National Aeronautics and
Space Administration

EXPLORE

Science Mission Directorate
Airborne Science Program

2023
Annual Report

COVER IMAGE:

DC-8 flying past the Statue of Liberty during AEROMMA. Photo credit: NASA DC-8 team

BACK COVER:

Top: The student cohort and mentors for the inaugural SARP East 2023 in front of the Dynamic Aviation B-200. Photo credit: NASA

Bottom: The student cohort and mentors for the 15th Annual SARP in front of the NASA AFRC DC-8. Photo credit: Jane Berg

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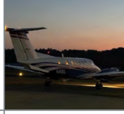


Figures and Tables

1. Leadership Comments

Bruce Tagg, Director of the Airborne Science Program.

Thanks for taking the time to learn about the NASA Earth Science Division (ESD) Airborne Science Program (ASP)!

This report provides an update of ASP capabilities, summaries of the amazing science and technology projects we supported this year, and exciting Program updates. In retrospect, it's clear that 2023 was another pivotal year for the Program. ASP supported 20 major campaigns – 2115 flight hours across every Earth science discipline. The TEMPO of satellite launches (that's a pun) is on the rise, which means NASA aircraft are being called on like never before to underfly satellites, including TEMPO, SWOT, and GEDI-ISS. Additionally, ASP also supported important process and modeling studies as we closed out the latest cohort of Earth Venture Suborbital-3 flight missions, S-MODE and IMPACTS. Finally, we balanced all of this with also flying multiple missions with our NOAA and USGS partners, including AEROMMA, STAQS, SABRE, and GEMx (see Appendix B: Acronyms, page 89).

When not directly supporting NASA flight projects, ASP is continually working to improve Program capabilities. Several years ago, the National Academies of Sciences, Engineering and Medicine (NASEM) recommended we find a replacement for our aging Douglas DC-8. After several studies, NASA acquired a gently used Boeing 777 (B777) that is currently undergoing modifications. The NASA B777 is planned to support operations in 2026 and will fly future Earth science missions in all disciplines. ASP is also funding modifications of a Gulfstream IV, which will serve as a developmental and operational platform for the UAVSAR follow-on mission, AirSAR-NG.

All of this has been made possible through the dedication, hard work, and skill of ASP team members across the country at various NASA field centers. Together, we will continue to grow our science capability to meet science requirements and ensure our missions are accomplished within budget and schedule. Thanks to you for your support of NASA Earth Science, and please let us know if you have any comments or suggestions for ASP leadership.

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 satellite missions. Aircraft modified with ports, inlets, internet, 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 onboard network 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 flight 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.

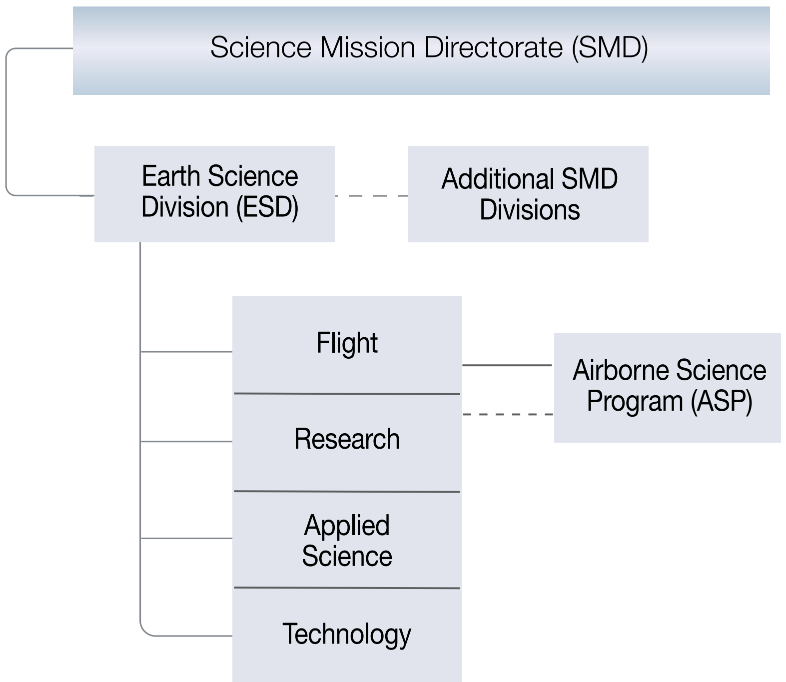


Figure 1. *Science Mission Directorate organization chart.*

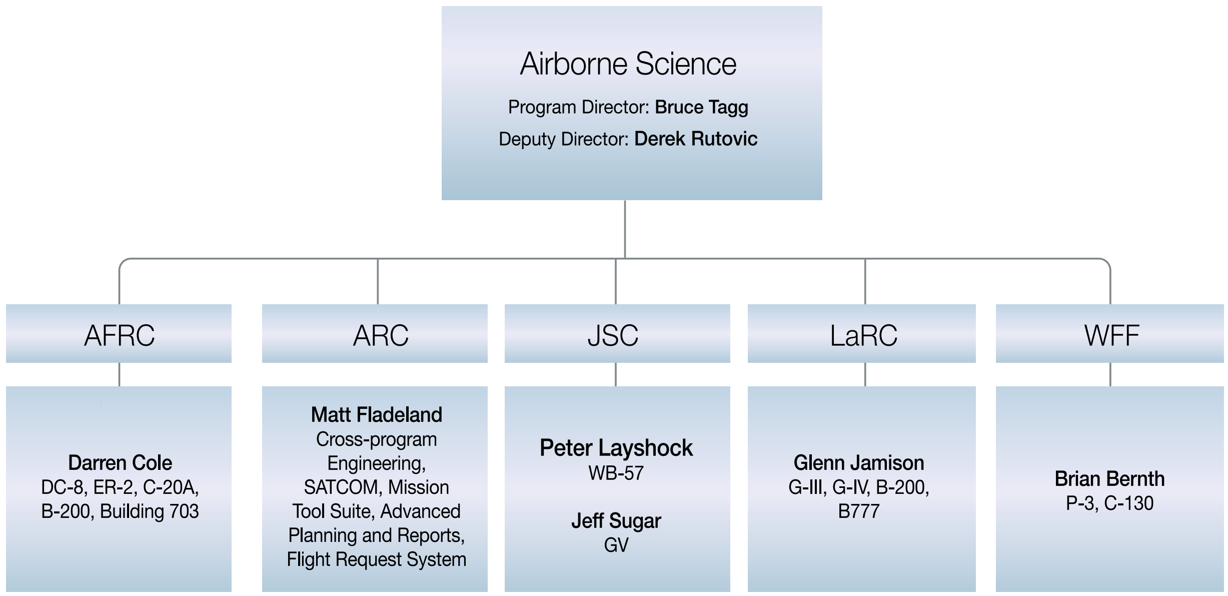


Figure 2. *Airborne Science Program organization chart.*

Flight Request System and Flight Hours

ASP maintains science-capable aircraft and instrument assets for research use in support of NASA SMD. The 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. The way to schedule the use of NASA SMD platforms and instrument assets is to submit a Flight Request (FR) for approval through SOFRS (*https://airbornescience.nasa.gov/sofrs*). The SOFRS team strives for continuous improvement by refining the user interface and reports produced.

In Fiscal Year 2023 (FY23), 118 FRs were submitted for flight activities using at least one of the following ASP components: an ASP-supported aircraft, ESD funding, or an ASP facility instrument (AVIRIS-3, AVIRIS-NG, AVIRIS-C, eMAS, LVIS, MASTER, NAST-I, and UAVSAR (L-band, P/Ka-bands)). A total of 54 Flight Requests were completed using 16 different aircraft for a total of 2415.2 flight hours. Of the remaining FRs, some were deferred, and the rest were canceled for various reasons.

Table 1 shows all SOFRS flight hours flown by all aircraft, including "Other (non-NASA) Aircraft," by funding source.

- Other NASA aircraft are NASA-owned aircraft but not subsidized by ASP.
- NASA ESD is under SMD. SMD (non-ESD) flight hours are those funded by SMD Program Managers not within ESD.

Table 2 shows the status of all Flight Requests and total flight hours by aircraft.

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 flown by funding source. "Other NASA" funding refers to funding from non-SMD Directorates, such as Exploration or Aeronautics. "Non-NASA" funding is funding from other agencies or commercial enterprises, and is often reimbursable.

Figure 3 is a histogram showing the history of total flight hours.

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

- The "Total FRs" column includes Flight Requests submitted for fiscal year FY23; these log numbers start with "23"
- The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY23.
- The "Total Partial FRs" column includes Flight Requests for which the total approved hours were not fully expended during FY23 and have been rolled over to the following year.
- The "Total FRs Completed" column includes only Flight Requests with the final status of "Completed."

The "Total Hours Flown" column includes all "Flight Hours Flown" for Flight Requests with a status of "Completed" or "Partial" for FY23.

Table 1. *NASA airborne science total FY23 hours flown by each NASA aircraft (per funding source). "Other" aircraft are identified in Table 3.*

Aircraft	NASA ESD	NASA SMD	Other NASA	Non - NASA	Not Listed	Total
ASP Supported Aircraft						
DC-8 - AFRC	178.1	0	0	7.9	0	186
ER-2 - AFRC	230.6	0	0	69.6	0	300.2
Gulfstream C-20A (G-III) - AFRC	154.5	0	0	0	0	154.5
Gulfstream III - LaRC	337	0	0	0	0	337
Gulfstream V - JSC	248.4	0	0	0	0	248.4
P-3 Orion - WFF	118.2	0	0	0	0	118.2
Other NASA Aircraft						
B-200*	271.9	0	0	0	0	271.9
Cirrus SR-22	5	0	0	0	0	5
Gulfstream III - JSC	0	18.4	0	0	0	18.4
Gulfstream IV - LaRC	0	0	0	0	0	0
Small UAS - ARC	0	0	0	0	0	0
WB-57 - JSC	0	0	0	0	0	0
Other	571.3	0	0	204.3	0	775.6
TOTAL	**2115**	**18.4**	**0**	**281.8**	**0**	**2415.2**

*Includes AFRC and LaRC

Table 2. *FY23 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	10	4	0	4	186.0
ER-2 - AFRC	17	10	0	5	300.2
Gulfstream C-20A (G-III) - AFRC	16	12	0	11	154.5
Gulfstream III - LaRC	10	8	0	6	337.0
Gulfstream V - JSC	16	4	0	3	248.4
P-3 Orion - WFF	2	1	0	1	118.2
Other NASA Aircraft					
B-200*	6	5	1	4	271.9
Cirrus SR-22	1	1	0	1	5.0
Gulfstream III - JSC	8	2	0	2	18.4
Gulfstream IV - LaRC	1	0	0	0	0
Small UAS - ARC	1	0	0	0	0
WB-57 - JSC	1	0	0	0	0
Other	29	19	1	17	775.6
TOTAL	**118**	**66**	**2**	**54**	**2415.2**

*Includes AFRC and LaRC

Table 3. *FY23 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	1	1	0	1	96.5
Alphajet	1	0	0	0	0
B-200 – Dynamic Aviation	18	13	0	11	449.8
Cessna 206	1	1	0	1	6
ISRO King Air**	1	0	0	0	0
Kenn Borek*	1	0	0	0	0
Kenn Borek Air Twin Otter	1	1	0	1	4.8
NRL P-3	1	0	0	0	0
Platform Aerospace Vanilla VA001 UAS***	1	1	0	1	15.5
Robinson R-44***	1	0	0	0	0
Twin Otter	1	1	0	1	165.3
Twin Otter CIRPAS	1	1	0	1	37.7
TOTAL	**29**	**19**	**1**	**17**	**775.6**

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

Table 4. *Summary of FY23 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	7	3	0	3	178.1
ER-2 – AFRC	11	9	0	4	230.6
Gulfstream C-20A (G-III) – AFRC	15	12	0	11	154.5
Gulfstream III – LaRC	9	8	0	6	337
Gulfstream V – JSC	11	3	0	3	248.4
P-3 Orion - WFF	2	1	0	1	118.2
Other NASA Aircraft					
B-200*	6	5	1	4	271.9
Cirrus SR-22	1	1	0	1	5.0
Gulfstream III – JSC	5	0	0	0	0
Gulfstream IV – LaRC	0	0	0	0	0
Small UAS – ARC	1	0	0	0	0
WB-57 - JSC	1	0	0	0	0
Other	24	17	1	15	571.3
TOTAL	**93**	**59**	**2**	**48**	**2115**

*****Includes AFRC and LaRC

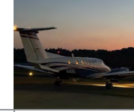


Table 5. All flight hours by funding source (FY18 through FY23).

Fiscal Year	ESD	SMD (Non-ESD)	Other NASA (non-SMD)	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	586.6	60.6	7.5	3069.8
2020	1614	0	129.9	0	0	1743.9
2021	2166	0	193.5	0	2.7	2424.9
2022	2111.8	0	233	390.6	12.7	2748.1
2023	2115	18.4	0	273.9	7.9	2415.2

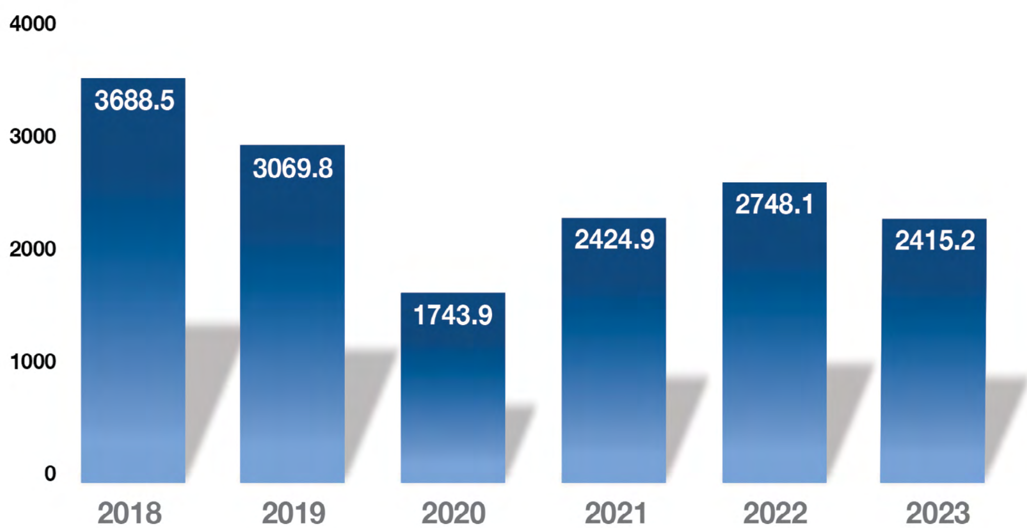


Figure 3. *Total annual ASP flight hours (FY18 through FY23).*

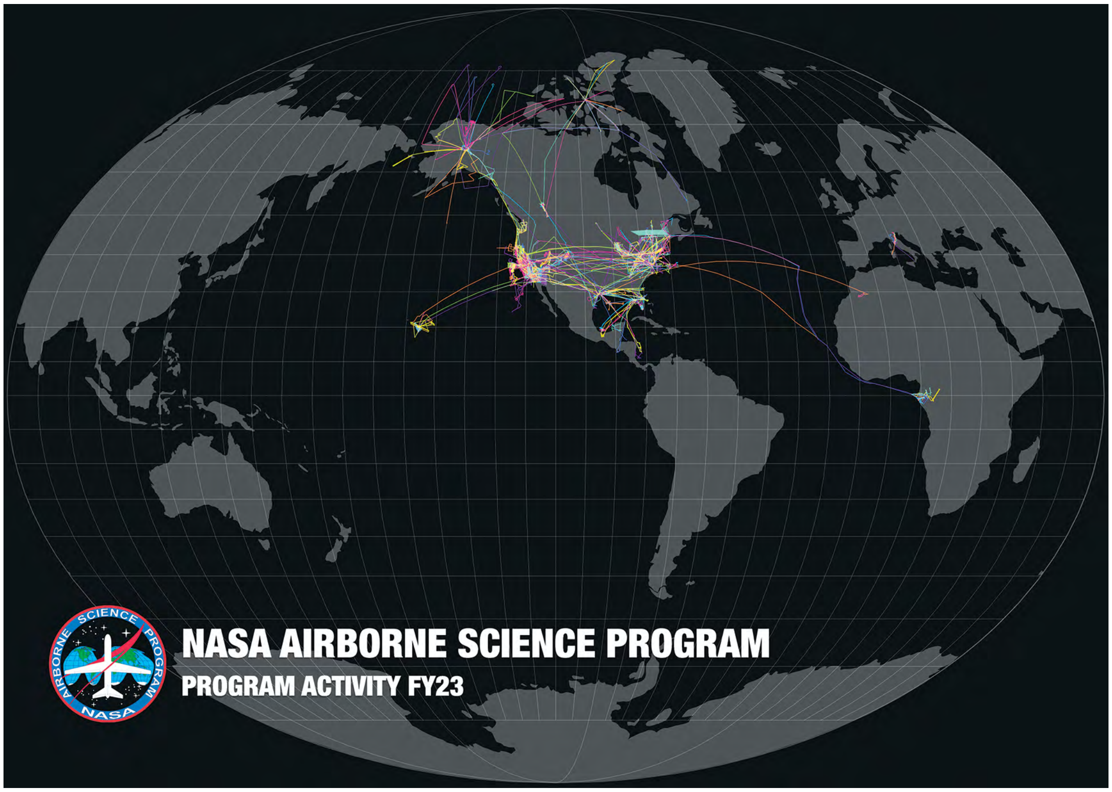


Figure 4. *Flight tracks in FY23 generated using ASP's Mission Tool Suite (MTS).* ***Image credit:*** *Aaron Duley*

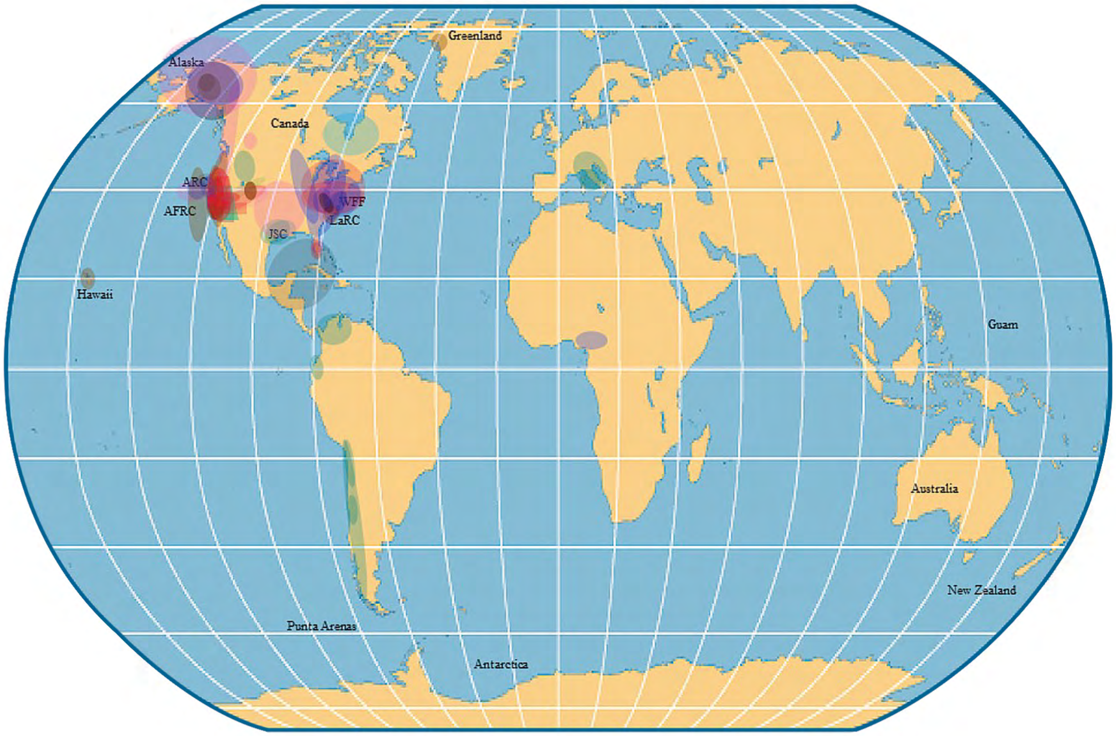
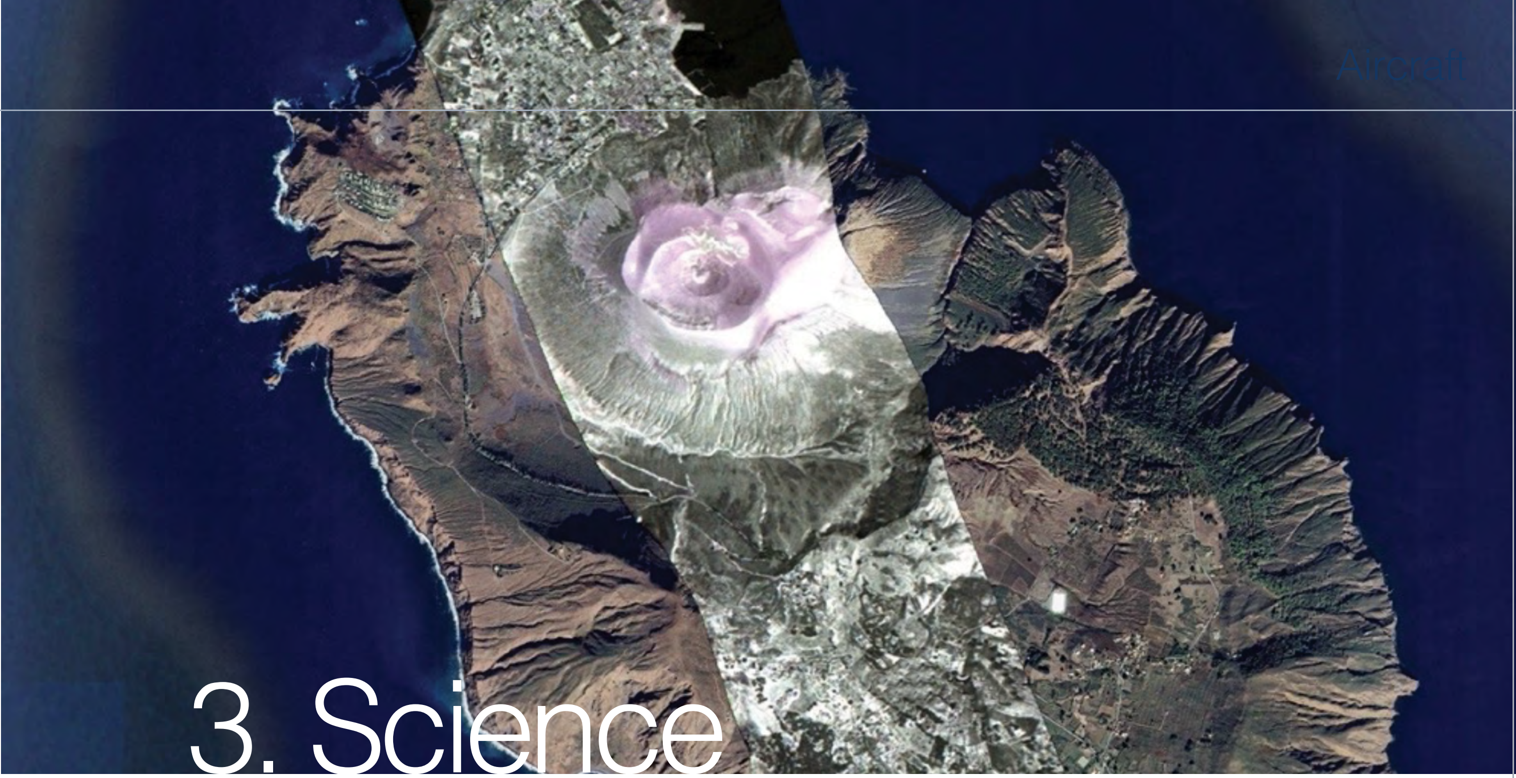


Figure 5. *Locations of FY23 ASP airborne campaigns.* ***Image credit:*** *Susan Schoenung*



3. Science

Major Mission Highlights

In FY23, ASP conducted over 2400 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. Two of the remaining Earth Venture Suborbital-3 (EVS-3) missions were able to carry out flight activities, completing their airborne phases. NASA campaigns not only deployed around the world to faraway destinations (e.g., Gabon, Ecuador, Greenland, Columbia) but also intensively studied processes occurring within the country: SnowEx in Alaska, AEROMMA around the Eastern U.S., IMPACTS along the Atlantic Coast, S-MODE and WDTS in California, UAVSAR in Hawaii, BlueFlux in Florida, and more. In 2023, ASP also branched out beyond the NASA SMD Earth Science Division to support the return of the

Table 6. *Major science missions supported by ASP in FY23.*

Mission		Flight Hours	Location	Aircraft
EVS	S-MODE	279.7	California	B-200 (A), G-III (L)
EVS	IMPACTS	227.9	U.S. Atlantic Coast	P-3, ER-2
R&A	STAQS	270.7	Multiple U.S. Cities	GV, G-III (L)
CM	Carbon Mapper	203.9	Ecuador, Columbia	B-200
R&A	UAVSAR (TE, ESI, Mauna Loa)	152.8	CONUS, Hawaii	G-III (radar)
NOAA	AEROMMA	150.4	Multiple U.S. Cities	DC-8
R&A	SWOT cal/val, includes AirSWOT	128.3	Pacific Ocean, St. Lawrence Seaway	GV, B-200 (A)
CMS	BlueFlux	96.5	South Florida	A-90
R&A	ABoVE	89.7	Alaska, Canada	B-200
R&A	ALOFT	77.6	Gulf of Mexico	ER-2
R&A	SnowEx	76.0	Alaska	B-200
R&A	LVIS Gabon	73.2	Gabon, Africa	G-III (L)
USGS	GEMx	69.6	Southwest California, Arizona	ER-2
ESA	HyTES Europe	59.7	Italy	B-200
R&A	FIRESENSE (Pre-fire)	59.4	California, Utah	G-III, B-200, B-200
ESTO	Signals of Opportunity	52.1	Colorado	B-200
R&A	Western Diversity Time Series	50.1	California	ER-2, B-200
R&A	SARP East + West	35.3	California, Virginia	DC-8, B-200

anticipated OSIRIS-REx capsule, the first U.S. mission to collect a sample from an asteroid, with the NASA SMD Planetary Science Division. Table 6 shows locations for major ASP missions (by most flight hours).

Earth Venture Suborbital: EVS-3 Final Campaigns in 2023

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 Investigation of Microphysics and Precipitation in Atlantic Coast-Threatening Snowstorms (IMPACTS) and Sub-Mesoscale Ocean Dynamics Experiment (S-MODE) completed airborne activities in 2023. The EVS-4 solicitation was posted in early FY23.

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, AVAPS, TAMMS, WISPER, Hawkeye, wing probes

The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) campaign wrapped up its third and final year in Winter 2023. IMPACTS was an EVS-3 investigation managed by the Earth Science Project Office (ESPO) that focused on monitoring snowstorms, specifically snowband formation and movement, instability within a storm, and snow particle physics.

