NOAA Uncrewed Aircraft Systems (UAS) FY21 Use Report

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Cover Photo

Lt. Chelsea Parrish (right) flies the APH-28-Ranger (Aerial Imaging Solutions, LLC) into Dr. Tomo Eguchi's (left) hands following the completion of a leatherback aerial survey in Monterey Bay, Calif. Photo: Scott Benson/NOAA

Annual Report Structure and Content

This report is an overview of NOAA's UAS Activities in fiscal year 2021. Information presented is structured to provide insight on NOAA UAS adoption, applications and integration. Report content is intended for the public, government officials, UAS pilots, academia, and NOAA partners.

Image 1: CDR Matthew Pickett, NOAA (Ret.) (left) and CAPT Brian Taggart, NOAA (Ret.) (right) from Oceans Unmanned is onboard the NOAA Ship Fairweather. Photo: Oceans Unmanned

Background

The National Oceanic and Atmospheric Administration (NOAA) supports economic vitality and affects more than one-third of America's gross domestic product. The scientific data collected by NOAA provides daily weather forecasts, severe storm warnings, and climate monitoring to support fisheries management, coastal restoration and marine commerce. Dedicated scientists continue to improve on traditional data collection methods surpassing the limits with cutting-edge technology to provide citizens, planners, emergency managers and other decision makers with reliable information to meet NOAA's mission:

"To understand and predict changes in climate, weather, ocean, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources."

Uncrewed Aircraft Systems (UAS) are a key technology for NOAA and are growing in importance to the agency every year. Despite the unprecedented challenges caused by the global COVID-19 pandemic, in FY21 NOAA continued to conduct research across the Agency on how UAS can be applied to NOAA missions, to transition NOAA missions on to UAS, and to operationally use UAS in support of critical agency missions and products. UAS operations flew more than any previous year with more than 50-percent more flight time in 2021 than in previous years, and the agency anticipates that UAS utilization will continue to grow across NOAA at a rapid rate.

Image 2: A Yuneec H520G NOAA UAS with petri dishes attached to it, flies over the well-known humpback whale, "Flame" - SEAK ID #1538, to collect respiration (blow) samples near Juneau, Alaska. This is part of a study to understand humpback whale hormones in the absence of tourism during the COVID-19 pandemic. Research Permit # 20648 Photo: Suzie Teerlink/NOAA.

UAS Use and Support Across NOAA

NOAA accomplishes its diverse missions through its six Line Offices, all of which either use UAS for mission execution or support UAS operations across the agency. A brief summary of each Line Office's role follows.

Office of Marine and Aviation Operations (OMAO)

In 2020, Congress established within NOAA's Office of Marine and Aviation Operations (OMAO) an Uncrewed Systems Operations Center (UxSOC). The UxS Operations Center is focused on supporting UxS operations and development across the agency, operating complex or multi-mission UxS on behalf of NOAA customers, and transitioning UxS into operations in all NOAA Line Offices.

The UxSOC absorbed the Uncrewed Aircraft Systems Division (UASD), which was previously part of the Aircraft Operations Center (AOC). The UASD plays a central role for all UAS at NOAA, providing policy input, oversight, training and guidance for NOAA UAS operations. These UAS operations provide a wide range of capabilities including UAS testing for hurricane research and operations from the Aleutian Islands to Antarctica, providing scientists and other government, academic, and industry partners with data in some of the most remote and harshest environments in the world.

UASD safely and efficiently leads NOAA operations in the rapidly growing field of Uncrewed Aircraft Systems (UAS) dramatically enhancing data collection and scientific research.

In addition to the UASD's role supporting UAS use across the agency, OMAO operates UAS from its fleet of ships where needed to support the ship's missions. For example, OMAO, in conjunction with the Office of Coast Survey, is investigating the use of UAS aboard hydrographic survey ships for coastline mapping and general situational awareness.

Office of Oceanic and Atmospheric Research (OAR)

OAR's mission is to conduct research to understand and predict the Earth system; develop technology to improve NOAA science, service, and stewardship; and transition the results so they are useful to society. UxS have the potential to be an integral part of NOAA's and OAR's mission. The Uncrewed System Research Transition Office (UxSRTO) sits within OAR, serving all of NOAA in the research, development and transition of UxS to meet NOAA's mission needs. OAR researchers are pioneering the development and application of UxS to improve our understanding of the Earth system from the top of the atmosphere to the bottom of the ocean. NOAA will only realize the full potential offered by UxS through research, development, and carefully planned transition of these technologies into their final application.

National Marine Fisheries Service (NMFS)

UAS fulfill many roles within the NMFS portfolio, especially in the realms of protected resource surveys and in habitat research and monitoring. The preponderance of NMFS UAS work involves small VTOL or hybrid UAS carrying sensors (visual light, hyperspectral and infrared cameras, as well as LIDAR sensors) at low altitudes to survey known features (animals, and specific areas, such as seal haulouts, salmon spawning habitat, restored wetlands, etc.). Such operations are extremely cost effective, providing copious data of great scientific relevance. These operations can be flown almost exclusively under FAA Part 107 regulations and using relatively inexpensive survey support infrastructure; cheap UAS, flown from land, small boats or ships without special modifications or gear.

There is a second sort of survey that will see massive utilization within NMFS once a few hurdles are cleared. This would be a survey where the existence or location of features are not known, and the survey covers a broad geographic range to document the presence or absence of the features, whether organisms, habitat features, etc. These are typically performed as line transect surveys, AKA "mowing the lawn." NMFS presently performs some line transect surveys from crewed aircraft using human observers as "sensors." These come at a high cost in terms of dollars, human exposure to hazards, and staff and contractor time. Such surveys would be much more frequently performed if they could be done inexpensively and safely. With advances in Beyond Visual Line of Sight (BVLOS) and Artificial Intelligence (AI) UAS based surveys could eventually be the inexpensive and safest method for data collection.

National Ocean Service (NOS)

The NOS Remote Sensing Division (RSD) has operated UAS for a wide variety of coastal and habitat mapping research projects. They use existing UAS capabilities to collect data in support of the Coast and Shoreline Change Analysis Program (CSCAP) to quickly analyze shoreline changes in port areas. In 2021 RSD completed three CSCAP collections, one with a NMFS partner. Additionally, RSD is developing the procedures and protocols for utilizing UAS for potential emergency response scenarios involving small ports and harbors, and oil spills.

RSD teamed up with the Hydrographic Surveys Division (HSD) to continue the program of training and qualifying UAS operators to pilot NOAA-owned UAS from NOAA hydrographic ships and small boats, as well as to develop capabilities to collect and process data acquired from the UAS. RSD successfully deployed on the NOAA Ship *Fairweather* this year and were able to certify a new UAS for NOAA shipboard operations.

NOS National Centers for Coastal Ocean Science (NCCOS) provides cutting-edge, high-quality, and reliable science-based benthic habitat mapping products so their customers and partners can make smart management and business decisions to address evolving economic, environmental, and social pressures on our ocean and coasts. NCCOS's approach uses diverse and state-of-the-art technologies to map and characterize the seascape from the intertidal zone to the EEZ. This includes uncrewed aerial, surface, and underwater vehicles; ships; aircraft; remotely operated vehicles; and satellites; and a range of sensors associated with each. NCCOS innovates, develops, and produces interactive data models visualizations for managers to make informed decisions and to identify critical information gaps. Specifically, NCCOS uses UAS to enhance remote sensing for habitat mapping. UAS provide high resolution imagery to augment crewed systems or in remote areas. Precise controls allow for long-endurance and repeatable surveys.

NOS Office of National Marine Sanctuaries (ONMS) is the trustee for a network of National Marine Sanctuaries and Marine National Monuments. UAS are a valuable tool in large-scale management of these marine protected areas. The use of UAS allows ONMS researchers to collect data with minimal disturbance and survey open waters for marine debris and marine wildlife. The ability for UAS to fly lower, slower, and quieter than conventional aircraft makes it valuable for wildlife surveys for seabirds, marine mammals and sea turtles as well as other scientific data collection. UAS are employed by ONMS to identify and locate marine archaeological sites and to support the enforcement efficiencies in highly-protected reserves.

National Weather Service (NWS)

NWS has continued to use UAS as tools in surveying both pre- and post-event areas in continued demonstration projects to determine the utility of UAS for some of our surveying and operational needs. UAS are especially valuable to survey remote or heavily wooded regions where automobile and/or foot traffic is difficult or impossible (and in cases is the only option), and in areas where ground-level observations cannot accurately give complete knowledge of the phenomena being surveyed.

For pre-event usage, NWS uses UAS in remote locations in Alaska Region to determine potential for ice jam flooding during spring breakup of frozen rivers and the potential for flooding caused by glacially dammed lakes. UAS have been helpful to the NWS in assessing potential flooding by mapping basins during normal conditions, and to assist in mapping regions and communities at risk of flooding. During post-event operations, UAS can be valuable tools in determining the types (e.g., straitline, tornadic), extent, and severity of wind damaging and other severe damaging events. Finally, UAS also offers the NWS a safe, cost-effective alternative to human inspections of equipment on NOAA-owned or NOAA-leased property (e.g., buildings, radomes, radio towers). UAS offer a means to inspect damage or potential causes of interoperability without one or more people climbing and/or traversing the equipment needed to be inspected. This last use of UAS will be expanded in the coming year.

National Environmental Satellite, Data, and Information Service (NESDIS)

The NESDIS mission to provide global environmental data to support the Nation's environment, security and economic quality of life is enhanced by employment of UAS assets across NOAA. Investing in a robust UAS community will improve data resources and provide a cost-effective sampling capability that allows surveying remote areas with a reduction of exposure to extreme environmental conditions *(eg. fire, drought, ice)*. UAS data when managed as an asset can create knowledge products that support immediate needs, predictive modeling capabilities and/or historic reconstructions.

