MET 4300

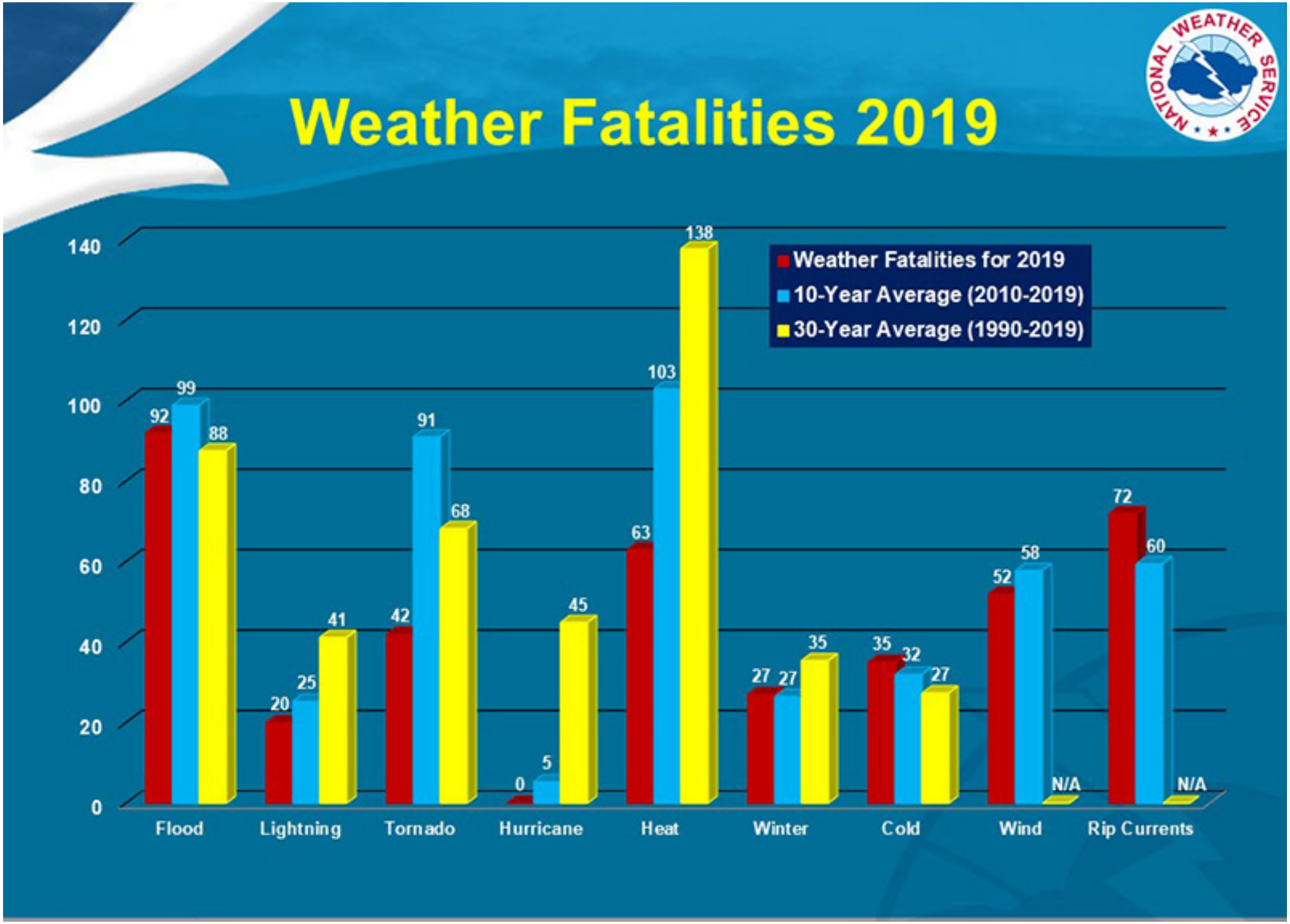
Lecture 29: Floods

Flooding of New Orleans in the aftermath of Hurricane Katrina, August 2005

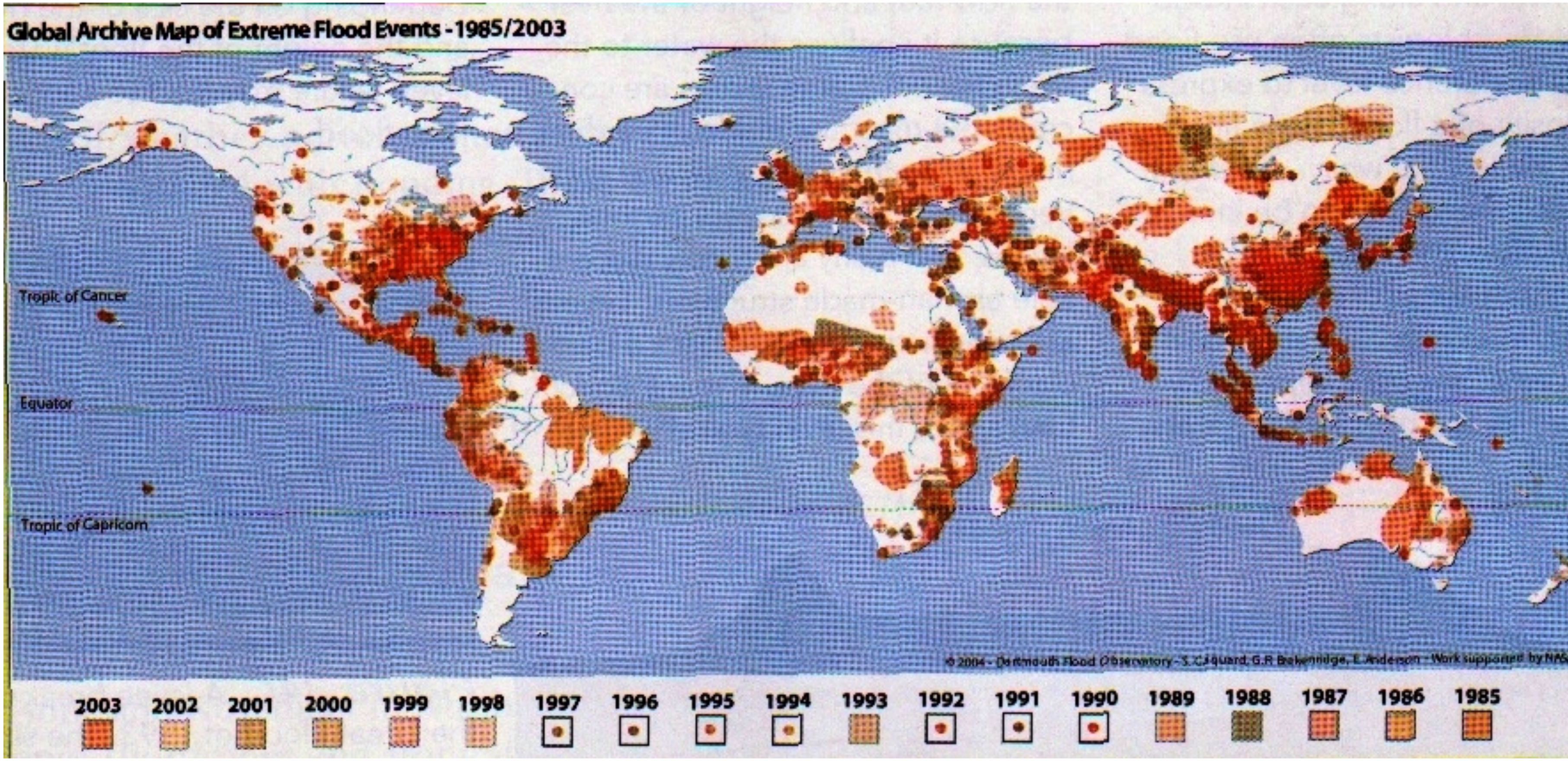
Overview of Floods

- **Floods** are #1 weather-related cause of property damage in US and #2 weather-related cause of deaths worldwide (drought is #1); New US statistics in 2019 showed that for 10-yr & 30-yr average, floods is #2 weather-related cause of fatalities in US (Heat is #1)
- **Personal property and agricultural losses** in the US exceed $1 billion in most years, sometime more with catastrophic flood events:
  - Most of Hurricane Katrina's $80 billion of damage was from flooding
  - Great Floods in the upper and lower Mississippi drainage in 1993 & 2011 each cost billions of dollars

US Weather Fatality Statistics by NWS

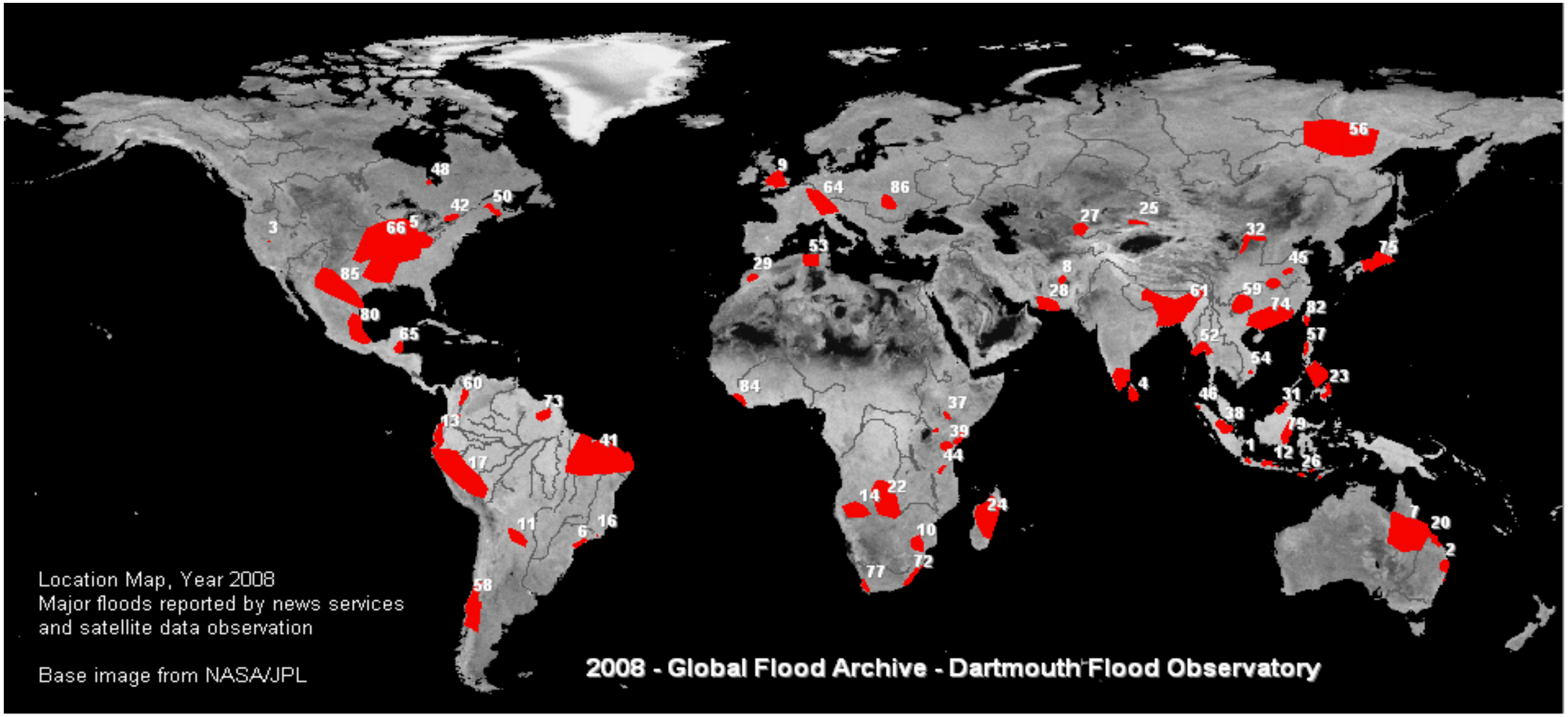


Where do Floods Occur Worldwide?



- Floods occur all continents except Antarctica.
- Largest number of flooding events in SE Asia (due to Asian Summer Monsoon).
- Most recorded monthly rain: 366 in, July 1861, Cherrapungi, India
- MONSOON rains cause flooding of Ganges and Bramaputra

Where do Floods Occur Worldwide?



- Worst historical floods: Yangtze in 1887,1908, 1911, 1935, 1938 & 1939, claiming 300,000-500,000 lives each, for a total of ~6 million. Mei-Yu front lies over the Yangtze in spring and can drop a lot of rain
- Europe: along the Alps and Carpathian mountains
- Africa: ITCZ; Madagascar/Australia: TCs;
- South America: Amazon river basin

Overview of Floods

- **Duration and Intensity of Floods depends on many factors**:
  - *Direct weather-related factors*: the intensity, duration, and number of rain events that occur in a region, and the size of the rainfall area and its orientation and movement with respect to a river drainage
  - *Indirect weather-related factors:* snowmelt from previous storms, ice jams on previously frozen rivers, and saturation level of soils.
  - *Non-weather related factors:* land use, levees and dams and their effect on drainages, and the topography a long a drainage. Katrina (2005)’s disaster is mainly due to the failure of levees and the below-sea-level elevation of New Orleans. Some floods have nothing to do with weather, such as tsunami.

