The NOAA Hurricane Hunters: A Historical and Mission Perspective

Jennifer Collins, University of South Florida
Paul Flaherty, NOAA Aircraft Operations Center

Abstract

The National Oceanographic and Atmospheric Administration (NOAA) Hurricane Hunters protect lives and property by using increasingly-sophisticated instrumentation to collect atmospheric data in and around the hurricane environment. This article describes why the NOAA Hurricane Hunters fly into severe weather, along with their day-to-day responsibilities when not flying into storms. In addition, this article highlights NOAA's entire fleet of aircraft, focusing on the two main platforms used by the Hurricane Hunter crews. With an emphasis on instrumentation and primary missions, ways in which the collected data is used by researchers and forecasters is discussed. T

Tropical cyclones are one of nature's most destructive weather events. As such, not only are they important financially, with hurricanes such as Andrew causing $US 38.4 billion of damage, but also in terms of loss of life, with storms such as the Labor Day 1935 Hurricane being responsible for just over 400 deaths. A tropical cyclone is a non-frontal (barotropic) synoptic scale low pressure system over tropical or sub-tropical waters with organized convection and definite cyclonic surface wind circulation (Holland, 1993). When considering storms in the North Atlantic and Eastern North Pacific, the weakest classification of a tropical cyclone is the 'tropical depression'. This may develop into a 'tropical storm' if wind speeds reach 17.5 m s-1 (34 knots) over a one-minute average. At this stage a name would be assigned to the system. Another classification is made at 33 m s-1 (64 knots) when the term 'hurricane' is used. A further distinction is made between a hurricane and an 'intense (or major) hurricane' when wind speeds become greater than 50 m s-1 (96knots). This may also be described as a major hurricane of category 3 or above, according to the Saffir-Simpson scale which describes hurricane wind speeds (Landsea, 1993; Elsner and Kara, 1999).

Tropical cyclones develop over the warm open ocean, and while satellites have been able to track their movement since 1961 (with Hurricane Esther being the first hurricane observed by satellite), aircraft reconnaissance has remained an important eye in the sky to get the most accurate information about the storm. Since its creation in the early 1960s, National Oceanographic and Atmospheric Administration (NOAA) Hurricane Hunters have provided the nation with increasingly-sophisticated atmospheric data in the hurricane environment, to aid NOAA and the National Hurricane Center (NHC) in depicting storms more accurately and in predicting hurricane track and intensity. The history of "hunting" hurricanes extends back to 1943 with the first flight into a hurricane eye by U.S. Army Air Forces (USAAF) Colonel Joseph Duckworth (Dorst 2007). By the following year, reconnaissance missions into tropical systems were being flown by the USAAF, with assistance from the U.S. Weather Bureau (USWB) and the U.S. Navy. In 1970, the U.S. government created NOAA, and transferred USWB services to the NOAA National Weather Service (NWS) (Dorst 2007). Currently, hurricane reconnaissance flights are conducted primarily by the US Air Force Reserve's 53rd Weather Reconnaissance

Squadron stationed at Keesler Air Force Base in Biloxi, Mississippi, while research and surveillance missions are conducted primarily by NOAA's Hurricane Hunters out of MacDill Air Force Base in Tampa, Florida (NOAA Aircraft Operations Center Science Section n.d.).

Since January 1993, NOAA Hurricane Hunter aircraft are operated and maintained by NOAA's Aircraft Operations Center (AOC) in Tampa. Currently under NOAA's Office of Marine and Aviation Operations (OMAO), NOAA's Hurricane Hunters and the AOC were born out of the Research Flight Facility (RFF), which operated out of the Miami International Airport from 1961 through 1992. NOAA's mission statement declares the following (NOAA (a) n.d):

"Science, Service, and Stewardship.

To understand and predict changes in climate, weather, oceans, and coasts,

To share that knowledge and information with others, and

To conserve and manage coastal and marine ecosystems and resources."

The very specialized NOAA aircraft directly support this mission by providing scientists with unique platforms to precisely observe, measure and chart the dynamics of our oceans and atmosphere.

Some of the AOC's duties include weather research and data accumulation, overseeing aircraft use pertaining to weather events, and providing planning services for fisheries and coastal management (Sullivan n.d.). During the hurricane season, the aircraft and crew gather data in and around tropical systems, providing this information to organizations such as the National Hurricane Center based in Miami, FL. This information is also available to the media, emergency managers, and to the public in near-real time. While the data is used by computer models to help forecast the track and intensity of the storm, it is also used by forecasters to verify pertinent storm information forecasted in prior model runs. This verification step becomes even more critical as individual computer models often output different track and/or intensification forecasts. By providing the data, forecasters are able to consider which models are handling the storm's track and intensity changes better than others. In addition, the provided data allows the different models to initialize with the same parameters in an area that is typically data sparse.

