Optimal Unmanned Aircraft Systems River Observing Strategy Workshop

February 21-23, 2012
Boulder, Colorado

Summary Report

authored by
Dr. Robert Moorhead, Mississippi State University and NOAA's Northern Gulf Institute
Robbie Hood, NOAA UAS Program Director
John "JC" Coffey, NOAA UAS Program Office

MISSISSIPPI STATE UNIVERSITY

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Organized by Mississippi State University and NOAA UAS Program Office

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Introduction

This document provides a summary of a workshop held at a National Oceanographic and Atmospheric Administration (NOAA) facility in Boulder, Colorado February 22-23, 2012 for the purpose of bringing together representatives of the NOAA National Weather Service (NWS) River Forecast Centers (RFCs) and representatives of vendors or operators of Unmanned Aerial System (UAS) platforms, sensors, and service providers. The workshop was a step towards integrating UASs into the workflow for the RFCs.

The body of the report summarizes the two days of presentations and discussions. Appendix A contains four tables: the workshop agenda, the workshop attendees, the RFC requirements that UAS could potentially address, and the UAS sensor resolutions needed for the RFC requirements. Appendix B identifies the lessons learned to date by multiple agencies, as well as their concerns and best practices.

Overview

A workshop was convened at a National Oceanographic and Atmospheric Administration (NOAA) facility in Boulder, Colorado February 22-23, 2012 for the purpose of bringing together representatives of the NOAA National Weather Service (NWS) River Forecast Centers (RFCs) and representatives of vendors or operators of Unmanned Aerial System (UAS) platforms, sensors, and service providers. The goals of the workshop were to:

- Get a better understanding of the RFCs observation requirements and areas of interest.
- Get a better understanding of the RFCs current capabilities and unmanned missions flown.
- Get a better understanding of current unmanned platforms, sensors and operators including those used by NOAA and other government agencies.
- Construct the foundation for an unmanned systems strategy for the RFC.

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 workshop was organized by Mississippi State University (MSU), the prime university in NOAA's Northern Gulf Institute (NGI), and by the NOAA UAS Program Office.

Four tables in Appendix A present the agenda for the workshop; the complete attendee list with contact information; a list of RFC requirements including physical parameters and resolution specifications having potential to be met by UAS; and a summary of these measurements by sensor type.

Although representatives from all 13 RFCs were not physically present at the workshop, a good representative mix of diverse regional issues was represented in person. Furthermore, representatives of other RFCs participated by videoconference connections. In addition, representatives of the US Forest Service and the US Geological Survey were present and shared their considerable relevant experience and knowledge.

Downloadable copies of the agenda and attendee information, as well as the presentations, are available from the workshop web site at the following URL:

http://www.northerngulfinstitute.org/noaa_uas_wksp_2012/

On day one, UAS platform and sensors vendors and operators made presentations describing their capabilities in the context of their understanding of RFC needs. Next, RFC representatives gave presentations on data needs they felt might have potential to be met by a UAS (Table 3). The following day some vendors/operators presented brief follow-up presentations to the new information they learned from the RFC presenters. A roundtable discussion followed. This discussion was focused on creating a prioritized list (Table 4) of RFC requirements that might be satisfied by a UAS mission and the resulting sensors/platform specifications needed to meet those requirements.

The workshop opened with welcoming remarks by John Coffey (NOAA UAS Program Office) and Dr. Robert Moorhead (Mississippi State University and the Director of NOAA's Northern Gulf Institute). Dr. Alexander "Sandy" MacDonald (Deputy Assistant Administrator for Laboratories and Cooperative Institutes, NOAA / OAR) delivered the keynote address with a presentation motivating the use of UAS to support the RFC mission.

Platform, Sensor, Operator Presentations

USGS – Mike Hutt

Mr. Hutt of the US Geological Survey (USGS) described their UAS program and missions focused on land use, hazards, and climate change. UAS can fly dangerous missions and obtain imagery from specific areas faster than satellites. USGS is concentrating on small UASs and hoping for a $50k price target in the near future. The recent loss of Landsat 5 leaves an information gap until its replacement is operating (likely 1 to 2 years from now). UAS could fill that information gap for plot level research. Collaboration is the key going forward. Airworthiness and pilot certifications are important. The FAA Modernization and Reform Act of 2012 will result in expedited access for UAS public aircraft.

In 2011 USGS had a Predator UAS collect data for a Mississippi River Inundation case study to detect and monitor floods. Mr. Hutt noted that all Department of Defense (DoD) assets come with video, which was a new sensor for USGS. He went on to note that hydrologists are looking at thermal surveys, but satellite based thermal resolution is inadequate. For monitoring erosion and flood mapping Synthetic Aperture Radar (SAR) is best. He noted that information management is becoming an issue for USGS.

In 2008 the USGS began their UAS program (May 2008); it took 3 years before they started flying missions (due to Certificate of Authority (COA) issues, asset availability, etc.). Their UAS fleet includes Ravens (used) and T-Hawks.

U.S. Forest Service – Tom Zajkowski

The USFS has formed a UAS advisory group to analyze implementation of UAS into the Forest Service (FS). One of the tasks is to develop a 3-5 year agency plan for UAS, with a goal of long term imagery and data collection. It is possible they will own a few aircraft for research, but will probably contract out for operational support.

They are using the RS-16 small UAS with color IR video with communication relay and meteorology data collection as a technology demonstrator. Their system provides near real-time video and maps distributed as KMZ files for easy rapid viewing. This project is on hold while the UAS advisory group develops procedure for using UAS in FS operations.

They are transferring the technology demonstrated on the NASA Ikhana to their manned fire mapping program. The FS has already installed datalinks on its aircraft, and is in negotiations with NASA about the transfer of the Autonomous Modular Sensor to the USFS.

