# HURRICANES (33)

I Main Topics

A Definition and characterization of hurricanes

B Conditions required for hurricanes

C Tornadoes vs. hurricanes

D Storm surges

E Case histories

II Terminology and classification of hurricanes (cyclones)

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqHED.html

A Terminology: hurricane = typhoon = strong tropical cyclone.

1 A tropical cyclone is the generic term for a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection (i.e. thunderstorm activity) and definite cyclonic surface wind circulation

2 Cyclone: a large-scale storm with heavy rain and winds that rotates around a low pressure center (the eye). The rotation is counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

3 A large, concentrated atmospheric/oceanic heat engine with sustained wind speeds greater than 74 mph.

B Classification: the Saffir/Simpson Hurricane Scale

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqD.html#D7

| Saffir-Simpson Category | Maximum sustained wind speed mph | Maximum sustained wind speed m/s | Maximum sustained wind speed kts | Minimum surface pressure mb | Storm surge ft | Storm surge m |
|---|---|---|---|---|---|---|
| 1 | 74-95 | 33-42 | 64-82 | greater than 980 | 3-5 | 1.0-1.7 |
| 2 | 96-110 | 43-49 | 83-95 | 979-965 | 6-8 | 1.8-2.6 |
| 3 | 111-130 | 50-58 | 96-113 | 964-945 | 9-12 | 2.7-3.8 |
| 4 | 131-155 | 59-69 | 114-135 | 944-920 | 13-18 | 3.9-5.6 |
| 5 | 156+ | 70+ | 136+ | < 920 | 19+ | 5.7+ |

Damage common in hurricanes of different strength

| Category/ Example | Damage |
|---|---|
| 1<br><br>Hurricane Earl (1998) | Damage primarily to shrubbery, trees, foliage, and unanchored homes. No real damage to other structures. Some damage to poorly constructed signs. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings. |
| 2<br><br>Hurricane Georges (1998) | Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major damage to buildings. Coast roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying areas required. |
| 3<br><br>Hurricane Fran (1996) | Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major damage to buildings. Coast roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying areas required. |
| 4<br><br>Hurricane Andrew (1992) | Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows and doors. Complete failures of roofs on many small residences. Complete destruction of mobile homes. Flat terrain 10 feet of less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore possibly required, and of single- story residences within 2 miles of shore. |
| 5<br><br>Hurricane Camille (1969) | Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. Major damage to lower floors of all structures less than15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Massive evacuation of residential areas on low ground within 5 to 10 miles of shore possibly required. |

http://hurricanes.noaa.gov/prepare/categories3.htm

## III Conditions required for hurricanes (necessary but not sufficient)

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqHED.html

1 Warm ocean waters (at least 26.5°C [80°F]) throughout a sufficient depth (at least on the order of 50 m [150 ft]). Warm waters are necessary to the heat engine of the tropical cyclone.

2 An atmosphere which cools fast enough with height such that it is potentially unstable to moist convection. Thunderstorm activity allows the heat stored in the ocean waters to be liberated for the tropical cyclone development.

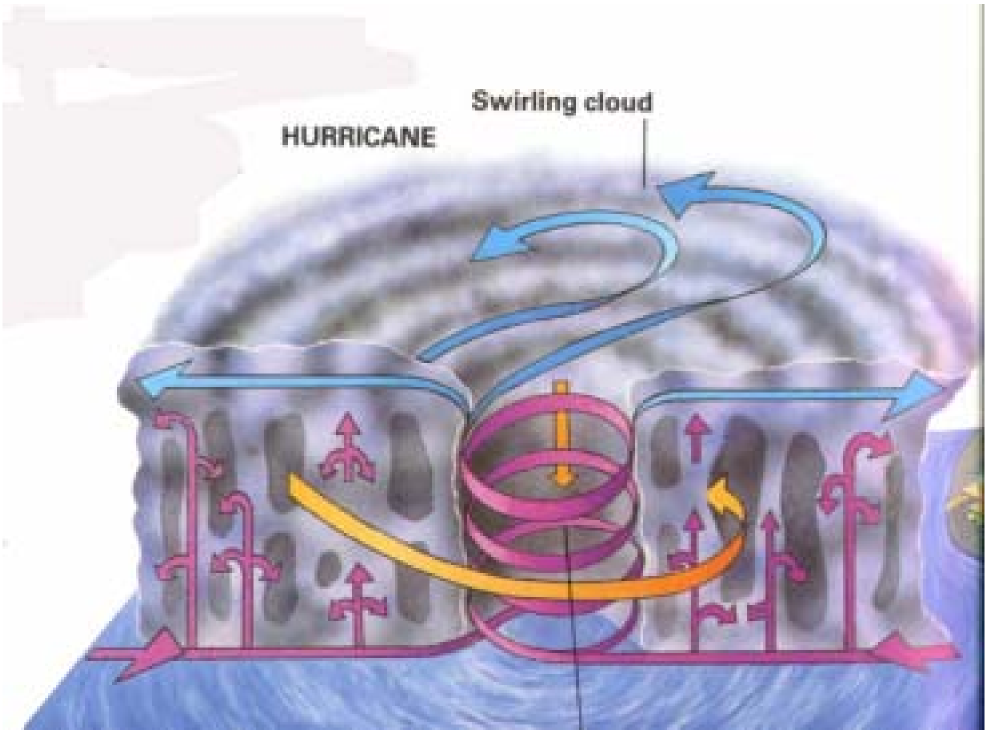
3 Relatively moist layers near the mid-troposphere (5 km [3 mi]). Dry mid levels are not conducive for allowing the continuing development of widespread thunderstorm activity.