“X”-Year Flood

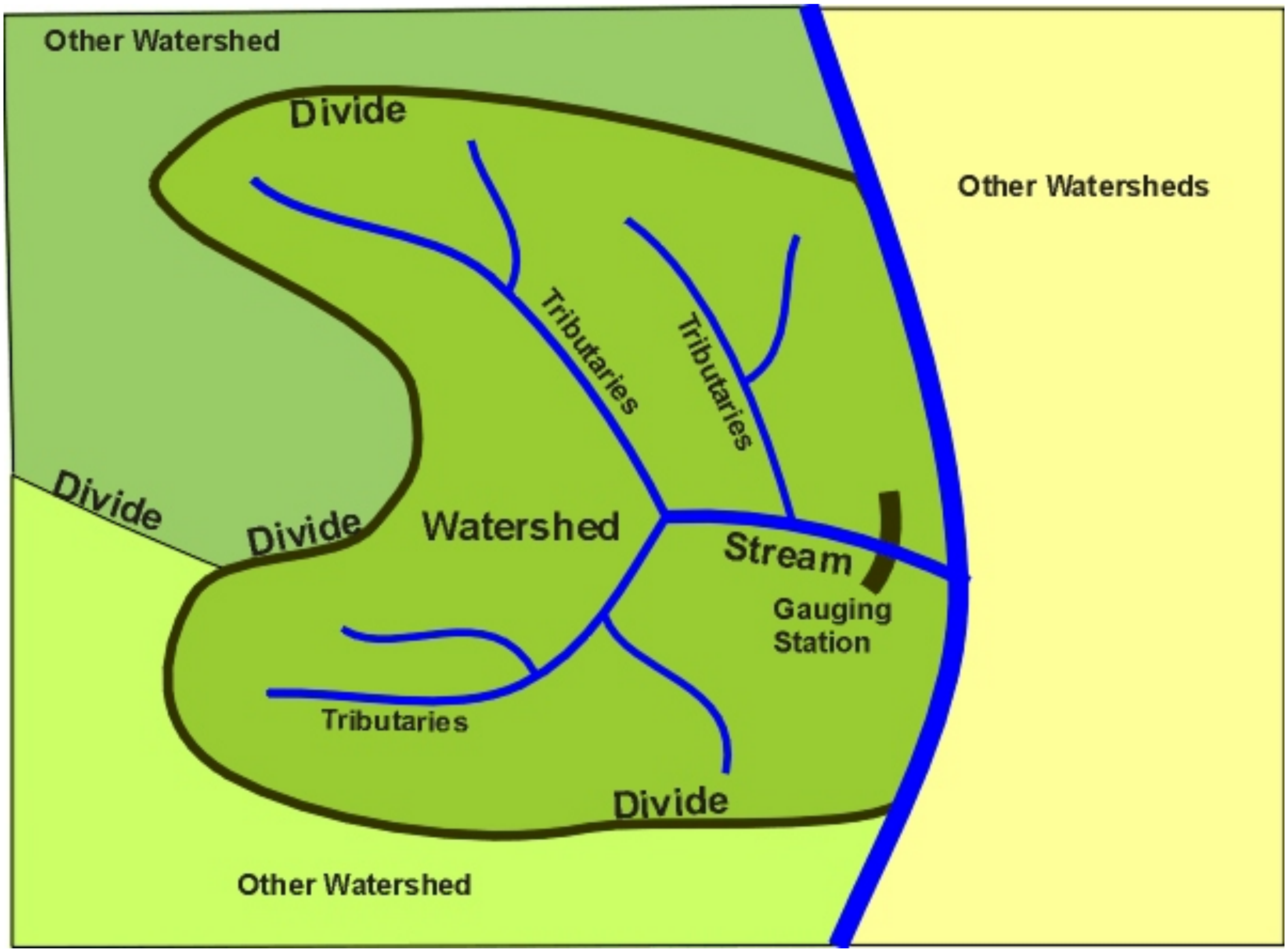
- Hydrologists often use terms like “100-year flood” or “500-year flood” to convey the idea of **a flood’s magnitude**.
- **The term “100-year flood”** means that, in any given year, there is a one in 100 chance of a flood of that particular magnitude. In other words, the probability of a flood of that magnitude in any given year is 1% (see table 25.1)
- In fact, **the actual amount of water** that causes a particular flood varies from river to river and even along a particular river.

TABLE 25.1 Flood Probabilities for Any Single Year

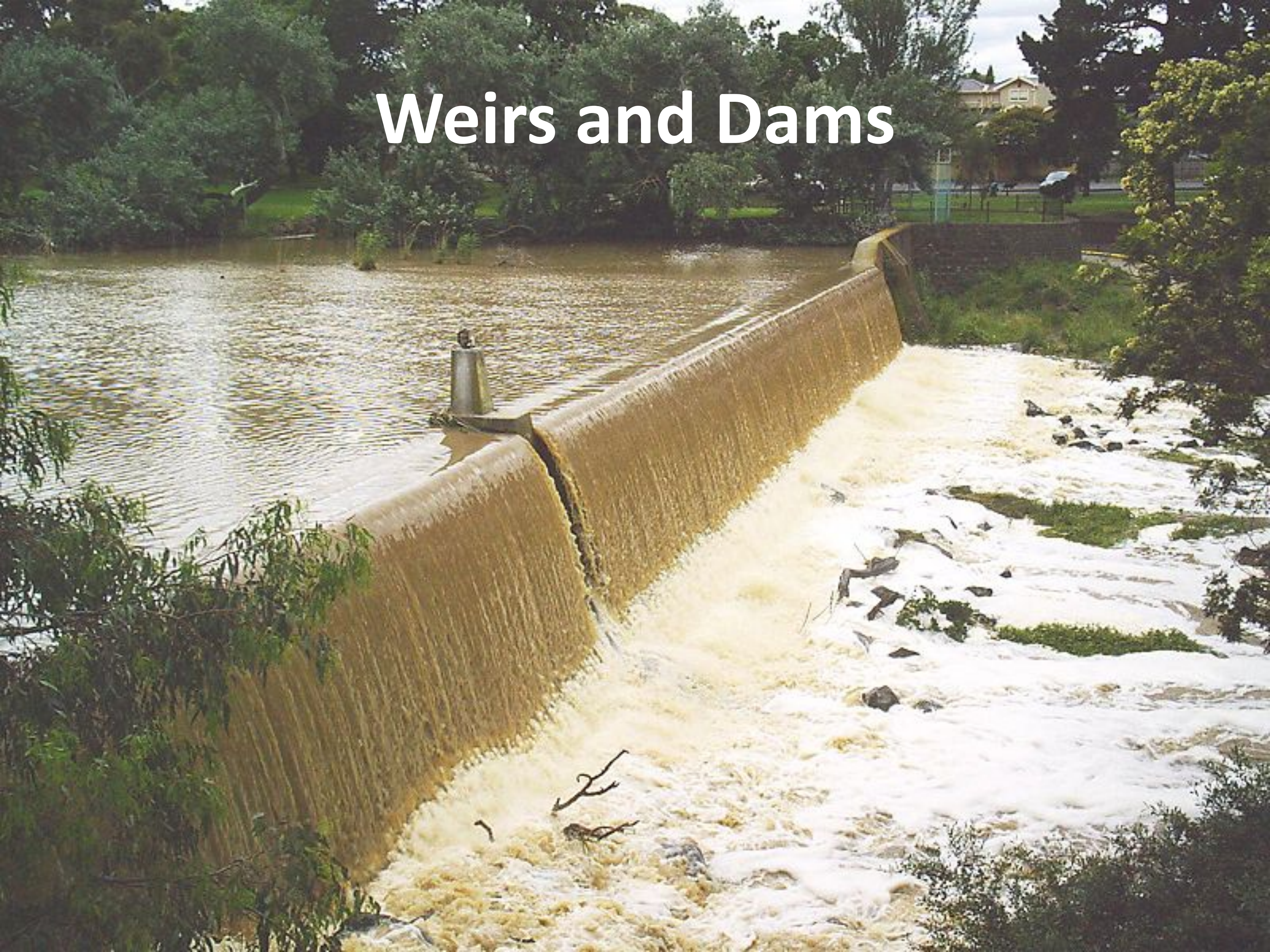
“X”-Year Flood	Probability of Occurrence in a Year
5	20%
10	10%
25	4%
100	1%
500	0.2%

- It’s sometime **a danger to use this term**, especially in areas where land use has changed substantially, which will redefine the criteria for “100-year flood” or “500-year flood” at a particular location.

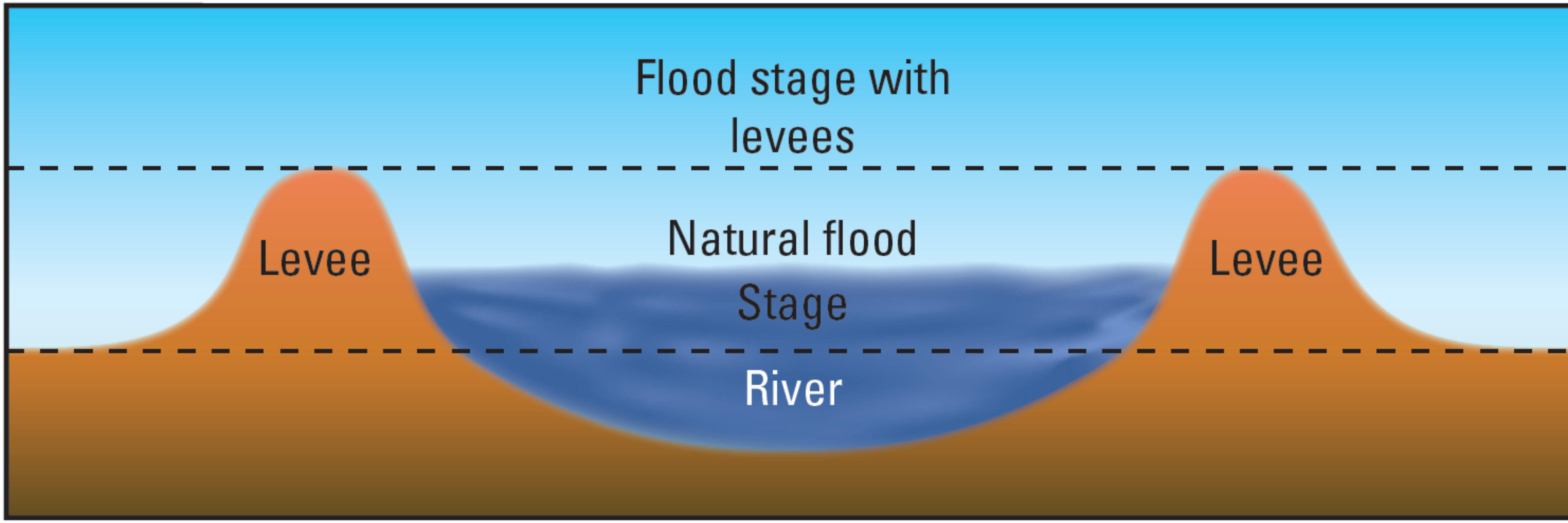
Watersheds: the geographic area that drains into a river or stream



Weirs and Dams



Levees



→Natural Levees form through sedimentation on river banks
→Artificial levees augment the natural ones
→Prevent floodwater retention upstream on the floodplain
→"Protection Effect" leads to development of vulnerable floodplain real-estate

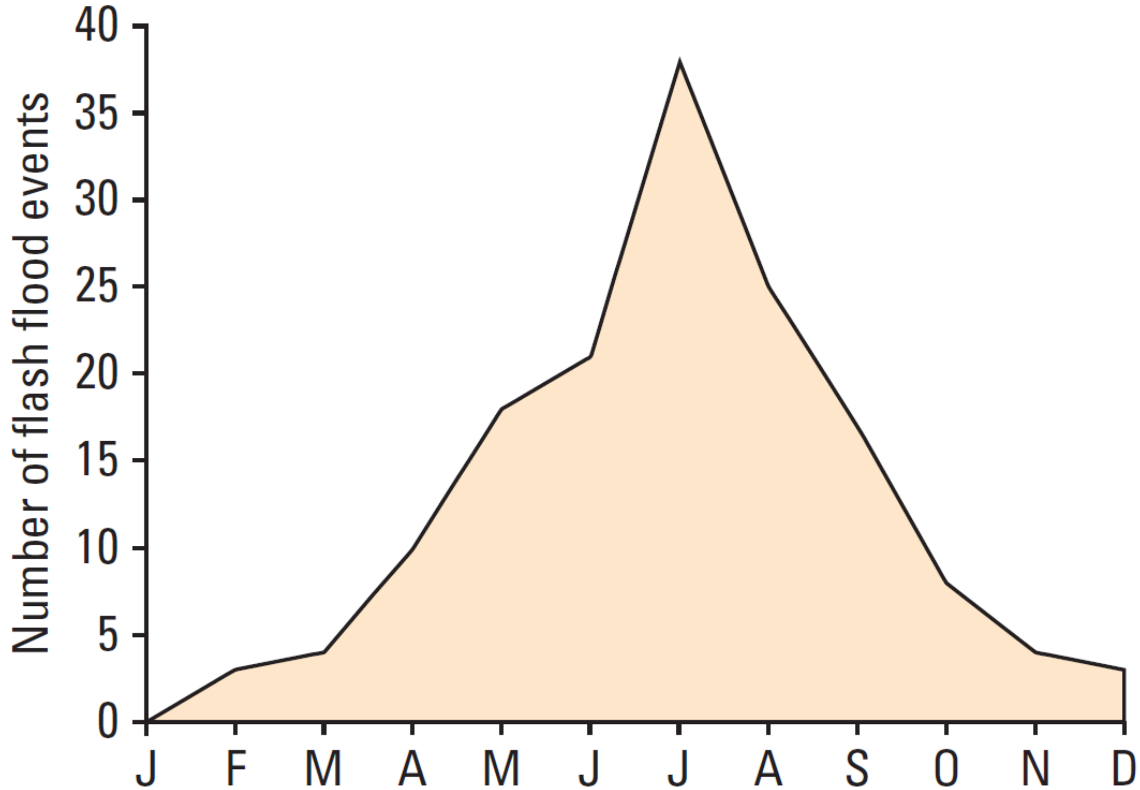
Types of Floods

- **Floods are classified based on their predictability and location.**
- **Three types:**
  - Flash Floods
  - Widespread Floods
  - Coastal Floods
- **Not every flood event can be categorized so clearly.** Some flood event can be a combination of these flood types. For example, an widespread flood can contains many local flash floods; land-falling hurricanes can cause both coastal floods and in-land floods.