Altavian – John Perry

The company has experience in UAS environmental data collection. All integrated services are in house: experienced and certified field crews, software and aircraft design, aircraft construction and systems integration, and processing of data and imagery to meet project deliverables.

University of Colorado – Ian Crocker

The CU LIDAR Profilometer and Imaging System (CULPIS) is a UAS system developed at the University of Colorado Boulder. CULPIS has been primarily used in arctic research but can be used in other regions. Its payload compartment carries an onboard Laser Range Finder for LIDAR observations. The university has a long history in UAS operations.

New Mexico State, Physical Science Lab – Doug Marshall

They have a UAV flight test center protected environment for researchers and developers to test systems. They have a blanket COA for their airspace (to 25K ft, 15K sq mi). The goal is integration of UASs into the national air space. They are involved in advising on rule-making, standards committees, FAA ARC II.

Tetracam/ Field of View – John Palacio/ David Dvorak

Tetracam is a multispectral imaging camera supplier for UAS. Field of View is a system integrator. Their joint presentation focused on multispectral imaging fundamentals and image processing. Field of View specializes in providing technology, training, and imaging services for those in the unmanned aircraft and agriculture industries.

ProSensing – Ivan PopStefanija

ProSensing is a systems engineering firm specializing in custom built radar and radiometer systems. Their Polarimetric Single and Multi-beam L-Band Radiometers can be used to measure near surface soil moisture, surface roughness, and ocean salinity. The single beam radiometer can be flown on a large UAS.

SpecTIR – Mark Landers

SpecTIR is a global aerial hyperspectral imaging company. Fundamentals of hyperspectral imaging were discussed and applications ranging from agriculture to wetland monitoring. Their software handles data and image processing along with advanced GIS. New sensors are being developed for UAS.

VT Group – Brian Prange

VT Group's presentation focused on the company's capabilities as a fully integrated program management provider for UAS missions. They do payload testing and verification. They build mobile ground control station. They presented a sample mission for Riverine Flood Control using Tier 1 and Tier 2 UAS.

ISR Group – Matt Parker

ISR Group is a military-focused UAS service provider that is moving into civil and commercial areas. ISR Group has its own training area with 32 sq. miles of airspace payload testing and integration and mobile ground station. They have global experience with many types of unmanned aircraft.

Airborne Innovations – Jon Becker

Airborne Innovations developed a multi-megapixel imaging systems (RaptorEye) for UAS. Cameras include visible and infrared. They worked with University of Alaska incorporating a RaptorEye camera and Resonan mini-hyperspectral camera into a ScanEagle.

Falcon UAV – Chris Miser

Falcon UAS focuses on affordable unmanned aerial HD photography and video for public safety. Cameras include visible, infrared, and gimbaled GoPro still and video cameras. They have worked with the Mesa County (Arizona) sheriff's office and obtained a COA for a sheriff's office in Florida. The Falcon UAV is hand-launched and parachute landing.

CU RECUV (Research & Engineering Center for Unmanned Vehicles) – Brian Argrow

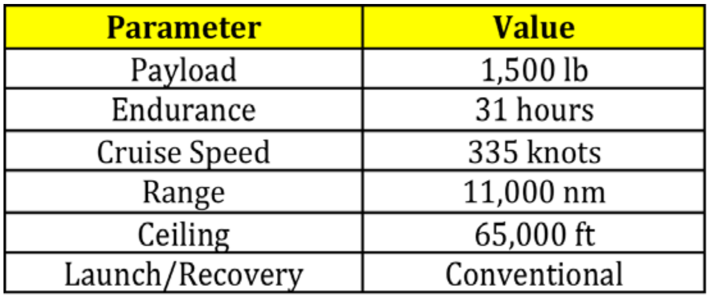
The RECUV works on Cooperative Mobile Sensing Systems, developing controls for heterogeneous UAS teams. They create mission-derived small UAS designs. Dr. Argrow showed an example mission in which they sampled supercell storm outflow. They are studying how to manage hundreds of small UAS for emergency response, for example in a plume sampling application. In partnership with Brigham Young University, they have received a planning grant from the National Science Foundation to establish an Industry/University Cooperative Research Center for Unmanned Aircraft Systems.

NOAA UAS Engineering and Resources / Capabilities – JC Coffey

Mr. Coffey presented an overview of Unmanned Aircraft Systems available to NOAA researchers, focusing on the Global Hawk and Ikhana from NASA; Manta; Puma AE; md4-1000; Raven; SkyWisp; and Emily. The capabilities of each of these platforms are summarized in Figure 1.

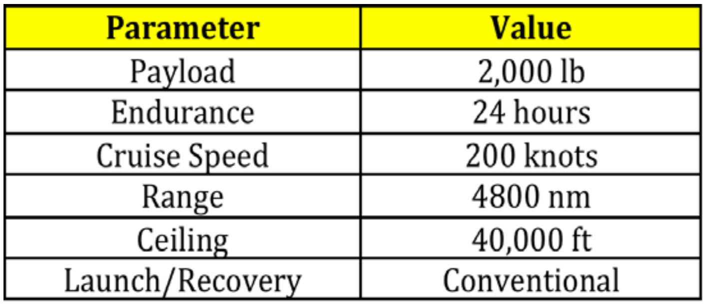
Figure 1. Capabilities of available UASs.

