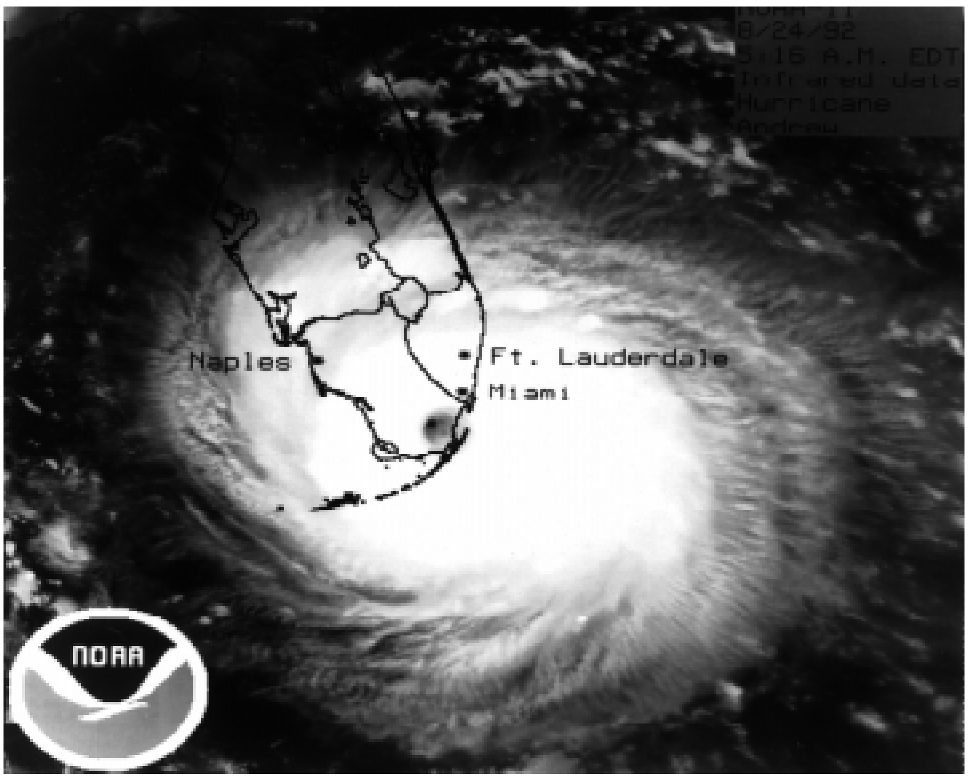
"HURRICANE!"

A Familiarization Booklet



HURRICANE ANDREW

Hurricane Andrew slammed into heavily populated south Florida as the most destructive storm in United States history. With sustained winds of 145 mph and gusts over 175 mph, Andrew annihilated homes and businesses along a 30-mile swath through the Dade County towns of Homestead, Leisure City, Goulds, Princeton, Naranja, and Florida City. When it was over, more than 60,000 homes were destroyed and 200,000 people were left homeless.

Andrew had a central pressure of 922 mb at landfall making it the third most intense hurricane of the 20th century. Only the infamous "Labor Day" hurricane that struck the Keys in 1935 and Hurricane Camille in 1969 along the Mississippi/Louisiana coasts were stronger. Damage was estimated at more than $20 billion.

Fifteen people died in Florida as a direct result of Andrew's fury. Another 26 lives were lost as a result of indirect effects of the hurricane within the next 3 weeks. The relatively low loss of life, compared to the hundreds that died in the 1935 storm and in Camille, stands as a testimony to the success and importance of hurricane awareness campaigns, preparedness planning, and actions by the joint efforts of Federal, state, county, and city emergency forces. The news media played a major role in the life-saving actions before, during, and after Andrew hit.

Historically, such powerful hurricanes have caused great loss of life from the storm surge. As Andrew came ashore first in the northwest Bahamas, storm surge reached an astonishing 23 feet. In Florida, a 17-foot storm tide, which headed inland from Biscayne Bay, is a record for the southeast Florida peninsula. Storm tides of more than 7 feet in Louisiana also caused severe flooding.

Evacuation from threatened coastal areas is the only defense from the storm surge's potential for death and destruction. After the National Hurricane Center issued hurricane watches and warnings, massive evacuations were ordered in Florida and Louisiana by emergency management officials. It is estimated that more than 2,000,000 people evacuated to safety in Florida and Louisiana as Andrew approached.

PREFACE

This booklet is a compilation of material on hurricanes gathered from several National Oceanic and Atmospheric Administration (NOAA)/National Weather Service publications in response to a myriad of requests received at the National Hurricane Center for hurricane information. Statistics and definitions have been updated and obsolete references have been deleted from the original works.

Cover: Hurricane Andrew. The NOAA spacecraft GOES routinely provides imagery every 30 minutes, day and night, using visible and infrared sensors. At an altitude of about 22,300 miles, the satellite orbits above the same point on the Equator. This satellite provides full disk images and a variety of images of sections of the full disk which are

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National Oceanic and Atmospheric Administration
National Weather Service

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"HURRICANE—The Greatest Storm on Earth"

There is nothing like it in the atmosphere. Even seen by sensors on satellites thousands of miles above the earth, the uniqueness of these powerful, tightly coiled storms is clear. They are not the largest storm systems in our atmosphere, or the most violent; but they combine those qualities as no other phenomenon does—as if they were designed to be engines of death and destruction.

In our hemisphere, they are called hurricanes, a term that echoes colonial Spanish and Caribbean Indian words for evil spirits and big winds. The storms are products of the tropical ocean and atmosphere, powered by heat from the sea, steered by the easterly trades and temperate westerlies, and their own fierce energy. Around their core, winds blow with lethal velocity, the ocean develops an inundating surge, and as they move ashore, tornadoes may descend from the advancing bands of thunderclouds.

Hurricanes are a major source of rain for those continental corners that fall beneath their tracks. Perhaps there are other hidden benefits as well. But the main consequence of the hurricane is tragedy.

In Asia, the price in life paid the hurricane has had biblical proportions. As late as 1970, cyclone storm tides along the coast of what now is Bangladesh killed hundreds of thousands of persons. An estimated 138 thousand were killed in Bangladesh in 1991. Our hemisphere has not had such spectacular losses, but the toll has still been high. In August 1893, a storm surge drowned between one and two thousand people in Charleston, South Carolina. In October of that same year, nearly two thousand more perished on the gulf coast of Louisiana. The Galveston storm of 1900 took more than 6,000 lives. More than 1,800 perished along the south shore of Florida's Lake Okeechobee in 1928 when hurricane driven waters broached an earthen levee. Cuba lost more than 2,000 to a storm in 1932. Four hundred died in Florida in an intense hurricane in September 1935—the "Labor Day" hurricane that shares with 1969's Camille the distinction of being the most severe to ever strike the United States.

Floods from 1974's Hurricane Fifi caused one of the Western Hemisphere's worst natural disasters in history, with an estimated 5,000 persons dead in Honduras, El Salvador, Guatemala, and Belize.

In the United States, the hurricane death toll has been greatly diminished by timely warnings of approaching storms. But damage to fixed property continues to mount. In 1965, Hurricane Betsy caused about \$6.5 billion[1] in damages in Florida and Louisiana. Flooding from Hurricane Agnes in the populated Northeast United States in 1972 totaled \$6.4 billion. In 1989, Hurricane Hugo at \$7 billion became the most costly hurricane when it struck South Carolina. Then Andrew smashed all records when it hit the densely populated coast of south Florida with more than \$20 billion in property damage.

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[1] All dollar figures have been adjusted to 1990 dollars based on U.S. Department of Commerce composite construction cost indexes.

The Season of Great Storms

It is the northern summer. The illusion of a moving sun caused by our planet's year-long orbit brings that star's rays northward to the Equator, then toward the Tropic of Cancer. Behind this illusory solar track, the sea and air grow warmer, and the polar winter beats its seasonal retreat.

This northward shift of the sun brings the season of tropical cyclones to the Northern Hemisphere. Along our coasts and those of Asia, it is time to look seaward.

Over the western Pacific, the tropical cyclone season is never quite over but varies greatly in intensity. Every year, conditions east of the Philippines send a score of violent storms howling toward Asia; but it is worse from June through November.

Southwest of Mexico, eastern Pacific hurricanes develop during the spring, summer, and autumn. Most of these will die at sea as they move over colder ocean waters. But there are destructive exceptions when storms curve back toward Mexico.

Along our Atlantic and gulf coasts, the nominal hurricane season lasts from June through November. Early in the season, the western Caribbean and Gulf of Mexico are the principal areas of origin. In July and August, the main area of formation begins an eastward shift; by early September, a few storms are being born as far east as the Cape Verde Islands off Africa's west coast. Again after mid-September, most storms begin in the western Caribbean and Gulf of Mexico.

In an average year, more than one hundred disturbances with hurricane potential are observed in the Atlantic, Gulf of Mexico, and Caribbean; but on an average, only 10 of these reach tropical storm stage, and only about six mature into hurricanes. On average, two of these hurricanes strike the United States, where they kill from about 50 to 100 people somewhere between Texas and Maine and cause hundreds of millions of dollars in property damage. In a worse-than-average year, the same storms cause several hundred deaths and property damage totaling <u>billions</u> of dollars.

For the National Oceanic and Atmospheric Administration (NOAA), the hurricane season means another hazard from the atmosphere at a time when tornadoes and floods and severe storms are playing havoc elsewhere on the continent. Meteorologists with NOAA's National Weather Service monitor the massive flow of data that might contain the early indications of a developing storm somewhere over the warm sea. Cloud images from satellites, meteorological data from hundreds of surface stations, balloon probes of the atmosphere, and information from hurricane-hunting aircraft are the tools of the hurricane forecaster.

In NOAA's research laboratories, scientists wait for nature to furnish additional specimens of the great storms to probe and analyze in hopes of gathering a greater understanding of the mechanics of the storms—thereby assisting the forecaster with his warnings.

Portrait of a Hurricane

Given that the hurricane, as an engine, is inefficient and hard to start and sustain, once set in motion, once mature, it is an awesome natural event indeed.

The young storm stands upon the sea as a whirlwind of awful violence. Its hurricane-force winds cover thousands of square miles, and tropical storm force winds—winds of 34 to 63 knots[1]—cover areas ten times larger. Along the contours of its spiral rainbands are dense clouds from which torrential rains fall. These spiral rainbands ascend in decks of cumulus and cumulonimbus clouds to the high upper atmosphere, where condensing water vapor is swept off as ice-crystal wisps of cirrus clouds by high-altitude winds. Lightning glows in the rainbands, and this cloudy terrain is whipped by turbulence.

