NOAA Unmanned Aircraft Systems (UAS) Program
2nd UAS Arctic and River Forecast Workshop

September 15, 2014
Anchorage, Alaska

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Summary Report

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Executive Summary

This document summarizes a workshop held in Anchorage, Alaska on September 15, 2014 for the purpose of bringing together representatives of the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) River Forecast Centers (RFCs) to discuss use of unmanned aerial systems (UAS) in RFC missions and to update the RFC requirements for UAS. The workshop was the second workshop of this type. The first workshop was held at the NOAA facility in Boulder, Colorado February 22-23, 2012. The workshop attendees discussed how UAS technology has advanced since February 2012 and how other NOAA entities have exploited UAS, especially in the Arctic.

The body of this report summarizes the full day of presentations and discussion. Four appendices contain the workshop agenda, the updated RFC UAS requirements including the sensor resolutions needed, a summary of federal unmanned systems interest groups, and a summary of a UAS/RFC program supporting the development of an improved flood model for coastal watersheds. Finally, a white paper advocating the use of UAS to support NOAA's Weather Ready Nation initiative, composed by the Science and Operations Officer at a NOAA/NWS Weather Forecast Office (WFO), is enclosed.

Overview and Opening Remarks

Overview

NOAA and its partners believe UAS and other unmanned systems have the potential to efficiently and safely bridge critical observation gaps in hard-to-reach regions of the Earth, such as the Arctic and remote ocean areas, and to advance the understanding of key processes in Earth systems. Optimizing unmanned capabilities will advance NOAA's mission goals through improved and cost-effective understanding of oceanic and atmospheric exchanges, hurricanes, wildfires, marine ecosystems, Polar Regions, hazards, and other environmental and ecological processes. Other potential NOAA missions will continue to be evaluated as new technology becomes available and as UAS begin more routine operations in national and international airspace.

The NOAA UAS Program was established to explore the potential of UAS for NOAA applications and to advise whether or not UAS use would be cost and performance effective. An Analysis of Alternatives (AOA), an analytical comparison of the operational effectiveness, cost, and risks of proposed materiel solutions to gaps and shortfalls in operational capability, has been performed to document the rationale for identifying and recommending a preferred solution or solutions to several pressing NOAA needs, such as monitoring in marine sanctuaries and observing marine life. Through numerous intra- and inter-agency operational demonstrations and assessments the AOA has been verified and validated.

The UAS Program Goals, as documented in the UAS Strategic Plan, are the following:

Goal 1: Increase access to UAS and related sensor technologies for the NOAA science community
Goal 2: Apply UAS and related sensor technologies to focused missions with high scientific return and that directly support NOAA's Next Generation Strategic Plan goals and objectives
Goal 3: Proactively engage stakeholders from across the NOAA enterprise and externally to ensure that needs for NOAA science, service, and stewardship in the UAS Program are continually and adequately satisfied

The U.S. Natural Hazard Statistics provide statistical information on fatalities, injuries, and damages caused by weather related hazards. These statistics are compiled by the Office of Services and the National Climatic Data Center from information contained in *Storm Data*, a report comprising data from NWS forecast offices in the 50 states, Puerto Rico, Guam and the Virgin Islands. (NOAA, NWS 2014.) This report can be found at http://www.nws.noaa.gov/om/hazstats.shtml. Figure 1 displays the weather fatalities through 2013 by weather event category, and confirms that flooding and weather associated with flooding consistently lead this statistic. This was a force behind the NOAA UAS Program support to capture the RFC observational requirements.

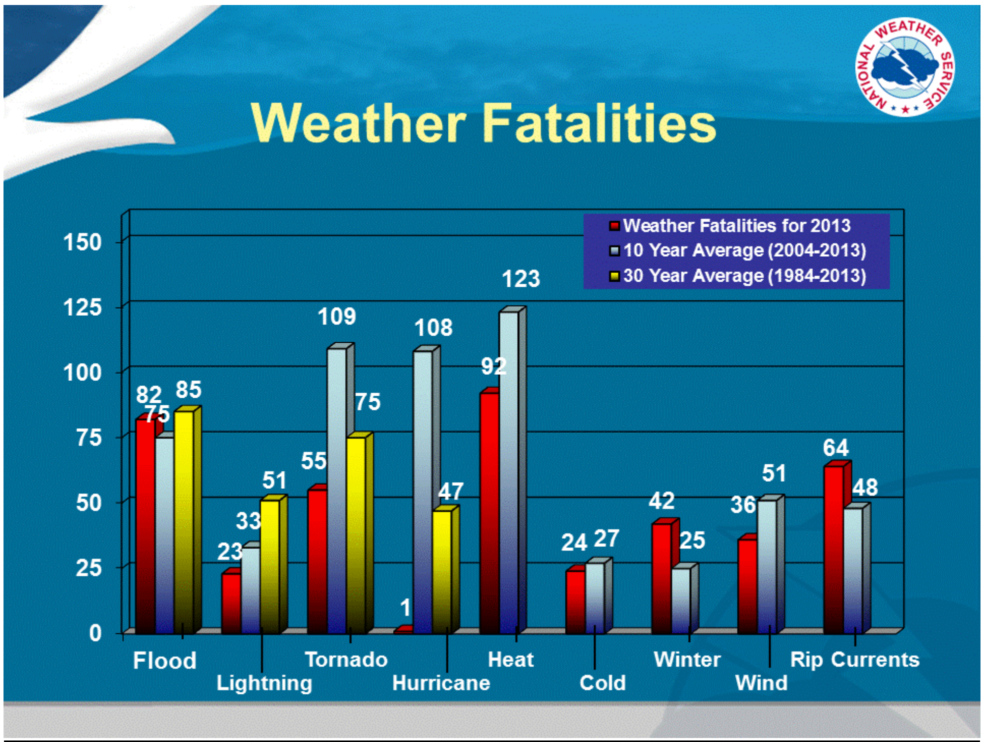

Figure 1. U.S. Natural Hazard Statistics through 2013

The mission of the RFCs is to produce timely and accurate water forecasts and information to support the National Weather Service (NWS), customers, and partners, using the best scientific principles to integrate and model water, weather, and climate information. Each RFC works with its partners to develop and implement improved procedures to enhance forecast services. The RFC workshops and mission operational assessments have assisted this process and formalized inter-agency data exchanges.

This workshop was convened in Anchorage, Alaska on September 15, 2014 for the purpose of bringing together representatives of the NOAA National Weather Service (NWS) River Forecast Centers (RFCs). The goals of the workshop were to:

- Document the RFC's observation requirements and areas of interest
- Document the RFC's current capabilities and unmanned missions flown
- Document current unmanned platforms, sensors, and operators including those used by NOAA and other government agencies
- Review applications and progress made in UAS capabilities
- Construct the foundation for an unmanned systems strategy for the RFC

The day began with RFC representatives presenting on what type of UAS work they have been involved in, how UAS have been useful, and what data needs may be filled by continued UAS integration. A group discussion followed and reviewed the list of priorities created during the previous workshop in 2012. During the afternoon, other NOAA entities presented their use of UAS.

Opening Remarks: Dr. Robert Moorhead, Director Northern Gulf Institute, and John "JC" Coffey, NOAA UAS Program Office

Mr. Coffey provided a background on UAS platforms, how they have been used, what has been successful, and what general advancements in UAS technology have been made. He suggested that UAS platforms will revolutionize observations, much like GPS did. UAS missions have been focused over the maritime and arctic regions where population densities are lower, meaning fewer flight restrictions and privacy restrictions. There have been many successful missions off the coast of Africa in hurricane operations as well as over Canada. The civilian version of the Predator UAS platform has been a great success. More recently, the envelope is being pushed with smaller platforms that are equipped with chemical, biological, and meteorological sensing payloads. It is very hard to launch and land UAS on ships; therefore, much focus has gone into UAS vertical takeoff and landing.

Dr. Moorhead shared work he has been involved with flying UAS platforms over the lower Pearl River watershed, a coastal watershed in Louisiana (see Appendix D). He then reviewed what requirements for UAS were outlined by RFCs during the Boulder, Colorado workshop in 2012.

Work in the lower Pearl River watershed

- Using hand launched small UAS (AV PUMA AE and Altavian Nova)
- Systems being designed for civil applications are struggling to obtain the durability and longevity of military reconnaissance platforms
- Much work is going into improving the robustness of small UAS.
- AeroVironment (AV) is working to improve the pointing accuracy of their payloads.
- We are getting to a point where we are "swimming in sensors and drowning in data," so now it is time to figure out how we can best use and share this data.
- Overflying the Pearl River watershed every two months to get data on drought versus saturation, pre and post storm, and leaf-on versus leaf-off conditions
- River Forecast Centers can then use this data to improve their forecast accuracy by understanding what conditions were like in the past and relating it to a current situation. Continued access to operating in airspaces will allow for the running of hydrologic models followed by the flying of UAS to validate the models.

Review of 2012 Meeting UAS Requirements

From the meeting held in Boulder, Colorado in 2012 the top three requirements were:

- Improved DEMs
- Rapid response of UAS platforms after catastrophic flood events
- Detailed information on levee breaches

Mr. Coffey emphasized the efficiency, effectiveness, economics and environmental friendliness of UAS. He noted the importance of continual flight missions to gather information that will improve lead time and forecast accuracy such as daily or bi-weekly missions to see how flood plains fill during Minnesota snow melts. Additionally, flights during events will help improve real time decisions and preparation.

River Forecast Center Presentations

Mike Deweese, NCRFC: UAS Applications and Requirements at the North Central River Forecast Center

Mr. Deweese presented a background of his RFC's area of responsibility and provided some example missions where they have had great success with UAS. He then provided an outlook of where he sees UAS continuing to help RFC operations.

Decision support service activities

- State EOC situational awareness
- Potential dam breaks

RFC Operations

- Ice jams
- Levee failures
- Inundation/inter-basin flows

Why flood forecasting is currently a substantial challenge
Floods are very dynamic in nature and there is no way to effectively predict river flooding because models are based on past events. It is difficult to track and keep the model balanced with the continuously changing conditions.

Benefits of UAS information
Information from UAS, like observing levee failures, is very important to adjusting the model to improve river forecast accuracy. It can provide the RFC more information about the levee breach, such as the exact location of failure and if it is a partial or full breach. The breaching of these levees is not something that can be built into the models. Therefore, real-time imagery is needed to know at what point and how much water will need to be taken out of the model to correctly predict water levels downstream.

A specific example of a successful UAS mission
NCRFC received a call from locals saying that the dam was breaking and they thought that if it broke they would see a 6 foot wall of water. NCRFC got the DHS Custom and Border Protection (CBP) to fly their UAS to check out the dam. They found the structural integrity was fine. They were able to run a model dam-break scenario and show what would happen if the dam somehow broke. With the current conditions, they found that there would be no more than a 2 foot rise in river height if the dam broke.

Red River situation
The Red River system is such that if there is a large enough event, the town of Fargo could be surrounded by water. Using UAS to observe the real-time dynamics of this system is very helpful to better understand the situation and expectations during large events.

Future applications of UAS

- Use to validate HEC-RAS model results
- Gather tile drain information
    - These tile drains have a large impact on agriculture and they are common in the lower 48. Currently, we have nearly no information on these tile drains and we need information about them for accurate hydrologic models. Therefore, aerial imagery from UAS would provide the ability to see and map the tile drain networks.
- One future project is developing a product that can show a video feed from the UAS next to a feed of the GPS location of the UAS plotted on a map. Integrating this into the chat room platform they currently use would allow the NCRFC to ask the flight crew to survey certain target locations.

