HURRICANES (33)

I Main Topics

- A Definition and characterization of hurricanes
- B Conditions required for hurricanes
- C Hurricane structure
- E Circulation
- F Thermodynamics
- G Wind, storm surge, and erosion
- H Case histories

Development of Hurricane Katrina

https://www.youtube.com/watch?v=z1ONNM_73-8

II Definition and classification of hurricanes

A Terminology: hurricane = typhoon = strong tropical cyclone

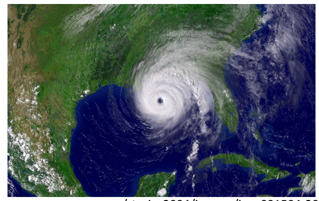
1 Cyclone

a 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.

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

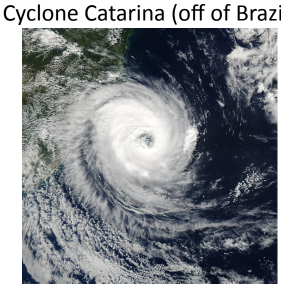
2 Tropical cyclone: a cyclone over tropical or sub-tropical waters with organized convection (i.e. thunderstorm activity)

Hurricane Ivan



http://www.noaanews.noaa.gov/stories2004/images/ivan091504-2015z2.jpg

Cyclone Catarina (off of Brazil)



http://en.wikipedia.org/wiki/South_Atlantic_tropical_cyclone

B Classification: the Saffir/Simpson Hurricane Scale

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	> 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+

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqD.html#D7 (No longer operative)

C Damage in hurricanes of different strength

Category/ Example	Damage
1 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 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 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 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 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 than 15 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://www.aoml.noaa.gov/hrd/tcfaq/tcfaqD.html#D7 (No longer operative)

4/10/15 GG454 5

III Conditions required for hurricanes (necessary but not sufficient)

- A Warm (> 26.5°C [80°F]) near-surface (~> 50 m) ocean waters
- B An atmosphere that cools fast enough with height to permit convection (thunderstorms)
- C Sufficient moisture near the mid-troposphere (~5 km)
- D Location at least 500 km from the equator (for Coriolis force to permit needed near-surface winds)
- E A near-surface disturbance with sufficient spin and convergence
- F Low vertical wind shear (< ~10 m/s) between ocean and upper troposphere

http://www.noaanews.noaa.gov/stories2010/20101129_hurricaneseason.html

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

4/10/15 GG454 6

IV Hurricane structure

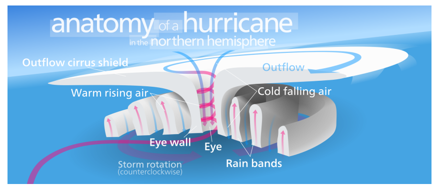
A Extends from ocean to ~12 km altitude

B Eye
  1 Diameter: 8 km - 200 km (usually ~30-60 km)
  2 Clear weather
  3 Near-vertical eyewall
  4 Highest winds at eyewall
  5 Low pressure at surface
  6 High pressure aloft

C Spiral rain bands

D Oblate overall shape

Diagram of a hurricane



http://en.wikipedia.org/wiki/Tropical_cyclone

V Circulation

A Counter-clockwise inflow in northern hemisphere

B Eyewall winds help draw moisture up

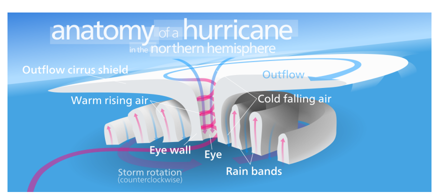
C Warm moist air from over the oceans spirals up to ~12 km altitude

D Cool, high pressure air sinks in the eye to 1-3 km above the surface

E Clockwise upper-level outflow in northern hemisphere

http://en.wikipedia.org/wiki/Tropical_cyclone

Diagram of a hurricane



Red colors = warm temperatures
Blue colors = cool temperatures

VI Thermodynamics

A Carnot engine cycle

1→2 Isothermal expansion

(T = constant)

