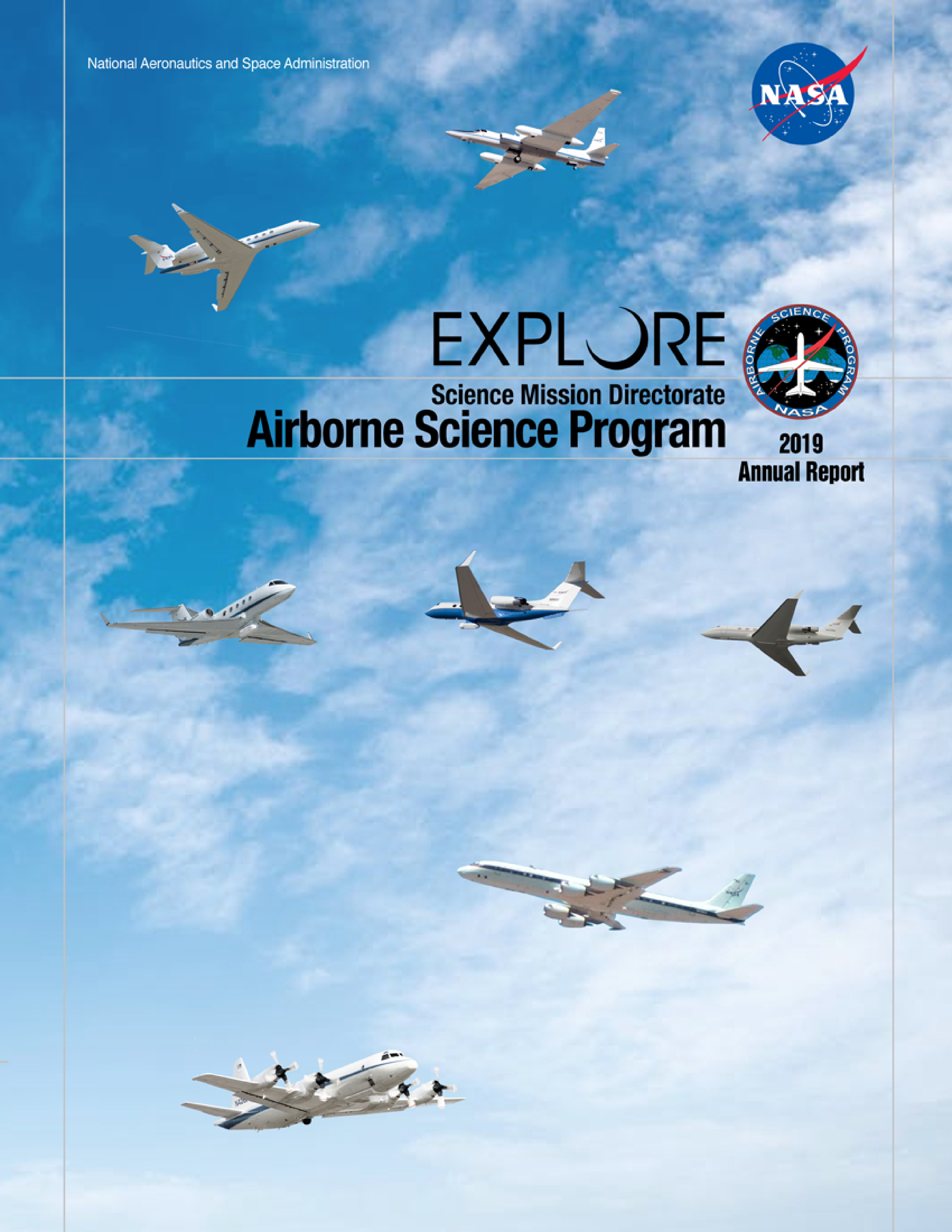
National Aeronautics and Space Administration



EXPLORE

Science Mission Directorate
Airborne Science Program

2019
Annual Report

National Aeronautics and Space Administration

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Annual Report

Figures and Tables

1. Leadership Comments

Bruce Tagg, Director of the Airborne Science Program.

I am pleased to present the 2019 Annual Report on the activities of the NASA Earth Science Division Airborne Science Program – the work of more than a thousand dedicated staff of scientists, engineers, maintainers and aircrew. The work we do leads to important scientific discoveries and highlights the more dynamics aspects of our changing planet. From the vastness of Antarctica, to storm clouds in the Philippines, NASA Airborne Science spans the globe. This year the Program flew 2415 Earth Science-specific flight hours using 23 different NASA and non-NASA aircraft.

The high impact science accomplished through the Program this year is truly impressive and we hope this report serves as a useful summary. Several aircraft teams, including the P-3, G-III and the new G-V helped improve our understanding of how sea ice and glaciers are changing at both poles during the Operation Ice Bridge (OIB) mission. Importantly, these flights coincided also with the now operational ICESat-2, thereby completing the primary goal of OIB to provide an airborne “data bridge” between ICESat and ICESat-2. The Arctic Boreal Vulnerability Experiment (ABoVE) used a range of aircraft to study Arctic surface change and impacts on global atmospheric chemistry. The P-3 team also supported the final year of data collection for the Earth Venture Suborbital-2 ORACLES investigation and the Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP^{2}Ex). Another multi-aircraft mission, FIREX-AQ, operating jointly with NOAA and USFS, saw the DC-8 and ER-2 make measurements to improve our understanding of wildfire emissions. Unfortunately, the DC-8 incurred damage to all four engines during FIREX-AQ. The incident is under investigation but the aircraft is in the process of having the engines replaced and will be back in service at the end of FY2020.

The Program also added capability with the modified JSC G-V, shared with the Human Spaceflight Program, as well as the modified LaRC G-III. These aircraft add significantly to our remote sensing capability with their 17-inch nadir portals and their ability to easily travel to almost anywhere in the world. The G-V team supported ABoVE right out of the gate, successfully carrying the Laser Vegetation Imaging Sensor (LVIS) lidar. Upgrades continued on the ER-2 aircraft, with one completing cabin upgrades, and the other beginning a similar process. The ARC team completed upgrades and returned the SIERRA-B small UAS to flight status to support instrument development by flying a cubesat synthetic aperture radar funded by the Earth Science Technology Office.

The Student Airborne Research Program (SARP) entered its second decade with another outstanding group of 28 students representing 28 different colleges from 20 states. The students were able to ride-along on the DC-8 during FIREX-AQ instrument checkouts, and used AVIRIS-NG data acquired on a contracted B-200. Four of the projects were featured at the American Geophysical Meeting Fall meeting, one of the most important Earth Science conferences of the year. SARP continues to be an important mechanism for training and recruiting the next generation of Earth Science Engineers and Researchers.

There are many exciting projects featured in this year's report and I want to thank you for taking the time to learn more about the NASA Earth Science Division and the Airborne Science Program accomplishments. I hope you enjoy reading about the Program and, as always, I welcome your feedback on the Program.

Bruce A. Tagg, Director
bruce.a.tagg@nasa.gov

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 in the entire life cycle of earth observing satellite missions. ASP capabilities support NASA Earth Science missions by:

- Improving models of Earth system elements through process studies
- Developing satellite mission instruments and algorithms
- Conducting science instrument calibration and validation
- Performing critical instrument testing and development
- Leading workforce development, including cultivating next generation scientists

The program accomplishes these goals by providing aircraft systems modified and adapted for science (Section 4), as well as aviation services to the science community (Section 5). ASP also facilitates use of non-NASA aircraft and equipment for Earth Science, as needed (Section 4).

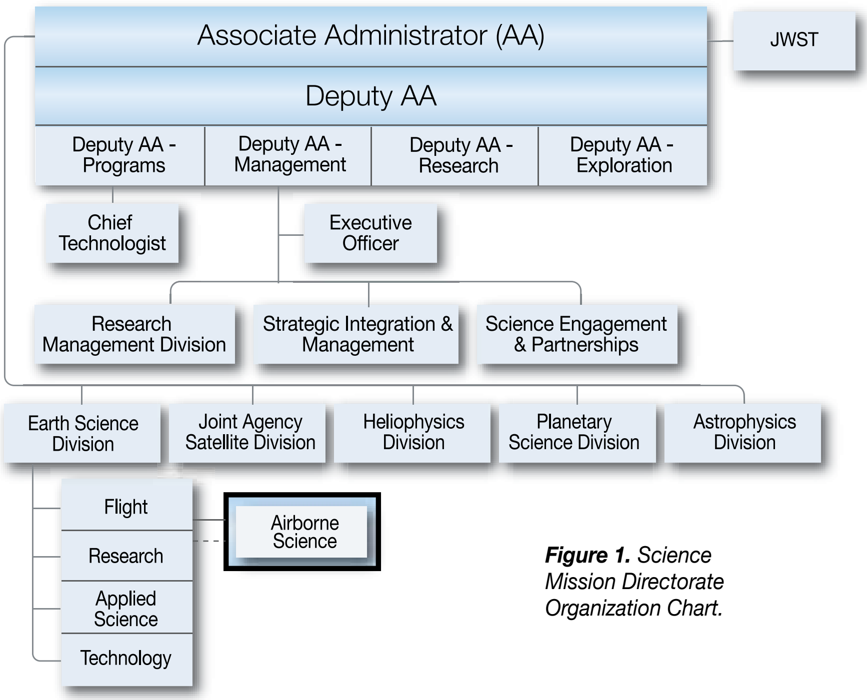


***Figure 1.** Science Mission Directorate Organization Chart.*

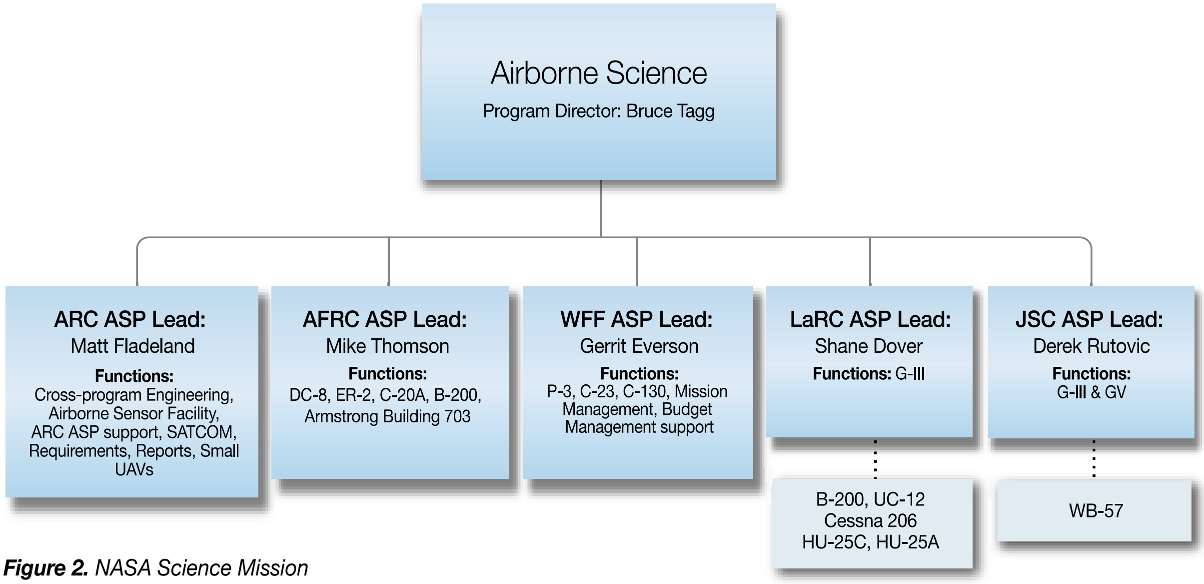


Figure 2. *NASA Science Mission Directorate Earth Science Division Airborne Science Program Center Roles and Responsibilities.*

Structure of the Program

The core elements of Program implementation take place at Flight Operations Centers. The organizational chart in Figure 1 above shows the role of ASP within SMD and ASP components are shown in Figure 2. Aircraft responsibilities are distributed among the NASA centers where the aircraft are based.

New Program Capabilities

Beginning in FY19, new ASP platform capabilities available to the science community include the Johnson Space Center (JSC) Gulfstream V (G-V), an additional G-III at Langley Research Center (LaRC), and an upgraded SIERRA Unmanned Aerial System (UAS) at Ames Research Center (ARC) (Section 4).

Flight Request System and Flight Hours

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

In 2019, 126 FRs were submitted for flight activities using at least one of the following ASP components: an ASP-supported aircraft, ESD funding, an ASP facility instrument (AVIRIS-NG, AVIRIS-C, eMAS, LVIS, MASTER, NAST-I and UAVSAR/L-Band), and/or an ASP Science Support Asset (DMS and POS AV Applanix). A total of 55 FRs were completed, using 20 different aircraft. Of the remaining FRs, some were deferred, and the rest were canceled for a variety of reasons. The 55 completed FRs flew a total of 3069.8 flight hours. The details are listed below. Table 1 shows all flight requests status and total flight hours flown by all aircraft (including "Other (non-NASA) Aircraft)." Table 2 shows a list of the "Other (non-NASA) Aircraft" requested and aircraft flown (Flight Request Status and Total Hours) broken out by specific aircraft. Table 3 shows only ESD flight requests and flight hours flown by aircraft. Figure 3 is a histogram showing the history of total flight hours flown. Table 4 shows all SOFRS flight hours flown by funding source. Figure 4 shows the global reach of flight activities in 2019.

***Table 1.** FY19 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[1] – AFRC[1]	8	6	0	5	506
ER-2 – AFRC[1]	22	8	1	1	73.1
Gulfstream C-20A (GIII) – AFRC[1]	14	11	0	9	145.5
Gulfstream III – JSC[1]	12	8	1	6	303.3
Gulfstream V – JSC[1]	4	4	0	4	272.9
P-3 Orion – WFF[1]	17	4	1	2	506.2
Other NASA Aircraft					
B-200[2]	9	5	0	5	137.0
C-130H – WFF[2]	2	1	0	1	113.6
Gulfstream III – LaRC[2]	1	0	0	0	0.0
HU-25A Guardian – LaRC[2]	2	1	0	1	64.0
SIERRA – ARC[2]	2	1	0	1	4.3
Twin Otter – GRC[2]	2	2	0	2	32.2
Other (non-NASA Aircraft)[3]	31	22	2	18	911.7
TOTAL	**126**	**73**	**5**	**55**	**3069.8**

[1]ASP Supported Aircraft.

[2]These aircraft are NASA-owned aircraft not subsidized by the Airborne Science Program.

[3]See Hours are detailed in Table 2 for totals.

Table 2. *FY19 Flight Request Status and Total Hours Flown by Other (non-NASA) Aircraft.*

"Other" Aircraft (non-NASA Aircraft	Total Frs	Total Approved	Total Partial	Total Completed	Total Hours Flown
A90 - Dynamic Aviation	3	3	1	2	376.6
Alphajet	1	0	0	0	0.0
B-200 - Dynamic Aviation	10	8	0	7	282.2
DC-3	3	2	0	2	152.8
Twin Otter CIRPAS*	1	1	0	1	3.7
Twin Otter International	4	3	1	2	49.7
Aeroscout	1	0	0	0	0.0
ISRO King Air*	1	1	0	0	0.0
Robinson R44 helicopter	1	0	0	0	0.0
SPEC LearJet*	1	1	0	1	40.3
SuperSwift	3	1	0	1	3.2
UK Twin Otter*	1	1	0	1	0.0
VT USL 26 Hexacopter*	1	1	0	1	3.2
TOTAL	**31**	**22**	**2**	**18**	**911.7**

*Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS), Indian Space Research Organization (ISRO), Stratton Park Engineering Company (SPEC), United Kingdom (UK), Virginia Tech (VT).

Table 3. *Summary of ESD-funded FY19 Flight Request Status and Flight Hours Flown by Aircraft*.*

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
DC-8 – AFRC[1]	4	4	0	4	506.0
ER-2 – AFRC[1]	15	6	1	1	73.1
Gulfstream C-20A (GIII) – AFRC[1]	10	9	0	7	98.0
Gulfstream III – JSC[1]	10	7	0	6	217.6
Gulfstream V – JSC[1]	4	4	0	4	272.9
P-3 Orion – WFF[1]	15	4	1	2	506.2
Other NASA Aircraft					
B-200[2]	8	4	0	4	122.3
C-130H – WFF[2]	2	1	0	1	113.6
Gulfstream III – LaRC[2]	1	0	0	0	0.0
HU-25A Guardian – LaRC[2]	1	0	0	0	0.0
SIERRA – ARC[2]	1	0	0	0	0.0
Twin Otter – GRC[2]	2	2	0	2	32.2
Other (non-NASA Aircraft)[3]	23	16	1	13	473.2
TOTAL	**96**	**57**	**3**	**44**	**2415.1**

[1]ASP-s Supported Aircraft.

[2]These aircraft are NASA-owned aircraft not subsidized by the Airborne Science Program.

[3]Other aircraft (total hours) are: A90 - Dynamic Aviation (5.1h), B-200 - Dynamic Aviation (221.6h), DC-3 (152.8h), Twin Otter CIRPAS (3.7h), Twin Otter International (49.7h), and SPEC LearJet (40.3h).

How to read Table 1,2 and 3

- These totals are based on the Flight Request's log number, and therefore include all Flight Requests whose with log numbers starting with "19".
- The "Total FRs" column includes submitted Flight Requests that were submitted and whose with log number starting with "19".
- The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY19.
- The "Total Partial FRs" column includes Flight Requests in for which the total approved hours were not fully expended during FY19 and have been rolled over to the following year.
- The "Total FRs Completed" column includes only Flight Requests whose final status is "Completed".
- The "Total Hours Flown" column includes all "Flight Hours Flown" for FY19 Flight Requests with a status of "Completed" or "Partial" for 2019.