Some requirements for UAS missions

- Real-time reconnaissance on levees
- River ice information. Channel ice conditions, ice movement, ice structure, ice jams
- Soil moisture and tile drain observations (high priority requirement for many RFCs)
- Geo-reference imagery over all scales
- Snowpack conditions
- Wind/wave conditions in Great Lakes
- NWS missions require timeliness and accuracy
- Rapid deployment capabilities
- Local imagery analysis or subject matter expert

Suggestions for identifying when to launch UAS

Use satellite data to gather initial indication that something is going on within the basin, like a levee breach. This would then signal that a UAS needs to be launched over the basin to provide a more detailed view of the basin to better understand the situation and adjust the model as needed to improve river forecast accuracy.

Susan van Cooten, LMRFC: Exploring UAS Applications for Coastal Flood Monitoring and Detection: Expanding LMRFC Prediction Capabilities and Decision Support Services

Dr. van Cooten presented UAS applications for coastal flood monitoring and detection. She presented the need for UAS information during Hurricane Isaac – a case where river forecasts were incorrect due to an unknown loss of water from the river system. During events like Hurricane Isaac, the LMRFC has to answer emergency manager (EM) questions about when they will need to close evacuation routes, when can they get people back, will it flood around shelters, and do we need to evacuate those shelters? UAS information will improve their ability to provide accurate information for these decision support services.

Hurricane Isaac Situation

- Louisiana experienced record rainfall amounts during Isaac
- There is a lack of forecast points in coastal areas. To correctly model coastal hydrology, you need information about this area to deal with things like storm surge coming into the area.
- Currently, no RAS modeling is in place, so forecasters have to make extrapolations based on historical floods. However, there have been no flood events in the Pearl River basin with historic rainfall information for late August since 1999 (little information to which to compare Isaac).

- During Isaac, it appeared that if surge had come in, and thinking that all storage had been used up, then the region was looking at 5 days of flooding for the Slidell area based on historic information.
- The stage forecast made by LMRFC was for 19.5 feet based on all the historic data and information they had available.
- This forecast did not verify. They could not, and still cannot, figure out where the water went. This is where UAS will help.

Benefits of UAS information

- (CI-Flow South) Coastal and Inland Flooding Observation and Warning project. They have a visual depiction of the modeling output. They overlay this model output with UAS data to verify and better adjust models to match reality.
- Event driven and seasonal UAS launches
    - Critical for model development, event verification, and forecaster operations and preparations
- UAS imagery would also help evaluate changes to riverine structures
    - Can then go in and update riverine structure changes in model
- Assess seasonal conditions of vegetation patterns
    - Know about the marsh conditions
- Improved forecast accuracy for decisions support services
- Need more soil moisture information
    - This will improve accuracy of runoff

UAS applications in Lower Pearl River Watershed.

- UAS imagery has been collected
- Flew the UAS imagery over gauges so they could correlate the two

Kevin Low, MBRFC: Missouri Basin River Forecast Center

Mr. Low provided an overview of MBRFC followed by some case studies that demonstrate the application of UAS during real-time events. He then identified some of the issues discovered as well as some needs that UAS can address.

Background

- Most of the basin is remote, and it is the largest CONUS RFC. This is a major reason why they want UAS information.
- Have over 16000 surveyed dams that modify flow
- Hundreds of augmented reaches
- Hydrology is much like North Central RFC and is affected by:
    - Mountain snowmelt
    - Plains snowmelt
    - Plains convection

2011 Missouri River Flood

- Flooding was everywhere in 2011, but the Missouri River flood from Fort Peck to the mouth got the most attention.
- Federal and non-federal levees were breached.

- When you lose levees, you lose water in the system and your model needs to be updated to account for this.
- Currently, with a levee breach you have to take out water in the model manually.
- How do you do this with so much information about breaches, like in 2011, when many levees are failing? How do you know the extent of the breach and where the breaches are occurring?
- The U.S. Army Corps of Engineers provides the code for which levee and what side broke. Then the MBRFC personnel have to find this levee in the databases, determine what river gauges are above and below the gauge, and then adjust the model by taking out the appropriate amount of water.
- DHS/CBP flew four different flights in 2011, concentrated north of Kansas City.
    - *Why fly?*
        - Determine areas of levee compromise
        - Estimate flow entering and exiting compromised levee units
            - Not just water lost to the system, but levees will allow water back in at a lower portion of the river
        - Assess flux of water storages behind levees

Lessons Learned

- CBP was very responsive
- Spin-up time was slow. It was several days before they finally got data, most likely due to NWS side rather than CBP.
- Things like flight clearance issues create delays. MBRFC request was made too late. Some federal levee units were already compromised by the time they put in the request.
- It was resource intensive preparing targets and the locations where to request data collection.
- Lack of experience at MBRFC to capitalize on CBP capability
- Bandwidth was not sufficient for video feed
- Need better cooperation in future events to go in together to capitalize on full capabilities of UAS

December 2012 event

- In December 2012, river gauges reached critically low levels
- Why? Maybe ice jam, or maybe lost to ice storage
- Never really knew, UAS information would have been useful to know what was going on and make more accurate forecasts

Sioux River flooding; June 2012

- Forecasts had impacts on Missouri river, including interstate closures and nuclear plant shutdown
- Over-forecasted for this event. Lost water during the event. Why?
- Lost water from system to levee breaches. Found out after the event, but during the event was not sure what was going on. UAS information would have been useful because they could have adjusted forecast for this loss of water and the nuclear plant probably would not have had to shut down.

UAS needs summary

- Levee breaches during major flooding (Time need: Hours-to-days)
    - Type of compromise

    - Breach width
    - Depth and areal extent of ponded storage
- Ice jam flooding (Time need: days)
    - Height of jam
    - Longitudinal extent of jam
- Dam compromise (Time need: minutes-to-hours)
    - Type of compromise
    - Surface area of impounded water
    - Location of flood wave (if dam has already been compromised)

Reggina Cabrera, SERFC: River Forecast Centers and Unmanned Aircraft Systems

Mrs. Cabrera provided an assessment of how UAS could assist in RFC operations in the SE and other regions who were unable to attend the workshop.

What areas UAS program will help.
- Real-time flood inundation and validation are needed
    - Starting to get and use hydraulic modeling but do not have verification. This is where the UAS program will help
    - Monitor flood waves and inundated areas during flooding
- Collection of higher resolution elevation data
- Collection of detailed floodplain areas
- Detailed information on levee and dam structures
- Mudslides mapping areas and verification of extent of event
- Landslide susceptibility mapping at proper resolution
- Measurements of winds/waves in reservoirs
- Flash flood verification in remote areas
- Monitor backwater effects and determination of flow direction in low-relief areas (e.g. Florida)
- Monitoring sediment transport, especially in estuaries. Need baselines as well as during and after flooding.
    - Moving towards doing this, not currently done
- Monitoring surface velocity will help determine spread of contaminants, plume characteristics (shape, speed), especially for areas where we do not have hydrodynamic models in place.

Possible project; Puerto Rico
- Very complex to forecast for
- Flash floods, karst landscapes, mudslide, landslide, surge, etc.
- Very interesting condensed area that we can learn a lot from
- Need to know more about karst to improve hydrological forecasting for the Island
- Mudslides and landslides mapping and verification
- Flash Flood verification
- Monitoring of karst areas (determine dry/wet channel reaches)

WGRFC UAS requirements
- Water supply in San Juan and Sangre de Cristo’s River
    - Focus would be on higher elevation snowpack
- Extreme flood situation for Rio Bravo

- Bathymetry/Topography

ABRFC UAS requirements

- Would like to know more about possible UAS usage during high impact flood events
- Monitoring of levees

NERFC UAS requirements

- Extension of inundated areas
- Evaluate the potential for dam failure
- Location and status of ice jams
- Wind effect in hydraulic models, e.g., determination of wind waves on Lake Champlain

Common topics

- Inundation mapping
- Visual content for before, during, and after flood images
- Monitoring of breaches and other water management structural systems

Questions?

- Can we determine water depth, velocity?
- Any use during tropical conditions?
- Could you collect channel bathymetry?

Robin Radlein, APRFC: Alaska-Pacific River Forecast Center

Mrs. Radlein presented UAS requirements in Alaska and river forecast challenges in data sparse regions.

Flooding

- What is causing the flooding and what can we do to determine where, when, and how bad it will be when it happens?
- Determination of location and extent of flooding is difficult in ungauged areas

Spring Ice Breakup and breakup of ice jams

- Dependent on factors such as ice thickness and condition, snow water equivalent of contribution area, timing of melt due to warming
- Observations of ice thickness and snow water equivalent are very sparse

Heavy Rainfall events

- Do not deal with convective rainfall like in CONUS, but post-tropical storms bring long-lived heavy rainfall events

Glacier Dammed Lake Releases

- Recurring fill and spill lakes formed by glaciers blocking mountain valleys or perched lakes
- Monitoring fill progress of remote lakes can only be accomplished with aerial observation; not all contributing lakes have been located or identified
- Hard to tell when glaciers are filled. Not easy to get to. So not really sure when they will release water

Each of these different types of flooding are where UAS information will be extremely useful.

UAS Applications

- DEM data available is inadequate for HEC-RAS modeling
- LIDAR surveys (really need better DEMS for modeling!)
- Would be happy with 10 meters (currently, resolution is….coarse)
- Alaska has a lot of places to use UAS. Not many river gauges, so UAS would provide information so they know what is going on

Snow water equivalent

- Gamma radiation flight lines. Snow attenuates the earth gamma radiation, therefore, you can learn about snow water equivalent by measuring this gamma radiation
- Putting similar gamma instruments on drones would allow a lot more observations and should be a lot cheaper

Ice thickness

- Have to drill out a core and then measure it. Not a very good distribution of information
- Would be nice if there was a sensor that could tell us what the thickness of ice is
- The Russians have one, so we must have one somewhere

Identifying locations of ice jams.

- Currently use pilot reports and images in a partnership with Alaskan Homeland Security and Emergency Management Agency and FAA
- Send official Ice Pi-Rep
- UAS could get us this information more often and in more hazardous flying conditions
- The Canadian SAR (Synthetic Aperture Radar) satellite data is in the microwave band and can identify multispectral ice products. Provide information about ice (i.e. slushy ices or breaking up in large chunks) that help with river forecasts. However, very coarse resolution. Therefore, would be useful to have some kind of microwave band information on UAS that can measure these ice characteristics

Monitoring Glacier dammed lakes

- UAS are needed to make important contributions to the understanding and monitoring of glacier dammed lake so forecast of river heights and flooding can be more accurate

Way out of the Box thinking

- Many 'bush' villages do not have access to NOAA weather Radio, Commercial TV, or Widespread internet access. They **do** use UHF radios
    - Possibility of sending UHF signals using UAS to provide information to individuals in remote locations

UAS Application Priority Breakdown

After the morning presentations from the RFCs, the attendees, both local and remote, updated the RFC UAS requirements and priorities. See Appendix A.

One requirement that became a higher priority during this discussion was the monitoring of coastal and lake conditions – winds, waves, and swell conditions. A new requirement was the need for a fulltime analyst, something considered very important as UAS information becomes more abundant. A nice add-on to any UAS would be the ability to transmit and disseminate information to remote areas using NOAA Radio, VHF, and UHF transmissions. The number one priority remained higher resolution DEMs because all RFCs agreed that higher resolution DEMs are needed to improve the hydrologic models that aid in all forecasting and preparation applications. Rapid response during and after catastrophic flooding events to track changes in river channel structure and morphology of debris remained the number two priority because it is incredibly important information to know this information to correctly forecast and adjust models during an event and for validating models in post-event analyses. Better understanding of tide, surge, waves, winds, and total storage in tidal plain became priority three because it is important and life threatening information for coastal communities and coastal RFCs. Detailed information of levee breaches and any inundation in real time moved to priority four. Rapid response photos to document extent of inundation to verify flash flooding, flood inundation maps, and enable production of flood maps for more locations became priority five. An important note about priority five is that this is focused on rapid, real-time data collection. Therefore, if it is not possible in a quick response situation to get exact geo-referencing for imagery, still fly the mission because it would be preferable to have any kind of real-time information during the event. That said, it is preferred that all data collected will be geo-referenced and this should not be an issue with current technology. Soil moisture stays as a high priority, but the ability to gather this data is still improbable due to technological restrictions (e.g. lacking UAS payload).

