Coyote technology and design is now owned exclusively by Raytheon who has partnered with NOAA to expand the capability to an operational observing tool that NOAA cannot live without. The boundary layer is the lowest layer of the atmosphere where hurricanes exchange momentum with the surface and extract heat and moisture from the ocean. This region of the storm has been identified in prior studies (e.g., Emanuel 1995; Cione et al. 2000; Cione and Uhlhorn 2003; Smith et al. 2009; Bryan and Rotunno 2009; Cione et al. 2013) to be of critical importance to hurricane intensification. Recent studies by Smith and Montgomery (2012) and Gopalakrishnan et al. (2013) have also shown a strong sensitivity to moisture conditions within the hurricane boundary layer. Despite the critical nature of this environment, routine collection of kinematic and thermodynamic observations remains elusive. Currently, temperature, moisture, and wind observations below 500 m within and surrounding the hurricane inner core are very limited since the primary source of data at these low altitudes are from point-source GPS dropsonde measurements. The lack of both thermodynamic and kinematic data coverage at low levels is a primary reason why hurricane boundary layer structure and associated physical processes within this critical region of the storm remain poorly represented in today's operational models (Zhang et al. 2012). In turn, inadequate representation of physical processes within the boundary can lead to errors in initialization and data assimilation, which can ultimately impact the accuracy of subsequent forecasts. It is believed that an improved understanding of boundary layer processes, through targeted, enhanced observation will be essential in order to improve future predictions of hurricane structure and intensity. In an effort to fill critical voids and provide unique, real-time data to NOAA's operational centers, multiple Coyotes were deployed into major hurricane Edouard (2014) using NOAA's manned P3 Hurricane Hunter aircraft. Over the next few years, testing of this potentially transformative emerging technology will continue, in the hopes of improving basic understanding and enhancing NOAA's operational hurricane prediction system. During this time, investments will be made to advance the existing Coyote platform into an operationally-feasible, economically-viable observing tool that can be routinely used by NOAA, US Air Force and other manned aircraft platforms to sample Hurricanes and other targetable atmospheric phenomenon. On July 27th an assessment of current Coyote capabilities in addition to a vision for possible operational implementation will be presented.

Early successes: In September of 2014, multiple Coyote UAS were released on successive days during P-3 reconnaissance missions into Hurricane Edouard. The limited data from these historic flights have already led to new insights within the tropical cyclone boundary layer and allowed researchers to make comparisons with operational fields in this critical region of the storm. In 2016, up to 7 additional Coyote UAS will be deployed into mature hurricane systems as opportunities present themselves. Two manuscripts have been written based on UAS data collected in Hurricane Edouard. Both submissions are currently in external peer review.

Anticipated Impacts: At TRL 9, the operational version of the Coyote observing system should provide the following benefits/upgrades over existing capabilities. 1. At 4h duration, the existing observational gap within the hurricane boundary layer will be filled, especially as it relates to thermodynamic data coverage (i.e. atmospheric temperature, moisture and ocean surface temperature). Wind coverage will also be greatly improved, especially below 500 meters The amount of 'volumetric' data coverage within the lowest km of the storm should be exponentially greater than what is collected today. The impact of this should be multi-fold including (but not limited

to): A. Increased understanding of a critically important, poorly sampled region of the storm B. Improved operational model physics and parameterizations (leading to future improved forecasts of intensity change) C. Enhanced real-time 'situational awareness' in the form of improved surface wind estimations currently used by the National Hurricane Center (leading to improved decision making warnings, evacuations) D. Improved data assimilation E. Enhanced coupled model validation F. Improved to storm surge model initialization (i.e. improved V10) 2. At 4h duration, the data per minute costs of the Coyote UAS observational platform should be approximately $40-50/minute. In comparison, today's GPS dropsonde concept of operations within the hurricane inner core costs roughly $140/minute (i.e. $800/5 minute observing period). The GPS dropsonde cannot remain airborne for extended periods of time or be controlled once released from the deployment aircraft. The Coyote will also be able to sample sea surface temperature directly under the storm. This capability is not possible with existing GPS dropsondes or from current satellite systems. While the GPS dropsonde has been, and will no doubt remain a critical asset in NOAA's observing tool kit, the advanced Coyote platform could significantly enhance existing capabilities in a number of ways. It also may be possible to utilize a portion of existing resources currently used for GPS Dropsonde acquisition to partially subsidize future Coyote UAS procurements.