NESDIS scientists maximize the value of UAS observations by combining them with other scientific capabilities. Scientists at the Center for Satellite Applications and Research are deploying UAS assets to calibrate and validate satellite derived sea ice records. This uncrewed aspect adds value by minimizing human exposure in this extreme environment and the aerial capability allows controlled data collection of ice features at higher resolution when compared to the satellites. The Concept of Operations for this sea ice capability is currently evolving while the system technology is undergoing development and testing. Other STAR scientists have been working with partners at MDE and University of Maryland to explore the ability to use UAS imagery to characterize septic leakage in the Chesapeake Bay. Knowledge gained from this project has clear value to societal and economic issues in the areas of public safety and aquaculture.

Reporting on NOAA UAS Adoption, Application, and Integration

The UAS Division in OMAO's UxS Operations Center tracks and quantifies all NOAA UAS flights. Flight data is collected by UASD Situation Reports (sitreps) that are required to be completed after each flight by NOAA UAS operators. Sitreps captured metrics for over 60 unique projects and over 1,000 UAS flights conducted in FY21. Data collected in the NOAA UASD Sitreps include

- **Project Information**
  - Contact
  - Date
  - Line Office and Field Office
- **Personnel and Project Type**
  - Mission Commander (MC)
  - Pilot in Command (PIC)
  - Second in Command (SIC)
  - Other Personnel
  - Project Type (animal survey, mapping, training, storm damage, etc.)
  - Data Products (video/still images, meteorological data, Lidar, etc.)
- **Flight Information**
  - UAS Platform
  - Payload
  - Flight Time
  - Number of Landings
  - Aircraft Status
- **Airspace Authorization**
  - NOAA Notification of Intent to Fly (NIF)
  - NIF Approval Number
  - Federal Aviation Administration (FAA) Certificate of Authorization (COA)
  - Low Altitude Authorization and Notification Capability (LAANC)
- **Mission Description**
  - Location
  - Project Name from NIF or Flight Authorization Memo
  - Additional Comments
  - Images

Image 3: Jacek Maselko hand catching a H520G during an airworthiness demonstration in Juneau, AK. Photo: Matthew Rogers/NOAA

Data collected under these metrics is analyzed by UASD to determine trends and patterns for decision making and to quantify how NOAA is using UAS platforms. This data is gathered in reports and shared with NOAA leadership, partners and operators. The collected data is also captured here in the NOAA UASD FY21 annual report.

Overview of NOAA UAS Activities for FY21

NOAA has continued to dramatically expand the collection and use of critical, high accuracy, and time-sensitive data by increasing the application and use of UAS across the agency's mission areas. Scientists continue to rely on UAS technology to collect data in some of the harshest environments in the world. FY21 UAS use has continued to grow as a favored tool by scientists, flying more than any previous year with flight time of over 55% from the previous year.

Flight Time by Fiscal Year (2012–2021)

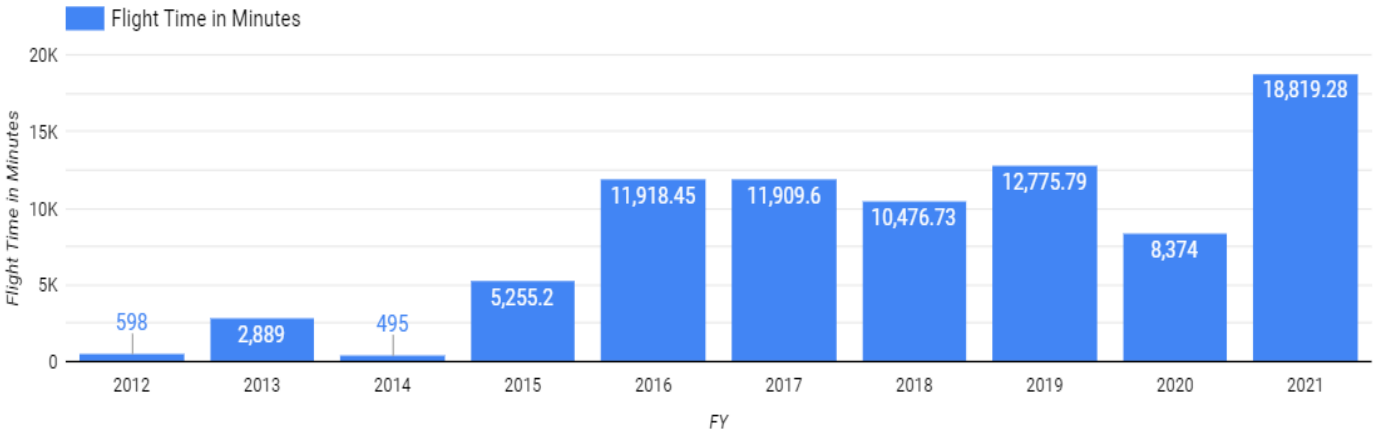
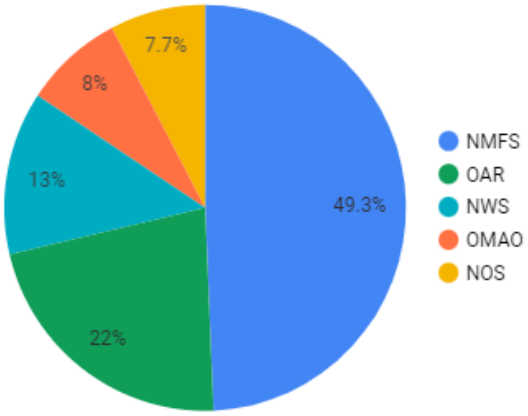


Figure 1: In FY21, NOAA UAS flew more than any previous year despite challenges by the COVID-19 pandemic.

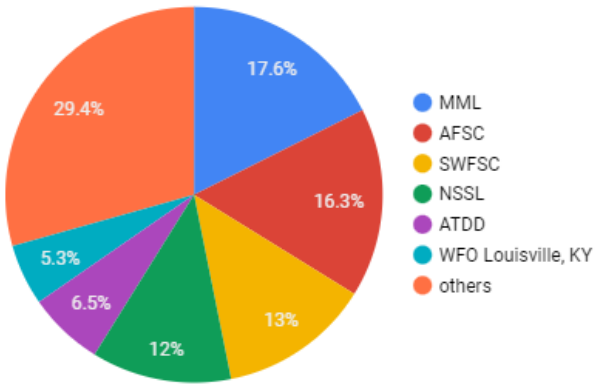
Flight Time by NOAA Line Office in FY21



NMFS flew nearly 50% of all NOAA UAS flight time. OAR completed over 22% of NOAA UAS flight time in FY21.

Figure 2: The pie chart shows the percentage flight time by NOAA line office in FY 2021.

Flight Time by NOAA Divisions and Centers in FY21



NOAA Line Offices are made up of many centers and divisions that focus on specific missions. The Marine Mammal Laboratory (MML), Southwest Fisheries Science Center (SWFSC) and Alaska Fisheries Science Center (AFSC) all fall under NMFS. In FY21 SWFSC flew over 13% of NOAA UAS flight time, supporting animal survey missions from leatherback sea turtle, salmon, beluga whale and gray whale surveys.

Figure 3: The pie chart shows the percentage light time by NOAA center in FY21.

UAS Aircraft Flight Time

In FY21, NOAA supported flight operations for over 30 different UAS platforms. These platforms ranged from fixed wing, vertical takeoff and landing (VTOL), and hybrid systems. These systems have all been evaluated and approved by UASD. The UAS platforms have also all undergone a NOAA UASD airworthiness assessment and standard operating procedures have been developed. In FY21 NOAA owned almost 100 UAS and operated in locations all over the world with operations as remote as Antarctica.

Percentage of Flight Time by Aircraft in FY21

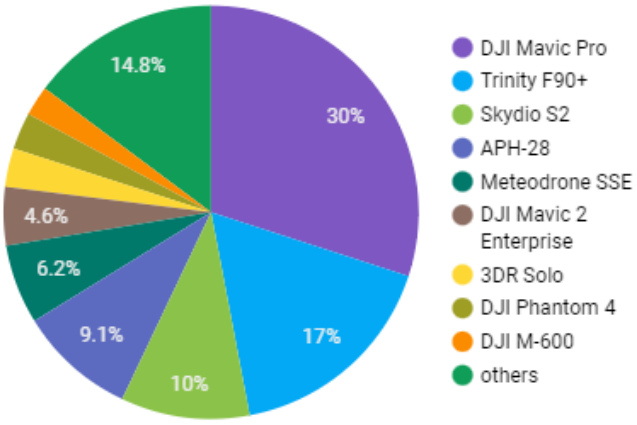


Figure 4 (left): The pie chart shows the percentage of flight time by type of UAS platform. Image 4 (right): APH-22, pictured above, was developed by Aerial Image Solutions. An Olympus E-PM2 camera and interchangeable lens system is organized in front of the drone by size order; the camera mounts on the underside of the hexacopter to be downward-facing.

NOAA UAS Platforms

NOAA supports over 30 approved UAS platforms across NOAA. Each platform is evaluated by UASD before it is approved for NOAA use. This approval includes airworthiness, standard operating, emergency and launch and recovery procedures. UAS platforms may also be individually evaluated for shipboard operations, hand launch and recovery, and Beyond Visual Line of Sight (BVLOS) operations. UASD works closely with scientists and pilots to identify UAS platforms to meet mission requirements. The scope of UAS mission requirements may include size of UAS, flight time, maximum payload weight, operating area, types of payloads, and landing area required. This close working relationship between scientists, pilots, and UASD enables the identification of UAS platforms best suited for mission success.

