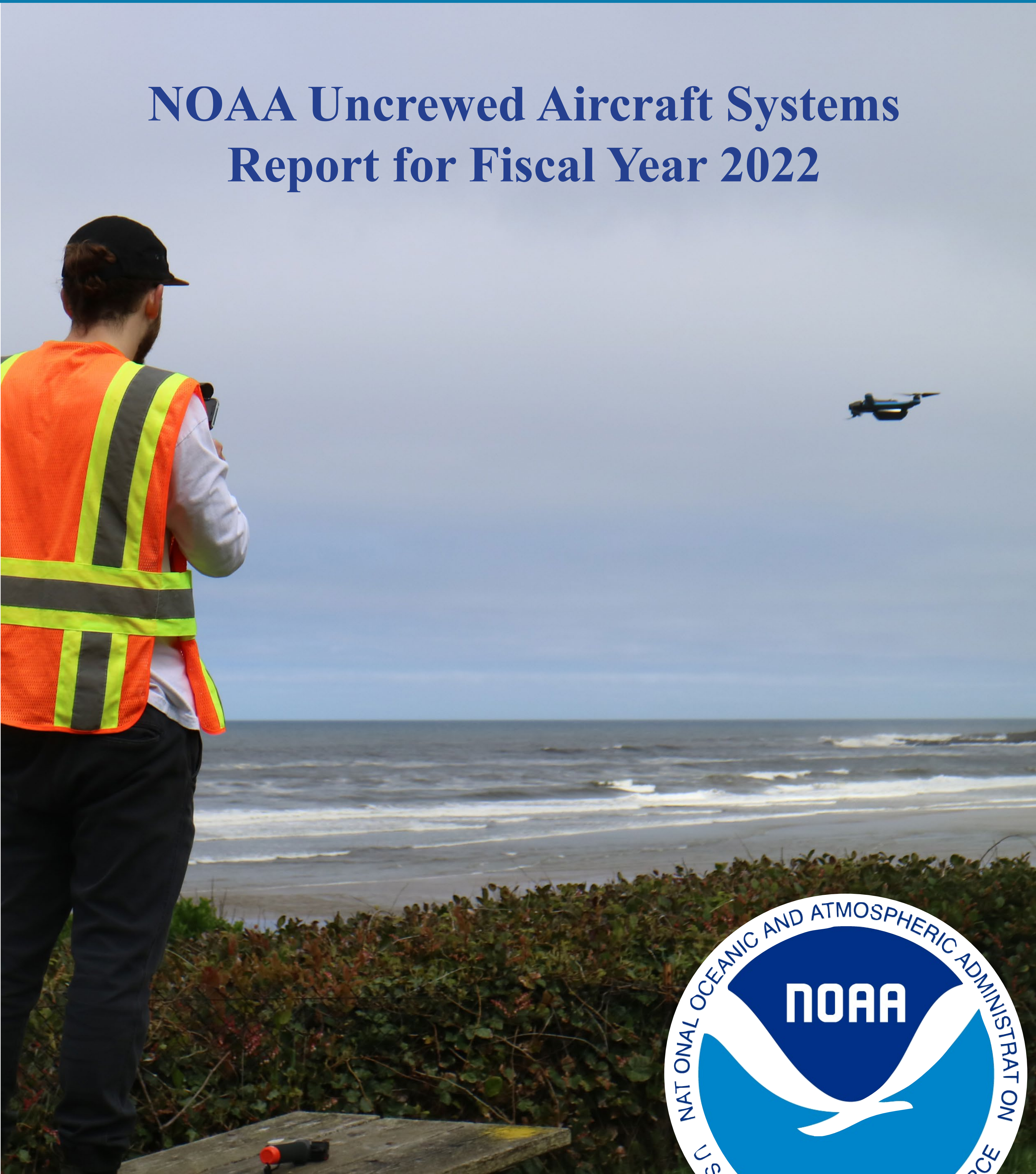
NOAA Uncrewed Aircraft Systems Report for Fiscal Year 2022



Forward

Dear Readers,

On behalf of the NOAA Uncrewed Systems Executive Oversight Board, we are pleased to present NOAA's Uncrewed Aircraft Systems (UAS) Annual Report for Fiscal Year (FY) 2022. Uncrewed Systems, and UAS specifically, are becoming vital tools in supporting NOAA's mission of science, service, and stewardship. NOAA is a leader in the innovative research and development of UAS to meet current and future observing and data collection requirements. UAS have vast potential to transform the way that NOAA meets its broad mission. However, it is only through ongoing efforts to research, develop, and transition these technologies into regular use throughout the Agency that we will realize this potential.

NOAA is continuing to develop UAS capabilities that are beginning to be applied to supplement traditional data acquisition methods. For example, NOAA flew over 1,000 UAS flight hours in FY 2022 which is enabling the transition of some UAS technologies into regular use in the Agency's diverse operations.

In FY 2022, the United States experienced devastating natural disasters ranging from tornadoes in Kentucky, hurricanes in the Southeast, wildfires on the West Coast, and ice jamming and flooding in Alaska. NOAA's efforts to examine the possible use of UAS to gather critical data on these events may one day inform weather forecasts, warning systems, and community recovery efforts. At the same time, NOAA is already using UAS to assess federally protected species and other societally valuable living marine resources and ecosystems. Throughout the year, NOAA continued to push the boundaries of UAS potential applications, flying UAS in diverse conditions and developing technological advances to meet NOAA's mission.

NOAA will continue to develop its UAS capabilities in support of science, service, and stewardship, while partnering with the nation's government, academic, and private sector leaders in uncrewed technologies. In doing so, we will foster innovation to benefit society and the environment.

This report highlights the breadth and depth of UAS-enabled work performed by NOAA. The development of UAS-enabled work and this report would not be possible without NOAA's dedicated workforce.

Very Respectfully,

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Rear Admiral Chad Cary & Gary Matlock, Ph.D.

NOAA Uncrewed Systems Executive Oversight Board Co-chairs

About the National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA), under the Department of Commerce, provides science, service, and stewardship to protect life, property, and Earth's natural resources. By collecting scientific data, NOAA provides daily weather forecasts, storm warnings, and climate monitoring; and facilitates fisheries management, marine commerce, and coastal restoration. NOAA Uncrewed Systems work is organized into Uncrewed Aircraft (UAS) and Uncrewed Marine Systems.

About the Uncrewed Systems Executive Oversight Board

The Uncrewed Systems Executive Oversight Board provides oversight of NOAA's UAS and Uncrewed Marine Systems efforts. It assures agency-wide strategies and initiatives are developed collaboratively and implemented consistently. It includes membership from across NOAA's line offices and reports to the NOAA Fleet Council. The Executive Oversight Board is co-chaired by the Office of Marine and Aviation Operations and Office of Oceanic and Atmospheric Research.

About the Uncrewed Systems Operations Center

The Uncrewed Systems Operations Center was established in Fiscal Year (FY) 2020, following receipt of funding to improve and expand Uncrewed Systems operations across NOAA. The Uncrewed Systems Operations Center sits within NOAA's Office of Marine and Aviation Operations and works to expand Uncrewed Systems applications, transition Uncrewed Systems into operational use, and provides corporate support to Uncrewed Systems operations. Within the Uncrewed Systems Operations Center sits the UAS Division that plays a central role in all NOAA UAS operations.

About the Uncrewed Systems Research Transition Office

The Uncrewed Systems Research Transition Office within NOAA's Office of Oceanic and Atmospheric Research works to leverage the abilities of Uncrewed Systems to improve NOAA's monitoring and understanding of the global environment. The Uncrewed Systems Research Transition Office focuses on the research, development, and transition of Uncrewed Systems technologies.

About the Annual Report

This Annual Report is an overview of the UAS work of NOAA in FY 2022. The information presented is structured to provide insight on NOAA UAS adoption, applications, and integration. This document was developed by the UAS Division with support from the Uncrewed Systems Operations Center.

Acknowledgements

This report was crafted by the UAS Division with support from the Uncrewed Systems Operations Center and the following: Sharon Mesick, Jessica Cherry, Jennifer Bowers, Michael Ondrusek, Eric Kihn, Sean Helfrich, Jim O'Sullivan, Patricia Quinn, Tim Bates, Bryan Cole, Derek Coffman, Kenneth Vierra, Trevor Joyce, Jefferson Hinke, David Detlor, Michael Gallagher, Martin Getrich, Rietta Hohman, Tim Battista, and Amy Uhrin.

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Cover Photo: A NOAA UAS operator pilots a UAS over a beach. Photo: National Centers for Coastal Ocean Science/NOAA

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Executive Summary

Uncrewed Aircraft Systems (UAS) have proven to be vital tools in enriching and expanding the science, service, and stewardship of NOAA in support of its broad mission areas. UAS serve as a force multiplier for NOAA-augmenting data collection at lower costs, increased safety, and reduced risk. UAS technology improves the collection of traditional scientific data while also providing novel and transformative means of data collection. This data supports NOAA's work in fisheries management, weather forecasting, disaster preparedness, and more. However, NOAA personnel are not simply users of UAS, but pioneers of UAS innovation as well. In Fiscal Year (FY) 2022, NOAA flew more UAS operations than any other year—16 percent more by flight time than in FY 2021. The FY 2022 UAS operations occurred in the upper reaches of the atmosphere and at the air-sea boundary. Flights took place from the Arctic to Antarctic, and across the United States. Over 1,800 flights were conducted using over 30 UAS platform types. In the coming years, NOAA will continue to utilize UAS, growing the benefit of the technology to NOAA, society, and the environment.

The UAS Annual Report is an overview of NOAA's UAS Program activities in FY 2022. It contextualizes NOAA's use of UAS across NOAA's six line offices:

- Office of Marine and Aviation Operations (OMAO)
- Office of Oceanic and Atmospheric Research (OAR)
- National Marine Fisheries Service (NMFS)
- National Weather Service (NWS)
- National Ocean Service (NOS)
- National Environmental Satellite Data and Information Service (NESDIS)

It also highlights the broader role of UAS in supporting NOAA mission areas. In order to support safe and efficient UAS use across NOAA, core services—including cyber security, training, and flight management—are provided by the Agency. These safety, security, and training facets of NOAA UAS work are reviewed in the report, with FY 2022 milestones noted. Additionally, analysis of NOAA's UAS usage in FY 2022 is included along with comparisons to past year's efforts.

Narratives from NOAA personnel can be found within this report that highlight the breadth and depth of science, service, and stewardship performed with UAS. NWS personnel safely and efficiently informed storm damage assessment reports of tornado, flooding, and ice jam events in Kentucky and Alaska. NESDIS worked in collaboration with the NWS to perform storm damage assessments and also explored the force multiplying potential of combining UAS and satellite-based datasets.

OAR pushed the boundaries of atmospheric sampling and UAS operational capacity with OMAO support. NMFS brought UAS to Antarctica in support of ecosystem based fisheries management. NOS explored the enhancement of kelp restoration mapping and marine debris detection via UAS. This is just a sample of UAS usage across NOAA missions.

This report is not an exhaustive file of NOAA's UAS work; however, it provides ample insight on NOAA UAS adoption, applications, and integration. The report's content is intended for the public, government officials, and other stakeholders in UAS.

Image 2: Researchers preparing to operate a Wingtra UAS. Photo: National Centers for Coastal Ocean Science/NOAA

Introduction

Uncrewed Aircraft Systems (UAS) technology is a critical tool for NOAA, and its importance to the Agency continues to increase each year. With the use of advanced technology, NOAA scientists are continuously improving traditional data collection methods to provide reliable information to citizens, planners, emergency managers, and decision-makers. Many NOAA programs pioneered the innovative use of UAS technology as a force multiplier — augmenting data collection at lower costs, increased safety, and reduced risk. NOAA's UAS use includes research and development efforts to test and evaluate new technologies that advance NOAA research, and transition cutting edge technology into operational use.