In the lower few thousand feet, air flows in toward the center of the cyclone and is whirled upward through ascending columns of air near the center. Above 40,000 feet, this cyclone pattern is replaced by an anticyclonic (clockwise in the Northern Hemisphere) circulation—the high-level pump that is the exhaust system of the hurricane engine.

At lower levels, where the hurricane is most intense, winds on the rim of the storm follow a wide pattern, like the slower currents on the rim of a whirlpool; like those currents, these winds accelerate as they approach the central vortex. This inner band is the eyewall, where the storm's worst winds are felt, and where moist air entering at the surface is chimneyed upward releasing heat to drive the storm. In many hurricanes, these winds exceed 90 knots—nearly twice that in extreme cases.

Hurricane winds are produced, as all winds are, by differences in atmospheric pressure or density. The pressure gradient—the rate of pressure change with distance—produced in hurricanes is the sharpest in the atmosphere, excepting only the pressure change believed to exist across the narrow funnel of a tornado.

Atmospheric pressure is popularly expressed as the height of a column of mercury that can be supported by the weight of the overlying air at a given time.[2]

In North America, barometric measurements at sea level seldom go below 29 inches of mercury (982 millibars). In the tropics, it is generally close to 30 inches (1,016 millibars) under normal conditions. Hurricanes drop the bottom out of those normal categories. The Labor Day hurricane that struck the Florida Keys in 1935 had a central pressure of only 26.35 inches (892 millibars). And the change is swift; pressure may drop an inch (3 millibars) per mile. Hurricane Gilbert in 1988 went through a remarkable intensification period after its center crossed Jamaica. The pressure fell from 960 millibars (28.35 inches) to 888 millibars (26.22 inches) in 24 hours. The latter was observed by a NOAA aircraft on September 13, 1988—the lowest sea level pressure ever recorded in the Western Hemisphere.

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[1] A knot is one nautical mile per hour; a nautical mile is about 1.15 statute miles.

[2] Weather maps show atmospheric pressure in millibars, units equal to a thousandth of a bar. The bar is a unit of pressure equal to 29.53 inches of mercury in the English system; and to one million dynes per square centimeters in the metric system.

At the center of the storm is a unique atmospheric entity and a persistent metaphor for order in the midst of chaos—the eye of the hurricane. It is encountered suddenly. From the heated tower of maximum winds and thunderclouds, one bursts into the eye, where winds diminish to something less than 15 knots. Penetrating the opposite wall, one is abruptly in the worst of winds again.

A mature hurricane orchestrates as much as a million cubic miles of atmosphere. Over the deep ocean, waves generated by hurricane winds can reach heights of 50 feet or more. Under the storm center, the ocean surface is drawn upward like water in a straw, forming a mound 1-3 feet or so higher than the surrounding ocean surface. This mound may translate into coastal surges of 20 feet or more. Besides this surge, massive swells pulse out through the upper levels of the sea—Pacific surfers often ride the oceanic memory of distant typhoons.

While a hurricane lives, the transaction of energy within its circulation is immense. The condensation heat energy released by a hurricane in one day can be the equivalent of energy released by fusion of four-hundred, 20-megaton hydrogen bombs. One day's released energy, converted to electricity, could supply the United States' electrical needs for about 6 months.

The Fatal Thrust Toward Land

From birth, the hurricane lives in an environment that constantly tries to kill it—and ultimately succeeds. The hurricane tends to survive while it is over warm water. But its movement is controlled by the forces that drive the storm ashore or over colder water beyond the tropics where it will weaken and die. This thrust away from the tropics is the clockwise curve that takes typhoons across the coastlines of Japan and into the Asian mainland and the Atlantic hurricanes into the eastern United States.

Even before a hurricane forms, the embryonic storm has forward motion, generally driven by the easterly flow in which it is embedded. As long as this westerly drift is slow—less than about 20 knots—the young hurricane may intensify. More rapid forward motion generally inhibits intensification in the storm's early stages. Entering the temperate latitudes, some storms may move along at more than 50 knots, but such fast-moving storms soon weaken.

At middle latitudes, the end usually comes swiftly: colder air penetrates the cyclonic vortex; the warm core cools and acts as a thermal brake on further intensification. Water below 80 degrees Fahrenheit does not contribute much energy to a hurricane. Even though some large hurricanes may travel for days over cold north Atlantic water, all storms are doomed once they leave the warm tropical waters that sustain them. The farther they venture into higher latitudes, the less fuel they receive from the sea. This lack of fuel finally kills the storms.

Over land, hurricanes break up rapidly. Cut off from their oceanic source of energy and with the added effects of frictional drag, their circulation rapidly weakens and becomes more disorganized. Torrential rains, however, may continue even after the winds are much diminished. In the southeastern United States, about a fourth of the annual rainfall comes from dissipating hurricanes, and sometimes the Asian mainland and Japan welcome typhoons to get water from the sky.

Hurricanes are often resurrected into extratropical cyclones at higher latitudes or combine with existing temperate-zone disturbances. Many storms moving up our Atlantic coast are in the throes of this transformation when they strike New England, and large continental lows are often invigorated by the remnants of storms born over the tropical sea.

"If a major storm strikes a coastal metropolitan center this year, the risk of fatalities is high because the endangered population will face congested evacuation routes, insufficient escape time, and has too little experience in hurricane survival. It is imperative that coastal residents and visitors alike take the threat seriously, acquaint themselves with hurricane safety rules, and evacuate immediately if advised to do so."

Dr. Robert C. Sheets
Director, National Hurricane Center

Destruction in a Hurricane

Hurricanes are the unstable, unreliable creatures of a moment in our planet's natural history. But their brief life ashore can leave scars that never quite heal. In the mid-1970's, the hand of 1969's Camille could still be seen along the Mississippi gulf coast. Most of a hurricane's destructive work is done by the general rise in the height of the sea called storm surge.

Hurricane winds are a force to be reckoned with by coastal communities deciding how strong their structures should be. As winds increase, pressure against objects is added at a disproportionate rate. Pressure force against a wall mounts with the <u>square</u> of wind speed so that a threefold increase in windspeed gives a ninefold increase in pressure. Thus, a 25 mph wind causes about 1.6 pounds of pressure per square foot. A four by eight sheet of plywood will be pushed by a force of 50 pounds. In 75 mph winds, that force becomes 450 pounds, and in 125 mph, it becomes 1,250 pounds. For some structures, this force is enough to cause failure. Tall structures, like radio towers, can be destroyed by gusty hurricane-force winds. Winds also carry a barrage of debris that can be quite dangerous.

All the wind damage does not necessarily come from the hurricane. As the storm moves shoreward, interactions with other weather systems can produce tornadoes that work around the fringes of the hurricane. Although hurricane-spawned tornadoes are not the most violent form of these whirlwinds, they have added to the toll we pay the hurricane.

Floods from hurricane rainfall are quite destructive. A typical hurricane brings 6 to 12 inches of rainfall to the area it crosses, and some have brought much more. The resulting floods have caused great damage and loss of life, especially in mountainous area where heavy rains mean flash floods. The most widespread flooding in United States history was caused by the remnants of Hurricane Agnes in 1972. Rains from the dying hurricane brought disastrous floods to the entire Atlantic tier of states, causing 118 deaths and some $2.1 billion in property damage.

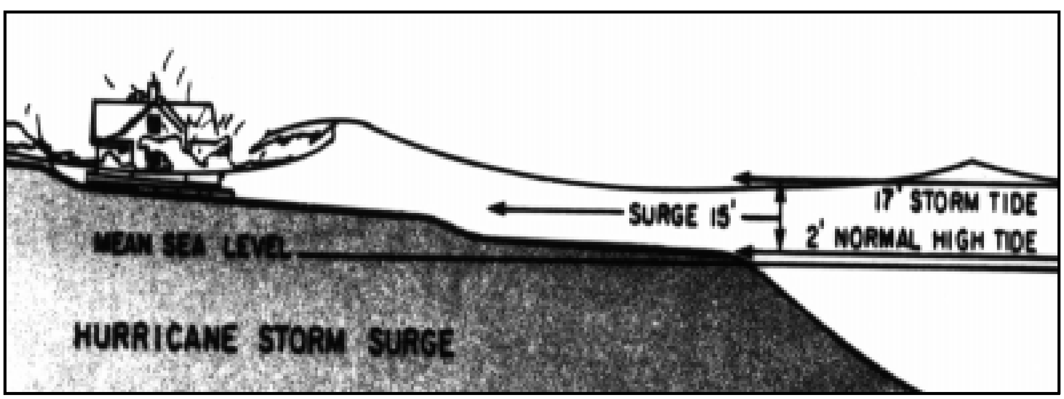
Storm Surge

The hurricanes' worst killer comes from the sea, in the form of storm surge, which claims nine of ten victims in a hurricane.

As the storm crosses the continental shelf and moves close to the coast, mean water level may increase 15 feet or more. The advancing storm surge combines with the normal astronomical tide to create the hurricane storm tide. In addition, wind waves 5 to 10 feet high are superimposed on the storm tide. This buildup of water level can cause severe flooding in coastal areas, particularly when the storm surge coincides with normal high tides. Because much of the United States' densely populated coastline along the Atlantic and gulf coasts lies less than 10 feet above mean sea level, the danger from storm surge is great.

Wave and current action associated with the surge also causes extensive damage. Water weighs some 1,700 pounds per cubic yard; extended pounding by frequent waves can demolish any structures not specifically designed to withstand such forces.

Currents set up along the coast by the gradient in storm surge heights and wind combine with waves to severely erode beaches and coastal highways. Many buildings withstand hurricane winds until their foundations, undermined by erosion, are weakened and fail. Storm tides, waves, and currents in confined harbors severely damage ships, marinas, and pleasure boats. In estuarine and bayou areas, intrusions of salt water endanger the public health and create bizarre effects, like salt-crazed snakes fleeing Louisiana's flooded bayous.



Hurricane Forecasters and Hunters

The day is past when a hurricane could develop to maturity far out to sea and go undetected until it thrust toward land. Earth-orbiting satellites operated by the National Oceanic and Atmospheric Administration (NOAA) keep the earth's atmosphere under virtually continuous surveillance, night and day. Long before a storm has evolved, scientists at NOAA's National Hurricane Center in Miami, Florida, have begun to watch the disturbance. In the satellite data coming in from polar-orbiting and geostationary spacecraft and in reports from ships and aircraft, they look for subtle clues that mark the development of hurricanes—cumulus clouds covered by the cirrostratus deck of a highly organized convective system; showers that become steady rains; dropping atmospheric pressure; intensification of the tradewinds, or a westerly wind component there.

