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What's new at the NOAA Aircraft Operations Center: Improving the quality of research products along with direct online access to the data

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1. Introduction

The NOAA Aircraft Operations Center (AOC) has been flying since 1961 (first under its original name the Research Flight Facility (RFF)). In the beginning, the RFF flew two Douglas DC-6 and one DC-4 aircraft along with a modified Martin B-57A Canberra high altitude jet bomber that had been fitted with meteorological instruments (see Figure 1). Beginning in 1962, the RFF flew missions for the next 20 years as part of Project Stormfury, an effort to not only gather knowledge about the origin and structure of hurricanes, but also, through cloud seeding, to attempt mitigating the destructiveness of these storms. In 1970, a WC-130B was acquired from the Air Force as part of this project.

In 1976, the RFF, then flying missions out of Miami International Airport, accepted the first of two W-P3D Orion weather research aircraft designated N42RF and nicknamed Kermit. The following year, N43RF (Miss Piggy) joined to form the two plane fleet that would become the backbone of NOAA's airborne atmospheric research capability for the next 32 years. This allowed older aircraft in the RFF inventory to be retired (the DC-6B having logged over 300 eyewall penetrations into 40 different hurricanes). In 1983, the Office of Aircraft Operations (OAO) was created and the two Orions were joined by a host of smaller aircraft that fly a variety of research missions in support of NOAA projects worldwide that range from surveying snow coverage in higher latitude regions to tracking whales and other sea mammals (see Figure 2). In 1993, the OAO, now re-designated the AOC, was moved from Miami to its present home in Hangar 5 at MacDill AFB in Tampa, FL. In 1996, the AOC procured a Gulfstream G-IV high altitude jet (nicknamed Gonzo). A third WP-3D was delivered from the Navy to AOC in January 2010. This presentation will briefly describe the myriad of missions flown by AOC using the WP-3D and G-IV aircraft. While the tropical cyclone (TC) research mission is, in many respects, our most high profile endeavor that gathers the most attention, there are many other missions that are equally vital flown throughout the year across the world.

Figure 1 Aircraft originally flown by the NOAA RFF (later to become the AOC). Douglas DC-6 (left), DC-4 (center), Martin WB-57A (right)

Figure 2 Aircraft flown today by the NOAA Aircraft Operations Center including the Lockheed WP-3D Orion (center) and the Gulfstream G-IV (upper left)

2. Tropical Cyclone Research

Since the men and women of AOC who fly the WP-3D and G-IV aircraft are known as "NOAA's Hurricane Hunters" we begin with the tropical cyclone missions. There are three types of flights: Dedicated research missions employing one or both type of aircraft, operational hurricane reconnaissance flown in support of the National Hurricane Center (NHC) as per the Hurricane Operations Plan (NHOP) involving storm penetration using the WP-3D, and synoptic surveillance missions flown by the G-IV at high altitude in the environment surrounding a tropical cyclone, also tasked by NHC through procedures established in the NHOP. The AOC shares the responsibility for providing the aircraft and crews for the two operationally tasked NHOP missions with the 53rd Weather Reconnaissance Squadron, the US Air Force Reserve Hurricane Hunters, who fly the WC-130J and are based out of Keesler AFB in Biloxi, MS. The AOC is unique in that it flies both operational and research missions. Depending on the number of storms in a given season, AOC personnel can get very busy. In the record setting 2005 Atlantic Basin Hurricane season, WP-3D and G-IV crews logged 123 tropical cyclone flights and 897 hours.

The NOAA G-IV and the USAF WC-130J aircraft perform synoptic surveillance flights from high altitude releasing dropsondes in tracks that stretch sometimes across as much as 2,000 kilometers through the Gulf of Mexico and western Atlantic. Data from these sondes are ingested by the global models and have proven to be highly effective in improving the initialization of these models. For example, initializing the exact orientation, extent, and strength of the western end of the sub-tropical ridge is essential to many track forecasts of Cape Verde tropical cyclones as they approach North America. The G-IV is especially well suited for this role since it can cover a very long track at 450 knots airspeed and can release sondes from the 150 millibar level, thereby sampling the entire depth of the troposphere (see Figure 3). The need for such a platform was first expressed during the tenure of Bob Sheets, NHC Director in the early 1990s. It was based on WP-3D flights flown as much as 10 years earlier where the feasibility of mapping the steering currents around a TC by dropping a pattern of sondes was first investigated by Robert Burpee and James Franklin. However, these early efforts were limited by the inability of the WP-3D to reach altitudes above 400 millibars under most circumstances. The arrival of the G-IV to AOC in 1996 brought the capability to reach the tropopause, even near the Equator where it is found up at around 45,000 feet.

