Hurricanes and Tropical Meteorology

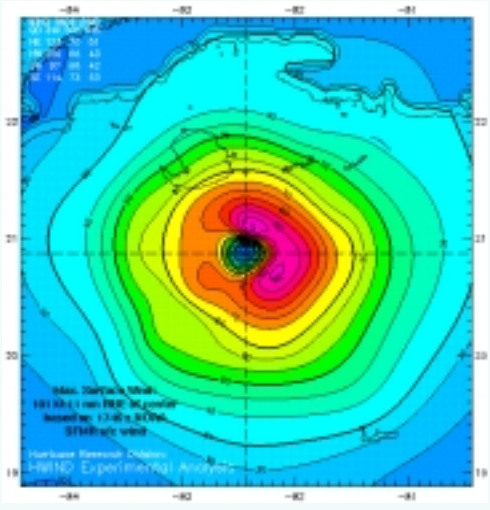
Background:

Inside the eyewall of Hurricane Floyd (September 1999). Wingtip of the NOAA WP-3D reconnaissance aircraft appears in the upper left corner.

Over the last 20 years, hurricane research at AOML has focused on improved scientific understanding of hurricanes and of tropical meteorology generally, with the ultimate objective of better forecasts on all spatial and temporal scales. Specific scientific goals for AOML's hurricane research derive from the U.S. Weather Research Program's (USWRP) Hurricanes at Landfall (HaL) focus (Marks and Shay, 1998, *Bull. Amer. Met. Soc.*). They reflect a broad consensus across the USWRP consortium composed of forecasters and researchers in academia and government. Within the USWRP framework, the first dedication is to cutting-edge science at the frontier of hurricane research, with an overwhelming bias for science that will improve forecasts and reduce human and economic losses. AOML's Hurricane Research Division (HRD) scientists lead airborne field observing campaigns, facilitate instrument and model development, provide the theoretical framework for understanding hurricane dynamics, and collaborate widely with scientists from universities and other government laboratories.

Challenges:

Studies of historical hurricanes show that cyclones in Simpson-Saffir categories 3 and 4 account for 80% of the economic losses. Most hurricanes that reach category 3 and all hurricanes that reach category 4 do so through rapid deepening. Thus, rapid deepening is important both because it is difficult to forecast and because it causes the most destructive hurricanes. A testable hypothesis is: Are the necessary and sufficient conditions for rapid deepening category 2 or greater initial intensity, an ocean that stays warmer than some threshold (~28°C), and low shear of the environmental wind; or are these conditions only necessary? If the latter, what else is essential?



Surface wind analysis plot for Hurricane Michelle (November 4, 2001). Wind analyses are used for determining the intensity and radial extent of the maximum sustained winds in tropical systems.

AOML must continue to strive for more and better observations of surface winds for assimilation into its analysis scheme, H*WIND. Analysis of surface winds is a key complement to a predictive capability because it enables rational hurricane-resistant design. HRD scientists are currently collaborating with National Weather Service (NWS) forecasters through the new Joint Hurricane Testbed (JHT) to make H*WIND fully operational.

Currently, the way to improve track forecasts is through improved specification of the flow around the storm. This strategy typically reduces forecast errors by 1-2% annually. In 15 to 20 years, the improvement will asymptote with <100 km error at 24 hours. Then, propagation due to the storm's internal dynamics will become the focus. Even before forecasts reach the deterministic limit, ensemble-

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An airborne expendable bathythermograph (AXBT) is launched from one of NOAA's WP-3D reconnaissance aircraft.