In Fiscal Year (FY) 2022, UAS operations flew more than in previous years (Figure 1), and the agency expects UAS utilization to continue to grow rapidly across NOAA. Data collection continues to rely on UAS technology not only in collecting traditional scientific data but by providing effective novel, transformative, and rapid response data. NOAA use of UAS is especially critical in remote and hazardous areas where traditional methods are limited. UAS operational support saves time and provides decision makers with fast reliable information. NOAA continues to value UAS technology as a growing economical and efficient tool to support and meet NOAA missions.

Image 3: A UAS operator flies a drone over a beach to survey marine debris. Credit: National Centers for Coastal Ocean Science/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 in table 1.

Table 1: UAS use and support within NOAA by line office.

Line Office	UAS Use and Support
Office of Marine and Aviation Operations (OMAO)	• facilitates across-NOAA projects to enhance UAS use. • executes UAS operations to support NOAA missions. • provides technical expertise to research missions. • provides UAS platform, and services to UAS users. • trains UAS operators and increases proficiency on UAS platforms. • operates UAS to evaluate platforms and integrate sensors. • tracks and manages NOAA UAS usage and resources. • transitions UAS into operational use across NOAA's broad mission space. • coordinates and ensures compliance with airspace regulations and protocol.
Office of Oceanographic and Atmospheric Research (OAR)	• supports across-NOAA UAS research and development. • develops and utilizes UAS to gather meteorological, atmospheric, and oceanic information in research laboratories and program offices. • tests and evaluates the use of UAS platforms and architecture to collect scientific data to understand complex systems that support Earth. • gathers data and transitions in into societally useful tools. • supports the transition of UAS into operational use across NOAA's broad mission space.
National Marine Fisheries Services (NMFS)	• tests and evaluates the use of UAS platforms to assess and manage living marine resources and their habitat. • gathers data on living marine resources and incorporates it into the fisheries and protected species management processes. • deploys UAS to increase safety and efficiency, and to reduce cost of fisheries and protected species surveys. • assesses marine mammal and endangered species populations through low disturbance surveys.

Line Office	UAS Use and Support
National Ocean Service (NOS)	• uses existing UAS capabilities to collect coastal and shoreline habitat data for incorporation into analytical tools. • develops procedures and protocols for UAS use during emergency response scenarios. • gathers data for coastal and habitat mapping projects. • enhances remote sensing for habitat mapping and characterization. • improves data models and visualization tools for managers through UAS-data incorporation. • collects data with minimal disturbance in national marine sanctuaries and national monument. • surveys open waters for marine debris and marine wildlife. • identifies and locates marine archaeological sites. • supports enforcement efficiency in highly-protected reserves.
National Weather Service (NWS)	• demonstrates the utility of UAS for weather event surveying (tornado, flooding, ice events, etc.) and other operations. • gathers pre- and post-weather event data. • performs maintenance inspections of NOAA equipment and property.
National Environmental Satellite, Data, Information Services (NESDIS)	• enhances acquisition of global environment data to support the environment, security, and economic quality of life. • reduces human exposure to extreme environmental conditions. • calibrates and validates satellite derived records. • provides high-resolution and site-specific data to replace and augment satellite data. • gathers data and incorporates it into predictive models, historic reconstructions, and other products.

Overview of FY 2022 NOAA UAS Adoption, Application, and Integration

NOAA tracks and quantifies all UAS operations within the Agency. This is conducted by the UAS operator with support from the UAS Division. The UAS Division then compiles and analyzes collected data to determine trends and patterns for UAS decision making and to quantify how NOAA uses UAS platforms. Collected metrics include the following: basic project information (date, offices involved), personnel and project type, flight information (UAS platform, payload, flight time, and landings), airspace authorization, and mission description (location, comments, and images). Those metrics are summarized in this report to highlight flight time by fiscal year, region, line office, program, mission, and UAS platform.

In FY 2022, the UAS Division gathered data on over 60 unique projects; over 21,000 minutes of operational flight, and over 1,800 UAS flights. They also supported the preparation of countless UAS operations. This data is shared with NOAA leadership, partners and operators.

Flight Time by Fiscal Year

NOAA continues to expand the collection and utilization of critical, high-accuracy, and time-sensitive data through the application and use of UAS. Scientists continue to rely on UAS technology to collect data in some of the harshest and most remote environments in the world. UAS use continued to grow in FY 2022 as a favored tool by scientists, with more time flown than any previous year (Figure 1). Over 21,900 minutes of flight time were logged by NOAA UAS users in FY 2022, 16 percent more than in FY 2021 and 50 percent more than FY 2018.

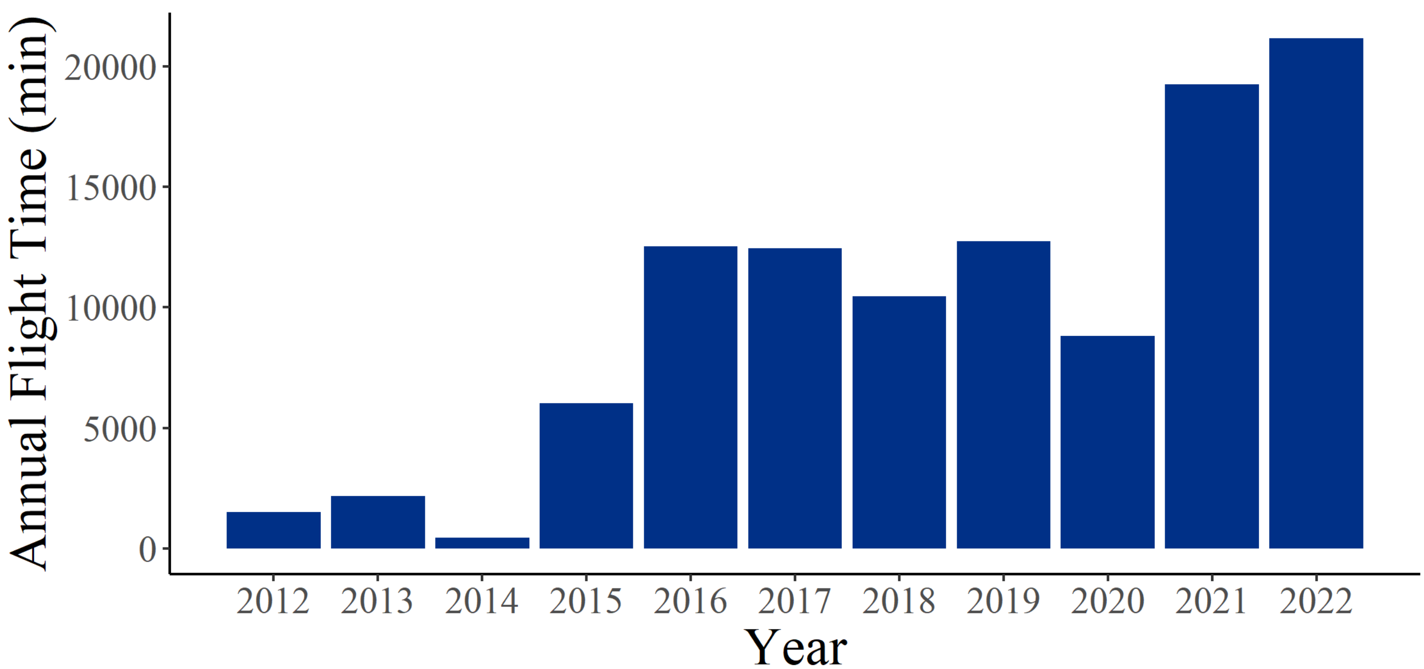

Figure 1: Flight time in minutes by NOAA UAS users from 2012 to 2022.

Flight Time by Region

NOAA UAS operations were planned across the United States, U.S. Exclusive Economic Zone, and in some areas internationally (i.e., Antarctica). Operations were planned in 41 states (Figure 2) with flights occurring in 22 of those states (Figure 3). Places in which operations were planned, but did not occur include regions that may require rapid response to storms or other emergency scenarios, and where UAS data collection was planned but not funded. Highest flight times were logged in Washington, Oregon, Alaska, and Florida. High flight time on the West Coast and Alaska can be attributed to the federally mandated surveys in the regions that occur using UAS. The west coast and Alaska host numerous marine mammal and seabird species that require population assessments. As the UAS Division is based out of Lakeland, FL, high flight time in Florida may be associated with training and testing of UAS there.

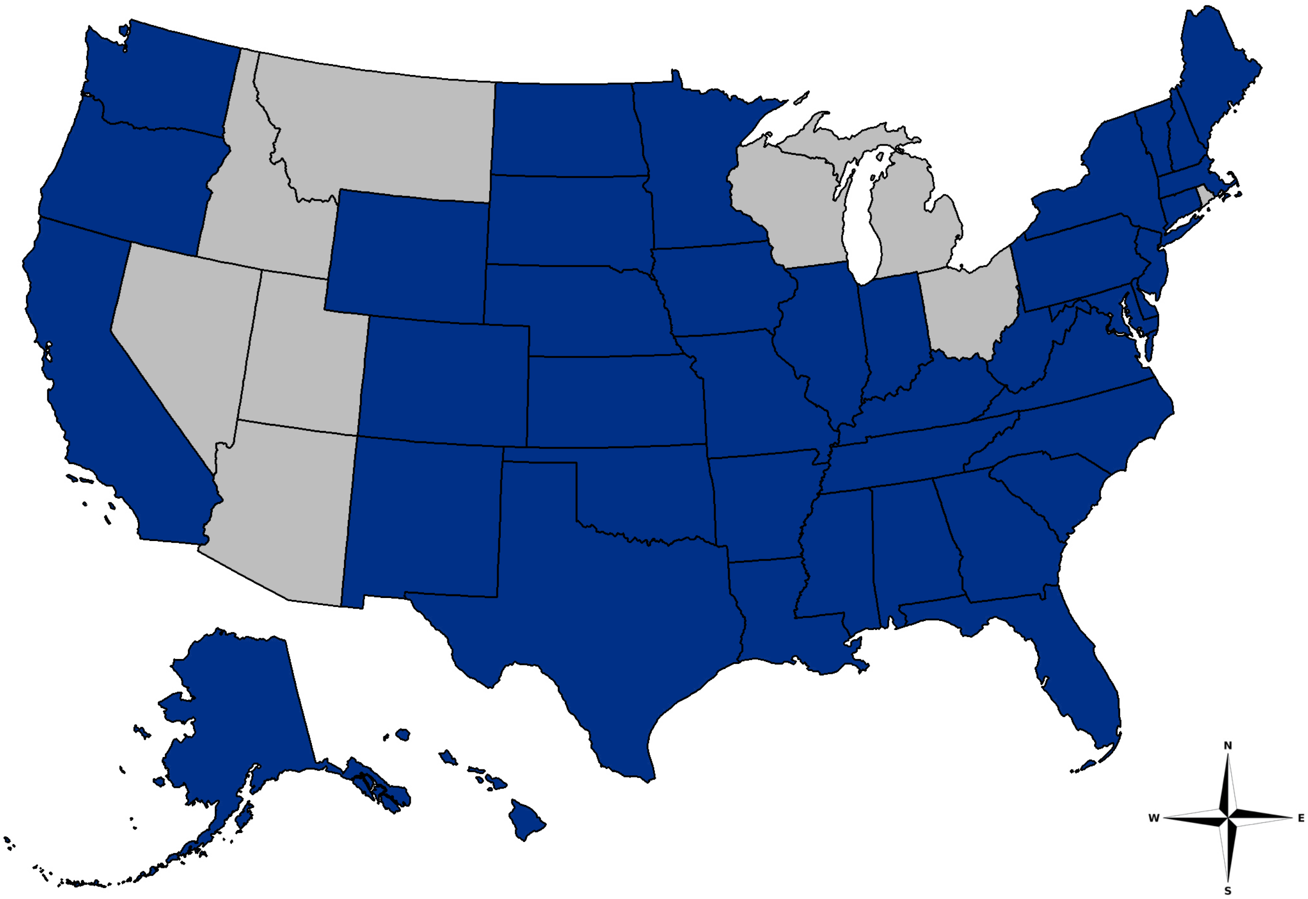

Figure 2: A map of planned NOAA UAS flight operations in the United States in FY 2022. Blue shaded regions indicate states where NOAA UAS operations were planned, while gray shaded regions are states where operations were not planned.