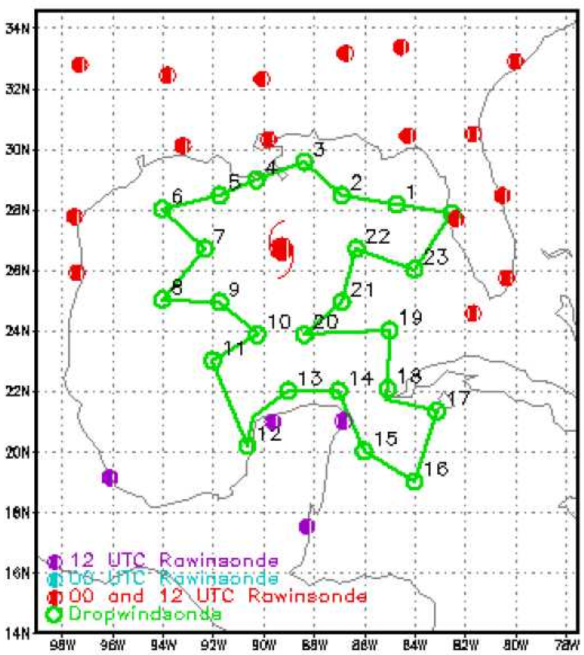


Figure 3 Example of a synoptic surveillance flight conducted by the G-IV and tasked by the NHC as Hurricane Katrina moved through the Gulf of Mexico during the early morning of 28 August, 2005. The green circles represent the locations of 23 dropsondes released to augment upper air data from the ground based radiosonde sites shown in red.

In terms of TC research, the AOC is a full participant in the US Weather Research Program's (USWRP) Joint Hurricane Testbed which strives to bring TC research tools into the operational realm as efficiently as possible. This includes efforts to improve the ability of the HWRF model to explicitly depict and forecast convective processes in a TC. John Gamache from the Atlantic Oceanographic and Meteorological Laboratory (AOML) Hurricane Research Division (HRD) has lead the effort to incorporate WP-3D tail Doppler radar (TDR) slices gathered during TC penetration flights into the Advanced Research high resolution version of the HWRF (ARW). These TDR slices, reflectivity and radial velocity products depicting the convective core and feeder bands of a TC, known as Superobs, are transmitted in near-real time from the aircraft into the server assimilating data for the ARW (see Figure 4). The National Center for Environmental Prediction (NCEP)'s Environmental Modeling Center (EMC) is working to get this capability as soon as possible to an operational status.