Low Altitude Rotary- and Fixed-Wing UAS Observations of Severe Storms to Fill Critical Data Gaps

Steven Koch (OAR/NSSL)

In recent reports from the National Research Council and instrumentation workshops, strong recommendations were made to develop and evaluate observing systems capable of providing detailed profiles of temperature, moisture, and winds within the atmospheric boundary layer (ABL) to help determine the potential for severe weather development. Unfortunately, these measurements are not very easy to acquire. Satellite observations of the storm environment lack the needed vertical resolution in the ABL and are primarily limited to cloud-free conditions, whereas ground-based remote sensing instruments provide profiles at essentially one location, are unevenly distributed, and degrade in vertical resolution rapidly with height. A promising approach is to capture the non-homogeneity of the pre-convective ABL with superb vertical resolution is to use highly capable fixed-wing and rotary unmanned aircraft systems (UAS) for profiling the ABL. These observing systems can provide a much-needed mobile observing system for monitoring rapidly evolving high-impact severe weather conditions not observed with current operational systems. They are also complementary to use of ground-based remote sensing of the ABL (e.g., using clear-air radars, aerosol and Doppler lidars, infrared and microwave radiometers, and laser ceilometers). UAS retain the ability to obtain proper statistical samples on the necessary horizontal, vertical, and temporal scales and are at a relatively mature level of development. However, the UAS regulatory environment is in the early stages of development. In the future we will see advances in detection and avoidance of hazards regardless of visibility conditions, autonomous operation, continued miniaturization of instrumentation and more routine use of small UAS for continuous vertical profiling of the atmosphere. The current capabilities of

UAS for severe weather applications, and the regulatory and other pertinent issues, will be briefly summarized.

Early successes: A fixed-wing Tempest aircraft was used in the 2010 field phase of the second Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2) to demonstrate the collection of in situ, above-ground observations within the rear flank downdraft outflow of supercell thunderstorms. The Tempest is a versatile, state-of-the-art UAS built on a legacy of successful applications of UAS sampling mesoscale phenomena. Results from the VORTEX2 operations of the Tempest far exceeded expectations but, ultimately, the number of missions and the sampling lengths were limited by the Federal Aviation Administration (FAA) requirements for UAS operations. However, since 2010, significant progress has been made to refine the process by which UAS operations in the National Airspace System are authorized; revisions that enable more deployment versatility thereby increasing both the likelihood of intercepting a supercell and the length of time that the storm outflow can be sampled. Moreover, the VORTEX2 project informed strategies for improving the Tempest UAS, developing its successor (TTwistor), and complementing it with rotary UAS to obtain frequent profiling at fixed sites. System changes promise to extend data collection periods, improve sensor accuracy, increase the spatial and vertical resolution of observed fields, and improve the overall system robustness. UAS like the Tempest and the DJI Flame Wheel F550 quadcopter and Meteodrone quadcopters involve small airframes uniquely capable of collecting targeted observations in pre-tornadic storms that have the potential to revolutionize the tornado warning decision process. However, the routine application of UAS for surveilling the pre-tornadic storm environment must be predicated on a demonstrable improvement in the accuracy and lead time of tornado warnings enabled through incorporation of these data into the warning decision process.

Anticipated Impacts: The capability being developed addresses the goal of the Weather-Ready Nation in the NOAA/OAR Strategic Plan: “Society is prepared for and responds to weather-related events” and the subsidiary objective to “determine how we can improve forecasts, warnings, and decision support for high-impact weather events.” This capability will provide NOAA/OAR/NSSL and NOAA/NWS with a much-needed mobile observing system for monitoring rapidly evolving high-impact severe weather conditions not observed with current operational systems. By refining successful strategies and establishing new ones for monitoring the atmospheric boundary layer using such systems with miniaturized, high-precision, and fast-response atmospheric sensors for obtaining such measurements, small UAS (both fixed wing and rotary) types can be adapted to meet NOAA requirements. Measurement uncertainties will be quantified, and weather forecasters will be presented with these unique observations for evaluation, and for use in assimilation within short-range convective prediction systems.