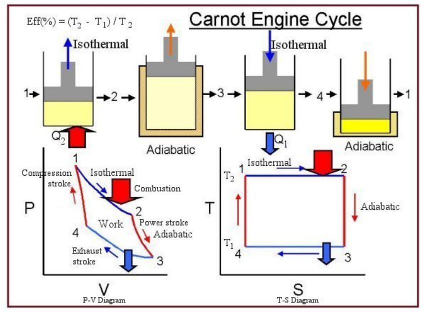
Heat enters gas (↑)

V increases (↑)

P decreases

S increases (→)

Gas does work on surroundings because V increases and P>0



P = Pressure T = Temperature
V = volume S = Entropy

https://universe-review.ca/R13-09-thermodynamics06.htm

VI Thermodynamics

A Carnot engine cycle

2→3 Adiabatic expansion*

(No heat change)

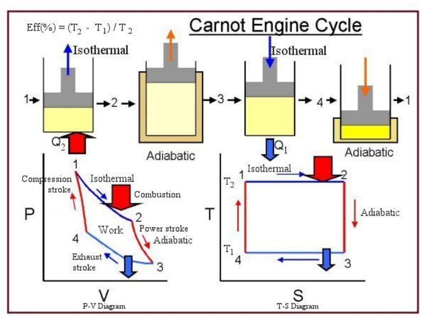
T decreases (↓)

V increases (↑)

P decreases

S = constant

Gas does work on surroundings because V increases and P>0



P = Pressure T = Temperature
V = volume S = Entropy

https://universe-review.ca/R13-09-thermodynamics06.htm

* Imagine a weight of sand atop the piston is removed

VI Thermodynamics

A Carnot engine cycle

3→4 Isothermal contraction

(T = constant)

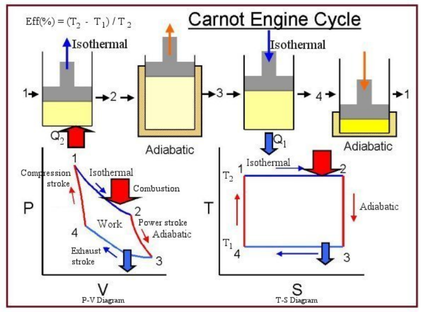
Heat leaves gas (↓)

V decreases (↓)

P increases

S = constant

Surroundings do work on gas because V decreases



P = Pressure T = Temperature
V = volume S = Entropy

https://universe-review.ca/R13-09-thermodynamics06.htm

4/10/15 GG454 11

VI Thermodynamics

A Carnot engine cycle

4→1 Adiabatic contraction

(No heat change)

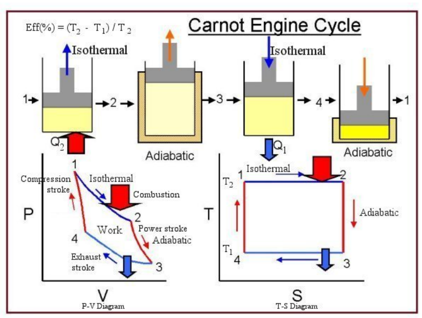
T increases (↑)

V decreases (↓)

P increases

S = constant

Surroundings do work on gas because V decreases



P = Pressure T = Temperature
V = volume S = Entropy

https://universe-review.ca/R13-09-thermodynamics06.htm

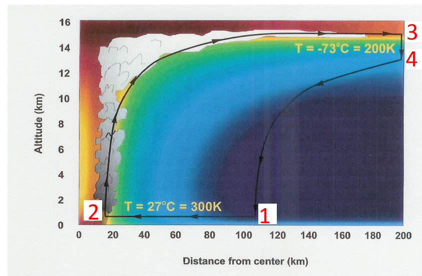
* Imagine a weight of sand atop the piston is added

4/10/15 GG454 12

VI Thermodynamics

B Hurricane

1→2 Isothermal expansion
(T = constant: ~27°C)
Heat enters air
V increases
P decreases
S increases
Gas does work on surroundings because V increases and P>0



http://aerosols.ucsd.edu/classes/sio217a/EmanuelK2005ch10.pdf

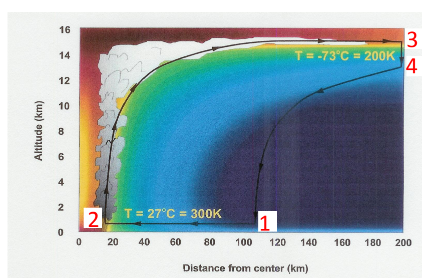
- Air flows along sea surface towards low-pressure eyewall
- <u>Heat is added to the air in the form of latent heat as sea water evaporates</u>; high winds at the eyewall aid evaporation.