Flash Floods

- **Flash Floods:** occur rapidly with little or no warning; Short duration and limited area, mostly on smaller rivers and streams; Often results in many injuries & fatalities. Flash floods are reported to kill ~140/year, many in cars
- **Causes of flash floods:**
  - Most commonly due to slow moving thunderstorms, usually in summer
  - Occasionally triggered by non-meteorological events such as a dam break during an earthquake.
  - Urban floods: Heavy rain and blocked or overloaded storm drains back water up from streets into dwellings

Flash Flood Occurrence



Monthly distribution of 151 flash floods occurring over a 5-yr period in 1970s in the US. The peak activity coincides with the time of year when T-storms are most common.

Widespread Floods

- **Widespread Floods:** occur when a large amount of rain falls over a watershed for many days so that significant portions of river basins draining the watershed are inundated for long periods
- Develop more slowly than flash floods and tend to last a week or more.
- Often described as “Leisurely disasters”: slowly and predictably destroying homes and property
- Much more property damage and greater economic losses than flash floods
- Fatalities are minimal due to warnings
- Causes: Usually due to multiple extratropical cyclones following the same storm track---often in springtime and may be aggravated by snowmelt

Coastal Floods

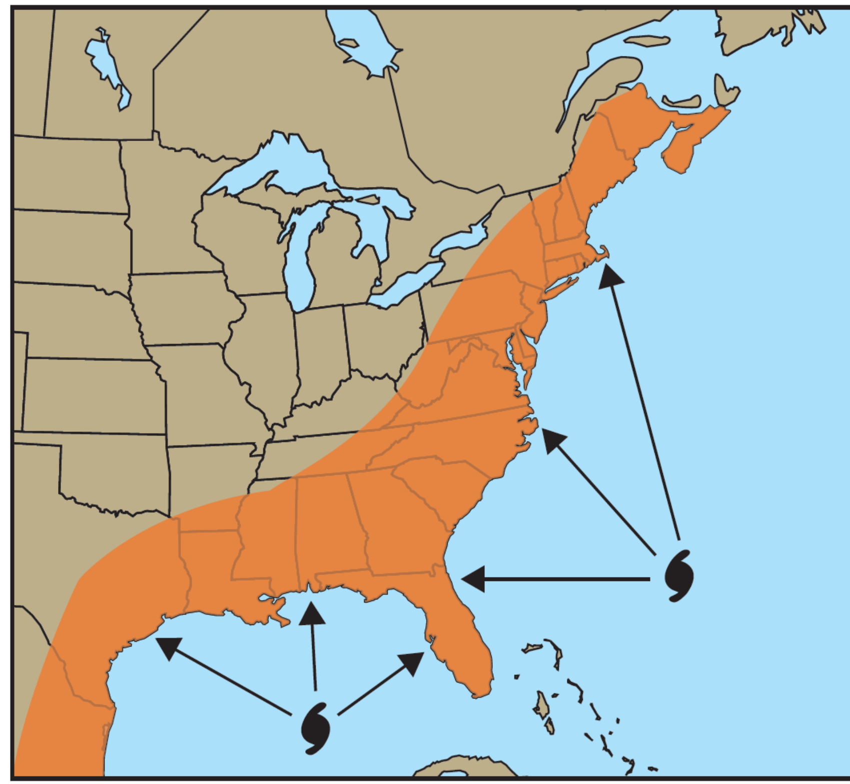
- **Coastal Floods:** occur when a rise in the ocean surface level due to storm surge develops during hurricanes (TCs) and strong extratropical cyclones (ETCs).
- Is more extreme along the East & Gulf Coasts of North American than along the West Coast because of the greater number of TCs & ETCs and the generally flat coastal topography.
- Coastal floods can develop as a result of non-meteorological phenomena, such as earthquake-generated tsunamis
- It’s moving water that’s lethal.

North American Flood Weather Patterns

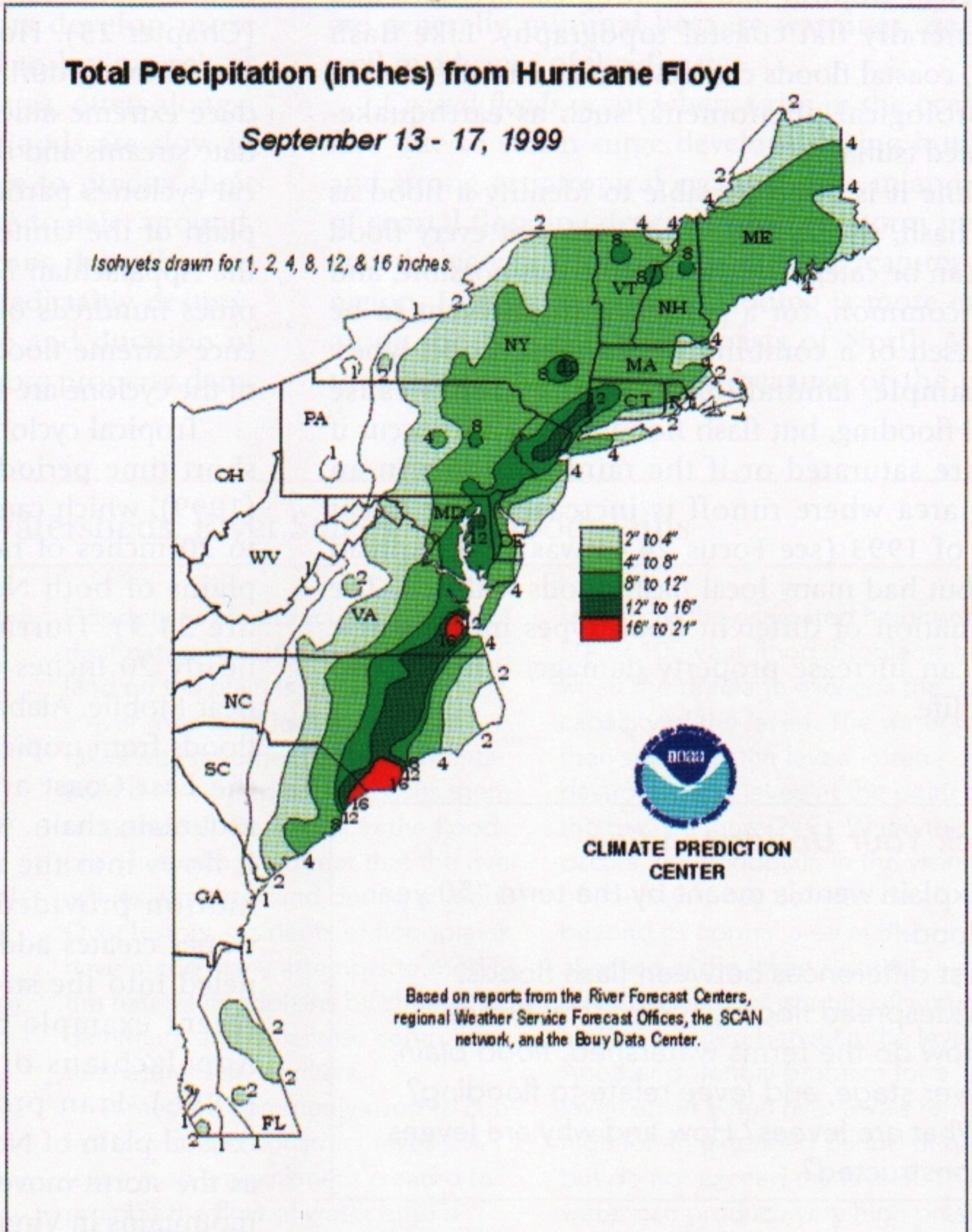
- **Many weather patterns** in NA are associated with flooding. They vary geographically and seasonally
- **A common feature** is their slow movement, leading to rainfall over a watershed for a long duration.
- **There are 8 patterns:**
  - 1. Flooding following landfalling tropical cyclones (TCs)
  - 2. Flooding from other tropical weather systems
  - 3. Flooding from frontal squall lines and mesocale convective systems (MCSs)
  - 4. Flooding from frontal overruning
  - 5. Flooding compounded by snowmelt
  - 6. Flash floods of the desert southwest
  - 7. Flash floods along the east slope of the Rocky mountains
  - 8. West coast floods

Flooding following landfalling tropical cyclones

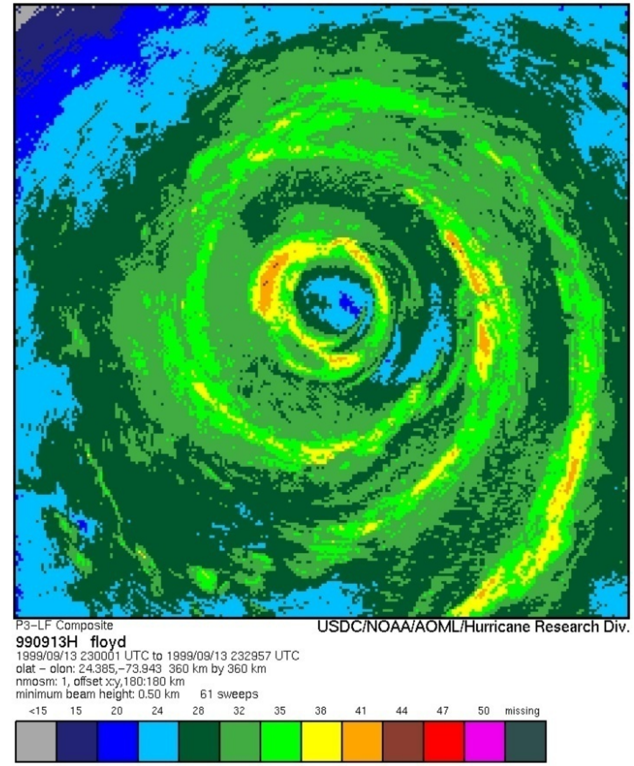
- **Coastal flooding due to storm surge**: Winds blow water onshore; Hurricane Storm Surge is the largest US threat to life
- **Inland flooding due to torrential rains** has emerged as another serious threat: for example, Hurricane Floyd (1999) in NC & VA, Georges (1998) in AL
- **Floods from TCs could be enhanced by the Appalachian Mountain**: TS Lee (2011) flooded mid-Atlantic to New England
- **Moisture from decaying TCs could be incorporated into extratropical cyclones**, causing heavy rain & flooding: Hurricane Agnes (1972) from VA to NY (120 deaths).
- **Urban regions are more vulnerable** (less absorptive capacity of the surface): TS Allison (2001) in Huston.



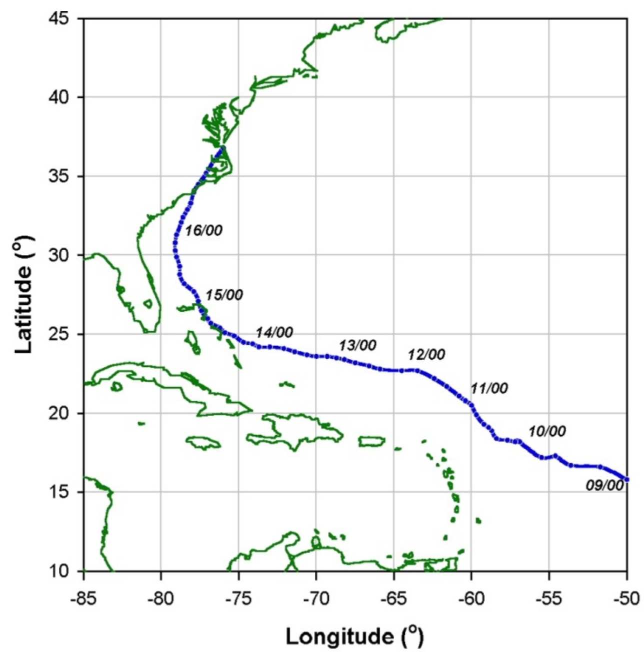
US regions affected by flooding from TCs



Total Precipitation (inches) from Hurricane Floyd
September 13 - 17, 1999
Isohyets drawn for 1, 2, 4, 8, 12, & 16 inches.
2" to 4"
4" to 8"
8" to 12"
12" to 16"
16" to 21"
ME
VT
NH
NY
MA
CT
PA
OH
MD
DE
WV
VA
NC
SC
GA
FL
CLIMATE PREDICTION CENTER
Based on reports from the River Forecast Centers, regional Weather Service Forecast Offices, the SCAN network, and the Bouy Data Center.

