National Aeronautics and
Space Administration

EXPLORE

Science Mission Directorate

Airborne Science Program

2022
Annual Report

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Figures and Tables

1. Leadership Comments

Bruce Tagg, Director of the Airborne Science Program.

This FY2022 Annual Report represents the work of hundreds of dedicated scientists, engineers, pilots, mechanics, and managers who all have the same goal in mind: fly safely and collect world-class science data from aircraft in support of NASA's mission. I'm happy to report that we were successful on both accounts this year, flying more than 2700 flight hours for science on at least 10 different aircraft with operations all over the U.S. including Alaska, as well as Greenland, South Korea, and off the coast of Africa. We supported the completion of several Earth Venture Suborbital projects this year, including Aerosol Cloud Meteorology Interactions Over the Western Atlantic Experiment (ACTIVATE) on our Falcon/HU-25 and B-200 (LaRC), and the Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) on the ER-2. We also continued support for the Arctic Boreal Vulnerability Experiment (ABoVE) and Part II of the Convective Process Experiment (CPEX). Our aircraft continue to support satellite calibration/validation activities and preparation for future satellite missions such as Surface Biology and Geology (SBG) by flying the Western Diversity Time Series (WDTS) and the SBG High-Frequency Time (SHIFT) series, as well as supporting CALIPSO nighttime validation flights. We also had another great cohort of students participate in the 14th year of the Student Airborne Research Program (SARP) aboard the DC-8.

It was also an important year in terms of reinvigorating the NASA science aircraft fleet by bringing on a G-IV that will be modified to support the next generation SAR. In preparation for continued "flying laboratory" research, NASA has procured a Boeing 777-200ER that will be modified and brought into service in FY2025 to replace the storied, but aging, DC-8. Our engineers have also been hard at work re-designing our onboard computing and telemetry systems as well as our ground segment, the Mission Tools Suite, resulting in increased capabilities and easier maintenance.

I want to thank my Deputy Derek Rutovic, my ghost writer Matt Fladeland, all the Center leads, and everyone that has worked so hard this year to support NASA Earth Science from aircraft. I would also like to thank and recognize the contributions of Dr. Melissa Martin who was invaluable to me as my Science Deputy this past year, but who has taken a new position within the Earth Science Division. I hope you enjoy reading about the program and as always, I welcome your candid feedback and thank you for taking the time to learn more about the NASA Airborne Science Program.

Bruce A. Tagg
and the ASP Leadership Team
Airborne Science Program

2. Program Overview

The Airborne Science Program (ASP) is an important element of the NASA Science Mission Directorate (SMD) Earth Science Division (ESD) because of its involvement and support throughout the entire life cycle of Earth observing space missions. Aircraft modified with ports, inlets, internet (IT), and communications systems support NASA Earth Science missions by:

- Providing a platform for testing future satellite or International Space Station (ISS) instruments
- Conducting underfligths for calibration and validation of on-orbit missions
- Simulating future satellite mission data for algorithms development with airborne prototype instruments
- Supporting process studies to provide high-resolution temporal and spatial measurements of complex local processes, which can be coupled to global satellite observations for a better understanding of the complete Earth system
- Leading workforce development through hands-on science and engineering opportunities

ASP accomplishes these goals by providing support of operations of mission critical, or core, aircraft; engineering for instrument mechanical, electrical, and IT integration; and onboard data systems and communications capabilities. The Program also assists NASA Principal Investigators (PIs) with access to commercial aviation services and use of non-NASA aircraft and equipment for Earth Science, as needed.

Program Structure

The Program is administered through SMD/ESD, with oversight and close coordination from the Flight Projects and Research and Analysis (R&A) Programs (Figure 1). Aircraft operations and science support responsibilities are distributed among the multiple NASA centers – Armstrong Flight Research Center (AFRC), Langley Research Center (LaRC), Wallops Flight Facility (WFF), Johnson Space Center (JSC), and Ames Research Center (ARC) – where the aircraft and support personnel are based, as shown in Figure 2.

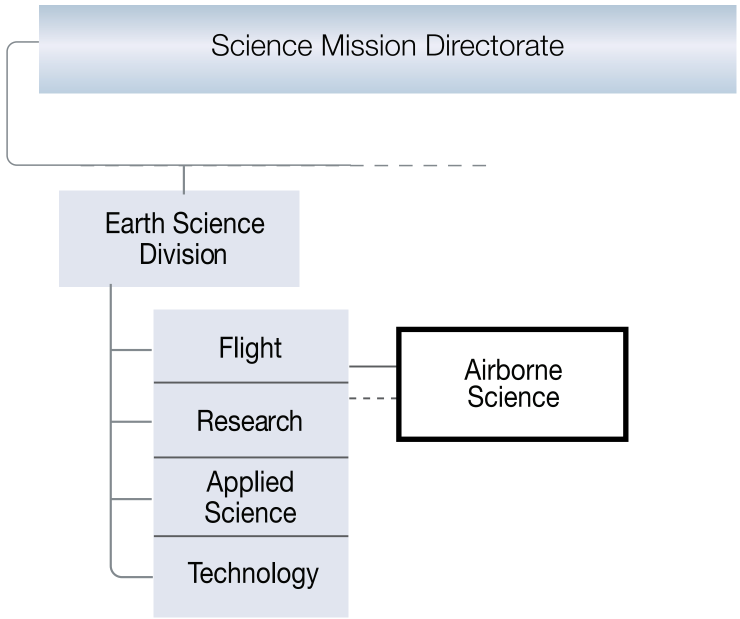


Figure 1. *Science Mission Directorate organization chart.*

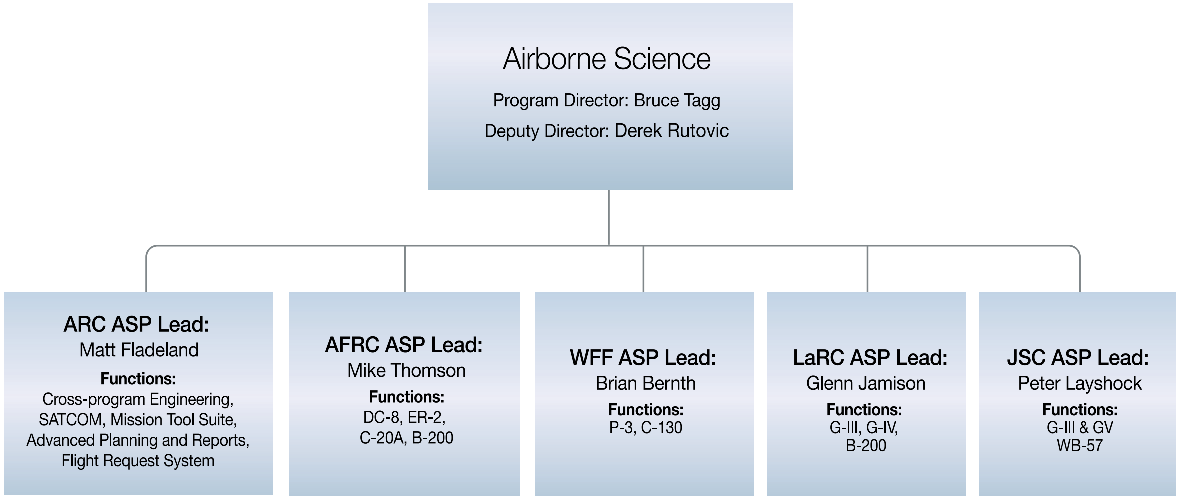


Figure 2. *Airborne Science Program organization chart.*

Flight Request System and Flight Hours

The Program's Science Operations Flight Request System (SOFRS) is a web-based tool used to track and facilitate the review and approval process for airborne science activities using ASP-supported aircraft, facility instruments, ASP science support assets, or any ESD-funded activities/missions using aircraft. To schedule use of NASA SMD platforms and instrument assets, submit a Flight Request (FR) for approval through SOFRS (*https://airbornescience.nasa.gov/sofrs*).

In FY2022, requesters submitted 133 FRs for flight activities using at least one of the following ASP components: an ASP-supported aircraft, ESD funding, an ASP facility instrument (AVIRIS-NG, AVIRIS-C, eMAS, LVIS, MASTER, NAST-I, UAVSAR). A total of 62 FRs were completed using 21 different aircraft. Of the remaining FRs, some were deferred and the rest were canceled.

The 62 completed FRs flew a total of 2748.1 flight hours. The details are listed below.

Table 1 shows all SOFRS flight hours flown by all aircraft, including "Other (non-NASA) Aircraft," by funding source. Table 2 shows the status of all flight requests and total flight hours. Table 3 shows flight request status and total hours for the specific "Other (non-NASA) Aircraft" requested. Table 4 shows only ESD flight requests and flight hours flown by aircraft. Table 5 shows all SOFRS flight hours by funding source. Figure 3 is a histogram showing the history of total flight hours flown over the past five years. Figure 4 shows the global reach of ASP flight activities in 2022.

SMD (non-ESD) flight hours are those funded by SMD Program Managers not within ESD. Other NASA aircraft are NASA-owned aircraft but not subsidized by the ASP program. All Other non-NASA aircraft supported are listed in Table 3.

Key to Tables 1, 2, 3, and 4:

- **Total FRs** includes all Flight Requests submitted for FY22 (log numbers start with 22)
- **Total FRs Approved** includes all approved Flight Requests, including those that may not have flown during FY22
- **Total Partial FRs** includes Flight Requests for which total approved hours were not fully expended during FY22 and have been rolled over to FY23
- **Total FRs Completed** includes only Flight Requests with a final status of Completed
- **Total Hours Flown** includes all flight hours flown for Flight Requests with a FY22 status of Completed or Partial

Table 1. *NASA airborne science total FY22 hours flown by each aircraft (per funding source).*

Aircraft	NASA ESD*	NASA SMD	Other NASA	Non - NASA	Not Listed	Total
ASP Supported Aircraft						
DC-8 - AFRC	157.3	0.0	74.0	6.9	0.0	238.2
ER-2 - AFRC	208.7	0.0	0.0	0.0	0.0	208.7
Gulfstream C-20A (GIII) - AFRC	264.4	0.0	0.0	0.0	0.0	264.4
Gulfstream III - JSC	31.5	0.0	0.0	0.0	0.0	31.5
Gulfstream III - LaRC	0.0	0.0	0.0	0.0	0.0	0.0
Gulfstream V - JSC	0.0	0.0	0.0	68.2	0.0	68.2
P-3 Orion - WFF	185.9	0.0	0.0	0.0	0.0	185.9
Other NASA Aircraft						
B-200**	391.9	0.0	70.0	0.0	0.0	391.9
C-130H - WFF	12.4	0.0	0.0	0.0	0.0	12.4
C-23 Sherpa - WFF	0.0	0.0	0.0	0.0	0.0	0.0
Gulfstream IV - LaRC	0.0	0.0	41.8	0.0	0.0	41.8
HU-25A Guardian - LaRC	298.8	0.0	0.0	0.0	0.0	298.8
SIERRA - ARC	0.0	0.0	0.0	0.0	0.0	0.0
WB-57 - JSC	139.5	0.0	0.0	32.0	0.0	171.5
Other (see Table 3)	434.1	0.0	117.2	283.5	0.0	834.8
TOTAL	**2124.5**	**0.0**	**233.0**	**390.6**	**0.0**	**2748.1**

*Includes AFRC (A) and LaRC (L)

Table 2. *FY22 flight request status and total hours flown by all aircraft.*

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
DC-8 - AFRC	12	5	0	5	238.2
ER-2 - AFRC	17	12	0	6	208.7
Gulfstream C-20A (GIII) - AFRC	21	15	0	14	264.4
Gulfstream III - JSC	8	2	0	2	31.5
Gulfstream III - LaRC	3	2	0	0	0.0
Gulfstream V - JSC	7	2	0	1	68.2
P-3 Orion - WFF	16	11	0	9	185.9
Other NASA Aircraft					
B-200*	7	5	0	5	391.9
C-130H - WFF	1	1	0	1	12.4
C-23 Sherpa - WFF	1	0	0	0	0.0
Gulfstream IV - LaRC	1	1	0	1	41.8
HU-25A Guardian - LaRC	1	1	0	1	298.8
SIERRA - ARC	1	0	0	0	0.0
WB-57 - JSC	4	2	0	2	171.5
Other (see Table 3)	33	17	0	15	834.8
TOTAL	**133**	**76**	**0**	**62**	**2748.1**

*Includes AFRC (A) and LaRC (L)

Table 3. *Flight request status and total hours flown by other (non-NASA) aircraft.*

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
A90 - Dynamic Aviation	2	2	0	2	154
Alphajet	1	0	0	0	0
B-200 - Dynamic Aviation	14	7	0	6	497.3
DC-3*	3	3	0	2	134
Helicopter	1	1	0	1	0
ISRO King Air**	1	0	0	0	0
Robinson R-44***	1	0	0	0	0
Super Swift 2***	1	0	0	0	0
SkyFish M6***	1	1	0	1	0.6
Twin Otter	1	0	0	0	0
Twin Otter CIRPAS	1	1	0	1	10.9
Twin Otter International	5	1	0	1	32
Vanilla-003***	1	1	0	1	6
TOTAL	**133**	**76**	**0**	**62**	**834.8**

*Flown by Airborne Imaging, Inc.
**ISRO – Indian Space Research Organization
*** Uncrewed Aerial Vehicle

Table 4. *Summary of FY22 ESD-funded flight request status and flight hours flown by aircraft.*

Aircraft	Tota FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
DC-8 - AFRC	9	3	0	3	157.3
ER-2 - AFRC	9	8	0	4	208.7
Gulfstream C-20A (GIII) - AFRC	19	15	0	14	264.4
Gulfstream III - JSC	4	2	0	2	31.5
Gulfstream III - LaRC	3	2	0	0	0.0
Gulfstream V - JSC	5	0	0	0	0.0
P-3 Orion - WFF	12	7	0	6	185.9
Other NASA Aircraft					
B-200*	6	5	0	5	391.9
C-130H - WFF	1	1	0	1	12.4
C-23 Sherpa - WFF	1	0	0	0	0.0
Gulfstream IV - LaRC	0	0	0	0	0.0
HU-25A Guardian - LaRC	1	1	0	1	298.8
SIERRA - ARC	0	0	0	0	0.0
WB-57 - JSC	3	1	0	1	139.5
Other (see Table 3)	29	15	0	13	434.1
TOTAL	**102**	**60**	**0**	**50**	**2124.5**

*Includes AFRC (A) and LaRC (L)

Table 5. *All flight hours flown by funding source over the past 5 years.*

Fiscal Year	ESD	SMD (Non-ESD)	Other NASA	Non-NASA	Funding Sources Not Listed in FR	Total Funded Flight Hours
2018	3125.8	6.4	451.5	103.6	1.2	3688.5
2019	2415.1	0.0	586.6	60.6	7.5	3069.8
2020	1614.0	0.0	129.9	0.0	0.0	1743.9
2021	2166.0	0.0	193.5	0.0	2.7	2424.9
2022	2124.5	0.0	233.0	390.6	0.0	2748.1

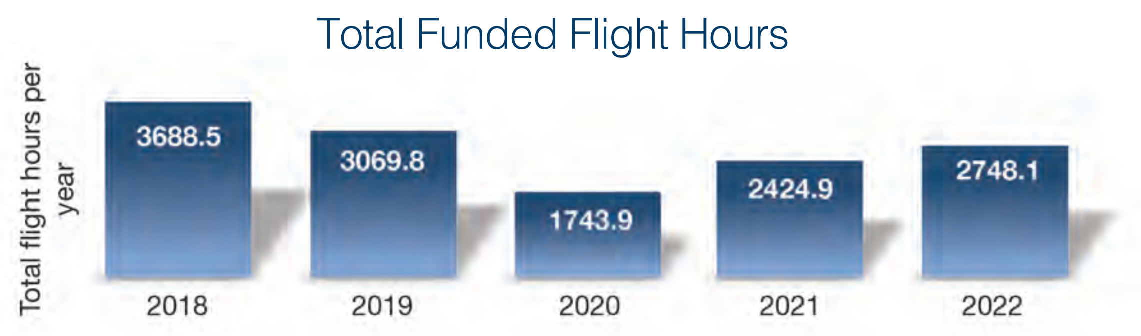


Figure 3. *ASP annual flight hours from FY18 through FY22.*

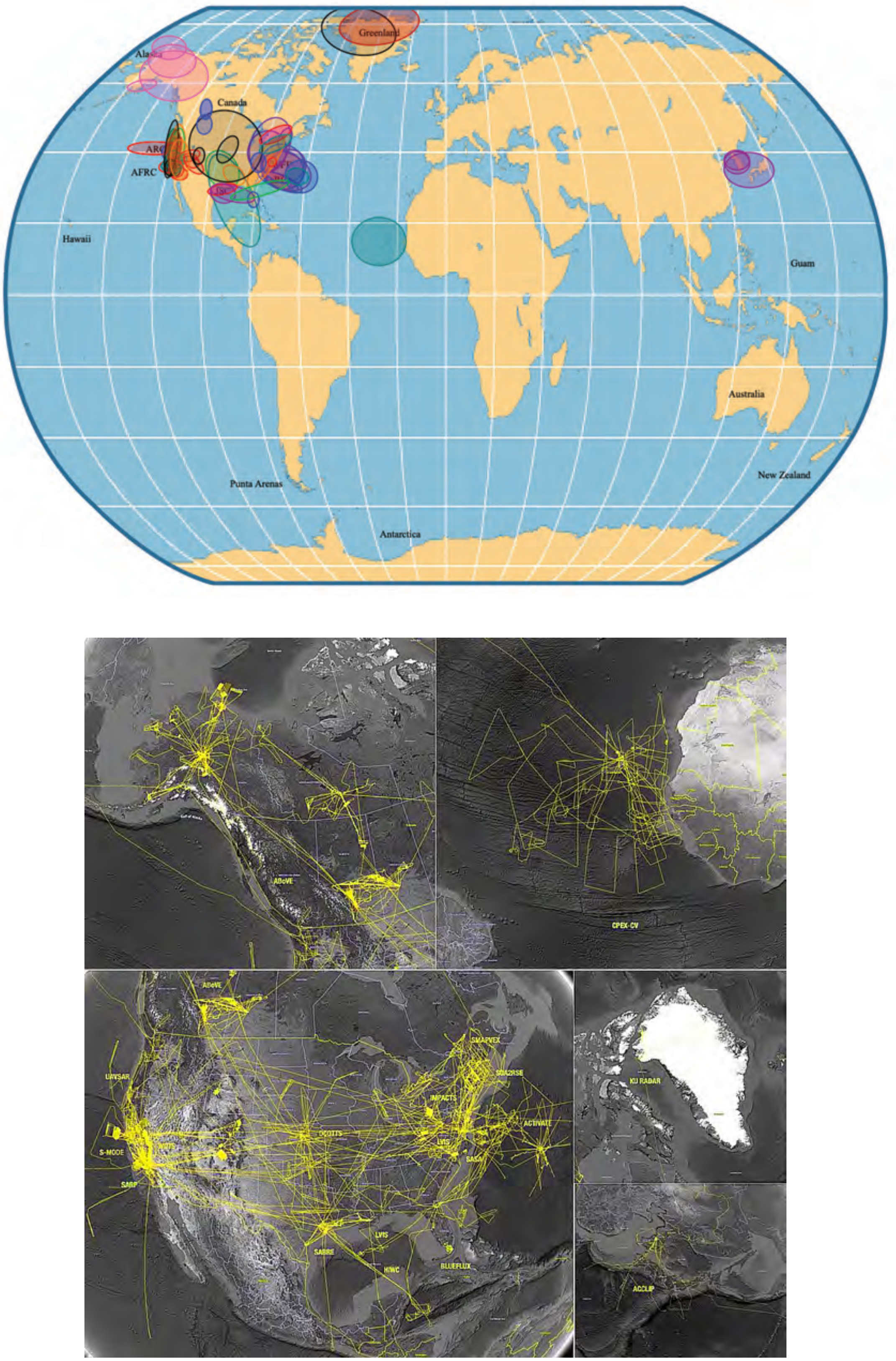
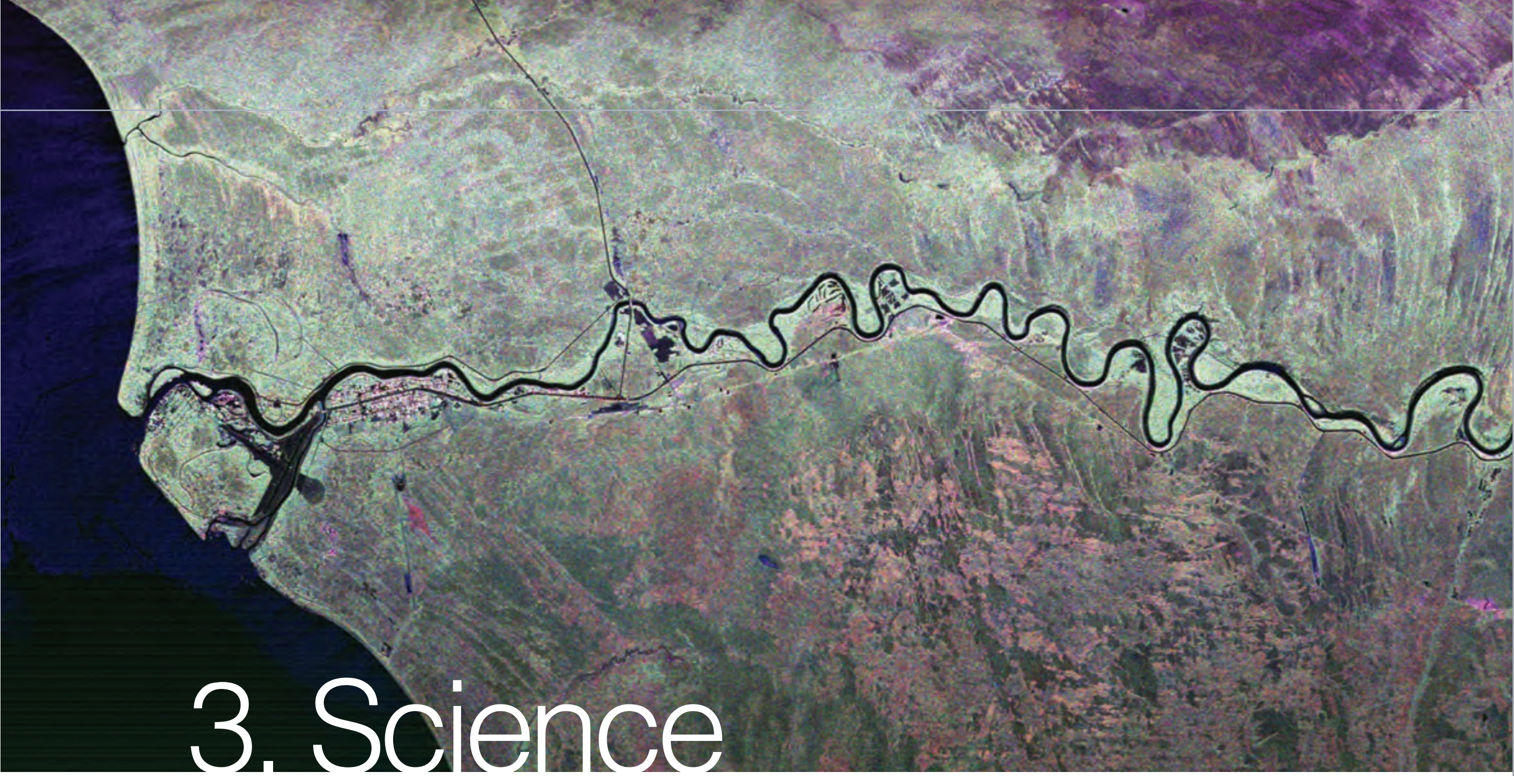


Figure 4. *Locations and flight tracks of FY22 ASP airborne campaigns.*
Figure credits: *Susan Schoenung and Aaron Duley*



3. Science

Major Mission Highlights

Despite continuing safety and logistics challenges introduced by a global pandemic, in FY22 ASP conducted over 2100 flight operation hours in support of Earth science process studies, instrument flight-testing, and support for Earth Science space missions in all phases, from definition to validation. Four of the remaining Earth Venture Suborbital-3 (EVS-3) missions were able to carry out flight activities, with two completing their airborne phases. In 2022, NASA campaigns were deployed further around the globe than 2021, with ACCLIP in South Korea; CPEX-CV in Cabo Verde; two missions to Greenland, including ICESat-2 calibration/validation (cal/val) and multi-channel snow radar flights; and two deployments to Bermuda. Table 6 shows activities for the largest missions by flight hours.

Table 6. *Major science missions supported by ASP in FY22.*

Mission		Flight Hours	Location	Aircraft
EVS	ACTIVATE	589.7	Atlantic Coast	HU-25A, B-200 (L)
	IMPACTS	202.0	Atlantic Coast	P-3, ER-2
	S-MODE*	185.3*	California	B-200 (A), G-III (L)
	DCOTSS	102.2	Mid-America (Kansas base)	ER-2
R&A	Carbon Mapper (Methane Sources)	283.5	CONUS	B-200
	ABoVE	171.1	Alaska, Canada	G-III (radar); B-200
	ACCLIP	139.5	Korea	WB-57
	CPEX-CV	119.4	Cabo Verde	DC-8
	G-LiHT	117.2	Alaska	A-100
	SMAPVEX 2022	79.1	Northeast Forests	G-III (radar)
	SHIFT	69.6	California Coast	B-200
	ICESat-2 (Summer Cal/Val)	68.2	Greenland	GV
	SASSIE	60.0	Alaska	Basler DC-3
	Multi-channel Snow Radar	47.3	Greenland	P-3
	BLUEFLUX	36.8	Florida	B-200
	UAVSAR (all other TE and ESI)	130.8	CONUS, Alaska, Canada	G-III (radar)
EDU	SARP	45.7	California	DC-8, B-200
	SaSa	20.9	Virginia	P-3

Earth Venture Suborbital

Earth System Science Pathfinder (ESSP) Earth Venture Suborbital (EVS) projects are flagship-equivalent, $15-30M, 5-year efforts that focus on the most compelling science questions for which aircraft measurements are critical to resolving uncertainties. EVS-3 projects ACTIVATE and DCOTSS completed airborne activities in 2022. IMPACTS and S-MODE carried out flight missions in 2022 and have scheduled final activities in 2023. The EVS-4 solicitation will be posted in early FY23.

Aerosol Cloud Meteorology Interactions Over the western ATlantic Experiment (ACTIVATE) – Year 3

PI – Armin Sorooshian, University of Arizona
Program – Earth Venture Suborbital-3
Aircraft – HU-25A, B-200 (L), UC-12B
Payload Instruments: CVI, AC3, RSP, HSRL-2, DLH, Dropsondes

On June 18, 2022, the Earth Venture Suborbital-3 (EVS-3) mission Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE) wrapped up its third and final year of flights with a transit flight back from Bermuda to the base of ACTIVATE's operations at NASA Langley Research Center (LaRC). This marked the 162nd joint flight of the NASA Langley HU-25A and Beechcraft King Air aircraft (LaRC B-200 (L), UC-12B), surpassing the mission's initial goal of 150 joint flights. The ACTIVATE team's aim is to provide important globally-relevant data about changes in marine boundary layer cloud systems, atmospheric aerosol particles, and multiple feedbacks that warm or cool the climate. Interactions between aerosol particles and clouds are associated with the largest uncertainty in estimates of total anthropogenic radiative forcing. Thus, improved knowledge of these interactions will improve our ability to forecast future climate change due to anthropogenic activities.

