

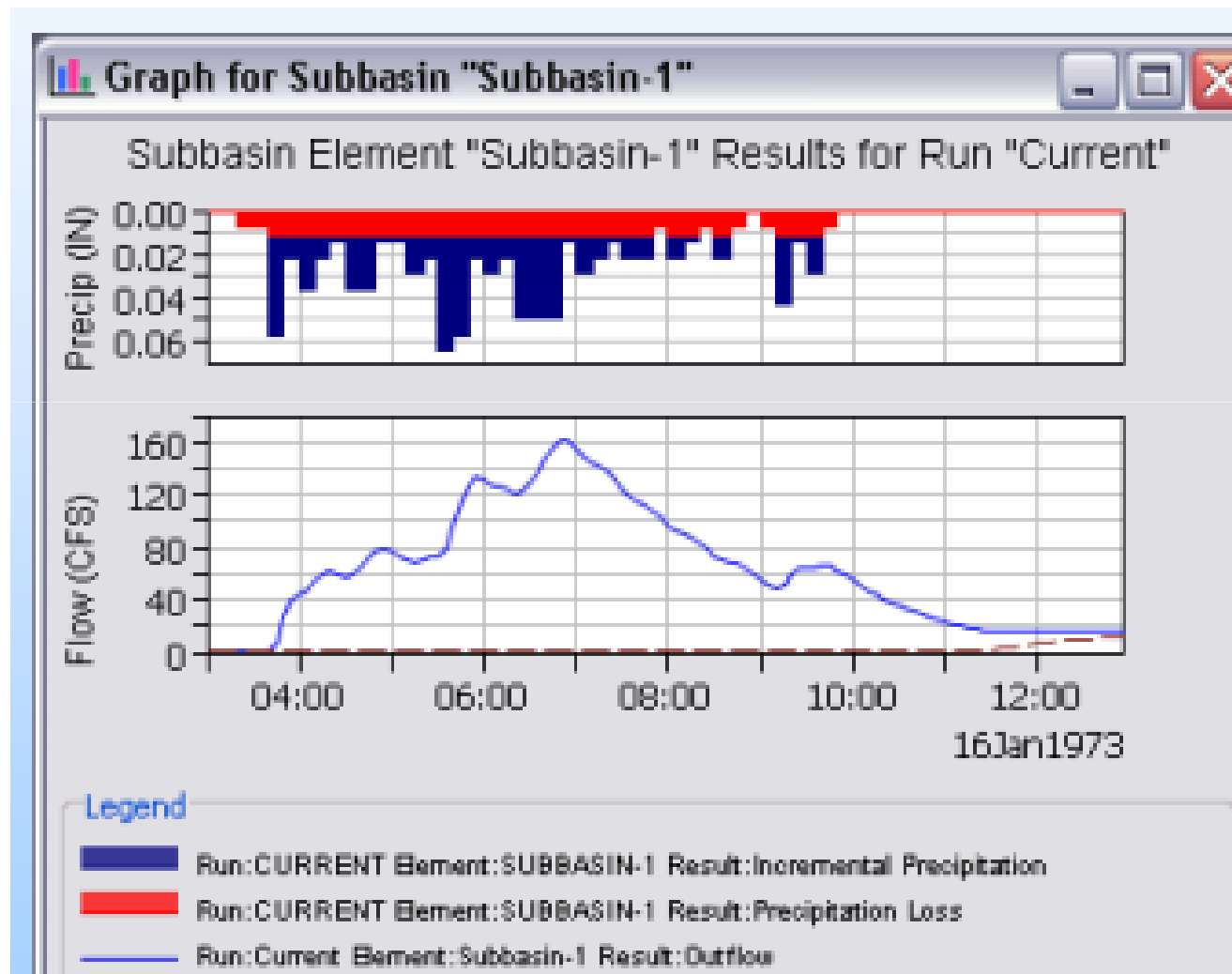
Part 1-b

Cause & Impact of Landfalling Tropical Cyclone

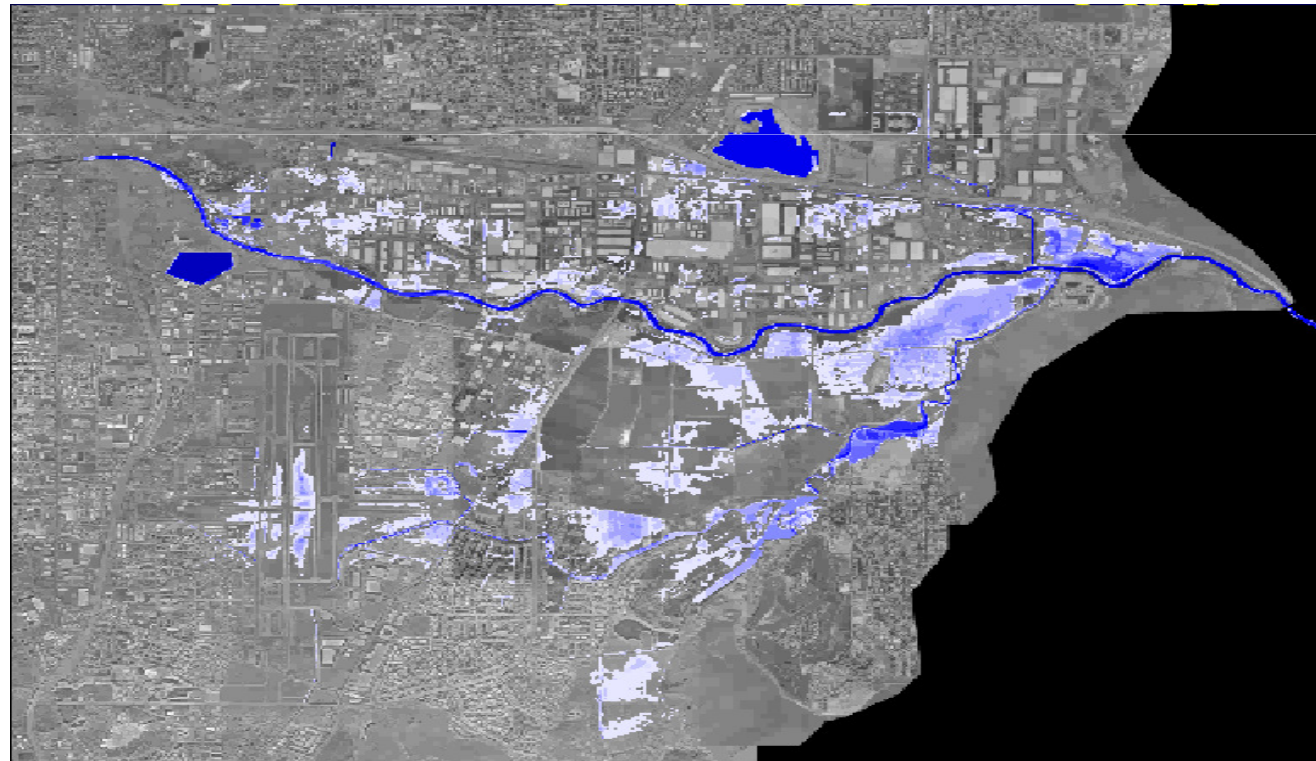
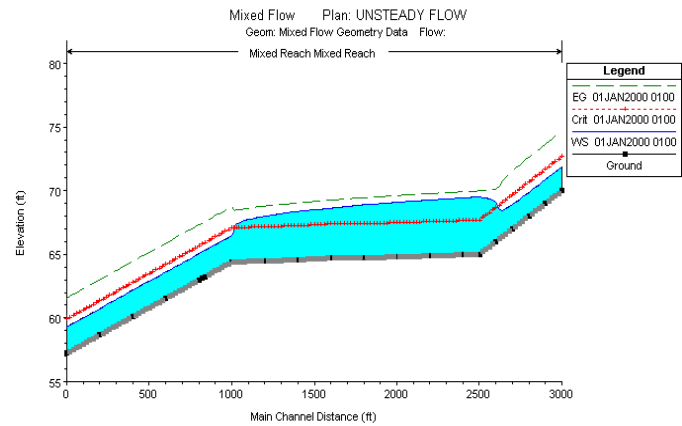
Rainfall & River Flooding

- In addition to high winds & storm surge, all tropical storms can produce torrential rains causing massive flooding & trigger landslides and debris floods
- Catastrophic **flash flooding** may occur as a result of intense rainfall over a relatively short duration. Longer duration storms, say a few days, can be equally devastating.