Global Hawk



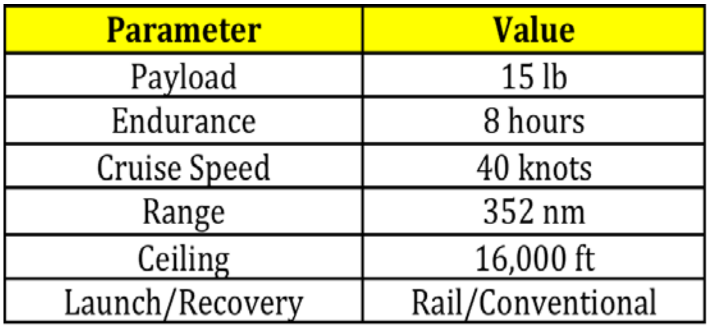
Parameter	Value
Payload	1,500 lb
Endurance	31 hours
Cruise Speed	335 knots
Range	11,000 nm
Ceiling	65,000 ft
Launch/Recovery	Conventional

Ikhana



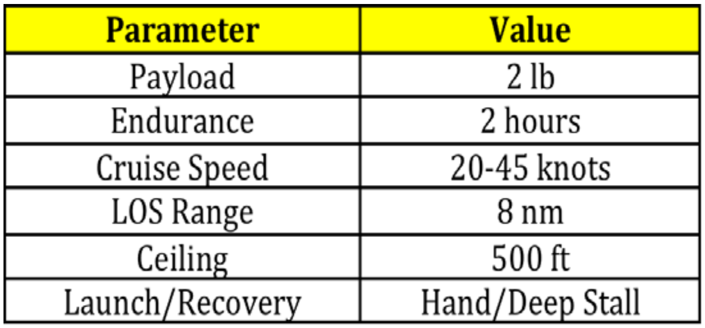
Parameter	Value
Payload	2,000 lb
Endurance	24 hours
Cruise Speed	200 knots
Range	4800 nm
Ceiling	40,000 ft
Launch/Recovery	Conventional

Manta



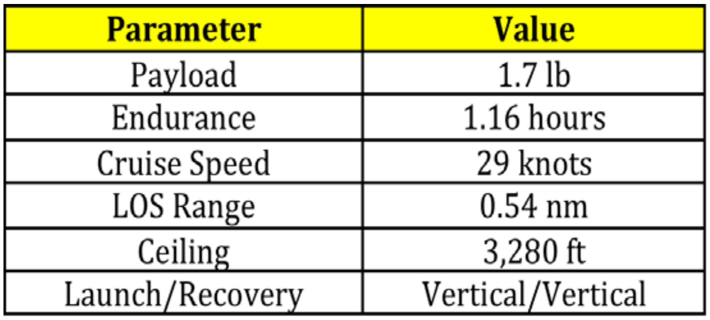
Parameter	Value
Payload	15 lb
Endurance	8 hours
Cruise Speed	40 knots
Range	352 nm
Ceiling	16,000 ft
Launch/Recovery	Rail/Conventional

Puma AE



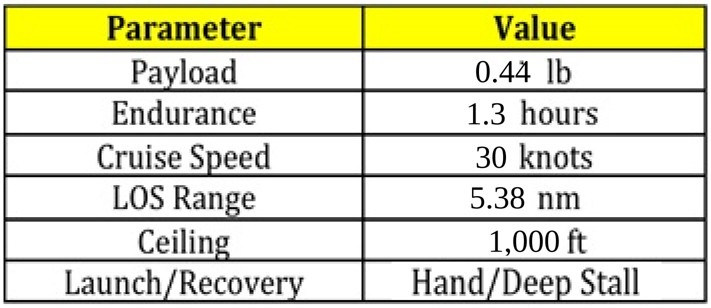
Parameter	Value
Payload	2 lb
Endurance	2 hours
Cruise Speed	20-45 knots
LOS Range	8 nm
Ceiling	500 ft
Launch/Recovery	Hand/Deep Stall

Md4-1000



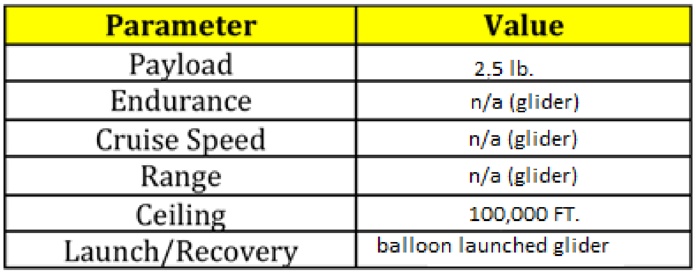
Parameter	Value
Payload	1.7 lb
Endurance	1.16 hours
Cruise Speed	29 knots
LOS Range	0.54 nm
Ceiling	3,280 ft
Launch/Recovery	Vertical/Vertical

Raven



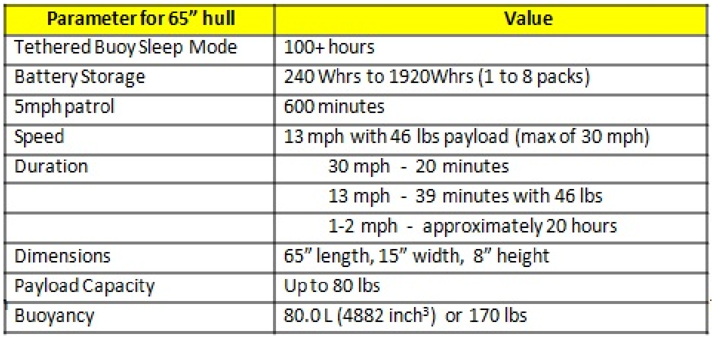
Parameter	Value
Payload	0.44 lb
Endurance	1.3 hours
Cruise Speed	30 knots
LOS Range	5.38 nm
Ceiling	1,000 ft
Launch/Recovery	Hand/Deep Stall

SkyWisp



Parameter	Value
Payload	2.5 lb.
Endurance	n/a (glider)
Cruise Speed	n/a (glider)
Range	n/a (glider)
Ceiling	100,000 FT.
Launch/Recovery	balloon launched glider