ACTIVATE included a three-year flight campaign (2020-2022), with two deployments per year (winter and summer seasons) to capture different aerosol and weather regimes over the northwest Atlantic Ocean. Flying in different seasons enabled sampling diverse cloud types, ranging from thinner stratocumulus to deeper cumulus clouds, including warm (liquid droplets) and mixed-phase clouds that contained ice. A unique ACTIVATE aspect was its methodical flight configuration, during which two aircraft were vertically coordinated to measure numerous geophysical variables of relevance to aerosol-cloud-meteorology interactions in the same vertical column of the atmosphere. Measurements included capturing data below, inside, and directly above boundary layer clouds, which were typically below 2 km above sea level. The HU-25A (low-flyer) flew in the boundary layer, where the clouds of interest were sampled, providing in situ measurements of trace gases, aerosol particles, clouds, and meteorology below, in, and above clouds. The UC-12B (high-flyer) flew at ~9 km to characterize atmospheric properties in the column beneath the plane with the Research Scanning Polarimeter (RSP) and the High Spectral Resolution Lidar-2 (HSRL-2). The UC-12B also deployed dropsondes to measure profiles of atmospheric state parameters. The ACTIVATE team will use data from these advanced remote sensors to assess and advance aerosol and cloud retrieval capabilities in studying aerosol-cloud interactions. In addition, joint deployment of these remote sensors will help assess current satellite (e.g., CALIPSO) measurements, as well as the NASA Atmosphere Observing System (AOS), to determine how satellite and suborbital measurements

Figure 5. *ACTIVATE team members and visitors.* ***Photo credit:*** *Johnathan Hair, LaRC*

can be used to address National Academies 2017 Decadal Survey recommendations for aerosol and cloud Designated Observables.

Based in Hampton, Virginia at NASA's LaRC, the ACTIVATE campaign mainly took place off the coast of Virginia in the form of "out-and-back" flights, typically ~3.5 hours in duration. During the 2022 winter and summer deployments, as pandemic-related travel restrictions were relaxed, aircraft were able to fly farther north toward New England and east to Bermuda. Incorporating refueling stops allowed the aircraft to return to LaRC on the same day. Data collection closer to Bermuda was a high priority, as it is farther removed from continental influences and the Gulf Stream, and thus more representative of "cleaner" marine conditions. As a result, the ACTIVATE team conducted operations from Bermuda for the last three weeks of the final deployment in June 2022. This proved to be very successful: 13 joint

Figure 6. *LaRC HU-25A and B-200 flying in Bermuda for ACTIVATE in 2022.* ***Photo credit:*** *Taylor Shingler, LaRC*

flights were executed, capturing interesting features such as African dust events that were mixing with the boundary layer clouds.

The ACTIVATE team now turns to archiving the final year of flights for public use by January 2023. Furthermore, the team has hosted numerous in-person and virtual open data workshops to broaden usage of the airborne data among the international community. The dataset is ideal for studies of factors governing aerosol particle activation into droplets, the lifecycle and properties of boundary layer clouds, and assessment and advancement of remote sensing retrievals for geophysical variables related to aerosols, clouds, and winds. The team is also exploring innovative ideas (e.g., gridded data of two aircraft measurements) to further enhance the use of ACTIVATE data. Early results from ACTIVATE science data analysis have been documented in 44 peer-reviewed publications, which provide relevant contextual information for future users of the data. The cold air outbreak conditions sampled during ACTIVATE winter seasons have been of particular interest, as climate models struggle to simulate the postfrontal clouds associated with these conditions.

Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS)

PI – Lynn McMurdie, University of Washington
Program – Earth Venture Suborbital-3
Aircraft – P-3, ER-2
Payload Instruments: CRS, HIWRAP, EXRAD, CoSMIR, AMPR, CPL, CDP, CAPS, 2D-S, HVPS-3, Nevzorov Probe, King Probe, Hawkeye Probe, RICE, WISPER, TAMMS, AVAPS

The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) is a NASA-sponsored field campaign to study wintertime snowstorms, focusing on East Coast cyclones. This large cooperative

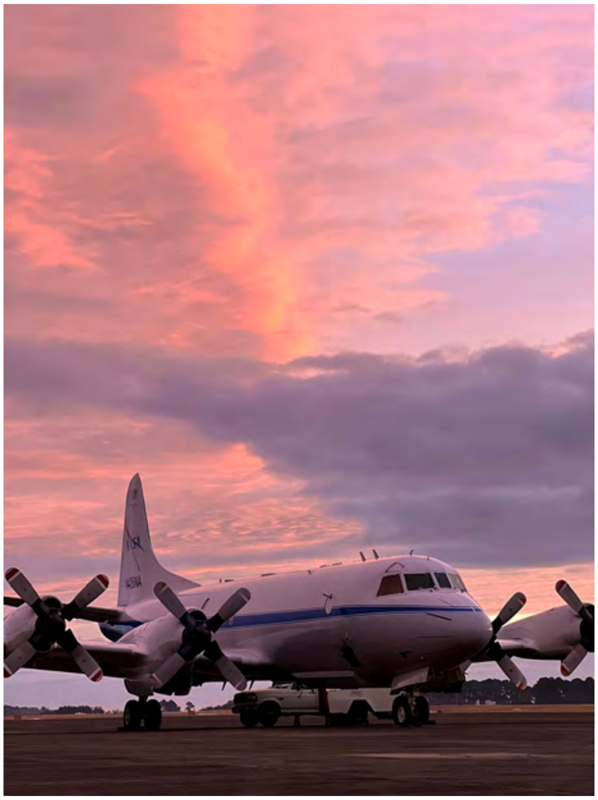


Figure 7. *P-3 at dawn before take-off for the IMPACTS flight on February 3, 2022.* ***Photo credit:*** *NASA*

effort began during the winter of 2020. After a pandemic-induced hiatus in 2021, the mission returned to the field in January 2022. A final deployment is planned for 2023. The mission studies precipitation variability in winter cyclones to improve remote sensing and numerical forecasts of snowfall. Snowfall within these storms is frequently organized in banded structures on multiple scales. The causes for the occurrence and evolution of a wide spectrum of snowbands remain poorly understood. IMPACTS's goals are to characterize the spatial and temporal scales and structures of snowbands, understand their dynamic, thermodynamic, and microphysical processes, and apply this understanding to improve remote sensing and modeling of snowfall.

The IMPACTS flight campaign utilizes two NASA aircraft flying in coordinated flight patterns to

GOES-16 ABI Geocolor satellite image of the 29 January 2022 New England blizzard.
Image source: NOAA/STAR.

Figure 8. *Satellite image of the January 2022 blizzard studied during IMPACTS.* ***Figure credit:*** *NOAA/STAR*

sample a range of storms spanning across the Midwest and East Coast. The satellite-simulating ER-2 aircraft flies above the clouds and carries a suite of remote sensing instruments, including cloud and precipitation radars, lidar, and passive microwave radiometers. The P-3 aircraft flies within the clouds and samples environmental and microphysical quantities in situ. Ground-based radar measurements from the National Weather Service network and a suite of radars located on Long Island, New York, along with supplemental soundings and the New York State mesonet ground network, provide environmental context for the airborne observations. The coordination between remote sensing and in situ platforms makes this a unique, publicly available dataset applicable to a wide variety of interests.

IMPACTS's successful return during the 2022 winter storm season sampled 13 events. In January and February 2022, two flights were timed with Global Precipitation Measurement (GPM) satellite overpasses. The P-3 aircraft with new pylons (see page 47) was based out of Wallops Island, Virginia, with one suitcase flight from Wright-Patterson Air Force Base in Ohio. The ER-2 was based at Pope Army Airfield in North Carolina. The two aircraft flew a combined total of 167.1 flight hours. Mobile ground units were dispersed across multiple locations, from the upper Midwest to northern New England. By utilizing these different take-off locations, the project sampled a variety of storms that occurred in the Midwest, along the Eastern Seaboard, and north into Canada. This wide net enabled sampling of precipitation and snowband structures at different times in a storm's lifecycle and within different regions of the storm itself. The aircraft observations, combined with surface-based radar observations, profiles from mobile sounding teams, data from the GPM overpasses, and the dataset collected during the 2020 winter storm season address the mission's overall objectives and are currently being analyzed by the science team. Several publications have already resulted from analysis of IMPACTS data. The recent Science Team Meeting highlighted new results and formed collaborations for future studies. The IMPACTS team is busy preparing for its final deployment in January and February 2023.

Dynamics and Chemistry of the Summer Stratosphere (DCOTSS)

PIs – Kenneth Bowman, Texas A&M University; Frank Keutsch, Harvard University
Program – Earth Venture Suborbital-3
Aircraft – ER-2
Payload Instruments: CAFE, CANOE, AWAS, HAL, ROZE, HWV, HUPCRS, MMS, PALMS, POPS, UCATS, WI-ICOS

The Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) project's main goal is to study the lower stratosphere. In the summer, strong convective storms over North America overshoot the tropopause into the lower stratosphere. These storms carry water and pollutants from the troposphere into the typically very dry stratosphere, where they can have a significant impact on radiative and chemical processes, potentially including stratospheric ozone. Material transported from the troposphere to the stratosphere by these storms may be trapped by the atmospheric circulation in the lower stratosphere. During the summer, atmospheric circulation over North America is dominated by a large high-pressure system, the North American Monsoon Anticyclone (NAMA).

An Earth Venture Suborbital 3 (EVS-3) project, DCOTSS uses the NASA ER-2 high-altitude research aircraft to measure the composition of these convective plumes and determine their effects on the chemistry and composition of the stratosphere. ER-2 flights for DCOTSS were based in Salina, Kansas, which offers an ideal location for sampling convective plumes in the stratosphere. The ER-2 carried an extensive suite of instruments to measure trace gases and aerosol properties and can operate at altitudes as high as 70,000 feet.

In summer 2022, the DCOTSS team successfully concluded intensive field observations and is now in the data analysis and publication phase of the project.

Despite challenges and delays related to the pandemic, the project succeeded in meeting all proposed observational thresholds. In total, the ER-2 flew a total of 24 science flights across 2021 and 2022:

- DCOTSS 2021: 12 science flights, 83 science flight hours
- DCOTSS 2022: 12 science flights, 85.5 science flight hours

Figure 9. *The ER-2 and study team at AFRC in 2022 for the last flight of the DCOTSS project.* ***Photo credit:*** *NASA*

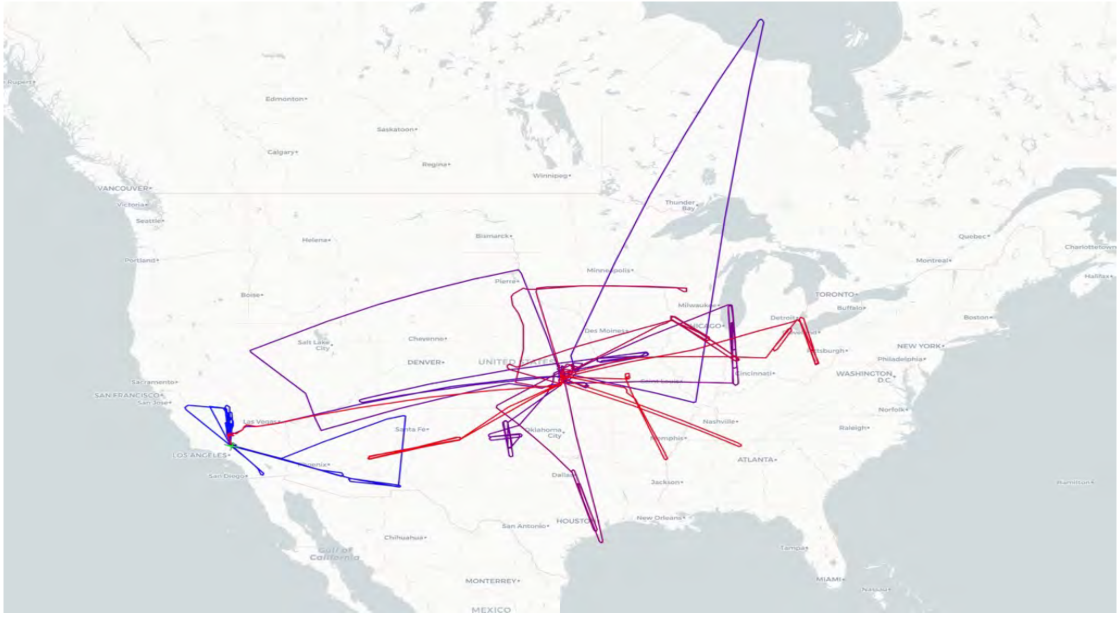


Figure 10. *ER-2 flight tracks during the summer 2022 DCOTSS campaign. (Flight track colors represent different dates.)*
Figure credit: *NASA*

Additionally, for the 2022 deployment, NASA LaRC and Lawrence Livermore National Laboratory independently launched radiosondes in coordination with the ER-2 flights.

Sub-Mesoscale Ocean Dynamics Experiment (S-MODE)

PI – Tom Farrar, Woods Hole Oceanic Institute
Program – Earth Venture Suborbital-3
Aircraft – G-III (L), B-200 (A), Twin Otter
Payload Instruments: PRISM, DopplerScatt, MASS

The Sub-Mesoscale Ocean Dynamics Experiment (S-MODE) is one of five investigations that make up the EVS-3 portfolio. The focus of S-MODE is ocean dynamics and how small-scale ocean eddies may play an important role in heat exchange between the ocean and the atmosphere. With a host of airborne remote sensing instruments and in-water in situ measurements, S-MODE can characterize the physical characteristics of these "submesoscale" ocean eddies at a granularity that is not possible for current ocean-monitoring satellites. After concluding a successful pilot field campaign in November 2021, the S-MODE team used lessons learned to conduct its first Intensive Operating Period (IOP-1), which started in August 2022 and continued through October 2022.

S-MODE field campaigns were conducted in concert with numerous robotic in-water platforms, many of which were deployed well in advance of the airborne flights. These platforms, the first of which were deployed from August to September 2022, provided reconnaissance in situ data of the science operations area, situated approximately 150 miles off the coast of San Francisco. During early October 2022, the remaining platforms traveled to join the mission. The M/V Bold Horizon research vessel traveled south from its mobilization port at Newport, Oregon, during the first week of October. On October 6, 2022, a B-200 (A) and a Twin Otter International (TOIL) Twin Otter aircraft transited to Moffett Federal Airfield and Watsonville Re-

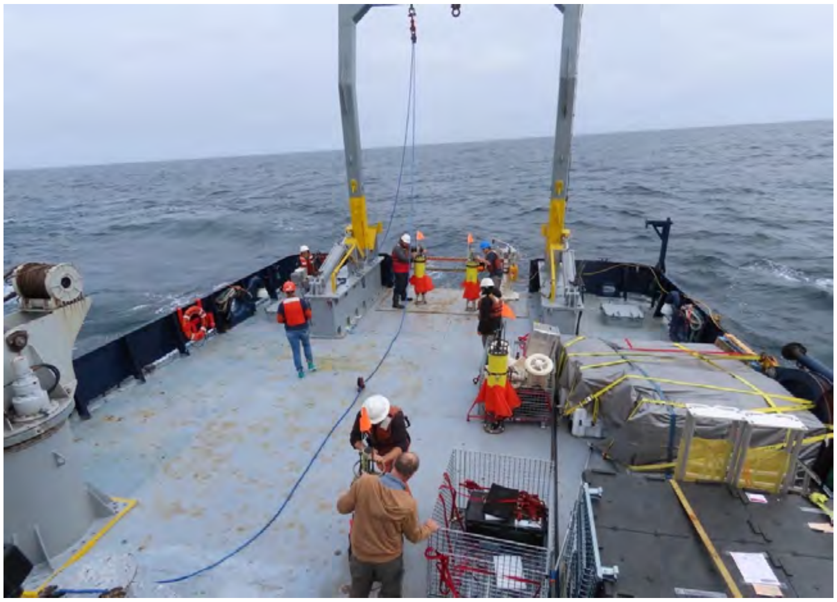


Figure 11. *M/V Bold Horizon science team preparing in-water instruments.* ***Photo credit:*** *Alex Kinsella, WHOI*

gional Airport, respectively, and the LaRC G-III arrived at Moffett Field on October 9, 2022.

The first week of flight operations did not provide a submesoscale target. A persistent low cloud deck blanketed the operations area and limited data collection opportunities for JPL's Portable Remote Imaging SpectroMeter (PRISM) and other optical airborne remote sensing instruments, including UCLA's Multiscale Observing System of the Ocean Surface (MOSES) flown on the B-200 and the Scripps Modular Aerial Sensing System (MASS) flown on the Twin Otter. However, JPL's state-of-the-art airborne Doppler Scatterometer (DopplerScatt) instrument is able to produce fine scale synoptic maps of ocean surface velocity whether there are clouds occluding the ocean surface or not.

Using DopplerScatt data and information gleaned from the in-water robotic platforms, the research vessel moved within the operations area to a promising ocean front with a sharp temperature gradient. Soon after, the persistent cloud deck cleared and the frontal area began to evolve rapidly, becoming unstable. Several instabilities along the front began to wrap around themselves in small-scale swirls – exactly the type of feature the S-MODE investigation was designed to characterize over four years ago. With the clouds leaving the area, all platforms – including the optical airborne instruments – had a clear view of the target. S-MODE Principal Investigator, Tom Farrar, stated that "the combination of early placement of in situ assets at a good site, clear skies, and skillful execution by the instrument and platform operators has allowed a data set that surpasses what we had hoped for when we envisioned S-MODE."

PRISM, flown on the LaRC G-III (NASA 520), was a key IOP-1 instrument. PRISM produces high-resolution maps of ocean color data. These data provide the team with another view of ocean dynamics, but through the lens of ocean biological data rather than direct measurements of ocean surface velocity.

Figure 12. *Left: Team members Delphine Hypolite (UCLA) and Federica Polverari (JPL) at ARC prior to the tenth B-200 flight of the S-MODE IOP-1 campaign.* ***Photo credit:*** *Hector Torres, JPL, Right: LaRC G-III team members after the fourth G-III science flight of the S-MODE IOP-1 campaign. Left to right: Matthew Brame (LaRC), Gregory Slover (LaRC), Eric Brunner (JPL), Holly Bender (JPL), Jeffrey Sherwood (LaRC), and Matthew Coldsnow (LaRC).* ***Photo credit:*** *Mark Helminger, JPL*

The airborne portion of the S-MODE IOP-1 field campaign concluded with the following tally:

- AFRC B-200 (NASA 801): 18 science flights, 80.5 flight hours
- LaRC G-III (NASA 520): 8 science flights, 47 flight hours
- TOIL Twin Otter: 13 science flights, 84 flight hours

With an incredible data set collected from IOP-1, the team looks forward to IOP-2, which will begin with early deployment of in-water reconnaissance assets in February 2023 and airborne deployments in April. The team expects a very exciting synergy during S-MODE IOP-2, as JPL's Surface Water and Ocean Topography (SWOT) satellite is also scheduled to begin collecting data in early 2023.

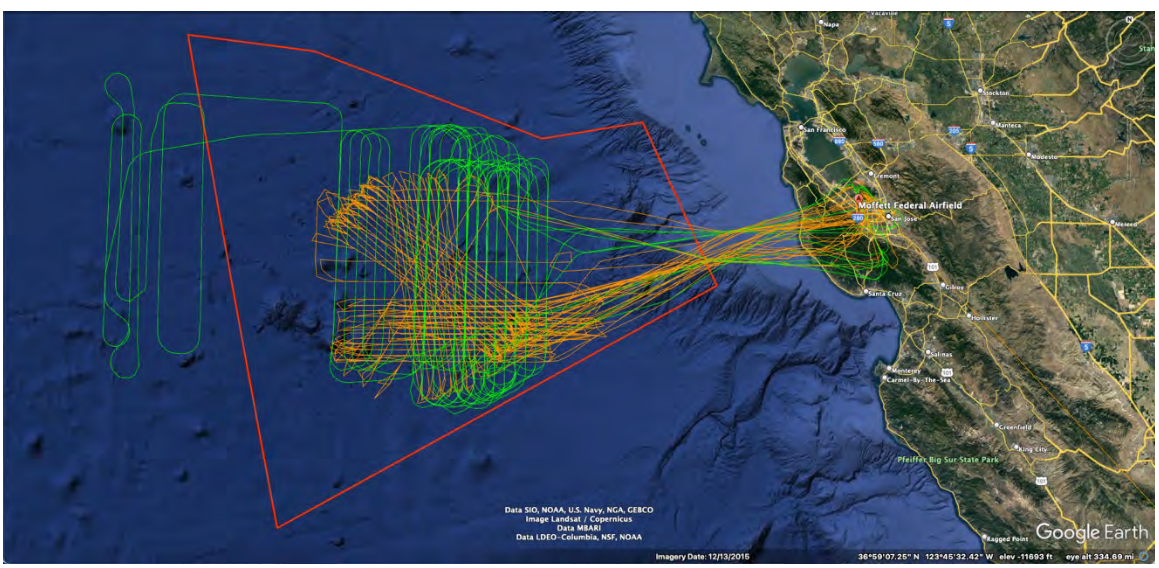


Figure 13. *S-MODE 2022 study area off the coast of California. Green tracks: LaRC G-III, yellow tracks: AFRC B-200.*
Figure credit: *Erin Czech, ARC*

Arctic Boreal Vulnerability Experiment (ABoVE)

PIs – Charles Miller, NASA JPL; Peter Griffith, NASA GSFC
Program – Terrestrial Ecology
Aircraft – C-20A, B-200
Payload Instruments: AVIRIS-NG, UAVSAR

NASA's Terrestrial Ecology Program carried out the fourth Arctic Boreal Vulnerability Experiment (ABoVE) airborne campaign during July and August 2022, after a two-year hiatus. The team acquired hyperspectral imagery from two instruments: AVIRIS-NG flown on a Dynamic Aviation B-200 and UAVSAR, a L-band polarized interferometric synthetic aperture radar (PolInSAR) provided by JPL, flown on the AFRC C-20A. These data collections supported investigators selected for Phase 3 of the ABoVE mission. In addition, they contributed to new requests from Canadian and other US ABoVE partners. The new data sets complement data collected during ABoVE airborne campaigns conducted in 2017, 2018, and 2019. Additionally, coordination of the AVIRIS-NG flights with German Space Agency's CoMET 2.0 Arctic payload enabled exploration of Arctic methane emissions using multiple complementary remote sensing instruments, including airborne precursors for the Methane Remote Sensing Lidar Mission (MERLIN) and Copernicus Carbon Dioxide Monitoring mission (CO2-M) satellites.

Goddard's LiDAR, Hyperspectral & Thermal Imager (G-LiHT)

PI - Bruce Cook, NASA GSFC
Program - Terrestrial Ecology
Aircraft - A-90
Payload instrument - G-LiHT

AVIRIS-NG flew a total of 116.3 flight hours on the B-200 and UAVSAR flew a total of 55.4 flight hours on the C-20A. The aircraft were based in Fairbanks, Alaska. The ABoVE mission received additional support from the G-LiHT payload,

Figure 14. *The C-20A in Yellowknife, NT, Canada after the August 16, 2022 sortie. This group was included in the ABoVE L-band SAR team on science flights. Left to right: instrument operator David Austerberry, ABoVE Project Manager Peter Griffith, Northwest Territories intern Ryan Walsh, and Northwest Territories intern Jacki Tsetta.* ***Photo credit:*** *NASA*

which flew on a commercial A-90 aircraft out of Kodiak and Aniak, Alaska. The G-LiHT mission flew 117.2 flight hours, primarily to collect data for the Forest Inventory and Analysis (FIA), but was also able to contribute carbon monitoring data to ABoVE.

Public events in Yellowknife, Northwest Territories, Canada and Fairbanks, Alaska allowed residents to tour the C-20A aircraft and learn more about how NASA is determined to understand and protect their lands, waters, and critical services these resources provide.

Figure 15. *The L-band SAR team was joined by German Aerospace Center's CoMET 2.0 Arctic team and the HALO aircraft (right) in Yellowknife, NT, Canada, for a public event on August 16, 2022. Fifty local residents toured the aircraft and learned about the measurements each team was making. The Canadian Broadcasting Corp (CBC), Cabin Radio, and other Canadian press conducted interviews and reported on the event.* ***Photo credit:*** *NASA*

Figure 16. *NASA/AVIRIS (N53W) and DLR HALO/CoMET 2.0 Arctic teams on the ramp in Inuvik, Northwest Territories, Canada after a successful joint flight over the Mackenzie Delta searching for methane sources on August 12, 2022.* ***Photo credit:*** *NASA*

Asian summer monsoon Chemical and CLimate Impact Project (ACCLIP)

PIs – Paul Newman, NASA GSFC; Laura Pan, National Center for Atmospheric Research
Program – Atmospheric Composition
Aircraft – NASA WB-57F, NSF/NCAR G-V
Payload Instruments:
NASA WB-57F: 2D-S, AWAS, BBR, Chi-WIS, CPI, COLD2, COMA, DLH, FCDP, ISAF, LIF-NO/SO2, MMS, PALMS, Roscoe, SP2, UASO3, UTLS-AMP
NSF/NCAR G-V Gulfstream: Fast-O3 and NO/NOy, Aerodyne, Picarro, GT-CIMS, TOGA, AWAS, VCSEL, NMASS, UHSAS, SP2, ERICA, HARP, 2DC, CDP, PPTH, MTP

In the summer 2022, NASA and the National Science Foundation's National Center for Atmospheric Research (NCAR) conducted a jointly-funded two-month campaign, Asian summer monsoon Chemical and CLimate Impact Project (ACCLIP), in the Republic of Korea. Two aircraft, the NASA WB-57F and the NCAR G-V, were outfitted with state-of-the-art sensors. Approximately 100 scientists from the US and other international research organizations participated in ACCLIP.

The Asian Summer Monsoon (ASM) is the largest meteorological pattern during the Northern Hemisphere (NH) summer season. Persistent convection and the large anticyclonic flow patterns in the upper troposphere and lower stratosphere (UTLS) associated with ASM lead to a significant enhancement in the UTLS of trace species with pollution and biomass burning origins. The monsoon convection occurs over South, Southeast, and East Asia, a region of uniquely complex and rapidly changing emissions tied to its high population density and significant economic growth. The coupling of the most polluted boundary layer on Earth to the largest dynamical system in the summer season through the deep monsoon convection has the potential to create significant chemical and climate impacts. An accurate representation of ASM transport, chemical, and microphysical processes in chemistry-climate models is needed for characterizing ASM chemistry-climate interactions and predicting its future impact in a changing climate. Therefore, the ASM plays a key role in ACCLIP, since it fundamentally sets up the anti-cyclone and leads to the uplift of various gases from the surface of Asia into the UTLS. The tall thunderstorms of the monsoon in Southern Asia can pump air and pollution from the surface to altitudes greater than

Figure 17. *The ACCLIP aircraft (NASA WB-57 and NCAR G-V) at United States Air Force Osan Air Base, South Korea.*
Photo credit: *NASA*

50,000 feet. Eventually, this air from the surface gets streamed to higher latitudes and mixed across the Northern Hemisphere.

ACCLIP's main goal was to observe the gases and particles being shed from the anti-cyclone into the Northern Hemisphere and then determine how they may be impacting the Earth's ozone layer and climate. A total of 31 research flights were conducted by ACCLIP aircraft: 14 NSF/NCAR G-V flights and 17 NASA WB-57F flights. On September 1, 2022, the WB-57F had the unique opportunity to conduct measurements over portions of super typhoon Hinnamnor.

The field portion of ACCLIP recently concluded, and the team is currently working on merging data files from the two aircraft. Although data are still being compiled, the science team has already made one important observation regarding the geographical extent of the monsoon: they observed a larger eastward extension compared to what the models had predicted. This provides important context for future observations. The science team looks forward to making additional discoveries as it nears the publication phase of the project.