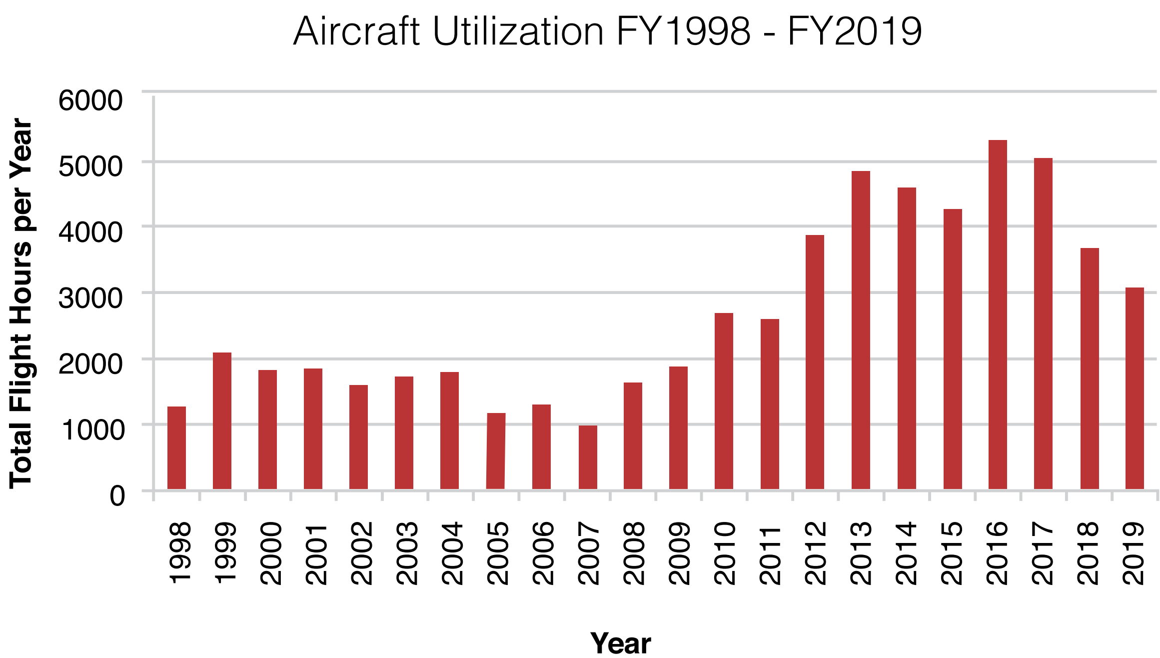


Figure 3. *ASP Annual Flight Hours from FY98 through FY19.*

Table 4. *All Flight Hours Flown by Funding Source.*

Fiscal Year	ESD	SMD (Non-ESD)**	Other NASA	Non-NASA	Funding Sources Not Listed in FR	Total Funded Flight Hours
2014	4069.4	28.5	419.5	12.8	69.9	4600.1
2015	3758.0	24.5	266.9	184.9	26.9	4261.2
2016	4752.1	16.6	285.6	260.5	0	5314.8
2017	4484.4	85.9	280.1	194.1	0	5044.5
2018	3125.8	6.4	451.5	103.6	1.2	3688.5
2019	2415.1	0.0	586.6	60.6	7.5	3069.8

**NASA Earth Sciences Division (ESD) is part of the Science Mission Directorate (SMD). The "SMD (Non-ESD)" column includes flight hours funded by SMD Program Managers not within ESD.

FY2019 Airborne Campaigns
(including OIB Fall 2019)

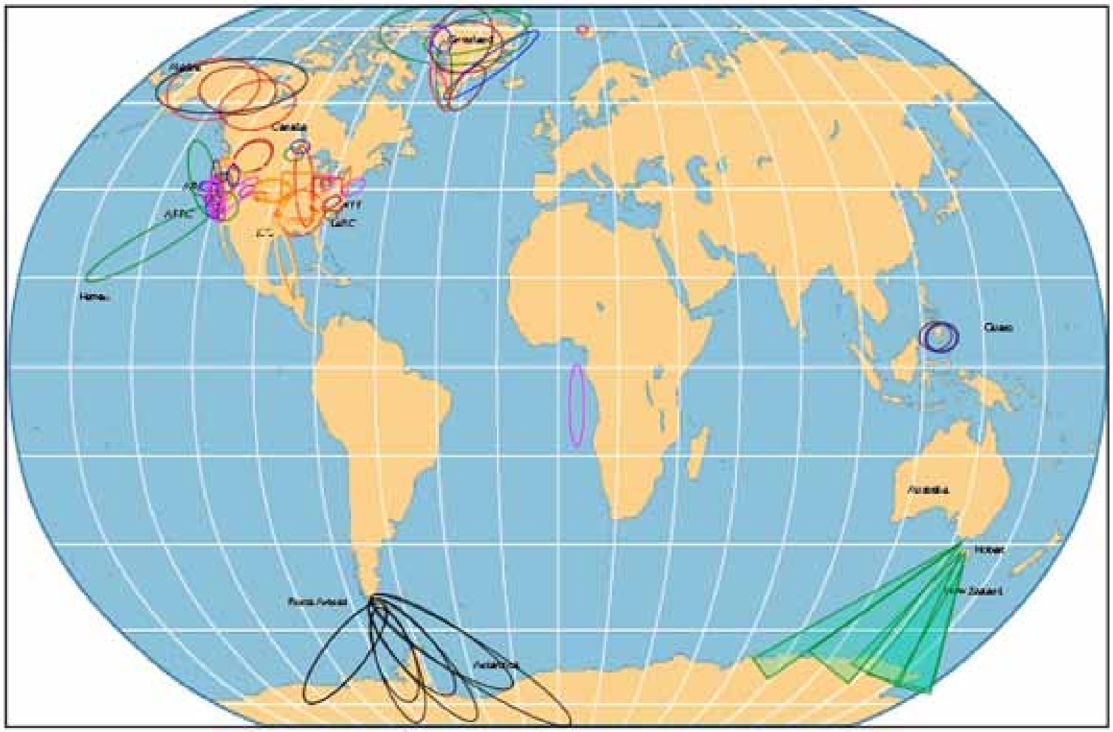


Figure 4. *2019 Locations of ASP Missions, including OIB Fall 2019 (FY20).*

3. Science

FY2019 Major Mission Highlights

ASP conducted nearly 3,100 flight operation hours in support of process studies, instrument flight-testing, and support for Earth Science space missions in all phases from definition to validation. This section of the report provides descriptions and statistics regarding the major missions supported in FY2019. These included three Earth Venture Suborbital-2 (EVS-2) missions that flew in FY2019, with two completing flight activities. Operation IceBridge (OIB) undertook campaigns in the Arctic and Antarctic, with the new JSC G-V flying the Antarctic for the first time out of Hobart, Australia. Two major process studies – FIREX-AQ and CAMP^{2}EX – flew in 2109. Table 5 shows flight hours for the largest missions.

Table 5. *FY19 Major Science Missions.*

Mission	Flight Hours	Location	Aircraft
OIB Arctic	300.1	Greenland, Canada	P-3
OIB Antarctica Fall 2018	292.8	Antarctic Peninsula, McMurdo	DC-8
OIB Antarctica Fall 2019 (FY20)	248.4	East Antarctica	G-V
ABoVE	290.9	Alaska, Canada	G-III, B-200, G-V
Airborne Snow Observatory	253.9	Colorado, California, Oregon, Wyoming, Washington	A-90
OMG	248.6	Greenland	G-III, Airtec DC-3
FIREX-AQ	221.4	Idaho, Kansas	DC-8, ER-2
CAMP2Ex	220.2	Philippines	P-3, SPEX Lear
ACT-America	192.2	Eastern U.S.	C-130, B-200
L-Band UAVSAR (combined missions)	155.5	Continental U.S.	G-III
G-LiHT/USFS Forest Health, Fire and Forest Inventory Campaign	117.6	Alaska	A90
ObseRvations of Aerosols above Clouds and their intEractionS (ORACLES)	110.0	São Tomé, Africa	P-3
NISAR UAVSAR AM-PM Campaign	85.7	South-East U.S.	G-III
NASA Fall Methane Survey	56.3	California	B-200
SARP 2019	28.6	California	DC-8, B-200
Long Island Sound Tropospheric Ozone Study, Phase 3	17.5	Long Island, NY	B-200

Operation IceBridge (OIB)

PI – Joe MacGregor, GSFC
Program – Cryosphere
Aircraft – P-3, DC-8, GV, DC-3

The final year of OIB was a busy one as the mission returned with the DC-8 to Antarctica for the final time in late 2018. During spring 2019, the P-3 returned to Greenland for the final time. And with the new capability of the G-V, a later summer mission was possible, providing collaborative observations with ICESat-2. Finally, in November 2019, the G-V flew a mission to Antarctica, but this time out of Hobart, Australia to reach East Antarctica.

Antarctic - Fall 2018. IceBridge completed its tenth consecutive year of airborne campaigns over parts of Antarctica and the surrounding sea ice in late 2018 deploying the DC-8 with an advanced instrument suite of laser altimeters, shallow and deep sounding radars, a gravimeter and thermal, hyperspectral and visible imagers. This campaign also included the first coordinated underflights of NASA's ICESat-2, a satellite laser altimeter that launched just a few weeks before the beginning of the campaign on September 15, 2018. The IceBridge team was able to complete 24 science missions over 288 flight hours and flew more than 200,000 km (half the distance to the Moon) and nearly 21,000 km of ICESat-2 ground tracks.

The first half of the campaign was based out of Punta Arenas, Chile, and in early November the campaign repositioned to Ushuaia, Argentina for the first time. IceBridge surveyed the massive A68 iceberg again, following its calving from the Larsen C Ice Shelf in July 2017, and was the first to capture the newly-calved Pine Island Glacier iceberg, B46.

While onboard the DC-8, IceBridge scientists interacted with 560 students from around the world during virtual classroom chat sessions, bringing the total number of students reached since 2012 to more than 10,000.

Figure 5. *A Triangular Iceberg Surrounded by Sea Ice in the Weddell Sea.* ***Photo credit:*** *Linette Boisvert / NASA*

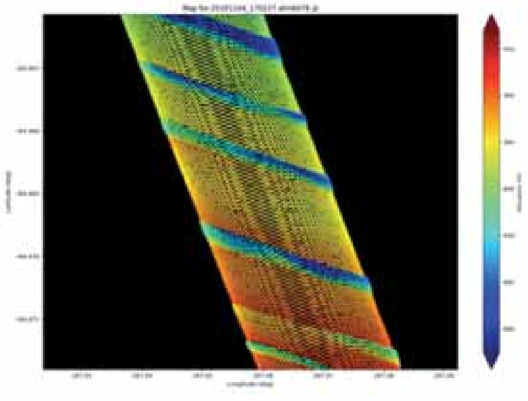
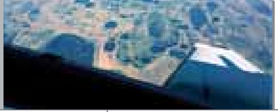


Figure 6. *Airborne Topographic Mapper (ATM) T6 Wide Scan Laser Altimetry of Crevassed Antarctic Ice.* ***Photo credit:*** *Matt Linkswiler / NASA*



Arctic - Spring 2019. In April and May 2019, OIB completed its final Arctic spring airborne campaign onboard WFF P-3 aircraft (N426NA). This was also OIB's final campaign onboard the P-3, which OIB used for nine Arctic and two Antarctic campaigns since 2009, adding to the remarkable legacy of more than twenty NASA P-3 campaigns since 1992 that surveyed Earth's changing polar ice. Although shorter than previous Arctic spring campaigns, the OIB team nevertheless completed 24 science missions in less than 7 weeks, again basing out of Thule Air Base in northwestern Greenland and later in Kangerlussuaq in southwestern Greenland.

A key focus of this campaign was to underfly ICESat-2's six-laser-beam instrument, so that its performance and geolocation could be assessed relative to heritage OIB instruments, including WFF's Airborne Topographic Mapper (ATM) laser altimeter. This campaign included numerous zero- and low-latency underflights of the satellite, which required daily re-planning of many missions. In the case of sea ice, which can drift hundreds of meters per hour in parts of the Arctic Ocean, the team again measured local winds to correct for drift between the time of the satellite overflight and our underpass, so that the same ice floes could be surveyed.

Weather primarily favored surveys of northeastern and southwestern Greenland. Cloudy conditions were more often prevalent in the Arctic Ocean, making for challenging mission selection over sea ice. The weather even conspired to force OIB's first-ever divert, from Thule Air Base to Kangerlussuaq, but we were able to return to Thule Air Base after only a single overnight. This last OIB campaign onboard a large aircraft included our last major media visit, which was from a BBC video production crew filming Frozen Planet II while based in Kangerlussuaq. The team again corresponded with K-12 students from around the world through the Mission Tools Suite (MTS).

Arctic - Summer 2019. The final OIB Greenland campaign took place onboard JSC's G-V aircraft during August-September 2019. The OIB team also met up in Thule with the OMG team and an AVIRIS-ng team sponsored by ICESat-2 (Figure 9). In the few weeks between the summer and fall campaigns, the aircraft de-integrated the OIB instrument suite, performed an astronaut direct mission, then re-integrated the OIB instrument suite – adding two additional instruments. The JSC team also integrated a supplemental oxygen system to provide enough breathing time for all science team members in the event of a loss of cabin pressurization over Antarctica.

Figure 7. *An unusually early start to the 2019 melt season during early May in southwestern Greenland was evidenced by bright blue meltwater ponds between crevasses.* ***Photo credit:*** *Brooke Medley / NASA*

Figure 8. *The OIB team in Kangerlussuaq along with the BBC Frozen Planet II crew.* ***Photo credit:*** *Michael Studinger / NASA*

Figure 9. *Three NASA missions met in Thule, Greenland in summer 2019. Operation IceBridge on the Gulfstream V, ICESat-2/ AVIRIS on the B200 King Air, and OMG on the Basler/Airtec DC-3.* ***Photo credit:*** *Eugenia DeMarco / NASA*

Antarctic - Fall 2019. In October and November of 2019, OIB completed its final polar airborne campaign aboard the G-V (N95NA), based out of Hobart, Tasmania. More than 35 personnel – mainly from JSC, GSFC, University of Kansas, and Lamont Doherty Earth Observatory – participated in this campaign to survey changing ice across the coast of the East Antarctic Ice Sheet and sea ice in the Southern Ocean (65–70° S, 95–165° E). In total, 20 science missions were flown – each typically 10 hours long – which, together with check flights and transits, totaled 248.4 flight hours. The flight tracks are shown in Figure 10.

The G-V Antarctic campaign was the first in the Antarctic to directly underfly the next-generation Ice, Cloud and land Elevation Satellite (ICESat-2) to compare measurements from ICESat-2's six laser beams to high-heritage OIB instruments, including the ATM laser altimeters. This campaign again included numerous zero- and low-latency underflights of the satellite, which required daily re-planning of many missions, particularly for sea ice. In total, OIB flew more than 4,500 kilometers of ICESat-2 ground tracks. The instrument suite included the standard OIB contingent of laser altimeters (ATM T-6, T-7), radar sounders (MCoRDS, Snow Radar), and nadir imagers (CAMBOT, FLIR, Headwall Nano-Hyperspec) with modifications enabling them to fit in the G-V's smaller payload volume. A new MCoRDS design was implemented in the aircraft belly, and a smaller hybrid gravimeter (iMAR/DgS) was deployed. All instruments reported excellent data collection throughout the campaign. Numerous gaps were filled in our understanding of snow accumulation, land and sea ice thickness, and sub-ice-shelf bathymetry beneath several fast-changing outlet glaciers.

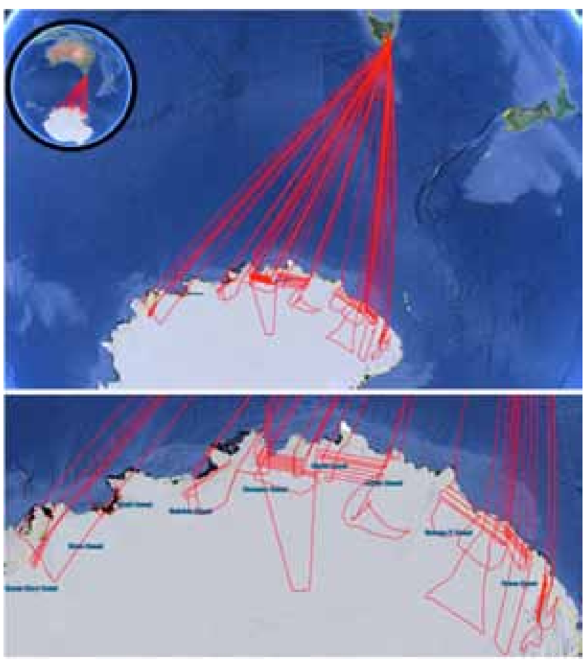


Figure 10. *G-V Flight Tracks in Antarctica During IceBridge in November 2019.* ***Image credit:*** *NASA*

Figure 11. *The OIB G-V Team at the Airport in Hobart, Tasmania.* ***Photo credit:*** *John Sonntag / NASA*

This first deployment of the G-V over Antarctica fulfilled the promise of being able to carry multiple instruments to the farthest reaches of the planet while safely and successfully completing the mission. The aircraft's range not only allowed it to safely operate over Antarctica but also provided the capacity to fly long routes over the Pacific Ocean, minimizing transit time.

Following the launch of ICESat-2, OIB has now completed its overarching objective to bridge the gap in laser altimetry of polar ice between ICESat-2 and its predecessor, ICESat. OIB Alaska will conduct two final campaigns in May and August 2020 to survey changing Alaskan glaciers. OIB has now begun mission closeout activities and the team extends thanks to the innumerable individuals in the NASA airborne science community who helped make this eleven-year mission a resounding success.

Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ)

PI – Jim Crawford, LaRC
Program – Atmospheric Composition and Chemistry
Aircraft – DC-8, ER-2, NCAR Twin Otter, NCAR G-IV, NCAR NightFox

NASA and NOAA joined forces to advance understanding of the environmental impact of fires during the FIREX-AQ study conducted during June through September 2019. Fires represent a unique scientific challenge: their atmospheric effects are difficult to quantify and predict. Fire activity is driven by natural and human causes and involves a multitude of potential fuels and combustion conditions. Smoke emissions undergo substantial chemical evolution during downwind transport, resulting in changes relevant to impacts on air quality, health, and climate. The overarching FIREX-AQ objectives were to provide measurements of trace gas and aerosol emissions from wildfires and prescribed fires in great detail, relate them to fuel and fire conditions at the point of emission, characterize the conditions relating to plume rise, follow plumes downwind to understand chemical transformation and air quality impacts, and then assess the efficacy of satellite detections for estimating the emissions from sampled fires.

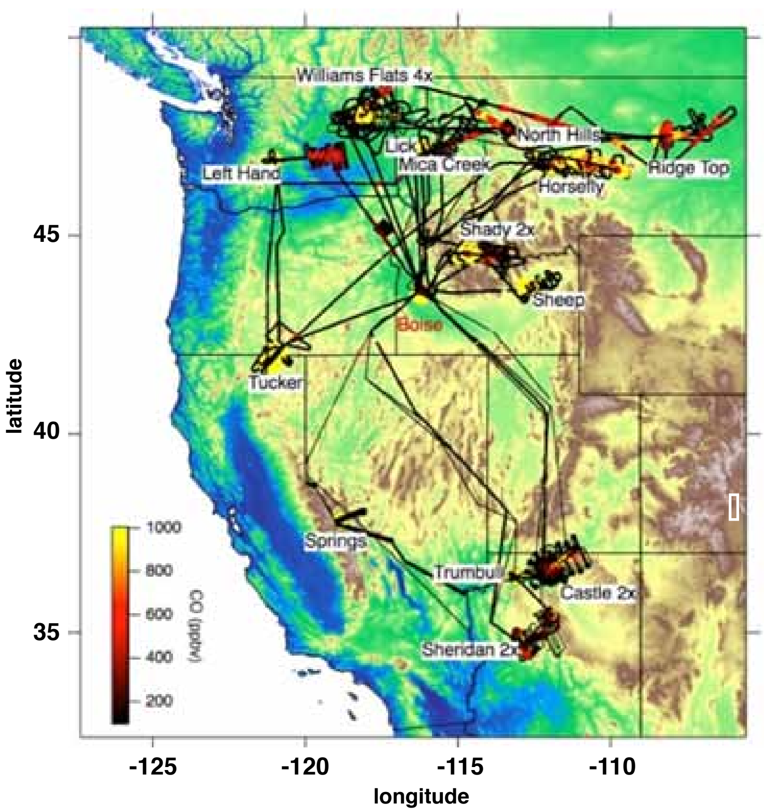
The campaign included scientists from NASA, NOAA, and university, commercial, and international institutions. The study was conducted in two phases, each supported by NASA's DC-8 flying laboratory carrying twenty-eight instrument teams. The first phase, based in Boise, Idaho, focused on western wildfires. This phase included three additional research aircraft: NASA's high-altitude ER-2 equipped with satellite-emulator instruments for remote sensing of fires and smoke, and two Twin Otters from NOAA, one instrumented for in-smoke chemistry and the other for remote sensing of fire dynamics. Assets on the ground included two mobile laboratories and an enhanced network of AERONET sunphotometers and lidars. During operations in Idaho, the DC-8 conducted thirteen flights and performed detailed sampling of sixteen wildfire smoke plumes. To understand how fire emissions evolve, some fires were sampled on multiple days. The Williams

Figure 12. *Smoke Clouds Over Williams Flat Fire in Washington State During FIREX-AQ.* ***Photo credit:*** *Samuel Hall / NCAR*

Flats fire (Figure 12) was sampled on four days, including a pyro-cumulonimbus event during which fire-induced convection lifted smoke to high altitudes where it can persist much longer in the atmosphere, increasing its relevance to climate impacts. The ER-2 supported this phase of the campaign with eleven science flights from NASA AFRC Building 703 in Palmdale, California. The NOAA Twin Otters carried out a total of 54 shorter flights.

