Hurricanes
Masters of Destruction

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Part A
General Information about Hurricanes

General Information on North Atlantic Hurricanes

Hurricanes are often called the greatest storms on Earth and are an awe-inspiring feature of tropical weather. North Atlantic hurricanes have a tremendous impact on people and economics of the southern United States and of countries in and around the Caribbean Sea. Hurricanes rank near the top of all natural hazards and Hurricane Andrew is one such example. Andrew caused almost $30 billion in damage to Florida and Louisiana, making it the costliest hurricane on record (Figure 1.1 shows some of the damage that a hurricane can cause). A look at Hurricane Andrew will be taken a little bit later (Elsner & Kara, 1999). This atlas will focus on hurricanes of the North Atlantic basin, but there are many other areas around the world that are affected by these huge weather systems. In this atlas there will be a focus on four hurricanes, each giving the history of its lifetime and any valuable statistics about the storm. Map 1.1 on page 3 shows the of the hurricanes that will be mentioned later on.

The first thing few things that a person needs to know is where, when, and how these systems are formed. There are many complex formulas and equations that explain this phenomenon, but this atlas will keep to the basics and try to explain hurricanes in an easy to understand manner. First of all, hurricanes do not start out as what their name implies. In almost every case, the first thing that appears is a tropical wave which is a small pressure drop along a latitude. This disturbance, as it is also called, sometimes has partial rotation and has a mass of organized oceanic thunderstorms. It becomes a tropical depression when a closed circulation is observed and the sustained winds of the system are less than 62 km/h. Once these winds everywhere in the system reach a sustained speed of 62 km/h, then it is classified as a tropical storm and given a name. If a system reaches tropical storm classification, it doesn't mean that it will turn into a hurricane. It can travel hundreds of kilometers in any of the above-mentioned stages without going to the next. If it does become a hurricane, the sustained winds have to be more than 120 km/h, and from there, there are five different categories of hurricanes, which can are shown in Table 1.1 (Fitzpatrick, 1999).

Fig. 1.1: Damage from a hurricane in Puerto Rico.

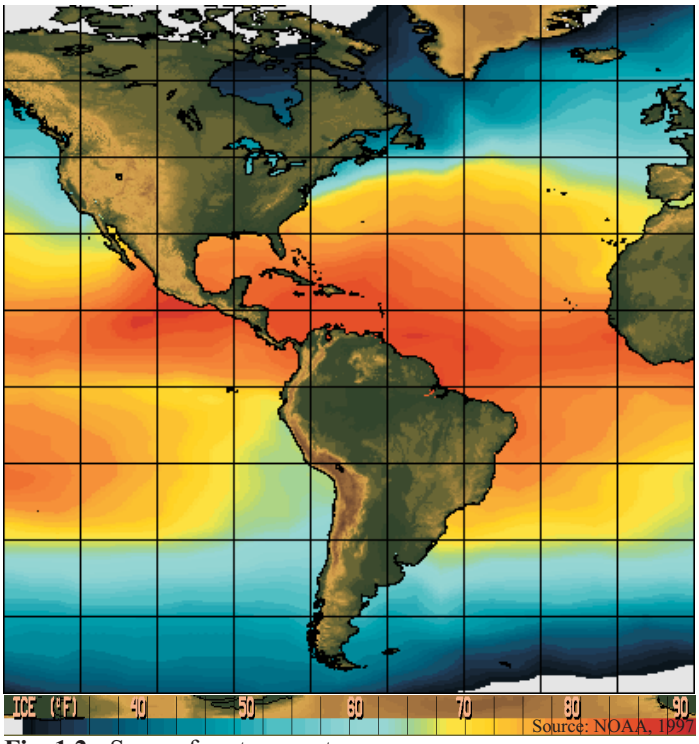


Fig. 1.2: Sea surface temperatures.

There are two distinct phases that a system goes through on its way to become a hurricane. The first is called the Genesis Stage and includes tropical disturbances and depressions. In this stage, convergence occurs to form the disturbance by producing a state of instability in the atmosphere which forms clouds. If the proper conditions exist, which include trough formation and a water temperature of at least 26.5 degrees C, a closed circulation will form and will result in a tropical depression. If the optimum conditions continue to exist, the winds will slowly increase and the system will eventually become a tropical storm. Favorable conditions for hurricane development can be seen in Table 1.2. Once a tropical storm is named, that is when the second phase starts, the Intensification Stage. In this stage a tropical storm may or may not become a hurricane, it all depends on the environmental conditions. Figure 1.2 shows the average sea surface temperatures of the Atlantic basin. Note the dark orange and red areas which show water temperatures favorable for hurricanes. The warmer the water, the greater the chances for genesis, the faster the rate of development, and the stronger these storms can become. As long as a system continues to move over warm water and doesn't encounter any wind shear, landfall, or movement over cold water, then the better the chances that it will form a major hurricane (Fitzpatrick, 1999).

The North Atlantic Hurricane season runs from June through until November, with the most active part of the season between August and October. During this time the environmental conditions are the most favorable with weak

General Information on North Atlantic Hurricanes

Map 1.1: Tracks of four North Atlantic Hurricanes.

wind shear, warm water, and cyclonic disturbances (Elsner & Kara, 1999). The biggest reason why the peak is in the later months of the season is because of the water's temperature which peaks at this time. The days are still longer than the nights until the fall, and therefore the water still accumulates heat late into the summer. Monsoon troughs are also most active during the late summer, and with the combination of warm water, hurricanes are more likely to form and be very intense during this time (Fitzpatrick, 1999).

Atlantic storms where first given names starting in 1950. These names were usually radio code words and masculine in nature. In 1953 the U.S. Weather Bureau switched to female names but in 1979 male names were added to the list. A name is only given to a storm when a tropical depression is upgraded to a tropical storm. Before the 1950's, tropical storms and hurricanes were identified by holidays for when they occurred (Labor Day Hurricane of 1935), the area of landfall (Galveston Hurricane of 1900), or even for a ship (Racer's storm in 1837). The World Meteorological Organization has six lists of names that are recycled every six years. The names of noteworthy storms are retired from the list and added by new ones (Rosenfeld, 1999).

