Extreme Weather Events and Climate Change

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Most material presented is from:

"Climate Change 2013: The Physical Science Basis". Intergovernmental Panel on Climate Change (IPCC)

***The views, opinions, and findings contained in this paper are should not be construed as an official National Oceanic and Atmospheric Administration or U.S. government position, policy, or decision.**

Outline

- **Introduction: general anthropogenic effects on the atmosphere**
- **Extreme temperatures: cold and heat waves**
- **Hurricanes and tropical storms**
- **Extratropical storm tracks and intensity**
- **Droughts and floods**
- **Thunderstorms and tornadoes**

Introduction

Human Effects on Climate:

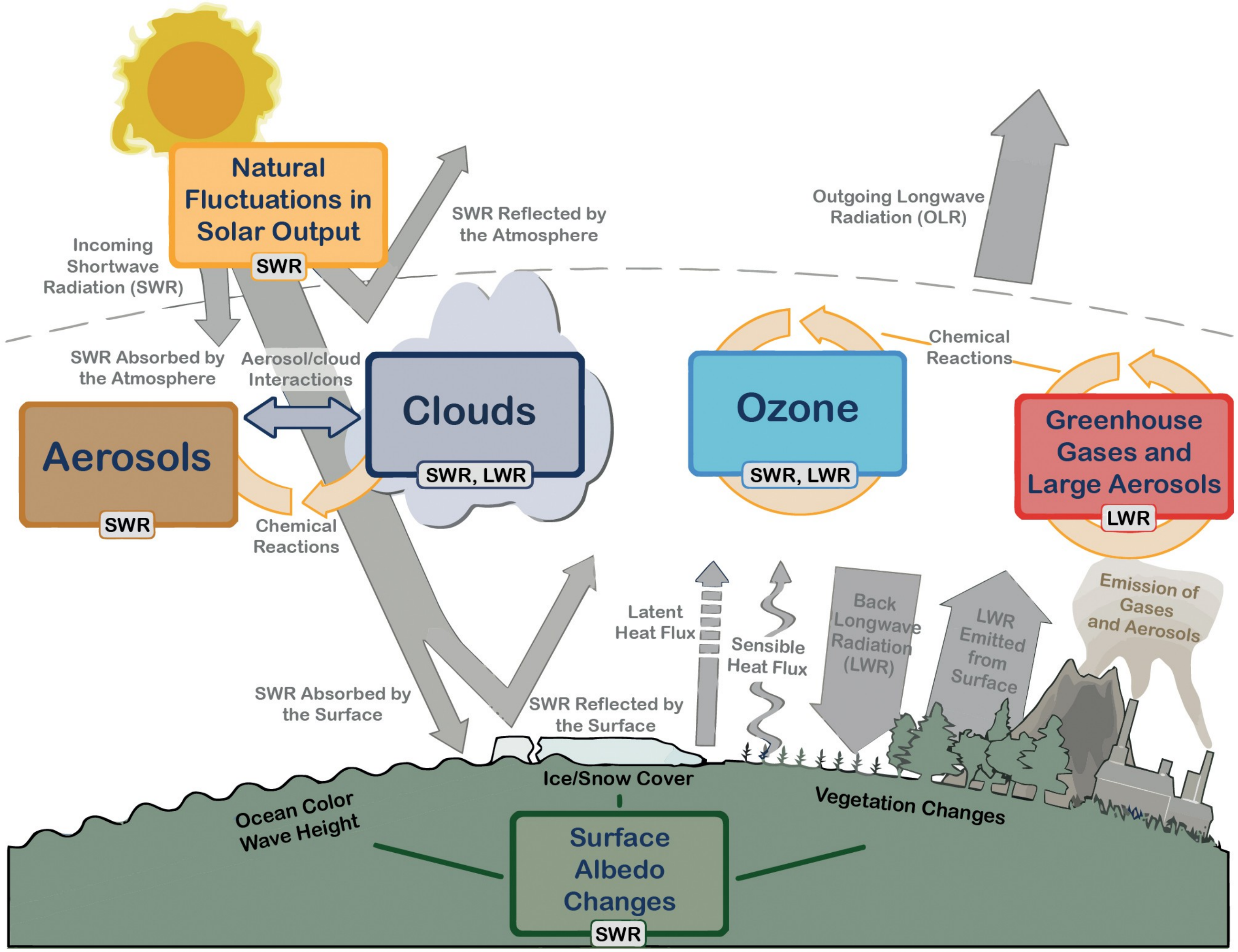
- ***Human activities are continuing to affect the Earth's energy budget emissions:***
  radiatively important gases and aerosols
  changing land surface properties.

- ***In the absence of external forcing, periodic and chaotic variations on a vast range of spatial and temporal scales are observed***.

- ***Global surface air temperatures over land and oceans have increased over the last 100 years.***

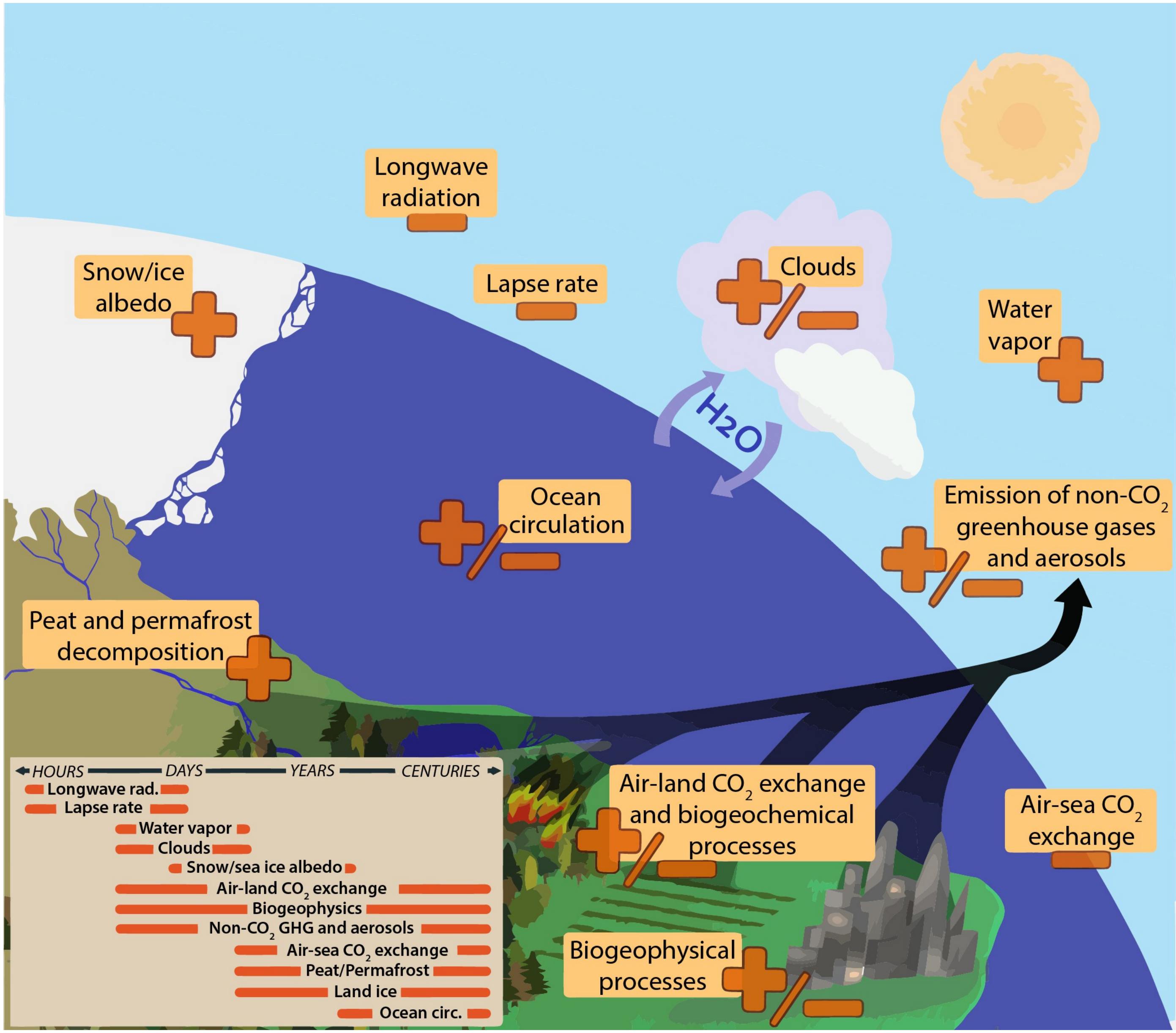
- ***The oceans' uptake of CO2 is having a significant effect on the chemistry of sea water***.

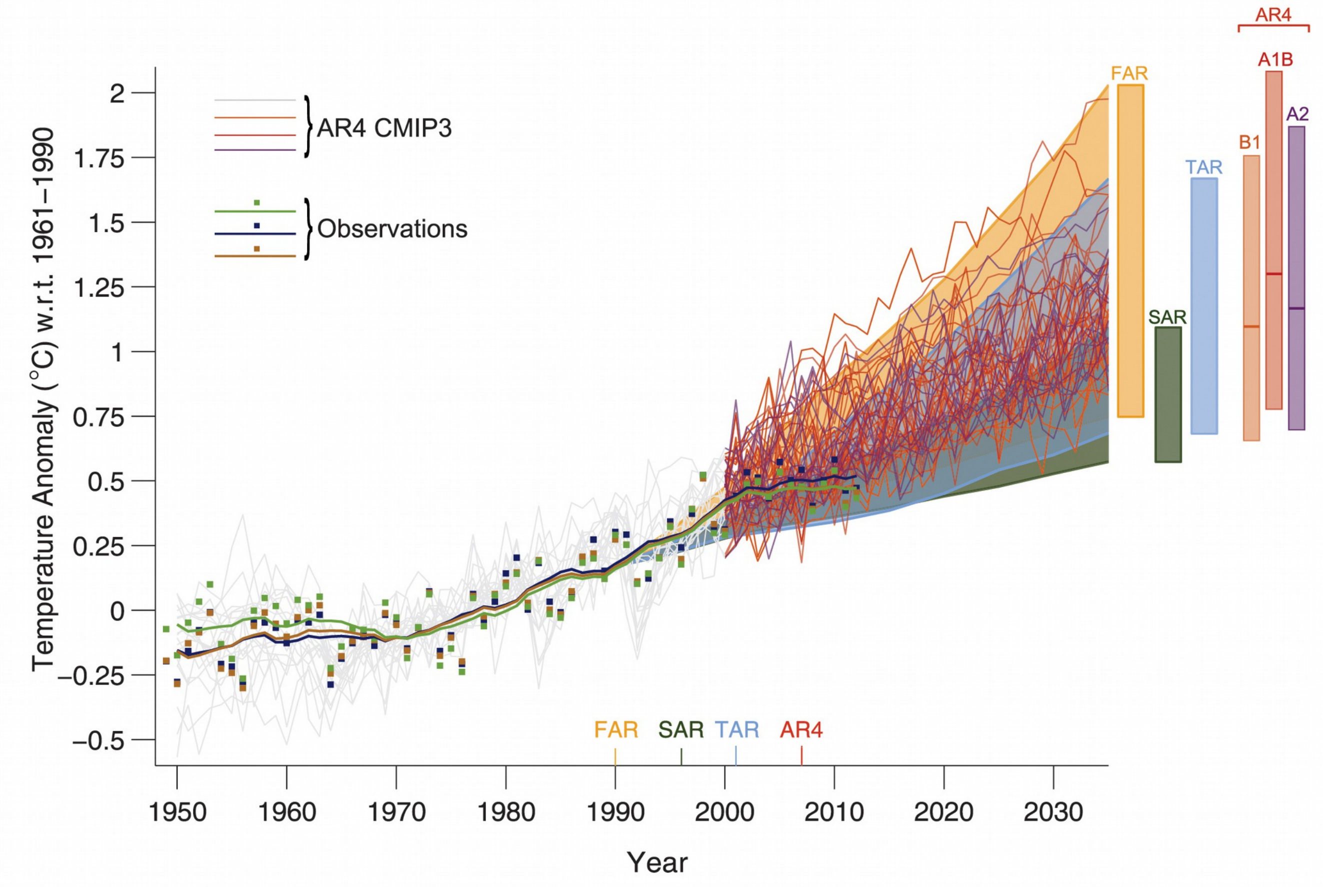
- ***Climate change, whether driven by natural or human forcing, can lead to changes in the likelihood of the occurrence or strength of extreme weather***.