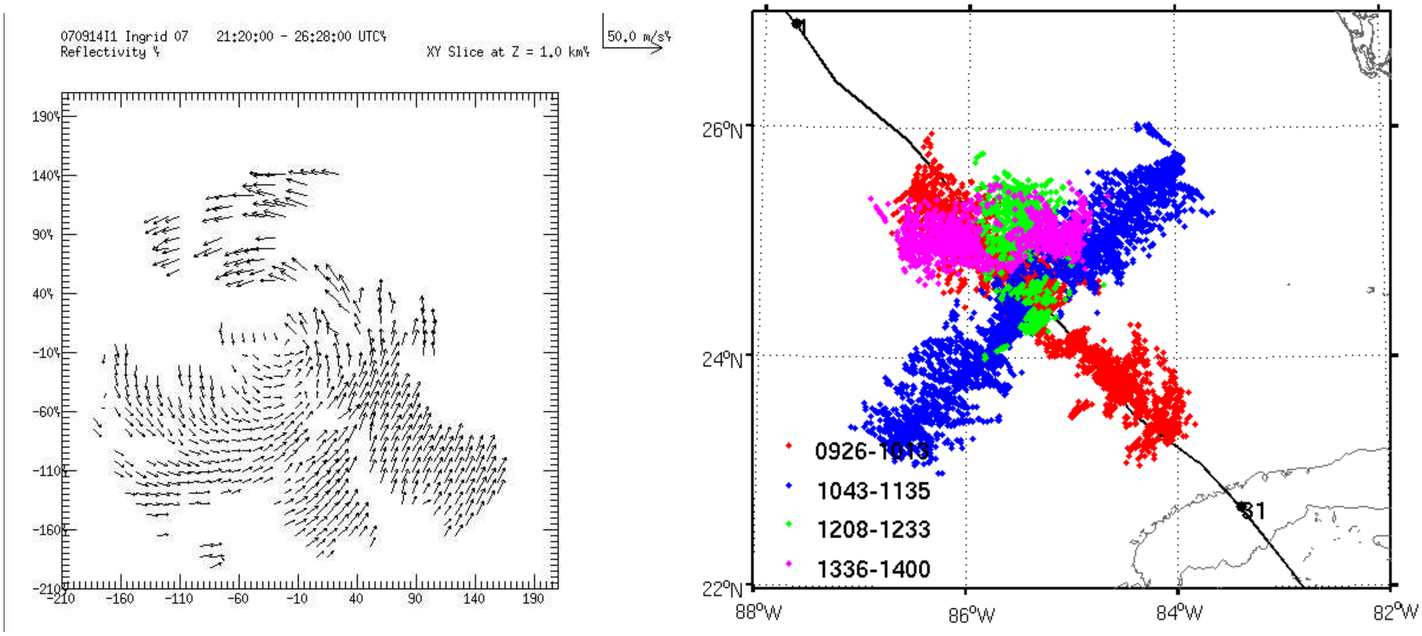


Figure 4 Left: Processed Superob data (depicting 1 km altitude wind vectors) from an NOAA AOC – HRD research flight into Tropical Storm Ingrid (14 Sept 2007 east of the Leeward Islands). Right: Plot of Superob locations taken during a WP-3D flight into Hurricane Gustav as it entered the SE Gulf of Mexico (31 August 2008). (From John Gamache, 2009 Interdepartmental Hurricane Conference)

Over the past few seasons, the AOC has flown both the WP-3D and the G-IV in a variety of missions as part of HRD's Intensity Forecast Experiment (IFEX). Two components of this study are: GENEX the Tropical Cyclogenesis Experiment, where flights are conducted into incipient tropical disturbances in an effort to capture processes that transform them into new born tropical cyclones and SALEX the Saharan Air Layer Experiment, where flights gather data on the interaction between TCs and tongues of very dry air that expand from North Africa into the Main Development Region (MDR) of the Tropical Atlantic. Several SALEX missions were flown by the G-IV this past season in the environment surrounding Hurricane Bill (see Figure 5). Simultaneous flights by the WP-3D penetrating the storm created data sets that will be able to track trajectories of this dry air from the periphery of Bill into the core region. Understanding the degree of "insulation" of the core from the Saharan Air Layer is a key to understanding thermodynamic modulation of hurricane intensity.