E.M.I.L.Y



Parameter for 65" hull	Value
Tethered Buoy Sleep Mode	100+ hours
Battery Storage	240 Whrs to 1920Whrs (1 to 8 packs)
5mph patrol	600 minutes
Speed	13 mph with 46 lbs payload (max of 30 mph)
Duration	30 mph - 20 minutes
	13 mph - 39 minutes with 46 lbs
	1-2 mph - approximately 20 hours
Dimensions	65" length, 15" width, 8" height
Payload Capacity	Up to 80 lbs
Buoyancy	80.0 L (4882 inch^3) or 170 lbs

University of Alaska Fairbanks – Greg Walker and Ro Bailey

Rivers flood annually just outside Fairbanks and ice jam flooding happens every year somewhere in Alaska. Small UASs offer safer, fast response to look at known risk spots. They are looking for fast launch, rugged-terrain capable systems; only small range is needed. Their interest is more in surveillance, as opposed to mapping. They can make survey-grade maps without survey-grade inertial navigation systems by using commercially available orthorectification software with ground control points and overlapping images. They can achieve 0.3 to 1.5 cm horizontal accuracies. The vertical error is 1.5 to 2 times the horizontal error.

River Forecast Center Presentations

Mike Deweese, North Central RFC (NCRFC)

A significant problem is how to validate model results under dynamic conditions. Imagery flown by NOAA Corps manned aircraft after a flood event was used to compare model versus actual inundation. Imagery confirmed the model has missed several areas of inundation.

Needs that might be met with UAS:

- Detailed information on levee breaches in near real time (location, width, depth)
- Levee monitoring in major floods (based on associated risk in the US Army Corp of Engineers National Levee Database)
- Soil moisture
    - Run off from agricultural tiled networks are a big issue
    - Historically have not kept good record of where tiles are located
        - If we could watch soil dry out, we could probably back out tile network
- River Ice conditions – from LiDAR? (ice cover type, jam locations, thickness, height, etc.)
- High resolution geo-referenced imagery over all scales (e.g., from detailed structural conditions to widespread inundation extents and channel bathymetry)
- Snowpack conditions (areal extent, water equivalent, depth, etc.)
- Wind/wave conditions in Great Lakes
- NWS Mission requires timeliness and accuracy – hard to balance those

Robin Radlein, Alaska Pacific RFC (APRFC)

- Need to predict/monitor flooding from freeze-up ice jams, breakup of ice jams, snow melt, glacier melt, heavy rains, or glacier dammed lake releases
- Determination of location and extent of flooding is difficult in non-gauge areas
- Snow cover data from gamma radiation flight lines not reliable (budget issues); need reliable source of snow water equivalent data
- Need reliable ice thickness on river updates
- Has seen a “georadiolocation” helicopter-based ice thickness measurement. Upgrade was expected that would provide stream velocity under the ice.
- Need to identify location of ice jams
- Currently using general aviation (GA) pilot report (PiRep) codes to extend reports beyond ground-based observations
- SAR data very helpful – used RadarSat 1, can’t get Radarsat 2 (cost limitation now that it is commercially owned)
- Monitoring glacier dammed lakes: Increased hydraulic head can lift glacial ice or flow through crevasses, greatly increasing flow thru glacier. This is a recurring event every 1-2 years
    - Currently they paint white lines on walls to make “gauges”, but no people there to monitor regularly. Also use CAP. But wonder if UAS can monitor these? Mountainous terrain a problem or not? (reply: mountains not a problem for UAVs)
- Finding Glacier dammed lakes is useful too!

- Topological data in Alaska is inadequate for HEC-RAS models rating curves (stage data versus discharge values dependent).
- Currently have 200-foot contour topological maps! Does not know if they have better raster DEMs; Mike Hutt said USGS working on getting better ones.
- Out of box idea:
  - Use UAS doing reconnaissance to relay communications of information to citizens w/limited access (have HF radio)
  - Suggestions: transponders on UAVs, cell phone UAV-to-ground, iridium (which is replacing meteor-trail communications)
- River temperature data might help monitor glacier dammed lake releases. It might also be used by Fisheries service.
- Once per year good enough for dammed lake search; need once/month for ice thickness
- Ice thickness accuracy need is approximately 1 foot

Thomas Adams, Ohio RFC (OHRFC)

OHRFC is responsible for the entire Ohio River, which includes drainage into Lake Erie.

Gamma network for snow cover is also not very timely distributed, and snow water equivalent (SWE) reported less densely than snow depth. SNODAS (Snow data assimilation system) estimates SWE twice daily (available from nohrsc.noaa.gov)

UAS needs:

- Verification of flood inundation area. MODIS resolution is too low for inundation validation. What is minimum resolution needed? 15-30 meters
- Identify levee breaks
- Measure changes in channel morphology following flooding
- Monitor possible dam breaks
- River surface velocity (containment spills)
- Bathymetric surveys in streams and rivers?
- Identify ice build-up (jams)
- Supplement remote sensing of SWE, snow cover, and soil moisture
- Map forest burn areas

Frank Bell, West Gulf RPC (WGRFC)

Forecast time scales:

- Flash flood guidance: 1-12 hours
- Deterministic forecasts: 1-5 days
- Probabilistic forecasts (in development) > 5 days

In the Rio Grande basin, precipitation data is limited by lack of auto gauges and incomplete radar coverage (in Mexico). Real-time observations are inhibited by criminal activity along the border.

Priorities:

- Document extent of inundation
- Vegetation and soil mapping (not as important now, but will be later)
- Rapid response inundation maps
- Thermal infrared or other sensor for depth of inundation?

Ed Capone, Northeast RFC (NERFC)

UAS applications:

- Need LiDAR to see river terrain 2 miles downstream and upstream of gauges.
- Supplement National Operational Hydrologic Remote Sensing Center (NOHRSC) flight lines for SWE data.
- Supplement NOHRSC soil moisture data.
- Extent and movement of algae blooms – Red Tide (East Coast).
- Visuals of changes in floodplain, such as the creation of oxbows, including channel changes
- Visuals of affected levees and dams during and after major flood event, including river changes after a dam failure

Roundtable Discussion Session (Summarized in Tables 3 and 4)

Discussions following the vendor, operator and RFC presentations focused on determining requirements—physical parameters to be measured, frequency of measurements (temporal resolution), spatial resolution in all relevant dimensions, and other parameter-specific quantities.