Some new requirements introduced include backwater influences in river levels; surface velocity, and subsurface flow identification. The subsurface flow identification would be focused on visual data collection to identify things like tile drains (nation-wide) and karst/karst landscapes (Puerto Rico and Florida). Stream characteristics, like surface velocity information, was added.

Structural integrity of levees and dams: The main focus is those levees that are not federally inspected by the Corps of Engineers. There are many levees around the country that are not federally managed and are locally managed and inspected, therefore, the monitoring of these structures using UAS would be beneficial to understanding their integrity. Slides and slope failures includes all types of slope failures: landslides, mudslides, avalanches, etc.

River ice conditions are a high priority and one that affect many northern RFCs. Glacier dam lake monitoring is information needed by the APRFC.

UAS use by other NOAA entities

Carven Scott, NWS Alaska Region Headquarters: Observational Gaps in Alaska

Mr. Scott provided background on NWS Alaska. NWS Alaska is unique because it was not always an official part of NOAA, it used to operate on its own. Now they are part of NOAA and operate as NWS stations in CONUS operate. For all of Alaska, there are only three forecast offices that cover an area as large as what 60 NWS offices would cover in the lower 48. Mr. Scott presented issues in Alaska NWS forecasting and why it makes a lot of sense to integrate UAS into the observational network.

Lack of Data Coverage

- There are many data gaps in Alaska
- Only 44 ASOS, 13 upper air sounding locations, 7 Doppler radars, 3 wind profilers
- Very sparse precipitation and river gauges
- NWS Alaska depends heavily on satellite data

Alaska Weather Challenges

- Heavy rain events (post-tropical systems from Japan), space weather, ice storms, volcanic ash, open water, extreme cold, blizzards, heavy snow, flooding (ice jam, coastal storm surge, heavy rain events), wild fires, sea ice
- Have on average 14 storms each year with hurricane force winds and central pressures similar to hurricanes
- These large storms are not well sampled but can have substantial impacts. In August 2012, one storm with a central pressure similar to a Cat-1 broke up and dispersed sea ice which made many coastal communities more vulnerable to flooding and sea ice intrusion.
    - Satellite data provides some information, but real-time high resolution is needed to better understand and mitigate sea ice break up events
    - Freezing spray is a major forecasting challenge that has the potential to be devastating to marine operations

Why should you care?

- In Alaska, there is only a 4-5 day supply of food for the state. 95% of the needed food is stored in Seattle in the floodplain of an earthen dam. If that were to fail, Alaska would be in a food shortage scenario.
- All Arctic marine transport must go through the Bering Strait
- Need to understand the physical parameters to provide decision support services. Currently ability to do this is limited due to lack of observations
    - Drilling in Chukchi and Beaufort Seas. Oil reserves off NE coast may be equal to reserves in Saudi Arabia

Why UAS?

- In situ observational density is an order of magnitude less than CONUS, it is insufficient
- Satellite imagery does not provide the information that is needed or that in situ measurements provide
- UAS have the ability to provide critical observation validation, especially in the boundary layer
- UAS could help answer a number of outstanding questions related to the atmosphere, ocean, and sea ice

- Need access to real time data over the oceans
- Radiosonde replacement is costing the NWS $750,000 a year; UAS may actually save money.
- Volcanos: need in situ observations to be able to understand the mass loading, concentration, and cloud extent and to be able to correctly model
- Ocean and sea ice: need to know temperature and salinity to understand and model sea ice breakup
- High latitude boundary layer acts much different than it does in the lower 48. UAS will fill in data needed in the boundary layer

Peter Wolf, NWS Forecast Office Jacksonville: Future NWS Update

- Moving to location-specific warnings. Changing from one size fit all
- More detailed and customizable forecast information from the NWS
- UAS will be a huge support in aviation forecasting, like cloud and turbulence forecasting
- There is a lot we do not know about sea breeze. We have some simulations of the structure of the sea breeze, but it would be advantageous to take measurement, using UAS, during events which would lead to a better understanding of the structure of the sea breeze and boundary layer conditions. Then we could know why and if a storm will or will not develop.
- We are headed in the direction of higher resolutions models. To have accurate high resolution models, we need greater data density. Two balloon launches a day is not enough. With UAS we will have more data to update and adjust models for better forecasts.

CAPT Phil Hall, Office of Marine and Aviation Operations: UAS Alaska/Arctic Flight Operations

Captain Hall provided an overview of the UAS that have been used by NOAA's Office of Marine and Aviation Operations (OMAO), what NOAA is doing with UAS, and some of the challenges in UAS operations.

Background

- OMAO works with all the programs that want to use UAS, making sure the right equipment, pilots, and resources are in place to operate UAS missions
- OMAO operates
    - PUMA UAS: Lots of experience flying them at National Marine Sanctuaries (NMS)
    - APH-22 Hexacopter: Very useful platform that has proven itself in marine applications
    - Quadcopters: Used alongside the PUMA and provides great visual imagery
    - Manta: Can carry large payloads
- Involved in Sensing Hazards with Operation Unmanned Technology (SHOUT) program, which seeks to mitigate the risk of satellite observing gaps. Data will be collected in the tropics and in the Northern Pacific

Aviation Challenges

- Logistics
- Infrastructure
- Multi-FIR Ops
- Non-approved navigation systems
- Weather

- Pilot qualifications

UAS Specific Challenges
- Obstacle detect and avoid abilities
- Regulatory issues
- Weather avoidance
- SATCOM above 60N latitude
- Polar navigation
- Certification issues
- Radio spectrum
- Weather avoidance
- Ice avoidance
- VMC avoidance

Remote operation needs
- Hazards to humans
- Quick and easy field repairs
- Batteries

Robyn Angliss, NOAA Fisheries Service: Use of UAS by NOAA Fisheries, 2009-present

NOAA's National Marine Fisheries Service (NMFS) requires detailed information on a variety of marine mammal species to support management and conservation needs for the species. Key data needed include information on abundance, distribution, trends in abundance, animal health, habitat, and behavior. NMFS started investigating the use of UAS for collecting some of these key parameters in 2009 and has used UAS for several aerial survey applications in recent years.

Collection of information on marine mammal abundance and distribution requires meeting pre-determined tolerances (e.g. calculated abundance estimates with a coefficient of <0.3 are considered "adequate"); in many cases, high resolution images (ground resolution as low as 1.4cm) are needed to resolve species identification or morphometrics in low-light situations.

Ship based ice seal survey using a ScanEagle in the Bering Sea; 2009
The Alaska Fisheries Science Center, National Marine Mammal Laboratory (NMML), in cooperation with the University of Alaska-Fairbanks and with partial support from the NOAA UAS Program, tested the use of a ScanEagle during spring 2009 to collect images of ice-associated seals from the NOAA Ship McArthurII located at the ice-edge in the Bering Sea. Ten flights were conducted successfully and launches and retreivals were conducted in light rain and snow; approximately 27,000 images were collected. Ice-associated seals did not demonstrate any disturbance during the flights. Although the D-SLR camera system performed well, there were some storage issues on longer flights. The project was an operational success, but the science goals were not met due to limited airspace access.

This project did highlight the need for improved image analysis of the high volume of images obtained from the UAS, and prompted a multiyear project to couple thermal sensors with D-SLR systems to speed post-processing.

VTOL UAS flights in Antarctica to penguins and seals; 2010-present
The NMFS Southwest Fisheries Science Center, with partial support from the NOAA UAS Program, assessed multiple VTOL UAS platforms for aerial surveys of gentoo penguins, chinstrap penguins, northern fur seals, and leopard seals in the Antarctic. VTOLs were preferred for this work because they are portable, quiet, and safe, and capable of surveying the areas of interest. The Aerial Imaging Solutions APH-22 best fit SWFSC's needs and has been used annually for Antarctic aerial surveys since 2010. The APH-22 is used to obtain imagery used for mapping penguin colonies and counting individuals, which have been confirmed accurate with counts conducted by observers on the ground. This system's aerial imagery can also be used to obtain accurate measurements of leopard seals with less risk to personnel and wildlife. A paper documenting this work has been published in Polar Science (Goebel et al 2015).

Assessment of PUMA, Scout UAS for Steller sea lion surveys; 2012
AFSC's NMML, in collaboration with the University of Alaska-Fairbanks (which had partial funding from the NOAA UAS Program), assessed two UAS, the PUMA fixed wing and Scout VTOL, for aerial surveys of Steller sea lions in the western Aleutians in 2012. This investigation documented that UAS might be useful for Steller sea lion assessment, but the imaging payloads for the PUMA and Scout failed to provide sufficient image resolution to meet NMML's survey needs.

Steller sea lion surveys in the Western Aleutians; 2014
AFSC's NMML surveyed 11 Steller sea lion rookeries in the Western Aleutians with the APH-22 UAS and a NOAA Twin Otter surveyed sites in the eastern Aleutians in 2014. The APH-22 was able to survey sites that manned aircraft had been unable to survey since 2008 due to persistently poor weather conditions. This combined approach resulted in the most complete Aleutian Steller sea lion survey since the 1970s. Imagery obtained with the APH-22 was of higher resolution than that obtained by the Twin Otter and could be used to read individually marked animals.

Monk seal surveys using PUMA; 2014
The NMFS Pacific Islands Fisheries Science Center, with support from the NOAA UAS Program, used a Puma to collect aerial imagery of monk seals in areas of the Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands. The Puma was deployed aboard the NOAA Ship Hi'ialakai from 16 – 23 June 2014 and flew seven missions (four from the Hi'ialakai, one from a small boat, and two from land). The Puma surveyed French Frigate Shoals, Nihoa, and Mokumanamana. One flight had to be aborted due to technical difficulties. Over six hours of footage (approximately one hour in infrared mode) were collected. FAA guidance limited Puma operation to line of sight only. The Puma was flown at an elevation of approximately 122 m to 366 m above ground level. While primary monk seal research goals of identifying individual animals, assessing injuries, and reading tags could not be met using the existing Puma payload, the Puma was able to meet secondary goals of counting individuals, identifying age classes and relative condition of seals. There was also no detectable disturbance to seals. A payload capable of capturing higher

resolution imagery will possibly increase the utility of the Puma for monk seal research in the future and will be tested.

NMFS use of UAS for these projects has provided valuable lessons learned that should be considered when developing future projects reliant on UAS:

Identify the project need / tolerances to determine best platform and payload
Both platform and payload capabilities are important, but the PIs primary consideration should be whether the payload is capable of collecting the required data at the necessary resolution. Once the sensor is identified, a platform capable of delivering that sensor to the study area should be selected.

Automating the counting of animals will speed data analysis
The time required to manually analyze data post-flight can be extensive, in some cases 30 hours of analysis per 1 hour of flight time. New processes for data collection and analysis may be very helpful for processing large volumes of data acquired by UAS. This may be accomplished with automated image analysis software designed to assist in post-flight processing.

Small swath width and slow speed of UAS have implications for survey design
UAS may fly slower, lower, and/or have a smaller "view" of the ocean than manned aircraft; requiring additional flight hours to obtain required a specified sample size.