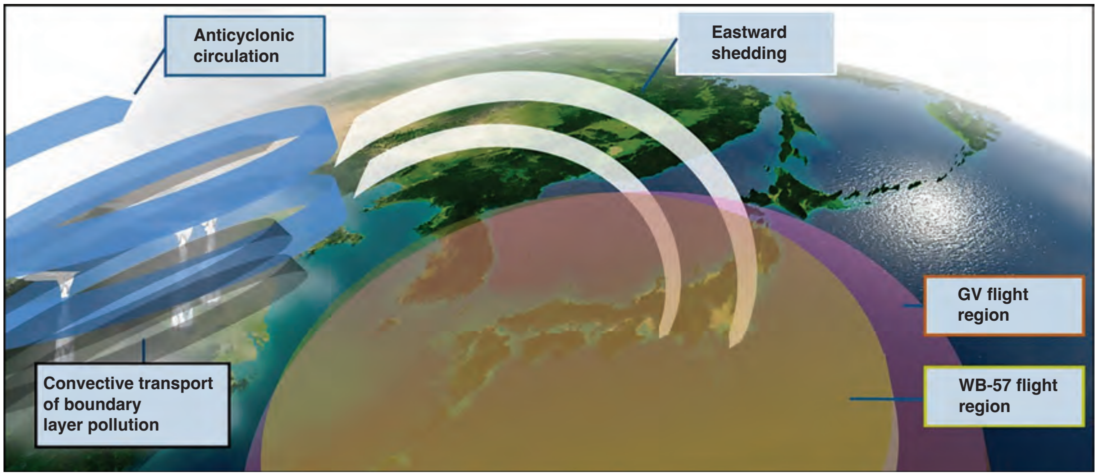


Figure 18. *Diagram showing flight regions for the two aircraft, NASA WB-57 and NCAR G-V, that flew with ACCLIP* ***Figure credit:*** *NASA*

Figure 19. *ACCLIP team and aircraft at USAF OSAN Airbase, South Korea.* ***Photo credit:*** *NASA*

Convective Processes Experiment – Cabo Verde (CPEX-CV)

Mission Scientists – Jonathan Zawislak, University of Miami/Cooperative Institute for Marine and Atmospheric Studies; Ed Nowottnick, NASA GSFC; Amin Nehrir, NASA LaRC
Program – Weather and Atmospheric Dynamics
Aircraft – DC-8
Payload Instruments: DAWN, APR-3, HALO, HAMSR, CAPS, AIRO, Dropsondes

In September 2022, NASA's Weather Program carried out the Convective Processes Experiment – Cabo Verde (CPEX-CV) with the AFRC DC-8 aircraft. The goals of CPEX-CV were to observe convective processes and lifecycles in a variety of dynamic, thermodynamic, and aerosol environments dominant in the northern East Atlantic during the Northern Hemisphere boreal summer. These environments include persistent (e.g., Intertropical Convergence Zone) and periodic (e.g., African easterly waves, tropical cyclones) phenomena, as well as large-scale forcing, local terrain effects (e.g., land-ocean transition off western Africa), aerosol-cloud interactions within the Saharan Air Layer (SAL), and marine boundary layer processes (e.g., cold pool dynamics).

The mission was flown with NASA-European Space Agency (ESA)'s Joint Aeolus Tropical Atlantic Campaign (JATAC), a collaborative experiment dedicated to validating measurements from the Atmospheric Dynamics Mission-Aeolus (ADM-Aeolus) satellite, which hosts the first wind profiling lidar in space. NASA contributed to this validation effort through satellite underflight legs with the DC-8, which had a suite of onboard remote sensors. ESA-partner agencies and universities contributed by hosting observing platforms in the Republic of Cabo Verde.

The DC-8 was equipped with active and passive remote sensors, as well as dropsondes. This permitted profiling measurements of tropospheric winds, water vapor, temperature, aerosols (dust), clouds, and precipitation. Likewise, in situ measurements of cloud, aerosol, and precipita-

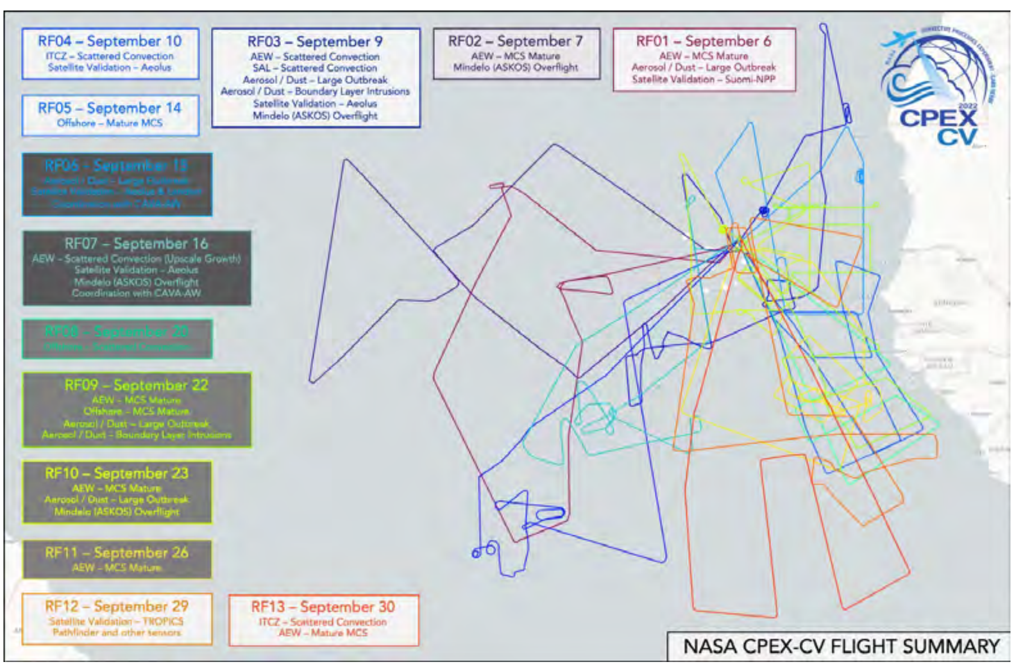


Figure 20. *The 13 DC-8 missions flown during CPEX-CV and the dedicated objectives of each flight.* ***Figure credit:*** *NASA*

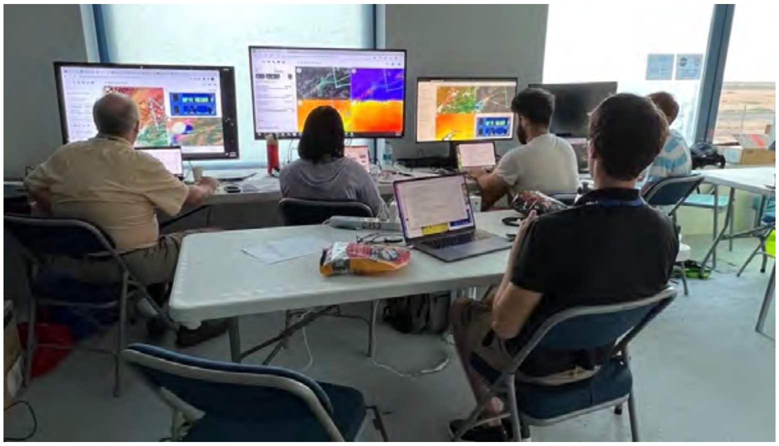


Figure 21. *CPEX-CV Mission Scientists, seen supporting a flight from the ground, consisted of a mix of graduate students and other early career scientists, as well as seasoned middle- and late-stage scientists.* ***Photo credit:*** *Jonathan Zawislak*

tion particles were made with the Cloud, Aerosol, Precipitation Spectrometer (CAPS) probe mounted on the aircraft wing.

Thirteen flights totaling over 90 flight hours were flown during CPEX-CV (Figure 21). Several flights targeted African easterly waves that accompanied SAL and convective systems moving off western Africa. These events likely developed into Major Hurricanes Florence and Ian in the western Atlantic and Caribbean. Although the genesis of these storms happened downstream several days after the flights, CPEX-CV did capture the genesis of Tropical Storm Hermine between the west coast of Africa and Cabo Verde.

Just over 400 dropsondes were released during the 13 CPEX-CV flights, targeting moisture, temperature, and aerosol gradients near/within the SAL, as well as within convection. Rawindsondes, launched three times per day from Sal Island, Cape Verde, complimented the dropsonde effort throughout the campaign.

The project included four dedicated Aeolus underflight legs, including two coordinated with JATAC's Calibration and Validation for Aeolus – Aerosols and Winds (CAVA-AW) Slovenian light WT-10 aircraft, as well as several overflights above ASKOS, a ground instrumentation site on São Vicente island, Cabo Verde.

CPEX-CV also transmitted quality-controlled dropsonde data from the DC-8 into the Global Telecommunications System (GTS) for delivery to the National Hurricane Center (NHC) and for assimilation into global forecast models, which included National Centers for Environmental Prediction (NCEP) and European Centre for Medium-Range Weather Forecasts (ECMWF). Given the sparsity of observations in the East Atlantic, especially from aircraft, the real-time transmission of dropsonde data offered a unique opportunity to target dropsondes observations in a region where large forecast errors are typical and observations infrequent.

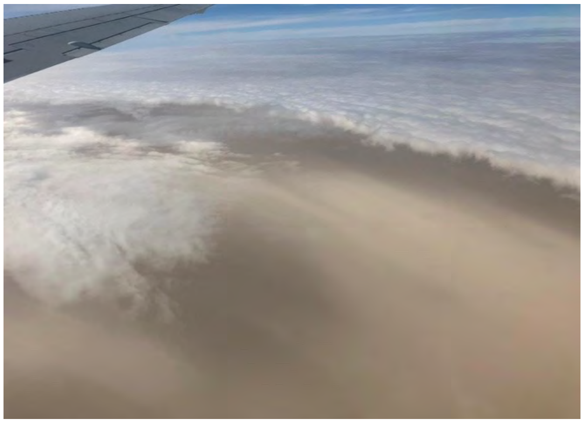


Figure 22. *Saharan dust mingling with cloud decks taken from the DC-8 during a CPEX-CV mission.* ***Photo credit:*** *Kris Bedka*

Salinity and Stratification at the Sea Ice Edge (SASSIE)

PI – Kyla Druschka, University of Washington
Program – Physical Oceanography
Aircraft – DC-3
Payload Instruments: PALS

Arctic sea ice cover has declined dramatically in recent decades, with substantial impacts on climate. Prediction of seasonal and long-term sea ice patterns remains poor, in part because we do not fully understand the complex interactions between the ocean, ice, and atmosphere. NASA's Salinity and Stratification at the Sea Ice Edge (SASSIE) mission seeks to unravel these interactions through an intensive field and modeling campaign focused on the fresh salinity anomalies generated by melting sea ice during the summer. SASSIE will quantify how these melt water layers evolve in time and space during late summer, and ultimately how they influence where and when sea ice forms again in the autumn. In addition, SASSIE measurements of surface salinity will be used to improve and validate satellite salinity algorithms, leading to better observability and predictability.

The SASSIE field campaign took place in August and October 2022 and included in situ and airborne components, which targeted a segment of the Beaufort Sea stretching from the north slope of Alaska to the sea ice edge (Figure 24). In August, four Wave Gliders – uncrewed, wave-powered vehicles that measure the upper ocean and surface weather – were launched and piloted from shore to sample the emerging open water as the sea ice retreated, leaving fresh melt water in its wake. An intensive ship-based campaign from September 5 to October 3, 2022, aboard the R/V Woldstad research vessel collected a suite of oceanic and atmospheric measurements that captured the evolution of the fresh surface layers around the sea ice edge during the transition to the colder autumn season. The SASSIE team also deployed around 30 drifters of floats to measure the coupled air-sea-ice system.

The airborne team was deployed at Deadhorse, AK from September 5 to 25, 2022. The airborne payload Passive Active L-band System (PALS) was installed on a Kenn Borek DC-3. PALS was developed at JPL and is primarily a

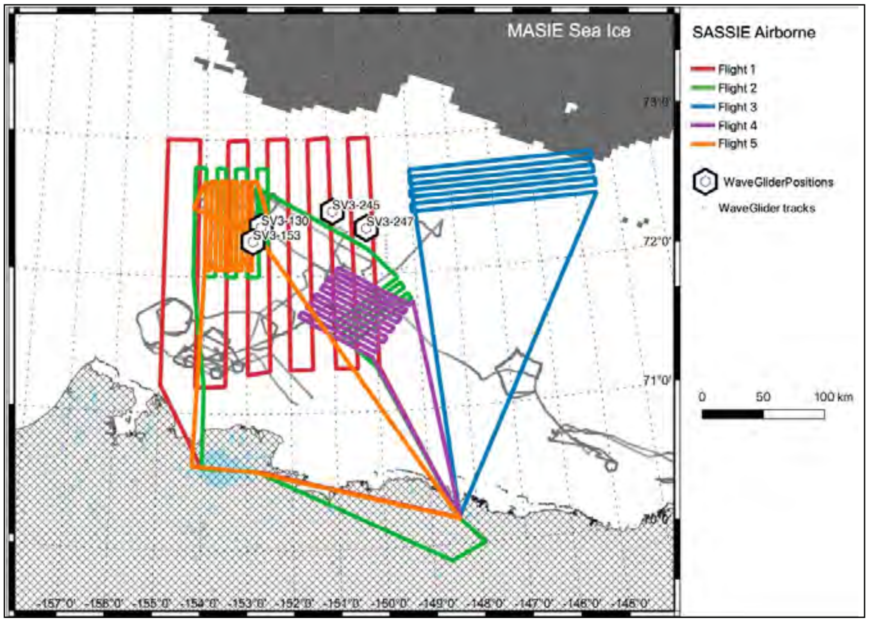


Figure 23. *The five aircraft flight tracks overlay positions of Wave Gliders deployed during SASSIE. A one-day snapshot of September 2022 sea ice (MASIE product) indicates extent of sea ice.* ***Figure credit:*** *NASA*

microwave radiometer that is extremely sensitive to salinity, temperature, and winds over the ocean surface. PALS also included a C/X-band radiometer sensitive to wind speed and an IR/visible camera sensitive to sea surface temperature.

Due to low visibility conditions at Deadhorse and surrounding airports, no flights were possible during the first week of deployment. The first flight was on September 11, 2022, followed by four more flights out of Deadhorse surveying grid regions of several hundreds of kilometers. In total, around 40 hours were flown. The flight planning and grids varied depending on the latest sea ice data and in situ measurements from the research vessel and Wave Gliders. The airborne team conducted science surveys with a variety of spatial sampling, including flights over open ocean and closer to the ice edge. This strategy allowed the SASSIE team to combine high precision but spatially limited in situ measurements with broader spatial coverage from the airborne measurements.

Airborne and in situ data processing are well underway and promise new insights into the coupled, multi-scale interactions between the ocean, atmosphere, and sea ice in the Beaufort Sea.

Blue Carbon Prototype Products for Mangrove Methane and Carbon Dioxide Fluxes (BlueFlux)

PIs – Glenn Wolfe, NASA GSFC; Benjamin Poulter, NASA GSFC
Program – Carbon Monitoring System
Aircraft – B-200 (DA)
Payload Instruments: CARAFE

Mangrove ecosystems are among the most productive ecosystems in the world. Mangroves store massive amounts of carbon in their stems, soils, and complex root systems, buffer shorelines from erosion, and provide a habitat for fisheries. Over the past several decades, coastal development, rising sea level, and increasing hurricane severity have led to the loss of mangroves. Recently, organizations proposing nature-based solutions to climate mitigation have renewed their interest in conserving and restoring these regions. NASA GSFC's Blue Carbon Prototype Products for Mangrove Methane and Carbon Dioxide Fluxes (BlueFlux) field campaign, supported by NASA's Carbon Monitoring System (CMS), began in 2022 and continues in 2023. BlueFlux aims to quantify the carbon cycle of mangroves by combining field and aircraft measurements with those from space-based instruments on the International Space Station (ISS) and polar orbiting missions. The carbon products developed from BlueFlux will enable conservation and restoration stakeholders to better understand how mangroves can contribute to "blue carbon" initiatives that intend to mitigate climate change through nature-based climate solutions.

A key BlueFlux measurement is the exchange of carbon dioxide and methane between mangroves and other wetland surfaces and the atmosphere. BlueFlux uses the NASA Carbon Airborne Flux Experiment (CARAFE) instrument suite to measure these fluxes directly, using a combination of gas analyzers and a wind probe flown on a Dynamic Aviation B-200. The approach derives fluxes using the eddy covariance method, integrating the covariance of high frequency changes in wind direction and trace gas concentration. Six BlueFlux deployments are planned, with the first test flights completed in April 2022 and the first science flights in October 2022. These flights were made at altitudes of 100-meters over Southern Florida, including the Everglades and Big Cypress National Parks (Figure 25), with roughly 25 flight hours per de-

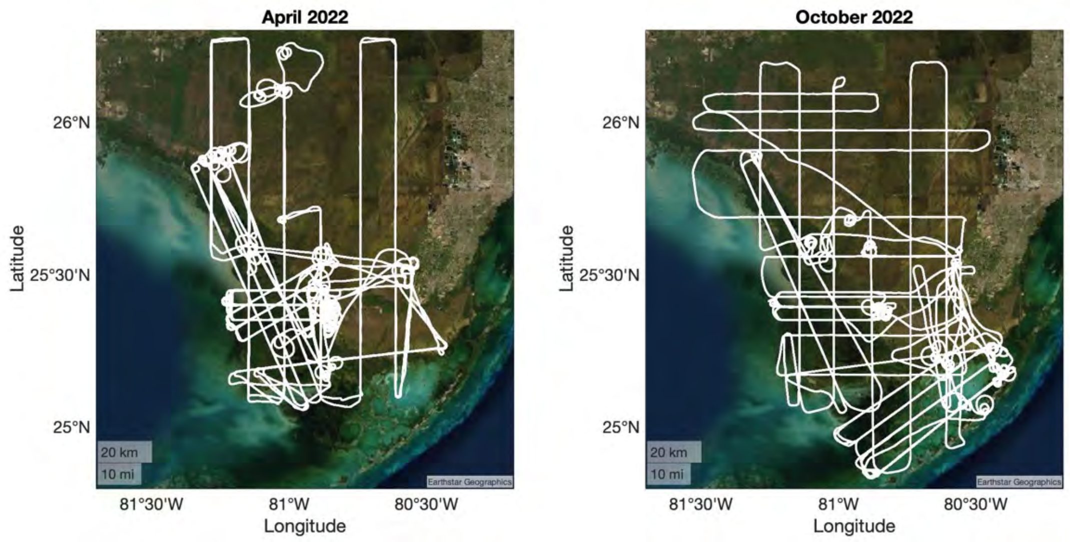


Figure 24. *CARAFE flight tracks and spirals during April and October 2022.* ***Figure credit:*** *Erin Delaria*

ployment covering large areas not represented by stationary flux towers.

BlueFlux CARAFE measurements will be combined with ground-based field studies to provide additional context. Field ecologist teams from Yale University and East Carolina University are using chambers to measure the gaseous fluxes of methane and carbon dioxide from stems, soil, roots, and water, and terrestrial laser scanners to collect structural information on the volume of emitting surfaces, which will help in partitioning the fluxes to individual ecosystem components. These measurements will enable scaling individual components back to the ecosystem (Figure 26) and will be used to help train satellite machine learning models. Scientists working with the Global Ecosystem Dynamics Investigation (GEDI) waveform lidar on the ISS and Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua and Terra, which measure surface reflectance, can use BlueFlux data to train machine learning models. Together, this will develop a twenty-year daily time series of gridded carbon flux products for southern Florida and potentially the greater Caribbean region. BlueFlux also provides an opportunity to better understand how hurricanes affect wetland regions. The BlueFlux October 2022 field campaign occurred approximately two weeks after Hurricane Ian passed over Florida. These measurements will help better define post-hurricane impacts, including how a heavy rain event affects wetland salinity levels and methane production.

The October 2022 BlueFlux field campaign provided the opportunity to engage with the public, students from the Florida Coastal Everglades (FCE) Long-term Ecological Research Network (LTER), and students and families from the Miccosukee, a tribal nation adjacent to the Everglades National Park. The event took place at Homestead Airport, Florida, which allowed tours around and inside the aircraft to teach attendees about the instruments. The field team also demonstrated the laser scanner and gas analyzers. The next BlueFlux field campaign is scheduled for February 2023.

Figure 25. *Photo of vegetation taken during the April 2022 BlueFlux flight mission, showing how the fluxes measured by the aircraft come from a mix of vegetation types and surface features that the ground campaign will separate.* ***Photo credit:*** *NASA*

Carbon Mapper (CM)

PI – Riley Duren, NASA JPL
Program –Atmospheric Composition and Chemistry
Aircraft – B-200 (DA)
Payload Instruments: AVIRIS-NG

Carbon Mapper, Inc., is a non-profit entity partnering with NASA and JPL. The Carbon Mapper (CM) mission significantly expanded its airborne program in 2022 in preparation for the expected Fall 2023 launch of the Carbon Mapper satellites. The CM Airborne Program deployed for a total of 146 science flight days, including 61 with the NASA/JPL AVIRIS-NG team and 85 with the Arizona State University (ASU) Global Airborne Observatory (GAO). Flights were conducted across 21 US states and five Canadian provinces and surveyed methane emissions enhancements over hundreds of facilities. This campaign mapped a total area exceeding 100,000 square kilometers and led to the identification of hundreds of large area and point source methane emissions from industrial sectors, including agricultural, energy, waste, and mining.

A major focus of the 2022 CM airborne campaign was on methane emissions from the waste sector, including unprecedented direct measurements of more than 200 operating landfills in 17 US states, as well as high-frequency temporal sampling of super-emitting landfill point sources in California, to better characterize variability. These landfill data and insights have proved valuable for direct engagements with landfill operators, state agencies, and the US Environmental Protection Agency (EPA).

Additional highlights of the 2022 CM airborne campaign include multiple surveys of the San Juan Basin in the Southwestern United States to characterize the intermittency of methane emissions from the region, which was initially captured by AVIRIS-NG in 2015. Carbon Mapper expanded its coverage of coal mining operations in the United States and Canada and continued to map significant US oil producing basins, including CM's first measurements of the Bakken shale, Anadarko Basin, and Piceance Basin. Carbon Mapper also detected and reported two potentially hazardous methane events, triggering responses and expedited repairs.

The CM airborne program is continuing ambitious plans for 2023. CM plans to conduct international surveys in Latin America using AVIRIS-NG, pending international approvals. Methane emission data obtained from these new regions will allow CM to better characterize the global prevalence of super-emitters, while facilitating interactions with a broader set of stakeholders for its methane data products.

While the airborne data constitutes the team's contemporary observing strategy, the entire CM airborne program is meant to inform the Carbon Mapper satellite constellation program. Connectivity between government and industry stakeholders is intended to facilitate use of CM satellite data products and expedite mitigation actions during hazardous events.

Carbon Mapper's relationship with JPL continues to be paramount to the launch of CM's first two satellite instruments in 2023. The Carbon Mapper program builds on 10+ years of methane research and airborne surveys conducted by team members and collaborators at NASA and JPL. The Carbon Mapper satellite program is built around the Carbon Plume Mapper instrument, a spaceborne imaging spectrometer being designed and built by NASA/JPL, leveraging extensive JPL imaging spectrometry instrument heritage, including AVIRIS-Classic, AVIRIS-NG, GAO-VSWIR, and most recently, the Earth Surface Mineral Dust Source Investigation (EMIT) instrument now operating on the International Space Station (ISS).

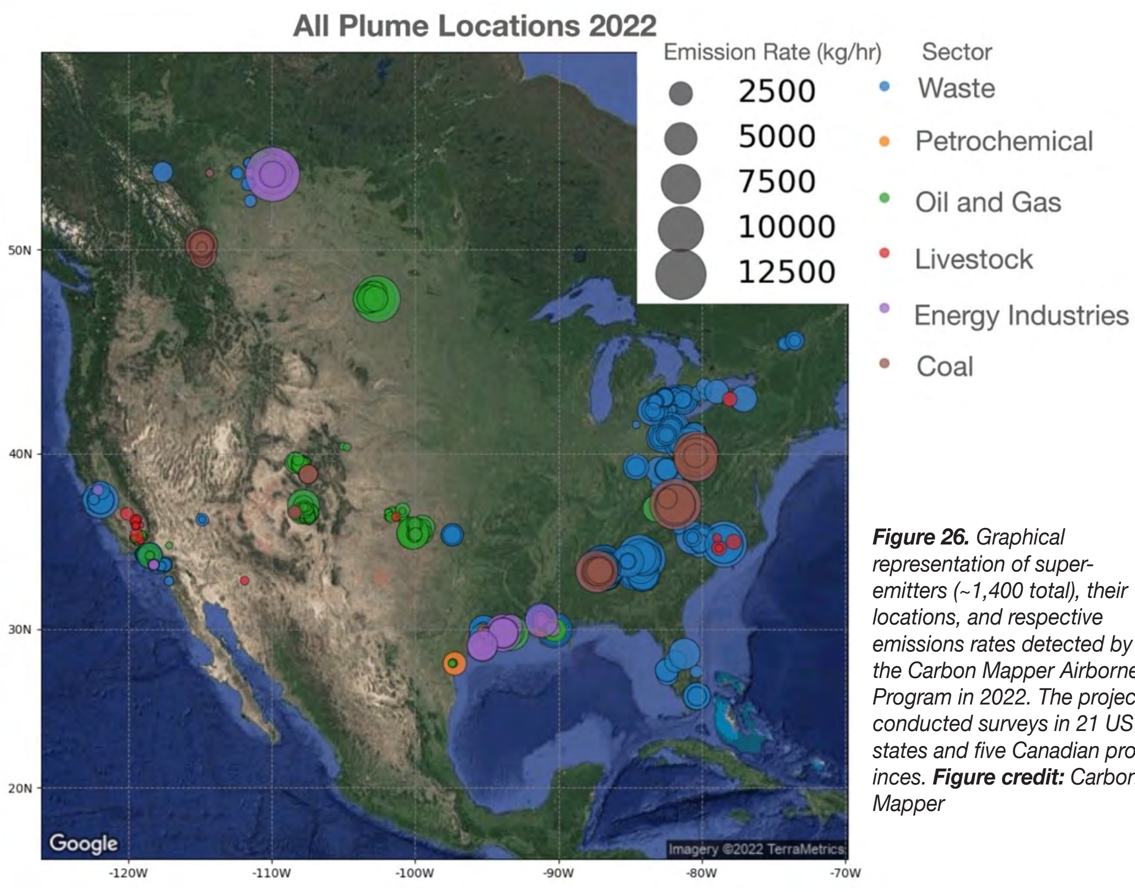


Figure 26. *Graphical representation of super-emitters (~1,400 total), their locations, and respective emissions rates detected by the Carbon Mapper Airborne Program in 2022. The project conducted surveys in 21 US states and five Canadian provinces.* ***Figure credit:*** *Carbon Mapper*

Uninhabited Arial Vehicle Synthetic Aperture Radar (UAVSAR)

PI – Yunling Lou, NASA JPL
Programs –Water and Energy Cycle, Earth Surface and Interior
Aircraft – C20-A (AFRC)

In FY22, the Uninhabited Arial Vehicle Synthetic Aperture Radar (UAVSAR) project supported 16 flight requests, eight principal investigators, and accomplished two deployments with multi-disciplinary science teams: SMAPVEX and ABoVE. The project also completed two short campaigns in the US West Coast. The AFRC C-20A/G-III conducted 53 science flights for a total of 263 hours. Most flights (51) carried the L-band instrument, and two flights carried the P-band instrument. The JSC G-III conducted five science flights carrying the P-band instrument, for a total of 25 hours.