The second phase of the campaign focused on small fires associated with prescribed and agricultural burning across the central and southeastern U.S. During this phase, the DC-8 flew solo, conducting an additional seven science flights from Salina, Kansas. Almost ninety individual small fires were sampled across a large number of fuel types and over a wide swath of the continental U.S. A highlight of this phase included a large prescribed burn in the Blackwater River State Park that was coordinated with scientists from the Tall Timbers Research Station. For this event, the availability of information from extensive prior sampling of fuels, plus real-time fire conditions on the ground during airborne sampling, provided unprecedented constraints on the factors contributing to the amount and composition of smoke and other fire-related emissions.

FIREX-AQ scientists are currently working to generate final quality-checked data for public release in early March 2020 and to prepare for their first science team meeting to discuss early impressions and detailed analysis plans for informing better interpretation of satellite data and improved representation of fires in atmospheric models.



FIREX-AQ 2019 wildfires:

- **14 different fires**
- **Some fires multiple times**
- **Nighttime flight**
- **Day old smoke downwind**
- **PyroCumulus**
- **Various fuels: grass, timber, etc.**
- **Remote sensing and in-situ data**

Figure 13. *FIREX-AQ Flights Over Wildfires in the Western U.S.*

Figure 14. *The FIREX-AQ Team with the DC-8.* ***Photo credit:*** *NASA*

Figure 15. *NOAA-provided Twin Otter Used for Supplemental Measurements.* ***Photo credit:*** *NASA*

Cloud, Aerosols, and Monsoon Processes Philippines Experiment (CAMP²Ex)

Program Scientist – Hal Maring, NASA;
Mission Scientist – Jeffrey Reid, NRL
Program – Atmospheric Composition and Chemistry
Aircraft – P-3, SPEC LearJet 35

CAMP²Ex was an interdisciplinary study of maritime tropical to subtropical aerosol-cloud relationships with three main focus areas:

- Aerosols: Properties, meteorology, lifecycle, air quality, and feedbacks to convection
- Convection: Warm to mixed phase cloud microphysics and organization
- Radiation: Diurnal cloud and aerosol radiative forcing and feedbacks

The Philippines provided an optimum environment for this mission due to its location, which permitted the observation of isolated and organized convections, ranging from pristine to highly polluted conditions with smoke from Borneo and Asian pollution during the Southeast Asian Southwest Monsoon transition.

The first phase of the campaign began with P-3 instrument integration and flight tests. Once the P-3 completed its transit to Clark International Airport in the Philippines, the research phase of CAMP²Ex started with two aircraft as the main research platforms of the campaign. The NASA WFF P-3 made research flights from August 24 to October 5, 2019 and the Stratton Park Engineering Company's (SPEC) LearJet 35 made research flights from September 7 to 29, 2019.

During the campaign, the P-3 flew 19 flights ranging in duration from 7 to 9 hours; the SPEC Learjet 35 conducted 13 flights, each approximately 3 hours in duration. The flights generally targeted the environment of shallow cumulus and cumulus congestus clouds, with measurements of microphysical, hydrological, dynamic, thermodynamic, and radiative properties. A typical flight pattern started at high altitude, sampling along warm convective lines. This was followed by downward flight in box spiral form to measure state profiles and radiation. Flights below cloud bases were conducted to sample mixed layers and ocean characterization. In addition, mid-level, above-cloud, and in-cloud sampling flights were also conducted.

Figure 16. *The NASA P-3 Aircraft as Seen from the SPEC LearJet During CAMP²Ex.* ***Photo credit:*** *NASA*

The campaign's successful outreach component reached over 39 different schools, 1500 students, and 100 teachers. Outreach activities included:

- Twelve in-person presentations by the CAMP²Ex team to students in grades 3 to second-year university
- Two tours of CAMP²Ex aircraft at Clark Airport
- Eight classroom chats with personnel on-board the P-3 and LearJet in-flight with the NASA Mission Tools Suite for Education
- Collaboration with the Global Learning and Observation to Benefit the Environment (GLOBE) Philippines Country Coordinator to target GLOBE schools and include GLOBE protocols as part of presentations

Figure 17. *CAMP²Ex P-3 Flight Tracks During the FY19 Mission.* ***Image credit:*** *NASA*

To further extend its impact, CAMP²Ex also collaborated with other organizations. CAMP²Ex coordinated joint-measurements of tropical meteorology, air-sea coupling, convection and aerosols with the Propagation of Inter-Seasonal Tropical Oscillations (PISTON) project's Sally Ride Research Vessel of the Office of Naval Research. The team also aligned extensive satellite underpasses and visualization and informatics components from organizations including JMA/JAXA (Japan), the European Space Agency (ESA)'s EUMETSAT, and others. CAMP²Ex also arranged extensive cooperation for meteorology measurements with the Philippines Atmospheric,

Figure 18. *The CAMP²Ex Team at Clark Airport in the Philippines.* ***Photo credit:*** *NASA*

Geophysical, and Astronomical Services Administration (PAGASA), the United Kingdom's Met Office (UKMO), the European Centre for Medium-Range Weather Forecasts (ECMWF), and PISTON. Finally, the team established an enhanced sampling site at the Manila Observatory to facilitate monitoring throughout the monsoon season, enabling ongoing work by the Manila Observatory.

Figure 19. *CAMP^{2}Ex hosted numerous school visitors. Students and teachers from Batasan Hills High School and Bagong Silangan High School pose by the NASA P-3B aircraft after a tour of CAMP^{2}Ex headquarters at Clark International Airport, Angeles City, Pampanga, Philippines on September 14, 2019.* ***Photo credit:*** *Monica Vazquez Gonzalez / NASA*

Arctic Boreal Vulnerability Experiment (ABoVE)

PI – Charles Miller, JPL
Program – Terrestrial Ecology
Aircraft – C20-A, G-III, B-200, G-V

The ABoVE science team continued airborne activities in 2019 with the objective of creating interannual time series to monitor Arctic ecosystem change. Airborne remote sensing in the ABoVE domain during 2019 included observations by NASA's Next Generation Airborne Visible InfraRed Imaging Spectrometer (AVIRIS-NG) imaging spectrometer, the Land, Vegetation and Ice Sensor (LVIS) full waveform lidar, and L-band synthetic aperture radar (SAR). These flights followed on the 2017 and 2018 ABoVE Airborne Campaigns, providing revisits of key locations and additional ground-truth calibration-validation data. The 2019 flights emphasized acquisitions for ABoVE's new Phase 2 research investigations.

AVIRIS-NG flights (on a Dynamic Aviation B-200) from July to early August characterized Arctic-boreal vegetation near peak greenness, as well as wetlands, inland waters and methane emissions hot spots. AVIRIS-NG flights targeted the tundra sites on the Seward Peninsula (in conjunction with ground and UAS measurements from NGEE-Arctic), Alaska's North Slope, the Mackenzie Delta, and the Canadian High Arctic Research Site near Cambridge Bay, Nunavik. The LVIS sensor, deployed aboard NASA's new G-V, exploited the extended range of that platform to acquire numerous long transects and underflights of ICESat-2 lines. LVIS acquisitions characterized tundra degradation, boreal forest biomass and structure, and the key tundra-taiga ecotone. Mapping of the Peace-Athabasca Delta was performed in conjunction with in situ water surface elevation measurements. L-band SAR flights on a NASA G-III occurred in early September, revisiting lines flown in 2017 and 2018. This enabled the ABoVE team to obtain accurate interferometric differencing and comparisons of interannual variability in permafrost active layer thickness, thermokarst, post-fire permafrost degradation, and boreal forest structure. The L-band SAR flights also provide key precursor data for NASA's upcoming NISAR satellite mission.

The ABoVE team is also coordinating with the ISRO L+C-band SAR project to obtain overflights of key ABoVE transects when that team operates out of Fairbanks for sea ice remote sensing during the 2019/2020 cold season.

Figure 20. *ABoVE researchers and airborne teams gather at the ABoVE Logistics Office in Fairbanks, AK for the Annual Canada Day/4th of July BBQ.* ***Photo credit:*** *NASA*

Figure 21. *Utqiagvik (Barrow), Alaska on July 12, 2019 during AVIRIS-NG observations. Conditions were ideal, with no clouds and unlimited visibility. The land surface was in its early greening phase, with many areas still relatively brown. There is a complete lack of sea ice near the coast despite the relatively early summer date.* ***Photo credit:*** *Michael Eastwood / JPL*

Earth Venture Suborbital-2 (EVS-2)

Flight operations for two Earth Venture Suborbital-2 were completed this year: ORACLES in late 2018 (FY2019) and ACT-America in the summer of 2019. Oceans Melting Greenland (OMG) flew in spring and fall 2019, and will fly again in 2020, with a final mission in 2021.

Atmospheric Carbon and Transport-America (ACT-America)

PI – Ken Davis, Pennsylvania State University
Program – Earth Venture Suborbital-2
Aircraft – C-130, B-200

The ACT-America EVS-2 team completed its fifth and final atmospheric measurement campaign at the end of July 2019. As with the previous four campaigns, which covered all four seasons, the team used two instrumented NASA aircraft operating out of NASA LaRC, WFF, Shreveport, Louisiana, and Lincoln, Nebraska to gather atmospheric measurements of greenhouse gases along with other trace gases and standard meteorological variables. The LaRC B-200 aircraft, carrying in-situ sensors, collected 88.5 hours of data and the WFF C-130 aircraft, carrying in-situ and remote sensors, collected 113.6 hours of data during 19 research missions. These missions occurred over the U.S. South, Midwest, and Mid-Atlantic regions, and also during transit flights between regions. In addition to the numerous level leg flights, the team made 244 quasi-vertical profiles of greenhouse gases and meteorological variables with the C-130 and B-200 aircraft using spirals or on-route ascents or descents. Summer is the most dynamic season for greenhouse gas activity, and the 2019 summer campaign obtained data during the beginning of summer, whereas the first summer campaign in 2016 obtained data later in the summer. The C-130 was also equipped with the LaRC High Altitude Lidar Observatory (HALO) instrument, measuring column-averaged CO_2, as well as cloud and aerosol properties.

Daily flight plans were designed based on prevailing meteorological conditions, synoptic scale settings, and source-sink distributions of different atmospheric tracers in the three regions. Research flight days were classified into frontal, fair weather, and Gulf inflow; some days were hybrids of these categories. During one fair-weather day, the team carried out an underflight of the TROPOMI satellite instrument. Airborne observations also sampled the atmospheric signatures of CO_2 and CH4 fluxes around oil and gas extraction regions, urban centers, agricultural lands, and forests. The team studied the distribution of greenhouse gases around several storms, often referred to as mid-latitude cyclones. In particular, front-relevant greenhouse gas structures in boundary layer and lower free troposphere were examined for two to three consecutive days to reveal the impact of frontal propagation and associated greenhouse gas transport mechanisms. The summer campaign included several sets of data unique to the ACT-America mission, including: data suitable for constraining biogenic CO_2 fluxes from south-central U.S. ecosystems in early summer and Midwestern U.S. agricultural systems impacted by extreme regional flooding; data from one warm conveyor belt case; and column-averaged methane number density data collected by the HALO lidar, including good test cases focused on Gulf Coast wetlands (previously unconstrained) and Mid-Atlantic coal and gas emissions. The team will use all measurements collected during the campaign to improve numerical models of greenhouse gas fluxes and atmospheric transport, improving our understanding of one of the most compelling issues in carbon cycle science.

With the conclusion of the final airborne campaign, the ACT-America team is currently analyzing and archiving data and publishing results from all five campaigns. In total, ACT-America has gathered over 1,140 hours of science data.

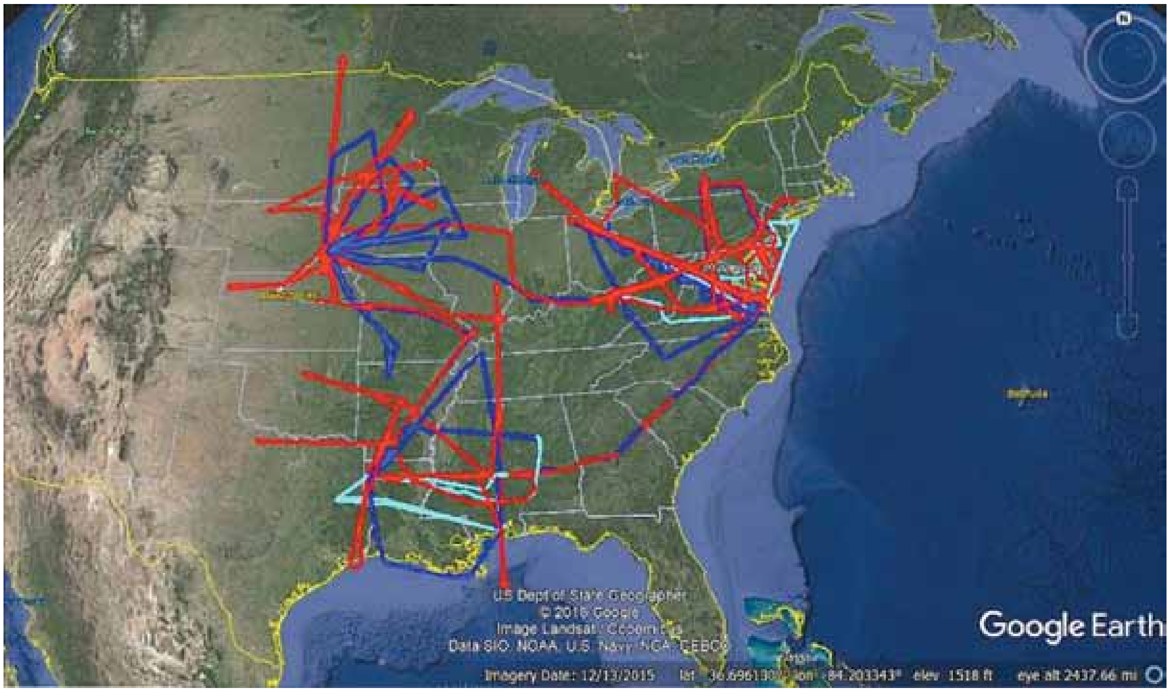


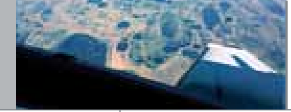
Figure 22. *B-200 and C-130 tracks over the three ACT-America regions (Mid-Atlantic, Midwest, and South) while collecting high-resolution measurements during the summer 2019 field campaign.* ***Image credit:*** *Sandip Pal / Texas Tech University*

Oceans Melting Greenland (OMG)

PI – Josh Willis, JPL
Program – Earth Venture Suborbital-2
Aircraft – G-III, DC-3

In 2019, OMG carried out its fourth survey of the oceans and ice around Greenland. OMG's objective is to investigate the role of warmer, saltier Atlantic subsurface waters in Greenland glacier melting. With 25 feet of potential sea level rise locked away in the Greenland ice sheet, OMG will help reveal how fast the oceans are eating away at the ice sheet from the edges and pave the way for improved estimates of future sea level. OMG flew two science flight missions in 2019: GLISTIN-A and AXCTD.

In March 2019, JPL's Glacier and Land Ice Surface Topography Interferometer (GLISTIN-A) radar instrument was installed on the JSC G-III. The GLISTIN-A, a single-pass interferometer, made high resolution, high precision elevation measurements (yearly campaign #4 of 4) of



Greenland's coastal glaciers. During the March deployment, GLISTIN-A conducted glacier survey flights out of Kangerlussuaq (Sondrestrom Air Base), Keflavik (Iceland), and Thule Air Base (Greenland). GLISTIN-A acquired 81 out of 81 planned OMG science flight lines.

In late August and early September 2019, OMG installed JPL's Airborne Expendable Conductivity Temperature Depth (AXCTD) system into a DC-3TP aircraft owned by Airtec. AXCTD probes are dropped from the aircraft into the ocean to measure ocean temperature and salinity on the ocean shelf. Because of the DC-3's ability to land on smaller, gravel runways, the crew and aircraft were able to stay in Greenland throughout most of trip, eliminating the need to transit from Iceland, as in some previous years. The aircraft deployed to Kulusuk in southeast Greenland for 10 days. While OMG was in Greenland, eight media companies – including NBC, CNN, CBS, The Weather Channel, and others – provided coverage of the flights. The DC-3 also deployed to Kangerlussuaq, Constable Point and Thule, Greenland, as well as Svalbard, Norway. OMG deployed 280 AXCTD probes in Greenland in 2019 and reached several fjords in north Greenland that were too choked with ice for data collection in previous years. Figure 23 shows the locations of AXCTD probe drops in FY19. The team was also able to sample a plume by deploying an AXCTD probe from the DC-3 into a freshwater opening. As shown in Figure 24, the plume of fresh meltwater escaping from underneath Helheim Glacier caused an opening in the ice.

Figure 23. *2019 AXCTD Survey of the oceans around Greenland. Yellow dots show planned drops, green dots show completed drops.* ***Image credit:*** *NASA*

FY19 was campaign four of six for OMG, which will fly again in FY20. In addition, OMG recently received permission to complete a no-cost contract extension that will enable the AXCTD campaign to continue through 2021.

Figure 24. *A large area of open water at the edge of Helheim Glacier one of east Greenland s biggest glaciers.*
Photo credit: *Josh Willis / NASA*

Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)

PI – Yunling Lou, JPL
Program – Terrestrial Ecology, Water and Energy Cycle, Earth Surface and Interior
Aircraft – G-III

The UAVSAR project supported 14 Flight Requests and 11 principal investigators with four different radar configurations aboard two NASA Gulfstream jets. The AFRC C-20A conducted 19 science/calibration flights and collected 403 data lines. The JSC G-III conducted 54 science/calibration flights and collected 1942 data lines. At least 15 peer-reviewed papers and one book chapter based on this work have been published in FY19. Links to publications are available at: https://uavsar.jpl.nasa.gov/cgi-bin/publications.pl

The NISAR AM/PM campaign for ecosystem calibration/validation exercise encompassed 18 UAVSAR L-band flights in the Eastern U.S. Flights were conducted around 6 AM and 6 PM to simulate the observation times of the NISAR space borne instrument, which will launch in 2022.

