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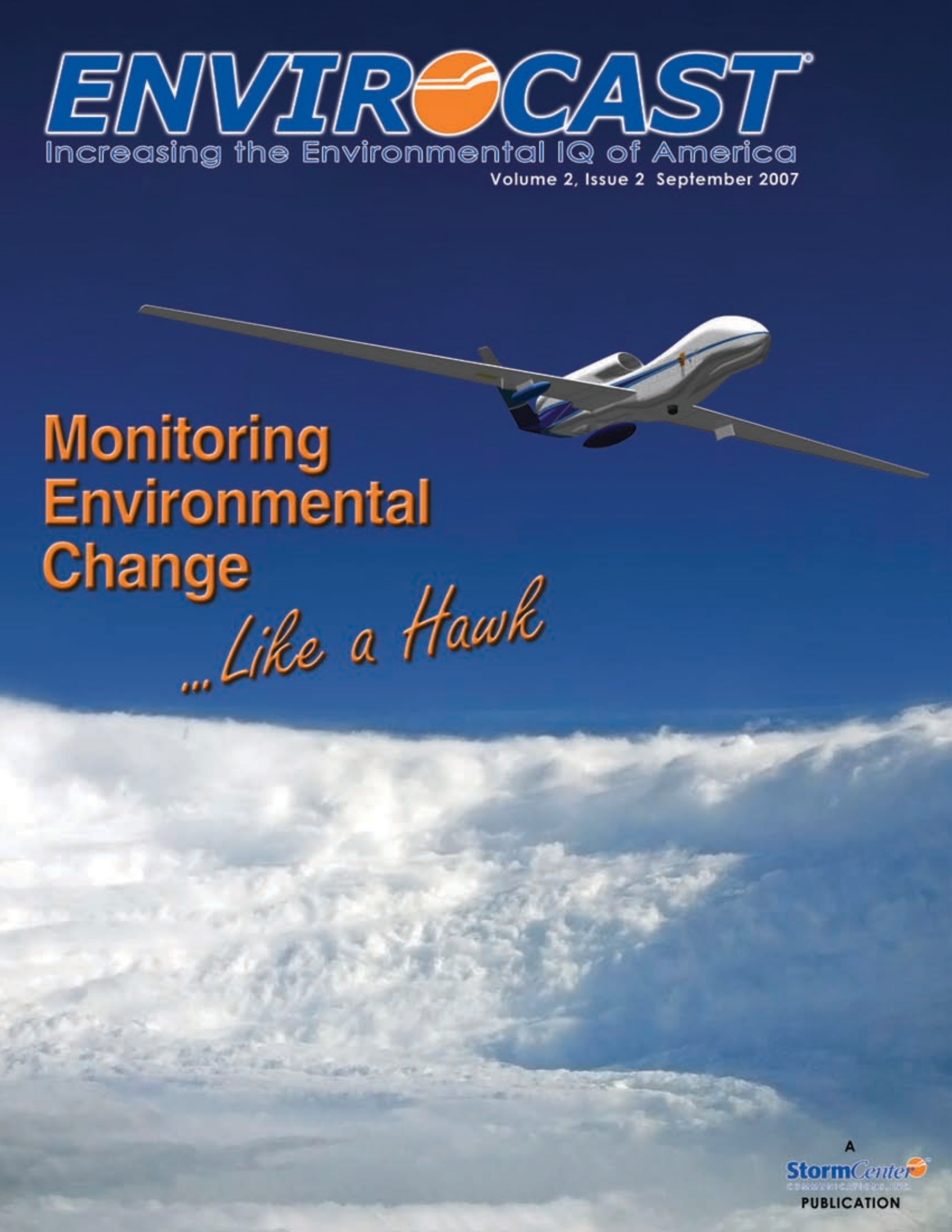
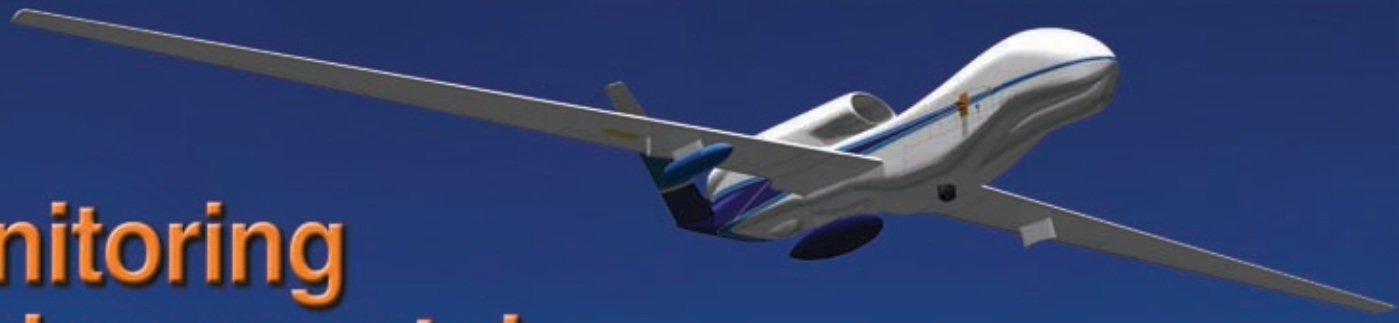