River flooding associated with heavy rainfall from tropical cyclones



Flood stages & inundation maps

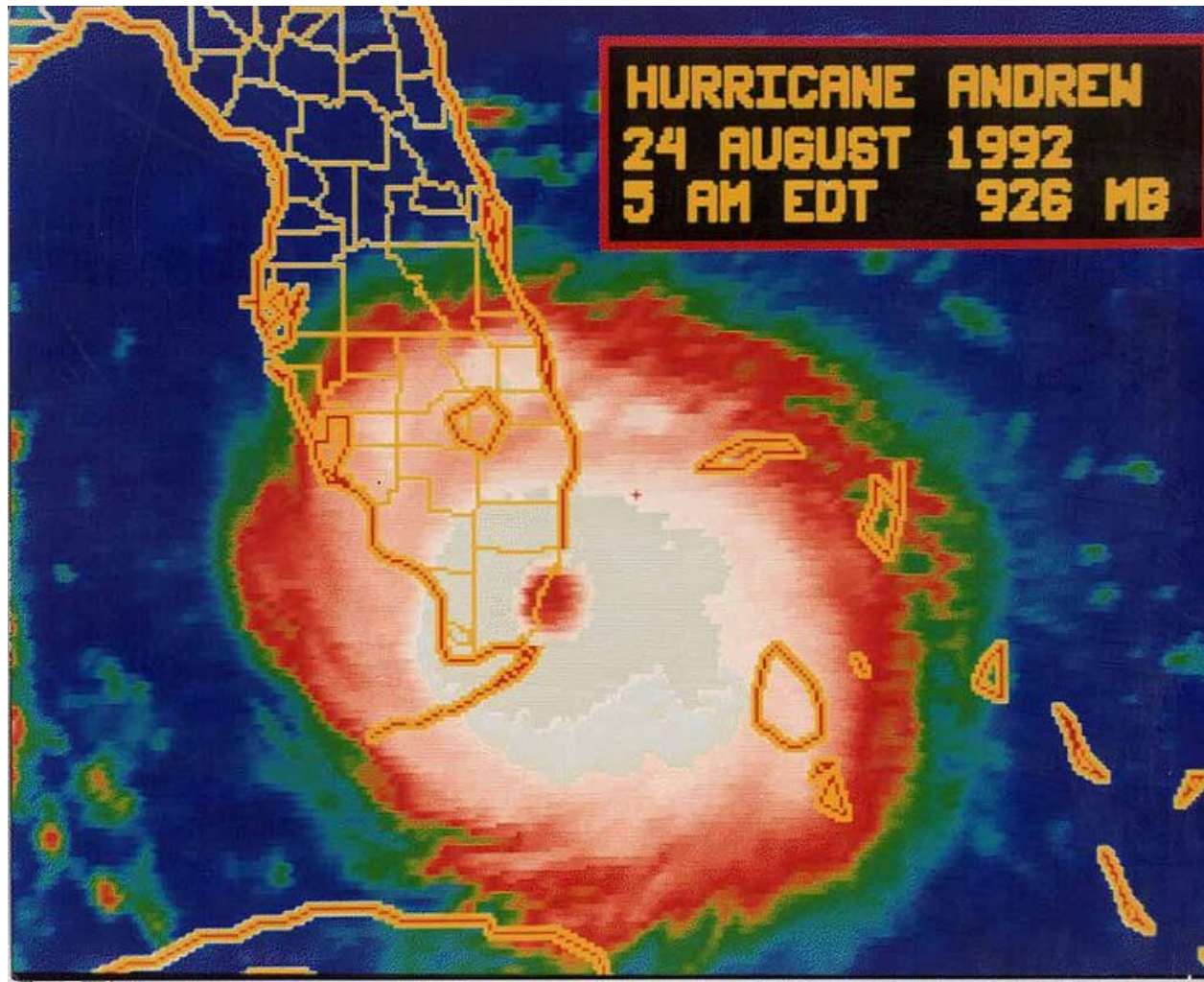


- Rain-triggered flooding is not confined to coastal areas. The reach of a large tropical storm can cause flooding well inland, especially along the estuaries.
- **Beneficial contributions** of tropical cyclones: rainfall for needed **water supply** in the region; and maintenance of **global heat balance**

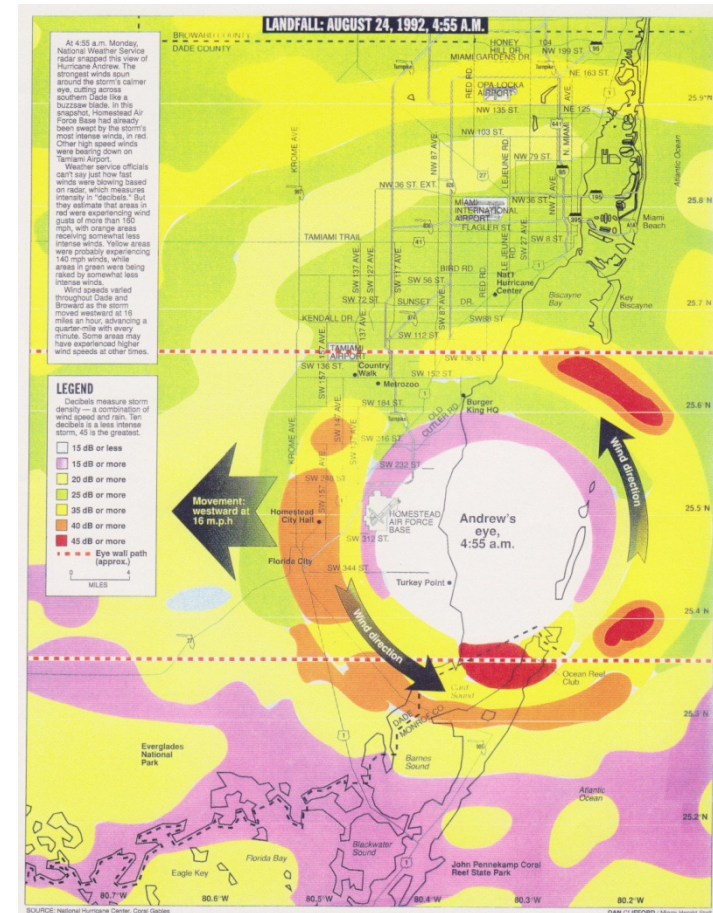
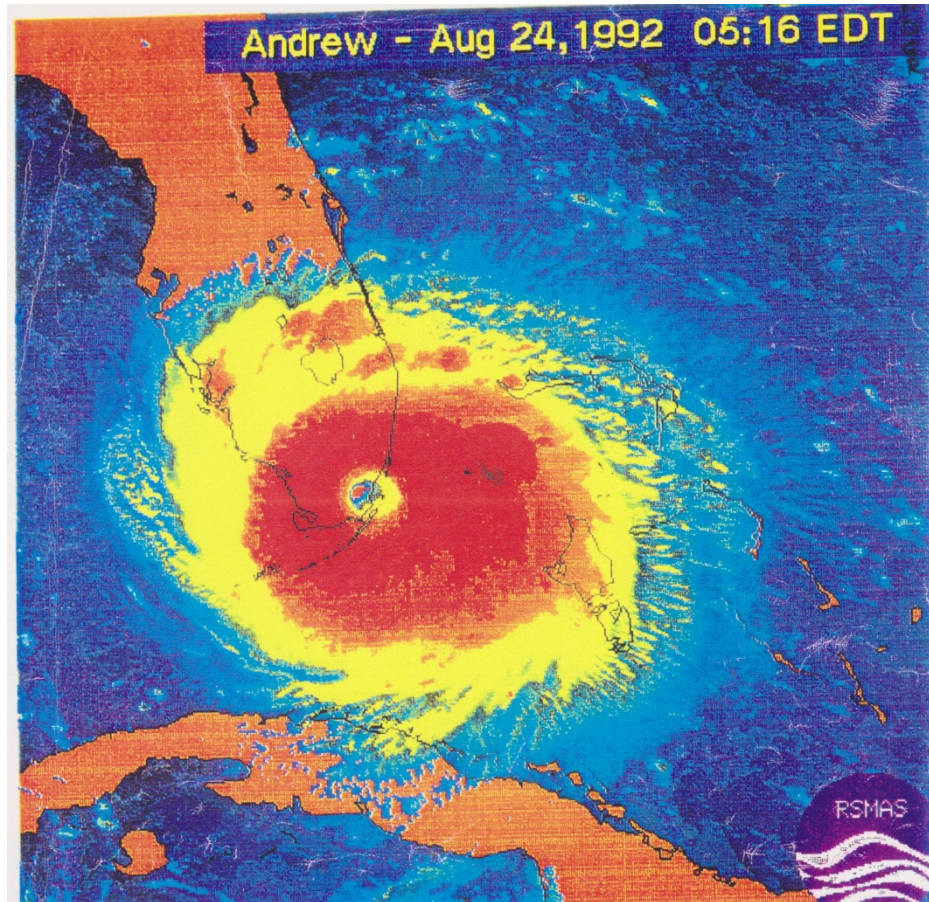
Cases of landfalling of catastrophic tropical cyclones