2019 also marked the fourth year of the OMG airborne campaign. Repeated observations with the Ka-band topographic mapping radar are enabling researchers to derive volume change estimates of over 200 marine-terminating glaciers in Greenland. New elevation maps are also revealing distinct regional regimes of inter-actions between glaciers and ocean water.

The ABoVE airborne campaign entered its third year and the resulting datasets are supporting an active community of researchers in the U.S., Canada, and Europe. UAVSAR L- and P-band datasets are being employed to study the role of temperature and landscape disturbances in shaping freeze/thaw patterns to predict soil water content and carbon emissions.

UAVSAR deployments are listed at: https://uavsar.jpl.nasa.gov/cgi-bin/deployments.pl. All three versions of the UAVSAR flew in 2019, as shown in Figure 25.

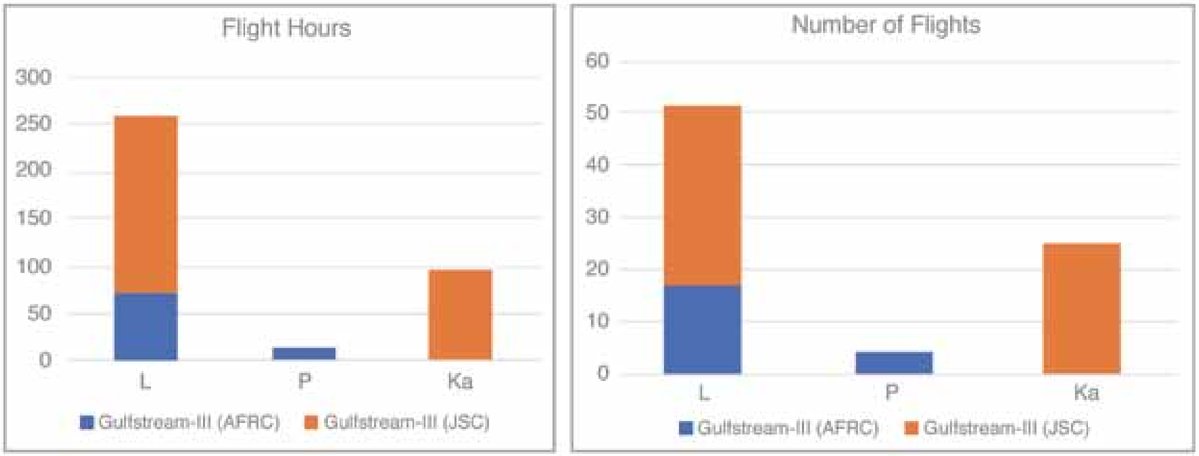


Figure 25. *Flight hours and number of flights for the three versions of UAVSAR – L-band, P-band (AirMOSS), and Ka-band (GLISTIN-A).*

Figure 26. *Left: JPL scientists Neda Kasraee and Adam Vaccaro survey a vegetation plot in Alabama during the NISAR AM/PM campaign.* ***Photo credit:*** *Victoria Meyer / JPL, Center: Data loggers record soil moisture measurements at a farm during the NISAR AM/PM campaign.* ***Photo credit:*** *Nathan Torbick / Applied Geosolutions. Right: UAVSAR coverage during the campaign flown on the JSC G-III.*

The NISAR AM/PM campaign generated L-band radar observations to support terrestrial ecology studies on soil moisture, crop type, and vegetation biomass. Results will inform the calibration/validation strategy for the NISAR instrument.

Fall 2019 marked the successful integration of India's Airborne Synthetic Aperture Radar (ASAR) instrument. In a collaboration between NASA and the Indian Space Research Organization (ISRO), the ASAR instrument was mounted on the AFRC G-III aircraft to image targets such as glaciers, natural hazards, wetlands, and permafrost. ASAR is a dual L- and S-band radar that mirrors the dual-wavelength NISAR satellite instrument, which is planned for launch in 2022. ASAR marks the first dual L- and S-band imaging radar observation over the U.S., and the datasets will be used to develop and refine algorithms in advance of the NISAR mission. The ASAR Phase-1 campaign in December 2019 covered sites in Alaska and California.

Figure 27. *Left: ASAR campaign instrument/aircraft teams.*
Photo credit: *Annemarie Peacock / JPL.*
Right: Scientists Erika Podest / JPL and Kyle McDonald / JPL servicing data loggers in Toolik prior to ASAR flights. ***Photo credit:*** *Erika Podest*

Goddard Lidar, Hyperspectral, and Thermal (G-LiHT) Forest Inventory

PI – Bruce Cook, GSFC
Program – Terrestrial Ecology
Aircraft – B-200

In 2019, the Goddard Lidar, Hyperspectral, and Thermal (G-LiHT) airborne imager flew an extensive Alaska mapping mission with the U.S. Forest Service (USFS). The instrument simultaneously mapped the composition, structure, and function of terrestrial ecosystems, providing co-registered, fine-scale observations (0.03 to 1 m), and data products covering large areas and environmental gradients to understand tree-scale ecosystem interactions with atmosphere, hydrosphere, and climate. The joint NASA-USFS Inventory of Interior Alaska project is designed to complete the final "missing piece" of U.S. forest inventory. The flight lines flown by G-LiHT in 2019 on a contracted B-200 aircraft are shown in Figure 27. A 10-year joint project, G-LiHT is scheduled to continue into the 2020s.

The G-LiHT study addresses:

- How much forest land is there, and how is it changing in response to climate change, fire, drought, insects, and disease?
- Are forest resources (species, size class, volume, productivity) sufficient to meet needs of local communities?
- Will ecosystems continue to support wildlife and local subsistence living?
- Are these ecosystems (including live/dead trees, shrubs, and soils) a net carbon source or sink?

In addition to the imaging data, the USFS employs extensive research on the ground in a standard protocol of measuring trees and woody debris, collecting soil samples, plus an additional effort to measure lichens and moss, which store substantial amounts of carbon. As a result, new statistical approaches have been developed that integrate ground-based and remote sensing data to significantly improve the precision, accuracy, and spatial estimates based on Forest Inventory and Analysis (FIA) data.

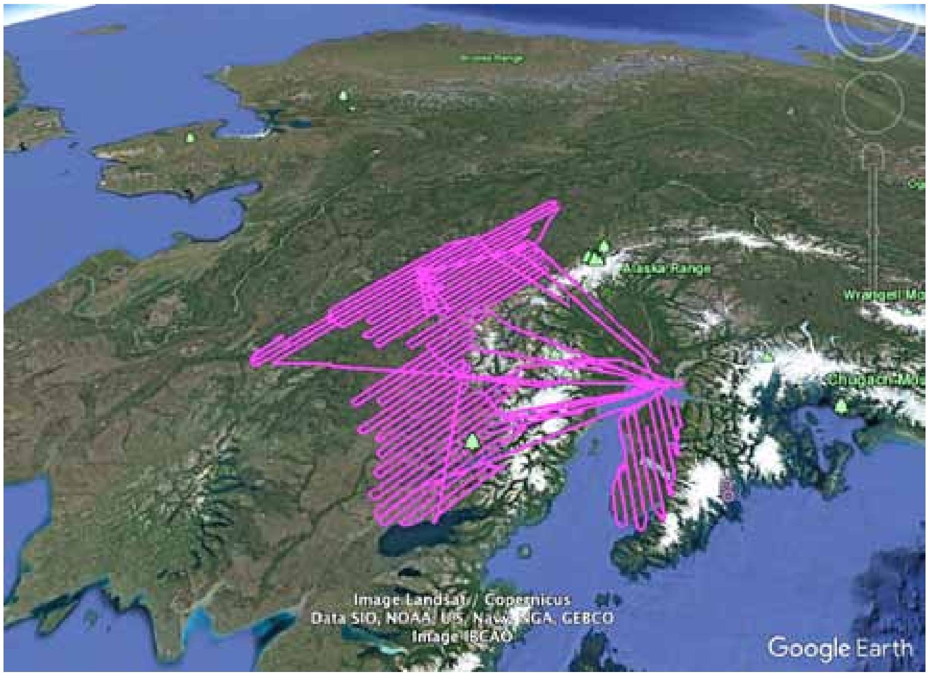
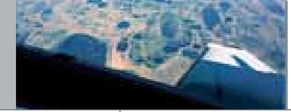


Figure 28. *2019 G-LiHT Flight Tracks Over Alaska.*



ASP Support to ESD Satellite and International Space Station Missions

A primary ASP purpose is to support Earth Science space flight missions, including satellite missions and missions on the International Space Station (ISS). ASP support includes airborne campaigns to collect data for algorithm development prior to launch, testing instrument concepts for satellite/ISS payloads or airborne simulators, and providing data for calibration or validation of satellite algorithms, measurements, or observations once in orbit. In FY19, ASP provided support to seventeen Earth Science space missions (Table 6). Support included significant flight hours for several of these missions, particularly ICESat-2, which launched in 2018, as well as for GEDI and ECOSTRESS on the ISS.

In 2019, some airborne process missions collected data that will also be valuable for future missions. Airborne campaigns are providing image data and instrument performance data to support SWOT, scheduled to launch in 2021, and NISAR, scheduled to launch in 2022. Future missions include a HyspIRI-like mission, currently identified as Surface Biology and Geology (SBG). In addition, ASP-supported missions that collected CO_2 measurements are also relevant to OCO-2, Suomi-NPP, and future missions that measure greenhouse gases.

Table 6. *Space Missions Supported by Aircraft Campaigns in FY19.*

Airborne Mission	Space Mission Supported	Flight Hours	Location	Aircraft
OIB	ICESat-2	548.5	Arctic, Antarctic	DC-8, P-3
ABoVE	ECOSTRESS, GEDI, SBG	290.9	Alaska, Canada	G-III, B-200, G-V
FIREX-AQ	ECOSTRESS, others	221.4	Idaho, Kansas	DC-8, ER-2
ACT-America	OCO-II	192.2	Eastern U.S.	C-130, B-200
G-LiHT	Landsat	117.6	Alaska	A90
L-band UAVSAR (Combined Missions)	NISAR	155.5	Continental U.S.	G-III
NISAR UAVSAR AM/PM Campaign	NISAR	85.7	South-East U.S.	G-III
SWOT Cal/Val Pilot Program	SWOT	49.7	Pacific Coast	G-V
Aeolus Cal/Val Checkout	Aeolus, Planetary Boundary Layer	44.6	Eastern Pacific	DC-8
GEDI Cal/Val	GEDI	43.1	Costa Rica	G-V
Long Island Sound Tropospheric Ozone Study (LISTOS)	TEMPO, TROPOMI	17.5	New York	B-200
PALS SMAPVEX Flights	SMAP	13.9	Texas	DC-3
California Continuity (HyspIRI Prep)	HyspIRI/SBG	9.8	California	ER-2
Red River Flood Prediction	SMAP, SBG, GCOM W1	6.8	North Dakota	G-III
Townsend Wisconsin 2019	HyspIRI/SBG	4.9	Wisconsin	B-200
NISAR/SMAP Complex Terrain Soil Moisture (CTSM) Complement	NISAR/SMAP	4.4	California	G-III
Coastal High Acquisition Rate Radiometers for Innovative Environmental Research (C-HARRIER)	PACE	3.7	California	Twin Otter

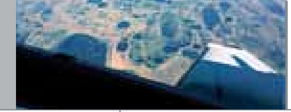
SWOT Calibration/Validation Pilot

PI – Luc Lenain, Scripps Institution of Oceanography
Program – Water and Energy Cycle
Aircraft – G-V

In preparation for the Surface Water and Ocean Topography (SWOT) satellite mission, scheduled for launch in 2021, the JSC G-V was assigned its first NASA Earth Science mission. The Modular Aerial Sensing System (MASS) instrument was installed over both portals, enclosed inside a pressure "dog house" structure in the plane. The MASS instrument, a waveform scanning lidar, was provided by the Scripps Institution of Oceanography to measure sea surface altimetry. The goal of this mission was to validate the instrument's performance in a geographic location over the Pacific Ocean under the track of the future SWOT satellite mission.

After smooth integration of the MASS instrument onto the G-V, the airborne campaign was carried out in the vicinity of JSC, and then from the Monterey, California Regional Airport over the identified SWOT calibration/validation (cal/val) site just off-shore. With 37.1 science flight hours, the mission finished on schedule, achieving all science objectives. Scripps Principal Investigator Luc Lenain declared "The G-V platform was demonstrated to be an ideal platform for this work, meeting the speed, endurance and flight altitude required for the project." Results from the mission are providing insights into the decorrelation length and time scales of the lidar topographic measurements over the ocean associated with submesoscale variability.

Figure 29. *The MASS instrument was installed to make use of G-V nadir portals.* ***Photo credit:*** *NASA JSC*



ASP Support to Instrument Development

Another foundational role of the Airborne Science Program is to support instrument development for the next generation of NASA Earth Observing Satellites. In 2019, ASP aircraft flew all of the instruments listed in Table 7. Many of these instruments have been developed under sponsorship of NASA's Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP) and Airborne Instrument Technology Transition Program (AITT). ESTO demonstrates and provides technologies that can be reliably and confidently applied to a broad range of science measurements and missions. Through flexible, science-driven technology strategies and a competitive selection process, ESTO-funded technologies support numerous Earth and space science missions.

Two of the IIP projects are presented in additional detail. The SRI CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD) project was the first EST assignment for the upgraded SIERRA-B UAS. The AITT project, airLUSI, is working to develop an airborne lunar spectral irradiance measurement capability.

Table 7. *Instrument Development Missions Supported by Airborne Activities in 2019.*

Mission	Flight Hours	Location	Aircraft
IIP Multiband Radiometer (MURI)	32	California	Twin Otter
HSRL 2 Ocean Profiling	16.7	Atlantic Coast	B-200
Air-LUSI	14.9	Palmdale California	ER-2
IPDA-Triple Pulse Lidar	14.7	LaRC	B-200
HyTES 2019 Low Altitude Flights	12	Colorado, Utah, Arizona, Nevada, California	Twin Otter
LVIS Fall 2018 Checkout Flight	9.5	Texas	G-V
SWESARR Engineering Flights	5.7	Grand Junction, Colorado	Twin Otter
CIRES-IDD	4.3	Crow's Landing, California	SIERRA
C-HARRIER	3.7	Monterey, California	Twin Otter

CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD)

PI – Lauren Wye, SRI
Program – ESTO ACT and IIP
Aircraft – SIERRA-B

Ground deformation measurements obtained with interferometric synthetic aperture radar (InSAR) technologies have the potential to improve short-term forecasting of natural hazards and enable more effective management of natural resources. For maximum impact, InSAR measurements must be precise (sub-cm level) and timely. Frequent acquisitions are needed to achieve both requirements. More observations per unit time provide enhanced deformation precision through averaging, and also ensure that an event is properly captured and characterized. Spaceborne platforms can only meet the required revisit rate via large constellations of small satellites. Low-cost UAS platforms potentially offer a competitive alternative to obtaining near-persistent access over remote areas. Under a NASA ESTO ACT and IIP grant, SRI has developed a miniaturized SAR/InSAR payload for resource constrained platforms. Called CubeSat Imaging Radar for Earth Science (CIRES), the S-band radar instrument is capable of moderate-resolution (5 m) and high-fidelity coherent InSAR operation (sub-cm ground deformation precision, SNR > 14 dB). CIRES was designed for rapid integration into a 16U bus and satisfies the power and thermal requirements of the CubeSat environment (Figure 30). Its modular nature lends itself to small unmanned aircraft, and the SRI team has integrated and tested the TRL-6 CIRES radar hardware on fixed-wing hobbyist group-II UAVs (Mugin III), on medium-class UAS from NASA's Airborne Science Program (SIERRA-B), on multi-rotor UAVs (XM2 Tango Heavy Lift), and even on small weather balloons.

CIRES successfully integrated and flew on the SIERRA-B UAS on August 6, 2019. SRI and the SIERRA-B team designed a new custom nosecone appropriate for radar payloads, one that was

Figure 30. *Top: CIRES was integrated into the ASP SIERRA-B UAS using a custom-built nose cone. Bottom: CIRES flew on SIERRA-B over Crows Landing, California in August 2019, obtaining the payload s first interfero-metric UAS-based verification data. The team deployed six radar calibration targets for characterization of CIRES height deformation measurement capabilities.* ***Image credit:*** *Lauren Wye / SRI*

RF-transparent, with appropriate airflow for heat management, and long enough to house the CIRES instrument (Figure 30). As part of the CIRES interferometric performance evaluation, SRI placed six corner reflector calibration targets around the Crows Landing airstrip, raising and lowering their elevation at fixed height intervals. This ground truth dataset enables characterization of the height change measurement sensitivity of the CIRES InSAR instrument. The SIERRA-B CIRES experiment represents the instrument's first airborne InSAR verification test. Later 2019 tests, conducted on a Cessna 208 Caravan commercial manned aircraft as part of a controlled urban flooding experiment at Muscatatuck Urban Training Complex (MUTC), completed the CIRES InSAR verification campaign, accomplishing mm-level ground deformation accuracies, the stated instrument design objective (Figure 31). This work is well aligned with the Surface Deformation and Change mission recommended by the recent National Academy of Science Decadel Survey.