When not flying into tropical systems such as Hurricane Katrina (Figure 1), the NOAA Hurricane Hunters are involved in other weather research and operational projects including winter storm reconnaissance (e.g. Majumdar et al. 2010), air quality studies (e.g. Langford et al. 2011), low-level jet experiments (e.g. Vera et al. 2006), atmospheric rivers over the Pacific (e.g. Neiman et al. 2011), BAMEX (Bow echo and mesoscale convective vortex experiment; e.g. Storm et al. 2011), drylines (e.g. Hane et al. 2001), mountain waves (e.g. Garvert et al. 2011), Madden–Julian oscillation (MJO) research (e.g. Kerns and Chen 2013), and a myriad of other meteorological and climatological studies.

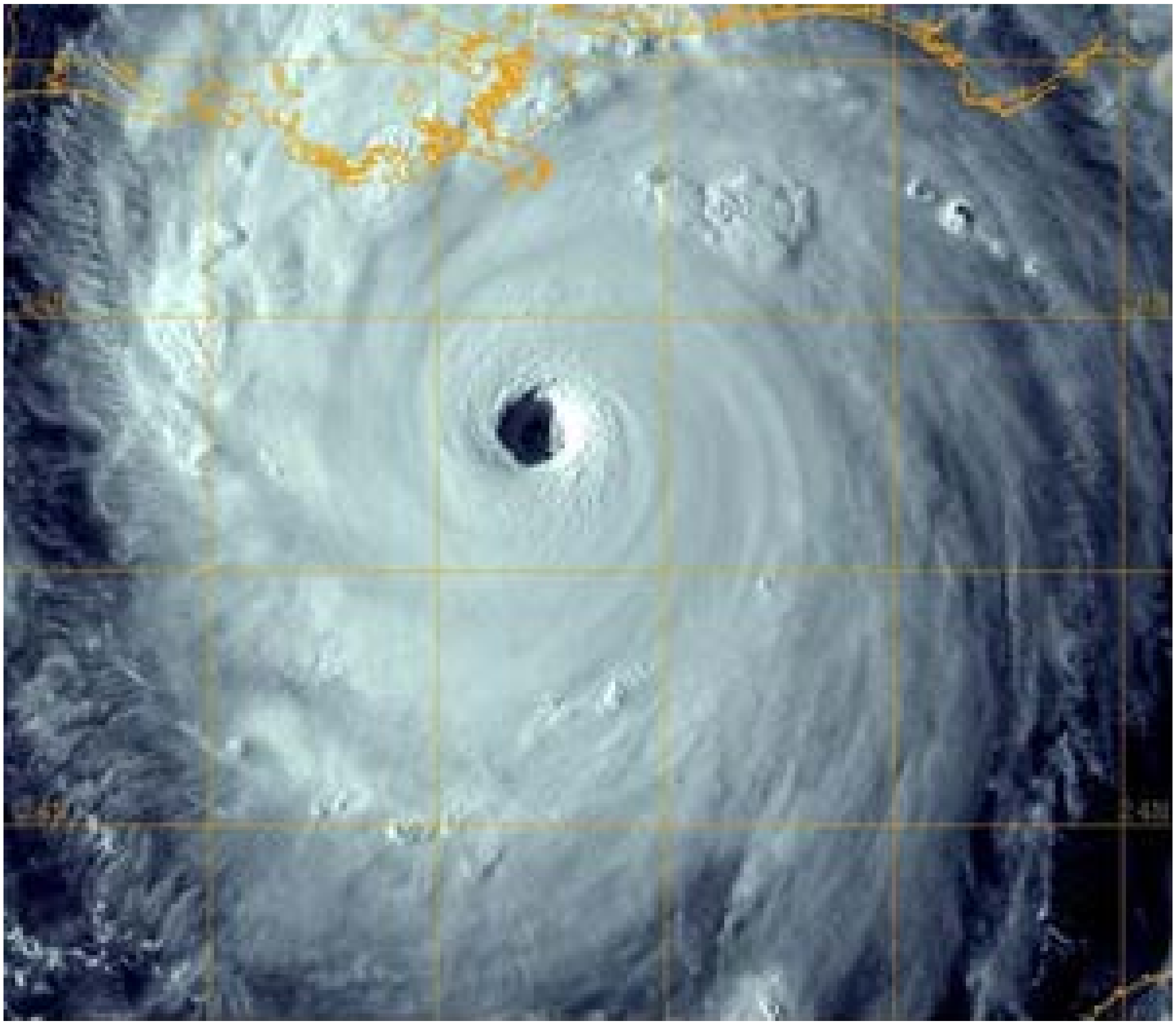

Figure 1. Hurricane Katrina, 2005 (This, and subsequent illustrations are from NOAA web sites, unless suggested otherwise.)