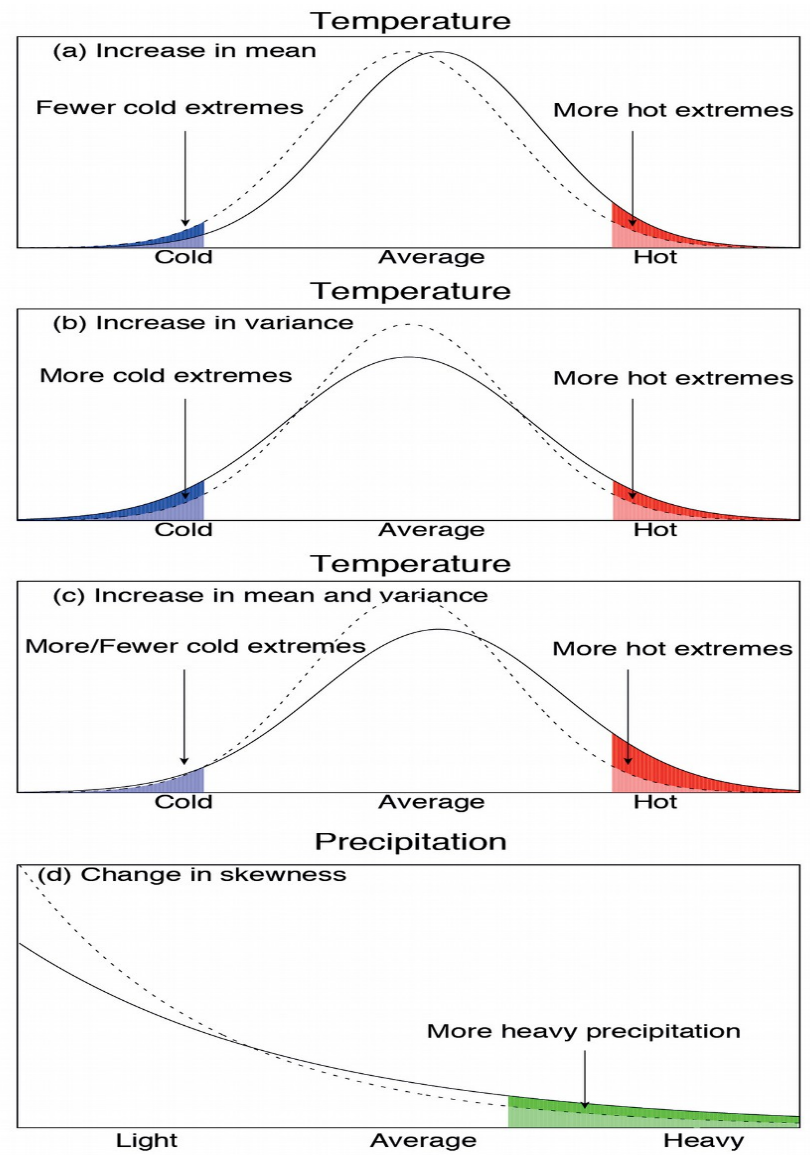
Atmospheric Energy Budget

Completing the Circle:
Land and Ocean interaction with the Atmosphere





Observed and Forecast Global Temperature



Expected Changes in Global Temperature and Precipitation

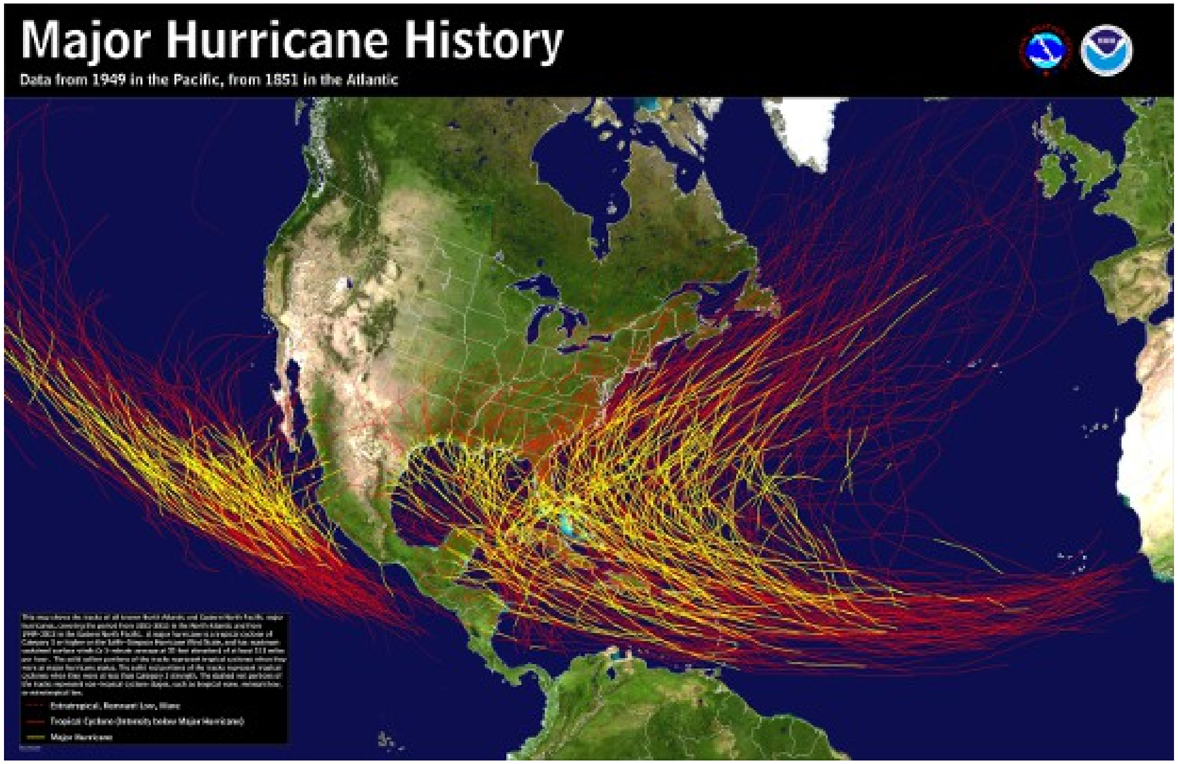
Hurricanes and tropical storms

- ***Global frequency of occurrence of tropical cyclones will either decrease or remain essentially unchanged***
- ***likely increase in both global mean tropical cyclone maximum wind speed and precipitation rates.***
- ***influence of climate change on tropical cyclones is likely to vary by region**, **low confidence in region-specific projections of frequency and intensity**.*
- ***medium confidence that precipitation will be more extreme near the centres of tropical cyclones making landfall in North and Central America***
- ***frequency of the most intense storms will more likely than not increase substantially in some basins***

Track of hurricanes:

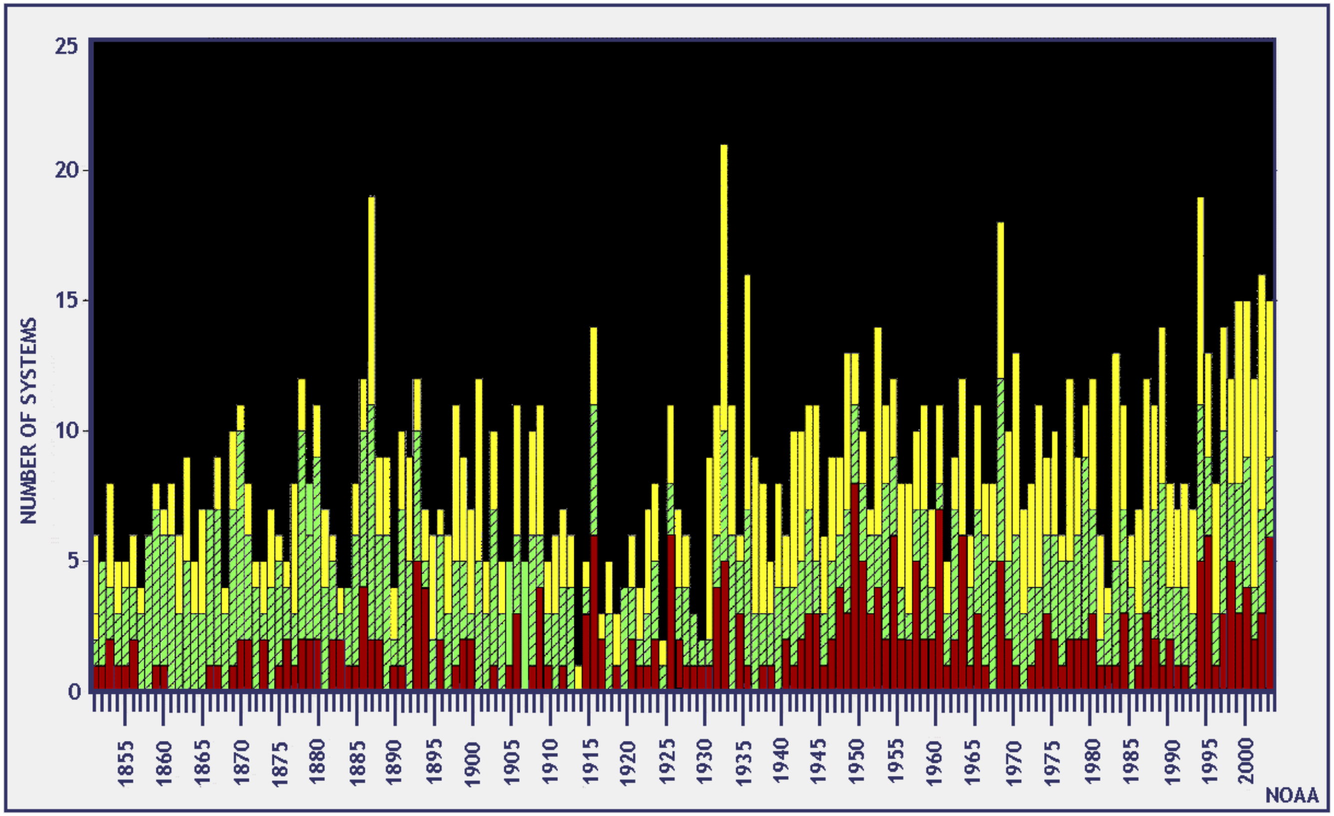
Data from 1949 in the Pacific, from 1851 in the Atlantic

http://www.nhc.noaa.gov/climo/images/1851_2013_mjrhurr.jpg

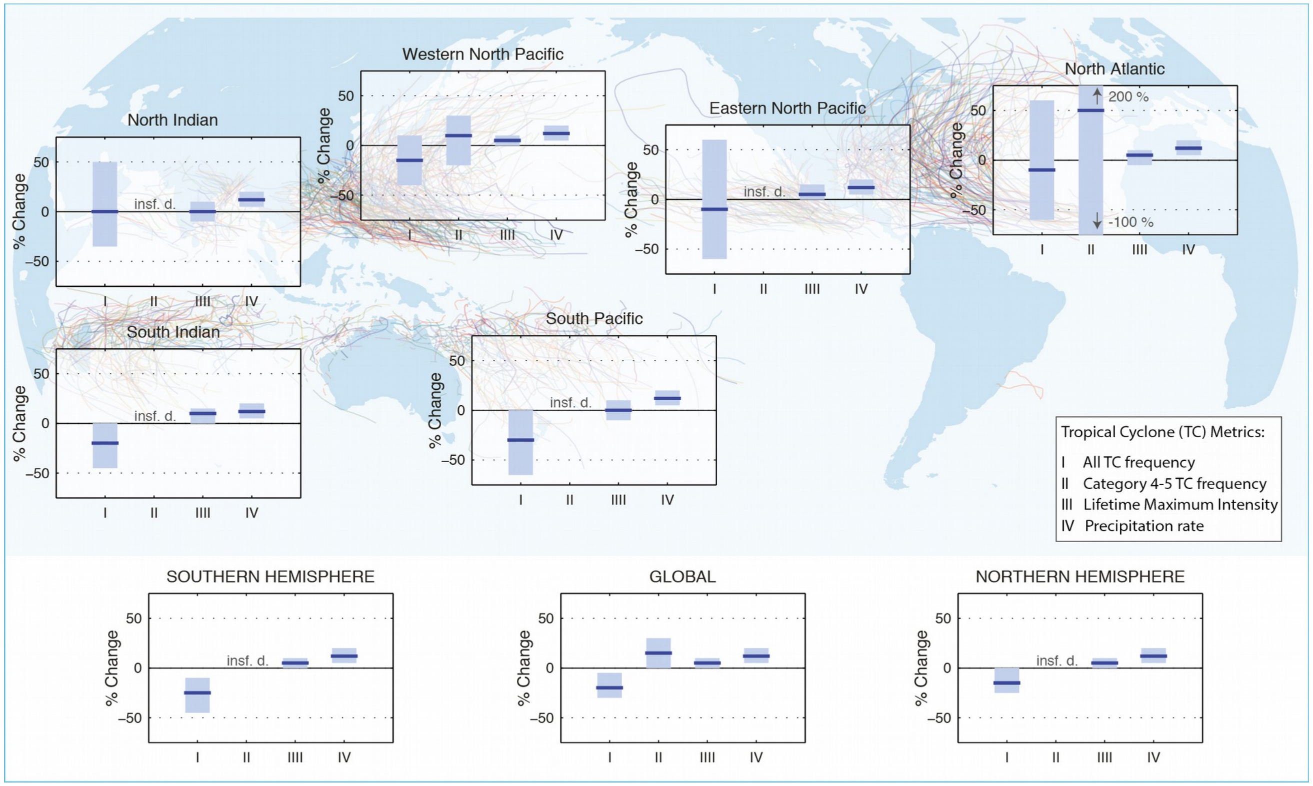


Yellow: Major Hurricane
Red: Tropical Storms
Red (dashed): Remnant Storm

Number of tropical systems (1855-2008)

