Satellites, Weather and Climate Module 29:
Flooding

This postcard, which depicts a wrecked home in flooded Waterbury on Nov. 4, 1927, was published by the E.T. Houston Studio in Montpelier.

SWAC
The UNIVERSITY of VERMONT
NSF
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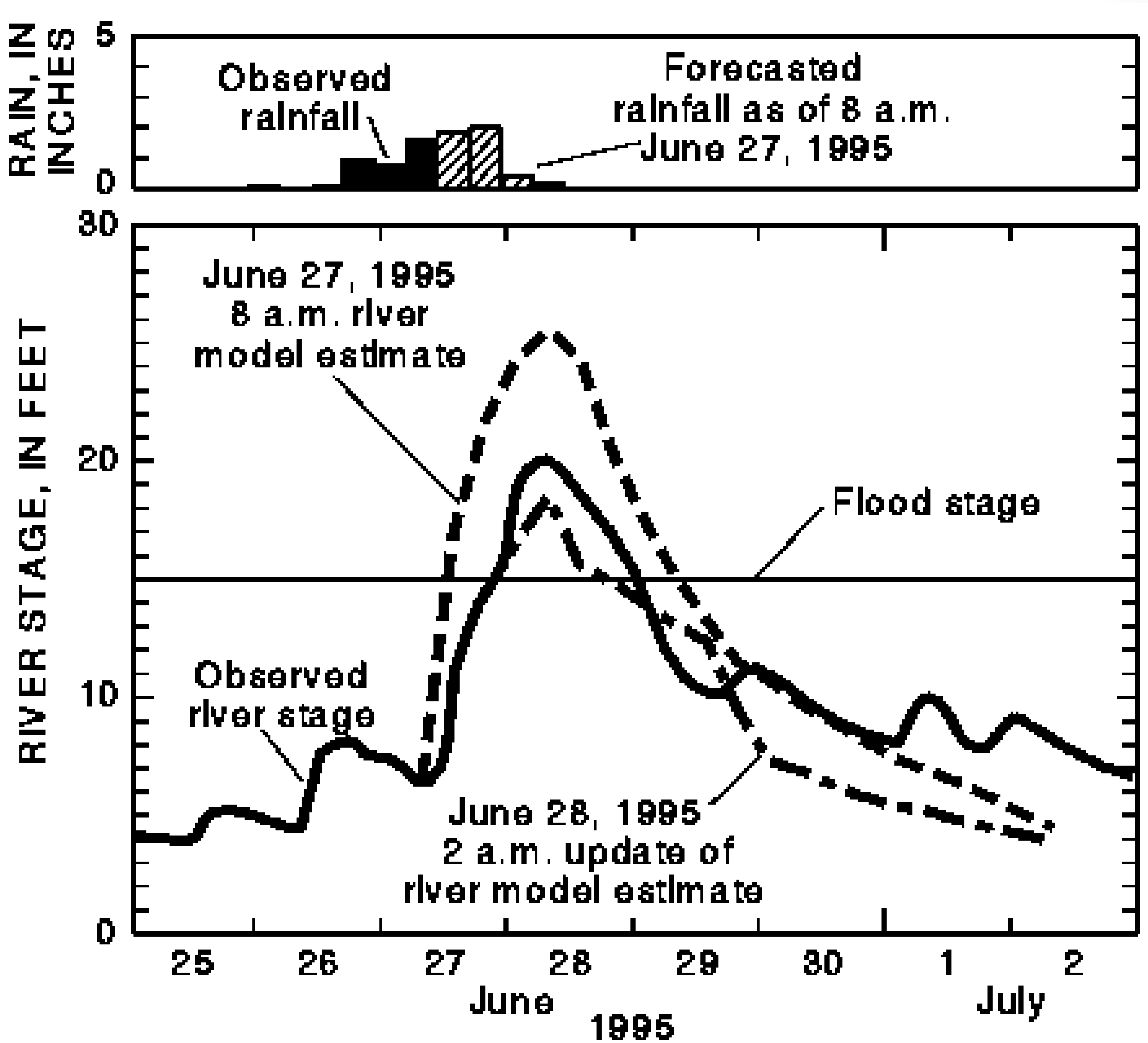
Outline

- flash flooding vs. flooding
- conducive meteorological factors
- conducive landscape factors
- case studies

Basic definitions

- flooding
  - long term event over the course of a week or more
- flash flood
  - takes place within 6 hours of the rain event

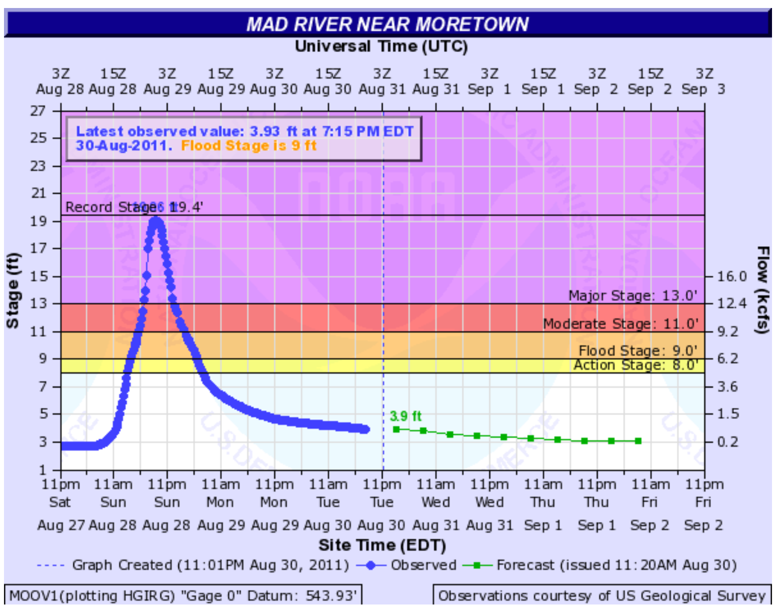
HYDROGRAPH

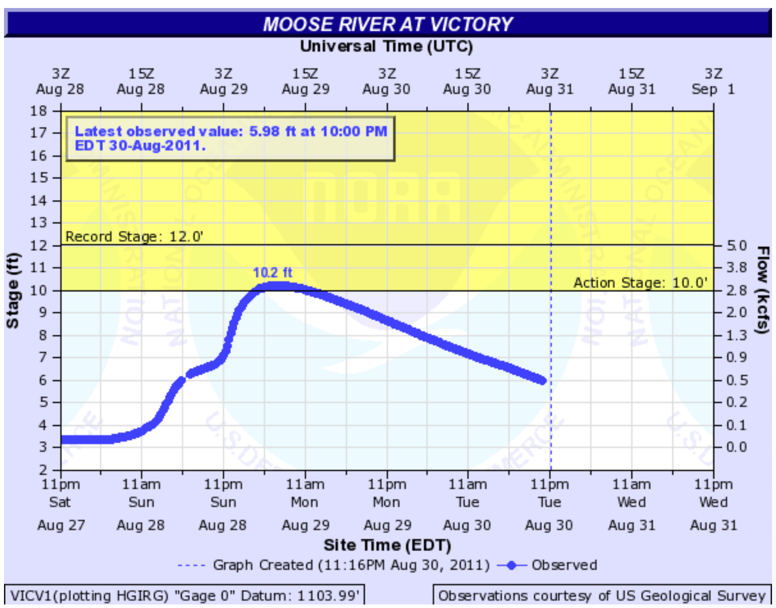


RAIN, IN INCHES
5
0
Observed rainfall
Forecasted rainfall as of 8 a.m. June 27, 1995
30
20
10
0
RIVER STAGE, IN FEET
June 27, 1995 8 a.m. river model estimate
Flood stage
Observed river stage
June 28, 1995 2 a.m. update of river model estimate
25
26
27
28
29
30
1
2
June
July
1995

Flash flooding during Irene

Riverine flooding during Irene



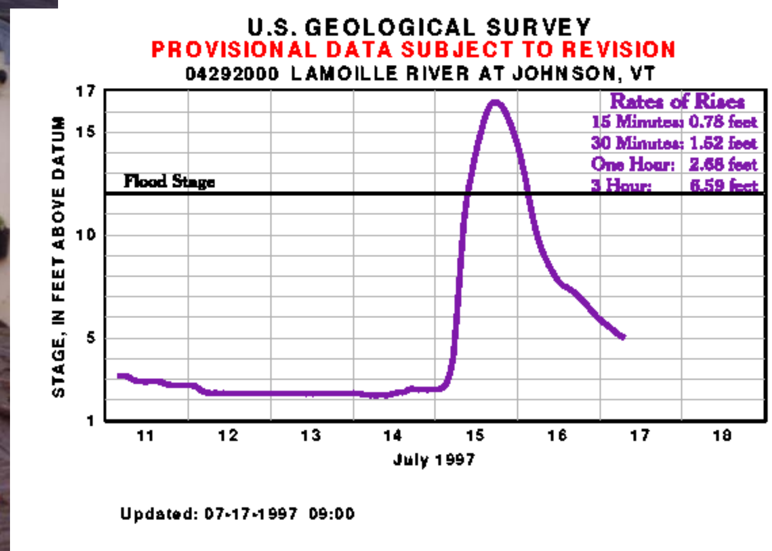


Flash flooding

- rapid onset
- can trigger mudslides
- slow-moving thunderstorms
- raging walls of water
- flow along steep canyons at incredible speeds

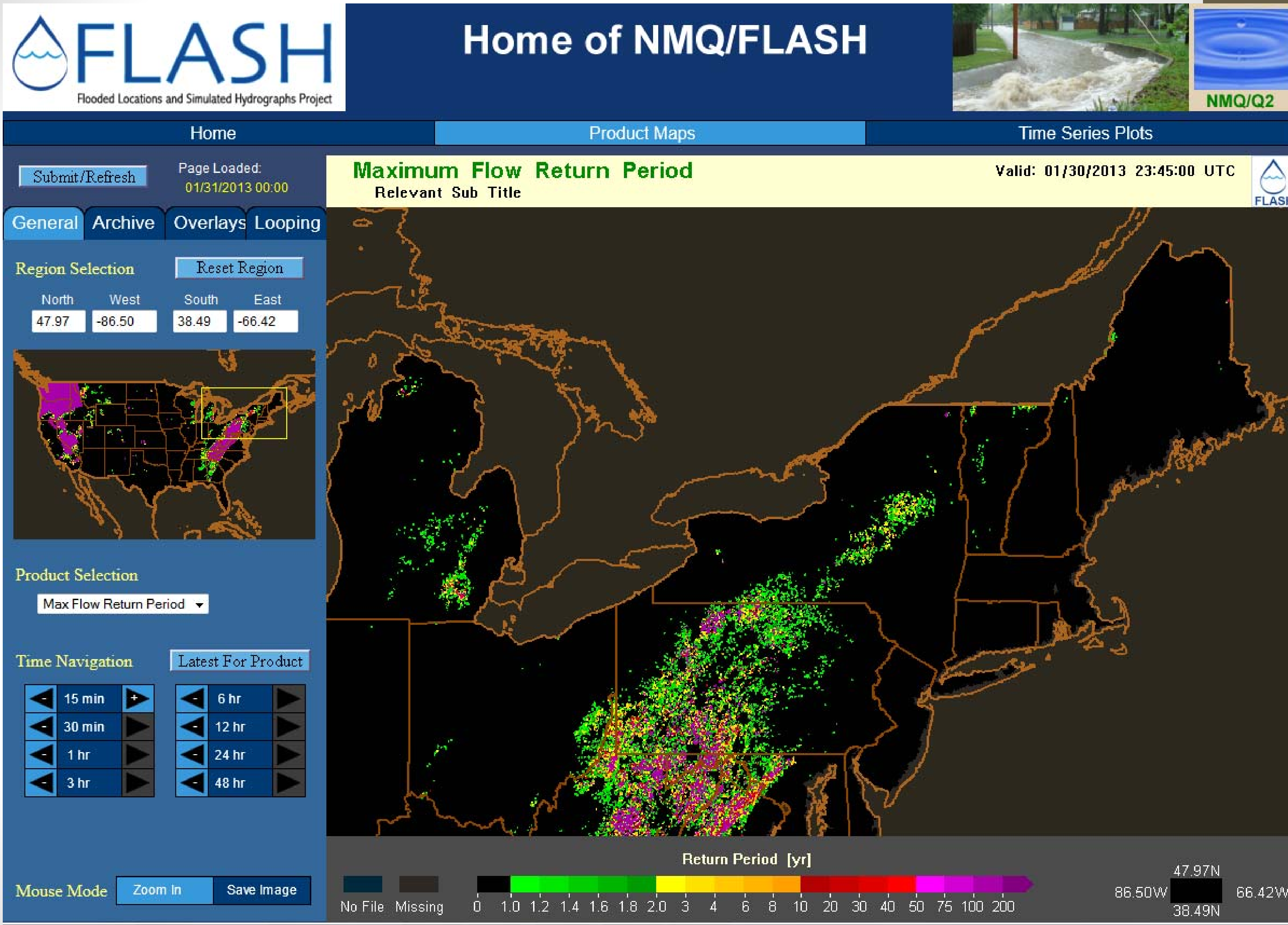
- ongoing menace especially where small streams in mountainous areas confined to narrow valleys or canyons