Then, if this hint of a disturbance blooms into a tropical storm, a time-honored convention is applied—it receives a name. Today, naming a storm is a signal which brings a considerably more elaborate warning system to readiness. Long-distance communications lines and preparedness plans are flexed.

As an Atlantic hurricane drifts closer to land, it comes under surveillance by weather reconnaissance aircraft of the U.S. Air Force Reserve, the famous "Hurricane Trackers," who bump through the turbulent interiors of the storms to obtain precise fixes on the position of the eye and measure winds and pressure fields. Despite the advent of satellites, the aircraft probes are the most detailed quantitative information hurricane forecasters receive. The hurricanes are also probed by the "flying laboratories" from NOAA's Aircraft Operations Center in Miami. Finally, the approaching storm comes within range of a radar network stretching from Texas to Maine and from Miami to the Lesser Antilles. Increasingly, that network is dominated by Doppler radar, capable of giving precise position data as well as measurements of wind speeds and rainfall.

Through the lifetime of the hurricane, advisories from the National Hurricane Center give the storm's position and what the forecasters in Miami expect the storm to do. As the hurricane drifts to within a day or two of its predicted landfall, these advisories begin to carry watch and warning messages, telling people when and where the hurricane is expected to strike and what its effects are likely to be. The first hurricane warning in the United States was flashed in 1873, when the Signal Corps warned against a storm approaching the coast between Cape May, New Jersey, and New London, Connecticut. Not until the storm has decayed over land and its cloudy elements and great cargo of moisture have blended with other brands of weather does the hurricane emergency end.

This system works well. The death toll in the United States from hurricanes has dropped steadily as NOAA's hurricane tracking and warning apparatus has matured. Although the accuracy of hurricane forecasts has improved over the years, any significant improvements must come from quantum leaps in scientific understanding.

The forecasters also know that science will never provide a full solution to the problems of hurricane safety. The rapid development of America's coastal areas has placed millions of people with little or no hurricane experience in the path of these lethal storms. For this vulnerable coastal population, the answer must be community preparedness and public education in the hope that education and planning before the fact will save lives and lessen the impact of the hurricane and what its effects are likely to be.

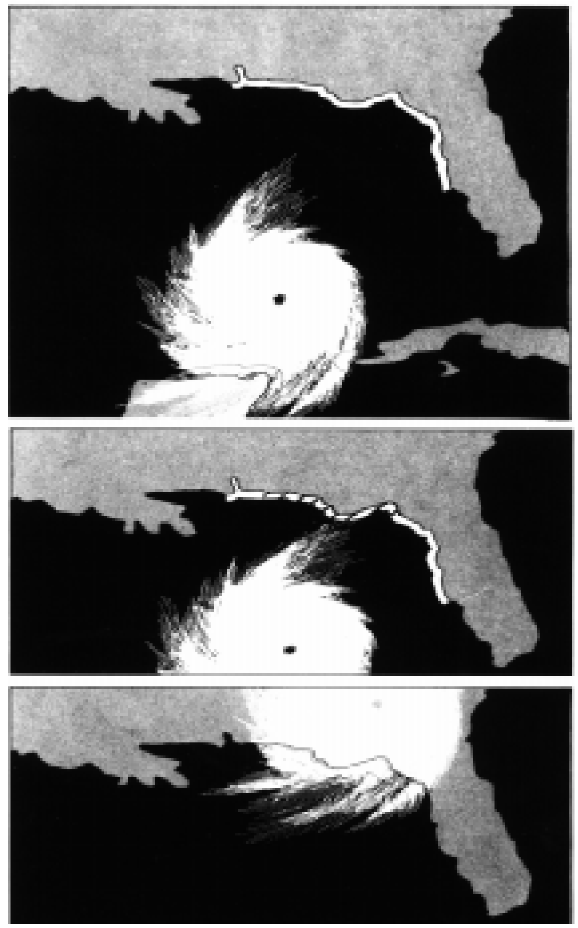
These diagrams show how hurricane watches and warnings and other advisories change as a hypothetical storm stalks Florida's northern gulf coast.

First, note the *extent* of the hurricane. Its dangerous core of high water and high winds is much larger than any of the communities in its path. When it comes ashore, its worst effects will be felt along some 50 miles of shoreline, with potentially dangerous heavy weather along a reach of coast several hundred miles long.

Then, note that NOAA hurricane forecasters "overwarn"—that is, the areas covered by their watches and warnings are larger than the approaching storm. This reflects the state of the art of hurricane forecasting and the enormous complexity of predicting what a large, destructive, and inherently erratic weather system is going to do.

The hurricane warning area appears in the second panel. It generally covers a much smaller area than the hurricane watch. Beyond the warning area, peripheral gale warnings and small craft cautionary statements are distributed around the predicted path of the hurricane.

In the third panel, the hurricane has moved ashore, and the watch and warning cycle ends; however, advisories continue to go out until the ocean and atmosphere behind the hurricane have had a chance to settle down.



The United States Hurricane Problem

The permanent populations of the hurricane-prone coastal counties of the United States continue to grow at a rapid rate. When weekend, seasonal, and holiday populations are considered, the number of people on barrier islands, such as at Ocean City, Maryland; Gulf Shores, Alabama; and Padre Island, Texas, increase by ten- to one-hundredfold or more. Also, these areas are subject to inundation from the rapidly rising waters, known as the storm surge, associated with hurricanes that generally result in catastrophic damage and potentially large losses of life. Over the past several years, the warning system has provided adequate time for the great majority of the people on barrier islands and along the immediate coast to move inland when hurricanes have threatened. However, it is becoming more difficult each year to evacuate people from these areas due to roadway systems that have not kept pace with the rapid population growth. This condition results in the requirement for longer and longer lead times for safe evacuation. Unfortunately, these extended forecasts suffer from increasing uncertainty. Furthermore, rates of improvements in forecast skills have been far outpaced by rates of population growth in areas vulnerable to hurricanes.

The combination of the growing populations on barrier islands and other vulnerable locations and the uncertainties in the forecasts poses major dilemmas for forecasters and local and state emergency management officials alike, i.e., how do you prevent complacency caused by "false alarms" and yet provide adequate warning times?

Preparations for hurricanes are expensive. When a hurricane is forecast to move inland on a path nearly normal to the coast, the area placed under warning is about 300 miles in length. The average cost of preparation, whether the hurricane strikes or not, is more than $50 million for the gulf coast. This estimate covers the cost of boarding up homes, closing down businesses and manufacturing plants, evacuating oil rigs, etc. It does not include economic losses due to disruption of commerce activities, such as sales, tourists canceling reservations, etc. In some locations, the loss for the Labor Day weekend alone can be a substantial portion of the yearly income of coastal business. An example of such losses were experienced along the Florida Panhandle during Hurricane Elena in 1985. If the width of the warned area has to be increased by 20 percent because of greater uncertainties in the forecast, the additional cost for each event would be $10 million. If uncertainties in the hurricane strength require warning for the next higher category of hurricane (Saffir/Simpson Scale, Hebert, et al., 1993), then major increases in the number of people evacuated and preparation costs would be required. Of course, if these uncertainties meant that major metropolitan areas, such as Galveston/Houston, New Orleans, Tampa, Miami, or a number of other major coastal cities, would or would not be included in the warning area, the differences in preparation costs would be substantially more than the $10 million. Also, the number of people evacuated would be substantially more than the tens of thousands of people.

For instance, in the case of the Galveston/Houston area, an increase in storm strength from a category 2 hurricane to a category 3 hurricane on the Saffir/Simpson Scale would require the evacuation of an additional 200,000 people. Likewise, if major industrial areas, such as Beaumont/Port Arthur, Texas, or tourist areas, such as Atlantic City, New Jersey, were affected by these uncertainties, the financial impact would be quite large.

Economic factors receive serious

consideration from the National Hurricane Center and local and state officials not only for direct but also for indirect effects on people response. People will not continually take expensive actions that, afterwards, prove to have been unnecessary. If we consistently overwarn by wide margins, people will not respond, and such actions could result in a large loss of life. To maintain credibility with the general public, the National Hurricane Center and the local and state officials cannot treat all hurricanes as if they were Camilles, Hugos, or Andrews.[1] Such an exaggerated approach may indeed provide maximum protection of life for a given event, but it endangers many more lives the next time when the threat may be even greater.

Finally, the hurricane problem is compounded by the fact that 80 to 90 percent of the people who now live in the hurricane-prone areas have never experienced the core of a major hurricane (Saffir/Simpson Scale—category 3 or stronger; Jarrell, et al., 1992). Many of these people have been through weaker hurricanes or been brushed by the fringe of a major hurricane. The result is a false impression of the damage potential of these storms. This frequently breeds complacency and delayed actions that could result in the loss of many lives. An example of the potential danger are those people living on barrier islands who might be reluctant to evacuate under "blue sky" conditions[2] until they see the actual threat (waters rising and winds increasing) (Simpson and Riehl, 1981). The result could be people trapped in those areas as waters cut off escape routes. This situation nearly happened for about 200 people on western Galveston Island during Hurricane Alicia in 1983.

This type of response primarily results from three major factors. First, major hurricanes are infrequent events for any given location. Second, for the past three decades, major hurricanes striking the United States coast have been less frequent than for the previous decades (Figure 1).

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[1] Hurricane Camille (1969), Hugo (1989), and Andrew (1992) were the most intense hurricanes to make landfall in the United States during the past three decades.

[2] Such an evacuation is presently required because of large populations with limited egress means.

(a)

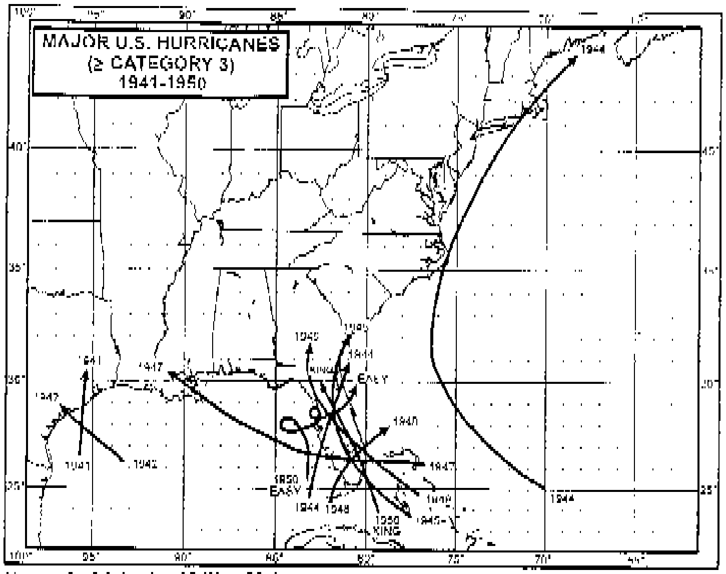


Figure 5. Major landfalling United States hurricanes (greater than or equal to a category 3) during the period 1941-1950.