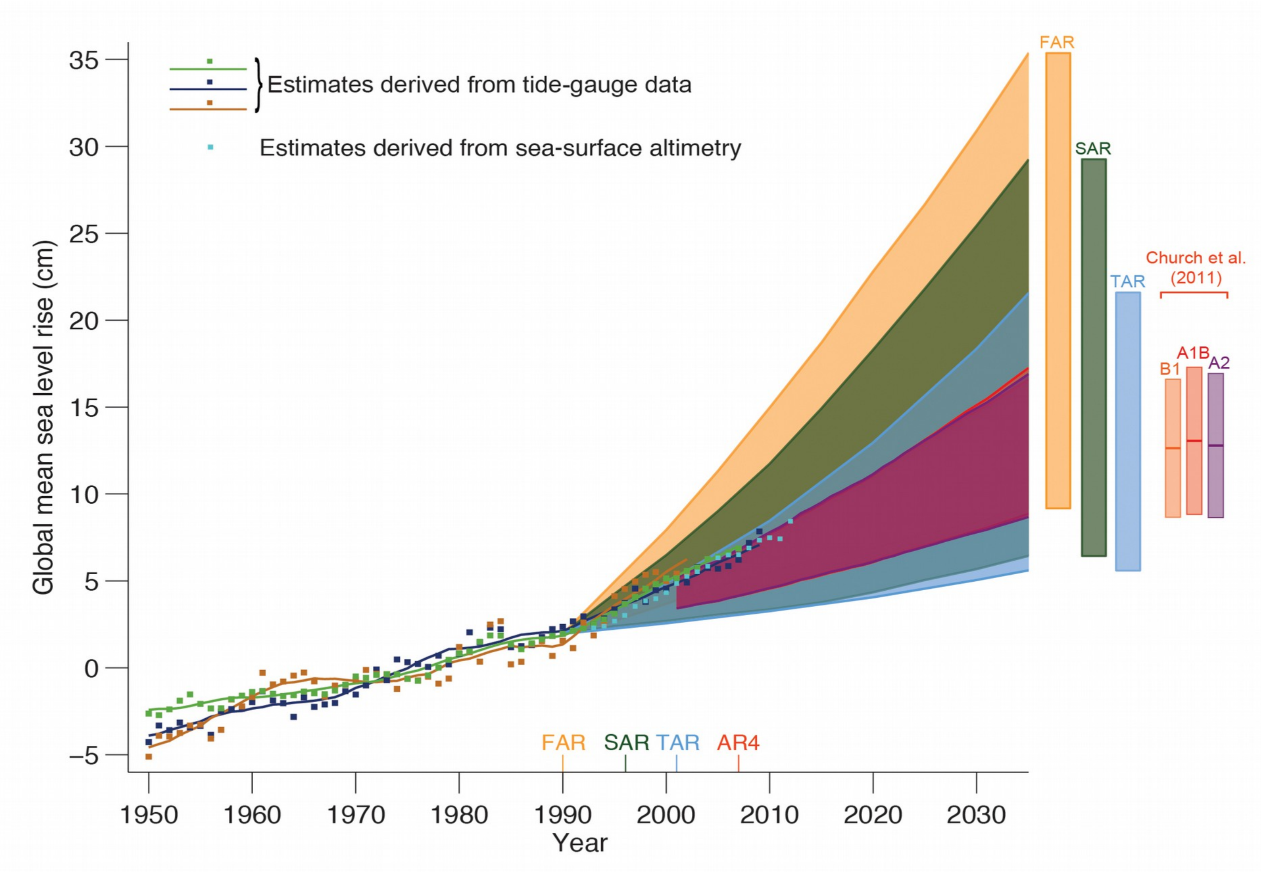


Yellow: **Named systems**
Green: **all hurricanes**
Red: Category 3 or greater



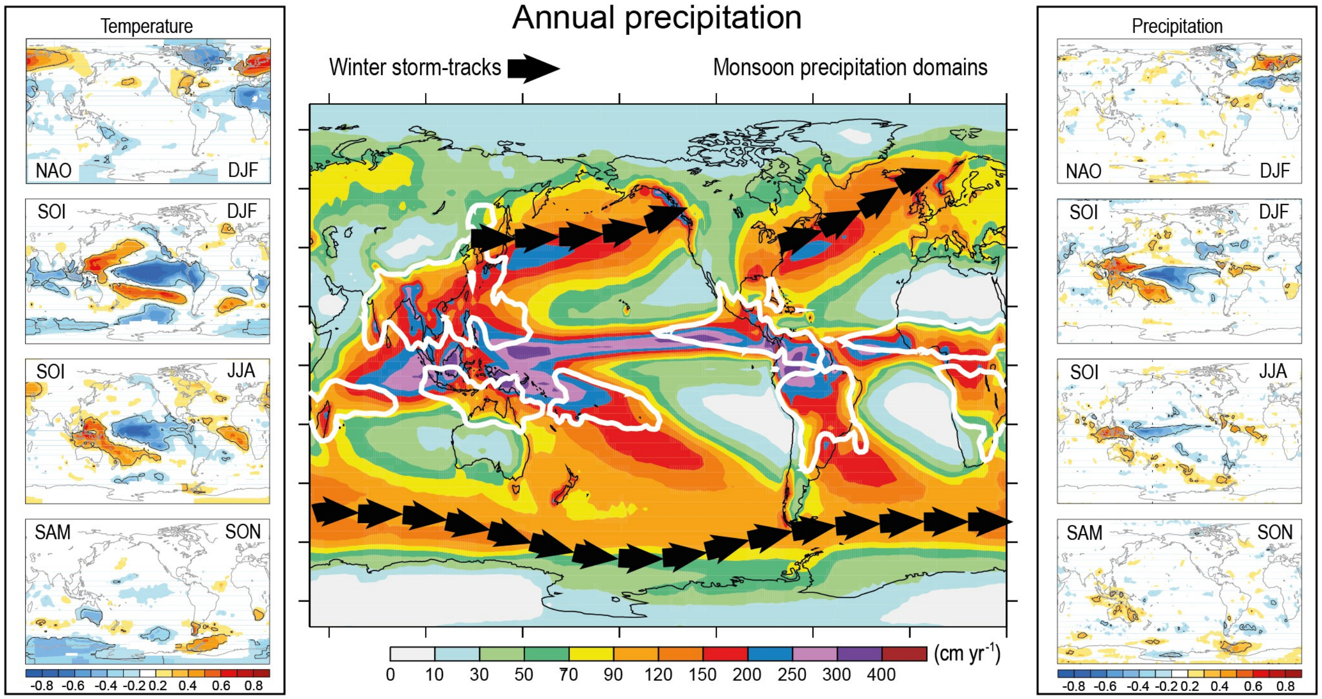
Tropical Cyclone Metrics

Sea Level Rise

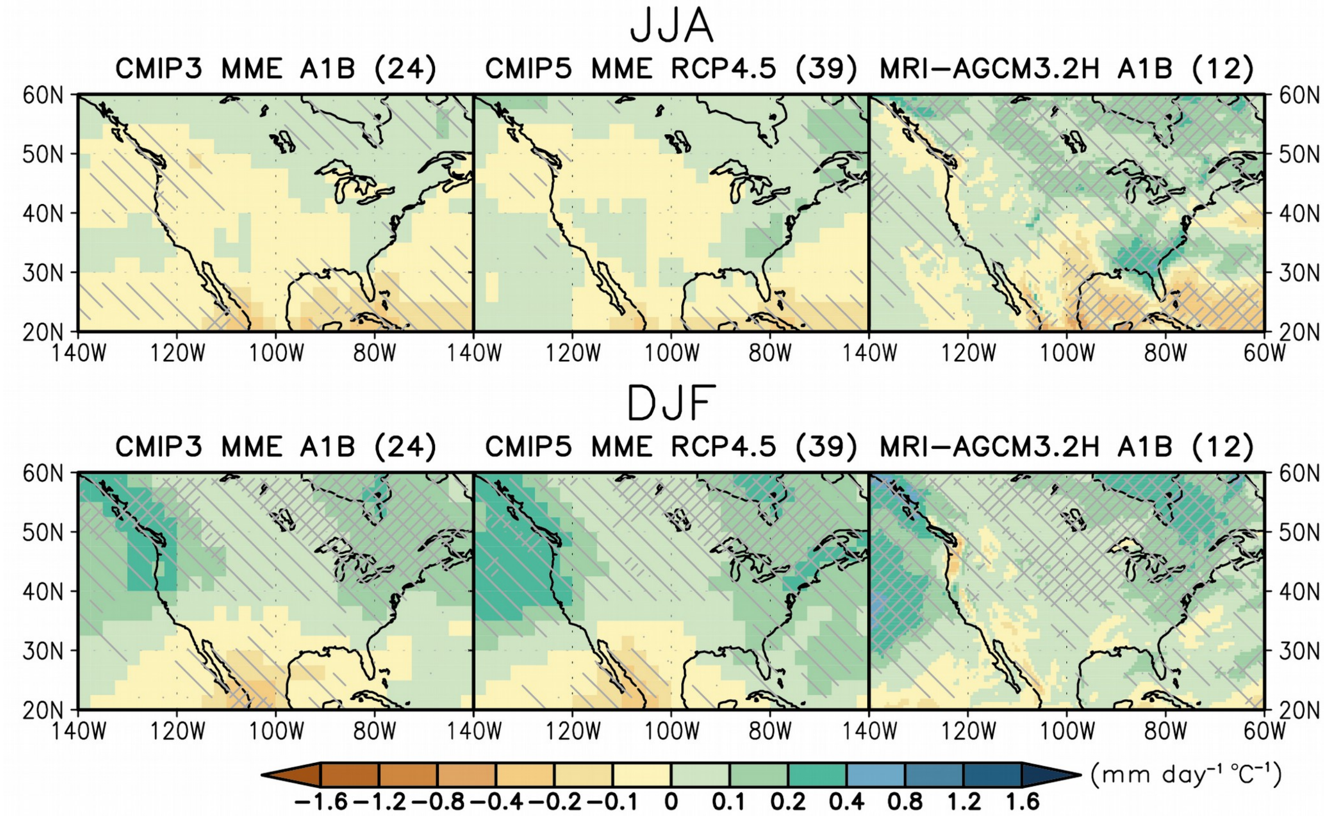


Extratropical storms

- ***The global number of ETCs is unlikely to decrease by more than a few percent.***
- ***It is more likely than not, based on projections with medium confidence, that the North Pacific storm track will shift poleward.***
- ***It is very likely that increases in Arctic, North American precipitation by the end of the 21st century (2081–2100)***
- ***More precipitation associated with enhanced extremes of storm-related precipitation.***



Annual Precipitation and Storm Tracks



Predicted precipitation changes

Southwest Monsoon Observations

- ***The warm season precipitation in northern Mexico and the southwestern USA is strongly influenced by the NAMS.***
- ***No distinct precipitation trends have been seen over the last half of the 20th century***
- ***Increasing intensity and decreasing frequency of events*, *as well as the decreasing length of the monsoon season itself*.**
- ***There has also been a systematic delay in monsoon onset, peak and termination***
- ***Increase in extreme precipitation events associated with land-falling hurricanes*.**
- ***Positive trends precipitation amounts have been detected in the northern fringes of the core area, that is, Arizona and western New Mexico.***

Southwest Monsoon Forecasts

- ***It has been difficult to simulate many important NAMS-related phenomenon in global climate models***
- ***Confidence in projections of monsoon precipitation changes is currently low***.
- ***No consensus on future changes of monsoon timing***.
- ***Temperature increases are consistently projected in all models.***
- ***This will likely increase the frequency of extreme summer temperatures, together with projected increase in consecutive dry days***.

REPORTS TO THE NATION
On Our Changing Planet

The North American Monsoon

And:

The North American Monsoon

David K. Adams and Andrew C. Comrie
University of Arizona

Bulletin of the American Meteorological Society
October 1997

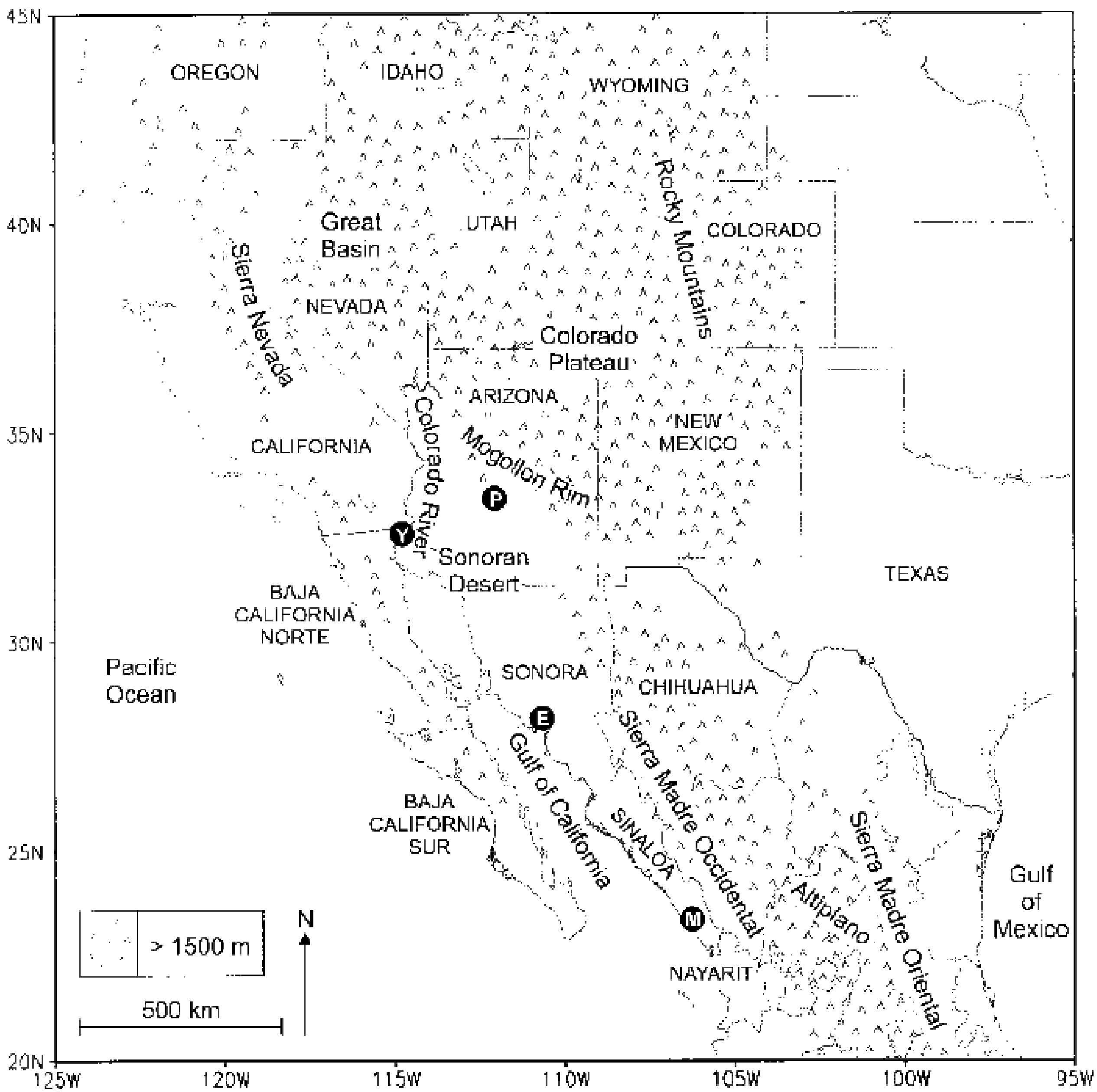


FIG. 1. Important physiographic features, states, and place names mentioned in the text: Empalme (E), Mazatlán (M), Phoenix (P), and Yuma (Y).

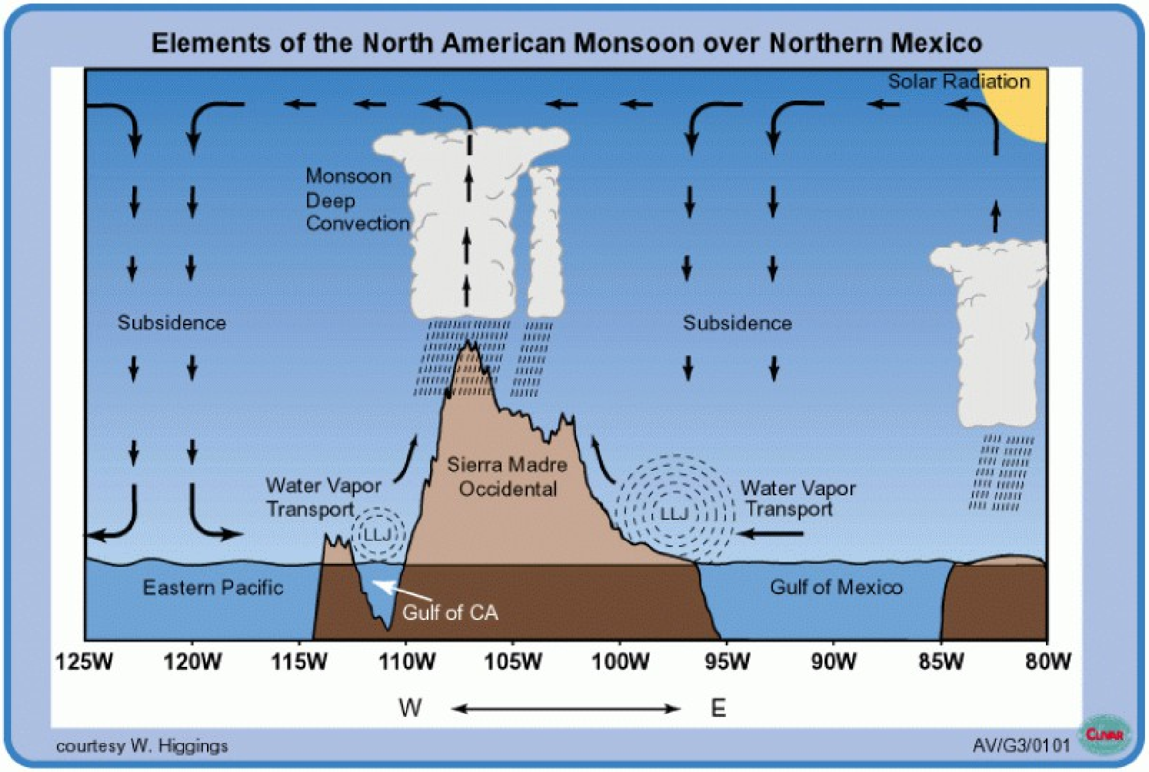


Figure 3. Schematic vertical (longitude-pressure) cross section through the North American Monsoon System at 27.5°N. Topography data was used to establish the horizontal scale and observed wind fields were used to establish the vertical circulations.