Flash flooding – Montgomery, VT
July 1997



Montgomery, VT

Photo credit: National Weather Service/BTV



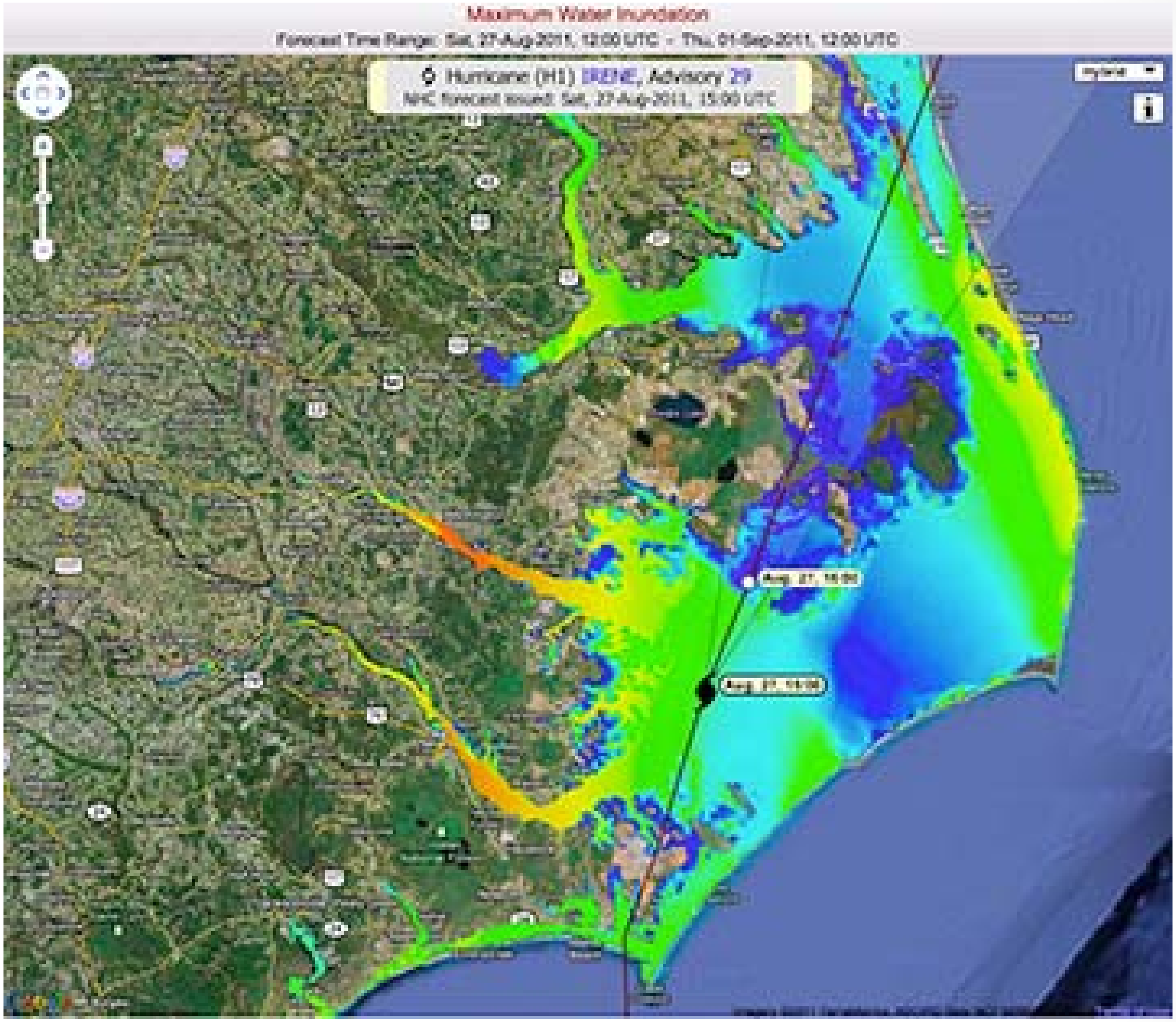
http://flash.ou.edu/

1. Types of flooding

- river
  - seasonal
  - hurricane remnants
- coastal
  - hurricane surges
  - tsunamis
- urban
  - inadequate runoff facilities
  - blocking of natural drainage
- ice jam
  - at critical points → serious local flooding during spring breakup

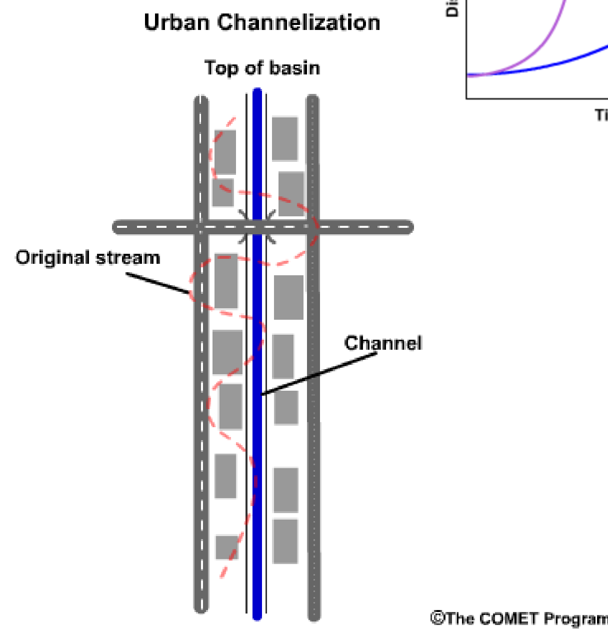
http://eijournal.com/2012/on-the-cutting-edge-of-emergency-management

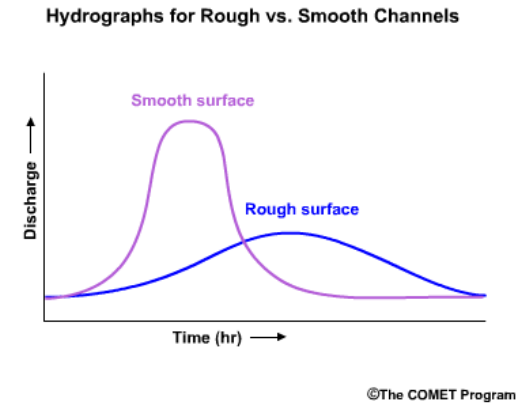
Coastal inundation predicted by CI-FLOW resulting from Irene



http://www.nssl.noaa.gov/projects/ciflow/surge.php

Urban flooding





http://www.meted.ucar.edu/hydro/basic/Runoff/print_version/03-basinproperties.htm

Flash Flood Example: Montpelier, VT

Wednesday, March 11, 1992

- **6:57 a.m.** A large ice jam on the Winooski River breaks loose about the Pioneer Street Bridge and travels through Montpelier. Ice jams just below the Bailey Avenue Bridge and dams the river.
- **7:05 a.m.** Filled with rain and snowmelt, the Winooski begins to overflow its banks along State Street and the North branch begins backing up onto Elm Street.
- **7:15 a.m.** Water surges dramatically into low-lying areas behind Main and State Streets, floating propane tanks from moorings, flooding parked cars and inundating store basements.
- **7:23 a.m.** Radio stations are notified of a flood emergency as first warnings are issued.
- **7:45 a.m.** Icy flood waters hit the steam heating boiler at MacPherson's Travel on Main Street and the boiler explodes, shattering the glass storefront and destroying the basement.
- **7:56 a.m.** Two to three feet of water is reported in front of Days Inn on State Street where an estimated 100 people are stranded. Flood waters pour onto Main Street, stalling cars and making the road impassable. Backed-up water from the swollen North Branch flows upstream on Elm Street.
- **8:09 a.m.** Evacuations begin of hundreds of stranded residents, workers and state employees on Main, State and Elm Street. Some wade to safety, while others are taken out by boat or by fire engines and dump trucks.

ERDC

2. Flood triggers

- deep snow cover
- frozen ground
- saturated soil
- full reservoirs
- existing bankfull conditions
- ice-covered rivers
- widespread, heavy rain

- topography
- ground cover

3. Seasonality of flooding

- winter
  - frozen soil
  - early thaws leading to ice jams
- spring
  - ice jams
  - snowmelt
- summer
  - heavy, prolonged rainfall
  - flash floods

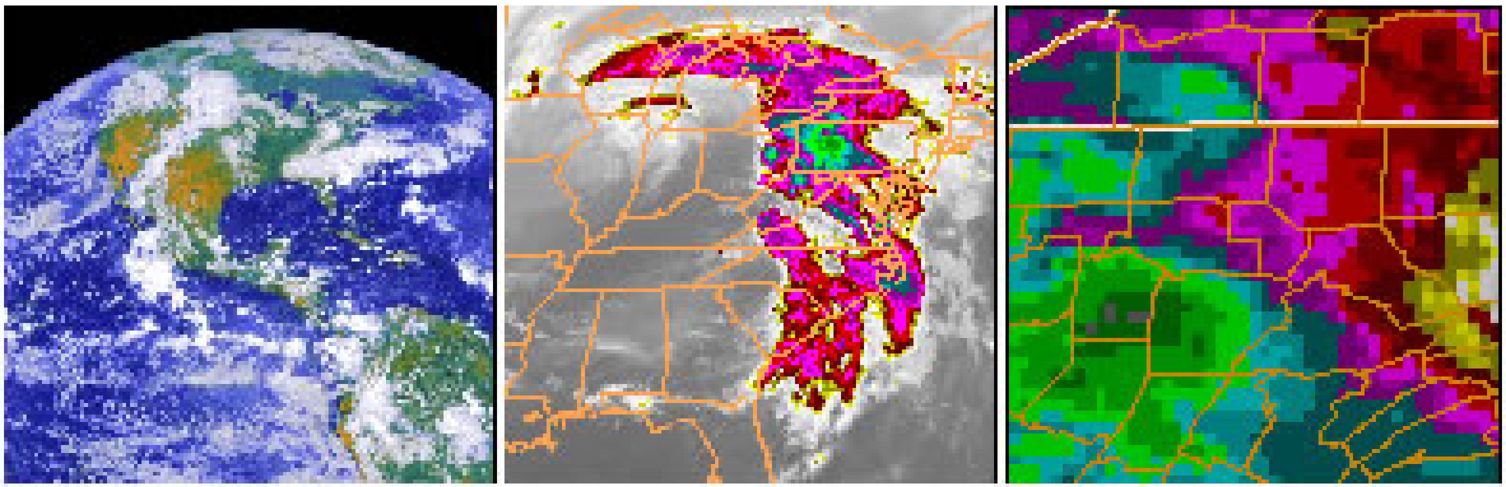
4. Meteorological conditions

- synoptic occluded fronts
- tropical cyclonic remnants

- isolated thunderstorms
- training

- cold air damming

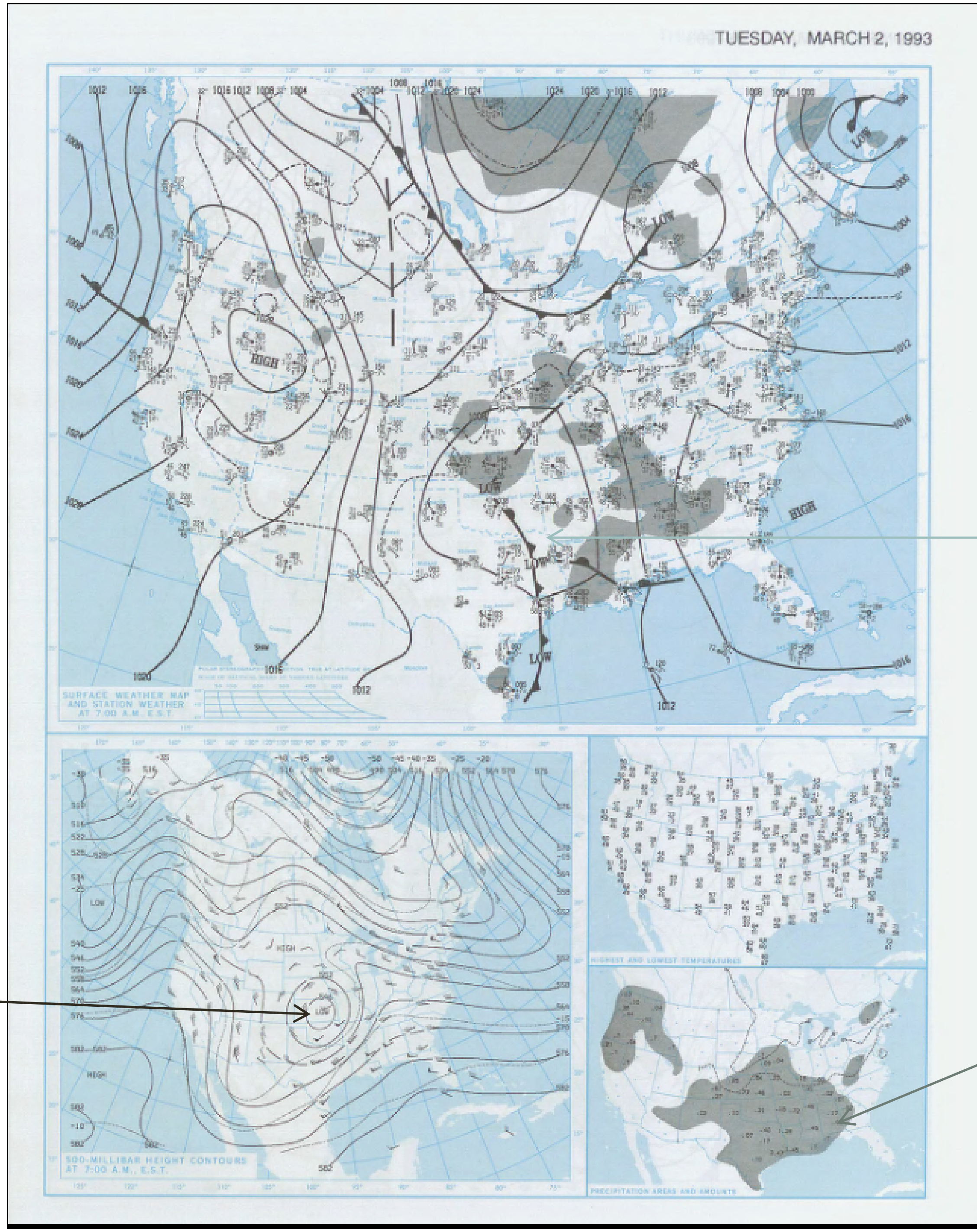
What does synoptic scale mean?