Colors show *total heat content in the air*, with warm colors designating high heat content, not temperature

VI Thermodynamics

B Hurricane

2→3 Adiabatic expansion
(No heat change)
T decreases by ~100°C
V increases
P decreases
S = constant
Gas does work on surroundings because V increases



http://aerosols.ucsd.edu/classes/sio217a/EmanuelK2005ch10.pdf

- Air rises along eyewall, cools, and water condenses
- Little heat exchange with surroundings
- Air temperature drops
- Air pressure drops as elevation goes up

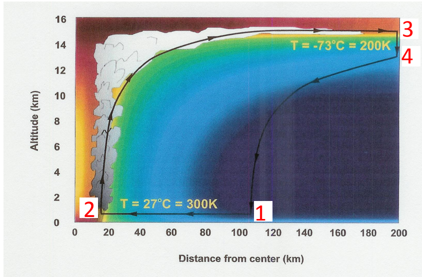
Colors show *total heat content in the air*, with warm colors designating high heat content, not temperature

VI Thermodynamics

B Hurricane

3→4 Isothermal compression
(T ≈ constant: approx. -73°C)
Heat leaves gas
V decreases
P increases
S = constant
Surroundings do work on gas because V decreases

- Air descends
- Heat leaves air in the form of radiation
- Air contracts



http://aerosols.ucsd.edu/classes/sio217a/EmanuelK2005ch10.pdf

Colors show *total heat content in the air*, with warm colors designating high heat content, not temperature

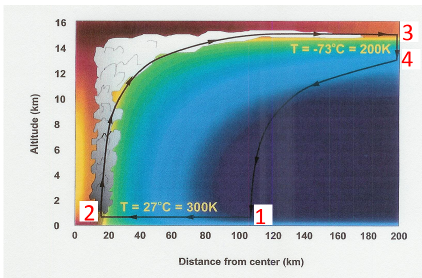
4/10/15 GG454 15

VI Thermodynamics

B Hurricane

4→1 Adiabatic expansion
(No heat change)
T increases to ~27°C
V decreases
P increases
S = constant
Surroundings do work on gas because V decreases

- Air descends to ocean
- Little heat exchange
- Air pressure increases



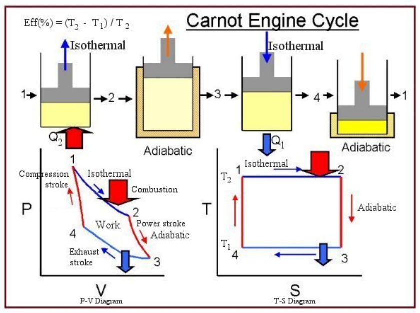
http://aerosols.ucsd.edu/classes/sio217a/EmanuelK2005ch10.pdf

Colors show *total heat content in the air*, with warm colors designating high heat content, not temperature

4/10/15 GG454 16

VI Thermodynamics

C A hurricane is like a great heat engine



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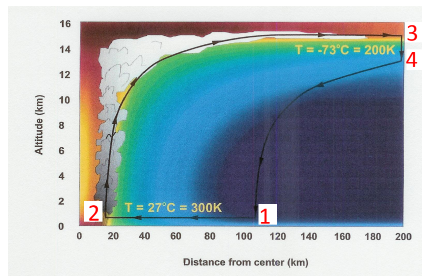


http://aerosols.ucsd.edu/classes/sio217a/EmanuelK2005ch10.pdf

VI Thermodynamics

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

D Energy release rate (power) through cloud/rain formation

1 $Power_{rain}$ = (mass of rain/day)(latent heat of condensation)

2 $Power_{rain} = 6.0 \times 10^{14}$ watts

~200 times the world-wide electrical generating capacity

E Kinetic energy (wind energy)

1 For a mature hurricane, kinetic energy generated equals the energy dissipated due to friction

2 Dissipation rate (per unit area)= (air density)(drag coefficient)(wind speed)^3

3 $Power_{wind} = 1.5 \times 10^{12}$ watts

~ 0.5 times the world-wide electrical generating capacity

F Heat released in the condensation process primarily lifts air and water; only a small portion drives the winds