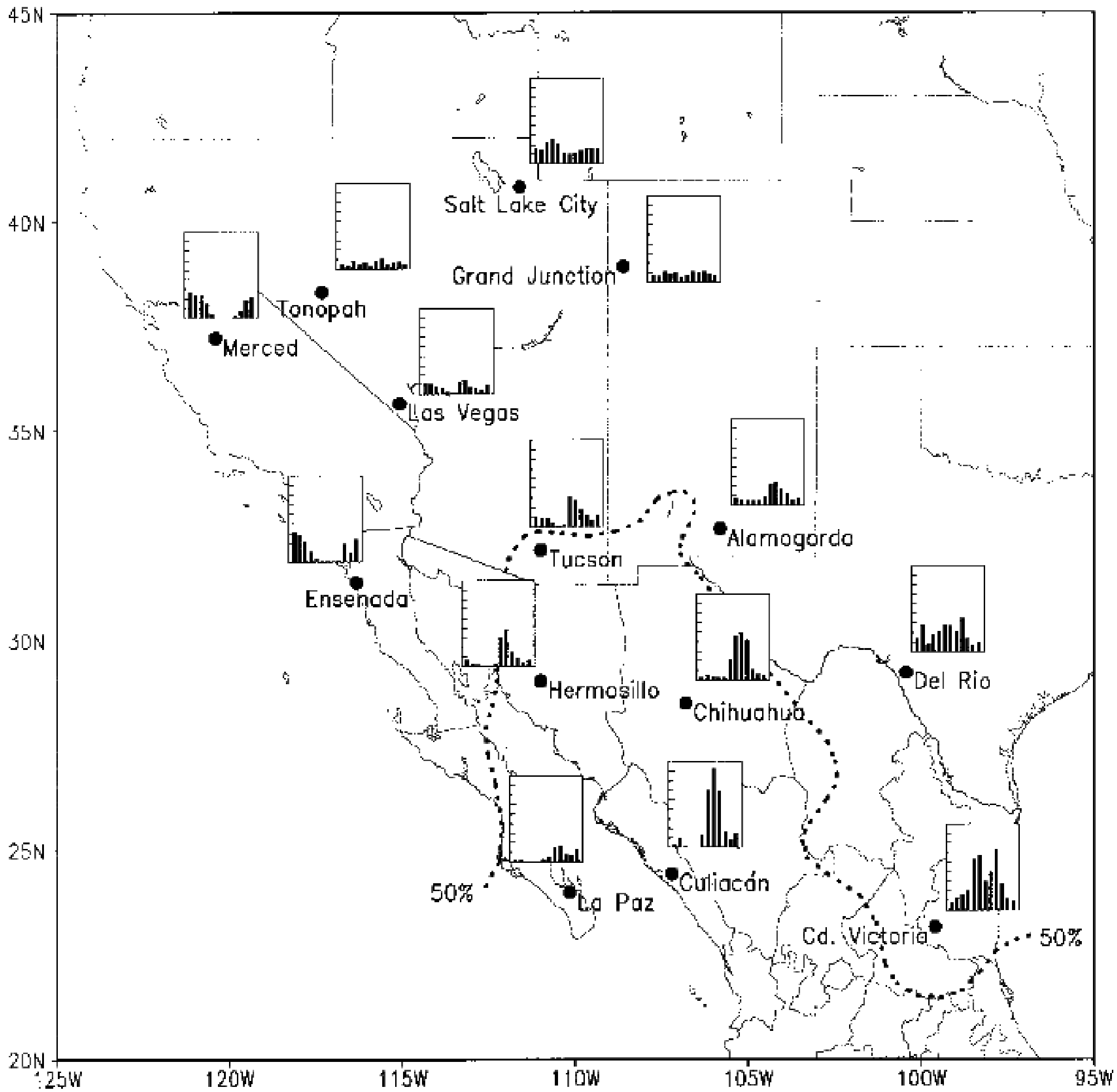


FIG. 2. Seasonal distribution of precipitation across southwestern North America. Note that northwestern Mexico shows the strongest monsoon signal, which diminishes through Arizona,

Nocturnal storms are most common in low deserts of southern Arizona

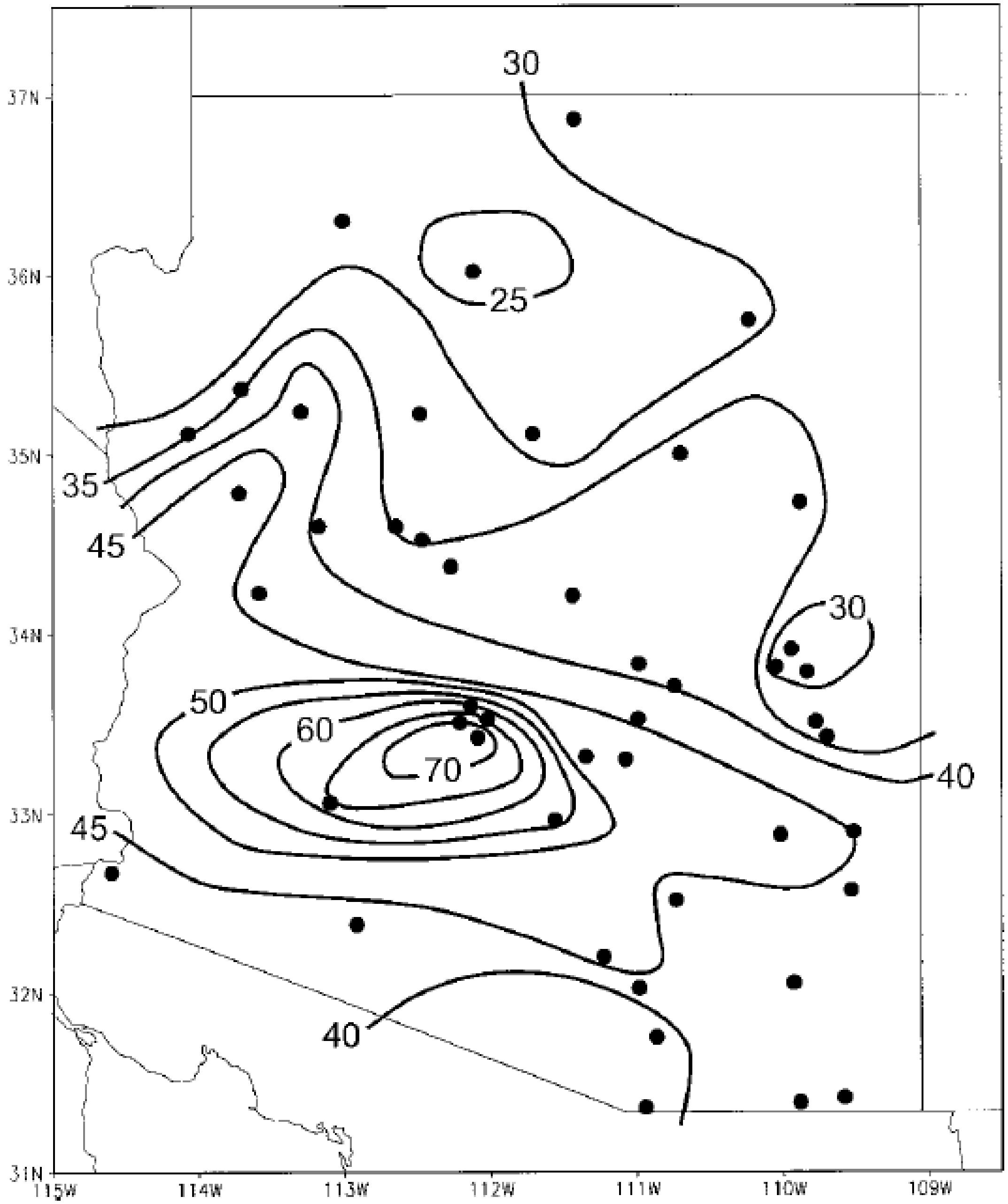


FIG. 7. Percentage of precipitation events occurring between 2000 and 0800 true solar time in Arizona for the months of July and August [redrafted from Balling and Brazel (1987)]. Note gradient from the Mogollon Rim and Colorado Plateau to the low deserts of central Arizona.

Tropical connection of moisture transport into the Desert Southwest

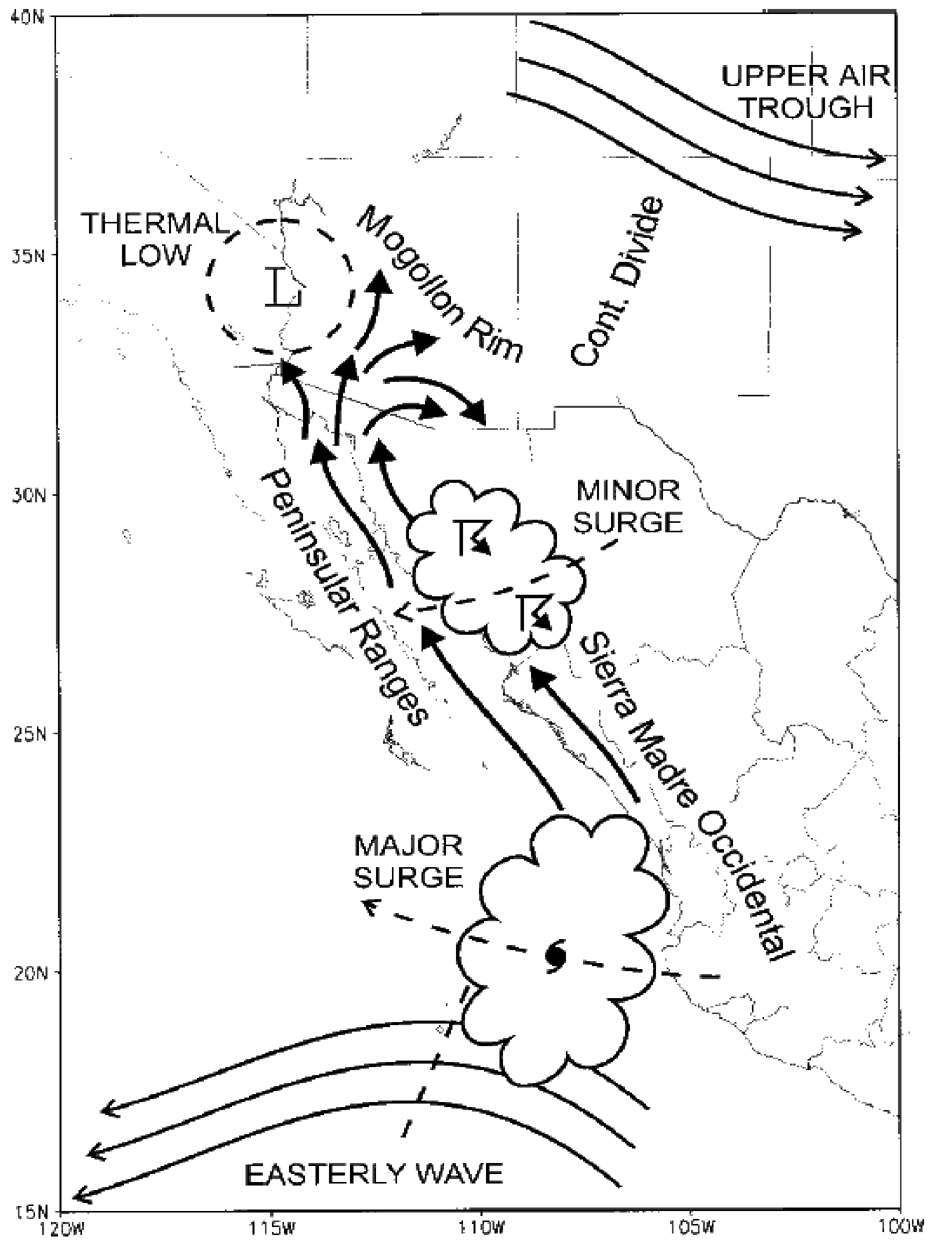
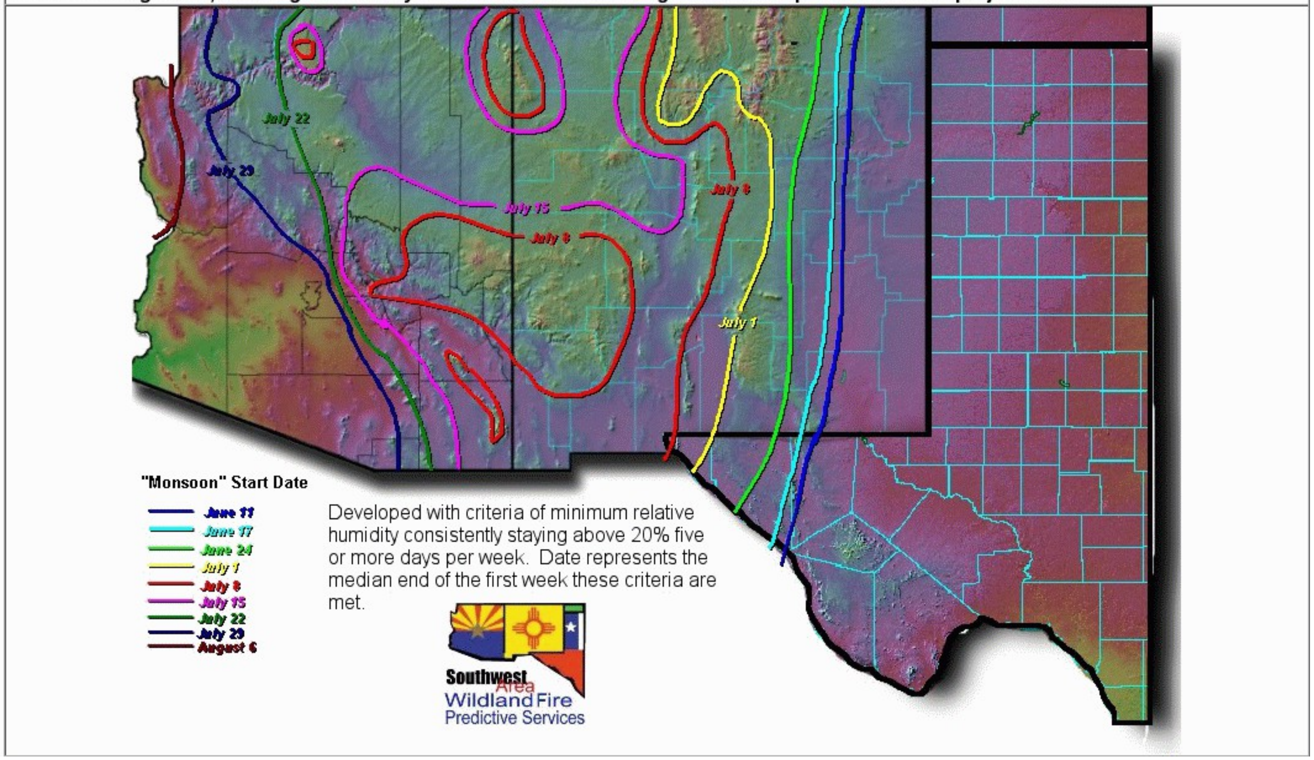