Global scale | Synoptic scale | Mesoscale

NOAA/The COMET Program

SYNOPTIC OCCLUDED FRONT

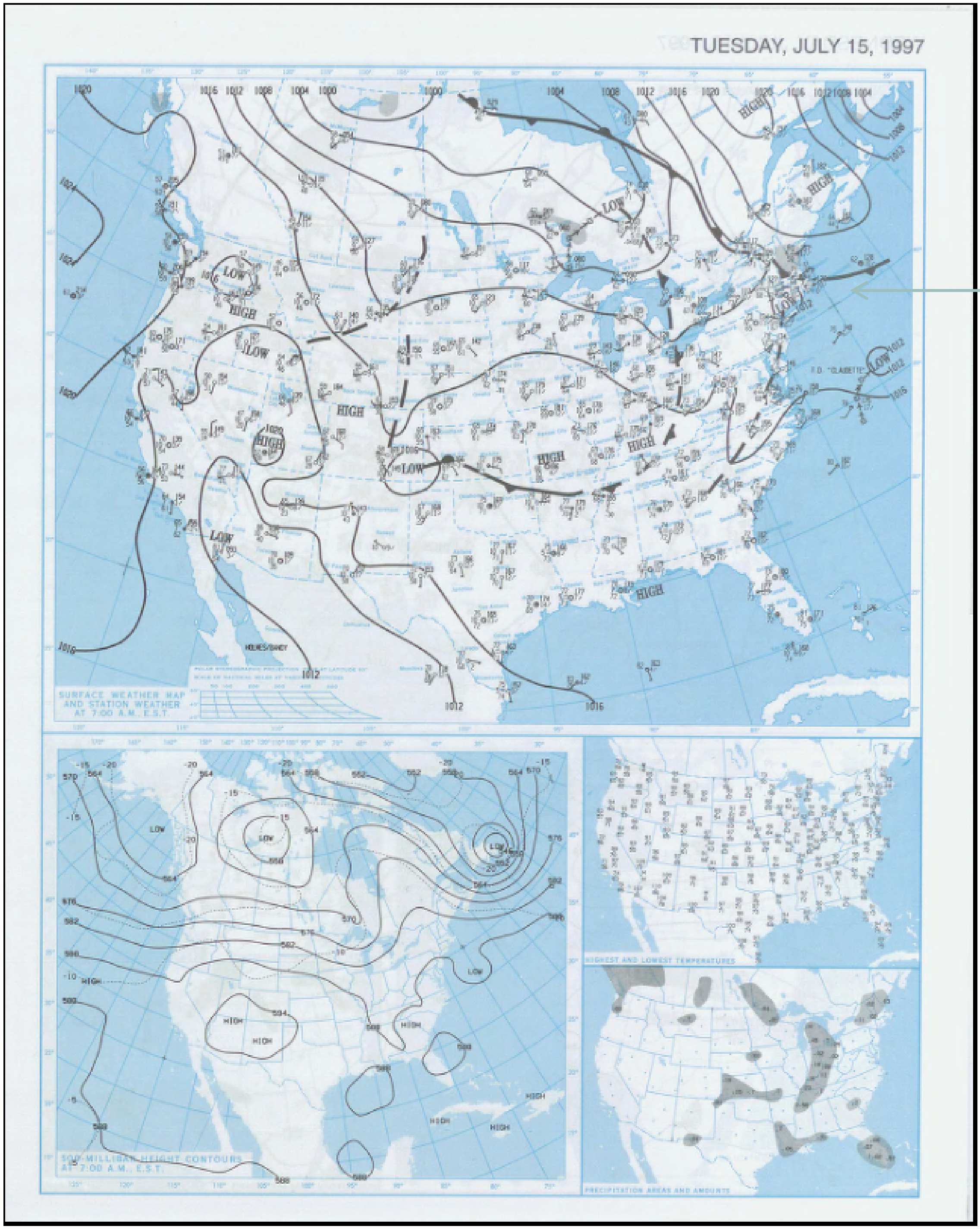


Occluded front at the surface

Upper level low pressure

Extensive precipitation shield

STATIONARY FRONT



Stationary front that brought flooding to Montgomery, VT

What about the synoptic fronts last week (21-27 January 2013)?

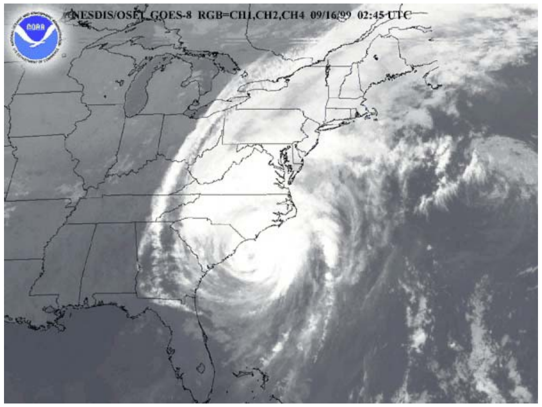
2. Meteorological conditions

- synoptic occluded fronts
- tropical cyclonic remnants

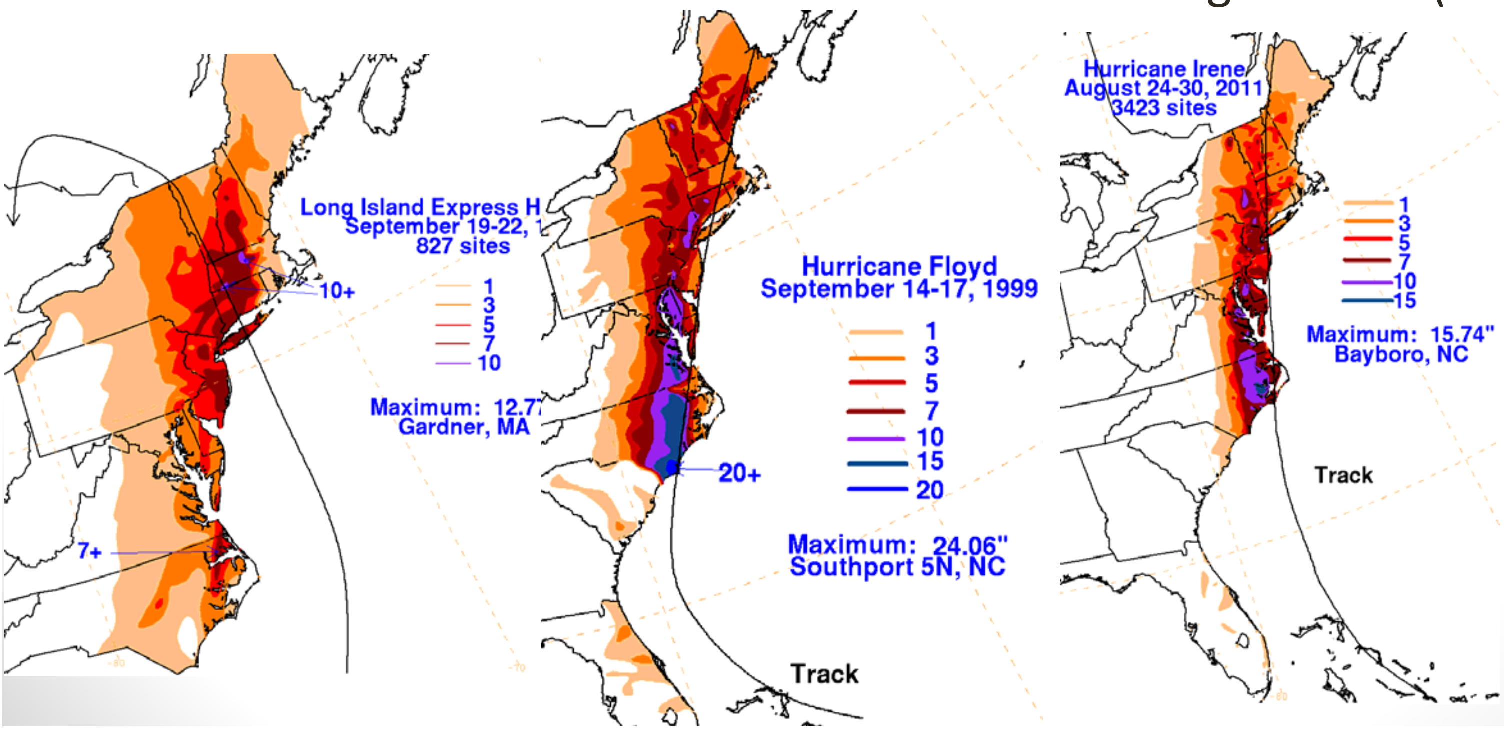
- isolated thunderstorms
- training

- cold air damming

Tropical cyclones & remnants



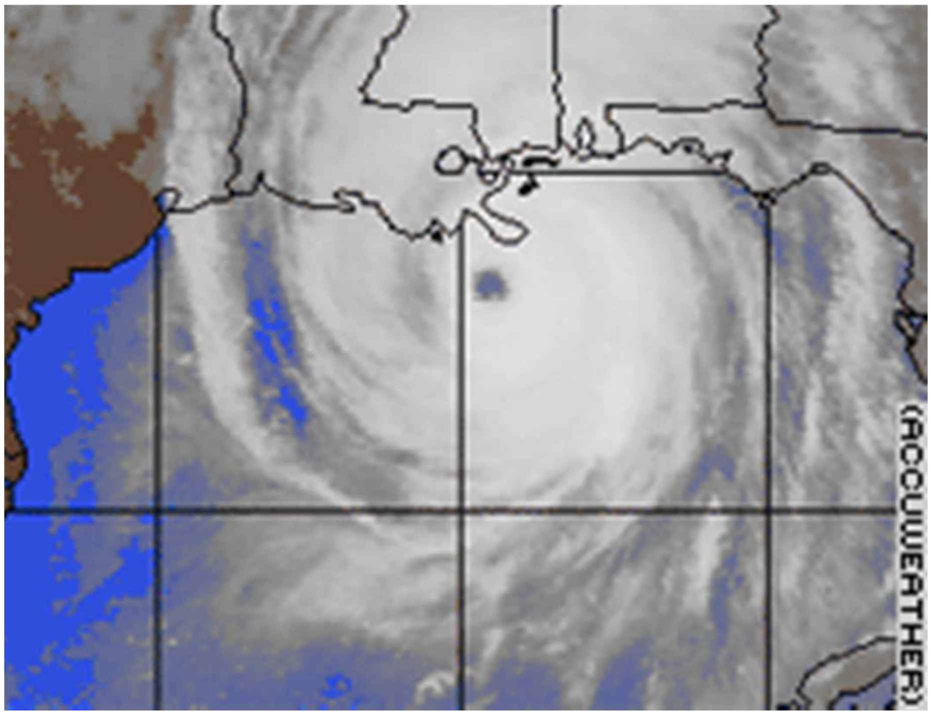
- November 1927
- August 1955 (Connie, Danny)
- June 1972 (Agnes)
- August 1998 (Bonnie)
- September 1999 (Dennis, Floyd)
- August 2011 (Irene)