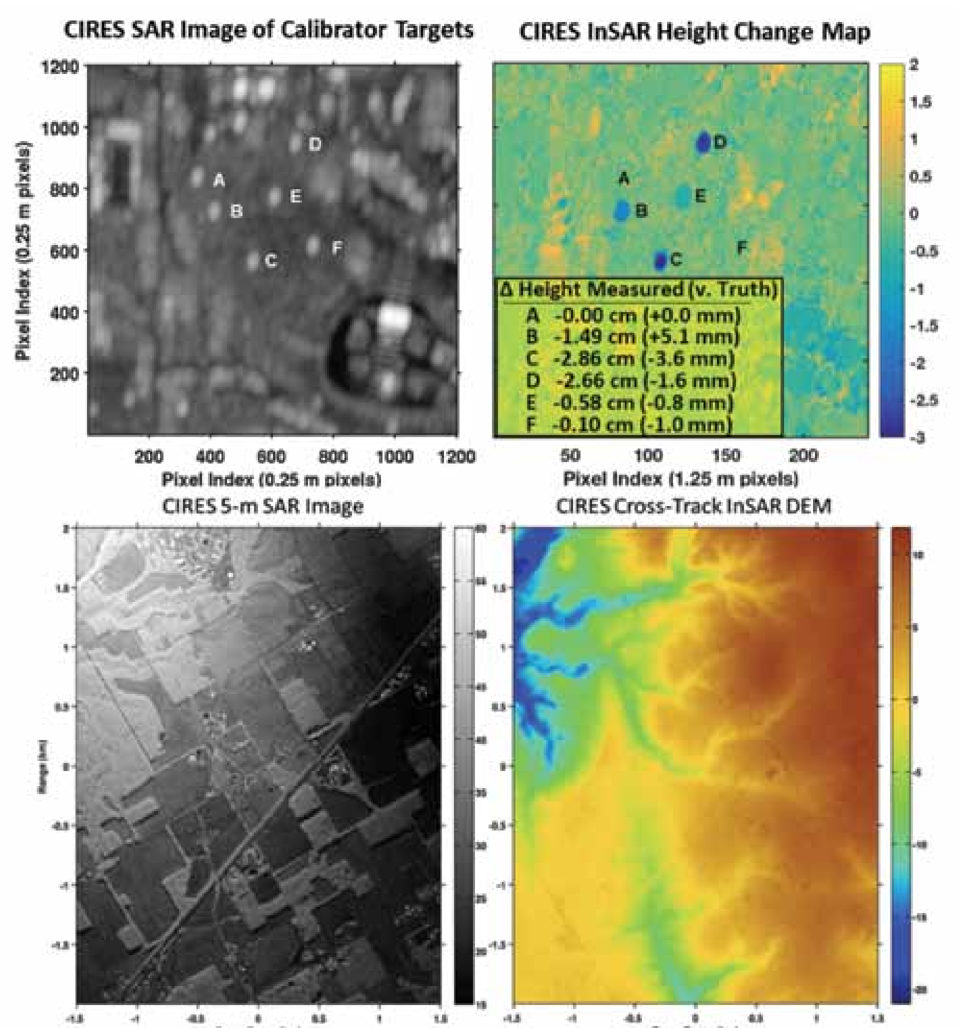


Figure 31. *Upper Left: 5-m resolution SAR image of six radar corner reflector targets. Upper Right: InSAR height deformation map demonstrating mm-level change detection of the six ground truth targets. Lower Left: 5-m resolution SAR image over wider scene. Lower Right: Corresponding digital elevation model height map (DTED Level 3) obtained from CIRES cross-track interferometric data.* ***Image credit:*** *Lauren Wye / SRI*

Airborne Lunar Spectral Irradiance (Air-LUSI) Instrument

PI – Kevin Turpie, University of Maryland-Baltimore County
Program – ESTO AITT
Aircraft – ER-2

The AITT project to develop a highly-accurate Lunar Spectral Irradiance measurement capability, Airborne LUnar Spectral Irradiance Instrument (Air-LUSI), was completed in FY19. The project adapted a mountain-top based experiment for measuring total spectral irradiance from the Moon for use on NASA's ER-2 aircraft.

The ultimate Air-LUSI mission objective was to make highly accurate (sub-0.5 % uncertainty), SI-traceable measurements of lunar spectral irradiance in the VNIR. To accomplish this, the Air-LUSI system employs an autonomous, robotic telescope system and a stable spectrometer housed in an enclosure, providing a robustly-controlled environment. These instrument subsystems are housed in one of the ER-2 aircraft superpods, with a small dorsal view port through which the telescope can observe the Moon. The airborne version of the system was implemented and integrated onto the ER-2 in about ten months, leading to Air-LUSI's engineering test flights in August 2018 and science mission flights in November 2019.

The Moon is a very useful calibration target for orbiting Earth-observing sensors because its surface is radiometrically stable and it has a flux output comparable to Earth scenes. To predict spectral lunar irradiance given an illumination and viewing geometry, the United States Geological Survey (USGS) has developed the Robotic Lunar Observatory (ROLO) model of exo-atmospheric lunar spectral irradiance. The USGS ROLO model currently represents the most precise knowledge of lunar spectral irradiance and is used frequently as a relative calibration standard by space-borne Earth-observing sensors. However, ROLO predictions are not traceable to the International System of Units (SI). Consequently, the Moon is not currently used as an absolute standard. An SI-traceable, exo-atmospheric, lunar spectral irradiance with uncertainties less than 1%, such as the measurements from Air-LUSI, would meet many sensor calibration uncertainty requirements.

Figure 32. *The Air-LUSI Deployment Team with the ER-2 Aircraft.* ***Photo credit:*** *NASA*

Air-LUSI successfully conducted its demonstration flight campaign from November 12 to 17, 2019. Each night of the campaign, the mission flew the ER-2 aircraft for two hours to observe the Moon at about 68,000 feet. Each observation lasted about 30 to 40 minutes and measured lunar spectral irradiance at wavelengths from about 380 to 1000 nm. These are unprecedentedly accurate measurements, currently estimated to be about 0.7% or better in the mid-visible range. These extremely accurate measurements were made for 10°, 21°, 34°, 46°, and 59° of lunar phase angle. The results for the five flights at these respective phase angles are shown in Figure 33. The Air-LUSI mission hopes to make this new capability available for use to improve photometric models of the Moon and calibration of Earth-observing satellites. The Air-LUSI team plans to work with NASA and the international community to further acquire and apply these valuable data. Such measurements could also be used, for example, to quantify biases in land and ocean-based vicarious calibration approaches. For ocean color sensors for example, this would help quantify biases stemming from atmospheric correction in vicarious calibrations using NOAA's Marine Optical Buoy.

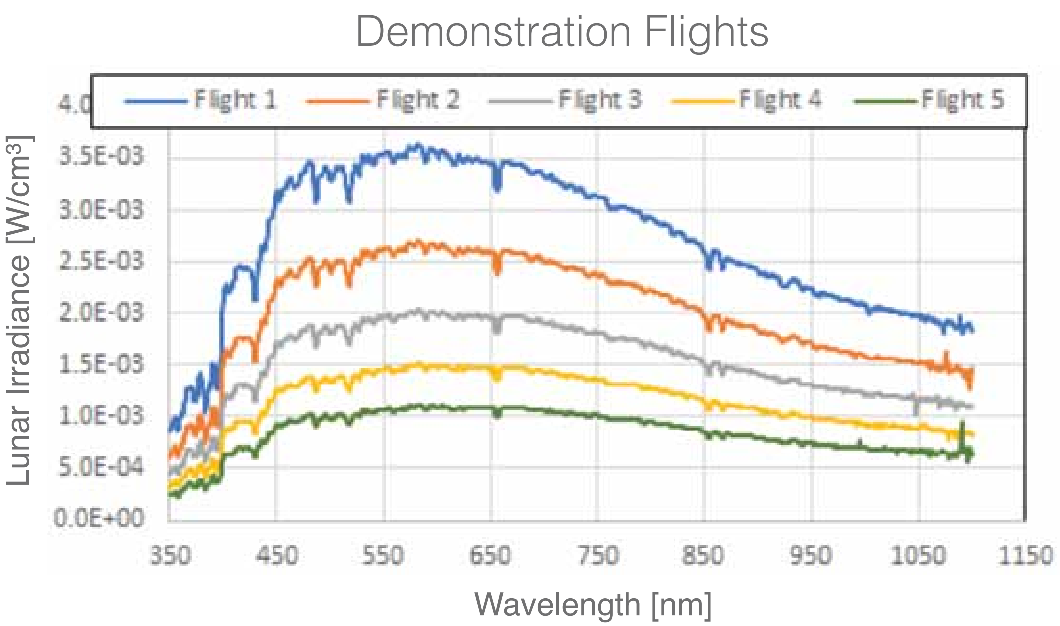


Figure 33. *The Air-LUSI campaign produced sensor calibrated lunar spectral irradiance results at 10°, 21°, 34°, 46°, and 59° of lunar phase angle.*

ASP Support to Applied Science

In 2019, as in previous years, several flight campaigns supported Applied Science or science goals of additional agencies. Table 8 lists campaigns with additional other user applications.

Table 8. *Airborne Support to Applied Science in FY19.*

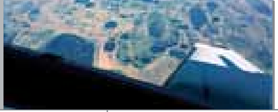
Mission	Flight Hours	Location	Aircraft
Harmful Algal Bloom	32.2	Lake Erie	Twin Otter
Mother Lode Mining for EPA	9.2	California	B-200
NASA Fall Methane Survey	56.3	California	B-200
SacDeltaLevees-CDWR-2 (California Department of Water Resources)	18.3	Sacramento	G-III
Satellite Enhanced Snowmelt Flood Predictions in the Red River of the North Basin	6.8	North Dakota	G-III

Upcoming Activities

Major upcoming missions are listed in Table 9. The flight calendar for the Earth Venture Suborbital-3 (EVS-3) missions is shown in Figure 34.

Table 9. *Planned Major 2020 Missions.*

Mission	Aircraft	Location	Science Program
ACCLIP Engineering Flights	WB-57	Houston	Atmospheric Composition
ACTIVATE	HU-25 Falcon, B-200	North Atlantic	EVS-3
DCOTSS	ER-2	Eastern U.S.	EVS-3
DELTA-X	G-III, B-200 (2)	Mississippi River Delta	EVS-3
IMPACTS	ER-2, P-3	U.S. East Coast	EVS-3
OMG	DC-3; G-III	Greenland	EVS-2
S-MODE	G-III, B-200	California (Pacific Ocean)	EVS-3
SARP	P-3	California	Education
SNOWEX	G-III, Twin Otter	Colorado, Alaska	Terrestrial Hydrology



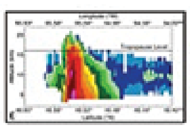
Mission	Location	Aircraft	CY2020				CY2021				CY2022			
IMPACTS	U.S. East Coast	P-3, ER-2	■			■	■			■	■			
DCOTSS	Based from Salinas, Kansas	ER-2			■				■				■	
S-MODE	Pacific Ocean off Monterey	G-III, B-200				■				■		■		
ACTIVATE	Western North Atlantic	HU-25, B-200	■	■			■	■			■	■		
Delta-X	Mississippi River Delta	G-III, B-200 (2)				■	■	■	■					

Figure 34. *EVS-3 Missions, Aircraft, and Nominal Flight Schedules (CY).*

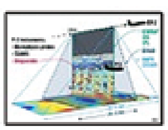
In addition, ASP plans to support instrument development, calibration and validation activities and process studies for upcoming missions dedicated to the Designated Observables, Explorer, and Incubation missions described in the 2017 Decadal Survey.[1]

EVS-3 Investigations

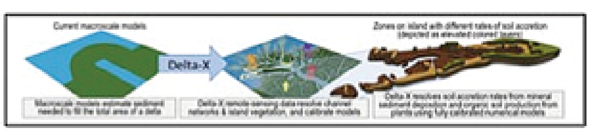
ACTIVATE - Aerosol Cloud meTeorology Interactions oVer the western ATlantic investigates how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean



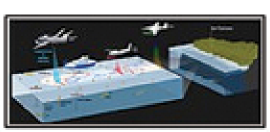
DCOTTS - Dynamics and Chemistry of the Summer Stratosphere investigates how strong summertime convective storms over North America can change the chemistry of the stratosphere



IMPACTS - Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms study the formation of snow bands in East Coast winter storms.



Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas



SMODE - Submesoscale Ocean Dynamics and Vertical Transport investigation to explore the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere

[1]Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from space ("ESAS 2017")

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. Contracted Aviation Services

Airborne Science Program Platform Capabilities

Platform Name	Center	Payload Accommodations	Duration (Hours)	Useful Payload (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)
ASP Supported Aircraft							
DC-8	NASA-AFRC	4 nadir ports, 1 zenith port, 14 additional view ports	12	30,000	41,000	450	5,400
ER-2 (2)	NASA-AFRC	Q-bay (2 nadir ports), nose (1 nadir port), wing pods (4 nadir, 3 zenith ports), centerline pod (1 nadir port	12	2,900	>70,000	410	>5,000
Gulfstream III (G-III)(C-20A)	NASA-AFRC	UAVSAR pod	7	2,610	45,000	460	3,400
Gulfstream III (G-III)	NASA-JSC	UAVSAR pod, Sonobuoy launch tube	7	2,610	45,000	460	3,400
Gulfstream III (G-III)	NASA-LARC	2 nadir ports	7	2,610	45,000	460	3,400
Gulfstream V (G-V)	NASA-JSC	2 nadir ports	10	8,000	51,000	500	>5,000
P-3	NASA-WFF	1 large and 3 small zenith ports, 3 fuselage nadir ports, 2 bomb bay 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
Other NASA Aircraft							
B-200 (UC-12B)	NASA-LARC	2 nadir ports, aft pressure dome with dropsonde tube, cargo door	6.2	4,100	31,000	260	1,250
B-200	NASA-AFRC	2 nadir ports	6	1,850	30,000	272	1,490
B-200	NASA-LARC	2 nadir ports, wing tip pylons, zenith site for aerosol inlet, lateral ports	6.2	4,100	35,000	275	1,250
C-130	NASA-WFF	3 nadir ports, 1 zenith port, 2 rectangular windows, wing mount for instrument canisters, dropsonde capable, cargo carrying capable	12	36,500	33,000	290	3,000
Cessna 206H	NASA-WFF	Wing pod, belly pod, modified rear window for zenith ports	5.7	1,175	15,700	150	700
Dragon Eye	NASA-ARC	In situ sampling ports	1	1	500+	34	3
HU-25A Guardian	NASA-LARC	1 nadir port, wing hard points, crown probes	5	3,000	42,000	430	1,900
Matrice 600	NASA-ARC	Imager gimbal	1	6	8,000	35	3
SIERRA-B	NASA-ARC	Interchangeable nose pod for remote sensing and sampling and one nadir port	10	100	12,000	60	600
WB-57 (3)	NASA-JSC	Nose cone, 12ft of pallets using either 3ft or 6ft pallets, 2 Spearpods2 Superpods, 14 Wing Hatch Panels	6.5	8,800	60,000+	410	2,500

Table 10. *Airborne Science Program Aircraft and their Performance Capabilities.*

are used when NASA aircraft are not available or do not meet specific mission requirements. The Program and Flight Centers support projects by evaluating vendors and providing airworthiness and flight safety reviews.

More information about using these aircraft is provided on the ASP website at: airborne-science.nasa.gov. The annual "call letter," also available on the ASP web site, is an excellent source of information describing how to request airborne services.

The ASP fleet includes aircraft that can support low-and-slow flights to those capable of flying high and fast. The aircraft have a wide variety of payload capacities. Aircraft performance characteristics are listed in Table 10. Their altitude/endurance characteristics are shown in Figure 35, with altitude/range provided in Figure 36.

NASA Earth Science Research Capable Aircraft

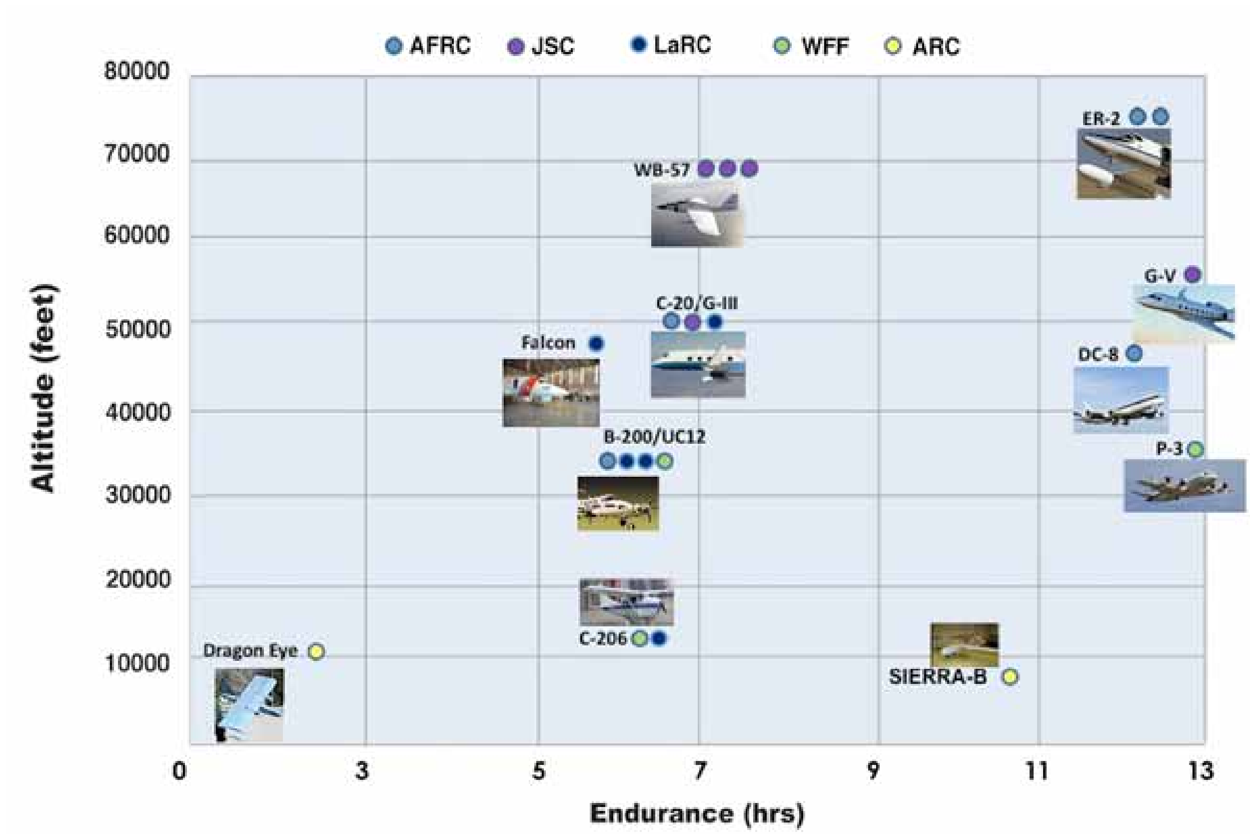


Figure 35. *A comparison of NASA science aircraft altitude and endurance capabilities.*

NASA Earth Science Research Capable Aircraft

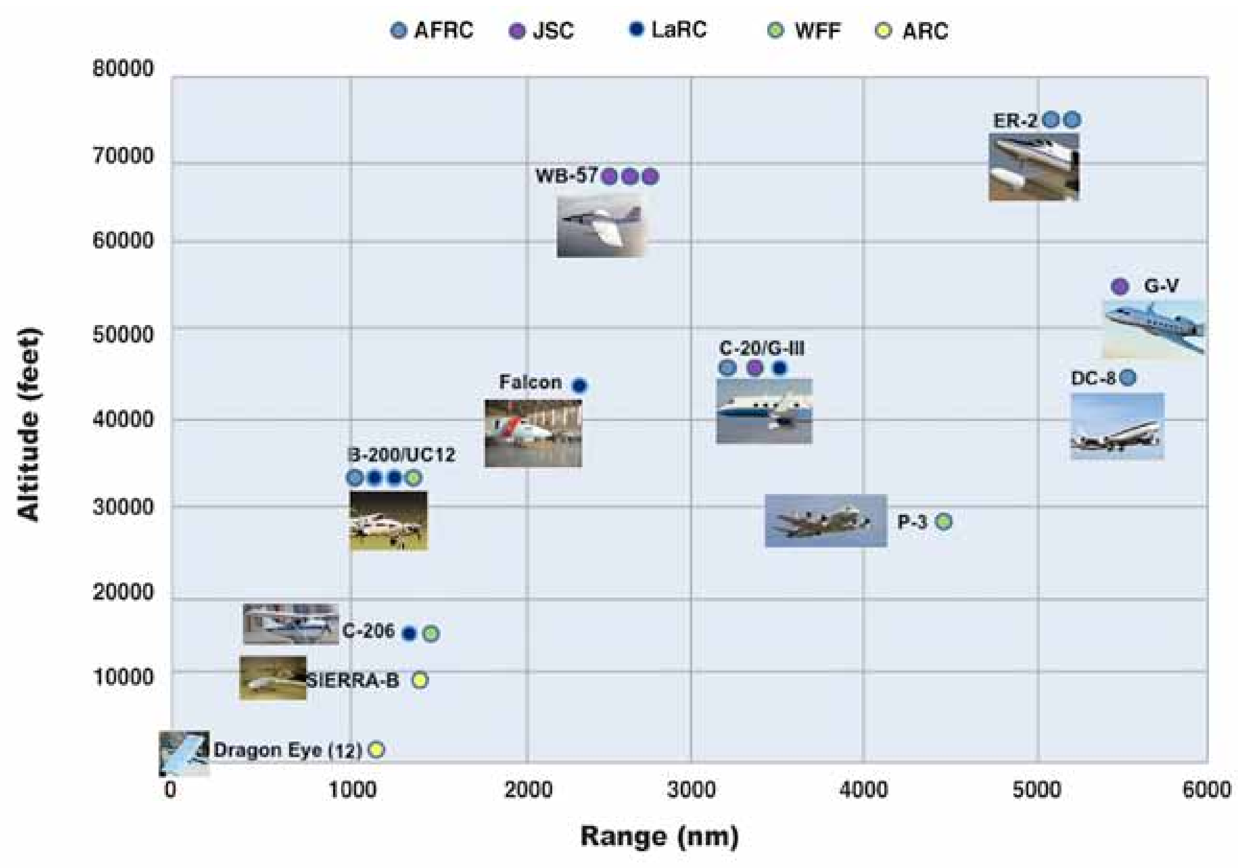


Figure 36. *A comparison of NASA science aircraft altitude and range capabilities.*

ASP-Supported Aircraft

The seven aircraft systems ASP directly supported (subsidized flight hours) in FY19 are the DC-8 flying laboratory, two ER-2 high altitude aircraft, P-3, C-20A (G-III), JSC G-III, and JSC G-V. Beginning in FY20, ASP will also provide flight hour support to the new LaRC G-III.

