National Aeronautics and
Space Administration

Science Mission Directorate
Airborne Science Program

2018 Annual Report

COVER PHOTO:
The NASA P-3 during takeoff from Thule Air Base, with the Greenland ice sheet in the distance. Photo credit: Jeremy Harbeck

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1. Leadership Comments

Welcome to the 2018 edition of the NASA Science Mission Directorate Earth Science Division Airborne Science Program's Annual Report. As can be seen in Figure 3 (page 6), this year, like the past six years, was another busy year for the program with nearly 3,700 flight hours flown. It may sound repetitive, but we travelled the globe again: from the Arctic to the Antarctic, the length of both the Pacific and Atlantic Oceans, throughout the U.S, including Alaska and Hawaii, back to Africa, and this year adding India and Europe. Whew! Please see Figure 4 (page 8) for a visual representation. We flew 18 science campaigns plus technology development and demonstration missions. NASA research aircraft also supported disaster response efforts following hurricane Florence and over the Kilauea Volcano lava flows. See Table 5 (page 9) for a breakdown of the missions. Additionally, the program's support for ongoing and upcoming satellite missions was extensive. Eighteen satellite missions were identified by Principal Investigators as being supported by Airborne Science missions. The most heavily supported satellite missions were OCO-2, ICESat-2 and CryoSat-2, HyspIRI, NISAR, LANDSAT, ACE, GEO-CAPE and TROPOMI on ESA Sentinel-5. As several of these were missions in formulation and are now being redesigned in accordance with the new Decadal Survey, the related data will be transferred to those new missions.

While budgets have been challenging the past few years, the program continues to make progress on enhancing our capabilities. The Johnson Space Center G-V nadir port and other modifications were accomplished in 2018, and the aircraft is available to start science missions in the spring of 2019. The Langley Research Center G-III also started nadir port and other modifications and is planned to be available to the science community in 2019. In addition, we completed the ER-2 809 Cabin Altitude Reduction Effort (CARE), which makes aircraft operations safer for the pilot, and are currently working cockpit avionics upgrades. The work is taking longer than planned, but we hope to have a working ER-2 by the early summer of 2019, while ER-2 806 undergoes its CARE modifications. Another effort we started in 2018 were studies for replacement aircraft. The current life expectancy of the DC-8 and C-20 is in the mid-2020s. We've received some input from the science community on what, if any, the requirements are for a future large airborne laboratory and radar platform, but continue to accept input and recommendations. To help keep it relevant throughout its continued life, the AFRC C-20 cockpit avionics were scheduled for upgrades in late 2018.

In addition to all the great science we help enable, we are extremely proud of the fact that the Student Airborne Research Program (SARP) celebrated its 10th anniversary this past summer. The program has 305 alumni from 199 schools in 48 states, the District of Columbia and Puerto

Rico. Ninety-four percent of alumni are currently employed in Science, Technology, Engineering and Math (STEM) fields or pursuing advanced degrees in STEM fields. Over 30 alumni have Ph.D.s in STEM fields. Since the program started supporting some of the alumni's participation in the American Geophysical Union Fall Meeting in 2011, there have been 62 student first-author presentations of their previous summer's research projects in scientific sessions and four students awarded AGU Outstanding Student Paper Awards. SARP alumni have participated as scientists and engineers in NASA Airborne Science Program missions all over the world (GRIP, HS3, KORUS-AQ, DISCOVER-AQ, DC3, PECAN, SEAC^{4}RS, AJAX, LMOS, UAVSAR, NAAMES, and future missions such as FIREX and CAMP^{2}Ex), while others have been accepted into NASA and NOAA co-op positions. We salute all the faculty, mentors and our program teams that have contributed to the success of this program and the way it has changed students' lives.

Looking forward, Earth Venture Suborbital-3 (EVS-3) selections were announced in September, and we are actively engaged in preparing support for the five selected missions over the next five years. See Figure 27 (page 37) for details. In addition to EVS-3 missions, upcoming major airborne missions include FIREX-AQ and CAMP^{2}Ex in 2019, and Operation Ice Bridge until 2020. The *2017-2027 Decadal Survey for Earth Science and Applications from Space* was also released in 2018 and we look forward to see how the Earth Science community wants our Airborne Science team to support it.

Randy and I hope you enjoy reading about the program and, again, we say thank you to the dedicated people who make up the program. We all know it doesn't happen without great people working hard and being committed to the NASA science mission. Please let us know what you think of the report and, as always, we welcome any and all feedback about the program.