When not flying science missions, hurricane hunters remain active through training and simulation exercises, reviewing aircraft regulations and policies, maintaining aircraft and scientific equipment, reviewing and updating data collection and quality control procedures, attending conferences on relevant scientific technologies and advancements (NOAA (b) 2012), and speaking with students and other public groups about the importance of the missions.

NOAA Flight Meteorologists, also known as Flight Directors, continually work to ensure that the data collected by the aircraft are of the highest quality. On a normal flight day, Flight Directors arrive at the office up to three hours before the planned take-off time in order to analyze the 'area of operations', or the storm environment. Along with mission scientists, they outline a plan that allows the aircraft to meet the science objectives of the day in a safe and efficient manner. Two hours before take-off, the Flight Director meets with the AOC flight crew to discuss the plan (Figure 2). During this time, AOC Flight Engineers, Mechanics, Engineers, Technicians, and visiting scientists work to prepare the aircraft for the mission (Figure 3). One hour before take-off, most of the crew is on the aircraft and preparing for departure.

Figure 2. Pre-Flight Briefing with the Aircrew. Professor Jennifer Collins from the University of South Florida (far right) is joining them on a mission into Hurricane Sandy to observe (Courtesy of Paul Flaherty)

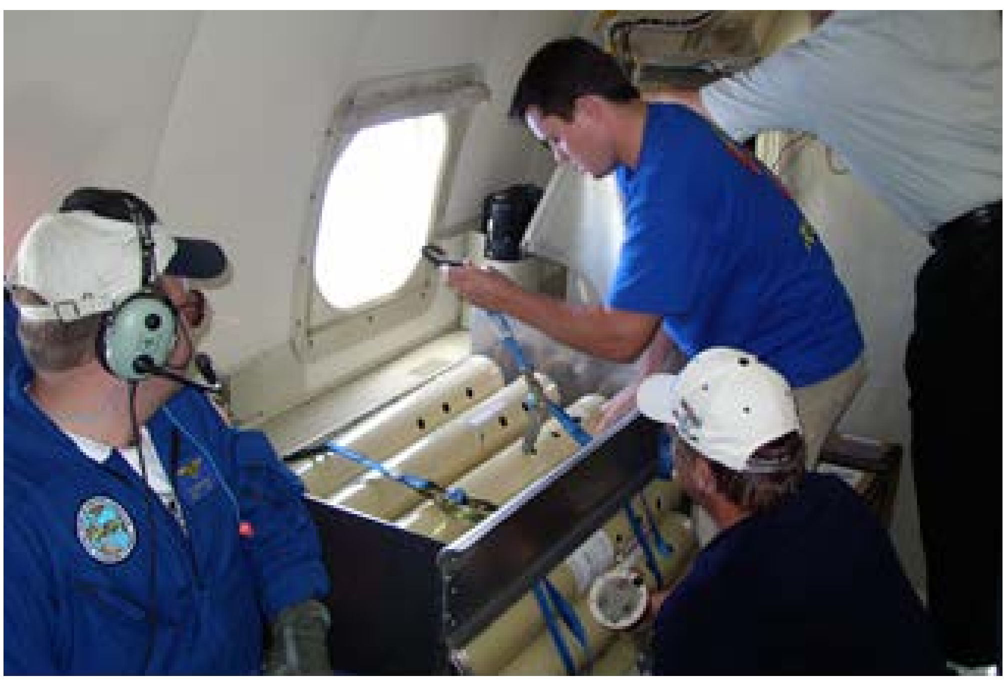

Figure 3. Scientists Help AOC Crewmembers Load and Secure Airborne Expendables for an Upcoming Mission (Courtesy of NOAA AOC)

NOAA's AOC has a fleet of aircraft (Figure 4, Figure 5 and Table 1). The two main platforms used by the NOAA Hurricane Hunters are the Lockheed WP-3D Orion which flies through the hurricane's eyewall at altitudes of 1,500-12,000 ft (and has a typical crew of 18 including pilots, meteorologists, engineers, navigators, technicians, and visiting scientists), and the Gulfstream IV (G-IV) jet which flies above the storm at altitudes of 40,000-45,000 ft with a smaller crew. The NOAA WP-3D Orion is a very sturdy plane that can withstand turbulence, has lots of horse power, is propeller-driven, and can fly for about ten hours. These airframe characteristics make the aircraft suitable for low-altitude flying, and a primary consideration for why the U.S. Navy used the P-3 Orion to defend the U.S. coastline from Russian nuclear submarines during the cold war era.

The NOAA G-IV has only a slightly shorter flying time up to about nine hours, but can cover a much greater distance. The WP-3D Orion's dimensions are approximately 120 ft long, 34 ft high and has a wingspan of roughly 100 ft. The G-IV is approximately 90 ft long,
25 ft high, and has a wingspan of just under 78 ft.