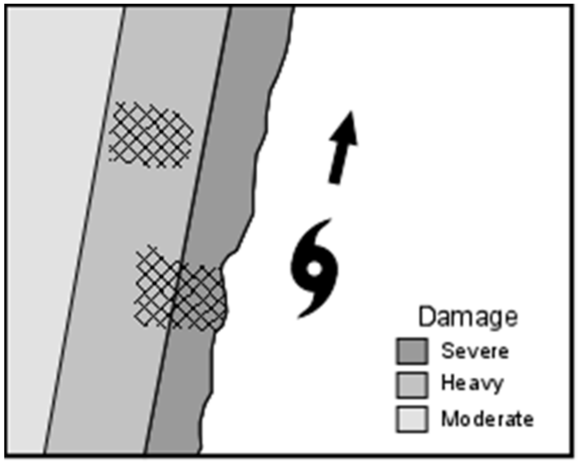


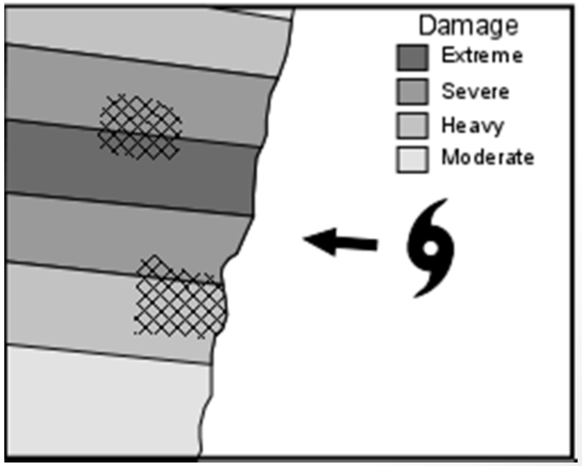
Courtesy: NOAA

Hurricane track and flooding

Katrina's landfall in New Orleans

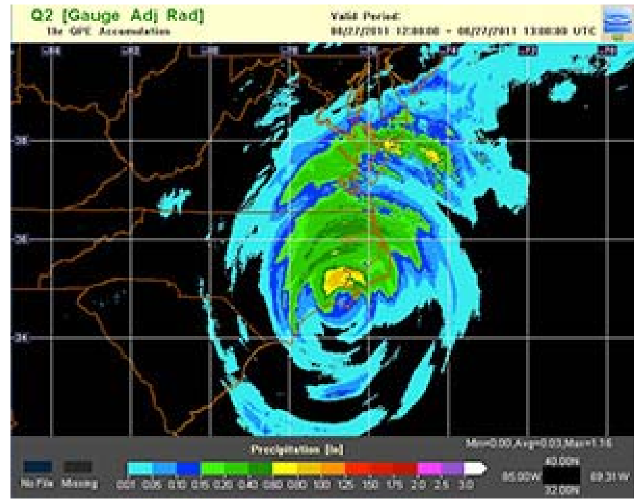






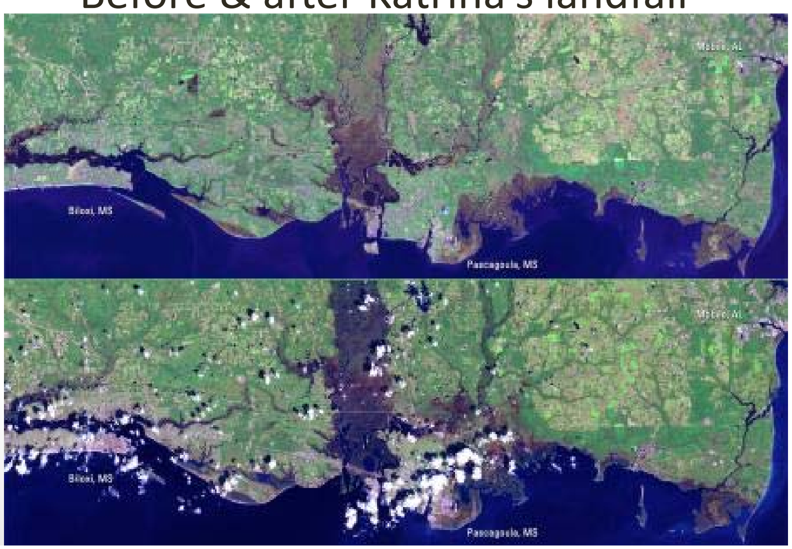
Comparing Katrina (2005) with Irene (2011)

Satellite/radar composite 3:57pm EDT

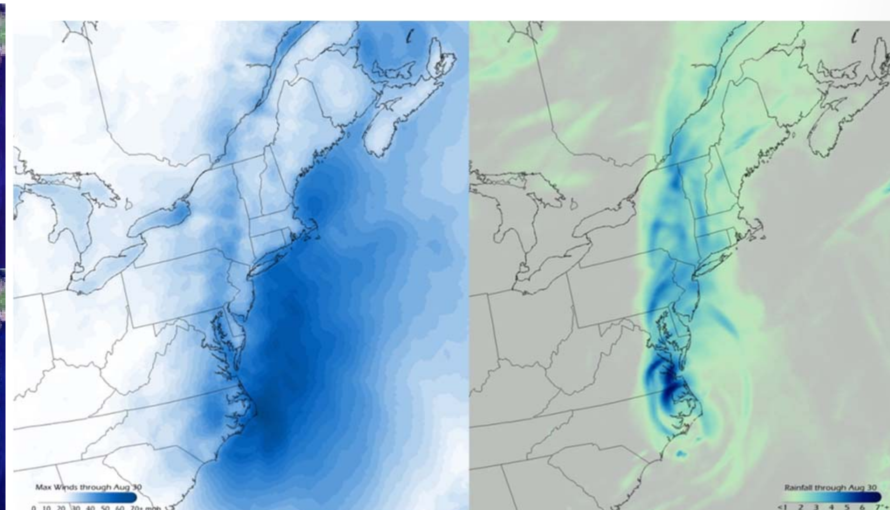


Radar precipitation of Irene

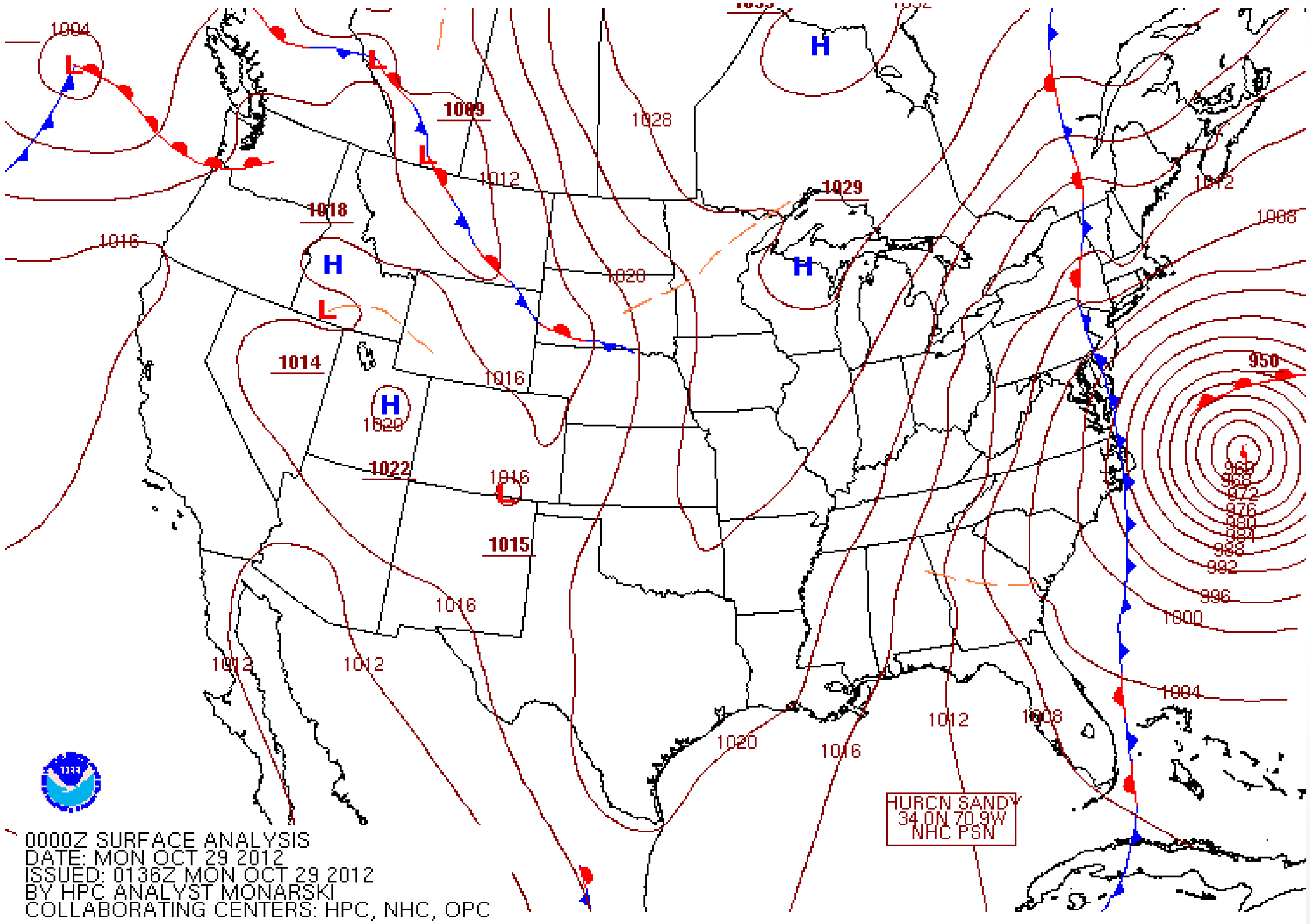
Before & after Katrina's landfall



Irene's winds and rain



Sandy ahead of quasi-stationary front

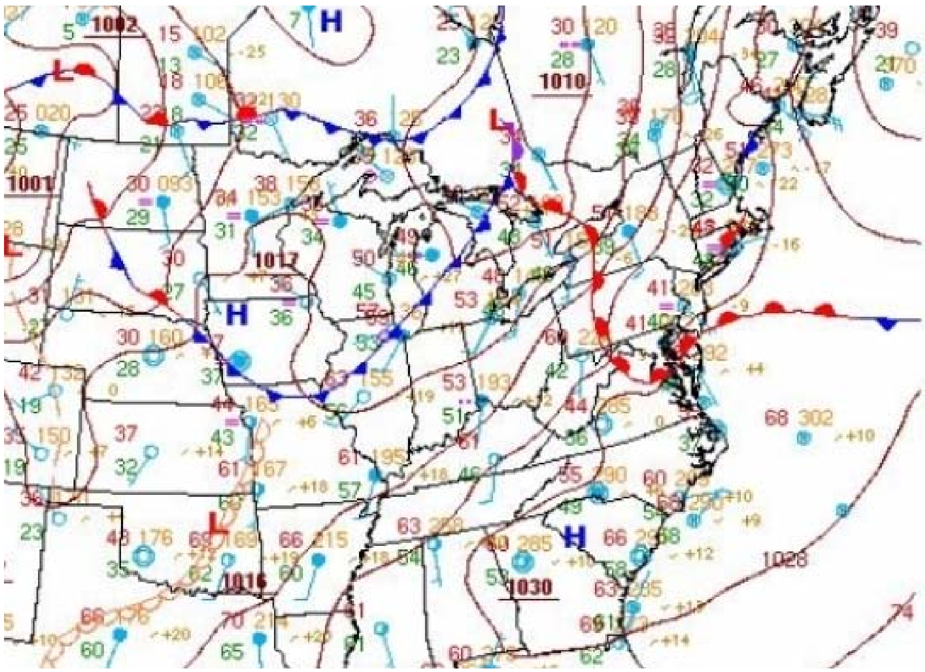


Severe storms - summer

Photo credit: NWS/BTV –Williston 29 June 2005

- thunderstorms associated with cold fronts, troughs
- heaviest rain with training or stalling
- most severe under abundant moisture conditions

