Steven A. Ackerman and John A. Knox THIRD EDITION

METEOROLOGY

Understanding the Atmosphere

Chapter 8

Atmospheric-Ocean Interactions: El Niño and Tropical Cyclones

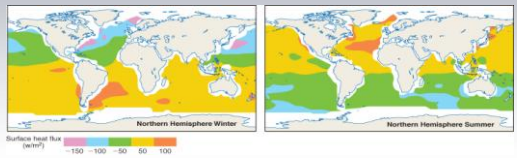


Figure 01: The energy gains and losses of Earth's oceans

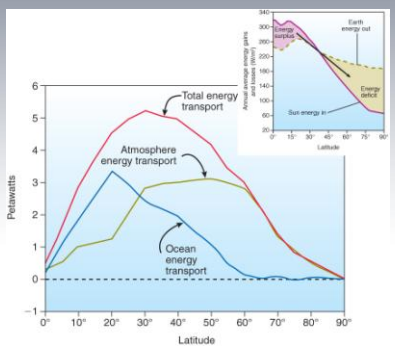


Figure 02: Energy transport versus latitude

Causes of Ocean Currents

- Wind (note that due to Coriolis Effect the current is to the right of the wind in the Northern Hemisphere and left in Southern)
- Temperature Differences (warm water rises and cool water sinks)
- Salinity Differences (salty water is heavier than fresh water so it sinks, especially when it is also cold

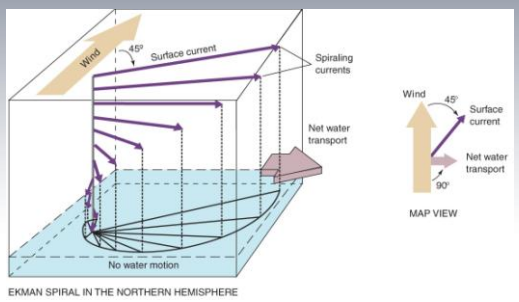


Figure 09: Ekman spiral

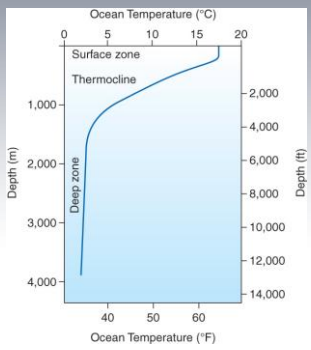


Figure 03: Temperature vs. depth in ocean

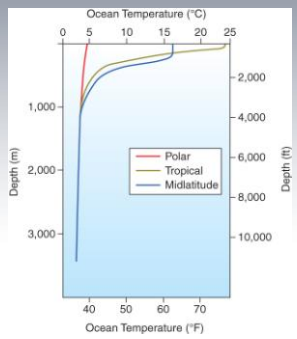
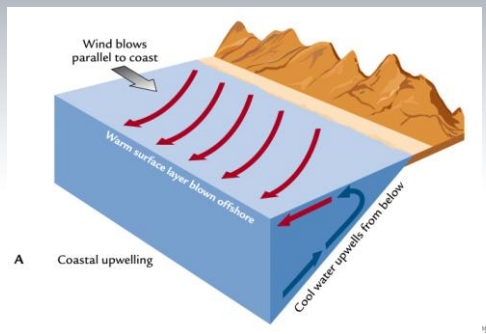
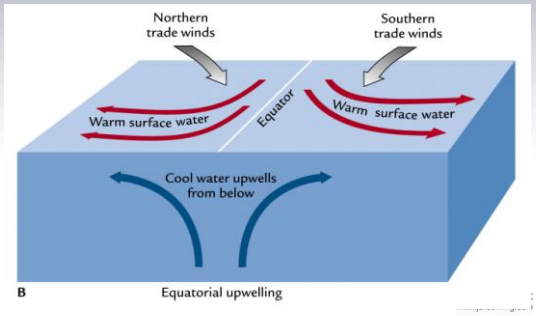


Figure 04: the depth and steepness of the thermocline are functions of latitude

Upwelling Along the Coast



Upwelling of water at Equator



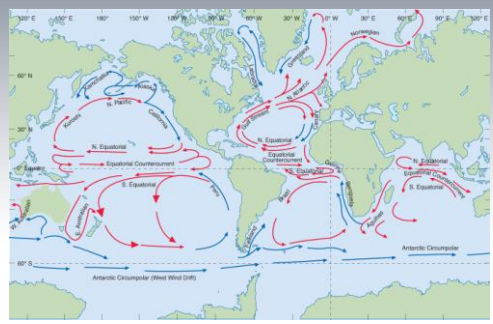


Figure 06: Ocean currents.