FIG. 4. Conceptualization of the gulf surge phenomenon. Major

18. Median "Monsoon" Start Dates Based on <u>Minimum</u> RH Not < 20 % for More Than 2 Consecutive Days. This likely reflects a significant *season slowing* event, affecting the severity of fire behavior on existing fires and the potential for new project fires.



Median monsoon start dates

Wet and Dry Jet Stream Patterns

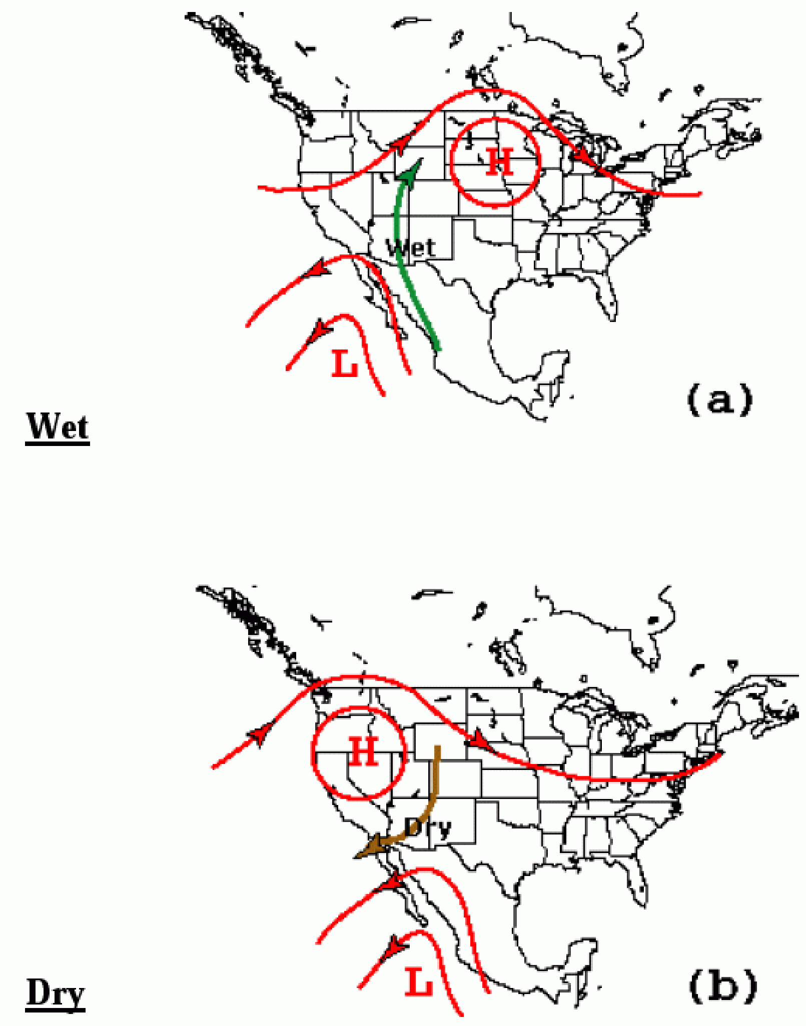


Figure 13. Schematic of the typical lower-tropospheric (700-hPa) circulation features (heights and winds) that accompany (a) wet and (b) dry Gulf of California moisture surges.

Related Phenomena and Risks

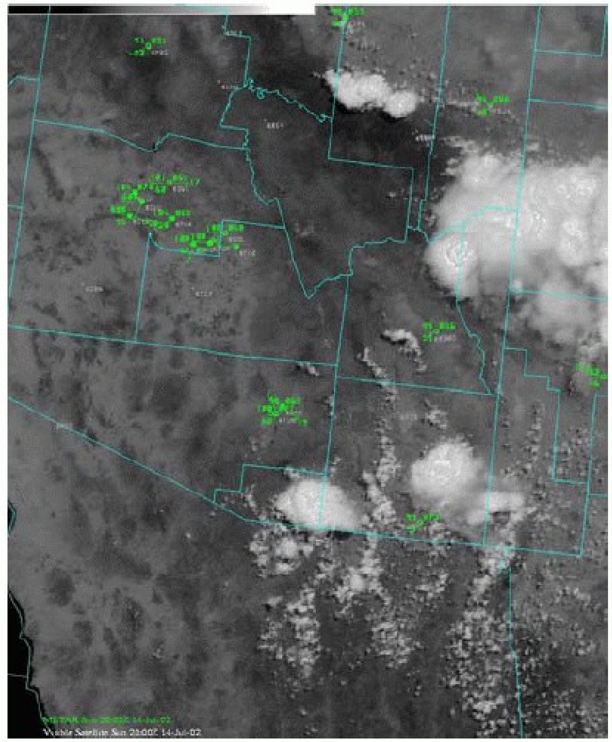


Figure 4. Typical visible satellite image taken in early afternoon (around 1:00 pm local time) showing thunderstorms building in the mountains northeast, east and southeast of Tucson, AZ.

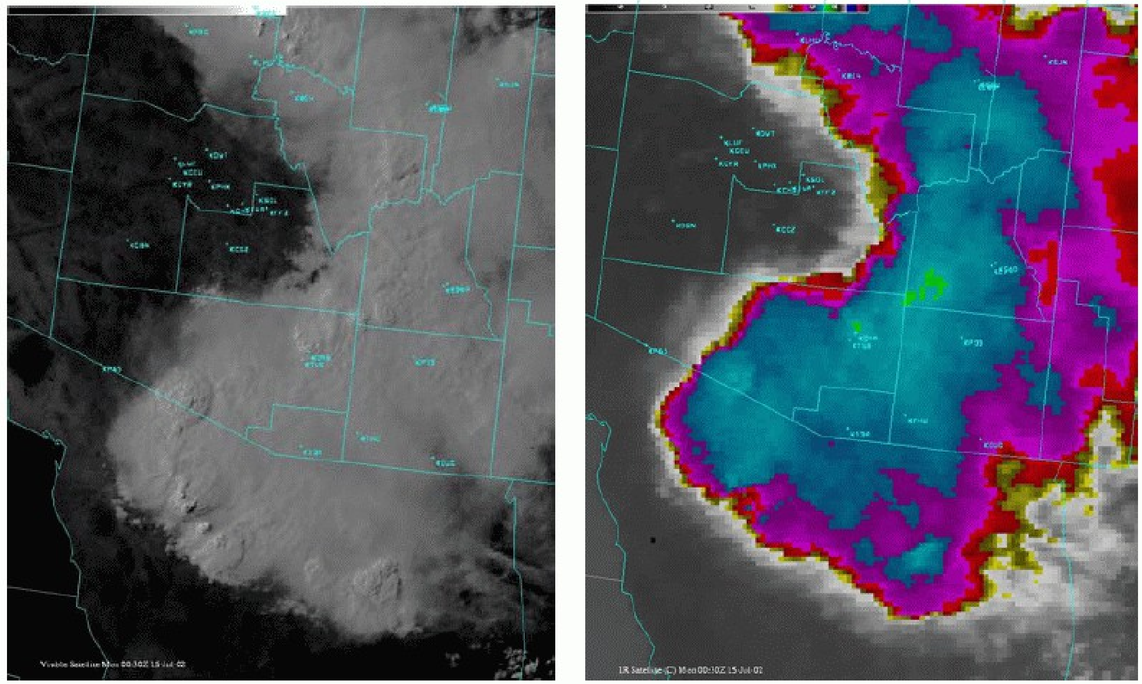


Figure 5. Visible (left) and infrared (right) satellite images taken later that afternoon (around 5:30 pm local time) showing that the storms have consolidated into a large mass and moved into the deserts

Satellite view of thunderstorms

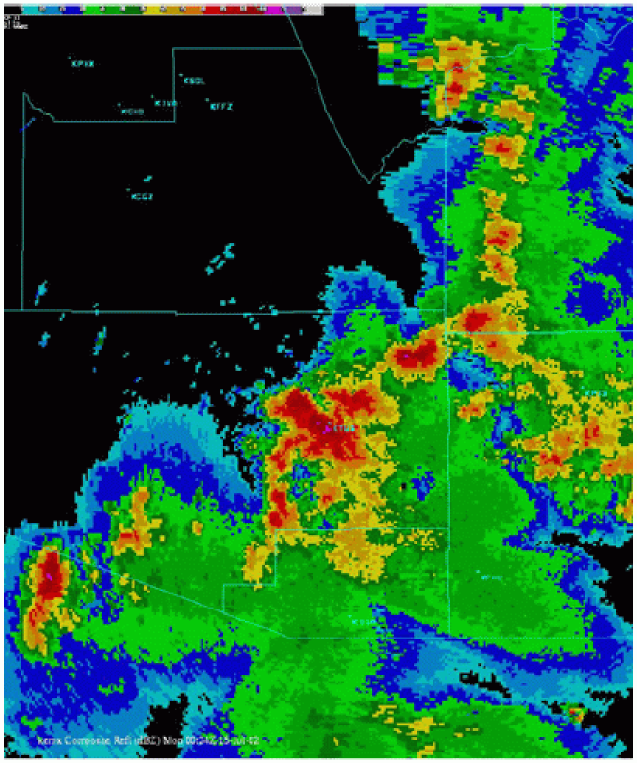


Figure 6. A line of severe thunderstorms detected by radar at 5:30 pm under the large cloud mass shown in Figure 5.