4 A minimum distance of at least 500 km [300 mi] from the equator such that the Coriolis force is sufficient to allow the near-surface wind conditions needed to maintain low pressures on the water surface.

5 A pre-existing near-surface disturbance with sufficient vorticity and convergence. Tropical cyclones cannot be generated spontaneously. To develop, they require a weakly organized system with sizable spin and low-level inflow.

6 Low values (less than about 10 m/s [20 kts 23 mph]) of vertical wind shear between the surface and the upper troposphere. Vertical wind shear is the magnitude of wind change with height. Large values of vertical wind shear disrupt the incipient tropical cyclone and can weaken or destroy a cyclone that has formed.

Cutaway diagram of a hurricane




http://mmem.spschools.org/grade5science/weather/hurricanediagram.html

Key points http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqA.html#a11

* Hurricanes draw warm moist air from over the oceans up into the atmosphere to an altitude of ~12 km where the water condenses. The air rises around the eye and in spiral rainbands. Condensation of water aloft liberates energy.
* Air sinks in the eye and along the rainbands, with the largest region of air subsidence being in the eye. The air moves from high pressure at high elevations to low pressure at the surface. Sinking air in the eye usually descends to 1-3 km above the surface, not to the surface.
* High pressure aloft causes moisture raised from the warm ocean to spread out in the spiral rain bands.
* The winds at the eyewall (edge of the large central spiral above) are the highest and help draw moisture up in the hurricane.
* Eyes range in size from 8 km [5 mi] to over 200 km [120 mi] across, but most are approximately 30-60 km [20-40 mi] in diameter

## 7 Energy

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqD.html#D7

1.the total amount of energy released by the condensation of water droplets or ...
2.the amount of kinetic energy generated to maintain the strong swirling winds of the hurricane.

It turns out that the vast majority of the heat released in the condensation process is used to cause rising motions in the thunderstorms and only a small portion drives the storm's horizontal winds.

Total energy released through cloud/rain formation:

An average hurricane produces 1.5 cm/day (0.6 inches/day) of rain inside a circle of radius 665 km (360 n.mi) or a volume of rain of $2.1 \times 10^{16}$ $cm^3$/day. A cubic cm of rain weighs 1 gm. Using the latent heat of condensation, this amount of rain produced gives $5.2 \times 10^{19}$ Joules/day or $6.0 \times 10^{14}$ Watts. This is equivalent to 200 times the world-wide electrical generating capacity - an incredible amount of energy produced!

Total kinetic energy (wind energy) generated:

For a mature hurricane, the amount of kinetic energy generated is equal to that being dissipated due to friction. The dissipation rate per unit area is air density times the drag coefficient times the windspeed cubed. One could either integrate a typical wind profile over a range of radii from the hurricane's center to the outer radius encompassing the storm, or assume an average windspeed for the inner core of the hurricane. Doing the latter and using 40 m/s (90 mph) winds on a scale of radius 60 km (40 n.mi.), one gets a wind dissipation rate (wind generation rate) of 1.5 x 1012 Watts. This is equivalent to about half the world-wide electrical generating capacity - also an amazing amount of energy - but 400 times less than that generated by the condensation of water.
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## IV Hurricanes vs. tornadoes

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqA.html#A7

| Property | Tornado | Hurricane |
|---|---|---|
| Diameter | 100s of meters | 100s of *kilometers |
| Produced by ... | a single convective storm | several to dozens of convective storms |
| Vertical Wind shear | "Substantial" | "low" ( < 10 m/s [20 kt, 23 mph]) |
| Horizontal temperature fields | large temperature gradient | near zero |
| Primary Location | Over land | Over oceans |
| Duration | Minutes | Days |

Note: tropical cyclones at landfall often provide the conditions necessary for tornado formation. As the tropical cyclone makes landfall and begins decaying, the winds at the surface die off quicker than the winds at, say, 850 mb. This sets up a fairly strong vertical wind shear that allows for the development of tornadoes, especially on the tropical cyclone's right side (with respect to the forward motion of the tropical cyclone). For the southern hemisphere, this would be a concern on the tropical cyclone's left side - due to the reverse spin of southern hemisphere storms.