NOAA UAS Inventory

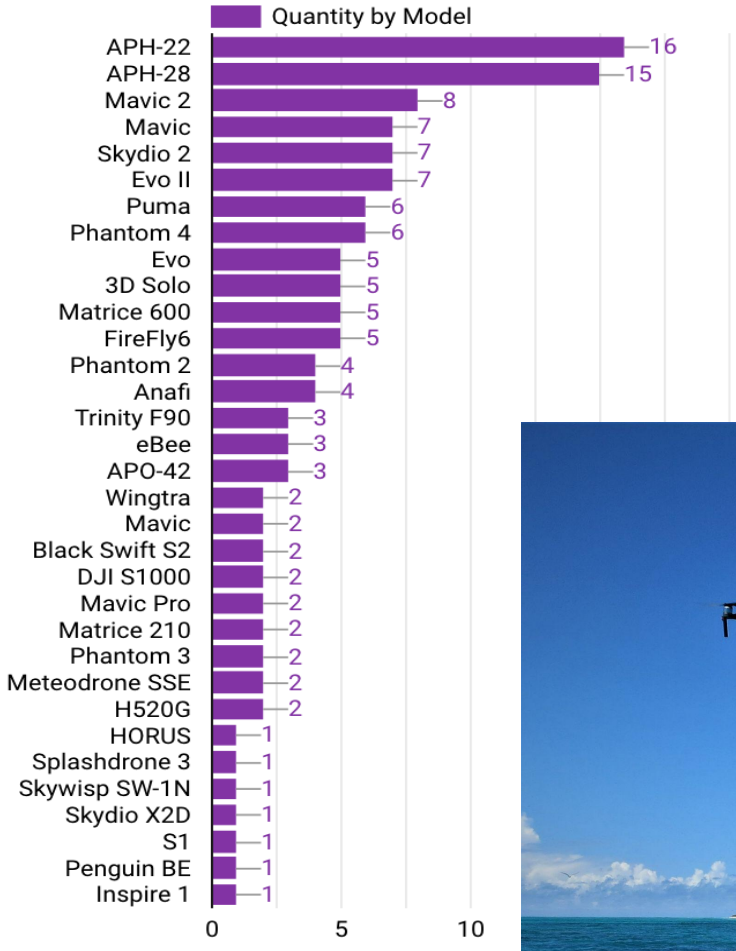


Figure 5: The bar graph shows the NOAA UAS inventory of platforms and quantity.

Image 5: UAS Pilot Keolohilani Lopes conducts UAS flights in the Papahānaumokuākea Marine National Monument (PMNM) with the Mavic 2 Pro Photo: Jason Leonard/NOAA

UAS Payloads and Data

NOAA scientists continue to collect various types of data in the field with UAS platforms. In FY21, animal survey data collection accounted for nearly 20 percent of flight time by NOAA UAS while training and proficiency flights totaled more than 25 percent of NOAA UAS flight time. Often, when conducting training or proficiency flights, UAS pilots operate platforms without expensive payloads. UAS payloads include meteorological sensors, video and still camera systems, multispectral cameras, lidar and whale mucus collectors.

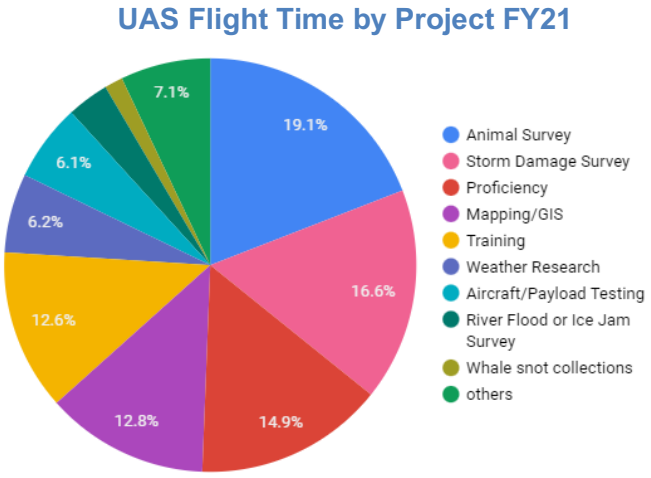


Figure 6: The pie chart shows the percentage of flight time conducted by NOAA UAS based on project type.

Image 6: Ed Dumas prepares the Meteomatics MM-641 flight. Photo: Travis Schulyer/ATDD

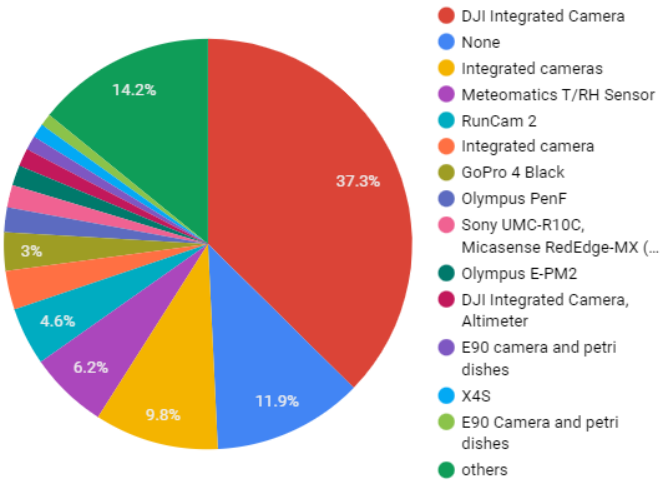


Figure 7: The pie chart shows the percentage of flight time conducted by NOAA UAS in FY21 based on payload type.

UASD Two-year Comparison

A comparison of UAS activity for FY20 and FY21 provides insights into how current policy, UAS adoption, and transition of technology has had an impact across NOAA's mission portfolio. NOAA UAS operators also flew 54 percent more in FY21 than FY20. In FY21, NOAA also added more than 25 new UAS and 6 new platform types. The use of UAS for storm damage assessment increased 800 percent over the previous year. Storm damage assessment is one project that highlights areas where NOAA UAS operators have built on previous successes with operations transitioning from research to operations assisting NOAA missions where technically feasible and beneficial.

Percentage of flight time by NOAA Line Office

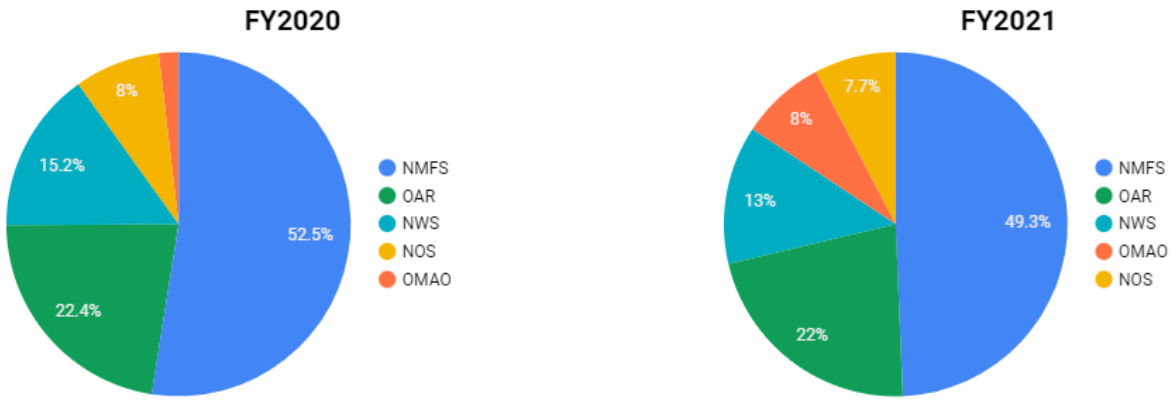


Figure 8: FY20 and FY21 flight time comparison by NOAA line office. In FY21 OMAO UAS operations increased from 2 percent to 8 percent.

Percentage of Flight Time by NOAA Center or Division

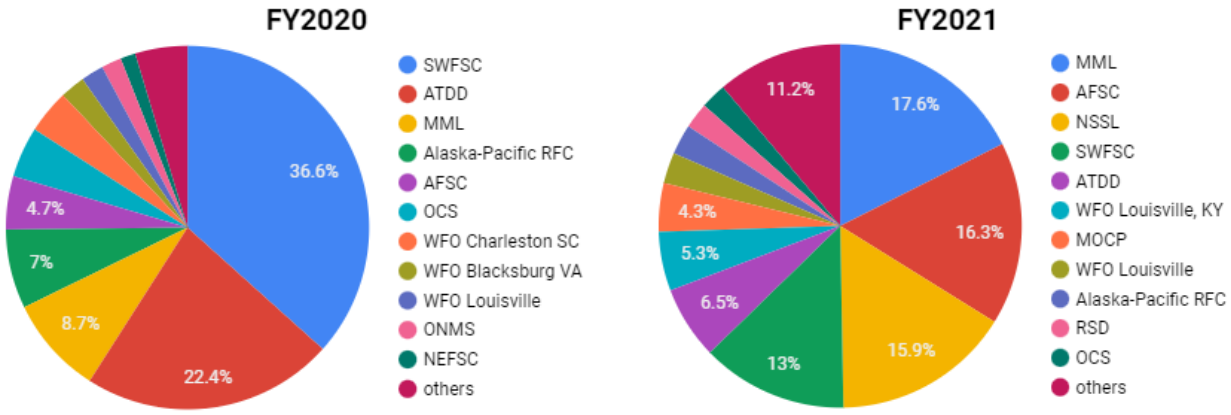


Figure 9: FY20 and FY21 percentage of flight time comparison by NOAA centers and divisions. In FY21, the MML more than doubled their percentage of flight time for all NOAA UAS operations. NOAA National Severe Storms Laboratory also began training for UAS operations in FY20 and in FY21, and flew more than 15 percent of all NOAA UAS operations.