Thunderstorm Precipitation as viewed from radar

Pyrocumulus

"King fire" Placerville, CA: 17 Sept. 2014

"Zaca fire", Santa Barbara County, CA: August 2007

Haboob

Phoenix AZ: 3 July 2014

Phoenix, AZ: 6 Sep 2014

Moisture Flow into the eastern Rockies and Desert Southwest

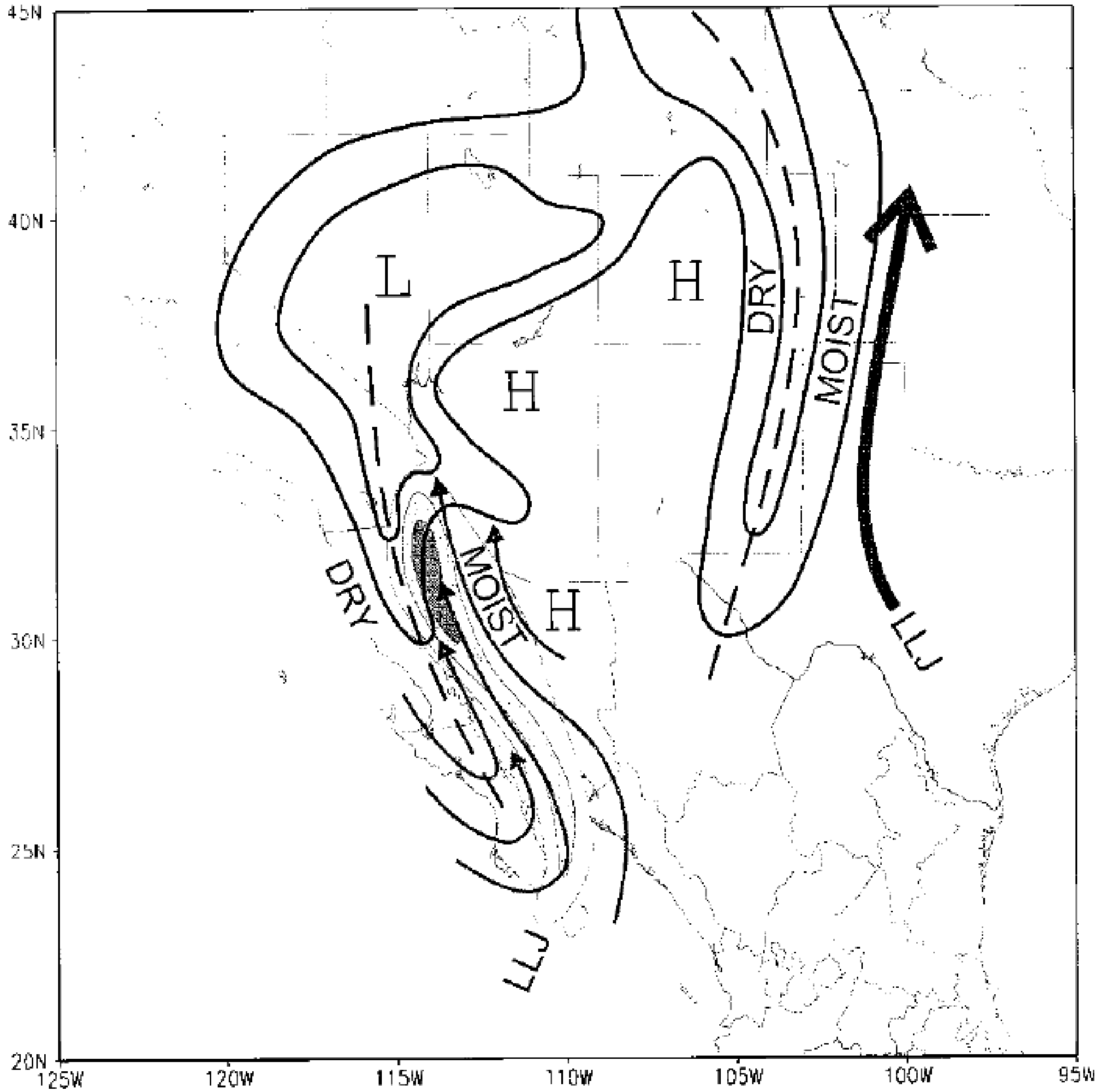


FIG. 5. Schematic of selected dynamic features during the NA

Colorado Flood: September 2013

http://coflood2013.colostate.edu/satellite.html

Boulder Area Flood of September 2013: Climate and Weather Information

* Near Dillon Road: *image courtesy of Will von Dauster, NOAA*

* Boulder High School Grounds: *image courtesy of Bruce Raup, NSIDC,CIRES/CU*

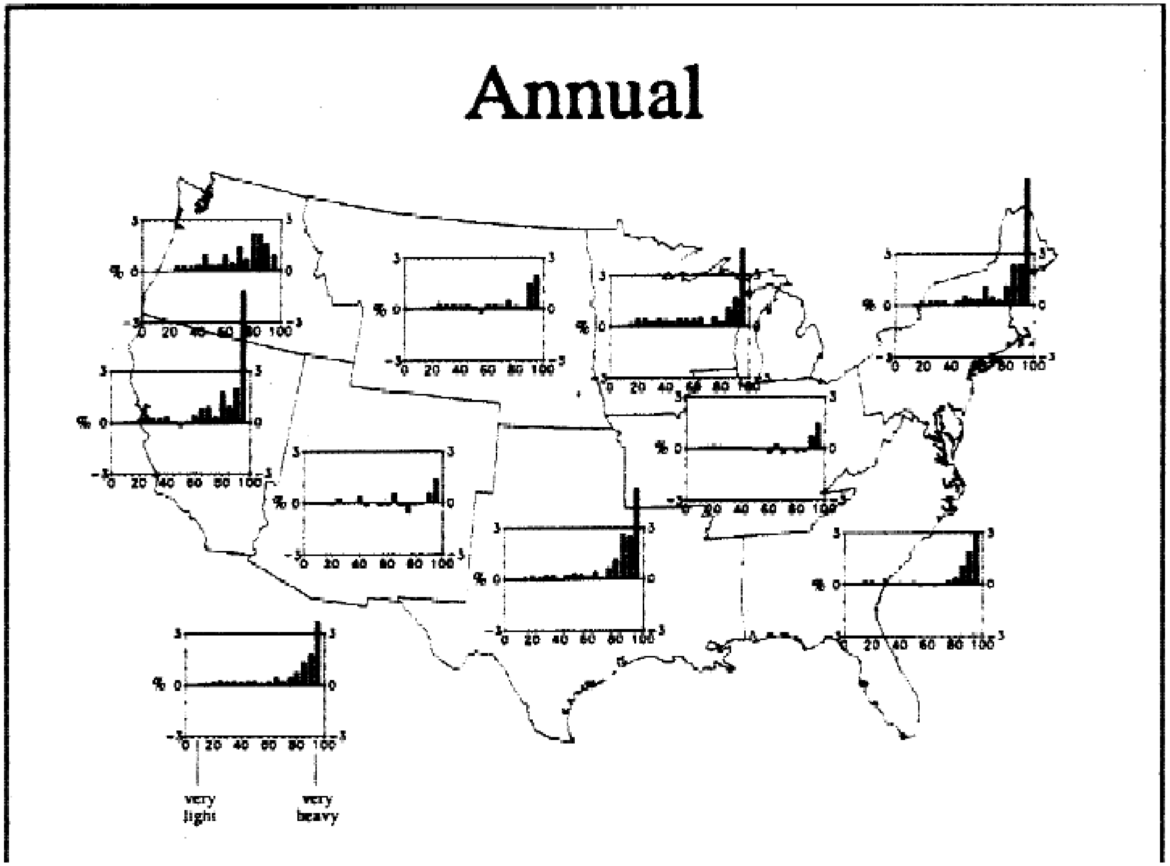
Water vapor flow from satellite

Trends of precipitation amount, frequency and intensity in the U.S.

Thomas R. Karl and Richard W. Knight,
Bulletin of the American Meteorological Society, Feb. 1998
NOAA/NESDIS/National Climatic data Center

* Near Dillon Road: *image courtesy of Will von Dauster, NOAA*

* Boulder High School Grounds: *image courtesy of Bruce Raup, NSIDC,CIRES/CU*



Trends (1910-96) expressed as percentage of mean annual precipitation for categories of precipitation.

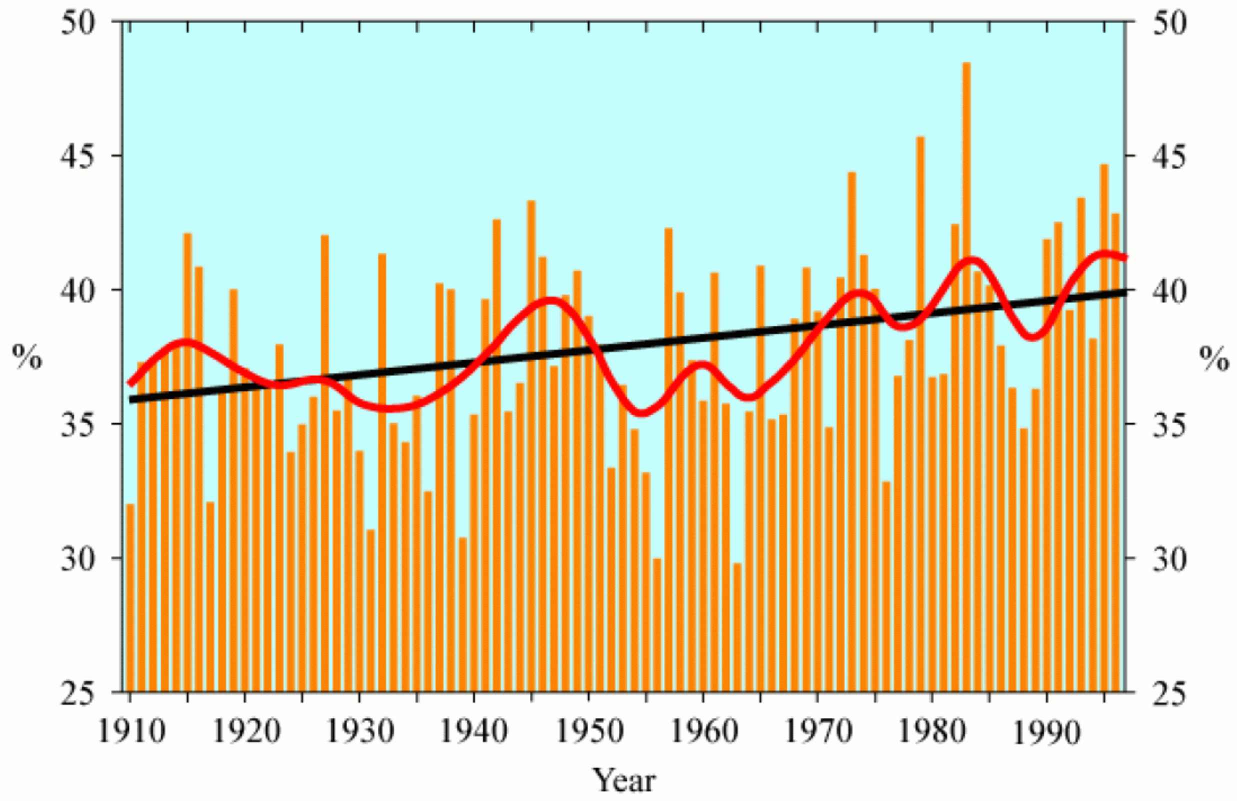


FIG. 2. Time series of the percent contribution of the upper 10 percentile of daily precipitation events to the total annual precipitation area-averaged across the United States. Smooth curve is a nine-point binomial filter, and the trend is also depicted.

National trends in intense precipitation

Precipitation and Damaging Floods: Trends in the United States, 1932-97.

Roger A. Pielke Jr. and Mary W. Downton
Environmental and Societal Impacts Group
National Center for Atmospheric Research
Boulder CO
Journal of Climate, Oct 2000

- **The relationship of climate, hydrology, and society in producing damaging floods is complex and NOT fully understood.**
- **Climate plays an important, but by no means determining role in the growth of flood damage in the U.S. in recent decades.**
- **This should provide optimism to decision makers seeking to reduce vulnerability to floods,**
- **Suggests that local actions can have a significant effect, independent of the climate variations of the future.**

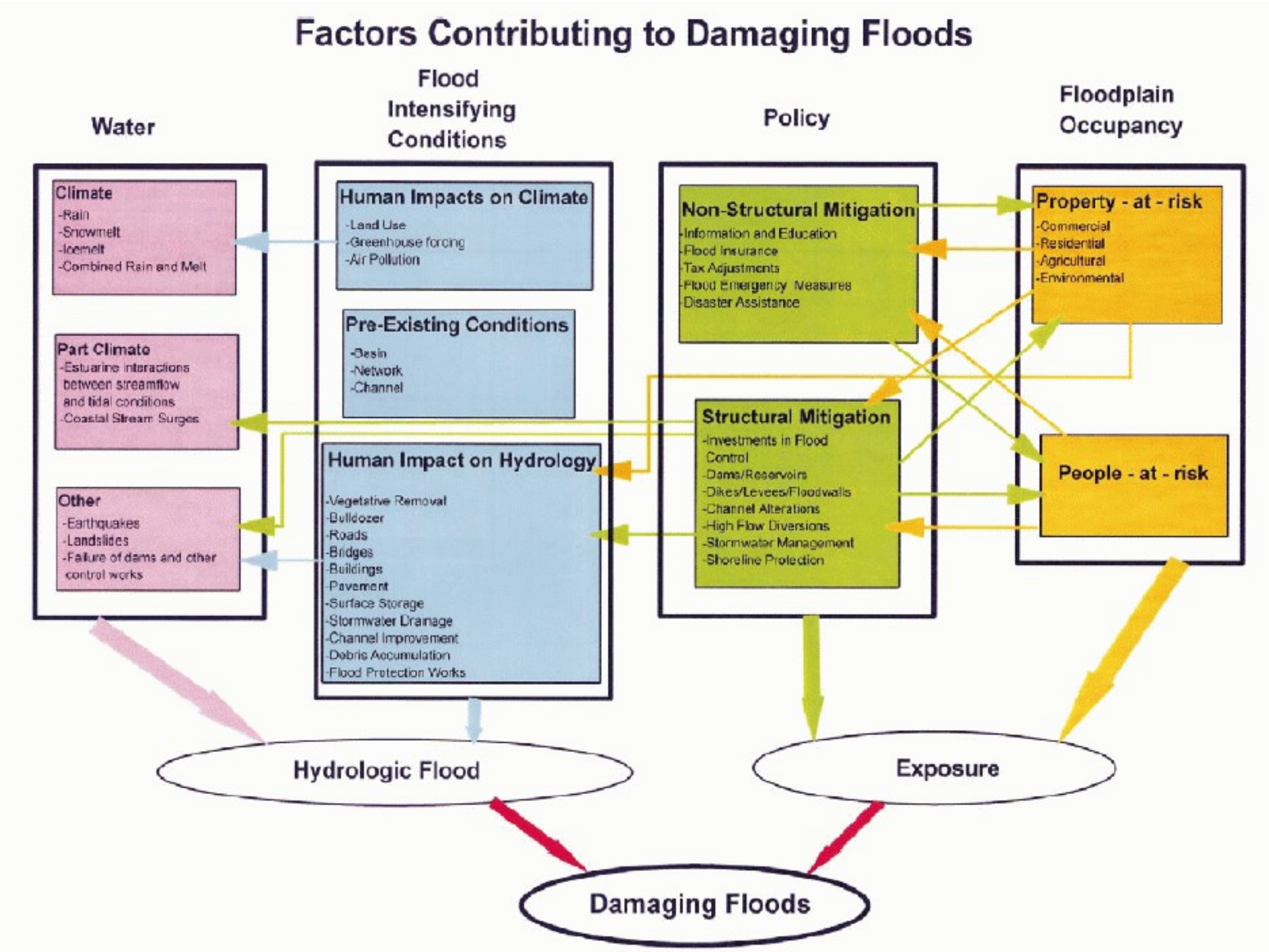


FIG. 2. Framework for understanding the interrelated factors responsible for the occurrence of damaging flood.