- **Hurricane Andrew**, August 24, 1993- Florida
- **Hurricane Allison**, June 5-9, 2001- Houston and TX and LA coasts
- **Hurricane Katrina**, Aug 29, 2005- New Orleans & LA and TX coasts
- **Hurricane Mitch**, Oct 26- Nov 5, Honduras, Salvador, Nicaragua, and Guatemala
- **Typhoon Morakot**, August 3-10, 2009, Taiwan
- **Typhoon Ketsana**, Sept 23-30, 2009, Manila, Philippine , Vietnam & Cambodia

Hurricane Andrew (Aug24,1993)

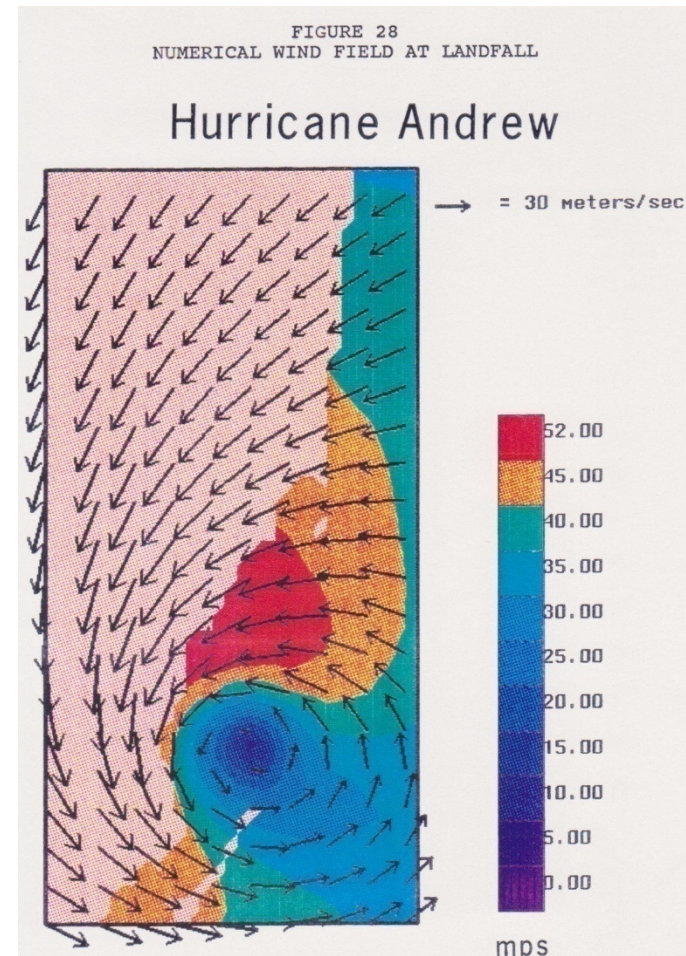
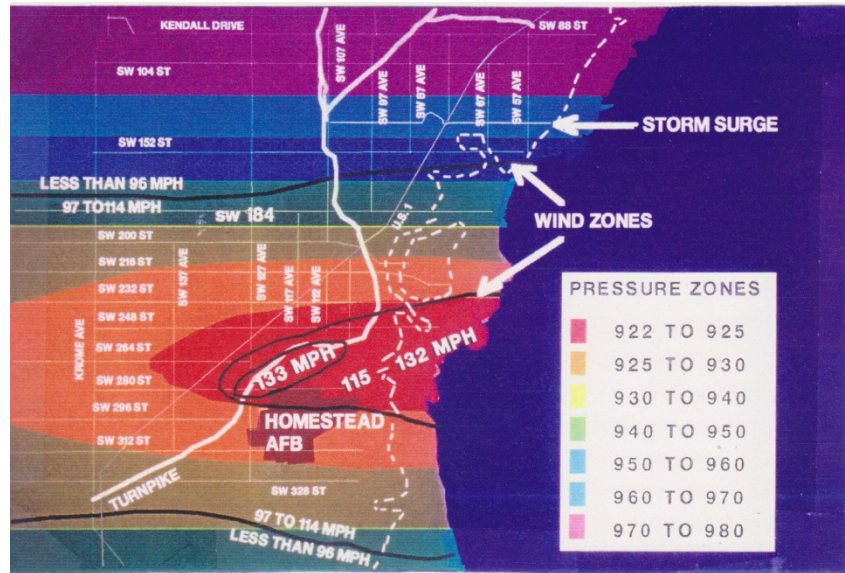


Hurricane Andrew (Aug24,1993)

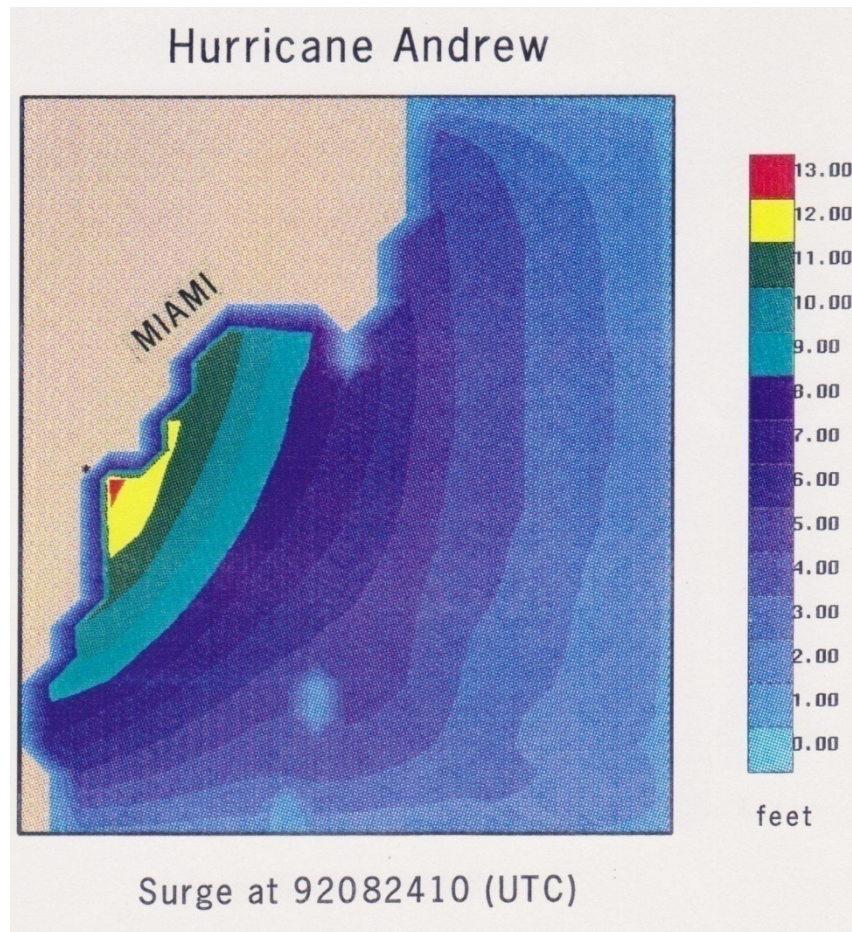


Source: Report on Hurricane Andrew Storm Summary & Impacts on Florida Beaches, by USACE & Florida DNR, May 1993