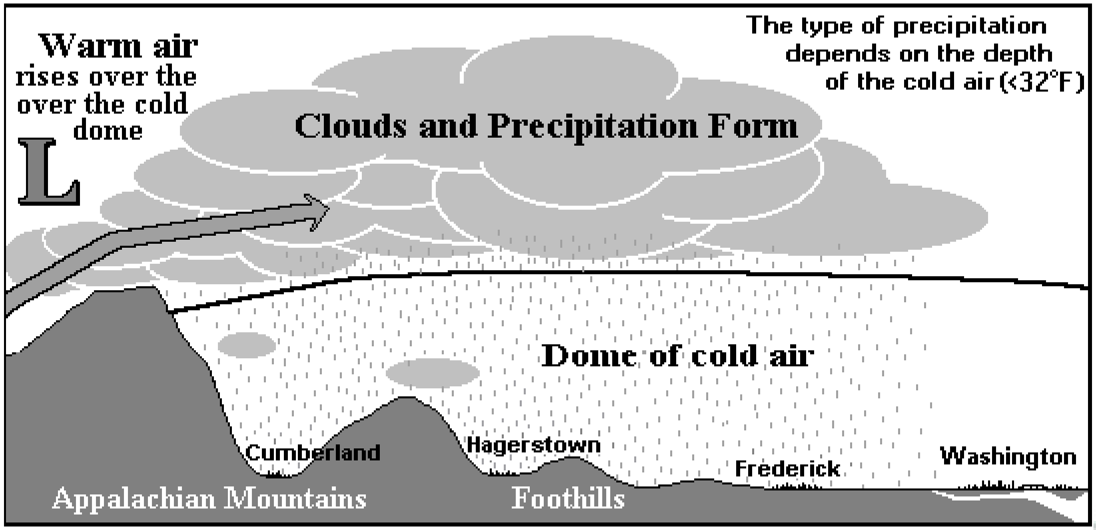
Cold air damming – 3 Dec 2012



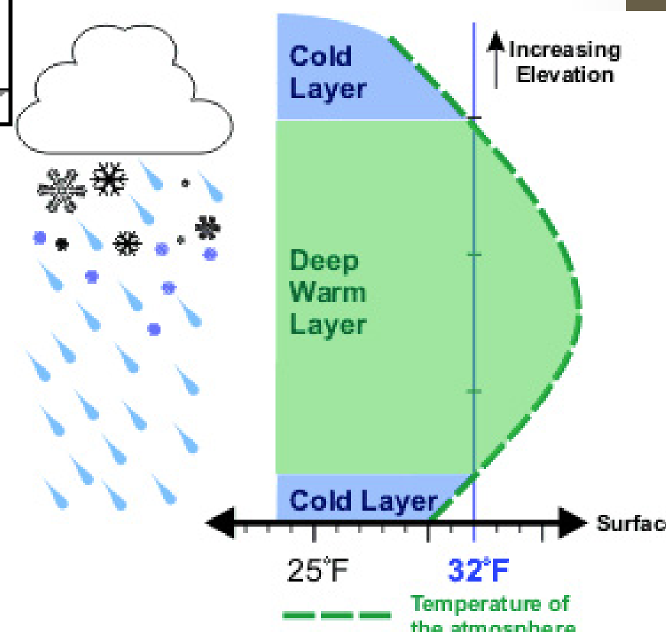
- **Cold Air Damming (CAD)**The phenomenon in which a low-level cold air mass is trapped topographically. Often, this cold air is entrenched on the east side of mountainous terrain. Cold Air Damming often implies that the trapped cold air mass is influencing the dynamics of the overlying air mass, e.g. in an overrunning scenario. Effects on the weather may include cold temperatures, freezing precipitation, and extensive cloud cover. NWS

http://www.wxedge.com/articles/20121203cold_air_damming

What does cold air damming mean?

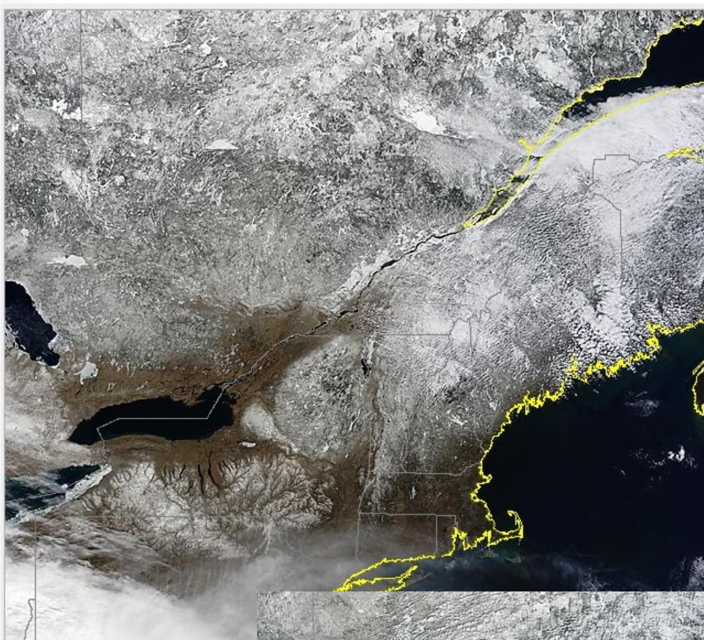


http://www.erh.noaa.gov/lwx/winter/md-winter.html

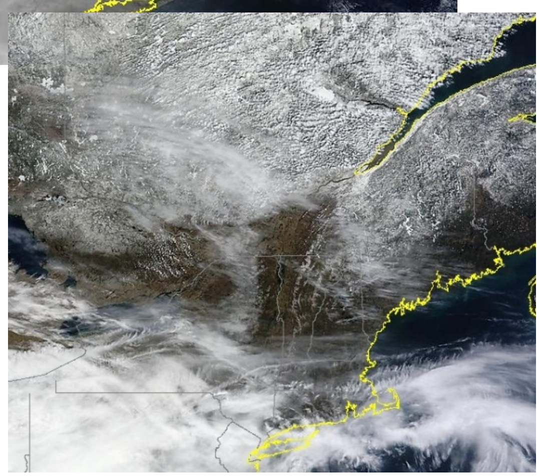


http://www.nc-climate.ncsu.edu/images/climate/winter/FZRA_Profile.jpg

5. Conditions on the ground



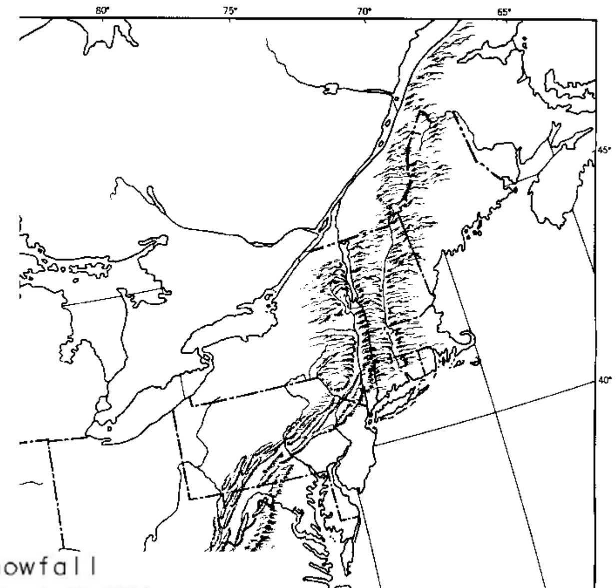
30 March 2011



22 April 2011

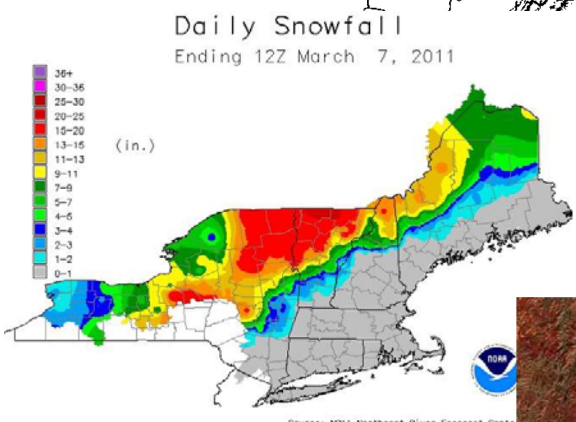
- snowmelt (exacerbated by heavy rain or record high temperatures)
- ice jams (e.g. Montpelier in March 1992)
- antecedent wet soil conditions

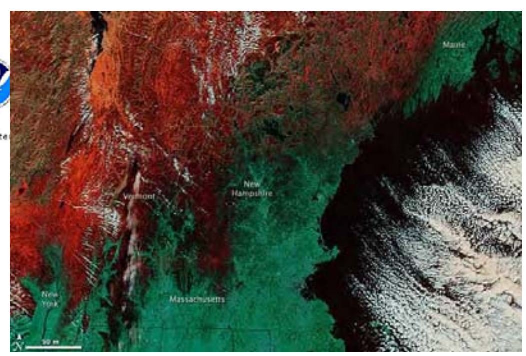
Topography plays a major influence



- moisture diverted along the western flank of the Appalachian mountains

- Green Mountains allow cold, dense air to accumulate in valleys
  - Champlain
  - St. Lawrence

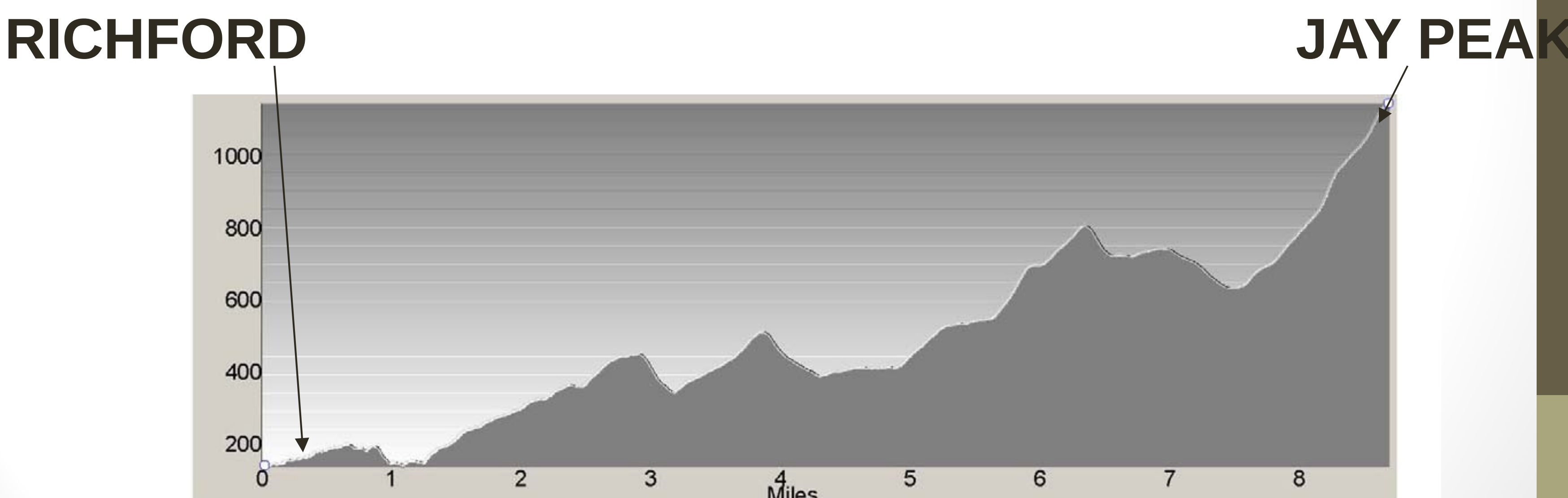




New England ice storm 11-12 Dec 2008

Flooding is enhanced by…

- topography
  - air is funneled
  - orographic uplift along the Greens



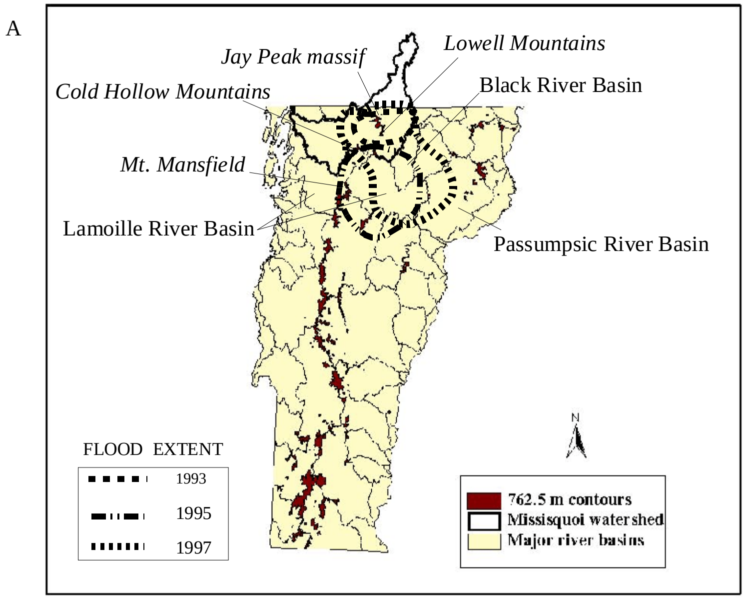
Total distance:	8 miles, 3609 feet	Climbing:	1527 meters	Latitude:	044° 59' 18.3" N
		Descending:	-519 meters	Longitude:	072° 39' 16.5" W
Ground distance:	8 miles, 4368 feet	Elevation change:	1008 meters	Elevation:	148 meters
		Min/Max:	137/1146	Grade:	2%

Flooding is also enhanced by…

- juxtaposition of roads and waterways
- repeat occurrences in preferred locations
  - Jay Peak, Route 100

Photo credit: NWS/BTV

Flood-prone regions



- warm season nocturnal cold fronts
- minor to no effects elsewhere
- million dollar damage