III Effects of hurricanes

A Wind

1 Drives waves

2 Affects buildings

B Storm surge

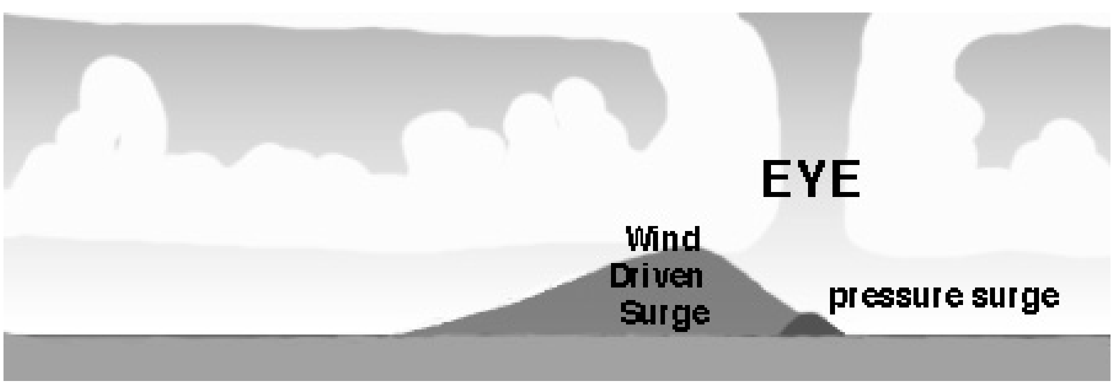
http://www.aoml.noaa.gov/general/lib/stormsurgey.html
http://hurricanes.noaa.gov/prepare/surge.htm
http://www.ncstormsurge.com

1 A dome of water as much as 50 miles wide, that sweeps across the coastline near where the eye of the hurricane makes landfall.

2 Can increase the water level by as much as 33' (10 m)

3 The stronger the hurricane, the higher the storm surge will be.

4 The most dangerous part of a hurricane. Nine out of ten hurricane fatalities are caused by the storm surge.



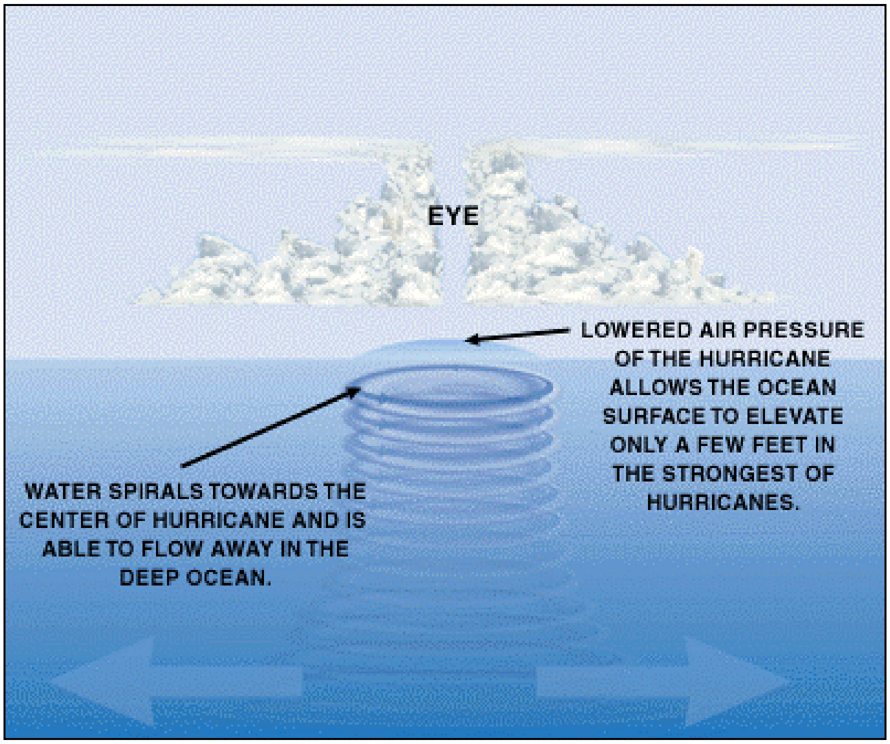

Contributions to storm surges. http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqC.html#C1

5 Depend upon the coastal topography, angle of incidence of landfall, speed of tropical cyclone motion, as well as the wind strength.