Figure 4. NOAA's Aircraft Operations Center Fleet. The NOAA G-IV is at the back middle, the two WP-3D Orion planes are at the back right and left, the King Air is at the front middle, the Turbo (Jet Prop) Commanders are at the front, and the Twin Otters are the blue planes (second from front) (Courtesy of NOAA AOC)

Aircraft Name	**Lockheed Martin WP-3D**	**Gulfstream G-IV-SP**	**De Havilland DHC-6 Series 360 Twin Otter**	**Hawker Beechcraft King Air 350CER**	**Gulfstream Jet Prop Commander 1000 AC-695A**
Instrumentation	C-band nose radar; lower fuselage C-band research radar – 360 deg. horizontal fan beam; tail Doppler X-band, GPS dropsonde atmospheric profiling system Airborne Expendable; Sea surface temperature radiometer; CO2 air temperature radiometer, Stepped Frequency Microwave Radiometer, C-band and Ku-band scatterometers	GPS dropsonde tube with 8-channel tracking capability; Satellite Communication System with voice/data transmission capability; Numerous Computer Systems; Tail Doppler Radar	Fully configurable; Instrumentation hatch can be removed for access to belly instrumentation and camera ports. Various camera mounts are available from the AOC for nose and belly camera ports	Dual sensor ports with optical glass pressure plates and electronically operated FOD doors, cargo door, convex observer windows	Gamma radiation detection system mounted in the cabin of the aircraft. Fully configurable cabin.
Primary Missions	OAR - Hurricane Research, NWS - Hurricane Reconnaissance, Midwest Thunderstorms	NWS - Hurricane Surveillance, OAS - Hurricane Research	NMFS - Marine Mammal Surveys, NWS - Snow Survey, OAR - Air Chemistry, NOS - Coastal Mapping, OMAO - Emergency Response	NOS - Coastal Mapping, OMAO - Emergency Response	NWS - Snow Survey, OMAO - Emergency Response
Powerplant	4 Allison T56-14 Turbo Prop engines. Each rated at 4600 Shaft Horse Power (SHP)	Two Fuselage Mounted Rolls Royce Tay 611-8 twin spool turbofan jet engines	2x Pratt and Whitney PT6A-27 Turboprop Engines	2x Pratt and Whitney PT6A-60A Engines, 1,050 (SHP)	2 Garrett TPE-331-10 (turboprop) 800 HP/each
Crew	18 (4 scientists /observers)	6 (4 scientists /observers)	2 pilots, up to 6 scientists	2 pilots, 3 observers	2 pilots, 1 observer as needed
Operational Airspeed	180 - 250 kts	Mach .77 - .80 at 41,000 to 45,000 ft	80 - 160kts	200kts+	120 - 250kts
Endurance	Up to 10.5 hrs	Up to 9.5 hrs	Up to 6.5 hrs	Up to 6 hrs	5-6 hrs

Scientific Power	4 Generators (3 are engine driven, 1 Auxiliary Power Unit) each generator yields 120 volt, 3 phase, 400HZ power 90 KVA max power	Two engine driven alternators, two Converters, 23KVA, 400 Hz, 3 phase AC power, 250 amps, 28 volts DC power	3KVA of 115 VAC, 60hz and 70A of 28VDC	250 amps @ 115 VAC / 28 VDC	Two 30 volt 300 ampere starter-generators, Two 24 volt lead acid batteries
Max Gross Weight	135,000 lbs	74,600 lbs	12,500 lbs	16,500 lbs	11,250 lbs
Empty Weight			8100 lbs	10,567 lbs	
Useful Load			4400 lbs		
Max Altitude				35,000 ft	35,000 ft

Table 1. NOAA's Aircraft Operations Center Fleet

Figure 5. History of the AOC's Hurricane Hunter Aircraft Dating Back to 1960. In this figure are the years the aircraft flew research and recon missions, along with their respective maximum altitudes and ranges. Note that these ranges are half of the maximum range for the aircraft, an depict how far out the plane can fly before having to return back to base. The background image is of an eyewall penetration intoHurricane Katrina (2005). (Figure arranged by Randall Hergert, University of South Florida).