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2. Program Overview

The Airborne Science Program (ASP) is an important element of the NASA Science Mission Directorate (SMD) Earth Science Division (ESD) because it is involved in the entire life cycle of earth observing satellite missions. The Program supports NASA Earth Science missions in the following capacities:

- Process studies to improve models of Earth system elements
- Satellite mission instrument development, algorithm development, and calibration and validation activities
- Instrument testing and development
- Workforce development / next generation of scientists

We accomplish these support goals by providing both aircraft systems modified and adapted for science, along with aviation services to the science community. The NASA aircraft and mission infrastructure are described in this report. ASP also facilitates use of non-NASA aircraft and equipment for Earth Science, as needed.

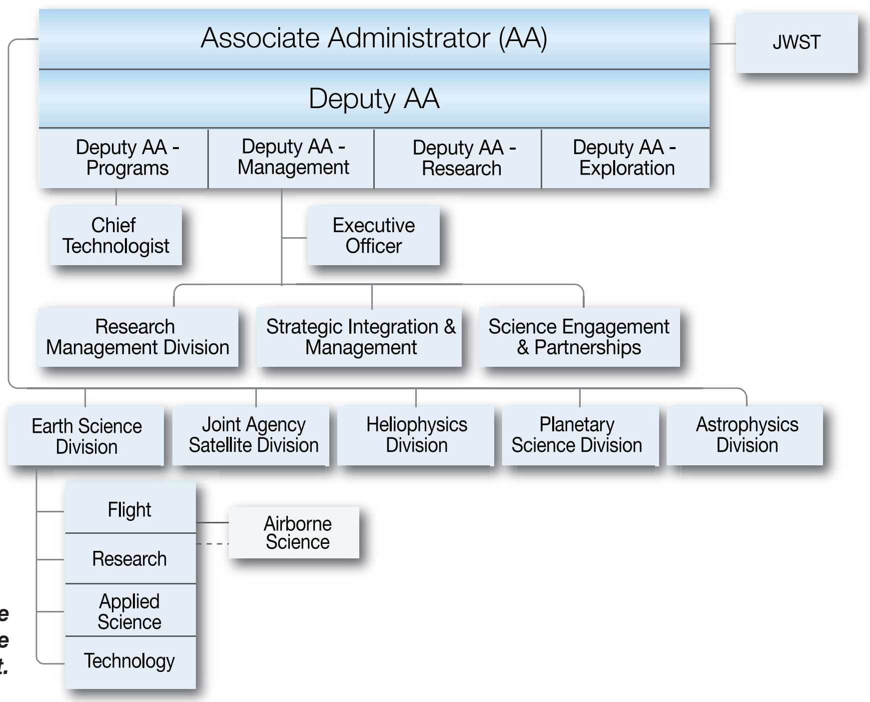


FIGURE 1 ***Science Mission Directorate organization chart.***

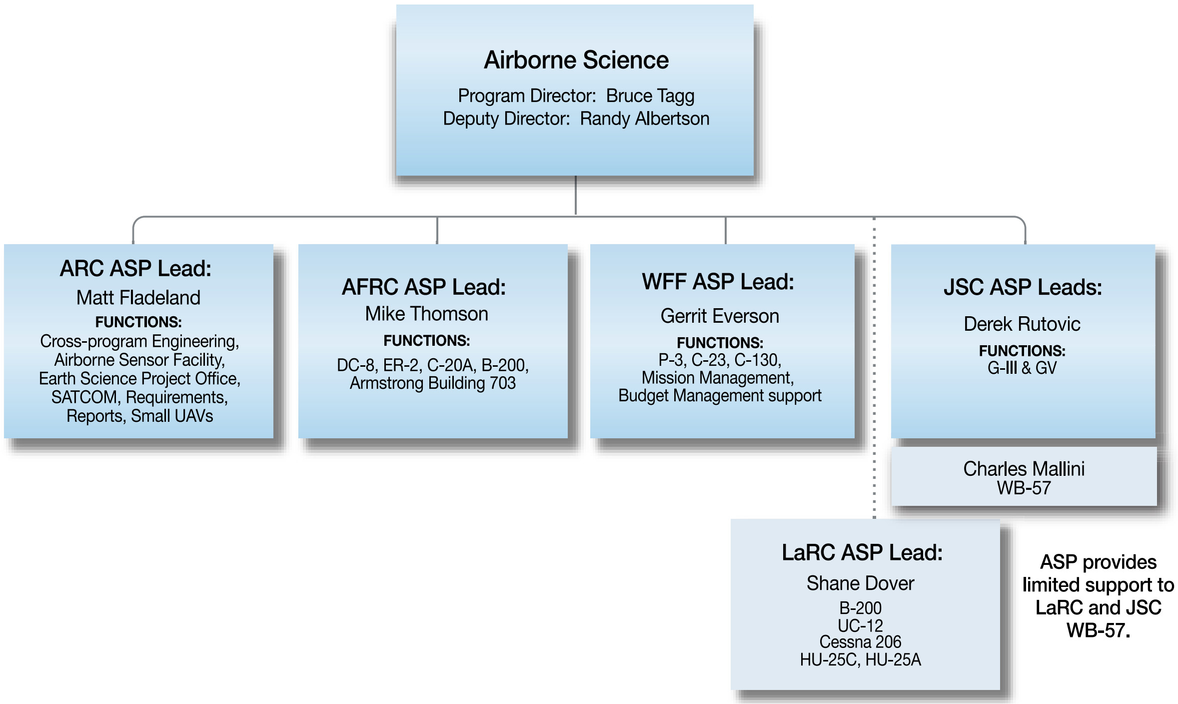


FIGURE 2 ***Airborne Science Program organization chart.***

Structure of the Program

Figure 1 shows the role of the Airborne Science Program within SMD. ASP components are shown in Figure 2. The aircraft responsibilities are distributed among the NASA centers where the aircraft are based.

New Program Capabilities

Completing development in 2018 were two new science-capable platforms: a G-V at Johnson Space Center (JSC) and a new G-III at Langley Research Center (LaRC). With new instrument windows and portals in place, both are performing their first science missions in 2019.

Flight Request System and Flight Hours