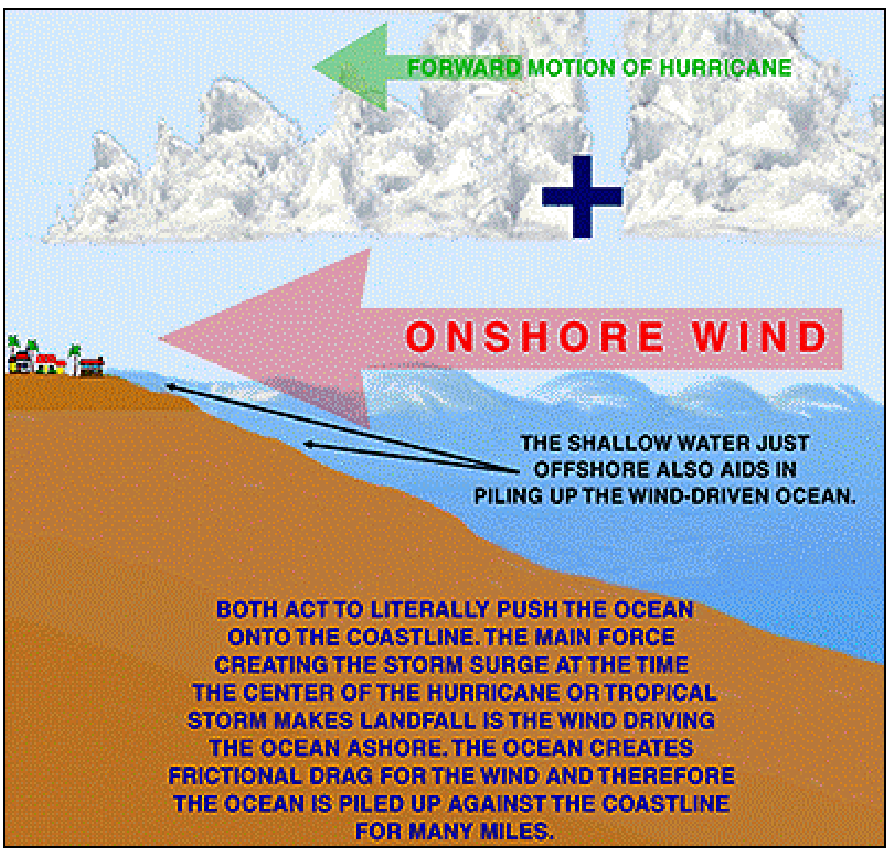
C Flooding

D Erosion

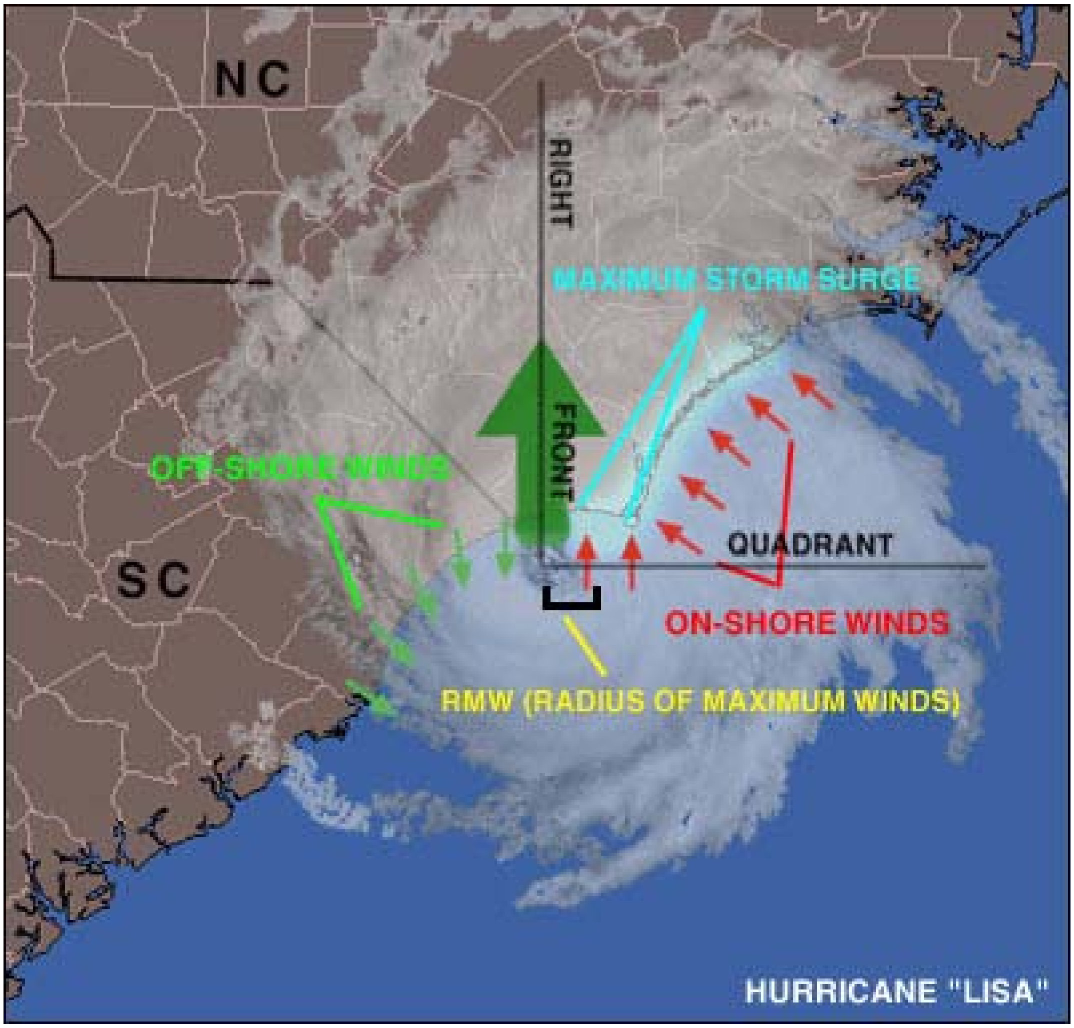
http://www.ncstormsurge.com

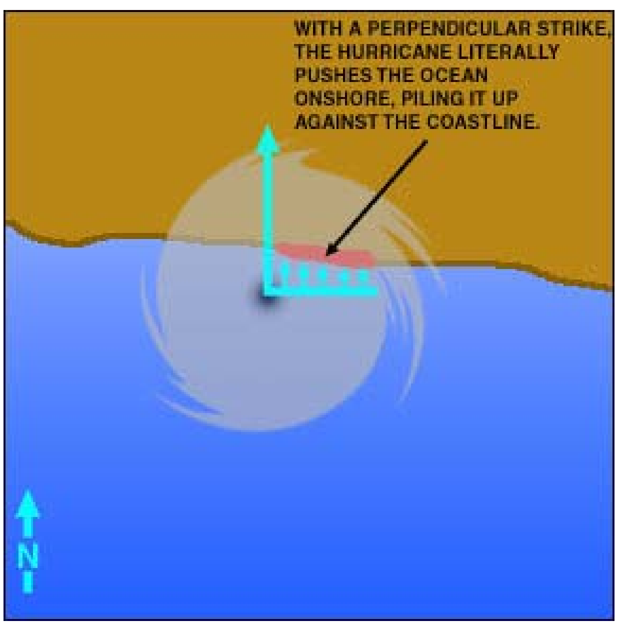



The low pressure in the eye and high pressure outside the eye causes the water surface to become elevated a few meet at most




The winds in a hurricane are what pile up most of the water in a storm surge, which can exceed 25’ in height.


NC
SC
RIGHT
FRONT
QUADRANT
MAXIMUM STORM SURGE
OFF-SHORE WINDS
ON-SHORE WINDS
RMW (RADIUS OF MAXIMUM WINDS)
HURRICANE "LISA"