DC-8

Operating Center:
Armstrong Flight Research Center (AFRC)

Aircraft Description:
The DC-8 airborne laboratory is a four-engine jet aircraft with a range in excess of 5,000 nm, a ceiling of 41,000 ft, and an experiment payload of 30,000 lb (13,600 kg). This aircraft has been extensively upgraded and modified to provide a world class airborne platform for collecting gas samples as well as carrying high mass/volume/power radar, lidar and imaging systems.

FY19 Science Flight Hours: 513

DC-8 FY19 Missions

Mission	Location	Science Program Area
Aeolus Cal/Val	California, Pacific Ocean	Weather
FIREX-AQ	Idaho, Kansas	Atmospheric Composition
OIB	Chile, Argentina	Cryosphere
SARP	California	Atmospheric Composition

FY19 Modifications and Impacts on Performance and Science:

The DC-8 aircraft received a cabin oxygen system upgrade in FY19. This upgrade will result in reduced maintenance costs and create common critical spares inventory with the SOFIA system. The aircraft also received forebody bracket repairs and 1A/2A maintenance. After the FIREX-AQ mission, engine inspection identified damage to all four engines. Engine repair is underway through January 2020. The DC-8 maintenance schedule is shown in Appendix A.

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

Figure 37. *The DC-8 Landing in Boise, Idaho during FIREX-AQ.* ***Photo credit:*** *Dan Chirica / NASA*

ER-2

Operating Center:
Armstrong Flight Research Center (AFRC))

Aircraft Description:
The ER-2 is a civilian version of the Air Force's U2-S reconnaissance platform. NASA operates two ER-2 aircraft. These high altitude science aircraft are unique in the world, providing NASA scientists with satellite-like observations above 98% percent of the Earth's atmosphere.

FY19 Science Flight Hours: 73.1

ER-2 FY19 Missions

Mission	Location	Science Program Area
California Continuity (HyspIRI prep)	California	Terrestrial Ecology
FIREX-AQ	California to Idaho fire region	Atmospheric Composition

FY19 Modifications and Impacts on Performance and Science:

Cabin Altitude Reduction Effort (CARE) modifications and reassembly were completed on the ER-2 809 in FY19, allowing ER-2 809 to participate in FIREX-AQ. Required pilot proficiency flights permitted only modest additional science during FY19. The purpose of the CARE modification is to structurally modify the aircraft to reduce cockpit cabin altitude from 29,000 ft to 15,000 ft when the aircraft is cruising at 65,000 ft. This modification is designed to reduce likelihood of decompression sickness, fatigue, and risk of permanent neurological injury. A similar CARE modification began on NASA ER-2 806 in late FY19. Completion is expected by December 2020. The ER-2 maintenance schedule is shown in Appendix A.

Figure 38. *The NASA ER-2 In Flight Over an Idaho Fire During FIREX-AQ.*
Photo credit: *Stu Broce / NASA*

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

P-3 Orion

Operating Center:
Wallops Flight Facility (WFF)

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

FY19 Science Flight Hours: 506.2

P-3 Orion FY19 Missions

Mission	Location	Science Program Area
$CAMP^2EX$	Philippines	Atmospheric Composition
OIB-Arctic	Greenland, Alaska	Cryosphere
ORACLES	Africa	Atmospheric Composition

FY19 Modifications and Impacts on Performance and Science:
In FY19, the P-3 Orion aircraft was modified to support dropsonde deployments. The pressurized dropsonde launcher enables sonde deployments over the full range of airspeeds and altitudes of the P-3. The system functions similarly to the dropsonde system installed on the NASA DC-8 aircraft and utilizes an electrically-controlled (manually-operated backup) gate valve to release sondes. Also in FY19, the P-3 Nadir #1 port aperture was enlarged to 31” x 21”. This rectangular opening allows installation of flat cover plates that can be modified for a variety of window sizes, including multiple windows on a single cover plate. Hardware was also manufactured in FY19 to covert the P-3 Nadir #2 port to a larger aperture size in FY20.

Figure 39. *The P-3 at Clark Airport in the Philippines During the $CAMP^2Ex$ Mission.*

Significant Upcoming Maintenance Periods:

- March-May 2020: Landing gear overhaul and annual maintenance period
- Annual: 6-8 week maintenance period (can be adjusted to meet mission needs)
- Fall 2021: Phased depot maintenance (4-6 month effort)
- Fall 2022: Phased depot maintenance (3-4 month effort)

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

Gulfstream G-V

Operating Center:
Johnson Space Center (JSC)

Aircraft Description:
The Gulfstream V (G-V) is a long-range, large business jet aircraft built by Gulfstream Aerospace, derived from the Gulfstream IV. It flies up to Mach 0.885, at up to 51,000 feet, and has a range of 6,500 nautical miles. JSC procured the G-V in 2016 as part of a shared usage agreement between the ISS Program and NASA ESD. The ISS program uses the G-V for Crew Return missions and ESD uses it to support airborne science missions in remote locations around the world. With significant accommodations for science payloads, the G-V flew four science missions in FY19 and made its first science campaign to Antarctica in November 2019 (FY20).

FY19 Science Flight Hours: 272.9

G-V FY19 Missions

Mission	Location	Science Program Area
ABoVE	Canada, Alaska	Terrestrial Ecology
GEDI Underflights	Costa Rica, U.S.	Terrestrial Ecology
OIB	Greenland	Cryosphere
SWOT Cal/Val	California	Water and Energy Cycle

FY19 Modifications and Impacts on Performance and Science:

1) The JSC team completed the baseline science modification to the G-V, including:
   a. Nadir portal modification
   b. Window pack design, analysis, fabrication, and assembly. JSC currently has three panes of fused silica that provides a 17.4" diameter aperture.
   c. Environmental testing (pressure) procedure and test equipment to verify airworthiness of windows prior to mission execution.
   d. Modified one window pack assembly to install an additional germanium window for a FLIR.
   e. Cabin floor vent to allow air to escape from the cabin to below floor should a window fail in flight.
   f. Supplemental oxygen system to support scientists in the event of a decompression event in the airplane over a remote location like Antarctica.

Figure 40. *NASA G-V after arriving at Hobart airport after a successful science flight. A brief rain shower created a rainbow in the background.* ***Photo credit:*** *Rod Anthony / NASA*

2) Initial science modifications to the aircraft include 2 nadir view ports to support active and passive remote sensing missions

Significant Upcoming Maintenance Periods:

1) 2020: NextGen avionics upgrade – mandated upgrade to communication and navigation equipment for world-wide operations

2) 2020/2021: Cockpit display upgrade due to part obsolescence and sustainment issues

Unlike the G-III, these G-V upgrades are completed entirely by Honeywell to maintain the avionics protection plan coverage for the aircraft.

Website:

https://airbornescience.nasa.gov/aircraft/G-V_-_JSC

Figure 41. *The JSC G-V has been modified for science missions.*

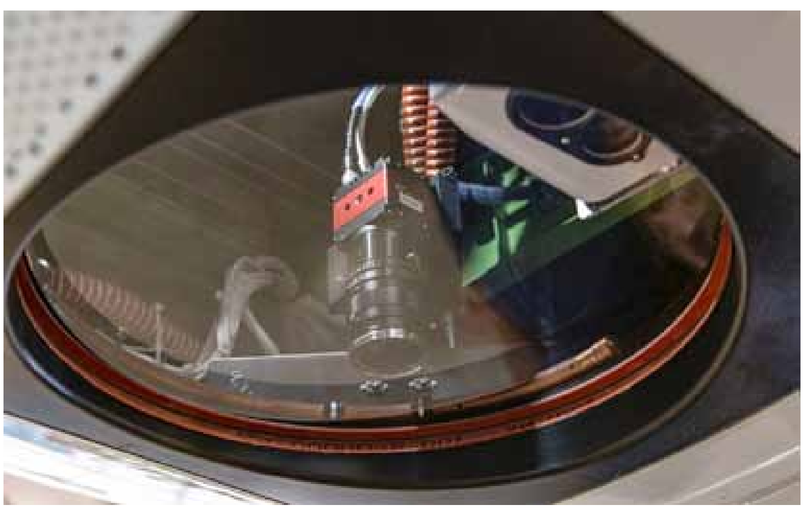


Figure 42. *The Continuous Airborne Mapping by Optical Translator (CAMBOT) camera seen through the G-V nadir port window. Also visible is the Headwall Hyperspectral Imager.* ***Photo credit:*** *Jeremy Harbeck / NASA*

C-20A (Armstrong G-III)

Operating Center:
Armstrong Flight Research Center (AFRC)

Aircraft Description:
The Gulfstream III is a business jet with routine flight at 40,000 feet. Both the AFRC and JSC platforms have been structurally modified and instrumented to serve as multi-role cooperative platforms for the Earth Science research community. Each can carry a payload pod for the three versions of JPL's UAVSAR instrument (L-band, P-band, Ka-band). Both are part of the ASP-supported fleet. Beginning during FY20, the LaRC G-III will also become part of the ASP-supported fleet, but it does not carry the JPL SAR pod.

FY19 Science Flight Hours: 140.5

C-20A (G-III) FY19 Missions

Mission	Location	Science Program Area
AZURE	Norway	Sounding Rocket Program
Environmental Controls on Landslide Motion Revealed by InSAR and Pixel Offset Tracking	Colorado	Earth Surface and Interior
Imaging Near-fault Deformation in Central and Northern California	California	Earth Surface and Interior
NISAR/SMAP CTSM Complement	California	Water and Energy Cycle
Plate Boundary UAVSAR	California	Earth Surface and Interior
SacDeltaLevees-CDWR-2	California	Earth Surface and Interior / Applied Science
SIF Aerobiology	California	Carbon Cycle
UAVSAR L-band Engineering	California	Earth Surface and Interior

FY19 Modifications and Impacts on Performance and Science:
The aircraft received a cockpit upgrade and Ops 1 and 2 maintenance. At the end of FY19, the aircraft was integrated with the ISRO L+S Band Pod in preparation for FY20 ASAR support.

Website:
http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Armstrong

Figure 43. *The AFRC C-20A in Alaska During the ASAR Campaign.*
Photo credit: *Andrew Barry / NASA*

JSC G-III

Operating Center:
Johnson Space Center (JSC)

Aircraft Description:
The G-III is a business jet with routine flight at 40,000 feet. The AFRC and JSC G-III platforms have been structurally modified and instrumented to serve as multi-role cooperative platforms for the Earth Science research community. Each can carry a payload pod for the three versions of JPL's UAVSAR instrument. The JSC G-III carried each SAR version during 2019.

FY19 Science Flight Hours: 303.3

JSC G-III FY19 Missions

Mission	Location	Science Program Area
ABoVE	Canada, Alaska	Terrestrial Ecology
Engineering Flights	California	Earth Surface and Interior
Landslide Mapping	Colorado	Earth Surface and Interior
NISAR AM/PM	Southeast U.S.	Earth Surface and Interior
OMG	Greenland	Cryosphere
Red River	North Dakota	Water and Energy Cycle
SacDelta	California	Carbon Cycle
Sierra Nevada Faults	California	Earth Surface and Interior

FY19 Modifications and Impacts on Performance and Science:

The JSC team changed both engines on the aircraft and replaced them with the two engines from the parts aircraft purchased in FY18. The right engine was due for replacement because of calendar and the left engine was replaced to more efficiently use the life in the serviceable engines that JSC owns (i.e., get the most life out of the engines with the least cost).

Significant Upcoming Maintenance Periods:

- NextGen Avionics Upgrade: mandated upgrade to communication and navigation equipment for world-wide operations
- Engine Changeout: The two engines removed from the airplane, with maintenance, have useful life remaining. JSC will send these engines to an overhaul facility for maintenance to make them serviceable. With this maintenance, the G-III engines are serviceable through the beginning of 2028.

Figure 44. *The JSC G-III Showing the UAVSAR Pod.*

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

LaRC G-III

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The Gulfstream III (a former U.S. Air Force C-20B) aircraft will become available for NASA science during FY20. The aircraft will become part of the ASP-supported fleet, potentially taking some load off the ER-2 for instrument test flights. Eventually, this aircraft (NASA 520) will replace the LaRC Dassault HU-25A Guardian aircraft (NASA 524) for airborne science. The nadir portals (each 18.16 in. x 18.16 in. 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. Six Researcher Interface Panels are being installed in the passenger cabin, which will accommodate up to ten researchers. The research system will also accommodate the NASA Airborne Science Data and Telemetry (NASDAT) system. The G-III aircraft has an advertised range of 3750 nm. The expected duration will be 7.5 hours and the nominal mission altitude is 45,000 ft.

First Missions (FY20):
The first mission with this aircraft will be flights of for an IIP project, the Compact Midwave Imaging System (CMIS), for the Applied Physics Laboratory, Johns Hopkins University. The CMIS suite will be installed in the aft nadir portal and use four custom-made optical panels.

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

Figure 45. *The NASA Langley Gulfstream III Aircraft at LaRC.*

Figure 46. *The LaRC G-III has been modified for science missions.*

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 11. *Other NASA Aircraft Available for Earth Science Missions.*

Aircraft	Operating Center
AlphaJet	Under agreement with ARC
B-200 King Air; UC-12B	LaRC, AFRC, WFF, or contracted
C-130 Hercules	WFF
Cessna 206H	LaRC
HU-25A Falcon / HU-25C Guardian	LaRC
SIERRA-B	ARC
Small UAS	AFRC, ARC, LaRC, JPL
Twin Otter	GRC or contracted
Viking-400 UAS (in development)	ARC, LaRC
WB-57	JSC

C-130 Hercules

Operating Center:
Wallops Flight Facility (WFF)

Aircraft Description:
The C-130 is a four-engine turboprop aircraft designed for maximum payload capacity. WFF operates two C-130 aircraft. In 2018, one was decommissioned after failure during NAAMES. The other supported the EVS-2 mission ACT-America.

FY19 Science Flight Hours: 113.6

C-130 FY19 Missions

Mission	Location	Science Program Area
ACT-America	Wallops Island, Virginia, Lincoln, Nebraska, and Shreveport, Louisiana	Atmospheric Composition

Significant Upcoming Maintenance Periods:

- Fall 2021: Phased Depot Maintenance (3-4 months).

Website:
http://airbornescience.nasa.gov/aircraft/C-130_Hercules

Figure 47. *The WFF C-130 and LaRC B-200 flew together during the ACT-America mission in FY19.*

B-200 / UC-12

Operating Center:
Langley Research Center (LaRC), Armstrong Flight Research Center (AFRC), Wallops Flight Facility (WFF)

Aircraft Description:
LaRC operates a conventional B-200 and a UC-12B (military version). Each has been extensively modified for remote sensing research. AFRC operates a Super King Air B-200 that has been modified for downward looking payloads. WFF operates a B-200 primarily for mission management operations. The Beechcraft B-200 King Air is a twin-turboprop aircraft capable of mid-altitude flight (>30,000 ft) with up to 1000 pounds of payload for up to 6 hours. The three B-200 aircraft have varying modifications to support science.

FY19 Science Flight Hours: 147.9

B-200 FY19 Missions

Mission	Location	Science Program Area
ACT-America	LaRC; Nebraska, Louisiana	Atmospheric Composition
HSRL-2	LaRC	ESTO AITT
IPDA	LaRC	ESTO IIP
LISTOS	LaRC; New York	Atmospheric Composition
LVIS	LaRC	Cryosphere

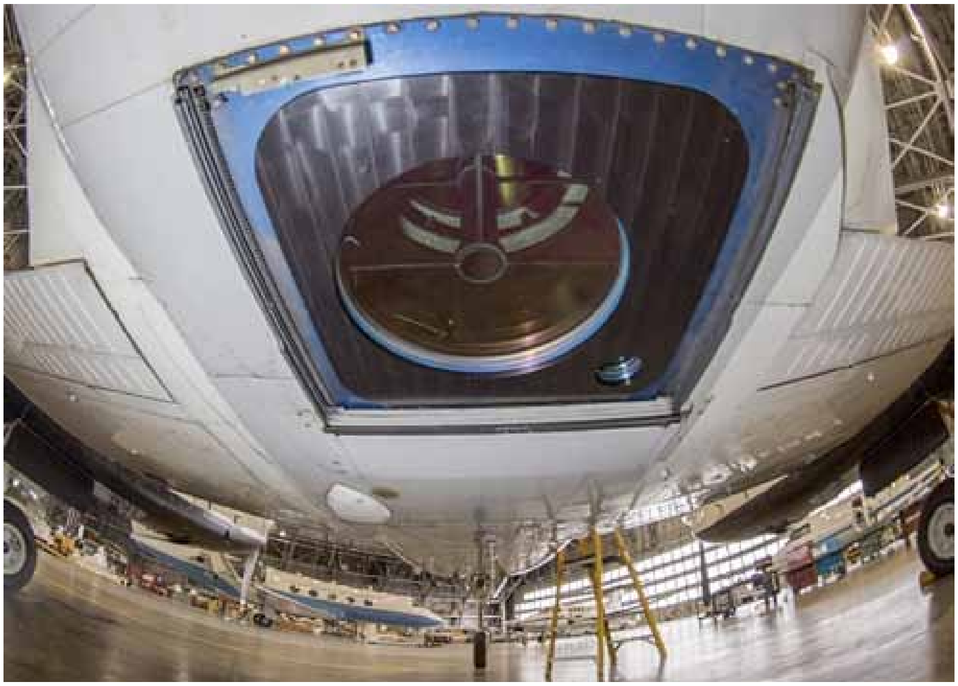


Figure 48. *Lasers from the triple-pulse integrated path differential absorption (IPDA) system were fired through a window in the belly of the LaRC B-200.* ***Photo credit:*** *David Bowman / NASA*

FY19 Modifications and Impacts on Performance and Science:

- Installed a portal on the top of the nose ahead of the windshield on the UC-12B (NASA 528)
- Installed a dropsonde launcher on the UC-12B (NASA 528) for upcoming EVS-3 mission ACTIVATE; this can also be installed on the B-200 (NASA 529)

Significant Upcoming Maintenance Periods:

Each aircraft undergoes phase inspections as a function of flight hours or elapsed time. A typical phase inspection has a duration of four weeks. The phase inspections occur as necessary, based on aircraft usage.