In an effort to help NOAA bridge the gap between science and younger generations, the AOC has given Muppet character names to their hurricane hunter aircraft. The two WP-3D Orion planes are nicknamed 'Kermit' and 'Miss Piggy', and the G-IV is called 'Gonzo'. The idea originated several years ago after one of the P-3's (N43RF) was nicknamed "The Pig" by the maintenance crew for being heavier and a little less tidy than N42RF. As a joke, one of the crew drew a picture of 'Miss Piggy' with a NOAA symbol, and placed it on N43RF (NOAA (c) 2007). Thinking it was a great idea, one of the pilots came up with the idea of contacting Henson Productions. Mr. Henson was thrilled with the idea. Together, it was agreed that they would create something similar to World War II nose art. As Kermit and Miss Piggy are such good friends and the two aircraft are very close, it was agreed to give N42RF the nickname 'Kermit'. The nose art was created by Henson Productions and has been part of the aircraft ever since. When the G-IV was acquired in 1996 as part of the Hurricane Hunters team, Henson Productions agreed once again to provide the nose art. NOAA chose the character of Gonzo because of the aircraft's non-standard nose radome on the NOAA G-IV.

As the demand for high-quality data acquisition in and around tropical cyclones increased over time, the technology and aircraft used for reconnaissance missions became more advanced and specialized. Meeting this demand, the NOAA P-3's have a variety of specialized equipment on board, including the C-band nose radar, the lower fuselage C-band research radar – 360 degree horizontal fan beam, tail Doppler X-band radar, a GPS dropsonde atmospheric vertical profiling system, airborne expendable oceanographic temperature/current/salinity probes, a CO2 air temperature radiometer, a stepped frequency microwave radiometer (surface winds), and both C-band and Ku-band scatterometers (surface winds). Both Hurricane Hunter platforms have advanced radar for weather avoidance and data collection. When flying in and around convective weather, the G-IV nose radar is constantly monitored by the pilots and the Flight Director (Figure 6).

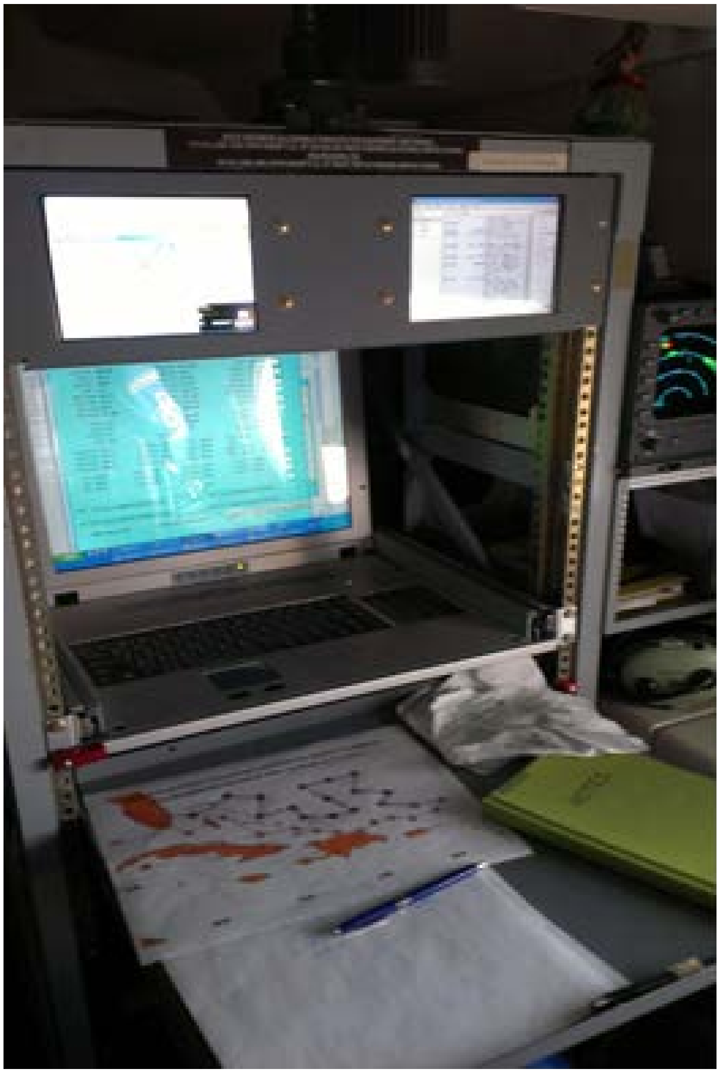

Figure 6. The G-IV Flight Director Station (Courtesy of NOAA AOC)

The Tail Doppler Radar (Figure 7) can detect precipitation and wind speed (Figure 8), obtaining 3-D wind fields within the storm.