A desired outcome of the workshop is input to the selection and preliminary design of potential UAS missions to demonstrate the ability to meet selected RFC requirements. Inputs to the selection process include parameters like coverage rate, data availability, environment, location, measurement, measurement resolution, minimum coverage area, operational readiness, season of opportunity, and survey frequency. In preliminary discussions prior to the workshop the following candidate missions were discussed:

- Ice flows – need to know size, movement, etc. in near real-time
- Ice jams – need to know height in near real-time
- Soil moisture before first freeze
- Soil moisture anomaly. That way it could be related to RFC model states.
- Rapid response for LiDAR after a catastrophic flooding event to track changes in river channel structure and morphology. This will help to update river models "quickly" to mitigate forecast errors should another storm hit quickly (i.e. Hurricanes Dennis and Floyd in NC; Isidore and Lili in LA)
- Vegetation and soil mapping to insure accurate river model parameter settings especially in response to drought
- Rapid response for photos to document extent of inundation to verify flood inundation maps and enable production of flood maps for more locations
- Thermal imagery or some other sensor array to attempt to measure depth of inundation to verify flood inundation maps and enable production of flood maps for more locations

It was noted that many of the requirements could be at least partially met by high-resolution visible imagery in lieu of or in addition to the listed sensors.

The roundtable session began with giving the vendor representatives opportunities to make additional comments on how their capabilities could meet RFC requirements discussed after their initial presentations.

Brian Prange (VT Group) noted a wide range of terrain data needs. He noted that EO/IR data streams are useful for verifying models and for monitoring levees to see if they overtop. Spill events are a great use of aerial assets. No one UAS solution exists for all issues but as partners we can leverage each other's experts.

John Perry (Altavian) commented that it is 10,000 times less energy intensive to fly a UAS vs. manned. Real time observations have intense data volume. Key points of interest need to be identified. Flood plain mapping does not require very accurate imagery. Need higher altitudes for greater coverage. Vertical mapping will need improvement. Low flying aircraft with ground control points is best for now. River basin costs can be improved with sampling strategies.

Ivan PopStefanija (ProSensing) mentioned that the approximate soil depth of moisture readings from their L-band radiometer is 5 cm. Brightness temperature is what is actually measured, which can be converted with training over the years to identify soil moisture. L-Band radiometers can be scaled to fit UAS but you lose coverage and resolution due to smaller antenna size. Surface roughness can be measured with a C-band radiometer.

Ian Crocker (University of Colorado) reported that the Center for Remote Sensing of Ice Sheets (CReSIS) at U. Kansas measures Ice thickness and snow depth from radar (www.cresis.ku.edu). In addition, he mentioned a company called Artemis, Inc. that has a small SAR that has been used for measuring the surface roughness of the Great Lakes. A small LiDAR can also be used to look at wave height and water elevation.

Next, the RFC representatives posed some questions for the vendors and operators. Some key points were:

- The line-of-sight (LoS) requirement for hand-launched UAVs only applies to the realtime video transmission, so one can still get command telemetry to it beyond LoS. LoS for operations refers to antenna-to-antenna, but for FAA, LoS requirement refers to eyeball to aircraft visibility. It was noted that flying remote locations, such as along the Yukon River to get ice thickness, could be limited due to lack of road access for UAS control vehicle.
- For levee breaches one needs length, breadth, and depth, as well as water storage on either side of the levee. A vendor noted that technology exists to measure water volume storage in flooding or levee breaches. Laser altimeter can give you water level heights.
- It would be nice to automate the detection of levee breeches so people won't have to watch hours of video. A ground-based system might seem good, but there are problems with ground-based systems including installation, maintenance, and land owners' permission. With sUAS-captured imagery, technically one is able to measure levee breech dimensions and depth of storage and flood height, but there may be logistics issues.
- The RFCs could make use of the National Guard training requirement for their UAS pilots to get them to fly useful missions for the RFCs.
- Pre-disaster data is needed that is easily available like MODIS. Need to understand lines of communication. When a disaster happens what do we currently have? What systems were used in the past and can we learn from each event. We are documenting what's out there but what is the readiness level? The UAS Program Office needs to work with RFCs in obtaining real time data and training people how to interpret the data. The UAS Program Office is looking at other agencies and how they are conducting their technologies and sharing it. They are looking at what other line offices need and are trying to possibly share missions. The UAS Program Office plans to pick a few demonstration projects that RFCs would like demonstrated, execute, observe, and review how the demonstration went.

After the joint roundtable discussion, the vendors were dismissed and a government-only meeting ensued. The discussions focused on priority RFC missions in the near future and several years out. The discussions and mission requirements are summarized in Tables 3 & 4 in the Appendix.

Acknowledgments

The support of Sara Summers (NOAA OAR/ESRL/GSD), Jim Aanstoos (NGI/MSU), and Louis Wasson (NGI/MSU) are graciously acknowledged. They greatly assisted in local arrangements, writing the report, and working with the vendors. The planning, execution, and reporting would not have been possible without them.

Appendix A

Table 1 shows the agenda for the workshop. Table 2 is the complete attendee list with contact information. Table 3 contains the prioritized RFC requirements with UAS potential. Table 4 contains the UAS sensor resolutions needed for the RFC requirements.