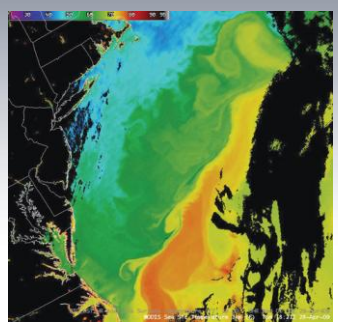


Figure 07: SST satellite image of the Gulf Stream

Courtesy of SSEC, University of Wisconsin-Madison

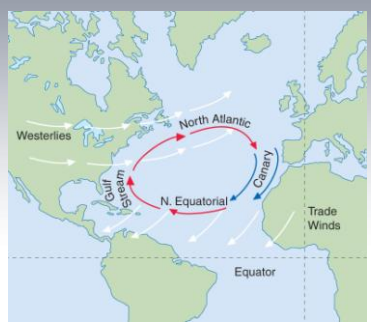
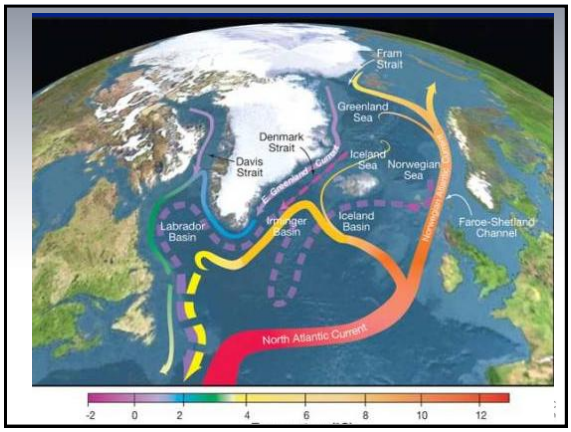


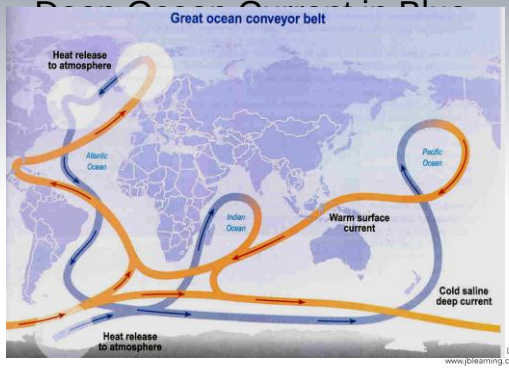
Figure 08: North Atlantic gyre

Influences of Currents on Climate

- West Coast - Low Latitude - cool waters (upwelling), low average temperature & temperature range, foggy though arid
- West Coast - High Latitude - warm waters, mild winters, small annual temperature range
- East Coast - Low Latitude - warm waters, modified continental climate
- East Coast - High Latitude - cool waters, cool summers & cold winters



Deep Ocean Current in Blue



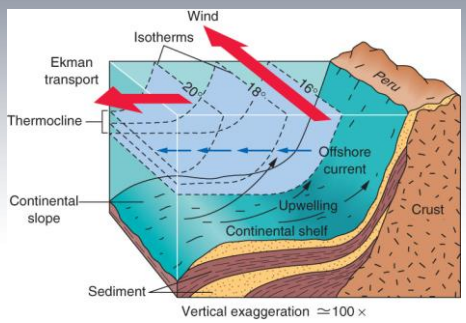
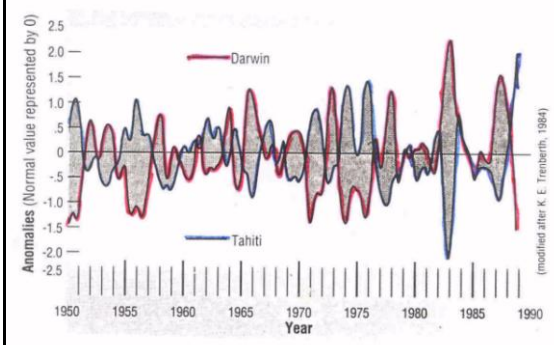