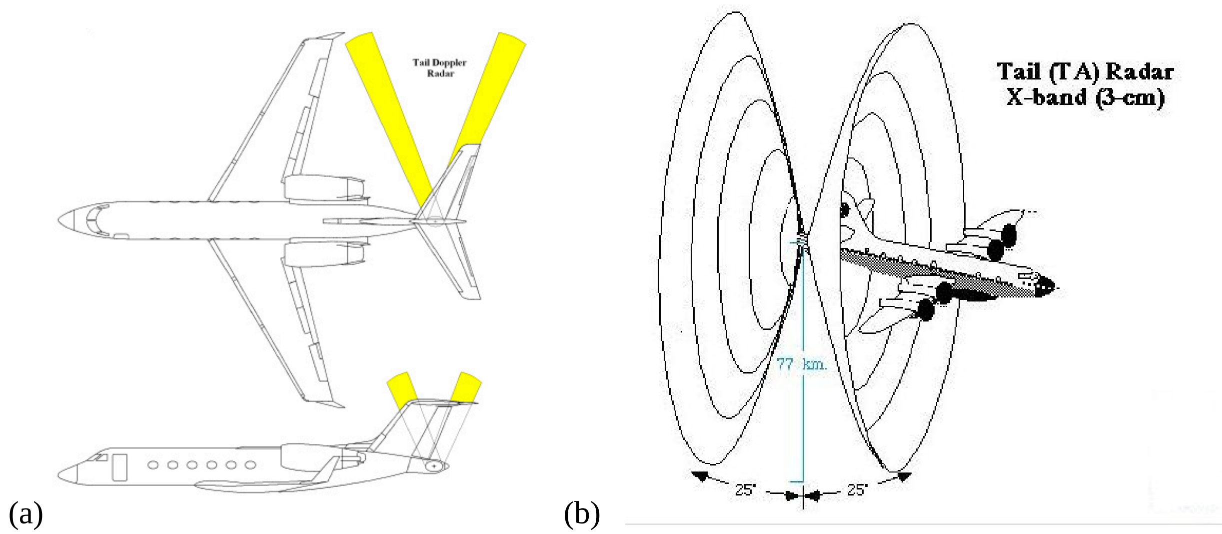

Figure 7. The Tail Doppler Radar's Location on the (a) NOAA G-IV and the (b) NOAA WP-3D Orion

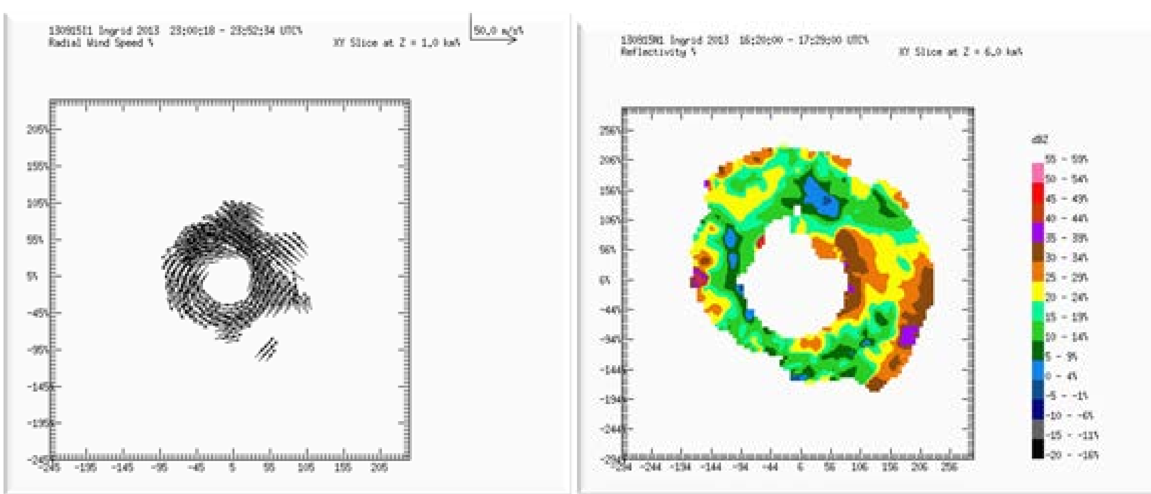

Figure 8. Examples of Tail Doppler Radar Output

GPS Dropsondes (Figure 9) are deployed from the aircraft descending through the atmosphere on a stabilizing parachute toward the ocean surface. During the descent, the dropsonde transmits meteorological information back to the aircraft. The information received and processed by aircraft systems includes atmospheric pressure, relative humidity, air temperature, altitude, wind direction and speed. This information is monitored and quality controlled by onboard meteorologists, coded into a World Meteorological Organization (WMO) message format, and transmitted from the aircraft in near-real time.

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The aircraft also have a multitude of fixed aviation and scientific probes. One unique example is the cloud physics probe on the P-3s which uses lasers to detect individual particles in clouds (Figure 10). There is also a long probe on the plane's nose which can be used to measure turbulent fluxes in the boundary layer.