Monitoring Environmental Change

...Like a Hawk

A StormCenter Communications, Inc. PUBLICATION



Monitoring Environmental Change ...Like a Hawk

Simulation of a Global Hawk flying above the eye of Hurricane Katrina. The actual picture in the eye was taken from a NOAA recon flight one day before Katrina slammed into the Gulf coast from Louisiana to Alabama.

Dave Jones

"Most of the area will be uninhabitable for weeks… perhaps longer…human suffering incredible by modern standards."

These were the words issued from the National Weather Service office in Slidell, Louisiana the day before Hurricane Katrina hit. The impacts from Katrina on the Gulf coast are still, in some locations, "incredible by modern standards."

While destruction in the wake of hurricanes is not totally avoidable, improved information collection prior to the landfall of a hurricane can lead to lives saved and a lowering of risk to the economy. That is why research and field experiments are turning to a relatively new form of data collection.

The National Oceanic and Atmospheric Administration (NOAA) is working right now to make sure forecasters have the data they need to continue issuing accurate forecasts as far ahead as possible that allow people to make good decisions. Good decisions are based on accurate forecasts. People's lives and the economy count on it.

Much of the input needed by numerical weather prediction models comes from satellites observing the land, oceans and the atmosphere. Accurate data must be collected, processed and used efficiently in order to turn around fast and accurate forecasts of land falling hurricanes. But more data needs to be collected over and around the developing tropical storm and hurricane environments for longer time periods so research scientists and operational forecasters can understand the complex influences that affect development in order to improve the detail and accuracy of forecasts. The visible sensors on board the GOES (Geostationary Operational Environmental Satellite) satellites can constantly monitor the developments of a tropical system by continuously imaging the position and structure of the storm. Polar Orbiting satellites can

Aerial images from a manned aircraft with NOAA's Remote Sensing Division shows what Hurricane Katrina's storm surge did to the coastline in Gulfport, MS. In this image the Grand Casino was devastated by the rapidly rising surge that ripped part of the building and deposited it down the street. Unmanned aircraft, however, are becoming a big part of gathering information about the atmosphere, calibrating and validating satellite data and even investigating developing tropical systems far out at sea. Image source: NOAA, processed and enhanced by StormCenter Communications, Inc.

collect data that can be used in numerical weather prediction, but they pass over quickly and do not allow for any time to "dwell" over a storm to gather more frequent information. In the future both NPOESS and GOES-R sensors will deliver improved imaging and data gathering capabilities at significantly higher resolutions.