Table 1. Workshop Agenda

Tuesday, February 21, 2012		
6:00pm – 8:00pm	Ice Breaker Reception	Earth System Research Laboratory
6:30pm – 7:30pm	Science on a Sphere Demonstration	Earth System Research Laboratory
Wednesday, February 22, 2012		
8:00	Welcome and Workshop Goals – Robert Moorhead, Robbie Hood, and JC Coffey	
8:10	Keynote Address: Dr. Sandy MacDonald	
	Platform/Sensor/Operators Presentations:	
8:30	Mike Hutt	USGS
8:55	John Perry	Altavian
9:20	Ian Crocker (CULPIS)	University of Colorado
9:45	Break	
10:10	John Palacio – multispectral sensors (REMOTE)	TetraCam
10:35	Ivan PopStefania – microwave/ SAR	ProSensing
11:00	Mark Landers – hyperspectral sensors	SpecTIR
11:30	Lunch	
12:30	Brian Prange	VT group
12:55	Matt Parker	ISR group
1:20	JC Coffey, NOAA UAS Systems	NOAA
1:35	Greg Walker (REMOTE)	University of Alaska, Fairbanks
1:45	Brian Argrow	U. Colorado
2:00	Break	
	RFCs and PIs Presentations:	
2:15	Michael Deweese	NCRFC
2:40	Robin Radlein	APRFC
3:05	Thomas Adams	OHRFC
3:25	Frank Bell	WGRFC
4:20	Ed Capone	NERFC
4:45	Closing remarks	
5:00	Adjourn	
Thursday, February 23, 2012		
8:00	Moorhead, Hood, Coffey—Summary of day 1	
8:05	Jon Becker	Airborne Innovations
8:10	Chris Miser	Falcon UAV
8:15	Doug Marshal	New Mexico State U.
8:20	Tom Zajkowski	US Forest Service
8:25	Platform/Sensor/Operators Response to RFCIs	
9:30	Break	
10:00	Roundtable Discussion	
11:30	Lunch	
1:00	Government only meeting to discuss proposals and future unmanned opportunities	
3:00	Adjourn	

Table 2. Workshop attendees.

Last Name	First Name	Affiliation	Email	Phone
Aanstoos	Jim	MSU	aanstoos@gri.msstate.edu	662-325-2647
Adams	Thomas E	NOAA/NWS-Ohio River Forecast Center	thomas.adams@noaa.gov	937-383-0528
Adler	John	NESDIS	John.adler@noaa.gove	301-713-7656
Becker	Jon	Airborne Innovations, LLC	jon@airborneinnovations.com	720-515-3720
Bell	Frank	NOAA/NWS/WGRFC	frank.bell@noaa.gov	817-797-5267
Bobo	Matt	Bureau of Land Mgt, DOI, Natl Operations Center	mbobo@blm.gov	303-236-0721
Brady	Lance	Bureau of Land Mgt, DOI, Natl Operations Center	lbrady@blm.gov	303-236-4242
Brown	Brad	VT-Group Unmanned Systems	bradley.brown@vt-group.com	971-205-5473
Cantrell	Mark	SpecTIR, LLC	mcantrell@spectir.com	775-329-6660
Capone	Ed	NERFC	edward.capone@noaa.gov	508-824-5116
Chadwick	Russ	NOAA ESRL	russ4cwop@gmail.com	
Clark	Douglas	Bureau of Reclamation	drclark@usbr.gov	303-445-2271
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Dvorak	David	Field of View	david.dvorak@fieldofviewllc.com	701-610-3482
Hanson	Leanne	USGS Fort Collins Science Center	hansonl@usgs.gov	970-226-9262
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Table 3. RFC requirements with UAS potential.

Requirement	*additional info*	*sensor*	*priority*	*improve warning time or accuracy*	*Frequency or speed of update*	*Horiz. Res.*	*Vertical Res.*
Soil moisture	The instrument to measure deep moisture is very large; will likely never fly on a small UAS	Polarimetric L-Band Radiometer			weeks	1km	10s of cm
Soil moisture	Moisture in top layer of soil could probably be measured by an instrument flown on a small UAS, but model can't ingest that data directly now	Polarimetric L-Band Radiometer	can't use 2+ years, but would really be useful		weeks	1km	<10 cm
Better river DEMs	to get better DEMs for reaches that only UAS might visit	LiDAR	priority #1	more accuracy	months-years	5cm (NCRFC) to 10m (APRFC)	
Rapid response after a catastrophic flooding event to track **changes in river channel** structure and morphology	will help to update river models "quickly" to mitigate forecast errors should another storm hit quickly; high flow and low flow need	LiDAR / altimeter	priority #2		hours-days	1m	
Vegetation and soil mapping to insure accurate river model parameter settings especially in response to drought	need height and density; different modeling if spring or fall	multi-spectral; MODIS	lower priority		weeks	30 or 250m	
Rapid response for **photos** to document extent of inundation to verify flood inundation maps and enable production of	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	VNIR, SAR	high priority		hours-day	30m	

flood maps for more locations	DEMs						
LiDAR to attempt to measure depth of inundation to verify flood inundation maps and enable production of flood maps for more locations		LiDAR / altimeter			hours-day	30m	5-25 cm
Detailed information on **levee breaches** in near real time (location, width, depth)		visible; IR; SAR; passive microwave	priority #3		yes	1m	10 cm
Levee monitoring in major floods (based on associated risk in USACE NLD)		Thermal IR; SAR; passive microwave			daily	<1m	
Sand boils		VNIR, SAR	high priority	significant	near real-time	<1m	
Slides		hyperspectral/SAR	high priority	significant	near real-time	1m	
River Ice conditions (ice cover type, jam locations, thickness, height, etc.)	might could get data from satellite; might could use USGS CLICK dataset	LiDAR / altimeter, visible, radar; SAR	high priority (March-May)	critical	yes	1m	10 cm
High resolution geo-referenced imagery over all scales (e.g., from detailed structural conditions to widespread inundation extents)	to validate forecasts	visible		more accuracy			
Snowpack conditions (areal extent, water equivalent, depth, etc.)		gamma radiation; passive microwave	priority for many RFCs	timing and accuracy	days	100m (northern plains) to 50km (AP)	