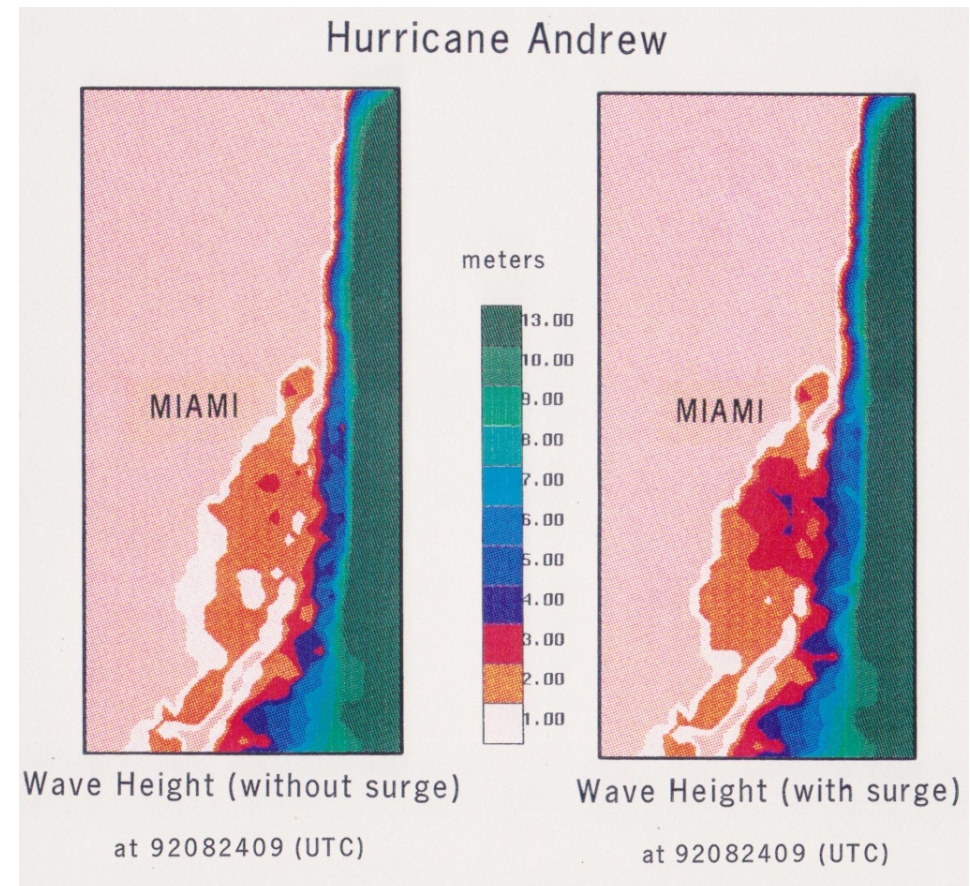
Pressure zones, wind zones and storm surge contour



Surge at landfall & waves height



Storm surges

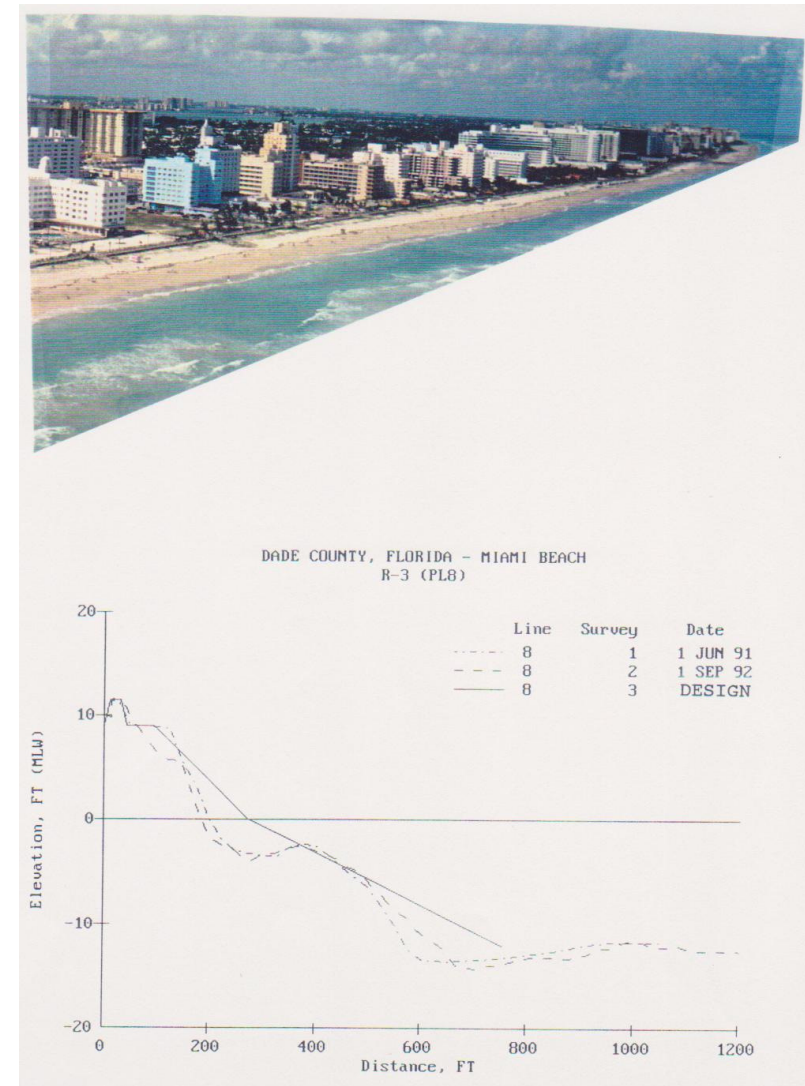


Wave Heights

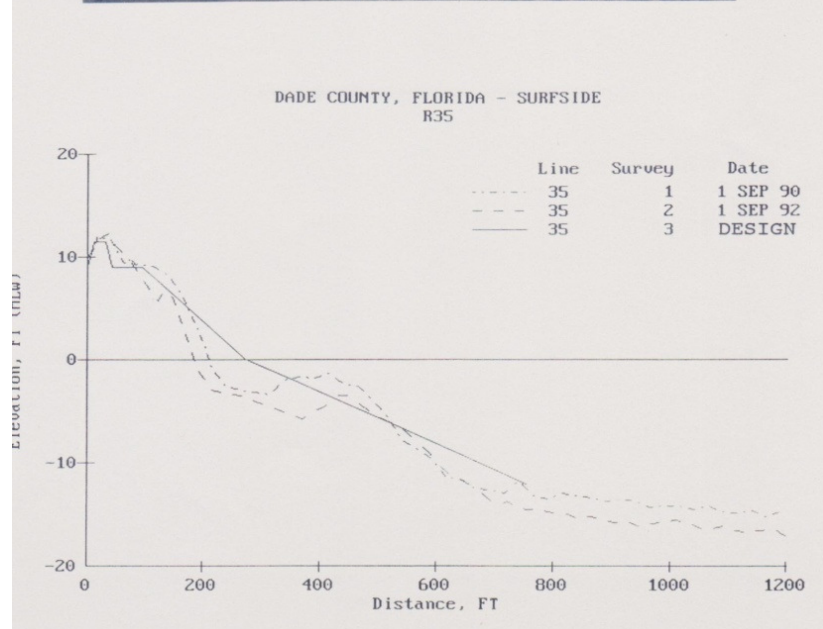
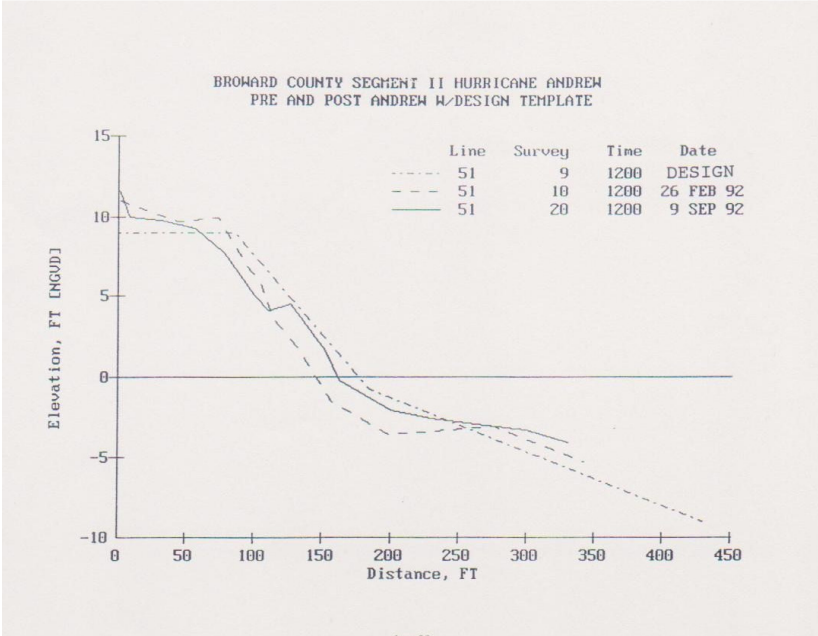
Impact of gusts on homes