Specifically, IMPACTS aimed to determine how multi-scale dynamical and microphysical processes within winter storms interact to produce banded regions of organized snowfall (i.e., “snowbands”). The objectives were to:

- Determine the key structures and key spatial and temporal scales of banded structures within midlatitude winter storms.
- Examine the dynamical processes associated with bands and generating cells, as diagnosed from in situ and Doppler-derived wind fields and vertical motions.
- Determine the microphysical processes and characteristics within and surrounding the banded structures and how they relate to snowfall reaching the surface and remote sensing of snow.
- Use observations in conjunction with models to improve understanding of snow bands, identify deficiencies in model microphysical parameterizations, and improve these parameterizations.

IMPACTS combined advanced radar, lidar, and microwave radiometer remote sensing instruments (HIWRAP, EXRAD, COSMIR, CRS, AMPR, and CPL) on the AFRC ER-2 with state-of-the-art microphysics probes and dropsonde capabilities (AVAPS, TAMMS, WISPER, Hawkeye, and wing probes) on the P-3 to sample U.S. East Coast winter storms. The aircraft commonly flew in a stacked formation to capture vertical information about snowstorms. While flights were typically localized around the Northeastern U.S., the aircraft flew as far west as Minnesota, and as far north as Canada. The P-3 was based at WFF, and the ER-2 was based at Dobbins Air Reserve Base (ARB). IMPACTS flight tracks are shown in Figure 6.

During the Winter 2023 deployment, the P-3 flew 118.2 hours, including 13 science flights and five calibration flights, and the ER-2 flew 103.7 hours, including 12 science flights and two calibration flights. Ten of the science flights

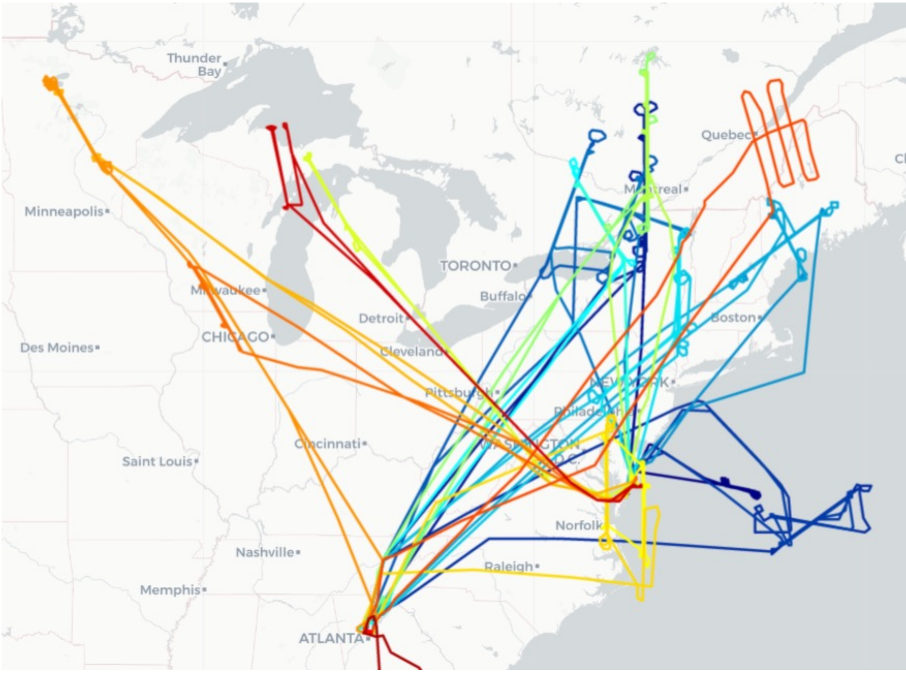


Figure 6. *Flight tracks for the Winter 2023 deployment of IMPACTS. Visualization provided by ASP's Mission Tools Suite (MTS).*

were coordinated between the two aircraft and two flights were coordinated with ground assets as well.

Thus concluded the IMPACTS campaign, which also deployed in 2020 and 2022. In total, the ER-2 and P-3 flew 240.6 hours and 272.3 hours, respectively, for the campaign. The massive amount of data collected will help researchers better understand and predict snowstorms by supporting weather (and additional) satellites including GOES-R, CloudSat, and GPM.

Figure 7. *PI Lynn McMurdie in front of the ER-2 ready for deployment for IMPACTS.* ***Photo credit:*** *Lynn McMurdie*

Figure 8. *Westminster High School students interview IMPACTS Project Manager Vidal Salazar inside the P-3 aircraft.* ***Photo credit:*** *Westminster High School*

Figure 9. *The WFF team attends an early pre-flight briefing aboard the P-3 prior to the day's science flight.* ***Photo credit:*** *Vidal Salazar*

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, MOSES, MASS

The Sub-Mesoscale Ocean Dynamics Experiment (S-MODE) entered its second Intensive Observation Period (IOP-2) in early April 2023, continuing through the beginning of May 2023.

The mission occurred in and over the Pacific Ocean, over 100 nautical miles offshore of San Francisco, California. S-MODE aimed to determine how sub-mesoscale (1-10 km) ocean dynamics, such as eddies and fronts, make important contributions to the vertical exchange of nutrients, heat, and gases in the upper ocean. These small-scale processes likely play an important role in climate change as well as the biology and survival of ocean life. S-MODE used a combination of in situ and remote sensing equipment to achieve its goals to:

- Measure the 3D structure of the sub-mesoscale features responsible for vertical exchange.
- Quantify the role of air-sea interaction and surface forcing in the dynamics and vertical velocity of sub-mesoscale variability.

Figure 10. *NASA B-200 aircraft with instrument operators, air crew, and ground crew at NASA ARC.* ***Photo credit:*** *Carrie Worth*

- Understand the relation between the velocity (and other surface properties) measured by remote sensing at the surface and just below the surface boundary layer.
- Diagnose dynamics of vertical transport processes at sub-mesoscales to mesoscales.

To achieve these goals, S-MODE used three aircraft, a research vessel, autonomous in situ instruments, and satellite data. The AFRC B-200 payload contained two instruments: the Doppler Scatterometer (DopplerScatt), which measured ocean vector winds and surface currents to investigate air-sea interaction, and the Multiscale Observing System of the Ocean Surface (MOSES), which measured sea surface temperature. S-MODE also flew the Portable Remote Imaging Spectrometer (PRISM) on the LaRC G-III. PRISM measured radiance, ocean color, and chlorophyll-a, which can imply nutrient levels and phytoplankton concentration. Finally, S-MODE also flew the Modular Aerial Sensing System (MASS) on a Twin Otter from Twin Otter International, which measured ocean surface and land topography, thermal imagery, hyperspectral imagery, visible imagery, and point temperature.

These flights were complemented by in situ measurements captured onboard the Research Vessel (RV) *Sally Ride*. One of the most important parts of the vessel payload was the EcoCTD, which was cast from the boat like a

Figure 11. *NASA Gulfstream III aircraft at NASA ARC with participation from the NBC Today Show.* ***Photo credit:*** *Jacob Soboroff/NBC*

Figure 12. *The RV Sally Ride science party with NASA HQ Program Manager Nadya Vinogradova Shiffer (second from right) in San Diego, California, prior to commencement of the S-MODE IOP-2 research cruise.* ***Photo credit:*** *Erin Czech*

fishing pole and sunk nearly 400 feet into the ocean. The EcoCTD provided information about the temperature, salinity, pressure, chlorophyll, backscatter, and oxygen in the ocean and was an important tool in deciding where to collect additional samples. Additional in situ measurements were collected using autonomous equipment launched from RV Sally Ride. This included the use of sea surface equipment, like wave gliders and surface drifters, as well as submersibles, like gliders and Lagrangian floats.

Finally, S-MODE scientists are comparing their observations with those from the Surface Water Ocean Topography (SWOT) satellite, which was launched at the end of 2022. SWOT completed one-day repeat crossovers over the S-MODE study area offshore of California. The S-MODE PRISM measurements will also have value for PACE (launching in 2024) and SBG in terms of "ground truthing" ocean surface imaging.

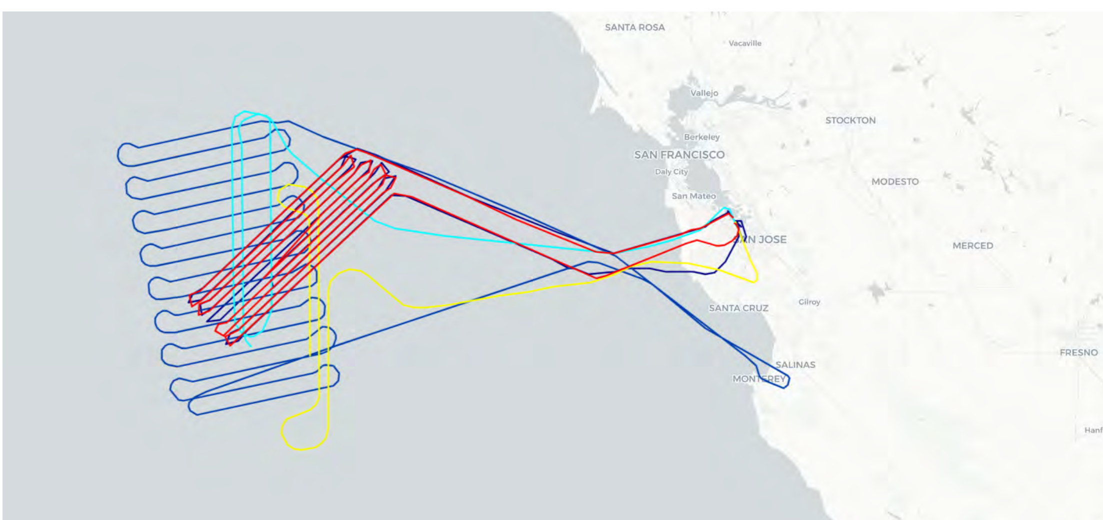
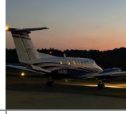


Figure 13. *MTS image on April 13, 2023, showing the AFRC B-200, LaRC G-III, and JSC GV. The GV was flying a cal/val mission for the SWOT satellite; the B-200 and the G-III were flying for S-MODE.*



Airborne Lightning Observatory for FEGS and TGFs (ALOFT)

PI – Nikolai Østgaard, University of Bergen; PS: Timothy Lang, NASA MSFC
Program – Weather and Atmospheric Dynamics
Aircraft – ER-2
Payload Instruments – Fly's Eye GLM Simulator, LIS package, BGO-gamma ray scintillators, iSTORM

NASA and the University of Bergen in Norway (UIB) teamed up in July 2023 to fly the ER-2 over thunderstorms in search of lightning and gamma-rays. The campaign, Airborne Lightning Observatory (ALOFT) for the Fly's Eye Geostationary Lightning Mapper (GLM) Simulator (FEGS) and Terrestrial Gamma-ray Flashes (TGFs), was incredibly successful in looking for TGFs, very energetic but short-lived radiation pulses from thunderstorms. Prior to ALOFT, it was assumed that TGFs were 10,000 times less frequent than lightning flashes, but the mission's strategic research flights proved otherwise. The ALOFT suite of instruments included gamma-ray instruments from UIB and U.S. Naval Research Laboratory (NRL), two lightning instruments from MSFC, and microwave instruments from MSFC and GSFC.

The ER-2 flew the mission from MacDill Air Force Base (AFB) in Tampa, Florida, providing airborne access to storms over Central America, where TGFs have been more commonly observed. ALOFT also flew three additional flights over Florida to hunt for gamma rays. Across ten research flights, ALOFT observed 130 TGFs – a higher number than initially anticipated.

Based on ALOFT observations, TGFs appear to occur while thunderstorms are also producing low-level but longer-lived enhancements in gamma rays, called "glows." ALOFT found that these glows commonly occur during the intensification to mature phases of thunderstorms, suggesting that gamma ray observations can potentially provide information about the evolution of thunderstorms. ALOFT uniquely allowed the observation of these glows in real time via telemetry from a gamma ray detector on the ER-2. This enabled ALOFT mission scientists

Figure 14. *Members of the ALOFT science team in front of the NASA ER-2 during the flight campaign based in Tampa, Florida.* ***Photo credit:*** *NASA*

to quickly relay updated instructions to the ER-2 pilots, leading to repeated overflights of glowing thunderstorms and thus maximizing the chances of observing TGFs.

ALOFT's other goals included validating lightning measurements by the International Space Station Lightning Imaging Sensor (ISS LIS) and the GLMs. ALOFT made five dedicated underflights of the ISS and flew entirely within the stereoviewing region of the GLMs on the West and East Geostationary Operational Environmental Satellites (GOES). In addition, ALOFT sensors tested new concepts for detecting lightning from space, which could be applicable to future NASA lightning-observing missions. Finally, the ER-2 payload included multiple active and passive microwave sensors for characterizing thunderstorm structure and evolution, making ALOFT observations of interest to the future NASA Atmosphere Observing System (AOS) and Investigation of Convective Updrafts (INCUS) missions.

CRYOUAS

PI – Brooke Medley, NASA GSFC
Programs – Research and Analysis, Cryospheric Science
Aircraft – Platform Aerospace/Vanilla Unmanned VA001 UAS
Payload Instruments – KU CReSIS Snow Radar

The CRYOUAS team, including Platform Aerospace and GSFC personnel, demonstrated science from the Vanilla Uncrewed Aerial System (UAS) flying out of Pituffik Space Base, near Thule AFB in Greenland. The UAS carried the University of Kansas (KU) Center for Remote Sensing of Ice Sheets (CReSIS) Snow Radar, which discriminates snow thickness over glacier ice to determine the topography of the underlying glacier surface. Although the instrument was flown routinely in Greenland for Operation IceBridge, this was the radar's first campaign on a Vanilla long endurance UAS. The Vanilla UAS — and other medium altitude, long endurance platforms — are well suited for sustained arctic observations in support of ICESat-2 and other cryospheric science observations.

Although the Arctic weather proved difficult, the CRYOUAS mission was able to fly on two dates. The first flight was 2.8 hours in duration, during which the team tested all systems and communications. No issues were reported, and some science data were also collected. Delayed by local air traffic and some mechanical and technical issues, the second CRYOUAS flight was ~13 hours, shorter than the twenty-four hours or more for which the team had hoped. The satcom worked well initially, but as the Vanilla UAS set out on the science flight, satcom degraded to the point where the UAS returned to line-of-sight communications at Pituffik. The team surveyed snow in the nearby area while attempting to troubleshoot the satcom. Just past 12 hours into the flight, the Vanilla's engine temperatures began to rise, and the aircraft struggled to maintain altitude, so it was returned to base to ease icing concerns. The skies were clear the following few days, but winds exceeded the Vanilla UAS threshold for takeoff, so no flight was attempted. The team returned home shortly thereafter.

Figure 15. *View of the Chamberlin Glacier from the Vanilla UAS tail camera.* ***Photo credit:*** *Platform Aerospace*

Hyperspectral Thermal Emission Spectrometer (HyTES) European Campaign 2023

PIs – Simon Hook, NASA JPL and Martin Wooster, King's College London
Program – Research and Analysis Program
Aircraft – Twin Otter
Payload Instruments – HyTES

In Summer 2023, JPL's Hyperspectral Thermal Emission Spectrometer (HyTES) participated in an airborne campaign in Italy, France, and Switzerland. This was the third collaborative campaign with Kings College, London (KCL) and the European Space Agency (ESA). The previous campaigns were in 2019 (UK/Italy) and 2021 (UK/Sweden). This campaign had two main objectives:

1. To study the effects of viewing angle on remotely sensed Land Surface Temperature (LST) measurements.
2. To provide Hyperspectral Thermal data over a variety of targets in support of upcoming NASA and other satellite missions (TRISHNA, a joint mission between ISRO and CNES, and LSTM, an ESA-led mission).

The multi-angular studies made use of two Twin Otter aircraft: one from Kenn Borek Air (KBA) for HyTES and another from the British Antarctic Survey (BAS) carrying several instruments owned by King's College, London. HyTES provided a nadir view with a ±25 degree swath, and the OWL thermal instrument on the BAS plane was on a pointable mount that could provide view angles beyond 35 degrees. The two planes flew coordinated patterns over the target areas with 1500 feet vertical separation between them at all times.

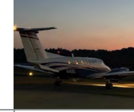
The KBA plane with HyTES was on site for the duration of the campaign and the BAS plane joined in for two Intensive Operation Periods (IOPs) designed to study multi-angular effects from May 21 to June 1 (IOP-1) and June 25 to July 2 (IOP-2). The satellite-support flights were mainly made using HyTES alone between and after the IOPs. These flights covered volcanoes, glaciers, geologic targets, areas with poor air quality for nitrogen-related observations, and instrumented ground calibration sites for LSTM, SBG, TRISHNA, and NITROSAT. KCL, JPL, and groups from Italy, France, Switzerland,

Figure 16. *HyTES team with two Twin Otter aircraft.* ***Photo credit:*** *NASA*

and Belgium provided ground instrumentation and manual, in situ measurements for many of the target sites.

The campaign had to overcome meteorological and technical challenges. There were periods of torrential rain with serious flooding early in May, which grounded the aircraft, and record-breaking heat in July, which threatened to overheat the instruments. The HyTES instrument also had several issues, all of which were solved in the field. HyTES flew 117.3 hours in 39 sorties of science flights. The aircraft and field data are currently being analyzed by teams at JPL and in Europe in preparation for publication.

Figure 17. *HyTES image of Vulcano Island, near Sicily, overlaid on Google Earth.* ***Image credit:*** *HyTES team*



UAVSAR Support to Solid Earth, Terrestrial Ecology, and Disaster Monitoring

PPIs – Yunling Lou, NASA JPL (P- and L-band), Zhong Lu, Southern Methodist University (P-band), Eric Fielding, NASA JPL (L-band), and Paul Lundgren (Ka-band), NASA JPL
Programs – Geodetic Imaging Program, Interior and Terrestrial Hydrology Program, Weather and Atmospheric Dynamics, Earth Surface and Interior
Aircraft – AFRC C20-A
Payload Instruments – UAVSAR/P-Band/AirMoss, UAVSAR/L-Band, UAVSAR/Ka-Band/Glistin-A

In FY23, the JPL Uncrewed Aerial System Synthetic Aperture Radar (UAVSAR) system flew 152.8 hours for Earth science on the AFRC C-20A aircraft, carrying primarily the L-band SAR. The breakdown of services is shown in Figures 18 and 19.

Solid earth missions were concentrated on landslides, faults, and geodetic imaging. The single use of the Ka-band SAR was in Hawaii for imaging at the Mauna Loa volcano eruption. The P-band and L-band systems were used to make pre-fire measurements in prescribed burn areas prior to the FireSense prescribed burn mission. This effort, the Fire and Smoke Model Evaluation Experiment (FASMEE), is co-sponsored by the U.S. Forest Service. UAVSAR's primary role in FASMEE is to determine how SAR imagery can be used to determine fuel loading by measuring biomass structure.

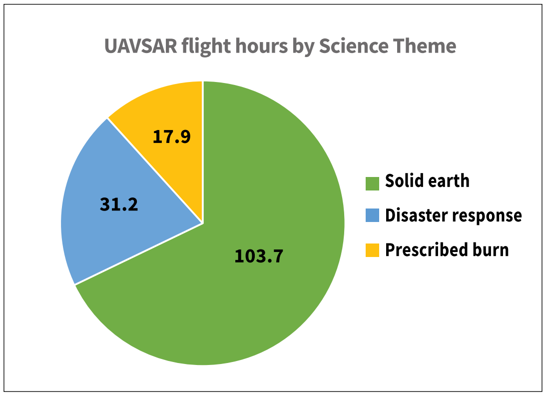


Figure 18. *UAVSAR FY23 flight hours by Science Theme.*

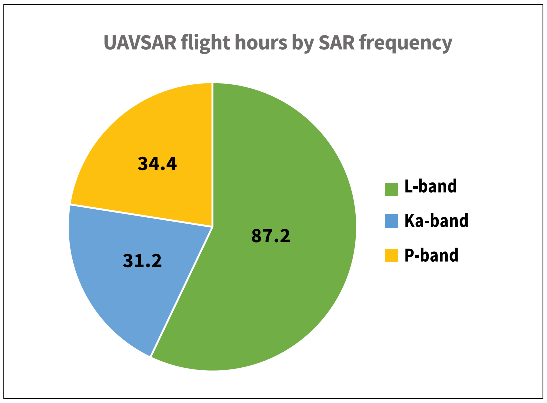


Figure 19. *UAVSAR FY23 flight hours by SAR frequency.*

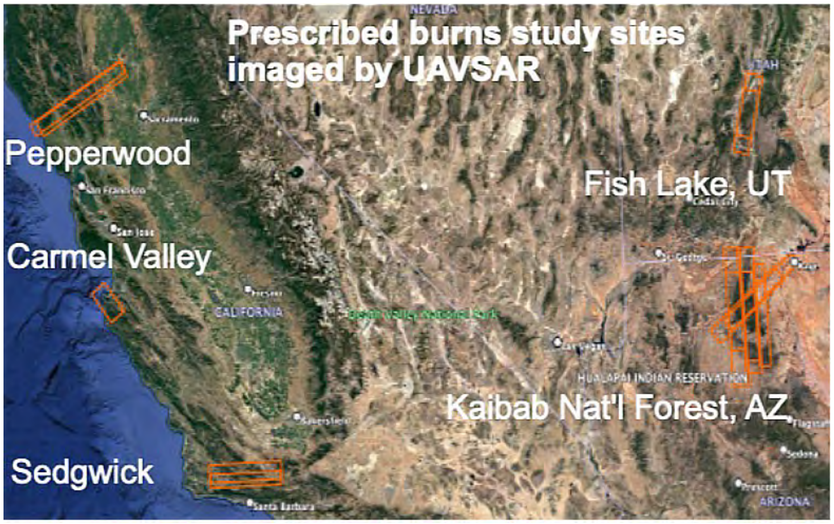


Figure 20. *UAVSAR study sites for prescribed burns in California, Arizona, and Utah.* ***Image credit:*** *NASA*

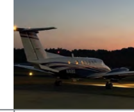
ASP Support to ESD Satellites and International Space Station Missions

In addition to Earth Venture Suborbital (EVS) missions, the primary ASP stakeholders are Earth Science spaceflight 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 (cal/val) of satellite algorithms, measurements, or observations once missions are in orbit.

In FY23, airborne missions provided support to multiple operational and future Earth science space missions. The ocean-focused Surface Water and Ocean Topography (SWOT) cal/val mission and the river-focused AirSWOT mission provided early data in support of SWOT, which was launched late in 2022. The Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) and Synergistic TEMPO Air Quality Science (STAQS) campaigns in 2023 provided data to support the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission, which launched earlier in the year, as well as the TROPOspheric Monitoring Instrument (TROPOMI), Ozone Monitoring Instrument (OMI), GOES-R, Suomi National Polar-orbiting Partnership (SNPP), and JPSS. Future missions include Surface Biology and Geology (SBG), supported by years of data from the Western Diversity Time Series (WDTS), and NASA-ISRO Synthetic Aperture Radar (NISAR), supported by years of UAVSAR data collected around the Continental U.S. (CONUS) and outside the Continental U.S. (OCONUS). Table 7 lists the support that ASP campaigns provided to ESD space missions in FY23.

Table 7. *Space-based missions supported by aircraft campaigns in FY23.*

Airborne Mission	Supported Space Mission	Flight Hours	Location	Aircraft
AEROMMA/STAQS	TEMPO, TROPOMI, OMI, GOES-R, SNPP, JPSS - NOAA-20	421.1	Pacific and Atlantic Coasts	DC-8, G-III, GV
IMPACTS	CloudSat, GOES R, GPM	221.9	Atlantic Coast	P-3, ER-2
UAVSAR Combined Missions	NISAR	152.8	CONUS, Hawaii	C-20A
SWOT cal/val	SWOT	128.3	Pacific Coast, Canada	GV, B-200
ABoVE	OCO II, SBG	89.7	Alaska	B-200
ALOFT	GOES-R	77.6	Florida, C. America	ER-2
GEDI cal/val	GEDI-ISS	73.2	Gabon	G-III
SnowEx	SCLP	37.7	Alaska	Twin Otter CIRPAS
Western Diversity Time Series	Landsat 8, SBG	35.2	California	ER-2
GRAV-D	GNSS	21	American Samoa, Hawaii	G-IV
QUAKES-I	STV	19	CONUS	GV
CRYOUAS	ICESat-2, Cryosat-2	15.5	Greenland	Vanilla VA001 UAS



Surface Water Ocean Topography (SWOT) Calibration/Validation

PI – Marc Simard, NASA JPL
Programs – Physical Oceanography Program, Hydrology Program, Interior and Terrestrial Hydrology Program – SWOT Project
Aircraft – GV, DA B-200
Payload Instruments – AirSWOT

In August 2023, the JPL AirSWOT instrument was flown over the St. Lawrence Estuary and Saguenay Fjord, Québec, Canada. AirSWOT is a Ka-band radar interferometer, typically installed on the fuselage of a B-200 aircraft (Figure 21), able to map water surface elevation with a spatial resolution of ~5 meters across a 3 km swath and along flight lines that can be several hundreds of kilometers long. Because it is airborne, it enables on-demand, fast repeat measurements that can capture dynamic tidal processes occurring in coastal environments. The waterways were selected because they encompass a large range of water surface conditions within a finite geographical region and relatively short time scales, providing an ideal location to collect water surface elevation measurements coincident with SWOT overpasses and with various in situ measurements.

The St. Lawrence Estuary is a highly dynamic system, with propagating tides reaching 7 meters. With its unique geomorphology, characterized by large cross-sections and numerous islands, it presents significant spatiotemporal variability in surface conditions at all scales. The adjacent Saguenay Fjord discharges into the St. Lawrence. With cliffs reaching 350 meters, the fjord allows scientists and engineers to study layover effects in some areas and for SWOT data validation in a standing tidal wave (low slope) environment.

SWOT, launched in December 2022, provides measurements with centimeter-level accuracy of water surface elevations and slopes at an unprecedented high spatial resolution (~50 m). However, its 21-day repeat-orbit does not allow consecutive observations during a tidal cycle. AirSWOT is the ideal complementary tool to assess SWOT spatiotemporal capabilities and limitations in these highly dynamic environments by making spatially explicit measurements before, during, and after SWOT overpass. In addition to tides, water surface within estuaries is impacted by several other factors, such as winds and internal waves, that can be quantitatively characterized and monitored with AirSWOT imagery. An extensive network of water level gauges, high frequency radars, and wave buoys provide the water surface's true conditions.

Figure 21. *The AirSWOT instrument was flown onboard a Dynamic Aviation B-200 aircraft.* ***Photo credit:*** *Roger Chao*

The AirSWOT mission was stationed in Bangor, Maine and flew the region of interest for five hours at a time across four different flights. Taking off from Bangor allowed AirSWOT to reach the desired altitude of 28,000 feet as it neared the region of interest. Figure 22 shows one coverage map. The first three flights coincided with mid-flight SWOT overpasses. In addition to serving as a cal/val tool for SWOT, AirSWOT data provide validation of in situ water level gauges and hydrodynamic models, which are used to understand and quantify the export of freshwater and carbon into the oceans and to support navigation, search and rescue, and pollutant recovery efforts.