	Central Pressure	Maximum Sustained	Storm Surge in Feet
Category	mb	Winds in Km/h	(approximate)
1 Minimal	> 979	120 - 154	4 - 5
2 Moderate	965 - 979	155 - 178	6 - 8
3 Extensive	945 - 964	179 - 211	9 - 12
4 Extreme	920 - 944	212 - 251	13 - 18
5 Catastrophic	< 920	> 251	> 18

Table 1.1: Saffir/Simpson Scale for Atlantic Hurricanes.

General Information on North Atlantic Hurricanes

The structure of a hurricane is very complex and therefore will will not be mentioned at great length. The dynamics of a hurricane can be seen in Figure 1.4. Hurricanes are made up of thunderstorm bands called spiral bands, and they extended outward from the center for about 800 km. These bands have light to moderate rain and the wind speed of the outer bands fluctuates from 48 to 64 km/h. As one approaches the center, winds will start to increase with the strongest winds found close to the center. A ring of thunderstorms surrounds the center which is called the eyewall and this is the most dangerous part of the hurricane. Once you pass through the eyewall you will be in the center of the hurricane. This area has hardly any wind at all and if you would look straight up you would see blue sky. The size of the eye can very from 11 to 80 km wide. Table 1.3 shows some of the characteristics that hurricanes have (Fitzpatrick, 1999).

There is no average path for Atlantic Hurricanes and no two follow the exact same path. Many North Atlantic Hurricanes do however move along paths that have common characteristics, especially if they form during the same time of year. Hurricanes have a tendency to move toward warm, moist air in the middle levels of the atmosphere. Atlantic hurricanes have a general path that takes them from the coast of Africa to the Caribbean Islands, all the while gradually moving in a northwest direction. Once they reach a certain latitude their path becomes more northerly and eventually they turn of towards the east. There are many hurricanes that never make landfall because they veer away from land due to water temperature or other atmospheric disturbances (Elsner & Kara, 1999).

Hurricanes have many elements to them that can produce devastating effects. They are associated with high wind, rain, storm surges, and tornado development. Atlantic hurricanes cause millions and even billions of dollars in damage all over the U.S., Caribbean, and Mexico. Scientists are able to predict where hurricanes will go, but they are not able to stop

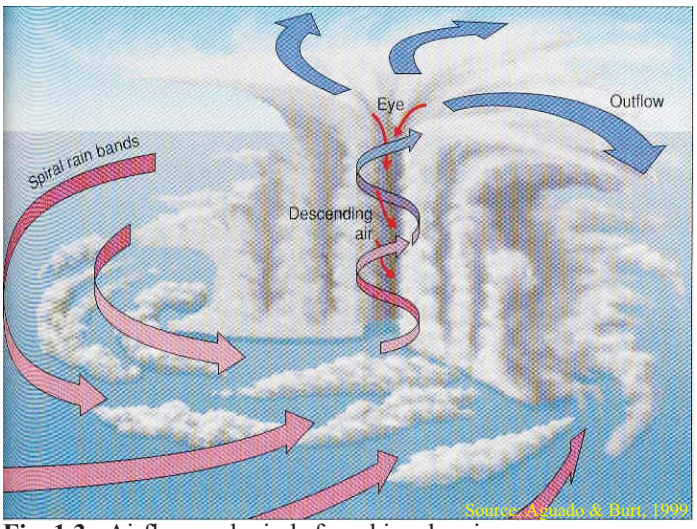


Fig. 1.3: Airflow and winds found in a hurricane.

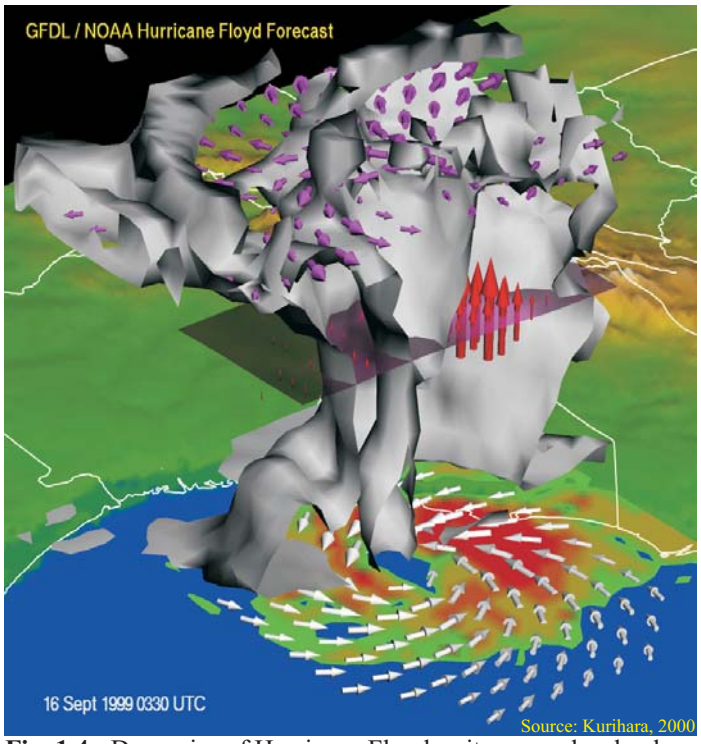
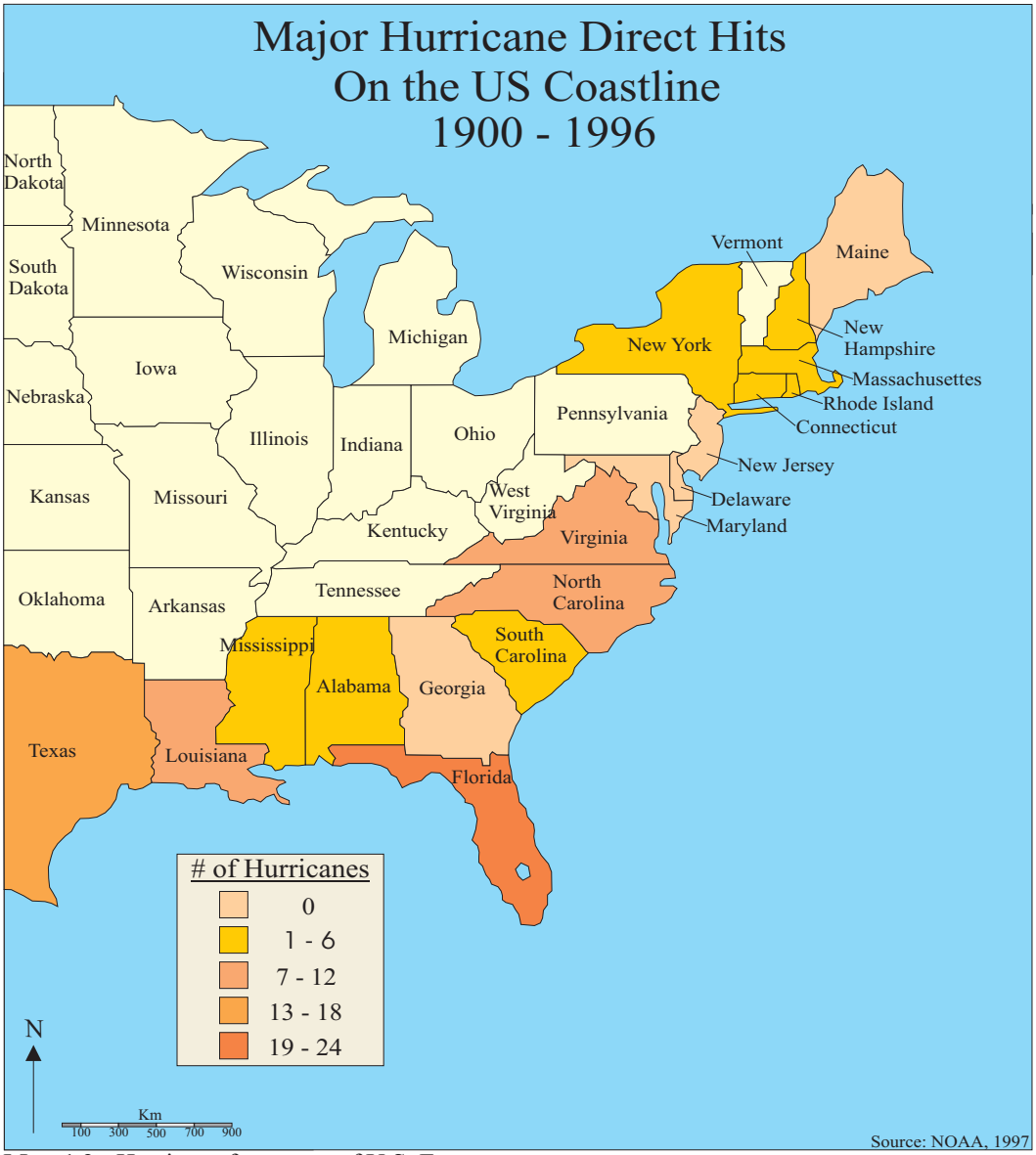