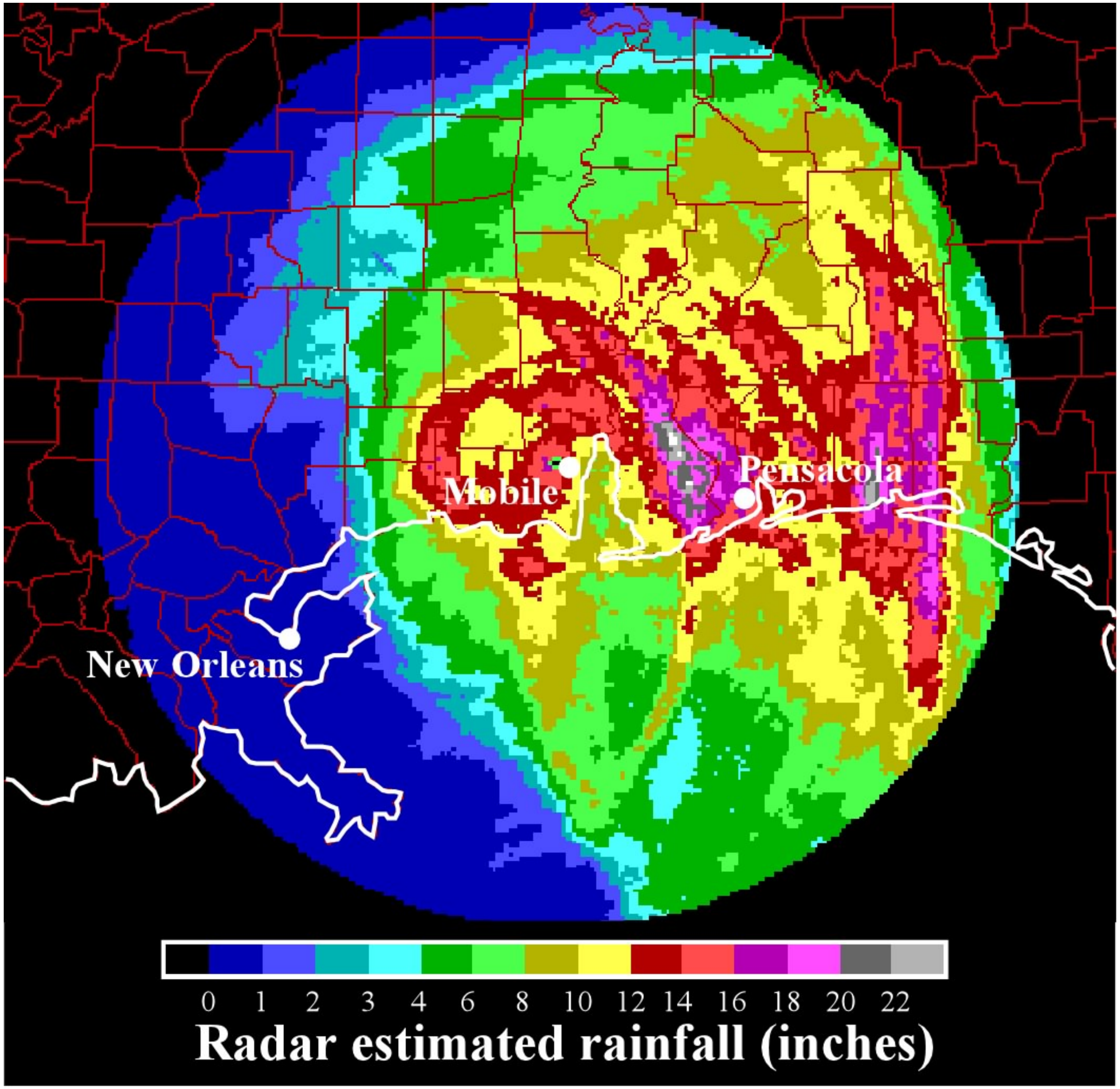


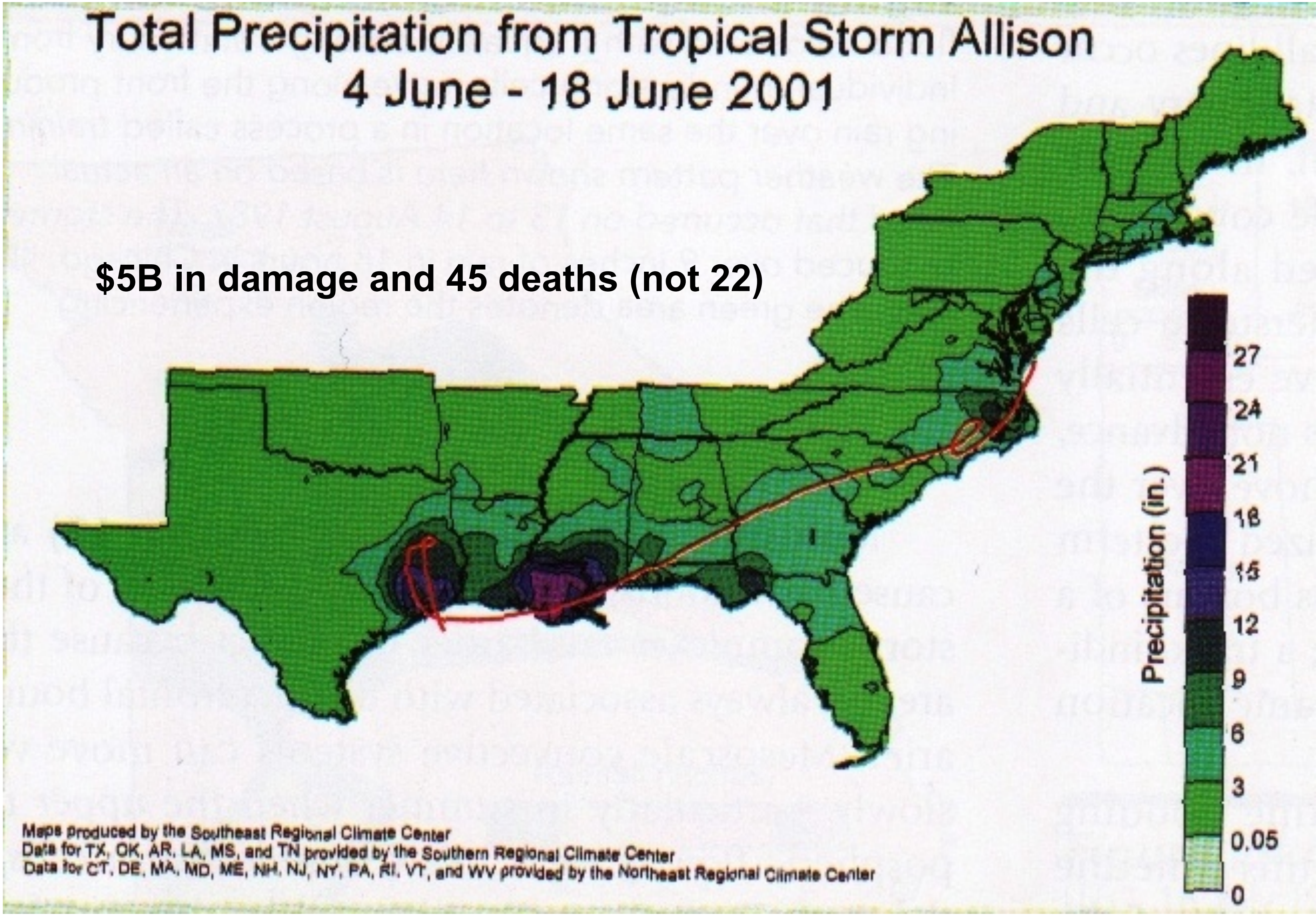
P3-LF Composite
USDC/NOAA/AOML/Hurricane Research Div.
990913H floyd
1999/09/13 230001 UTC to 1999/09/13 232957 UTC
olat - olon: 24.385,-73.943 360 km by 360 km
nmosm: 1, offset x:y,180:180 km
minimum beam height: 0.50 km 61 sweeps
<15 15 20 24 28 32 35 38 41 44 47 50 missing



Latitude (°)
Longitude (°)
45
40
35
30
25
20
15
10
-85 -80 -75 -70 -65 -60 -55 -50
16/00
15/00
14/00
13/00
12/00
11/00
10/00
09/00

Accumulated rainfall estimated by a radar near Mobile AL during the landfall of Hurricane Georges of 1998





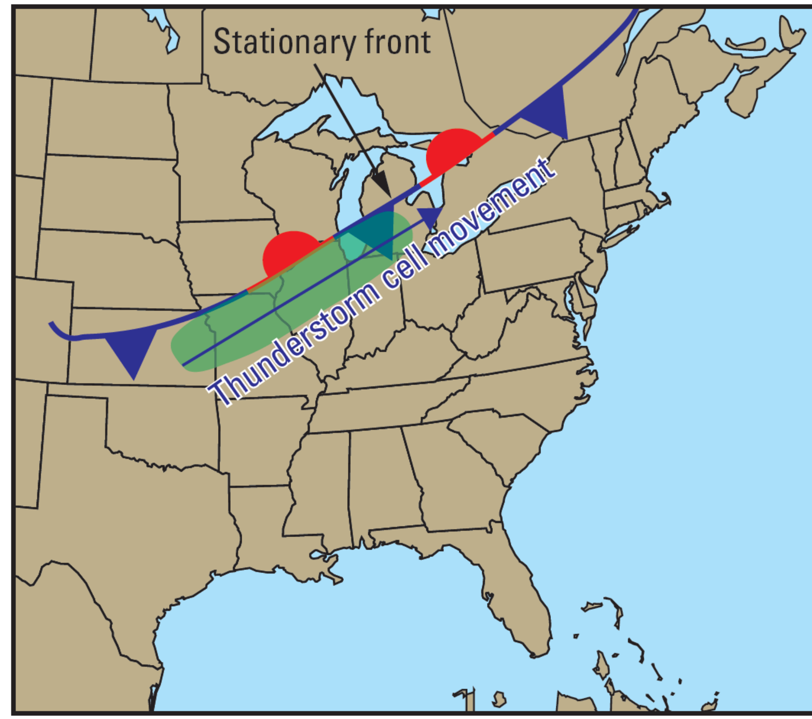
$5B in damage and 45 deaths (not 22)

Flooding from other tropical weather systems

- Most flooding in **Central American, the Caribbean Islands, and Hawaii** occur from TCs. But flooding in these tropical regions can also occur **due to thunderstorms over higher topography under conditions with high moist & CAPE,** often during the passage of easterly waves in the late spring, summer and early fall or when cold fronts move in & stall.
- **Flooding in these regions is enhanced by deforestation and poor infrastructure:** Extreme rainfall in Haiti in May 2004 (more than 3300 people dead or missing), more than 90% of the country is deforested, causing mudslides during heavy rains

Flooding from Frontal Squall Lines (stationary front) and MSCs

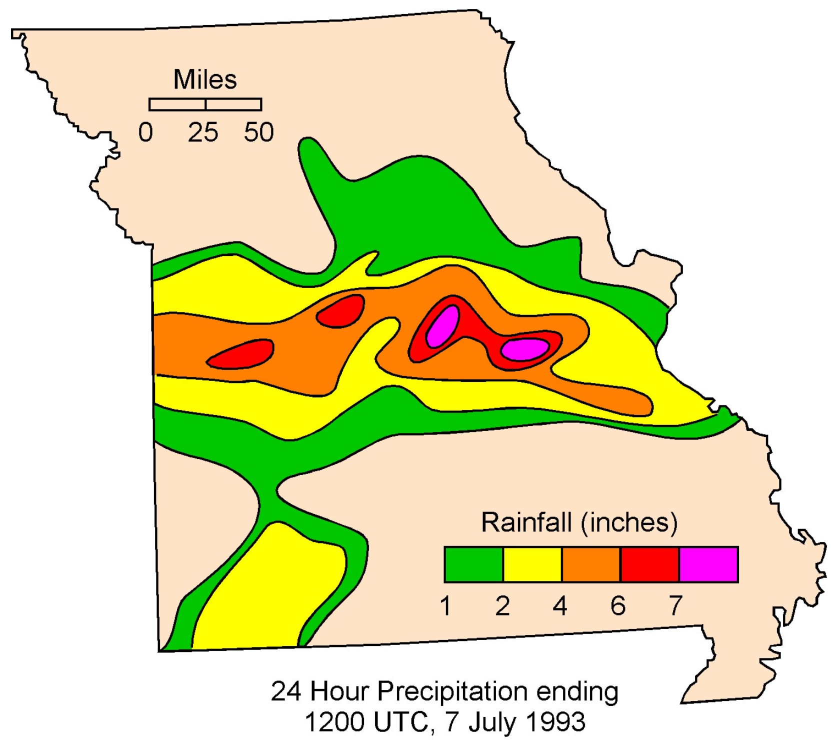
- **T-storms from frontal squall lines and MCSs** most commonly generate floods between the Rockies and the Appalachian mountains. Flood-generating T-storms typically form in the warm side of weak boundaries in late spring and summer
- **Flooding from stationary fronts with conditionally unstable air ahead of it**: winds flow parallel to the front; existing and new cells also move parallel to the front. Since the front does not move, **new cells continuously move over the same region—cell training**. A lot of rain reaches the ground because of:
  - Heavy rain rate
  - Long rain duration