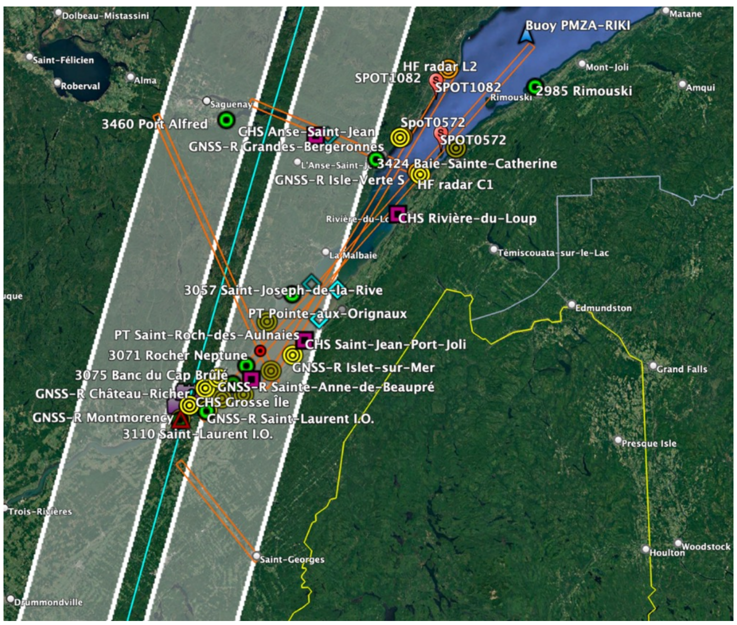


Figure 22. *AirSWOT data coverage (orange) on August 23, 2023 taken during an early morning SWOT overpass (white shade). Geometric icons indicate the location of continuous in situ measurements.* ***Figure credit****: Marc Simard*

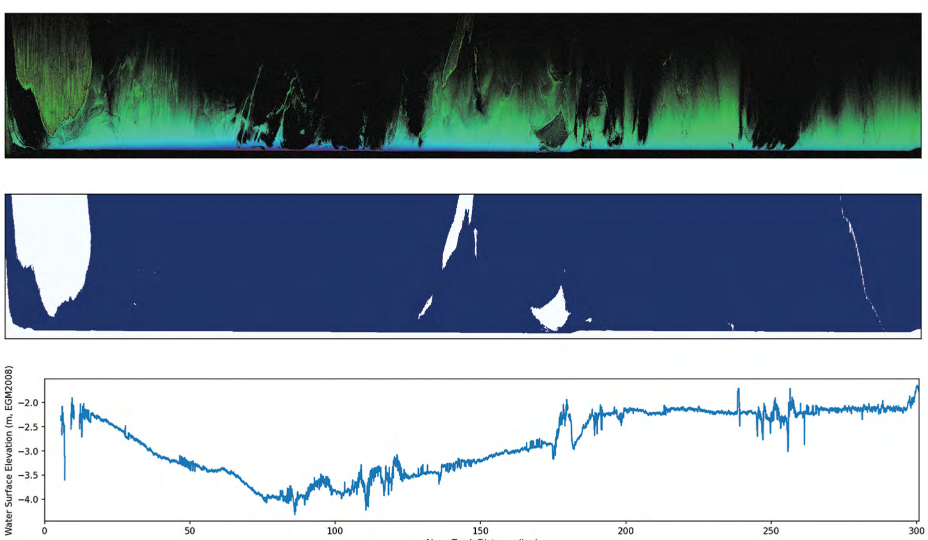


Figure 23. *(a) AirSWOT interferogram collected on August 28, 2023 at 13:55 UTC, during a period of falling tide. The flight line begins near Île d'Orléans, Québec, Canada and extends northeast along the St. Lawrence River. (b) Mask, with water in blue and land in white. (c) Corresponding AirSWOT water surface elevation profile showing how water level varies along-track with respect to the EGM 2008 geoid. While the profile avoids islands, exposed mud flats at low tide may impact elevation measurements around islands.* ***Figure credit:*** *Michael Denbina*

Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) and Synergistic TEMPO Air Quality Science (STAQS)

PIs – Steven Brown, NOAA (AEROMMA) and Laura Judd, NASA LaRC (STAQS)
Programs – Tropospheric Composition Program, Earth Venture Suborbital-3 Program
Aircraft – DC-8 for AEROMMA and G-III (L), GV for STAQS
Payload Instruments – ACES, ACOS, AMP, AOP, AVIRIS-NG, BrC-PILS, CAPS-PIP, CCN, CSU-NH3, DLH, GCAS/HSRL2, HALO, HR-AMS, I-CIMS, ISAF, iWAS, J-CAFS, J-OHR, LGR, LIF-SO2, LI-NEPHELOMETER, TSI-NEPHELOMETER, LTOF-CIMS, MMS, NNOX, NOYO3, OPALS, PALMS-NG, PFP, PILS, PTR-MS, SP2, S-HIS

To accelerate NASA's Tropospheric Emissions: Monitoring of POllution (TEMPO) mission science, the Synergistic TEMPO Air Quality Science (STAQS) mission was designed to integrate TEMPO satellite observations with traditional air quality monitoring. Between June 26 and August 26, 2023, the STAQS team successfully completed their airborne air quality campaign. The campaign included 16 science flights in various locations in California, ten in New York City, New York, ten in Chicago, Illinois, two in Baltimore, Maryland, and two in Toronto, Canada using the LaRC G-III (147.3 flight hours total) and JSC GV (123.4 flight hours total) platforms.

Instrument teams included JPL's Airborne Visible-Infrared Imaging Spectrometer – Next Generation (AVIRIS-NG) and LaRC's High Altitude Lidar Observatory (HALO) on the G-III, with LaRC's High Spectral Resolution Lidar (HSRL)-2 on the GV. GSFC's GEOstationary Coastal and Air Pollution Events (GEO-CAPE) Airborne Simulator (GCAS) flew on both aircraft. The instrument suite mapped out nitrogen dioxide, formaldehyde, aerosols, ozone, and methane multiple times per day within the cities of interest.

A key highlight included coincident measurements collected with TEMPO first light on August 2, 2023, in Chicago and on several other days, with coincident TEMPO and airborne measurements. These will be key for assessing TEMPO nitrogen dioxide, formaldehyde, ozone, and aerosol products and using them for science applications. The mission also included partnerships with NOAA, NIST, EPA, and several academic research teams through the AEROMMA+CUPiDS, GOTHAAM, EPCAPE, STAQS, and others (AGES+) effort.

Figure 24. *Group photo of STAQS team with GV at Wright-Patterson AFB.* ***Photo credit:*** *Mónica Vázquez González*

In coordination with STAQS, the NASA DC-8 flew NOAA's Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) mission, which also completed its flights in August 2023. The NASA DC-8 flew a payload of NOAA and NASA instruments to address emerging research needs in urban air quality, marine emissions, climate feedbacks, and atmospheric interactions at the marine-urban interface and future satellite capabilities of monitoring atmospheric composition over North America.

The DC-8 had the low-flyer role in close coordination with the STAQS project's high-flying JSC GV and LaRC G-III platforms. The mission flew over 30 hours out of AFRC in June 2023 in conjunction with the Student Airborne Research Program (SARP), collecting data off the Pacific Coast, over the Los Angeles Basin and the Central Valley. In July and August, AEROMMA flew 82 hours out of WPAFB in Ohio over New York, Chicago, and Toronto. Finally, the campaign wrapped up back at AFRC with an additional 26 flight hours in California.

The major objectives for AEROMMA included providing timely information to environmental managers and stakeholder groups about climate and air quality emissions, improving the next generation NOAA weather-chemistry models, reducing global climate model uncertainties, and quantifying emissions, chemistry, and microphysics in urban and marine areas. AEROMMA also aimed to assess value and reduce risks for future satellite missions, such as NOAA's Geostationary Extended Observations (GeoXO).

Figure 25. *Low altitude view from the DC-8 as AEROMMA flies over New York City.* ***Photo credit:*** *Rafael Mendez Pena*

Figure 26. *The AEROMMA team at WPAFB in Dayton, Ohio.* ***Photo credit:*** *Mónica Vázquez González*

Global Ecosystem Dynamics Investigation (GEDI) Cal/Val with LVIS

PI – James Blair, GSFC
Program – Terrestrial Ecology Program
Aircraft – G-III (L)
Payload Instruments – LVIS (LVIS Facility and LVIS Classic)

The NASA LaRC G-III aircraft successfully completed multiple overflights of Gabon, Africa, and adjacent areas in the Republic of the Congo. The purpose of this mission, sponsored by the ESD Terrestrial Ecology program, was to measure forest height and structure in Central Africa, and – at the request of the European Space Agency (ESA) – to repeat coverage over sites flown as a part of AfriSAR in 2016. The G-III aircraft was deployed to São Tomé, São Tomé and Príncipe, from May 17 to June 1, 2023. While deployed, the aircraft flew ten science flights (47 research flight hours) with GSFC's Land, Vegetation, and Ice Sensor (LVIS) Facility and Classic units as the research payload.

LVIS is an airborne, wide-swath imaging laser altimeter system that collects data on surface topography and the three-dimensional structure of vegetation. The LVIS sensors utilize 1064-nm wavelength lasers and multiple detectors to record return pulses reflected from the surface, allowing highly detailed determination of range and return pulse shape. Combined with aircraft position and attitude knowledge, the sensor produces topographic maps with decimeter accuracy and uniquely captures the vegetation height and structure measurements of overflown terrain. One of the

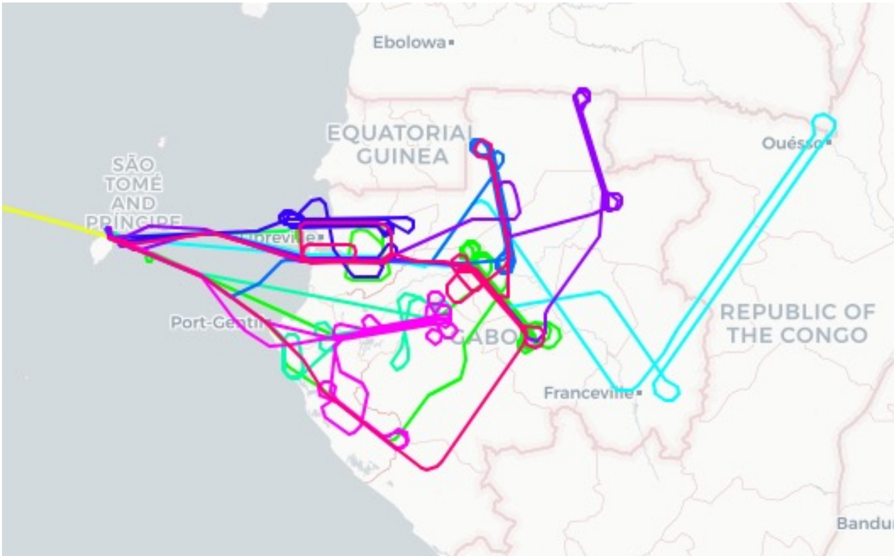


Figure 27. *GEDI G-III flight tracks over São Tomé and Príncipe and Gabon, Africa. Visualization provided by MTS.*

instruments was collecting data specifically for GEDI validation, while the other collected data to meet the ESA request. The two LVIS units were installed in the forward and aft nadir portals of the aircraft. A total of 21 flights (81.7 flight hours), including instrument check flights, transit flights, and research flights, were flown by the aircraft to accomplish this mission. The aircraft and sensors performed well throughout the deployment and all major science sites were successfully mapped.

The LVIS team also successfully tested the Starlink high-speed, satellite-based internet at the São Tomé airport. During the deployment, Mr. Tulinabo S. Mushingi, U.S. Ambassador to Angola and São Tomé and Príncipe, visited the NASA G-III aircraft in São Tomé between research flights. The NASA team briefed the ambassador on the science mission, the aircraft's capabilities, and some observations on conduct-

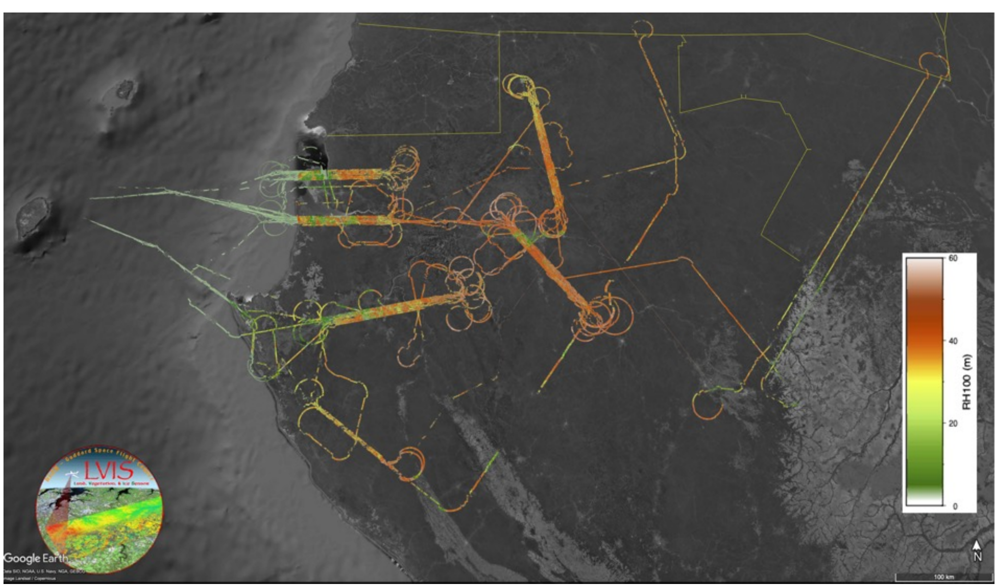


Figure 28. *LVIS topography signals during the GEDI cal/val mission. The color chart indicates topographical heights. Visualization provided by LVIS team.*

Figure 29. *(left to right) Ben Gullett, Foreign Service Officer, U.S. Embassy for Angola and São Tomé and Principe; a local employee of the U.S. Embassy for Angola and São Tomé and Principe; Mark T. Sandeen, Research Pilot, LaRC; Tulinabo S. Mushingi, U.S. Ambassador to Angola and São Tomé and Principe.* ***Photo credit:*** *Michelle Hofton*

Western Diversity Time Series (WDTS)

PI – Robert Green, NASA JPL
Programs – Research and Analysis, Earth Surface and Interior, Biological Diversity
Aircraft – ER-2
Payload Instruments – AVIRIS C (Classic), MASTER

Since 2011, multi-spectral imagery has been collected annually over six California locations using primarily the MODIS/ASTER Airborne Simulator (MASTER) and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) instruments. This time series data-set is invaluable for algorithm development and process understanding, as the imagery spans multiple seasons over many years. Originally planned for the future Hyperspectral InfraRed Imager (HyspIRI) mission, the data set now serves as precursor to Surface Biology and Geology (SBG) and will also be used in post-launch cal/val activities.

In FY23, the campaign was flown on the ER-2 for a total of 50 flight hours. It included a new instrument, PICARD, which produced the images in Figure 30. An additional flight of MASTER on a B-200 aircraft complemented Student Airborne Research Program (SARP) activities.

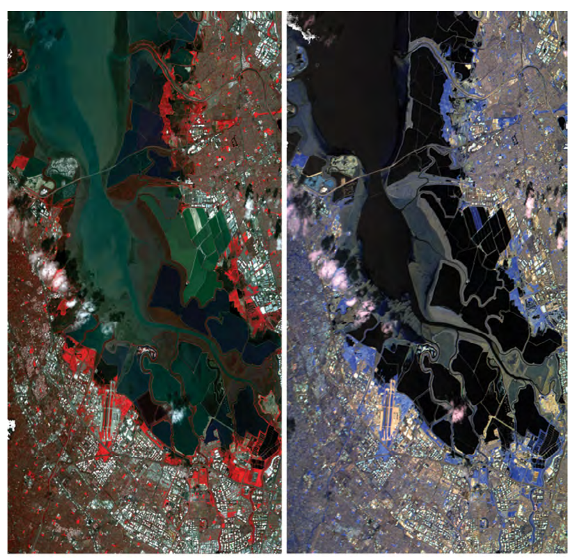


Figure 30. *PICARD imagery from WDTS flight on April 12, 2023. Left image is VNIR, right image is SWIR.*

ASP Campaigns on Commercial Aviation Service (CAS) Platforms

As noted in the Program description, Section 2, many Earth Science missions fly on non-NASA aircraft. Some of these aircraft are commercially contracted. The following missions flew on CAS platforms.

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

PI – Glenn Wolfe, NASA GSFC
Program – Ocean Biology and Biogeochemistry Program
Aircraft – DA A90
Payload Instruments – Picarro G2311-F, Aventech AIMMS-20, CARAFE, Picarro G2401-m, ROZE

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) program, began in 2022 and ends in 2024. BlueFlux will quantify the carbon cycle of mangroves by combining new field and aircraft measurements with observations from space-based instruments on the International Space Station (ISS) and polar orbiting missions. BlueFlux carbon products will enable conservation and restoration stakeholders to better understand how mangroves can contribute to "blue carbon" climate solutions.

Mangroves are among the most productive ecosystems in the world. Mangrove forests store massive amounts of carbon in their stems, soils, and complex root systems, buffer shorelines from erosion, and provide a habitat for coastal life. Over the past several decades, coastal development, rising seas, and increasing hurricane severity have led to the loss of mangroves. Organizations proposing nature-based solutions to climate mitigation have sustained interest in conserving and restoring these regions.

A key BlueFlux measurement is the exchange of carbon dioxide and methane between the biosphere and the atmosphere. GSFC's Carbon Airborne Flux Experiment (CARAFE) employs a combination of gas analyzers and a wind probe flown on a Dynamic Aviation A90 King Air to provide near-direct flux observations via the eddy covariance method. The CARAFE team has executed four BlueFlux airborne deployments (April and October, 2022; February and April, 2023), with the final deployment scheduled for July 2024. Flights over the Everglades and Big Cypress National Parks in southern Florida typically involve level legs at an altitude of 100 meters. With 25 science flight hours per deployment, flights mapped the full breadth of ecosystems, with extra emphasis on mangroves along Florida's western coast and routinely overlapped stationary flux towers for intercomparison and upscaling. These flights included observations of ozone fluxes using GSFC's Rapid Ozone Experiment (ROZE). Figure 31 shows all low-level legs for the first four deployments; cumulative flight distance across all 2023 deployments was 11,818 km. White squares denote locations of ground-based flux measurement sites operated by collaborators.

Ground-based field studies provide additional context. Field ecologist teams from Yale University and East Carolina University are measuring gaseous fluxes of methane and carbon dioxide from stems, soil, roots, and water, while terrestrial laser scanners collect structural information on the volume of emitting surfaces. These observations will help partition fluxes to individual ecosystem components.

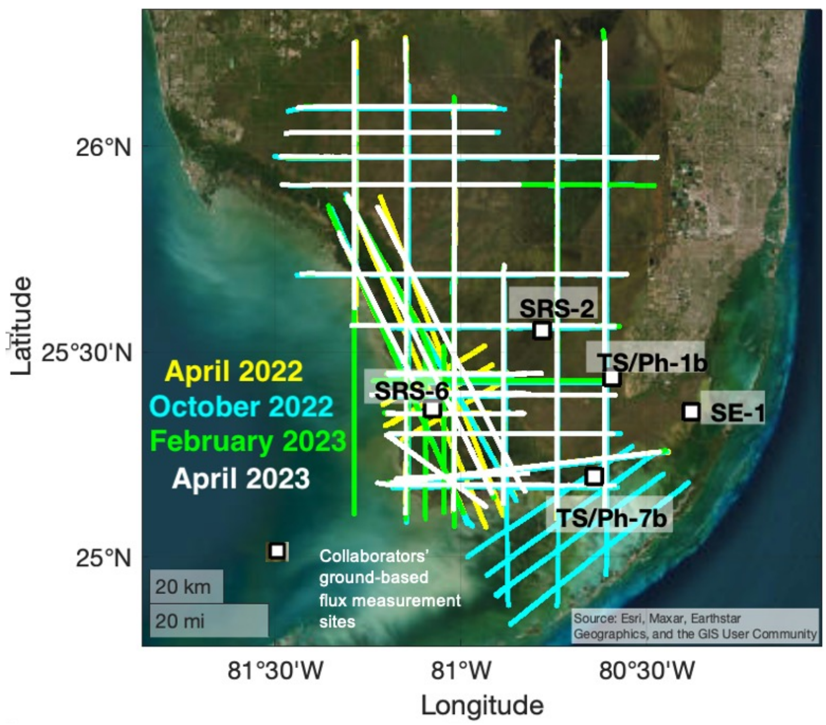


Figure 31. *BlueFlux airborne observations map carbon dioxide and methane exchange across the diverse ecosystems of southern Florida. Visualization provided by Esri, Maxar, and Earthstar and generated by the BlueFlux team.*

Airborne and ground-based observations provide multi-scale constraints that will be combined with satellite-based remote sensing and machine learning for regional, long-term upscaling. Key satellite products include those derived from Global Ecosystem Dynamics Investigation (GEDI) and Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance. A major BlueFlux objective is to develop a twenty-year daily time series of gridded carbon flux products for southern Florida (and potentially the greater Caribbean region). This product will inform carbon cycle science and stakeholder activities. BlueFlux exemplifies how the synergy of ground-based, airborne, and satellite observations can extend our understanding of biosphere-atmosphere interactions and provide unique research products with real-world applications.

BlueFlux also provides a serendipitous opportunity to better understand how hurricanes affect wetland regions. The October 2022 field campaign occurred approximately two weeks after Hurricane Ian passed over Florida. Measurements may reveal post-hurricane impacts, including how a heavy rain event affects wetland salinity levels and methane production. Early results indicate significantly higher methane fluxes during these flights compared to other deployments.

The October 2022 and April 2023 BlueFlux efforts also included engagements with the public, students from the Florida Coastal Everglades (FCE) Long-term Ecological Research Network (LTER), local environmental non-profits, and community members from the Miccosukee and Seminole tribal nations adjacent to the Everglades National Park. The outreach events took place at the Homestead and Marathon Airports in Florida and featured tours around and inside the aircraft, field team instrument demonstrations, and conversations with NASA and academic scientists.

SnowEx

PI – Batuhan Osmanoglu, NASA GSFC
Program – Hydrology Program
Aircraft – Twin Otter CIRPAS
Payload Instruments – AVIRIS-NG, SWESARR

In 2023, the Next Generation Airborne Visible/ Infrared Imaging Spectrometer (AVIRIS-NG) was deployed for SnowEx, a multi-year NASA study to quantify snow mass in different climates, canopy types, and terrains. The campaign focused on tundra and boreal regions, including three sites around Fairbanks, Alaska, to measure snow albedo. Flights occurred during the melting period, covering a transition from dry and thick snow in April to patchy and wet snow in May. Coincident surface reflectance measurements, snow depth, and grain size were conducted to calibrate and validate AVIRIS-NG retrievals.

Between April 7 and May 5, 2023, AVIRIS-NG successfully completed 11 flights, acquiring ground-reflected radiances from Caribou Poker, Creamer's Field, and Delta Junction, Alaska.

These data provide a comprehensive time series to study changes in high-latitude snow properties during spring, when temperatures rise and snow melts. This supports SnowEx objectives to evaluate how to combine different remote sensing technologies to accurately observe snow throughout the season in various landscapes.

The acquired AVIRIS-NG data help divide snow cover into different types by mapping grain characteristics and melt sequences to spectral reflectances. Each snow type contributes differently to Earth's hydrology and climatology, so snow reflectance and albedo inferred from AVIRIS-NG fills existing gaps in our knowledge of seasonal snow cover. Moreover, this work ultimately leads to new spaceborne snow mission concepts, including precursor studies for NASA's SBG mission. In addition, improving seasonal terrestrial snow estimation through SnowEx has the potential to advance the accuracy of snow estimation on sea ice and perennial snow estimation on glaciers and ice sheets.

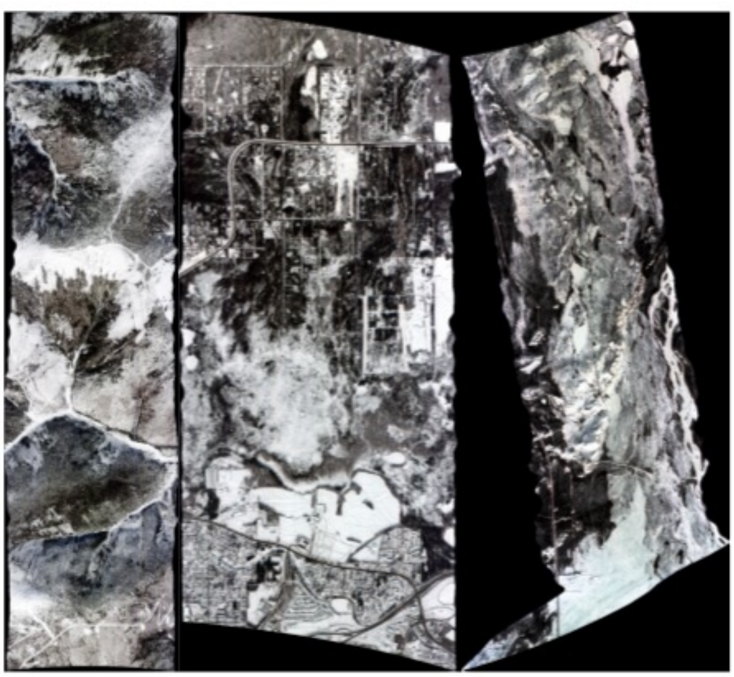


Figure 32. *(left to right) True-color RGB images of AVIRIS-NG measured radiances over Caribou Poker, Creamer's Field, and Delta Junction during SnowEx 2023 flights. Reflectance spectra inform snow type (e.g., dry versus wet snow). Visualization provided by SnowEx.*

Arctic Boreal Vulnerability Experiment (ABoVE)

PI – Charles Miller, NASA JPL
Program – Terrestrial Ecology Program
Aircraft – DA B-200
Payload Instrument – AVIRIS-3

The Arctic Boreal Vulnerability Experiment (ABoVE) team completed their fifth airborne campaign between July and August 2023, acquiring hyperspectral imagery using AVIRIS-3 on a DA B-200 aircraft (N53W) based out of Fairbanks, Alaska. These acquisitions were guided by the requirements of the ABoVE Phase 3 investigations and requests from ABoVE partners in the U.S. and Canada. The new data complement previous data collected during the ABoVE airborne campaigns in 2017, 2018, 2019, and 2022.

ABoVE collected data in nearly all (~80%) areas of interest between Fairbanks and Deadhorse, Alaska: the flights completed surveys of NGEE-Arctic sites on the Seward Peninsula and sites near Kotzebue, Noatak, and Atqasuk, and favorable conditions in southern Yukon allowed science flights to Whitehorse and Skagway. However, extraordinary wildfires in Canada prevented planned sorties in northern Yukon and in the Northwest Territories and mechanical problems prevented flights near Utqiagvik, Alaska.