Interrelated factors leading to damaging floods

Trends in property losses due to floods are affected by increasing population and wealth

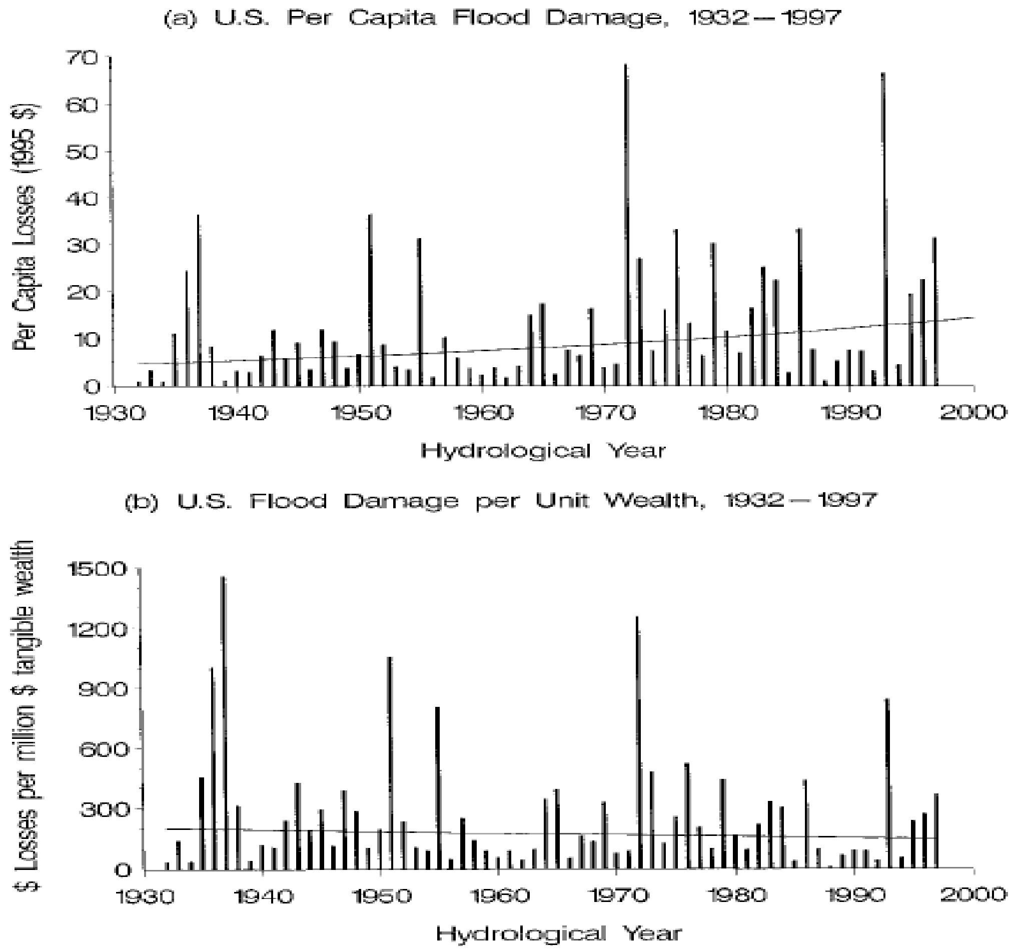


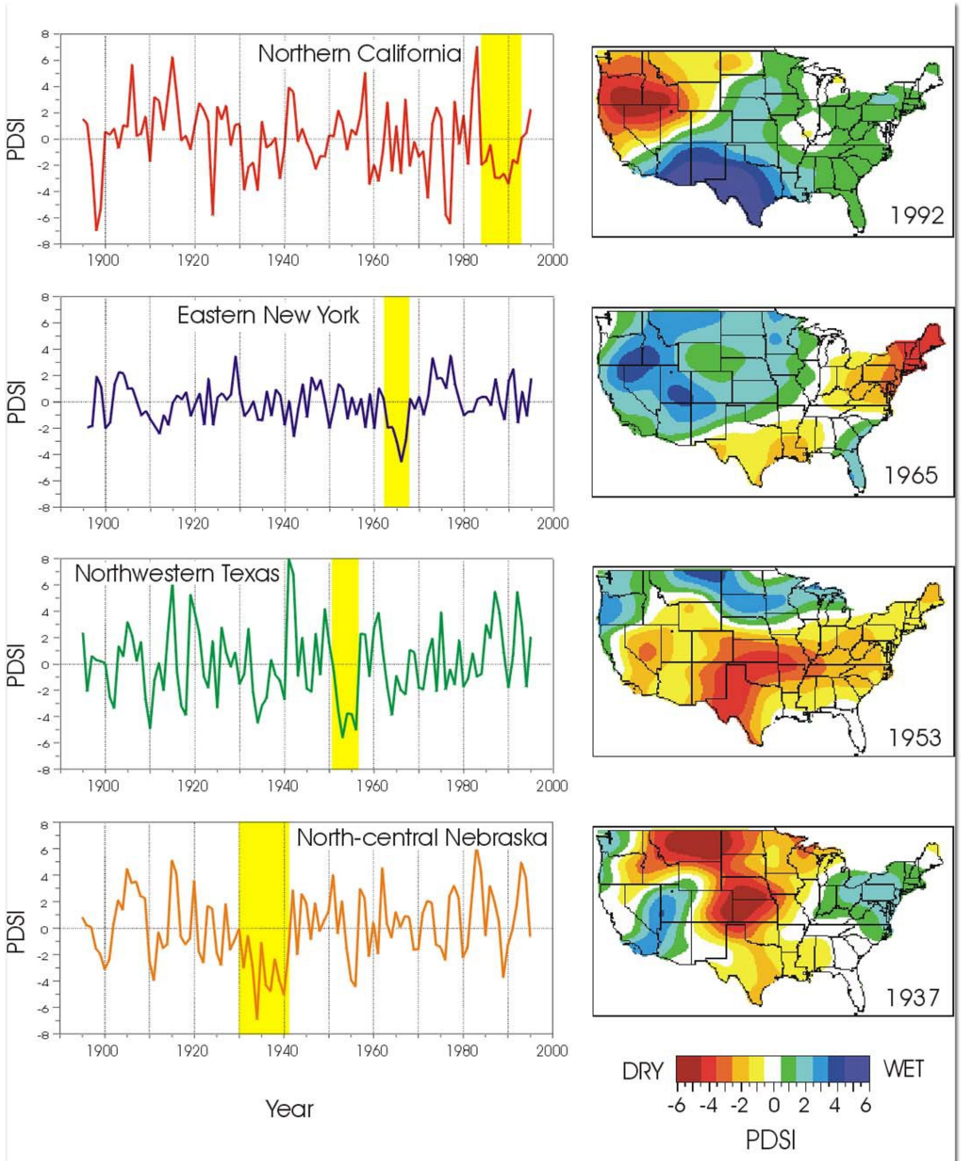
FIG. 3. (a) U.S. per capita flood damage 1932–97 adjusted to current 1995 dollars. (b) U.S. flood losses per million dollars tangible wealth 1932–97 adjusted to current 1995 dollars.

North American Drought
Varying patterns of 20th Century Drought

NOAA/National Climate Center

- ***The timing and evolution of droughts, and the areas impacted are variable.***
- ***Difficult to understand just what causes drought onset and persistence.***
- ***The central High Plains appears to be the region most often affected by the most persistent droughts.***
- ***The southern Plains, and parts of Texas in particular, appear to suffer from the highest frequency of drought.***
- ***Evidence from the instrumental record indicates that drought can affect any region of the U.S.***

https://www.ncdc.noaa.gov/paleo/drought/drght_temporal.html



Notable droughts in different regions

North American Drought: Reconstructions, Causes, and Consequences

Edward R. Cook*, Richard Seager, Mark A. Cane
Lamont-Doherty Earth Observatory, Palisades, NY 10964 USA
David W. Stahle,
Dept. of Geosciences, University of Arkansas, Fayetteville, AR 72701

- ***Severe drought is the greatest recurring natural disaster to strike North America.***
- ***Tree-ring chronologies has now allowed for the reconstruction of past drought over North America covering the past 1,000 years.***

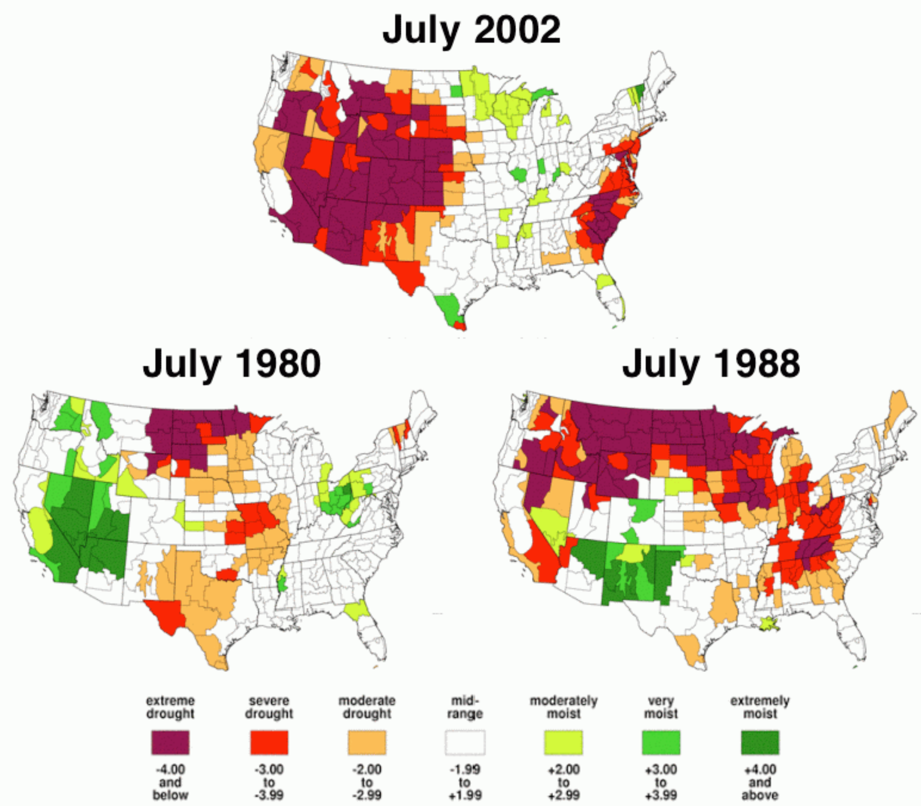


Figure 1. Maps showing the U.S. regions most affected by drought in 1980, 1988, and 2002. The drought metric used for this purpose is the Palmer Drought Severity Index (Palmer, 1965). Note that the 2002 drought was mostly restricted to the inter-montane West, while the other two droughts were located more so in more agriculturally important regions of the Great Plains and Corn Belt. (Maps from http://www.ncdc.noaa.gov/oa/climate/research/drought/palmer-maps/).

Recent droughts in the Southwest, Southeast, and northern Plains

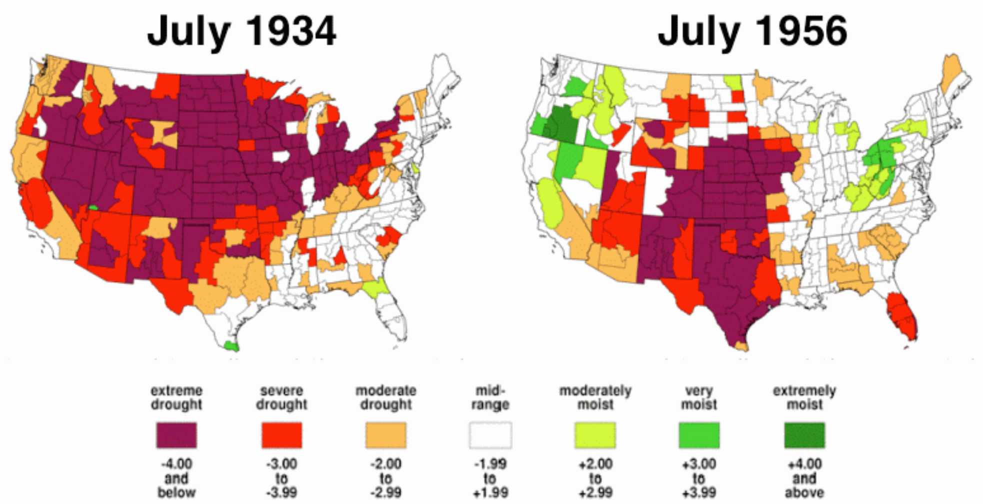


Figure 2. Maps showing the U.S. regions most affected by drought in 1934 and 1956. These two years are part of the Dust Bowl and Southwest droughts, considered to be the worst of the 20th century. (Maps from http://www.ncdc.noaa.gov/oa/climate/research/drought/palmer-maps/).

Dust bowl and plains droughts

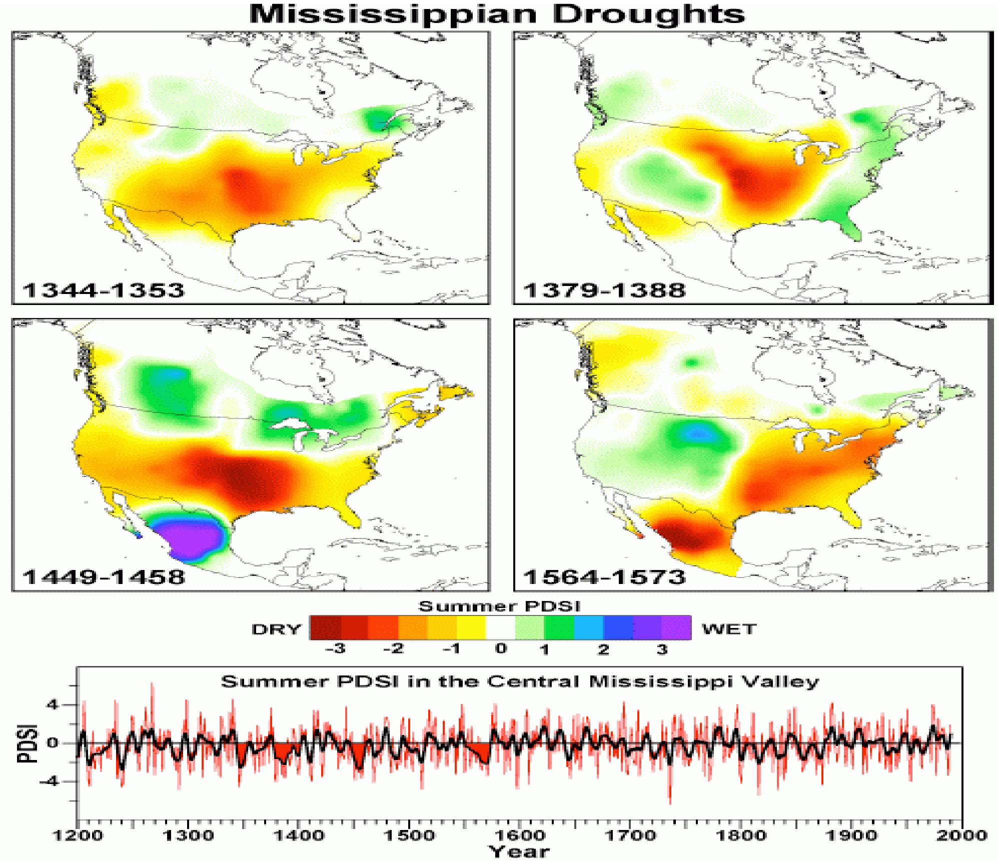


Figure 12. Four intense decadal droughts over the central United States may have contributed to the syndrome of social and environmental change that resulted in the decline of complex Mississippian chiefdoms in the 14th and 15th centuries. The impacts of the 16th century drought