(b)

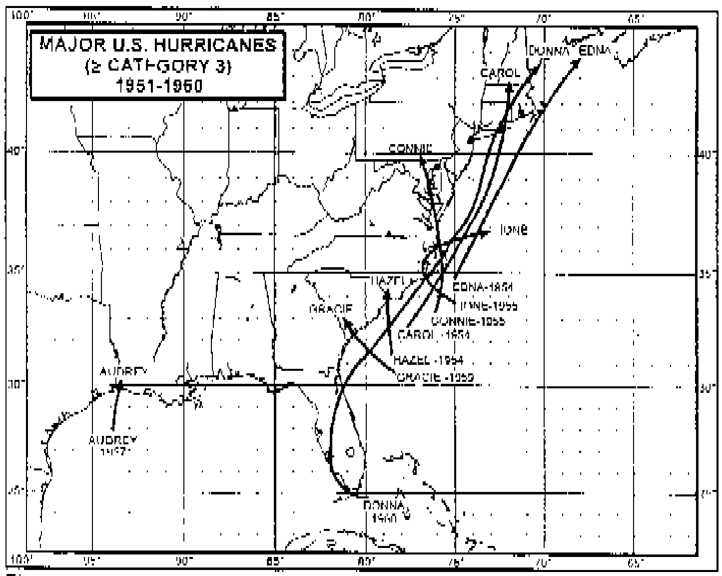


Figure 6. Major landfalling United States hurricanes (greater than or equal to a category 3) during the period 1951-1960.

Figure 1a.b

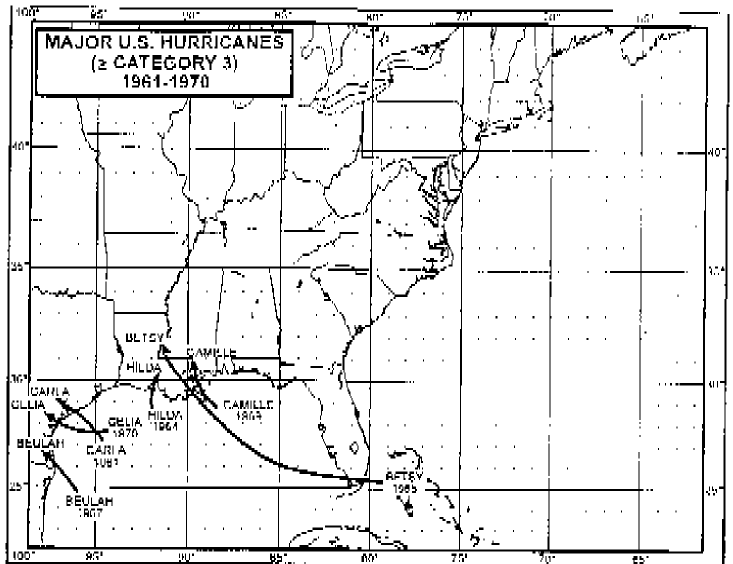


Figure 7. Major landfalling United States hurricanes (greater than or equal to a category 3) during the period 1961-1970.

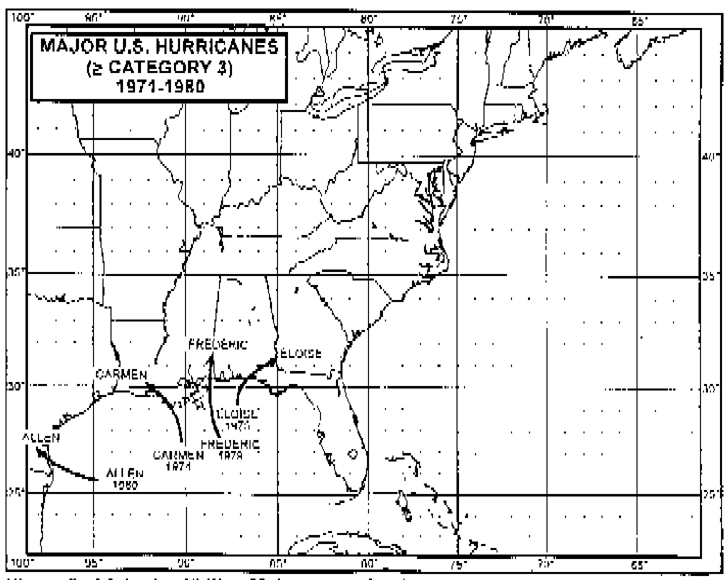


Figure 8. Major landfalling United States hurricanes (greater than or equal to a category 3) during the period 1971-1980.

Figure 1 c,d

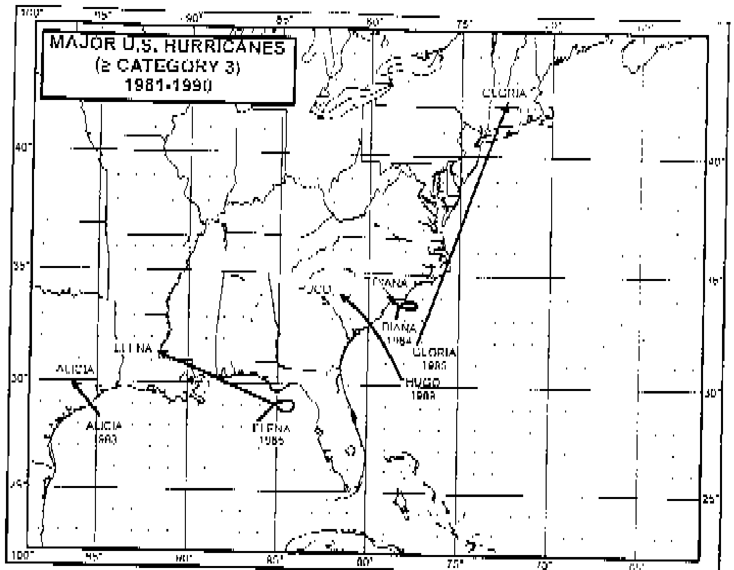


Figure 9. Major landfalling United States hurricanes (greater than or equal to a category 3) during the period 1981-1990.

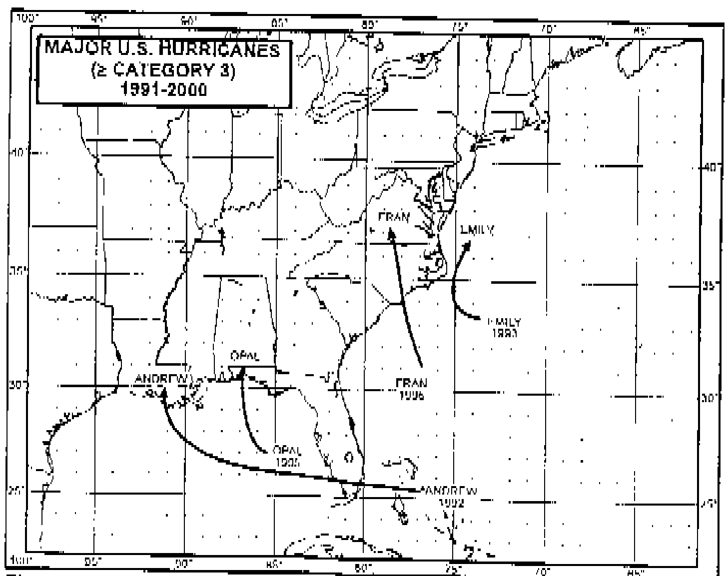


Figure 10. Major landfalling United States hurricanes (greater than or equal to a category 3) during the period 1991-2000.

Figure 1 e,f

The United States Hurricane Problem (Continued...)

Finally, it has been during this period of low hurricane activity that the great majority of the present coastal residents moved to the coast. The results of these factors is illustrated in Figure 2. The right side of this figure shows that property damage has spiraled upward in tandem with coastal development. The large amount of damage for the 1990's is primarily the result of a $20-25 billion loss caused by Hurricane Andrew in 1992. The left side of Figure 2 shows the loss of life during this period.

This figure clearly demonstrates the improvement in the effectiveness of hurricane warning, forecast, and response programs since the turn of the century. However, with the tremendous increase of populations in high-risk areas along our coastlines, the concern is that we may not fare as well in the future when hurricane activity inevitably returns to the frequencies experienced during the 1940s-60s.