Cell training along a stationary front: Individual T-storm cells move along the front producing rain over the same location (weather pattern of flood in Aug. 1987 in Chicago. Green indicates flooding areas)

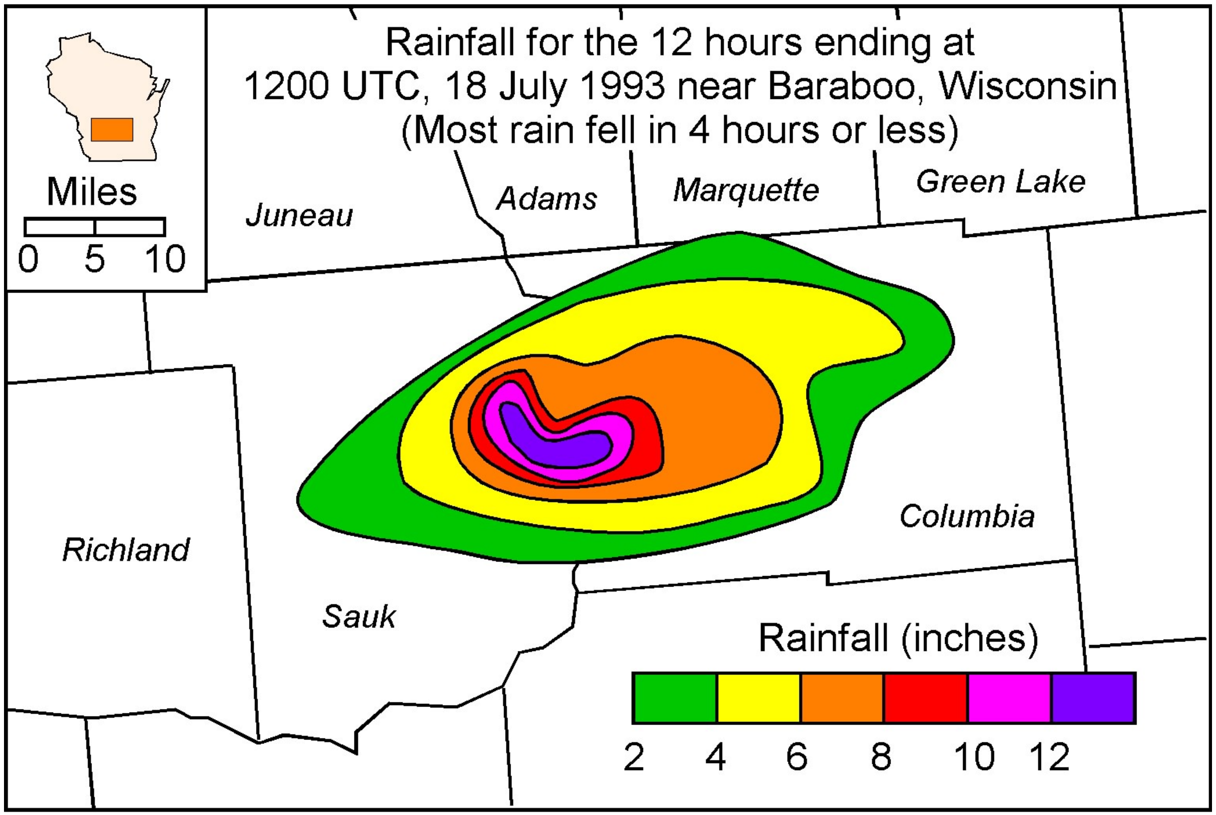
Flooding from Frontal Squall Lines (stationary front) and MSCs

- **Flooding from MCSs**: MCSs can move slowly, keep generating new T-storms along gust front, resulting a heavy rain accumulation in a localized area.
- MCSs were an important component of **the great flood of 1993 over the upper Mississippi river basin (Fig. on the right-->)**.



Rainfall in Missouri. An MCS that moved across the state produced the rain. This was one event of many during the great 1993 Mississippi Flood.

Individual MSCs are large, move slowly and may last a day or more

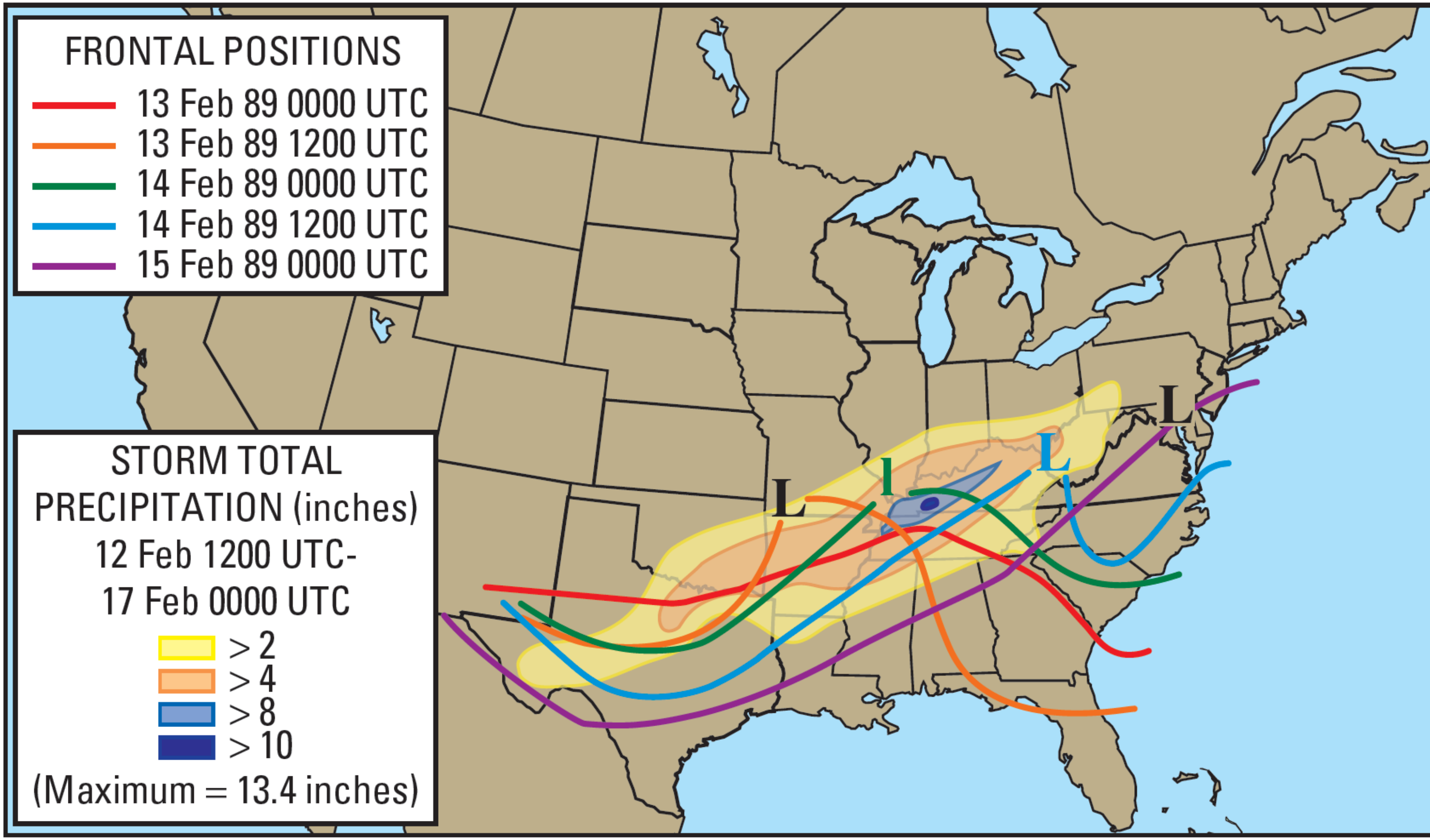


A nearly stationary MCS produced the rain and was part of the "Great Flood of 1993"

Flooding from Frontal Overrunning

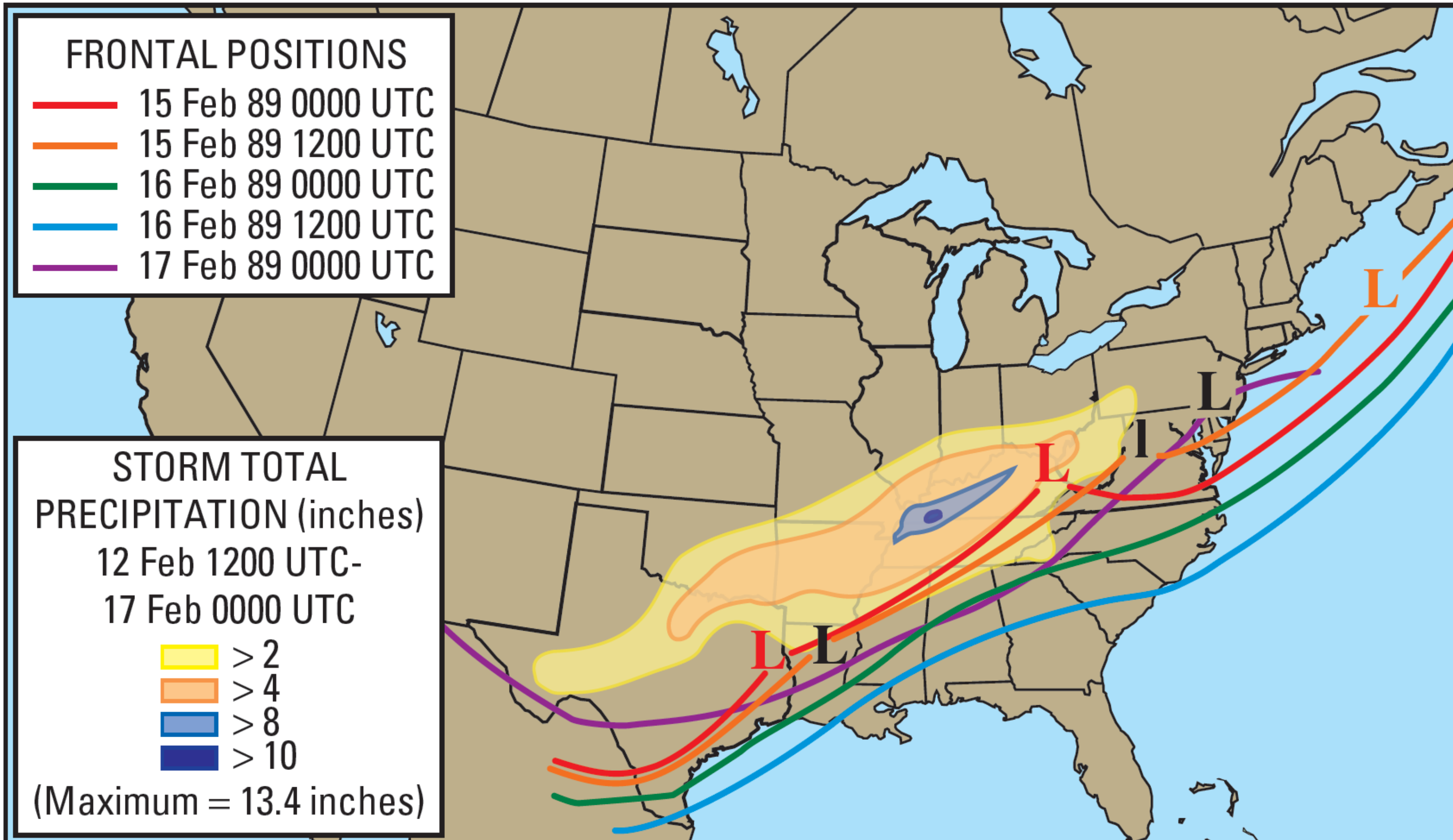
- During cold season, east-west oriented warm fronts often develop across the SE US. **These fronts sometimes stall, or move so slowly that they are stationary.**
- Warm, moist air from the Gulf flows northward over cool airmass north of the front. This process is called **frontal overrunning**, producing T-storms and heavy rain north of the frontal boundary if the air rising over the front is conditionally unstable.
- If the front is present in a region for several days, rain accumulation can lead to **local flash flooding or even widespread flooding**.