Applications of Small Rotary Wing UAS for Protected Species Research

Wayne Perryman (NMFS/SWFSC)

Vertical aerial photographs are a tool used world wide to collect data for assessments of protected species. However the manned platforms used to collect these images are very expensive to operate and are unavailable in some more remote locations. For some applications, mall UAS have the

potential to provide better data, at less cost, with no risk to scientists in the field and with almost no disturbance to the species being sampled. The APH-22, a small multi rotor UAS, carrying a high end mirrorless digital camera has demonstrated that it can collect images of superior quality to those collected from manned platforms and that it can be safely and effectively operated by scientists in the field. The system can be deployed from ships, boats, or from shore and, because of it capability to take off and land vertically, it can be used in a wide range of research/monitoring applications. The aircraft can be flown in winds up to 25 its, but typical operating conditions are limited to winds up to 15 kts.

Early successes: System tests of the APH-22 have been conducted over shore-based targets (penguins and pinnipeds) in the Antarctic and along the Aleutian Islands. In all cases, counts of adults and young of the year have not differed from those made by scientists on the ground. In the marine environment, the system has been used to collect vertical images for determination of size and shape for North Atlantic Right Whales, Southern and Northern Resident Killer Whales, and Eastern North Pacific Gray Whales. Size data from these images will provide information on growth of individuals while shape data will allow scientists to ask questions about nutritive and reproductive condition of the animals imaged. These kinds of data allow scientists to address questions concerning how changing environments directly impact the health of recovering and recovered species. We are also finding that the quality of the images is so high that individual animals can be identified giving us the opportunity to track condition and reproductive success of individuals. Here again we can begin to look at how recruitment may be related to changes in the environment and thus prey availability.

Anticipated Impacts: We are already finding ways to combine use of manned and unmanned platforms to take advantage of the capabilities of each system in population assessments. For instance, we can now deploy small UAS to remote sites in the Western Aleutians to sample Steller sea lion rookeries in locations where weather conditions and lack of airports create significant risks to manned aircraft operations. Thus the manned platforms cover widely dispersed areas where logistic support is available while the unmanned systems focus in smaller, more remote sections of the survey area. In the Antarctic we are building a model that will allow us to calculate mass of leopard seals from aerial photographs, allowing for better calculation of drugs used to sedate these dangerous animals. We are also beginning to test these systems for collection of breath of large cetaceans. Analysis of the micro biome from a breath sample can provides clues regarding the underlying cause for animals that appear anomalously thin. These kinds of data are particularly relevant to studies of impacts of military sonar on animals living near test sites. These systems have the potential to greatly improve the efficiency and safety of efforts to disentangle large whales. Current techniques require multiple close approaches in small boats and split second decisions on where and what to cut. With recorded/live video from a small UAS, much of the activity could be conducted without risk and with a much better understanding of the condition of the entangled animal.

The Printed Optical Particle Spectrometer (POPS) and Miniature Scanning Aerosol Sun Photometer (miniSASP) Instruments

RuShan Gao (OAR/ESRL/CSD)

Atmospheric aerosols play many important roles in the environment. Consisting of microscopic particles suspended in the air, aerosols scatter and absorb sunlight, thereby reducing visibility and exerting a direct effect on climate. Aerosols also influence cloud formation, lifetime, and optical properties, resulting in indirect climate effects. In many regions, aerosols are a primary air pollutant and produce significant negative impacts on human health. Frequent vertical profile measurements of aerosol number and size distribution and aerosol optical depth (AOD) are highly desired for air quality, climate, and satellite validation research. We have developed and commercialized a pair of low-cost, light-weight and low power consumption instruments to meet these needs that are particularly suitable for balloon sonde and sUAS (small Unmanned Aircraft System) sampling, wide-scale deployments, citizen science activities, and numerous other applications. The Printed Optical Particle Spectrometer (POPS) measures 405 nm laser light scattered by individual particles to determine aerosol number concentration and size distribution. 3D printing technology was used in the construction of the instrument to reduce cost, manufacturing complexity, and weight. The resulting instrument is able to size particles in the diameter range 140 – 3000 nm. The POPS weighs about 800 g and consumes 7 W of power. The Miniature Scanning Aerosol Sun Photometer (miniSASP) continuously scans the sky to measure direct and scattered sunlight in four wavelength bands (infrared, red, green, and blue). The wavelengths allow determination of the aerosol Angstrom exponent and are chosen to overlap wavelengths used by the MODIS and VIIRS satellite instruments. The miniSASP has a well-defined field of view and can rapidly compensate for a tilting platform. It weighs less than 400 g and has an average power consumption of less than 5 W. Materials costs for both the miniSASP and POPS are approximately $1500.