Figure 10: Ekman winds

Darwin versus Tahiti Pressure



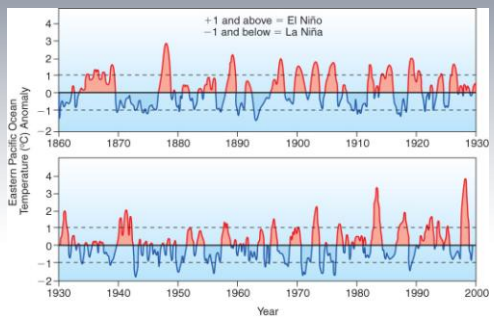
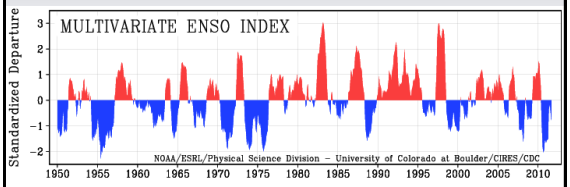


Figure 11: Temperature anomalies

Courtesy of University of Washington, Joint Institute for the Study of the Atmosphere and Ocean (JISAO)

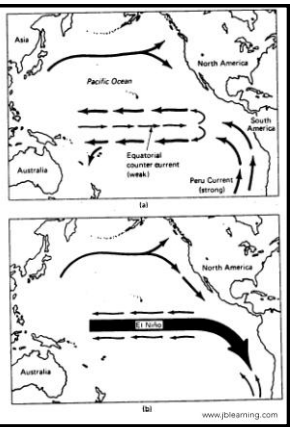
Multivariate El Nino/Southern Oscillation Index



Pacific Ocean Currents During Normal and El Nino periods

Normal

El Nino



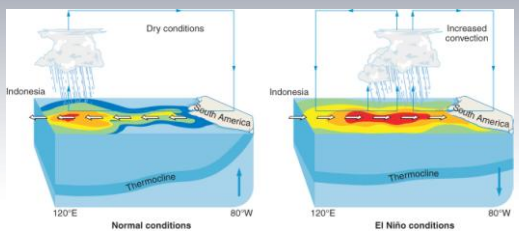
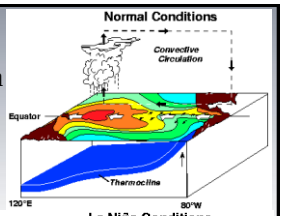
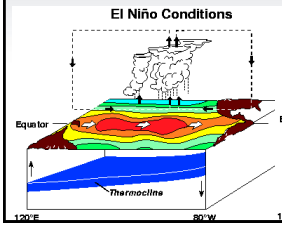
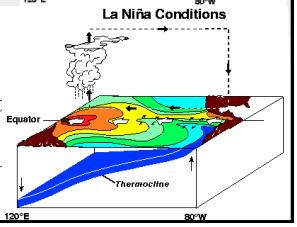


Figure 12: Trade winds & El Niño, T-storms

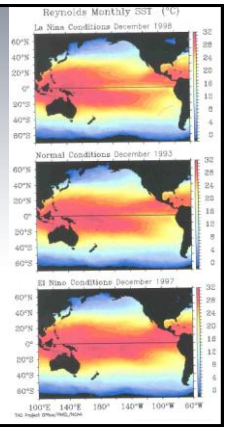
El Nino and La Nina Conditions



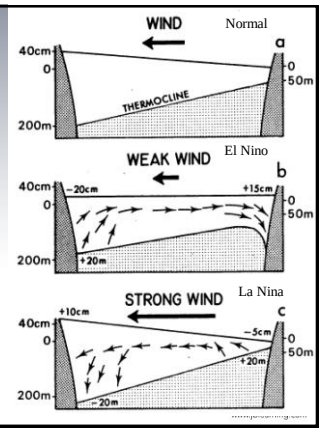




Average Monthly Sea Surface Temperature (SST) During La Nina (top) Normal (middle) El Nino (bottom)



Changing Wind causes change in Sea Surface and Thermocline



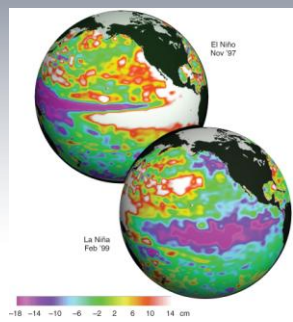


Figure 13: Satellite observations of changes in sea level height during El Niño (Top) and La Niña