WITH A PERPENDICULAR STRIKE, THE HURRICANE LITERALLY PUSHES THE OCEAN ONSHORE, PILING IT UP AGAINST THE COASTLINE.
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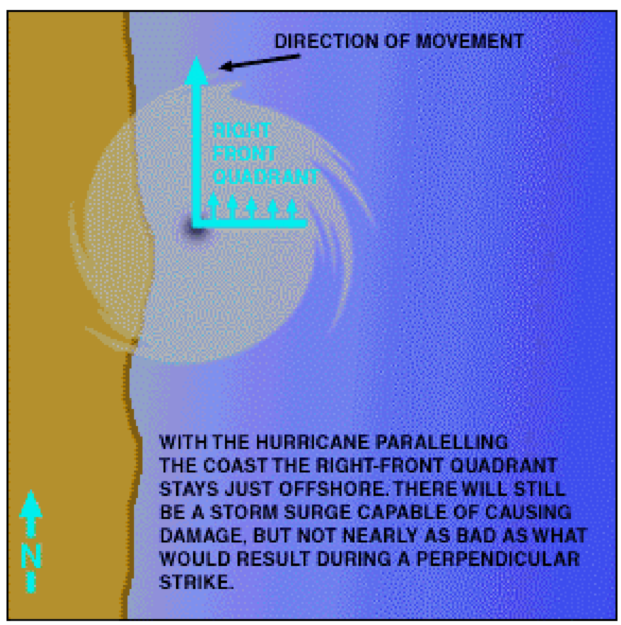
DIRECTION OF MOVEMENT
RIGHT
FRONT
QUADRANT
WITH THE HURRICANE PARALELLING THE COAST THE RIGHT-FRONT QUADRANT STAYS JUST OFFSHORE. THERE WILL STILL BE A STORM SURGE CAPABLE OF CAUSING DAMAGE, BUT NOT NEARLY AS BAD AS WHAT WOULD RESULT DURING A PERPENDICULAR STRIKE.
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## VII Case histories

