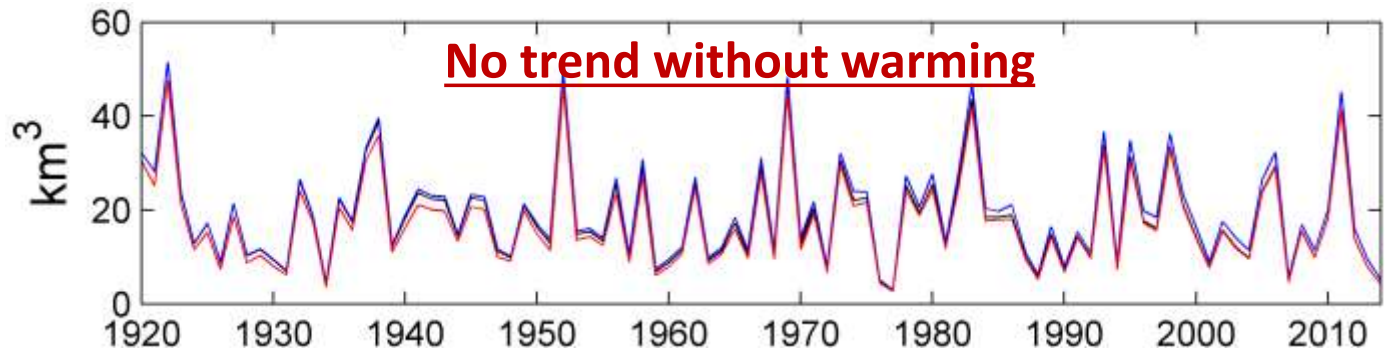
- In addition to the reconstructed time series (the 'base scenario'), we removed the warming trend and simulate hydrological conditions using the VIC model ('Detrended-T scenarios' without climate change)
- Removing long-term T trend; preserving daily variation
- Two detrended-T scenarios:



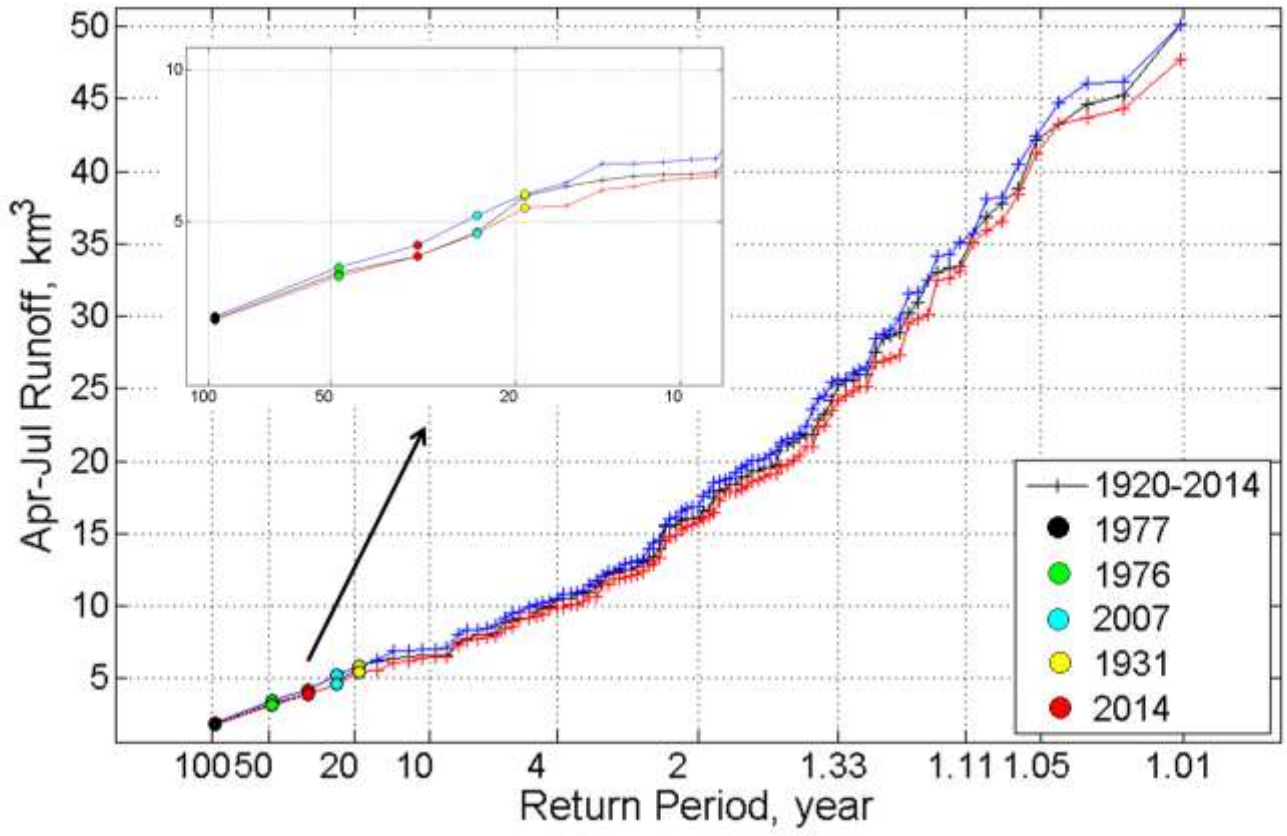
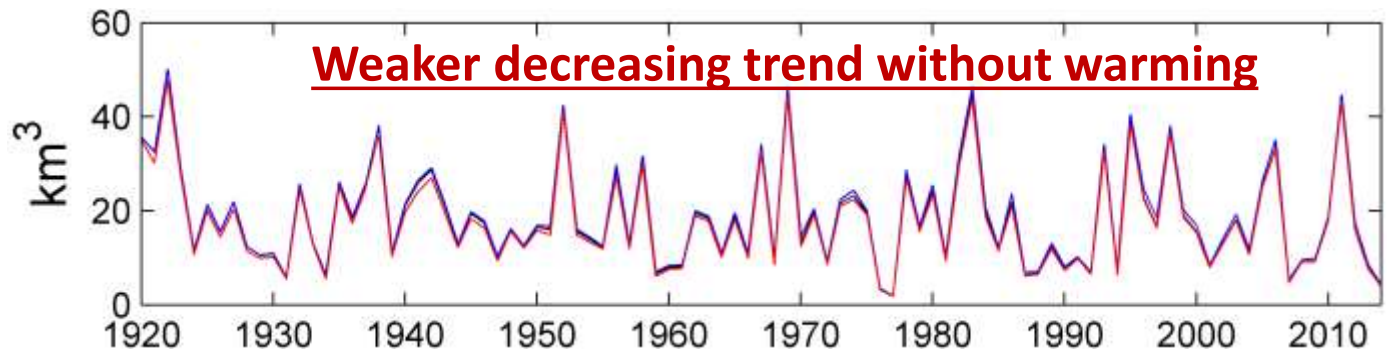
**Apr 1  
SWE**