Flight Time by UAS Platform

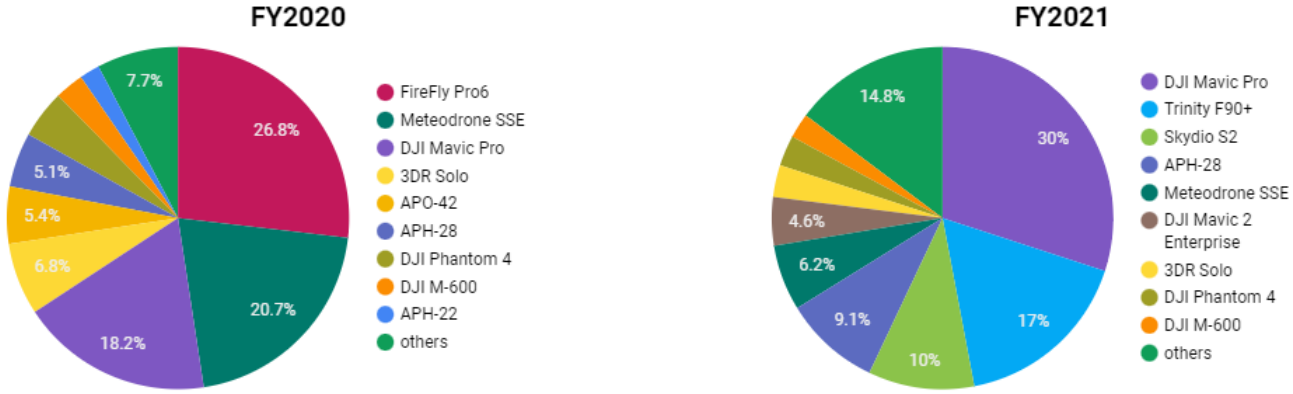


Figure 10: FY20 and FY21 percentage of flight time comparison by UAS platforms. In FY21 DJI Mavic Pro flight time nearly doubled. The Trinity F90 was introduced in FY20 and flew 17 percent of NOAA UAS flight time with MicaSense RedEdge-MX Dual-Camera, multispectral sensor and Quantum-Systems Qube240 Lidar sensor.

Flight Time by Project

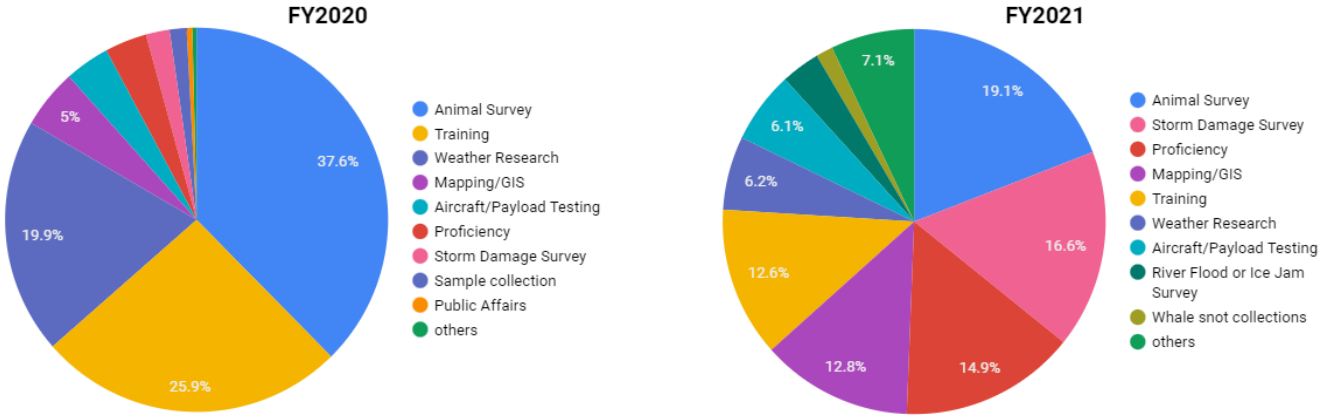


Figure 11: FY20 and FY21 percentage of flight time comparison by project. In FY21, Storm damage assessment UAS projects flew more than 16 percent of all NOAA UAS flight time, which is a dramatic increase from FY2020. Many of these flights also used the Trinity F90. UAS proficiency flights also increased as more of NOAA's workforce is initially trained; these proficiency flights are critical to maintaining skills and competency.

FY21 Program Highlights

Using Small UAS for Hydrologic and Storm Damage Surveys

Author: Dan McKemy (PI)

The NWS office in Louisville, KY, completed its first full FY21 with the drone project funded by the UxS Operations Center and it was a big success! Project operations began in late FY20 when NWS Louisville received funding to begin purchasing equipment and training staff to fly UAS. During FY21, numerous river flood and storm damage surveys were conducted with drones and they proved to be valuable resources.

Image 7: NWS Louisville Meteorologist Dan McKemy flies one of the drones used for hydrology and storm damage surveys. Photo: John Gordon/NOAA

The busiest time of year for flooding across the NWS Louisville region is typically in the spring, and FY21 spring turned out to be a very active one! Widespread heavy rain impacted the region in late February 2021, and resulted in moderate to major river flooding across much of central Kentucky in early March 2021. Some of the rivers across central Kentucky reached their all-time top ten crests during this event. NWS Louisville sent out survey teams on four separate days and were able to use drones to assess flooding impacts (Figure 2) and pass along imagery to the Ohio River Forecast Center and other partners/agencies. Videos, still imagery and orthomosaics were also collected in the image capturing process and will be used to verify river flood impact statements and flood models.

Image 8: Flooding is found along the Ohio River northeast side of Louisville, Kentucky. Photo: Dan McKemy/NOAA

Toward the latter end of FY21, NWS Louisville developed an ArcGIS StoryMap using data collected from that flood event. One of the challenges that NWS Louisville has faced with some of the datasets is that the data is very large and hard to share with some of their partners. The ArcGIS StoryMap allows users to access and view smaller file-size versions of the data with an internet connection.

High-resolution versions of data from the flood event can be requested through NWS Louisville's VLAB page.

The link to the ArcGIS StoryMap can be found below:

https://storymaps.arcgis.com/stories/49bd41c135cd4c90923672ad66496e78

The severe weather season also picked up during the spring months across the region, and the drones proved their usefulness in storm damage surveys. On multiple occasions, the drones were able to confirm the

occurrence of a tornado whereas ground surveys in those same areas would have led to inconclusive results. One of the more notable events from this past spring; where drones were extremely vital; occurred on March 25, 2021 when several tornadoes impacted central Kentucky. In one county, where NWS Louisville was surveying, the damage was very sporadic and visual ground-level signs for tornadic damage were unclear.

Once the NWS Louisville survey team flew the drone, they quickly discovered that a tornado had occurred, as they were able to detect 'ground swirls' in a nearby field that only a tornado would leave behind (Image 7). The survey team would have had no reason to go into that field as no visual damage occurred at ground level, and it's possible that the damage would have been misclassified as straight-line wind damage had it not been for the drone.

Image 9: A tornado path was observed in a field in Grayson County, Ky. The cyclonic 'swirls' are readily evident in the image. Photo: Dan McKemy/NOAA

The drones have enhanced the quality and accuracy of survey operations since the project began in late FY20. NWS Louisville is appreciative of the funding it has received to be able to use drones in aerial survey operations, and plans to continue using them in river flood and storm damage surveys through FY23 via the RFP they applied for in FY20.

Using UAS Mapping Capabilities to track Endangered Pacific Salmon and Inform Management

Principal Investigator: Lee R. Harrison

Co-Investigators: Michael L. Aslaksen, Timothy J. Beechie, Carl J. Legleiter, Brandon T. Overstreet, George R. Pess, and Jason Woolard

Project Summary

The National Marine Fisheries Service (NMFS) is a federal agency under NOAA that is responsible for the stewardship of the nation's living marine resources and their habitat. One of the key elements of this mission is dictated by the Endangered Species Act (ESA), which directs NOAA Fisheries to recover protected marine species while also allowing for economic and recreational opportunities. Each year, water and fisheries managers make critical decisions about water allocations in the Western United States, which primarily involves making a choice between using water for environmental purposes (e.g., salmon) or for agriculture. These decisions are based, in part,on a series of coupled physical-biological models developed by NMFS for evaluating the impacts of water operations, fisheries management, and environmental variation on salmon population dynamics. Currently, one of the key limitations of these decision support tools is the lack of continuous, high-quality river topographic and bathymetric (topo-bathymetric) data, which are required inputs for predictive hydrodynamic models.

The primary goal of this project, funded by the UxS Operations Center, is to advance existing topo-bathymetric riverine mapping capabilities. To address the project goal, NMFS is developing a novel mapping approach which combines UAS-based, near-infrared (NIR) Lidar data and multispectral imagery to generate topo-bathymetric digital elevation models (DEMs). The UAS workflow involves:

(1) Mapping the topography of dry land and water surface elevations using NIR Lidar sensors.
(2) Estimating water depths using spectrally based remote sensing techniques.
(3) Converting depths to bed elevations by subtracting depth estimates from Lidar-based water surface elevations.
(4) Merging Lidar topography and image-based bathymetry to form a continuous, topo-bathymetric DEM. The specific aim is to produce topo-bathymetric DEMs of sufficient accuracy to support multi-dimensional hydrodynamic models, used to guide critical water management decisions.

NMFS is using a Quantum-Systems Trinity F90+ VTOL fixed-wing platform (Figure 1a) for the purpose of evaluating its topo-bathymetric mapping capabilities. The Trinity F90+ has proven to be a reliable platform on prior NOAA missions, and the interchangeable payload design makes it a cost-effective solution to transition new sensors and payloads to operational status. Initial testing on the American River in California proved that water depth (i.e. bathymetry) could be successfully mapped using a MicaSense RedEdge-MX Dual-Camera imaging system (Figure 1b), which is a radiometrically-calibrated spectral imager with ten bands between 400-900nm. To more effectively map river corridor topography via UAS, NMFS procured a Quantum-Systems Qube240 Lidar sensor (Image 9) in summer 2021. The Qube240 is a geomatics grade Lidar scanner that has been fully integrated with the Trinity F90+ platform.