Website:

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

http://airbornescience.nasa.gov/aircraft/B-200_UC-12B_-_LARC

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

http://airbornescience.nasa.gov/aircraft/B-200_King_Air_-_WFF

CESSNA 206H

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The NASA LaRC Cessna 206H is an all-metal, six-seat, high-wing, single-engine general aviation airplane equipped with tricycle landing gear and is designed for general utility purposes. The aircraft was acquired by NASA in 2001 to provide a low-cost research platform for advanced pilot displays and to serve as a platform for atmospheric science instruments. The aircraft has been reconfigured for science. In addition to internal space in the aft section of the cabin for instrumentation, up to 300 lbs. can be carried in the Cessna production belly cargo pod and 100 lbs. in a custom-designed pod, which attaches to the right wing strut. The aircraft is equipped with NASA LaRC's General Aviation Baseline Research System, which includes GPS, Air Data, Attitudes and Heading Reference System (ADAHRS), out-the-window video, a Researcher Workstation, and control position transducers on the aileron, rudder, elevator, pitch trim and throttle.

FY19 Science Flight Hours: 9.6

Cessna 206H FY19 Missions

Mission	Location	Science Program Area
EPA TEROS	Eastern U.S.	Terrestrial Ecology / Applied Science

FY19 Modifications and Impacts on Performance and Science:
None

Website:

http://airbornescience.nasa.gov/aircraft/Cessna_206H

HU-25A Falcon/Guardian

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The HU-25C and HU-25A Falcons are modified twin-engine business jets based on the civilian Dassault FA-20G Falcon. The HU-25C completed an OIB mission early in FY16 and has been placed into flyable storage. The HU-25A replacement is now in active service.

FY19 Science Flight Hours: 64

HU-25A FY19 Missions

Mission	Location	Science Program Area
Sounding Rockets	Marshall Islands	Sounding Rockets

FY19 Modifications and Impacts on Performance and Science:

Installed underwing pylons, fuselage crown probes, and a flush air data system on the HU-25A (NASA 524) for the upcoming EVS-3 mission ACTIVATE.

Significant Upcoming Maintenance Periods:

Maintenance is a function of number of flight hours flown.

Website:

http://airbornescience.nasa.gov/aircraft/HU-25C_Guardian

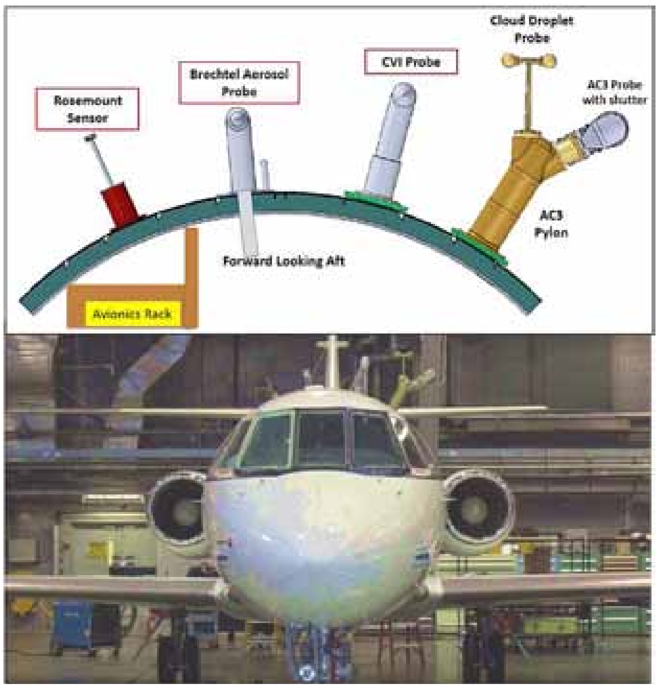


Figure 49. *Cloud and aerosol probes have been installed for the ACTIVATE mission.*

Figure 50. *The HU-25A Flew a Sounding Rocket Project in FY19.*

WB-57 High Altitude Aircraft

Operating Center:

Johnson Space Center (JSC)

Aircraft Description:

The WB-57 is a mid-wing, long-range aircraft capable of operation for extended periods of time from sea level to altitudes in excess of 60,000 feet. The sensor equipment operator (SEO) station contains navigational equipment and controls for the operation of the payloads located throughout the aircraft. The WB-57 can carry up to 8800 pounds of payload. JSC maintains three WB-57 aircraft.

FY19 Science Flight Hours: 0

FY19 Modifications and Impacts on Performance and Science:

None; the aircraft team is preparing to support the ACCLIP mission in FY20.

Website:

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

Figure 51. *The WB-57 is in preparation for ACCLIP flights in FY20.*

SIERRA-B UAS

Operating Center:
Ames Research Center (ARC)

Aircraft Description:
The Sensor Integrated Environmental Remote Research Aircraft (SIERRA)-B aircraft is a high wing, 480 lb. gross weight monoplane (UAS Class III) with twin tail booms and inverted V-tail. It can perform remote sensing and atmospheric sampling missions in isolated and often inaccessible regions, such as the open ocean, or the Arctic/Antarctic. UAS missions are of particular value when long flight durations or range-measurement requirements preclude a human pilot or where remote or harsh conditions place pilots and high-value aircraft at risk. Designed by the U.S. Naval Research Laboratory and developed at NASA ARC, the SIERRA-B is well suited for precise and accurate data collection missions because it is large enough to carry up to 100 pounds of scientific instruments and fly up to 12,000 feet, yet is small enough not to require a large runway or hangar.

FY19 Science Flight Hours: 6

SIERRA-B FY19 Missions

Mission	Location	Science Program Area
SRI CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD)	Crows Landing, California	ESTO IIP

Figure 52. The SIERRA-B Returned to Service in FY19.

FY19 Modifications and Impacts on Performance and Science:
SIERRA-B completed flight qualification and began working with payloads in November 2019.

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

Website:
http://airbornescience.nasa.gov/aircraft/SIERRA_-_ARC

5. Aircraft Cross-Cutting Support and IT Infrastructure

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

Cross-cutting support for ASP missions is managed at ARC. through the Airborne Sensor Facility (ASF) and the National Suborbital Research Center (NSRC). Specific activities include providing facility instruments, satellite telemetry and mission tools data services, and assistance with payload integration engineering. Additional support for mission management and real-time flight tracking is provided by ARC through the Mission Tools Suite (MTS).

ASP Facility Science Infrastructure

Facility Instrumentation

The ASP provides a suite of facility instrumentation and data communications systems for community use by approved NASA investigators. Currently available ASP instrumentation (listed in Table 10) includes stand-alone precision navigation systems, and a suite of digital tracking cameras and video systems. Real-time data communications capabilities, which differ from platform to platform, are also described below, and are integral to a wider Sensor Network architecture. In addition, ESD, through the Research and Analysis (R&A) Program and the EOS Project Science Office, maintains a suite of advanced imaging systems that are made available to support multidisciplinary research applications. These are supported at various NASA field centers including JPL, ARC and LaRC. The ASF also maintains a spectral and radiometric instrument calibration facility, which supports the wider NASA airborne remote sensing community. Access to any of these assets is initiated through the ASP Flight Request process. (See page 4).

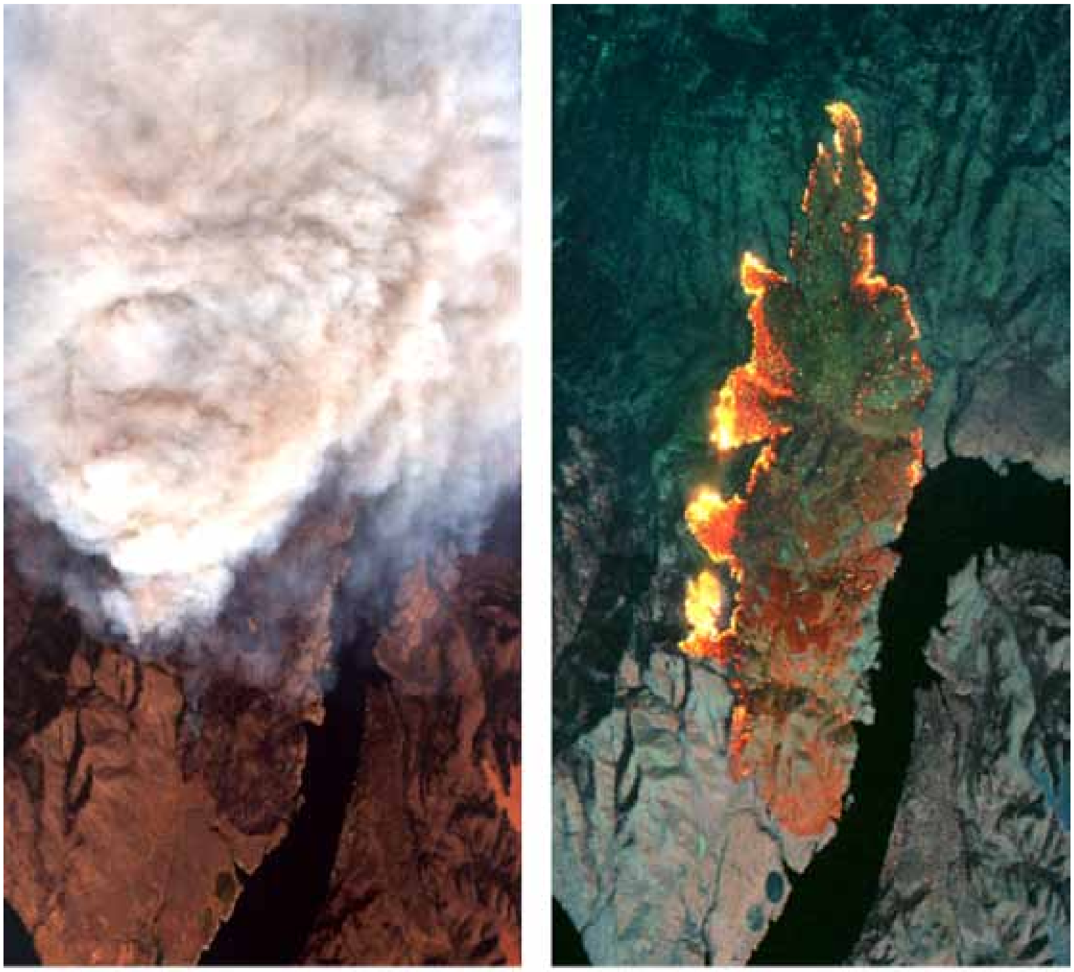
Sensor Network IT Infrastructure

A state-of-the-art real-time data communications network has been implemented across the ASP core platforms. Utilizing onboard Ethernet networks linked through airborne satellite communications systems to the web-based MTS, the sensor network is intended to maximize the science return from both single-platform missions and complex multi-aircraft science campaigns. It leverages data visualization tools developed for the NASA DC-8, remote instrument control protocols developed for the Global Hawk aircraft, and standard data formats

devised by the Interagency Working Group for Airborne Data and Telecommunication Systems (IWGADTS.) The sensor network architecture includes standardized electrical interfaces for payload instruments, using a common Experimenter Interface Panel (EIP); and an airborne network server and satellite communications gateway known as the NASA Airborne Science Data and Telemetry (NASDAT) system; and a web-based application programming interface (API) for interfacing to customer software and other agencies. These capabilities are now operational, as indicated in Table 12.

Table 12. *ASP, EOS, and R&A Facility Equipment.*

Airborne Science Program Facility Equipment		
Instrument / Description	**Supported Platforms**	**Support Group / Location**
DMS (Digital Mapping System) 21 MP Natural Color Cameras	Most ASP Platforms	ASF / ARC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/Precision IMU	All ASP Platforms	3 at ASF / ARC
PPOS AV 610 (2) Applanix Position and Orientation Systems; DGPS w/ Precision IMU	All ASP Platforms	2 at ASF / ARC; 2 at WFF
Dew Point Hygrometers	DC-8, P-3, C-130	NSRC
IR surface temperature pyrometers	DC-8, P-3, C-130	NSRC
LN-251 EGI (Embedded GPS/INS) Position and Orientation Systems	DC-8, P-3, C-130	NSRC
High Altitude Radar Altimeter	DC-8, P-3, C-130	NSRC
Forward and Nadir 4K Video Systems	DC-8, P-3, C-130, ER-2	NSRC; ASF (ER-2)
Total Air Temperature Probes	DC-8, P-3, C-130	NSRC
MVIS 4K Video Camera (Nadir)	ER-2	ASF
FLIR Vue Pro R 640 (45 Degree and Nadir)	DC-8	NSRC
45-degree Visible Camera	DC-8	NSRC
EOS and R&A Program Facility Instruments		
Instrument / Description	**Supported Platforms**	**Support Group / Location**
MASTER (MODIS/ASTER Airborne Simulator) 50 ch Multispectral Line Scanner V/SWIR-MW/LWIR	B200, DC-8, ER-2, P-3, WB-57	ASF / ARC
Enhanced MAS (MODIS Airborne Simulator) 38 ch Multispectral Scanner	ER-2	ASF / ARC
PICARD (Pushbroom Imager for Cloud and Aerosol R&D) 400 – 2450nm range, Δλ 10nm	ER-2	ASF / ARC
AVIRIS-ng Imaging Spectrometer (380 - 2510nm range, Δλ 5nm)	Twin Otter, B-200	JPL
PRISM (Portable Remote Imaging SpectroMeter) (350 - 1050nm range, Δλ 3.5nm)	Twin Otter, ER-2	JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, Δλ 10nm)	ER-2, Twin Otter	JPL
UAVSAR Polarimetric L-band Synthetic Aperture Radar, Capable of Differential Interferometry	G-3/C-20	JPL
NAST-I Infrared Imaging Interferometer (3.5 – 16mm range)	ER-2	LaRC



RGB (0.654um-0.546um-0.462um) CIR (4.060um-2.210um-1.602um)

Figure 53. *MASTER Imagery (Left: Visible, Right: Infrared) collected during overflight of the Williams Flat fire during FIREX-AQ.*

NASA Airborne Science Data and Telemetry System

The NASA Airborne Science Data and Telemetry (NASDAT) system provides experiments with:

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

Satellite Communications Systems

Several types of airborne satellite communications systems are currently operational on the core science platforms. High bandwidth Ku- and Ka-band systems, which use large steerable dish antennas, are installed on the WB-57. INMARSAT Broadband Global Area Network (BGAN) multi-channel systems, using

Table 13. *Satellite Communications Systems on ASP Aircraft.*

Satcom System Type/Data Rate (Nominal)	Supported Platforms	Support Group/Location
Ku-Band (1 channel system) / > 1 Mb/sec	WB-57	ARC; AFRC; JSC
Inmarsat BGAN (2 channel systems) / 432 Kb/sec per channel	DC-8, WB-57, P-3, AFRC B200, ER-2	ARC
Iridium (1 4 channel systems) / 9.6 Kb/sec (4 channel NASDAT system)	Most ASP Platforms	ARC

electronically-steered flat panel antennas, are available on many of the core aircraft. Data-enabled Iridium satellite phone modems are also in use on most of the science platforms as well. 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. Satcom systems in operation on ASP aircraft are listed in Table 13.

Payload Management

ASP provides a variety of engineering support services to instrument teams across all program platforms. These services include mechanical engineering, electrical and network interface support, and general consulting on the operational issues associated with specific aircraft.

ASP staff assist investigators during all phases of airborne integration and flight testing. Instrument investigators provide a Payload Information Form that includes instrument requirements for space, power, aircraft data, location of the instruments, and any applicable inlet or window access needs. The staff then uses the provided information to complete engineering design and analysis of instrument and probe installations on the aircraft and provides wiring data and display feeds to instrument operators.

A high-speed data network (wired and wireless) is maintained on each of the aircraft so on-board investigators have access to display data available on the aircraft. Video, aircraft state parameters, and permanent facility instrument data are recorded, quality controlled, and posted on the science mission and ASP data archives. Satcom services are provided with multichannel Iridium and high bandwidth INMARSAT services. These services allow for real time chat with scientists on the ground and other aircraft. NSRC engineers also work with investigators to send appropriate data up to and down from the aircraft to allow for real time situational awareness to scientists on the ground and in flight.

Along with general payload engineering services, the ASF designs and builds custom flight hardware for the ASP real-time sensor network (i.e., the network host and navigation data server [NASDAT] and standardized EIPs). ASF personnel also support the ER-2 program, providing payload integration and field operations support, as required for the real-time sensor network and the MVIS video system.

Mission Tool Suite

The ASP Mission Tool Suite (MTS) is a decisional support and situational awareness system that assists with the execution of airborne missions. The system's primary purpose is to provide a central interface for program asset tracking, reporting, and onboard instrument telemetry, including access to land- and space-based observations to support mission operational objectives. MTS enables more responsive and collaborative measurements among instruments on multiple aircraft, satellites, and on the surface to increase the scientific value of the measurements.

In addition to supporting flight and program activities over this past year, the MTS team has advanced what will become the next major release of the system. Mission support priorities, including additional requirements listed below, have made the next release important for a variety of reasons. A major objective of the system is to provide a flexible, reliable, and capable platform to accommodate the diverse requirements of program stakeholders. To this end, the goal is to continue to push and refine the system's core capabilities, and in doing so, improve the efficiency and effectiveness of flight missions. Figure 54 highlights the progression of MTS functions since 2011.