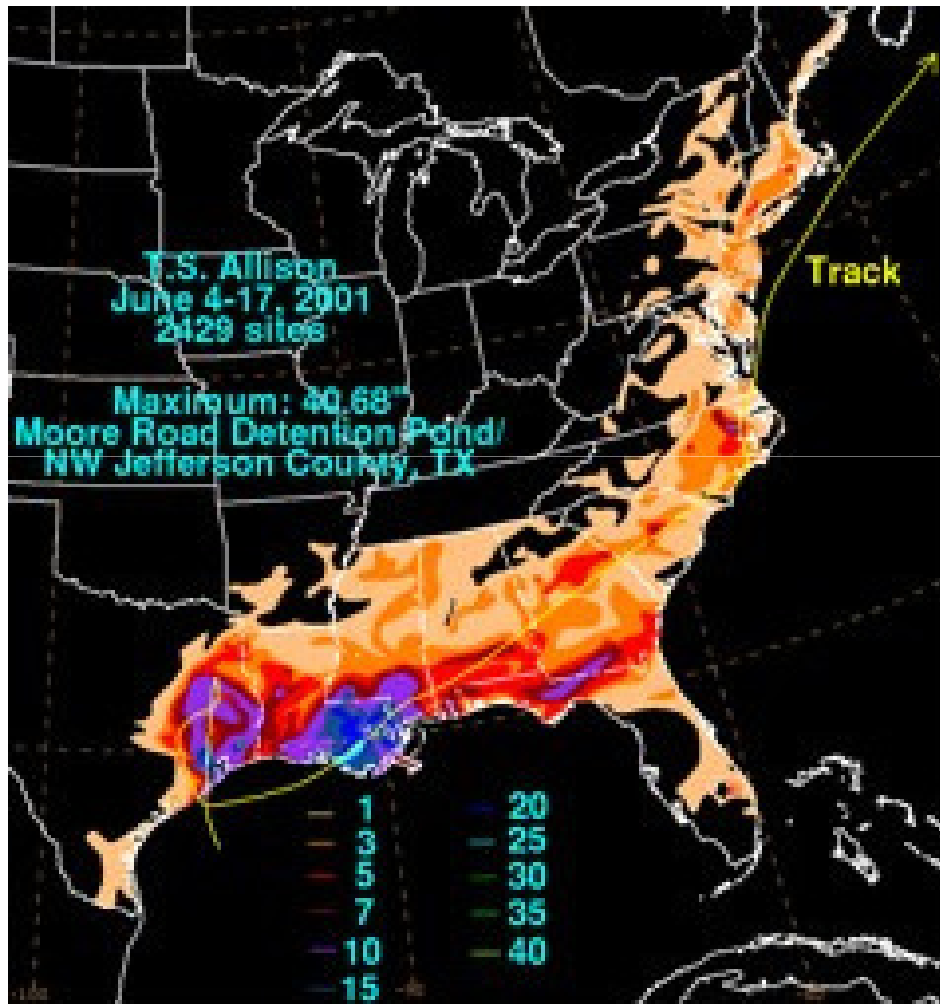
Impacts on beaches of Florida



Erosion and accretion of beach profiles



Hurricane Allison, June 5-9, 2001



* Credit: NOAA

* Hurricane Allison's swath of rainfall – 25-50 cm or more rainfall in coastal TX & LA for nearly 6 days.