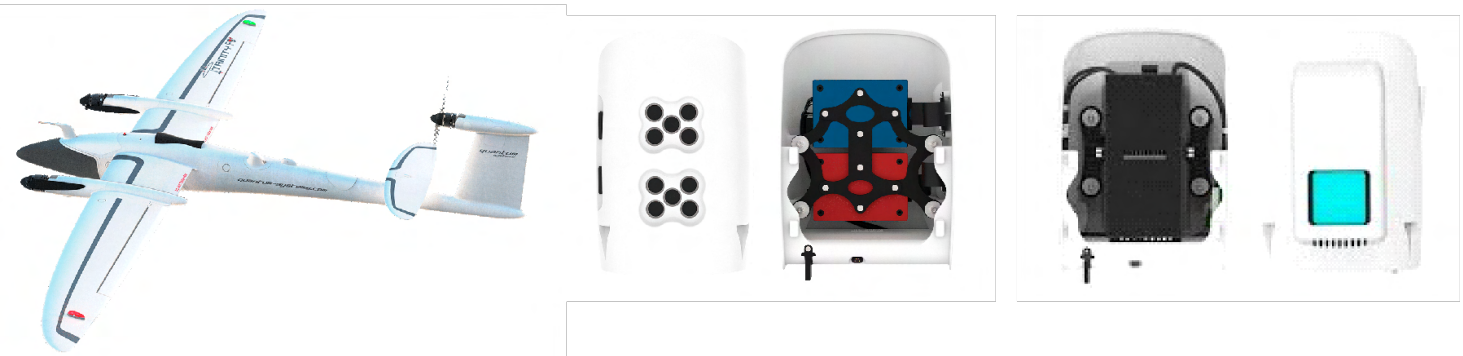


Image 10: (a) Quantum-Systems Trinity F90+ UAS platform; (b) MicaSense RedEdge-MX Dual-Camera, multispectral sensor; (c) Quantum-Systems Qube240 Lidar sensor

NMFS tested the mapping potential of the Qube240 Lidar scanner on the Sacramento River in fall 2021. The Sacramento River (Figure 2) is a lowland, meandering river and is the largest river in California that supports three populations of Pacific salmon. NOAA's SWFSC is actively involved in science projects aimed at informing water management and salmon recovery throughout the Sacramento River, which is a high-priority river system for the Agency.

Image 11: Oblique aerial view of the Sacramento River located in California, USA.: Photo: Lee Harrison/NOAA

Initial results from the Sacramento River found good agreement between elevations measured with GPS survey equipment and those obtained from the UAS Lidar scanner. The Lidar scanner was able to obtain accurate ground elevations through riparian vegetation of different densities, and also provided precise measurements of water surface elevations.

UAS-based depth maps provided bathymetric DEMs with comparable errors to conventional remote sensing data. Overall, initial testing from the Sacramento River showed the promise of using the Trinity F90+ UAS platform and integrated Lidar and multispectral sensors for generating topo-bathymetric DEMs on a large river. Additional testing on rivers located in the Pacific Northwest is planned for summer/fall 2022.

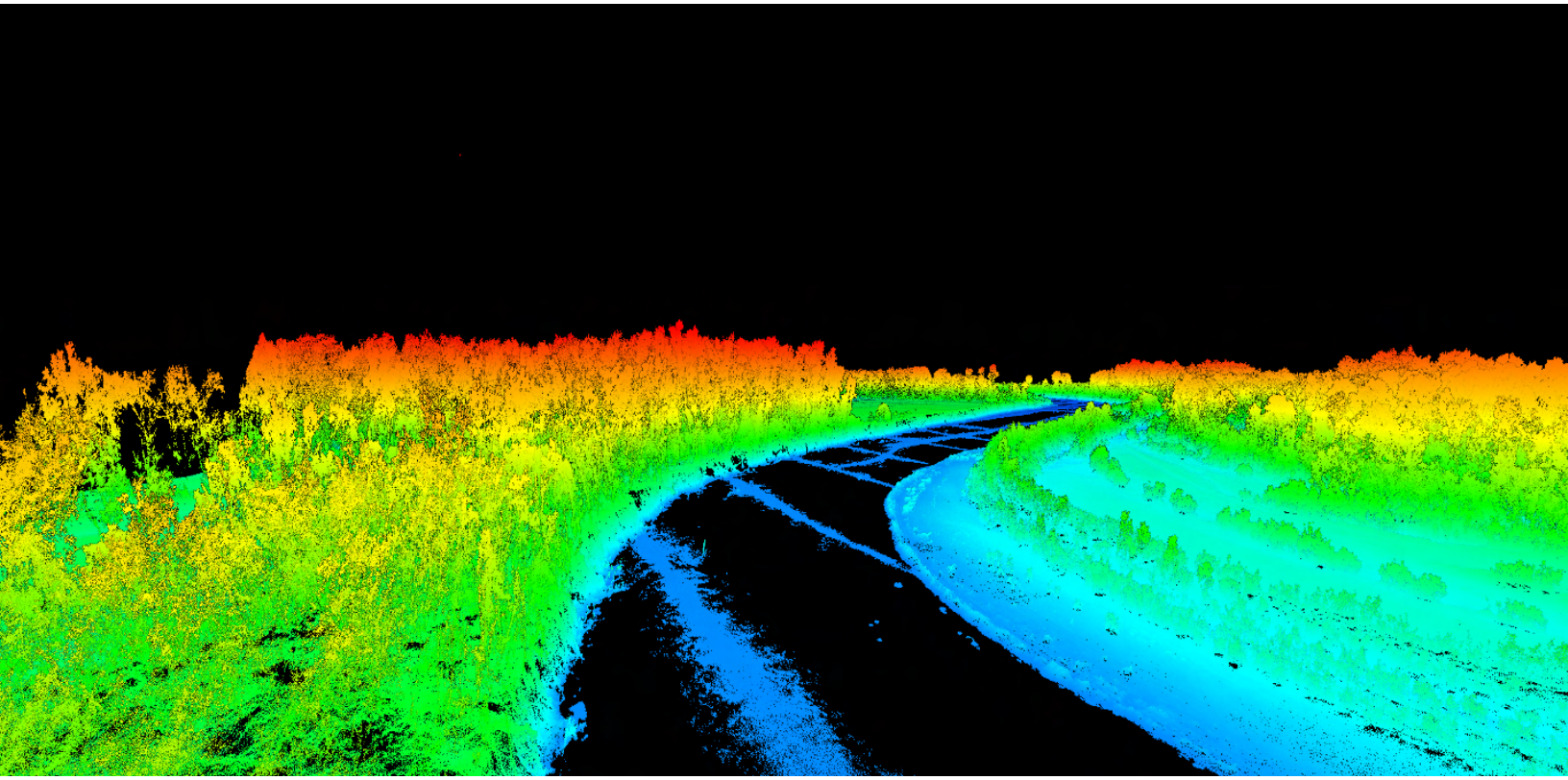


Image 12: Three-dimensional view of UAS-based Lidar topography data collected along the Sacramento River in California. Photo: Lee Harrison/NOAA

The topo-bathymetric mapping capabilities developed in this study will support the broader goal of increasing UAS operations within NOAA. Developing UAS-based mapping tools is vital for NOAA Fisheries to complete their mission to protect endangered species. In addition, advancing UAS-based Lidar mapping capabilities in NOAA will directly benefit multiple NOAA line offices tasked with mapping coastal and riverine environments throughout the United States

Supporting Atmospheric Turbulence and Diffusion Division Collection of Atmospheric, Meteorological and Climate Data using UAS

Author: Ed Dumas (PI)

For many decades, NOAA's Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, TN has been making direct measurements of turbulence, air temperature, relative humidity, and the exchange of mass, momentum, and energy between the surface of the Earth and the lower atmosphere. ATDD has used towers, full-scale aircraft, and is now using small Uncrewed Aircraft Systems (sUAS) to help fulfill its mission.

Image 13: The BlackSwift S2 fixed-wing sUAS prepares for launch at Oliver Springs Airport inMay 2021. Photo: Ed Dumas/NOAA

In March2019, ATDD entered into an agreement with a small, private airport in Oliver Springs, TN to use sUAS to make routine measurements of temperature, humidity, and wind in atmospheric lower boundary layer. ATDD selected Oliver Springs airport because of its close proximity to Oak Ridge and the limited number of full-scale aircraft operations that occur there. The primary end-user of the Oliver Springs data was the NWS Weather Forecast Office (WFO) in Morristown, TN. A primary driver for this work is the lack of suitable atmospheric profiles made on a routine basis in the East Tennessee region. For example, the closest NWS rawinsonde launch site is located in Nashville, more than 200 km away. Due to differences in terrain throughout the state of Tennessee, the rawinsonde data from the Nashville office are sometimes not adequate for accurate forecasts in East Tennessee, particularly when severe weather events threaten.

With the advent of sUAS and the proximity of the ATDD facility to the Oliver Springs airport, the opportunity to make low-cost, routine atmospheric profiles to help the Morristown NWS office became possible.

In July, 2019, with assistance from the UAS Division, ATDD was able to apply for and receive a Certificate of Authorization (COA) from the FAA to allow sUAS flights at the Oliver Springs airport up to 1000 meters above ground level. Since this COA does not allow for flight beyond visual line of sight, the maximum altitude that each aircraft could be flown was limited by its size, the visual acuity of the pilot, and the meteorological conditions present during the flight.

Image 14: Travis Schuyler and Ed Dumas at the Oliver Springs airport preparing for a research flight in September 2020.Photo: Travis Schulyer).

ATDD flew the Meteomatics Meteodrone SSE, a small multi-rotor aircraft optimized to make measurements of wind speed and direction, air temperature, relative humidity, and air pressure as a function of altitude. The flights typically began around sunrise and continued until about 3-4 hours after sunrise. Data from these flights were made available in near real-time to forecasters at the Morristown WFO and provided them with more localized information on the state and evolution of the boundary layer in their county warning area that could have been obtained from the rawinsonde launches in Nashville. Additionally, the sUAS data were used as inputs into meteorological models used to run particle dispersion simulations.

Results from this work were disseminated to the scientific community through two manuscripts that have been or will soon be submitted for publication in peer-reviewed journals, as well as two non-peer-reviewed publications and eight presentations. Although the sUAS work at Oliver Springs has concluded, ATDD will continue to use its sUAS fleet during targeted field studies on land-atmosphere interactions and boundary layer processes.