ASP maintains science-capable aircraft and instrument assets for research use, in support of NASA's SMD. The Science Operations Flight Request System (SOFRS) is a web-based tool used to track and facilitate the review and approval process for airborne science activities using ASP- supported aircraft, facility instruments, ASP science support assets or any ESD-funded activities/missions using aircraft. The way to schedule the use of NASA SMD platforms and instrument assets is to submit a Flight Request (FR) for approval through SOFRS (https://airbornescience.nasa.gov/sofrs). The SOFRS team strives for continuous improvement by refining the user interface and reports produced.

There were 158 FRs submitted in 2018 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 68 FRs were completed, using 22 different aircraft. Of the remaining FRs, some were deferred and the rest were canceled for various reasons. The 68 completed FRs flew a total of 3,688.5 flight hours. The details are listed below. Table 1 shows all flight requests status and flight hours flown by aircraft. Table 2 shows a list of the "Other" requested aircraft flown (Flight Request Status and Total Hours). Table 3 shows only ESD flight requests and flight hours flown by aircraft. Figure 3 is a histogram showing the history of flight hours usage. Table 4 shows all SOFRS flight hours flown by funding source. Figure 4 shows the global reach of ASP flight activities in FY18.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
DC-8[1] – AFRC[1]	13	7	0	7	398.8
ER-2 – AFRC[1]	30	21	5	8	293.3
Gulfstream C-20A (GIII) – AFRC[1]	18	17	4	10	241.6
G-III – JSC[1]	19	10	0	8	224.0
G-V – JSC[1]	1	0	0	0	0.0
P-3 Orion – WFF[1]	8	3	1	2	390.9
Other NASA Aircraft					
B-200[2]	15	9	0	9	429.2
C-130H – WFF[2]	4	4	0	4	310.5
C-23 Sherpa – WFF[2]	2	0	0	0	0.0
Dragon Eye – ARC[2]	1	0	0	0	0.0
Global Hawk – AFRC[2]	3	1	0	1	31.8
HU-25A Guardian – LaRC[2]	1	1	0	1	24.8
SIERRA – ARC[2]	4	0	0	0	0.0
Twin Otter – GRC[2]	3	3	1	2	64.0
Other (non-NASA Aircraft)[2]	36	22	1	16	1279.6
TOTAL	**158**	**98**	**12**	**68**	**3688.5**

TABLE 1 ***FY18 ASP-ESD Flight Request Status and Total Flight Hours Flown, by aircraft.****

[1]ASP Supported Aircraft: flight hours are subsidized by the program.