VII Wind, storm surge, and erosion

A Wind

1 Drives waves

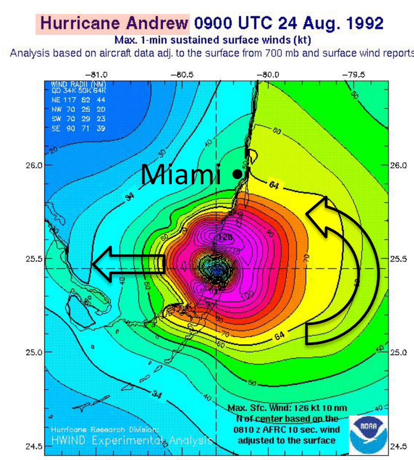
2 Drives storm surge

3 Affects buildings

4 Example

   a Higher wind speeds over water

   B Higher wind speeds at leading edge



http://www.storm2k.org/phpbb2/viewtopic.php?f=6&t=28765

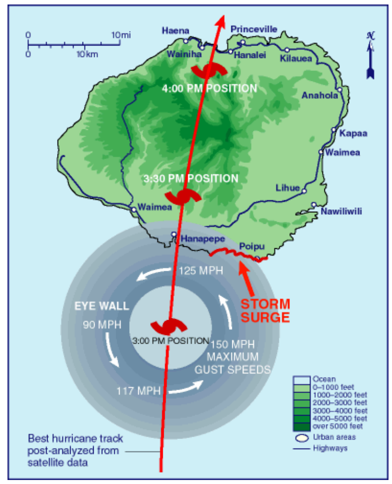
A Wind

5 Kinetic energy variation
Hypothetical example assuming uniform angular wind speed about eye

$$\frac{K.E._{leading}}{K.E._{trailing}} \approx \left(\frac{v_{leading}}{v_{trailing}}\right)^2 = \left(\frac{v_{wind}+v_{storm}}{v_{wind}-v_{storm}}\right)^2$$

$$If\ v_{wind} = 200 km/hr\ and\ v_{storm} = 30 km/hr$$

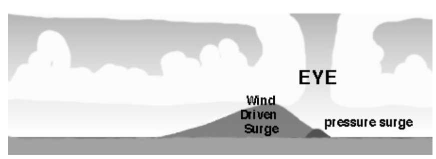
$$\frac{K.E._{leading}}{K.E._{trailing}} = \left(\frac{200+30}{200-30}\right)^2 = \left(\frac{230}{170}\right)^2 \approx 1.8$$



4/10/15 GG454 21

B Storm surge

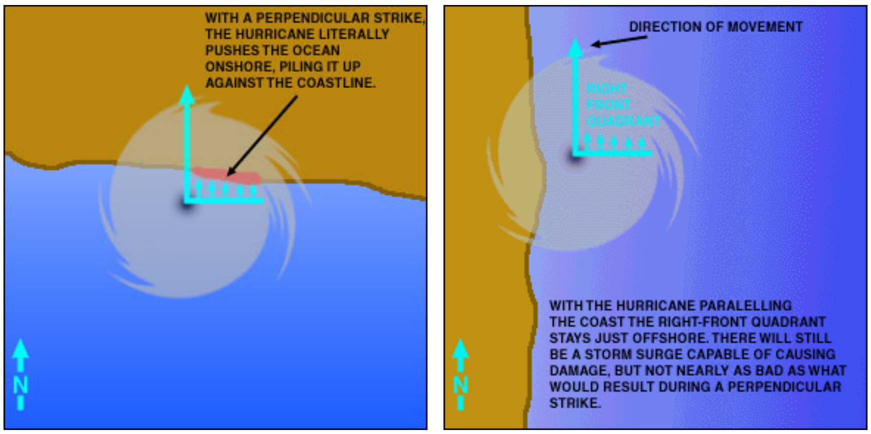
1 A dome of water piled up by wind
2 Can be 80 km wide, 10 m tall
3 Height increases with wind
4 Causes 90% of fatalities