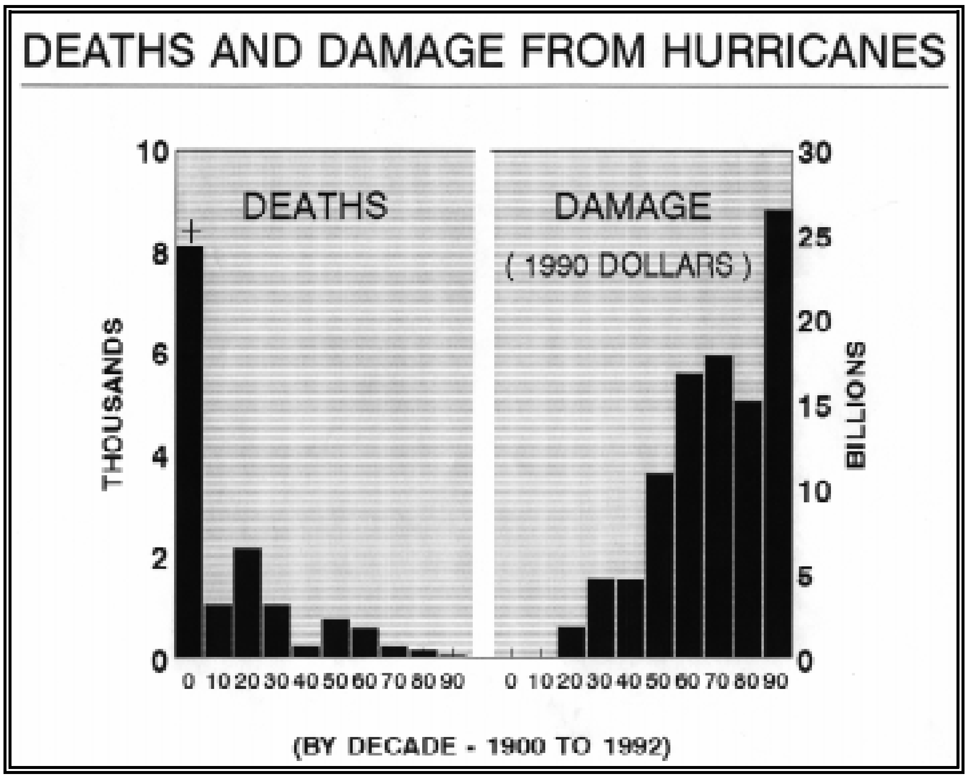
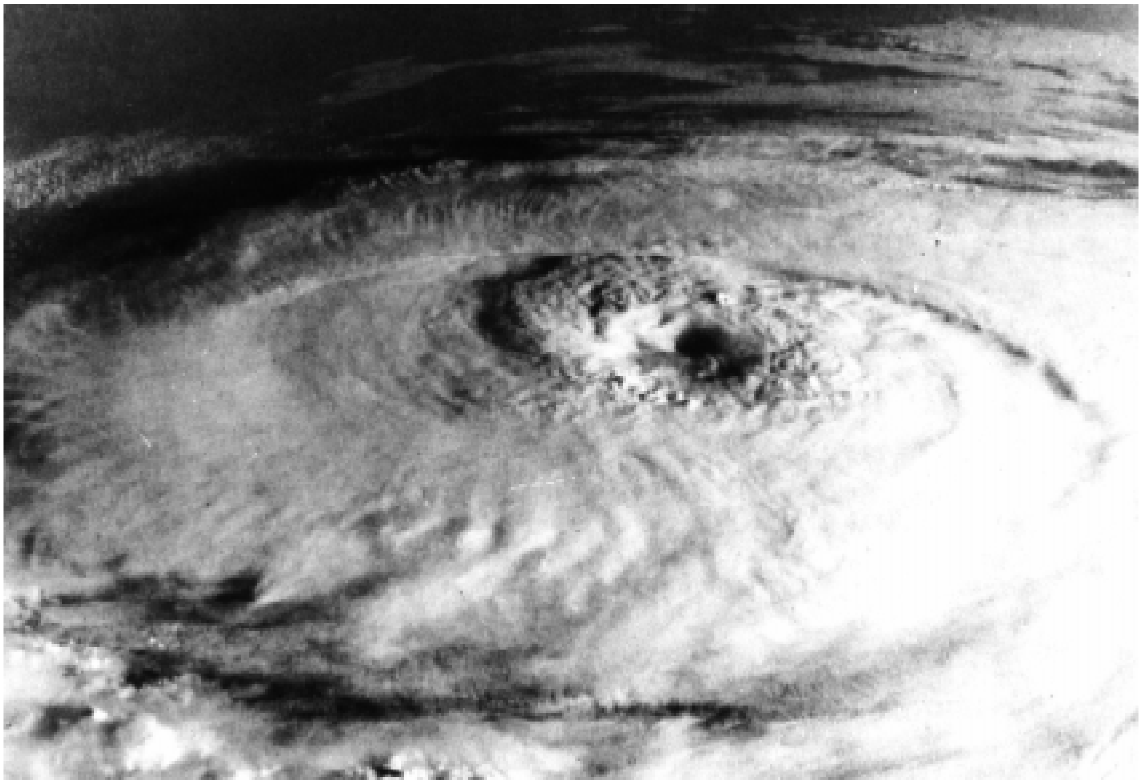


Fig. 2 — Loss of life and property in the continental United States due to hurricanes from 1900 to 1992 (modification and update of Gentry 1974).



Anatomy of a Hurricane[1]

by Dr. Robert C. Sheets

Shortly after noon on September 12, 1988, Kingston, Jamaica, lay under the eye of Hurricane Gilbert. The city had already endured the leading edge of the storm; but, sheltered by mountains to the north, it had not felt its full fury. Now as the relatively calm storm center moved off to the west and the wind direction shifted from the north to the south, Gilbert unleashed its full power.

Within minutes, violent winds were ripping the roofs off buildings, felling trees, and downing power and telephone lines. With communications knocked out, ham radio operators reported sustained wind speeds of 121 miles (195 kilometers) an hour and gusts to 147 miles (235 kilometers) an hour. At Manley International Airport, the wind tossed airplanes about like so many plastic models. Debris flew everywhere. Surging tides flooded low-lying areas. Blowing spray and rain were so heavy that observers could not see more than a few feet beyond their windows.

As Gilbert pounded Jamaica, officials of the National Hurricane Center in Coral Gables, Florida, pored over computer models and electronic displays to update their forecast of the storm's strength and direction. Calls went out to the areas directly in its path—the Cayman Islands, Cuba, Mexico. The Center's director and hurricane specialists briefed the press on the storm's progress, fielding thousands of phone and direct television interviews.

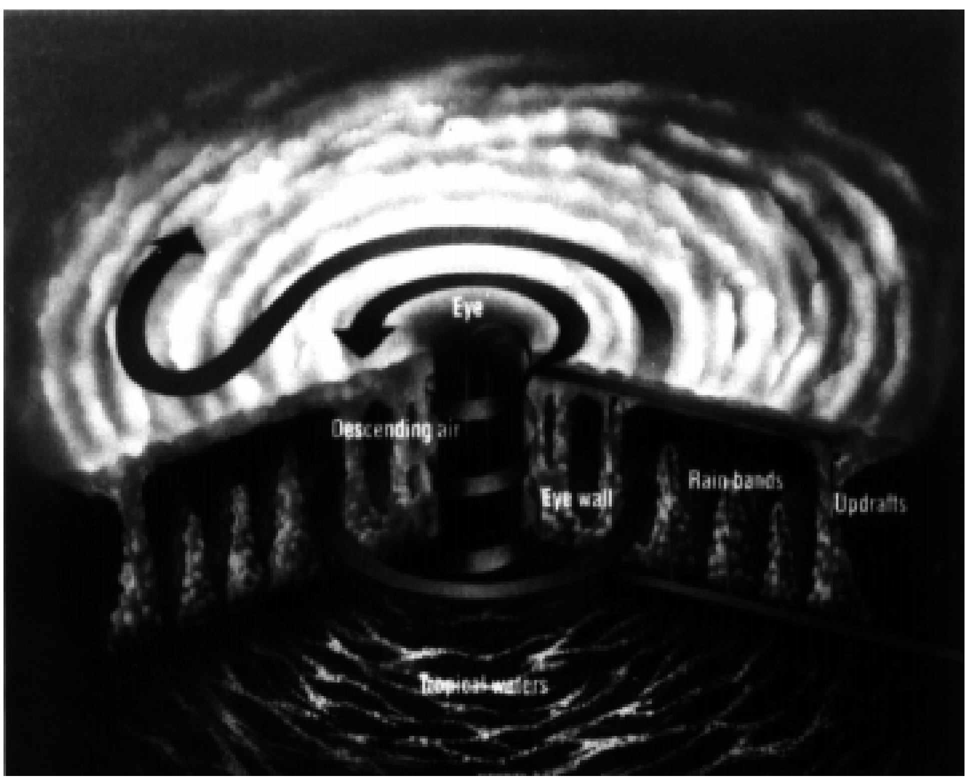
After battering Jamaica for 6 hours, the storm center moved off to the west. The toll: 45 dead, some 500,000 homeless, four-fifths of the island's houses damaged or destroyed, and roughly $2 billion in damage. But Gilbert had only begun to flex its muscles. Before it was over, the hurricane would become the storm of the century with sustained winds of 185 miles (300 kilometers) an hour and gusts of over 200 miles (320 kilometers) an hour.

Birth of a Storm

As is the case with the majority (60 to 70 percent) of the hurricanes that form in the North Atlantic from June to November each year (the official hurricane season), Gilbert began as a cluster of clouds moving off the northwest coast of Africa. The embryo of the storm—first observed by satellite on September 3—was associated with a tropical wave: a wrinkle in the uniformly eastern flow of the trade winds. Over the next several days, the system moved westward across the Atlantic in the trade wind belt.

Then, on September 8, as it approached the Lesser Antilles, its showers and thunderstorms began to coalesce. Satellite pictures showed that the system had developed the counterclockwise, cyclonic circulation typical of North Atlantic tropical storms. With wind speeds still under 39 miles (63 kilometers) an hour, it was classified as a tropical depression.

A hurricane rotates around an eye (facing page), its region of lowest pressure. To fill the low-pressure void, moist air rushes toward the eye, spiraling upward to create an eye wall (below). Once atop the eye, the air cools and descends back into the storm. Outside the eye, towers of warm moist air form updrafts that produce rainbands.



The process by which the system formed and subsequently strengthened depended on at least three conditions: warm surface waters, high humidity, and the ability to concentrate heat in the vertical. The latter factor depends on winds at all levels of the development system to be essentially from the same direction at the same speed. A storm like Gilbert begins to form when air is warmed by contact with the water (gaining sensible, or measurable, heat) and is moistened by evaporation from it (gaining latent heat that will later be released through condensation). The need for these conditions explains why hurricanes form only in warm months over warm waters.

As the air warms, it rises, spiraling inward toward the center of the system. And the closer it gets to the center, the faster it moves. The reason is partial conservation of angular momentum—the same principle that causes a figure skater to spin slowly with arms extended and to spin faster with arms tucked in. The strong winds created by the moving air produce turbulent seas, and huge amounts of spray become suspended in the air. The suspended spray, in turn, increases the rate of evaporation so that the storm begins to feed on itself.

In a hurricane, the center is a relatively calm area, the eye. The most violent activity takes place in the area immediately around the eye, called the eyewall. There, as the spiraling air rises and cools, moisture condenses into tiny droplets, forming clouds and rainbands. The condensation releases latent heat, which causes the air to rise still farther; and that, in turn, results in more condensation. The result is a column of rapidly rising air that produces an intense low pressure area near the storm center.

At the top of the eyewall (about 50,000 feet, or 15,250 meters), most of the air is propelled outward in an anticyclonic flow. (Without this flow, the air's upward motion would be stifled, and pressure at the center of the storm would begin to rise.) However, some of the air moves inward and sinks into the eye. This air is warmed rapidly by compression; and as it warms, its moisture-holding capacity increases and the air dries out. As a result, in intense hurricanes, the eye becomes nearly cloud-free.

At the middle to upper levels of the storm, the temperature is much warmer in the eye than outside it. This temperature difference creates a large pressure differential across the eyewall, contributing to the violence of the storm. Hurricane-force winds can produce waves 50 to 60 feet (15 to 18 meters) high in the open ocean. When the storm meets land, the combination of low pressure and high winds produces a dome of high water—the storm surge—that is pushed ashore and floods low-lying area.