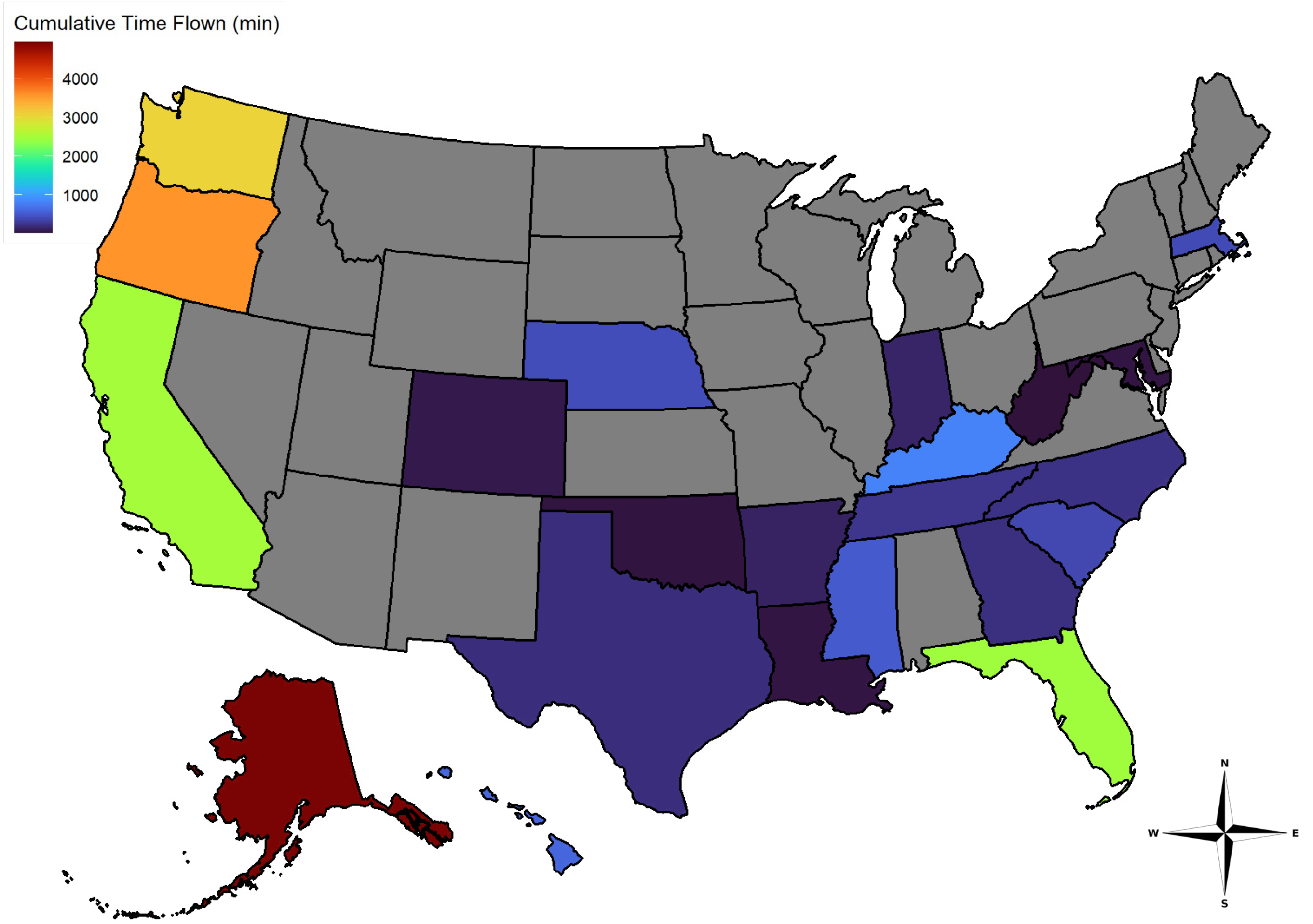

Figure 3: A map showcasing the flight time of NOAA UAS in minutes during FY 2022 per state. Warmer colors indicate more flight time in a region, while cooler colors indicate less flight time. Gray regions represent states where no NOAA UAS flight time was recorded.

Flight Time by NOAA Line Office

UAS were used across all NOAA line offices in FY 2022 (Figure 4). Details of how various line offices and their programs used UAS to support NOAA missions can be found in the NOAA Program FY 2022 Highlights section of this report. In FY 2022 NESDIS performed its first UAS operations, and OMAO nearly doubled their flight time compared to FY 2021. In FY 2022, NMFS flew more than 50 percent of all NOAA UAS flights and made up more than 60 percent of NOAA UAS flight time.

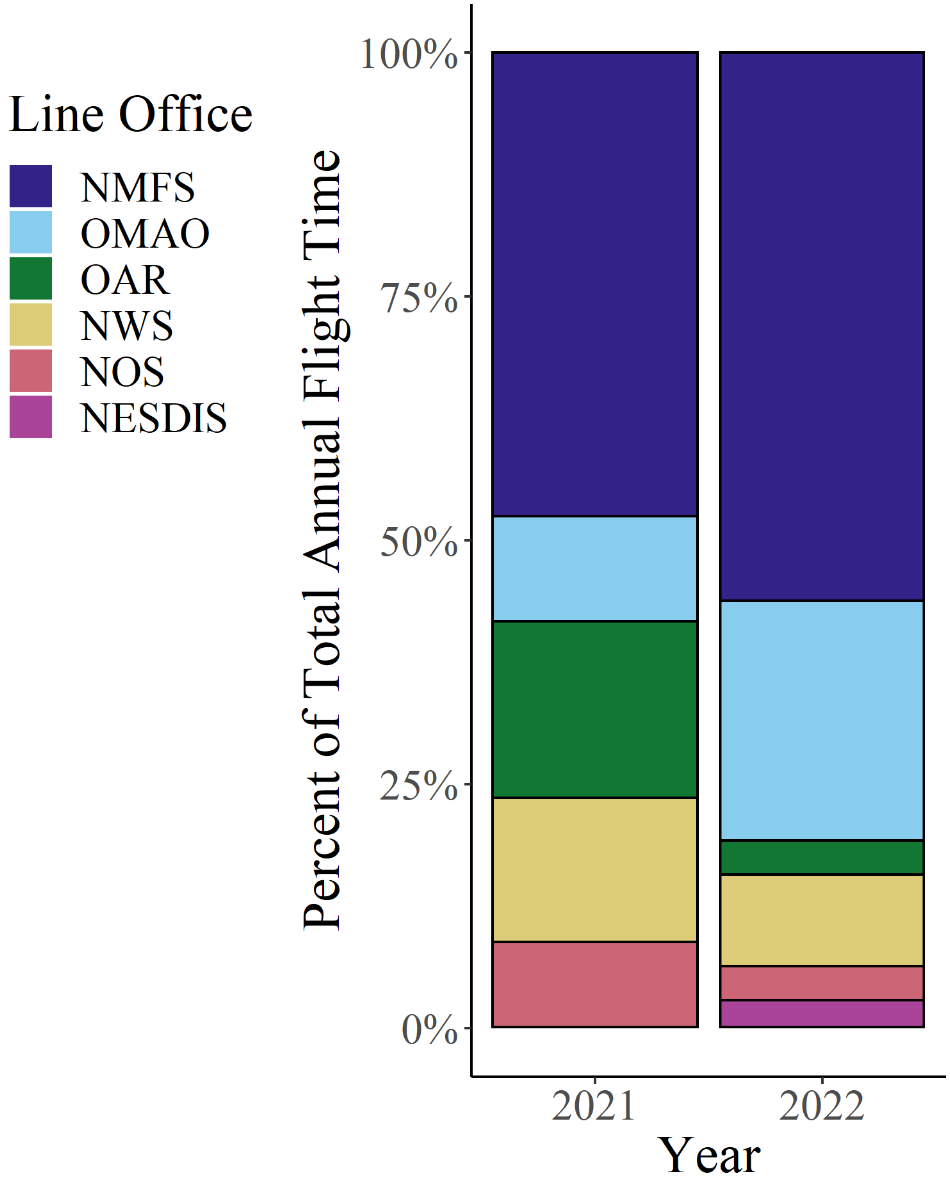

Figure 4: Percentage of total NOAA UAS flight time per Line office in FY 2021 compared to FY 2022.

Flight Time by NOAA Program

Within NOAA's line offices are a diverse suite of program offices, field offices, divisions, and operational centers. Different programs within a single line office may use UAS differently to support a different NOAA mission area. For example, within NWS, Weather Forecast Offices are using UAS to perform storm damage surveys while NWS Regional Headquarters are exploring the use of UAS to assess NOAA equipment and property. Both these applications of UAS support NWS's vision of a weather-ready nation and other broad NOAA missions. Collectively, over 17 unique programs and divisions used UAS to complete their duties (Figure 5).

In FY 2022, NMFS Regional Fisheries Science Centers performed a significant amount of flight time, with the Southwest Fisheries Science Center completing more flight time than any other NOAA program or office. Marine Mammal Laboratories and NOAA's UAS Division also performed a significant amount of flight time in FY 2022. Southwest Fisheries Science Center and Marine Mammal Laboratories flight time is often associated with aerial animal surveys, while UAS Division flight time is often attributed to training UAS operators and testing platforms. Variability in flight time between FY 2021 and FY 2022 across offices may be a byproduct of a reduced demand for UAS operations (e.g., less events requiring UAS surveys occurred in one year over another), or a reallocation of available UAS resources (e.g., programs finished or started a funded project period between years).

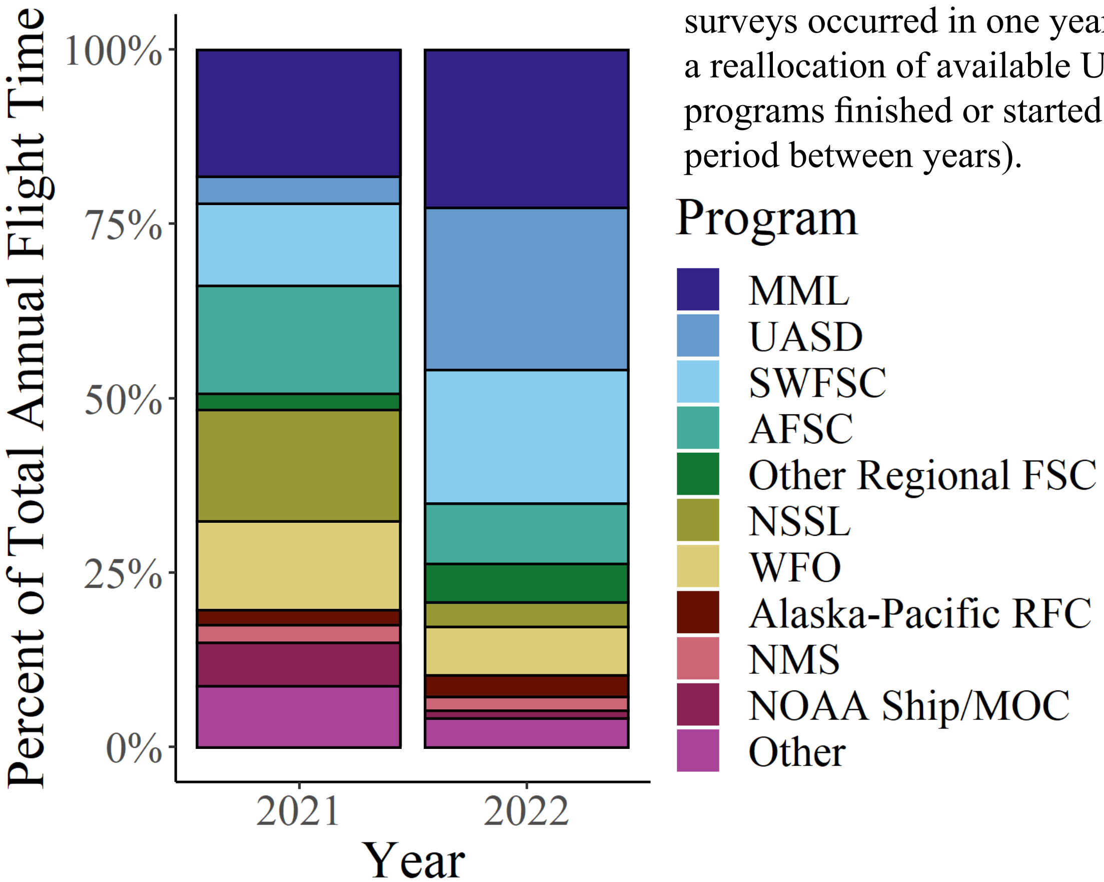

Figure 5: Percentage of total NOAA UAS flight time per Program in FY 2021 compared to FY 2022.