The Marine Mammal Protection Act (MMPA) requires a research permit for disturbance due to UAS flights
The MMPA requires a permit issued from NOAA Fisheries Office of Protected Resources or US Fish and Wildlife for any activities that result in a "take" of marine mammals, which includes any change in behavior (ranging from moving into the water to looking at the UAS) caused by UAS.

NMFS will continue to apply lessons learned to refine its existing projects that use UAS and intends to continue expanding on the use of UAS. It is also in NMFS future plans to:

Compare UAS and manned aerial surveys for large whales
AFSC's NMML is planning a project with funding from the Bureau of Ocean Energy Management and the Office of Naval Research to evaluate the ability of UAS technology (i.e., platforms, payloads, sensors, and software) to collect data to photograph cetaceans, identify species, estimate group size, and identify calves and compare those results to conventional aerial surveys conducted by human observers in fixed-wing aircraft.

Revise the strategic plan for using UAS to meet NMFS research goals
NMFS is revising their strategic plan in FY15 to describe how UAS may be used to meet NMFS' research needs.

Publish the results of past projects in peer-reviewed journals
It is critical to publish the results of past UAS projects so that the broader research community can learn from the experiences of others. NMFS will focus on publicizing and publishing UAS research

results in FY15 through convening a workshop in October 2014 directed at using UAS to study wildlife and wildlife habitat, followed by the preparation of a special issue on this topic in the Journal of Unmanned Vehicle Systems in late 2015.

Continue to use manned aircraft
While NMFS is excited about UAS as a new research tool, the agency expects to continue to rely heavily on manned aircraft to meet it's research needs.

Tim Bates; UW/PMEL. Aerosol/Radiation, VNIR/NIR/TIR Imaging, Net Solar and Longwave Radiation, Meteorological Fluxes, Atmospheric Dropsonde, and Ocean T/S Microbuoy Payloads for Earth Observations using a Manta Unmanned Aerial System (UAS)

Dr. Bates reviewed some of the international collaboration projects they have been conducting in the Arctic including the use of UAS to study aerosols. He presented some of the UAS they used and the instrumentation suite they were able to add to the payload.

The inability for climate models to depict atmospheric constitutes, like black carbon, is a large reason for uncertainty in climate models.

Arctic research

- Ny-Alseud: most northern civilization in the world and is a great location for research
- Used the Manta science payload to measure
    - Total particle number
    - Aerosol light absorption
    - Aerosol size distributions
    - Temperature/RH
    - Radiant flux densities
    - Distributions using pyrgeometers and pyranometers
    - Net longwave and shortwave radiation
- Had to filter samples for post flight chemical analysis
- UAS measurements lined up well with ground based measurements
- Manta flights, did 18 flights in 38 hours
- Flight path: ascend to 2000 m and then descend back in greatest density of black carbon aerosols. Generally inversion at 1000-1500 m where the boundary layer was capped
- Aerosols number counts were higher aloft. Black carbon was recorded in higher levels showing the vertical transport of black carbon

New LDEO payloads

- Improved Aerosol/Radiation payload with OOPC and upward looking radiometer
- Improved visible and infrared imaging payload. Precise measurements of ice, snow, and ocean surface temperatures to 0.1 C resolution
- Hyperspectral aberration corrected imaging spectrometer payload. Spectral radiation of the upper ocean and sea ice to determine ocean color and ice-age
- Up and downward looking hemispheric pyrgeometers and pyranometers
- Meteorological payload
- Turbulent momentum, sensible and latent heat fluxes
- Dropsonde payload (4 dropsondes)

Future

- Test flight in Yakima in January 2015
- Svalbard flights in April 2015 to demonstrate performance of new payloads, such as the ability to drop dropsondes and gather atmospheric data on the way down. Maybe drop instruments down on ice sheets and ice flows. An atmospheric dropsonde could also record ocean temperature and salinity information once it is in the ocean
- Looking for funding to repeat the black carbon transport/deposition study in the Arctic
- Continue efforts for shipboard launch and recovering. Possibly convert Mantas to VTOL

Todd Jacobs: NOAA USCG Healy Deployment

Mr. Jacobs discussed PUMA AE operations from the Healy and reviewed their use of UAS in Arctic intelligence, surveillance, reconnaissance (ISR) and environmental response management applications. One of their greatest challenges was the inability to fly when winds were greater than 25 knots. They would be able to operate 80% of days rather than 20% if UAS could operate up to 35 knots.

PUMA AE operations from Healy

- Landed on water and ice
- Tested deck landing
- Tested net capture system
- Conducted ISR operations while streaming full motion video
- Sea ice ridge detection/monitoring
- Produced a DEM of ice ridge and surrounding area
- Monitored marine environment and marine mammals
- Usefulness in search and rescue scenarios
- Detection and monitoring of oil spilled from ship or oil exploration
- Detection and monitoring of marine debris from ship
- Prepared for future boundary research from UAS
- Utilized NOAA's Environment Response Management Application (ERMA)
- Coordinated with ONR Marginal Ice Zone Experience
- Coordinated with the University of Alaska Fairbanks (UAF) for ScanEagle flight operations coordination and data exchange
- Had an aerostat (balloon) that had IR sensors. PUMA flights along with the aerostat showed similar measurements
- Beyond 12 miles from shore, they operated under “due regard" operations
- Most interested in the net capture system. Allows for smaller ship and harsher environment flights
- ERMA coordination provided ability to stream data directly and provide real-time data

Primary limitation

- Cannot emphasize enough how challenging an environment it is to operate any UAV in the Arctic
- Platform recovery process and sensors must continue to be expanded. "Due regard" operations must be expanded

Partnerships are crucial

- People, property, and platforms (data captured) are valuable
- Must maximize operations and date sharing opportunities

Robbie Hood, Director, NOAA UAS Program: NOAA UAS Weather and Sea Ice Observations

The focus of UAS missions have been on high impact weather and marine weather. A major reason for this is because of the ability to fly over the oceans with less restrictions than over the interior United States. Ms. Hood presented some key accomplishments in UAS missions and discussed an upcoming project, SHOUT.

Key UAS Accomplishments

- High impact weather flights with Global Hawk in collaboration with NASA. Just recently were able to overfly and observe progression of Hurricane Edward from tropical cyclone to hurricane
- Have been able to develop dropsonde system for Global Hawk in collaboration with NSF. Data from these sondes can be stitched together and boundary layer cross sections can be created.
- Hoping by 2016 will have the Global Hawk ready to fly up around the Alaska regions
- Lower Mississippi River Forecast Center demonstrations with PUMA and Nova
- Development of Fire Weather UAS through NSF collaboration
- Hope to develop UAS to carry payloads of air constitute sensors with ability to fly through volcanos
- Development of EMILY unmanned surface marine vehicle. The EMILY was developed to go into the eye of a hurricane, but could be very useful in Arctic.
- Two peer-reviewed journal articles published in 2014

New project coming: Sensing Hazards Using Operational Unmanned Technology (SHOUT)

Overview: Demonstrate and test prototype UAS to fill satellite data gaps. Could we put UAS in flight to collect targeted observations around high impact events to both fill satellite data gaps and to replace satellite observations if satellites are unavailable? Will help to supplement weather models.

Objective 1:

- Conduct data impact studies

Objective 2:

- Evaluate cost and operation benefit through detailed analysis of life-cycle operational costs and constraints

SHOUT General plan

By 2015

- Take real data from Global Hawk and apply this data into operational forecast model
- 10 NOAA-dedicated Global Hawk missions

By 2016

- Fly from west coast and go up to Alaska and focus on providing real time data to aid in Alaskan forecasting

How can you deploy UAS efficiently and effectively to get the most important information to those who need it?

NCEP has been experimenting with the dropsonde data from the Global Hawk to see the impacts of providing the model the supplemental data.

- Found positive impacts. Greater improvements in forecast than before with only satellite data
- 10% improvement in track forecasts
- 15% improvement in intensity forecasts at 12-60 hour interval
- Much improved storm size forecast

Next Steps

- Global Hawk remotely sensed data are next priority study
- HIRAD: Dual polar scanning radar that will give surface wind measurements
- HIWRAP: Vertical wind measurements
    - Combining HIRAD surface wind, dropsonde wind, and HIWRAP VAD wind assimilated shows a more realistic and better understanding of the tropical system winds. Putting that information into the models will help improve the models.

Ice monitoring UAS projects

- There are sensors that measure sea ice thickness and at least one that measures snow depth
- Some polar monitoring systems include: NASA Sierra, UAF Scan Eagle, and CU Data Hawk

Summary

The workshop reaffirmed the fact that Unmanned Aerial Systems (UAS) can provide great value to the mission of NOAA's NWS/RFCs. UAS add value to many of their observational needs. UAS are efficient, effective, economical, and environmentally friendly. They are cost and performance effective. They are another tool that can be used which provides unique capabilities and value for many requirements.

The RFCs identified their top 5 UAS requirements as:

- Better river **DEM**s
- Rapid response during and after a catastrophic flooding event to track **changes in river channel** structure and morphology and debris
- Observations of tide, surge, total storage in tidal plain, etc. (for **total water level**)
- Detailed information on **levee breaches** and any inundation in near real time (location, width, depth)
- Rapid response **photos** to document extent of inundation to verify flash flooding, flood inundation maps, and enable production of flood maps for more locations

The exhaustive list of requirements can be found in Appendix B. In general, the RFCs perceived UAS as being able to provide: a more rapid response than manned fixed wing assets in many cases, higher resolution in focused areas, unobtrusive access to sensitive areas, and persistent observations of areas of potential and evolving disasters.

Other NOAA offices and programs presented information on other uses of UAS within NOAA: coverage gaps in weather measurements, backup instrument when unable to obtain satellite data, marine bird habitat analysis, marine mammal observations, solar radiation studies, meteorological flux studies, delivery of atmospheric dropsondes and microbuoys, search and rescue operations, sea ice monitoring, oil spill monitoring, marine sanctuary monitoring, fire weather monitoring, and hurricane formation studies.

Appendix A: Workshop Agenda

NORTHERN GULF INSTITUTE
a NOAA cooperative institute

NOAA Unmanned Aircraft System (UAS) Program
2nd UAS Arctic and River Forecast Workshop
15 September 2014
Anchorage, Alaska

Agenda

0730: Welcome

0740: NOAA NWS River Forecasting Center Update: Robert Moorhead & John "JC" Coffey

- (Brief last report, summarize range of UASs, discuss progress, discuss plans)

0820: Break

0830: North Central RFC: Mike Deweese

0850: Lower Mississippi RFC: Suzanne van Cooten (*remote*)

0920: Missouri Basin RFC: Kevin Low

0940: Southeast RFC: Reggina Cabrera

1000: Alaska Pacific RFC: Robin Radlein

1030: Summarize needs: Robert Moorhead

1100: Discuss next steps and discuss coordinating with other federal agencies: John "JC" Coffey

1200: Lunch

1300: Discuss "Other NWS UAS Applications" – (Carven Scott)

1400: NOAA UAS Flight Operations – (Phil Hall)

1420: NOAA Wildlife Observations – (Robyn Angliss, NMFS)

1440: NOAA Air Chemistry Observations – PMEL Manta Missions (Dr. Timothy Bates)

1500: NOAA UAS Marine Domain Awareness Observations– Arctic Shield (Todd Jacobs, *remote*)

1520: NOAA Weather and Sea Ice Observations – MIZOPEX and SHOUT (Robbie Hood, *remote*)

1540: Wrap-Up (JC Coffey)

1600: Adjourn

1800: No Host Dinner at the Snowgoose Restaurant and Brewpub (JC Coffey)

Appendix B: RFC requirements with UAS potential.