Tracking Gilbert

By September 9, when the system that would become Gilbert came within range of reconnaissance aircraft, satellite pictures indicated that the clouds were rapidly becoming better organized. The aircraft (which are operated by the Air Force and the National Oceanic and Atmospheric Administration (NOAA) and fly directly into a storm's eye) soon found that wind speeds were over 39 miles (63 kilometers) an hour. The system therefore was designated tropical storm Gilbert. (Each year, hurricanes and tropical storms are named in alphabetical order from a list approved by the U.S. World Meteorological Organization [WMO].) It moved through the Lesser Antilles late that day.

Gilbert then strengthened rapidly. Late on September 10 with winds blowing at 74 to 95 miles (120 to 153 kilometers) an hour, it reached category 1 status on the Saffir/Simpson Scale, used to measure hurricane strength. About 12 hours later, it attained category 2 status—with winds of 96 to 110 miles (154 to 177 kilometers) an hour—and took direct aim at the island of Jamaica.

At the National Hurricane Center in Coral Gables, several types of satellite images flowed into computers and electronic display systems and were filtered, enhanced, colorized, animated, and analyzed by the satellite meteorology staff. Cloud motions were used to estimate winds at various levels in the atmosphere around the hurricane, while data from aircraft pinpointed the exact location of the storm and its strength and wind field distributions. Along with surface observations from land stations, ships and buoys, and weather balloons throughout the region, this information was fed into computer models to determine the extent of the hurricane, its changes with time, and expected storm surge heights and areas of inundation—information that would be used by local officials to determine what areas needed to be evacuated.

As the storm center passed south of the Dominican republic, an electronic display of satellite pictures showed a massive, rotating cloud system that covered most of the eastern half of the Caribbean, with the hurricane's eye clearly visible. Based on the computer models, the National Hurricane Center forecast that the center of Gilbert would pass directly over Jamaica shortly after noon on September 12. John Blake, director of the Jamaican Meteorological Services, discussed the situation over a restricted telephone line with the director of the National Hurricane Center. By the early afternoon of September 11, the "hurricane watch" issued early in the day for Jamaica (warning of the possibility of a hurricane) was upgraded to a "hurricane warning" (indicating the probability of a hurricane within the next 12 to 24 hours).

With reports indicating that Gilbert was rapidly gaining strength, Jamaica prepared for the onslaught of a major hurricane with winds in excess of 100 miles (160 kilometers) an hour. Residents in low-lying areas that might be covered by the storm surge, those in potential flash flood areas, and those in substandard housing were moved to places of refuge as fast as resources permitted.

The National Hurricane Center, meanwhile, in its capacity as the Regional Tropical Meteorological Center of the WMO, provided guidance and advice for countries throughout the region. Several phone calls were made to the meteorological services of Cuba and Mexico and to government officials in the Cayman Islands to discuss the storm's probable impact and the wording for warnings. Similar discussions were held with officials in south Florida and with other branches of the National Weather Service. Complete forecast and warning packages were produced every 6 hours, with intermediate advisories at 3-hour intervals.

A Record Storm

Gilbert struck Jamaica as a category 3 hurricane—a storm with winds of 111 to 130 miles (178 to 209 kilometers) an hour—and continued to strengthened. It reached category 4 status—winds of 131 to 155 miles (210 to 249 kilometers) an hour—before its center passed about 20 miles (32 kilometers) south of Grand Cayman Islands at 9 a.m. on September 13. The maximum sustained surface winds near the storm center approached 140 miles (225 kilometers) an hour at this time.

Then, less than 2 hours after passing Grand Cayman, Gilbert became a rare category 5 hurricane with winds in excess of 155 miles (250 kilometers) an hour. And by 6 p.m. on September 13, the storm attained the lowest sea-level pressure ever measured in the Western Hemisphere: 26.22 inches (888 millibars) of mercury. (Pressure is considered the most accurate measure of storm strength, with lower pressure indicating a stronger storm.) It is likely that the hurricane reached a minimum pressure as low as 26.15 inches (885 to 886 millibars) of mercury between measurements taken by reconnaissance aircraft.

By comparison, the lowest pressure measured in deadly Hurricane Camille of 1969 was 26.73 inches (905 millibars). The previous record was 26.34 inches (892 millibars) recorded in the violent but small 1935 Florida Keys hurricane. Among factors cited as contributing to Gilbert's strength were the facts that the storm strengthened over very warm waters and that its eye was much smaller than average, which had the effect of concentrating the hurricane's energy.

Hurricane strength, in general, is unrelated to overall size. However, very strong hurricanes usually have relatively small eyes—less that 10 miles (16 kilometers) in diameter. But, in addition to its strength, Gilbert was huge. As the storm approached Mexico, satellite pictures showed that its circulation covered the entire western half of the Caribbean, Central America, and the southeastern Gulf of Mexico.

The center of Hurricane Gilbert moved across the east coast of the Yucatan Peninsula near

Cozumel on the morning of September 14. It was the first landfall of a category 5 hurricane in the Western Hemisphere in nearly 20 years. (The last occurrence was in 1969 with Hurricane Camille.) Cancun and other resort areas were hit hard. At Cancun Beach, the 20-foot (6-meter) storm surge picked up a Cuban freighter several miles offshore and tossed it ashore like a toy boat.

As the center moved inland over the large landmass of the peninsula, the source of energy for the core—warm water—was cut off. The inner eyewall then weakened, nearly dissipating by the time the center had crossed the Yucatan. However, the tentacles of Gilbert reached well out over the Gulf of Mexico and the Caribbean, maintaining the hurricane's outer strength.

In fact, the stronger winds began spreading out over an even larger area than before until they covered large portions of the gulf ahead of the center. These strong winds stirred up the waters, bringing cool water from below to the surface. The effect of these cooler waters was to additionally reduce the energy that the storm would normally absorb. This helped limit the strength of the showers and thunderstorms at the storm's core.

In the nearly 2 days it took for the storm to move from Yucatan across the southwestern gulf to northern Mexico, the central pressure remained nearly constant. The inner eyewall never reformed and started to reappear only near landfall on the Mexican coast. However, with the storm's strength spreading farther from the center, hurricane-force winds and high tides were felt along the lower Texas coast, well away from the core.

Grand Cayman did record a maximum sustained wind of 137 miles (220 kilometers) an hour with a gust of 155 miles (250 kilometers) an hour, but these extreme conditions were not experienced for a prolonged time. The final factors that prevented more damage were that buildings were generally well constructed and that most structures were on the west end of the island. The cyclonic circulation primarily produced onshore winds on the north and east coasts, with much shorter periods of onshore wind on the west and south coasts.

Timely and accurate warnings were also credited with keeping loss of life to a minimum. Frequent updates on the storm's progress were provided by the National Hurricane Center for the broadcast networks, local television and radio stations, and print media throughout the region. A Spanish-speaking meteorologist provided briefings for Hispanic stations. Several broadcasters produced extended public service programs and documentaries. And, more than 100,000 callers dialed the hurricane hotline number.

Finally, in spite of the damage Gilbert generated, the storm had a beneficial aspect. As its remnants moved toward the northeast across the United States, it brought some much-needed rain to the drought-stricken Midwest.

A Record Year

The 1988 Atlantic hurricane season produced 11 named storms, 5 of which reached hurricane strength. The number of named storms was slightly above the long-term average of nine to ten, and the number of hurricanes was slightly below the average of six. However, 1988 will be remembered as a season of record-breaking hurricanes.

In addition to Gilbert, Hurricane Joan broke intensity records. Joan was a category 4 hurricane on the Saffir/Simpson Scale when it struck Nicaragua on October 22. There had never been a record of a hurricane of this intensity at so low a latitude in the western Caribbean. Joan's minimum pressure at landfall near Bluefields, Nicaragua, was 27.46 inches (930 millibars), and the storm had sustained winds of nearly 135 miles (217 kilometers) an hour. Joan earned another distinction when it crossed Central American from Atlantic to Pacific and was renamed Tropical Storm Miriam—a rare though not unprecedented event.

Joan and Gilbert combined to produce more than $5 billion in damage and more than 500 deaths through the Caribbean, Central America, and Mexico. When a later hurricane, Helene, reached full strength, 1988 became the first year since 1961 to experience three hurricanes with strengths of category 4 or more.

While Texas felt the fringe of giant Hurricane Gilbert, the United States on the whole was not severely affected by the 1988 hurricanes. Tropical Storms Beryl, Chris, and Keith, and Hurricane Florence made landfall on the continental United States. Beryl and Florence struck in eastern Louisiana and Mississippi, while Chris moved inland near the Georgia-South Carolina border. Keith, a large late-season storm just below hurricane strength, affected most of the west coast of Florida and, later, central Florida and the east coast, north of Palm Beach. Total direct damage from these storms was estimated to be near $60 million—an amount well below the annual average of more than $1 billion over the past decade.

Gilbert's high winds blew aircraft around like toys at the Kingston, Jamaica, airport. By the time the storm reached the Texas coast, its strength had largely dissipated although it provided much needed rain.

Hurricane Warning Service

The history of the Weather Service over the past century would be bland indeed without a detailed account of the growth of the Nation's hurricane warning service. Today, the hurricane warning and forecast service stands as the finest of its kind in the world, distinguished by its character, credibility, and the confidence that our Nation has in it. But that wasn't always the case.

The Weather Bureau was created as a civilian agency in 1890 mainly because of a general dissatisfaction with weather forecasting under the military. The hurricane of 1875 that destroyed Indianola, Texas, without much warning was a contributing factor.

It was not until the Spanish American War of 1898 that an effort was made to establish a comprehensive hurricane warning service. President McKinley stated that he was more afraid of a hurricane than he was of the Spanish Navy. He extended the warning service to include warnings for shipping interests as well as the military. Before that, hurricane warnings were only issued for the United States coastal areas. Hurricane warning stations were established throughout the West Indies. A forecast center was established in Kingston, Jamaica, and later moved to Havana, Cuba, in 1899. The warning service was extended to Mexico and Central America. This recognition of the international responsibility for the United States hurricane warning service continues today under the auspices of the World Meteorological Organization of the United Nations.

In 1900, the infamous Galveston hurricane killed 6,000 people—the greatest natural disaster in United States' history. There was no formal hurricane warning, and this calamity prompted the transfer of the warning service to Washington, DC, where it remained until 1935.