[2]These aircraft are NASA-owned not subsidized by the Airborne Science Program. B-200 includes (B-200 – AFRC, B-200 – LARC, B-200 - UC–12B).

[3]See Table 2 for details.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
A90 - Dynamic Aviation	8	6	0	5	555.2
Alphajet	2	2	0	1	35.4
B-200 - Dynamic Aviation	9	6	1	3	206.1
DC-3	2	1	0	1	5.5
Twin Otter CIRPAS	1	1	0	0	0.0
Aeroscout	1	0	0	0	0.0
Airtec BT-67	1	1	0	1	217.0
Basler BT-67	1	1	0	1	111.4
ISRO King Air	1	1	0	1	147.0
SkyTEM helicopter	2	0	0	0	0.0
SPEC LearJet	1	0	0	0	0.0
SuperSwift	2	2	0	2	2.0
Tarot Hexacopter	1	1	0	1	0.0
UAS	1	0	0	0	0.0
No aircraft selected	1	0	0	0	0.0
TOTAL	**34**	**22**	**1**	**16**	**1279.6**

TABLE 2 ***List of "Other" Aircraft Flown (Flight Request Status and Total Hours).***

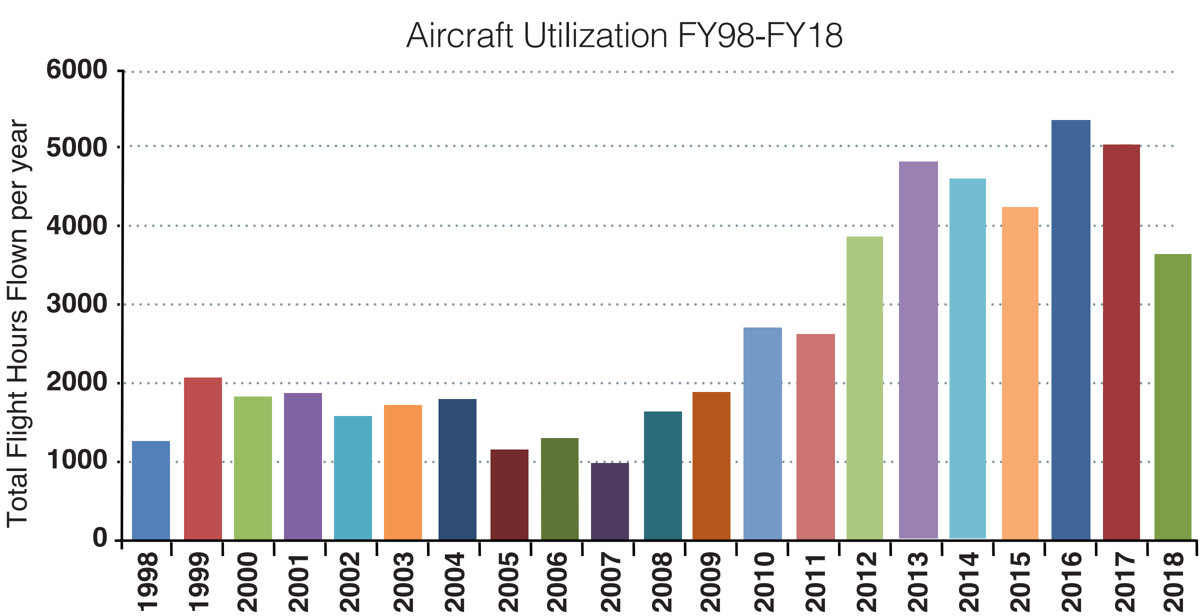


FIGURE 3 ***ASP flight hours FY98 – FY18.***

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
DC-8[1] – AFRC[1]	7	4	0	4	254.5
ER-2 – AFRC[1]	19	15	4	7	283.7
Gulfstream C-20A (GIII) – AFRC[1]	14	14	3	8	235.1
Gulfstream III – JSC[1]	16	10	0	8	224.0
Gulfstream V – JSC[1]	0	0	0	0	0.0
P-3 Orion – WFF[1]	7	3	1	2	390.9
Other NASA Aircraft					
B-200[2]	13	9	0	9	429.2
C-130H – WFF[2]	4	4	0	4	310.5
C-23 Sherpa – WFF[2]	1	0	0	0	0.0
Dragon Eye – ARC[2]	1	0	0	0	0.0
Global Hawk – AFRC[2]	1	0	0	0	0.0
HU-25A Guardian – LaRC[2]	1	1	0	1	24.8
SIERRA – ARC[2]	3	0	0	0	0.0
Twin Otter – GRC[2]	3	3	1	2	64.0
Other[3,4]	28	18	1	13	909.1
TOTAL	**118**	**81**	**10**	**58**	**3125.8**

TABLE 3 ***Summary of ESD-funded FY18 Flight Request Status and Flight Hours Flown by aircraft.****

[1]ASP Supported Aircraft.