Fig. 1.4: Dynamics of Hurricane Floyd as it approaches land.

them, therefore the public has to be aware of how they can protect themselves and their property from these massive storms. People living along the coasts are especially vulnerable because they will feel all the effects of a hurricane; floods, wind, rain, beach erosion, tornadoes, lightning, damage to buildings, and storm surges. The best way to protect yourself if you live in one of these areas is to evacuate when you are told to do so. Staying being and riding out the storm is not a very smart choice. Map 1.2 shows the frequency of hurricanes that made landfall on the eastern U.S. between 1900 and 1996. Texas and Florida are the states that have been hit with the most hurricanes and are the most vulnerable. There have been many hurricanes in the past and there will be many more to follow. Some even believe that hurricanes in the future will be bigger and more powerful than ever before, due to an increase in average global temperatures. For now though, we will take a look at some hurricanes from the past.

General Information on North Atlantic Hurricanes



Map 1.2: Hurricane frequency of U.S. East coast states.

Characteristic	Range
Storm Diameter	200-1300 km
Surface Winds	> 33 m/s
Lifespan	1-30 days
Eye Diameter	16-70 km
Direction of Motion	Westward then northward
Energy Source	Latent Heat Release

Table 1.2: General conditions of North Atlantic Hurricanes.

Condition	Criteria
Warm ocean surface	> 26.5 degrees C
Unstable atmosphere	> 7 degrees C/km
Minimum latitude	> 8 degrees N
Weak wind shear	< 10 m/s

Table 1.3: Environmental conditions favorable for hurricane devlopment.

Part B
Hurricanes from the Past

Hurricane Andrew August 16 - 28 1992

Formation And History

Hurricane Andrew was a small and ferocious hurricane that produced unprecedented economic devastation along a path through the southern Florida peninsula to south-central Louisiana. Damage in the United States was estimated to be near $25 billion, making Andrew the most expensive natural disaster in U.S. history at that time. Hurricane Andrew brought with it violent winds and storm surges characteristic of a category 4 hurricane on the Saffir/Simpson Hurricane Scale.

From satellite pictures and upper-air data, Hurricane Andrew formed from a tropical wave that crossed from the west coast of Africa to the tropical North Atlantic Ocean on August 14. As the convection became more focused in a region of cyclonic cloud rotation, on August 16th, the transition from a tropical wave to a tropical depression took place. The depression grew stronger during the day, and by midday on the 17th, the storm became Hurricane Andrew and was moving rapidly in a west to west-northwest direction towards the Lesser Antilles. Between August 17th and 20th, the tropical storm was being steered to more of a northwesterly track that would spare the Lesser Antilles from being hit.

Satellite images suggested that Andrew was losing power at this time and by the 20th found that the cyclone had degenerated to the extent that only a diffuse low-level circulation center remained. At this time it was estimated that Andrew was a tropical storm with 40 knot surface winds and a very high pressure of 1015 mb. During August 21st however, Andrew started turning towards the west, accelerated to near 16 knots and quickly intensified.

Andrew reached hurricane strength on the morning of August 22th and just 36 hours later, it reached the borderline between a category 4 and 5 hurricane and was at its peak intensity. By the 23rd, the pressure had dropped to 922 mb and the hurricane was rapidly deepening. When the it passed over the western portion of the Great Bahama Bank it weakened and the pressure rose to 941 mb but re-intensified during the last few hours before land fall when it moved over the Straits of Florida. Its track can be seen on Map 2.1.