The Air Force and NOAA operate WC-130 and P-3 "hurricane hunter" aircraft respectively to gather critical

data to relay back to forecasters at the National Hurricane Center (NHC) in Miami. Slicing through the eyewall of a hurricane, buffeted by howling winds, blinding rain, hail, and violent updrafts and downdrafts before entering the relative calm of the storm's eye, NOAA's two P-3 turboprop aircraft probe wind and pressure changes, repeating the grueling experience again and again during the course of a ten-hour mission.[1]

For years NOAA pilots have flown P-3s into hurricanes at low altitudes (1,500-10,000 ft.) to collect research-mission data critical for computer models that predict hurricane intensity and landfall. This information is used differently than the hurricane reconnaissance information provided to the National Hurricane Center by U.S. Air Force Reserves WC-130s. Information from both types of flights, however, directly contributes to the safety of Americans living along the vulnerable Atlantic and Gulf coasts.

This kind of flight, however, is dangerous and does put lives at risk. NOAA also operates a higher altitude manned aircraft called the Gulf Stream IV (G-IV).

NOAA hurricane hunter WP-3D Orion (back) and Gulfstream IV aircraft (front) in flight. Image courtesy: NOAA

The Gulfstream IV Observes at Higher Altitudes

Since the beginning of the 1997 hurricane season, the G-IV jet has flown missions around every Atlantic-based hurricane that has posed a potential threat to the United States. The jet's mission covers thousands of square miles surrounding the hurricane, gathering, with newly developed GPS dropwindsondes, vital high-altitude data needed for improved numerical forecast models. The G-IV has added a vital new dimension as it maps the steering currents that influence the movement of hurricanes. The G-IV does not fly into the eye of the hurricane but remains outside of the storm zone.

Data from GPS dropwindsondes that measure pressure, temperature, humidity, and wind information are relayed to the aircraft for transmission by satellite to the National Hurricane Center in Miami and the National Centers for Environmental Prediction in Camp Springs, MD. There the data are available for many numerical forecast models, providing important information about regions—mostly over oceans—in which there are no other high resolution sources of weather data. The G-IV, since it is a manned aircraft can remain in the air for a maximum of 8 hours and 45 minutes (with a 1 hour fuel reserve) and can only fly up to a maximum ceiling height of 45,000 feet.

UAS – A Real Opportunity

There is a way to collect more information around and over a hurricane at higher resolutions for a much longer duration without endangering pilot's lives. It's called a UAS. The Unmanned Aircraft System or in layman's terms…remotely controlled airplanes. UASs can fly for long periods of time and can collect enormous amounts of data while the pilot sits safely at a ground control station out of harm's way.

NOAA has recognized that UAS technology offers a new and improved way to meet scientific and operational objectives in the coming years. Operating sensor payloads on a UAS fleet could play a crucial role in the detection and attribution of climate change, improvement of weather predictions, management of water resources, monitoring and evaluation of ecosystems and sanctuaries and atmospheric and oceanic research. UAS platforms have the potential to carry instruments to remote locations in a manner that could not otherwise be achieved with conventionally piloted aircraft.

"UAS have proven capable of filling some crucial gaps and taking on missions not suitable for humans. As the technological maturity of UAS continues to increase, they also have potential as a lower cost alternative to traditional research and operational missions." says Vice Adm. Conrad C. Lautenbacher Jr. (Ret.), NOAA Administrator.[2]

Building upon those findings, Dr. Sandy MacDonald, Director of NOAA's Earth System Research Laboratory (ESRL) in Boulder, CO, says that "UASs are safe to operate, can stay up in the air for a long time and collect very useful data. They can fly missions that are too dangerous or too long to be practical for human piloted aircraft."

1 *Eos, Transactions, American Geophysical Union, Vol.8, No.20 16 May 2006, Pages 197,201*

2 *Commentary by Vice Adm. Lautenbacher, Aerospace America, August 2007, pg. 35*

Positioning to Fly

NASA Dryden Flight Research Center in Edwards, CA is the lead NASA center for large UASs and plans to establish a Global Hawk Project Office. Two Global Hawk U.S. Air Force Advanced Concept Technology Demonstration aircraft, which are slated to be transferred to NASA Dryden yet this year, will provide a tremendous opportunity for NOAA to work together with NASA in conducting critical missions for the advancement of weather, climate and hazard observation and forecasting. Andrew Roberts, Director of Airborne Science at NASA HQ says, "The Global Hawk platform is particularly suited to satisfy the unique needs of a broad range of users in the science community and we are looking forward to working with NOAA to address gaps in observations that may prove to significantly enhance weather forecasts. NOAA is the operational arm and NASA is the new technology enabler that works to prove the applicability of UAS technology. By working together with NOAA we can demonstrate future operational missions that NOAA can incorporate into its programs."