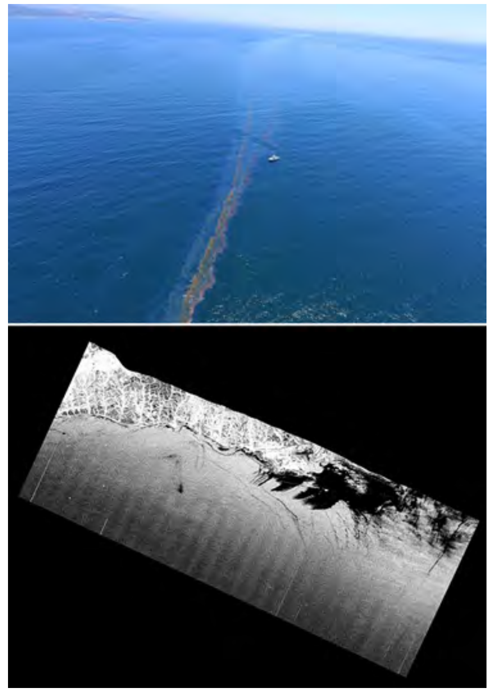


Figure 27. *Santa Barbara, California oil spill and SAR image taken during the UAVSAR mission.*
Figure credit: *Cathleen Jones, JPL*

Two campaigns addressed hazards:

- Santa Barbara oil slick mapping (October 2021, June-July 2022)
- Huntington Beach oil spill (October 2021)

As part of the Marine Oil Spill Thickness (MOST) project, led by Frank Monaldo from the University of Maryland, UAVSAR acquired observations over a natural oil seepage off the

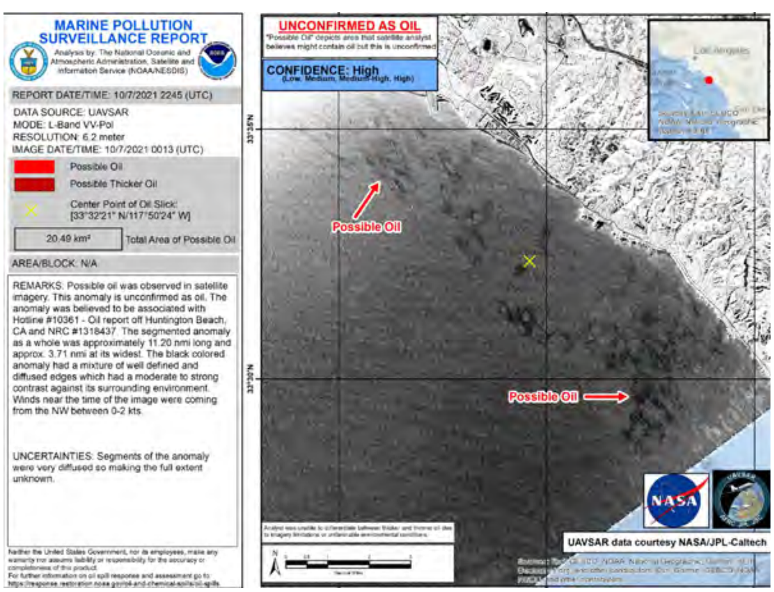


Figure 28. *Oil spill report for the area surveyed by UAVSAR.*
Figure credit: *NOAA*

coast of Santa Barbara, California. Flights were coordinated with crews from NOAA and the US Coast Guard, who conducted in-situ observations. These airborne SAR observations are being used to determine oil thickness and practice workflow for disaster response.

UAVSAR also supported a disaster response flight on October 6, 2021, over a major oil spill detected off the coast of Orange County, California on October 2, 2021. The flight was requested by NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) in coordination with the NASA Disasters Program Office. A JPL team led by C. Jones helped produce the first Marine Pollution Surveillance Report from UAVSAR imagery.

Figure 29. *L-band image of Hay River, Northwest Territory, Canada.* ***Figure credit:*** *JPL*

The ABoVE, SMAPVEX and TomoSAR missions, all of which used the L-Band UAVSAR, are described on pages 18, 32 and 42, respectively. Figure 29 shows an L-band image of the Hay River obtained during ABoVE.

In FY22, at least 50 peer-reviewed papers were published based on UAVSAR data. One example is a paper by Simon Kraatz and colleagues utilizing PolSAR observations to evaluate methodologies for mapping cropland with satellite data *(https://doi.org/10.1029/2022EA002366)*. Publication links are available at: *https://uavsar.jpl.nasa.gov/cgi-bin/publications.pl.*

UAVSAR Next Generation Airborne SAR Update

Development of the next generation airborne SAR is underway, including plans to transform UAVSAR into a more robust and capable facility instrument suite. The development will improve platform reliability by making it possible to use the more maintainable G-IV aircraft. The NASA G-IV will be modified to accommodate two radar antennas for simultaneous dual-frequency operation, such as joint P- and L-band SAR operations for ecosystem and land deformation studies. Planned updates include modernizing the radar electronics by implementing a digital beamforming capability. This will enable it to serve as a testbed for future technologies needed to make new measurements, such as surface and vegetation structure, to support future decadal survey themes. The new capability is expected to be ready for operation in 2 to 3 years.

ASP Support to ESD Satellites and International Space Station Missions

In addition to EVS, the primary ASP stakeholders are Earth Science space flight missions, including satellite missions and missions on the International Space Station (ISS). The program provides platforms to collect data for algorithm development prior to launch, testing instrument concepts for satellite/ISS payloads or airborne simulators, and providing data for calibration or validation of satellite algorithms, measurements, or observations once in orbit. In FY22, ASP provided support to multiple operational Earth Science space missions (Table 7). Return of an IceBridge team to Greenland provided summer data for ICESat-2. A final cal/val campaign for CALIPSO was able to fly night flights out of Bermuda.

Several FY22 airborne process missions also collected data valuable to future missions. Airborne campaigns are providing image data and instrument performance data to support TEMPO, scheduled to launch in 2023, and NISAR, scheduled to launch in 2024. Future missions include SBG, which is supported by years of data now identified as the WDTS and a new activity, SHIFT series.

Table 7. *Space missions supported by aircraft campaigns in FY22.*

Airborne Mission	Space Mission Supported	Flight Hours	Location	Aircraft
ACTIVATE	CALIPSO	589.7	Atlantic Coast	UC-12B, HU-25A
IMPACTS	CloudSat, GOES R, GPM	202.0	Atlantic Coast	B-200
ABoVE	SBG, OCO-II, Landsat 8	171.1	Alaska, Canada	G-III, B-200
ACCLIP	AURA	139.5	South Korea	WB-57
UAVSAR Combined Missions	NISAR	130.8	CONUS, Alaska	G-III
CPEX-CV	GPM, CALIPSO	119.4	Cabo Verde	DC-8
G-LiHT	Landsat 8	117.0	Alaska	A90
SMAPVEX 2022	SMAP, NISAR	79.1	Northeast Forests	G-III (SAR)
SHIFT	SBG	74.0	California Coast	B-200
ICESat-2 Summer Cal/Val	ICESat-2	69.6	Greenland	GV
S-MODE	SWOT	57.8	Pacific Coast	B-200, G-II (L)
Multi-channel Snow Radar	ICESat-2	47.3	Greenland	P-3
CALIPSO Night Flights	CALIPSO	25.5	Bermuda	B-200
Western Diversity Time Series	SBG	23.7	California	ER-2

Soil Moisture Active Passive Validation Experiment (SMAPVEX) 2022

PI – Seungbum Kim, NASA JPL
Program – Terrestrial Hydrology Program
Aircraft – C-20A
Payload Instruments: UAVSAR (L-band)

The retrieval of soil moisture under forest canopy has long been an important and challenging goal for remote sensing. The performance of the Soil Moisture Active Passive (SMAP) radiometer-based soil moisture product meets the mission requirements, which apply to conditions when vegetation density is less than in typical forests (up to 5 kg/m^2 vegetation water content). Now Soil Moisture Active Passive Validation Experiment (SMAPVEX) aims to expand the domain of validated retrievals by conducting a field experiment in the temperate forests of the northeastern US.

The team selected two locations for the experiment, each encompassing a single SMAP 33-km pixel. The areas are located in central Massachusetts and upstate New York. A temporary soil moisture network of about 20 stations was deployed at each site. Two intensive SMAPVEX observation periods (IOP) took place, including airborne observations and manual measurements of soil moisture and forest vegetation. The airborne segments made use of a NISAR-like radar (UAVSAR). The ground measurements included lidar, radiometer, reflectometer, and more.

The Massachusetts (MA) site is fully forested, whereas the Millbrook, New York (MB) site is partially non-forested. The experiment was designed to test the SMAP retrieval in fully forested and partially forested cases because significant portions of the U.S. and the globe have non-uniform forest cover at the SMAP resolution scale.

While the campaign was planned with the airborne radiometer since 2019, UAVSAR was added to the SMAPVEX campaign in January 2022 to support NISAR's soil moisture algorithm development. The NISAR soil moisture products will provide unprecedented 200-m resolution information globally every 12 days. By comparison, SMAP data are refreshed every 3 days at a spatial resolution of 9 to 25 km. UAVSAR's high spatial resolution supports unique opportunities to investigate challenging issues that may not be feasible to study otherwise. These include

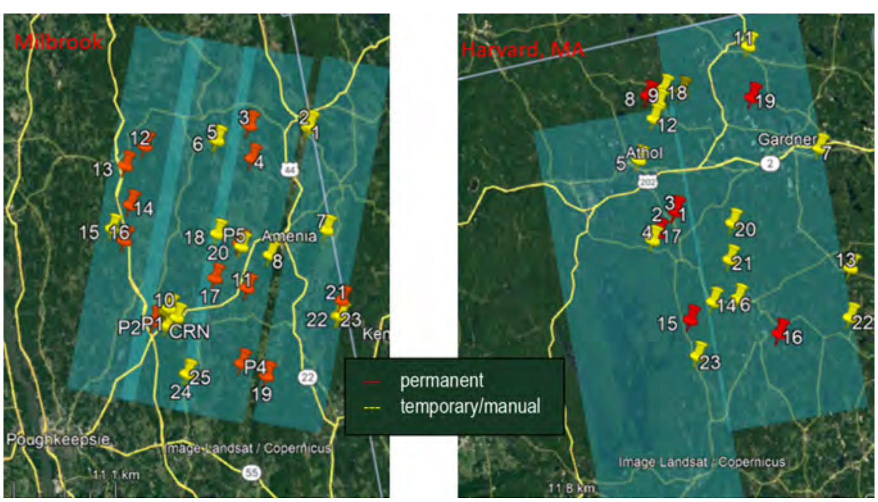


Figure 30. *Soil moisture ground sample locations in Millbrook, New York (MB) and Harvard, Massachusetts (MA). UAVSAR swath shows 30-50 deg processed strip (MA) and 25-60 deg strip (MB).* ***Figure credit:*** *NASA*

how terrain slope affects retrieval performance, how the direction of satellite viewing between ascending and descending tracks influences estimates, whether high-resolution helps in heterogeneous vegetation covers, how well radar-based retrievals perform versus radiometer-driven inversion, and more.

Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) Summer Calibration/Validation

PI – Nathan Kurtz, NASA GSFC
Program – ICESat-2
Aircraft – GV
Payload Instruments: LVIS, Chiroptera-4X

NASA's Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) has been taking global measurements of surface height since October 2018. A key part of ICESat-2's science objectives is the measurement of the Earth's polar sea ice cover, specifically the retrieval of sea ice freeboard (the portion of sea ice and snow floating above the water surface), which is then used to determine the total thickness of the sea ice. In the Arctic, the time series of measurements from ICESat (launched in 2003) to ICESat-2 has shown a loss of nearly 6,000 cubic kilometers, or one-third of the total volume of Arctic sea ice in the last two decades, driven largely by declines in the multi-year ice coverage and the transition to a dominantly seasonal ice cover. This ICESat earlier measurement time series used data from the fall and spring months, when quality data were available from each satellite. However, developing a year-round sea ice thickness time series would be extremely beneficial for better understanding Arctic sea ice thickness change and for improving seasonal sea ice predictions and forecasts. Recent measurements from ICESat-2 have shown great promise toward the potential retrieval of sea ice freeboard and thickness during the summer melt season. This is due to ICESat-2's capa-

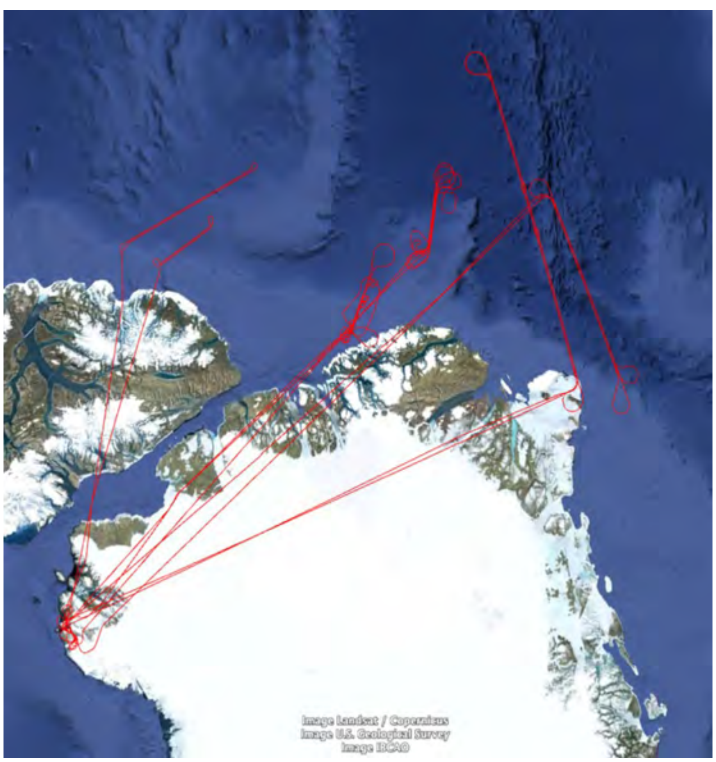


Figure 31. *Map of GV flight lines with spiral patterns showing maneuvers to lower aircraft altitude over the sea ice.* ***Figure credit:*** *NASA*

Figure 32. *The view from the GV over the Wolstenholme Fjord in Greenland during the 2022 ICESat-2 cal/val flights.* ***Photo credit:*** *Kate Ramsayer*

bility to measure through the clouds that are prevalent in summertime, as well as the small footprint size of the laser, which is suitable for the heterogeneous surface of summer sea ice. However, summer melting of snow on sea ice causes formation of melt ponds on the surface, which can contaminate measurements of sea ice freeboard and thickness from ICESat-2's green (532 nm) laser.

To better understand ICESat-2 measurements of Arctic summer sea ice freeboard, the mission launched an airborne calibration and validation campaign using the NASA GV based out of Thule, Greenland. The GV was equipped with NASA's Land, Vegetation, and Ice Sensor (LVIS) laser altimeter and camera system, as well as the Chiroptera-4X commercial lidar and imaging system operated by the Bureau of Economic Geology at the University of Texas at Austin. The team conducted a total of six science flights between July 11-26, 2022. The flights targeted ICESat-2 orbits in regions with different sea ice conditions, including young ice, older consolidated ice, melt ponds at different stages of draining, ridged ice, and smooth ice.

The first two flights used LVIS to map long lines along the ICESat-2 orbit track. The remaining four flights featured "racetrack" patterns – short repeat lines along two of the three ICESat-2 strong beams at high altitude (~33,000 feet) – to obtain broad coverage with LVIS and multiple passes at low altitude (~1,600 feet) to obtain coverage with the bathymetric and topographic dual lidar system from Chiroptera-4X, which accounted for sea ice drift during the time between the airborne measurements and satellite overpass. The final flight took advantage of the Cryo2Ice campaign conducted by the European Space Agency (ESA) to create an orbital resonance between ICESat-2 and its CryoSat-2 radar altimeter and obtain coincident data along the two satellite tracks.

The three primary goals of the ICESat-2 calibration and validation campaign were to:

1) Assess ICESat-2 sea ice height (ATL07) and freeboard (ATL10) standard data products during the Arctic summer melt season.
2) Improve ICESat-2 ATL07 and ATL10 accuracy and precision during the Arctic summer melt season.
3) Assess the feasibility for a melt pond depth recovery algorithm that could become part of the ICESat-2 set of standard data products.

The campaign hosted media personnel from NASA, Spotify, and CNN, with additional coverage during the campaign in USA Today. Preliminary geolocated imagery data are now available and final processing of data products from the campaign is ongoing, with a public release of all data in late 2022.

Surface Biology and Geology (SBG) High-Frequency Time Series (SHIFT)

PIs – Dave Schimel, NASA JPL; Ryan Pavlick, NASA JPL
Program – SBG
Aircraft – B-200
Payload Instruments: AVIRIS-NG

High-Frequency Time Series (SHIFT) is a pathfinder campaign for the proposed Surface Biology and Geology (SBG) satellite mission (expected to launch no earlier than 2028). SBG would be part of NASA's Earth System Observatory, a set of Earth-focused missions aimed at addressing climate change and its consequences for health, natural resources, hazards, and food security. In 2022, the SHIFT campaign collected a first-of-its-kind months-long weekly time series of airborne imaging spectroscopy measurements over a vast 640 square mile study area in Santa Barbara County, California and the nearby coastal ocean. SHIFT was jointly led by NASA's Jet Propulsion Laboratory (JPL), The Nature Conservancy, and the University of California Santa Barbara (UCSB).

The SHIFT flight domain stretches from The Nature Conservancy's Jack and Laura Dangermond Preserve near Point Conception headland, north and east through the Santa Ynez valley including the Sedgwick Reserve of the University of California Natural Reserve System (UCNRS), and west to the Los Padres National Forest in the San Rafael mountains. SHIFT flight lines also covered most of the Santa Barbara County coast and adjacent kelp forests from the southern portion of Vandenberg Space Force Base east to the UCNRS Carpinteria Salt Marsh Reserve. In May, the SHIFT campaign also collected AVIRIS-NG spectral imagery coincident with a UCSB-led Plumes and Blooms research cruise in the Santa Barbara channel.

Starting in late February 2022, SHIFT collected weekly high spatial (~5 meter) and high spectral (5 nm) resolution visible-to-shortwave infrared (VSWIR) measurements with the NASA Airborne Visible/Infrared Imaging Spectrometer – Next Generation (AVIRIS-NG) instrument. The flights continued through late May 2022 to capture the dynamic spring green-up and summer-dry down of California's Mediterranean ecosystems. A final SHIFT flight and coincident ground measurements were collected in mid-September 2022 in the late dry season. The total number of FY22 flight hours for the SHIFT campaign was 69.6 hours.

After each flight, SHIFT AVIRIS-NG measurements were rapidly calibrated, atmospherically corrected, and made available to researchers. Teams of scientists from JPL, UCSB, UCLA,

Figure 33 *SHIFT campaign flight areas in southern California.* ***Figure credit:*** *NASA*

University of Wisconsin, and elsewhere then spent three days at Sedgwick Reserve and Dangermond Preserve surveying vegetation plots and collecting leaf samples. The leaf samples were flash frozen in liquid nitrogen and sent to the University of Wisconsin for laboratory analysis. Data from hundreds of vegetation plots collected over the course of the campaign are being combined with the weekly AVIRIS-NG imagery to make dynamic maps of nearly two dozen functional traits of plant communities, such as the nitrogen and sugar content of the plant leaves. These maps will help researchers understand how ecosystems function and aide conservation organizations in protecting the flora and fauna that we all depend upon for a variety of ecosystem goods and services.

Over 60 researchers from institutions around the country are using SHIFT data. Researchers from several universities, including UCSB, University of California Los Angeles (UCLA), and the University of Minnesota, are investigating the physiology and resilience of oak species. Oak trees play an important role in many southern California ecosystems, providing food and habitat for numerous wildlife species, but are under threat from hotter and more frequent extreme droughts. Along the coast, researchers from UCLA and UCSB are using SHIFT data, together with drones, autonomous vessels, and scuba divers, to understand the health and dynamics of giant kelp and phytoplankton, two other important keystone organisms affected by anthropogenic climate change. A US Geological Survey researcher is working with SHIFT data to improve maps of surface geology and mineral composition. A team from Cornell University and JPL is studying the potential of imaging spectroscopy for the early detection and mitigation of grapevine disease, which causes millions of dollars in damage to the US grape and wine industry each year. Another team of researchers, led from Sonoma State University, has deployed a network of low-cost audio recorders throughout Sedgwick Reserve. Bioacoustic data from this sensor network are being combined with SHIFT vegetation maps to understand factors related to conserving bird diversity.

Data from the SHIFT campaign are enabling scientists to understand the costs and benefits associated with collecting frequent data from a future SBG satellite. The SHIFT data archive will continue to allow the SBG team and the broader research community to design and test the algorithms and data systems needed to turn SBG's raw spectral data into usable information for multiple science and applications communities.

CALIPSO Nighttime Validation Flights (CALIPSO-NVF)

PI – Jason Tackett, NASA LaRC
Program – CALIPSO
Aircraft – B-200 King Air
Payload Instruments: HSRL-2

In August 2022, the LaRC HSRL and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) teams, in collaboration with the NASA Research Services Directorate, successfully completed an airborne deployment of the High Spectral Resolution Lidar (HSRL-2) out of Bermuda for a series of nighttime underflights of the CALIPSO satellite. Airborne measurements from the NASA LaRC HSRL-2 instrument are essential for verifying the CALIPSO lidar calibration accuracy and for acquiring information on aerosol optical properties used for its aerosol profile retrievals. By flying under the CALIPSO ground track, HSRL-2 provided an independent measurement of lidar-attenuated backscatter with a higher signal-to-noise ratio. The majority of HSRL underflights prior to the CALIPSO Nighttime Validation Flights (CALIPSO-NVF) campaign have been during the daytime, leaving nighttime highly undersampled for adequate validation. Evaluating the accuracy of the CALIPSO 532 nm nighttime calibration is critical, because it is a fundamental requirement for the lidar's 532 nm daytime calibration and the 1064 nm channel.

Figure 34. *The CALIPSO deployment crew. Left to right: Matt Coldsnow, Taylor Shingler, Mike Wusk, Dave Perez.* ***Photo Credit:*** *Taylor Shingler*

To obtain this important validation dataset, a four-person crew was deployed to Bermuda for two weeks to fly the HSRL-2 on board the LaRC B-200 King Air as CALIPSO passed within range of the aircraft. The western Atlantic Ocean was selected for CALIPSO-NVF to allow unobstructed, 45-minute flights along the satellite ground track. Science and support staff from the CALIPSO and HSRL teams communicated remotely from LaRC to monitor weather and establish flight plans. Five nighttime underflights were executed in total; four occurred in cloud-free skies, yielding ideal data from both instruments for calibration and validation. The fifth flight targeted measurements beneath cirrus clouds to assess the accuracy of CALIPSO aerosol retrievals through high clouds at night, an important but previously unexplored validation target. Total research flight time was 17.7 hours, sampling 2,200 km along the CALIPSO ground track – exceeding the deployment's science objectives. With CALIPSO wrapping up its 16-year mission in 2023, CALIPSO-NVF provided an important near end-of-mission benchmark assessment that will inform algorithm development for the final CALIPSO data release.

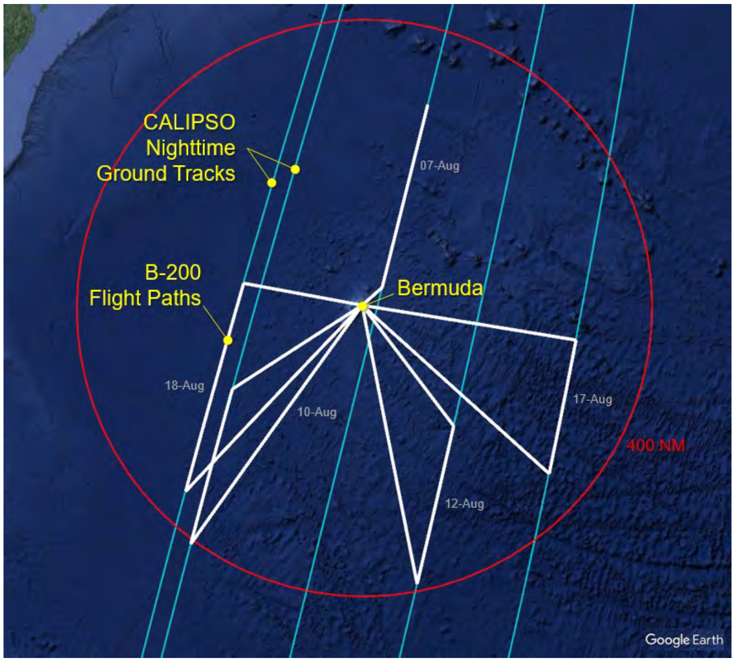


Figure 35. *Aircraft flight paths and co-located CALIPSO ground tracks during the deployment.* ***Figure credit:*** *NASA*

ASP Support for Instrument Development

FY22 included some Program flight hours for instrument development, including ASP airborne support for the Earth Science Technology Office (ESTO). Some of the instruments are being developed specifically for airborne use, while others are being developed as precursors or simulators for satellite instruments. In 2022, ASP aircraft flew the instruments listed in Table 8. Some of these instruments have been developed under sponsorship of ESTO's Instrument Incubator Program (IIP) and Airborne Instrument Technology Transition Program (AITT). ESTO demonstrates and provides technologies that can be reliably and confidently applied to a broad range of science measurements and missions. Through flexible science-driven technology strategies and a competitive selection process, ESTO-funded technologies support numerous Earth and space science missions, including Multi-channel Snow Radar, Synergies of Active Optical and Active Microwave Remote Sensing Experiment (SOA2RSE), Cornell Aeronautics Laboratory Three Dimensional (CAL3D)/Tomographic Synthetic Aperture Radar (TomoSAR), and Signals of Opportunity (SoOp) Synthetic Aperture Radar (SoOpSAR).

Table 8*. Instrument development missions supported by airborne activities in FY22.*

Mission	Flight Hours	Location	Aircraft
Multi-channel Snow Radar	47.3	Greenland	P-3
SOA2RSE (HALO + VIPR)	26.0	Atlantic coast	P-3
CAL3D/TomoSAR	25.3	California, Maine	G-III
SoOpSAR Snow	15.8	Colorado	B-200

Multi-channel Snow Radar

PI – John Paden, Kansas University; Nathan Kurtz, NASA GSFC
Program – Airborne Instrument Technology Transition
Aircraft – P-3
Instruments: Multi-channel Snow Radar, LVIS

Measurements of snow depth on ice sheets, sea ice, and land are critically needed to understand major climate processes in the cryosphere. Almost two decades ago, the University of Kansas' Center for Remote Sensing and Integrated Systems (CReSIS) began work on a new kind of radar with an ultra-wide bandwidth to enable resolution of snow layers and snow depth measurements with the centimeter level accuracy needed for snow depth research. The instrument was flown operationally as part of NASA's Operation IceBridge mission from 2009-2019 and fundamentally changed our understanding of snow on sea ice and ice sheets across the Arctic and Antarctic. The data provided new information to show the loss of snow over the increasing amounts of seasonal sea ice in the Arctic and provide information on the annual accumulation of snow over major areas of Greenland and Antarctica.

However, it was recognized that the snow radar could be potentially improved by constructing a multichannel system capable of taking swath measurements. CReSIS had previously developed a multichannel radar system for sounding of ice sheet thickness, which enabled the resolution of crossing channels in the ice sheet bed. These swath processing techniques applied to the snow radar system increase the across-track resolution of the radar to reduce the impact of surface roughness, enable a less ambiguous identification of layers for snow depth on sea ice research, improve ice sheet and snow on land layer detection and tracking, and provide an opportunity for snow water equivalent (SWE) measurements.