Early successes: POPS and miniSASP were first integrated onto the NOAA PMEL Manta small unmanned aerial system (sUAS) and conducted test flights in Yakima, Washington in January 2015. The instruments were subsequently successfully operated on the Manta during a scientific field mission in Svalbard, Norway in April 2015. Since then, they have been operated on weather balloon sondes, other sUASs, and light aircraft, making measurements in environments from the Arctic to the tropics and at altitudes from the ground to the stratosphere.

Anticipated Impacts: The small size, light weight and low power consumption of these miniaturized instruments allows them to be flown on balloons and small UAS, and the low cost allows them to be widely deployed. These measurements will fill critical data gaps in observations of aerosol optical depth (AOD), especially in the ability to provide vertically resolved aerosol size distributions and AOD. International interest in these instruments will promote global coverage of AOD measurements. These observations will be used to validate/improve satellite AOD retrievals and improve climate model predictions and projections.

Integrated Hyperspectral Detection of HABS with Airborne and Handheld Sensors

Steven Ruberg (OAR/GLERL)

Prevalent harmful algal blooms (HABs) require routine monitoring in order to warn drinking water processing managers in Lake Erie that potentially toxic blooms may be moving towards water intake systems. Current space-borne satellites only provide a total of approximately 60-70 cloud free images a year for the Great Lakes, including Lake Erie. In order to provide more frequent updates to drive hydrodynamic models that predict bloom location, NOAA GLERL began routine flyovers of water intake systems in FY15 with a hyperspectral camera that flies under the clouds, but also provides a ground resolution of 1 meter pixel size depending on the altitude and an increased number of bands to pull out different spectral features in the imagery. The enhanced spectral resolution allows user to begin to design maps of phytoplankton functional types, including species that are potentially toxic. This goes beyond the typical cyanobacteria index and provides a concentration for cyanobacteria as well as other bloom forming species, i.e. diatoms, dinoflagellates, and cryptophytes. The benefit is that water intake managers will be able to know what other bloom forming species are headed towards their water intake systems, beyond cyanobacteria and also more frequently with hyperspectral imagery than currently inherently cloud-covered satellite imagery. NOAA GLERL in collaboration with the Cooperative Institute for Limnology and Ecosystems Research (CILER) also maintains a weekly sampling schedule that includes ship-based hyperspectral detection using the Satlantic Hypergun. This ship-based instrumentation along with the airborne hyperspectral imagery, offers an improvement on current capabilities to remotely sense HABs in the Great Lakes. Emerging technology efforts are currently in development to place the airborne hyperspectral sensor on an unmanned aerial system (UAS) to increase the frequency of flyovers.

Early successes: The early success of the hyperspectral flyovers include over 15 flyovers during FY2015 over ship-based sampling and water intake locations in Lake Erie as well as Saginaw Bay. These efforts are ongoing and flyovers will begin again during the week of June 20, 2016 for FY2016, with coincident flyovers by NASA Glenn with their hyperspectral imaging sensor. New field tests for this summer and fall will include increased atmospheric correction efforts with SPARC mirrors as well as a SeaPRISM as a planned operational node for AERONET-OC. On the algorithm development, cultures for different phytoplankton types endemic to Lake Erie have been recently obtained to begin to create a spectral library, with the end goal of providing maps of phytoplankton bloom types to water intake managers and as a possible input into the HAB Tracker.