4/10/15 GG454 22

B Storm surge

5 Effect of storm direction relative to coast



Source of graphic unknown

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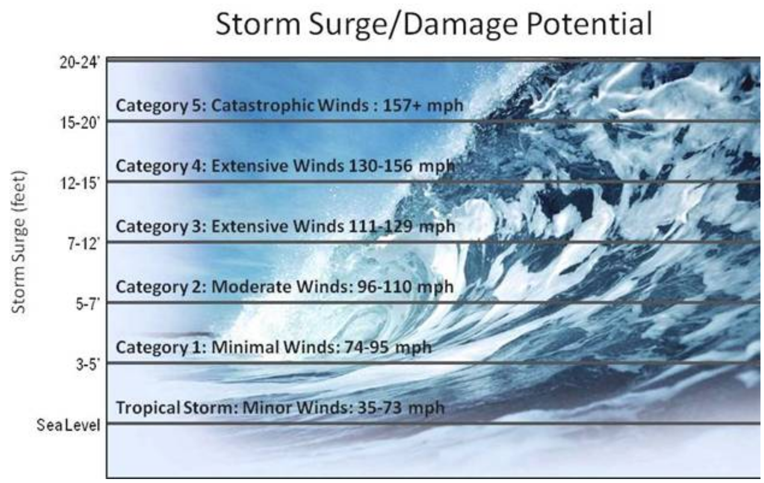
Hurricane Katrina storm surge

https://www.youtube.com/watch?v=gd8WiiXNxho

4/10/15 GG454 24

C Wind and storm surge



http://www.scdhec.gov/HomeAndEnvironment/DisasterPreparedness/Hurricanes/ABCsofHurricanes/images/tidal-surge.jpg

D Erosion

July, 1992

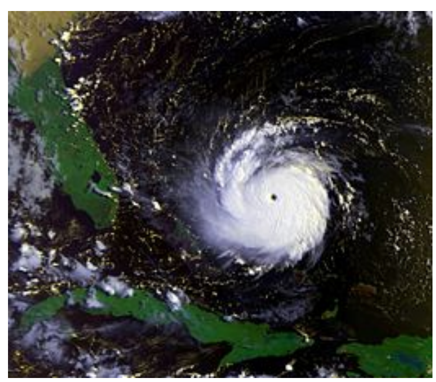
Several days after passage of Hurricane Andrew in August, 1992

Part of the Isles Dernieres. central Louisiana, swept by sustained winds in excess of 135 miles per hour during Hurricane Andrew
http://pubs.usgs.gov/fs/hurricane-impacts/

VIII Case histories

A Hurricane Andrew: Category 5 (8/16/92- 8/28/92)

1 Storm parameters
- A 165 mph winds at Elliot Key
- B 146 mph winds at Turkey Point Generating Station
- c 4m maximum swell



http://en.wikipedia.org/wiki/Hurricane_Andrew

A Hurricane Andrew: Category 5 (8/16/92- 8/28/92)

2 Direct casualties and damage estimates
   a Fatalities: 38 confirmed.
   b Damage (est.): ~$25-34 billion
   c 175,000 to 250,000 homeless
   d 85,000 homes and apartments uninhabitable; many destroyed
   e 600,000 homes and businesses lost power and phone services
   f Area of heavy damage: more than 64 km (40 miles) diameter

Destruction at a mobile home park

http://en.wikipedia.org/wiki/Hurricane_Andrew

4/10/15 GG454 29

A Hurricane Andrew: Category 5 (8/16/92- 8/28/92)

g Utilities temporarily lost: power, drinking water, communications, and sewage facilities (no pumps)
h Underground water and gas mains damaged by uprooted trees
i Street and highway signs blown away and traffic lights lost, hampering rescue and relief efforts.
j 12,620 miles of local power distribution line and more than 631 miles of high-power feeder lines knocked down.
k ~1.4 million customers affected.
l Estimated time for utility repairs: 6 months

Trees bent and snapped by Hurricane Andrew

http://www.nasa.gov/vision/earth/lookingatearth/halverson_paper.html

4/10/15 GG454 30

A Hurricane Andrew: Category 5 (8/16/92- 8/28/92)

3 Turkey Point Generating Station (6th largest in U.S.; 2 nuclear and 2 fossil fuel units)
- a Built to withstand winds of 235 mph (380 km/hr); damage to nuclear units described as "minimal"
- b One 400-foot-tall concrete exhaust stack heavily damaged and eventually demolished
- c 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
- d Fire protection system water tank collapsed; system inoperable for nearly a week
- e Damage: ~$90 million.