A funded ROSES AITT proposal provided support for development and testing of this new multichannel snow radar system. The team assembled and tested two different versions of a frequency multiplier circuit in preparation for full integration of the system onto the NASA P-3 aircraft. The frequency multiplier uses a series of frequency doublers and a down-converter stage driven by a 38 GHz phase-locked oscillator (PLO) to generate a 2-18 GHz waveform starting from a 2.5-3.5 GHz baseband signal. Analysis of the waveform revealed a degradation in its fidelity over the 14-16 GHz and 17-18 GHz sub-bands, thereby reducing the effective bandwidth of the signal to ~13 GHz instead of the desired 16 GHz (18.75 % reduction). To meet the delivery schedule, the team integrat-

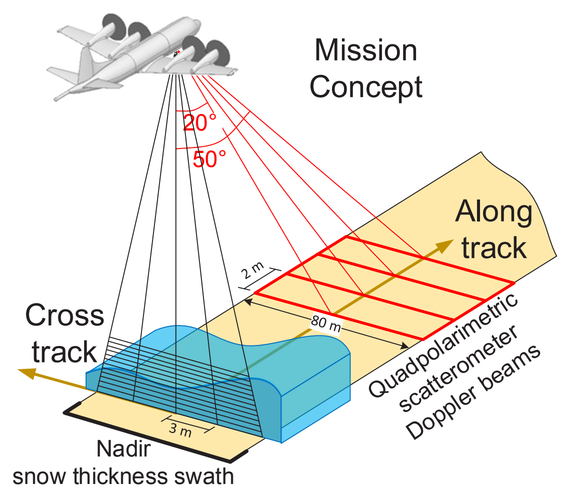


Figure 36. *Mission concept for multichannel snow radar instrument flights.* ***Figure credit:*** *John Paden*

ed a commercial 65-GSPS arbitrary waveform generator (AWG) into the system and turned the frequency multiplier module into a secondary test payload/spare.

In April 2022, this new multichannel snow radar system was deployed to Thule, Greenland. Also onboard was NASA's LVIS instrument to provide coincident laser altimetry and optical imagery data for independent verification and testing of the surface layer tracking of the radar. The team made two science flights with this instrument package. The first flight was conducted over the Greenland Ice Sheet, with data collected over prior lines flown by Operation IceBridge, as well as over ice camps, most notably the East Greenland Ice-core Project (EastGRIP) site. The flight was a success, with only some data loss due to clouds at the beginning and end of the flight. The second flight over Arctic sea ice included five passes along four ICESat-2 tracks, with one repeat pass flown for 3D imaging with the snow radar. The lines also coincided with measurements taken by a ground survey team from Environment and Climate Change Canada, which will be used to assess the snow depth retrievals. Data were then collected under an ICESat-2 track over the central Arctic sea ice pack north of Greenland also, with the flight taking place about 8 hours after the satellite pass. Swath processing to assess data quality is ongoing.

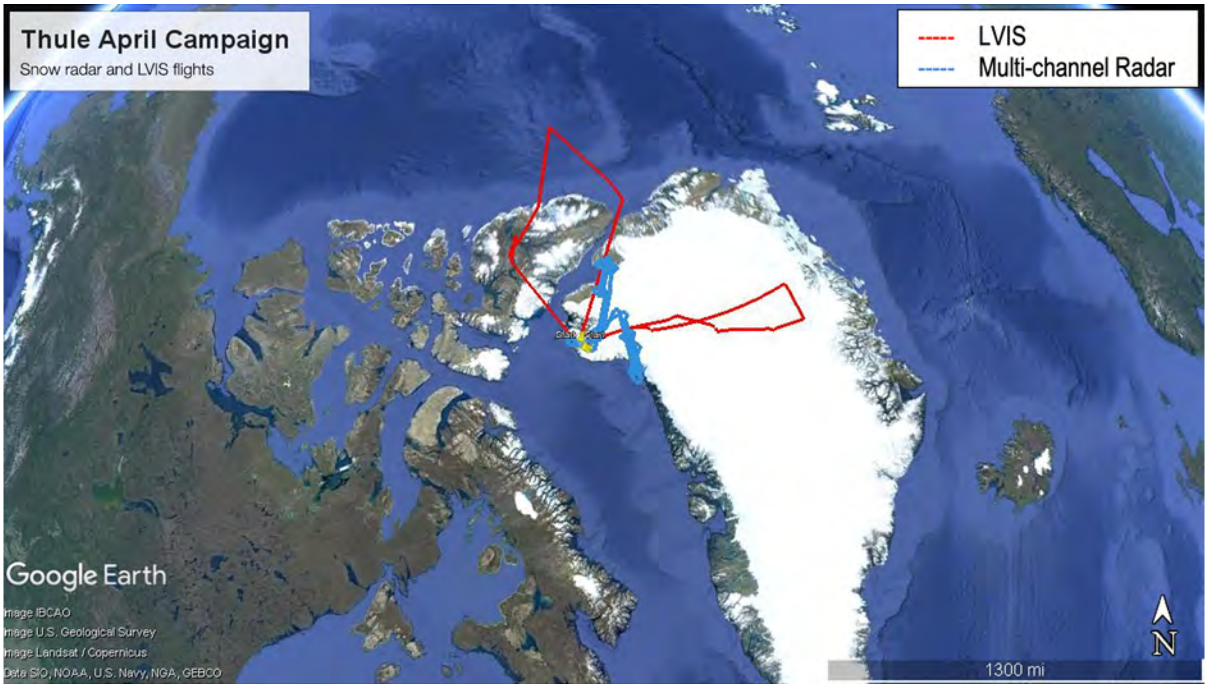


Figure 37. *Multi-channel Snow Radar flights over Greenland in April 2022.* ***Figure credit:*** *NASA*

Synergies of Active Optical and Active Microwave Remote Sensing Experiment (SOA2RSE)

PI – Amin Nehir, NASA LaRC
Program – Airborne Instrument Technology Transition
Aircraft – P-3
Instruments: HALO + VIPR

The Synergies of Active Optical and Active Microwave Remote Sensing Experiment (SOA2RSE) served as a first opportunity to evaluate the synergistic retrievals of moisture profiles in clear and cloudy conditions retrieved from the High-Altitude Lidar Observatory (HALO) and Vapor In-Cloud Profiling Radar (VIPR) remote sensing instruments, respectively. High vertical resolution and accurate profiles of water vapor are important atmospheric geophysical observables for applications spanning spatial and temporal scales from weather to climate. HALO and VIPR employ the differential absorption technique at the optical and microwave frequencies, respectively, that enable the only direct method for remotely measuring water vapor profiles in the atmosphere. Evaluation of the synergy between these two instruments/measurement techniques will inform the formulation of the next generation of airborne and space-based Earth observing system.

The SOA2RSE flights were carried out on the NASA P-3 after the conclusion of the 2022 Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) mission. At that time, most of the IMPACTS payload was removed, except HALO, VIPR, Advanced Vertical Atmospheric Profiling System (AVAPS) dropsondes, and the National Suborbital Research Center (NSRC) data system. NASA's Wallops Flight Facility and the western Atlantic Ocean were selected as the SOA2RSE deployment location and flight domain to maximize flight opportunities and allow for validation of the joint observations using dropsondes and ACTIVATE Earth Venture Suborbital-3 (EVS-3) observations. The SOA2RSE team successfully carried out 25 flight hours across four local daytime research flights, two of which were in coordination with the ACTIVATE mission and used to provide context on the distribution and composition of the cloud fields observed by HALO and VIPR. The HALO and VIPR measurements were validated using 30 dropsondes across a range of atmospheric conditions and cloud types, from moist convective frontal systems to extremely dry post-frontal conditions. The SOA2RSE campaign successfully collected the first joint observations of

Figure 38. *The SOA2RSE deployment team. Top to bottom: Lee Thornhill, Matt Lebsock, Rory Barton-Grimley, Ryan Bennett, Amin Nehrir.*
Photo credit: *Amin Nehrir*

Figure 39. *Photo of the NASA P3-B captured from the ACTIVATE B-200 nadir camera.* ***Photo credit****: Taylor Shingler*

remotely sensed water vapor profiles in clear and cloudy conditions by employing active optical and active microwave differential absorption techniques. This provided an important dataset that will help inform the architecture of the next Earth observing system.

CALD3D / TomoSAR

PIs – Yunling Lou, NASA JPL; Paul Siquiera, University of Massachusetts Amherst
Program – Terrestrial Ecology
Aircraft – G-III (Radar)
Instruments: TomoSAR L-band and P-band

Cornell Aeronautics Laboratory Three Dimensional (CAL3D) is a campaign to collect coincident L-band and P-band Tomographic Synthetic Aperture Radar (TomoSAR) data over some of the world's tallest forests in California. This campaign collected data over Northern California coastal redwood forest near Redwood National Park, as well as over two sites in the National Ecological Observatory Network (NEON) run by the National Science Foundation located near Kings Canyon National Park. TomoSAR enables 3D imaging of forest structure that can be used to estimate forest height, canopy density, above-ground biomass, and other important ecological parameters (Figure 40). CAL3D collected data at the L-band and P-band frequencies to quantify differences between the two frequencies in accurately imaging tall, dense forests. For accurate estimates of forest vertical structure, the radar data must contain backscattered signals from both the forest itself as well as the ground surface underneath the forest, which requires significant penetration of the radar microwaves into the forest canopy. In tall, dense forests, the ability of L-band microwaves to sufficiently penetrate the forest canopy can be limited, causing large errors. P-band frequencies have greater penetration depth and should be more suitable for high biomass forest areas; this will be tested and quantified using the UAVSAR data collected by CAL3D.

Data from this campaign will provide valuable insight into the design of future spaceborne missions such as the Surface Topography and Vegetation (STV) mission, which was identified as a targeted observation recommended in the 2017 Decadal Survey. TomoSAR data were also collected over the Howland Forest in Maine, in conjunction with SMAPVEX 2022.

Signals of Opportunity Synthetic Aperture Radar (SoOpSAR) Snow

PI – Simon Yueh, NASA JPL
Program – ESTO IIP
Aircraft – B-200 (A)
Instrument: P-band Receiver

Mountain watersheds play an outsized role in global hydrology and function as "water towers" to supply downstream needs that serve a large portion of the global population and its economy. Despite its importance, global mountain snow water equivalent (SWE) remains essen-

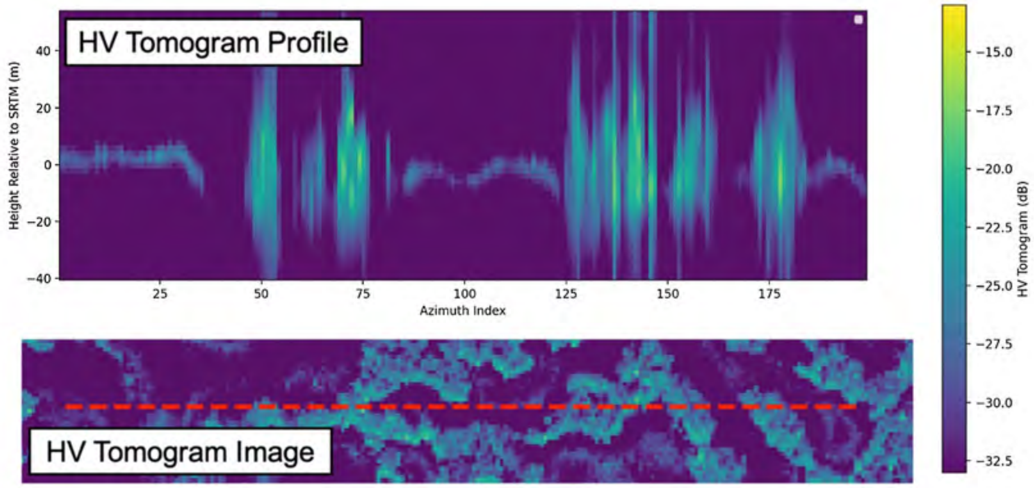


Figure 40. *A tomogram profile showing the vertical structure of forested areas in Lope National Park, Gabon, using L-band TomoSAR data collected from a previous experiment. CAL3D data will be used to create similar profiles showing vertical structure at L- and P-band over tall, dense forests in California and other areas.* ***Figure credit:*** *JPL*

tially unobserved by satellites. A spaceborne P-band Signals of Opportunity Synthetic Aperture Radar (SoOpSAR) concept has been proposed for the remote sensing of terrestrial snow. A P-band SoOp takes advantage of signals already being broadcast by existing communication satellites using a constellation of SmallSats with receivers measuring phase change and amplitude of the reflected signal. Long wavelength P-band signals are highly attractive due to their ability to penetrate forest canopies and deep snow found in mountain environments, with negligible sensitivity to snow grain microstructure and stratigraphy. They also have reduced sensitivity to liquid water compared to shorter wavelengths. Based on measured phase changes in the reflected signal, SWE retrievals are provided in dry snow conditions, with snow depth retrievals provided in wet snow conditions. Prior to snow onset and after snow disappearance, the measured amplitude of the reflected signal yields retrievals of rootzone soil moisture, which provides additional insight into the antecedent conditions before snow and the partitioning and fate of snow melt water into soil water storage versus runoff.

In 2022, an AFRC B-200 airborne campaign began to acquire data to support P-band SoOpSAR concept development. The campaign includes two observation periods, one each for snow-free and snow-on conditions. The snow-free flights were completed August 23-26, 2022, with flights over Sagehen Creek in northern California and Grand Mesa, Colorado (Figure 41). The snow-on observation period is planned with approximately ten flights in late January-February 2023 over the same sites, as well as an additional site near the Central Sierra Snow Laboratory in California.

P-band SoOpSAR receivers have a center frequency of 372 MHz and a bandwidth of 5 MHz. Two SoOpSAR P-band antennas were installed on the B-200, one on a zenith port to receive the direct signals from the US Navy's Mobile User Objective System (MUOS) and the other on a nadir port to receive the reflected MUOS signal from the ground. The direct and reflected signals were cross-correlated (no signal decoding required) to detect the amplitude and phase of reflected signals near the specular point. The team used Shuttle Radar Topography Mission (SRTM) digital elevation map (DEM) and GPS position of aircraft to compute the location of specular point. The peak values of the cross-correlation peak from all passes are illustrated at the location of aircraft in Figure 42. The power of the cross-correlation peak of data acquired at the Sagehen Creek site indicates stronger reflections over Independence Lake than the valleys and meadow.

The data from the snow-free and snow-on campaigns will be analyzed to determine the response of P-band SoOp signals to the change of snow depth and water equivalent, which will be acquired by in situ snow sampling and airborne lidar surveys.

Figure 41. *2022 SoOpSAR Snow field campaign locations.* ***Figure credit:*** *Google Earth*

Figure 42. *Collected SoOpSAR data showing the peak values of the cross-correlation peaks from all aircraft passes.* ***Figure credit:*** *Google Earth*

ASP Support to Applied Sciences

In 2022, as in previous years, several flight campaigns supported the NASA Applied Sciences Program or science goals of additional agencies. Of particular interest in 2022 was the opportunity for Airborne Science to work with the Disasters element of Applied Sciences to obtain oil-spill related imagery (Table 9).

Table 9. *Airborne science support to Applied Science goals.*

Mission	Flight Hours	Location	Aircraft
Oil Spill Disaster	14.3	California	G-III (radar)
Disaster Management – Monitoring	5.1	California	G-III (radar)

Upcoming Activities

In 2023, the remaining two EVS-3 missions – IMPACTS and S-MODE – will complete their airborne phases. Initial cal/val for the recently launched SWOT mission will take place. A new joint initiative with the USGS, the Geological Earth Mapping Experiment (GEMx), will begin a 3-year series on the ER-2. Major upcoming missions are listed in Table 10.

Table 10. *Planned major 2023 missions.*

Mission	Aircraft	Location	Science Program
IMPACTS	ER-2, P-3	US East Coast	EVS-3
S-MODE	G-III, B-200	California (Pacific Ocean)	EVS-3
AEROMMA	DC-8	California, New York	Atmospheric Composition
STAQS	GV	LA, NY, Chicago, Toronto	Atmospheric Composition
GEMx	ER-2	CA, NV, AZ	Earth Surface and Interior/USGS
SWOT Cal/Val (Ocean)	GV	Pacific Ocean	SWOT
SWOT Cal/Val (River)	B-200	St. Lawrence Seaway	SWOT
ABoVE	G-III, B-200	Alaska	Water and Energy Cycle
SnowEx	G-III, B-200, GV	Alaska	Water and Energy Cycle
SHIFT	B-200	California	SBG, PACE
BioSCape Test Flights	G-III, GV	Virginia, Texas	Biodiversity Program
BLUEFLUX	B-200	Florida	Carbon Monitoring System
Carbon Mapper	B-200, GV	CONUS	SBG, PACE
WDTS	ER-2	California	Carbon Cycle and Ecosystems
LVIS/GEDI	GV	Texas	Cryosphere
QUAKES	GV	Western US	Earth Surface and Interior
Vanilla Ice	Vanilla UAS	Greenland	Cryosphere
SABRE	WB-57	Texas	NOAA
ISRO NISAR Collection	ISRO KingAir	India	NISAR
SARP	DC-8	California	SMD R&A
SARP-EAST	B-200 (L)	Virginia	SMD R&A

4. Aircraft

NASA maintains and operates a fleet of highly modified aircraft unique in the world for their ability to support Earth observations. These aircraft are based at NASA Centers. ASP-supported aircraft have direct funding support from ASP for flight hours and personnel. Other NASA aircraft are also available for science missions. In addition, NASA missions employ commercial aviation services (CAS) under protocols established by NASA Headquarters. More information about using these aircraft is provided on the ASP website at: airborne-science.nasa.gov. The annual "call letter," also available on the ASP website, is an excellent source of information describing how to request airborne services.

FY2022 Aircraft Highlights

The ASP fleet includes aircraft that can support low and slow flights, as well as those capable of flying high and fast. The aircraft also have a wide variety of payload capacities. Several aircraft modifications and upgrades were completed to ASP platforms in FY22 that either enhance payload capability for the science community or help sustain the aircraft into the future. A new capability is the redesigned extended pylons on the P-3, allowing payloads and sensors to extend into the freestream minimizing aerodynamic influences from the wing. Fleet modification highlights for FY22 are listed in Table 11.

Table 11. Enhancement modifications to ASP aircraft in FY22.

Aircraft	Modification	Impact
Payload Enhancements		
P-3	Pylon aerodynamic modification	Enables use of extended pylons for selected payloads
P-3	Permanent payload data system	Enhances science capability
LaRC G-III	Sonobuoy/dropsonde capability installed	Enhances science capability
JSC GV	Dropsonde capability installed (uses nadir portal)	Enhances science capability
Aircraft Upgrades		
ER-2 #806	CARE modifications competed	Pilot health
ER-2 #809	Began Automatic Dependent Surveillance-Broadcast (ADS-B) upgrade	FAA compliance
ER-2 #809	GPS approach upgrade	Enhances operational capability
LaRC G-III	FMS upgrade	Avoided part obsolescence

Figure 43. *New P-3 wing pylons carrying canister probes for the IMPACTS mission.* ***Photo credit:*** *NASA*

ASP Fleet Summary Characteristics

Aircraft performance characteristics and payload accommodation summaries are listed in Table 12. FY22 is the final year of operations for the HU-25A Falcon at LaRC; the aircraft will be decommissioned and dispositioned in FY23. The fleet of aircraft is shown in Figure 44. The altitude, endurance, and range capabilities are shown in Figure 45. Figure 46 indicates payload capability for the aircraft.

Table 12. *Airborne Science Program aircraft and their performance capabilities.*

Platform Name	Center	Payload Accommodations	Duration (Hours)	Useful Payload (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)
ASP Supported Aircraft							
DC-8	NASA-AFRC	4 nadir ports, 1 zenith port, 14 additional view ports	12	50,000	41,000	450	5,400
ER-2 (2)	NASA-AFRC	Q-bay (2 nadir ports), nose (1 nadir port), wing pods (4 nadir, 3 zenith ports), centerline pod (1 nadir port)	12	2,900	>70.000	410	5,000
G-III/C-20A	NASA-AFRC	UAVSAR pod	7	2,610	45,000	460	3,000
G-III	NASA-JSC	UAVSAR pod, sonobuoy launch tube	7	2,610	45,000	460	3,000
G-III	NASA-LaRC	2 nadir ports, dropsonde / sonobuoy	7	2,610	45,000	460	3,000
GV	NASA-JSC	2 nadir ports, dropsonde capability	12	8,000	51,000	500	5,500
P-3	NASA-WFF	1 large and 3 small zenith ports, 3 fuselage nadir ports, 4 P-3 aircraft window ports, 3 DC-8 aircraft window ports, nose radome, aft tailcone, 10 wing mounting points, dropsonde capable	14	14,700	32,000	400	3,800
WB-57	NASA-JSC	Nose cone, 12 ft of pallets for either 3 ft or 6 ft pallets, 2 Spearpods, 2 Superpods, 14 Wing Hatch Panels	6.5	8,800	>60,000	410	2,500
Other NASA Aircraft							
B-200	NASA-AFRC	2 nadir ports	6	1,850	30,000	272	1,490
B-200	NASA-LaRC	2 nadir ports, wing tip pylons, zenith site for aerosol inlet, lateral ports	6.2	4,100	35,000	275	1,250
C-130	NASA-WFF	3 nadir ports, 1 zenith port, 2 rectangular windows, wing mount for instrument canisters, dropsonde capable, cargo carrying capable	10	36,500	33,000	290	3,200
Cirrus SR22	NASA-LaRC	Unpressurized belly pod	6	932	17,500	175	970
HU-25A Guardian	NASA-LaRC	1 nadir port, wing hard points, crown probes	6	3,000	42,000	430	2,075
Matrice 600 (UAS)	NASA-ARC	Imager gimbal	1	6	8,000	35	3
SIERRA-B (UAS)	NASA-ARC	Interchangeable nose pod for remote sensing and sampling, 1 nadir port	10	100	12,000	60	600
WB-57 (2)	NASA-JSC	Nose cone, 12ft of pallets for either 3ft or 6ft pallets, 2 Spearpods, 2 Superpods, 14 Wing Hatch Panels	6.5	8,800	60,000+	410	2,500

National Aeronautics and Space Administration

AIRBORNE SCIENCE PROGRAM

Observing Platforms for Earth System Science Investigations

	Performance		
Platform	Endurance (Hours)	Useful Payload (lbs)	Range (nmi)
DC-8	12	50,000	5,400
ER-2	12	2,900	5,000
P-3	14	14,700	3,800
G-III (LaRC) G-III (JSC) G-III (AFRC)	7	2,600	3,000
G-V	12	8,000	5,500
WB-57	7	2,500	8,800

Visit the NASA Airborne Science Program Website for More Information - https://airbornescience.nasa.gov

Figure 44. *NASA Airborne Science Program supported aircraft.* ***Figure credit:*** *NASA*

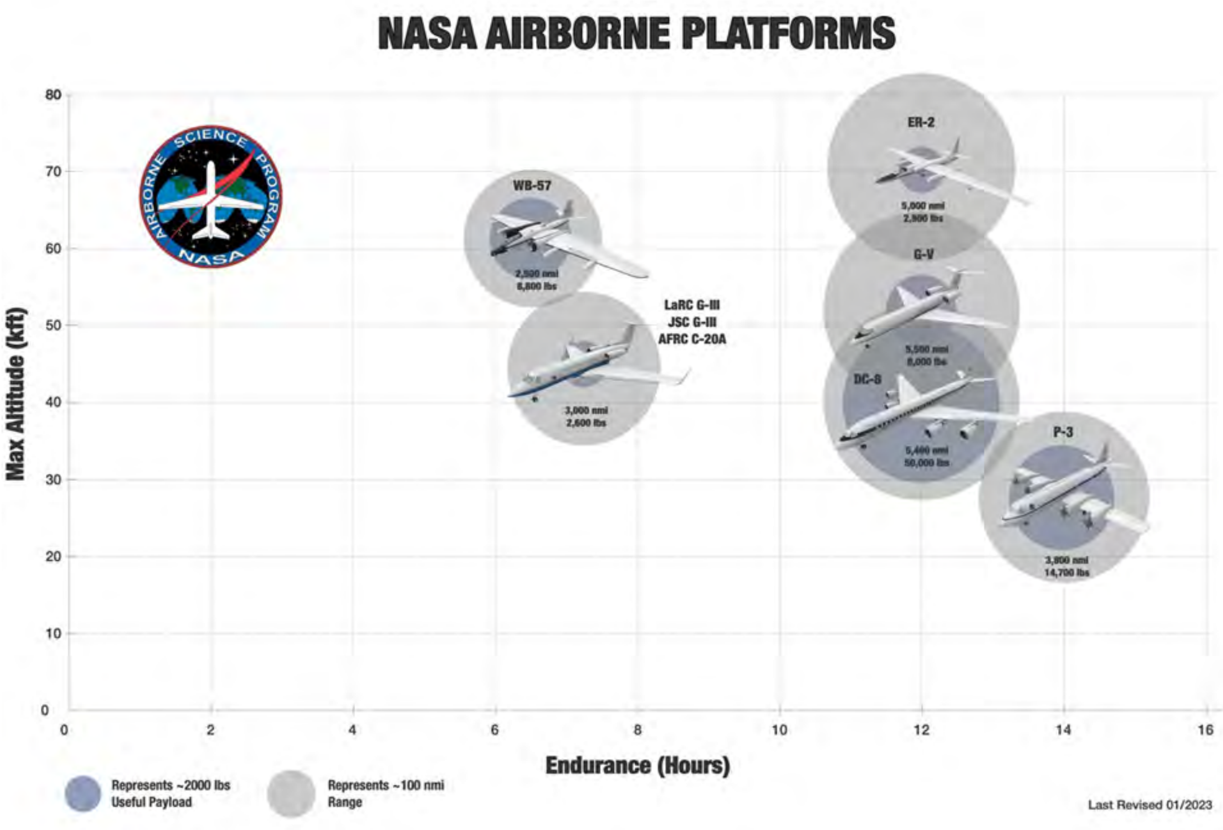


Figure 45. *NASA Earth Science aircraft capabilities in altitude, range, and relative payload weight capacity.* ***Figure credit:*** *NASA*

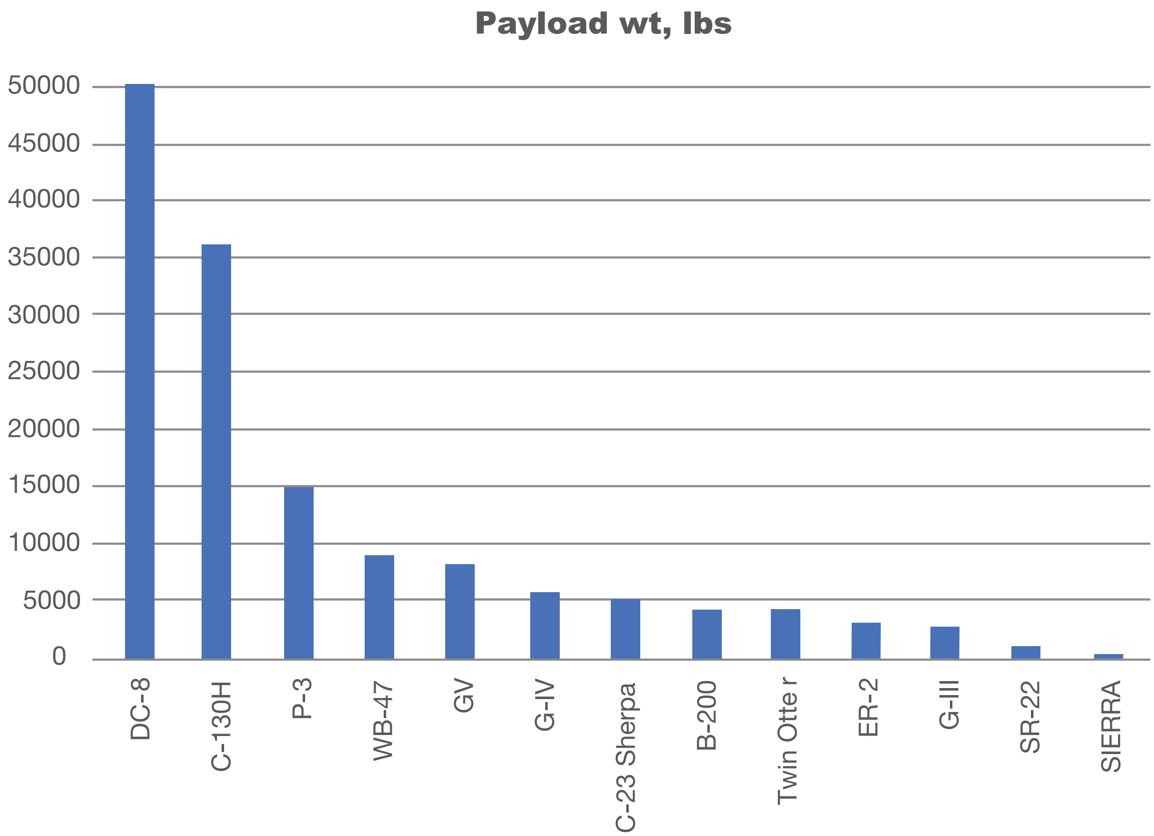


Figure 46. *NASA Earth Science aircraft payload weight capacity.* ***Figure credit:*** *NASA*

ASP-Supported Aircraft

The eight aircraft systems ASP directly supported with subsidized flight hours in FY22 were the DC-8 flying laboratory, two ER-2 high altitude aircraft, P-3 Orion, C-20A (G-III), JSC G-III, LaRC G-III, JSC GV, and a WB-57 at JSC (partial support).