Anticipated Impacts: The impacts to services will be increased coverage of Lake Erie HAB events for water intake managers in the region, where space-borne satellites are not able to capture the bloom location on weekly timescales. The data from the hyperspectral sensor will improve the HAB tracker model output by increasing prediction capabilities, due to the fact that the HAB Tracker relies on space-borne satellite data to update the location of the cyanobacteria bloom and does not account for different functional types of phytoplankton. The hyperspectral data lends more information on community dynamics throughout the bloom period by pulling out different different functional groups of phytoplankton, also important for ecosystem model development.

Unmanned Aircraft for Airborne Gravity Measurements

Vicki Childers (NOS/NGS)

Developing the capability for measuring gravity from an unmanned aircraft was proposed and awarded under the Small Business Innovation Research (SBIR) program. This required identifying an unmanned platform and sensor (gravimeter) that would meet requirements as defined by the NOAA National Geodetic Survey's (NGS) Gravity for the Re-definition of the American Vertical Datum project (GRAV-D). Aurora Flight Sciences Corp. under a Phase II SBIR, WC-133R-14-CN-0101, has successfully combined the best of manned and unmanned surveillance aircraft capabilities. They have coupled their Centaur aircraft with the Micro-g Lacoste (MGL) TAGS-7 gravimeter to provide useable and reliable data to NGS. The Centaur OPA is a fielded system operated by Aurora Flight Sciences. The Centaur is an Aurora-modified Diamond DA-42MPP aircraft where the modification enables interchangeable flight operations in a manned and unmanned mode of flight operations. It is additionally unique in the sense there is a third mode called the "augmented" mode of operation. This mode allows a "hands-off" safety pilot to be on-board the aircraft while it is controlled remotely from a ground control station just as an unmanned aircraft is controlled. Real mission operations and test operations can be flown using this augmented mode. The concept of operations that will be used includes manned flight operations in locations where the team cannot obtain approval for unmanned flight and for test operations, and unmanned flight operations in locations where the team has approval to fly in the unmanned mode. This allows the system to be used anywhere, anytime regardless of FAA approval to fly in the unmanned mode. In addition to the platform integration, Micro-g modified the sensor to work with the unmanned aircraft system. This capability is currently in a transition to operations of this platform and sensor combination developed under the NOAA Phase II SBIR to governmental and commercial services will constitute a successful SBIR Phase III transition through the NOAA Technology Transfer Office.

Early successes: A successful flight test was completed in April 2016 that confirmed the gravimetric data was suitable to NGS and this capability is now in the transition to operations phase. The test was conducted out of Aurora's facilities at the Manassas Regional Airport in Virginia. The system was operated in its "augmented" mode of operation where a hands-off safety pilot was on-board with remote control performed at the ground station just like any unmanned aircraft. This allowed testing the system over Virginia without the need to have the FAA approve unmanned operations. The test flights on the Centaur included the MGL TAGS-7, GPS receivers on the aircraft and ground, and an inertial measurement unit on the aircraft to improve positioning. Five flights were conducted on five different days and repeated lines that had previously collected data for comparison. The data results show that not only were the gravity measurements repeatable within specifications, but the aircraft performed extremely well with minimal motion during flight, being able to repeat a line with high accuracy, and providing real time adjustments to airspeed to maintain a constant ground speed. The system is ready for commercial operations and can be flown manned or unmanned.

Anticipated Impacts: This capability will impact the GRAV-D project by likely reducing cost of operations, reducing human risk in operations, improving environmental impacts. The GRAV-D program will bring large societal and economic benefits to the United States, with an estimated $522 million in annual economic benefits and approximately $240 million saved from improved floodplain

mapping alone. The current systems used by NOAA consume between 70-750 gallons of jet fuel per hour of flight operation. The Centaur-based system uses approximately 8 gallons of jet fuel per hour of flight operation, and will have reduced transit times due to longer endurance and on-station times. This will greatly reduce fuel cost and carbon emissions. In addition, this capability has already generated interest in the private sector. Areas such as oil, gas & mineral exploration as well as transportation sectors will benefit from high accuracy gravity data collection with the capability for unmanned operations. Specifically, a California High Speed Rail project is likely to use this capability for accurate and efficient design of a rail system.

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