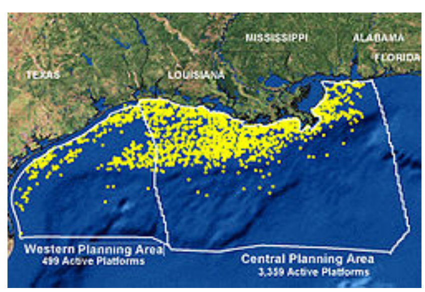
http://en.wikipedia.org/wiki/Turkey_Point_Nuclear_Generating_Station

4/10/15 GG454 31

A Hurricane Andrew: Category 5 (8/16/92- 8/28/92)

3 Louisiana
- a 13 offshore oil and gas production platforms reported destroyed—four with no trace.
- b ~40 additional offshore drilling rigs and production platforms damaged
- c 5% of the nation's gas supply reported as temporarily lost

NOAA map of the 3,858 oil and gas platforms in the Gulf of Mexico in 2006



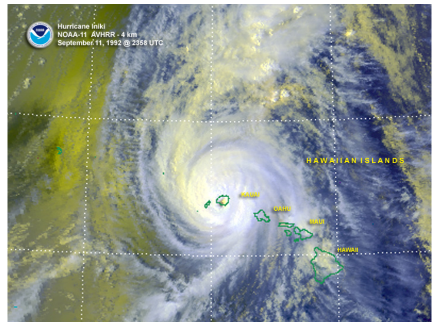
http://en.wikipedia.org/wiki/Oil_platform

4/10/15 GG454 32

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

1 Storm parameters
- a 227 mph peak recorded winds
- b Highest sustained winds at landfall: 145 mph
- c 1.8m maximum “storm tides”
- d 10.5 maximum wave heights

Hurricane Iniki making landfall on Kauaʻi



http://en.wikipedia.org/wiki/Hurricane_Iniki

4/10/15 GG454 33

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

2 Direct casualties and damage estimates
- a Fatalities: 6
- b Injuries: > 100
- c Damage estimate: ~$3 billion
- d 1,421 homes destroyed
- e 14,350 homes damaged or destroyed on Kauai
- f ~90% of the wood-frame building son Kauai damaged
- g 63 homes destroyed by waves or storm surge on Kauai south coast
- h Homes with major damage: 5,152
- i Homes with minor damage: 7,178

Hotel deck on second story destroyed, Poipu

4/10/15 GG454 34

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

- j Electric power and telephone service were lost throughout the island, and only 20 percent of power restored four weeks after the storm.
- k Hawaii Telephone reported ~6,000 poles (both power and telephone) collapsed. Replacement estimated at one to two months, leaving approximately 80% of Kauai without power.
- l Relief efforts initially hampered by sparse facilities for aircraft and ships, in addition to damage to communications and roadway systems.

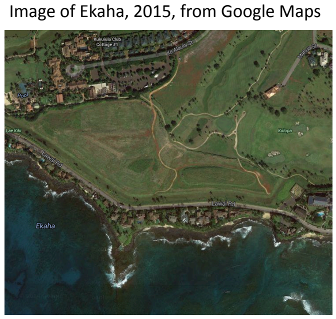
Downned power pole

http://commons.wikimedia.org/wiki/Category:Hurricane_Iniki

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

- m Extensive crop damage (e.g., sugar cane; banana, papaya, nut trees)
- n Several houses at Poipu collapsed pushed several hundred feet inland

Image of Ekaha, 2015, from Google Maps



Water run up at Ekaha, Kauai, 1992

http://www.hilo.hawaii.edu/~nat_haz/gallery_view.php?p=68

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

- The design wind for the region was 80 mph
- Residential construction generally not engineered; poorly designed and built
- Dry rot prevalent, especially in damaged older homes
- Wind mostly damaged wood-frame and older light metal buildings rusted or weakened by architectural modifications.
- Local, state, and federal facilities were well-designed and built of concrete and steel (with some unreinforced masonry); none of these structures were damaged

Wind damage at home

http://commons.wikimedia.org/wiki/File:Hurricane_iniki_1992.jpg

4/10/15 GG454 37

References

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4/10/15 GG454 38