Applying National Weather Service (NWS) Alaska UAS for Flood Impacts

Author: Jessica Cherry

Image 15: Jessica Cherry tests a DJI Mavic Pro Uncrewed Aerial System in the periglacial environment near Cordova, Alaska. Photo: Brian Taggart/Oceans Unmanned

Cordova, AK is a community whose landscape and economy are undergoing rapid change. The Eyak Tribe who resides there is unique both culturally and linguistically; their homelands are a crossroads region between those of the Ahtna Dené and the Tlingit of the Southeast Panhandle. The last living fluent Eyak speaker, Marie Smith Jones, died in 2008 at the age of 89, but not before working tirelessly to p5reserve her language in books, recordings, and testimony to the United Nations. Below the Marie Smith Jones Memorial Bridge over the Eyak River, NWS monitors water levels and flooding conditions near one of the Tribe's traditional settlements. Near the settlement, salmon climb fish ladders into Eyak Lake to spawn, and families launch skiffs to fish downriver.

Aside from English, Tagalog and other Filipino languages are commonly heard throughout the streets, canneries, and other businesses in Cordova. Cordova is a fishing town when fish are prevalent, which attracts men and women from all corners of the world to work there. The flood prone areas, retreating glaciers, and collapsed bridges make for an interesting visual story near the small town of Cordova, which contains a population of about 2,500 people.

Two NOAA retirees, Brian Taggart and Matt Pickett, formed Oceans Unmanned, which is a small non-profit organization that protects the oceans and coastal marine environments using unmanned technology. At a harbor, Prince William Sound, Taggart and Pickett tested UAS mapping package that flew from the NOAA Ship *Fairweather* to assist the ship's hydrographic mission. Funding support in FY21 came from the UxS Operations Center.

Besides flood hazards to homes on the Eyak River, heavy rains can threaten the hydropower infrastructure running near Power Creek along Eyak Lake's shoreline. Hydropower provides 60 percent of the energy used in Cordova, but flooding and erosion along the creek can expose power lines and cut off road access to the power plant.

Near the Sheridan Glacier in the verdant Chugach National Forest, the U.S. Geological Survey (USGS)GS maintains two river gages to support its partners with the U.S. Forest Service, the State Department of Transportation, and NWS. As the glacier retreats and the size of its periglacial lake swells, the character of the

outflowing river (its gravel transport and hydrology) change; these changes affect the downstream bridges and river crossings.

On the Copper River Delta, the more than 100-year-old Million Dollar Bridge (MDB); which once provided access to the Kennicott Mine and was considered one of the greatest engineering feats of all time; also has a USGS river gauge monitoring the river's rises and falls. However, the MDB is now inaccessible due to erosion and another collapsed roadway on a different channel of the river. The USGS must take a boat or helicopter to access the gage and assess ongoing conditions of the now isolated site. The MDB was repaired after Alaska's 1964 earthquake, and should the MDB ever collapse, the negative impacts on the highly-valued copper river salmon run are predicted to be significant.

The UAS videography, Brian and Matt's UAS mapping, and the *Fairweather's* crew efforts must all work around the challenging logistics of support in a town all but shut down by the latest epidemic, COVID-19. Cordova makes for a fascinating place where the future must confront the past, which remains written on the landscape, fisheries, and people who live there.

Image 16: Sheridan Glacier near Cordova, AK. Photo: Jessica Cherry/NOAA

Collecting UAS Data for NOAA Ship *Fairweather* Operations

Authors: LTJG Carly Robbins and Matthew Canning

Navigating the sound

Prince William Sound is located on Alaska's southern coast, just southeast of Anchorage. The sound is an extensive body of water with an area of about 2,500 square miles, and it is home to many beautiful islands, wildlife habitats, vast forests, dazzling blue glaciers, indigenous villages, and ports. Fishing, transportation of goods and oil, and tourism are the sound's major economic source, which deteriorated immensely after the Exxon Valdez oil spill, which occurred on March 1989. Due in part to its remote nature, the sound took many years to clean up and recover from one of the largest and worst environmental disasters in U.S. history. Tourism and fishing expeditions have begun to increase. With the increase in potential traffic, depths on nautical charts require higher accuracy to ensure the safety of vessels traversing in and around Alaska's many natural wonders.

The NOAA Ship *Fairweather,* from NOAA's Office of Marine and Aviation Operations began he journey to Prince William Sound in March of 2021, which is right at the beginning of the ship's field season under commanding officer, CAPT John "Jay" Lomnicky. Departing from Seattle, WA, *Fairweather* transited the Inside Passage and the Gulf of Alaska for four days to reach Prince William Sound. Upon reaching the survey

grounds it was necessary for the ship's navigators to maneuver around ice sheets and icebergs in order to protect her hull and propellers.

Image 17: A Skydio2 drone takes an aerial image of the Fairweather while it is approaching an iceberg at Prince William Sound. Photo: LT Shelly Devereaux/NOAA

Glaciers in Prince William Sound have been rapidly decreasing in size due to climate change. With glacial retreat revealing unsurveyed areas of the seafloor, it is pressing that we provide modern data to update nautical charts so that viewers can identify underwater hazards and improve maritime safety.

The extent of ice loss was noticed by the *Fairweather* crew as soon as the ship arrived at the survey grounds. Icebergs dotted the seascape, hiding most of their extent beneath the silty, cerulean water. Despite the challenge of navigating through large ice chunks, *Fairweather* and the attached launches surveyed up to the current ice limits, pushing further inshore during the summer months as the ice continued its unfortunate shrinking. The areas where glacial retreat occurred were largely uncharted, making the *Fairweather* crew the first to survey areas that haven't been exposed in all of human history.

Fairweather conducted UAS operations to survey the extent of the Columbia Bay Glacier, which has retreated significantly from the last charted extents in 2010. The *Fairweather* kept a safe quarter-mile distance from the glacier face, due to any potential ice calving events. The UAS imagery gave additional situational awareness to successfully navigate through rapidly changing ice flows and uncharted territory.

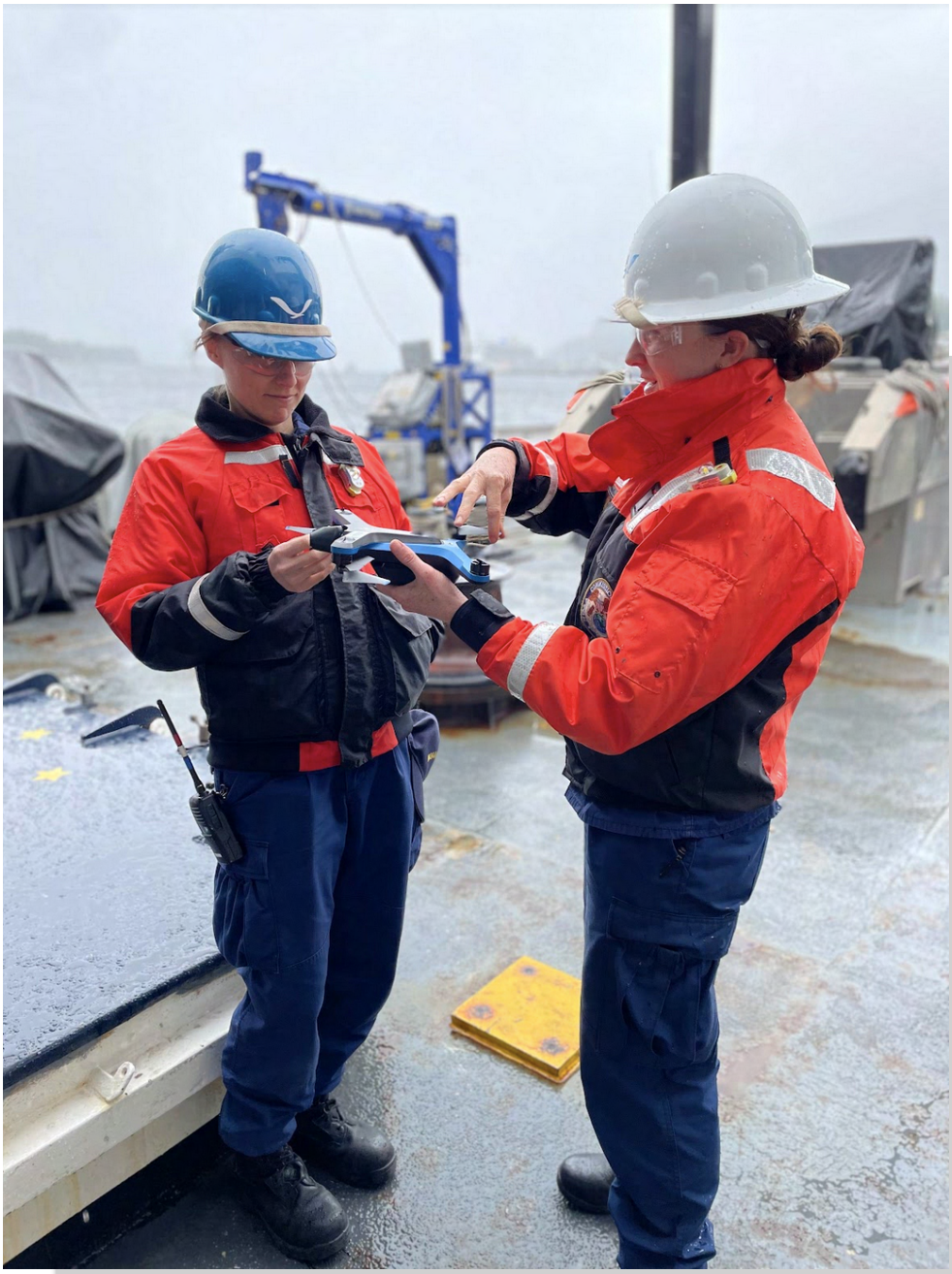


Image 18: NOAA Corps officers ENS Alexis Ferguson and LT Shelley Devereaux prepare to launch the Skydio for a glacier approach. Photo: LTJG Carly Robbins/NOAA