Another unique but important piece of equipment is the Stepped Frequency Microwave Radiometer (SFMR; Figure 11). Also known as 'Smurf', the SFMR detects microwave radiation emitted from the ocean's surface. As increasing winds alter the sea-state of the ocean, the emitted radiation changes as well. Computers use this information, along with current surface water temperatures, to determine wind speeds based on the levels of microwave radiation detected.

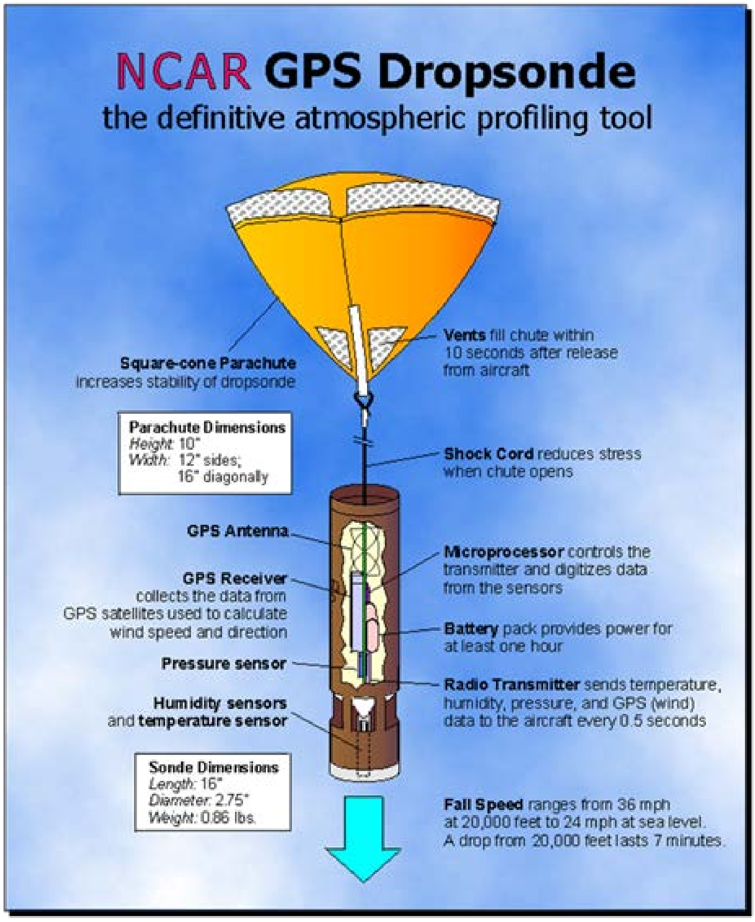

Figure 9. GPS Dropsonde (Courtesy of NCAR)

Figure 10. The Cloud Physics Probe on the P-3 (Courtesy of NOAA AOC)