Acronyms: MML—Marine Mammal Lab, SWFSC—Southwest Fisheries Science Center, AFSC—Alaska Fisheries Science Center, FSC—Fisheries Science Center, NSSL—National Severe Storms Lab, WFO—Weather Forecast Office, NMS—National Marine Sanctuaries, MOC—Marine Operations Center

Flight Time by Mission

NOAA UAS operators employ UAS technology in varied ways to support NOAA mission areas (Figure 6). In FY 2022 a significant amount of flight time went towards animal surveys, hydrology and mapping surveys, and testing and training of new UAS and UAS users. Animal surveys often include aerial population assessments of marine mammal and seabird populations. Population assessments of many surveyed species are required under the [Marine Mammal Protection Act] and [Endangered Species Act]; however, many of these populations live in remote, hazardous, or hard-to-access environments. UAS provide an efficient and safe tool to augment present surveys or gather data where crewed vehicles cannot get to.

The high percentage of flight time associated with training and aircraft/payload testing may be connected to the continued increase in UAS operations within NOAA. Testing and training is critical to continue to increase the UAS proficiency of the NOAA workforce and to be innovative in addressing data needs. NOAA also provides UAS expertise and data to other federal and state agencies, state and local governments, tribal groups, and non-government groups when requested. For example, flight time for storm damage surveys has supported Federal Emergency Management Agency (FEMA) natural disaster relief efforts. Similar to the variability observed in flight time between FY 2021 and FY 2022 across programs, variability in flight time associated with different project types between the two years may be attributed to demand or a reallocation of available UAS resources.

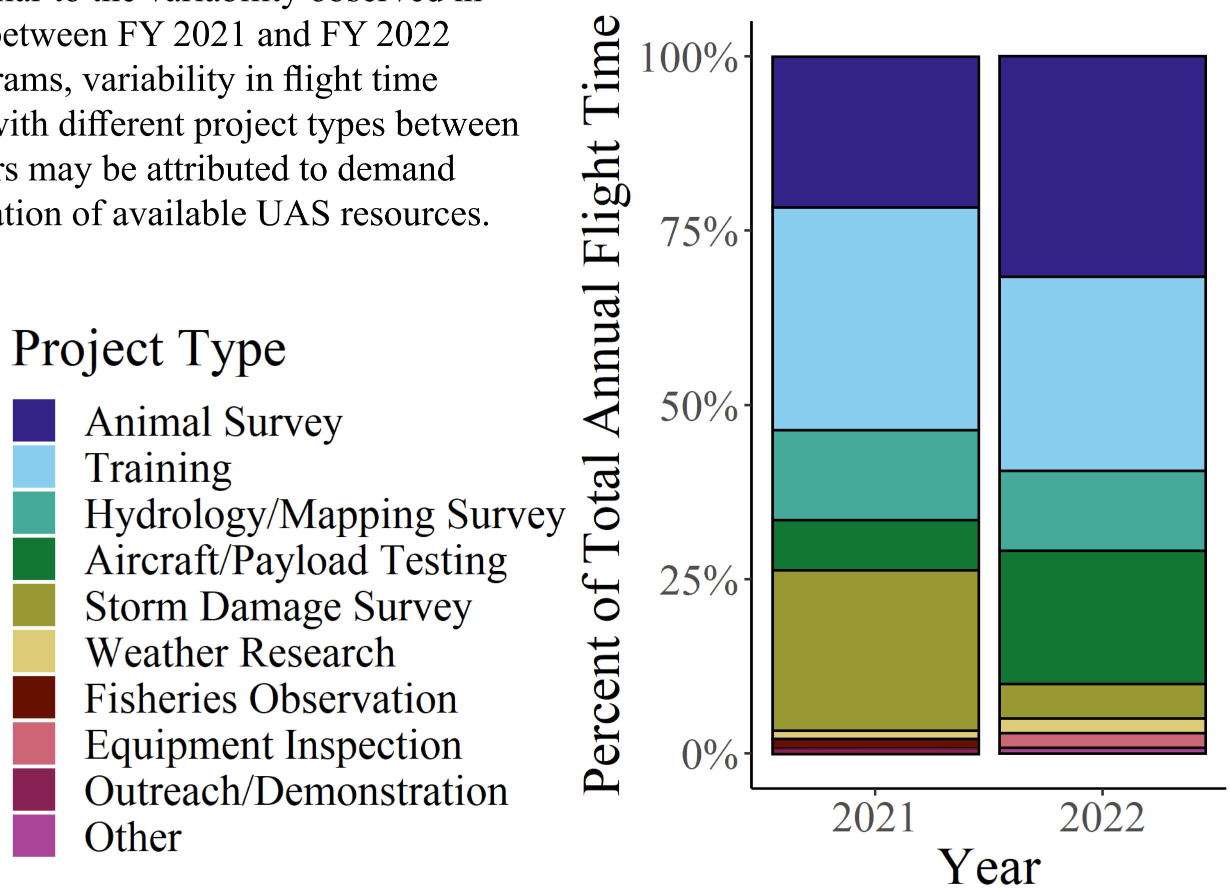

Figure 6: Percentage of total NOAA UAS flight time by mission areas in FY 2021 compared to FY 2022.

Flight Time by Platform

There are numerous UAS platforms on the market and different variables influence UAS platform preference across NOAA. NOAA UAS user platform types range from off-the-shelf commercial platforms to custom designed systems that fulfill a specific mission. Some manufacturers produce multiple platforms while others focus on a single UAS design. Others are affordable and lend themselves to fulfilling a variety of purposes. Most vary to some degree in size, endurance, payload capabilities, and wing type. Such variables affect decisions on UAS platform choice.

For example, the FVR-55 was developed for NOAA atmospheric sampling by a private-sector partner through the NOAA [Small Business and Innovation Research awards]. NOAA UAS use is also migrating towards U.S.-based companies. NOAA personnel used over 30 unique UAS platforms produced by over 15 unique manufacturers in FY 2022 (Figure 7, Figure 8). DJI produced the most used platforms; however, fewer operations were performed in FY 2022 then in FY 2021 using DJI products. This change in use may be attributed to attempts to align with future federal requirements to use U.S.-based UAS components as DJI is a foreign manufacturer. The high amount of flight time put in on the FVR-55 platform in FY 2022 can be attributed to a 10 day research cruise in FY 2022, in which NOAA researchers were able to conduct fully autonomous shipboard operations of the UAS with a full payload of scientific equipment.

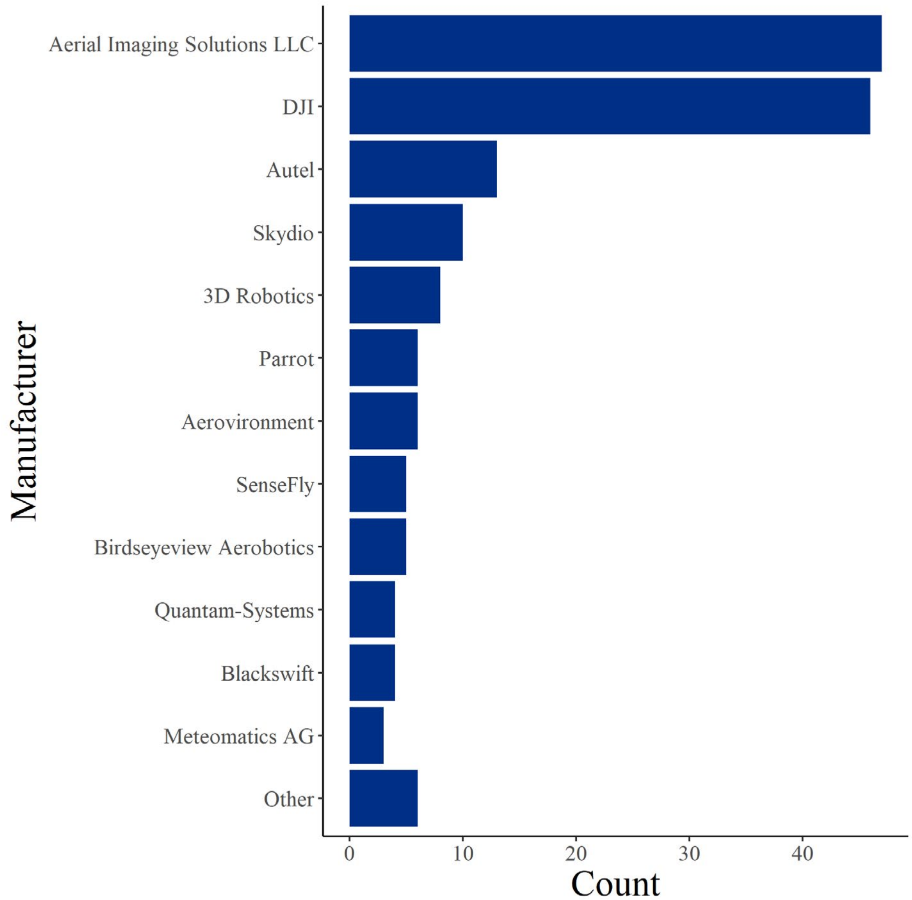

Figure 7: Number of UAS owned by NOAA of different manufacturers in FY 2022.