Figure 33. *(left to right) The ABoVE AVIRIS-NG team: Luis Rios (instrument operator), Robin Larsen (pilot), Kait King (pilot), Mike Eastwood (instrument lead).* ***Photo credit:*** *NASA*

Figure 34. *ABoVE B-200 aircraft in Fairbanks, Alaska.* ***Photo credit:*** *Mike Eastwood*

Carbon Mapper (CM)

PI – Riley Duren, Carbon Mapper, Inc.
Program – NASA JPL Program, Atmospheric Composition and Chemistry
Aircraft – DA B-200 King Air
Payload Instruments – AVIRIS-NG

Carbon Mapper, Inc., is a non-profit organization focused on making methane and carbon dioxide data actionable and accessible. Carbon Mapper (CM) partners with NASA and JPL on CM's ongoing Airborne Program, which is setting the stage for the 2024 launch of two Carbon Mapper Coalition satellites, of which NASA JPL is also a partner. Between January and March of 2023, CM conducted its first international airborne campaign in Latin America, which focused on detection and quantification of methane and carbon dioxide point source emissions from the energy, waste, and mining sectors. CM and the AVIRIS-NG team spent three months surveying priority industrial areas in Chile, Ecuador, and Colombia. These flights were part of a broader set of airborne remote sensing data collected by CM in 2023, which included over 100 days of data collection across ten states using Arizona State University's Global Airborne Observatory (GAO).

A major focus for the international campaign was to build partnerships with in-country stakeholders to inform mitigation and policy implementation, enhance capabilities along flare detection, and improve emissions estimates. CM worked closely with governments, nonprofit partners, philanthropic organizations, and industry to secure the permissions needed for the surveys, as well as to demonstrate the value of remote sensing methane data. The Chilean Minister of Environment highlighted the campaign during remarks at the 2022 United Nations Climate Change Conference (COP27) and the survey in Chile received recurring coverage in the country's largest newspaper, *El Mercurio*.

During the campaign, CM completed 26 science survey days across the three countries. In Chile, CM was able to survey 40% of the country's total

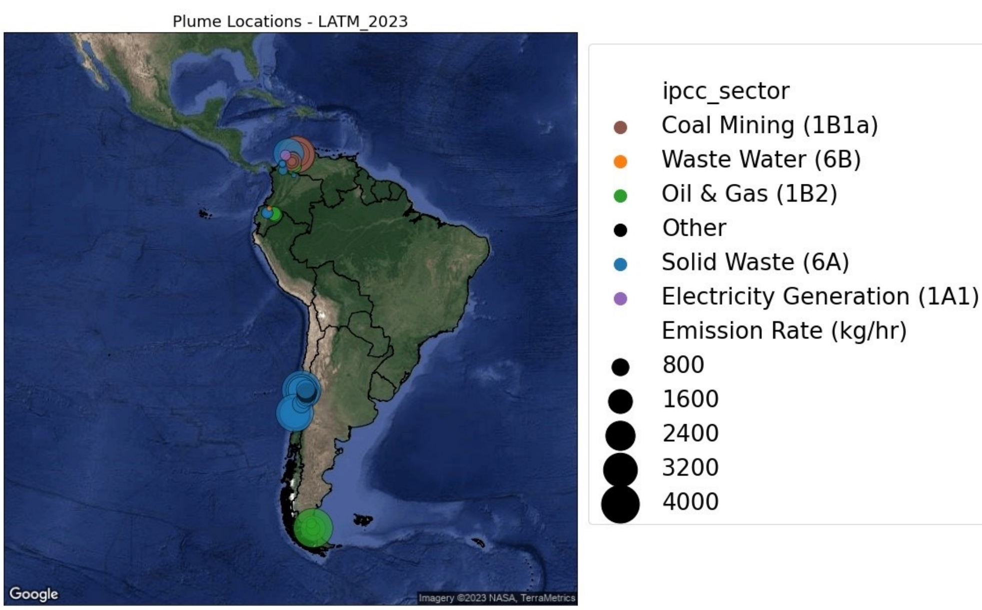


Figure 35. *Representation of super emitters and their relative emission rates, as detected during 2023 Carbon Mapper airborne surveys in Latin America. The project conducted surveys in three South American countries: Chile, Ecuador, and Colombia.*

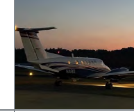


Figure 36. *View from the Carbon Mapper aircraft of Quintero Harbor, located west of Santiago, Chile.* ***Photo credit:*** *Carbon Mapper/NASA JPL*

landfills. The surveys also provided a unique opportunity to compare airborne observations at sites like Chile's Relleno Sanitario Loma Los Colorados with data collected by the NASA Earth Surface Mineral Dust Source Investigation (EMIT) sensor aboard the ISS. In Ecuador, the surveys helped enhance CM's flare detection capabilities, and in Colombia, a unique collaboration with the government and National University provided an opportunity to compare observations with inventory assessments.

The airborne campaign in South America was an important part of laying the foundation for the CM Coalition satellites, which will also include a JPL-designed and -built imaging spectrometer in collaboration with Planet Labs. The insights gained during this campaign not only helped to support in-country action and understanding of current emissions, but also to build connections with global stakeholders of CM data products, including building capacity needed for rapid mitigation. CM's program builds on 10+ years of methane research and airborne surveys conducted by team members and collaborators at NASA and JPL.

EL MERCURIO

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SANTIAGO DE CHILE, LUNES 7 DE AGOSTO DE 2023

Ahora se trabaja en la mitigación con los operadores de estos lugares. El vertedero de El Molle tiene una emisión similar a uno de los sitios de disposición final más contaminantes del planeta, ubicado en India.

El relleno sanitario El Molle es el que más emite a nivel nacional, con más de dos toneladas de metano por hora, según el análisis. En la imagen, la pluma de gas de metano identificada durante uno de los sobrevuelos del área. "Estas tecnologías permiten develar problemas invisibles, con esto trabajaremos para bajar esas emisiones urgentemente", dice Marcelo Mena, CEO del Global Methane Hub.

Los rellenos sanitarios son la principal fuente de emisiones de metano en el país

Luego de meses de trabajo, se identificaron las mayores fuentes de emisión de metano en el país. Esto se logró gracias a la tecnología de vanguardia empleada por Carbon Mapper, una organización sin fines de lucro sita en EE.UU. cuyo objetivo es lograr que los datos de metano y CO_2 sean de fácil acceso y permitan movilizar acciones concretas de mitigación.

A principios del año, sobrevolaron el país con una aeronave equipada con un espectrómetro de imágenes —el Airborne Visible/Infrared Imaging Spectrometer - Next Generation del NASA Jet Propulsion Laboratory— para cuantificar las emisiones de Chile, a través de imágenes de plumas de metano.

Trabajaron con el Global Methane Hub —fondo filantrópico internacional para apoyar la mitigación del metano y prevenir el calentamiento global—, y visitaron los puntos de interés para el país, definidos por los ministerios del Medio Ambiente, Ciencia y Energía.

El metano es el componente principal del gas natural que se usa para calefacción o generación eléctrica, y "se forma principalmente por la descomposición anaeróbica de la materia orgánica (proceso en el cual microorganismos descomponen material biodegradable en ausencia de oxígeno) y la digestión de animales como vacas", explica Marcelo Mena, CEO del Global Methane Hub y académico PUCV.

"El efecto instantáneo del metano en la temperatura es más alto, pero decae más rápido en la atmósfera. El CO_2 se mantiene por mucho tiempo, por eso su potencial de calentamiento es mayor mientras más largo sea el período que se considera. Si tú reduces una tonelada de metano, eso tiene cien veces más efecto en reducir la temperatura en los próximos veinte años (comparado con reducir el CO_2)", acota Luis Cifuentes, investigador del Centro del Cambio Global UC y experto en cambio climático, quien no tiene relación con este estudio.

En ese contexto, para él esta iniciativa es "absolutamente necesaria, porque las mayores fuentes de metano no están asociadas a un combustible, por lo que son más difíciles de identificar".

Según el Inventario Nacional de Gases de Efecto Invernadero —que elabora el Ministerio del Medio Ambiente junto con los ministerios de Energía y de Agricultura—, las principales fuentes de emisión de metano de Chile son los rellenos sanitarios, las plantas de tratamiento de aguas servidas, el ganado y los planteles porcinos.

Carbon Mapper ha realizado estudios en EE.UU., Canadá y Latinoamérica, el primero en esta región fue en Chile. En la foto, la aeronave que lleva el espectrómetro.

La investigación confirmó el rol central de los sitios de disposición final. "Estudiamos un gran número de rellenos sanitarios en el país (además de otras fuentes) y detectamos importantes emisiones de metano en gran parte de los sitios analizados. Realizamos estudios en alrededor del 40% de los rellenos sanitarios conocidos de Chile y detectamos emisiones de metano en el 29% de estos sitios", explica Riley Duren, CEO de Carbon Mapper, a "El Mercurio".

"Como esperábamos, las principales fuentes de emisión puntuales de metano detectadas fueron los rellenos sanitarios y vertederos", precisa la ministra del Medio Ambiente, Maisa Rojas. Estos se encuentran "principalmente en la zona centro-sur, que es donde hay mayor disposición de residuos orgánicos domiciliarios", añade.

Mena destaca el caso del relleno sanitario El Molle, que sirve a la Región de Valparaíso. "Con sus más de dos toneladas de metano por hora, en los próximos veinte años este relleno sanitario podría calentar el clima tanto como 410.000 autos. El Molle tiene emisiones similares al relleno sanitario de Ghazipur, en Delhi (India), que fue detectado como una de las principales fuentes contaminantes del planeta por un satélite".

Colaboración

Para abordar este problema, "hay un trabajo público-privado. Los ministerios del Medio Ambiente, de Sanidad, de Salud, están trabajando con esto, y nosotros (Global Methane Hub y Carbon Mapper) estamos iniciando un trabajo con los operadores de estos rellenos sanitarios para poder disminuir las emisiones", dice Mena.

Según explica, tiene que ver con mejores prácticas, como tapar la basura para que no se descomponga al sol, pero también se requiere un trabajo más sistemático para evitar que lleguen residuos orgánicos al relleno sanitario.

El viernes se reunieron con Veolia, empresa enfocada en la gestión de agua, residuos y energía. Actualmente, la compañía cuenta con 3 de los 5 rellenos sanitarios más grandes del país, entre estos, el de El Molle.

Pilar León, directora de Técnica y Performance de Veolia Chile, comenta que "en cada uno de los rellenos se está trabajando en un ambicioso plan de reducción, que va desde el aumento en la quema de metano en la etapa inicial y el aprovechamiento energético como fin último (dado que el metano se puede recuperar y usar)".

Además, dice que para Veolia este tipo de estudios son muy valiosos, porque les permite focalizar aún más sus acciones y lograr mayor efectividad. Mena destaca la buena disposición de la empresa por colaborar y trabajar las emisiones.

A nivel nacional, este esfuerzo se enmarca en que "Chile está fuertemente comprometido con reducir las emisiones de metano del país, de forma rápida y sostenida en el tiempo, complementando los esfuerzos de reducción de dióxido de carbono", indica Rojas. El país se comprometió en la COP27 a cambiar la tendencia creciente de emisiones de metano en 2025, con la actualización de su Contribución Determinada a Nivel Nacional.

En tanto, Mena señala que Carbon Mapper volverá el próximo año. "Vamos a ver si estas intervenciones están funcionando y al mismo tiempo tenemos la intención de seguir mirando qué es lo que pasa con las fugas de metano en el sur de Chile, en el contexto de la extracción de petróleo y gas".

Duren agrega: "Planeamos continuar con el seguimiento de las observaciones en Chile usando los satélites —trabajamos para desarrollar e instalar dos satélites para el próximo año— para entregar enfoques y conocimientos adicionales respecto de la naturaleza y persistencia de las fuentes de emisión".

Figure 37. *Front page of El Mercurio, Chile's largest newspaper, showcasing the Carbon Mapper mission, published on August 7, 2023.*

ASP Support for Instrument Development

Aircraft provide an important test vehicle to determine the readiness of payloads for space-flight missions. FY23 ASP provided significant support to the Earth Science Technology Office (ESTO) under the Office'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. Some of the instruments are being developed specifically for airborne use, while others are being developed as precursors or simulators for satellite instruments. In FY23, JPL Laser Hygrometer (JLH), Quantifying Uncertainty and Kinematics of Earth Systems Imager (QUAKES-I) and SAR-Fusion, Open Path Ammonia Laser Spectrometer (OPALS), Signals of Opportunity Synthetic Aperture Radar (SoOpSAR) Snow, Aerosol Wind Profiler (AWP), and the Pushbroom Imager for Cloud and Aerosol Research and Development (PICARD) were flown or prepared to fly to support numerous Earth and space science missions.

Table 8. *Instrument development missions supported by airborne activities in FY23.*

Mission	Flight Hours	Location	Aircraft
SoOpSAR SNOW	52.1	Colorado, California	B200
OPALS (Part of AEROMMA)	-	Continental U.S.	DC-8
JPL Laser Hygrometer	11	California	G-II
QUAKES	19	Western U.S.	GV
AWP test flights and Part of EcoDemonstrator	14.3 (FY23)	LaRC	G-III DC-8
PICARD	12	California	ER-2

Signals of Opportunity Synthetic Aperture Radar (SoOpSAR) Snow

PI – Simon Yueh, NASA JPL
Program – ESTO IIP
Aircraft – AFRC B-200
Payload Instrument – SoOpSAR

Snow is the fastest changing component of the water cycle and the least known and monitored. Terrestrial snow plays an important role in weather and climate forecasts through its influence on the heat exchange between land and atmosphere.

Models that predict how snow evolves seasonally and into a warmer future are largely unconstrained by measurements or have poor parameterization of snow processes, leading to large uncertainties. The hydrology of snow-dominated watersheds is also changing as the climate warms. Spring snow accumulation has substantially declined over the last half-century in the Western U.S., and similar patterns are apparent globally. The most important snow water towers in the Alps, Andes, High-Mountain Asia,

and Western North America are also the most vulnerable to these climate change drivers and other socioeconomic pressures.

Yet despite snow's importance to basic human and ecosystem needs, we are not currently able to measure how much fresh water is stored in mountains globally. In situ snow observations are challenging and often impractical, so spaceborne investigations are essential for frequent and global monitoring of terrestrial snowpack.

The 2017 Earth Decadal Survey established the Explorer mission line, which calls for PI-led concepts in seven investigation categories. In the past few years, under the support of the IIP program and internal JPL investment, the P-band Signals of Opportunity Synthetic Aperture Radar (SoOpSAR) concept has been developed to provide an affordable technology for remote sensing of snow from space.

The SoOpSAR team carried out an airborne campaign to acquire data to simulate the spaceborne P-band SoOpSAR concept with multiple receivers on separate satellites with offsets in ground tracks. To demonstrate the spaceborne observation geometry, the campaign included aircraft flights with multiple racetracks over selected test sites (Figure 38).

The campaign included three operation periods in 2022-2023 for snow-free and snow-on conditions. The snow-free flights were completed in August 2022 with a set of flights over the Sagehen Creek in northern California and Grand Mesa, Colorado. The 2023 snow-on observations were completed February 1-10 and March 2-8 over the same sites and an additional site around the Central Sierra Snow Laboratory.

Figure 38. *SoOpSAR flight tracks in Colorado.*
Image credit: *Simon Yueh*

The P-band SoOpSAR receivers were installed on the AFRC B-200 aircraft. One of the two SoOpSAR antennas was installed on a zenith port to receive the direct signals from the U.S. Navy's Mobile User Objective System (MUOS) and the other antenna was installed on a nadir port to receive the reflected MUOS signal from the ground. Two receiver channels in the SoOpSAR receiver simultaneously record the signals from the two antennas.

The direct and reflected signals are cross-correlated (no signal decoding is required) to detect the amplitude and phase of reflected signals for any location of interest. The relative phase calibration stability of the two receiver channels must be maintained to within 4 degrees for the spaceborne SoOpSAR concept. Therefore, a built-in calibrator with a common noise diode and reference load was included in the Front-End Board (FEB) of the receiver for the 2023 flights (Figure 40).

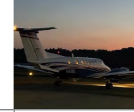
Radio Frequency (RF) switches are used to switch the receiver inputs to the calibrator at a selectable interval. The phase of the cross-correlation of the data from direct and reflected channels for built-in calibration cycles can be used to test the phase calibration stability of the receiver. The data show the relative phase could be kept stable over the duration of each flight with a drift of less than 2 degrees over a few hours, and day-to-day consistency of about 0.5 degrees, much less than the 4 degree requirement.

Data from multiple aircraft tracks were used to develop a multistatic SAR algorithm based on match filtering. As a result of the SAR processing, a radar image with a spatial resolution of 5 meters can be obtained (Figure 41). The images acquired from three different campaign periods are similar, as expected, demonstrating the consistent performance of the airborne SoOpSAR receiver over a period of eight months. To assess the spatial resolution of the radar images, the regions of images with a large spatial contrast were examined, such as areas around the tree lines. Figure 42 indicates the lesser reflection from a forested region than the surrounding open area. The spatial contrast provides support to the spatial resolution achieved by the multistatic SAR processing.

The airborne P-band SoOp campaign data have confirmed the viability of P-band SoOpSAR instrument receiver design by showing that the necessary phase calibration stability of SoOp receivers can be obtained with a well-defined internal calibration scheme. The multistatic SAR processing can be performed to achieve high spatial resolution by using data from multiple airborne or satellite tracks.

Additionally, the results further suggest that the SoOp techniques can be used to develop high resolution passive synthetic aperture radars at higher frequencies, such as using the Global

Figure 39. *SoOpSAR team with AFRC B-200 aircraft in Colorado.* ***Photo credit:*** *Simon Yueh*



Navigation Satellite System (GNSS) signals as the SoOp sources. This may lead to cost-effective high-resolution NASA L-band SoOpSAR missions for imaging of land surface soil moisture and vegetation cover with unprecedented sub-daily revisits.

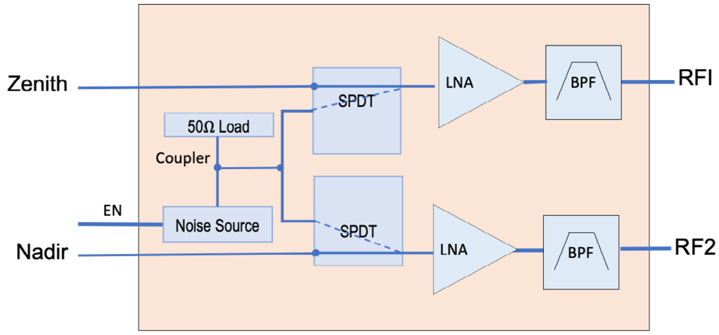


Figure 40. *SoOpSAR receiver has two parallel receiving channels to simultaneously record data from direct and reflected signals. A built-in calibration scheme with a noise diode and reference load provides relative phase and gain calibration.*

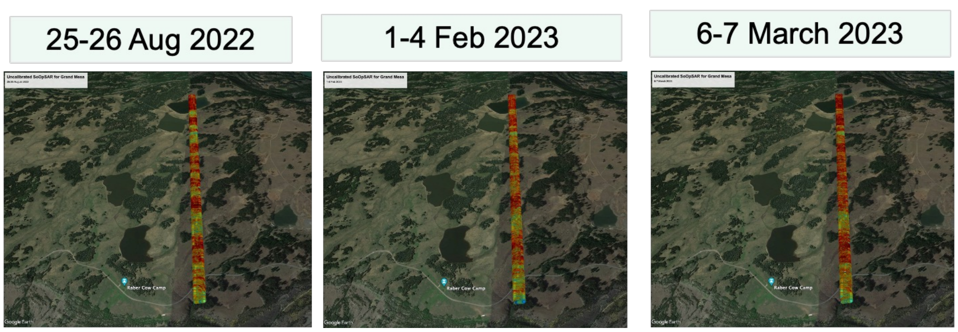


Figure 41. *Airborne SoOpSAR images indicating intensity of reflection, captured over the western part of Grand Mesa, Colorado, show strong reflection over reservoirs and some open areas over land. The features are repeatable in the data across three campaign periods.*

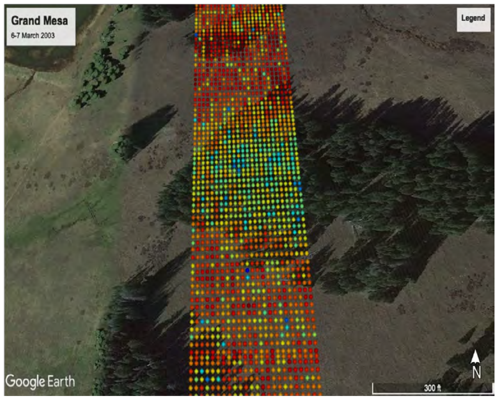


Figure 42. *Magnifying the data shows a weaker reflection over a forested region on the Grand Mesa than the surrounding open areas. This demonstrates the multistatic SAR processing with a high spatial resolution of 5 meters.*

JPL Laser Hygrometer (JLH)

PI – Robert Herman, NASA JPL
Program – ESTO IIP
Aircraft – NGC G-II
Payload Instrument – JLH

In FY23, the JPL Laser Hygrometer (JLH) continued a multi-year collaboration with the Northrop Grumman Corporation (NGC), flying on their Gulfstream-II aircraft to study upper tropospheric regions that are supersaturated with ice. These regions often have high humidity and can form aircraft contrails. The humidity is sufficiently high enough that contrails are not only formed but can remain persistent for hours and even seed larger cirrus clouds, which can have a significant impact on Earth's climate.

In the two-year period 2022 to 2023, JLH performed well and provided accurate in situ water vapor data over the California high desert and the southern Sierra Nevada Mountain range. Of the 40 flights, 36 were carried out during contrail season (November through May). In Autumn 2022, there was a six-month flight hiatus while the G-II's right engine was out for servicing. Flights resumed in March 2023, and the last flight of the mission was April 7, 2023. From these data, a climatology of the upper tropospheric humidity over California is being built.

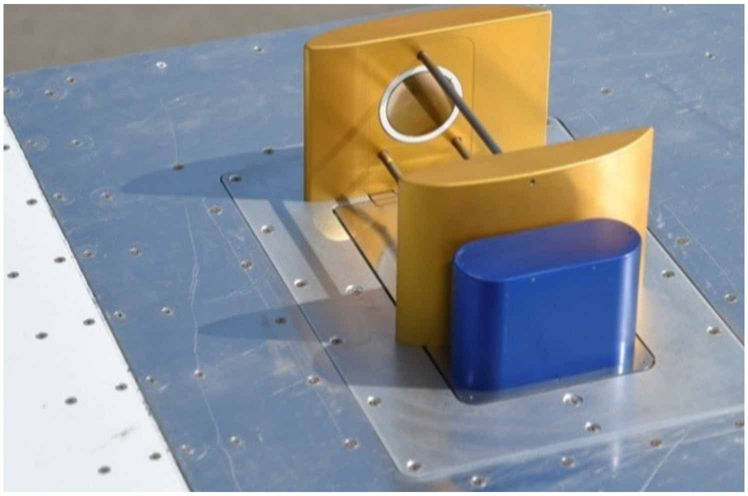


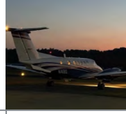
Figure 43. *The JLH instrument mounted on the NGC G-II aircraft.* ***Photo credit:*** *Kevin Hamer/NGC*

Quantifying Uncertainty and Kinematics of Earth Systems Imager (QUAKES-I) and SAR-Fusion

PI – Andrea Donnellan, NASA JPL
Program – Earth Surface and Interior Program
Aircraft – GV, G-III
Payload Instruments – QUAKES-I and SAR-Fusion

Surface topography is essential for understanding land surface processes and for mapping or correcting other observables relative to terrain. Two stereoimaging instrument suites, Quantifying Uncertainty and Kinematics of Earth Systems Imager (QUAKES-I) and SAR-Fusion, provide 3D structure maps of the land surface from visible and short-wavelength infrared (SWIR) images. These instrument suites were designed as complementary instruments supporting UAVSAR.

QUAKES-I captures down-looking color imagery used to produce 3D structure or stereoimage products of targets such as earthquake ruptures, earthquake-prone regions, volcanoes, land-



slides, wildfire denudation and erosion, glaciers, vegetation, and ecosystems. QUAKES-I is an array of eight cameras that use a nadir port of the JSC GV aircraft. QUAKES-I flew during October 2022, providing Digital Elevation Models (DEMs) of California faults.

SAR-Fusion consists of two visible and two SWIR cameras that look through the window of the Gulfstream-III at an oblique angle to the ground in the same swath as UAVSAR. SAR-Fusion flew December 2022, capturing DEMs of Mauna Loa and Kīlauea volcanoes alongside the Ka-band of UAVSAR. These measurements can support disaster response and science objectives. The stereoimagers also support NASA's Surface Topography and Vegetation (STV) incubation study.

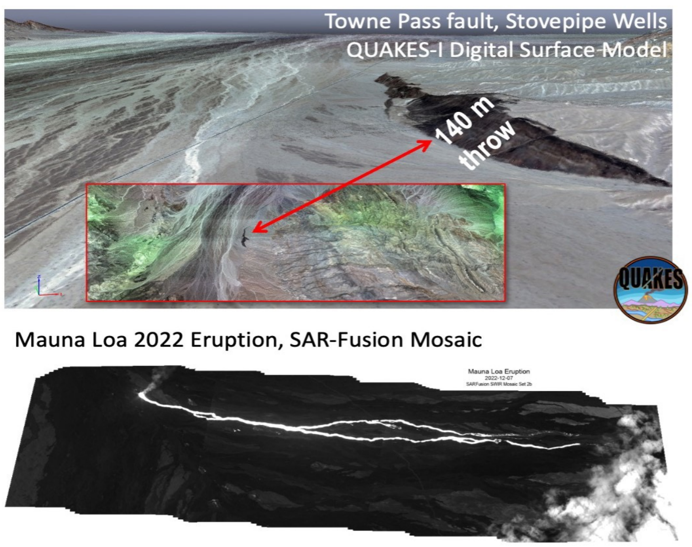


Figure 44. *Digital surface model and image mosaic derived during QUAKES-I and SAR-Fusion mission.*

Open Path Ammonia Laser Spectrometer (OPALS)

PI – Mark Zondlo, Princeton University
Program – IIP
Aircraft – DC-8
Payload Instrument – OPALS

Ammonia (NH_3) is a very "sticky" and semi-volatile molecule with a large measurement range (i.e., parts per-billion near ground sources and parts-per-trillion at higher altitude). Ammonia is challenging to measure using traditional inlet tubes and sample cells: it can aerosolize or vaporize as it enters the warm aircraft cabin, biasing the measurements and results. The Open Path Ammonia Laser Spectrometer (OPALS) instrument provides an innovative method to measure in situ ammonia in support of atmospheric chemistry science studies. OPALS is mounted outside the aircraft, eliminating temperature variations and the need for tubing.

The instrument uses a Herriott optical cell designed by Princeton University and the National Center for Atmospheric Research (NCAR), which reflects light numerous times between a pair of spherical mirrors separated by Invar metering rods about 480 mm apart to minimize thermal expansion and contraction.