UASs Fill the Gap

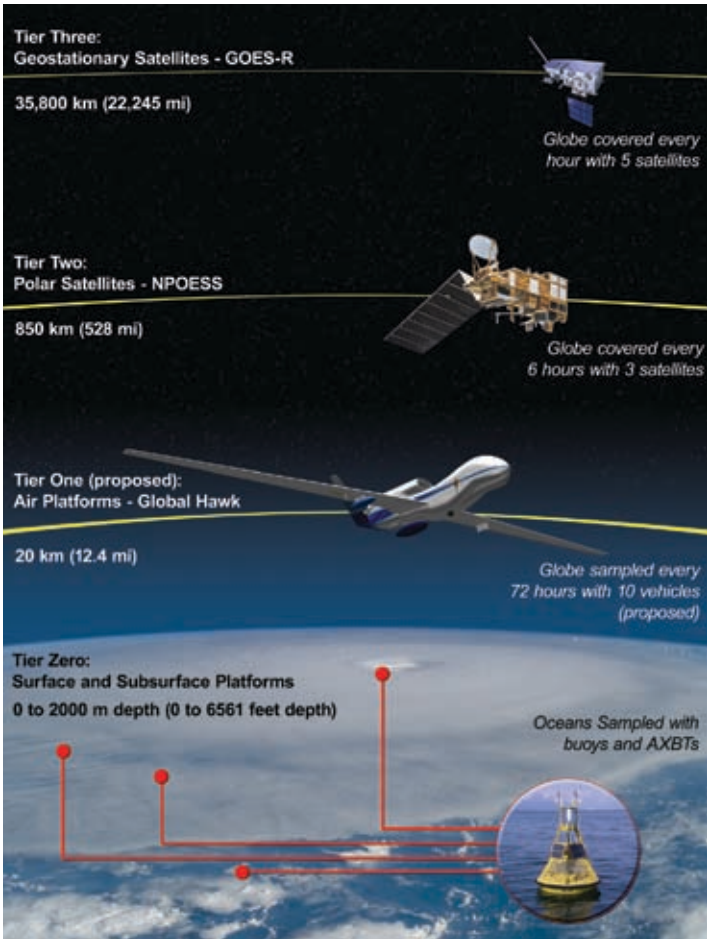
UASs can play a very important role in the overall Global Earth Observation System of Systems (GEOSS). Take a look at the figure to the right, satellites in both geostationary and polar orbits collect critical information necessary to monitor developing weather and environmental situations and provide critical input to numerical weather prediction models. There is a gap, however between the polar orbiting satellites and the ground based observation networks such as surface observation systems, buoys and ships.

The gap is in the middle where UASs such as the Global Hawk, built by Northrop Grumman Corporation, can fill a tremendous niche. "Global Hawk provides a much longer dwell capability which allows for key measurements to be taken over developing storms that satellites and manned aircraft cannot provide," says Dr. Leo Andreoli, Director of Environmental Systems at Northrop Grumman in Redondo Beach, CA. He continues, "Those measurements can then feed back into numerical weather prediction models with higher resolution and lead to more detailed and accurate weather forecasts that help people and decision makers. This is true for developing hurricanes, wild land fires, hazards, climate change observations and more."