An Example of Flooding from Frontal Overrunning



Frontal positions every 12 hours for 4 days beginning at 00Z 13 Feb. 1989.
The total precipitation over the 4 days is shown on both panels.
Over 13 inches of rain in Kentucky led to over $50M in damage and 3 fatalities

An Example of Flooding from Frontal Overrunning

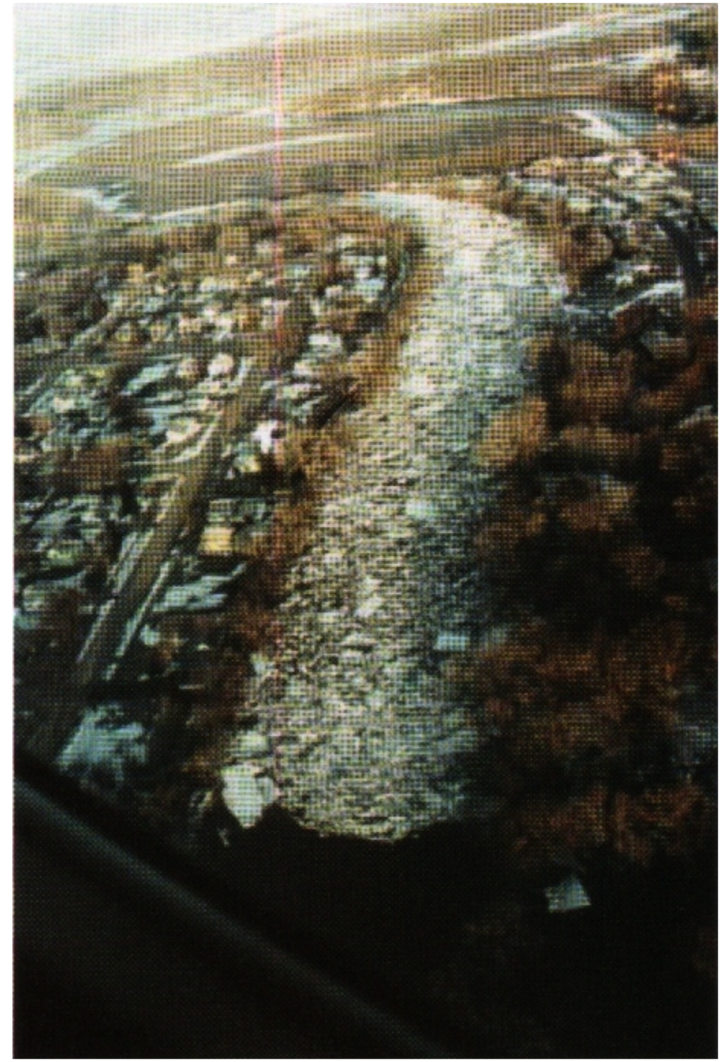


Frontal positions every 12 hours for 4 days beginning at 00Z 13 Feb. 1989. The total precipitation over the 4 days is shown on both panels.

Over 13 inches of rain in Kentucky led to over $50M in damage and 3 fatalities

Flooding Compounded by Snowmelt and Ice Jams

- Many damaging widespread floods in the northern US occur when the rapid melting of a winter snowpack enhances runoff from heavy spring rains.
- Waterways become clogged with ice jams restricting runoff
- In some cases, extreme flooding from snowmelt can occur even without heavy rain, such as the example shown in the figure.



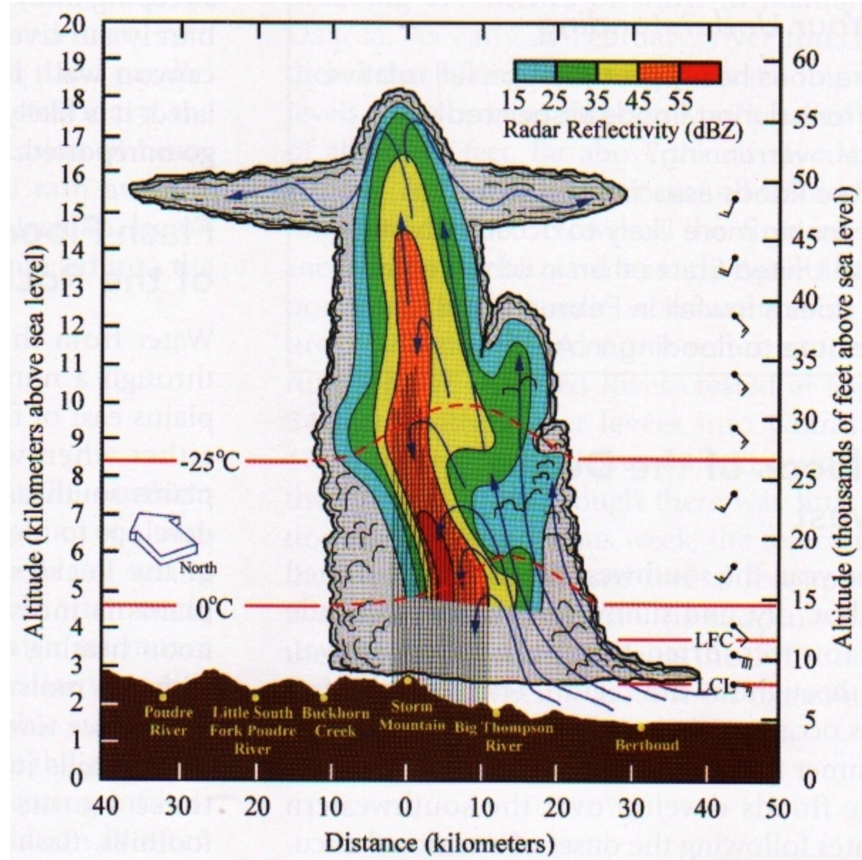
Ice jam on the Red Lake River, a tributary that flows into the Red River at Grand Forks, North Dakota, during the flood of 1997

Flash Floods of the Desert Southwest

- SW Deserts are hot and dry and received very little rainfall. But intermittent streams, or “Arroyos (dried riverbeds)” common through the region testify that floods do happen .
- Summer NA monsoon brings sudden convective rain, short-duration but very intense rainfall
- Within the canyons the height of the water builds rapidly, forming a wall of water that roars down the canyon without warning.
- Example: Antelope Canyon flooding in AZ Aug 13, 1997, killed a group of tourists

Flash Floods Along the East Slope of the Rocky Mountains

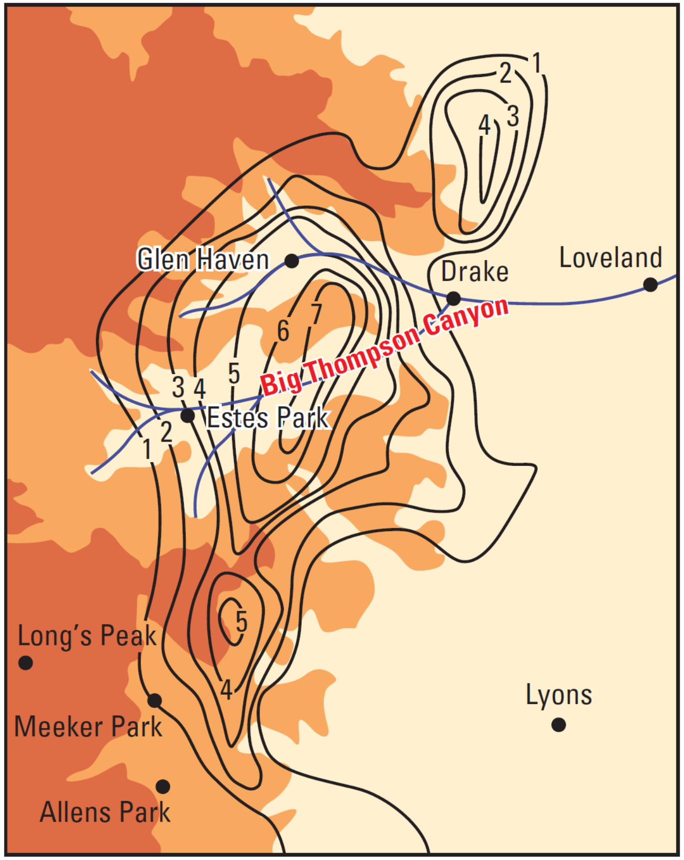
- In summer, the flow on the plains east of the Rockies becomes easterly.
- When the air is conditionally unstable, afternoon heating can produce towering T-storms over the foothills just east of the Rockies.
- When these storms remain near stationary, flash floods can be disastrous.
- Example: Big Thompson flood of 31 July 1976-→



Modeling of the initial cells of the Big Thompson storm (winds, LCL, LFC, and radar reflectivity).

Big Thompson Flood

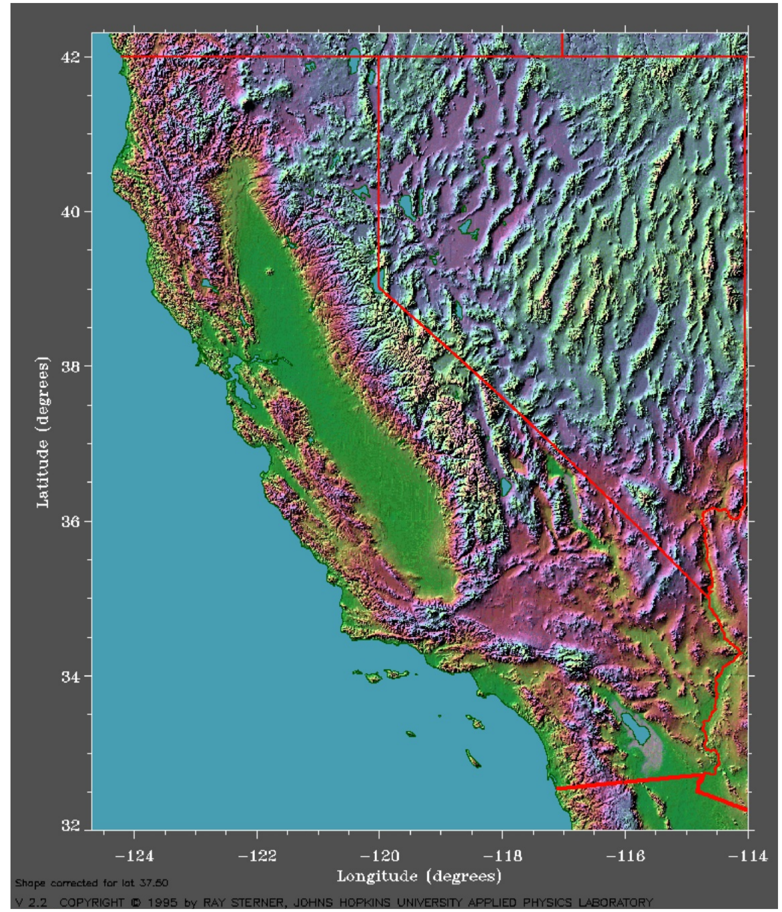
- Occurred on 31 July 1976 in the Big Thompson (BT) Canyon CO, located
- BT river begins east slope of the Rockies and drains onto plains
- Nearly stationary, multicell storm developed over the BT watershed
- Upslope, conditionally unstable flow in low shear
- Cells trained over BT
- Rained 6 in in 5 h
- Wall of water , 10-15 ft high claimed ~139 hikers and picnickers



Heavy rainfall accumulated throughout the lifetime of the BT storm (contours are rain in inches). Elevations are shown in darkest (above 9000 ft), darker (8000-9000 ft), and light (below 8000ft)

West Coast Floods

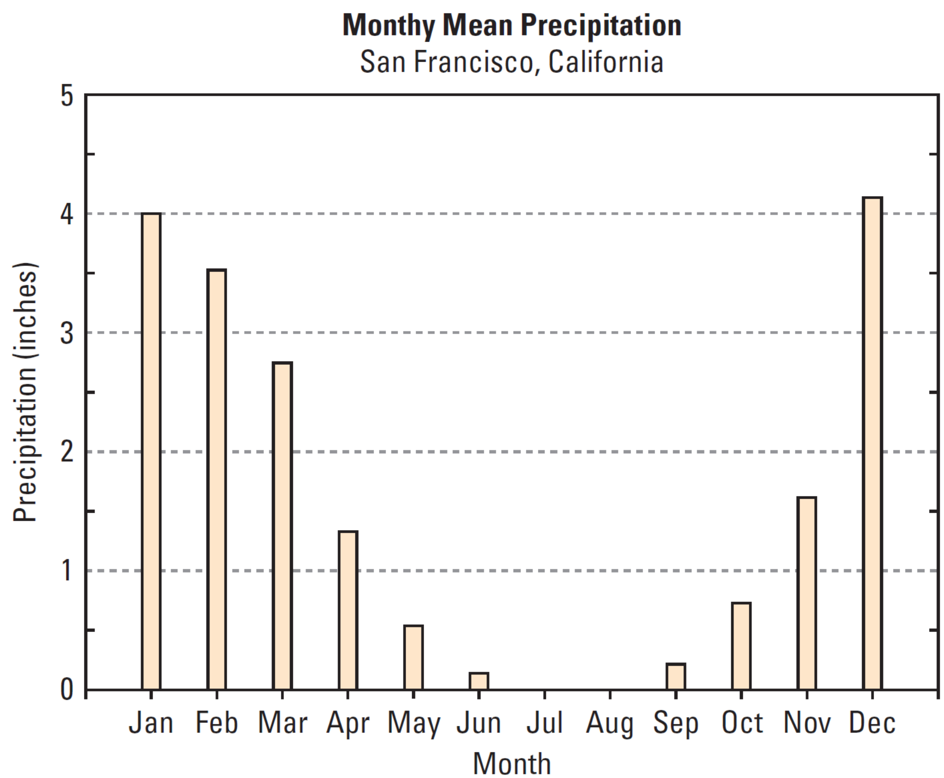
- Wintertime flooding is the greatest danger in the mountains along west coast
- Flash flooding in the river valleys of the Sierra Nevada, Cascade, and Coastal Ranges often lead to widespread flooding.
- This mainly happens in the **central valley of California (green area on the figure).**