Figure 45. *The OPALS instrument, as seen from the exterior of the DC-8, showing the metering rods and spherical mirrors.* ***Photo credit:*** *Adam Webster*

Once the cell was built, OPALS had a surprisingly challenging DC-8 integration starting with the 2022 Student Airborne Research Program (SARP), overcome by a multidisciplinary team consisting of personnel from multiple NASA centers, National Suborbital Research Center (NSRC), NCAR, and Princeton University in time for 2023 test flights.

To assist with integration, NSRC designed, fabricated, and assembled a support structure using novel kinematic joints to attach OPALS to the aircraft in an airworthy, safe, and scientifically sound way. The resulting OPALS installation was aerodynamically and structurally complex, requiring detailed analysis of airflow and structure. AFRC and LaRC engineers worked together to define the specific flight conditions to be analyzed. This was no easy task given the compressed schedule and almost infinitely possible flight conditions. The team developed an analysis matrix that conservatively covered DC-8 operational conditions and yet was executable in the time available.

Personnel from the aerodynamics branches at LaRC and AFRC worked together to create a full-aircraft Computational Fluid Dynamics (CFD) model for determining aerodynamic loads. They then mapped the results of the CFD analysis to a Finite Element Model of the installation to perform structural analysis, which revealed some areas of the optical cell requiring minor modifications. LaRC manufactured and modified this hardware shortly before the first flight of the instrument, which verified airworthiness on the DC-8.

Excitingly, OPALS was finally able to test fly during the NOAA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) mission during Summer 2023. OPALS measured ammonia from sources ranging from vehicle combustion downwind of large cities to agricultural air masses.

AEROMMA flights confirmed there were no major optical alignment issues outside the aircraft during flight. They also identified potential improvements, which can be nearly impossible to predict based upon laboratory and theoretical studies alone. For example, the team used flight results to improve the output of light into the exterior mirrors, as well as laser and fiber optomechanical coupling efficiencies.

Now that the instrument is up and running, the OPALS team has a busy schedule ahead. They will continue to examine in-flight spectral analyses and improve optical signal recoveries and calibrations. OPALS will fly its first designated mission in Airborne and Satellite

Investigation of Asian Air Quality (ASIA-AQ) in early 2024. This successful demonstration of the OPALS instrument represents an innovative development in capturing data about an otherwise difficult-to-measure atmospheric gas.

***Figure 46.** Ryan Boyd, SARP 2022 alumnus, working on the OPALS instrument on the DC-8 aircraft. **Photo credit:** Ryan Bennett*

Aerosol Wind Profiler (AWP)

PIs – Kristopher Bedka and John Marketon, NASA LaRC
Program – Airborne Instrument Technology Transition (AITT) and NOAA Joint Venture Program
Aircraft – G-III (L), DC-8
Payload Instruments – AWP, AVAPS

Measurements of 3D wind fields with high precision, spatial resolution, and vertical resolution are necessary for studying a broad spectrum of atmospheric processes:

- Turbulent sensible and latent heat fluxes.
- Aerosol and pollution transport.
- Planetary boundary layer circulations.
- Cloud formation and evolution.
- Development of weather systems including mid-latitude, tropical cyclones, and severe thunderstorms.

Existing wind observations from geostationary satellite atmospheric motion vectors and low-Earth-orbit passive microwave imagers and scatterometers often cannot resolve key details of these phenomena, especially in the vertical dimension.

Doppler wind lidars (DWLs) are uniquely capable of addressing these 3D wind measurement needs. The LaRC's Doppler Aerosol WiNd (DAWN) lidar, a coherent-detection DWL operating at a 2-micron wavelength, has flown on many NASA airborne science campaigns since 2010, most recently Convective Processes Experiment-Cabo Verde (CPEX-CV) in September 2022. DWLs operate on the following principle: aerosol particle movement causes a Doppler shift to the frequency of backscattered light;

DWLs can use this to retrieve a vertical wind profile when sufficient aerosol backscatter is detected.

The NASA Earth Science Technology Office (ESTO) and ESD supported the transition of the Wind Space Pathfinder (Wind-SP) 2-micron lidar transceiver into a new instrument, the Aerosol Wind Profiler (AWP), NASA's next-generation airborne DWL instrument. AWP is a significant improvement over DAWN in several respects:

- AWP provides a 20x increase in pulse repetition rate and has an improved lidar figure of merit, resulting in improved aerosol backscatter sensitivity and spatial detail of wind profiles.
- AWP has a nadir beam path and a steered off-nadir path, enabling measurement of the full 3D (horizontal and vertical) wind vector.
- AWP reduces mass by 50% and volume by 65% while adding the second lidar beam path. The reduced mass and volume enable straightforward installation of AWP on multiple airborne platforms, including G-III, GV, DC-8, P-3, and B777.

AWP was integrated onto the LaRC G-III in Dec 2022; in Jan 2023, three engineering and technology demonstration flights were flown from LaRC, totaling 14.3 flight hours. The flights enabled the first usage of a new dropsonde tube aboard the G-III, where ten Advanced Vertical Atmospheric Profiling System (AVAPS) dropsondes were released. AWP measured winds up to 80 m/s (155 knots) that generated mountain wave turbulence over western Virginia. The final flight sampled an airmass ahead of a rapidly developing mid-latitude cyclone that generated tornadic thunderstorms over southeast Texas and southern Louisiana.

AWP was selected by the NOAA Joint Venture Program to demonstrate suborbital DWL wind measurement capability and simulate space-borne DWL measurements. The first phase of this flight campaign was intended to be aboard the LaRC G-III in late-May 2023, but due to a reprioritization of the G-III for another mission, was shifted to piggyback on the October 2023 NASA EcoDemonstrator campaign. The components required to integrate AWP on the DC-8 were

Figure 47. *AWP installation in the LaRC Gulfstream III aft nadir portal (left) and DC-8 aft cargo bay (right).*
Photo credits: *Kris Bedka and John Marketon*

adapted from the AWP P-3 installation designs and were analyzed and fabricated in just a three-month period. AWP can be integrated on the P-3 in the future with minimal additional investment. AWP collected over 50 hours of wind profile data with up to ~1 km spatial and 66-meter vertical detail during EcoDemonstrator. This completed the first phase of the NASA-NOAA Joint Venture flights; the second phase is scheduled for September to October 2024 aboard the LaRC G-III.

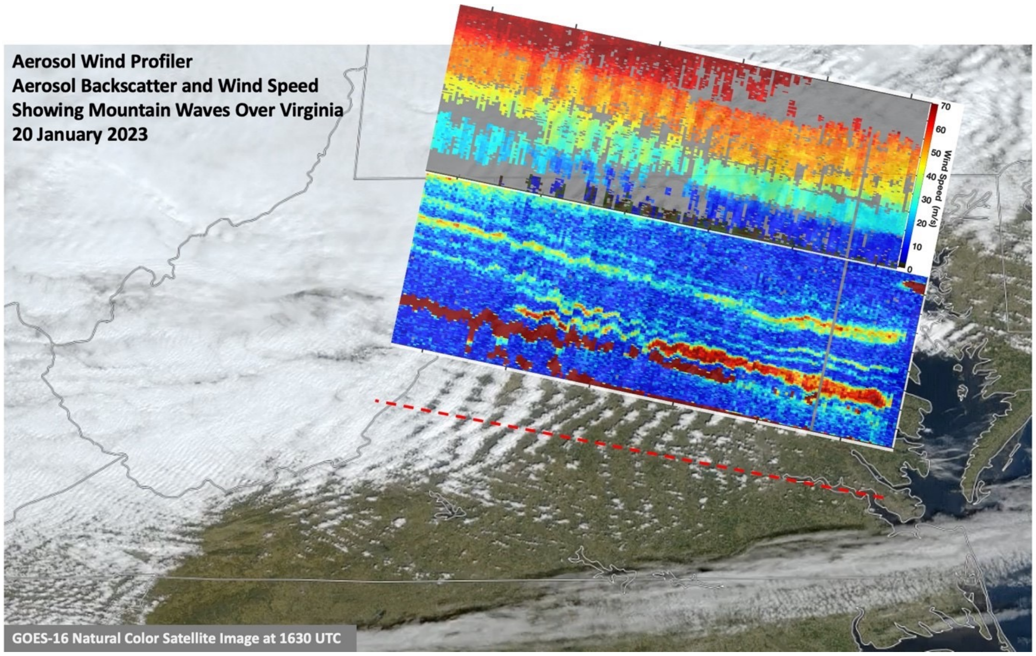


Figure 48. GOES-16 Natural Color Satellite Image on January 20, 2023, with a segment of the LaRC Gulfstream-III flight track and the corresponding AWP wind speed (a) and signal-to-noise ratio (b) profiles.

Pushbroom Imager for Cloud and Aerosol Research and Development (PICARD)

PI – James Jacobson, Universities Space Research Association
Program – ESD EOS Project
Aircraft: ER-2
Payload Instruments – eMAS, PICARD

The Pushbroom Imager for Cloud and Aerosol Research and Development (PICARD) instrument is an imaging spectrometer with 204 channels in the visible (VIS) through short-wave infrared (SWIR) (i.e., 400 to 2450 nm). PICARD consists of two Offner spectrometers mounted to a single four-mirror anastigmat telescope designed to produce a distortion-free 50-degree field of view over cloud scenes from a high-altitude aircraft (e.g., ER-2, GV). PICARD was originally designed to study optical properties of high-altitude clouds and aerosols relevant to the radar electronics planned for the AOS mission by implementing a digital beamforming capability. This modification will enable the aircraft to serve as a testbed for future synthetic aperture radar (SAR) technologies needed to make new measurements, such as surface and vegetation structure, and to support future decadal survey themes.

In the past year, the PICARD instrument has undergone engineering exercises that have improved overall system stability and data quality. While working to develop an integration solution for the NASA GV, the PICARD team has improved the system incrementally as opportunities arose.

One major milestone was the PICARD science validation deployment on the ER-2 during the Western Diversity Time Series (WDTS) mission in Fall 2022, and again in Spring 2023. While not a prime instrument for this mission, these flight opportunities facilitated major improvements. This series of flights saw the first success of the newly implemented internal thermal regulation system, which has greatly improved the ability to maintain calibration of PICARD's SWIR camera.

PICARD was also deployed for further validation flights on the ER-2 during the 2023 Geological Earth Mapping Experiment (GEMx) mission, with the goal to acquire vicarious calibration targets, as well as coincident satellite overpass data to further refine the system and compare to other payloads aboard the ER-2 for WDTS. The Airborne Sensor Facility (ASF) is also looking forward to characterizing PICARD at the Goddard Laser for Absolute Measurement of Radiance (GLAMR) facility in February 2024 and deploying it for the Plankton, Aerosol, Cloud, ocean Ecosystem Postlaunch Airborne eXperiment (PACE-PAX) mission in Fall 2024.

Figure 49. *PICARD instrument installed in the ER-2 pod.*
Photo credit: *NASA*

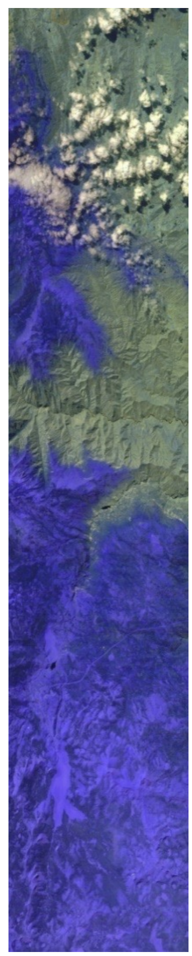


Figure 50. *False-color short-wave infrared PICARD image over Yosemite National Park on March 31, 2023. Red, green, and blue channels are mapped to the 2.15, 1.55, and 1.15 micrometer wavelength PICARD bands, therefore snow appears deep blue, clouds appear white, and vegetation appears yellow green in the image.*

ASP Partnerships and Interagency Support

NASA ASP collaboration extends beyond ESD, often partnering with NOAA, USGS, and others on interagency projects. In FY23, these projects included NOAA's Gravity for the Redefinition of the Vertical Datum (GRAV-D) and Stratospheric Aerosol processes, Budget, and Radiative Effects (SABRE), and USGS's Geological Earth Mapping Experiment (GEMx), detailed below. Additionally, FY23 brought exciting intra-agency collaboration between ASP and NASA's Planetary Science Division and Heliophysics Program, including supporting OSIRIS-REx (the return of a sample from asteroid Bennu) and imaging sounding rockets in Norway with Vorticity Experiment (VortEx).

NOAA Gravity for the Redefinition of the Vertical Datum (GRAV-D)

PI – Jeffery Johnson, NOAA
Program – NOAA GRAV-D Project
Aircraft – G-IV
Payload Instruments – Project-supplied INS and airborne gravimeter

NOAA's National Geodetic Survey (NGS) is collecting airborne gravity data to modernize the way that heights, or elevations, are determined in the U.S. and its territories. NGS has been collecting airborne gravity data as part of the Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project since 2008. This ambitious 15-year effort has resulted in data being collected over the entire continental U.S., Alaska, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands (CNMI), Puerto Rico, and Virgin Islands. The GRAV-D data will be combined with other satellite, terrestrial, and marine data sets to create a modernized vertical datum that, among other things, will provide civilian agencies, universities, and industry with elevations accurate to 2 cm wherever possible when using survey-grade Global Navigation Satellite System (GNSS) equipment. The modernized vertical datum, known in the U.S. as the

Figure 51. *LaRC Gulfstream IV (N522NA) on the tarmac at Pago Pago International Airport in American Samoa supporting the GRAV-D project in June 2023.* ***Photo credit:*** *Taylor Thorson*

North American-Pacific Geopotential Datum of 2022 (NAPGD2022), is a joint project between the U.S., Canada, and Mexico.

In June 2023, the GRAV-D team successfully collected data over the American Samoan region and the Hawaiian Islands with the LaRC Gulfstream IV (N522NA). These Pacific Island regions have been challenging to complete because of difficulties securing long-range aircraft capable of reaching and safely flying over these regions. The ability to partner with NASA was instrumental in collecting these data to meet a December 2023 deadline.

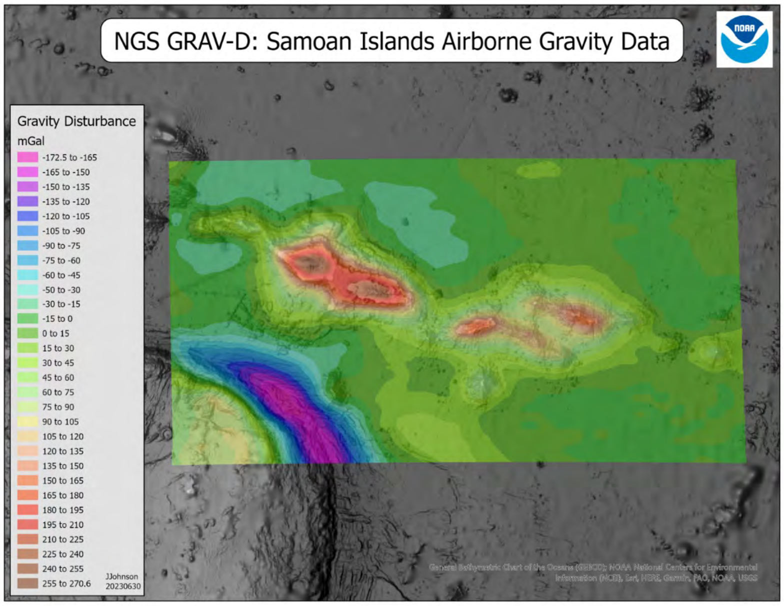


Figure 52. *Gravity Disturbance data using GRAV-D data over the American Samoan region. In this case, Gravity Disturbance is the difference between gravity at flying height and normal gravity at the same location. Normal gravity can be calculated assuming a homogeneously dense ellipsoid model of the Earth.*

NOAA Stratospheric Aerosol processes, Budget, and Radiative Effects (SABRE)

PIs – Troy Thornberry, NOAA CSL and Eric Jensen, CU CIRES
Program – NOAA
Aircraft – WB-57
Payload Instruments – MMS, PALMS-NG, Roscoe, SP2, SO2-LIF, NO-LIF, DLH, UASO3, NOAA-AMP UHSAS, NOAA-AMP CDA, NOAA-AMP NMASS, ACOS, CAPS Depol, SOAP, Strat-CIMS

The first science deployment of NOAA's Stratospheric Aerosol processes, Budget, and Radiative Effects (SABRE) was conducted February and March 2023 using a NASA JSC WB-57 high altitude research aircraft to sample the late winter Arctic stratosphere. This was the first deployment of a NASA WB-57 for high latitude winter operations, but the aircraft and crew took the challenging conditions in stride to successfully complete the mission.

The SABRE project, a component of the NOAA Earth Radiation Budget (ERB) Initiative, is a multi-year airborne science campaign to study the processes controlling the formation, transport, chemistry, microphysics, and radiative properties of aerosols in the upper troposphere and lower stratosphere (UTLS). A series of high-altitude research aircraft deployments to different regions and in different seasons will provide extensively detailed in situ measurements to characterize UTLS aerosol processes. These observations

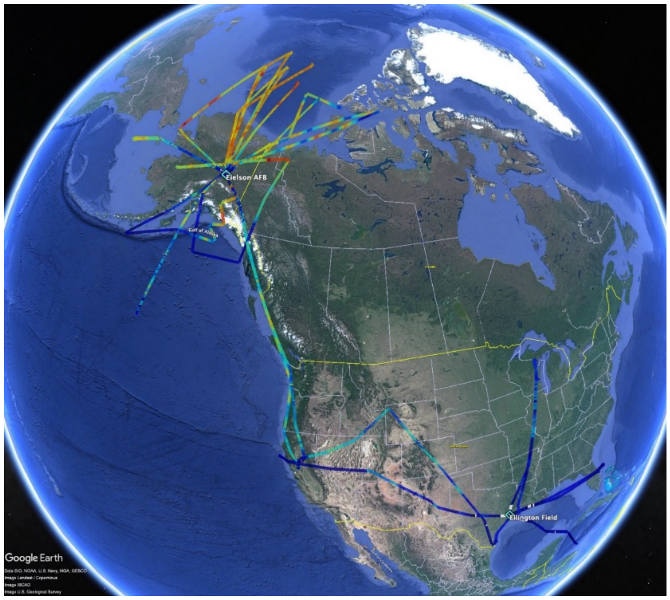


Figure 53. *SABRE flight tracks showing variations in ozone levels.*

are critical for improving the ability of global models to accurately simulate the radiative, dynamical, chemical, and climate impacts of natural and anthropogenic changes in stratospheric aerosol loading.

SABRE 2023 field operations began in late January with instrument integration onto a NASA WB-57 (N926NA) at JSC Ellington Field in Houston, Texas. Three science flights were conducted from Ellington Field:

- Southern sortie to survey aerosol and trace gases in the subtropical UTLS.
- Midlatitude UTLS survey over the central U.S.
- Flight to Cape Canaveral targeting the exhaust plume of a SpaceX Falcon-9 launch.

The team and aircraft then relocated to Eielson AFB, Alaska.

Transit flights from Texas to Alaska (with a stop in California) were conducted as high-altitude (suited aircrew) science flights and provided the opportunity to survey the UTLS across the latitude range from 30° to 64° N. Twelve local science flights were conducted from Eielson AFB (64.6 N, 147.1 W) during the period of February 28 to March 23, 2023. These flights included:

- Surveys of high-latitude UTLS aerosols and trace gases in aged Arctic air masses outside the polar vortex.
- Sampling of air transported down from the mesosphere through the polar vortex to the lower stratosphere.
- Sampling of intrusions of low latitude, polluted air into the polar lowermost stratosphere.
- UTLS surveys south of Eielson AFB.

The return transit flights at the end of March were also conducted as high-altitude science flights and provided another opportunity for measurements across a wide latitude range.

The SABRE 2023 science payload included seventeen instruments measuring aerosol size distribution and composition, as well as trace gas species relevant for analysis of dynamics and photochemical processes. These instruments were supported by teams from the NOAA

Chemical Sciences Laboratory, NOAA Global Monitoring Laboratory, University of Colorado Cooperative Institute for Research in Environmental Sciences, NASA LaRC, NASA ARC, University of Vienna, and Harvard University.

Evolution of the Arctic polar vortex over the SABRE 2023 study period played a major role in setting the science goals for individual research flights. A persistent high-pressure ridge over Alaska during the early part of the deployment led to flight plans targeting intrusions of lower-latitude air and their influence on the polar stratosphere. As the ridge broke down, flight plans targeted vortex filaments and a mix of vortex and non-vortex air. When the residual vortex passed over the study region, the research flight tempo was increased, with back-to-back flights providing extensive sampling of the lowermost edge of the polar vortex itself. University of Wisconsin Real-time Air Quality Modeling System (RAQMS) forecasts were used for flight planning to target filaments, features, and gradients.

Analysis of the SABRE 2023 data is still in its initial stages, but an early result was published in Proceedings of the National Academy of Sciences (PNAS) in October 2023, reporting the surprisingly large fraction of polar stratospheric aerosol particles containing anthropogenic material ablated during rocket and satellite atmospheric reentry. Additional science questions that will be investigated using the 2023 data include:

- How do the aerosol number, mass, size distribution, and composition evolve with the age of stratospheric air?
- What is the role of meteoric smoke particles in determining the overall properties of stratospheric aerosols?
- How do variations in aerosol impact stratospheric reactive nitrogen and halogen species partitioning?

The SABRE 2023 team is grateful for the warm welcome and generous support the project received from Eielson AFB that helped to make the mission a success.

Figure 54. *SABRE team with the WB-57.* ***Photo credit:*** *Max Dollner/University of Vienna.*

USGS Geological Earth Mapping Experiment (GEMx)

PI – Raymond Kokaly, USGS
Program – USGS
Aircraft – ER-2
Payload Instruments – AVIRIS-NG, AVIRIS-3, HyTES, MASTER

In a collaboration with the United States Geological Survey (USGS), the AFRC ER-2 aircraft flew high over the Southwestern regions of the U.S., initiating the 5-year Geological Earth Mapping Experiment (GEMx) project. By acquiring hyperspectral data, the GEMx mission seeks to identify and map critical mineral deposits in the Western U.S. to determine if there are new, previously unknown resources for materials such as lithium and rare-earth elements.

The U.S. depends on a reliable supply of earth materials to support its economy and national security, and such materials have been deemed "critical" minerals because disruption of their supply would have significant negative impacts. Undiscovered deposits of at least some of these critical and strategic minerals almost certainly exist in the U.S., but modern geophysical data is needed to increase our knowledge of these resources.

For a project of this scale and detail, the instrumentation must be both precise and sweeping. Therefore, researchers used AVIRIS, HyTES, and MASTER on the ER-2 to collect the measurements over the country's arid and semi-arid regions.

Instruments on the ER-2 acquired wide swaths of data at ~65,000 feet with every overflight. The 2023 campaign included data acquisitions on eight days between September 5 and 26 for a total of nearly 70 flight hours. Collected data cover more than 170,000 square kilometers, including parts of Southern Oregon, Northwestern California, California Central Valley, Southern Nevada, Eastern California, Southeastern California, and Southwestern Arizona (Figure 55).

The GEMx mission, data, and its data products can help the public, along with local, state,

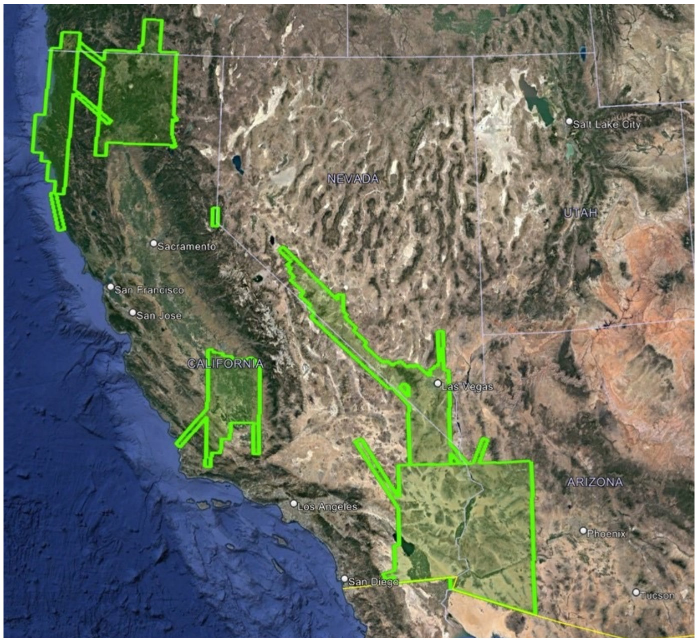


Figure 55. *Areas covered during the GEMx 2023 mission.* ***Figure credit:*** *Raymond Kokaly/USGS*

and federal agencies, make effective decisions regarding management of natural resource deposits, including critical mineral resources like copper. Analyses of GEMx data will result in actionable information for scoping, prioritizing, and conducting activities under various USGS projects. The GEMx partnership with NASA is expected to continue for an additional 4 years. As with all NASA projects, the data from this mission will be publicly accessible to the benefit of communities and researchers now and in the future.

Hypervelocity OSIRIS-REx Reentry Imaging and Spectroscopy (HORIS)

PI – Carey Scott, NASA LaRC
Program – NASA SMD Planetary Science Division
Aircraft – G-III (J), WB-57, G-IV
Payload Instruments – MARS1, MARS2, SAMI

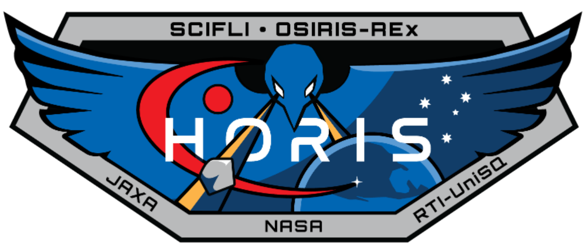


Figure 56. *HORIS mission patch.* ***Design credit:*** *Theo Chawla*

LaRC Scientifically Calibrated In-Flight Imagery's (SCIFLI) Hypervelocity OSIRIS-REx Reentry Imaging and Spectroscopy (HORIS) mission consisted of four imaging aircraft and three imaging ground stations, with more than twenty spectrometers and cameras between them, collecting critical data of NASA's first asteroid sample return mission.

The Origins, Spectral, Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) Sample Return Capsule (SRC) successfully landed back on Earth the morning of September 24, 2023, seven years after its launch in 2016. During its long journey, the spacecraft traveled to the carbon-rich asteroid Bennu to measure its size, shape, and orbit. OSIRIS-REx also collected the largest regolith sample from an asteroid surface to date, which will give scientists around the world insight into the formation of our solar system. After the SRC was delivered to Earth's atmosphere, the spacecraft, now OSIRIS-Apophis Explorer (OSIRIS-APEX), is continuing on to complete an extended mission, with the goal of reaching near-Earth asteroid Apophis in 2029.

The OSIRIS-REx SRC is a blunt-nose cone 81 centimeters in diameter and 50 centimeters tall. It weighs ~46 kilograms. The capsule, covered in a Phenolic Impregnated Carbon Ablator (PICA) heat shield and SLA back shell, entered Earth's atmosphere at 44,498 kph (27,650 mph), making it one of the fastest human-made objects to fly in Earth's atmosphere. The SRC, equipped with a drogue and main parachute, landed in the Utah Test and Training Range.