[2]These aircraft are NASA-owned not subsidized by the Airborne Science Program. B-200 includes (B-200 – AFRC, B-200 – LaRC, B-200 - UC–12B).

[3]Other Non-NASA contracted aircraft requested include: Aeroscout, SkyTEM helicopter, SPEC LearJet, Tarot Hexacopter, Twin Otter International and UAS.

[4]Other Non-NASA contracted aircraft actually flown include: A90 - Dynamic Aviation, Alphajet, B-200 - Dynamic Aviation, DC-3, Airtec BT-67, Basler BT-67, ISRO King Air and SuperSwift.

***How to read Table 1 and Table 3**

- These totals are based on the Flight Request's log number, and therefore include Flight Requests whose log number starts with "18".
- The "Total FRs" column includes Flight Requests that were submitted and whose log number starts with "18".
- The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY18.
- The "Total Partial FRs" column includes Flight Requests in which the total approved hours were not fully expended during FY18 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 Flight Requests with a status of "Completed" or "Partial" for 2018.

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

TABLE 4 ***All SOFRS flight hours flown over the past 5 fiscal years by funding source.***

**The NASA Earth Sciences Division (ESD) is under the Science Mission Directorate (SMD). "SMD (Non-ESD) Flight Hours" are for those hours funded by SMD Program Managers not within ESD.