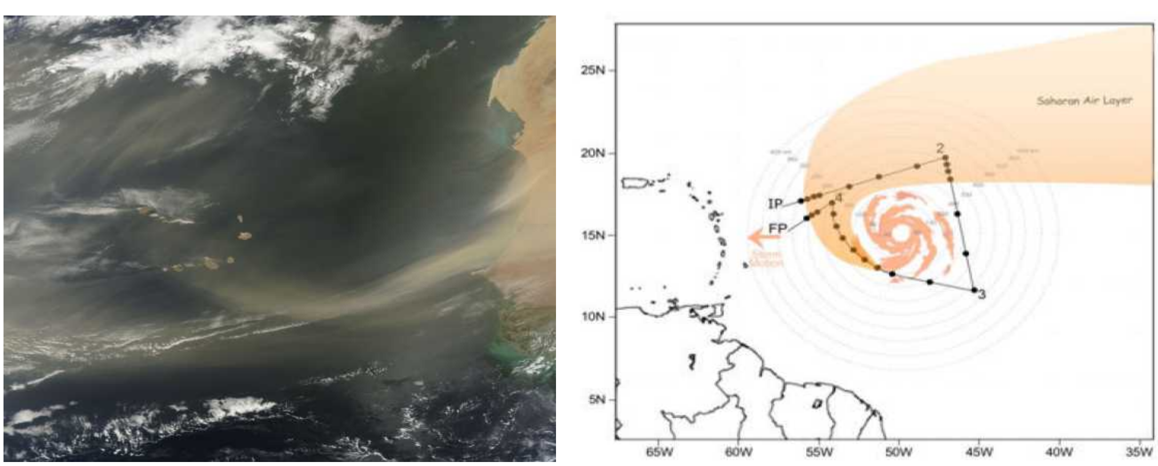


Figure 5 Visible imagery of the SAL (left). Interaction of the SAL with a tropical cyclone (right)

The Coupled Boundary Layer Air-Sea Transfer (CBLAST) experiment, initiated by the Office of Naval Research (ONR) in 2000 under the leadership of Peter Black, was a six year project that relied heavily on the two WP-3D aircraft. Hurricanes Fabian and Isabel in 2003, and Frances, Jeanne and Ivan in 2004, yielded a wealth of in-situ data gathered during stepped-descent patterns flown into the boundary layer (at altitudes as low as 70 meters) between feeder bands. These flights yielded the first direct surface momentum and enthalpy flux measurements based on real data gathered in hurricane force wind conditions.

Tropical cyclones comprise only a portion of the broader field of tropical meteorological studies. Field experiments examining tropical convection, both on a mesoscale and larger scales, make excellent use of airborne platforms. One of the most ambitious of these in recent decades, studying, in this case, large scale convective processes, was the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) project from November 1992 through the end of February 1993. Seven aircraft were involved, including both AOC WP-3Ds, along with the NCAR Electra, the NASA DC-8 and ER-2, as well as a United Kingdom C-130 and the Flinders Institute for Atmospheric and Marine Sciences Cessna 340. The two WP-3Ds were deployed out of Guadalcanal in the Solomon Islands flying 26 project missions. TOGA COARE studied the Warm Pool, the persistent area of very high heat content oceanic waters that dominates thousands of square miles of the near Equatorial western Pacific, and the large swath of convection it generates. Better understanding of the feedback mechanisms across the tropical air-sea interface, as well as the mechanisms that regulate the intraseasonal oscillation (ISO), variations between large scale periods of active and suppressed convective cloudiness, were two valuable research goal met in the study.

The Tropical Cloud Systems and Processes (TCSP) project, based out of Costa Rica in 2005, examined cloud variation in the monsoon belt of the tropical Eastern Pacific along with tandem flights into Hurricane Emily (with the WP-3D flying below the NASA ER-2). The Observing System Research and Predictability Experiment (THORPEX) has been a long term research project under the WMO's World Weather Research Program. The overall goal of THORPEX is to increase the skill of forecasts out to the 14 day time frame to mitigate the impact of weather that would potentially be destructive or adverse to large populations. There are both tropical and winter areas of study. NOAA participation, under the leadership of Dr Mel Shapiro, has included most recently, G-IV flights as part of Winter TPARC (the THORPEX Pacific Asian Regional Campaign) from January through March 2009 based out of Yokota AFB in Japan.

3. Ocean Winds and Winter Storm Projects

Ocean Winds is an ongoing project that uses the Imaging Wind and Rain Airborne Profiler (IWRAP) developed by the Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts at Amherst. IWRAP WP-3D flights are conducted on behalf of the NOAA Line Office the National Environmental Satellite Data Information Service (NESDIS) under the direction of Dr Paul Chang. The goal of this program is to gather wind data over the oceans using aircraft based C and Ku band scatterometers to aid in development of an operational satellite-based Dual Frequency Scatterometer (DFS) that offers significant advantages over the QuikSCAT. These advantages include greatly improved ability to sense surface winds below areas of heavy precipitation as well as a better ability to resolve extreme wind speed regimes. To obtain design and calibration data in this environment, IWRAP flights have been conducted for several years into powerful Aleutian and Icelandic Lows as well as tropical cyclones (see Figure 6). The IWRAP system is just the latest in scatterometer technology that has been flown by the AOC for the past two decades.