Snow line location	need to know where snow line is	visible	lower priority		weeks	200m	
Wind / wave conditions in Great Lakes	compact version suitable for UAV	C-Band Radiometer, SAR		accuracy	hours-days	0.5km	
Monitoring **Glacier Dammed Lakes**		visible	high priority for APRFC	critical	weeks-month	1m	1m
The extent of suspended sediments / Turbidity / water quality issues	from flooding, an incident, or a toxic spill; dam removal	visible, hyper-spectral	future		hours	1m	
water temperature	fishes, algae bloom; glacier dam releases	Thermal IR; passive microwave for surface	future		hours-days	5m	
Coastal / surge and wave height / wave run-up information, inundation, extent		C-Band Radiometer, SAR; visible			hours	0.5km	<0.5m
Map forest burn areas	probably can use USGS / USFS	visible	not		days	30m	

Table 4. UAS sensor resolutions needed for RFC requirements.

	horizontal resolution	***vertical resolution***
LiDAR		
better river DEMs	5cm (NCRFC) to 10m (APRFC)	
change in river morphology after flood	1m	
flood inundation	30m	5-25cm
river ice	1m	10cm
multispectral		
vegetation and soil mapping	250m	
flood inundation	30m	
levee breeches	1m	
sand boils	<1m	
hyperspectral		
slides	1m	
suspended sediments / Turbidity / water quality issues	1m	
mini-SAR		
flood maps	30m	
levee breeches	1m	10cm
levee monitoring	<1m	
sand boils	<1m	
slides	1m	
river ice	1m	10cm
winds/waves and coastal surge	0.5km	<0.5m

Appendix B

Multi-Agency UxS Lessons Learned, Concerns and Best Practices

Department of Defense's Experience and Pioneering

Numerous departments and organizations of the United States Government have published and updated individual roadmaps and/or master plans for each of the unmanned systems domains (i.e., air, ground, maritime). It has been recognized that opportunities for efficiencies and greater interoperability could be achieved by establishing strategic planning for unmanned systems via an integrated approach, which is evidenced in the publication of this first Unmanned Systems Strategy and the Department of Defense's (DoD) Integrated Unmanned Systems Roadmap. While the DoD's Roadmap identified the various systems in the inventory and captured all of the research, development, test, and evaluation (RDT&E), Procurement, and Operations and Maintenance (O&M) funding programmed for unmanned systems, other government organizations (DHS, DoI, DoA, NASA, NOAA and others) are still in the process of inventorying systems and total life-cycle costs. However, it is clear across all unmanned systems users that our goals and objectives converge in the pursuit of development and employment of unmanned systems with a focus on the technological challenges that would need to be addressed to achieve more effective interoperability.

This section will summarize the updated multi-agency lessons learned, concerns and best practices from decades of unmanned systems (UxS) operations, demonstrations and workshops beginning with DOD's challenges for unmanned systems. Unmanned programs should be structured to assist in overcoming the federal government's common challenges as outline in the **Department of Defense's (DoD) Unmanned Systems Integrated Roadmap FY2011-2036.** This roadmap defines a common vision, establishes the current state of unmanned systems in today's force, and outlines a strategy for the common challenges that must be addressed to achieve the shared vision.

"The challenges facing all military Services in the Department (and across the Federal government) include:

1) **Interoperability:** To achieve the full potential of unmanned systems, these systems must operate seamlessly across the domains of air, ground, and maritime and also operate seamlessly with manned systems. Robust implementation of interoperability tenets will contribute to this goal while also offering the potential for significant life-cycle cost savings.

2) **Autonomy:** Today's iteration of unmanned systems involves a high degree of human interaction. DoD must continue to pursue technologies and policies that introduce a higher degree of autonomy to reduce the manpower burden and reliance on full-time high-speed communications links while also reducing decision loop cycle time. The introduction of increased unmanned system autonomy must be mindful of affordability, operational utilities, technological developments, policy, public opinion, and their associated constraints.

3) **Airspace Integration:** DoD must continue to work with the Federal Aviation Administration (FAA) to ensure unmanned aircraft systems (UAS) have routine access to the appropriate airspace needed within the National Airspace System (NAS) to meet training and operations requirements. Similar efforts must be leveraged for usage of international airspace. (This includes operation sites for unmanned ground, surface, and undersea vehicles, as well.)

4) **Communications:** Unmanned systems rely on communications for command and control (C2) and dissemination of information. DoD must continue to address frequency and bandwidth availability, link security, link ranges, and network infrastructure to ensure availability for operational/mission support of unmanned systems. Planning and budgeting for

UAS Operations must take into account realistic assessments of projected SATCOM bandwidth, and the community must move toward onboard pre-processing to pass only critical information.

5) Training: An overall DoD strategy is needed to ensure continuation and Joint training requirements are in place against which training capabilities can be assessed. Such a strategy will improve basing decisions, training standardization, and has the potential to promote common courses resulting in improved training effectiveness and efficiency.

6) Propulsion and Power: The rapid development and deployment of unmanned systems has resulted in a corresponding increased demand for more efficient and logistically supportable sources for propulsion and power. In addition to improving system effectiveness, these improvements have the potential to significantly reduce life-cycle costs.

7) Manned-Unmanned Teaming: Today's force includes a diverse mix of manned and unmanned systems. To achieve the full potential of unmanned systems, DoD must continue to implement technologies and evolve tactics, techniques and procedures (TTP) that improve the teaming of unmanned systems with the manned force."