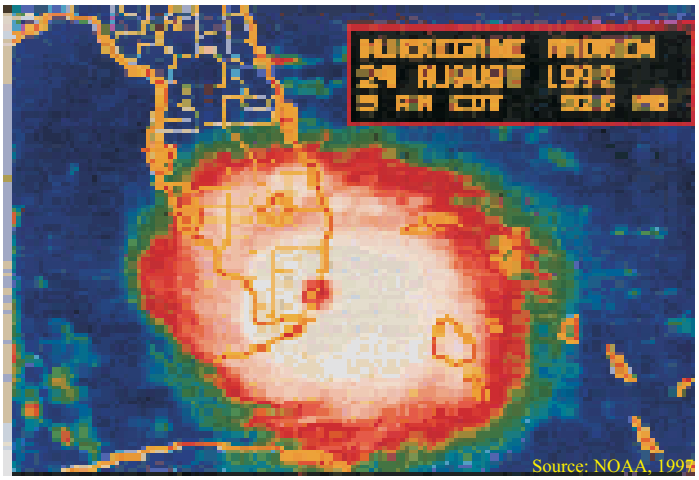


Fig. 2.1: Hurricane Andrew making landfall near Miami, Fl.

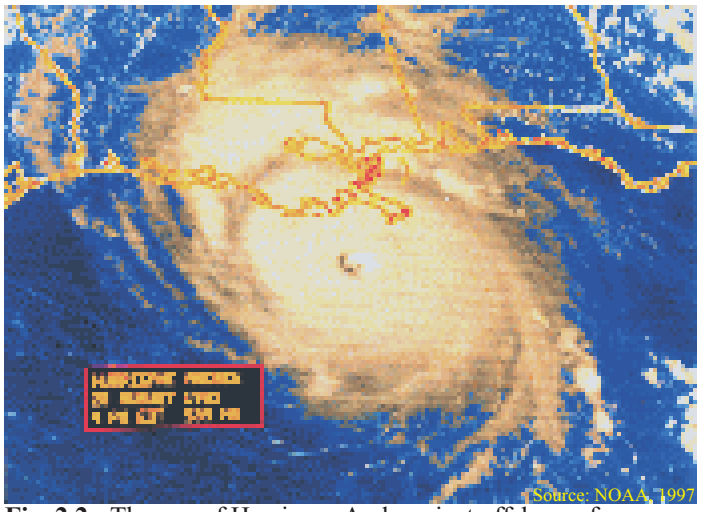


Fig. 2.2: The eye of Hurricane Andrew just offshore of Louisiana.

The maximum sustained surface wind speed during landfall over Florida was estimated at 125 knots (145 mph) with gusts up to at least 50 knots (175 mph); these numbers correspond to a category 4 hurricane.

As Andrew moved westward and crossed the extreme southern portion of Florida (Figure 2.1), its pressure rose slightly but was still considered a major hurricane when it entered the Gulf of Mexico. At this point, the hurricane once again gained strength and started to turn toward the west-northwest. The hurricane eventually struck the south-central Louisiana coast as a category 3 hurricane on August 26th (Figure 2.2). After this, it weakened rapidly to tropical storm strength in about 10 hours and to a depression 12 hours later. During this time, Andrew moved northward and then northeastward producing heavy, and by midday on August 28th, it began to merge with a frontal system over the mid-Atlantic states.

Meteorological Statistics

A) **Minimum Pressure**

When Andrew was about 15 nautical miles (one hour travel time) from the mainland, the pressure reading was 932 mb, which was predicted to be the pressure when it made landfall, but then later was revised to 922 mb. This made it the third lowest landfall reading in the United States this century. Only the Labor Day Storm in 1935 (892 mb) and Hurricane Camille in 1969 (909 mb) were lower.

B) **Maximum Wind Speed**

The maximum winds in Andrew on August 24th likely occurred in the northern eyewall with estimates of about 125 knots for the maximum sustained winds. The strongest reported wind near the surface occurred at the Fowey Rocks weather station. This station was within the northwest part of Andrew's eyewall and reported wind of 123 knots with gusts up to 147 knots. The strongest gust reported from near the surface occurred in the northern eyewall. Here an amateur

Hurricane Andrew
August 16 - 28
1992

meteorologist reported a gust of 184 knots. This speed was tested in a wind tunnel and was found to have more likely been around 154 knots.

C) **Storm Surge**

During the morning of August 24th, Andrew generated storm surge along the shorelines of southern Florida. The surge arrived at the time of high astronomical tide and ranged from 4 to 7 feet. The storm surge in Louisiana was at least 8 feet and caused flooding throughout many regions along the coast.

D) **Tornadoes**

There were no confirmed reports of tornadoes associated with Andrew in Florida but some funnel sighting were reported. In Louisiana, one tornado was produced several hours prior to Andrew's landfall and five others occurred during landfall. Alabama received two tornadoes and damaging tornadoes in Georgia on August 27th were attributed to Andrew.

E) **Rainfall**

Andrew dropped significant rain to cause local floods even though it was relatively small. Rain in excess of 7 inches was recorded in southeast Florida, Louisiana, and Mississippi. In neighboring states, 5 inches of rain fell.

Map 2.1: Track of Hurricane Andrew in 1992.

<u>Casualty And Damage Statistics</u>

The number of deaths that are directly attributed to Andrew is 26. This low number is attributed to the combination of good hurricane preparedness and evacuation programs. Massive evacuations were ordered in Florida and Louisiana as the likelihood of landfall increased. In the Florida Keys about 55,000 people left and a total of about 1.2 million people were evacuated in Florida.

Total estimates for the amount of damage that Andrew caused were estimated at about $25 billion. Andrew had its biggest impact in Dade County, Florida where over 25,000 homes were destroyed and over 101,000 homes damaged. More than 99% of all mobile homes in Homestead, Florida were completely destroyed and the Miami Herald reported $0.5 billion in losses to boats in southeast Florida. Total damage in Louisiana was estimated at $1.1 billion, with the most devastated areas corresponding closely in location to the regions where Andrew's eyewall and accompanying core of destructive winds passed through. Andrew's effect was even felt in the Gulf of Mexico were it is estimated that $0.5 billion in damage was sustained, mostly to oil drilling platforms. Damage was also reported on the artificial reef system of southeast Florida.