Operationally tasked NCEP flights in support of the Winter Storms Operations Plan (WSOP) have been conducted by the G-IV aircraft since the late 1990s. The Winter Storm Reconnaissance Program, now in its tenth season, has resulted in at least a 20 percent increase in model forecast accuracy of Pacific storms striking the U.S. West Coast. These missions serve both an operational and research purpose. Dropsondes are deployed along prescribed tracks in the North Pacific (by crews deployed each winter to Alaska, Hawaii or Japan) to better initialize global numerical models, providing data to fill the huge voids in this portion of the globe. These flights have been demonstrated to significantly enhance the ability of the global models to operationally predict the development and track of large maritime baroclinic lows in real time. Regression analysis is then performed in an ongoing effort to better target dropsonde location and timing to optimize sampling and model assimilation schemes.

Figure 6 WP-3D deployed to St John's Newfoundland for NESDIS Ocean Winds winter storm research missions gathering data with the IWRAP C band airborne profiling radar of ocean surface wind speeds and direction.

Over the years, WP-3Ds have participated in multiple field experiments studying the processes involved in development of Nor'easters off the Atlantic Seaboard. From January 15 through March 15, 1986 the AOC participated in the Genesis of Atlantic Lows Experiment (GALE) that focused on mesoscale phenomena and air-sea interaction. The Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA), flown in the winter of 1988-89, focused on "bombs", the most extreme baroclinic intensification cases with deepening rates of 30 millibars or more over a 12 hour interval.

4. Air Quality Projects

The addition of N44RF, the third WP-3D, will greatly enhance the AOC's capabilities in the field of air chemistry studies. Two events in subsequent hurricane seasons brought attention to the need for a dedicated air chemistry platform. In August 2004, NOAA received criticism from the media when it was learned that one of the WP-3Ds was unavailable as Hurricane Charley was moving toward landfall along the Gulf Coast of southwestern Florida. At the time, the P-3 was in Portsmouth, NH participating in the New England Air Quality Study (NEAQS). While there was no impact on the ability of the NOAA/USAF Reserve Hurricane Hunter teams to meet the operational tasking requirements of the NHC, there was a perception that flying NEAQS somehow interfered with resource allocation to the TC recon mission. The following year in the wake of Hurricane Katrina, and with the suggestion by some climatologists that the destructiveness of this storm was an early symptom of climate change, there was a call for the expansion of AOC participation in air chemistry projects worldwide (which are presently limited to one project every other year, generally in even numbered years). With two WP-3D aircraft needed for hurricane season and ongoing winter season commitments, it has always been a logistical challenge to reconfigure a plane for air chemistry instrumentation flights, and then return it to its TC research configuration by June.

As a result, a plan was devised to acquire a third P-3. This plane would come from the US Navy inventory after a program of extensive refurbishment in Halifax, Nova Scotia (unlike the first two which were built by Lockheed specifically for NOAA's use). This aircraft is to be used primarily as an air chemistry platform. N44RF would be fitted year-round with instrumentation intended to meet the needs of air quality studies, allowing the other two WP-3D's to be available for any TC requirements. While N44RF will also be outfitted with the ability to perform operational tropical cyclone reconnaissance flights as tasked by NHC in the NHOP (being fully capable of measuring flight level winds, pressure and thermodynamic parameters along with the ability to release dropsondes), it will not have the full complement of TC research tools seen in the other WP-3D aircraft (it will not be fitted with a lower fuselage radar or tail Doppler radar).