### A Hurricane Andrew: Category 4 (8/16/92- 8/28/92)

http://www.nhc.noaa.gov/1992andrew.html
http://marine.usgs.gov/fact-sheets/hurricane/hurricane-txt.html
http://www.eqe.com

Fatalities: 38 confirmed.
Damage estimate: ~$25 billion.

People left homeless: 175,000 to 250,000 people;
85,000 homes and apartments are uninhabitable, many totally destroyed.
600,000 homes and businesses have lost electrical and phone services

Area of heavy damage: more than 40 miles in diameter.

Utilities temporarily lost
Power, drinking water, communications, and sewage facilities (no pumps)
Underground water and gas distribution mains damaged by uprooted trees.
Street and highway signs blown away and traffic lights lost, hampering rescue and relief efforts.

Florida Power & Light reports 12,620 miles of local power distribution line and more than 631 miles of high-power feeder lines knocked down. ~1.4 million customers affected. Estimate for time of final utility repairs: six months.

Turkey Point Generating Station (two nuclear and two fossil fuel units), sustained damage that may keep it off-line for several months. One of the plant's 400-foot-tall concrete exhaust stacks sustained heavy structural damage and had to be demolished by explosives. A tank of heavy bunker fuel spilled an estimated 12,000 gallons of fuel, some of which spread to the ground near the nuclear reactors. The two nuclear units were shut down as a safety precaution before the hurricane hit and sustained minimal damage, although the fire protection system's water tank collapsed, rendering the system inoperable for nearly a week. Damage to the site was estimated at about $90 million.

In Louisiana, 13 offshore oil and gas production platforms were reported as destroyed--four of which disappeared leaving no trace. Approximately 40 additional offshore drilling rigs and production platforms were also damaged. It has been reported that 5% of the nation's gas supply has been temporarily lost.

B Hurricane Iniki: Category 5 (9/11/92)

http://members.aol.com/Rosendalhe/hurrican2.htm

http://www.eqe.com/publications/iniki/iniki.htm

Fatalities: 6
Injuries: > 100
Damage estimate: ~$3 billion

14,350 damaged or destroyed homes on Kauai (Red Cross figures).
~90% of the island's wood-frame buildings damaged
Homes completely destroyed: 1,421.
Homes destroyed by wave action or storm surge on the south coast: 63
Homes with major damage: 5,152
Homes with minor damage: 7,178