Hurricane Andrew was a small system and did not incur as much damage as a larger hurricane or one that made landfall a little further to the north, but the winds produced a tremendous amount of structural damage. (NOAA, 1997

Hurricane Bertha
July 5 - 14
1996

Formation And History

Hurricane Bertha formed during the early part of the hurricane season that moved across the islands of the Northeastern Caribbean Sea (Figure 3.1) as a category 1 hurricane and made landfall on the North Carolina coast as a category 2 hurricane (Figure 3.2). Bertha's maximum sustained winds reached their highest on July 9 while located to the north of Puerto Rico. The last hurricane to reach such a strength this early in the season was Hurricane Alma in 1966.

Bertha formed from a tropical wave that moved from Africa to the Atlantic on July 1st. The track of a circulation center began on July 5th, when the circulation is believed to have reached the surface and become a tropical depression, in the central tropical Atlantic. The track of Bertha followed a fairly smooth curved path around an Atlantic subtropical high pressure ridge. The depression moved toward the west-northwest for three days at a fast speed of 20 to 25 knots. It strengthened into a hurricane with maximum sustained winds of 75 knots on July 8th as the center moved across the Leeward Virgin Islands.

Maximum sustained winds reached 100 knots on the July 9th and the track was gradually turning northwestwards. At this time, Bertha was centered 120 nautical miles north of Puerto Rico, but had passed within 30 nautical miles of the islands earlier. Most of Puerto Rico only experienced tropical conditions because the strongest winds were located in the northeast quadrant of the hurricane which did not come in contact with the island. The hurricane continued on its northwestward path at a speed of 15 to 20 knots, and the center of Bertha moved parallel to the Bahama islands. The winds did not have much of an affect here either because the strongest winds were located to the northeast of the center.

On the 10th and 11th, the movement of Bertha became north-northwestward and the center moved parallel to the coast of Florida and Georgia at a distance of 150 to 175 nautical miles offshore. Bertha made landfall on the coast of North Carolina on July 12th. The hurricane had been gradually weakening since its top wind speed of 100 knots on the 9th to 70 knots on the 11th.

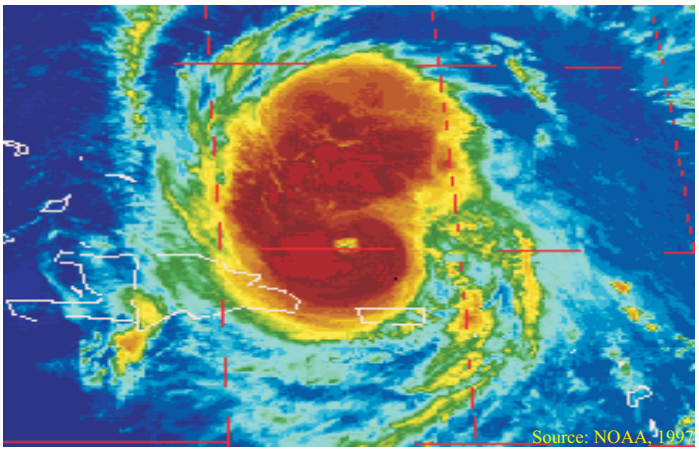


Fig. 3.1: Radar image of Bertha in the Caribbean.

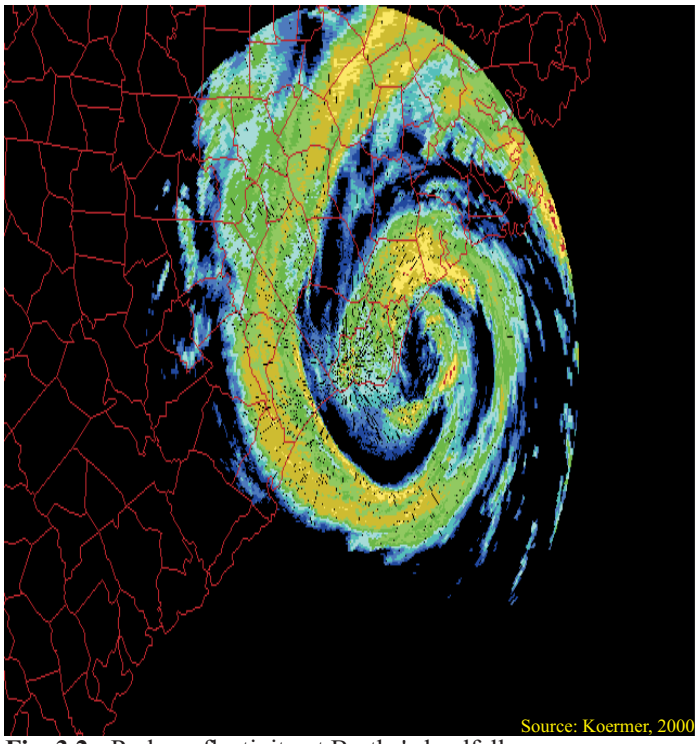


Fig. 3.2: Radar reflectivity at Bertha's landfall.

About 12 hours before landfall, the winds started to increase and the estimated maximum sustained wind speed at the time of landfall was 90 knots. Once Bertha moved inland over eastern North Carolina it quickly lost hurricane strength .

Bertha then moved northeastward along the U.S. east coast, with 40 to 50 knot sustained winds from northern North Carolina to New England. On July 14th, Bertha was declared extratropical when the center moved from the Maine coast to New Brunswick. It then followed a course through the Maritime Provinces and just south of Greenland on the 17th. Bertha's entire track can be seen on Map 3.1.

Meteorological Statistics

A) **Minimum Pressure**

The minimum observed pressure of Hurricane Bertha was 960 mb, which occurred on July 9th. This reading was based on a dropsonde measurement. During landfall, the pressure observed was 977 mb and the lowest pressure assumed was 974 mb.

B) **Maximum Wind Speed**

A maximum sustained wind speed of 100 knots was observed on the same day, also with a dropsonde measurement. Observations from the Leeward and Virgin Islands, but since the circular eyewall was 20 to 30 nautical miles across, it is believed that hurricane conditions could have occurred. At the time of landfall, it is estimated that the sustained surface winds were at 90 knots.

Hurricane Bertha
July 5 - 14
1996

C) **Storm Surge**

Storm surge heights for Hurricane Bertha are not as high as most other hurricanes, partly due to the fact that it was not as strong. Coastal storm surge flood heights, from Florida through New England, ranged from 1 to 4 feet. There were values however of 5 feet that were estimated on parts of the North Carolina coast.