- Note: Hurricane Camille in 1969 produced a burst of 30-50 cm rain in 3-5 hrs

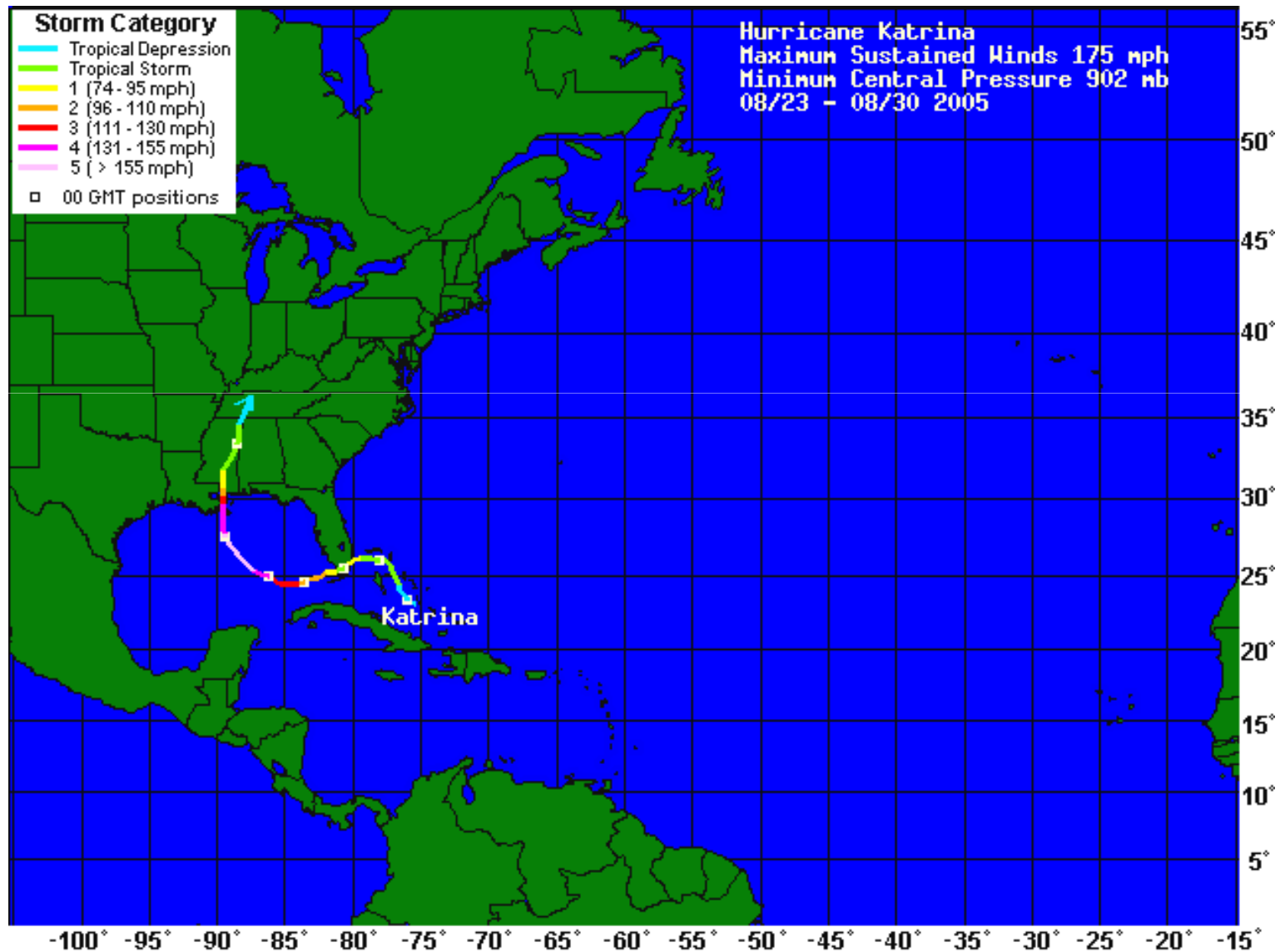


* sources: HSS, & Dan Wallach

Houston skyline after Hurricane Allison

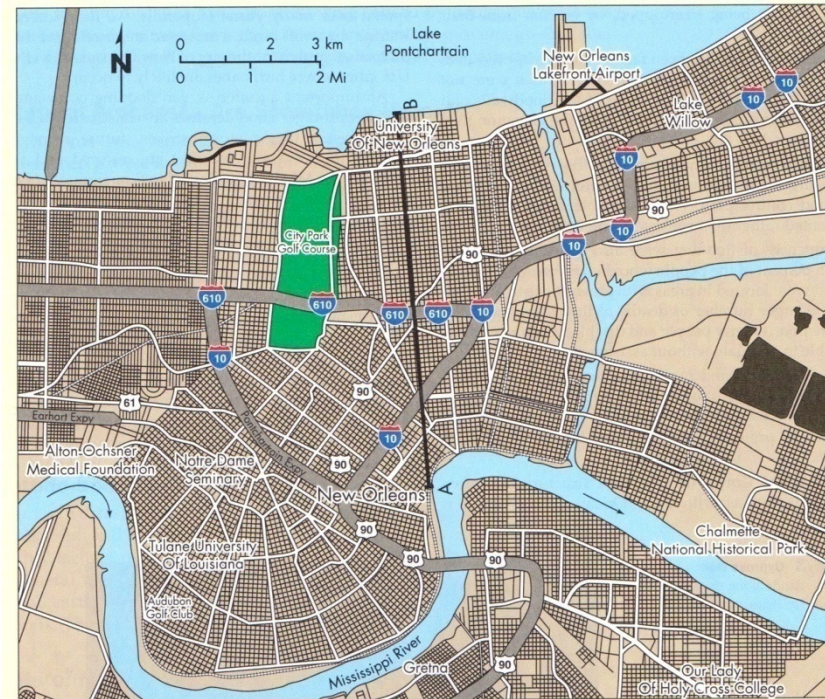
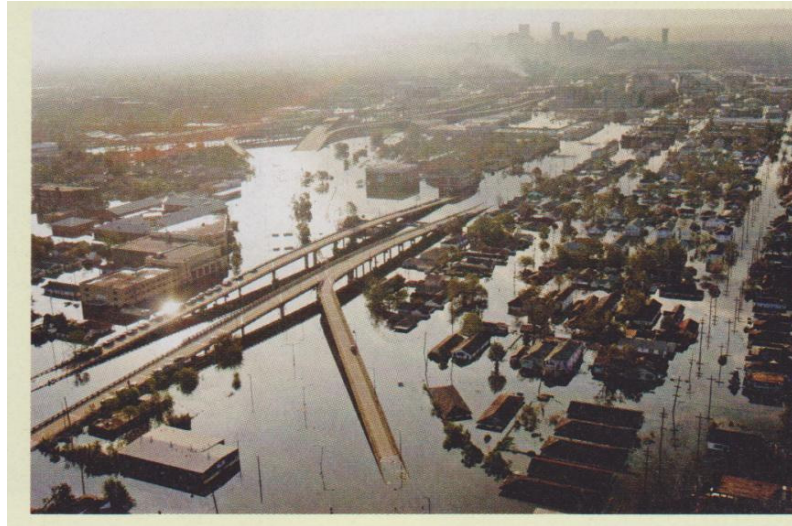


Hurricane Katrina, Aug 29, 2005



Hurricane Katrina

Flooding in New Orleans, USA



SOURCE: U.S. Army Task Force Hope

MSNBC

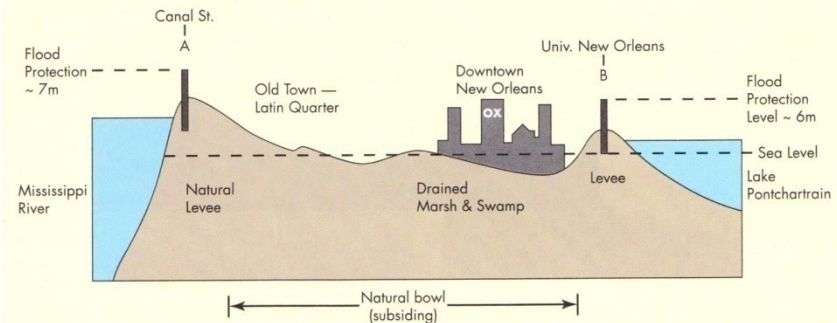
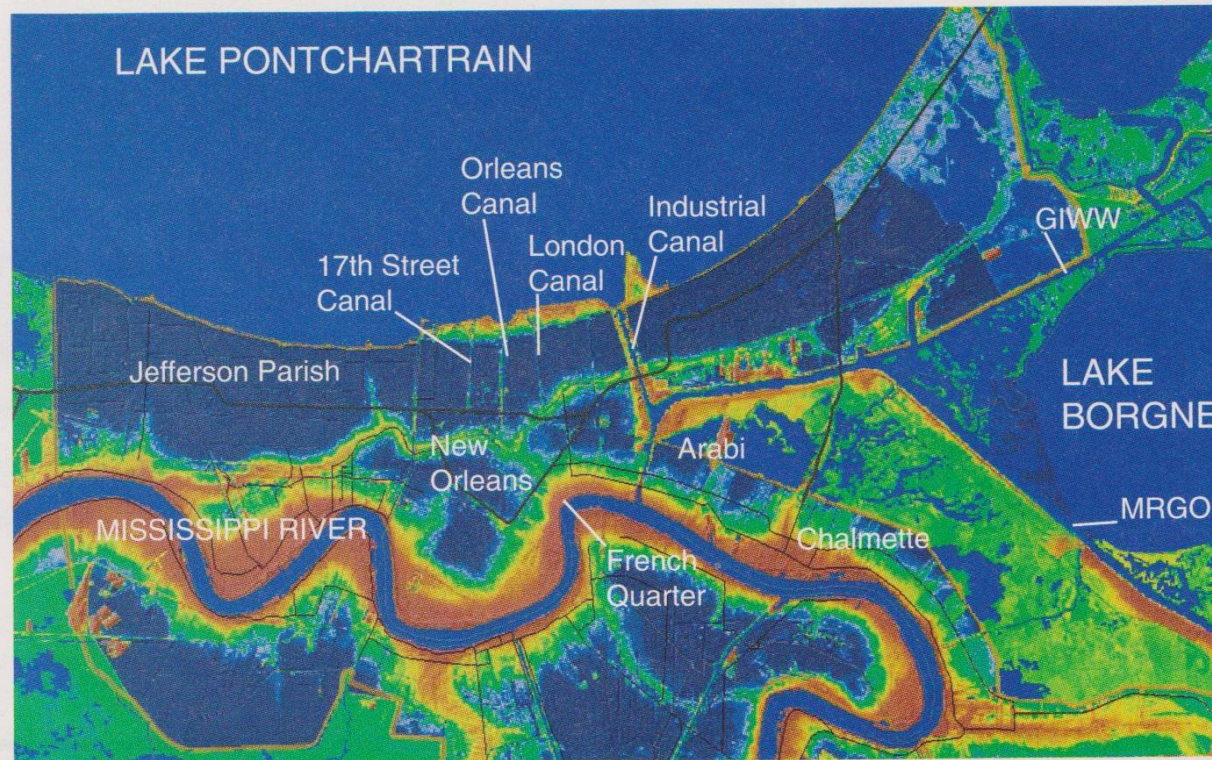
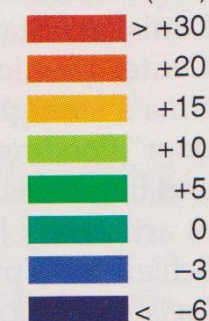


Figure 5.2 Map and cross section of New Orleans. Much of the city is below sea level between the Mississippi River and Lake Pontchartrain. (Edward A. Keller)



Land “below ground zero” includes densely settled areas of metropolitan New Orleans, as seen in this topographic map prepared by the Center for the Study of Public Health Impacts of Hurricanes at Louisiana State University. The banks of the Mississippi rise more than 20 feet, but much of the land between the river and Lake Pontchartrain is 5 feet or more below sea level. Flooding caused by Hurricane Katrina came from two directions. A storm surge from the east converged along two canals, the Gulf Intracoastal Waterway (GIWW) and the Mississippi River Gulf Outlet (MRGO). Later, high water in Lake Pontchartrain burst through concrete flood walls on the 17th Street canal and the London Avenue canal. The Industrial Canal may have been battered from both directions. (Elevation map courtesy of Louisiana State University.)

elevation (feet)



Source: American Scientist, Nov-Dec 2005, p. 497
Natural & Unnatural Disasters, by Brian Hayes

New Orleans two weeks after Hurricane Katrina



* Detailed assessment on the failure of New Orleans Hurricane Protection System will be presented in **Part 2**