Courtesy of JPL/NASA

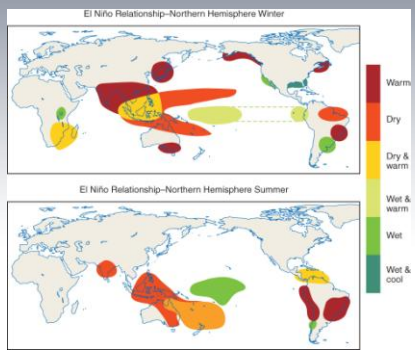


Figure 14: El Niño weather

Source: NOAA

Region	1877–1878	1899–1900	1972–1973	1982–1983	1998–1998
India	Century's worst drought	Century's second-worst drought	Century's second-worst drought	Intense drought	[No unusual drought or flooding]
Philippines	Moderate drought	Intense drought	Moderate drought	Century's worst drought	Moderate drought
Australia	Intense drought	Century's worst drought	Intense drought	Intense drought	Intense drought
North China	Century's worst drought	Century's second-worst drought	Intense drought	Intense drought	Moderate drought
Yangzi River, China	Intense flooding	[No unusual drought or flooding]	[No unusual drought or flooding]	Intense flooding	Intense flooding
South Africa	Intense drought	Moderate drought	Intense drought	Intense drought	Intense drought
East Africa	Moderate drought	Moderate drought	Intense drought	Intense drought	Intense drought
Sub-Saharan Africa	Moderate drought	Intense drought	Century's worst drought	Intense drought	[No unusual drought or flooding]
Northeast Brazil	Intense drought	Moderate drought	Intense drought	Intense drought	Intense drought
South Brazil	[No data]	[No data]	[No unusual drought or flooding]	Intense flooding	[No unusual drought or flooding]

Figure T01: Global Impacts of Five Major El Niño Events

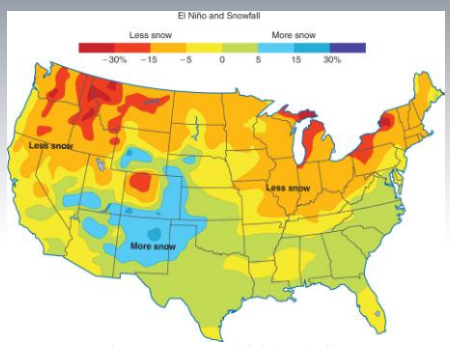


Figure 15: USA snowfall during El Niño

Impacts of El Nino on Snowfall by Angel, Jim, Image courtesy of the Midwestern Regional Climate Center, Illinois State Water Survey

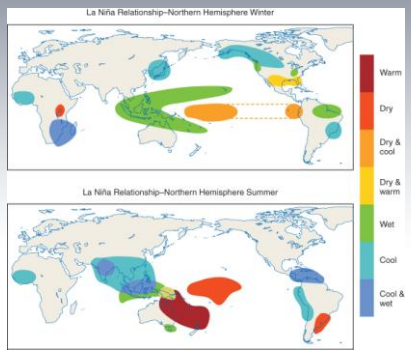


Figure 17: La Niña weather

Source: NOAA

Tropical Cyclones

Atlantic Ocean – Hurricanes
Pacific Ocean – Typhoons
Indian Ocean – Cyclones

Necessary Conditions

- Must take place over water (latent heat)
- Water surface temperature > 27°C (80°F)
- Latitude > 5° (Coriolis needed to rotate wind)
- Weak wind shear in vertical (concentrated heat moves together with wind)
- Preexisting disturbance (concentrate heat in one location)

Growth of Hurricane

- Warm moist surface – thunderstorms likely
- Preexisting disturbance organizes them
- Latent heat release heats locality
- Weak wind shear keeps heat together
- Warm air aloft expands & forms surface low
- Low causes warm moist air to converge inward
- This causes more heating and lifting of air
- As air moves in, get cyclonic rotation (Coriolis)
- As rotating air converges on low, radius decreases so speed increases

What they are like

- Tropical Disturbance: winds < 23 mph
- Tropical Depression: winds 23-40 mph
- Tropical Storm: winds 40-73 mph
- Hurricane: winds > 73 mph
- Typical large hurricanes - 300 mi diameter
- Pressure drop in center 20-70 mb
- Winds spiral in up to 180 mph near center to a continuous ring of thunderstorms
- Inside ring, air is calm and sinking called the eye of the hurricane
- Rain around eye is 6-20 in/day