Intense decadal droughts in Mississippi valley

Agricultural potential and "climate shifts" in the southwest

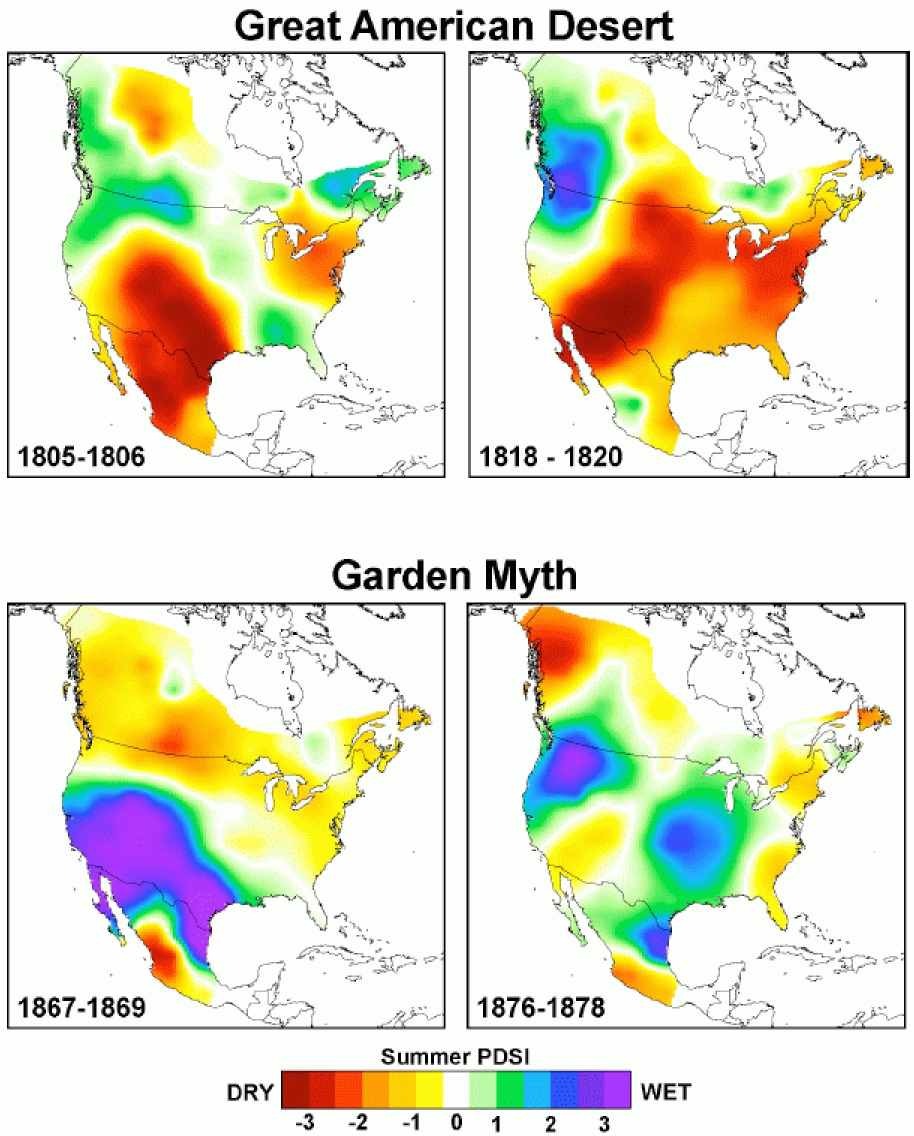
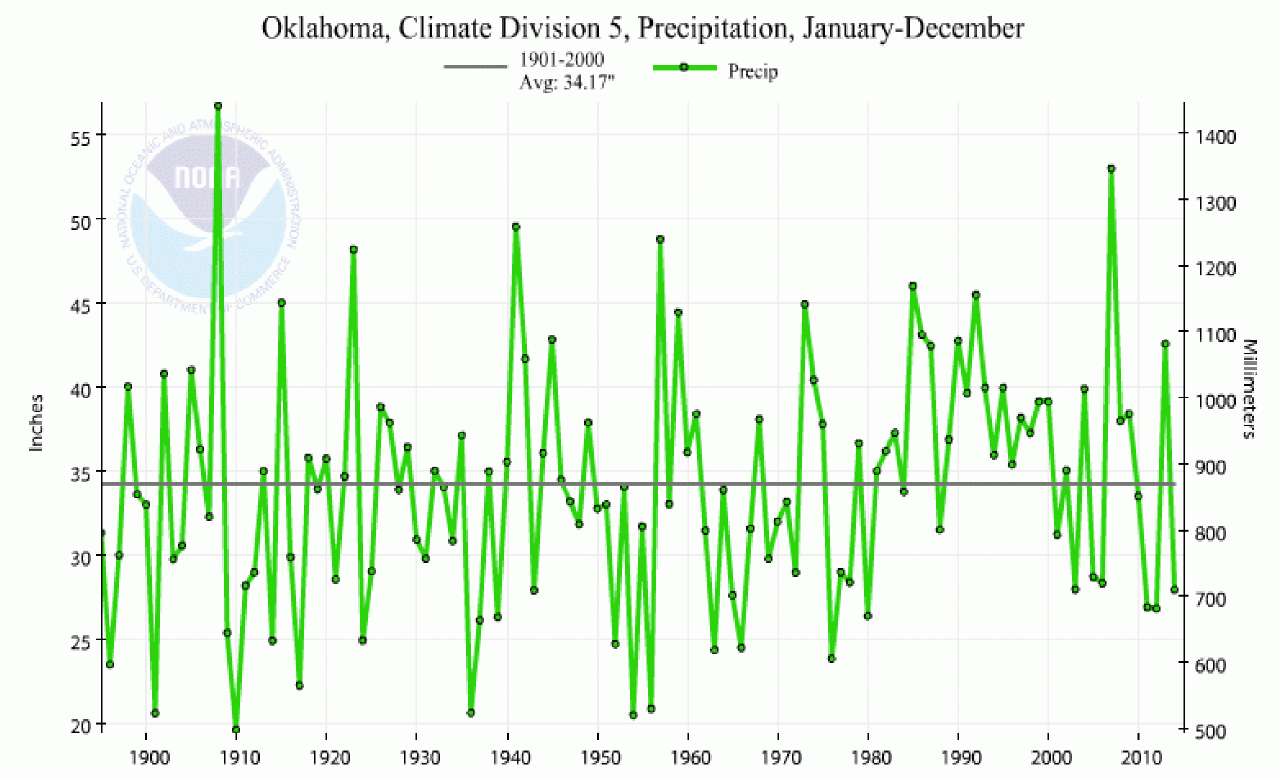


Figure 13. Perceptions of the agricultural potential of the American West were influenced by prevailing climatic conditions (Lawson and Stockton 1981). The Pike expedition of 1806-1807



Annual Recorded Precipitation: Central Oklahoma

Recent wet periods:
1980-2000 , 2007, 2015...(23" in May 2015)

Recent drought: 2000-2014

Increased variability of tornado occurrence in the United States

Harold E. Brooks(1), Gregory W. Carbin(2), Patrick Marsh(2)

NOAA/National Severe Storms Lab (1)
NOAA/National Weather Service Storm Prediction Center

Science, 17 October 2014

- **Mean annual tornadoes has remained relatively constant (excluding weakest tornadoes)**

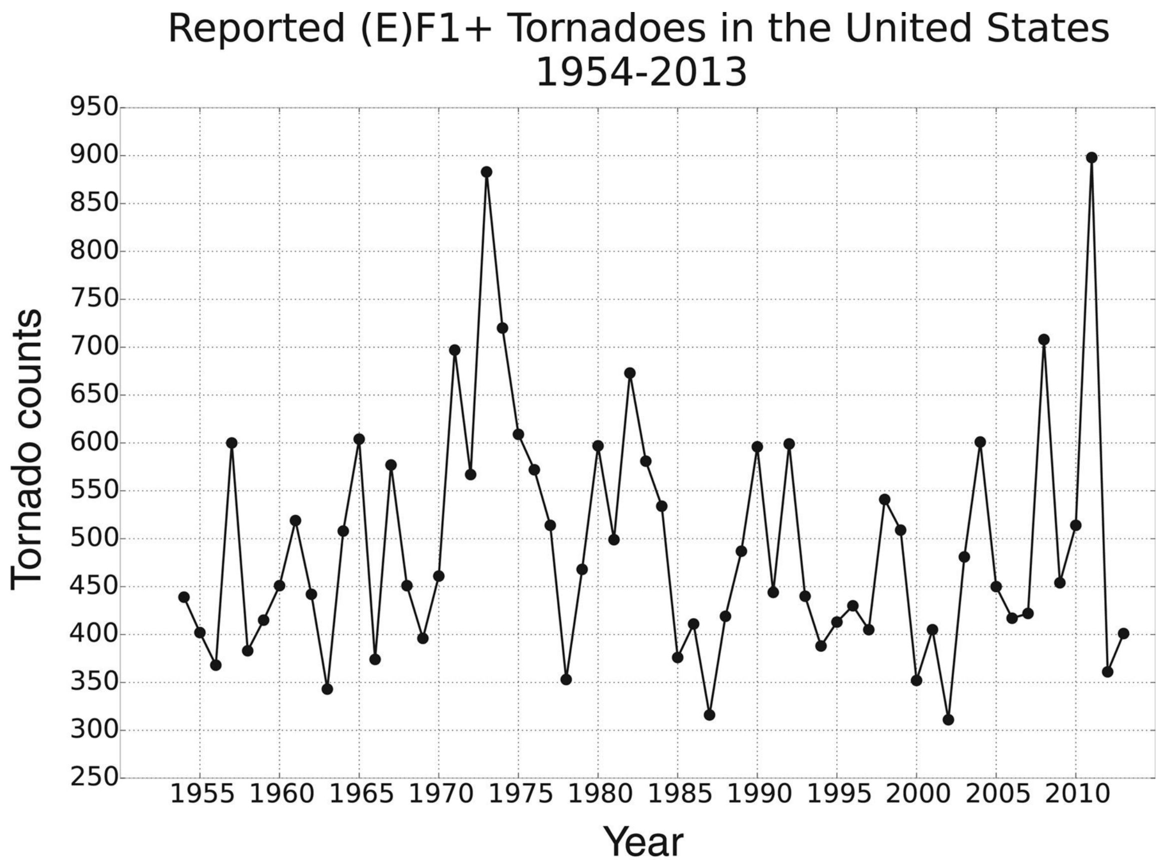
- **Variability of occurrence has increased since the 1970's:**

  decrease in days per year with tornadoes

  increase in days with many tornadoes

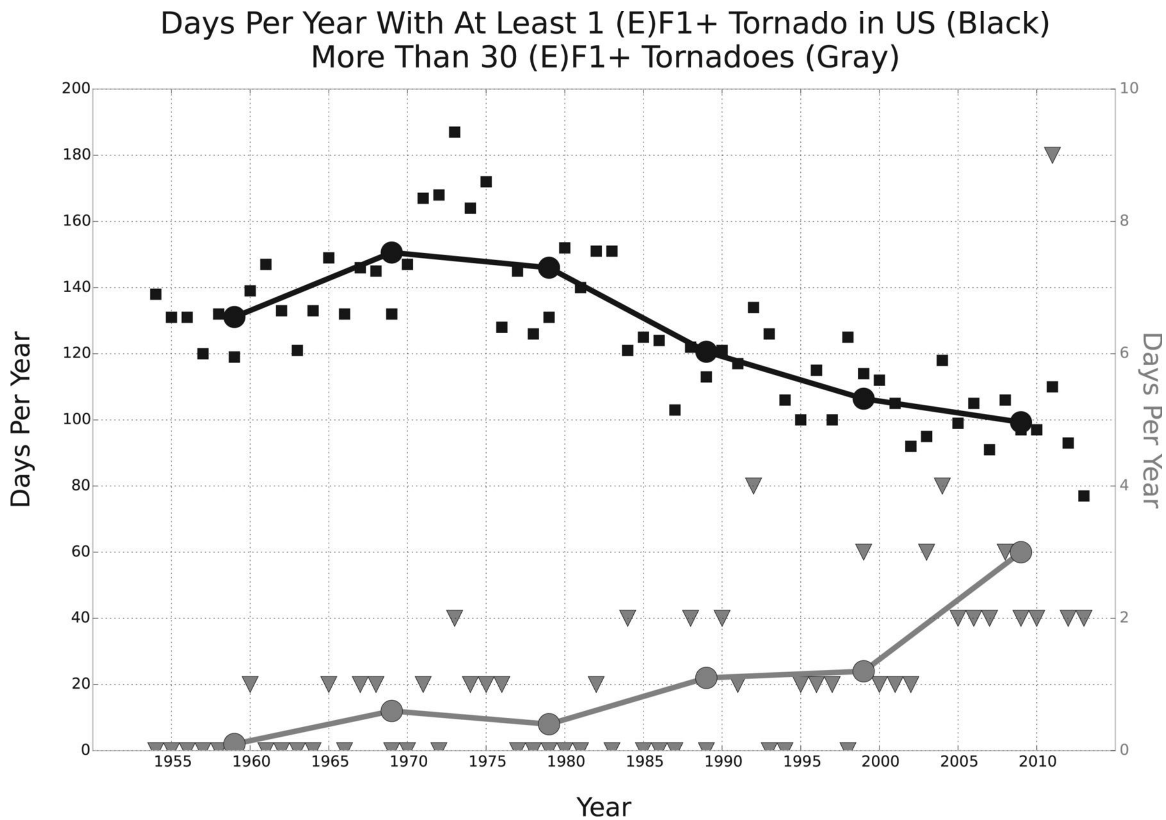
- **Greater variability on annual and monthly time scales**

- **Changes in the timing of the start of the tornado season**



Strong tornadoes from 1954 to 2013:

- ***much interannual variability***
- ***no long-term linear trend***.



- ***Number of days with at least one tornado in the United States has decreased from a mean of 150 to a mean of 100.***

- ***Number of days with many tornadoes has increased dramatically***

Tornado Summary

- ***Convective instability is projected to increase in the United States with warming over the next century***
- ***Wind shear term is projected to decrease***
- ***Net effect: the frequency of environments supportive of severe thunderstorms is projected to increase over the 21st century***
- ***Fraction of those storms that are tornadic may decrease***
- ***Difficult to have confidence in changes in mean tornado occurrence.***

Thunderstorm in Barrow AK: 14 June 2013

Thunderstorm in Barrow (animated gif)

Summary

- **More extreme precipitation**
  Including hurricanes and thunderstorms

- **Additional effects on flood impact besides climate**

- **Possible shift in large-scale storm tracks**

- **Variability in southwest monsoon uncertain:**
  Poorly modeled
  Delayed unset (prolonged seasonal heat and drought)
  Northward extent
  Variety of phenomenon: wind, dust, lightning, fire and flood

- **Droughts**
  Reoccur in most any region
  Change in severity uncertain

- **Local action can have a significant effect on hazard mitigation**
  Planning, Preparation, Execution