FY2018 Airborne Campaigns

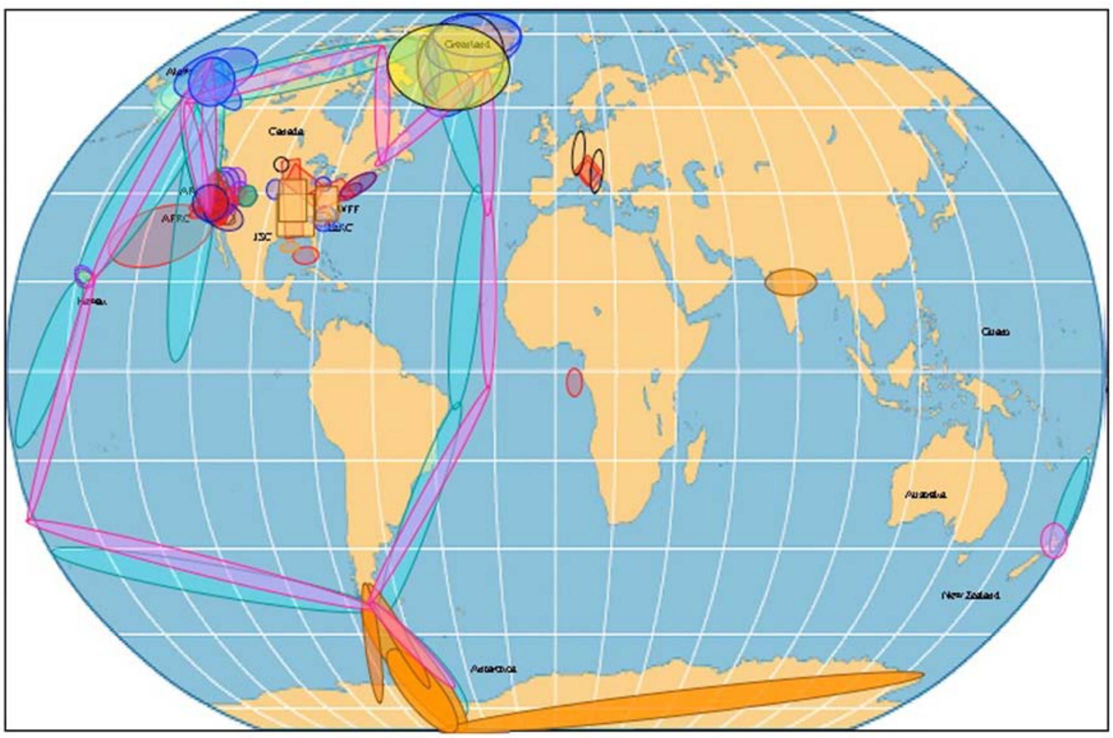
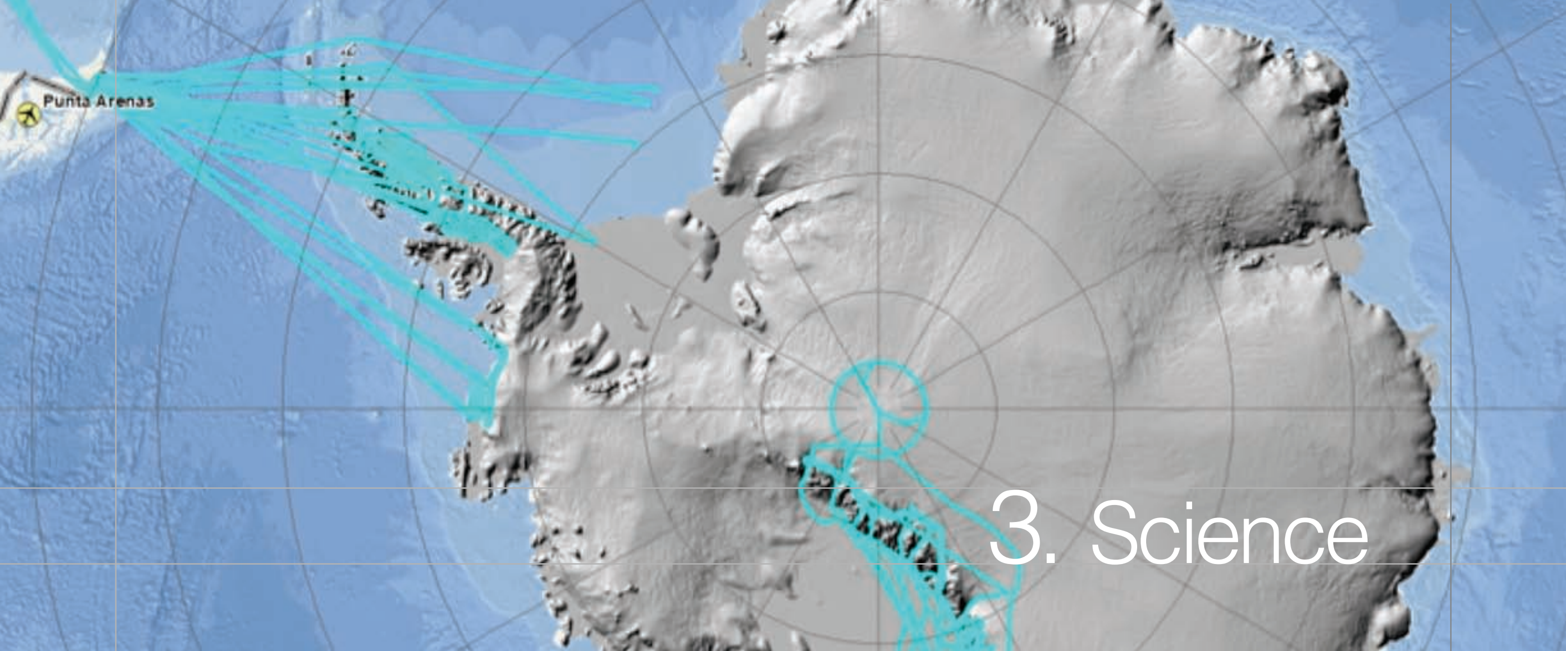


FIGURE 4 ***Locations of ASP missions in 2018.***



3. Science

Major Mission Highlights

In FY18 ASP conducted nearly 3,700 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. Four Earth Venture Suborbital-2 (EVS-2) missions flew in 2018, with two completing flight activities. Operation IceBridge (OIB) undertook campaigns in both the Antarctic and the Arctic. Flight hours for the largest missions are shown in Table 5.