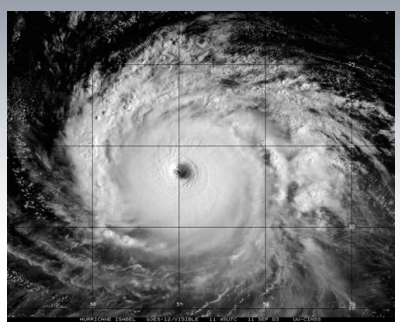
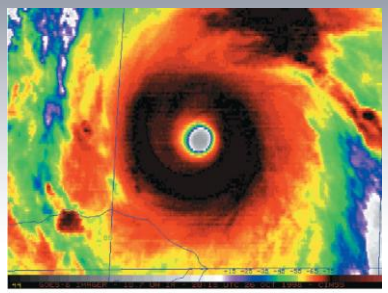


Figure 19: Hurricane Isabel

Courtesy of CIMSS/University of Wisconsin-Madison

Figure 20: Andrew damage

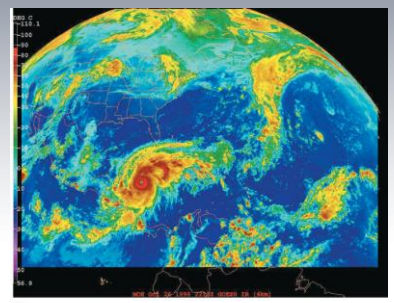
Courtesy of NOAA



(a)

Figure 21A: Hurricane Mitch satellite images

Courtesy of CIMSS/University of Wisconsin-Madison



(b)

Figure 21B: Hurricane Mitch satellite images

Courtesy of CIMSS/UW-Madison

Rank	Tropical Cyclone (Unnamed Before 1950)	Year	Minimum Pressure at Landfall	Saffir–Simpson Category at Landfall	Deaths (U.S. Only)	U.S. Damage (Million 2005 U.S. Dollars)
1	Katrina (Louisiana, Mississippi, Alabama)	2005	920	3	1,500	100,000
2	"Great Miami" (southeast Florida, Alabama)	1926	935	4	243	98,051
3	Ike (Louisiana, Texas)	2008	940	2	114	29,600
4	Andrew (southeast Florida, Louisiana)	1992	922	5	58	44,878
5	"Galveston" (north Texas)	1900	931	4	8,000	36,096
6	North Texas	1915	945	4	275	30,585
7	"New England" (New York, Rhode Island)	1938	946	3	600	22,549
8	Southwest Florida	1944	962	3	300	22,070
9	"Lake Okeechobee" (southeast Florida)	1928	929	4	1,836	18,708
10	Betsy (southeast Florida, Louisiana)	1965	948	3	75	16,863
11	Donna (Florida, eastern U.S.)	1960	930	4	50	16,339
12	Camille (Mississippi, Louisiana, Virginia)	1969	909	5	256	14,870
13	Agnes (northwest Florida, northeast U.S.)	1972	980	1	122	14,515
14	Ivan (Alabama, northwest Florida)	2004	946	3	57	14,200
15	Wilma (south Florida)	2005	950	3	35	14,000
16	Charley (southwest Florida, South Carolina)	2004	941	4	30	14,000
17	Diane (northeast U.S.)	1955	987	1	184	13,875
18	Hugo (South Carolina)	1989	934	4	26	12,718
19	Carol (northeast U.S.)	1954	960	3	60	12,291
20	Southeast Florida, Louisiana, Alabama	1947	940	4	51	11,266

Figure T02: The Most Damaging Tropical Cyclones to Affect the United States 1900–2009

Figure 22: Inside eye wall

© Chris Sattlberger/Photo Researchers, Inc.