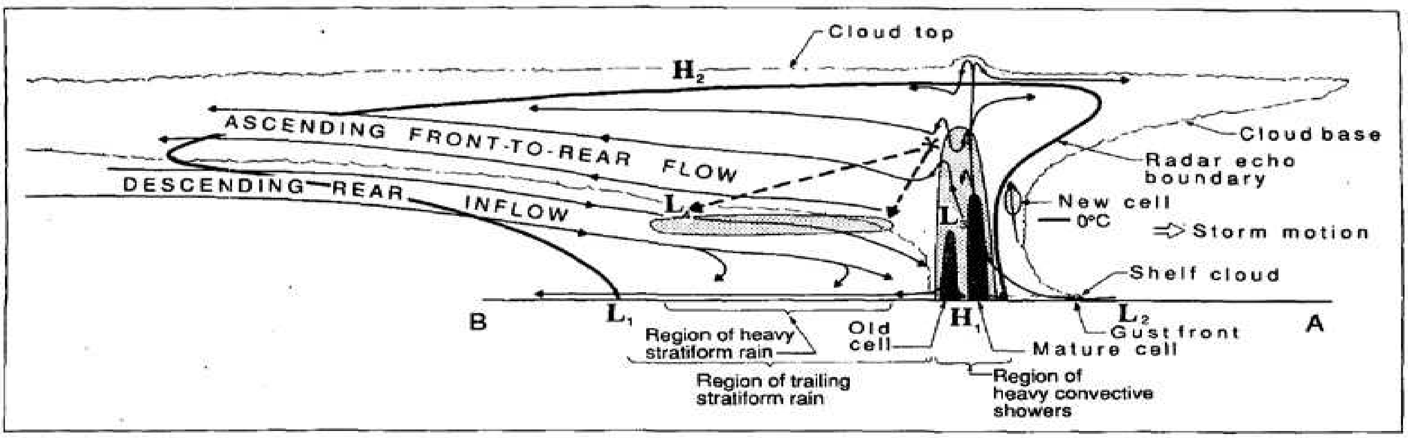
AOC flies air quality missions under the auspices of the Chemical Sciences Division of the Earth Systems Research Laboratory (ESRL) under the OAR (Office of Atmospheric Research) Line Office. AOC participation in major air quality studies dates back to the early 1980s with the Arctic Gas Air Sampling Program (AGASP) flown under the direction of Russ Schnell of NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL). With the WP-3D operating out of Bodo, Norway (above the Arctic Circle), AOC was part of the most extensive airborne sampling effort to date collecting measurements of the polar haze layer.

In March and April of 2008, the AOC deployed to Fairbanks, Alaska for ESRL's Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC 2008) project. These flights sampled the mass concentration and size distribution of soot particles over the Arctic Ocean along with a host of other parameters including the absorptive properties of polar aerosols, their chemical constituents and their relationship to trace gases.

From the bitter Arctic to the heat of a Houston summer, in August and September of 2006, a WP-3D was deployed to Houston to study the density and distribution of ozone as well as the aerosol precursors and processes that lead to the formation of ozone in an urban environment. The Texas Air Quality Study (TexAQS) is an ongoing project that began with a field experiment in 2000. In the summer of 2006, the WP-3D crew flew for several weeks over the Houston metro area, generally at altitudes below 2000 feet. Other air chemistry projects in recent years have seen the WP-3D deployed to a variety of other locations within the Continental US including Nashville, TN and Boulder, CO.

5. Severe Weather

For the past three decades the AOC WP-3Ds have been involved in a series of experiments conducted over the Great Plains in the Spring months studying severe mesoscale weather phenomena such as supercells, squall lines, bow echoes, MCSs, and electrification. The Preliminary Regional Experiment for the Stormscale Operational and Research Meteorology Program-Central Phase (PRESTORM 1985) was an ambitious effort to gather data over an 8 week span across Oklahoma and Kansas using ground based wind profilers and portable radars (two 10 cm wavelength Doppler radars from NSSL placed in central Oklahoma and two 5 cm NCAR systems in central Kansas). Both WP-3Ds were deployed for this project to compliment the ground radars providing the best collection to date of airborne Doppler radar slices detailing the kinematic structure of how an MCS develops and evolves. The case study of an especially intense and persistent MCS which formed on June 10, 1985 and lasted into the morning of June 11th, is the subject of dozens of papers that were written in subsequent years (from one of which see Figure 7 below):



Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) was a National Severe Storms Laboratory project that saw the WP-3Ds deploy to Oklahoma from April through June in 1994 and 1995. The Bow Echo and Mesoscale Convective System Experiment (BAMEX) brought the aircraft to St Louis, MO in May and June of 2003. While the emphasis continued to remain primarily on collecting additional Doppler radar data sets of intense mesoscale convective events, as was the case with PRESTORM and VORTEX, in BAMEX there was also a wealth of data collected on cloud microphysics and electrification of MCSs.