In the 1920's, there were several hurricanes that hit with little or no warning that led to dissatisfaction with the hurricane service out of Washington. The coastal communities felt that Washington was insensitive to the hurricane problem. In 1926, a very strong hurricane (category 4 by today's standard) brought great devastation to southeast Florida, including Miami and Ft. Lauderdale, causing more than 200 deaths. The warnings for that storm were issued at night when most residents were asleep and unaware of the rapidly approaching hurricane. In 1928, another severe hurricane hit south Florida and killed an estimated 1,800 people who drowned when Lake Okeechobee overflowed. In 1933, the largest number of tropical storms—21—developed. Nine of them were hurricanes and two that affected the east coast of the United States, including Washington, were badly forecast and warned. In 1934, a forecast and warning for an approaching hurricane in the very sensitive Galveston area was badly flubbed by Washington.

Those incidents led Congress and the President to revamp and decentralize the hurricane warning service. Improvements included 24-hour operations with teletypewriter hook-up along the gulf and Atlantic coasts; weather observations at 6 hourly intervals; hurricane advisories at least four times a day; and a more adequate upper air observing network. New hurricane forecast centers were established at Jacksonville, Florida; New Orleans, Louisiana; San Juan, Puerto Rico; and Boston, Massachusetts (established in 1940).

In 1943, the primary hurricane forecast office at Jacksonville was moved to Miami where the Weather Bureau established a joint hurricane warning service with the Army Air Corps and the Navy under the direction of Grady Norton. It was also in 1943 that Col. Joseph Duckworth made the first intentional plane reconnaissance into the eye of a hurricane. The following year, regular aircraft reconnaissance was begun by the military giving hurricane forecasters the location and intensity of the storms for the first time.

Grady Norton continued as head of the Miami Center until his death in 1954 during Hurricane Hazel that ravaged the east coast of the United States. Norton established a strong and popular reputation as an extraordinary forecaster with the tremendous ability to communicate with residents along the hurricane vulnerable coastlines. Gordon Dunn, who served as Norton's assistant in Jacksonville, was selected as Norton's successor, and the Miami Office was officially designated as the National Hurricane Center in 1955.

In the 1950's, a number of hurricanes in addition to Hazel struck the east coast, causing much damage and flooding. Congress responded with increased appropriations to strengthen the warning service and intensify research into hurricanes. The Weather Bureau organized the National Hurricane Research Project under the direction of Dr. Robert H. Simpson. The Air Force and the Navy provided the first aircraft to be used by the project to investigate the structure, characteristics, and movement of tropical storms.

In 1960, radars capable of "seeing" out to a distance of 200 to 250 miles from their coastal sites were established at strategic locations along the Atlantic and gulf coasts from Maine to Brownsville, Texas. On April 1, 1960, the first weather satellite was placed in orbit giving hurricane forecasters the ability to detect storms before they hit land.

Gordon Dunn retired in 1967 and was succeeded by Dr. Simpson, who placed a renewed emphasis on research and development activities at the Center through satellite applications and the development of statistical and dynamic models as forecast aids. Dr. Simpson retired after the 1973 hurricane season and was succeeded by his Deputy, Dr. Neil Frank, who served until 1987. Dr. Frank's tenure was marked by great emphasis on the need for hurricane preparedness along the hurricane-prone communities in the United States as well as in the Caribbean. He and his staff created an increased national awareness of the hurricane threat through the cooperation of local and state emergency officials and the enlistment of the news media and other Federal agencies in the campaign to substitute education and awareness for the lack of first-hand experience among the ever-increasing coastal populations.

Dr. Robert Sheets is the current Director of the National Hurricane Center and at a time where the future holds even greater promise to improve the hurricane warning capability of the National Weather Service. New technology and advances in the science under the Weather Service's modernization program now underway will lead to improvement and more effective warning and forecasting of hurricanes.

The next GOES series of satellites is expected to provide more accurate and higher resolution sounding data than presently available from geosynchronous satellites, and similar improvements can be expected from the polar orbit satellite systems.

Major improvements in longer range hurricane forecasts (36-72 hours) will come through better quality and quantity of observations and improved dynamical models. Global, hemispheric, and regional models show considerable promise.

Present operational reconnaissance aircraft provide invaluable data in the core of the hurricane. Doppler radar are now an integral part of the National Oceanic and Atmospheric Administration's research aircraft operations providing entire data fields within several miles of the aircraft's path.

NEXRAD (Next Generation Radar) will add new dimensions to hurricane warning capabilities. They will provide much needed information on tropical cyclone wind fields and their changes as they move inland. Local offices will be able to provide more accurate short-term warnings as rainbands, high winds, and possible tornadoes move toward specific inland locations. Heavy rains and flooding frequently occur over widespread inland areas.

Improved observing systems and anticipated improvements in analysis, forecasting, and warning programs require efficient accessing, processing, and analysis of large quantities of data from numerous sources. These data also provide the opportunity for improved numerical forecasts. The Class VII computer at the National Meteorological Center will permit operational implementation of next generation hurricane prediction models.

Products must be provided to users which optimize the desired response. AWIPS (Advanced Weather Interactive Processing System) will be the primary tool for accomplishing this task. Critical hurricane information needed by local, state, and other Federal agencies, as well as the private sector, will be displayed graphically and transmitted to the user faster and more complete than ever before, making more effective warning and evacuation response.

The future of the Nation's splendid hurricane warning and forecast service is indeed brighter than ever before!

Sources for above:

"The National Hurricane Center—Past, Present, and Future" by Dr. Robert C. Sheets, Weather and Forecasting, June 1990.

"A Brief History of the United States Hurricane Warning Service" by G.E. Dunn, 1971.

Hurricane Reconnaissance

Aerial weather reconnaissance is vitally important to the forecasters of the National Hurricane Center. Reconnaissance aircraft penetrate to the core of the storm and provide detailed measurements of its wind field as well as accurate location of its center; information that is usually not available from any other source. This information helps the meteorologist determine what is going on inside a storm as it actually happens. Aircraft data coupled with data from satellites, buoys, and land and ship reports, makes up an important part of the information available to the hurricane specialists for their forecast of speed, intensity, and direction of movement of the storm.

The National Hurricane Center is supported by specially modified aircraft of the U.S. Air Force Reserve (USAFR) and the National Oceanic and Atmospheric Administration's (NOAA) Aircraft Operations Center (AOC). The USAFR crews are known as the "Storm Trackers" and are part of the 815th Tactical Airlift Squadron which is based at Keesler Air Force Base near Biloxi, Mississippi. They fly the Lockheed WC-130 "Hercules," a four-engine turboprop aircraft which carries a crew of six people and can stay aloft for up to 14 hours. NOAA flies Lockheed WP-3 "Orions," another four-engine turboprop that carries a crew consisting of from seven to seventeen persons and can stay aloft for up to 12 hours. The NOAA/AOC aircraft and crews are based at Miami International Airport. Both units can be deployed as needed in the Atlantic, Caribbean, Gulf of Mexico, and the Central Pacific Ocean.

Meteorological information obtained from aerial reconnaissance include winds, pressure, temperature, dew point temperature, and location of the storm center. A parachute-borne weather sensor dropped from the plane measures the storm characteristics below the aircraft. Data from the storm environment is available as often as once every minute. This information provides a detailed look at the structure of the storm and a clear indication of its intensity.

Aerial weather reconnaissance in one of nature's most destructive forces is not without risk. In September 1955, a Navy P2V and its crew of nine plus two Canadian newsmen were lost in the Caribbean Sea while flying in Hurricane Janet. Three Air Force aircraft have been lost flying in typhoons in the Pacific.

Flying into a hurricane is a unique experience. Weather crew members who have flown combat missions say that their feelings before both missions were similar. There is a blend of excitement and apprehension. Adding to the tension is the knowledge that no two hurricanes are alike. Some are gentle while others are like raging bulls. Preparations for flying into a hurricane must be thorough. All crew members are highly trained specialists. Loose objects are tied down or stowed away, and crew members wear seat belts and safety harnesses. Once the aircraft's radar picks up the storm, the crew determines the easiest way to get inside. In a well developed storm, this can be a difficult challenge. Winds at flight level often exceed 100 miles an hour, and the wall cloud surrounding the center can be several miles thick. Rain often comes in torrents, and updrafts and downdrafts are usually strong and frequent. Inside the eye, however, the conditions are much different; many times the ocean is visible and there is blue sky and sunshine above. The flight level winds are nearly calm. Often the wall cloud presents a stadium effect.

Both the WC-130 "Hercules" and the WP-3 "Orion" operate most efficiently at altitudes of 24,000 to 30,000 feet. Since most storms occur some distance from the aircraft's home station, the crew usually flies to the storm as high as they can because this helps to conserve fuel. About 200 miles from the storm, the aircraft descends to its storm operating level. If the storm is in its infancy, such as a depression or tropical storm with winds less than 50 mph, then the crew operates as close to the surface of the sea as can be done safely—usually about 1,500 feet. If the storm is more fully developed, either a hurricane or a strong tropical storm, then the aircraft flies its pattern, including penetrations to the center at 10,000 feet altitude. A typical mission will last from 10-12 hours during which time the crew will penetrate to the center of the storm anywhere from 3 to 6 times. When its mission is completed, the aircraft will climb back to altitude for the trip home.

The job of tying the reconnaissance effort together rests with a small group of former Air Force people assigned to the Hurricane Center. This unit, under the Chief, Aerial Reconnaissance Coordination, All Hurricanes (known by the acronym CARCAH), is responsible for coordinating requirements and arranging for supporting flights. Data relayed back to the Center by satellite downlink is checked for accuracy by CARCAH and then transmitted to the world-wide meteorological community through both military and civilian communications circuits.

Saffir/Simpson Hurricane Scale

All hurricanes are dangerous, but some are more so than others. The way storm surge, wind, and other factors combine determines the hurricane's destructive power. To make comparisons easier—and to make the predicted hazards of approaching hurricanes clearer to emergency forces—National Oceanic and Atmospheric Administration's hurricane forecasters use a disaster-potential scale which assigns storms to five categories. Category 1 is a minimum hurricane; category 5 is the worst case. The criteria for each category are shown below.

This can be used to give an estimate of the potential property damage and flooding expected along the coast with a hurricane.

Category	**Definition—Effects**
ONE	**Winds 74-95 mph:** No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage.
TWO	**Winds 96-110 mph:** Some roofing material, door, and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.
THREE	**Winds 111-130 mph:** Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet ASL may be flooded inland 8 miles or more.
FOUR	**Winds 131-155 mph:** More extensive curtainwall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Major damage to lower floors of structures near the shore. Terrain continuously lower than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.
FIVE	**Winds greater than 155 mph:** Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline may be required.