Historic floods

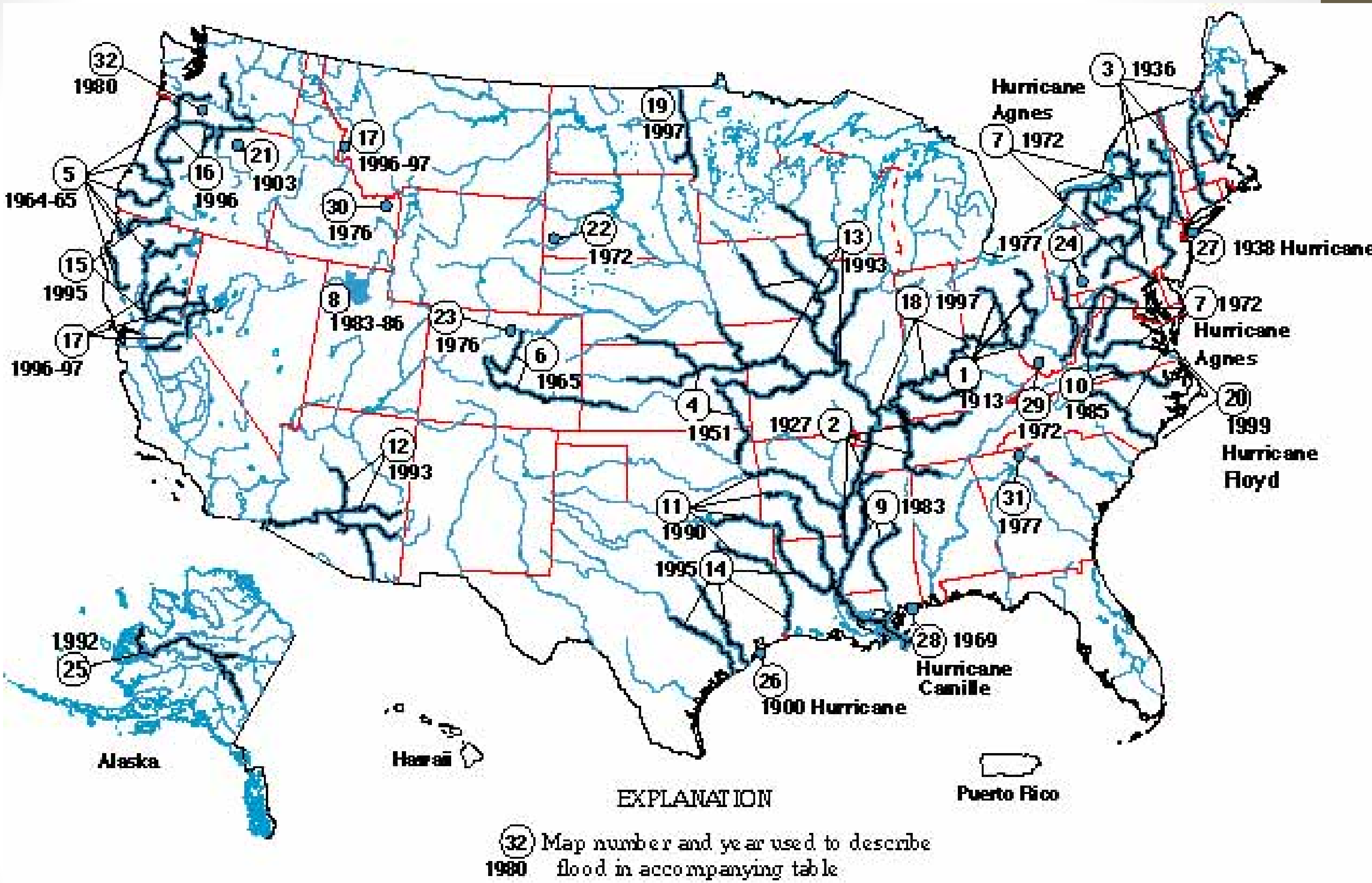
Flooding

PAST FLOODS

Summary of Historical Floods

Floods that caused damage on the Winooski River in the Bolton area occurred in 1785, 1810, 1826, 1828, 1830, 1862, 1869, 1912, 1927, 1933, 1936, and 1938. Records of peak flows or stages are not available for most of the floods prior to 1912. The most severe flood since at least 1830 was that of November 1927, when a peak flow of 97,500 cubic feet per second was estimated at Bolton Dam. A high water mark of 371.0 feet above mean sea level was recorded immediately downstream of the dam. Loss of life and damage were extensive. The greatest floods prior to 1927, those of July 1830 and October 1869, are estimated from high water marks to have had peaks approximately 80 and 65 percent, respectively, of the 1927 flood. More recent flood elevations have been reduced somewhat by operation of the Wrightsville and East Barre Detention Reservoirs since 1935 and the Waterbury Reservoir since 1937.

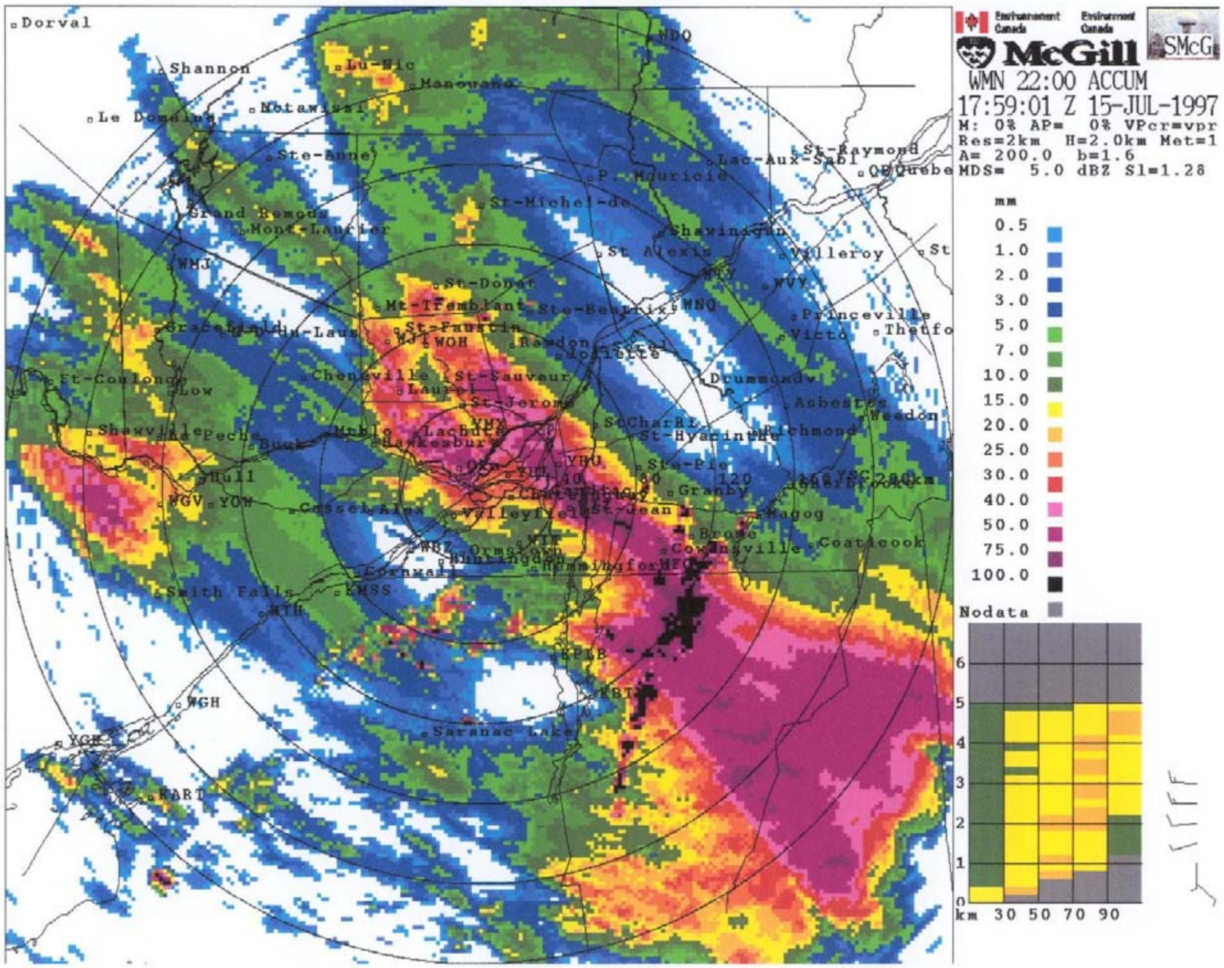
Courtesy: UVM Special Collections



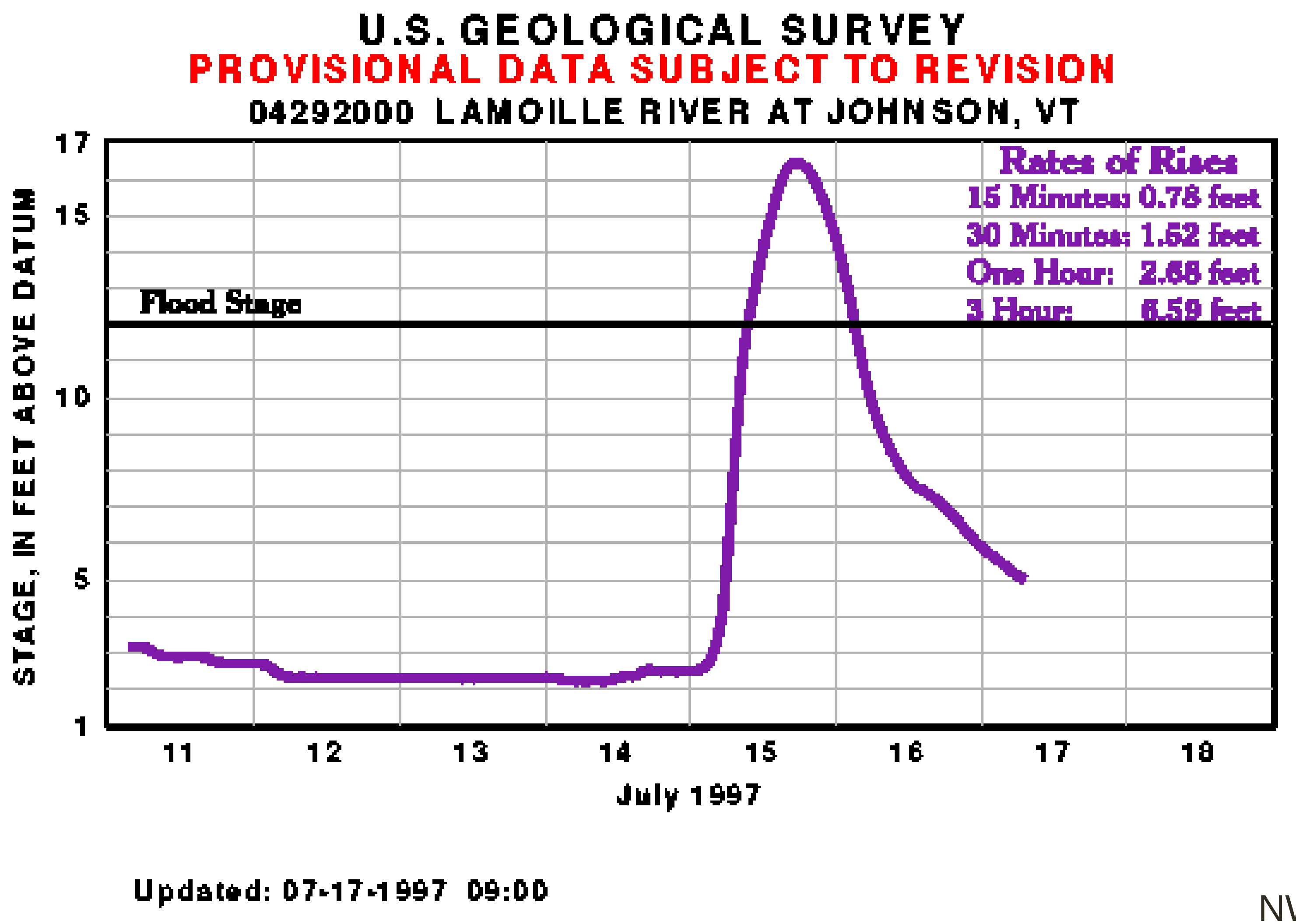
http://www.cuttingedge.org/News/n1695.cfm

Case study of the July 1997 flood

Rainfall totals for 22 hours on 14-15 July 1997



Flood discharge



NWS/BTV

Floodwaters + logs = havoc

Photo credit: NWS/BTV

Roadways became rivers

Photo credit: NWS/BTV

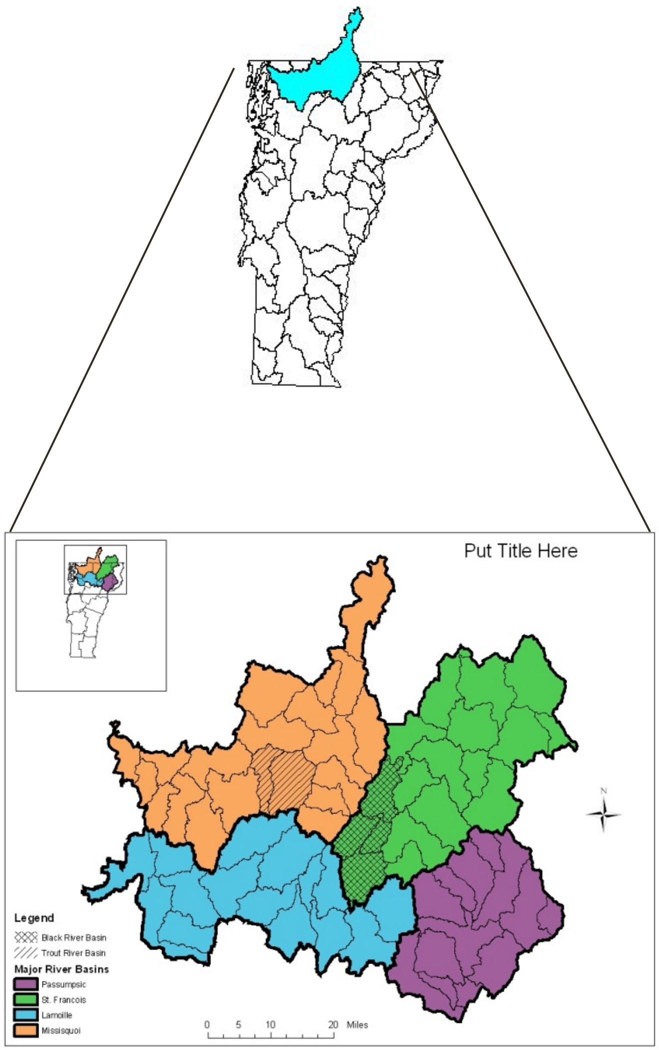
Juxtaposition of rivers & roads takes a toll on infrastructure