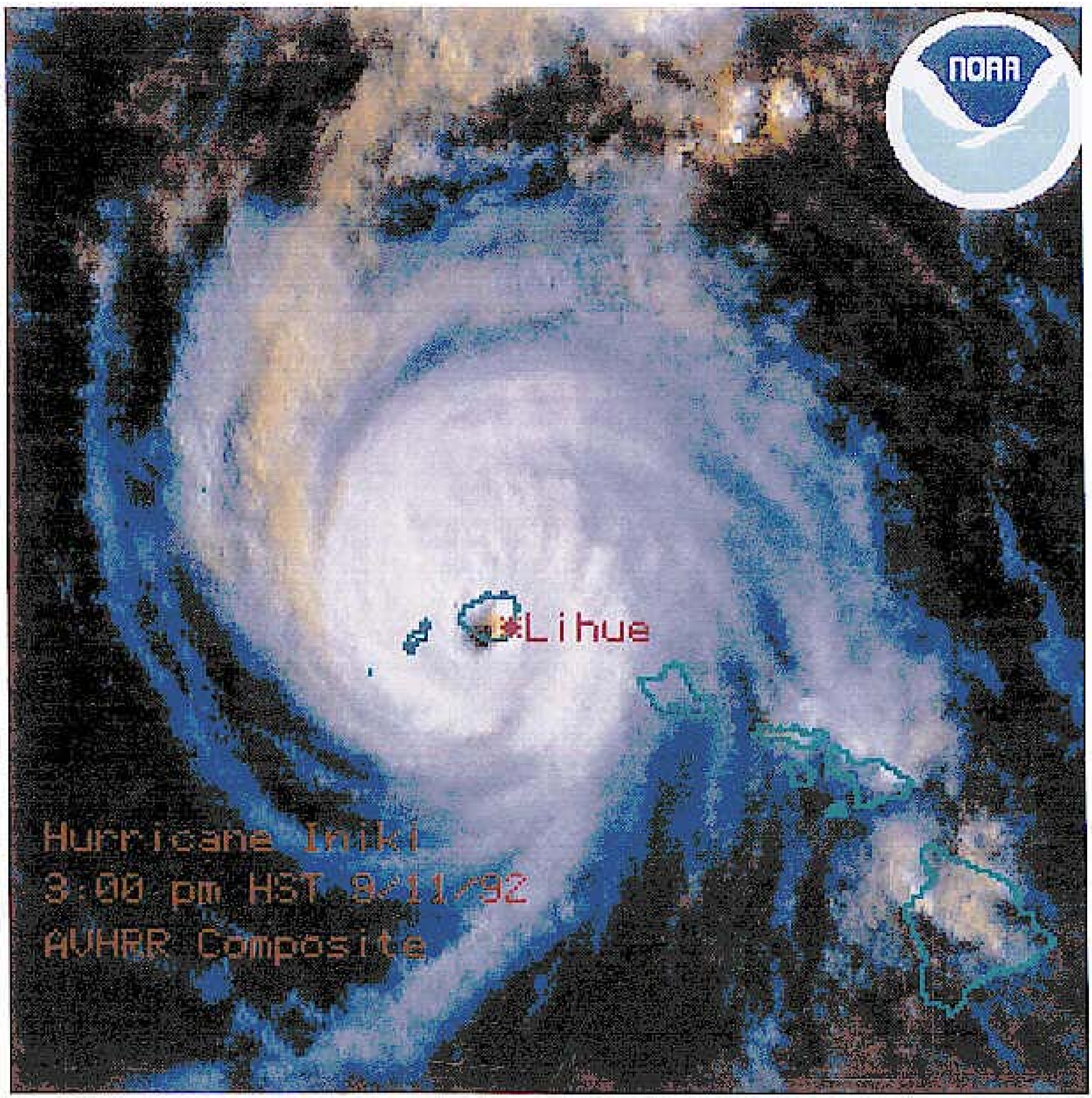
Electric power and telephone service were lost throughout the island, and only 20 percent of power restored four weeks after the storm. Forty percent of the island's power is generated by sugar cane waste-burning cogeneration plants, which were undamaged and operational. Utility substations also appear to have incurred little damage. Even though power generation is mostly functional, downed poles prevent power distribution. Hawaii Telephone reports that about 6,000 poles (both power and telephone) collapsed. Replacement estimated at one to two months, leaving approximately 80% of Kauai without power.

Relief efforts initially hampered by sparse facilities for aircraft and ships, in addition to damage to communications and roadway systems.

Crop damage extensive. Sugar cane stripped or severely set back. Tender tropical plants, such as banana and papaya, were destroyed. Fruit and nut trees were broken or uprooted.

Several houses on the shoreline at Poipu collapsed and were pushed several hundred feet inland, away from their foundations. Residential construction generally not engineered, and poorly designed and built. Dry rot was prevalent, especially in older homes that were damaged.

Wind damage varied, affecting mostly wood-frame and older light metal buildings that had deteriorated due to rust or were weakened by architectural modifications. According to the Uniform Building Code, the design wind for the region is 80 mph, which is only slightly higher than that for California. Local, state, and federal facilities were well-designed and built of concrete and steel, and some unreinforced masonry. None of these structures were damaged.




Hurricance Inkiki, 9/11/92. http://www.geocities.com/drgeorgepc/

Hurricane Iniki storm surge damage, Poipu beach, Kauai. SJM 2/10/02.