The HORIS observation campaign had three science objectives (in order of importance):

1. Obtain calibrated near ultraviolet (UV), visible (VIS), and near infrared (IR) thermal data on the heatshield and gas thermal shock layer of the vehicle, as well as the non-equilibrium plasma in the vehicle wake during the high-Mach number region of reentry through peak heating (approximately Mach 23).

Figure 57. *The OSIRIS-REx shortly after landing in the Utah desert on September 24, 2023.* ***Photo credit:*** *NASA*

2. Collect data on the wake chemistry and interaction during high-Mach reentry conditions.
3. Use IR imagery for initial acquisition of the vehicle at or near horizon break to enable a stabilized track on the vehicle during the region of maximum scientific interest, including peak heating.

To accomplish these complex goals, the aircraft and ground stations were equipped with UV through mid-wave IR sensors and tracking telescopes designed for acquiring spectroscopic and trajectory data on the OSIRIS-REx SRC re-entry vehicle. The imaging platforms were spread out along the SRC trajectory to collect a data set that included both front- and side-looking views of the capsule. SCIFLI, in partnership with aircraft engineers at JSC, developed new single-pane, large-aperture optical windows to increase the quality and quantity of the data collected from the Gulfstream aircraft. The new large-aperture windows, made of optical-grade fused silica, met the strict operational waveband requirements for the imaging goals, as well as the material strength to withstand the mechanical loads from the aircraft in flight. With a 16.4-inch clear aperture, the new HORIS optical windows are the largest single-pane glass windows ever flown on a Gulfstream aircraft.

In the weeks leading up to SRC reentry, the HORIS team integrated all instruments onto the aircraft and meticulously tested each to ensure functionality on the ground. Then, the aircraft participated in a local instrument check flight (ICF) based out of their home NASA center. System checkouts used stars to compare with the ground tests and to demonstrate the spectrographs would function as intended during flight. One week out from SRC reentry, the HORIS airborne team deployed to Salt Lake City, Utah, while the ground teams deployed to their respective locations. Once in place, the team participated in two mission dress rehearsals, flying in the intended mission airspace, to finalize configurations, procedures, and protocols in preparation for the mission.

On mission day, the HORIS team successfully collected scientific imagery and spectroscopy of the SRC. Additionally, the WB-57 aircraft provided the live streaming footage for NASA TV and assisted the recovery forces in locating the capsule after touchdown. The data collected by this team will help researchers in the Entry Systems Modeling project better understand the aerothermodynamic environment the capsule

Figure 58. *HORIS team members Carey Scott (NASA) and Tait Pottebaum (OKSI) discussing installation of SAMI on NASA 522.* ***Photo credit:*** *Mary Emmerson*

Figure 59. *Inside (a) and outside (b) views of fused silica optical windows.* ***Photo credit:*** *Arianna Haven*

experienced as it traveled through the atmosphere. This information, coupled with knowledge of the SRC's thermal protection system material, will aid in the development and refinement of computational modeling tools NASA uses when designing planetary exploration missions and will ultimately influence future spacecraft thermal protection system (TPS) designs.

The HORIS mission was a complex, collaborative effort. It consisted of nearly one hundred team members from organizations around the world, including, but not limited to, NASA HQ, JSC, AFRC, LaRC, and GSFC; JAXA; MARS; OSKI; University of Southern Queensland (UniSQ), University of Oxford, and University of Stuttgart; and Rocket Technology Incorporated (RTI).

In addition, it required significant coordination with military test ranges in Nevada and Utah, as well with as the Federal Aviation Administration (FAA) to facilitate NASA aircraft clearance in restricted airspace and around commercial airliner jetways.

The number of domestic and international researchers, aircraft, and ground stations involved, paired with the difficult task of acquiring, then tracking, a vehicle the size of a truck tire traveling at 12 km/s from an aircraft during full daylight certainly makes this one of SCIFLI's most logistically and technically challenging missions to date. The team's success reflects on the incredibly talented group of people who contributed to the project.

Figure 60. *Screenshots from WB-57 IR and visible footage on NASA TV's livestream of the reentry.*

Vorticity Experiment (VortEx) Norway

PIs – Gerald Lehmacher and Miguel Larson, Clemson University
Program – NASA SMD Heliophysics Program
Aircraft – G-IV
Payload Instruments – SLR cameras

The NASA Gulfstream IV aircraft successfully imaged two sounding rockets for the Vorticity Experiment (VortEx) mission, launched from Andoya Space Center, Norway on March 23, 2023.

VortEx aims to characterize mesoscale dynamics (~10 to 500 km) in the upper mesosphere and lower thermosphere (~90 to 120 km), a region that also contains the Earth's turbopause. Rocket and ground-based measurements were combined to distinguish between:

- Divergence in the horizontal flow field and motions that are divergent (e.g., gravity waves).
- Vorticity in the horizontal flow field and motions that are vortical (these are expected to occur in quasi-stratified mesoscale turbulence).

These processes are crucial for a better description of subgrid processes and eddy diffusion in global atmospheric models. The G-IV provided an airborne optical platform from which to image the chemical releases from the sounding rockets.

VortEx has identical payloads, 36.361 and 36.362, which carry rocket-powered ampules and canisters that release trimethyl aluminum (TMA) for wind observations. Each TMA payload is launched with an instrumented payload, 41.127 and 41.128, with instruments from Clemson University and Embry-Riddle Aeronautical University. Salvo 1, which included 36.361 and 41.127, was launched on March 23, 2023. The payloads were launched two minutes apart. Unfortunately, launch conditions were not met for 36.362 and 41.128, and as a result, those payloads were scrubbed; the next launch attempt will be Fall 2024.

Clemson University provided the aircraft payload, which consisted of several digital SLR cameras and the associated mounting truss.

Figure 61. *VortEx Norway mission dress rehearsal with all payloads vertical.* ***Photo credit:*** *Danielle Johnson*

The aircraft was based at Trondheim, Norway from March 13 to March 26, 2023, when the aircraft returned to NASA LaRC. A total of 29.2 research flight hours were flown, out of a mission total of 49.5 flight hours. All airborne instruments operated successfully.

Figure 62. *Northern lights seen on VortEx Norway launch night.* ***Photo credit:*** *Danielle Johnson*

Figure 63. *Launch of 36.361 VortEx Norway.* ***Photo credit:*** *Danielle Johnson*

Upcoming Activities

FY24 holds many exciting opportunities for air-borne science, including ASP projects with international stakeholders. Biodiversity Survey of the Cape (BioSCape) will collect biodiversity data in terrestrial and marine ecosystems near Cape Town, South Africa, over a ~2-month period, marking the first time that such a comprehensive study has been done on the biodiversity hotspot to date. Additionally, the air quality in multiple Asian countries (e.g., Thailand, Republic of Korea, Philippines) will be studied using a suite of instruments on the G-III (L) and DC-8. This Airborne and Satellite Investigation of Asian Air Quality (ASIA-AQ) mission marks the DC-8's final airborne campaign after many decades in service. In addition, the P-3 and G-III (L) will study summer sea ice melt, Arctic clouds, and radiation processes in Greenland and Norway in Summer 2024.

In the upcoming year, ASP will also support a handful of spaceborne instruments, including Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and Earth Surface Mineral Dust Source Investigation (EMIT), in their post-launch phases through airborne campaigns totaling 330 flight hours of dedicated cal/val time.

During FY24, ASP will continue supporting multi-year missions, including Stratospheric Aerosol processes, Budget, and Radiative Effects (SABRE), which will continue to study the transport, chemistry, microphysics, and radiative properties of aerosols in the upper troposphere and lower stratosphere and their impact on the climate system through flights in Texas and OCONUS. Finally, Student Airborne Research Program (SARP) will enter its 16th year and SARP-East its second.

Table 9. *ASP's planned major 2024 missions.*

Mission	Aircraft	Location	Science Program	Requested Hours
ASIA-AQ	DC-8, G-III (L)	Asia, including Thailand, Philippines, S. Korea, and Malaysia	Tropospheric Chemistry Program	400
ARCSIX	P-3, G-III (L)	Greenland, Norway	Radiation Science Program	371
GHG Center Methane Surveys	DA B-200	CONUS, OCONUS, including Chile, Ecuador, Colombia	ESD U.S. Greenhouse Gas Center	220
BioSCape	GV, G-III (L)	South Africa	Biological Diversity	200
AfriSAR	AFRC G-III (C-20A)	Africa	Interior and Terrestrial Hydrology and Terrestrial Ecology	193
PACE PAX cal/val	ER-2, Twin Otter CIRPAS	California	Ocean Biology and Biogeochemistry and Radiation Science	180
SABRE	WB-57	CONUS, OCONUS	NOAA	167
EMIT cal/val	DA B-200	CONUS	ESD U.S. Greenhouse Gas Center	150
Carbon Mapper	DA B-200	CONUS	Carbon Mapper, Inc.	100
FireSense	B-200 (L), B-200 (AFRC)	California	Tropospheric Composition	95
MINNOW	Twin Otter CIRPAS	CONUS	CMS	80
QUAKES-I STV	GV, AFRC B-200	Western U.S.	Earth Surface and Interior	72
WHyMSIE	ER-2	CONUS	n/a	50
AWP demo	G-III (L)	Virginia	Weather and Atmospheric Dynamics	45
AirMOSS for Ice Sounding	AFRC G-III (C-20A)	Greenland	Cryospheric Science	43
SARP	P-3	CONUS	Tropospheric Composition	40
BlueFlux	DA A-90	Virginia, Florida	Ocean Biology and Biogeochemistry, CMS	35

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: *https://airbornescience.nasa.gov.* The annual "call letter," also available on the ASP website, is an excellent source of information describing how to request airborne services (*https://airbornescience.nasa.gov/sofrs/*).

FY2023 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. One of the most exciting enhancements to the ASP fleet is the acquisition of a Boeing 777-200 Extended Range (B777-200ER), which was acquired to replace and extend the capabilities of the NASA DC-8 (retiring in 2024). The newly acquired B777 is currently undergoing modifications at NASA LaRC, to include several nadir and window ports, power, data and communications systems, and instrument operator accommodations. First B777 operations are planned for FY26 from LaRC.

Other significant modifications to the ASP fleet in FY23 are listed in Table 10.

Table 10. *Enhancement modifications to ASP aircraft in FY23.*

Aircraft	Modification	Impact
Payload Enhancements		
P-3	Upgraded aft radome and added two 3.5" diameter aft facing ports	Enhances science capability
JSC GV	Aircraft Environmental Details (ambient air & surface temp, air flow, humidity, dew point)	Provides environment Information for payload managers
Aircraft Upgrades		
WB-57 (926 and 927)	Installed Voice over IP (VoIP) line between the aircraft and the CAPCOM at the ground station	Allows for clearer real-time notifications and requests, which are critical in both imaging and in situ atmospheric sampling missions.
WB-57 (926 and 927)	Upgraded both legacy Satcom systems with the SpaceX Starlink system	Allows for better real-time observation of instrument data by science teams on the ground, and improved situational awareness during observation missions
P-3	Experimenter Power Control panel upgraded and converted to digital	Improves experimenter power control
GV, ER-2 (806)	Installed Iridium Certus (all ASP-supported aircraft have now been upgraded to Iridium Certus.)	Increased data speeds from 9.8kbps to ~88kbps. Provides more stable air-to-ground chat and data transfers.

ASP Fleet Summary Characteristics

ASP aircraft performance characteristics and payload accommodation summaries are provided in Table 11. The fleet of aircraft is shown in Figure 64. The altitude, endurance, and range capabilities are shown in Figure 65. Figure 66 indicates payload capability for each aircraft.

Table 11. *ASP aircraft and their performance capabilities.*

Platform Name	NASA Center	Payload Accommodations	Duration (Hours)	Useful Payload (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)
ASP Supported Aircraft							
DC-8	AFRC	4 nadir ports, 1 zenith port, 14 additional view ports	12	50,000	41,000	450	5,400
ER-2 (2)	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	AFRC	UAVSAR pod	7	2,610	45,000	460	3,000
G-III	LaRC	2 nadir ports, dropsonde / sonobuoy	7	2,610	45,000	460	3,000
G-IV	LaRC	AirSAR next gen (future)	7.5	5,610	45,000	459	4,000
GV	JSC	2 nadir ports, dropsonde capability	12	8,000	51,000	500	5,500
P-3	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	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	AFRC	2 nadir ports	6	1,850	30,000	272	1,490
B-200	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	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	LaRC	Unpressurized belly pod	6	932	17,500	175	970
Matrice 600 (UAS)	ARC	Imager gimbal	1	6	8,000	35	3
SIERRA-B (UAS)	ARC	Interchangeable nose pod for remote sensing and sampling, 1 nadir port	10	100	12,000	60	600

Figure 64. *NASA Airborne Science Program-supported aircraft.*

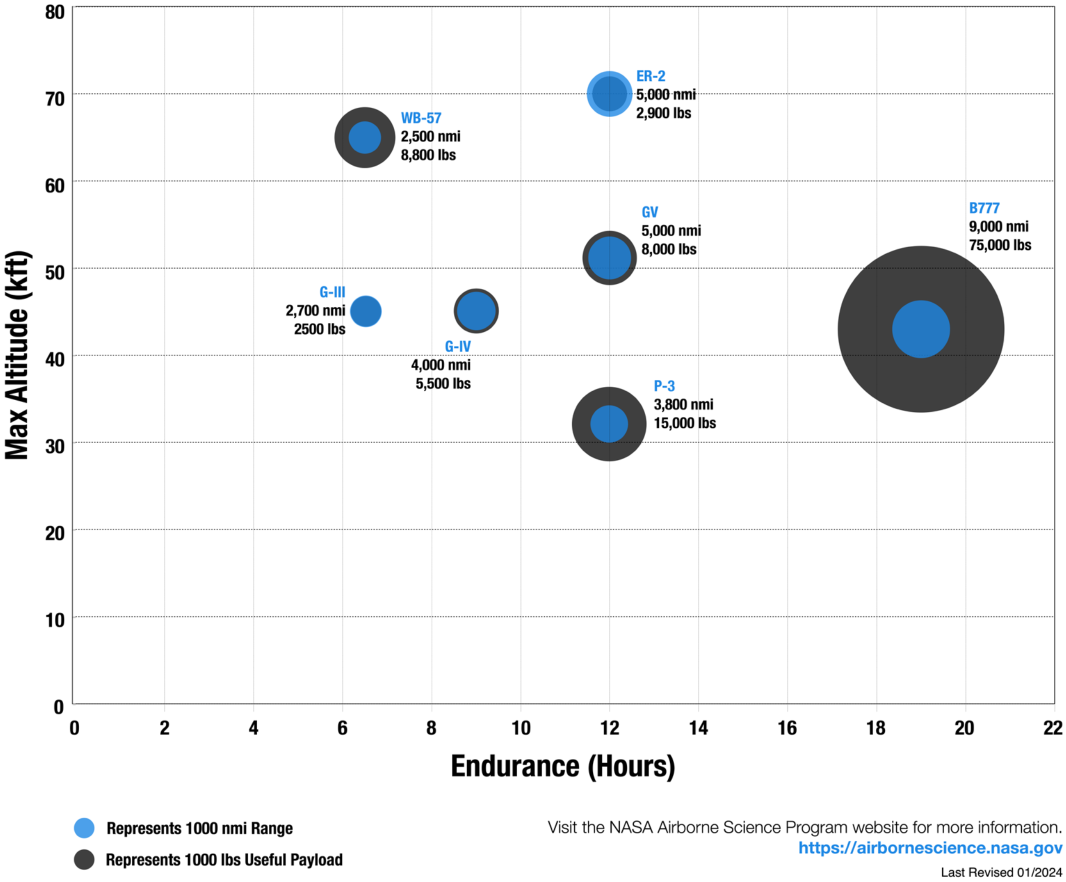
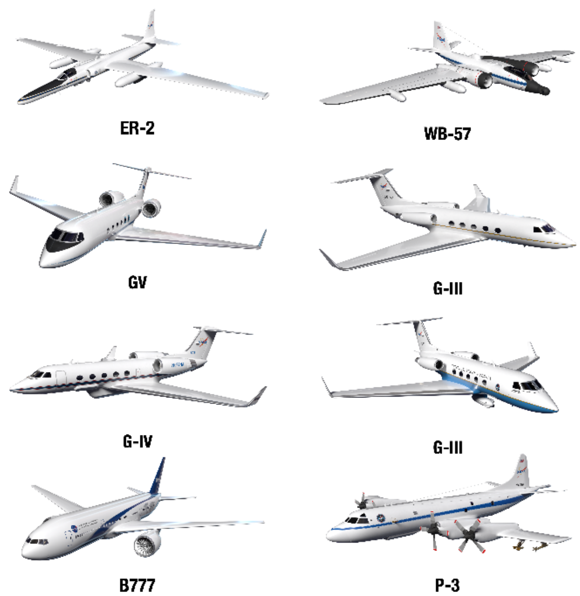


Figure 65. *NASA Earth science aircraft capabilities in altitude, range, and relative payload weight capacity.*

National Aeronautics and Space Administration

AIRBORNE SCIENCE PROGRAM



AIRCRAFT PERFORMANCE

PLATFORM	MAX ALTITUDE (FT)	USEFUL PAYLOAD (LBS)	RANGE (NMI)	ENDURANCE (HOURS)
ER-2	70,000	2,900	5,000	12
WB-57	65,000	8,800	2,500	6.5
GV	51,000	8,000	5,000	12
G-IV	45,000	5,500	4,000	9
G-III	45,000	2,500	2,700	6.5
B777	43,000	75,000	9,000	19
P-3	32,000	15,000	3,800	12

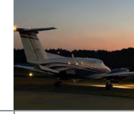
Visit the NASA Airborne Science Program website for more information.
https://airbornescience.nasa.gov

Last Revised 01/2024

Figure 66. *ASP-supported aircraft fleet.*

ASP-Supported Aircraft

The eight aircraft systems ASP directly supports with subsidized flight hours are two ER-2 high altitude aircraft, P-3 Orion, C-20A (G-III), LaRC G-III, JSC GV, and a WB-57 at JSC. Beginning in 2025, ASP will support the B777 in place of the DC-8. The JSC G-III is no longer ASP-supported nor available for ESD use.



DC-8

Operating Center:
NASA 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.

Figure 67. *DC-8 on low approach to the Sacramento International Airport during AEROMMA 2023.*
Photo credit: *Ed Boogaard*

FY23 Science Flight Hours: 185.9

Table 12. *DC-8 FY23 missions.*

Mission/Project	Location	Science Program Area
CPEX-CV	Cabo Verde	Weather and Atmospheric Dynamics
OCELOT	California	Airborne Science
AEROMMA	California, Ohio	Tropospheric Composition
SARP	California	Airborne Science

FY23 Modifications and Impacts on Performance/Science:
None

Significant Maintenance Periods:
- Completed 1A, 2A, 3A, and C1 maintenance checks and other minor modifications and repairs during FY23.
- Retirement FY24 Q3 disposition.

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

ER-2

Operating Center:
NASA 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. These high-altitude aircraft are used as platforms for investigations at the edge of space. Although two ER-2 aircraft operate out of AFRC, data correspond to the N806NA aircraft only.

Figure 68. *NASA ER-2 visited by students during the IMPACTS mission.* ***Photo credit:*** *NASA*

FY23 Science Flight Hours: 240.7

Table 13. *ER-2 FY23 missions.*

Mission/Project	Location	Science Program Area
IMPACTS	Georgia	Earth Venture Suborbital-3
WDTS	California	Research and Analysis, Earth Surface and Interior, Biological Diversity
PICARD	California	EOS
GEMx / EMRI	California, Nevada, and Arizona	Earth Surface and Interior
ALOFT	Florida	Weather and Atmospheric Dynamics

FY23 ER-2 Modifications and Impacts on Performance and Science:

- Engine repair October to November 2022.
- 200-hour inspection in October 22 and May 2023.
- Wing blade inspection in August 2023.
- Iridium upgrade in October 2022.

Significant Upcoming Maintenance Periods:

- On #806:
  - o Moved aircraft to Edwards AFB in early 2024.
  - o After FY24: 600-hour maintenance and up grade GPS LPV landing, replace wing blade, and replace fuselage Kapton wiring.

Website:

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

P-3 Orion

Operating Center:
NASA 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.

Figure 69. *P-3 returning to NASA WFF following the conclusion of IMPACTS flights.* ***Photo credit:*** *NASA*

FY23 Science Flight Hours: 132.9

Table 14. *P-3 Orion FY23 missions.*

Mission/Project	Location	Science Program Area
IMPACTS	Virginia	Earth Venture Suborbital-3
P-3 Maintenance and Training	Virginia	Airborne Science

FY23 P-3 Modifications and Impacts on Performance and Science:

- The P-3 entered Phased Deport Maintenance (PDM) in FY23 after the completion of the IMPACTS 2023 mission. While in depot maintenance, the following modifications were made to the aircraft:
  - o Upgraded the Experimenter Power System to covert the control panel to digital power monitoring/displays and improve switches for controlling experimenter power.
  - o Painted the flight station, cabin, galley, and lavatory.
  - o Replaced cabin floor coverings.
  - o U.S. Navy flare pistol port converted to 3.5” diameter zenith port to support upward looking KT-19 IR sensors.
  - o Replaced P-3B aft radome with P-3C aft radome to provide tail boom mounting location for instruments as well as the addition of two 3.5” diameter aft facing ports, which are standard on P-3C aft radomes.
  - o Reactivated bomb bay doors for opening and closing in flight. This provides the ability to drop large research equipment from the aircraft. Bomb bay mounting hardware, release mechanisms and separation analysis will be custom to each item to be release from the bomb bay. Airspeed and maneuver limitations apply when open and closing the bomb bay doors in flight.

Significant Upcoming Maintenance Periods:

- Once the aircraft returns from PDM, it will be inducted into a Conditions Based Maintenance (CBM) program moving forward.
- Currently, the only major maintenance coming due in the next 5 years is a landing gear overhaul, currently scheduled for Fall 2026. However, this schedule may change once the aircraft is inducted into the CBM program.

Website:

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

Gulfstream GV

Operating Center:
NASA JSC

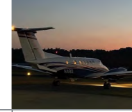
Aircraft Description:
The Gulfstream V (GV) is a long-range, large business jet aircraft built by Gulfstream Aerospace, derived from the Gulfstream IV. It flies at speeds up to Mach 0.885, an elevation of up to 51,000 feet, and has a range of 5,000 nautical miles. JSC procured the GV in 2016 as part 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.

Figure 70. *The GV at Monterey Regional Airport, California, during the SWOT cal/val mission.* ***Photo credit:*** *NASA*

FY23 Science Flight Hours: 229.4

Table 15. *GV FY23 missions.*

Mission/Project	Location	Science Program Area
QUAKES	Western U.S.	Earth Surface and Interior
BioSCape Test Flights	Houston	Biological Diversity
SWOT Cal/Val Experiment	West Coast USA	ESD SWOT
STAQS	Los Angeles, New York City, Chicago, Toronto	Earth Venture Suborbital-3



FY23 GV Modifications and Impacts on Performance and Science:

- Iridium Certus
  - o Joined the ASP fleetwide effort to upgrade the Iridium data connection. Increased speeds from 9.8 kbps to ~88 kbps. Provides more stable air-to-ground chat and data transfers.
- ADS-B In Antenna/Receiver (pending FAA buyoff)
  - o Permanently installed ADS-B in antenna and provided a receiver (Stratus III). This provides payloads with increased situational awareness, which is particularly helpful for radiating payloads.
- Payload 28 VDC
  - o Made 1400 W 28 VDC available for payload use. Previously, the aircraft had (and still has) 650 W to split between the control rack equipment and payload use. Now, the 650 W is strictly dedicated to the rack/data system.
- Aircraft Environmental Details
  - o Developed system to gather internal environmental details (ambient air and surface temp, air flow, humidity, dew point). Can be used to log payload/window/cabin information. Great for Aerosol Optical Depth (AOD) use at least.

Significant Upcoming Maintenance Periods:

- Mini-portal cabling, to be completed FY24:
  - o Data connections now available. More robust cabling installed and added 115 VAC 60 Hz single phase.
- Dual defog capability, to be completed FY24:
  - o Designed/built dual defog capability. Previously, the aircraft could only provide heated/forced air at one window/instrument location. Having two available enables supporting more payloads that require it during joint flights.
- Mini viewports, to be completed FY24:
  - o Gulfstream GV aircraft (S/N 672) modified by Yulista/NASA Johnson Space Center adds two miniature nadir optical viewports in the lower aft fuselage for research missions (Figure 71). The portals are installed at FS 650, along LBL 33.15, and at RBL 33.15.
- The Gulfstream aircraft have a rolling inspection/maintenance scheduled based upon flight hours, cycles, and calendar.

Website:

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

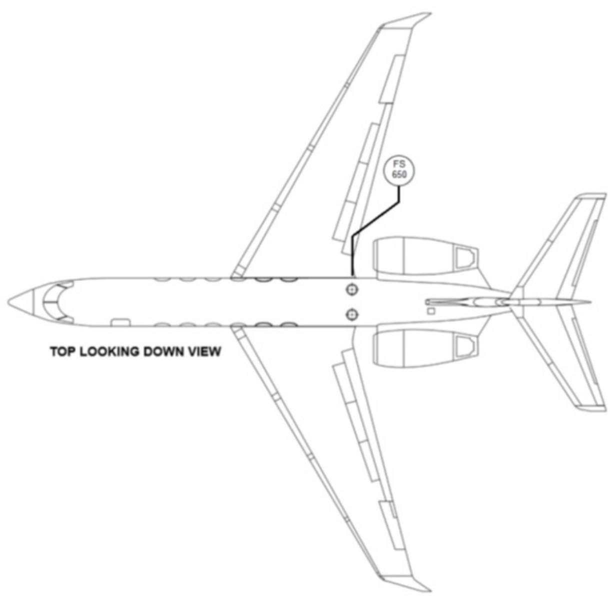


Figure 71. *The GV general modification zone, located in the aft lower belly.*

Gulfstream III (G-III)

The G-III is a business jet supporting routine flight at 40,000 feet. NASA ASP supported three G-III aircraft for Earth Science in FY23: one at AFRC, one at JSC, and one at LaRC. The AFRC and JSC platforms were structurally modified and instrumented to carry the payload pod for the three versions of JPL's UAVSAR instrument (L-band, P-band, Ka-band). Support for the JSC aircraft ended in 2023, but support for the ARC G-III continues. The LaRC G-III does not carry the pod but has been modified with nadir portals to support remote sensing payloads.