Mission	Aircraft	Flight Hours	Location
OIB-Arctic	P-3	346.4	Greenland, Alaska
OIB-Antarctic	Basler, DC-8	221.4	Antarctica
ACT-America	C-130, B-200	447.9	CONUS
OMG	G-III, DC-3	258.0	Greenland
Airborne Snow Observatory	A90	245.7	Colorado, California
ATom	DC-8	236.7	Global
HyTES / HyspIRI	ER-2	190.9	Hawaii, California
G-LiHT Forest Health	A90	150.2	Alaska, Florida
ABoVE	G-III, B-200	125.2	Canada, Alaska
Long Island Sound Tropospheric Ozone Study	B-200, Falcon	123.5	Long Island Sound
G-LiHT Hurricane Response	A90	103.1	Florida, Puerto Rico
AVIRIS-ng Europe	B-200	90.5	Switzerland
NDMAX-ECLIF	DC-8	76.6	Germany
Kilauea Response	G-III	68.0	Hawaii
HIWC-II	DC-8	67.6	Atlantic Ocean / Pacific Ocean
ORACLES (FY18)	P-3	44.5	São Tomé
ACEPOL	ER-2	40.0	California
UAVSAR – all versions	C-20A, G-III	359.0	U.S., Canada
Technology test and demonstration	ER-2, B-200	143.3	California, multiple U.S. locations

TABLE 5 ***Major Science Missions in FY18.***

Operation IceBridge (OIB) in FY18

PI – Nathan Kurtz, GSFC
Program – Cryosphere
Aircraft – P-3, DC-8, Basler

In FY18, OIB returned to both the Antarctic and Arctic. In a new adventure, far reaches of Antarctica were explored using a contracted Basler BT-67 aircraft.

A dual-aircraft campaign was completed in Antarctica in late 2017 (FY18) with a mixture of new areas covered, as well as repeats of historic lines to assess changes in the polar ice cover. In the first campaign, the NASA P-3 aircraft, based out of Ushuaia, Argentina, was equipped with the traditional IceBridge instrument suite of laser altimeters, shallow and deep sounding radars, gravimeter, magnetometer, and thermal and visible imaging systems. In the second campaign, a Basler BT-67 aircraft, based primarily out of McMurdo Station, Antarctica, carried a laser altimeter and depth sounding radar.

The P-3 Antarctic campaign logged 11 research flights totaling 156 flight hours and traveled a distance of 85,106 km. The campaign flew extensive coverage of sea ice in the Weddell Sea, including two underflights of the TanDEM-X spacecraft in coordination with the German Aerospace Center (DLR). New gravity surveys of the Larsen C and Venable Ice Shelves were also completed, including the first up-close look at the massive A68 iceberg that calved off the Larsen C glacier in July.

The Basler campaign, which flew right up to year's end, completed 16 flights totaling 108 flight hours and traveled a distance of 33,880 km. The science lines for the campaign were a mixture of new missions as well as lines

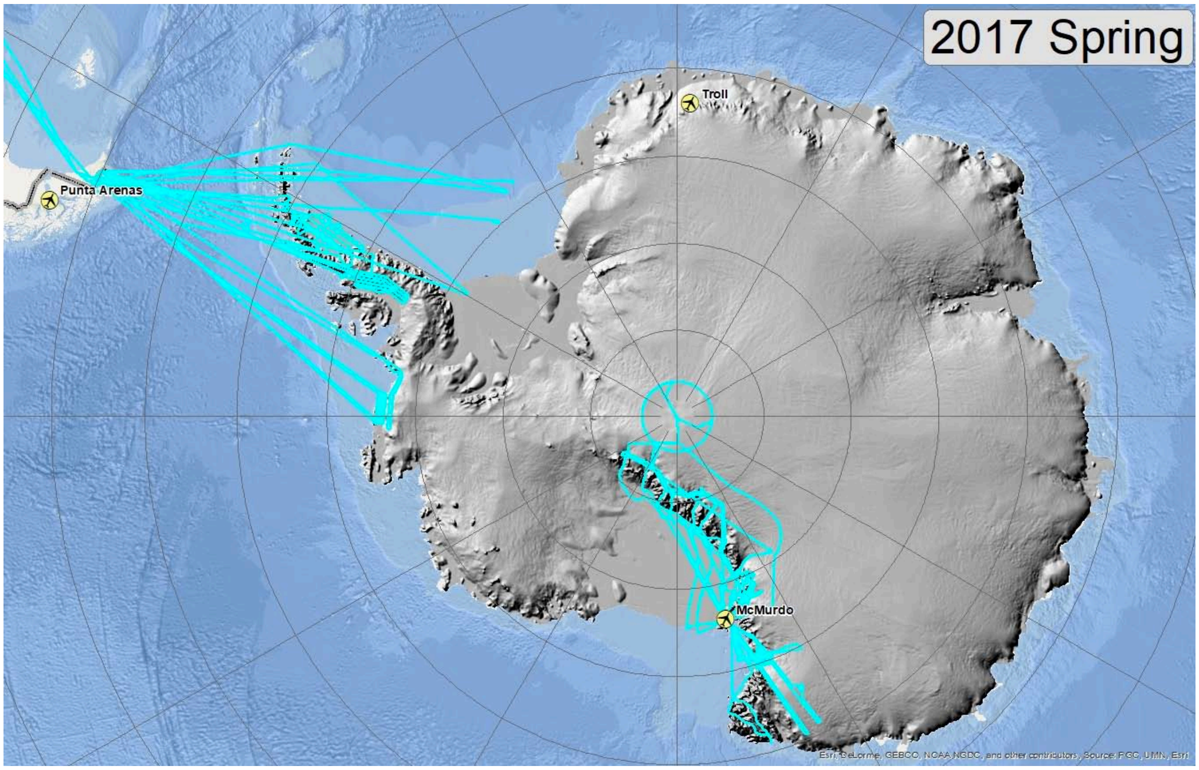
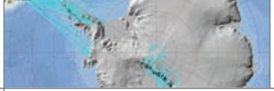