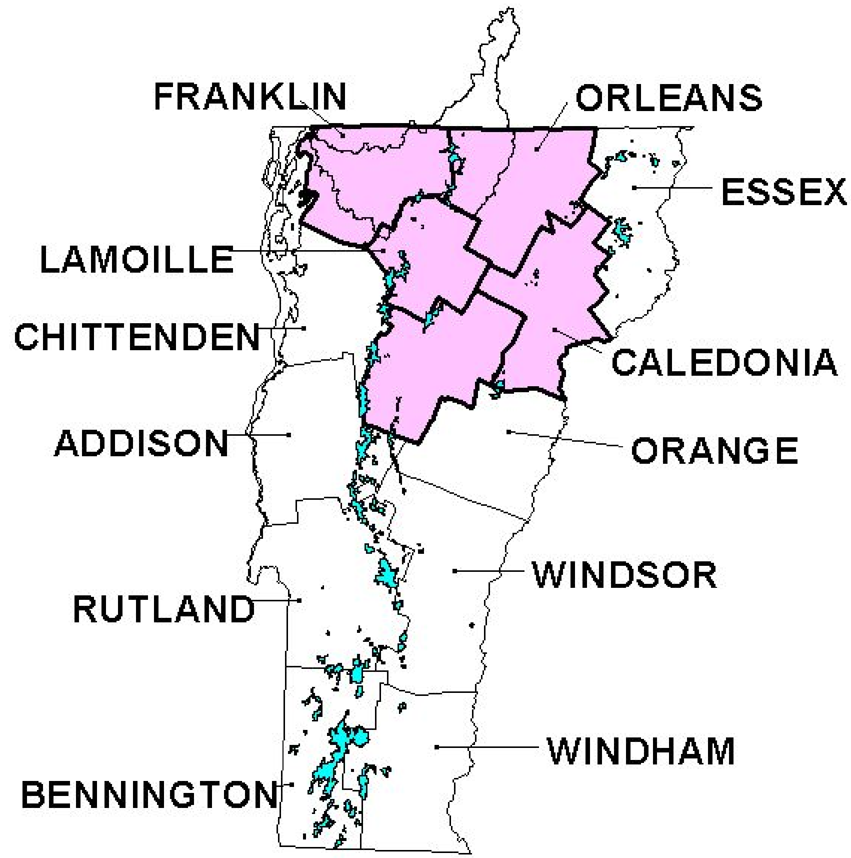
Photo credit: NWS/BTV

The aftermath – floodwater recession

Photo credit: NWS/BTV

Drainage basins & disaster declaration for 14-15 July, 1997





Impacts of flooding

- transportation
  - roadways, bridges
  - isolation of entire communities

- agriculture
  - reduction in corn yields
  - contamination of crops
  - isolation leads to dairying dilemmas

Impacts of flooding

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Case study of the 1927 flood

The 1927 flood - summary

- similar to July 1830 & October 1869 floods (VT & elsewhere New England)
- record-setting intensities and storm totals
- highest flood stage in the Connecticut River Valley BUT Winooski River Valley suffered most damage
- river destruction
    - new high water marks
    - carved new courses
    - moved millions of cubic feet of earth in hours

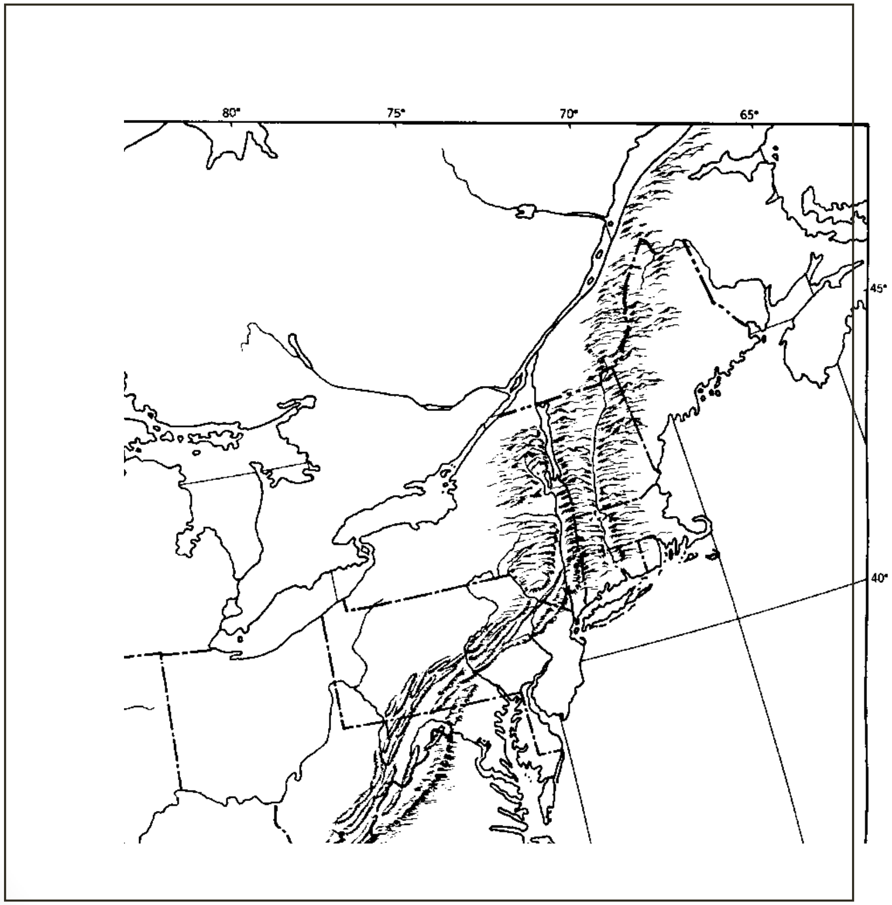
COUNTY	TOWN	STORM TOTAL (inches)
Bennington	Bennington	7.63
	Searsburg Mountain	8.30
Rutland	Rutland	8.47
Windsor	Cavendish	7.96
	White River Junction	6.41
	Woodstock	7.38
Washington	Northfield	8.63
Orange	Chelsea	7.35
Chittenden	Burlington	5.62
Caledonia	St. Johnsbury	6.39

Somerset 9.65" at 2096 feet (near border of Bennington and Windham)

Role of topography

NASA MODIS image
12 Sept. 2012

Case study – Flood of 1927 atmospheric ingredients



- flood of record for many river gauges
- preceded by drought
- antecedent precipitation
  - 150%
  - Rutland 7.37" 212%
  - Bloomfield 8.78 290%
- north-south trough with a cold front
- hurricane remnants

Other contributing factors

UVM Special Collections

- orographic uplift over the Berkshires, Taconics and Green Mountains
- steep slopes along many rivers & excess runoff – high velocity
- narrow valleys - transportation
- lack of forest cover
  - 78% 1998
  - 63% 1948
  - 20-30 % late 1800s

Reasons for damage & loss of life

- unprecedented flow in areas where unexpected & AT NIGHT
- downstream arrival of great masses of floating debris (wooden bridges, buildings)
- very high velocities of flow due to steep slopes caused lot of erosion of sand and gravel. Covered meadow lands and ruined them.
- some river channels inadequate (Bolton Falls and Proctor)

Take home messages

- amount of available water in the atmosphere
- role of topography
- importance of soil moisture conditions
- build resiliency everywhere especially in flood-prone regions

Flood frequency analysis

- download discharge data by time interval
- sort in descending order
- rank by year with 1 being the largest
- calculate return interval RI = n+1/rank
- 1/RI = probability of flood of this size or larger in given year
- plot discharge again log of RI

Case study of the 1993 Mississippi flood

NASA Earth Observatory

What happened (meteorological conditions)?

- excessive precipitation + extraordinary areal extent

- wet autumn in 1992
- wet spring
- preceded by 130% 150% of normal

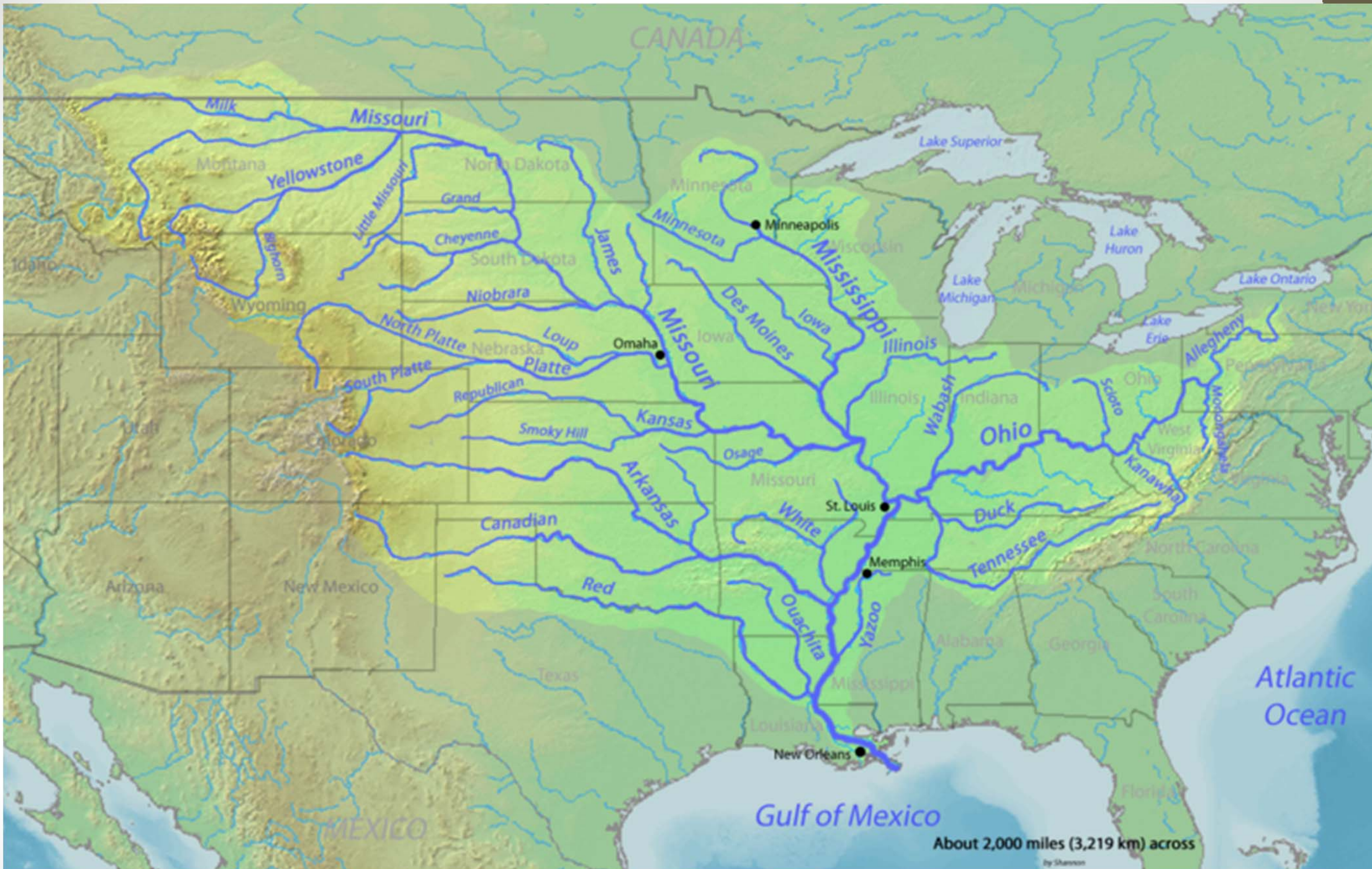
- persistent weather patterns early June and July