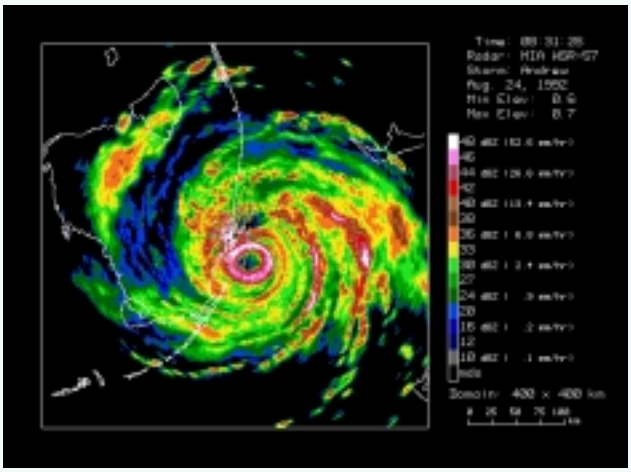
based probabilistic techniques will predominate. Track forecasting is an important and scientifically elegant topic to which AOML would like to commit more resources.

A shift of emphasis from hurricane winds to quantitative rainfall forecasting was envisioned in the USWRP long-term planning. This investigation leverages AOML's expertise in cloud microphysics and radar with NASA's capabilities in remote sensing through NASA's recurring Convection and Moisture Experiment (CAMEX) field campaigns. It entails both basic science and technique development. The hurricane is an ideal laboratory for study of precipitation processes because of the strong kinematic control by the stable, long lasting vortex. A key first step, supported under JHT, is development of a climatology and persistence forecast model (R-CLIPER) for hurricane rainfall, based upon remotely-sensed data. As studies of intensity change and surface winds mature, resources will be shifted to rainfall.

During the 1970s, 1980s, and early 1990s, these storms were relatively rare. The 1990s saw a return to the higher levels of activity that characterized the middle of the 20th century. This shift appears to be largely independent of global warming. It is instead a manifestation of the Atlantic Multidecadal Oscillation, a 70-year cycle in the Atlantic thermohaline circulation. Increasingly detailed and reliable predictions of these cycles will prove vital as tropical cyclones pose a dramatically increased threat to the Caribbean islands and east coast of North America during the first two or three decades of the 21st century.

Priorities:

The Hurricane Research Division's most important scientific goal is advancement of physical understanding of hurricane intensity change and implementation of increasingly skillful intensity forecasts. A particular target of this work is rapid intensification, the phenomenon that will unquestionably cause the next hurricane catastrophe. An equally important technology transfer effort is analysis of hurricane surface winds. This work is essential to support forecasting, emergency management, design of survivable structures, wise land use, and insurance regulation. The effort to improve track forecasts through synoptic surveillance and targeted observations continues, but with somewhat fewer resources than in the past. Quantitative estimation and prediction of tropical cyclone rainfall is becoming an increasingly vital part of AOML's program because drowning in fresh water inland is a significant cause of hurricane-related mortality.



Radar image of Hurricane Andrew (August 1992) about to make landfall in south Florida.

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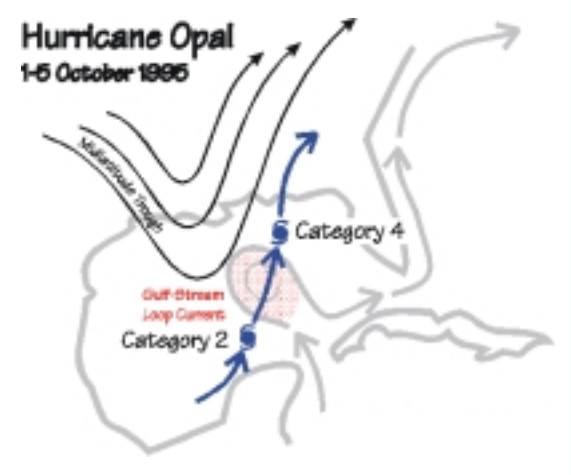
AOML commits a modest, but sustained, effort to sophisticated understanding of the climatology of hurricane occurrence. This research is the key to preparing the human and natural environments for the rare, but extreme, events that dominate hurricane impacts.