ESRL Building in Boulder — *NOAA's Earth System Research Laboratory (ESRL) in Boulder, CO. ESRL, led by Dr. Sandy MacDonald, was formed to pursue a broad and comprehensive understanding of the Earth system. This system comprises many physical, chemical and biological processes that need to be dynamically integrated to better predict their behavior over scales from local to global and periods of minutes to millennia. ESRL is a part of NOAA's Office of Oceanic and Atmospheric Research (OAR). Picture courtesy of Will von Dauster.*

Global Hawk in the Future

In the not too distant future, there could be multiple Global Hawk aircraft at the ready. These aircraft would be



A future observation architecture that includes the GOES-R series of advanced environmental satellites in geosynchronous orbit supported by the NPOESS satellite constellation gathering critical data for environmental prediction models and even further supported by the Global Hawk gathering data in areas where higher resolution information is needed. Global Hawk sensors could supply the missing pieces of information needed to pinpoint future weather developments such as rapidly intensifying tropical systems. All of these platforms work in concert with each other allowing NOAA to constantly monitor the health of the earth and the status of storm clouds beyond the horizon, saving lives and property.

poised to investigate any developing tropical systems way out in the Atlantic where the P-3 or WC-130 cannot reach and still have time to study the storm.

Typically when tropical waves emerge off the coast of Africa, the GOES satellite (orbiting at 22,300 miles above the earth) and Polar-Orbiting (POES) satellites (orbiting around 500 miles above the earth) will keep a watchful eye on them until they get closer to land and show signs of developing into possible tropical depressions (winds of less than 38 mph), tropical storms (winds of between 39 and 73 mph) or hurricanes (winds of 74 mph and greater). The task of the Global Hawk would be to collect as much information as possible on the developing system so NOAA can predict with more certainty whether or not the developing tropical wave may be growing into the next potential billion dollar disaster along the U.S. coastline.

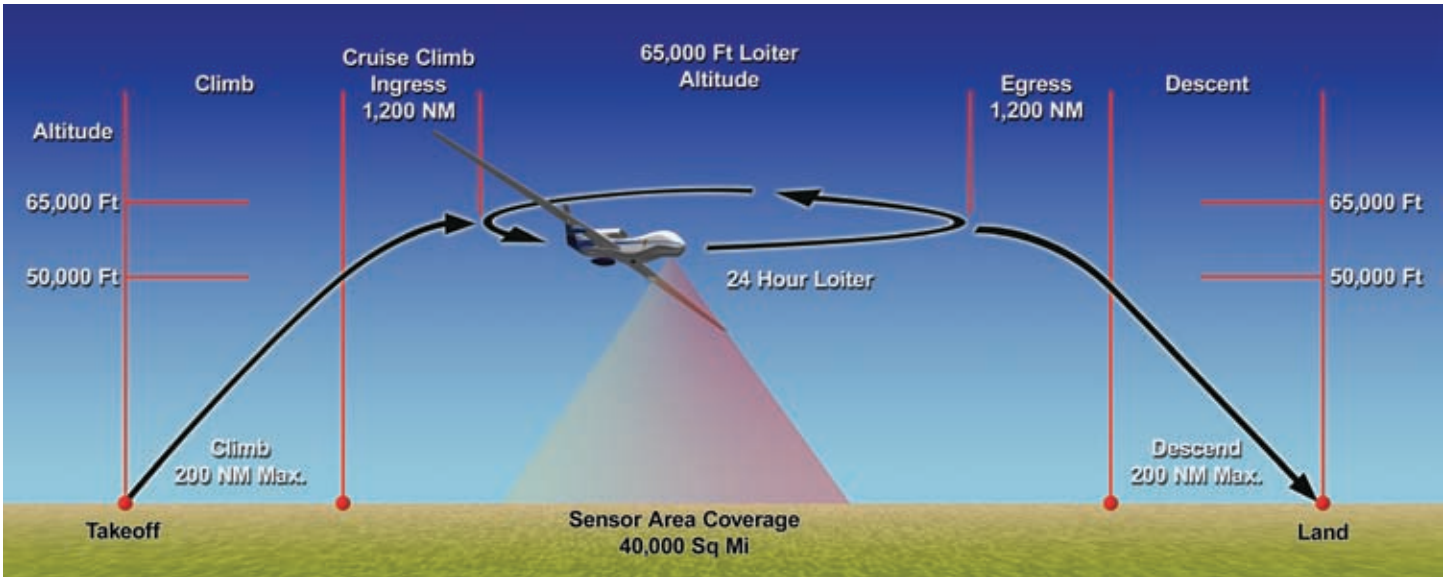
With an incredible flight duration of at least 30 hours and range (at least 11,000 nautical miles) the Global Hawk could investigate a wave as it emerges from the coast of Africa near the Cape Verde islands. The Global Hawk has a long range and can stay aloft for extended observations.