		RFC Requirements September 2014					
Requirements	***realtime need?***	***additional info***	***sensor***	***priority***	***improved warning time***	***hor-res***	***ver-res***
Better river **DEM**s	months-years	to get better DEMs for reaches that only UAS might visit	lidar	priority #1	more accuracy	1m (NC) to 10m (AP)	5cm (most) to 50cm (AP)
Rapid response during and after a catastrophic flooding event to track **changes in river channel** structure and morphology and debris.	hours-days	will help to update river models "quickly" to mitigate forecast errors should another storm hit quickly; high flow and low flow need	visible / lidar / altimeter	priority #2		10 cm (visible); 1m (lidar)	5 cm
Observations of tide, surge, total storage in tidal plain, etc. (for **total water level**)	hourly during event	river state at high and low tide; have UAVs up under event if possible; quickly after event	visible and lidar	priority #3		1m	5cm
Detailed information on **levee breaches** and any inundation in near real time (location, width, depth)	realtime	Quick response to locate levee breaches; assess the flux of water out and back into the system	visible; IR; SAR; passive microwave	priority #4		1m	10cm
Rapid response **photos** to document extent of inundation to verify flash flooding, flood inundation maps, and enable production of flood maps for more locations	hours-day	peak of flood is best, but on rising and falling would be good; need good enough resolution to resolve buildings and such; raw video initially and then DEMs	visible, VNIR, SAR, lidar	priority #5		20 cm	

Levee monitoring during major floods (based on associated risk in USACE NLD). Structural integrity of levees and dams (sand boils, sluffing, etc.)	daily	during an event you want to monitor more closely; USACE monitors large system	visible, Thermal IR, VNIR, SAR, passive microwave	high priority	significant	<1m	
Slides or slope failures	near realtime	for areas where prone to happen in space or time; not a good time for people to be on levee	hyperspectral/SAR	high priority	significant	1m	
Coastal / surge and wave height / wave run-up information … inundation extent	hours	required for response as opposed to planning; need compact sensor suitable for UAV	C-Band Radiometer, SAR; visible	high priority		10m	<0.5m
River Ice conditions (ice cover type, jam locations, thickness, height, etc.)	realtime	might could get data from satellite; might could use USGS CLICK dataset	lidar / altimeter, visible, radar; SAR; Russian sensor	high priority (March-May)	critical	1m	10cm
Fulltime analyst / SME		especially for realtime data collection	all	high priority			
Snowpack conditions (areal extent, water equivalent, depth, etc.)	days		gamma radiation; passive microwave	priority for many RFCs	timing and accuracy	100m (northern plains) to 50km (AP)	0.25 cm
Monitoring **Glacier Dammed Lakes**	weeks-month		visible	high priority for APRFC	critical	1m	
Backwater influences in river levels; surface velocity	hours	priority is water surface elevation	lidar			1m	5cm
Subsurface flow identification	days-weeks	includes karst and tiles	visible; doppler radar; IR (for tiles)			1 m	

Deep (>5cm) soil moisture	weeks	The instrument to measure deep moisture is very large; will likely never fly on a small UAS	Polarimetric L-Band Radiometer			1km	10s of cm
Lidar to attempt to measure depth of inundation to verify flood inundation maps and enable production of flood maps for more locations	hours-day		lidar / altimeter			30m	5cm
High resolution geo-referenced imagery over all scales (e.g., from detailed structural conditions to widespread inundation extents)		to validate forecasts	visible		more accuracy		
Wind / wave / swell pattern conditions in lakes and along coast	hours-days	required for planning as opposed to response; need compact sensor suitable for UAV	C-Band Radiometer, SAR		accuracy	10m	<0.5m
The extent of suspended sediments / turbidity / water quality issues	hours	from flooding, an incident, or a toxic spill; dam removal	visible, hyperspectral	future		1m	
Water temperature	hours-days	fishes, algae bloom; glacier dam releases	Thermal IR; passive microwave for surface	future		5m	0.5 C
Vegetation and soil mapping to insure accurate river model parameter settings especially in response to drought	weeks	need height and density; different modeling if spring or fall	multi-spectral; MODIS	lower priority		250m	
Snow line location	weeks	need to know where snow line is	visible	lower priority		150m	

Dissemination of information	realtime	might require co-location with UAS operator or you have to figure out a way to transmit	NOAA Radio; VHF & UHF transmission	low hanging fruit; good add-on	Yes		
Map forest burn areas	days	probably can use USGS / USFS	visible	not priority for NOAA		30m	

Appendix C: Interagency Unmanned Systems Coordination and Best Practices

The technology readiness of Unmanned Systems (UxS) for robust operations has been rapidly increasing during the last decade. This progress can be attributed in large part to U.S. military systems which have contributed more than 90% of the funding and operational hours towards these disruptive technologies. Additionally, Federal agencies such as the National Aeronautic and Space Administration (NASA), the National Ocean and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the U.S. Geological Survey (USGS), and the U.S. Forestry Service (USFS) have been demonstrating the viability of unmanned platforms as civilian scientific observing systems. Interagency UxS coordination, best practices, and roadmaps are shared to ensure increased efficient, effective, economical, and environmentally friendly multi-mission operations.

The hurdles of UAS access to national and international air space are expected to diminish as governing policies and regulations are implemented during the next few years especially as the Federal Aviation Administration (FAA) small Unmanned Aircraft Systems (UAS) rules are published in 2015-16. These highly anticipated federal rules for commercial UAS operations are expected to require operators to have a license and limit flights to daylight hours, below 400 feet, and within sight of the person at the controls. The UxS industry has awaited commercial rules for many years, hoping the rules would pave the way for widespread drone use in industries such as maritime, agriculture, farming, filmmaking, and construction. Current FAA policy allows recreational drone flights in the U.S., but essentially bars UAS from commercial use.

As unmanned observing systems are becoming routine components of scientific field experiments and operations, the time has come to “plan for the success” of these robotic systems within an optimized operational observing strategy providing critical information for warnings and forecasts of high impact weather and disasters. Unmanned observing systems can provide increased range, endurance, or data resolution when targeted adaptive strategies are needed to complement current operational observing systems. Unmanned observing systems could be especially effective in filling critical data gaps associated with high impact weather systems, such as hurricanes developing and intensifying in data void regions of the ocean.

As unmanned systems have continued to gain popularity and operational utility, federal UxS interest groups have been established to formalize policy and procedures for these systems. The following interagency groups have been working towards maximizing measurable societal benefit, scientific return, cost-effectiveness, and operational efficiencies:

- Interagency Working Group on Facilities and Infrastructure (IWG-FI)
  - Subcommittee Unmanned Systems (SUS)
- Interagency Committee on Aircraft Policy (ICAP)
  - Unmanned Aerial System Subcommittee

- Interagency Coordinating Committee Geoscience Research Aircraft (ICCAGRA)
- Joint Program Development Office (JPDO)
- Office Federal Coordinator for Meteorology (OFCM)
    - Joint Action Group for Unmanned Aircraft System Environmental Monitoring (JAG/UAS-EM)

The following is a brief description of each group.

Interagency Working Group on Facilities and Infrastructure (IWG-FI)

The **Interagency Working Group on Facilities and Infrastructure (IWG-FI)** is composed of federal oceanographic facilities managers. It advises the Subcommittee on Ocean Science and Technology (SOST) on policies, procedures, and plans related to oceanographic facility use, upgrades, and investments. This group also provides guidance on requirements and other matters relative to national oceanographic assets to the SOST.

In 2010, the IWG-FI formed the Task Force on Unmanned Systems (TFUS). This task force was initiated to advise the IWG-FI on policies, procedures, and plans relating to unmanned systems uses, upgrades, and investments. The scope of this task force included: Autonomous Underwater Vehicles (AUV), Gliders, Unmanned Aircraft Systems (UAS), Unmanned Surface Vessels (USV) and Lagrangian Platforms. In 2012, TFUS was approved by the IWG-FI co-chairs to become a standing committee called the **Subcommittee on Unmanned Systems (SUS)**. The goals of the group, to advise the IWG-FI on policies and plans related to unmanned systems, remain the same.

Interagency Committee for Aviation Policy (ICAP)

The General Services Administration (GSA) established the **Interagency Committee for Aviation Policy (ICAP)** in 1989 at the direction of the Office of Management and Budget (OMB). Eighteen Federal agencies are members of the ICAP. With advice from the ICAP, GSA makes policy for Federal aviation management. The ICAP coordinates the policy views of the Federal aviation community and also assists agencies in providing aviation services to support their missions. GSA chairs and facilitates ICAP, provides support for aviation management, and operates a management information system to collect and report data related to Federal aviation operations. The ICAP's Subcommittee on Unmanned Aircraft was established in 2013.

Interagency Coordinating Committee for Airborne Geosciences Research and Applications (ICCAGRA)

The **Interagency Coordinating Committee for Airborne Geosciences Research and Applications (ICCAGRA)** was established to improve cooperation, foster awareness, and facilitate communication among sponsoring agencies having airborne instruments for research and applications, and serves as a resource to senior level management on airborne geosciences issues. The Committee addresses interagency cooperation issues as they pertain to the use of airborne platforms (including UASs) and payloads for individual investigators as well as national and international field campaigns. The members include the Department of Commerce (NOAA), the Department of Defense (Office of Naval Research), the Department of Energy (DoE), the Department of the Interior (DoI), NASA, and NSF, as well as several others.

Joint Planning and Development Office (JPDO)

The Next Generation Air Transportation System (NextGen) represents a substantial and long-term change in the management and operation of the national air transportation system. This is a comprehensive initiative that involves not only the development of new technology, but also the leveraging of existing technologies. This includes satellite navigation and control of aircraft, advanced digital communications, and enhanced connectivity between all components of the national air transportation system.

The JPDO Overview VISION 100 – Century of Aviation Reauthorization Act (P.L. 108-176) created the **Joint Planning and Development Office (JPDO)** to manage the partnerships designed to bring NextGen online which will include UASs. These partnerships include private-sector organizations, academia, and the following government departments and agencies: Department of Transportation (DOT), Department of Commerce (DOC), Department of Defense (DOD), Department of Homeland Security (DHS), FAA, NASA, White House Office of Science and Technology Policy (OSTP), Office of the Director of National Intelligence (ODNI) – (Ex Officio).

Office Federal Coordinator for Meteorology (OFCM),
Joint Action Group for Unmanned Aircraft System Environmental Monitoring (JAG)

The Joint Action Group for Unmanned Aircraft System Environmental Monitoring (JAG) was established in response to interagency interest in developing UAS environmental monitoring capabilities as discussed in the two Mini-workshops conducted by OFCM in 2011 and 2012. The JAG is needed to help determine how we utilize UAS, develop interagency demonstration projects beginning with tropical cyclone reconnaissance in the western Pacific area and missions in other areas of interest. Work done by the JAG will lead to a national strategy for UAS utilization for environmental monitoring as tasked by Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR).

As one can see, many organizations are represented on these committees with increased collaboration opportunities. Figure C-1 is the Interagency Committee Action Matrix which displays the responsibilities group.