Iniki storm surge effects. http://www.geocities.com/drgeorgepc/

## C Closing comments

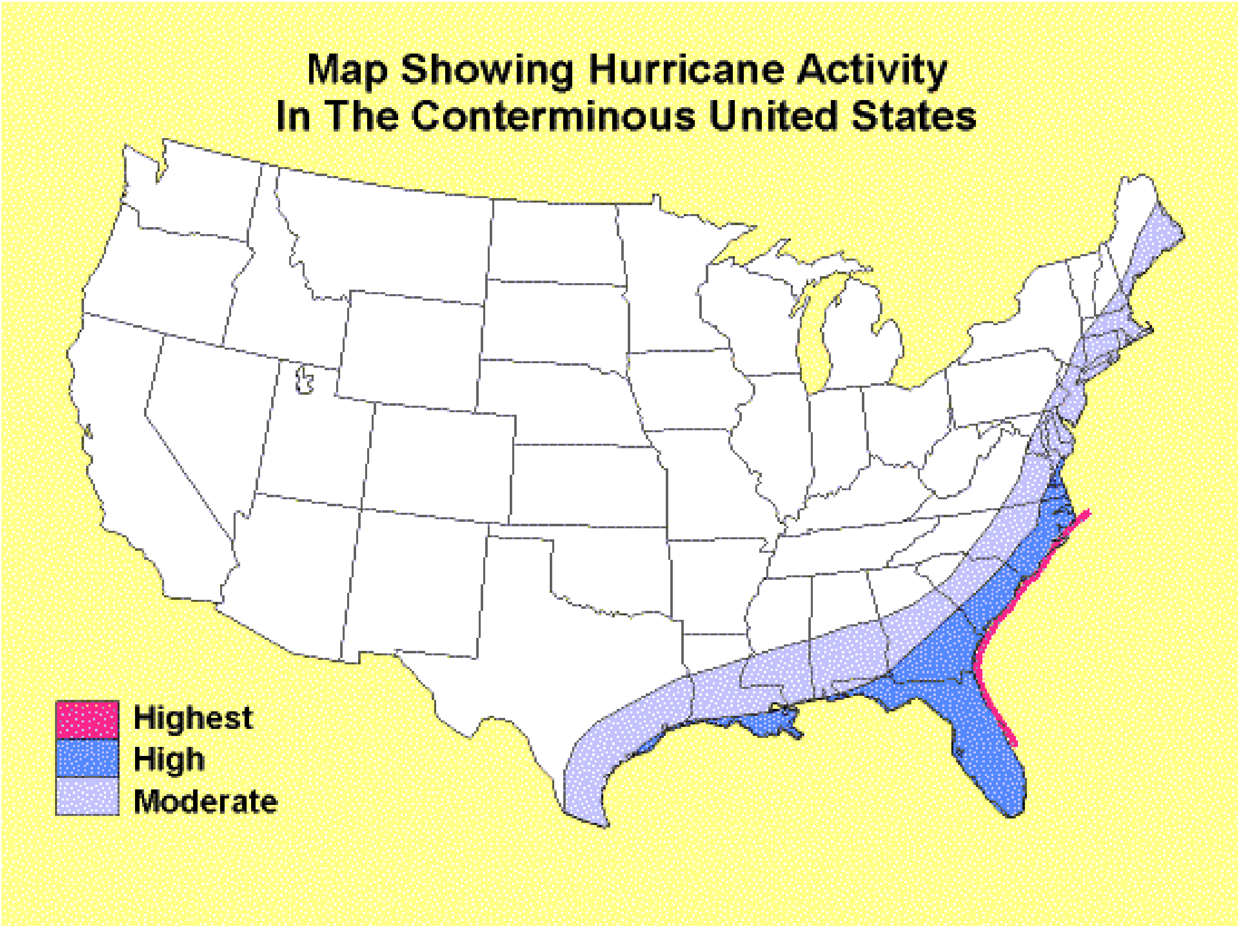
Both hurricanes Andrew and Iniki graphically illustrate the potential of hazardous natural phenomena (such as hurricanes, earthquakes, and conflagrations) to significantly harm the lives and economy of a region. Nonetheless, the widespread extent of the damage caused by Andrew is surprising because the sustained wind speed was within the design criteria of the South Florida Building Code. This code is the most stringent code for wind loads in the United States, so a greater proportion of buildings and structures should have withstood the hurricane with little or no damage.

Coverage gaps in the code, such as mobile homes, and the frequency of non-engineered structures put many people and their property unwittingly at risk. Most non-coastal damage was caused by rain and wind infiltration of buildings. The code and its enforcement could be improved to better safeguard the integrity of building envelopes, and thus significantly reduce damage in future hurricanes.

Iniki, in striking Kauai, missed the state's major population center on Oahu. Observed damage indicated that engineered structures withstood the wind forces well, and damage was confined to those of poor design and construction. This was also true of Andrew, showing that the knowledge exists to engineer economical structures that will withstand winds of the forces seen in Andrew and Iniki.

Power and telephone services could have been restored quickly after both hurricanes had the aboveground utility poles remained intact. Utility poles by their very nature are susceptible to wind forces, but had these utilities been buried, there would have been minimal disruption of services.

Hurricane risks, like those from fire and earthquake, are quantifiable and controllable. Appropriate decisions with regard to siting, design, construction, and improving facilities can provide good protection from such losses.




Hurricane risk

http://www.colorado.edu/hazards/wp/wp94/wp94.html