Global Hawk flights would expand the observation domain of the hurricane forecasters to the entire Atlantic basin where any possible storm that affects the U.S. could form. The recon missions would not place anyone at risk as operation of the system can occur from basically anywhere. Having several Global Hawks would enable a constant stream of observations to be taken as one aircraft could fly out to relieve another that needs to be refueled. This capability would provide an unprecedented high resolution data stream for direct input into weather forecast models.

As the storm intensifies dropwindsondes could be released into the eye wall remotely from high altitudes above the storm for added vertical slices of the storm… all without putting human lives at risk. The data would be immediately relayed back to the plane and on to the National Hurricane Center.

The Global Hawk would not replace the P-3 or the WC-130 because it does not penetrate the eye wall at low altitudes but flies at much higher altitudes to avoid severe winds and turbulence. This is extremely advantageous since the Global Hawk, with its ability to climb to a ceiling of more than 60,000 feet, could fly over most storms and perform critical remote sensing missions and deploy dropsondes in key storm locations significantly enhancing the ability to evaluate the storm. The Global Hawk is also able to carry a wide array of instruments that could measure critical parameters as identified by forecasters and researchers.

That indeed is the mission of a particular NOAA group in Boulder,CO, to find out ways to collect very important weather and atmospheric parameters that might just lead to the next natural disaster. It is this kind of thinking that motivates Dr. Marty Ralph, director of NOAA's UAS project activities which include the HALE (High Altitude, Long Endurance) UAS demonstration projects in three locations, the Arctic, Pacific and the Hurricane testbed with the latter focusing on tropical storm reconnissance. Dr. Ralph is developing strategies for UAS use within NOAA.



The Global Hawk UAS can take off in a relatively short distance and climb to 50, 000 feet within 200 nautical miles of the take off location then cruise to 60, 000+ feet where it can loiter over a developing system for 8 to 24 hours, depending on the distance needed to reach the area of interest, while collecting observations over an 11,000 nautical mile range. This kind of data collection capability would likely lead to improvements in tropical cyclone intensity and track forecasts.

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Dr. Ralph's passion is obvious when he says, "The potential exists for UAS technology to revolutionize monitoring of the earth system with contributions to better understand the planet and how mankind is affecting it and being affected by it. This includes monitoring the arctic pack ice which is a barometer of global climate change as well as monitoring and protecting the ecosystem of the Northwest Hawaiian Islands national monument."

Dr. David Fahey the HALE UAS Chief Scientist for the NOAA UAS project and a Research Physicist with NOAA's Earth System Research Lab (ESRL) says, "The Global Hawk will uniquely enable us to collect data for input into numerical weather prediction models in order to improve their accuracy." He continues, "A Global Hawk does not sleep, it is able to monitor continually for long periods of time. Envision a Global Hawk monitoring weather developments in the eye of a hurricane; when an observational threshold is reached alerts are sent to decision makers who jump into action to protect lives and property."