DC-8

Operating Center:
Armstrong Flight Research Center (AFRC)

Aircraft Description:
The DC-8 airborne laboratory is a four-engine jet aircraft with a range in excess of 5,000 nm, a ceiling of 41,000 ft, and an experiment payload of 30,000 lbs (13,600 kg). This aircraft, extensively modified as a flying laboratory, is operated for the benefit of airborne science researchers.

FY22 Science Flight Hours: 238.2

DC-8 FY22 Missions

Mission/Project	Location	Science Program Area
CPEX-CV	Cabo Verde	Weather and Atmospheric Dynamics
HIWC	Florida	Weather and Atmospheric Dynamics
SARP	California	Airborne Science Program
AFRL Star Tracker Demonstration	California	Airborne Science Program

FY22 Modifications and Impacts on Performance/Science:
None.

Significant Upcoming Maintenance Periods:

- The DC-8 had major schedule maintenance completed offsite in FY21; the next scheduled major offsite maintenance is in FY26, unless the aircraft is retired.
- Maintenance – Q1 2023 (1 month)
- 1A, 2A, 3A, C1, and 3C maintenance – Q2 2023 (3 months)
- 1A and 3A maintenance – Q4 2023 (3 weeks)

Website:
http://airbornescience.nasa.gov/aircraft/DC-8

Figure 47. *Students, mentors, and crew pose with the DC-8 after the first flight of the SARP campaign during summer 2022.* ***Photo credit:*** *Lauren Hughes*

ER-2

Operating Center:
Armstrong Flight Research Center (AFRC)

Aircraft Description:
The ER-2 is a civilian version of the Air Force's U2-S reconnaissance platform. NASA operates two ER-2 aircraft. NASA operates two ER-2 aircraft (N809NA and N806NA). These high-altitude aircraft are used as platforms for investigations at the edge of space.

FY22 Science Flight Hours: 82.7 (N809NA) + 125.8 (N806NA)

ER-2 FY22 Missions

Mission/Project	Location	Science Program Area
IMPACTS	North Carolina	Earth Venture Suborbital-3
Air-LUSI	California	Earth Venture Suborbital-3, Ocean Biology and Biogeochemistry
DCOTSS	Kansas	Earth Venture Suborbital-3 Program
WDTS	California	Research and Analysis, Earth Surface and Interior, Biological Diversity

FY22 Modifications and Impacts on Performance and Science:

- AFRC completed Cabin Alltitude Reduction Effort (CARE) re-assembly of TN806 during May 2019 – March 2022 (Includes a 6-month work stoppage due to the pandemic).
- ER-2 TN809 began the Automatic Dependent Surveillance-Broadcast upgrade, the Global Positioning System (GPS) approach upgrade, along with a routine 600-hour maintenance of the aircraft and replacing the Kapton wiring in the wings. Expected completion is summer 2023. The ADS-B addition to the aircraft brings it into FAA compliance, while the GPS approach upgrade will allow the aircraft to operate in more international airfields than when only equipped with the Instrument Landing System (ILS) approach. These improvements allow for more operational sites for science missions.

Significant Upcoming Maintenance Periods:

- On #809:
  - 600-hour maintenance – Q3 2023 (16 months)
- On #806:
  - 200-hour maintenance – Q3 2023 (2 weeks)
  - 600-hour maintenance, wing blade replacement, fuselage Kapton wiring replacement – Q1 2024 (estimated 3 months; awaiting proposal from Lockheed Martin on the wing blade replacement)

Website:
http://airbornescience.nasa.gov/aircraft/ER-2

Figure 48. *Ground crew helps the ER-2 pilot after the aircraft landed at Salina Regional Airport during DCOTSS. The campaign was based out of Salina, Kansas during the month of June 2022.* ***Photo credit:*** *Charles Rankin*

P-3 Orion

Operating Center:
Wallops Flight Facility (WFF)

Aircraft Description:
The P-3 is a four-engine turboprop aircraft designed for endurance and range and is capable of long duration flights. The WFF P-3 has been extensively modified to support airborne science-related payloads and activities.

FY22 Science Flight Hours: 185.9

P-3 Orion FY22 Missions

Mission/Project	Location	Science Program Area
IMPACTS	Virginia	Earth Venture Suborbital-3
SOA2RSE	Virginia	Earth Science Technology Office, Weather and Atmospheric Dynamics
KU Snow Radar AITT	Greenland	Tropospheric Composition
SaSa	Virginia	Science Engagement and Partnerships Division

FY22 Modifications and Impacts on Performance and Science:

- The ASP data system was permanently installed in the aircraft. Moving the ASP data system from its original instrument rack to other permanent mounting areas freed up P-3 floor space to support additional science racks and seats in the aircraft.
- Extended wing pylons were modified to improve aerodynamic flow around the wing pylons and reduce impact to the P-3 aileron structures, enabling future science use of the extended wing pylons.

Website:

http://airbornescience.nasa.gov/aircraft/P-3_Orion

Significant Upcoming Maintenance Periods:

- Programmed Depot Maintenance (PDM) and Painting – March 2023 to January 2024
- The P-3 will be moved to a Conditions Based Maintenance (CBM) program after PDM. Under CBM, intervals for major maintenance activities will be recalculated with the expectation they will be needed less frequently due NASA's reduced flight hours compared to the heavier US Navy duty the maintenance program is currently based on.
- Other than PDM/Painting in 2023, CBM maintenance activities can be rescheduled to accommodate future missions' requested flight windows.

Figure 49. *The P-3 aircraft at WFF during the 2022 deployment of IMPACTS.* ***Photo credit:*** *NASA*

Gulfstream GV

Operating Center:
Johnson Space Center (JSC)

Aircraft Description:
The Gulfstream V (GV) is a long-range, large business jet aircraft built by Gulfstream Aerospace, derived from the Gulfstream IV. It flies up to Mach 0.885, up to 51,000 feet, and has a range of 5,000 nautical miles. JSC procured the GV in 2016 as part of a shared usage agreement between the ISS Program and NASA ESD. The ISS program uses the GV for Crew Return missions and ESD uses it to support airborne science missions in remote locations around the world.

FY22 Science Flight Hours: 68.2

GV FY22 Missions

Mission/Project	Location	Science Program Area
ICESat-2	Greenland	ICESat-2

Figure 50. *The view from the GV over the Wolstenholme Fjord in Greenland during the 2022 ICESat-2 cal/val flights.* ***Photo credit:*** *Kate Ramsayer*

FY22 Modifications and Impacts on Performance/Science:
Added dropsonde capability. This capability occupies one of the two GV nadir ports when in use.

Significant Upcoming Maintenance Periods:

- Gulfstream aircraft will require approximately 10 weeks of maintenance per calendar year, distributed throughout the year based on scheduled inspection periods.

Website:
https://airbornescience.nasa.gov/aircraft/Gulfstream_V_-_JSC

Figure 51. *GV at hanger in Thule for 2022 ICESat-2 cal/val campaign.* ***Photo credit:*** *Robert Switzer*

Gulfstream III (G-III)

NASA ASP supports three G-III aircraft for Earth Science: one at AFRC, one at JSC, and as of 2020, one at LaRC. The G-III is a business jet supporting routine flight at 40,000 feet.

The AFRC and JSC platforms have been structurally modified and instrumented to carry the payload pod for the three versions of JPL's UAVSAR instrument (L-band, P-band, Ka-band). The LaRC G-III does not carry the pod but has been modified with nadir portals to support remote sensing payloads. The LaRC G-III is now dropsonde/sonobuoy capable. Features specific to each aircraft, along with their FY22 science activities, are described below.

C-20A (AFRC G-III)

Operating Center:
Armstrong Flight Research Center (AFRC)

FY22 Science Flight Hours: 264.4

C-20A (G-III) FY22 Missions

Mission	Location	Science Program Area
ABoVE	Canada, Alaska	Terrestrial Ecology
Santa Barbara Oil Slick	California	Disaster Management
Landslide Kinematics	California	Earth Surface and Interior
SMAPVEX	Maine	Geodetic Imaging
Plate Boundary	California	Interior and Terrestrial Hydrology
L-band Engineering	California	Interior and Terrestrial Hydrology
P-band Engineering	California	Geodetic Imaging
Disaster Response	California	Geodetic Imaging, Disaster Management
Howland Forest TomoSAR	California	Geodetic Imaging
California Tomography Experiment	California	Geodetic Imaging, Interior and Terrestrial Hydrology

FY22 Modifications and Impacts on Performance and Science:
None.

Website:
https://airbornescience.nasa.gov/aircraft/Gulfstream_C-20A_GIII_-_AFRC

Significant Upcoming Maintenance Periods:

- The C-20A maintenance schedule is updated on the ASP website.
  - 72-month inspection – Q1 2023 (~3 months)
  - Engine overhaul – Q3 2023 (~2 months)

Figure 52. *Members of the ABoVE science team and flight crew pose in front of the C-20A during the 2022 campaign.* ***Photo credit:*** *Chip Miller*

JSC G-III

Operating Center:
Johnson Space Center (JSC)

The JSC G-III carried the P-band version of the SAR in 2022.

FY22 Science Flight Hours: 31.5

JSC G-III FY22 Missions

Mission/Project	Location	Science Program Area
AirMOSS	Pacific Northwest, California	Geodetic Imaging

FY22 Modifications and Impacts on Performance/Science:
None.

Website:
https://airbornescience.nasa.gov/aircraft/Gulfstream_III_-_JSC

Significant Upcoming Maintenance Periods:

- Gulfstream aircraft will require ~10 weeks of maintenance per calendar year, distributed throughout the year based on scheduled inspection periods.
  - 72-month maintenance starting in December 2022 (~3-4 months)
  - Engine Swap in early CY2023 (~2 months)
  - Engine Swap in early CY2024 (~2 months)

Figure 53. *The JSC G-III taking flight to collect data. The P-band radar pod is mounted underneath.* ***Photo credit:*** *Tony Landis*

LaRC G-III

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The Gulfstream III (a former US Air Force C-20B) aircraft became available for NASA science during FY20. The nadir portals (each 18.16 inch x 18.16 inch with external shutters) allow the aircraft to support Earth science sensors. The G-III has available pressure domes that can be installed over the portals so instruments can be flown open to the atmosphere. The aircraft is dropsonde / sonobuoy capable. Six Researcher Interface Panels are installed in the passenger cabin to accommodate up to ten researchers. The research system also operates with the NASA Airborne Science Data and Telemetry (NASDAT) system. The G-III aircraft has an advertised range of 3750 nautical miles.

FY22 Science Flight Hours: **0 (47 including S-MODE in October 2022 – FY23)**

FY22 Modifications and Impacts on Performance/Science:
Aircraft is in flight status. A cross-center team installed a dropsonde system, expanding the aircraft's research capabilities.

Website:
https://airbornescience.nasa.gov/aircraft/Gulfstream_III_-_LaRC

Significant Upcoming Maintenance Periods:
- Semi-annual maintenance, January 3, 2023 to February 23, 2023
- Maintenance, August 21, 2023 to September 29, 2023
- Maintenance, January 3, 2024 to February 9, 2024
- Maintenance/engine swap, April 25, 2024 to May 15, 2024

Figure 54. *LaRC G-III at sunset in Adelaide, Australia.* ***Photo credit:*** *James Scott*

WB-57 High Altitude Aircraft

Operating Center:
Johnson Space Center (JSC)

Aircraft Description:
The WB-57 is a mid-wing, long-range aircraft capable of extended operation from sea level to altitudes in excess of 60,000 feet. The sensor equipment operator (SEO) station contains navigational equipment and controls for operation of the payloads located throughout the aircraft. The WB-57 can carry up to 8,800 pounds of payload. JSC maintains three WB-57 aircraft.

FY22 Science Flight Hours: 171.5

WB-57 FY22 Missions

Mission/Project	Location	Science Program Area
ACCLIP	Republic of Korea	Upper Atmosphere Research Program
SABRE	Texas	NOAA

FY22 Modifications and Impacts on Performance/Science:
None.

Significant Upcoming Maintenance Periods:

- WB-57 aircraft require one major phase maintenance period (~4 months) every 24 months and one minor phase maintenance period (~3 months) between each major.
- Major and minor phase inspections are staggered so at least one of the three aircraft is always operational.

Website:

http://airbornescience.nasa.gov/aircraft/WB-57

Figure 55. *The WB-57 (N926NA) in flight for ACCLIP during the summer of 2022 in the Republic of Korea.*
Photo credit: *Rafael Mendez*

Other NASA Earth Science Aircraft

Other NASA aircraft, as described here, on the Airborne Science website, and in the annual ASP Call Letter, are platforms operated by NASA centers. Although not subsidized by the ASP program, these aircraft are also modified to support Earth-observing payloads. These aircraft are available for science through direct coordination with the operating center.

Table 13. *Other NASA aircraft available for Earth science missions.*

Aircraft	Operating Center
B-200 King Air; UC-12B	LaRC, AFRC, or contracted
G-IV	LaRC
SIERRA-B	ARC
Small UAS	AFRC, ARC, LaRC, JPL
SR22	LaRC
Twin Otter	Contracted

B-200 / UC-12

Operating Center:

Langley Research Center (LaRC), Armstrong Flight Research Center (AFRC), Ames Research Center (ARC)

Aircraft Description:

The Beechcraft B-200 King Air is a twin-turboprop aircraft capable of mid-altitude flight (>30,000 ft) with up to 1,000 pounds of payload for up to 6 hours. LaRC operates a conventional B-200 and a UC-12B (military version). AFRC operates a Super King Air B-200 that has been modified for downward-looking payloads. This aircraft was flown to ARC in September 2021 for S-MODE flights and completed the entire mission off the coast of San Francisco, California before returning to AFRC.

The three B-200 aircraft have varying modifications to support science, as listed in Table 12.

B-200 FY22 Missions

Aircraft	Mission	Location	Science Program Area	FY22 Flight Hours
UC-12B	ACTIVATE	Virginia/ Atlantic Ocean	Earth Venture Suborbital-3 & Radiation Science	22.6
B-200 (LaRC)				99.4
B-200 (AFRC)	S-MODE	California	Earth Venture Suborbital-3	59.7
B-200 (AFRC)	SoOPSAR SNOW	California	Hydrology	15.8
B-200 (LaRC)	CALIPSO	Bermuda	Modeling Analysis & Prediction	27.3

FY22 Modifications and Impacts on Performance and Science:

- AFRC B-200 (N801NA):
  - Integration of SoOpSAR hardware (see page 48) for the first campaign in August 2022. This integration activity permits future SoOpSAR missions on NASA 801 with less effort since airworthiness has already been certified by AFRC. Measurement of snow levels and soil density using the SoOpSAR equipment provides a new capability for the aircraft.

Significant Upcoming Maintenance Periods:

- The maintenance schedule for AFRC B-200 (N801NA):
  - Phase 1 and 2 maintenance – Q1 2023 (6 weeks)
  - Phase 3 and 4 maintenance – Q3 2023 3 months)

Websites:

http://airbornescience.nasa.gov/aircraft/B200_-_LARC

http://airbornescience.nasa.gov/aircraft/B200_-_AFRC

Figure 56. *AStudents from Victor Scott Primary in Bermuda sit at the hangar door and look across the runway at one of the LaRC B-200 aircraft during the 2022 deployment of ACTIVATE.* ***Photo credit:*** *Bermuda Institute of Ocean Sciences*

Figure 57. *AFRC B-200 arrives at ARC for S-MODE in October 2022.* ***Photo credit:*** *Erin Czech*

HU-25A Falcon/Guardian

Operating Center:

Langley Research Center (LaRC)

Aircraft Description:

The HU-25C and HU-25A Falcons are modified twin-engine business jets based on the civilian Dassault FA-20G Falcon. The HU-25A completed active service with ACTIVATE Campaign #6.

FY22 Science Flight Hours: 296.0

HU-25A FY22 Missions

Mission	Location	Science Program Area
ACTIVATE	Virginia/Atlantic Ocean	Earth Venture Suborbital-3

FY22 Modifications and Impacts on Performance and Science:

None.

Significant Upcoming Maintenance Periods:

HU-25A aircraft is to be excessed.

Figure 58. *The HU-25A and UC-12B on the tarmac prior to flight during ACTIVATE.* ***Photo credit:*** *David C. Bowman*

SR22

Operating Center: Langley Research Center (LaRC)

Aircraft Description:
The Cirrus Design SR22 aircraft is a composite construction, single-engine production general aviation aircraft with a maximum of two onboard operators. The SR22 can fly for a maximum of 6 hours with a payload of 932 pounds. It can reach a maximum of 12,500 feet without supplemental oxygen (or 17,500 feet with supplemental oxygen) at an air speed of 175 knots.

FY22 Science Flight Hours: 0

FY22 Modifications and Impacts on Performance/Science:
None.

Significant Upcoming Maintenance Periods:
Maintenance is a function of number of flight hours flown.

Website: https://airbornescience.nasa.gov/aircraft/Cirrus_Design_SR22_-_LaRC

Figure 59. *The Cirrus Design SR22 aircraft.* ***Photo credit:*** *NASA*

G-IV

Operating Center: Langley Research Center (LaRC)

Aircraft Description:
The Gulfstream IV (G-IV) aircraft is twin turbofan business-class aircraft with a maximum of ten onboard operators. The G-IV can fly for a maximum of 8 hours with a payload of 5,610 pounds. It can reach a maximum of 45,000 feet at an air speed of 459 knots.

FY22 Science Flight Hours: 67.2

G-IV FY22 Missions

Mission/Project	Location	Science Program Area
Cusp Region Experiment	Iceland	Financial Management, Airborne Science Program
36.360 Kaeppler	Alaska	Financial Management

FY22 Modifications and Impacts on Performance/Science:
None.

Significant Upcoming Maintenance Periods:
Maintenance is a function of number of flight hours flown.

Website: https://airbornescience.nasa.gov/aircraft/Gulfstream_IV_-_LaRC

Figure 60. *The Gulfstream IV aircraft.* ***Photo credit:*** *NASA*

Non-NASA Commercial Aircraft

As indicated previously in Table 1, commercial air services (CAS) provided a significant number of flight hours during FY22. The single largest provider has been Dynamic Aviation, flying B-200 aircraft. Many of thèse flight hours were for the AVIRIS-ng instrument.

In 2019, NASA Headquarters made revisions to NPR 7900 governing NASA sponsored flight projects and this levied new safety and mission assurance requirements on companies that provide aviation services to NASA science projects. To address challenges in transitioning to compliance with these new requirements, ASP managers participated in an Agency-wide working group to assist in defining a NASA standard, similar to CFR PART 135, to assess the overall quality and safety of CAS providers.

The new process has Mission Directorates requesting an audit from the aviation support team inside NASA HQs Office of Safety

Table 14. *NASA Commercial Aviation Services (CAS) companies completing audits. (Bolded names indicate companies flying airborne science in FY22.)*

NASA Commercial Aviation Services (CAS) Inspections	
Vendor	**Inspection Date**
Twin Otter International	4/28/21
Dynamic Aviation	5/12/21
Calspan	6/4/21
Airborne Imaging Inc.	6/9/21
JL Aviation	6/9/21
Scientific Aviation	6/16/21
Airtech, Inc	6/24/21
Aerodynamics	6/30/21
Axis GeoAviation	7/7/21
Zero G	7/14/21
H211/Blue City Holdings	7/29/21
Flight Research Incorporated	8/12/21
Mountain Air Helicopters	8/25/21
Global X	9/13/21
Yukon Air Services	10/5/21
Wright Air Services	10/7/21
Maritime	10/19/21
Alaska Land Exploration	10/21/21
Kenn Borek	11/17/21
Air Center Helicopters	1/12/22
Acasta Heliflight	4/19/22
Summit Helicopters	4/22/22
Vertical Solutions	5/4/22
Remote Helicopters	5/18/22
Nautilus Aviation	6/2/22
Presidential Aviation	6/29/22
HeloAir	7/12/22
Aurora Flight Sciences Corporation	7/27/22
Global Air Charters	8/10/22
No Limits Helicopters	8/24/22
V Speed Films / Hosking Aviation	9/21/22
Joby Aviation	10/19/22
Prevailance Aerospace	11/3/22
Adaptive Aerospace Group	11/30/22
Shier Aviation/Corporate Helicopters	12/14/22
Wing Aviation	1/11/23
Airborne Imaging	1/31/23

and Mission Assurance. Once a contractor is audited, the report is reviewed by the relevant Flight Operations Center with authority over the science project that is requesting the flight service. If the provider is approved by the Flight Operations Chief the aircraft would then proceed through the NASA Airworthiness process through a NASA Flight Center. Table 14 is a list of companies that were audited in FY2021-23.

Progress in High Altitude Long Endurance Aircraft

The Ames Airborne Science Office continues to support evaluation and demonstration of High Altitude Long Endurance (HALE) Uncrewed Aircraft (UAS) for science. The partnership with U.S. Forest Service (USFS) and Swift Engineering under an SBIR Phase III was delayed a year and is now scheduled to fly the multi-camera payload on the Swift Ultra Long Endurance (SULE) platform for fire imaging over Gila National Forest in 2023. The Ames Office also initiated a partnership with USFS through the Space Technology Mission Directorate (STMD) to fund a flight demonstration of the Aerostar Thunderhead steerable balloon for providing imagery and LTE communications over remote fires.

In FY2022, ASP was approved to solicit an SBIR subtopic on high altitude long endurance platforms as well as aircraft for extreme environments. The solicitation focused on technologies that could provide 30+ day endurance with accommodations for a 10kg science payload. In FY2022, five projects (listed in Table 15) were selected for development of prototypes or designs of next generation aircraft.

The Skydweller is a medium altitude long endurance aircraft based on the Solar Impulse aircraft that flew around the world with crew and broke the aviation world record for endurance. The company, Skydweller Aero, is interested in supporting NASA science with the uncrewed version of the aircraft and is also funded to design a high-altitude version. Moonprint was funded to develop a next generation airship along with Gossamer Aerospace, who will build the lighter-than-air

Table 15. *NASA SBIR-funded HALE development projects.*

Platform name	Company	Status
Skydweller	Skydweller Aero	Medium altitude demonstrated
S-HALE	Moonprint Solutions LLC	LTA commercial
SACOS	Electra.aero Inc.	Dawn One demonstrated
SULE II	Swift Engineering	SULE demonstrated
S-2 VTOL	Black Swift	Adapting current fixed wing

(LTA) system. Electra was funded to refine and scale up their existing prototype, the Stratospheric Airborne Climate Observatory System (SACOS), as well as to optimize the design for NASA Earth Science. Swift Engineering is developing a larger scale version of their SULE platform to accommodate larger payloads. Finally, BlackSwift was funded to develop a Vertical Takeoff and Landing (VTOL) version of their fixed wing UAS, which is used for volcanic monitoring.

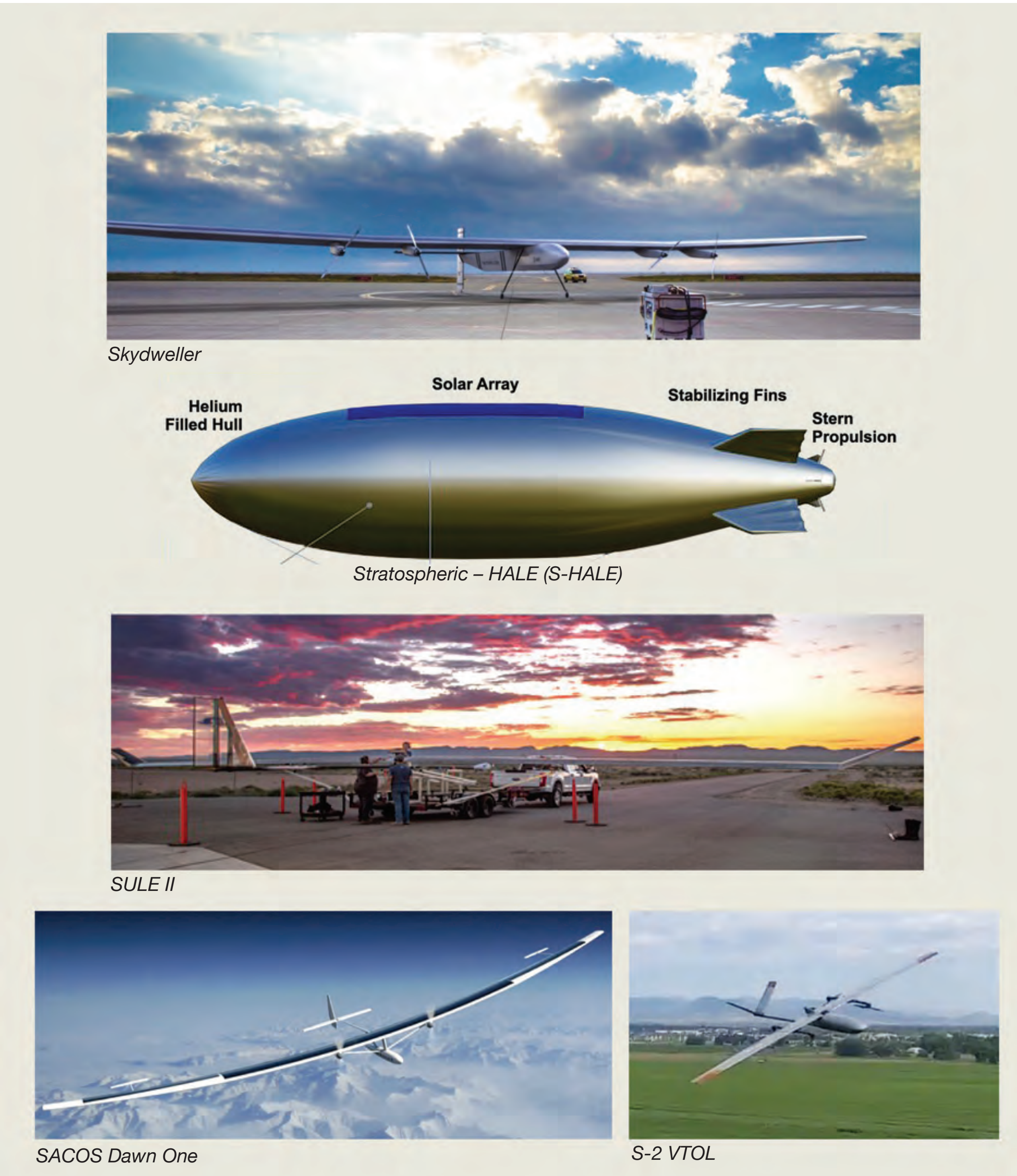


Figure 61. *HALE Aircraft with SBIR Phase I development awards.* ***Figure credit:*** *NASA*

5. Aircraft Cross-Cutting Support and IT Infrastructure

Aircraft support entails aircraft facility instrument operations and management, engineering support for payload integration, flight planning and mission management tools, flight navigation data hardware and software support, and flight data archiving and distribution.