Committee	Regulatory	Policy	Standards	Collaborations	Joint Ops	Sharing	Manned	UAS	USV	AUV	Data
ICAP	X	X	X	X	X	X	X	X			
ICCAGRA			X	X	X	X	X	X			X
IWG-FI		X		X	X	X	X	X	X	X	X
SUS		X		X	X	X		X	X	X	X
JPDO	X	X	X	X		X	X	X			
OFCM UAS-EM		X		X	X	X	X	X			X

Figure C-1. Interagency Committee Action Matrix

Through these committees coordination and best practices are shared. As mentioned in the 2012 NOAA RFC UAS report the DOD continues to lead operations and their ***Unmanned Systems Integrated Roadmap (FY2013-2038)*** contains numerous best practices and lessons learned. Non-military use operators generated the ***FEDERAL UNMANNED SYSTEMS: STATUS, ISSUES AND RECOMMENDATIONS*** which was submitted to: National Science and Technology Council, the Subcommittee on Ocean Science and Technology, and Interagency Working Group on Facilities and Infrastructure. The goal of this whitepaper was to develop a coordinated federal effort and approach to maximize the efficiency and capabilities of unmanned systems across the government. Individual agencies' strategies, roadmaps, and visions were leveraged to identify challenges that might stand in the way of maturing those visions to a shared collaborated vision. The whitepaper did not identify specific requirements, as the individual agencies will continue to identify requirements gaps and utilize internal processes to determine which requirements to fund. Instead, core areas are identified that are challenges to further growth in unmanned systems and chart out science, technology, and policy paths that will enable unmanned systems to fulfill an expanding role in supporting the users. Based on the challenges and issues identified, the following recommendations were developed as potential solutions to those challenges:

- Establish an overarching Inter-Agency Agreement (IAA) between Federal agencies. An IAA between agencies for unmanned systems would improve agency inter-relationships, work load sharing, and allow for the transfer of unmanned systems and technology. The IAA will enhance inter-agency program transparency, coordinate the definition and efficiency of utilization rates across communities, decrease duplicative Federal resource expenditures, and coordinate acquisition, operations, training and life-cycle maintenance.
- Establish consolidated operations centers for Federal unmanned systems. In order to harness the full potential of unmanned systems and strengthen mission effectiveness, federal agencies should establish consolidated operations centers. Standards and interface specifications need to be established to achieve modularity, commonality, and interchangeability across payloads, control systems, telecommunications interfaces, data, and communication links.
- Define common capability descriptions, metadata standards, data models, and architectures. The enterprise-wide adoption and execution of proper data management practices, with emphasis on accepted metadata standardization, fosters improved operating efficiencies in Federal and partner programs and reporting that supports government transparency. This model improves the single agency stovepipe model by applying consistent policy, improved organization, better governance, and understanding of the electorate to deliver outstanding results.
- Establish asset pools for Federal unmanned systems. Federal organizations should share unmanned systems, personnel, technologies and information, strategic and operating plans, observing and performance requirements, technology assessments, impact studies, system and business case analyses and lessons learned. A successful “asset pool” will generate an inventory of unmanned systems, data requirements, sensors and operating facilities.
- Develop a federally coordinated acquisition strategy for Federal unmanned systems. The Federal government, working with industry, academia, and international partners, must take a coordinated, disciplined, and comprehensive approach to the development and acquisition of unmanned systems from a “Program of Record” perspective. Figure C-2 displays the Department of Defense (DOD) UAS Programs of Record for 2013 and beyond. Understanding of full life-cycle costs and opportunities for intergovernmental asset sharing must be better exploited while capitalizing upon commonality, standardization, and acquisition strategies.

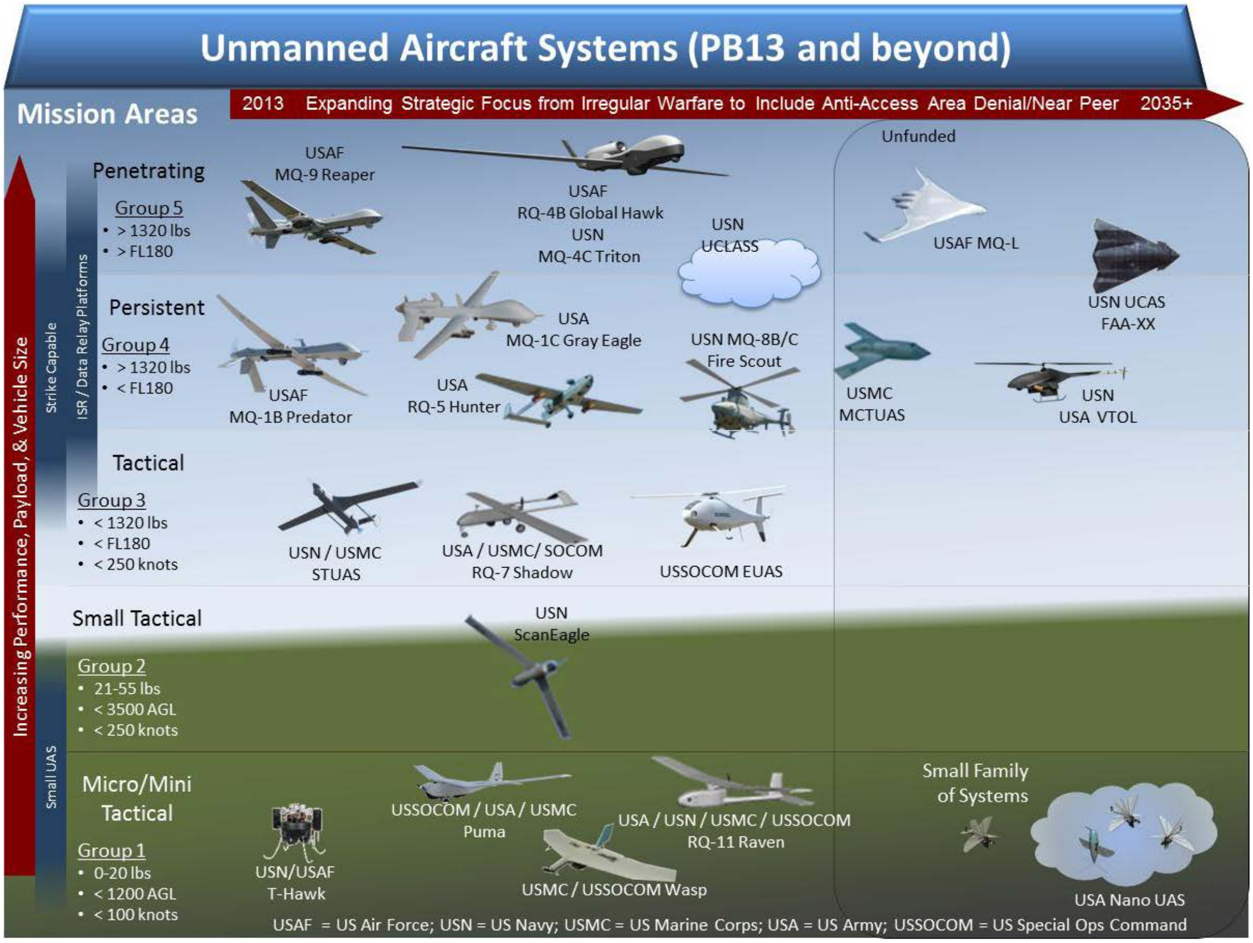

Figure C-2. Department of Defense (DOD) UAS Programs of Record (2013 and beyond)

Success in each of these areas is critical to achieve a Federal Government shared vision and realize the full potential of unmanned systems at an affordable cost, with improved efficiency and assured safety of operations. Implementation of these specific recommendations will go far to assuring that success is achieved. Development of an implementation plan will be undertaken by the SUS and will address communications, affordability, interoperability, centralized coordination, and data gathering and management. Specific timelines, milestone decision points, and agency coordination junctures and goals will also be included.

As the Federal Agencies, such as NOAA, NASA, DOI, and DoD, continue to develop their strategic plans and roadmaps, there is a clear need for convergence to enable sharing of assets, operators, sensors, logistics, etc., across the agencies. A federally coordinated effort applied now would significantly improve the overall efficiency, effectiveness, and safety of Federal government unmanned system operations.

Submitted by: John "JC" Coffey

Appendix D: Mapping the Pearl River Coastal Watershed

Starting in fall 2011, a program to collect high resolution data to develop a high-resolution hydrologic / hydraulic model of the water movement and levels in the Pearl River Coastal Watershed was initiated. UAS was seen as both a driver and an enabling tool. The initial focus was on about 80 square miles in the Pearl River watershed stretching from Bogalusa, Louisiana (top center in Figure D1) all the way to the tidal plains. This initial focus was based on several factors, including the last USGS river gauge being at Bogalusa and the lack of knowledge of the topography and land cover in the area after Hurricanes Katrina and Isaac. The objectives were to measure the water extent often (in dry and wet conditions, in different seasons, as well as before, during, and after extreme weather events, as possible). Other objectives included determining vegetation type and percent cover in the flood plain, determining available storage in adjacent dry areas, and determining water flow rates and directions in stems.

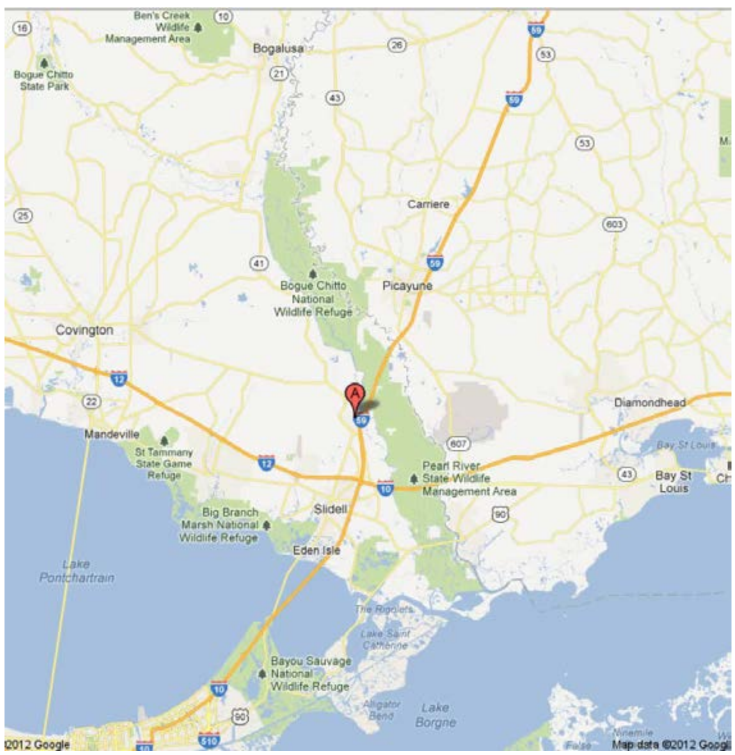

Figure D1: The Pearl River Coastal Watershed, stretching from Bogalusa, Louisiana to the tidal plains.

Initial estimations were that we could collect data at an adequate resolution over the 60-80 square mile area with a Puma AE in 60-70 hours of flying and that 3-4 people could do the collection over a 2 week period. Analyzing available maps led to the expectation most launches and recoveries in the northern 50% of the area could be from land, while most of the launches and recoveries in the southern 250% could be from a boat in the Pearl River (land in the water). After much planning and several delays, a test mission was executed 6-7 November 2013. We alternated flying a Puma AE and an Altavian Nova, as indications were the Puma was more durable, but the Nova had more appropriate payloads for our mapping requirements. We alternated flying the 2 systems over 1.5 days.

As a point of reference, both UAVs could cover about a square mile per hour, each could fly about 60 minutes on one battery, each could fly 20-35 miles per hour, each had a wing span of about 9 feet and a length of 6 feet, and each weighed about 15 pounds. Each were able to be hand launched from a small (19') boat (see Figure D2).

Figure D2: Preparing to launch an Altavian Nova. Boat is pointed into the wind. Pilot is watching the area to see and avoid. The operator is watching the display to make sure all systems are working properly.