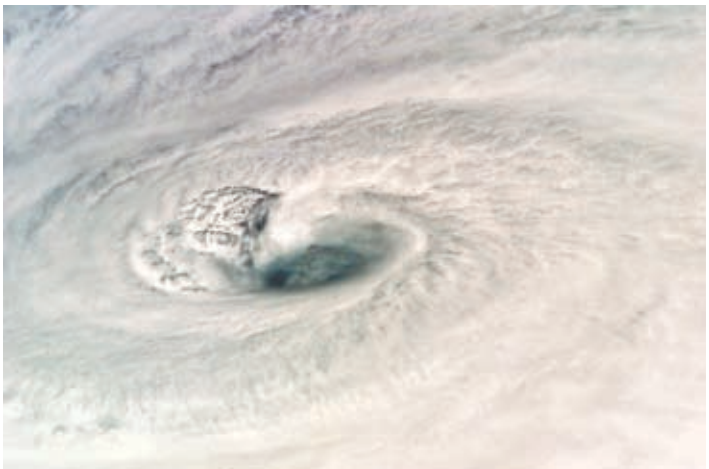
Eyewall Observations – A Key to Intensification

One of the hot topics with regard to hurricane research is to better understand the phases of development involved that lead to rapid intensification. Like ice skaters that draw in their arms to spin faster, the hurricane exhibits characteristics of transformation within the eyewall during the course of its lifecycle. These eyewall replacements seem to occur more frequently in major hurricanes (category 3 and above) where the inner eyewall gets surrounded by an outer eyewall with lower winds. But as time progresses the outer eyewall dominates and cuts off the inner eyewall. The constriction of the now dominant outer eyewall results in a rapid intensification of the hurricane (lowering of the central pressure and an increase in the winds). It is critical to know when this phase takes place in relationship to landfall.

Robert A. Houze Jr., et. al. in a recent research article in *Science* suggest that eyewall replacement is a key process in hurricane intensity change. He goes on to suggest that a possible new approach to forecasting hurricane intensity changes is to increase the amount of observations around targeted small-scale storm features that are likely to be associated with storm intensity change. This may provide timely input into operational forecasts of hurricane intensity.[3]

Climate Monitoring

Another benefit of using UAS technology is to gather repeated observations at high resolution over the polar regions. While polar orbiting satellites frequently pass over the North and South Poles, unmanned aircraft can collect much more detailed data, observe the extent of sea ice and anticipate changes in Arctic climate and ecosystems.



Hurricane Dean — *Astronauts aboard the International Space Station and the crew of the Space Shuttle Endeavour passed over hurricane Dean on August 18, 2007 at noon local time and snapped this digital image with a hand-held camera. Dean was undergoing rapid intensification at this time as seen by the towering eyewall thunderstorms and eventually became a category 5 storm, making landfall early on August 21, 2007 as the most powerful hurricane ever to hit North America since records have been kept. Image source: NASA's Earth Observatory, Processed by StormCenter Communications, Inc. NASA Image ID: S118-E-07919.*

NOAA is also planning to fly over the Pacific to help monitor and protect our unique natural resources in the Northwest Hawaiian Islands National Monument and improve storm prediction.[4]

The Observing System Architecture

When many weather forecasters are asked what type of data collection systems are needed to enable them to improve the accuracy of their forecasts, the first two platforms that come to mind are satellites and ground-based systems such as radar. The satellites can gather an enormous amount of data on a regular basis for input into numerical weather prediction models. As a matter of fact, today most of the data that goes into numerical weather prediction models comes from satellites. Ground based in-situ observation platforms provide crucial data on the state of the atmosphere and are used as ground truth to verify the accuracy and contribute to the calibration of satellite measurements and weather forecast models. More ground-based sensors allow for more frequent and accurate calibration and validation of satellite sensor accuracy. When it comes to validating

3 *Research article, Science MS no: RA1135650/CJH/ATMOS*

4 Commentary by Vice Adm. Conrad C. Lautenbacher Jr. (Ret.), NOAA Administrator in Aerospace America August 2007, pg. 35.

Calibration & Validation (CAL/VAL)

A UAS such as the Global Hawk can work in tandem with satellites. Concurrent collection of data from a satellite and a UAS will provide scientists with opportunities to compare atmospheric observations made with independent sensors. These comparisons are an essential component of the calibration and validation (CAL/VAL) of satellite sensors that operate in space over multiyear periods. These coincident datasets are extremely valuable because data collected by satellites are used in all types of analysis from global change to accurate surface wind measurements over the ocean. Satellite measurements are used in measuring Essential Climate Variables (ECVs) that have been identified as the main climate parameters needed to monitor climate change and man's contribution to it.