Cross-cutting support for ASP missions is managed at ARC and is implemented through a cooperative agreement with the Bay Area Environmental Research Institute (BAERI), who operates the National Suborbital Research Center (NSRC). The Airborne Sensor Facility operates facility instruments and a calibration lab supporting the EOS Program. Engineering support is also supplied from ARC, JSC, and LaRC. The ASP Cross-Program Engineering team provides investigators with the support needed to successfully integrate their payloads onto NASA or other science aircraft. The group has the following primary objectives:

- Support operations and development of aircraft onboard accommodations for science payloads
- Travel across the Agency to support flight projects
- Conduct research on next generation information technology and telemetry solutions for aircraft

2022 was a busy year, with the team supporting missions at nearly every NASA Center and on nearly every ASP science aircraft. Missions supported in FY2022 included IMPACTS (P-3, ER-2), SaSa (P-3), DCOTSS (ER-2), WDTS (ER-2), ACTIVATE (UC-12/B200, HU-25), HIWC (DC-8), CPEX-CV (DC-8), SARP 2021 (DC-8), and SARP 2022 (DC-8). The ASP Cross-Program Engineering team enabled missions to stay on schedule and improved the efficiency of each flight hour by providing instrument installation and aircraft modification designs, custom-designed software interfaces, in-flight real-time and post-processed data, along with a myriad of other services to NASA flight projects.

The team directly supported aircraft with substantial improvements to onboard data systems and assisted in the design or documentation of aircraft modifications. The team worked to improve Inmarsat high bandwidth SATCOM on the ER-2, added onboard Wi-Fi to support the pilot, and assisted with video tracking camera solutions, including the PTZ and MVIS camera systems. The team also made major updates to the DC-8 and P-3 data systems just in time for HIWC/CPEX-CV and IMPACTS, respectively. Added capabilities include Iridium Certus Satcom, ADS-B aircraft tracking, and Wi-Fi/LTE connectivity for ground operations.

The NASA Airborne Science Data and Telemetry (NASDAT) system serves as the heart of the aircraft onboard data systems, connecting aircraft data, science data, and satellite communications. This system has served NASA for over a decade. The NASDAT Next-Generation project was initiated to develop an updated replacement system. Milestones include integrating Iridium Certus SATCOM and down selecting for the primary data processor and gateway. This work has also contributed to the design and implementation of a permanent onboard data system aboard the P-3, which is scheduled to be completed in Q1 FY2023.

There is no slow-down in sight, with the team planning to pivot to 777 engineering support through much of FY2023, while also supporting missions on the DC-8 (AEROMMA, SARP 2023, Eco-Demonstrator), P-3 (IMPACTS), ER-2 (IMPACTS, WDTS, ALOFT), and LaRC G-III (AWP, S-MODE, STAQS).

Further support for mission management and real-time flight tracking is provided by ARC through the Mission Tools Suite (MTS).

ASP Facility Science Infrastructure Update

Facility Instrumentation

The ASP provides a suite of facility instrumentation and data communications systems for community use by approved NASA investigators. Currently available ASP instrumentation (Table 16) includes standalone precision navigation systems, a suite of digital tracking cameras and video systems, and various air data measurement instruments. Real-time data communications capabilities (Table 17) differ from platform to platform and are integral to a wider Sensor Network architecture. In addition, ESD, through the Research and Analysis (R&A) Program and EOS Project Science Office, maintains a suite of advanced imaging systems that are made available to support multidisciplinary research applications. These are supported at various NASA field centers, including JPL, ARC, and LaRC. The ASF also maintains a spectral and radiometric instrument calibration facility, which supports the wider NASA airborne remote sensing community. Access to these assets is initiated through the ASP Flight Request process (see page 4).

Sensor Network IT Infrastructure

A state-of-the-art, real-time data communications network has been implemented across the ASP core platforms. Utilizing onboard Ethernet networks linked through airborne satellite communications systems to the web-based MTS, the sensor network is intended to maximize the science return from single-platform missions and complex multi-aircraft science campaigns. It leverages data visualization tools developed for the NASA DC-8, remote instrument control protocols developed for the Global Hawk aircraft, and standard data formats devised by the Interagency Working Group for Airborne Data and Telecommunication Systems (IWGADTS). The sensor network architecture includes standardized electrical interfaces for payload instruments using a common Experimenter

Interface Panel (EIP); NASDAT system, an airborne network server and satellite communications gateway; and a web-based application programming interface (API) for interfacing to customer software and other agencies.

Table 16. *ASP facility equipment and instruments.*

Airborne Science Program Facility Equipment		
Instrument / Description	**Supported Platforms**	**Support Group**
Dew Point Hygrometers	DC-8, P-3	NSRC
IR Surface Temperature Pyrometers	DC-8, P-3	NSRC
LN-251 Embedded GPS/INS Position and Orientation System	DC-8, P-3	NSRC
Combined Altitude Radar Altimeter	DC-8	NSRC
Forward and Nadir 4K Video Systems	DC-8, P-3	NSRC
Total Air Temperature Probes	DC-8, P-3	NSRC
Ice Detector	DC-8	NSRC
MVIS 2K Video Camera (Nadir)	ER-2	NSRC
Pan-Tilt-Zoom (PTZ) Camera	ER-2	NSRC
FLIR Vue Pro R 640 IR Camera (45° and Nadir)	DC-8	NSRC
45° HD Video Camera	DC-8	NSRC

EOS and R&A Program Facility Instruments				
Instrument		**Description**	**Supported Platforms**	**Support Group**
MASTER	MODIS/ASTER Airborne Simulator	50 ch multispectral line scanner V/SWIR-MW/LWIR	B200, DC-8, ER-2, P-3, WB-57	ASF/ARC
MAS	Enhanced MODIS Airborne Simulator	38 ch multispectral scanner	ER-2	ASF/ARC
PICARD	Pushbroom Imager for Cloud and Aerosol R&D	400-2450 nm range, Δλ 10 nm	ER-2	ASF/ARC
AVIRIS-ng	Airborne Visible/Infrared Imaging Spectrometer-Next Generation	Imaging spectrometer 380-2510 nm range, Δλ 5 nm	Twin Otter (CAS), B200	JPL
PRISM	Portable Remote Imaging SpectroMeter	350-1050 nm range, Δλ 3.5 nm	Twin Otter (CAS), ER-2, GV, LaRC G-III	JPL
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer	Classic imaging spectrometer 400-2500 nm range, Δλ 10 nm	ER-2, Twin Otter (CAS)	JPL
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar	Polarimetric L-band synthetic aperture radar capable of differential interferometry	G-III/C-20	JPL
NAST-I	National Airborne Sounder Tester-Interferometer	Infrared imaging interferometer 3.5 -16 mm range	ER-2, DC-8	LaRC

NASA Airborne Science Data and Telemetry (NASDAT) System

The NASDAT provides experiments with:

- Platform navigation and air data
- Highly accurate time stamping
- Baseline Satcom, Ethernet network, and Sensor-Web communications
- Legacy navigation interfaces (RS-232, RS-422, ARINC-429, Synchro, IRIG-B)
- Recorded cockpit switch states on the ER-2 and WB-57 aircraft
- Optional mass storage for payload data

In FY22, development efforts continued on the next generation of onboard information technology in support of science payloads. One goal of this effort is to investigate modular, upgradeable systems that enable incremental improvements as sub-system element improvements become available. Milestones included integrating Iridium Certus SATCOM and down selecting for the primary data processor and gateway.

Satellite Communications Systems

Several types of airborne satellite communications systems are currently operational on the core science platforms (Table 17). A high bandwidth Ku-band system, which uses a large steerable dish antenna, is installed on the WB-57. Inmarsat Broadband Global Area Network (BGAN) multi-channel systems, using electronically-steered flat panel antennas, are available on many ASP core and other NASA aircraft. Data-enabled Iridium satellite phone modems are also in use on most of the ASP science platforms. Although Iridium has a relatively low data rate, unlike the larger systems, it operates at high polar latitudes and is lightweight and inexpensive to operate.

Mission Tool Suite (MTS)

The Mission Tool Suite (*https://mts2.nasa.gov*) is a web-based software application that serves as the unified endpoint for many of the key enabling technologies available through the ASP Sensor Network, including visualization of mission information sources to aid real-time decision making. MTS is primarily used to observe real-time telemetry from remote sensing airborne platforms in concert with meteorological, airspace, satellite, and other mission products. A primary MTS objective is to improve situational awareness for all participants in NASA Airborne Science missions. MTS aims to increase the efficiency and effectiveness of flight missions, serving as a collaborative observational window into measurements between instruments on multiple aircraft, satellites, and on the surface to increase the overall scientific value of those measurements.

Table 17. *Satellite communications systems on ASP aircraft*

Satcom Type	Channels	Data Rate, Nominal	Supported Platforms	Support Group
Ku-band	1 channel systems	>1 Mb/sec	WB-57	JSC
Inmarsat BGAN	2 channel systems	432 Kb/sec per channel	DC-8, WB-57, P-3, ER-2, GV	ARC/NSRC, JSC
Iridium	CERTUS	88 kbps in / 22 kbps out	Most ASP Platforms	ARC/NSRC

To close out a very active 2022, the MTS team released software milestone version in December 2022. This version addresses feedback received throughout the year and was focused on improving existing capabilities rather than introducing new features. A major goal of the 2.7.0 release was to target usability improvements to better assist new users. A main feature is the addition of in-application help (*https://mts2.nasa.gov/view/dashboard/#/help/*). MTS help content is available when users need assistance using the software: simply consult the built-in help system for detailed, easy-to-follow instructions and illustrations. ASP hopes this feature will be especially useful for new users or those needing help with advanced features.

The MTS team also made significant backend enhancements, optimizing the code to run faster and more efficiently to improve performance and reliability of the data aggregation and data presentation pipelines. These changes will improve software reliability and limit downtime.

The MTS team continues to improve the 3D model offerings available for Earth observing platforms. The 3D models are available for download in a variety of formats via the *https://airbornescience.nasa.gov/content/3D_Models* page. This repository also includes pre-rendered scenes of most of the NASA ASP fleet (Figure 62).

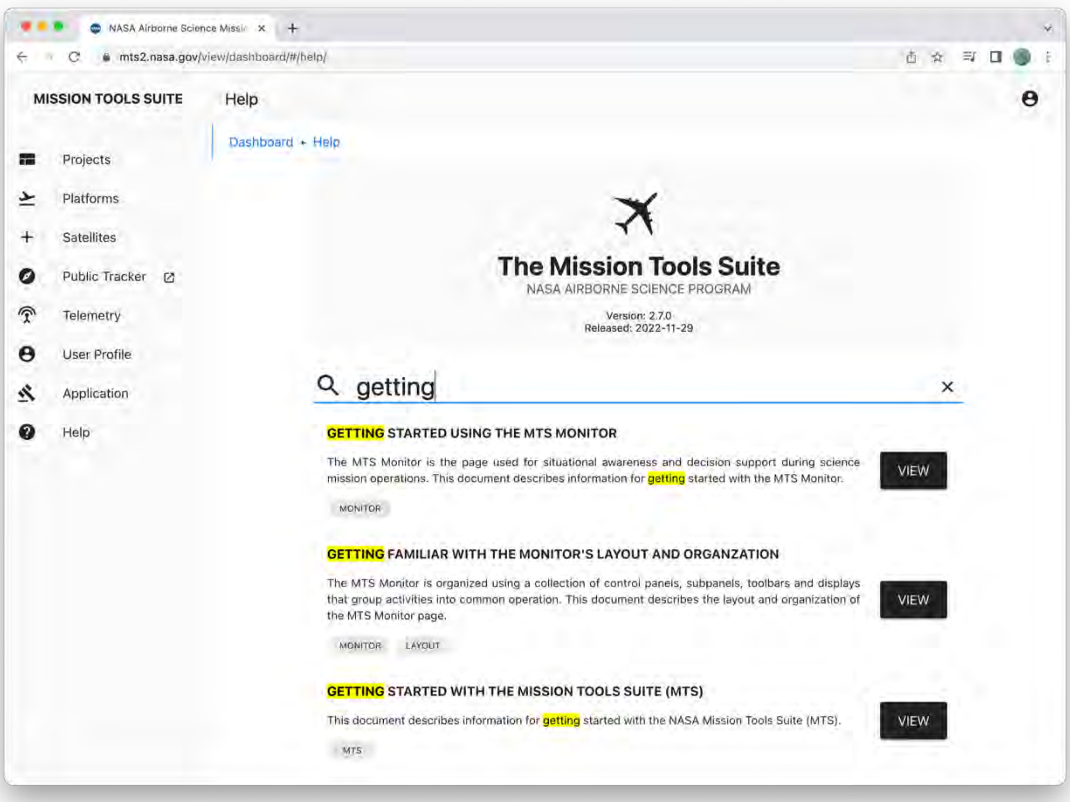


Figure 62. *The MTS Help page (https://mts2.nasa.gov/view/dashboard/#/help/) provides guidance to ASP users through a simple-to-use search interface.* ***Figure credit:*** *NASA*

Figure 63. *MTS-rendered illustration of P-3 during IMPACTS snowstorm.* ***Figure credit:*** *Aaron Duley*

In 2023, the MTS team will continue to make usability improvements. A major change will be upgrading the current login scheme to use Agency Launchpad authentication. Existing NASA MTS users will be able to log into the system using their Launchpad credentials. Non-NASA users will be migrated as NASA guest account holders. ASP will provide additional guidance as this feature gets closer to being released.

6. Advanced Planning

ASP maintains and operates a diverse fleet of aircraft and infrastructure that support a varied and evolving stakeholder community. ASP leadership conducts a yearly strategic planning activity to ensure the Program maintains currently required capabilities, renews these assets, and, as new technologies become available, extends the observational envelope to enable new Earth science measurements. ASP also plans strategically, through formal meetings, to discuss lessons learned following all major campaigns.

ASP asset and service requirements are collected and communicated through the program's Flight Request System (webpage: *http://airbornescience.nasa.gov/sofrs*), annual 5-year plan update, and ongoing discussions with Mission and Program managers and scientists.

ASP strategic planning is focused on:

- ASP-supported (Core) Aircraft – maintenance, upgrades, determining future composition of the fleet
- Cross-cutting Infrastructure Support – support for ASP-supported and other NASA aircraft (e.g., providing tracking tools for all Earth science missions)
- Observatory Management – improved tools for managing assets and requirements while improving the service to science investigators
- New Technology – bringing new technologies to bear on observational challenges, including application of advanced telemetry systems, on-board data processing, IT mission tools, and new platforms
- Educational Opportunities – providing learning opportunities for the public, students, and the next generation of scientists

Needs Assessment Update

ASP personnel monitor upcoming Earth science space missions for potential airborne needs to support:

- Algorithm development
- Instrument test
- Calibration and validation activities
- Process studies

An updated ASP Needs Assessment report was published in 2022 (*https://airbornescience.nasa.gov/sites/default/files/documents/ASPNeedsAssessment_Report2022.pdf*). The Assessment and annual 5-year plan focus on planning for satellite and ISS Earth Science missions, such as those previously defined in the Program of Record (POR), Earth Venture Program, and 2017 NRC Decadal Survey report. This includes the soon-to-be-launched TEMPO, PACE, and NISAR missions. In 2023, airborne cal/val activities will support the recently launched SWOT mission.

Designated Observable missions under development on the basis of the Decadal Survey, along with Incubation studies and Explorer missions, are beginning to drive the future needs for airborne support. The AOS mission, for example, has a mandatory suborbital component to complement the space observations. The SBG mission team has an ongoing need for airborne data for algorithm development and to provide data for the Applied Science Early Adopter Program. Reports from the Planetary Boundary Layer (PBL) *https://science.nasa.gov/earth-science/decadal-pbl*) and Surface Topography and Vegetation (STV) (*https://science.nasa.gov/earth-science/decadal-stv*) technology incubation study teams and workshops call for airborne activities that include technology test flights, technology development programs,

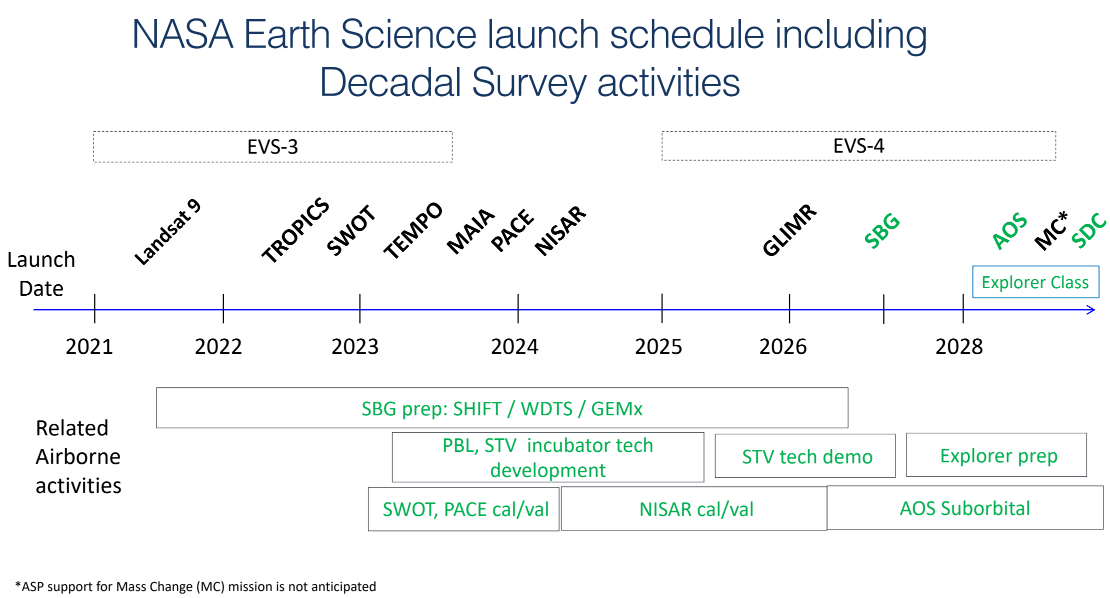


Figure 64. *The Designated Observable missions will need airborne support.* ***Figure credit:*** *NASA*

and airborne concepts, particularly the use of uncrewed aircraft.

ASP also continues to support existing space missions (e.g., A-Train satellites), as well as other "foundational" missions, such as CALIPSO, GPM, OCO-2, and ICESat-2. Once launched, missions require mandatory cal/val, often making use of airborne capabilities. New missions on the ISS, several small satellites, and collaborations with NOAA, ESA, and other space agencies are also targets for airborne support.

In 2022, ASP personnel participated in science team meetings and program reviews to collect requirements (Table 18).

Table 18. *Activities supporting ASP requirements information gathering.*

Activity
Participation in AGU Fall Meeting
Participation in Solid Earth team meeting
Remote participation in NASA Earth Science Division community workshops
Remote participation in PACE Applications Workshop
Remote participation in AOS Community Forum
Remote participation in SBG Community workshop
Remote participation in AOS Suborbital team meeting
Remote participation in SMD Town Hall
Participation in Federal UAS Workshop
Remote participation in Fall Tactical Fire Remote Sensing Advisory Committee meeting

Five-year Plan

The ASP Program maintains a 5-year plan (*https://airbornescience.nasa.gov/content/5_Year_ASP_Plan)* for planning and scheduling. Significant maintenance periods for the various aircraft are indicated. A copy in Appendix A depicts plans by science area and aircraft platform. A snapshot of potential flight campaigns for the Decadal Survey Designated Observable and Incubation Study missions is shown in Figure 65.

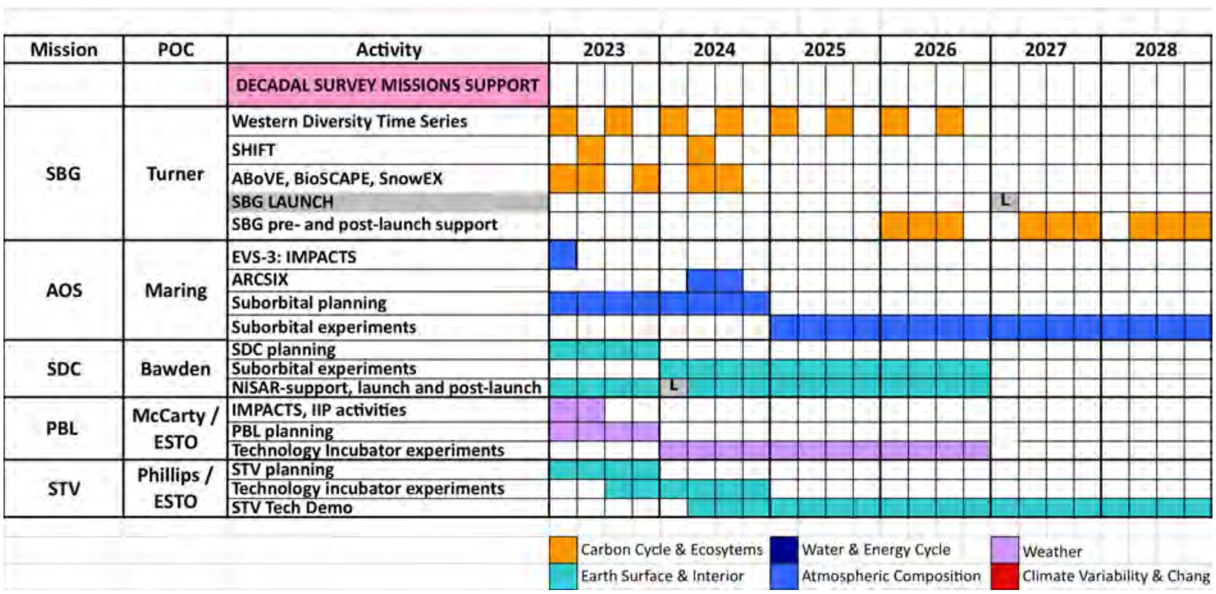


Figure 65. *Forecasted ASP support for missions identified in the 2017 Decadal Survey. (L indicates launch date.)*
Figure credit: *NASA*

7. Education, Training, Outreach, and Partnerships

Student Airborne Research Program (SARP) 2022

The 14th annual NASA Student Airborne Research Program (SARP) occurred June 12 through August 5, 2022. SARP is an eight-week internship for 28 senior undergraduate students. This hands-on research experience gave the interns the unique opportunity to fly aboard the NASA DC-8 aircraft based at AFRC in Palmdale, California. The students then spent the remainder of the summer conducting a focused project in Earth system science using NASA airborne and remote sensing data in one of four topical areas – land, air, oceans, or aerosols. Students were mentored by graduate students and faculty from UC Irvine, UC Santa Cruz, UC Santa Barbara, San Diego State University, UC Riverside, Arizona State University, and CSU San Bernardino.

SARP continues to promote diversity, equity, and inclusion in STEM disciplines. The 2022 interns were selected from 28 institutions in 17 states and

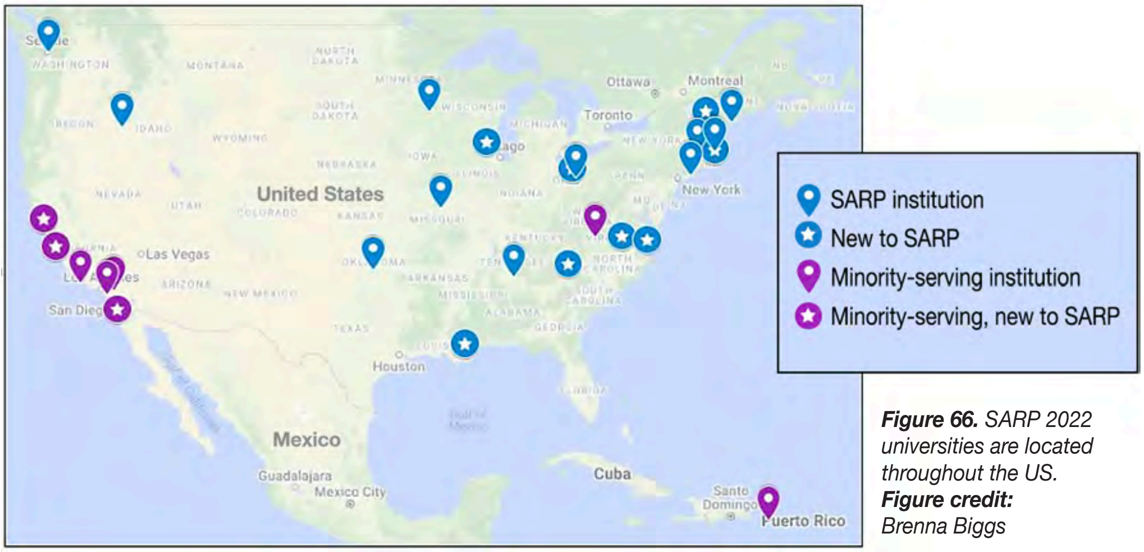


Figure 66. *SARP 2022 universities are located throughout the US.* ***Figure credit:*** *Brenna Biggs*

Puerto Rico, with nearly one third of the students representing a minority-serving institution. Twelve of the students attended an institution not represented in SARP in previous years and over half the interns came from institutions that offer limited research opportunities.

During their time at AFRC, students networked with NASA personnel and distinguished professors, toured various platforms, attended lectures from prominent scientists, and – perhaps most excitingly – participated in three science flights on the NASA DC-8 aircraft. Students also collected additional scientific data through sonde launches, mobile lab trips, and local ground truthing. Students launched ten sondes near Palmdale, California to collect vertical profiles of meteorological data and ozone.

After two weeks of rigorous lectures and sampling opportunities at AFRC, the program moved to the UC Irvine campus. For the remaining six weeks of the program, students learned how to code using various programming languages, analyzed samples collected during the DC-8 flights in the Rowland-Blake laboratory, arranged weekly group dinners, and hosted special guests, such as Karen St. Germain and Kate Backer from NASA's Earth Science Division. At the end of the summer, students presented their results to their peers, NASA guests, and friends and family. Four exceptional students were fully funded to present their research at the American Geophysical Union (AGU) 2022 Fall Meeting in December.

SARP has ambitious plans for its 15th year. In addition to a new Program Manager, Ryan Bennett of NSRC, SARP is branching out to the US East Coast. In 2023, SARP will accept nearly double the number of applicants across the two programs.

Figure 67. *A SARP student demonstrates how to use gas chromatography to determine the methane concentration in samples collected during flights on the NASA DC-8 to special guests Karen St. Germain and Kate Becker during a tour of the Rowland-Blake laboratory at UC Irvine.* ***Photo credit:*** *Brenna Biggs*

Figure 68. *Students prepare to launch ozonesondes at NASA's AFRC B703 in Palmdale, California.* ***Photo credit:*** *Brenna Biggs*

Student Airborne Science Activation Program (SaSa)

NASA's Student Airborne Science Activation (SaSa) program is on a mission to broaden the ethnic and racial diversity of researchers in the Earth sciences. SaSa is designed for undergraduates enrolled at minority-serving institutions to participate in authentic NASA field research. In addition to being an acronym, the program's name is derived from the Kiswahili word "sasa," which means "now." It was adopted to convey the urgency of the mission, because, even as minority groups have increased as a proportion of the US population over the past 40 years, minority representation in the geosciences has remained relatively low.