6. Examples of Other Past Projects

The versatility of the WP-3D and G-IV prove them to be ideal platforms for data collection in a multitude of other atmospheric studies. The South American Low Level Jet Experiment (SALLJEX) flown over Bolivia in January of 2003 was akin to projects studying similar phenomena in the late Spring and early Summer months over the U.S. Great Plains. Alpine Experiment (ALPEX) and Mesoscale Alpine Programme (MAP) are examples of projects that have brought the WP-3D aircraft to the Alps of Europe to collect data on the complex air flow patterns of downslope mountain wind events.

WP-3D GhostNet flights conducted out of Hawaii in March and April of 2005 helped detect more than 1800 pieces of ocean debris caught in 122 derelict nets. Discarded or lost fishing nets wreak havoc worldwide on marine life with significant economic and environmental impact. These flights, performed in conjunction with real-time examination of satellite imagery mapping sea surface temperature (SST) and currents, found the largest debris concentrations were found just north of the North Pacific Transition Zone Chlorophyll Front (TZCF) within the North Pacific Subtropical Convergence Zone (STCZ). Debris densities were significantly correlated with SST, chlorophyll-*a* concentration (Chl*a*), and the gradient of Chl*a*. A Debris Estimated Likelihood Index (DELI) was developed to predict where high concentrations of debris would be most likely in the North Pacific during spring and early summer.

In the winter of 2008, the AOC flew missions in support of The Hydrometeorology Testbed (HMT) Atmospheric Rivers project. This involved studying the "Pineapple Express", the conduit of deep moisture that feeds from the subtropical Pacific northward into large winter storms impacting the western U.S. coastline. Similar studies were conducted during the past decade using both the WP-3D and G-IV in California Landfalling Jets (CALJET), Pacific Landfalling Jets (PACJET) and North Pacific Experiment (NORPEX).

7. The Present and the Future at the NOAA Aircraft Operations Center

In addition to the arrival of N44RF, the third WP-3D discussed earlier, there are several other notable things happening at the Aircraft Operations Center. In the late Fall of 2009 a tail Doppler radar (TDR) was installed on the G-IV (see Figure 8). This system will undergo extensive testing during the Spring of 2010 (after the current Winter Storm deployment to Japan and elsewhere in the Pacific). Several technological challenges must be overcome, not the least of which will be removing much more aircraft motion imparted into the Doppler signal as the radar would be carried onboard a jet aircraft flying roughly twice as fast as the WP-3D.

Should the TDR successfully become integrated into the G-IV suite of instruments, it would open up some intriguing research applications. Being able to look down from above the Bright Precipitation Band (the layer of enhanced reflectivity associated with the mixture of hydrometeors near the freezing level) will bring a new research perspective to examining convection associated with both tropical cyclones and continental severe weather phenomena.

High altitude tropical cyclone core region flights, employing the G-IV TDR, are envisioned as a possible future mission profile to be flown once a strategy for doing it safely can be established. Actual penetration of convective towers at altitudes near the tropopause will never be attempted, however, the TDR allows Doppler reflectivity and velocity products to be gathered from a safe stand-off distance. In addition to the TDR, future plans call for installation of the Stepped Frequency Microwave Radiometer (SFMR) also on the G-IV to augment the operational SFMR capability now in place on the WP-3D aircraft.