Sierra Nevada range is to the east, Cascade mountains to the NE and N, Coastal Ranges to the W, and Tehachapi to the S

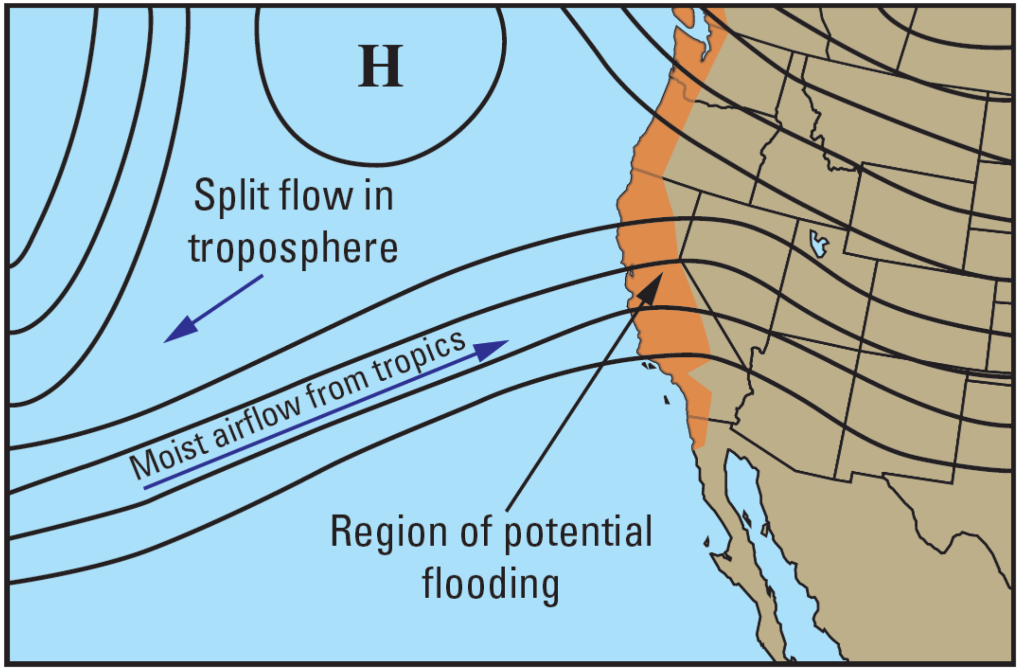
The Central Valley of California

- Was wetland in 1800
- Water is now constrained by reservoirs in the foothills of the Sierra and Coast ranges, as well as by a system of levees.
- Only drainage is where the Sacramento River cuts through the Coast Range into San Francisco Bay
- Rains only in winter, presenting an interesting water management challenge…

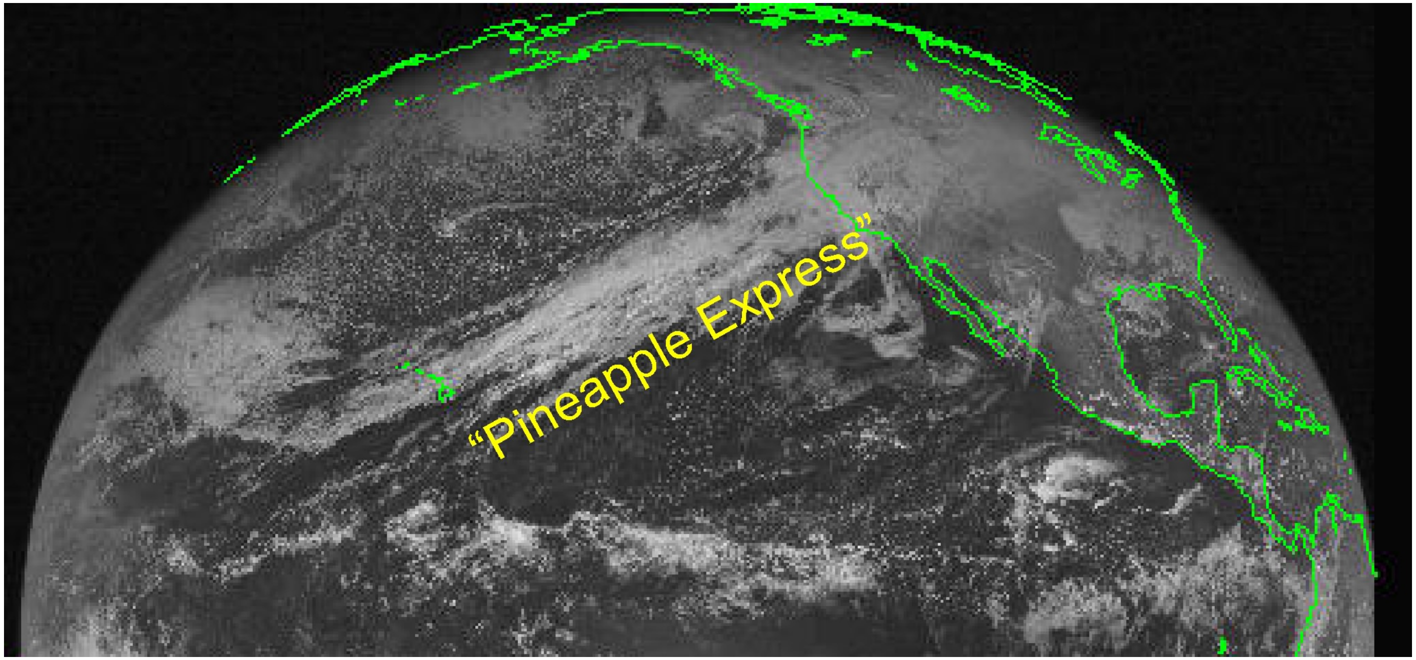


Winter Storm Weather Pattern: Pineapple Express

- Split flow often present in the middle troposphere during flooding events in California.
- The lower branch of the flow brings tropical moisture into the Coastal Mountains and the Sierra Nevada.
- **Storms** develop within the southern branch of the jet and can move into the coast **every 36-48 hours**.



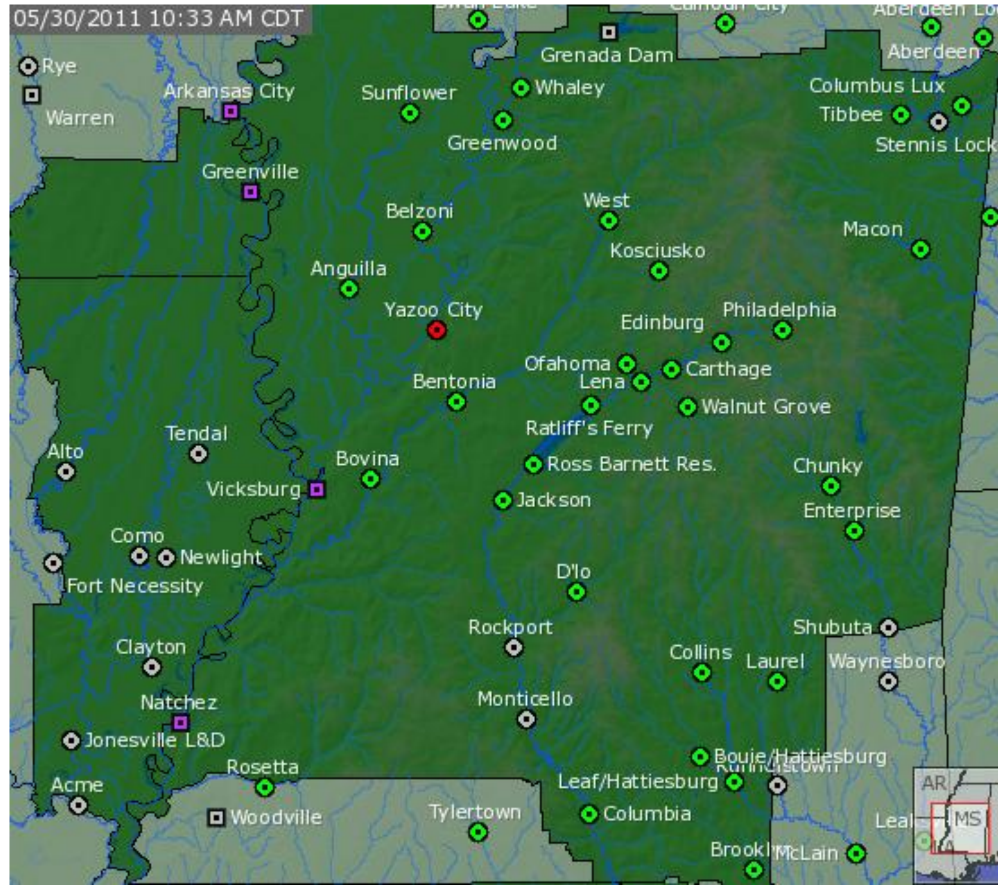
Visible Satellite Images of Pineapple Express



- New storm every 36 to 48 h, following the same track.
- On satellite images, this flow appears as a band of clouds stretching from Hawaii to the West Coast.
- Mountains force air to rise, leading to heavy precipitation.
- Significant flooding events of this type occur in California most recently in 2010 & 2006.
- This weather pattern can also lead to flash flooding & mudslides in hilly regions

Flood Forecasting

- NWS's Hydrometeorological Prediction Center (HPC) provides river and flood forecasts and warning.
- 13 river forecast centers monitor river flooding conditions by using streamflow gauges and water-stage monitoring systems.



River gauge reports across central Louisiana on May 30 2011 showing major (purple), moderate (red), and no (gray & green gauges) flooding

Flood Forecasting

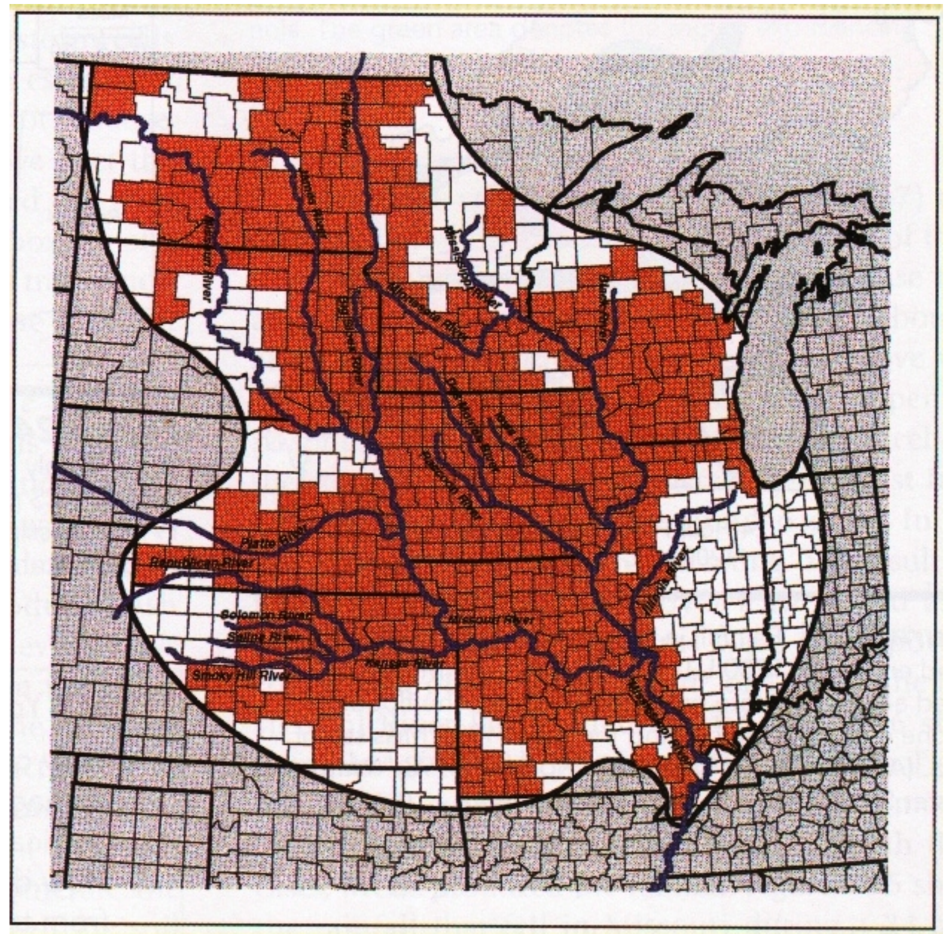
- Numerical models for > 1 day, plus satellite images
- For large-scale flooding, persistence of a pattern
- Analysis of the morning sounding's stability
- **WSR-88D: very important for identifying flash flooding** ---Storm total precipitation, recognize training, MCSs, etc. NOWCASTING
- Advisories
  - **Flood Watch-**--potential for flooding conditions
  - **Flood warning-**--flooding imminent
  - Apply to **flash, urban, river, stream, coastal** … flooding