C-20A (AFRC G-III)

Operating Center:
NASA AFRC

FY23 Science Flight Hours: 152.8

Table 16. *C-20A (G-III) FY23 missions.*

Mission	Location	Science Program Area
Remote quantification of evolving stability conditions in deep-seated landslides from InSAR displacement rate measurements, structural mapping, and geomechanical modeling	Colorado	Earth Surface and Interior
PNW Deep-Seated Landslides	California, Oregon, Washington	Interior and Terrestrial Hydrology
Landslide kinematics in response to ongoing climate shifts	Portland, Maine	Earth Surface and Interior
Where the Fault Meets the Road: Structure, Deformation and Rheology of the Urban Hayward Fault	California	Earth Surface and Interior
UAVSAR L-band Engineering Flights	California	Interior and Terrestrial Hydrology
Mauna Loa Eruption Response	Hawaii	Geodetic Imaging
UAVSAR California Science	California	Geodetic Imaging
FASMEE Prescribed Burn	Utah, Arizona, Colorado, California	Atmospheric Composition
Deformation and Rheology of the Urban Hayward Fault	California	Geodetic Imaging
PNW Deep-Seated Landslides	California, Oregon, Washington	Interior and Terrestrial Hydrology
FASMEE Prescribed Burn	Utah, Arizona	Atmospheric Composition

Figure 72. *The C-20A on deployment in Oregon.* ***Photo credit:*** *UAVSAR team.*

FY23 C-20A Modifications and Impacts on Performance and Science:

- Completed 72-month inspection and maintenance.
- Conducted mini-overhaul on engines slated to replace C-20 engines in FY24.

Significant Upcoming Maintenance Periods:

- FY24: Engine swap in November 2023.
- FY24: OPS1/OPS3 Maintenance, mid-November 2023 to mid-February 2024.
- FY25: OPS1/OPS2 Maintenance, December 2024 to February 2025.
- FY26: OPS1/OPS3 Maintenance, December 2025 to February 2026.
- FY27: OPS1/OPS2 Maintenance, December 2026 to February 2027.
- FY28: OPS1/OPS3 Maintenance, December 2027 to February 2028.

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

JSC G-III

Operating Center:
NASA JSC

Figure 73. *HORIS Airborne Imagery Team with G-IV, JSC WB-57, JSC G-III, and RTI aircraft.* ***Photo credit:*** *Mary Emmerson*

FY23 Science Flight Hours: 18.4

Table 17. *JSC G-III FY23 missions.*

Mission/Project	Location	Science Program Area
SCIFLI OSIRIS-REx Capsule Entry	Dugway Proving Grounds, Utah	Planetary Science Division

FY23 Modifications and Impacts on Performance and Science:
None.

The aircraft is no longer ASP-supported nor available for NASA Earth Science Division use.

LaRC G-III

Operating Center:
NASA LaRC

Aircraft Description:
The Gulfstream III (a former U.S. 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 can be equipped with pressure domes over the portals so instruments can be flown open to the atmosphere. The G-III aircraft has an advertised range of 3750 nautical miles.

Figure 74. *The LaRC G-III aircraft in the hanger at NASA ARC during S-MODE.* ***Photo credit:*** *NASA*

FY23 Science Flight Hours: 344.9

Table 18. *LaRC G-III FY23 missions.*

Mission/Project	Location	Science Program Area
AWP Transition Flights	LaRC	ESTO-IIP
LVIS Facility Integration and Engineering	LaRC	GSFC Laser Remote Sensing Branch
S-MODE	ARC	Earth Venture Suborbital-3
STAQS	LaRC, AFRC, Ohio	Tropospheric Composition

FY23 LaRC G-III Modifications and Impacts on Performance and Science:
None; aircraft is in flight status.

Significant Upcoming Maintenance Periods:

- Semi-annual maintenance: December 4, 2023 to January 5, 2024.
- Maintenance/engine swap: April 2, 2024 to April 25, 2024.
- Maintenance: June 17, 2024 to July 26, 2024.
- Maintenance: October 4, 2024 to January 3, 2025.

Website: https://airbornescience.nasa.gov/aircraft/G-III_-_LaRC

WB-57 High Altitude Aircraft

Operating Center:
NASA JSC

Aircraft Description:
The WB-57 is a mid-wing, long-range aircraft capable of extended operation from sea level to altitudes more than 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. The flight hours and data in Table 19 reflect only the N926NA aircraft.

Figure 75. *The WB-57 aircraft taking flight in Alaska during SABRE.* ***Photo credit:*** *Max Dollner/University of Vienna*

FY23 Science Flight Hours: 112.2

Table 19. *WB-57 FY23 missions.*

Mission/Project	Location	Science Program Area
NOAA SABRE	Fairbanks, Alaska	NOAA

FY23 WB-57 Modifications and Impacts on Performance/Science:

- The WB-57 program executed two modifications that improve air/ground communications and data throughput.
  - o Using the satellite communications data link, the air crew now has a Voice over IP (VoIP) line between the aircraft and the ground station. This allows for clearer real-time notifications and requests, which are critical in WB-57 imaging missions, as well as in situ atmospheric sampling.
  - o The legacy satellite communication systems on board the aircraft were more than a decade old and unable to take advantage in the latest breakthroughs available for aviation satcom services. This year, the program upgraded these legacy systems with the SpaceX Starlink system, which has improved data throughput by an order of magnitude. This capability was a much-needed upgrade and allows for better real-time observation of instrument data by science teams on the ground and improves situational awareness during observation missions.

Significant Upcoming Maintenance Periods:

- N927NA: Major phase inspection (4-6 months) in 2024 and 2027 and minor phase inspections (2-4 months) in 2025, 2026, and 2028.
- N926NA: Major phase inspection (4-6 months) in 2026 and minor phase inspections (2-4 months) in 2024, 2025, 2027, and 2028.

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

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 20. *Other NASA aircraft available for Earth science missions.*

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

B-200

Operating Center:

NASA LaRC, NASA AFRC

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. The UC-12B (N528NA) was excessed via GSA in FY23. AFRC operates a Super King Air B-200 modified for downward-looking payloads.

The B-200 aircraft have varying modifications to support science, as listed previously in Table 11.

FY23 Science Flight Hours: **LaRC B-200: 38.6**
AFRC B-200: 234.5

Table 21. *B-200 FY23 missions.*

Aircraft	Mission	Location	Science Program Area
B-200 (LaRC)	FireSense	AFRC	Tropospheric Composition
	SARP-East (SLAP)	LaRC	Research and Analysis
B-200 (AFRC)	S-MODE	ARC	Earth Venture Suborbital-3
	SoOpSAR	California, Colorado	ESTO IIP

FY23 AFRC B-200 Modifications and Impacts on Performance and Science:

None.

Significant Upcoming Maintenance Periods:

Maintenance schedule for AFRC B-200 (N801NA):

- Phase 1 and 2:
  - o March 2024
  - o September 2025
  - o March 2027
  - o September 2028
- 8,000 Cycle/6-Year Main Landing: June to July 2029
- Phase 3 and 4:
  - o December 2024
  - o June 2026
  - o December 2027
  - ` o June 2028
- Hose Replacement (flammable fluids and brakes): April 2024.
- Wing Attachment Bolt and Hardware Inspection: April to May 2024.
- Garmin 530 Electrical Bond Check: January 2026.
- Nose Landing Gear Replacement: October 2026.
- Propeller Overhaul: September 2027.
- 15,000 Cycle/15-Year Inconel Wing Attach Bolt Replacement: February 2029.

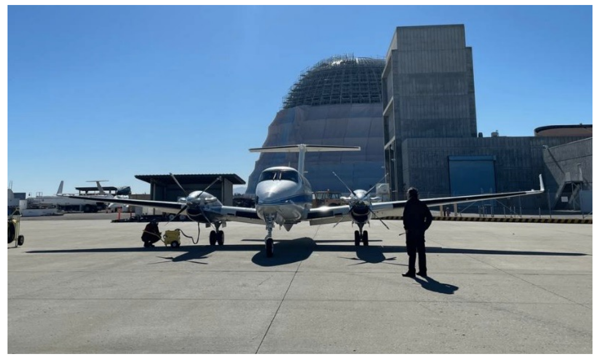


Figure 76. *AFRC B-200 at ARC for S-MODE.* ***Photo credit:*** *NASA*

Websites:

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

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

Gulfstream IV (G-IV)

Operating Center:

NASA LaRC

Aircraft Description:

The 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.

FY23 Science Flight Hours: 48.1

Table 22. *G-IV FY23 missions.*

Mission/Project	Location	Science Program Area
VortEx	Norway	Heliophysics
HORIS	Utah	Planetary Science Division

FY23 Modifications and Impacts on Performance and Science:

None.

Significant Upcoming Maintenance Periods:

- Maintenance: October 24, 2023 to December 7, 2023.
- G-IV will become ASP-supported starting in FY24. It will be transferred to NASA AFRC in April 2024 and modified to carry next generation SAR.

Websites:

https://airbornescience.nasa.gov/aircraft/Gulfstream_IV - LaRC

Figure 77. *NASA LaRC Airborne Team during the HORIS mission.* ***Photo credit:*** *Mary Emmerson*

Cirrus Design SR22

Operating Center:

NASA 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.

Figure 78. *Cirrus Design SR22 aircraft.* ***Photo credit:*** *NASA*

FY23 Science Flight Hours: 13.9

Table 23. *SR22 FY23 missions.*

Mission/Project	Location	Science Program Area
SARP-East (EPA-TEROS)	LaRC	Research and Analysis
STAQS (chase)	LaRC	Tropospheric Composition

FY23 SR22 Modifications and Impacts on Performance and Science:

- Installed EPA's Transportable Environmental Resource Observation Suite (TEROS) in commercial off-the-shelf (COTS) belly pod with nadir portals, enabling the Cirrus Design SR22 aircraft to be used for low cost/low altitude/low speed sampling.

Significant Upcoming Maintenance Periods:

- Maintenance is a function of number of flight hours flown.

Website: https://airbornescience.nasa.gov/aircraft/Cirrus_Design_SR22 - LaRC

B777: Introducing the New Flying Laboratory

This past fiscal year has seen a whirlwind of activity surrounding the transformation of NASA's new Boeing 777 (B777) from a passenger aircraft into an airborne research laboratory. It began without a single engineering design requirement committed to paper and has ended with a portion of the detailed design completed, technical drawings released, components purchased, and the start of wire harness fabrication. ASP's cross-cutting engineering team came together in October 2022 to begin requirements development and has studiously worked the "in-house" design process, completing a Systems Requirements Review in early January 2023, all Preliminary Design Reviews by July, and the first Critical Design Review for the Research Rower System in September. To provide context on the extent of this effort, the Research Power System alone comprises a total of 16 electrical drawings over 72 sheets, with the critical designs of other complex systems, such as the Mission Intercom System, following closely behind.

This good work is of no benefit to the science community unless it can be translated into actual aircraft modifications. Selected procurements, especially of long lead items, has been ongoing to ensure the modification team has the necessary components in hand when engineering designs are complete. In addition, NASA LaRC executed an interagency agreement to access a vendor with an extensive history of modifying Navy aircraft to support the B777. The expanded team is holding weekly meetings, working through the completed designs, and implementing plans to modify the B777. The program also completed an exterior scan of the B777, primarily to aid the aerodynamic analysis to locate science instruments, probes, and sensors. Figure 79 shows the computer model stemming from this scan.

The engineering team plans to finish all "in-house" designs by the end of 2023, with internal modifications completed by the middle of 2024. At that point, the jet will be ready for major maintenance, landing gear overhaul, a new livery, and portal modifications, with the intent to be ready to support science missions in FY25.

Figure 79. *Computer model rendering of the B777.*

Airborne Science with Commercial Aviation Services (CAS)

NASA-funded projects are required to use NASA-operated aircraft when possible and feasible, to reduce project risk associated with the platform and to make most efficient use of existing facilities. Use of CAS is governed by NPR 7900.3D Chapter 10. These projects largely involve smaller payloads with the need to fly “low and slow” profiles or for initial payload check-out at lower altitudes.

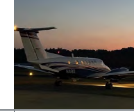
Prior to contracting, CAS providers must be audited by a Safety and Mission Assurance team in coordination with a NASA Flight Center. If the Chief of Flight Operations reviews the audit teams findings and approves use of the vendor, the contract can be let, and then the project would conduct an Airworthiness and Flight Safety Review and Flight Readiness Review (FRR) or Operational Readiness Review (ORR).

IIn FY2023, the NASA HQ Safety and Mission Assurance team, in partnership with a multi-directorate CAS working group, drafted a new standard (the NASA CAS Requirements Interim Guide) to guide industry on NASA requirements concerning airworthiness, flight safety, safety management, and maintenance and operations procedures. The standard largely follows guidance already contained in FAA CFR Part 135. Table 3, included previously, and repeated below, indicates that most non-NASA aircraft hours flown in FY23 were CAS.

Table 3. *FY23 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	1	1	0	1	96.5
Alphajet	1	0	0	0	0
B-200 – Dynamic Aviation	18	13	0	11	449.8
Cessna 206	1	1	0	1	6
ISRO King Air**	1	0	0	0	0
Kenn Borek*	1	0	0	0	0
Kenn Borek Air Twin Otter	1	1	0	1	4.8
NRL P-3	1	0	0	0	0
Platform Aerospace Vanilla VA001 UAS***	1	1	0	1	15.5
Robinson R-44***	1	0	0	0	0
Twin Otter	1	1	0	1	165.3
Twin Otter CIRPAS	1	1	0	1	37.7
TOTAL	**29**	**19**	**1**	**17**	**775.6**

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



Uncrewed Aircraft Systems (UAS) for NASA Earth Science

Uncrewed aircraft systems are of interest to the science community for collecting observations that are beyond the capabilities of crewed aircraft (e.g., high altitude long endurance, or low and slow), and where high spatial or temporal resolution measurements might be more cost effective for a small-scale site of interest. Currently the utility of UAS to NASA science is hampered by the inability to reliably fly beyond visual line of site of the ground control station and pilots. While NASA has demonstrated this capability with a variety of different classes of aircraft, until more formal rules, procedures, and likely new technologies, are introduced, use of UAS by the science community continues to be limited to only the most compelling use cases, such as remote arctic sea ice survey (page 26) and to collect observations over disaster events, such as wildfires or hurricanes.

ASP has identified high altitude long endurance UAS or high-altitude pseudo-satellites (HAPS) as a compelling platform class with significant interest from the science community. The STV Incubation team called out the need for HAPS to provide observations related to landslides and volcanoes. Similarly, the SBG science team has discussed using HAPS in between orbits for tracking vegetation change.

In FY23, working together with the NASA Small Business Innovative Research Program (SBIR), the Airborne Science Office at NASA Ames is supervising a new Phase II contract with Electra LLC for its Stratospheric Atmospheric Carbon Observing System (SACOS). This solar electric fixed wing UAS will undergo modifications to the autopilot, engines, and planning software to optimize the aircraft for Earth observation missions. ASP also continues to support the Swift Engineering Ultra Long Endurance (SULE) project, which is currently in a Phase IIE study that will conclude with payload flight testing in FY24.

Another ASP-lead HAPS project started in FY23, with funding from the Space Technology Mission Directorate (STMD) Flight Opportunities Program, and the USFS National Interagency Fire Center is the Stratospheric Tactical Radio and Tactical Overwatch (STRATO) project (PI Don Sullivan). This flight project will demonstrate the use of a station-seeking balloon for providing last mile communications and IR remote sensing capabilities to remote fire camps. This is aligned with the NASA ESD FireSense project as well as the NASA Aeronautics Research Mission Directorate's Advanced Capabilities for Emergency Response Operations (ACERO) project. The Aerostar Thunderhead team has integrated a Motorola transmitter and gimbal system, a COTS IR camera, and a Starlink receiver to serve as data backhaul for the flight demonstration. The balloon will be launched early Summer 2024 to enable evaluation of the capability, assess logistics challenges, and assess operational feasibility.

SACOS

SULE

Aerostar Thunderhead balloon

Figure 80. *High Altitude Platforms Systems (HAPS) currently under development include the Stratospheric Airborne Climate Observatory System (SACOS) (**Photo credit:** Electra.com), and Swift Engineering Ultra Long Endurance (SULE) aircraft (**Photo credit:** SWIFT Engineering), both funded under the NASA SBIR Program. The Aerostar Thunderhead balloon is an operational system available through the NASA Flight Opportunities Program. (**Photo credit:** Aerostar)*

5. Aircraft Cross-Cutting Support and IT Infrastructure

Each Flight Operations Center that operates ASP-funded aircraft has its own engineers associated with aircraft maintenance and operations. The Program also funds a cross-agency team of engineers that provide Program-wide support to NASA projects and maintain and improve upon onboard payload data systems, networks, science supporting instrumentation, and other payload accommodations. The National Suborbital Research Center (NSRC) is managed by NASA ARC through a Cooperative Agreement. This team works together with engineers at the various NASA flight centers to provide investigators with the support needed to successfully integrate their payloads onto NASA or other science aircraft. The group's primary objectives are to:

- 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.

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 was completed in Q1 FY23.

Standing up the NASA B777 was an important engineering effort in FY23. The Cross-Program Engineering team supported NASA LARC by performing significant design efforts leading toward aircraft modification PER/PPR/PDR, including development of system block diagrams, wiring diagrams, and notional floor plan layouts of payloads and supporting aircraft workstations. The team provided invaluable design guidance based on its decades of heritage from integrating and operating payloads on the DC-8.

Onboard Data and Communications

All aircraft in the ASP fleet have been modified to enable acquisition, processing, and telemetry of data from their primary payloads to maximize the science return of each flight. Science teams access this network through the Mission Tools Suite (MTS). The sensor network architecture includes standardized electrical interfaces for payload instruments using a common Experimenter Interface Panel (EIP); the NASA Airborne Science Data and Telemetry (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.

In FY23, the Program began the process of migrating to an updated and modular onboard network approach, the NASA Airborne Science Data and Telemetry System (NASDAT) Next Generation unit. This included upgrading all core aircraft to higher bandwidth Iridium Certus service. Several types of airborne satellite communications systems are currently operational on the core science platforms (Table 24). 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.

NASA cross-program engineering also operates and distributes science support data to primary payloads. These instruments collect important reference information used as metadata for instrument data processing. These instruments include meteorological measurements, visible still and video imagery, and other airborne instrumentation.

Table 24. *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

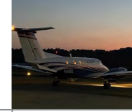


Table 25. *ASP science support instruments.*

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	B-200, DC-8, ER-2, P-3, WB-57	ASF/ARC
eMAS	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, $\Delta\lambda$ 10 nm	ER-2	ASF/ARC
AVIRIS-ng	Airborne Visible/Infrared Imaging Spectrometer-Next Generation	Imaging spectrometer 380-2510 nm range, $\Delta\lambda$ 5 nm	Twin Otter (CAS), B-200	JPL
PRISM	Portable Remote Imaging SpectroMeter	350-1050 nm range, $\Delta\lambda$ 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, $\Delta\lambda$ 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
LVIS	Land, Vegetation, and Ice Sensor	Geodetic laser altimeter system	GV (NASA and NSF), LaRC G-III, B-200 (NASA and CAS), P-3, C-130, DC-8	GSFC
NAST-I	National Airborne Sounder Tester-Interferometer	(1064 nm) Infrared imaging interferometer 3.5 -16 mm range	ER-2, DC-8	LaRC

Mission Tool Suite (MTS)

The Mission Tool Suite (MTS) at *https://mts2.nasa.gov* is a web-based application integral to the ASP Sensor Network, offering key technologies, including real-time decision-making aids through mission information source visualization. MTS is essential for observing real-time telemetry from airborne platforms, integrated with various mission products, (e.g., meteorological data, airspace information, satellite feeds). Its primary aim is to enhance situational awareness for participants in NASA airborne science missions, striving to augment the efficiency and scientific value of flight missions by providing a collaborative observational window.

In November 2023, the MTS team released software version 2.7.9. This update, based on user feedback, focused on enhancing existing capabilities, mainly performance and stability improvements. Looking forward to 2024, the MTS team is actively developing what will be the third major release. This upcoming version is poised to lay the groundwork for the next generation of MTS, with plans to open-source parts of the codebase. In 2024, focus will be on streamlining user interface features, making the software more intuitive for new users and enhancing product visualization and mission science planning capabilities. This approach aims to further simplify the user experience and expand the tool's functionality, ensuring MTS continues to be a pivotal resource in NASA's airborne science missions.

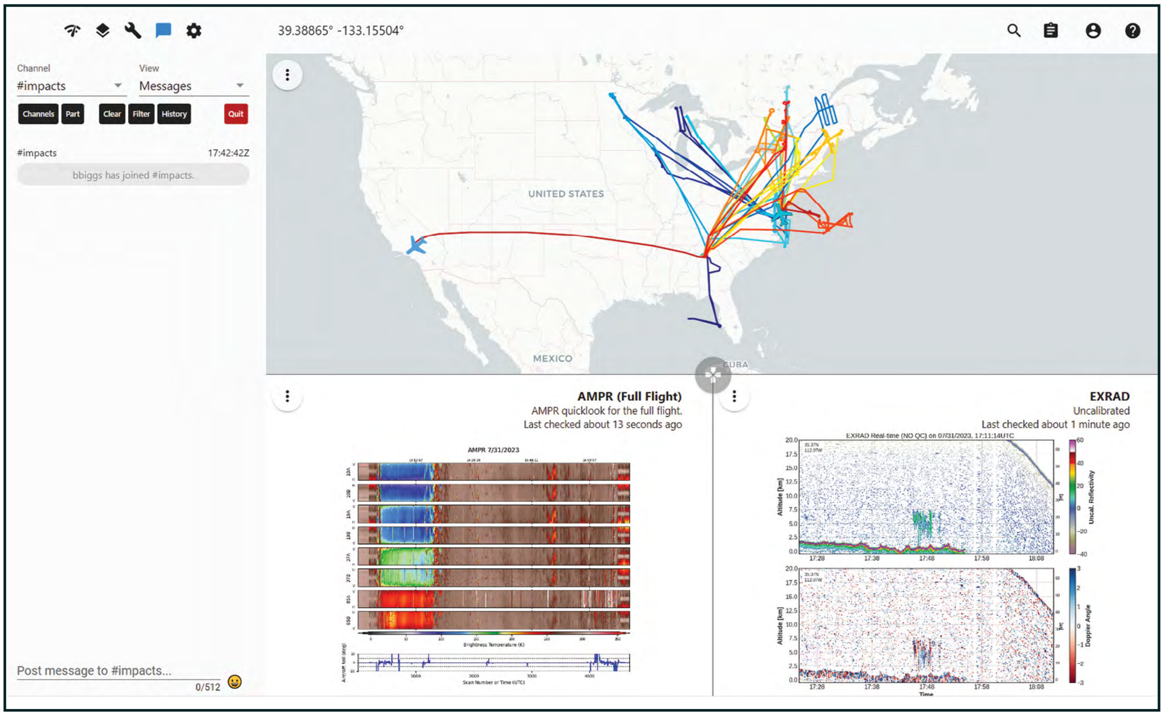


Figure 81. *Example of Mission Tools Suite (MTS) interface, showing the chat feature, real-time platform tracking and previous flight tracks, quicklooks of Advanced Microwave Precipitation Radiometer (AMPR) on the P-3 and ER-2 Doppler Radar (EXRAD) on the ER-2.*

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 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 (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.

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

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

In discussion with Program managers, a 5-year plan is updated twice a year with a focus on planning airborne activities for satellite and ISS Earth science missions, Earth Venture Program, and 2017 NRC Decadal Survey support. This includes recently launched missions, as well as soon-to-be launched PACE and NISAR. ASP also continues to support existing space missions (e.g., A-Train satellites), as well as other "foundational" missions, such as GPM and ICESat-2, and now SWOT and TEMPO. 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 also require airborne support. Airborne activities in 2023 supported multiple spaceborne missions, including CloudSat, GEDI-ISS, GNSS, GOES, GPM, ICESat-2, JPSS, OMI, SWOT, TEMPO, and TROPOMI.

Designated Observable missions under development based on the Decadal Survey, along with Technology Incubation studies, are beginning to drive the future needs for airborne support. The Atmosphere Observing System (AOS) mission, for example, has a mandatory suborbital component to complement the space observations. The Surface Biology and Geology (SBG) mission team has an ongoing need for airborne data for algorithm development and to provide data for the Applied Science Early Adopter Program. The Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV) Technology Incubation study teams have met in workshops to identify planning and airborne activities that include technology test flights, technology development programs, and airborne concepts, particularly the use of uncrewed aircraft. ASP advanced planning personnel are members of these teams and Figure 82 shows expected airborne support for these missions. When the first Explorer missions are selected in the next year, these are also likely to need airborne support for instrument or algorithm development. Finally, a new set of Earth Venture Suborbital missions is expected to be awarded in 2024, and these, by definition, will plan for the use of NASA ESD aircraft.

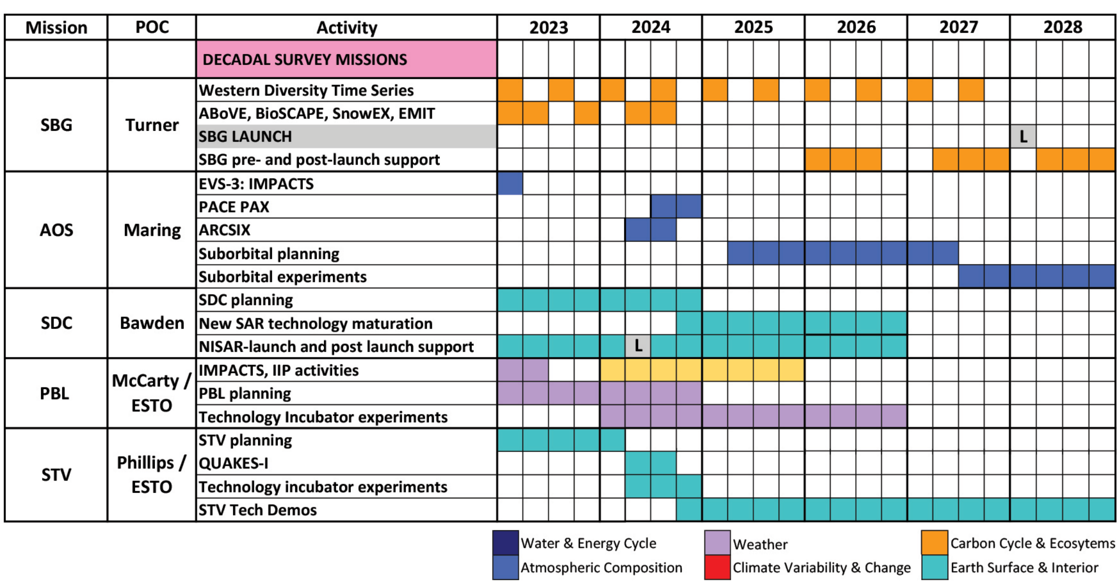
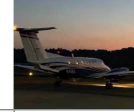


Figure 82. *The Designated Observable and Technology Incubator missions all need airborne support.*



In 2023, ASP personnel also participated in science team meetings and program reviews (Table 26) to collect requirements.

Table 26. *Activities supporting ASP requirements information gathering in FY23.*

Activity
Annual Solid Earth Team Meeting
Annual ECOSTRESS Meeting
Annual AGU Fall Meeting
Quarterly NASA SMD Town Hall
Temporary B777 PER, PPR, and FER meetings
Weekly Earth Communications Meetings
Annual ESTO Earth Science Technology Forum (ESTF)
Annual CMS Applications Workshop and Meeting
Temporary NASA-ISRO NISAR Town Hall
Annual Federal UxS Workshop
Monthly NASA Earth Science Division community workshops
Annual SBG Community Workshop
Monthly TOPS Community Forums
Monthly BioSCape Meetings
Temporary STELLA Webinar
Monthly GLOBE Meetings
Quarterly AOS Community Forum
Bimonthly AOS Suborbital team meeting
Quarterly in PACE meeting
Semi-annual 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. Appendix 1 depicts plans by science area and aircraft platform.