The Puma captured video at 29.97 Hz, with frame sizes of 720x480, a field of view of 31.5 degrees cross track and 21 degrees along-track. The footprint was thus 450 feet cross-track at 800 feet AGL, with a GSD of about 7.5 in per pixel cross-track. The Nova captured single images with a frame size of 5184x3456, a field of view of 21 degrees cross-track and 31 degrees along-track. The footprint was thus 300 feet cross-track at 800 feet AGL, with a GSD of about 1.0 in per pixel cross-track.

There were more issues with the Puma than just the lower resolution. The Puma payload was not designed to hold a nadir orientation. It also was also designed to "lookat" the next waypoint when that point becomes active, meaning the operator has to drive the camera back towards nadir, away from the target. The absolute pointing accuracy was poor, being as much as 60m off in areas. The relative pointing accuracy was more on the order of 10-20m in most places. The inability of the Puma payload to hold a nadir orientation and the poor pointing accuracy were much more significant issues in creating an adequate map than the limited spatial resolution and the video format.

The Nova, on the other hand, has the camera in a fixed nadir position and has a very precise pointing accuracy, close to 1.5 meters absolute. Creating maps is much easier.

After two multi-day missions in the summer of 2014, we modified our concept of operation to focus only on the lower 20-30 square miles of the area for several reasons. After a more thorough analysis of the area, we discovered that most of the northern 60-70% of the area is too covered and littered with standing and fallen trees to safely operate and recover a UAS. Fortunately since the initiation of the program, 4 river gauges have been installed about 10 miles north of the tidal plains on the I-10 bridge pilings and 5 river gauges have been installed about 5 miles north of the tidal plains on the Hwy 90 bridge pilings. These gauges provide reading for water level and flow rate in the major stems of the river braids. Thus high spatio-temporal information for the area north of I-10 was been deemed by the hydrologists of less interest or importance. Additionally we have learned that realistically it takes a crew of 3-4 about 3.5 days to collect 2 inch resolution (we have increased the FOV on our camera to 60°) over the lower 25 square miles in optimal weather. Only 4-5 hour-long flights per day are feasible due to operating from a boat and the inability to access all the area easily, as well as the need to archive and pre-process the data daily to make sure we have good collections. All launch and recoveries are from a boat in the Pearl River stems.

Figure D3: Area of imagery collection. The dark green area has been overflown once, the light green twice, the yellow three times, the orange four times, and the red five times. The earlier collections are at 1 inch resolution (yellow, orange, and red areas)

After a 3.5 day mission from 23-26 September 2014, we have collected high resolution imagery over the area indicated in Figure 3D. The dark green shows the areas overflown that week. Earlier flights in November 2013, July 2014, and August 2014 produced the earlier datasets.

An image server with the imagery collected is available at http://www.gri.msstate.edu/geoportal/. The site presently contains the individual images and small mosaics of each hour-long flight. Additional mosaics and higher resolution mosaics may be added later.

We intend to continue to collect imagery data over this area approximately every 2 months through the summer of 2016.

Enclosure 1: Small Unmanned Aerial Vehicles as a Powerful Tool for Advancing the National Weather Service Mission, in Support of a Weather Ready Nation

National Oceanic and Atmospheric Administration (NOAA)

National Weather Service (NWS)

White Paper

Small Unmanned Aerial Vehicles as a Powerful Tool for Advancing the National Weather Service Mission, in Support of a WeatherReady Nation.

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Executive Summary

As an agency within the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS) is evolving to better support a WeatherReady Nation. This evolution requires a shift from text products and one-size-fits-all information to customizable, up-to-date information that meets the variety of decision needs of a variety of decision-makers. It requires more accurate and timely forecasts and warnings that provide location-specific information needed for the decisions being made. An exciting new technology may improve the services the NWS provides to decision-makers.

Small unmanned aerial vehicles (UAVs) can fly video camera equipment and weather sensors at low altitudes, providing meteorologists with information not previously available to them that can be critical for providing better decision-support services. From more accurate high-resolution model output leading to customizable warnings, to better information for fire weather, aviation, or marine support, to research that supports improved forecasts and warnings, the data provided by a small UAV could further NWS efforts to achieve its two-pronged mission of protecting life and property and enhancing the national economy.

This document illustrates the many potential applications of small UAVs to the NWS mission, and a cost-effective methodology in which this effort can be accomplished.

Introduction

The National Weather Service (NWS), an agency within the National Oceanic and Atmospheric Administration (NOAA), is on an evolutionary path in support of a WeatherReady Nation (NWS 2013). This effort aims to develop a more weather resilient nation better prepared to respond to, and recover from, natural disasters such as tornadoes, hurricanes, floods, and winter storms.

The focus of the WeatherReady Nation evolution, within the individual Weather Forecast Office (WFO), is Decision-Support Services (DSS), the means of providing critical information in support of a variety of decisions made by a variety of decision-makers. DSS requires an operational shift at the WFO, from simply generating forecast and warning text products that present one-size-fits-all information that is updated as needed, to customizable, always up-to-date threat information, in a form that customers can understand and base decisions on. This includes a shift from:

- an average forecast for the day, to hourly forecast trend information;
- warning information that everyone gets, to customizable, location-specific information that includes time of threat for a location, and potential impact; and
- a focus on large-scale global computer forecast models, to high-resolution, impact-focused models.

One of the most significant advances in support of accurate DSS is high-resolution short-term numerical weather prediction models, such as the HRRR and the NARRE (Fig 1). These models can predict a variety of hazards hours in advance. However, their accuracy can be dependent on the data ingested into the models.

The NWS acquires weather data at surface stations every hour, 24 hours per day. Aloft, however, data are only collected twice per day through radiosondes connected to weather balloons (Fig 2). The problem is that hazard environments can change rapidly, both in time and space. Without environment measurements prior to hazard formation, meteorologists are left to depend on computer model forecasts, which incorporate satellite and radar data as well as surface observations. When the model accurately predicts hazard environments, it can produce an accurate hazard-related forecast utilized for DSS efforts. Otherwise, the model may not accurately predict the hazard, impeding DSS efforts.

For other efforts, from damage surveying, to flood/surge inundation mapping, to fire weather support, there is clear value in acquiring data from above to improve DSS efforts.

Small Unmanned Aerial Vehicles

A new technology has been developed over the past decade that aims to meet the data requirements of the NWS in providing effective decision-support services (DSS) to decision-makers. Small unmanned aerial vehicles (UAVs), loaded with either a video camera or weather sensor payload, which can fly at low altitudes, could accomplish many of these requirements.

Prioria Robotics, Inc. is a company in Gainesville, Florida that manufactures several small UAV models that could accomplish this in a cost-effective manner. Prioria manufactures two key UAVs, the **Maveric** fixed-wing UAV (Fig 3), and the **Hex** vertical-takeoff-or-landing (VTOL) UAV (Fig 4). These vehicles can support a payload to meet the varying NWS requirements.

System Information about the **Maveric** UAV, from Prioria Robotics, Inc.:

- Length: 26.5 in
- Wingspan: 29.5 in
- Weight: 2.6 lb
- Payload: 300 g
- Wireless range: 10-15km Line-of-Sight
- Typical Operating altitude/Max altitude: 300-800ft / 25,000 ft
- Dash / Cruise / Stall speeds (in kts): 55 / 26 / 18
- Endurance: 45-60 min, depending on configuration and conditions

System information about the **Hex** UAV, from Prioria Robotics, Inc.:

- Takeoff weight: 14 lb

- Wheelbase: 31 in
- Payload: 2 kg
- Speed: 23 kts
- Endurance: 15 min
- Range: 2km
- Typical Operating Altitude: 100-300ft

Prioria has considerable experience, authorizations, and contracts with respect to its UAVs, including the following:

<u>Certificates of Authorization</u>
- Oak Ridge National Laboratory
- Oregon State University
- Missouri University of Science and Technology
- Cochise College
- North Carolina State University

<u>Government Certifications</u>
- Transport Canada (Special Flight Operations Certificate)
- Army Test and Evaluation Command

<u>Major Government Contracts</u>
- Canadian Armed Forces
- US Army Rapid Equipping Force
- US Navy
- Commonwealth of Australia

<u>Selected Flight Trials/Operational Events</u>
- Multiple TNT demonstrations
- AFSOC summer camp
- Trial Imperial Hammer (NATO)
- USASOC evaluation at Ft. Bragg
- Trident Spectre
- US Department of Homeland Security Testing
- US Army Test and Evaluation Command Testing
- The Adaptive Red Team/Technical Support Operational Analysis

There are a number of advantages of Prioria's UAVs when it comes to NWS applications:
- their UAVs are easy to dis-assemble and re-assemble, and ship from one office to another. They can be easily and rapidly positioned based on need. Since they are not required during lengthy periods of quiet weather, cost-effective resource-sharing options exist.
- their UAVs have achieved considerable flight time, supporting multi-year UAV longevity.
  - Over 4,500 sorties with all Maverics combined since 2008, with these UAVs still flying after 6 years.
  - Over 200 flights over 3 years on a single Hex, with the Hex still flying.

- their UAVs are small, and can be operated by just one or two people, vs. a team of three or more people required to fly other types of UAVs.
- training is simple, involving a one week basic operator training course for the Maveric as well as the Hex, and additional one-week advanced operator and maintenance training courses.

Achievable NWS Requirements Using Small UAVs

There are numerous data requirements for the NWS that could be achieved using small UAVs. The following is a lengthy, but not necessarily a complete, list of potential utilizations.

1) More complete/accurate storm damage surveys.
This would be particularly useful in rural areas with few roads which make ground surveys difficult. Aerial surveys yield much more accurate results more quickly than ground surveys where roads may not intersect a damage path.

2) Better river flood and storm surge inundation mapping using more recent topographic data.
We presently utilize data that are several years to perhaps a decade old. Having the latest information can support high-resolution inundation mapping which we are presently exploring. LIDARs are becoming light enough and inexpensive enough (under $10,000) to include as a payload on a small UAV for topographic mapping.

3) Acquiring low-level temperature/moisture information for improved short-term winter storm (precipitation-type) forecasts.
Accurate high-resolution model forecasts require more frequent low-level thermal/moisture environment analyses than the twice/day radiosondes provide. More accurate short-term forecasts of precipitation-type changeover are critical in decision support, and could be achievable through frequent UAV low-level environment measurements of temperature and humidity.

4) Acquiring low-level environment information more frequently, in support of higher-resolution model forecasts of severe thunderstorm and tornado potential.
Storm environments can change rapidly in time and space, as demonstrated with NOAA's prior Wind Profiler Demonstration Network. Having shear information is critical for determining tornado potential. While WSR-88D radars provide vertical wind profile information, it has accuracy issues, and is lacking prior to storm development.

5) Acquiring low-level environment information more frequently, in support of higher-resolution model forecasts of excessive rainfall and flooding.
Environments supporting excessive rainfall and floods depend on certain environmental conditions. More frequent low-level environment analyses support better high-resolution model output that thus support more timely and accurate forecasts/warnings.

6) Potential utility for monitoring boundaries that may lead to thunderstorm initiation, especially in situations when satellite view is blocked by high cloudiness.
It may be possible to discriminate between boundaries likely to initiate new thunderstorms and those that do not. In addition, lightning potential can be more accurately discerned with better low-level temperature and moisture data (relating to atmospheric instability and potential thunderstorm depth above the freezing level).

7) More frequent low-level environment analyses for more accurate high-resolution model forecasts in support of NWS Decision Support Services prior to and during high-impact events.
The future of the NWS focuses on decision-support, including on-site support. UAVs could provide critical local area (and upstream area) information to provide better decision-support guidance to the key partners of the NWS (e.g. emergency managers, other government agencies, etc.).