D) **Tornadoes**

Hurricane Bertha spawned several tornadoes in three different states. Seven tornadoes were confirmed with five of them in Virginia, one in North Carolina, and one in Maryland.

E) **Rainfall**

Total rainfall amounts from Hurricane Bertha ranged from 5 to 8 inches along a coastal strip from South Carolina to Maine.

Casualty And Damage Statistics

Just like with most hurricanes, Bertha caused much damage and resulted in lost lives. Twelve deaths were related to Hurricane Bertha in some way. One, in Florida, was from an evacuating military jet crashing into a house. Another was a surfer from Puerto Rico and one was from St. Martin who fell off a boat.

Map 3.1: Track of Hurricane Bertha in 1996.

Damage was not as great for this hurricane but nonetheless, there still was damage. The U.S. Virgin Islands, along with North Carolina were declared federal disaster area. It was estimated that Bertha damaged almost 2500 homes on St. Thomas and St. John, and for many, it was a second hit in the ten months since Hurricane Marilyn devastated the same area.

The primary effects in North Carolina were to the counties along the coast. Areas here experienced storm surge flooding and beach erosion, roof damage, fallen trees, piers washed away, and damage to crops. More than 5000 homes were damaged, mostly from the storm surge. Minor wind damage was also reported along the path of the storm all the way to New England.

Damage estimates were around the $135 million mark in insured property, primarily along coastal North Carolina, and $250 million in total damages. (NOAA, 1997)

Hurricane Erin
July 31 - August 6
1995

Formation And History

Erin formed from a tropical wave that crossed from the coast of Africa to the tropical eastern Atlantic Ocean on July 22, 1995. This wave was comprised of two distinct low-level circulation centers that were oriented from northwest to southeast and moved together toward the west-northwest over the next five days. By July 27th, both of the circulation centers were generating deep convection a few hundred miles to the northeast of the Leeward Islands. Tropical storm force winds (35 knots) started building by midday on the 30th but no classification was given to this system at this time. It was still a tropical wave because the system did not have a closed circulation at low levels. Wind speeds reported by ships in the northern part of the cloud pattern were around 40 knots. The system became officially known as Tropical Storm Erin on the 31st. Erin's entire track can be seen on Map 4.1.

Erin's movement and development was being affected by an upper-level low near Florida, and as a result, the track of the center was deflected to a course that was over or near much of the Bahama Island chain. Erin became a hurricane while centered over the Bahamas on the evening of the 31st and made landfall on August 1st, as can be seen in Figure 4.1, near Vero Beach, Florida as a category 1 hurricane. As Erin was crossing Florida, its track bent back to west-northwest during the morning of the 2nd. As it was crossing, it was loosing strength and only had tropical storm strength winds of about 50 knots, but it remained well organized. Erin started re-intensifying once it was back over warm water in the Gulf of Mexico. Its track gradually swung back to northwestward at about 10 knots.

Hurricane Erin made its final landfall near Pensacola, Florida during the late morning of August 3rd. At this time, sustained winds were around 85 knots in a small area of its northeastern eyewall. Figure 4.1 shows its dynamics at that time. Overnight, between the 3rd and 4th, Erin weakened to a tropical storm in southeastern Mississippi and was downgraded to a tropical depression when its track shifted to the north on the 5th and to the east on the 6th at which time the depression merged with a frontal system over West Virginia.

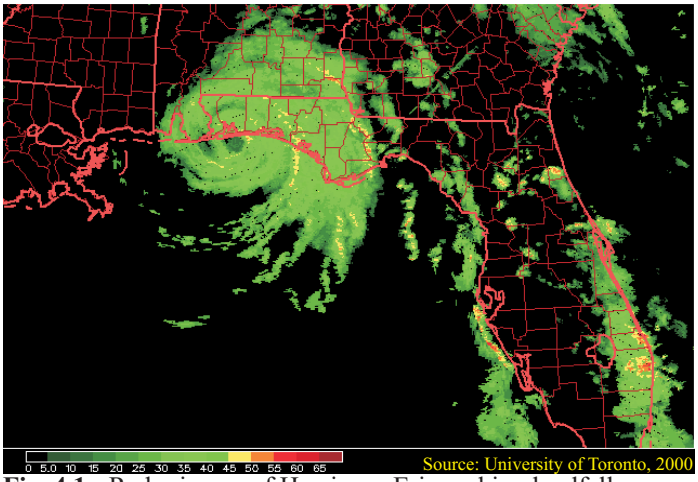


Fig. 4.1: Radar image of Hurricane Erin making landfall.

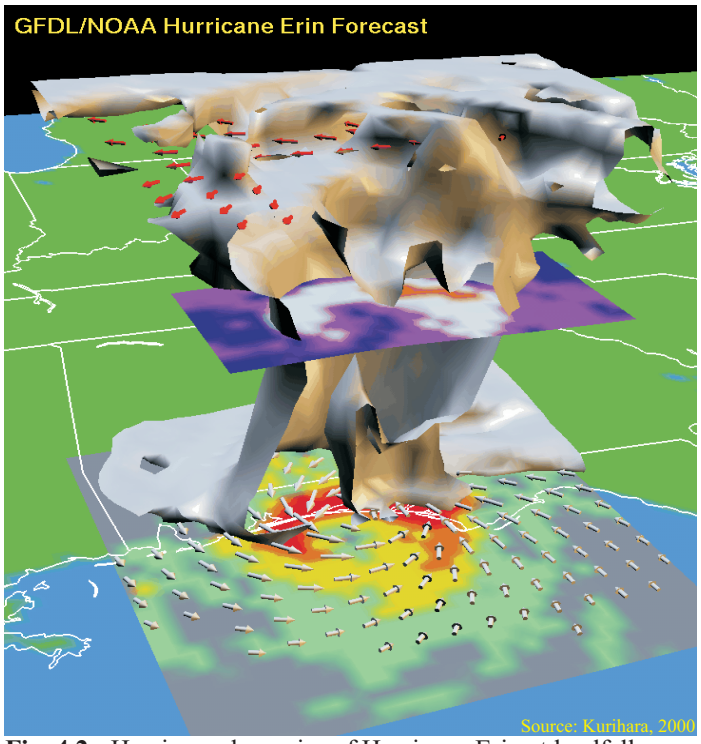


Fig. 4.2: Hurricane dynamics of Hurricane Erin at landfall.