GV Needs Assessment Report

The ASP Advanced Planning team drafted a business class aircraft needs assessment and subsequent report to document the sustained need for another science-modified GV (or equivalent) aircraft. The report was compiled based on interviews from PIs, Program Managers and Program Scientists, SOFRS flight requests, and previously published material.

In 2023, ASP awarded 5 contracts to companies in response to a Requests for Proposals (RFP) to scope out potential commercial business jet operations to support NASA Earth Science. ASP is being proactive in finding alternatives to the NASA GV given high demand for this class of platform.

7. Education, Training, Outreach, and Partnerships

Student Airborne Research Program (SARP) and SARP-East 2023

The Student Airborne Research Program (SARP) is an annual program sponsored by the Science Mission Directorate at NASA Headquarters. SARP provides undergraduate students with hands-on research experience in all aspects of a major scientific campaign. Participants fly onboard NASA research aircraft and assist in the operation of instruments to sample and measure atmospheric gases and aerosols, as well as to image land and water surfaces in multiple spectral bands.

Each student works on a multi-disciplinary team to study surface, atmospheric, and oceanographic processes and develop an individual research project with their mentors. At the end of the program, participants create and give a final presentation to their peers, mentors, and NASA personnel. This year marked the 15th year of the program and – excitingly – the inaugural year of the new SARP-East (SARP-E) program on the East Coast. These programs are summarized in Table 27.

Table 27. *SARP and SARP-East program summary.*

	SARP 2023	SARP-E 2023
Location	NASA AFRC, UC Irvine	Virginia, near LaRC
Timeframe	June 18 to August 11	June 5 to July 28
Students	24	22
Mentors	5	5
Faculty	4	5
Flight hours	62	16.7
Number of flights	13	13
Platforms	DC-8, LaRC G-III, JSC GV	LaRC Cirrus SR22, DA B-200

Figure 83. *NASA SARP-E intern Karla Lemus (left) assists NASA Scientist Emeritus Anne Thompson as she leads NASA SARP-E interns in releasing an ozone sonde from the parking lot of the VCU Rice Rivers Center on June 16, 2023.* ***Photo credit:*** *NASA/ Angelique Herring*

The 15th annual SARP completed thirteen total flights using the AFRC DC-8 (5 flights), LaRC G-III (5 flights), and JSC GV (3 flights), representing a total of 65 flight opportunities and the first time that SARP students flew concurrently on three NASA aircraft from three different NASA centers! Students had a unique opportunity to participate in ongoing airborne campaigns as part of the SARP experience – the joint NASA/NOAA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) mission on the DC-8, and the NASA Synergistic TEMPO Air Quality Science (STAQS) mission on the G-III and GV.

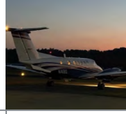
Flights were centered around two major regions and themes: the California Central Valley flights focused on dairies, agriculture, and oil field emissions, while the Los Angeles Basin/ Southern California flights focused on megacity

Figure 84. *SARP students with the DC-8 at NASA AFRC.* ***Photo credit****: Jane Berg*

emissions, diurnal atmospheric composition changes, and Salton Sea emissions. The students collected additional data during ground surveys and whole air sampling at field sites, including the California Central Valley, Salton Sea, Santa Barbara Channel, and Sedgwick Reserve.

The inaugural SARP-E completed thirteen total flights using the LaRC Cirrus SR22 (six flights) and the DA B-200 (seven flights). The aircraft flew over the Chesapeake Bay, beginning from the mouth of the Chesapeake and going north in a raster pattern, covering the waterways and tributaries. The SR22 and B-200 payloads were the EPA's Transportable Earth Resources Observation Suite (TEROS) and NASA GSFC's Scanning L-band Active Passive (SLAP) instrument, respectively. Additional data were provided to the students for their analysis from a flight of the LaRC G-III aircraft (with no students onboard), equipped with the NASA JPL Airborne Visible/Infrared Imaging Spectrometer – Next Generation (AVIRIS-NG) and NASA Langley High Altitude Lidar Observatory (HALO). The SARP and SARP-E programs were a complete success and will hopefully inspire the next generation of airborne scientists.

Figure 85. *The 2023 SARP-East participants in front of the DA B-200.* ***Photo credit:*** *NASA*



Appendices

Appendix A

5-year Plan

Atmospheric Composition and Chemistry

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
1) Atmospheric Composition and Chemistry				
1.1) Asia-AQ	200	Lefer	GEMS, TROPOMI	DC-8; G-III (2)
1.2) PACE LAUNCH		Lorenzoni	PACE	
1.3) SABRE	200	Jucks		WB-57
1.4) ARCSIX	300	Maring/Markus	ICESat-2	G-III (2); P-3
1.5) SARP West - 24	20			P-3
1.6) SARP East - 24	20			B-200 L
1.7) Greenhouse Gas Center - 24		Lefer	OCO-2, TEMPO	Other B-200
1.8) PACE PAX	60	Lorenzoni	PACE	ER-2
1.9) FireSense UAS Demo		Lefer		Other
1.10) WHyMSIE		McCarty	AOS	ER-2
1.11) Greenhouse Gas Center - 25		Lefer	OCO-2, TEMPO	Other B-200
1.12) SARP East - 25	20			P-3
1.13) SARP West - 25	20			777
1.14) Upper Atmosphere campaign in development		Jucks	AURA	ER-2; WB-57
1.15) AOS Suborbital prep		Maring	AOS	ER-2; P-3; 777

Carbon Cycle and Ecosystems

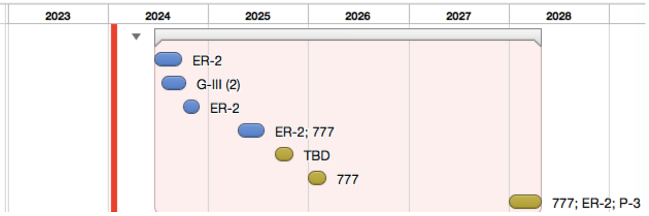
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
2) Carbon Cycle & Ecosystems Science				
2.1) PACE LAUNCH			PACE	
2.2) CMS - next solicitation		Hibbard / Jucks		
2.3) Ocean color opportunity		Lorenzoni		G-III (2)
2.4) NISAR LAUNCH			NISAR	
2.5) STV demo - forest topography		Margolis/Phillips	STV	G-III
2.6) LVIS-GEDI -24	15	Margolis	GEDI	NASA GV
2.7) AFRISAR	80	Margolis		G-III
2.8) BLUEFLUX (CMS) - 24	150	Lorenzoni / Jucks		Other B-200
2.9) Western Diversity - 24	30	Turner	SBG	ER-2
2.10) ABoVE UAVSAR and G-LiHT - 24	30	Margolis	NISAR	G-III; Single Otter
2.11) PACE PAX	60	Lorenzoni	PACE	ER-2
2.12) CMS - placeholder	100	Hibbard / Jucks	OCO-2	TBD
2.13) STV demo - 25		Margolis/Phillips	STV	G-IV
2.14) LVIS-GEDI -25	15	Margolis	GEDI	NASA GV
2.15) Western Diversity - 25	30	Turner	SBG	ER-2
2.16) Terrestrial Ecology field campaign		Margolis		B-200 D
2.17) SBG Pathfinder	30	Turner	SBG	TBD
2.18) LVIS-GEDI -26	15	Margolis	GEDI	NASA GV
2.19) Western Diversity - 26	30	Turner	SBG	ER-2
2.20) Arctic COLORS	100	Lorenzoni		TBD
2.21) GLIMR cal/val		Lorenzoni	GLIMR	TBD

Water and Energy Cycle

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
4) Water and Energy Cycle				
4.1) PACE LAUNCH			PACE	
4.2) P-band (AirMOSS) Greenland	18	Bawden		G-III
4.3) PACE-coastal water quality mission (PRISM?)		Entin/Lorenzoni	PACE	TBD
4.4) New SNOW mission		Entin		TBD
4.5) Snow Radar comparison (SoOpSAR)	12	ESTO/Siquiera		B-200 D

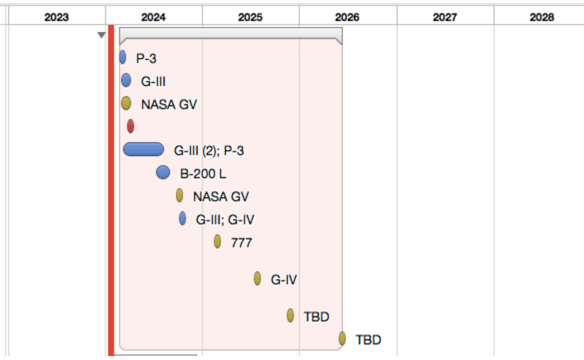
Weather and Atmospheric Dynamics

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor
6) **Weather and Atmospheric Dynamics**			
6.1) COSMIR-H	16	ESTO / McCarty	PBL incubator
6.2) AWP / NOAA	12	Lefer	
6.3) WHyMSIE		McCarty	AOS
6.4) Next Weather field campaign		McCarty	AOS
6.5) PBL technology development		ESTO	PBL incubator
6.6) Weather mission in development		McCarty	
6.7) AOS Suborbital prep		Maring	AOS



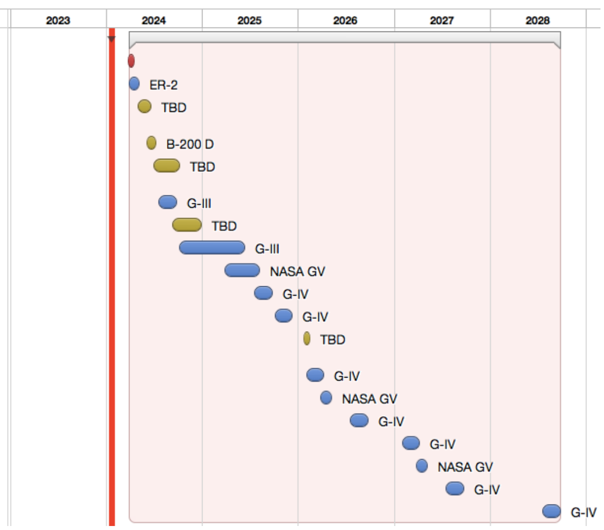
Climate Variability and Change

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor
3) **Climate Variability and Change**			
3.1) ICESAT-II Lake Ice	20	Markus	ICESat-2
3.2) P-band Ice-sounding test	37	Markus	
3.3) SWOT cal/val /repeat	120	Shiffer	SWOT
3.4) NISAR LAUNCH		Bawden	NISAR
3.5) ARCSIX	300	Maring/Markus	ICESat-2
3.6) CASALS test flight	20	ESTO	future cryo
3.7) ICESAT-2 cal/val repeat (?)		Markus	ICESat-2
3.8) NISAR cal/val		Bawden	
3.9) Possible joint Norwegian cryo mission (Antarctica SCAR/Rings)		Markus	
3.10) Combine NISAR cal/val (new SAR) w PALS		Shiffer	NISAR
3.11) Joint SASSIE / SWOT cal/val		Shiffer	SWOT
3.12) EXPLORER class ocean concept		Shiffer	



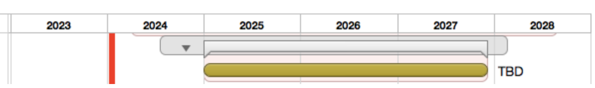
Earth Surface and Interior

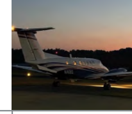
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor
5) **Earth Surface & Interior**			
5.1) NISAR launch			
5.2) USGS (GEMx/EMRII)	100	Phillips	Landsat / SBG / EMIT
5.3) UAV vulcanology / glaciology demo - mission in development	72	Phillips	SBG
5.4) QUAKES-24	36	Phillips	STV
5.5) STV technology development		Phillips/ Bawden/ ESTO	STV incubator
5.6) UAVSAR - Landslides & Faults - 24	20	Phillips	NISAR
5.7) STV Tech Demo (Quakes ++?)		Phillips	STV
5.8) NISAR cal/val -24	100	Bawden	NISAR
5.9) USGS (GEMx) -25	100	Phillips	Landsat / SBG / EMIT
5.10) UAVSAR - Landslides & Faults - 25	20	Phillips	NISAR
5.11) NISAR cal/val -25	12	Bawden	NISAR
5.12) European vulcanology mission (HyTES)		Phillips	SBG / HyTES
5.13) NISAR cal/val -26	12	Bawden	NISAR
5.14) USGS (GEMx) -26	100	Phillips	Landsat/SBG / EMIT
5.15) UAVSAR - Landslides & Faults - 26	20	Phillips	NISAR
5.16) NISAR cal/val -27	12	Bawden	NISAR
5.17) USGS (GEMx)/SDC/STV Demo -27	100	Phillips	Landsat/SBG / EMIT
5.18) UAVSAR - Landslides & Faults - 27	20	Phillips	NISAR
5.19) UAVSAR - Landslides & Faults - 28	20	Phillips	NISAR



Earth Venture Suborbital

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor
8) **EVS**			
8.1) EVS-4			





Appendix B

Acronyms

2D-S	stereo optical imaging instrument
2DC	hydrometeor imaging probe
4STAR-B	Spectrometers for Sky-Scanning, Sun-Tracking Atmospheric Research-B

A

ABoVE	Arctic-Boreal Vulnerability Experiment
AC3	Axial Cyclone Cloud water Collector
ACCLIP	Asian summer monsoon Chemical and Climate Impact Project
ACES	Airborne Cavity Enhanced Spectrometer
ACOS	Atmospheric CO2 Observations from Space
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAHRS	Attitudes and Heading Reference System
ADM-Aeolus	Atmospheric Dynamics Mission-Aeolus
ADS-B	Automatic Dependent Surveillance-Broadcast
AEROMMA	Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas
AFB	Air Force Base
AFRC	NASA Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AGU	American Geophysical Union
Air-LUSI	Airborne Lunar Spectral Irradiance
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AIRO	Aircraft In-Situ Radio Occultation
AirSWOT	Airborne Surface Water and Ocean Topography
AITT	Airborne Instrument Technology Transition
AJAX	Alpha Jet Airborne Experiment
ALADIN	Atmospheric Laser Doppler Instrument
ALOFT	Airborne Lightning Observatory for FEGS and TGFs
AMP	Aerosol Microphysical Properties
AMPR	Advanced Microwave Precipitation Radiometer
AOD	Aircraft Operations Division

AOP	Aerosol Optical Properties
AOS	Atmospheric Observing System
API	Application Programming Interface
APL	Applied Physics Laboratory
APR-3	Airborne Precipitation Radar-Third Generation
ARB	Air Reserve Base
ARC	NASA Ames Research Center
ARINC	Aeronautical Radio, Incorporated
ARMD	Aeronautics Research Mission Directorate
ASAR	Airborne Synthetic Aperture Radar
ASF	Airborne Sensor Facility
ASKOS	Aeolus ground instrumentation
ASM	Asian Summer Monsoon
ASP	Airborne Science Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATM	Airborne Topographic Mapper
ATTREX	Airborne Tropical Tropopause Experiment
AVAPS	Advanced Vertical Atmospheric Profiling System
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer-Next Generation
AWAS	Advanced Whole Air Sampler
AWP	Aviation Weather Program
AXCTD	Airborne Expendable Conductivity Temperature Depth

B

BAERI	Bay Area Environmental Research Institute
BAS	British Antarctic Survey
BBR	Broadband Radiometers
BGAN	Broadband Global Area Network
BioSCAPE	Biodiversity Survey of the Cape
BLUEFLUX	Blue Carbon Prototype Products for Mangrove Methane and Carbon Dioxide **Fluxes**

C

CAFE	Compact Airborne Formaldehyde Experiment
Cal/Val	calibration/validation
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMBOT	Continuous Airborne Mapping by Optical Translator
CAMP^{2}Ex	Cloud, Aerosol, and Monsoon Processes Philippines Experiment
CANOE	Compact Airborne NO2 Experiment
CAPS	Cloud, Aerosol, and Precipitation Spectrometer
CAR	Cloud Absorption Radiometer
CARAFE	Carbon Airborne Flux Experiment
CARCAH	Chief, Aerial Reconnaissance Coordination, All Hurricanes
CARE	Cabin Altitude Reduction Effort
CAS	Commercial Aviation Services
CBM	Conditions-Based Maintenance
CDP	Cloud Droplet Probe
CEAMS	Citizen-Enabled Aerosol Measurements for Satellites
CFDC	Continuous Flow Diffusion Chamber
CH_4	methane
Chi-WIS	Chicago Water Isotope Spectrometer
CHIME	Copernicus Hyperspectral Imaging Mission for the Environment
CIRPAS	Center for Interdisciplinary Remotely Piloted Aircraft Studies
CMIS	Compact Midwave Imaging System
CMS	Carbon Monitoring System
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-M	Copernicus Carbon Dioxide Monitoring
COA	Certificate of Authorization
COLD 2	Carbon Oxide Laser Detector 2
COMA	Carbon Monoxide Measurement and Analysis
CoMET	Carbon dioxide and METhane
CONUS	Continental United States

CoSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
COVID	Coronavirus disease/SARS-CoV2
CPDLC	Controller Pilot Data Link Communications
CPEX-AW	Convective Processes Experiment-Aerosols and Winds
CPEX-CV	Convective Processes Experiment-Cabo Verde
CPI	Cloud Particle Imager
CPL	Cloud Physics Lidar
CRS	Cloud Radar System
CVI	Counterflow Virtual Impactor
CY	Calendar Year

D

DAWN	Doppler Aerosol WiNd
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DEM	digital elevation map
DGPS	Differential GPS
DISCOVER-AQ	Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DLH	Diode Laser Hygrometer
DLR	German Aerospace Agency
DMS	Digital Mapping System
DO	Designated Observable
DOE	United States Department of Energy
DPOPS	DCOTSS Portable Optical Particle Spectrometer

E

ECMWF	European Centre for Medium-Range Weather Forecasts
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
Edu	education
EIP	Experimenter Interface Panel
eMAS	Enhanced MODIS Airborne Simulator
EMIT	Earth Surface Mineral Dust Source Investigation
EOS	Earth Observing System

ESA European Space Agency

ESD Earth Science Division

ESI Earth Surface and Interior

ESPO Earth Science Project Office

ESSP Earth System Science Pathfinder

ESTO Earth Science Technology Office

EV Earth Venture

EVS Earth Venture Suborbital

EXRAD ER-2 X-band Doppler Radar

F

FAA Federal Aviation Administration

FASMEE Fire and Smoke Model Evaluation Experiment

FCDP Fast Cloud Droplet Probe

FEGS Fly's Eye Geostationary Lightning Mapper Simulator

FER Final Engineering Review

FIA Forest Inventory and Analysis

FIREX-AQ Fire Impacts on Regional Emissions and Chemistry Experiment-Air Quality

FLIR Forward Looking Infrared

FR Flight Request

FY Fiscal Year

G

G-LiHT Goddard's Lidar, Hyperspectral, and Thermal

GAO Global Airborne Observatory

GCAS GeoCAPE Airborne Simulator

GEDI Global Ecosystem Dynamics Investigation

GEMx Geological Earth Mapping Experiment

GEO-CAPE GEOstationary Coastal and Air Pollution Events

GLM Geostationary Lightning Mapper

GLOBE Global Learning and Observations to benefit the Environment

GOES-R Geostationary Operational Environmental Satellite-R (GOES-16)

GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	NASA Glenn Research Center
GSA	General Services Administration
GSFC	NASA Goddard Space Flight Center
GT-CIMS	Georgia Institute of Technology-Chemical Ionization Mass Spectrometer
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 Sounding Radiometer
HAPS	high-altitude pseudo-satellites
HARP	HIAPER Airborne Radiation Package
HCNO	fulminic acid
HIWC	high ice water content
HIWRAP	High Altitude Imaging Wind And Rain Profiler
HS3	Hurricane and Severe Storm Sentinel
HSRL	High Spectral Resolution Lidar
HUPCRS	Harvard University Picarro Cavity Ring Down Spectrometer
HVPS-3	High Volume Precipitation Spectrometer 3
HWV	Harvard Lyman-α Photofragment Fluorescence Hygrometer
HYPPOS	HyperMapping with Hyperspectral Precise Pointing Optical Sensor
HyTES	Hyperspectral Thermal Emission Spectrometer

I

ICESat	Ice, Cloud, and land Elevation Satellite
ICOS	Integrated Cavity Output Spectroscopy
IIP	Instrument Incubator Program
ILS	Instrument Landing System

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 (aircraft capability)

IWGADTS Interagency Working Group for Airborne Data and Telecommunication Systems

J

JATAC Joint Aeolus Tropical Atlantic Campaign

JLH JPL Laser Hygrometer

JPL NASA Jet Propulsion Laboratory

JSC NASA Johnson Space Center

K

KORUS-AQ Korea-United States Air Quality

L

LaRC NASA Langley Research Center

LARGE Langley Aerosol Research Group Experiment

LIAISE Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment

LiDAR Light Detection and Ranging

LIF-NO Laser Induced Fluorescence-Nitrogen Oxide

LIF-SO_2 Laser Induced Fluorescence-Sulphur Dioxide

LTER Long Term Ecological Research

LVIS Land, Vegetation, and Ice Sensor

M

MAGIC	Monitoring of Atmospheric composition and Greenhouse gases through multi-Instruments Campaigns
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
METAR/TAF	Aviation Routine Weather Report/Terminal Aerodrome Forecast
MMS	Meteorological Measurement System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOOSE	Michigan Ontario Ozone Source Experiment
MOSES	Multiscale Observing System of the Ocean Surface
MSFC	NASA Marshall Space Flight Center
MTP	Microwave Temperature Profiler
MTS	Mission Tools Suite
MTS-O	Mission Tools Suite-Outreach
MUOS	Mobile User Objective System
MURI	Multi-band Radiometer
MVIS	Miniature Video Imaging System

N

NAAMES	North American Aerosols and Marine Ecosystem Study
NAMA	North American Monsoon Anticyclone
NASDAT	NASA Airborne Science Data and Telemetry
NASEM	National Academies of Sciences, Engineering and Medicine
NAST-I	National Airborne Sounder Tester-Interferometer
NAVO	Naval Oceanographic Office
NCEP	National Centers for Environmental Prediction
NEON	National Ecological Observatory Network
NHC	National Hurricane Center
NISAR	NASA-ISRO Synthetic Aperture Radar
NMASS	Nucleation-Mode Aerosol Size Spectrometer

NO	nitrogen monoxide
NO_2	nitrogen dioxide
NOAA	National Oceanographic and Atmospheric Administration
NOy	reactive nitrogen oxides
NRC	National Research Council
NSRC	National Suborbital Research Center

O

OCO-2	Orbiting Carbon Observatory-2
OIB	Operation IceBridge
OLYMPEX	Global Precipitation Measurement Mission Olympic Mountains Ground Validation Experiment
OMG	Oceans Melting Greenland
OPALS	Open Path Ammonia Laser Spectrometer
OSU	Oregon State University

P

PACE	Plankton, Cloud, and ocean Ecosystem
PALMS	Particle Analysis by Laser Mass Spectrometry
PALS	Passive Active L- and S-band Sensor
PBL	planetary boundary layer
PDM	Programmed Depot Maintenance
PDR	Preliminary Design Review
PER	Preliminary Engineering Review
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol Research and Development
PIF	Payload Information Form
PLO	phase-locked oscillator
PMD	Palmdale Airport
POPS	peroxides and formaldehydes instrument
POR	Program of Record
POS	Position and Orientation Systems
PPR	Preliminary Peer Review
PRISM	Portable Remote Imaging Spectrometer
PTZ	pan, tilt, and zoom

Q

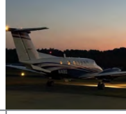
QUAKES-I	Quantifying Uncertainty and Kinematics of Earth System Imager

R

R/V	research vessel
R&A	research and analysis
RICE	Rosemount Icing Detector
Roscoe	aerosol and cloud lidar instrument
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
SCIFLI	Scientifically Calibrated In-Flight Imagery
SDC	Surface Deformation and Change
SEO	sensor equipment operator
SHARC	SCIFLI Hayabusa 2 Airborne Re-entry Observation Campaign
SHIFTS	SBG High Frequency Time Series
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SIO	Scripps Institute of Oceanography
SLAP	Scanning L-band Active Passive
SMAP	Soil Moisture Active Passive
SMAPVEX	Soil Moisture Active Passive Validation Experiment
SMD	Science Mission Directorate



SMOS	Soil Moisture and Ocean Salinity
SnowEx	Snow Experiment
SOA^{2}RSE	Synergies of Active Optical and Active Microwave Remote Sensing Experiment
SOFRS	Science Operations Flight Request System Sounder Testbed-Interferometer
SoOp	Signals of Opportunity
SoOpSAR	Signals of Opportunity Synthetic Aperture Radar
SP2	Single Particle Soot Photometer
SRTM	Shuttle Radar Topography Mission
STAQS	Synergistic TEMPO Air Quality Science
STEM	Science Technology Engineering and Math
STMD	Space Technology Mission Directorate
STV	Surface Topography and Vegetation
SWE	snow water equivalent
SWESARR	SWE Synthetic Aperture Radar and Radiometer
SWIR	Short Wave Infrared
SWOT	Surface Water and Ocean Topography

T

TAMMS	Turbulent Air Motion Measurement System
TCCON	Total Carbon Column Observing Network
TCEQ	Texas Commission on Environmental Quality
TEMPO	Tropospheric Emissions: Monitoring Pollution
TGF	Terrestrial Gamma-ray Flash
TOGA	Trace Organic Gas Analyzer
TOIL	Twin Otter International Limited
TOLNet	Tropospheric Ozone Lidar Network
TomoSAR	Tomography Synthetic Aperture Radar
TRACER-AQ	Tracking Aerosol Convection Interactions Experiment-Air Quality
TROPOMI	Tropospheric Monitoring Instrument

U

UAS	unmanned aircraft system, uncrewed aerial system
UASO3	Unmanned Aircraft Systems Ozone

UAV	unmanned aerial vehicle
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UC	University of California
UCATS	UAS Chromatograph for Atmospheric Trace Species
UCLA	University of California Los Angeles
UHSAS	Ultra-High Sensitivity Aerosol Spectrometer
USFS	United States Forest Service
USGS	United States Geological Survey
USRA	Universities Space Research Association
USVI	United States Virgin Islands
UTLS	Upper Troposphere/Lower Stratosphere
UTLS-AMP	Upper Troposphere/Lower Stratosphere-Aerosol Microphysics Package
UV	ultraviolet

V

VCSEL	Vertical Cavity Surface Emitting Laser Hygrometer
VHF	very high frequency
VIPR	Vapor in-cloud Profiling Radar
VNIR	Visible Near Infrared
VSWIR	visible to short wave infrared

W

WAS	Whole Air Sampler
WDTS	Western Diversity Time Series
WFF	NASA Wallops Flight Facility
WHOI	Woods Hole Oceanographic Institute
WI-ICOS	Water Isotopologues-Integrated Cavity Output Spectrometer
WISPER	Water Isotope

National Aeronautics and Space Administration

NASA Ames Research Center
Moffett Field, CA 94035

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