Other Government Agencies' Coordination and Focus

These challenges were reviewed and considered as the **National Ocean Council's (NOC) Interagency Working Group on Facilities and Infrastructure (IWG-FI)** established the **Subcommittee on Unmanned Systems (SUS)** to advise, assist, and make recommendations to the IWG-FI on policies, procedures, and plans relating to unmanned systems. The goal of this subcommittee is to develop a coordinated federal effort to maximize the efficiency and capabilities of unmanned systems. Part of this analysis included an expansion of DOD challenges listing and included:

1) Infrastructure Requirements: While unmanned systems can be autonomous, most are remotely piloted. In all cases, they require significant manning to maintain common lifecycle infrastructure. Common lifecycle infrastructure includes activities, hardware, and facilities necessary for:

- Launch and recovery systems,
- Command, control and communications (C3) & interoperability,
- Data quality control, quality assurance, distribution, archiving and stewardship,
- Storage, maintenance, upgrades, repair and shipping (including permits),
- Sensor integration and calibration,
- Operator training and certification.

To support all these activities, hardware and facilities are necessary whether an institution or agency has one, ten, or one hundred unmanned systems. As the diversity of vehicle systems increases, these activities must be duplicated for each unique platform, further raising the level of required manning, C3 considerations, maintenance facilities, and additional operator training and certification. DoD and commercial aviation have shown that the fewer the types of aircraft flown, the easier the resulting maintenance, training, etc. The DoD is coalescing on fewer, more capable unmanned aircraft to simplify and standardize unmanned systems common lifecycle infrastructure. On the oceans side, fleets of Navy Gliders and Autonomous Undersea Vehicles (AUV's) will be maintained and operated at one central location, minimizing personnel and infrastructure requirements.

Across the interagency, it is quite likely that common or similar vehicle mission and operational requirements and system functional requirements will arise. To avoid redundancy of design and development effort and to leverage ongoing efforts across the interagency, it is imperative that participating agencies share unclassified future-looking mission and operational requirements, technology development, and design information to the highest degree possible. Such information could pertain to long-term (e.g., 5 to 10 years) strategic planning for future mission or operational requirements as well as near-term technology development, design and engineering of unmanned vehicles as well as sensors and on-board analysis systems, power/energy systems, propulsion systems, and control systems.

2) Interagency Coordination and Asset Sharing: Greater coordination among U.S. government agencies would improve unmanned system operations and help to meet the safety challenges of allowing routine access, thereby enhancing both research and operations. One major challenge identified between collaborators is the mechanism to transfer funding between partners which leads to administrative barriers to collaboration greater than the technical ones. Furthermore, it is acknowledged that the true import of an unmanned systems program does not lie within the operation of the platform; rather it is the data and information these platforms provide. While each agency possesses its own specific mission requirements (at least in the physical environment), the vast majority of supporting data are universally applicable. As we move towards an earth-system or eco-system approach to our analysis and prediction capabilities, basic science, applied research, and actual operations demand a synergistic approach to unmanned system use. Improved efficiencies of operations and cost reduction could be realized by formulating an interagency commonality.

3) Data Management: By definition the human operator is not on the UxS platform, hence the only feedback mechanisms UxS relay to the operators and payload managers is in the form of data. Therefore data management is an extremely critical function for the safe operations of UxS. According to OMB Circular A-16, “Data management and particularly geospatial data management is one of the essential components for addressing the management of the business of government and for supporting the effective and economical use of tax dollars.” To support mission-critical functions, the Federal Government makes large investments in acquiring and developing geospatial data. Historically these investments were largely uncoordinated and often lacked transparency, sometimes resulting in data deficiencies, lack of standardization, inefficient use of resources, lack of interoperability, or inability to share data. Of particular note, Unmanned Systems will significantly increase the amount of data received, but lack the personal feedback provided by manned platforms as the scientist/technician on board understands the conditions in which the data were collected. The enterprise-wide adoption and execution of proper data management practices not only foster improved operating efficiencies in Federal and partner programs but also include reporting that supports government transparency. This model cures the single agency stovepipe model by applying consistent policy, improved organization, better governance, and understanding of the electorate to deliver outstanding results.

The DoD’s UAS Control Segment (UCS) Working Group is tasked to develop and demonstrate a common, open, and scalable UAS architecture supporting UAS Groups 2 to 5. The UCS Working Group comprises government and industry representatives and operates using a technical society model where all participants are encouraged to contribute in any area of interest. This effort incorporates the best practices of the services’ development efforts which include, but not limited to, the following:

- Definition of a common functional architecture, interface standards, and business rules
- Use of open-source and Government-owned software as appropriate
- Competitive acquisition options
- Refinement of message sets to support all operational requirements of the systems previously defined.

To ensure quality and usability of datasets by a broad range of agencies and programs, the data must be:

- Discoverable – published and available
- Reliable – coordinated by a recognized national standard
- Consistent – supported by defined schema, standards and understood content definitions to ensure their integrity
- Current and applicable – maintained regularly and adaptable to current needs
- Resourced – established and recognized as an enterprise investment.

The Office of the Federal Coordinator for Meteorological Services and Supporting Research's results from workshop, "**UTILIZATION OF UNMANNED AIRCRAFT SYSTEMS FOR ENVIRONMENTAL MONITORING"** published in May 2011 included similar challenges, lessons learned and take-aways. The River Forecasting Center's workshop reemphasized (captured in the workshop's goals) that one must take a disciplined and end-to-end approach to observation requirements, concept of operations for data capture, and evolved data management systems in order to provide a strategy to address these challenges and to meet the goals of coordinating federal efforts to maximize the affordability, efficiency and capabilities of unmanned systems.

The NOAA UAS Program is appreciative of the time and efforts of the River Forecasting Centers (RFCs) and the Northern Gulf Institute and is looking forward to the continued exploration, capture, and dissemination of the RFC's data requirements. Formal actions from this workshop include: formulating an unmanned systems strategy, demonstrations in the RFC's areas of interest and continue support of RFC's unmanned systems strategic plan.