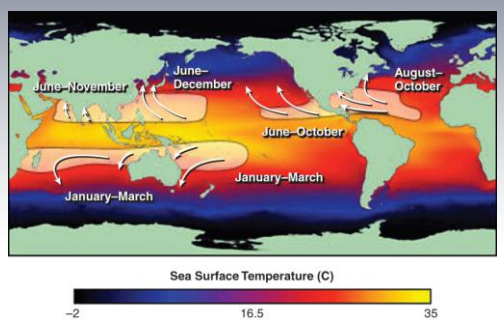


Figure 23: Hurricane paths and SST

Courtesy of NASA

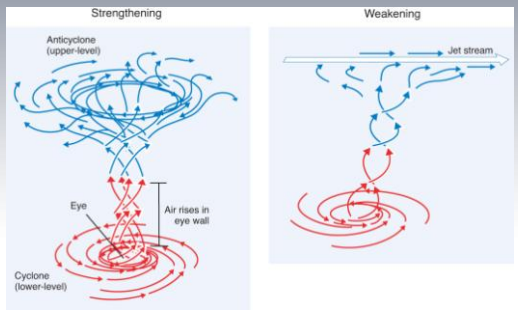


Figure 25: Swirling winds

Adapted from Nese, J. and Grenci, L., A World of Weather: Fundamentals of Meteorology. Kendall/Hunt, 1998.

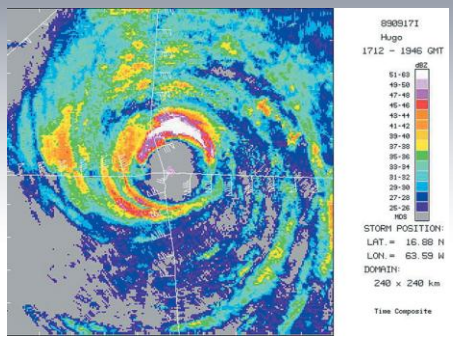


Figure 26: Hurricane Hugo

Courtesy of NOAA

Figure B01: Hurricane hunter plane

Courtesy of UCAR/NSF/NOAA

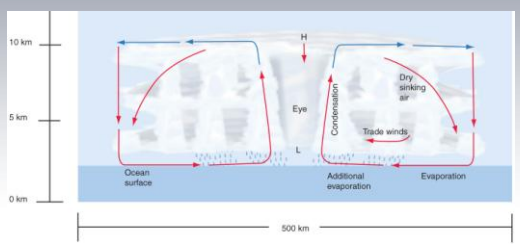


Figure 27: Cross section of processes involved in fueling a hurricane

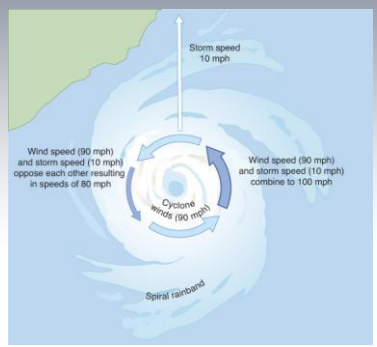


Figure 28: Hurricane relative winds

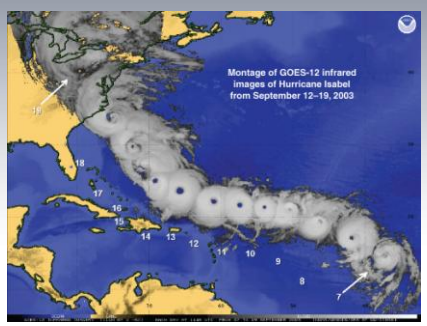


Figure 30: Isabel Montage

Courtesy of Gary Wade, CIMSS/NOAA

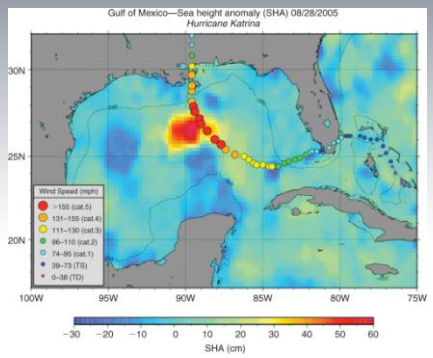
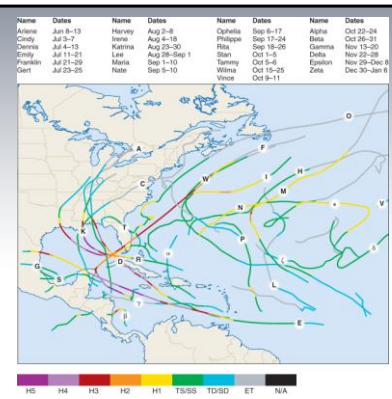


Figure 32: Katrina and SSTs



Data from NOAA Coastal Services Center: http://csc-s-maps-q.csc.noaa.gov/hurricanes/viewer.html