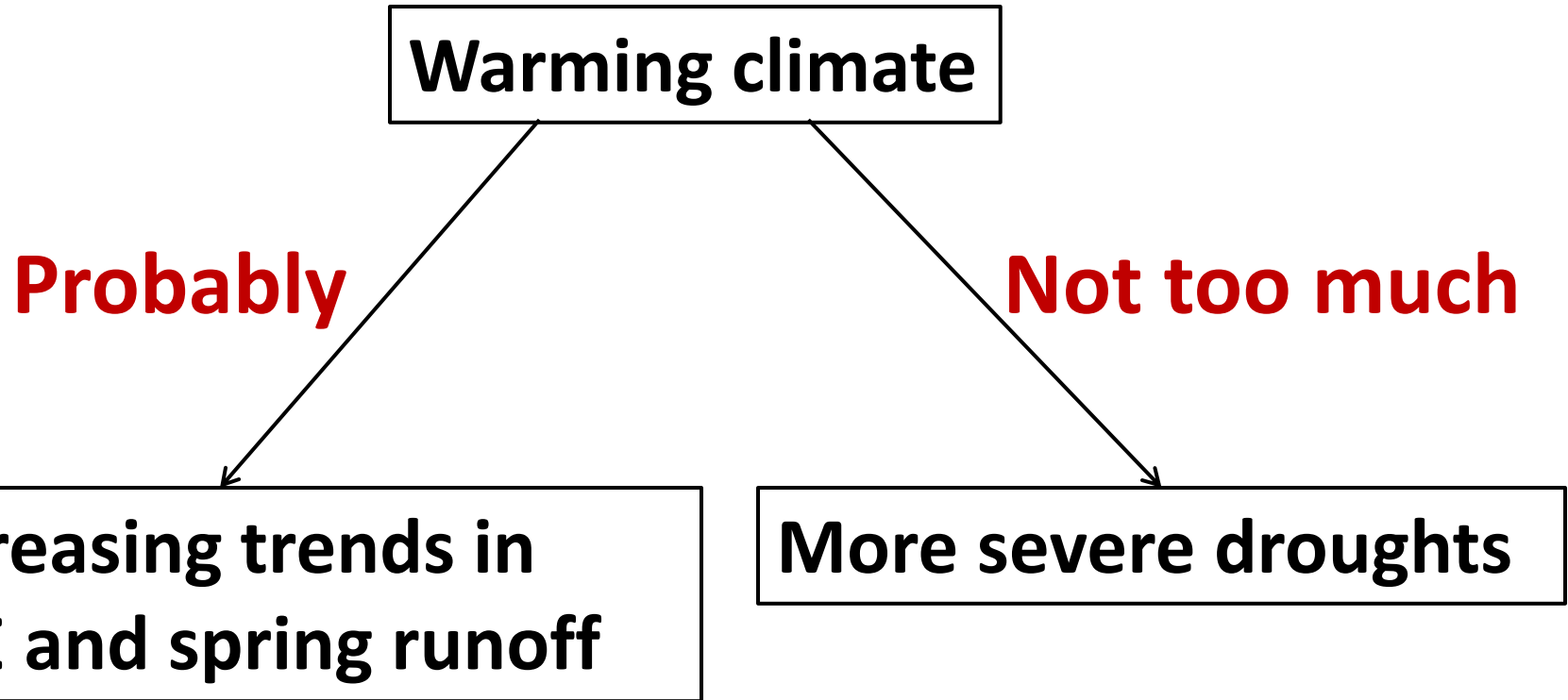
**Apr 1  
SWE**



# Spring runoff



3. Is there a link between climate change and drought events in California?



# So what role has global warming played in the current drought?

- Probably little or none – lots of natural variability in the record, CA droughts mostly occur under La Nina conditions, and last winter was ENSO-neutral
- The last winter (and the previous one to a lesser extent) were anomalously warm, and one can argue that part of this is related to long-term warming
- But – Das et al (2010) show that Sierra (annual) runoff is relatively insensitive to winter warming (vs summer), so arguably it's mostly about timing (when the water goes “under the bridge”)

# Food for thought:

- Climate models mostly predict continental drying (esp. mid latitude), leading to increasing drought frequency, severity, and length – trends that should be showing up by now
- Observations (or at least LSMs driven by observations) generally don't show this – certainly not over continental U.S. (or globally, see Sheffield et al., 2012!) – although there is some (weak) evidence over the Western U.S. that in the balance between (increasing) precipitation and (increased) evaporative demand that some areas are experiencing increased drought incidence
- Is this just a manifestation of natural variability, or is there some fundamental issue in the climatic (e.g. radiative) sensitivity of the global models?