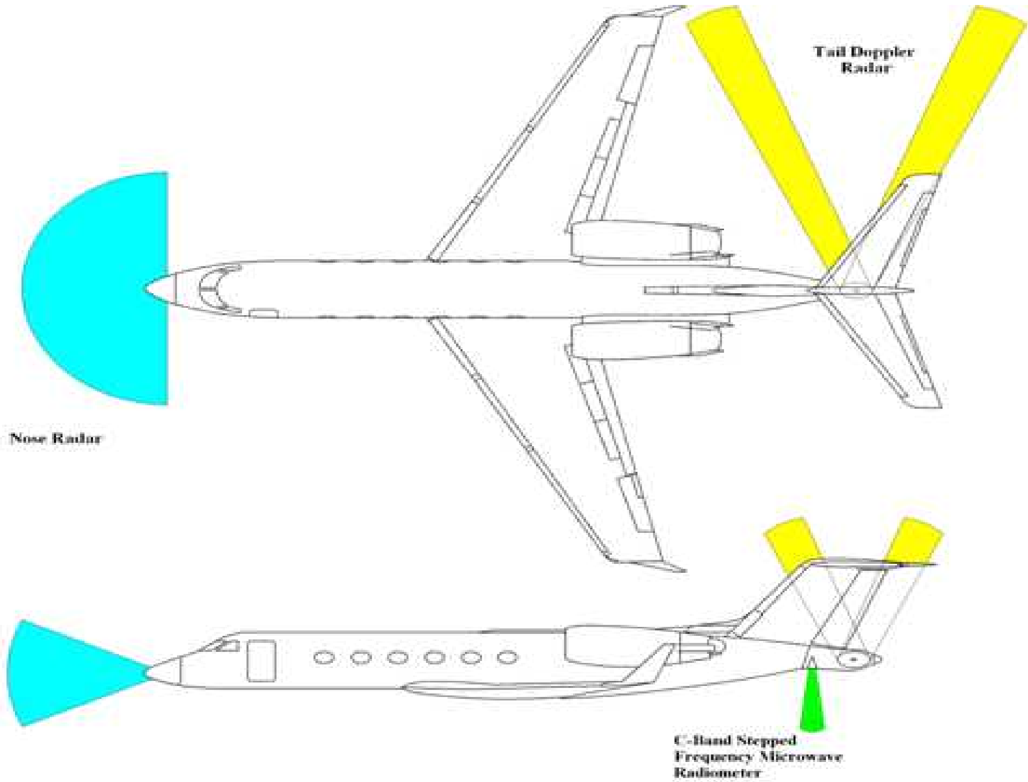


Figure 8 The Tail Doppler Radar system that will undergo testing in the Spring of 2010

The ability of the AOC to deliver post-mission processed (quality checked) research data to the customers more quickly after a flight was bolstered by the addition of two new Flight Director positions in 2009 (bringing the number of Flight Director / Research Meteorologists in the Science and Engineering Branch (SEB) of AOC up to eight (six permanent civilians and two rotating NOAA Corps officers). The efficiency of delivering data to all interested researchers will be greatly enhanced by the work of two NOAA Hollings Scholarship summer interns, Lindsey Norman and Kelly Scott, along with John Hill, an AOC SEB software engineer, who developed a web accessible historical flight data base. Once it is populated, anyone with internet access will be able to go to the NOAA AOC website and choose from an archive of flight data dating back two decades. This data base will include raw flight level data as well as post processed files in the NetCDF format along with all dropsonde data in the D file format.

Testing of the new data system that will better integrate the multitude of sensors onboard the WP-3D onto a latest-generation display is currently underway. Under the direction of NOAA Corps Flight Director LTJG Jackie Almeida and SEB software engineers Sean McMillan, John Hill, and Leonard Miller, a program of transition to the new data system is scheduled for completion prior to the beginning of the 2010 Atlantic Hurricane Season.

The two older WP-3D aircraft are scheduled for an extensive maintenance rework later this decade (including replacement of the wings) that will extend their service life well into the future. Manned reconnaissance will be augmented in the coming years by unmanned aerial systems (UASs). In a test program spearheaded by NOAA Corps Flight Director LCDR Nancy Ash, one such vehicle was successfully flown this past summer. The Coyote is a small UAS (see Figure 9) that is deployed from the free fall chute of the WP-3D (the tube from which AXBTs are launched). With wings that extend upon deployment and a highly efficient electrically powered prop engine, the three foot long, 12 lb Coyote can fly for approximately 90 minutes at any altitude up to 20,000 feet. One potential application envisioned for Coyote is for it to be released into a tropical cyclone and fly at very low altitudes (perhaps even lower than the 70 meters flown by the WP-3D in CBLAST) providing long interval sampling of the boundary layer in a variety of environmental settings.

Figure 9 The Coyote unmanned aerial system that was successfully launched and controlled from a NOAA WP-3D in the summer of 2009.