Demonstrating Hurricane UAS Area-I Operations

Author: Monica Allen, NOAA OAR Public Affairs

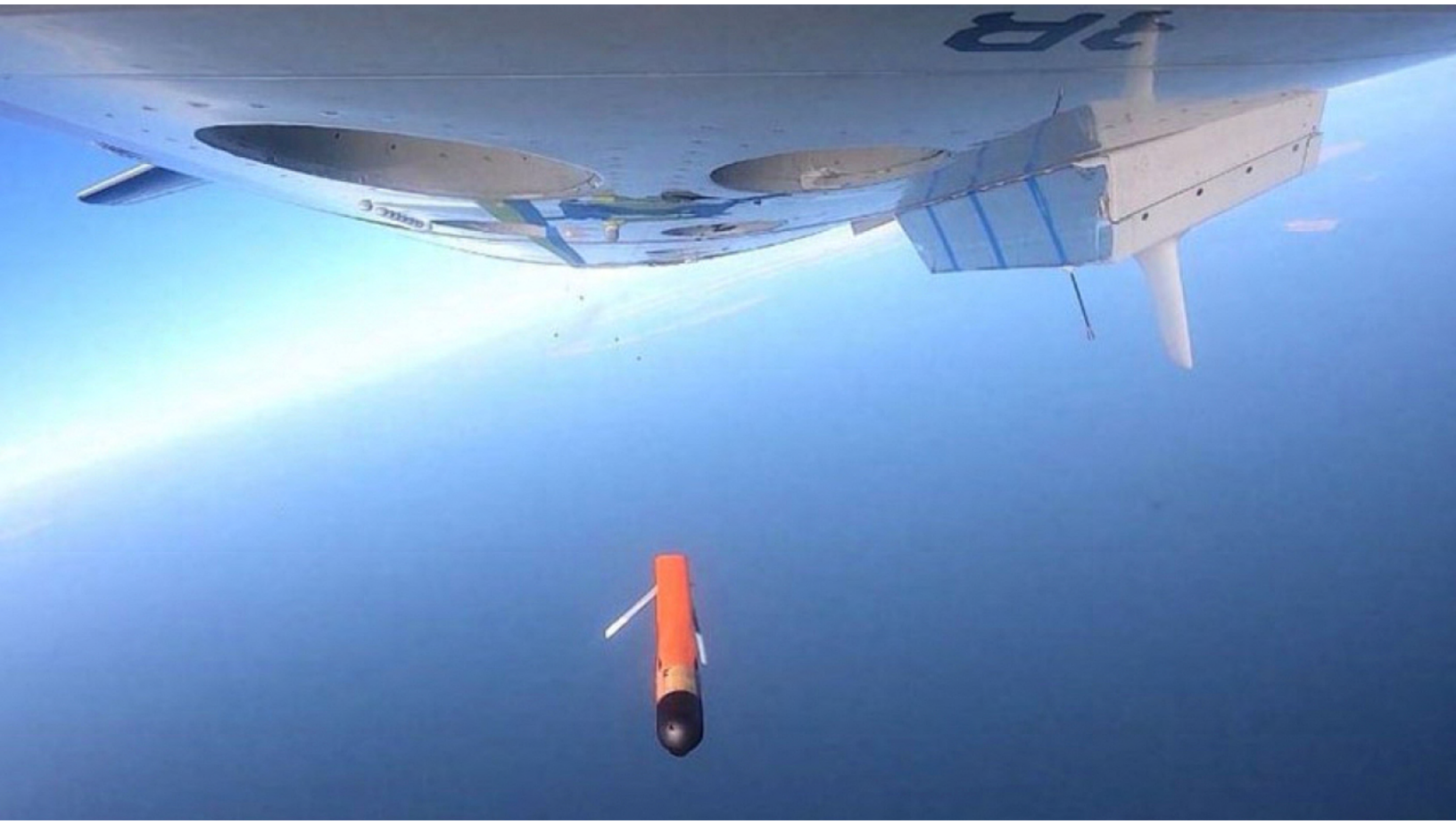


Image 19: View of the underside of the NOAA Hurricane Hunter plane as the Altius-600 uncrewed aircraft is deployed high over a field during flight tests on January 15, 2021. (Courtesy of Area-I/With permission)

In the week of January 11, when skies were clear over Maryland, NOAA scientists launched a new small uncrewed aircraft (a research drone) from a NOAA Hurricane Hunter plane operated by OMAO's Aircraft Operations Center to test its ability to gather weather data that could improve hurricane forecasts.

“We’re hopeful this new technology, once it can be successfully tested in a hurricane environment, will improve our understanding of the boundary layer and advance NOAA forecast models used in forecasts,” said Joseph Cione, lead meteorologist at NOAA’s Atlantic Oceanographic and Meteorological Laboratory Hurricane Research Division. “Ultimately, these new observations could help emergency managers make informed decisions on evacuations before tropical cyclones make landfall.”

Image 20: Cione holds an ALTIUS-600 in front of NOAA WP-3D Orion Hurricane Hunter. Photo: Area-I

For many years, NOAA Corps pilots have flown the agency's two WP-3D Orion Hurricane Hunters into the eye of tropical storms to gather vital weather data. But they avoid the perilous lower eyewall in the *boundary layer* where the ocean meets the atmosphere. This violent area of high winds and towering ocean waves is of key interest to scientists, but it is too dangerous for piloted aircraft to fly through.

Instead, scientists aboard the Hurricane Hunters release sensors tethered to parachutes known as *dropsondes*, which gather data and record wind speed and direction, temperature, moisture and pressure as they drop from the sky all the way down to the ocean.

"Dropsondes give us 'snapshots' of weather conditions, while the continuous flow of data collected by uncrewed aircraft provide something closer to a movie," said Cione, who conducted the drone test missions out of Patuxent River Naval Air Station. "Deploying the uncrewed aircraft from NOAA Hurricane Hunters will ultimately help us better detect changes in hurricane intensity and overall structure."

NOAA worked closely with Area-I, the Georgia-based aerospace company that created Altius-600, to adapt it for sampling weather data. The Altius-600 is the second generation of small uncrewed, remote-controlled aircraft offsite link that NOAA has used to collect hurricane data. The drone offers exciting, new data-gathering features such as the ability to fly up to four hours and travel distances of up to 265 miles from its point of launch.

NOAA Corps test pilots and NOAA engineers also coordinated closely with the Naval Air Station Patuxent River's Atlantic Test Range and the Navy's unmanned aircraft test squadron UX-24 to successfully execute the test flights, which are required to certify the Altius-600 for operational use in hurricane conditions.

The Altius-600 is the first of three small uncrewed aircraft systems NOAA is testing. The research supports the NOAA Uncrewed Systems Strategy to expand the use of uncrewed systems. The development and testing of the uncrewed systems is supported by NOAA's UxS Operations Center and NOAA's Small Business Innovation Research Program.

Surveying North Atlantic Right Whale using UAS

Author: Elizabeth Josephson

Researchers at NOAA's Northeast Fisheries Science Center have been using Aerial Imaging Systems (AIS) sUAS platforms since 2015, starting with some groundbreaking work on Atlantic menhaden and bluefin tuna using AIS's APH-22. More recently, NMFS has primarily been using sUAS to survey gray seal haul outs and pupping colonies as well as to photograph right whales for population monitoring and health assessments. The APH-22 continues to be the workhorse of our fleet, but NMFS also flies an APH-28, a larger model with longer endurance.

While experiencing limitations due to COVID- 19, NMFS was able to continue some sUAS operations in FY21. The drone team surveyed a gray seal haul out in Buzzards Bay, MA in August 2021. Data collected from this type of survey gives information on population distribution and abundance, seal entanglement rates, and health status.

Image 21: Gray seals are found on Gull Island in Buzzards Bay MA. Photo: Beth Josephson/NOAA

The North Atlantic right whale is one of the most endangered species in the world. Scientists at NEFSC have been incorporating sUAS photography into our efforts to research and protect these threatened animals. On the calving grounds off the Florida and Georgia coast and in Northeastern waters where feeding and other activities take place, NEFSC scientists have been enhancing aerial survey and boat-based photo-id work with sUAS missions, launched from a small boat or from a larger research vessel. In FY21, they were able to continue sUAS/small boat activities in Cape Cod Bay in early spring, collecting imagery with the APH-22 for photo-id and health assessment.

Image 22: A right whale is photographed from the APH-22. Photo taken under NOAA scientific permit #21371. Photo credit: Lisa Conger/NOAA

Image 23: A right whale calf approaches the research vessel. Photo taken under NOAA scientific permit #21371.Photo credit: Beth Josephson/NOAA

Launching the Papahānaumokuākea Marine National Monument Uncrewed Aerial Systems (UAS)

Authors: Jason Leonard, Keolohilani Lopes, Brain Hauk

The Papahānaumokuākea Marine National Monument (PMNM) UAS program was launched in 2021. PMNM leadership saw the advantages of utilizing this technology to conduct research and monitor the most remote island chain in the world. PMNM is a 1,400 mile stretch of coral islands, seamounts, banks and shoals that support an incredible diversity of coral, fish, birds, marine mammals and other flora and fauna, many of which are unique to the Hawaiian archipelago. PMNM worked closely with NOAA'sUAS Division to get our program started safely. Training and proficiency flights were conducted on the island of Oahu to build capacity.