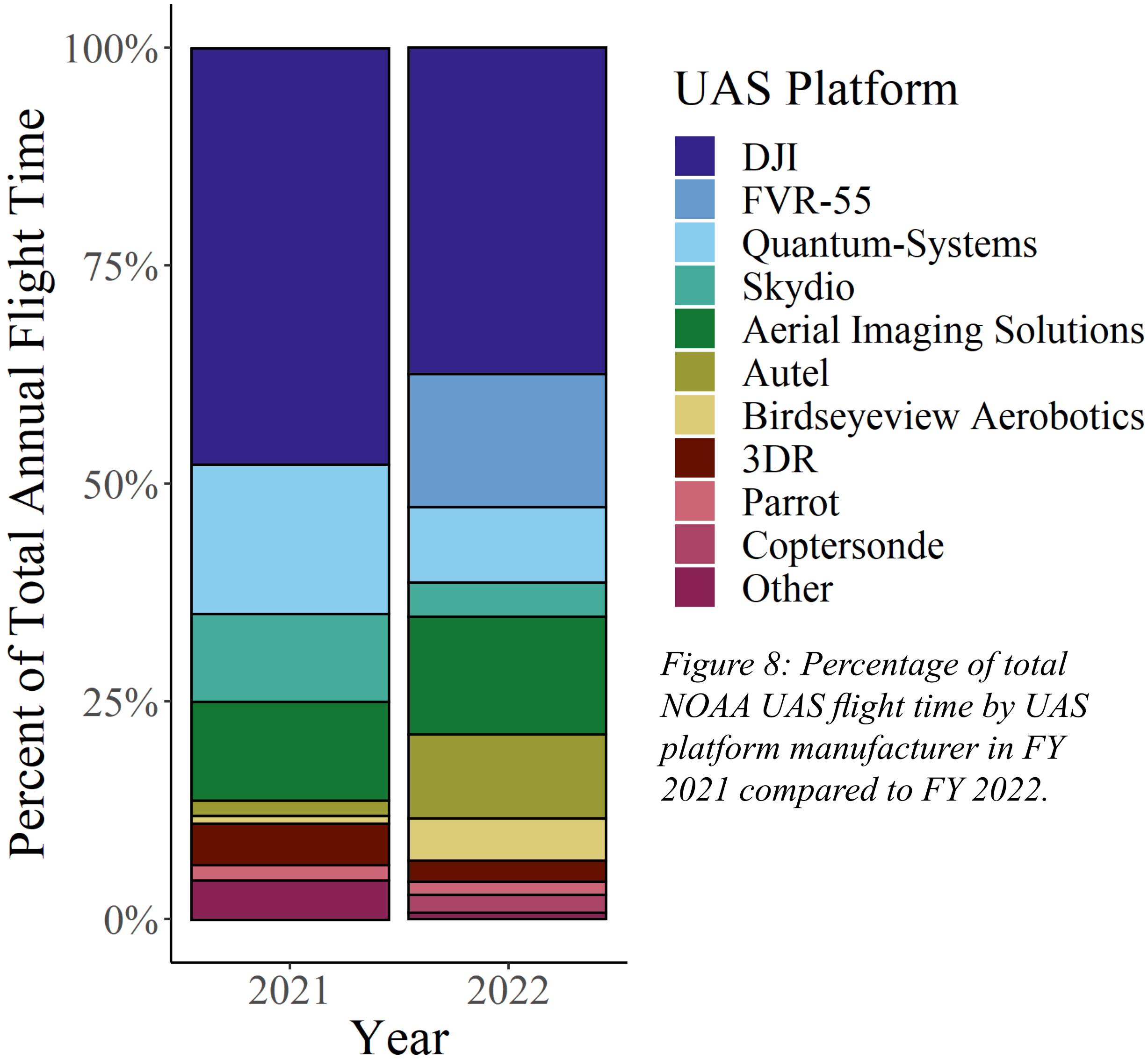

Figure 8: Percentage of total NOAA UAS flight time by UAS platform manufacturer in FY 2021 compared to FY 2022.

UAS Corporate Services

The UAS Division within OMAO's Uncrewed Systems Operations Center provides core services for all NOAA UAS operations and centralized support to ensure safe, cost-effective and compliant operations of UAS by NOAA. These core services include the following: operations coordination, cyber security, safety considerations, training, and curriculum development.

Operations Coordination

NOAA's UAS Division oversees the operations of UAS across all six NOAA line offices. The UAS Division ensures adherence to federal and state regulatory guidance by vetting operations through a standard and non-standard approval process. They work closely with agencies like the Federal Aviation Administration (FAA) to enable NOAA UAS operations across distinctly different areas of responsibility within the National Airspace System. In addition to promoting safe and responsible UAS activity, the UAS Division collaborates with industry partners to incorporate technological advancements and best practices to support NOAA's missions of environmental understanding, conservation, and resource management.

Cyber Security

As with any computer or IT system, UAS pose certain cyber security risks that require effective management. While the cyber security risks of data collected by NOAA are mitigated by the public and non-sensitive nature of the data, NOAA is working to consider best UAS cyber security practices. NOAA has established an Uncrewed Systems Cyber Working Group to develop policies and procedures for UAS cyber security. These policies encompass various aspects such as UAS component procurement, physical isolation of specific UAS from government computer networks, and data encryption.

The Uncrewed Systems Cyber Working Group comprises all NOAA line office IT Security Officers as voting members and operates under the guidance of the NOAA Uncrewed Systems Executive Operations Board with the participation of the NOAA Office of the Chief Information Officer. The Uncrewed Systems Cyber Working Group has devised Cyber Security Principles for UAS that are primarily based on, and consistent with, the Cyber Security Best Practices for Operating Commercial Unmanned Aircraft Systems set forth by the Cyber Security and Infrastructure Security Agency of the Department of Homeland Security.

Image 4: UAS Division personnel lead classroom event on NOAA UAS work. Photo: UAS Division/NOAA

Safety Considerations

Operators of NOAA UAS are required to receive flight authorization from the UAS Division to confirm compliance with NOAA and FAA regulations. The UAS Division conducts Operational Risk Management assessments to identify and mitigate potential risks associated with UAS operations. The primary aim of these assessments is to enhance the safety and success of NOAA UAS missions. All NOAA UAS projects undergo an Operational Risk Management evaluation, which covers various types of operations including those from shore, ship, small boat, high altitude, Beyond Visual Line of Sight, and launch and recovery operations. In unique UAS operation cases, addendums and project specific assessments are added to the Operational Risk Management evaluation.

The Operational Risk Management assessment process identifies hazards that exist for all UAS operations with risk control measures implemented to reduce the level of risk. The control measures are continually reviewed and evaluated to improve the safety of NOAA UAS operations.

Image 5: The UAS Division Instructor trains NOAA personnel on flying a UAS. Photo: UAS Division/NOAA

Training and UAS Curriculum Development

To meet UAS operator requirements and enhance the proficiency of the NOAA UAS workforce, the UAS Division developed a comprehensive training curriculum for across-NOAA use. Under this curriculum, UAS Division conducted 59 days of training in FY 2022. The UAS Division trained personnel on four platforms: 3DR Solo, Autel Evo II, DJI Matrice 600, and Parrot Anafi. This training enhanced the proficiency of 28 newly trained UAS operators. Additionally, the UAS Division developed a range of modules tailored to NOAA's specific missions which included certifications and hands-on training in the field. Providing customized training programs that cater to the unique requirements of NOAA's mission areas saves government resources.

NOAA Program FY 2022 Highlights

The following seven narratives were contributed by UAS users across NOAA to highlight the breadth and depth of work conducted using UAS within NOAA. Each narrative highlights different UAS uses, UAS platforms, and NOAA programs to support different NOAA missions.

Deployed into the eye of Hurricane Ian with Altius UAS

Author: Laura Chaibongsai—Office of Oceanic and Atmospheric Research, Atlantic Oceanographic and Meteorological Laboratory

NOAA hurricane researchers have added a new tool to their toolbox. For the first time, an Area-I Altius-600 UAS was deployed into a hurricane by scientists at NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) while onboard a NOAA WP-3D Orion hurricane hunter aircraft (N42RF, "Kermit").

Image 6: Altius demonstration model with Hurricane Hunter, NOAA WP-3D Orion "Miss Piggy," at NOAA's Aircraft Operations Center in Lakeland, FL during the second UAS flight test window on May 25, 2022. Photo: NOAA

This UAS is capable of operating in low- and medium-altitude maritime environments—areas of the storm too dangerous for humans to go—and features a range of 275 miles while traveling at speeds of up to 100 miles per hour. The UAS, which is designed with an airframe that can handle considerable damage, has its actions controlled through onboard programming and/or by aircraft-based operators. In September 28, 2022, the hurricane hunters transected Category 4 Hurricane Ian during a period of rapid intensification (AOML later on determined it to be a Category 5). Despite extreme turbulence, the crew successfully launched the 27 pound UAS, which then completed a two-hour mission, acquiring critical measurements to understand these complex storm systems.

Upon release, the uncrewed aircraft deployed its 8-foot wingspan and acquired a center fix on the eye of the hurricane at 4,500 feet. It then dropped to 3,000 feet within the eye to collect temperature, pressure, and moisture values. The crew then directed it into the eyewall where it completed a series of circumnavigations at different altitudes. At less than 2,300 feet above the sea surface the UAS recorded winds over 187 knots (216 miles per hour), and at one point even descended to as low as 200 feet above the sea surface.

In extreme environments, like hurricanes, operators are limited by the ability to deploy instrumentation safely.

Fixed systems, like weather stations and buoys, collect data at ground level. Saildrones and gliders provide tracking data at and below the ocean surface, while hurricane hunter aircraft provide a mobile look from the upper levels of the atmosphere. Dropsondes released from aircraft gather high-resolution data along a vertical path, and weather balloons provide the same, but rising from the ground into the atmosphere.

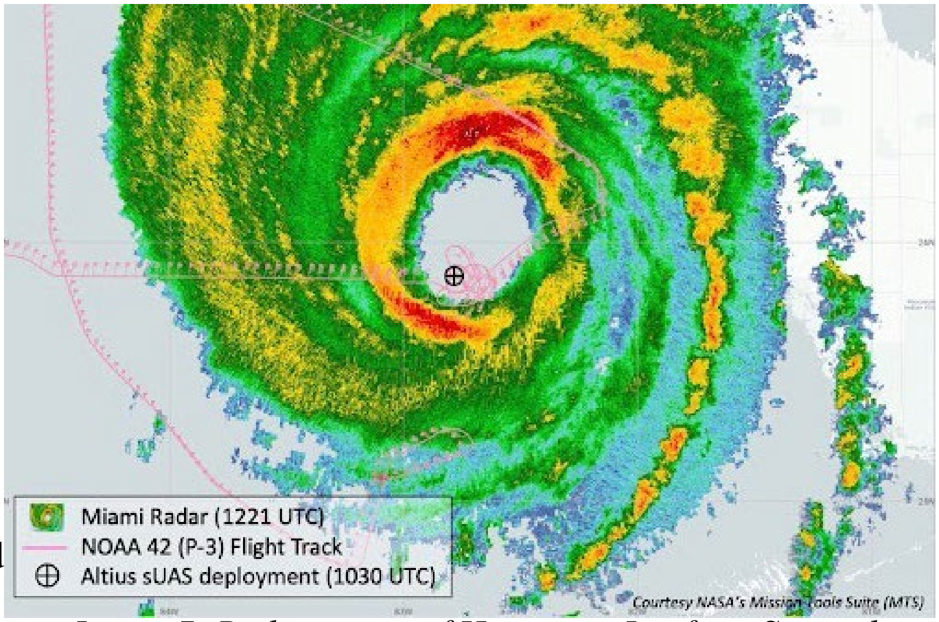

Image 7: Radar image of Hurricane Ian from September 28th showing the NOAA P-3's flight track and the location of the Altius-600 deployment within the eye. Photo: AOML/ NOAA

Drones, such as the Area-I Altius-600, can dive into the storm and have the ability to track along lower altitudes.

Scientists at the National Hurricane Center, Environmental Modeling Center, and Hurricane Research Division at AOML are now using the datasets provided by these new UAS to better understand the extremely turbulent hurricane boundary layer environment. This ability, coupled with other observing systems, helps clarify how these tropical systems function.

Missions like these help improve the accuracy of future hurricane models by understanding the storm's track, intensity, and structure. This information also helps NOAA improve the safety of operations and target future research more precisely.

Assessment of Aerosols' Impacts on the Earth's Radiation Budget with UAS

Author: Trish Quinn—Office of Oceanic and Atmospheric Research, Pacific Marine Environmental Laboratory

For over three decades, NOAA's Pacific Marine Environmental Laboratory (PMEL) has made shipboard observations of atmospheric properties. This global ocean data set has been used by atmospheric researchers to validate and improve chemical transport and climate models and satellite-derived products. In 2016, with a NOAA Phase I and II Small Business Innovation Research award, PMEL began a collaboration with Latitude Engineering (now part of L3Harris Technologies) to develop a UAS for shipboard launch and recovery.

Image 8: FVR-55 in flight. Photo: PMEL/NOAA

The impetus was to add vertical profiles of aerosol and cloud properties to the shipboard surface measurements to fulfill OAR's mission to conduct "research to understand and predict the Earth System" and to conduct the NOAA-wide mission of "understanding and predicting changes in climate, weather, oceans, and coastal regions." In addition, the proposed work fulfills the 2020 congressional mandate for NOAA to lead a multi-year research initiative, the Earth Radiation Budget program, and to investigate natural and human activities that might alter the reflectivity of the low-level marine clouds. Although many of the research cruises conducted by PMEL had a crewed aircraft component, the addition of a UAS launched from a ship provides more flexibility with ship personnel being in control of the timing and frequency of flights at a lower cost.