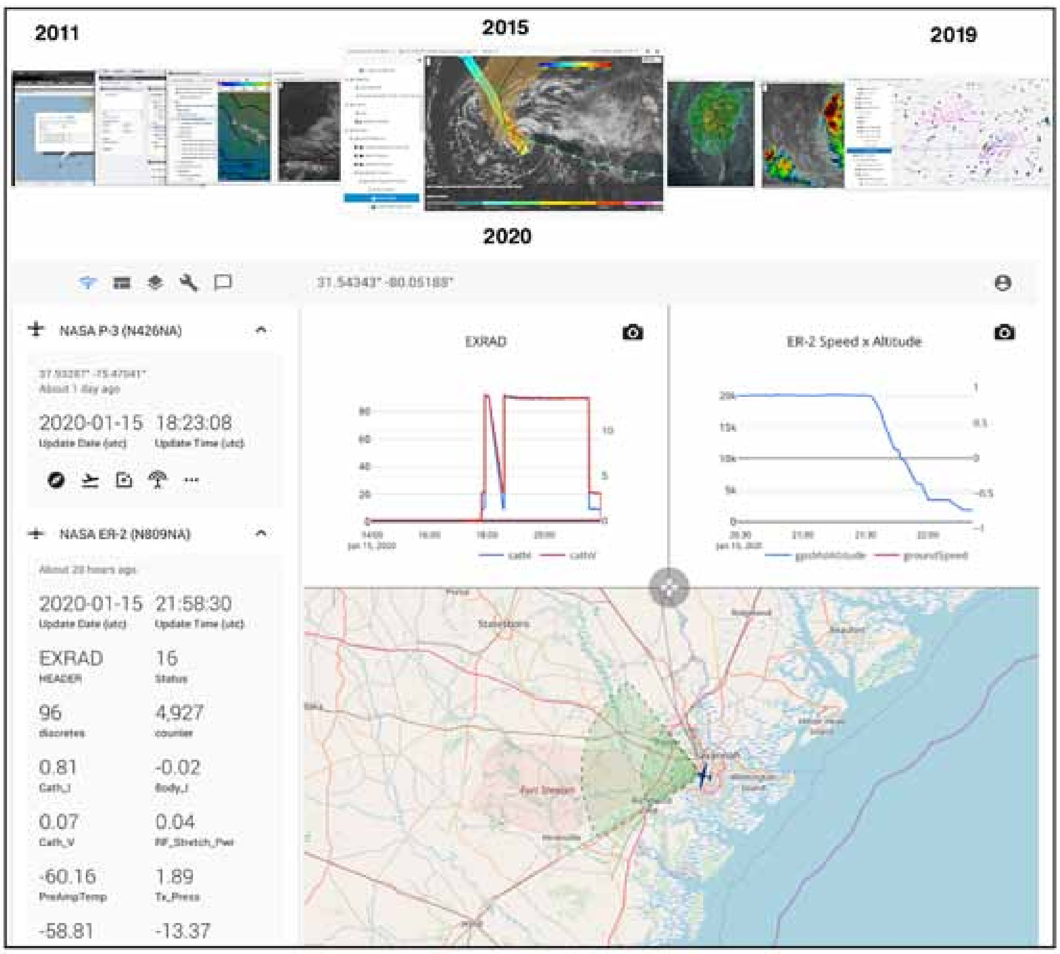


Figure 54. *The MTS user interface screen as It developed (2011 to 2020). The new MTS user interface will extend exiting decision support capabilities, enabling users to better customize their view with multiple maps, plots, and other informational overlays.*

Several features of the new system support for map projections that better serve polar missions (e.g., polar stereographic), automatic ground overlay re-projection, a more capable user interface that simplifies the process of simultaneously monitoring tracked assets across different products stacks, product video playback, and multi-channel chat. Other features make it easier for the cross-cutting infrastructure team to manage the application, and be more responsive to new IT security directives, including two-factor authentication for non-NASA users. Integration with the ASP calendar will automatically tag telemetry and other stored data for post-mission reports and visualization. The team is targeting testing to begin early February 2020, and release by the end of March. Feedback and suggestions from users are welcomed and encouraged.

The MTS team would also like to remind program stakeholders about the free access to high-quality digital models of program assets (Figure 55). Three-dimensional (3D) models are useful for aircraft visualization, public education and outreach, and are the foundation for providing the next generation interfaces that will include augmented- and virtual-reality displays. The ASP has freely available 3D digital models of NASA aircraft, including: C-20 (with/without UAVSAR), DC-8, P-3, G-V, Twin Otter, WB-57, ER-2, B-200s (LaRC, AFRC), SIERRA-B, and the C-130. Additional information is available at the ASP website.

Figure 55. *The Mission Tool Suite Provides 3D Models of ASP Aircraft.*

6. Advanced Planning

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

ASP asset and service requirements are collected and communicated through the program flight request system (http://airbornescience.nasa.gov/sofrs), annual 5-year schedule 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 observational challenges, including application of advanced telemetry systems, on-board data processing, IT mission tools, and new platforms.
- Educational Opportunities

Requirements Update

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

- Algorithm development
- Instrument test
- Calibration and validation activities

In recent years, much attention has been focused on planning for satellite and ISS Earth Science mission, such as those previously defined in the 2007 NRC Decadal Survey report. This has included SMAP and ICESat-2 and soon-to-be-launched SWOT and NISAR and the upcoming PACE mission. The remaining missions named in the 2007 Decadal Survey report are being redesigned according to guidance from the 2017 report.

ASP also continues to support existing space missions (e.g., A-Train satellites), as well as other "foundational" missions such as GPM, OCO-2, and Suomi NPP. Once launched, these missions require mandatory cal/val, often making use of airborne capabilities. New space missions on the

Figure 56. *The NASA Earth Science Fleet – airborne activities support missions in operation as well as those in the pre-launch Implementation phase.*

International Space Station, several small satellites, and collaborations with ESA and other space agencies are also targets for airborne support.

The 2017 NRC Decadal Survey for Earth Science has recommended new space activities and flight missions based on a series of "Designated Observables." New airborne support activities are anticipated for these missions and other complementary missions as they develop.

ASP personnel are also preparing an update of the "Requirements Report" in 2020, given the information in the 2017 Decadal Survey, new ESTO IIP and AITT selections, preparations for EVS-4, and new input from the science community.

Participation in science team meetings and program reviews in 2019 to describe ASP capabilities and collect requirements information are listed in Table 14.

Table 14. Activities to Support ASP Requirements Information Gathering.

Activity
Participation in 2019 PARCA/OIB Workshop
Participation in 2019 Ocean Sciences Meeting
Headquarters Visit to Review Program Area Inputs to 5-year Plan
Participation in ABoVE Science Team Meeting
Presentation at USGS Pecora Conference
Participation in 2019 ESTO Forum
Participation in 2019 AGU Fall Meeting
Participation in Solid Earth Team Meeting
Participation in Carbon Monitoring System Meeting

5-year Plan

The Program maintains a five-year plan for out-year planning and scheduling. Significant maintenance periods for the various aircraft are indicated. A copy in Appendix A depicts plans by science area and aircraft platform. The 5-year plan is also available on the ASP website.

7. Education, Training, Outreach, and Partnerships

Student Airborne Research Program 2019

The eleventh annual NASA Student Airborne Research Program (SARP) took place from June 16 to August 9, 2019 at NASA AFRC and the University of California, Irvine. SARP provides a unique opportunity for rising senior undergraduate students majoring in science, mathematics, or engineering fields to participate in a NASA Airborne Science research campaign. The goal of SARP is to stimulate interest in NASA's Earth Science research and aid in the recruitment and training of the next generation of scientists and engineers, many of whom get their first hands-on research experience during this program.

The 28 SARP 2019 participants came from 28 different colleges and universities in 20 differ-

Figure 57. *The 2019 SARP participants represented 20 different states and 28 different colleges and universities.*

Figure 58. *2019 SARP Students, Mentors, and Faculty with the NASA DC-8 Airborne Laboratory. Photo credit: NASA*

ent states (Figure 57). Student participants were competitively selected based on outstanding academic performance, future career plans, and interest in Earth system science.

The students flew onboard the NASA DC-8, from which they sampled and measured atmospheric gases to study pollution and air quality. The DC-8 overflew dairies, oil fields, and wineries in the San Joaquin Valley and the Los Angeles basin, as well as the Salton Sea, at altitudes as low as 1,000 ft to collect air samples and measure atmospheric gases.

During the SARP flights, the DC-8 was preparing for the FIREX-AQ campaign to study the impacts of U.S. wildfires and agricultural fires on air quality and climate. The DC-8 carried the full scientific payload for FIREX-AQ during the SARP flights, providing a multi-benefit opportunity for the science team to simultaneously test the instruments, collect data over a variety of sources and topography, and mentor students.

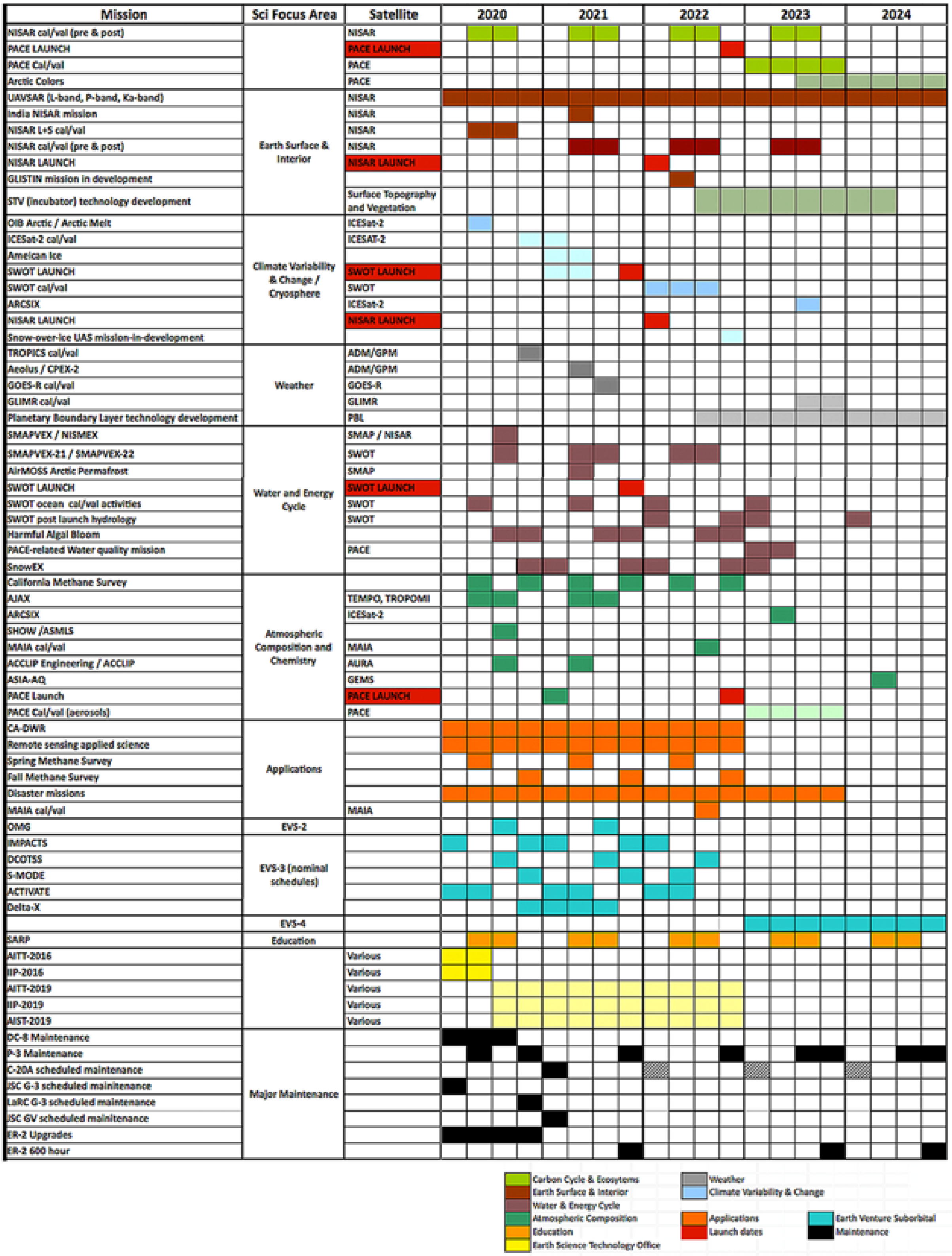
SARP students also used data from a remote-sensing instrument (AVIRIS-NG) on a King Air B-200 owned and operated by Dynamic Aviation to study drought, fire burn scars, and post-fire mudflows in Southern California, as well as ocean biology along the California coast. In addition to airborne data collection, students took measurements at field sites near Santa Barbara, Fresno, and the Salton Sea.

The final six weeks of the program took place at the University of California Irvine, where students analyzed and interpreted data collected aboard the aircraft and in the field. From this data analysis, each student developed a research project based on his or her individual area of interest. In addition to the new data collected during the program, students had the opportunity to use data gathered by SARP participants in previous years, as well as data from other NASA aircraft and satellite missions. Four students submitted conference abstracts to present the results of their SARP research at the American Geophysical Union Fall Meeting.

Appendices

Appendix A

5-year Plan



Appendix B

Acronyms

A

AA	Associate Administrator
ABoVE	Arctic-Boreal Vulnerability Experiment
ACCP	Aerosols and Clouds, Convections and Precipitation
ACCLIP	Asian summer monsoon Chemical and Climate Impact Project
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ACT-America	Atmospheric Carbon and Transport-America
ADS-B	Automatic dependent surveillance – broadcast
AFRC	Armstrong Flight Research Center
AERONET	AErosol RObotic NETwork
AGU	American Geophysical Union
Air-LUSI	Airborne Lunar Spectral Irradiance
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AITT	Airborne Instrument Technology Transition
AJAX	Alpha Jet Airborne Experiment
ARC	Ames Research Center
ARINC	Aeronautical Radio, Incorporated
ASAR	Airborne Synthetic Aperture Radar
ASF	Airborne Sensor Facility
ASO	Airborne Snow Observatory
ASP	Airborne Science Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATC	Air Traffic Control
ATM	Airborne Topographic Mapper
AVIRIS **AVIRIS-NG**	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation
AXCTD	Airborne Expendable Conductivity Temperature Depth

B

BBC	British Broadcasting Company
BGAN	Broadband Global Area Network

C

C-HARRIER	Coastal High Acquisition Rate Radiometers for Innovative Environmental Research
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
Cal/val	Calibration / Validation
CAMBOT	Continuous Airborne Mapping by Optical Translator
$CAMP^2EX$	Cloud and Aerosol Monsoonal Processes - Philippines Experiment
CARE	Cabin Altitude Reduction Effort
CCE	Carbon Cycle and Ecosystems
CDWR	California Department of Water Resources
CIR	Color Infrared
CIRES-IDD	CubeSat Imaging Radar for Earth Science - Instrument Development and Demonstration
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
CH_4	methane
CMIS	Compact Midwave Imaging System
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Authorization
CTSM	Complex Terrain Soil Moisture
CY	Calendar Year

D

DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DEM	Digital Elevation Map
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)

E

eMAS	Enhanced MODIS Airborne Simulator
EOS	Earth Observing System
EPA	Environmental Protection Agency
ESA	European Space Agency
ESD	Earth Science Division
ESPO	Earth Science Project Office
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
EV, EVS-2, EVS-3	Earth Venture, Earth Venture Suborbital-2, Earth Venture Suborbital-3

F

4Star	Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research
FIA	Forest Inventory and Analysis
FIREX-AQ	Fire Impacts on Regional Emissions and Chemistry Experiment – Air Quality
FR	Flight Request
FY	Fiscal Year

G

GCAS	GeoCAPE Airborne Simulator
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GEDI	Global Ecosystem Dynamics Investigation
G-LiHT	Goddard’s Lidar, Hyperspectral and Thermal
GLISTIN-A	Glacier and Ice Surface Topography Interferometer - Airborne
GLOBE	Global Learning and Observation to Benefit the Environment
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center

H

H_2O Water

HALO High Altitude Lidar Observatory

HDVIS High Definition Time-lapse Video System

HSRL High Spectral Resolution Lidar

HyspIRI Hyperspectral Infrared Imager

HyTES Hyperspectral Thermal Emission Spectrometer

I

ICESat Ice, Cloud, and land Elevation Satellite

IIP Instrument Incubator Program

IMPACTS Investigation of Microphysics and Precipitation for Coast-Threatening Snowstorms

InSAR Interferometric Synthetic Aperture Radar

IPDA Integrated Path Differential Absorption

IR Infrared

IRIG-B Inter-range instrumentation group - B

IRIS Irradiance Instrument Subsystem

ISRO Indian Space Research Organization

ISS International Space Station

IWGADTS Interagency Working Group for Airborne Data and Telecommunication Systems

J

JAXA Japanese Aerospace Exploration Agency

JPL Jet Propulsion Laboratory

JSC NASA Johnson Space Center

JWST James Webb Space Telescope

K

L

LaRC	Langley Research Center
LiDAR	Light Detection and Ranging
LISTOS	Long Island Sound Tropospheric Ozone Study
LVIS	Land, Vegetation, and Ice Sensor

M

MAIA	Multi-Angle Imager for Aerosols
MAS	MODIS Airborne Simulator
MASS	Modular Aerial Sensing System
MASTER	MODIS/ASTER Airborne Simulator
MCoRDS	Multichannel Coherent Radar Depth Sounder
METOP-SG	Meteorological Operational - Second Generation
MODIS	Moderate Resolution Imaging Spectroradiometer
MSFC	Marshall Space Flight Center
MTS	Mission Tools Suite

N

NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NASDAT	NASA Airborne Science Data and Telemetry
NAST-I	National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed - Interferometer
NISAR	NASA-ISRO SAR
NOAA	National Oceanographic and Atmospheric Administration
NPP	National Polar-orbiting Partnership
NRC	National Research Council
NSF	National Science Foundation
NSRC	National Suborbital Research Center

O

OCO-2 Orbiting Carbon Observatory - 2

OIB Operation Ice Bridge

OMG Oceans Melting Greenland

ORACLES Observations of Aerosols Above CLouds and their InteractionS

P

PACE Plankton, Cloud, and ocean Ecosystem

PARCA Program for Arctic Regional Climate Assessment

PDM Programmed Depot Maintenance

PI Principal Investigator

PICARD Pushbroom Imager for Cloud and Aerosol R&D

PISTON Propagation of Inter-Seasonal Tropical Oscillations

PMD Palmdale Airport

POS Position and Orientation Systems

PRISM Portable Remote Imaging Spectrometer

R

R&A Research and Analysis

RGB Red Green Blue

ROLO Robotic Lunar Observatory

S

S-MODE Submesoscale Ocean Dynamics and Vertical Transport

SAR Synthetic Aperture Radar

SARP Student Airborne Research Program

SatCom	Satellite Communications
SBG	Surface Biology and Geology
SEO	sensor equipment operator
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SI	International System of Units
SIF	solar-induced fluorescence
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SnowEx	Snow Experiment
SNPP	Suomi National Polar-orbiting Partnership
SOFRS	Science Operations Flight Request System
SPEC	Stratton Park Engineering Company
STEM	Science Technology Engineering and Math
SWIR	Short wave infrared
SWOT	Surface Water and Ocean Topography

T

TB	Terra bytes
TEMPO	Tropospheric Emissions: Monitoring Pollution
TROPOMI	Tropospheric Monitoring Instrument

U

UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

V

VHF Very High Frequency

VIPR Vapor in-cloud Profiling Radar

W

WFF Wallops Flight Facility

X

Y

Z

BACK COVER:

Top: View from the ER-2 cockpit on a mission over Iceland. Photo credit: NASA

Bottom: Three NASA missions met in Thule, Greenland in summer 2019. Operation IceBridge on the Gulfstream V, ICESat-2/AVIRIS on the B200 King Air, and OMG on the Basler/Airtec DC-3. Photo credit: Eugenia DeMarco / NASA

National Aeronautics and
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