Figure 33: 2005 hurricane season

Figure 34: Aerial damage of Katrina

Courtesy of NGS Remote Sensing Division/NOAA

Category	One-Minute Sustained Winds in mph (km/h)	Example Storms	Damage
1	74–95 (119–153)	Agnes (1972) Dolly (2008)	*Very dangerous winds will produce some damage:* Damage primarily to trees and unanchored mobile homes; some coastal flooding
2	96–110 (154–177)	Floyd (1999) Frances (2004)	*Extremely dangerous winds will cause extensive damage:* Some damage to roofs, doors, windows, trees and shrubbery; flooding damage to piers
3	111–130 (178–209)	Celia (1970) Ivan (2004)	*Devastating damage will occur:* Some structural damage; large trees blown down; flooding near shoreline and possibly inland; mobile homes destroyed
4	131–155 (210–249)	Hugo (1989) Charley (2004)	*Catastrophic damage will occur:* Extensive damage to doors and windows; major damage to lower floors near shore; terrain may be flooded well inland
5	>155 (>249)	Camille (1969) Andrew (1992)	*Catastrophic damage will occur:* Complete roof failure and some building failures; massive evacuation; flooding causes major damage to lower floors of all shoreline buildings

Figure T03: The Saffir–Simpson Scale for Hurricanes

Figure 37: Photo of Floyd flooding

Courtesy of Dave Saville/FEMA News Photo

Figure 38: Tracks of the Galveston hurricane and Katrina

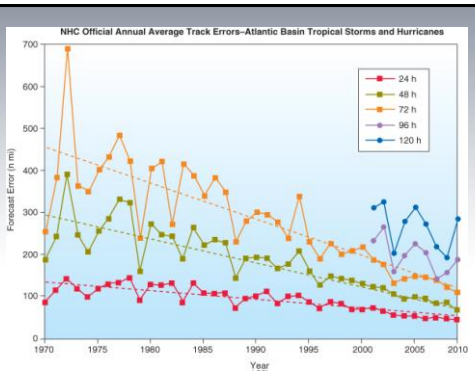


Figure 39: Track forecast errors

Source: NOAA

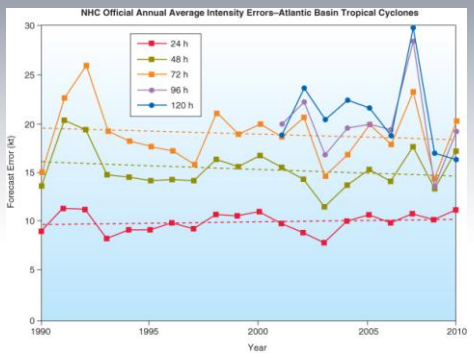


Figure 40: Intensity forecast errors

Source: NOAA

Figure 41: Katrina forecast

Courtesy of National Weather Service/NOAA

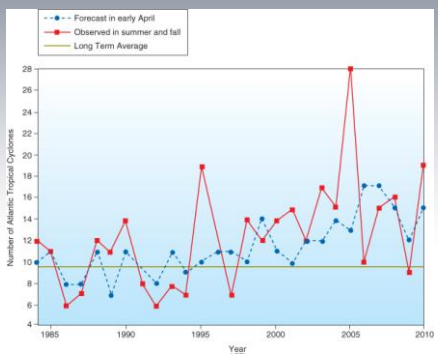


Figure 42: Gray's forecasts

Death of a Hurricane

- If move overland, source of moisture cut off and friction increases
- If move toward poles, water cools, often will merge with an extra-tropical cyclone

Damage from Hurricanes

- High winds – loose items act as missals
- Rain – flooding, erosion, mud slides
- Storm Surge – higher than normal tides
  - Generally does the most damage
  - Especially bad on top of high tide
  - Typically 10-20 ft. high
  - Caused by low pressure & wind pushing water up on land
  - On top of this, can have 10-15 ft. waves

Frequency of Tropical Storms

- North Atlantic – 7.5/yr. (max in September with 2.6/yr., season is May – November)
- South Atlantic – none (water too cold)
- North Pacific – 26.7/yr. (5.6/yr. in east, 21.1/yr. in west)
- South Pacific – 2.3/yr. (all in west)
- North Indian – 7.5/yr.
- South Indian – 6.0/yr.

Benefits of Tropical Storms

- One of the main sources of rain in parts of Mexico and other areas
- Northward transport of heat – would need other mechanism or would increase north to south temperature gradient