These data may help improve short-term high-resolution computer model output, that can support better short-term forecasts and warnings. A key example is "Warn-On-Forecast", a methodology of utilizing high-resolution convective models to help extend threat lead times for severe thunderstorms and tornadoes. Frequent low-level environment analyses are critical to the accuracy of the model output used for short-term forecasts and warnings.

8) Improved aviation forecasts of low conditions at times when satellite view is blocked by high clouds.
UAVs could provide critical above-surface information at times when satellite data are not helpful, leading to more accurate aviation forecasts for aviation decision-makers.

9) Near-site environment information in support of better spread of wildfires, as well as spread of smoke and hazard material spill fumes.
Currently, IMETs bring surface observation equipment when providing wildfire support. Having a means to collect data above the ground may be critical for HYSPLIT/CAMEO/ALOHA modeling of fire/smoke/fume spread. In addition, video cameras can help fire crews better assess fire spread, to better place resources out of harm's way.

10) Research-to-Operations…serve as a tool for improving our understanding of, and modeling of, meteorological phenomena.
This is a wide-ranging item for better understanding what we try to model/predict. For example, a research study on why some boundaries (e.g. outflow boundaries, sea breezes) generate convection, while others do not, in seemingly similar environments.

11) A beneficial tool for the ecological realm that the NWS is evolving toward (e.g. red bloom monitoring).
Collaborative partnerships between multiple NOAA agencies are achievable with UAVs. The NWS is starting to explore these avenues.

12) A potential tool for last-minute tsunami threat assessment, as well as swell assessment.
Our office has lost most of its buoys…making it difficult to assess swell and rip current hazard, which is the greatest weather-/water-related source of loss of life in the JAX area of responsibility. UAVs could allow the NWS to monitor swell conditions just offshore, and provide more accurate beach hazard forecasts.

13) Possible tool for monitoring river conditions for improved river flood forecasts.
This can be particularly valuable in situations with multiple crests…initial crests can lead people to assume a threat has ended, when a greater crest is still upstream. We presently do not have enough river observation equipment deployed to know where/when these additional crests (from delayed runoff) will occur.

14) Better assessment of river (lake) ice to improve forecasting of ice jam freeze-up and break-up potential.
This could lead to improved warning information of floods caused by ice jams.

15) Assessment of road conditions during and shortly after a weather event.
After winter weather or excessive rainfall events, road conditions are important to people. While reports of road closures or weather-related road impacts are relayed by law enforcement and DOT to the NWS, the extent of the issues would be better revealed through UAV imaging.

16) Potential tool for visually assessing landslide/avalanche potential in areas of terrain.
While some measurements are available for the NWS, a larger-scale view from UAVs may be more valuable.

17) Wildfire burn scar evaluation for evaluating flood and mudslide potential.
Burn scars left by large wildfires contribute to an increase risk of flash floods and mudslides. While large burn scars can be evaluated using satellite data…small UAVs can assist in evaluating small-scale scars.

18) Evaluating structural integrity of levee's and earthen dams.
In partnership with other agencies (e.g. Emergency Management, USGS), small UAVs could be utilized to evaluate the structural integrity of a levee or dam to make better flash flood warning decisions for communities with sufficient lead time to take protective action.

19) Improved forecasts where observation data are missing (e.g. impacts of rivers/lakes on temperature and wind forecasts over adjacent land areas, and monitoring wind/wave conditions on inland lakes).
The NWS designs a gridded forecast database that supports customizable forecast information for decision support. This includes location-specific information. In areas where no surface observation data are available, the accuracy of these forecasts for those locations is unknown. UAVs could be utilized to evaluate thermal and moisture differences in these areas compared to areas where surface observation equipment are available, leading to better location-specific forecasts in data-void areas.

20) Possible low-level air quality utilization for UAVs.
The air quality program is a new one for the NWS. UAVs could provide beneficial low-level environment information in support of air quality forecasts…in a partnership with local governments.

21) Potential monitoring of conditions that promote dense fog, and smoke/fog combos, that generate dangerous conditions on highways/interstates.
Predicting dense fog vs. heavy dew is a present-day weather challenge, and usually relates to moisture depth through a shallow layer above the ground. Computer models are not very good at predicting this, as they may mishandle shallow moisture depth. UAV data just above the ground may help forecasters discriminate between heavy dew environments and dense fog environments.

This utility could allow response by law enforcement/DOT to prevent accidents/fatalities when these conditions occur. The conditions can be difficult to see at night on satellite imagery, especially when blocked by a layer of high-level cloudiness. UAVs could be used to assess road conditions.

22) Determining the accuracy of questionable weather observation data (e.g. from non-NWS sources).
Some surface observation data are not owned by the NWS, and can be of questionable accuracy. Bad data can lead to erroneous analyses and short-term model forecasts. UAVs might provide a means to evaluate the accuracy of these observations, compared to NWS observation sites, and allow forecasters to remove bad data from being used in numerical model forecasts.

23) Satellite and Radar Data "Truthing" for small-scale features.
Satellite data are more reliable for detecting large-scale vs. small-scale features. Small UAVs could be utilized to confirm what satellite data suggest. Radar data only show conditions above the ground. Small UAVs could be used to confirm conditions at the ground resulting from the weather hazards indicated by radar imagery.

24) A tool for collecting before and after damage imagery.
This could be beneficial for areas in the path of a tropical cyclone, and even a "derecho" (large convective wind-producing system).

25) Better area-of-responsibility assessment for new employees of a given office.
It is critical for a new forecaster to understand their area of responsibility, including creeks that are flashy in nature, areas particularly susceptible to flood or storm surge inundation, etc. Imagery of terrain, key topographic features, key problem areas (e.g. levees), and more could be valuable information to new forecasters.

Benefits of Small UAVs to the NWS

Most of the above requirements are achievable with a small UAV that can ascend up to a level of 1,000 to 1,500 ft (although reaching a level of 3,000 to 5,000 ft would be even more advantageous), and return to its launch point, making the vehicle and its payloads re-usable. For NWS applications, the UAV would carry the following payloads, either together or interchangeably:

- Video camera that records ground-level imagery from a height of up to 400 ft AGL;
- Weather sensor package that records data up to at least 1,000 to 1,500 ft AGL; and
- Other useful payloads (e.g., LIDAR).

The NWS could achieve many mission-related benefits from utilizing small UAVs, such as:

- much more accurate storm damage surveys;
- improved river flood forecasting by recognizing inundation from multiple crests, and providing more data input for river forecast models;
- greater data input into more frequently run, high-resolution models;
- ability to evaluate the accuracy of questionable observation data (particularly from non-NWS sources); and
- research that could support improved operations, such as improved understanding of why some boundaries generate thunderstorms and others do not, despite being in similar environments.

In addition, there are some utilizations that can support multi-agency collaborations, be it within NOAA, or with others such as the Department of Transportation, regional or local Emergency Management agencies, etc.

Cost-Effective UAV Solutions for the NWS

The small UAVs being considered generally range in price from $35,000 to $75,000. While the upfront cost may be substantial, the operating costs in subsequent years would be small due to:

- the re-usable nature of the payloads; and
- UAV lifespan of at least 5 years.

In addition, the ease of transporting these resources to where they are needed can reduce the NWS UAV requirement from 240 UAVs (considering 2 per unmanned aviation system for each of 120 field offices), at a cost of $12-18 million, to a shareable resource of 40 UAVs (for 20 unmanned aviation systems) at just one-sixth of the cost ($2-3 million). The ability to share resources with other agencies and organizations could also reduce the cost burden to any one agency or organization.

The real value is seen in the national economic savings resulting from improved DSS (e.g. not closing a business, when located within a warning area, but not directly in the path of the hazard). For the improvement in the short-fuse warning program with the change from “county-based” to “storm-based”, which reduced warning area where no threat existed by over

70%, one study demonstrated potential economic savings of at least $100 million per year to U.S. citizens (NWS 2007). Savings of at least that amount could be expected by acquiring the observation data necessary to support the high-resolution models to be used in the future "Warn-on-Forecast" initiative that aims to increase warning lead times up to an hour. Efforts that reduce closures of businesses, airports, schools, etc., where no imminent threat exists, would dramatically support the additional mission of the NWS in "enhancing the national economy".

The Need for a Full Demonstration of Small UAV Capabilities

The potential benefits to the NWS, and to the customers the agency serves, are numerous and substantial enough to support a large-scale demonstration of the capabilities of small UAVs. They have been demonstrated on numerous occasions with respect to low-altitude imaging. Further investigation, and UAV design refinement, will be needed to demonstrate capability of flying at altitudes of 1,000 ft AGL and higher, within conditions such as heavy precipitation, icing, and stronger turbulent flow that may reach or exceed 40kts, to record observations above the ground. The demonstration would evaluate:

- Air worthiness of the UAV in carrying a given payload to a given height;
- Ability to collect the needed data and return it to the launch site;
- Ability to efficiently relocate the UAV to alternate locations; and
- Demonstration of cost-effectiveness for the NWS.

References

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NWS 2013: *National Weather Service Weather-Ready Nation Roadmap.* http://www.nws.noaa.gov/com/weatherreadynation/files/nws_wrn_roadmap_final_april17.pdf

Figures

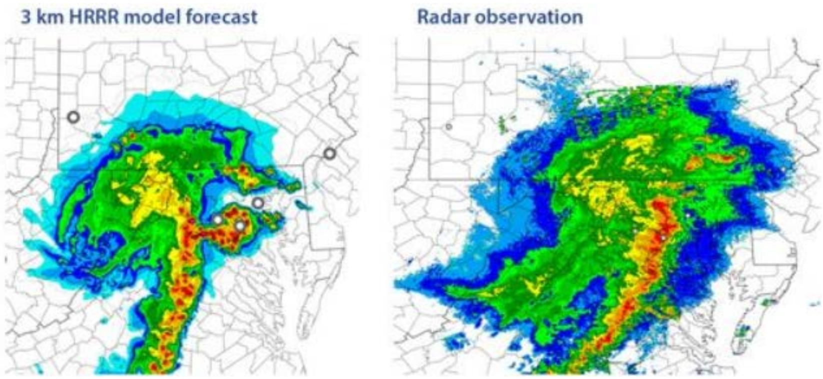

Figure 1. Comparison of HRRR model radar reflectivity forecast vs. radar observation for a severe thunderstorm line event in the Mid-Atlantic region. (source: USAToday.com)

Figure 2. Example of a balloon launch with a radiosonde. (source: NOAA)

Figure 3. Maveric UAS, from Prioria Robotics, Inc. *(source: http://www.prioiria.com/maveric/)*

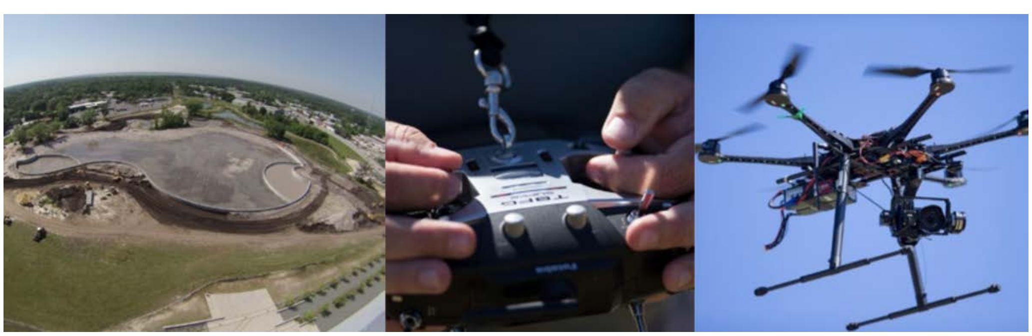

Figure 4. HEX UAS, from Prioria Robotics, Inc. (source: http://www.prioria.com/hex/)