Click on the title for the tables listed below:

The Deadliest Mainland United States Hurricanes (1900-1996)
The Costliest mainland United States Hurricanes (1900-1996)
The Most Intense Mainland United States Hurricanes (1900-1996)

Terms To Know

By international agreement, **TROPICAL CYCLONE** is the general term for all cyclone circulations originating over tropical waters, classified by form and intensity as follows:

TROPICAL WAVE: A trough of low pressure in the trade-wind easterlies.

TROPICAL DISTURBANCE: A moving area of thunderstorms in the Tropics that maintains its identity for 24 hours or more. A common phenomenon in the tropics.

TROPICAL DEPRESSION: A tropical cyclone in which the maximum sustained surface wind is 38 mph (33 knots) or less.

TROPICAL STORM: A tropical cyclone in which the maximum sustained surface wind ranges from 39-73 mph (34-63 knots) inclusive.

HURRICANE: A tropical cyclone in which maximum sustained surface wind is 74 mph (64 knots) or greater.

SMALL CRAFT CAUTIONARY STATEMENTS: When a tropical cyclone threatens a coastal area, small craft operators are advised to remain in port or not to venture into the open sea.

TROPICAL STORM WATCH: Is issued for a coastal area when there is the threat of tropical storm conditions within 36 hours.

TROPICAL STORM WARNING: A warning for tropical storm conditions, including sustained winds within the range of 39 to 73 mph (34 to 63 knots) which are expected in a specified coastal area within 24 hours or less.

HURRICANE WATCH: An announcement that hurricane conditions pose a possible threat to a specified coastal area within 36 hours.

HURRICANE WARNING: A warning that sustained winds of 74 mph (64 knots) or higher are expected in a specified coastal area within 24 hours or less.

STORM SURGE: An abnormal rise of the sea along a shore as the result, primarily, of the winds of a storm.

FLASH FLOOD WATCH: Means that flash flood conditions are possible within the designated watch area—***be alert***.

FLASH FLOOD WARNING: Means a flash flood has been reported or is imminent—***take immediate action***.

Hurricane Safety Advice

Be Prepared **BEFORE** the Hurricane Season:

- ✓ Know the storm surge history and elevation of your area.
- ✓ Learn safe routes inland.
- ✓ Learn location of official shelters.
- ✓ Review needs and working condition of emergency equipment, such as flashlights, battery-powered radios, etc.
- ✓ Ensure that enough non-perishable food and water supplies are on hand to last for *at least* 2 weeks.
- ✓ Obtain and store materials, such as plywood and plastic, necessary to properly secure your home.
- ✓ Check home for loose and clogged rain gutters and downspouts.
- ✓ Keep trees and shrubbery trimmed. Cut weak branches and trees that could fall or bump against the house. When trimming, try to create a channel through the foliage to the center of the tree to allow for air flow.
- ✓ Determine where to move your boat in an emergency.
- ✓ Review your insurance policy to ensure it provides adequate coverage.
- ✓ Individuals with special needs should contact their local office of emergency management.
- ✓ For information and assistance with any of the above, contact your local National Weather Service office, emergency management office, or American Red Cross chapter.

When a "**Hurricane WATCH**" is issued:

- ✓ Frequently monitor radio, TV, NOAA Weather Radio, or hurricane hotline telephone numbers for official bulletins of the storm's progress.
- ✓ Fuel and service family vehicles.
- ✓ Inspect and secure mobile home tie downs.
- ✓ Prepare to cover all window and door openings with shutters or other shielding materials.
- ✓ Check food and water supplies.
  - — Have clean, air-tight containers on hand to store at least 2 weeks of drinking water (14 gallons per person).
  - — Stock up on canned provisions.
  - — Get a camping stove with fuel.
  - — Keep a small cooler with frozen gel packs handy for packing refrigerated items.
- ✓ Check prescription medicines—obtain at least 10 days to 2 weeks supply.
- ✓ Stock up on extra batteries for radios, flashlights, and lanterns.
- ✓ Prepare to store and secure outdoor lawn furniture and other loose, lightweight objects, such as garbage cans, garden tools, potted plants, etc.
- ✓ Check and replenish first-aid supplies.
- ✓ Have on hand an extra supply of cash.

When a **"Hurricane WARNING"** is issued:

- ✓ Closely monitor radio, TV, NOAA Weather Radio, or hurricane hotline telephone numbers for official bulletins.
- ✓ Follow instructions issued by local officials. *Leave immediately if ordered to do so.*
- ✓ Complete preparation activities, such as putting up storm shutters, storing loose objects, etc.
- ✓ Evacuate areas that might be affected by storm surge flooding.
- ✓ If evacuating, leave early (if possible, in daylight).
- ✓ Leave mobile homes in any case.
- ✓ Notify neighbors and a family member outside of the warned area of your evacuation plans.

If Evacuating:

Plan to evacuate if you...

- — live in a mobile home. Do not stay in a mobile home under any circumstances. They are unsafe in high wind and/or hurricane conditions, no matter how well fastened to the ground.
- — live on the coastline or on an offshore island, or live near a river or in a flood plain.
- — live in a high-rise. Hurricane winds are stronger at higher elevations. Glass doors and windows may be blown out of their casings and weaken the structure.

- ✓ Stay with friends or relatives or at a low-rise inland hotel or motel outside of flood zones. Leave early to avoid heavy traffic, roads blocked by early flood waters, and bridges impassible due to high winds.
- ✓ Put food and water out for pet if you cannot take

it with you. *Public shelters do not allow pets nor do most motels/hotels.*

✓ Hurricane shelters will be available for people who have no other place to go. Shelters may be crowded and uncomfortable, with no privacy and no electricity. Do not leave your home for a shelter until government officials announce on radio and/or television that a particular shelter is open.

What to bring to a shelter: first-aid kit; medicine; baby food and diapers; cards, games, books; toiletries; battery-powered radio; flashlight (per person); extra batteries; blankets or sleeping bags; identification, valuable papers (insurance), and cash.

If Staying in a Home:

Reminder! Only stay in a home if you have not been ordered to leave. If you *ARE* told to leave, do so immediately.

✓ Store water:
- — Fill sterilized jugs and bottles with water for a 2-week supply of drinking water.
- — Fill bathtub and large containers with water for sanitary purposes.

✓ Turn refrigerator to maximum cold and open only when necessary.
✓ Turn off utilities if told to do so by authorities.
✓ Turn off propane tanks.
✓ Unplug small appliances.

Stay inside a well constructed building. In structures, such as a home, examine the building and plan in advance what you will do if winds become strong. Strong winds can produce deadly missiles and structural failure. If winds become strong:

- — Stay away from windows and doors even if they are covered. Take refuge in small interior room, closet, or hallway. Take a battery-powered radio, a NOAA Weather Radio, and a flashlight with you to your place of refuge.
- — Close all interior doors. Secure and brace external doors, particularly double inward opening doors and garage doors.
- — If you are in a two-story house, go to an interior first-floor room or basement, such as a bathroom, closet, or under the stairs.
- — If you are in a multiple-story building and away from the water, go to the first or second floors and take refuge in the halls or other interior rooms away from windows. Interior stairwells and the areas around elevator shafts are generally the strongest part of a building.
- — Lie on the floor under tables or other sturdy objects.

Be alert for tornadoes which often are spawned by hurricanes.

If the "EYE" of the hurricane should pass over your area, be aware that the improved weather conditions are <u>temporary</u> and that the storm conditions will return with winds coming from the <u>opposite</u> direction sometimes in a period of <u>just a few minutes</u>.

<u>**AFTER** the storm passes</u>:

✓ Stay in your protected area until announcements are made on the radio or television that the dangerous winds have passed.

✓ If you have evacuated, do not return home until officials announce your area is ready. Remember, proof of residency may be required in order to re-enter evacuation areas.

✓ If your home or building has structural damage, do not enter until it is checked by officials.

✓ Avoid using candles and other open flames indoors.

✓ Beware of outdoor hazards:

- — Avoid downed power lines and any water in which they may be lying.
- — Be alert for poisonous snakes, often driven from their dens by high water.
- — Beware of weakened bridges and washed out roads.
- — Watch for weakened limbs on trees and/or damaged overhanging structures.

✓ Do not use the telephone unless absolutely necessary. The system usually is jammed with calls during and after a hurricane.

✓ Guard against spoiled food. Use dry or canned food. Do not drink or prepare food with tap water until you are certain it is not contaminated.

✓ When cutting up fallen trees, use caution, especially if you use a chain saw. Serious injuries can occur when these powerful machines snap back or when the chain breaks.

The Naming of Hurricanes

For several hundred years, many hurricanes in the West Indies were named after the particular saint's day on which the hurricane occurred. Ivan R. Tannehill describes in his book "HURRICANES," the major tropical storms of recorded history and mentions many hurricanes named after saints. For example, there was "Hurricane Santa Ana" which struck Puerto Rico with exceptional violence on July 26, 1825, and "San Felipe" (the first) and "San Felipe" (the second) which hit Puerto Rico on September 13 in both 1876 and 1928.

Tannehill also tells of Clement Wragge, an Australian meteorologist, who began giving women's names to tropical storms before the end of the 19th Century.

An early example of the use of a woman's name for a storm was in the novel "STORM" by George R. Stewart, published by Random House in 1941 and since filmed by Walt Disney. During World War II, this practice became widespread in weather map discussions among forecasters, especially Air Force and Navy meteorologists who plotted the movement of storms over the wide expanses of the Pacific Ocean.

In 1953, the United States abandoned as confusing a 3-year old plan to name storms by phonetic alphabet (Able, Baker, Charlie) when a new, international phonetic alphabet was introduced. That year, this Nation's weather services began using female names for storms.

The practice of naming hurricanes solely after women came to an end in 1978 when men's and women's names were included in eastern North Pacific storm lists. In 1979, male and female names were included in lists for the Atlantic, Caribbean, and Gulf of Mexico.

Experience shows that the use of short, distinctive names in written, as well as in spoken communications, is quicker and less subject to error than the older more cumbersome latitude-longitude identification methods. These advantages are especially important in exchanging detailed storm information between hundreds of widely scattered stations, airports, coastal bases, and ships at sea.

The use of easily remembered names greatly reduces confusion when two or more tropical cyclones occur at the same time. For example, one hurricane can be moving slowly westward in the Gulf of Mexico, while at exactly the same time another hurricane can be moving rapidly northward along the Atlantic coast. In the past, confusion and false rumors have arisen when storm advisories broadcast from one radio station were mistaken for warnings concerning an entirely different storm located hundreds of miles away.