Meteorological Statistics

A) **Minimum Pressure**

The hurricane's lowest pressure was 973 mb and was reported by Hurricane Hunters on August 3rd. This measurement was taken while Erin was near the southern coast of Florida.

B) **Maximum Wind Speed**

The highest wind at the surface was a gust to 128 knots that was reported along with a tornado on the Turks and Caicos Islands. Several reports of hurricane force winds were received from the Bahamas, including 68 and 70 knots during the passage of the northeast part of the eyewall over Cat Island on August 1st. Several amateur radio reports included gusts to around 90 knots in the Bahamas

A wind speed of 85 knots was estimated on August 3rd as Erin was making landfall on the panhandle of Florida. This took place within a small sector of the northeastern eyewall. The highest wind speed measured at an official reporting station in the Florida panhandle was an 88 knot gust at the Pensacola Naval Air Station and amateur radio operator's relayed unofficial observations of gusts near 95 knots.

C) **Storm Surge**

On the southeastern coast of Florida, Erin generated a storm surge of 2 to 4 feet during landfall. Storm tides averaged 1 to 2 feet along the west-central Florida peninsula. Along the northwestern Florida coast, as the hurricane made its second landfall, storm tides were estimated at 3 and 7 feet, depending on the area.

Hurricane Erin
July 31 - August 6
1995

D) **Tornadoes**

This hurricane did not produce many tornadoes, and of the ones that it did, none of them were very strong. One tornado caused minor damage while another killed two horses. In Florida, a couple of weak tornadoes were reported over the panhandle.

E) **Rainfall**

Rainfall was pretty heavy in southern portions of Florida were up to 12 inches of rain fell in some of the areas. In the north, near the panhandle, up to 5 inches of rain was reported.

Map 4.1: Track of Hurricane Erin in 1995.

Casualty And Damage Statistics

This was a relatively mild hurricane and as a result there were not very many deaths. There were no deaths reported in the Bahamas or in Florida, but a total of six people died in the Atlantic and Gulf of Mexico waters. Three in the sinking of a gambling and cruise ship, a surfer who drowned in a rip current, and a man and daughter who were swept away in an inflatable boat.

All of the Bahamas islands suffered some sort of damage, but most of it rather minor. Some structural damage, sunken boats, crop loss, and flooding were all reported. A total of about $400,000 in damages were reported in the Bahamas.

The American Insurance Services Group estimated Erin caused $375 million as the loss to insured property in the United States. In Florida there was $350 million, $20 million in Alabama, and $5 million in Mississippi. The total amount of damages, however, is more in the range of $700 million.

Wind damage occurred over east-central and northeast Florida. Freshwater flooding from rainfall occurred in widespread regions along the Florida gulf coast. Many boardwalks, beach access ways and dune systems were damaged. Minor beach erosion was reported northward to the Georgia border and along the west-central Florida coast. The most significant structural damage during the final landfall occurred near Pensacola. More than 2000 homes were damaged, crop losses were reported and some beach erosion occurred. In Alabama about 100 homes were damaged and there was widespread tree, power line, and crop damage. (NOAA, 1997)

Hurricane Fran Aug. 23 - Sept. 8 1996

Formation And History

Hurricane Fran was a hurricane that moved across the Atlantic Ocean during the peak of the hurricane season. It made landfall on the North Carolina coast which resulted in a significant storm surge, widespread wind damage and extensive flooding from the Carolinas to Pennsylvania. When it made landfall, it was a category three hurricane on the Saffir/Simpson Hurricane Scale.

Hurricane Fran formed from a tropical wave that emerged from the west coast of Africa on August 22nd as can be seen in the map on the opposite page. This system became a tropical depression just southeast of the Cape Verde Islands on August 23rd. This tropical depression moved westward during the next couple of days without much development. Fran then began to move in a west-northwest direction and while the deep convection became more concentrated and was estimated to have reached hurricane status on August 29th about 400 nautical miles east of the Leeward Islands.

On August 30th, Fran weakened to just below hurricane strength and started to turn toward the northwest and slow from its previous speed of 15 knots to about 5 knots. Fran regained hurricane status on August 31th and moved west-northwest gaining speed. Fran moved on a track roughly parallel to the Bahama Islands with the eye remaining a little more than 100 nautical miles to the northeast of the islands (Figure 5.1). On September 4th, Fran became a category three hurricane and gradually turned toward the northwest to north-northwest due to a powerful tropical cyclone centered over Tennessee. Fran's peak intensity occurred on September 5th when the hurricane was centered about 250 nautical miles east of Florida (Figure 5.2). Its minimum central pressure dropped to 946 mb and maximum sustained surface winds reached 105 knots.

Fran was moving northward at about 15 knots when it made landfall on the coast of North Carolina on September 6th. At landfall, the minimum central pressure was estimated at 954 mb and the maximum sustained winds at 100 knots. Fran weakened to a tropical storm while over North Carolina and to a

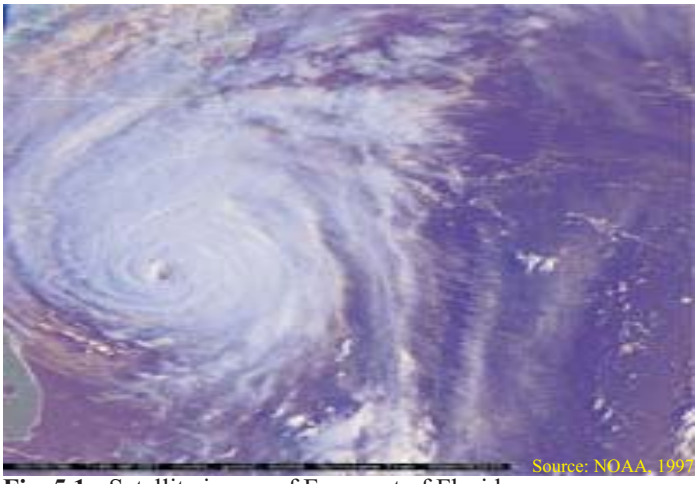


Fig. 5.1: Satellite image of Fran east of Florida..