Hurricane Opal's northward careen across the Gulf of Mexico, showing schematically the storm's rapid deepening as a result of interaction with a "digging" mid-latitude trough and its passage over a deep pool of warm water in an eddy spun off from the Gulf Stream.

Research Goals and Actions for 2002-2007:

Goal:

Improve understanding of hurricane intensity change by employing several promising avenues

Actions:

- Provide measurements and analysis to elucidate two-way coupled sea-air interaction in hurricanes
- Provide analysis of the roles of shear and trough interaction
- Use chemical tracers to understand tropical cyclone dynamics and thermodynamics
- Test statistical prediction of rapid intensification onset (**JHT**, indicates work being transitioned to operations under the Joint Hurricane Testbed)

Goal:

Improve measurement and analysis of surface winds in tropical cyclones

Actions:

- Analyze dropsonde and remotely-sensed observations of boundary layer winds
- Perform analysis of winds during catastrophic landfalls
- Implement operational objective surface wind analysis (**JHT**)

NOAA's Gulfstream-IV SP jet is a state-of-the-art high altitude research platform. It was acquired in 1996 to improve NOAA's tropical cyclone forecast capability by being able to deploy dropsondes from high altitudes over large areas of open sea, where few observations are availabe.

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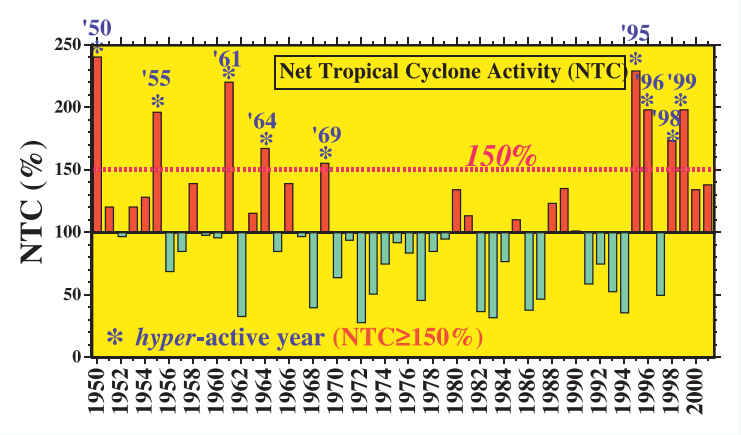
Goal:

Establish climatology of hurricane intensity and occurrence

Actions:

- Analyze decade-to-decade fluctuations in hurricane occurrence
- Analyze economic and human impacts of hurricane landfall to establish the vulnerability of society to these events
- Utilize the climatology to improve prediction of the seasonal activity six months in advance



Net tropical cyclone activity is a measurement of overall activity that includes the number, strength, and duration of storms. Atlantic basin tropical cyclone activity has increased dramatically since 1995.

Goal:

Improve prediction of hurricane tracks

Actions:

- Continue optimal targeted aircraft observations to establish better methods of decision making (**JHT**)
- Conduct ensemble forecasting and determine/develop better methods (**JHT**)

Goal:

Improve quantitative precipitation estimates for tropical systems

Actions:

- Use airborne and spaceborne remote observations of precipitation to establish predictive relationships
- Perform observational studies of precipitation processes
- Derive the climatological storm-relative distribution of hurricane rainfall (**JHT**)

Anticipated Impacts:

This research will reduce expense and disruption due to warning of areas that do not actually experience the hurricane. It will also mitigate property damage to some extent and reduce the probability of catastrophic loss of life. Finally, it will support rational design of the built and social environments to make them resilient against the hurricane threat.

Beyond 2007:

As understanding and forecasts of intensity change improve, the research emphasis will shift more strongly to quantitative precipitation forecasting. When the improvement in track forecasts due to more accurate specification of the steering current begins to reach a deterministic limit, the effect of storm propagation will need reexamination. At about the same time, ensemble-based, probabilistic forecasts will yield further improvement in all aspects of the forecast problem.