The chart shows just how flexible the Global Hawk platform is if it were to carry the NAST-I sensor to provide calibration and validation of the GOES-R Advanced Baseline Imager (ABI). The Global Hawk can gather data in 10 of the 16 wavelengths slated for the ABI sensor on board GOES-R meaning that significant prototype products can be produced and CAL/VAL activities could take place before GOES-R is launched to ensure accurate measurements are made once GOES-R is in orbit.

GOES-R ABI range (µm) (resolution 0.64 µm vis, >2 µm vis/NIR)	NAST-I range (µm) (resolution 1.4 nm)
0.45-0.49	
0.59-0.69	
0.846-0.885	
1.371-1.386	
1.58-1.64	
2.225-2.275	
3.80-4.00	3.7-5.05
5.77-6.6	5.0-7.775
6.75-7.15	
7.24-7.44	
8.3-8.7	7.69-15.5
9.42-9.8	
10.1-10.6	
10.8-11.6	
11.8-12.8	
13.0-13.6	

and verifying satellite observations over the oceans, the observation platforms are few and far between.

The contribution that the UAS platform makes to the overall observing system architecture is as simple as "filling in the middle." The figure in the right hand column on page 4 shows the critical observing systems and where the Global Hawk fits in perfectly. By collecting more frequent data in this part of the atmosphere, especially when observing severe storm development such as hurricanes, the Global Hawk can act like a hurricane watchdog, dwelling for long periods of time over the storm providing frequent "cat-scans" of the "patient" while dropping radiosondes to collect atmospheric profiles in key parts of the storm. Direct links with NOAA's National Hurricane Center (NHC) and the National Centers for Environmental Prediction (NCEP) would provide the conduit for a direct flow of high resolution data into numerical weather prediction models. This would address one of the greatest challenges confronting medium range weather prediction which is minimizing errors associated with uncertainties in the model's initial state. Collecting more mid-level data from platforms such as the Global Hawk, especially over hurricanes, allows models to more accurately characterize the initial state of the atmosphere and minimize forecast errors. With more population moving to the coastline every year, hurricane forecasts must continue to improve in order to provide ample time for evacuations of densely populated areas.

A Mobile QuikScat

QuikScat, a NASA research sensor, measures broad wind fields over the ocean and can help hurricane forecasters pinpoint whether the storm is a tropical storm or has hurricane force winds. In 2006, QuikScat revealed that tropical storm Helene was actually hurricane Helene with category 2 winds. In areas where there are few ships and buoys, QuikScat is the best way to determine surface wind speeds and is a useful tool in NHC's arsenal.

As QuikScat ages Global Hawk could help fill-in the gap that a disabled QuikScat might leave. With an active microwave sensor attached to the belly of the plane, Global Hawk could become a deployable QuikScat, investigating the slightest cloud swirl for development or gather critical wind information from a rapidly intensifying storm. The Global Hawk also has the ability to carry dropsondes and can dwell high above any hurricane at an altitude of 55,000 to 65,000 ft, unlike virtually all manned aircraft. This ability allows the Global Hawk to monitor wind speeds while deploying dropsondes over virtually the entire storm development area.

By leveraging off of military applications for the Global Hawk, Northrop Grumman is applying this advanced system of systems technology to save lives and property by supporting NOAA in their mission. From Homeland security to weather and climate forecasting the Global Hawk provides critical reconnaissance missions that were never before possible.

About the Author

Dave Jones is founder, president & CEO of StormCenter Communications, Inc. (www.stormcenter.com) in Ellicott City, MD. StormCenter focuses on "Raising the Environmental IQ of America™" through innovative technologies and programs in partnership with public and private companies across the nation. He is also a director on the board of the Foundation for Earth Science, a 501 (c) 3 corporation in Northern Virginia. Dave can be reached via dave@stormcenter.com.

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GOES-R

NPOESS

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