L3Harris developed a fully autonomous Fixed Wing Vertical Takeoff and Landing Rotator (FVR-55) UAS capable of carrying a 13 pound payload, with an altitude ceiling of 10,000 feet, and an endurance of up to 4.5 hours (Image 7). This meant the UAS could take off vertically from a platform on a ship and hover in place like a helicopter, but also fly like a plane at high altitudes for long periods of time. Although the original plan was for the FVR-55 to have a take-off weight of 55 pounds so that it could be classified as a small UAS under FAA guidelines, its total weight was approximately 62 pounds including the plane itself, fuel, and payload. As a result, the PMEL and L3Harris team submitted for and acquired an FAA waiver to fly the fully equipped FVR-55.

Over the past decade, PMEL has developed two payloads, Clear Sky and Cloudy Sky. The Clear Sky payload is designed to assess aerosol direct radiative forcing and includes measurements of aerosol particle number concentration, size, composition, light absorption, and aerosol optical depth. The Cloudy Sky payload is designed to assess aerosol-cloud interactions and has instruments to measure aerosol and cloud drop number concentration and size.

The first shipboard flights (eight in total) with payloads onboard took place offshore of Key West, FL from a TowBoatUS vessel in March of 2022. Flights lasted one to three hours and included either the Clear or Cloudy Sky payload. The landing accuracy was less than or equal to 2.8 feet. This mission demonstrated the successful, fully autonomous shipboard operation of the FVR-55 with payloads. Unfortunately, the flight authorizations in place limited flights to line of sight and below 1,200 feet, which was below cloud height.

The first science flights of the FVR-55 in marine stratocumulus clouds were conducted from the Tillamook UAS Test Range near the coast of Oregon. The flight authorization in place allowed flights up to 10,000 feet over the airport and in offshore warning areas, although a chase plane was required to escort the UAS to the warning areas. Fourteen flights were conducted with the Clear or Cloudy Sky payload, and over the airport or the offshore warning areas (up to 24 nautical miles from the airport). Flight times ranged from two to four and a half hours. The team tested the placement of the UAS-flight personnel at the beach or airport control tower to explore operationality of the system.

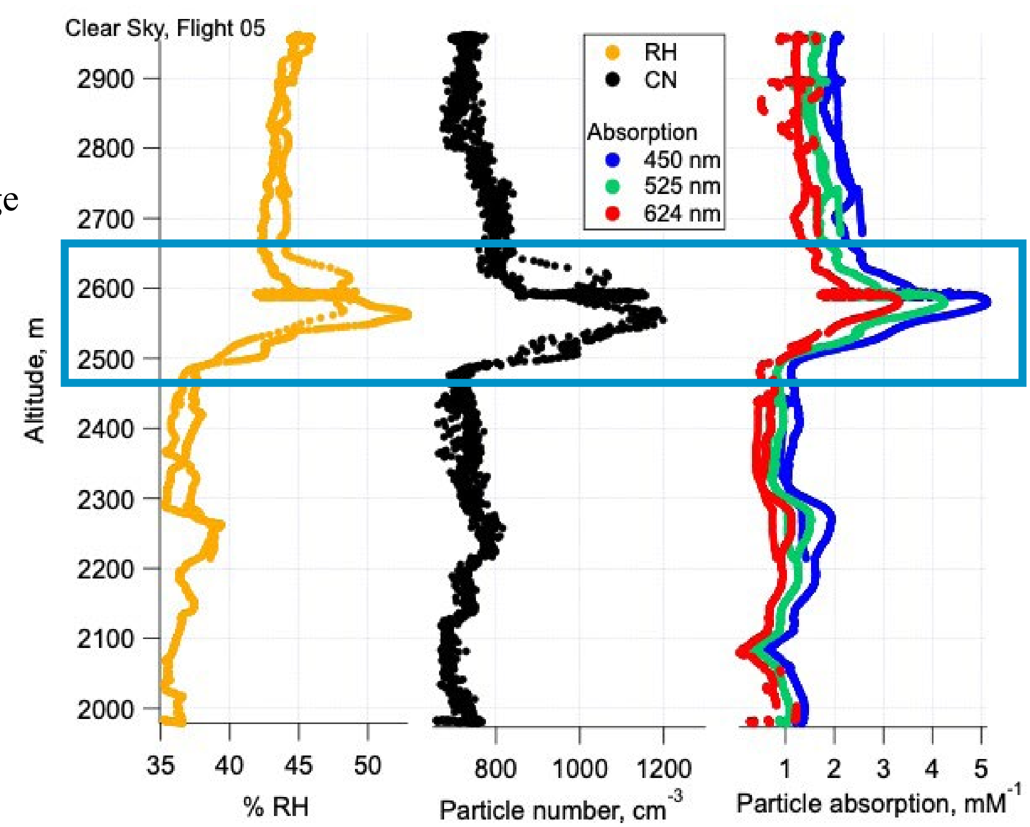

Figure 9: Samples from FVR-55 science flights with the Clear Sky payload. Spike in measurements at 8,500 feet (2,550 meters) indicate a fire plume detected in samples (highlighted in blue box). Measurements include relative humidity (RH, yellow line), particle number concentration (CN, black lines), and light absorption at three wavelengths (blue, green, and red lines).

Science results of note include the detection of fire plumes approximately 8,500 feet above sea level (Figure 9). The results also show strong correlations between particle number concentration and cloud drop size for low altitude clouds for all cloud liquid water contents sampled. The correlation for high altitude clouds is not as clear and warrants further investigation.

Next steps include switching from the FVR-55 to a larger UAS (FVR-90) to allow for added instrumentation and flight durations of up to 10 hours. Instrumentation to be added to the payloads includes a full particle sizing system (20 nanometer to 3 micrometer particle diameter) and upward and downward radiometers. These additions will improve assessments of connections between aerosol number and size, cloud drop radius, and cloud albedo. A second campaign at the Tillamook UAS Test Range is planned for summer 2023.

First Beyond Visual Line of Sight UAS Mission to Map and Count Penguins in Antarctica

Author: Trevor Joyce—National Marine Fisheries Service, Southwest Fisheries Science Center; Jefferson Hinke—National Marine Fisheries Service, Southwest Fisheries Science Center/ Antarctic Ecosystem Research Division

Image 9: Preparing the FireFly 6 Pro UAS for mapping missions over Adelie and Gentoo penguin colonies. Photo: SWFSC/NOAA

A key mission of the Antarctic Ecosystem Research Division (AERD) at NOAA Fisheries' Southwest Fisheries Science Center (SWFSC) is to develop an understanding of how the international krill fishery operating in Antarctic waters may impact other Antarctic wildlife that consume the main target of this fishery: Antarctic krill (*Euphausia superba*). Three species of brush-tailed penguins (*Pygocelis spp.*), nesting in the South Shetland Islands off the Antarctic Peninsula, primarily or exclusively consume Antarctic krill. Over the last three decades, AERD scientists have monitored the number of penguin chicks raised each year by Adelie (*Pygocelis adeliae*), Gentoo (*Pygocelis papua*), and Chinstrap (*Pygocelis antarcticus*) penguins, which is one important indicator of how these populations are responding to natural variability and to the impacts of the krill fishery.

During this project Dr. Trevor Joyce, a contractor affiliated with the SWFSC's Marine Mammal and Turtle Division, and Dr. Jefferson Hinke from AERD flew a series of UAS missions at AERD's Copacabana Field Camp on King George Island, Antarctica (lat. 62°10'41" S, long. 58°26"46' W) using the FireFly6 Pro Fixed Wing Vertical Takeoff and Landing UAS (Image 8). The purpose of these flights was to collect very high-resolution aerial images (0.7–1.2 centimeter ground sampling resolution) of the penguin colonies in order to count the number of penguin chicks produced in the current breeding season . A UAS census approach has the potential to achieve more precise counts of penguin chicks compared to traditional "boots-on-the-ground" counting methods by minimizing "skipping" and "double-counting" errors that become unavoidable when manually counting large aggregations of animals. UAS flights also cause little to no disturbance of penguin colonies compared to human researchers moving through the colonies.

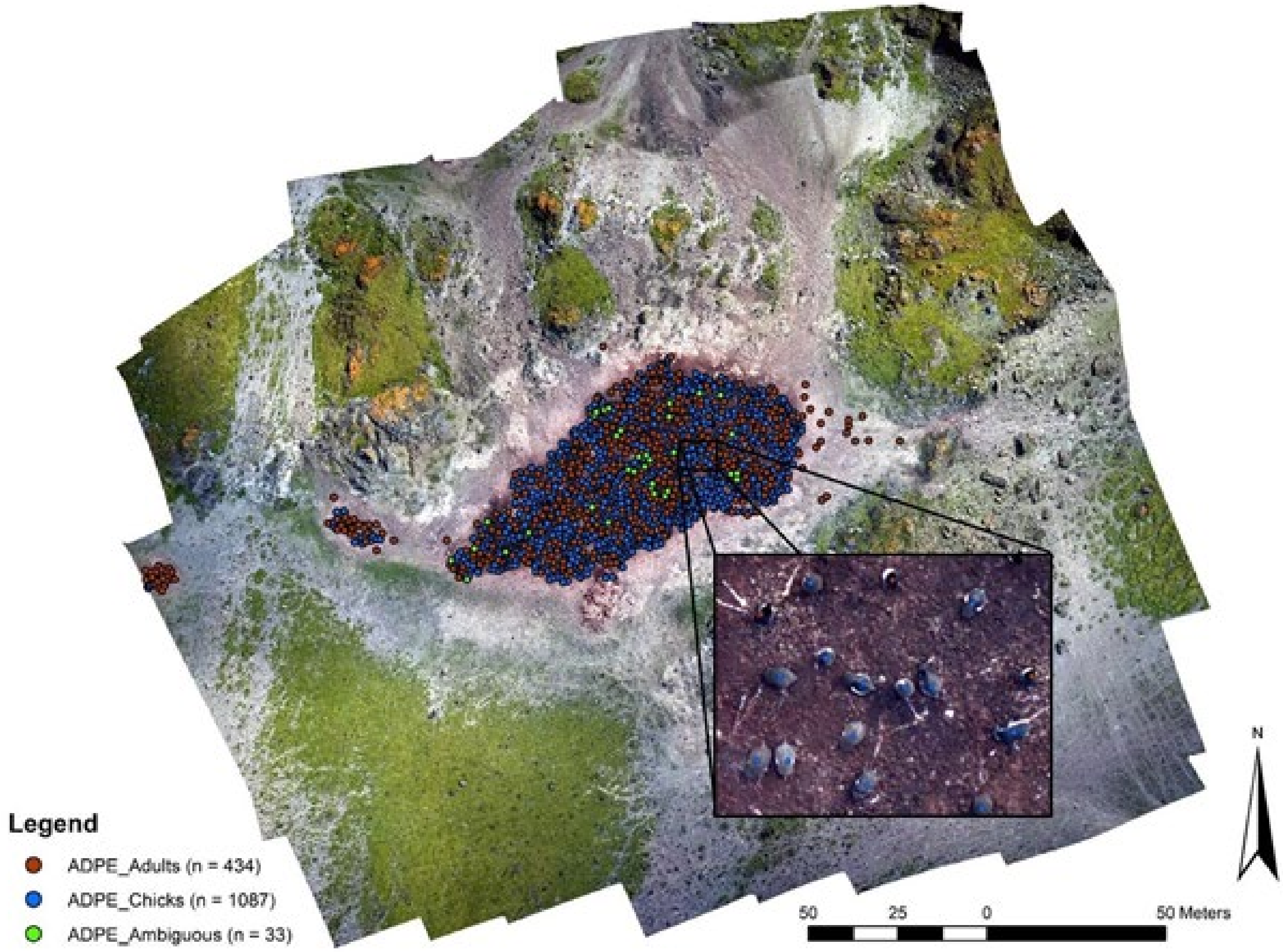

Figure 10: Orthomosaic of Adelie penguin colony at Rakusa Point, King George Island, Antarctica. Color of dots indicates life stage. Photo: SWFSC/NOAA

Aerial images and associated flight telemetry data collected during these flights were combined using photogrammetry software called Agisoft MetaShape, which produces "orthomosaics" stitching together numerous separate images into a coherent, spatially-referenced, high-resolution surface that overlays seamlessly on a three-dimensional terrain model (similar to GoogleEarth but at a much higher resolution). This orthomosaic surface was then used to count and map penguin chicks and adults (Figure 10). The spatially-referenced orthomosaics will also allow the precise mapping of colony boundaries which will serve as an important baseline to measure future shifts in colony size and distribution as breeding conditions change in the rapidly warming Antarctic Peninsula region.