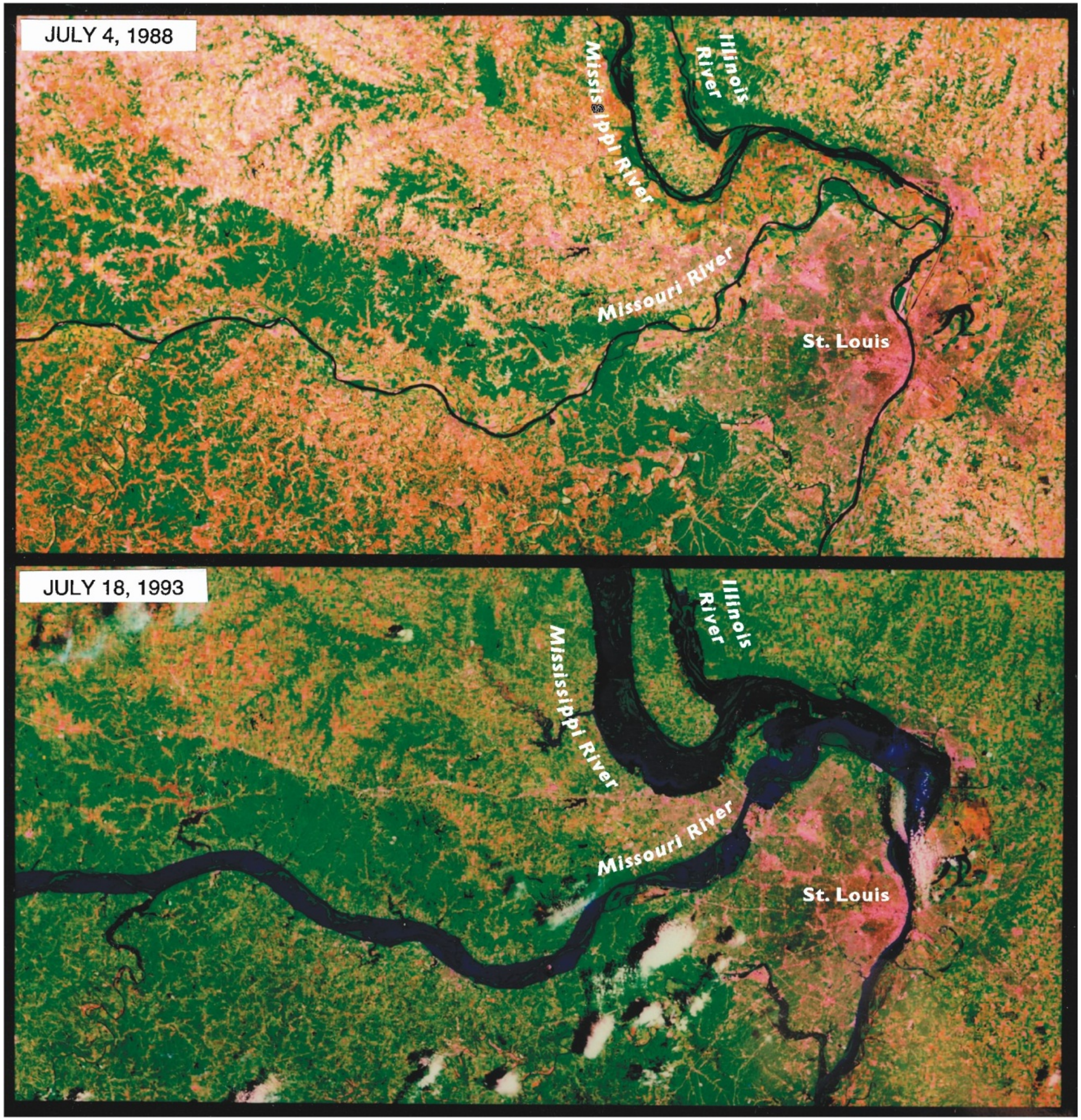
Flood Safety

- Any flooding, whether a minor street flooding or a major flooding, should be treated seriously.
- As little as 6-inches of rapidly moving water can sweep off a person off his/her feet.
- A foot of water can wash away a car.
- **Never drive through a flooded area; Leave your vehicle and climb to higher ground.**
- **If the vehicle stalls in water, abandon it immediately**
- Pay attention to flooding warning, be alert at night
- **Evacuate quickly & orderly & immediately following an evacuation order**; don’t return for personal belongs– a lesson learned during Hurricane Katrina (2005)

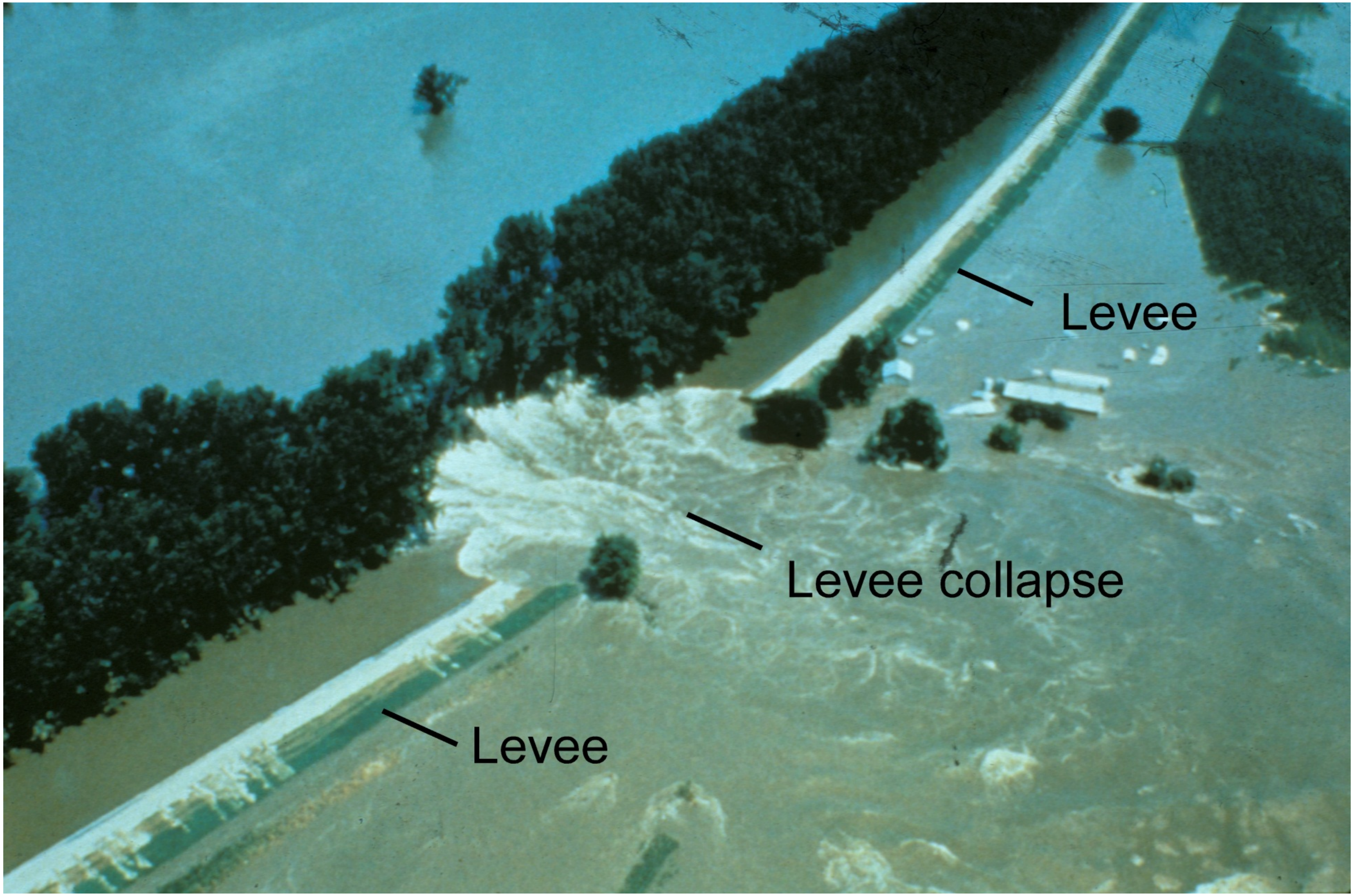
Great Flood of 1993

- 500-yr Event in upper basin of Mississippi and its tributaries
- Damage $15-20B
- 48 Deaths
- 50,000 homes destroyed
- Stopped barge and rail transport
- Caused by a large number of MCSs.
- Many events produced flash floods on the Mississippi's tributaries
- Aggravated by 1991-1993 El Niño





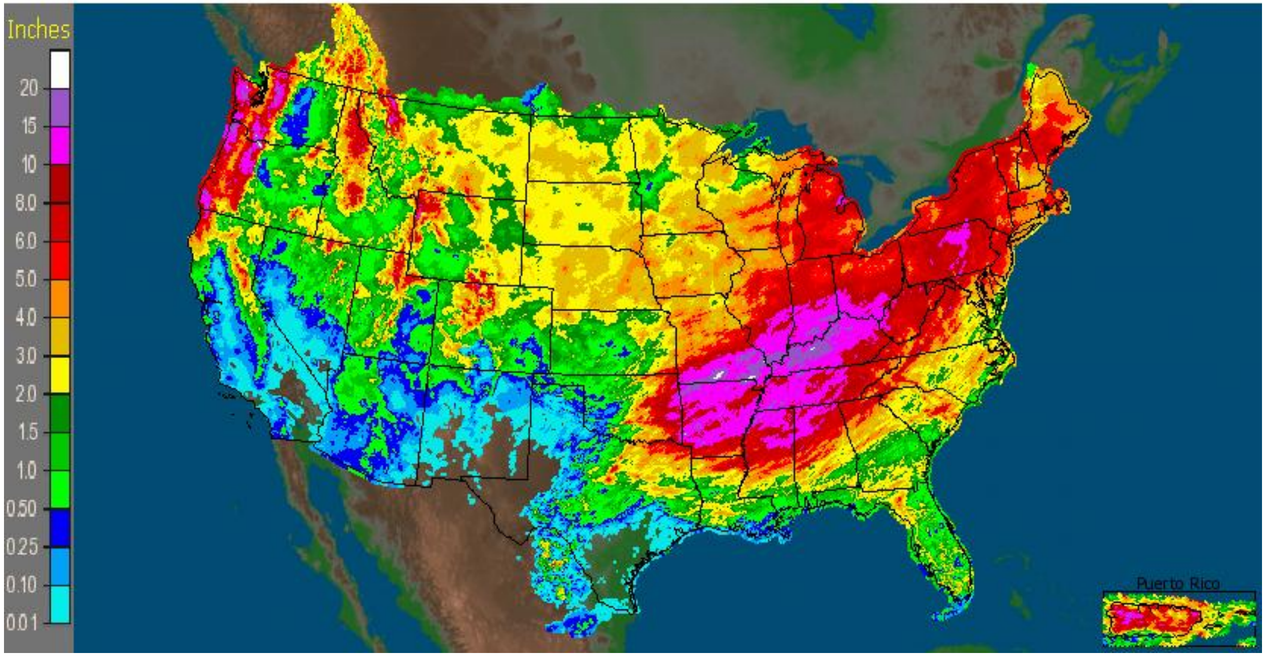
LANDSAT images of the junction of the Mississippi, Missouri, and Illinois rivers on **(top)** July 4, 1988 during the severe drought of 1988, and **(bottom)** July 18, 1993, during the Great Flood of 1993.



A levee break during the Mississippi Great Flood of 1993.

The Mississippi River during the Great Flood of 1993. A levee is visible as a linear feature extending diagonally across the photo.

Lower Mississippi Flood in April 2011



April 2011 rainfall totals across the US. Note the heavy rain across the Ohio River basin.

- Begin with flooding on the Ohio river
- Due to repeated passage of cyclones across the central US
- The heavy rainfall developed as frontal squall lines, and lines of supercell T-storms were triggered by cold & upper-level fronts of these cyclones
- Flood was compounded by snowmelt

Summary

- Annual flood impacts: >$1B, 75-100 lives
- Kinds of floods: Flash, Widespread, Coastal
- Watersheds encompass the land drained by a stream and its tributaries
- Levees protect a stream's flood plain from normal flooding. Protection effect.
- Floods caused by long-lasting, heavy rainfall: 8 flood weather patterns in North America
- Advisories & Safety
  - Watch—Flooding likely
  - Warning---Flooding imminent or happening
  - Nowcasting with radar and satellite