Hurricane Mitch, Oct 26- Nov 5, 1998



Track of Hurricane Mitch

From October 26 to November 1, 1998



Hurricane track & rainfall extremes

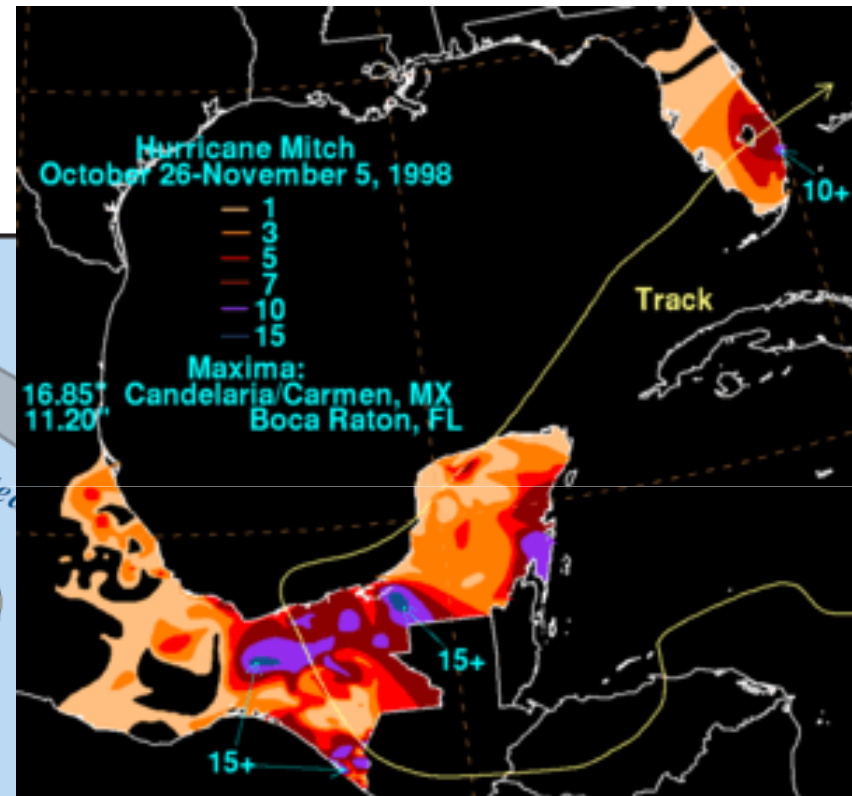
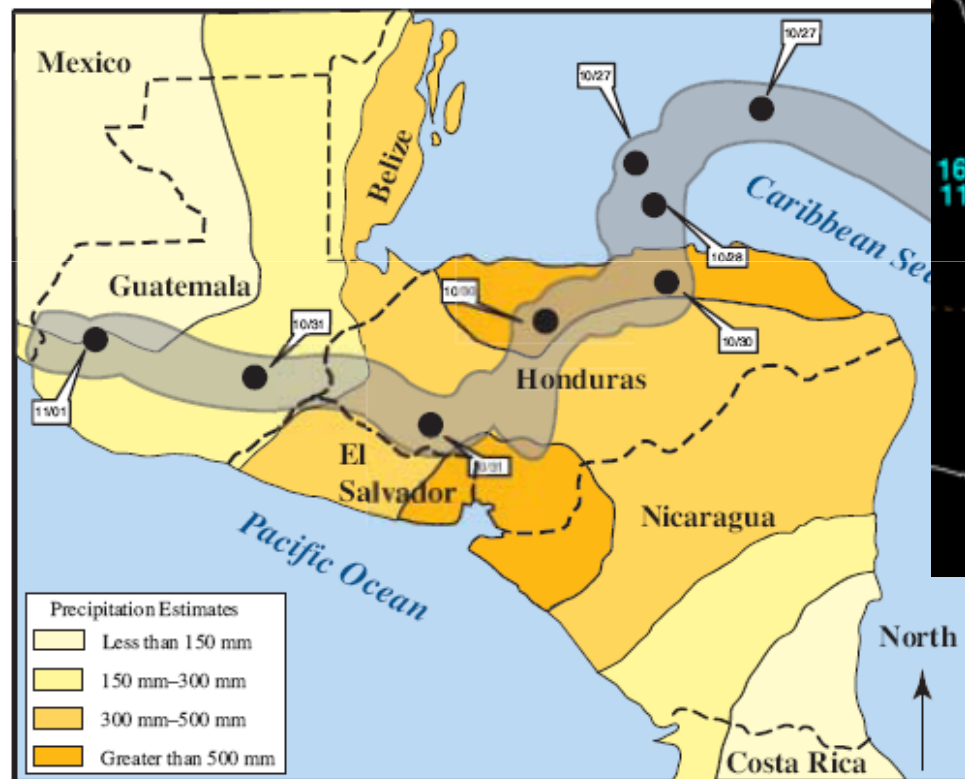


Figure 2. Schematic diagram showing the track of Hurricane Mitch in Central America and rainfall estimates from 25 October to 17 November 1998. Modified from Hellin and Haigh (1999).

Hurricane Mitch, Oct. 1998

- Intense rainfall caused massive landslides in Honduras in Oct 30, 1998.
- The hurricane continued to produce torrential rains, reaching a rate $> 100 \text{ mm/hr}$ which caused catastrophic floods & landslides throughout the region.