During these UAS mapping operations Dr. Joyce and Dr. Hinke also flew the first Beyond Visual Line of Sight (BVLOS) UAS missions conducted by the NMFS. BVLOS flights crossed the tidewater inlet of the Ecology Glacier from a ridge above the Copacabana Field Camp to map Adelie penguin colonies at Rakusa Point along the western shore of Admiralty Bay. This project, funded and facilitated by the NOAA OMAO Uncrewed Systems Operations Center and by the OAR Uncrewed Systems Research Transition Office, will open new possibilities for conducting UAS marine wildlife surveys by more than double the range and increasing up to four-fold the spatial coverage that can be achieved during UAS mapping and survey missions. By increasing the spatial scale over which UAS operations can be safely conducted, BVLOS flights greatly expand the utility of UAS technology in wildlife research.

Image 10: Adelie penguin adult and chick. Photo: SWFSC/NOAA

Evaluation of Kelp Restoration Efforts in Greater Farallones National Marine Sanctuary utilizing UAS

Author: Rietta Hohman—National Ocean Service, Greater Farallones National Marine Sanctuary and Greater Farallones Association

Along the north coast of California, more than 90 percent of kelp forests have been lost over the past decade. Ecological stressors; including marine heatwaves, a boom in urchin populations and the loss of important urchin predators (including the sunflower star [*Pycnopodia helianthoides*]) have led to a catastrophic loss of kelp forest habitat in the Greater Farallones National Marine Sanctuary (GFNMS). The Kelp Restoration Project—a partnership between Greater Farallones Association (GFA) and GFNMS—was established to address this severe loss and implement strategies for kelp restoration, research, monitoring, and community engagement identified by the GFNMS Advisory Council and outlined in the Sonoma-Mendocino Bull Kelp Restoration Plan. One major indicator of kelp forest ecosystem health is kelp canopy extent, or the amount of kelp that can be seen on the surface of the ocean. In GFNMS, bull kelp (*Nereocystis leutkeana*) is the dominant foundation species that forms distinct layers of kelp blades, stipes, and floats on the ocean's surface.

Mapping kelp canopy also allows us to research the response of kelp forests to environmental drivers, monitor kelp forest dynamics, and explore connectivity between kelp beds. Ultimately, it is one of our most important tools for planning and evaluating kelp restoration efforts.

Remote sensing tools, such as UAS, can provide the means to understand the status of kelp forests by mapping the kelp canopy layer without the need for costly and time consuming subtidal surveys. Staff from the GFA-GFNMS Kelp Restoration Project deployed UAS annually in 2019–2022 to monitor kelp and have partnered with many other groups to capture these data including The Nature Conservancy; California State University, Monterey Bay; University of California Los Angeles and the Kashia Band of Pomo Indians (Image 11).

UAS have emerged as cost-effective and flexible remote-sensing tools that provide higher resolution imagery compared to other remote sensing options. The research team is able to plan deployments in ideal conditions to capture high-resolution kelp canopy data. UAS platforms have additional operational considerations such as being able to take advantage of rapidly changing weather conditions such as avoiding rain, fog, tides, reflective glint from the sun, and white caps on waves from high winds. All of these conditions impact how much kelp canopy can be detected in imagery. Other platforms, such as satellites and planes, tend to have much lower resolution (2–30 meters as opposed to centimeters for cameras mounted on UAS). In a comparison of imagery of the same area, bull kelp canopy extent detected from UAS imagery was 37-percent greater than what was detected by satellite imagery, and another study demonstrated a 50-percent increase in kelp canopy extent from low tide to high tide using UAS imagery. These studies show that UAS are effective tools to map kelp canopy on a local scale, especially during restoration efforts—fine-scale data captured consistently for these restoration projects will be invaluable to understanding kelp dynamics and restoration success.

Image 11: UAS pilots launch a Phantom 4 Pro to map kelp canopy at Kashia Coastal Reserve in Sonoma County, CA. Photo: Rietta Hohman/NOAA

As a trade-off however, coastal access to deploy UAS can be incredibly limited in areas along the rugged Sonoma, CA coastline while deploying from a vessel has additional challenges, such as movement of the vessel and objects on the deck that might interfere with the UAS launch and recovery capabilities. For the most comprehensive information about kelp forests in the region, it is best to pair UAS imagery with satellite imagery.

We are conducting UAS flights in Drakes Bay, CA to evaluate experimental outplanting studies, and to explore the connectivity between the estuarine habitat and nearby kelp forest dynamics. We also launched a biomass conversion study in partnership with the California Department of Fish and Wildlife to determine a formula to derive bull kelp biomass from UAS imagery. This study involved deploying divers underwater to count and measure bull kelp stipes, blades, and floats while a UAS simultaneously mapped kelp canopy cover from above. We will be using these data to determine the relationship between kelp canopy cover and actual biomass of bull kelp in the water, which will inform future blue carbon assessments and harvest regulated by the state.

In 2023, we will launch an experimental dynamic kelp restoration project design that will heavily rely on UAS. Our team will map kelp canopy in GFNMS early in the bull kelp growth season to detect locations of natural emergent kelp beds. Once these locations are identified, we will focus kelp restoration efforts there with the goal of protecting and growing these existing kelp beds and monitoring kelp canopy using UAS to assess restoration progress and success.

In short, remote sensing using UAS is invaluable to our kelp restoration project and will continue to be an integral part of our ongoing and future work.

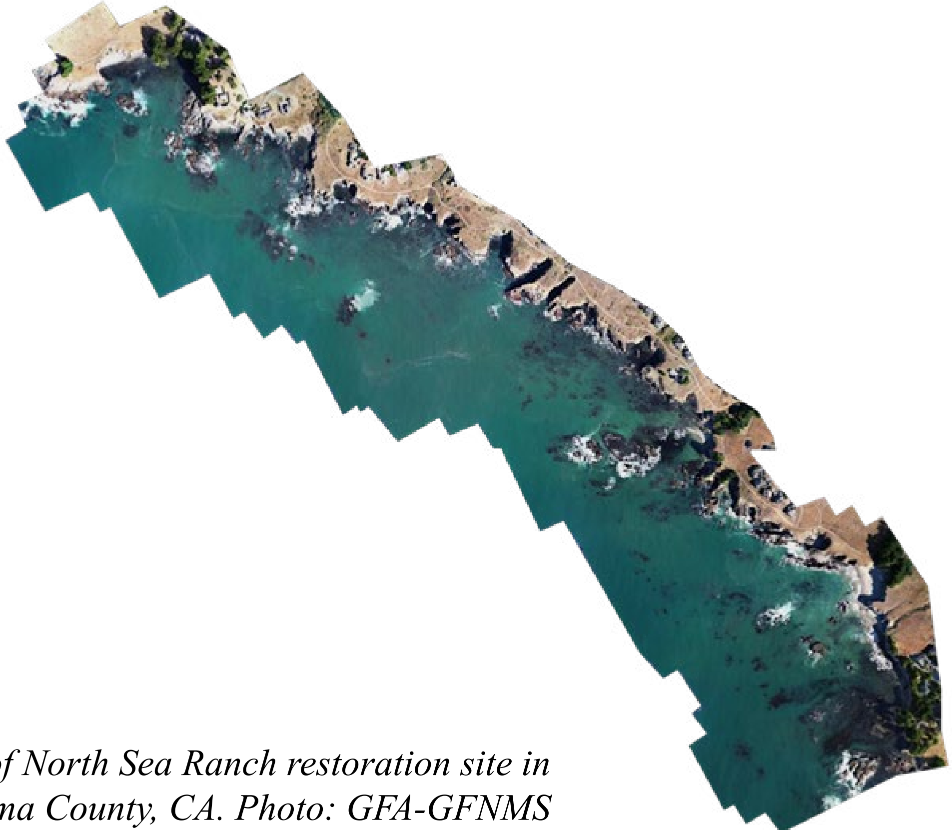

Figure 11: Orthomosaic of North Sea Ranch restoration site in Sonoma County, CA. Photo: GFA-GFNMS

Enhanced Shoreline Marine Debris Detection with UAS

Authors: Tim Battista—National Ocean Service, National Centers for Coastal Ocean Science; and Amy V. Uhrin—National Ocean Service, Marine Debris Program

Marine debris is a persistent environmental pollution problem that can harm marine life, degrade marine and coastal habitats, interfere with navigation safety, and pose a threat to wildlife and human health. NOAA's Marine Debris Program (MDP, within National Ocean Service) serves as the U.S. Federal lead for assessment, prevention, and removal of marine debris. They work with partners across the Nation to conduct debris shoreline surveys to identify debris accumulations, locations, and sources as part of the Marine Debris Monitoring and Assessment Project (MDMAP). Detection and categorization of shoreline debris is currently conducted through field surveys using established protocols, which entail walking defined shoreline transects while visually identifying and recording debris. Data from these surveys have been used to assess spatial and temporal trends in shoreline debris, inform behavior change campaigns focusing on specific items, and assess the effectiveness of legislation targeting specific items. Detecting and identifying debris quickly and accurately is key to cleanup and response actions. NOAA's National Centers for Coastal Ocean Science (NCCOS) and MDP, in collaboration with Oregon State University (OSU) and ORBTL AI, partnered to investigate three complementary technologies with the potential capability to enhance marine debris detection and classification on shorelines.

Image 12 (left): Researchers test a polarimetric camera on a pole-mounted platform to test marine debris detecting software. Image 13(right): UAS operator flies a UAS over marine debris to test detection (right). Photo: Kyle Herrera/OSU

The research team investigated and codified a process to enhance the detection and identification of marine debris on shorelines using UAS, machine learning, and polarimetric imaging cameras. Polarimetric cameras are fitted with special filters that capture information about the surface characteristics of objects such as surface texture (i.e., smooth, rough, shiny, gritty), material type (i.e., plastic, metal, natural), and shape (i.e., flat, curved). For this reason, polarimetric information is very helpful for detection and classification of man-made objects.

The project team conducted experiments at three different locations in Oregon and Texas to test the combined capabilities of these emerging technologies for marine debris shoreline surveys (Image 12, Image 13).

To simulate image collection from a UAS before outfitting one with a polarimetric camera, the team partnered with the U.S. Coast Guard and captured polarimetric imagery from a helicopter flight. This allowed the researchers to mimic the altitude and speed at which the UAS system would be flown. Subsequently, the team developed custom hardware and software that enabled the polarimetric camera to be flown on a UAS, without a human operator to adjust exposure settings. Polarimetric images were shown to improve automated classification of debris on shorelines compared to standard red-blue-green images. Operational guidelines (NOAA Technical Memorandum) on how to best conduct surveys using a UAS integrated with a polarimetric camera were produced.