Summer 2022 marked the inaugural year of the SaSa program. The 25 participants participated in an eight-week, hands-on research experience in all components of a scientific research campaign. Students used the University of Maryland – Baltimore County campus as home base. There, they received learning experiences from NASA subject matter experts, graduate mentors, faculty advisors, and guest lecturers, as well as professional development training, including scientific abstract writing, comprehensive literature review, networking, and professional presentations. The interns gained knowledge and skills through hands-on research and participated in five science flights July 6-15 (Figure 67). Finally, students spent the last two weeks analyzing data and making final presentation posters about their summer research projects.

The students worked on a shared a blog (*https://blogs.nasa.gov/earthexpeditions/2022/08/03/student-scientists-flying-high/*) that demonstrated their excitement for the SaSa mission.

The P-3 payload included Cloud Absorption Radiometer (CAR), Langley Aerosol Research Group Experiment (LARGE), and four piggy-back instruments: Spectrometers for Sky-Scanning, Sun-Tracking Atmospheric Research-B (4STAR-B), a longwave infrared channel spectropolarimeter, Continuous Flow Diffusion Chamber (CFDC) – Ice ActivationSpectrometer and a Multispectral Infrared Camera from Howard University.

Students learned how to work with data from several instruments, including analyzing data from ground-based instruments, and did independent research projects in Earth System sciences. They presented posters to NASA scientists, engineers, other personnel, family, and friends at NASA's Goddard Space Flight Center on July

Figure 69. *The SaSa class of 2022, along with some of the NASA and university researchers who supported the program, pose on a rooftop at the University of Maryland – Baltimore County during the program's kickoff on June 6, 2022.* ***Photo credit:*** *NASA*

Figure 70. *The SaSa class of 2022 going to board NASA P-3 aircraft at NASA's Wallops Flight Facility during their first science flight on July 6, 2022.* ***Photo credit:*** *NASA*

29, 2022. Finally, the students celebrated the culmination of the SaSa program's summer 2022 session with a Close-out Ceremony and Student Awards.

SaSa hopes to continue to provide authentic engagement to students, which will lead to greater diversity in Earth sciences (*https://www.nasa.gov/feature/ames/toward-greater-diversity-in-earth-sciences-nasa-s-student-airborne-science-activation*). This will raise the science literacy in minority institutions and align them perfectly with one of the primary NASA SciAct objectives: Improve US Scientific Literacy.

Mission Tools Suite – Outreach (MTS-O)

NASA flies airborne scientific missions all around the world. For nearly all ASP-supported campaigns, participants utilize the online Mission Tools Suite platform (see page 69), which packages all flight resources in one location and allows accessibility in flight and from the ground simultaneously and in real time. MTS is a hub for planning, communication, and situational awareness. It provides real-time telemetry from airborne and spaceborne platforms, links ground science support with flight scientists, pilots, and engineers, and is adapted for the unique needs of each mission.

Although MTS is currently used for airborne missions, a downscaled version has been created for outreach purposes: Mission Tools Suite – Outreach (MTS-O). MTS-O features are similar to the full version and it is used to connect mission participants to K-12 students and educators. MTS-O features live flight tracking and camera feeds, real-time satellite products and data visualization, and live text chats between classrooms and mission participants. It is free to use and is web-based, with no additional application or download required. MTS-O connects K-12 students to NASA scientists, pilots, and engineers in a relatively low-cost and accessible way.

One of the most popular MTS-O features is the chat function. NASA ASP missions already use internet relay chat (IRC) clients (e.g., XChat, HexChat) as the main method of communication between mission personnel on the plane and on the ground. MTS-O leverages this existing system by adding an educational chatroom, the "#askairborne" channel, where students and teachers can informally ask questions directly to scientists and mission personnel while the airborne platform is flying.

MTS-O has been used for over a decade during eleven large-scale NASA missions to connect scientists to over 28,000 students worldwide:

- 2012 – 2014: Hurricane and Severe Storm Sentinel (HS3)
- 2012 – 2019: Operation IceBridge (OIB)
- 2013 – 2015: Airborne Tropical Tropopause Experiment (ATTREX)
- 2013: Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ)
- 2015: Global Precipitation Measurement Mission Olympic Mountains Ground Validation Experiment (OLYMPEX)
- 2015 – 2017: North American Aerosols and Marine Ecosystem Study (NAAMES)
- 2016: An International Cooperative Air Quality Field Study in Korea (KORUS-AQ)
- 2019: Cloud, Aerosol, and Monsoon Processes Philippines Experiment (CAMP2Ex)
- 2020: Investigation of Microphysics and Precipitation for Atlantic Coast Threatening Snowstorms (IMPACTS)
- 2021: Tracking Aerosol Convection Experiment– Air Quality (TRACER-AQ)
- 2022: Aerosol Cloud Meteorology Interactions Over the Western Atlantic Experiment (ACTIVATE)

During the pandemic, MTS-O connected to over 3,000 students worldwide through the TRAC-

Figure 71. *Students in Empangeni High School (a GLOBE school) in Empangeni, South Africa, chatted live with the Operation IceBridge team in-flight.* ***Photo credit:*** *Helena Joubert*

Figure 72. *Students in Empangeni High School (a GLOBE school) in Empangeni, South Africa, working on Operation IceBridge activities.* ***Photo credit:*** *Helena Joubert*

ER-AQ and ACTIVATE campaigns. In FY23, MTS-O will be used to connect to additional students by leveraging connections with the Global Learning and Observations to benefit the Environment (GLOBE) Program, a citizen science network that connects students around the world and provides instructions and a platform for uploading their observations for scientists to use, typically to validate satellite measurements.

Appendices

Appendix A

5-year Plan

5-year plan by Science Area

Atmospheric Composition and Chemistry

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
1) Atmospheric Composition and Chemistry				
1.1) TEMPO LAUNCH		Lefer	TEMPO	
1.2) AEROMMA	200	Lefer	GOER-R, TEMPO, SNPP	DC-8
1.3) GOTHAMM-AQ	80	Lefer EPA	TEMPO	G-III (2)
1.4) STAQS	100	Lefer	TEMPO, Sentinel 5P	NASA GV
1.5) FireSense Demo		Lefer		B-200 D
1.6) PACE LAUNCH		Lorenzoni	PACE	
1.7) Asia-AQ (Phase1)	200	Lefer / Jucks	GEMS, TROPOMI	DC-8; NASA GV
1.8) FireSense Demo -2		Lefer		B-200 D
1.9) ARCSIX	300	Maring/Markus	ICESat-2	DC-8; G-III (2)
1.10) FireSense UAS Demo		Lefer		Other
1.11) MAIA LAUNCH		Lefer	MAIA	
1.12) Asia-AQ (Phase2)	200	Lefer / Jucks	GEMS, TROPOMI	DC-8; NASA GV
1.13) GEOCarb LAUNCH		Jucks	GEOCarb	
1.14) GEOCarb cal/val (AJAX?)	??	Jucks	GEOCarb	TBD
1.15) AOS Suborbital prep		Maring	AOS	TBD
1.16) FIREX-AQ (2)	150	Lefer		DC-8; ER-2

Carbon Cycle and Ecosystems
Terrestrial Ecology, Biodiversity, Carbon Monitoring

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
2) Carbon Cycle & Ecosystems Science				
2.1) SHIFT	20	Turner	SBG	Other B-200
2.2) LVIS-GEDI -22		GSFC	GEDI	G-III (2)
2.3) UAVSAR-TE-23	20	Bawden/Margolis	NISAR	G-III
2.4) BLUEFLIX (CMS) - 23	150	Hibbard		Other B-200
2.5) WDTS - 23 spring	30	Turner	SBG	ER-2
2.6) AVIRIS-23	20	Turner/Margolis	SBG	Other B-200
2.7) LVIS-GEDI -23		Margolis	GEDI	NASA GV
2.8) Western Diversity - 23 fall	30	Turner	SBG	ER-2
2.9) BioSCape	250	Turner	SBG, BioMASS	NASA GV; G-III (2)
2.10) NISAR LAUNCH			NISAR	
2.11) UAVSAR-TE-24	60	Bawden/Margolis	NISAR	G-III
2.12) BLUEFLIX (CMS) - 24	150	Hibbard		Other B-200
2.13) SHIFT - repeat	20	Turner	SBG	Other B-200
2.14) AVIRIS-24	20	Turner/Margolis	SBG	Other B-200
2.15) STV demo - forest topography		Margolis/Phillips	STV	G-III
2.16) Western Diversity - 24	30	Turner	SBG	ER-2
2.17) PACE LAUNCH			PACE	
2.18) PACE PAX		Lorenzoni	PACE	ER-2
2.19) SBG Pathfinder	30	Turner	SBG	TBD
2.20) Arctic COLORS	100	Lorenzoni		TBD
2.21) GLIMR cal/val		Lorenzoni	GLIMR	TBD

Water and Energy Cycle
Terrestrial Hydrology

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2021–2027
4) Water and Energy Cycle				
4.1) SnowEX / SWESAR		Entin	GCOM-W1	Other B-200
4.2) SnowEX / AVIRIS / UAVSAR - 23	75	Entin	GCOM-W1, GPM, SBG	G-III; Other B-200
4.3) SWOT post-launch hydrology cal/val (AirSWOT)	120	Shiffer	SWOT	B-200 D
4.4) SLAP support for PBL		Entin	PBL	Other B-200
4.5) SnowEX - 24 (?)		Entin		
4.6) PACE LAUNCH			PACE	
4.7) PACE-coastal water quality mission (PRISM?)		Entin/Lorenzoni	PACE	TBD

Climate Change and Variability Cryosphere and Physical Oceanography

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2021–2027
3) Climate Variability and Change				
3.1) SWOT Launch			SWOT	
3.2) S-MODE - 2022-23		Shiffer	SWOT	G-III (2); B-200 D
3.3) Vanilla UAS Snow mission repeat			ICESat-2	Other
3.4) SWOT post launch ocean cal/val (SCRIPPS MASS)	120	Shiffer	SWOT	NASA GV
3.5) SWOT post-launch hydrology cal/val (AirSWOT)	120	Shiffer	SWOT	B-200 D
3.6) NISAR LAUNCH		Bawden	NISAR	
3.7) SWOT cal/val	120	Shiffer	SWOT	NASA GV
3.8) ICESAT-2 cal/val		Markus	ICESat-2	NASA GV
3.9) ARCSIX	300	Maring/Markus	ICESat-2	DC-8; G-III (2)
3.10) EXPLORER class ocean concept		Shiffer		TBD

Earth Surface and Interior

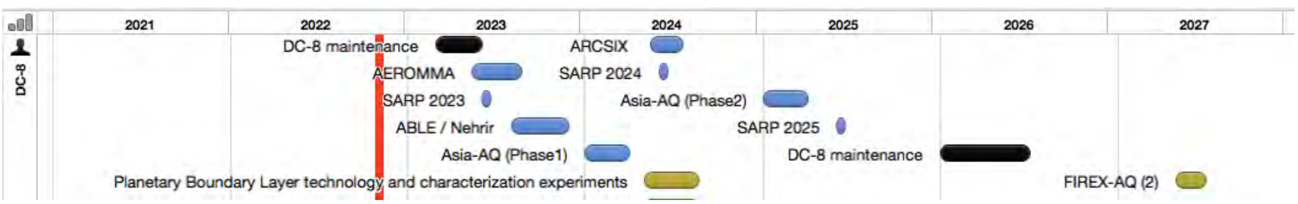
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2021–2027
5) Earth Surface & Interior				
5.1) QUAKES	36	Phillips	STV	NASA GV
5.2) Landslide mission	18	Phillips	NISAR	G-III
5.3) USGS (GEMx/EMRII)	100	Phillips	Landsat / SBG	ER-2
5.4) STV technology development		Phillips/ Bawden/ ESTO	STV incubator	TBD
5.5) AirMOSS mission	18	Bawden		G-III
5.6) QUAKES-23	36	Phillips	STV	NASA GV
5.7) NISAR LAUNCH			NISAR	
5.8) NISAR cal/val -24	100	Bawden	NISAR	G-III
5.9) UAV vulcanology / glaciology demo - mission in development	72	Phillips	SBG	TBD
5.10) USGS (GEMx) - 24	100	Phillips	Landsat / SBG	ER-2
5.11) QUAKES-24	36	Phillips	STV	NASA GV
5.12) STV Tech Demo (Quakes ++?)		Phillips	STV	TBD
5.13) NISAR cal/val -25	12	Bawden	NISAR	G-III
5.14) USGS (GEMx) -25	100	Phillips	Landsat / SBG	ER-2
5.15) European vulcanology mission		Phillips	SBG	TBD
5.16) NISAR cal/val -26	12	Bawden	NISAR	G-III
5.17) USGS (GEMx) -26	100	Phillips	Landsat/SBG	ER-2
5.18) NISAR cal/val -27	12	Bawden	NISAR	G-III

Weather and Atmspheric Physics

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2021–2027
6) Weather and Atmospheric Dynamics				
6.1) ALOFT	55	McCarty	GOES-r	ER-2
6.2) GOES-R cal/val	100	McCarty	GOES-R	ER-2
6.3) TROPICS underflight		McCarty	TROPICS	TBD
6.4) IIP / AITT instrument demos		ESTO / McCarty	PBL incubator	ER-2
6.5) Planetary Boundary Layer technology and characterization experiments		ESTO	PBL incubator	DC-8; Any Twin Otter
6.6) Next Weather field campaign		McCarty	AOS	TBD; ER-2
6.7) AOS Suborbital prep		Maring	AOS prelaunch	TBD

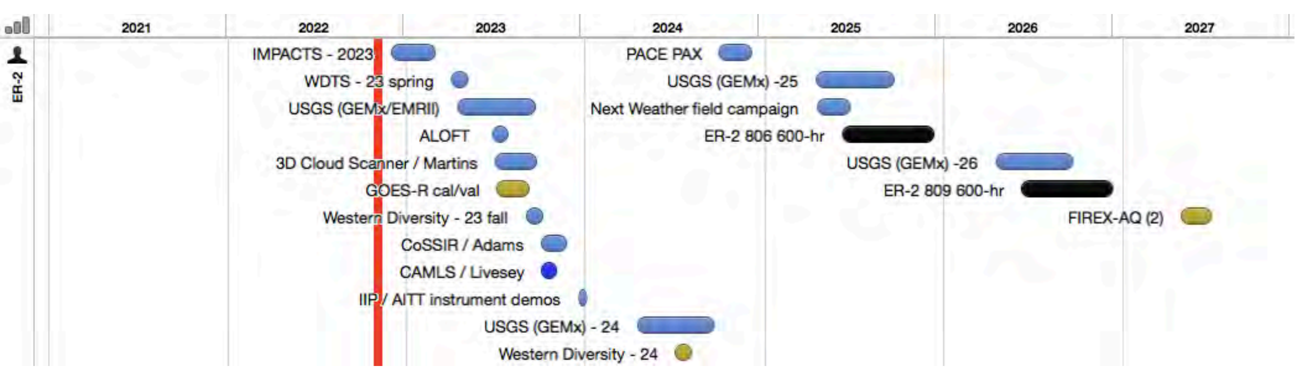
5-year plan by Aircraft

DC-8

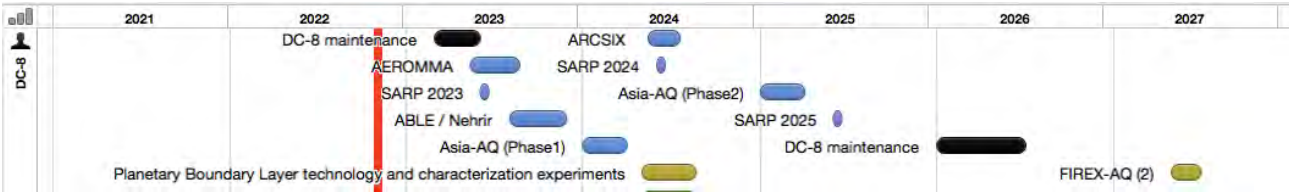


P-3

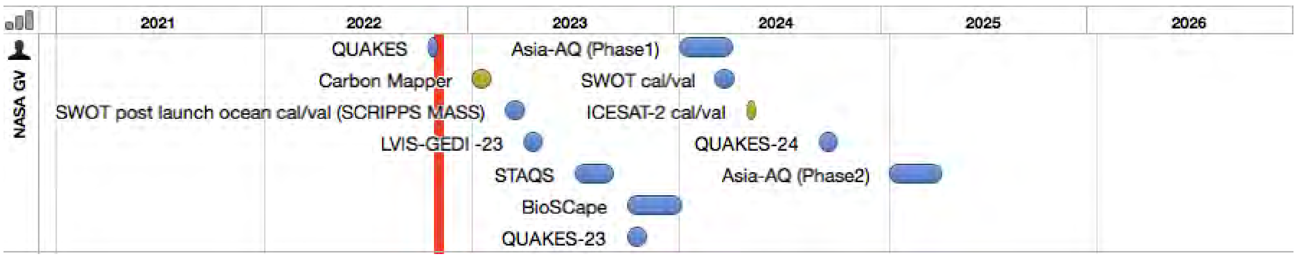
ER-2



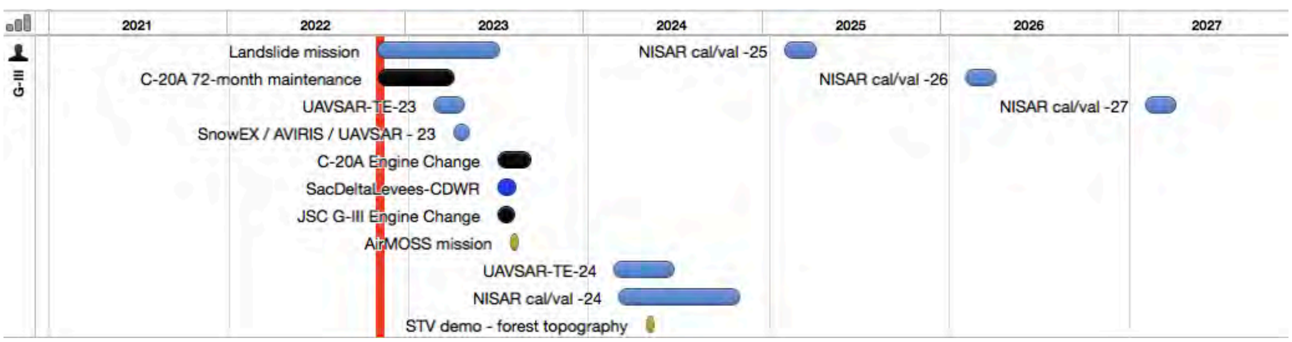
G-III (with ports and dropsonde capability)



G-V (with ports)



G-III (UAVSAR)



Appendix B

Acronyms

A

ABoVE	Arctic-Boreal Vulnerability Experiment
AC3	Axial Cyclone Cloud water Collector
ACCLIP	Asian summer monsoon Chemical and Climate Impact Project
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADS-B	Automatic dependent surveillance – broadcast
AEROMMA	Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas
AFRC	Armstrong Flight Research Center
AGU	American Geophysical Union
AIRO	Aircraft In-Situ Radio Occultation
AirSWOT	Airborne Surface Water and Ocean Topography
AITT	Airborne Instrument Technology Transition
AJAX	Alpha Jet Airborne Experiment
ALOFT	Airborne Lighting Observatory for FEGS and TGFs
AMPR	Advanced Microwave Precipitation Radiometer
AOS	Atmospheric Observing System
API	Application Programming Interface
APL	Applied Physics Laboratory
ARC	Ames Research Center
ARINC	Aeronautical Radio, Incorporated
ASF	Airborne Sensor Facility
ASM	Asian Summer Monsoon
ASP	Airborne Science Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVAPS	Advanced Vertical Airborne Profiling System
AVIRIS, AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation
AWAS	Advanced Whole Air Sampler

AWG	Arbitrary Waveform Generator
AWP	Airborne Wind Profiler

B

BAERI	Bay Area Environmental Research Institute
BBR	Broadband Radiometers
BGAN	Broadband Global Area Network
BLUEFLUX	Blue Carbon Prototype Products for Mangrove Methane and Carbon Dioxide Fluxes

C

CAFÉ	Compact Airborne Formaldehyde Experiment
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
Cal/val	Calibration / Validation
CANOE	Compact Airborne NO_2 Experiment
CAPS	Cloud, Aerosol, and Precipitation Spectrometer
CARAFE	Carbon Airborne Flux Experiment
CARE	Cabin Altitude Reduction Effort
CAS	Commercial Aviation Services
CAVA-AW	Calibration and Validation for Aeolus – Aerosols and Winds
CBM	Conditions-Based Maintenance
CH_4	methane
Chi-WIS	Chicago Water Isotope Spectrometer
CM	Carbon Mapper
CO	Carbon monoxide
CO_2	Carbon dioxide
CO2-M	Carbon Dioxide Monitoring
COA	Certificate of Authorization
CONUS	Continental USzzz
CPI	Cloud Particle Imager
COLD 2	Carbon Oxide Laser Detector 2

COMA	Carbon Monoxide Measurement & Analysis
COVID	Coronavirus Disease
CPEX-CV	Convective Processes Experiment – Cabo Verde
CReSIS	Center for Remote Sensing and Integrated Systems
CRS	Cloud Radar System
CVI	Counterflow Virtual Impactor
CY	Calendar Year

D

DAWN	Doppler Aerosol WiNd
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DLH	Diode Laser Hygrometer
DLR	German Aerospace Agency
DO	Designated Observable
DOE	Department of Energy (U.S.)

E

EECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
eMAS	Enhanced MODIS Airborne Simulator
EMRI	Earth Mapping Resource Initiative
EOS	Earth Observing System
ESA	European Space Agency
ESD	Earth Science Division
ESI	Earth Surface and Interior
ESO	Earth System Observatory
ESPO	Earth Science Project Office
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
EV, EVS-2, EVS-3	Earth Venture, Earth Venture Suborbital-2, Earth Venture Suborbital-3

F

FAA	Federal Aviation Administration
FCDP	Fast Cloud Droplet Probe
FLIR	Forward Looking Infrared
FR	Flight Request
FY	Fiscal Year

G

GAO	Global Airborne Observatory
GEDI	Global Ecosystem Dynamics Investigation
GEMx	Geological Earth Mapping experiment
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	Glenn Research Center
GSA	General Services Administration
GSFC	Goddard Space Flight Center
GTS	Global Telecommunications System

H

H_2O	water
HAL	Harvard Halogen Instrument
HALE	High altitude long endurance
HALO	High Altitude Lidar Observatory
HAMSR	High Altitude Monolithic Microwave integrated Circuit (MMIC) Sounding Radiometer (HAMSR)
HIWC	High Ice Water Content
HSRL	High Spectral Resolution Lidar
HUPCRS	Harvard University Picarro Cavity Ring Down Spectrometer
HWV	Harvard Lyman-α Photofragment Fluorescence Hygrometer
HyTES	Hyperspectral Thermal Emission Spectrometer

I

ICESat	Ice, Cloud, and land Elevation Satellite
ICOS	Integrated Cavity Output Spectroscopy
IIP	Instrument Incubator Program
IMPACTS	Investigation of Microphysics and Precipitation for Coast-Threatening Snowstorms
IMU	Inertial measurement unit
InSAR	Interferometric Synthetic Aperture Radar
IOP	Intensive Operating Period
IR	Infrared
IRC	Internet Relay Chat
IRIG-B	Inter-range instrumentation group - B
ISAF	In situ Airborne Formaldehyde
ISRO	Indian Space Research Organization
ISS	International Space Station
IT	Internet technology
IWGADTS	Interagency Working Group for Airborne Data and Telecommunication Systems

J

JATAC	Joint Aeolus Tropical Atlantic Campaign
JPL	Jet Propulsion Laboratory
JSC	NASA Johnson Space Center

K

KU	University of Kansas

L

LARGE	Langley Aerosol Research Group Experiment
LaRC	Langley Research Center
LiDAR	Light Detection and Ranging
LIF-NO	Laser Induced Fluorescence – Nitrogen Oxide
LIF-SO2	Laser Induced Fluorescence – Sulphur Dioxide

LTE	Long Term Evolution
LTER	Long Term Ecological Research
LVIS	Land, Vegetation, and Ice Sensor

M

MAIA	Multi-Angle Imager for Aerosols
MAS	MODIS Airborne Simulator
MASS	Modular Aerial Sensing System
MASTER	MODIS/ASTER Airborne Simulator
MC	Mass Change
MERLIN	Methane Remote Sensing Lidar Mission
MMS	Meteorological Measurement System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSES	Multiscale Observing System of the Ocean Surface
MSFC	Marshall Space Flight Center
MTS	Mission Tools Suite
MTS-O	Mission Tools Suite - Outreach
MUOS	Mobile User Objective System
MVIS	Miniature Video Imaging System

N

NAMA	North American Monsoon Anticyclone
NASDAT	NASA Airborne Science Data and Telemetry
NAST-I	National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed - Interferometer
NEON	National Ecological Observatory Network
NISAR	NASA-ISRO SAR
NO, NO_2	Nitrogen Monoxide, Nitrogen Dioxide
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council
NSRC	National Suborbital Research Center
NVF	Nighttime Validation Flights

O

OCO-2	Orbiting Carbon Observatory - 2

P

PACE	Plankton, Cloud, and ocean Ecosystem
PALMS	Particle Analysis By Laser Mass Spectrometry
PALS	Passive Active L-band System
PBL	Planetary Boundary Layer
PDM	Programmed Depot Maintenance
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol R&D
PLO	Phase-Locked Oscillator
PRISM	Portable Remote Imaging Spectrometer
PTZ	Pan-Tilt-Zoom

Q

R

R&A	Research and Analysis
ROSES	Research Opportunities in Space and Earth Sciences
ROZE	Rapid Ozone Experiment
RSP	Research Scanning Polarimeter

S

S-MODE	Submesoscale Ocean Dynamics and Vertical Transport
SABRE	Stratospheric Aerosol processes, Budget, and Radiative Effects
SAL	Saharan Air Layer
SAR	Synthetic Aperture Radar
SARP	Student Airborne Research Program

SaSa	Student Airborne Science Activation
SASSIE	Salinity and stratification at the Sea Ice Edge
SatCom	Satellite Communications
SBG	Surface Biology and Geology
SBIR	Small Business Innovative Research
SDC	Surface Deformation and Change
SEO	sensor equipment operator
SHIFTS	SBG High Frequency Time Series
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SIO	Scripps Institute of Oceanography
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SnowEx	Snow Experiment
SOFRS	Science Operations Flight Request System
SOA2RSE	Synergies of Active Optical and Active Microwave Remote Sensing Experiment
SoOp	Signals of Opportunity
SP2	Single Particle Soot Photometer
SRTM	Shuttle Radar Topography Mission
STAQS	Synergistic TEMPO Air Quality Science
STEM	Science Technology Engineering and Math
STV	Surface Topography and Vegetation
SWE	Snow Water Equivalent
SWOT	Surface Water and Ocean Topography

T

TEMPO	Tropospheric Emissions: Monitoring Pollution
TOIL	Twin Otter International Limited
TomoSAR	Tomographic SAR
TRACER-AQ	Tracking Aerosol Convection Interactions Experiment – Air Quality
TROPOMI	Tropospheric Monitoring Instrument

U

UAS	Unmanned Aircraft System, Uncrewed Aerial System
UAV	Unmanned Aerial Vehicle
UASO3	UAS Ozone
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UC	University of California
UCATS	UAS Chromatograph for Atmospheric Trace Species
UCLA	University of California Los Angeles
UCNRS	University of California Natural Reserve System
UCSB	University of California Santa Barbara
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UTLS	Upper Troposphere / Lower Stratosphere
UTLS-AMP	Upper Troposphere / Lower Stratosphere Aerosol Microphysics Package
UV	Ultra-violet

V

VIPR	Vapor in-cloud Profiling Radar
VSWIR	Visible to Short wave infrared

W

WDTS	Western Diversity Time Series
WFF	Wallops Flight Facility
WHOI	Woods Hole Oceanographic Institute

XYZ

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