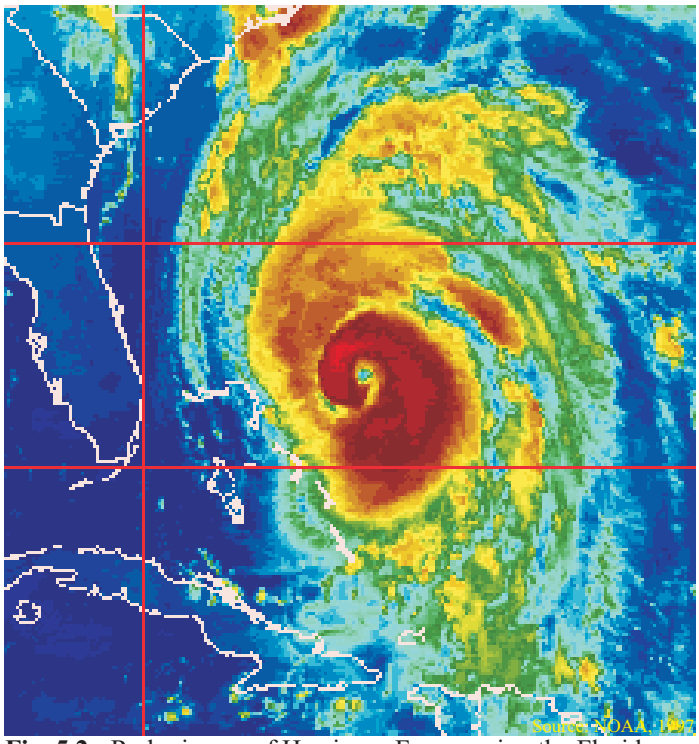


Fig. 5.2: Radar image of Hurricane Fran nearing the Florida coast.

tropical storm while over North Carolina and to a tropical depression while moving through Virginia. The tropical cyclone moved over the eastern Great Lakes and was absorbed into a frontal system on September 10th. Fran's entire track can be see on Map 5.1.

Meteorological Statistics

A) **Minimum Pressure**

There were many statistical observations taken during this storm. Many flights were taken into the center of the hurricane to determine many different readings of how the hurricane was progressive and to predict where it might go. The minimum central pressure reported was 946 mb on September 4th. An aircraft radar observed a circular eye with a diameter of 25 nautical miles this same day.

B) **Maximum Wind Speed**

Around the same time, a maximum sustained wind measurement of 114 knots was given. As the hurricane was approaching the North Carolina coast, a radar on land measured winds in excess of 120 knots.

C) **Tornadoes**

When Hurricane Fran made landfall, several tornadoes were indicated by Doppler radar in North Carolina and Virginia

D) **Storm Surge**

The storm surge ranged from 8 to 12 feet. Water marks on buildings were higher but this was due to the effect of breaking waves.

Hurricane Fran Aug. 23 - Sept. 8 1996

Map 4.1: Track of Hurricane Fran in 1996.

E) **Rainfall**

Rainfall totals of more than 6 inches were very common near the path of Fran and some radar precipitation estimates were as high as 12 inches. Extensive flooding was reported well inland from the Carolinas all the way north to Pennsylvania. This flooding was considered to be the most severe in several years.

Casualty And Damage Statistics

Hurricane Fran was responsible for 34 deaths, most of which were caused by flash flooding in the Carolinas, Virginia, West Virginia, and Pennsylvania. Storm surge on the North Carolina coast destroyed or seriously damaged many beachfront houses and there was widespread wind damage to trees, roofs, and power lines as Fran moved inland over North Carolina and Virginia. Nearly half a million tourists and residents were ordered to evacuate the coast in both North and South Carolina and more than 4.5 million people were left without power.

The Property Claim Services Division of the American Insurance Services Group reports that Fran caused an estimated $1.6 billion dollars in property damage to the United States. This estimate includes $1.275 billion in North Carolina, $20 million in South Carolina, $175 million in Virginia, $50 million in Maryland, $20 million in West Virginia, $40 million in Pennsylvania, and $20 million in Ohio. (NOAA, 1997)

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Glossary

C

Convergence

A region in the atmosphere where air accumulates.

D

Dropsonde

An instrument dropped from a plane that measures the profile of the atmosphere from the aircraft to the ground. This instrument falls at 1,000 feet per minute, measuring pressure, temperature, wind, and moisture.

E

Extratropical Cyclone

A storm that develops in association with the polar front.

Eye

A region in the center of a hurricane where the winds are light and skies are clear to partly cloudy.

Eyewall

The portion of a hurricane immediately adjacent to the eye; usually the region of highest wind speed and most intense precipitation.

F

Funnel Cloud

A column of rapidly rotating air similar to a tornado, except that the column has not extended to the ground.

H

Hurricane

A large mass of organized, oceanic thunderstorms occurring in the Atlantic Ocean with maximum sustained winds of at least 44 km/h (74 mph) somewhere in the storm.

M

Monsoon Trough

Areas where the Intertropical Convergence Zone is displaced 10-20 degrees away from the equator. This occurs in regions where air or water temperature increases away from the equator. The vast majority of genesis cases or associated with monsoon troughs.

N

Nautical Mile

Equals 6,076 feet compared with a normal mile of 5,280 feet.

Glossary

S

Saffir/Simpson Hurricane Scale

A scale relating a hurricane's central pressure, maximum sustained winds, and storm surge to the possible damage it is capable of inflicting. The scale ranges from Category 1 being a minimal hurricane and Category 5 being a catastrophic hurricane.

Storm Surge

An abnormal rise of the sea along a shore due to a meteorological influence, especially a hurricane.

Sustained Winds

The average wind speed over a period of time at roughly 33 feet above the ground. In the Atlantic Ocean this averaging is performed over a 1-minute period.

T

Tropical Depression

A large mass of organized, oceanic thunderstorms with sustained wind speeds less than 60 km/h (39 mph).

Tropical Disturbance

A large mass of organized, oceanic thunderstorms that has persisted for 24 hours.

Tropical Cyclone

The internationally designated general term for all large cyclonically rotating thunderstorm complexes over tropical oceans.

Tropical Storm

A large mass of organized, oceanic thunderstorms with maximum sustained winds between 60 and 120 km/h (39 and 73 mph). A storm is given a name at this stage.

Tropical Wave

A westward moving trough, shaped like an upside down "V" similar to a wave, imbedded in northeasterly winds in the tropics. They are also known as easterly waves.

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