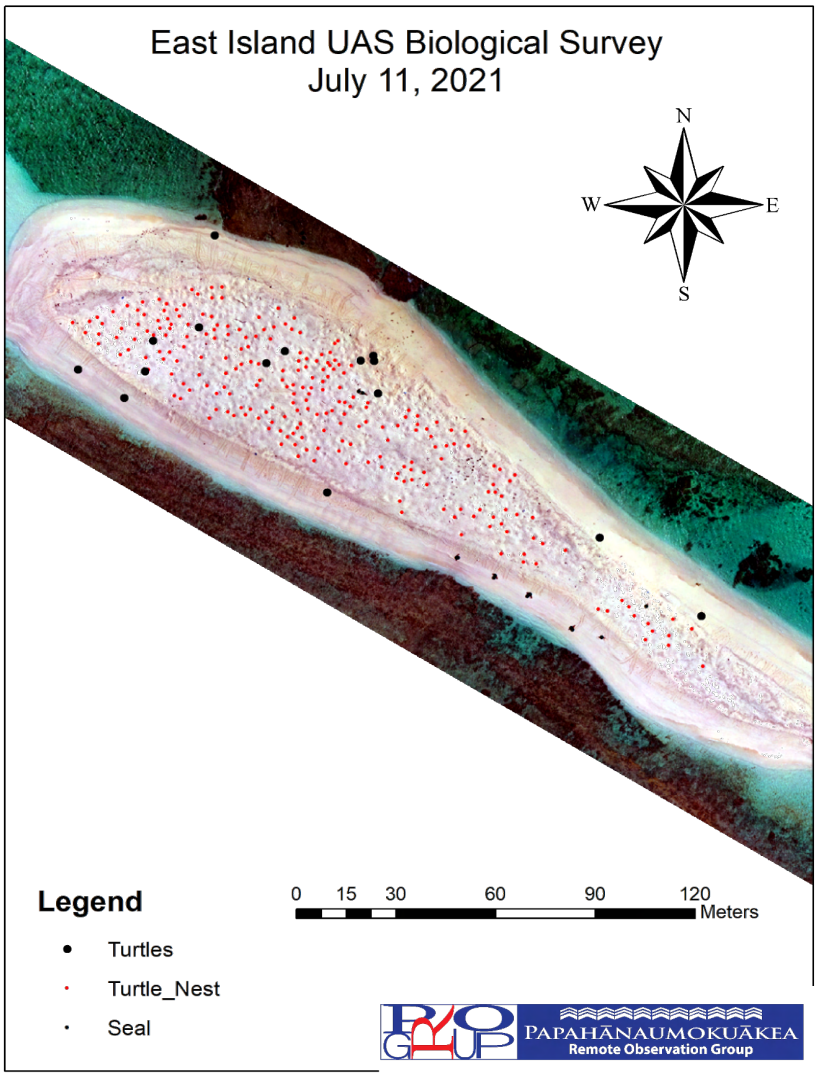
Image 24: Manawai (also known as Pearl and Hermes) Atoll lagoon aerial image of eastern lagoon area showing the invasive acting Chondria tumulosa as dark paths in the sandy bottom. These "Chondria Trails" extend ~35 kilometers and transects the entire atoll Photo: Keolohilani. Lopes/ NOAA.

The inaugural year for PMNM's Papahānaumokuākea Remote Observation (PRO) Group began with two, 20-day expeditions into the remote marine national monument. The PRO Group successfully integrated over 20 UAS flights to supplement primary mission objectives. These flights collected imagery that was useful in detecting the full extent of the invasive acting, newly discovered red macroalga, *Chondria tumulosa*. This alga is of particular interest due to its relatively rapid expansion coupled with the ability to smother coral reefs, killing the sessile biota beneath it.

In addition to the alga data, a high-resolution 3D reconstruction of East Island was created. This 11-acre sandy islet was completely destroyed after Hurricane Walaka made a direct hit to the area on October 4, 2018. Since

that time, the island has been naturally restored from local accretions allowing the landmass to, once again, support nesting green sea turtles and provide critical habitat for endangered Hawaiian monk seals.

UAS data products collected by the PRO Group are currently being used in the development of peer reviewed publications showing the changes in land mass over time. This research has provided managers with a better understanding as to how these low islets recover from disturbances and are used by protected species, which rely heavily on them. Lastly, UAS was used in a reconnaissance mission to investigate an abandoned life raft located on Seal & Kittery Island. UAS was used to ensure no human survivors or remains were present to guide any potential response. The use of UAS technology verified that no humans were physically present, and the USCG confirmed that all survivors had been rescued at-sea. The UAS greatly increased PMNM's ability to conduct reconnaissance in very difficult areas to access.



Future PRO Group projects will focus on cultural heritage research and monitoring. PMNM is of great importance to Native Hawaiians, with significant cultural history and the highest density of sacred sites in the Hawaii archipelago. UAS will be used for monitoring and documenting these important sites, many of which are in very difficult areas to access. Another project will be assisting with large mammal entanglement response operations. Hawaiian Island Humpback Whale National Marine Sanctuary has successfully used UAS for this important work and we will utilize their expertise and experience to further expand our capacity on Oahu.

Image 25: A 3D reconstruction of East Island at Lalo (also known as French Frigate Shoals). The UAS collected images are "stitched" together to create a centimeter resolution image of the site. Photo: K. Lopes/NOAA

NOAA UAS Safety, Cybersecurity, and Training

Operational Risk Mitigation (ORM) Process

OMAO's UASD conducts Operational Risk Management (ORM) assessment to identify and mitigate risks associated with UAS operations to increase safe and successful NOAA UAS missions. Most NOAA UAS operations fall under a “Wide Area” ORM. It is a broad document that covers most standard UAS operations. Some unique UAS operations require addendums and non-standard UAS operations require a project specific ORM. Regardless, all NOAA UAS projects are evaluated for ORM. This can include operations from shore, ship, small boat, high altitude, Beyond Visual Line of Sight (BVLOS) and launch and recovery operations. Operators are required to receive a Flight Authorization from NOAA UASD to confirm compliance with NOAA and FAA regulations.

The ORM Assessment identifies hazards that exist for all UAS operations. These hazards are then assessed and given an initial Risk Assessment Code (RAC) based on hazard severity and probability. Risk control measures are implemented to reduce the level of risk and assessed by the UASD ORM team. These controls can be additional Personal Protective Equipment, additions to checklists, increased UAS separation and additional safety measures. The RAC will be reassessed by the ORM team once control measures are in place. These control measures are continually reviewed and evaluated to improve safety of NOAA UAS operations.

Image 26: A school of Risso’s dolphins during SWFSC Half Moon Bay Leather Sea Turtles Project, photographed from APH-28-Ranger (Aerial Imaging Solutions, LLC). Photo: LT Chelsea Parrish/NOAA

UAS Cyber Security

Like any computer or IT system, UAS have certain cyber security related risks that must be properly managed. NOAA uses an Uncrewed Systems (UxS) Cyber Working Group (CWG) to develop UAS cybersecurity policies and procedures. These cover UAS component acquisition, air-gapping certain UAS from government computer networks, and data encryption. All NOAA Line Office IT Security Officers (ITSOs) are voting members, and the group works under the authority of the NOAA UxS Executive Operations Board with the participation of the NOAA Office of the Chief Information Officer. The UxS CWG developed Cybersecurity Principles for UAS that are largely based on, and consistent with, the DHS Cybersecurity and Infrastructure Security Agency (CISA) Cybersecurity Best Practices for Operating Commercial Unmanned Aircraft Systems. In addition, any cybersecurity risks are minimized by the fact that the data NOAA collects is publicly visible and of a non-sensitive nature.

Training Plan Curriculum and Strategy

To meet the increased demand of NOAA UAS operations, UASD has been focused on developing a training plan that defines curriculum and strategy. The training plan curriculum and strategy in FY21 has strived to safely and effectively increase UAS workforce proficiency within NOAA. To accomplish these goals and meet training demands, the UASD team has grown with the addition of a NOAA UAS flight instructor. In FY21 the flight instructor has been focused on developing training modules for users across NOAA for specific UAS platforms. These training modules, once finalized, will include training certifications and hands-on training in the field. UASD-conducted training saves government funds and allows UASD to customize training programs tailored to NOAA specific missions. The following modules have been under development in FY21:

- Initial UASD
- UAS Operations
- Airspace Awareness and Coordination
- Mission Commander
- Beyond Visual Line of Sight (BVLOS)
- Trainer Training

UASD Flight Instructor

NOAA's has its first dedicated UAS flight instructor/trainer in the UAS Division who is serving in a critical role in managing NOAA's significant UAS growth curve and providing expertise to unique and complex missions. The trainer brings a wealth of UAS experience from private industry and government. In this new role with NOAA, the UAS Division trainer is developing standardized training programs, training UAS operators and will train operators to become UAS trainers as well. With this background and experience, the UAS Division trainer is able to identify platforms for operational NOAA missions and safety concerns, and a dependable member of the ORM team.

NOAA UAS Successes and FY22 Outlook

NOAA continues to grow its use of UAS as the technology and its applications evolve. In FY21, UAS operations flew more than any previous year with over 60 projects and flight time up 55 percent from FY20. UAS-supported projects included more than 30 different platforms ranging from fixed wing, VTOL, hybrid systems, and systems over 55lbs. In FY21, NOAA added six new UAS models to the approved list of UAS platforms after conducting a UASD airworthiness assessment on each platform.

NOAA UAS operations have dramatically expanded collection and use of critical, high-accuracy, and time-sensitive data. This is especially apparent with the use of UAS for storm damage assessment with an 800-percent increase in flight time from FY20 to FY21. NOAA teams are able to quickly get on site with UAS platforms to collect data critical to understanding severe weather. In FY22, NOAA anticipates that UAS operations will continue to increase as a force multiplier for many NOAA programs.

OMAO's UASD continues to grow with the addition of a UAS flight instructor. In FY22, training modules will be developed to conduct NOAA UAS training which further supports NOAA UAS operations by increasing workforce proficiency in UAS use and operations. These training opportunities will provide cost savings to the government and also provide tailored training solutions built around NOAA's mission of science, service, and stewardship.

FY22 will be an exciting year for NOAA UAS operations. Scientists and UAS pilots continue to leverage UAS platforms in innovative ways for critical data collection. Advances in UAS technology will continue to provide additional UAS applications for data collection, and UAS regulations will continue to evolve. NOAA will continue to provide guidance and policy oversight to all NOAA UAS operators by keeping NOAA line offices and partners up to date with new government regulations and proposed policy changes to ensure decisive strategic initiatives so that NOAA UAS are positioned to continue without a pause in operations.

Program success is built upon the drive and passion of NOAA's UAS pilots

Image 27: LT Chelsea Parrish(left) and LT Brandon Tao (right) are holding an APH-28, which was flown to survey Beluga Whales in Cook Inlet, AK. Photo: Tomo Eguchi/NOAA