- stalled

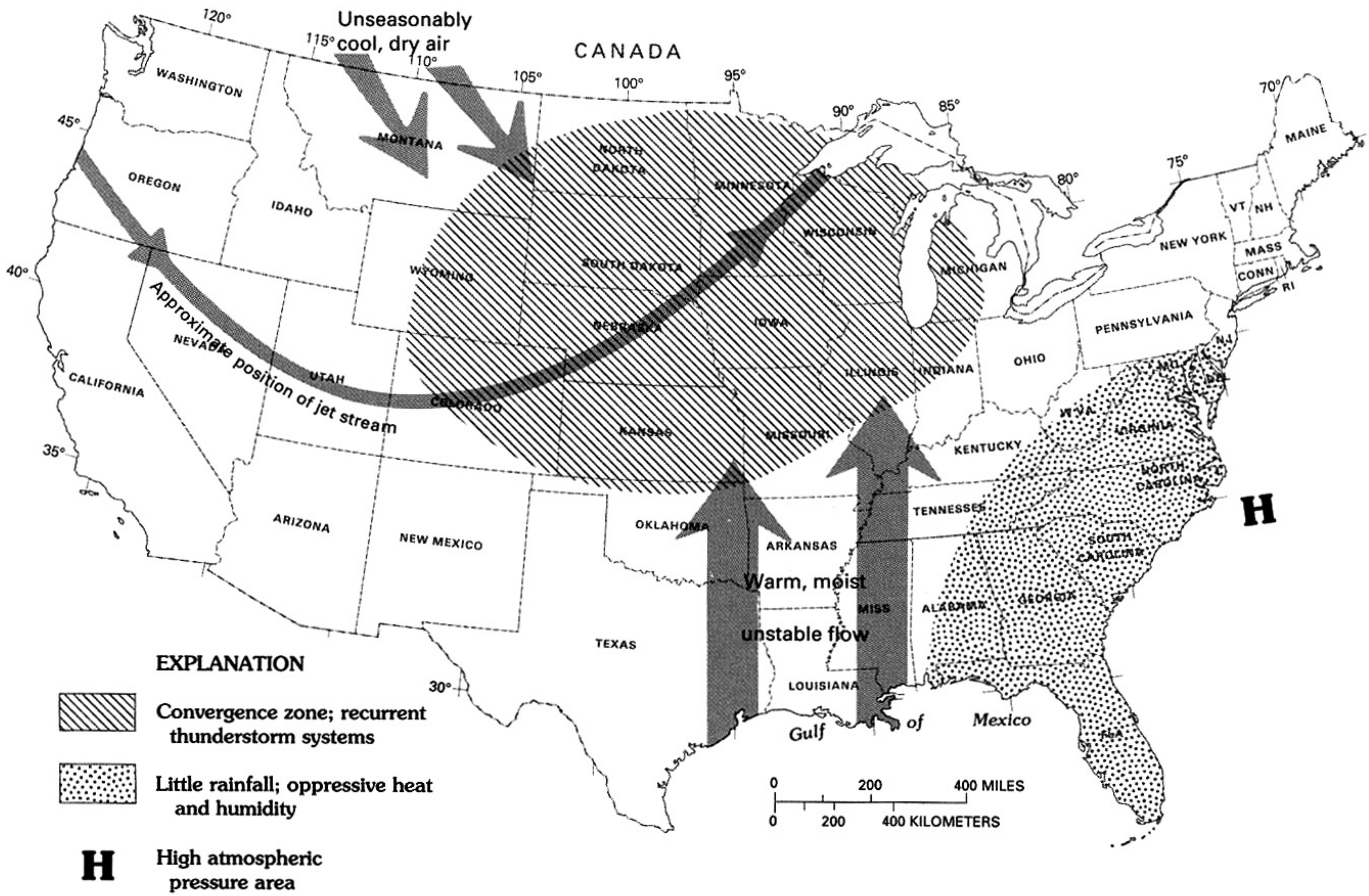
- unseasonably cool, dry air from NW

- blocking high over the SE

- flooding throughout upper Mississippi River Basin including lower Missouri River



http://upload.wikimedia.org/wikipedia/commons/thumb/2/23/Mississippirivermap.png/800px-Mississippirivermap.png



http://www.mnforsustain.org/images/water_climate_chap2_Box.2.1a_us_flood.jpg

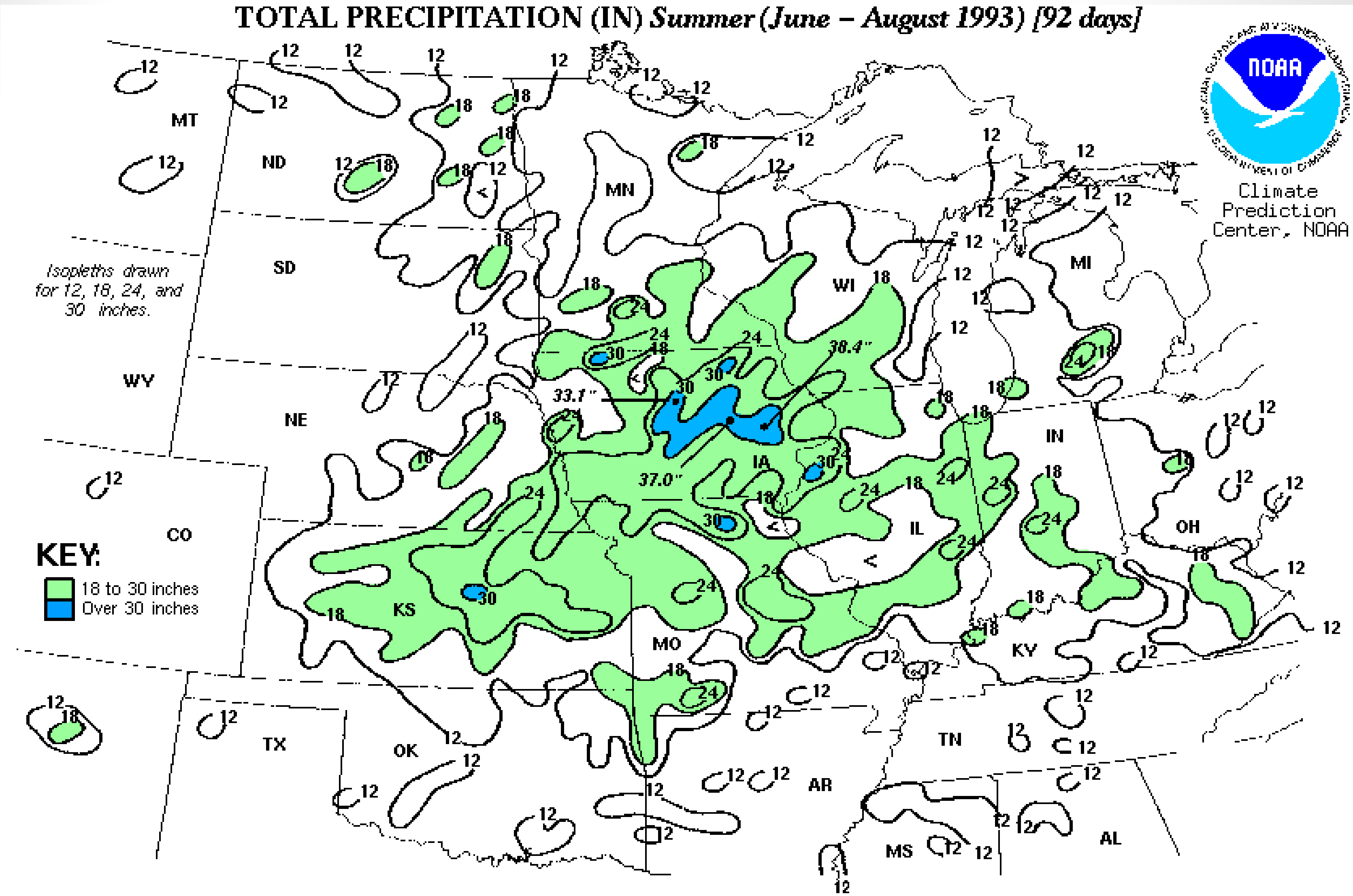
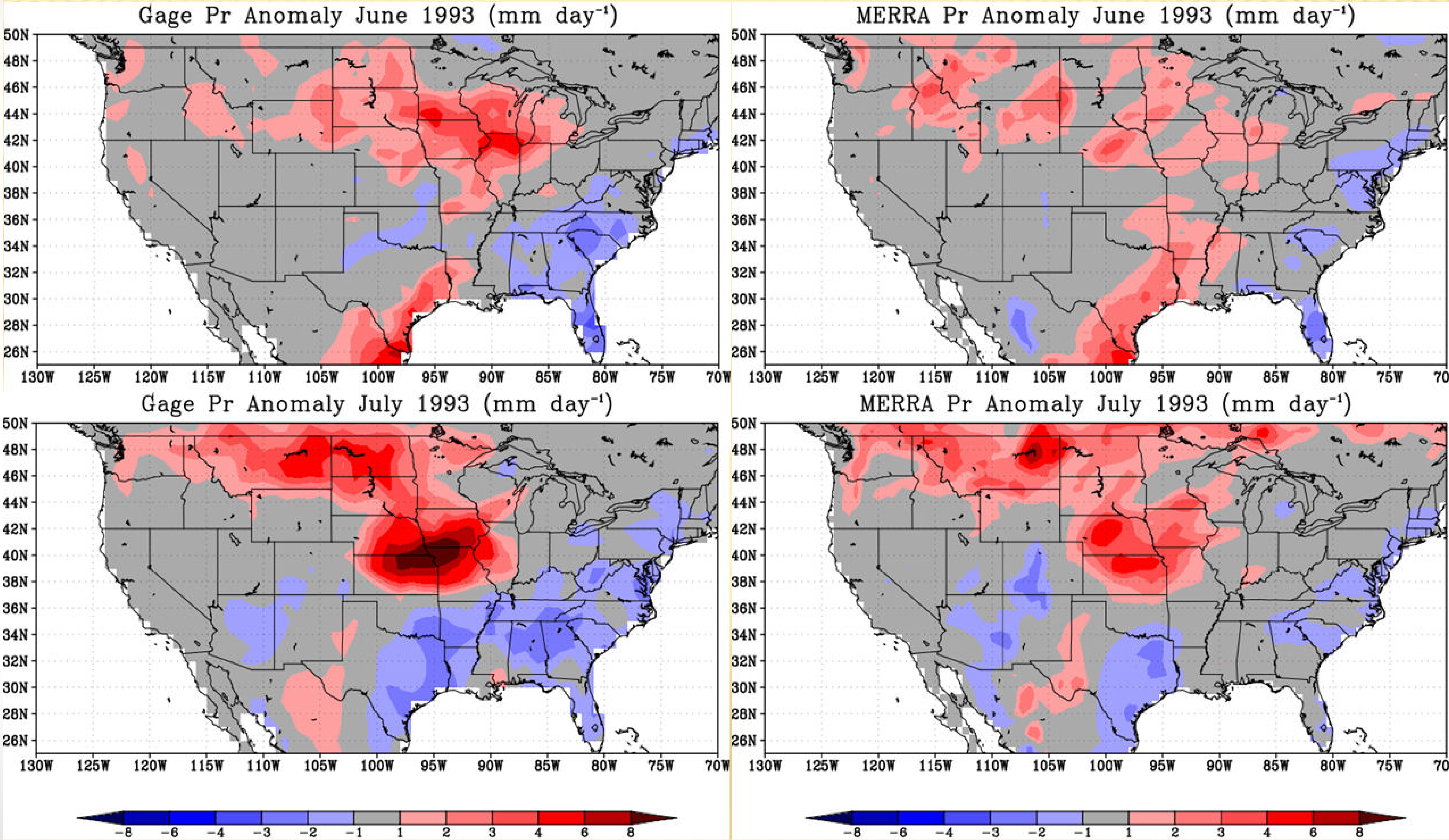


FIGURE 2.2 Total precipitation, based on reports from the River Forecast Centers during Summer (June - August), 1993. Over 18 inches of rain drenched large sections of the central Great Plains, central Gulf Coast, and the lower reaches of the Missouri and Ohio River Valleys during the 64-day period ending June 11, 1995 (Figure 2.1). Between 2 and 3 feet of precipitation inundated some areas near the intersections of Missouri, Kansas, Oklahoma, and Arkansas as well as portions of the Mississippi Delta (most of which fell within a few days in the latter region). During Summer 1993, the heaviest precipitation was observed primarily north and west of the currently-affected region, but portions of eastern Kansas and northern Missouri received exceptionally heavy precipitation and endured severe, prolonged river flooding during both episodes.

http://www.cpc.ncep.noaa.gov/products/special_summaries/95_2/figure2_2.gif

FLOODING IN THE MIDWEST, SUMMER OF 1993



http://merra-reanalysis.blogspot.com/2010/01/1993-flood.html

Bankfull conditions

- Missouri river crested
  - at St. Charles, MO 12.0m, in Kansas City 14.9m
- Mississippi river crested
  - at St. Louis at 15.1m 1.9m above previous record set in 1973, + 6m above flood stage
- aftermath - Missouri River expanded from 800m wide to 8-10km north of St. Joseph, MO and 13-16km wide east of Kansas City, 32km near confluence with Mississippi - > half of St. Charles County under water

Impacts of Mississippi flooding

- lack of potable water
- bridges destroyed/damaged
- barges stranded estimated $3 million per day lost in revenue
- airport closings
- over 7 million acres of farmland flooded, over $5 billion crop losses
- over 500000 homes damaged/destroyed
- over 77 small towns near rivers completely flooded
- levees collapsed