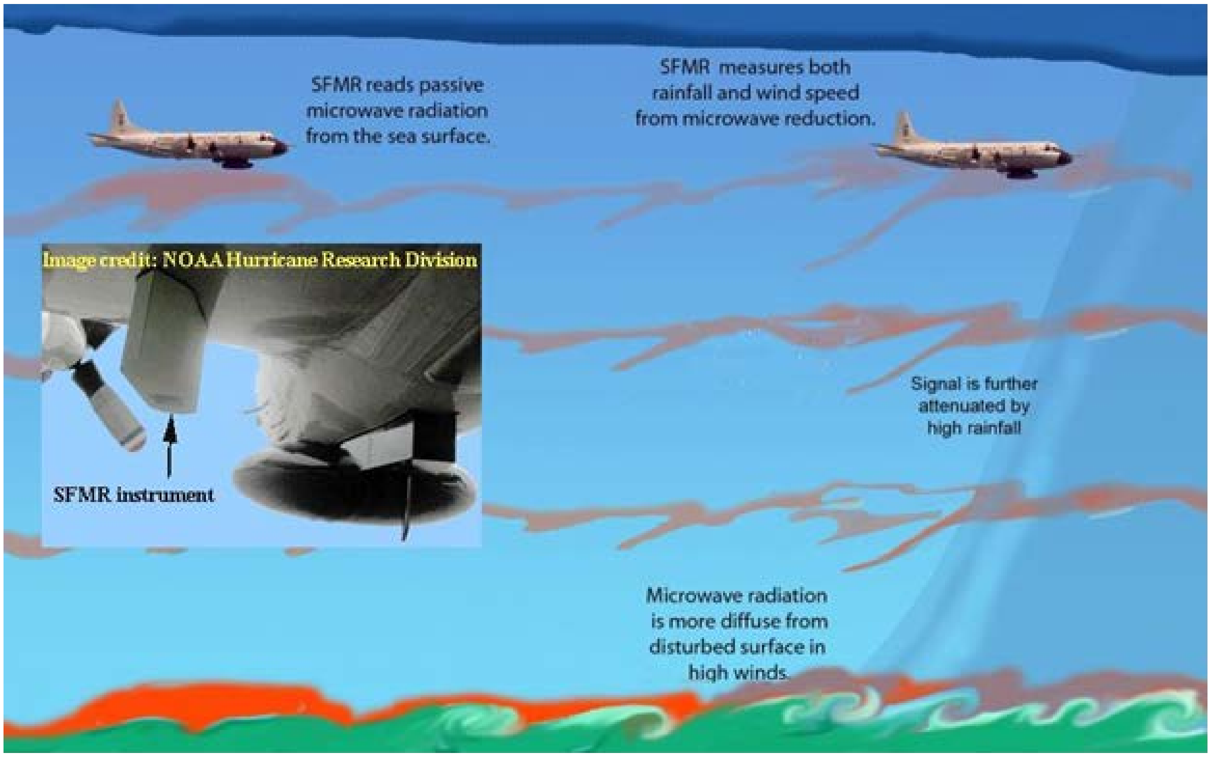

Figure 11. The SFMR Instrument and How it Works

The data collected by both platforms are used in real time to understand the storm's structure as well as the upper level steering winds. The data are also used in computer models which help forecast the storm's track and intensity. The collected data are also important post-season for research scientists. NOAA's Hurricane Hunters have amassed a myriad of data, much of it at the time of this publication is still on paper and tapes, which means the data are vulnerable to damage from possible fire or storm surge at low-lying MacDill Air Force Base.

The work of the AOC does not end once a hurricane makes landfall. During the aftermath of a land-falling hurricane, the AOC provides information and services, as directed, towards organized relief efforts (NOAA (b) 2012). For example, after Hurricane Katrina made landfall along the U.S. Gulf Coast in 2005, NOAA crews flew over affected areas documenting breached levees, reporting on the condition of NOAA facilities, and providing high-resolution imagery of the area. Today, NOAA relies on AOC's Hawker Beechcraft King Air 350 twin-engine turboprop to provide this high-resolution aerial imagery over areas affected by land-falling hurricanes. After Hurricane Sandy devastated coastal areas along the Northeast U.S. in 2012, AOC crews flying both the King Air and a NOAA Twin Otter "surveyed over 1,649 miles of coastline to document coastal damage and impacts to navigation" (NOAA (d) 2012). Regardless of the time of year, AOC personnel and aircraft may be called upon to provide aerial information to assist with relief efforts. After the 11 September 2001 attacks in New York and Washington, D.C., AOC crews were sent to fly over both the World Trade Center and the Pentagon (NOAA (e) n.d.). After the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, AOC crews were on scene shortly after the crisis began. AOC's response helped "collect and provide mission-critical information to guide the emergency response" (NOAA (f) n.d.). With international events, "NOAA works closely with the Department of Homeland Security, Department of Defense, Department of the Interior and others to provide coordinated remote sensing response capabilities" (NOAA (g) 2010). After the devastating January 2010 earthquake near the capital of Haiti, AOC crews were once again called upon to help with the relief efforts. Over Haiti, imagery provided by AOC were used "to support detailed damage assessment, locate and digitize footprints of major demolition projects necessary for long-term recovery and rebuilding, and preserve a high-resolution record of the initial post-disaster state to assess recovery efforts" (NOAA (h) 2010).

Florida experiences at least twice as many landfalling hurricanes as any other state. After using a GIS to plot the tracks of all tropical cyclones from 1851-2011 using data from the International Best Track Archive for Climate Stewardship (IBTrACS), Collins and Matyas (2013) showed that 269 passed through some part of Florida, yielding an average of 1.67 landfalls per year. When considering the future impacts of tropical cyclones to coastal Florida residents, one must consider that with the shallow bathymetry, the infrastructure built near its shores, along with the high coastal population density, the costs of Hurricane Andrew could easily be surpassed if a similar storm were to hit a major Florida city such as Miami and Tampa in the future. The NOAA Hurricane Hunters, as well as the University of South Florida, have recently forged a collaboration through the NOAA Preserve American Internal Funding (PAIF) initiative (NOAA PAIF 2013) to digitize and preserve the valuable data collected to benefit future research and public education. With so many vulnerable locations which may one day be in the path of a future landfalling hurricane, such information is vital. With more and more people moving to vulnerable coastal areas in Florida and elsewhere, this information is even more important to hurricane forecasters and researchers. Ultimately, emergency managers and the public benefit most from these data, especially if they one day find themselves making critical decisions based on a forecast of a tropical cyclone heading their way.

A link to a video:

http://oceantoday.noaa.gov/hurricanehunters/welcome.html

Acknowledgements

The authors would like to thank the editor, Dr. Christopher Meindl, as well as the anonymous reviewers for their constructive comments. Illustrations are from NOAA websites, unless stated otherwise.

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