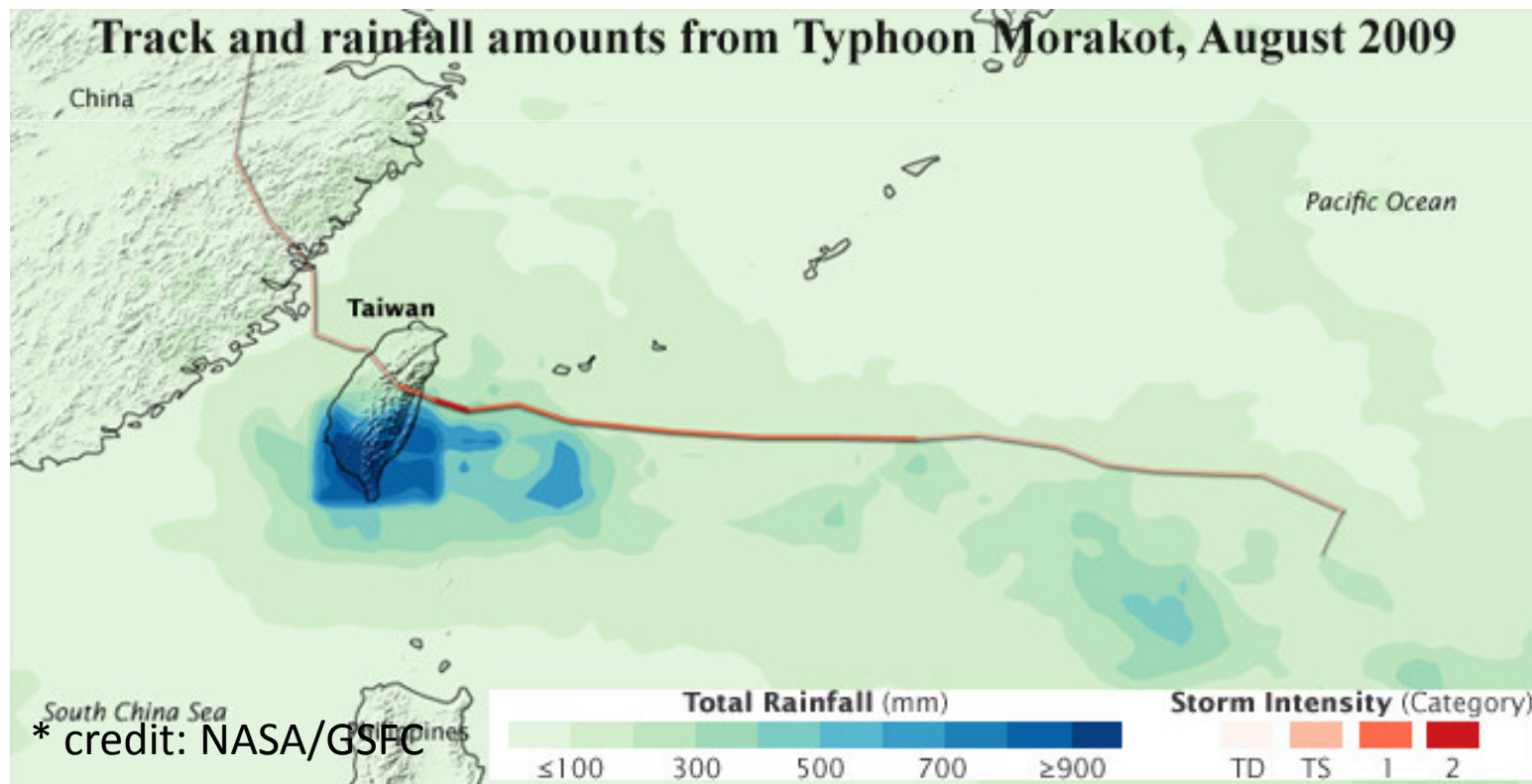




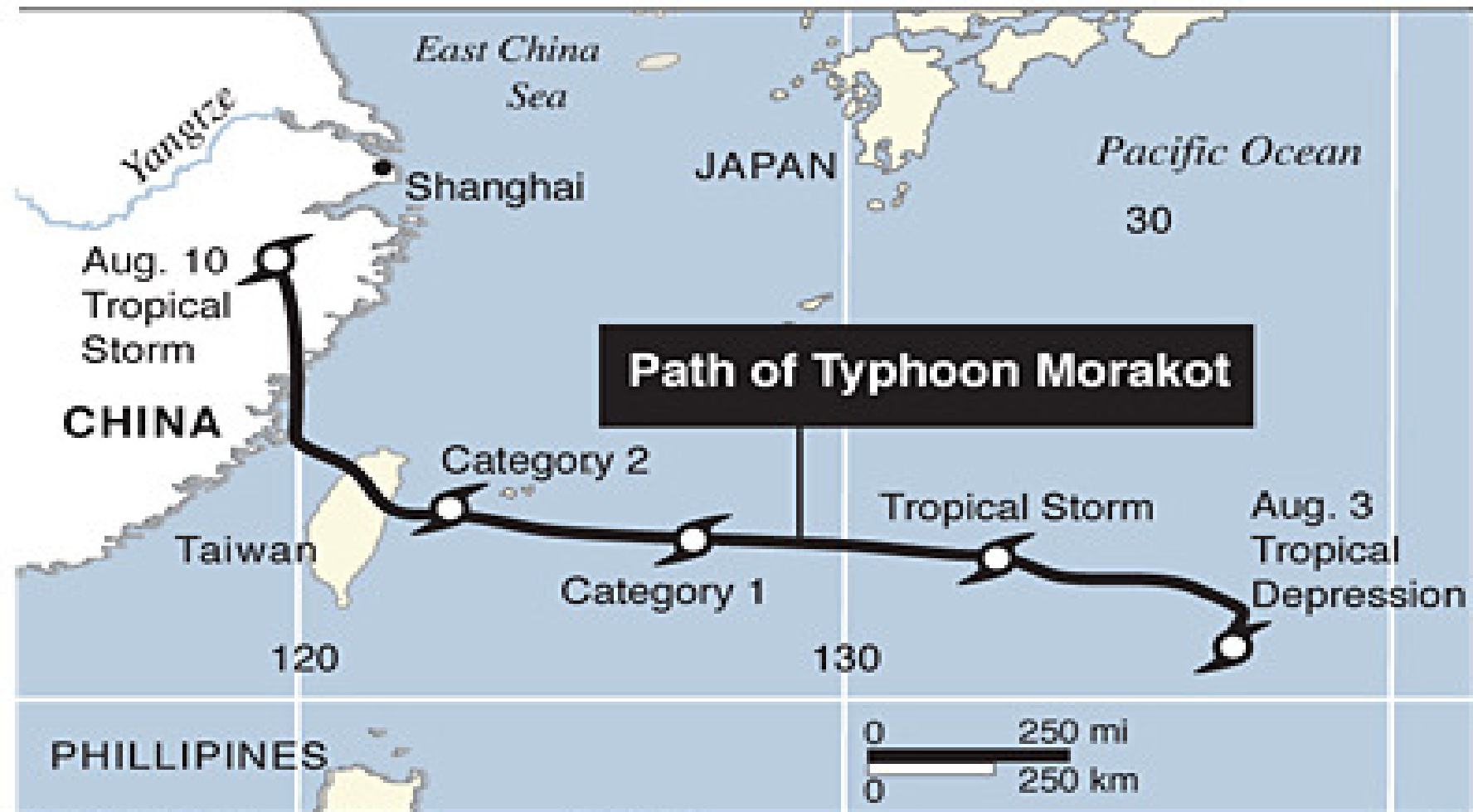
*source: USGS

Typhoon Morakot (August 2009)

- Caused severe damage to central-southern Taiwan with record breaking rain of 2,900 mm in 3 days, and highest regional single day rainfall of 1,403 mm
- Catastrophe damages to infrastructures & communities due to flooding, landslides, and mud/debris flow.



MORAKOT'S PATH: AUGUST 3-10, 2009



SOURCES: Weather Underground; ESRI

Mud & Debris Floods

- Natural disturbance, such as earthquake, and human interaction & land-use, such as de-forestation, plantation & mining, also affect the impact of storm rainfall on hill-slope stability.
- This leads to landslides and debris flooding along the river course.

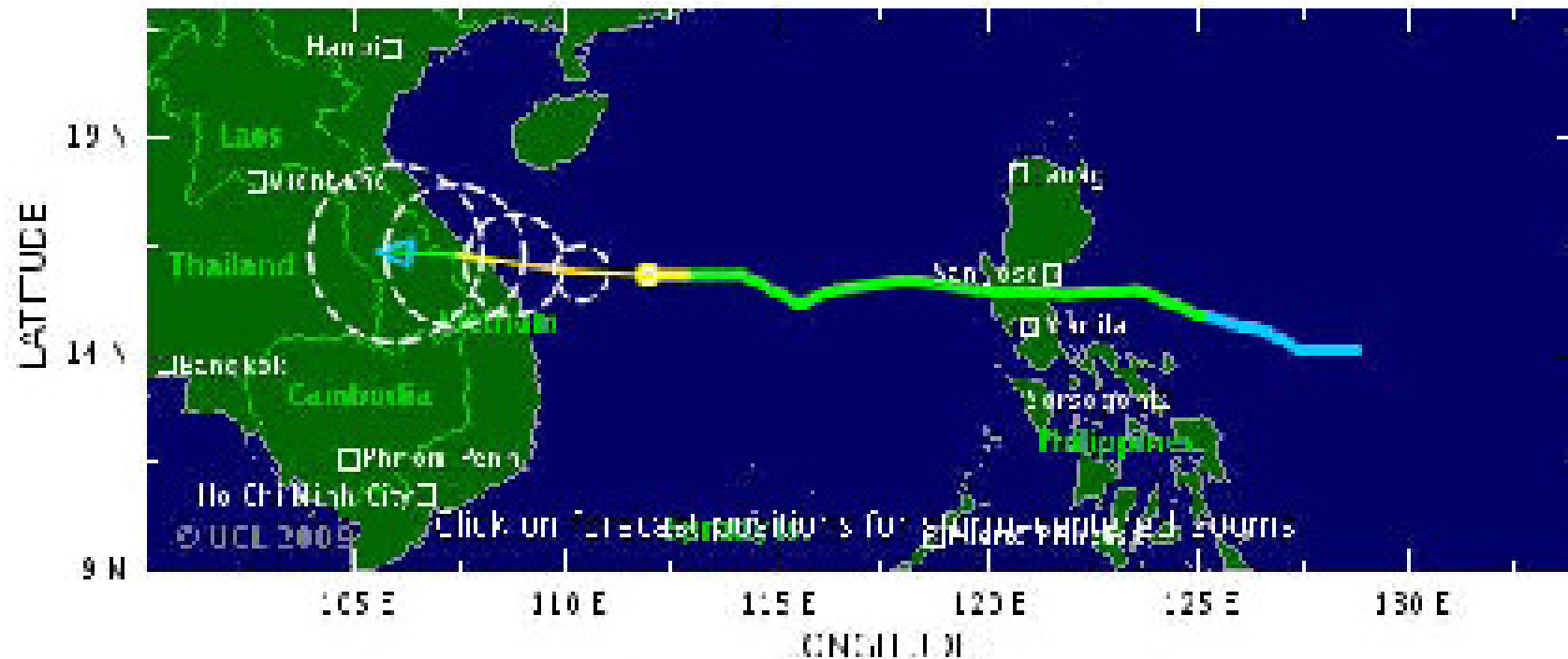


Source: Disaster Risk Reduction by Walter Hayes, UNC, U.S.



*sources: HSS & David Petley

Typhoon Ketsana, Sept 23-30, 2009



Impact on Metropolitan Manila

- **Nearly a month's worth of rain fell in just six hours on Saturday (Sept 26, 2009) on Manila, Philippine, stranding thousands on rooftops in the city and elsewhere as tropical storm Ketsana slammed ashore.**
- **The flood waters reached two stories high in many areas in Metro Manila**
- **Typhoon track continued on to Vietnam & Cambodia**



People are stranded in Cainta, Province of Rizal , eastern Manila .



Devastation brought by Tropical Storm Ketsana in Cainta, province of Rizal , eastern Manila .



Waist-deep floodwaters after heavy rains dumped by Tropical Storm Ketsana (locally known as Ondoy) on Saturday, Sept. 26, in Manila , Philippines .

End of Part 1