To develop the machine learning model for classifying debris from the images, the team used high-resolution aerial imagery collected in Hawaii in 2015 to assemble a data set of labeled shoreline marine debris objects. This data set consisted of 5,733 hand-labeled marine debris objects spread across 1,224 small sub-images. In the end, a free, open-source machine learning model called DebrisScan was launched which allows users to upload and process their own aerial images to generate debris-labeled photos and information about potential debris including the material type, distribution, and quantity (Figure 12).

Collectively, the workflows and software tools developed during this project serve to provide automatic and efficient detection, identification, and geolocation of debris items through an objective and repeatable process. The results of this project provide strong indication that using these technologies for detection of macro-sized marine debris can complement and enhance existing shoreline debris detection methods.

Next steps include operationalizing the use of Uncrewed Systems by transferring the technological solutions to existing marine debris response programs for continued detection and mapping. This innovative technology and corresponding operations were funded and supported by the Uncrewed Systems Research Transition Office.

Figure 12: DebrisScan results of a high-resolution image taken via UAS. Colored labels indicated identified debris. Photo: OSU and ORTBL AI

Applying UAS to Weather Event Research and Damage Assessment

Author: James M. O'Sullivan—National Weather Service, Office of Observations

UAS are tools that may increase the efficiency and accuracy of NWS damage surveys and other pre- and post-weather event survey efforts. When surveying areas of damage, deployment of UAS may allow the NWS to achieve better spatial and/or intensity results compared to traditional methods. UAS allows viewing of damage areas not accessible via a ground survey(s), and are especially valuable for surveying remote or heavily wooded regions where automobile and/or foot traffic is difficult or impossible, and in areas where ground-level observations cannot accurately give complete knowledge of the phenomena being surveyed. In FY 2022 NWS Regional Headquarters and Weather Forecast Offices (WFO) used UAS to assess tornado and flood damage in Kentucky, and develop safer and more efficient NOAA property inspections at facilities along the east and south of the United States.

Image 14: Storm damage imagery taken via UAS following a historic tornado outbreak in Bowling Green, KY in December, 2021. Photo: NWS-Louisville/NOAA

One of the worst tornado outbreaks to impact NWS WFO-Louisville area of responsibility occurred in December 10–11, 2021. Eighteen tornadoes touched down or moved through central Kentucky. NWS WFO Louisville survey teams were out for over a week surveying the tracks and damages of the tornadoes and utilized UAS on several occasions as the weather allowed. Some of the worst damages (Image 14) in the region occurred in Bowling Green, KY, where a high-end Enhanced Fujita Scale (EF-3) tornado with winds of 165 miles per hour resulted in 17 fatalities and 63 injuries.

Three weeks after the December tornado outbreak, the NWS WFO-Louisville's region experienced another tornado outbreak on New Year's Day. This outbreak resulted in eight tornadoes touching down across southern and central Kentucky. UAS once again were utilized to assess the damage and were key in determining tornado path length and width on some of the surveys.

Image 15: Flooding in eastern Kentucky in August 2022. Photo: WFO-Louisville/NOAA

At the end of July 2022, eastern Kentucky experienced historic flash flooding. This catastrophic event occurred as thunderstorms dumped over ten inches of rain in some locations. Unfortunately, 39 lives were lost from the flooding, and many homes and businesses were completely destroyed or suffered significant damage. NWS WFO-Louisville's Senior Service Hydrologist worked with the OMAO to coordinate flights and permissions to launch UAS in eastern Kentucky to survey the post-flood damage (Image 15). The data collected with UAS were shared with federal and state agencies who will utilize it in future hydrology products and reports.

In FY 2022, NWS also began a demonstration project using UAS. UAS will assist NWS Eastern Region Headquarters and Southern Region Headquarters' Systems Operations Divisions to conduct maintenance inspections of NOAA Weather Radio towers and Next Generation Weather Radar (NEXRAD) radomes. These flights will be able to provide visual clues and identify issues and risks associated with the operation of NOAA Weather Radio transmissions and other facility issues like damage to NEXRAD across these two NWS Regions. UAS-based inspections can save NWS several thousands of dollars and valuable time per inspection. In instances where damage is confirmed, UAS inspections may also streamline the repair process and/or mitigation efforts.

Image 16: Ice jam flooding in Circle, AK. Photo: Kyle Van Peursem/NOAA

Assessment of Ice Jam Flooding and Storm Damage in Alaska with UAS: a collaboration between the National Weather Service and the National Centers for Environmental Information

Author: Jessica Cherry—National Environmental Satellite Data Information Services, National Centers for Environmental Information

Image 17: At the National Tsunami Warning Center in Palmer, Alaska, a pilot uses a small UAS to inspect an instrument tower for damage from a mid-winter wind storm. Photo: NESDIS/ NOAA

Ice jamming during spring river breakup along the Yukon, Kuskokwim, and other large rivers is a frequent cause of damaging floods in Alaska. In May of 2022, an ice jam impacted the village of Circle, flooding parts of town along the Yukon River. There to capture images of the flood was National Weather Service (NWS) forecaster and UAS pilot Kyle Van Peursem. Van Peursem had flown into Circle on a chartered Cessna aircraft as part of the annual River Watch effort, a joint program between NWS and the State of Alaska's Department of Homeland Security and Emergency Management (DHSEM). Passengers on the River Watch charter flights include a river ice observer from the Alaska-Pacific River Forecast Center, an emergency manager from DHSEM, and sometimes local elders who have traditional knowledge of the area. The Cessna flights pass up and down the largest rivers and the team lands in villages to convey what they see to local emergency responders, mayors, and Tribal leaders. It was on such a stop that Van Peursem had the opportunity to collect video for situational awareness of flood causes and impacts to the community (Image 16).

Prior to the imagery collection, National Centers for Environmental Information's UAS mission commander and project Principal Investigator, Jessica Cherry, had run Van Peursem and two other NWS UAS pilots through refresher training in Anchorage, AK. Unlike entities with continuous operations, the project team does proficiency exercises as needed between their full schedule of forecasting and decision-support activities with key partners. The UAS is another tool for supporting Impact-based Decision Support Services (IDSS). IDSS are forecast advice and interpretative services the NWS provides to help core partners, such as emergency response personnel and public safety officials, make decisions when weather, water, and climate impacts the lives and livelihoods of the American people. In this case, the imagery was made available through Facebook and the Alaska Weather Show on statewide TV.

Other missions in 2022 included a mid-winter wind storm damage assessment at the National Tsunami Warning Center in Palmer, AK. There, Cherry used the UAS to look for damage to the facility's roof and instrument towers (Image 17). A spot forecast by the Anchorage Weather Forecast Office (WFO) and the Alaska Aviation Weather Unit was used to execute the flights in a narrow window between marginal weather. Another mission flown by Rick Fritsch, a NWS UAS pilot based at the local WFO-Juneau, surveyed treefall near the airport from a prior storm (Image 18). Small UAS are proving to be a valuable asset for a variety of NWS applications in Alaska.

Image 18: Storm-driven treefall surveyed by small UAS in Juneau, AK. Photo: NESDIS/NOAA

UAS Program Success and FY 2023 Outlook

NOAA is continuously evolving and adapting to the dynamic field of UAS, recognizing their growing significance as a reliable and valuable resource within NOAA operations. During FY 2022, NOAA conducted over 60 coordinated projects, and over 1,800 UAS flights. This culminated in more UAS flight time accrued by the agency than any previous year. Over 21,000 flight minutes were logged which is a 16-percent increase from FY 2021. These projects and flights utilized over 30 distinct UAS platform types, including fixed wing, vertical take-off and landing, and hybrid systems. NOAA also developed training modules to improve NOAA-wide workforce proficiency in UAS and trained 28 new UAS operators. Other UAS core services provided in FY 2022 maintained the safety, efficiency, and compliance of NOAA UAS operations.

Through UAS operations, NOAA has significantly increased the collection and utilization of precise and time-sensitive data across the agency. UAS operations have played a critical role in obtaining data related to severe weather, marine mammal and fisheries surveys, mapping, and other projects that support NOAA's mission.

Looking forward to FY 2023, NOAA UAS operations are set to continue expanding with innovative uses of UAS platforms for data collection. As UAS technology advances and regulations evolve, the UAS Division and Uncrewed Systems Executive Oversight Board will provide guidance and policy oversight to all of NOAA, ensuring seamless operations that align with NOAA's strategic initiatives.

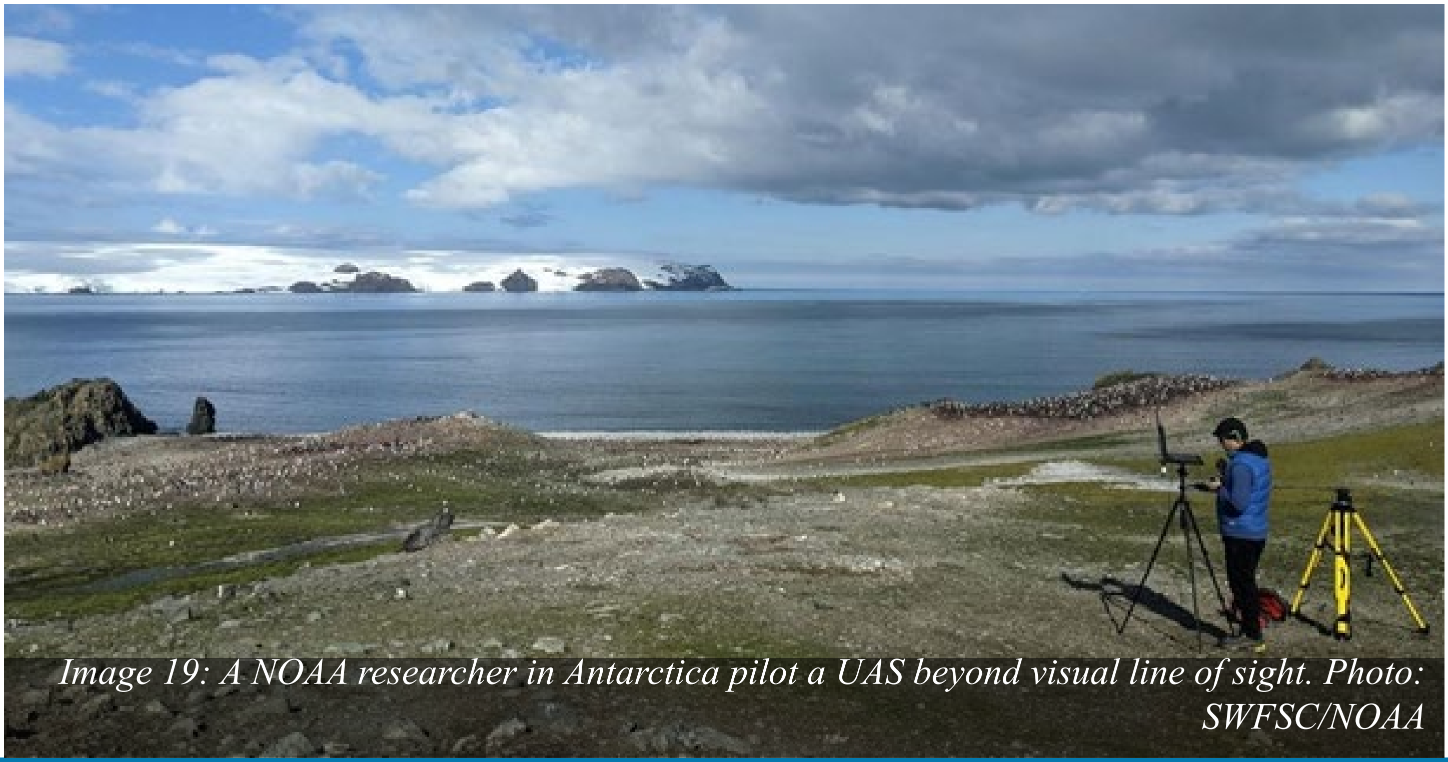

Image 19: A NOAA researcher in Antarctica pilot a UAS beyond visual line of sight. Photo: SWFSC/NOAA