FIGURE 5 ***OIB flight lines in the Antarctica Spring of 2017 (early FY18), with focus on the "Pole Hole".***

flown previously in 2013 (with the P-3 based out of McMurdo) and in 2016. The highest priority lines included surveys of the Trans-Antarctic Mountains, as well as the 88-degree "Pole Hole." The "Pole Hole" line is the area of many orbit crossings for the ICESat-2 satellite that launched in September 2018. Surveys of the area are necessary to establish a calibration target for the satellite measurements. NASA Goddard Space Flight Center (GSFC) staff also performed ground surveys of the line, as an independent way of verifying the data. These data will be essential for tying together the airborne record from IceBridge with the satellite records from ICESat and ICESat-2. The map in Figure 5 shows the extent of flight lines into Antarctica.

For the Spring 2018 Arctic campaign, the P-3 flew from Fairbanks and then returned to Greenland. As always, the Airborne Topographic Mapper (ATM) was a major instrument. (See Figure 6.) NASA scientists conducted the longest flight of the campaign, 8.5 hours on the P-3. OIB is yielding unprecedented 3-D views of Arctic ice sheets, ice shelves and sea ice. These flights provide a yearly, multi-instrument look at the behavior of the rapidly changing features of the Greenland ice. As of the 2018 campaign, IceBridge has bridged the gap between the ICESat and ICESat-2 records of measurements.

FIGURE 6 ***Jim Yungel (NASA WFF engineer) giving a mid-flight overview of the ATM (Airborne Topographic Mapper) system to NBC field correspondent Jacob Soboroff in the rear of the NASA P-3. In the background, left to right: Brad Soeder (NASA avionics tech), Jefferson Beck (NASA Earth Science producer), Alex Kyriacou (NBC sound engineer).***



Earth Venture Suborbital – 2 (EVS-2)

EVS-2 missions continued during 2018. Three missions – ATom, NAAMES, and ORACLES – all completed flight activities. ORACLES returned home in October 2018, crossing into FY19. ACT-America will finish in 2019, while OMG has flights scheduled into 2020. The progress of the missions is listed in Table 6. The map in Figure 7 shows the broad reach of these missions during 2018.

Mission	Aircraft	Locations Flown	Status
ATom	DC-8	Multiple locations, including transects over the Atlantic and Pacific Oceans.	ATom-4 completed this mission in 2018.
NAAMES	C-130	North Atlantic and off Greenland coast	Due to aircraft failure, only data from ship (R/V Atlantis) were obtained in 2018.
ACT-America	C-130, B-200	Midwest, South, and Eastern US	ACT-America will complete in 2019.
ORACLES	P-3	Coast of Africa from São Tomé	ORACLES finished in late 2018 with the campaign returning to São Tomé.
OMG	G-III, C-130	Greenland coast	OMG will fly GLISTIN again in 2019 and finish with sonde drops in 2019 and 2020.

TABLE 6 ***EVS-2 Mission Progress in FY18.***

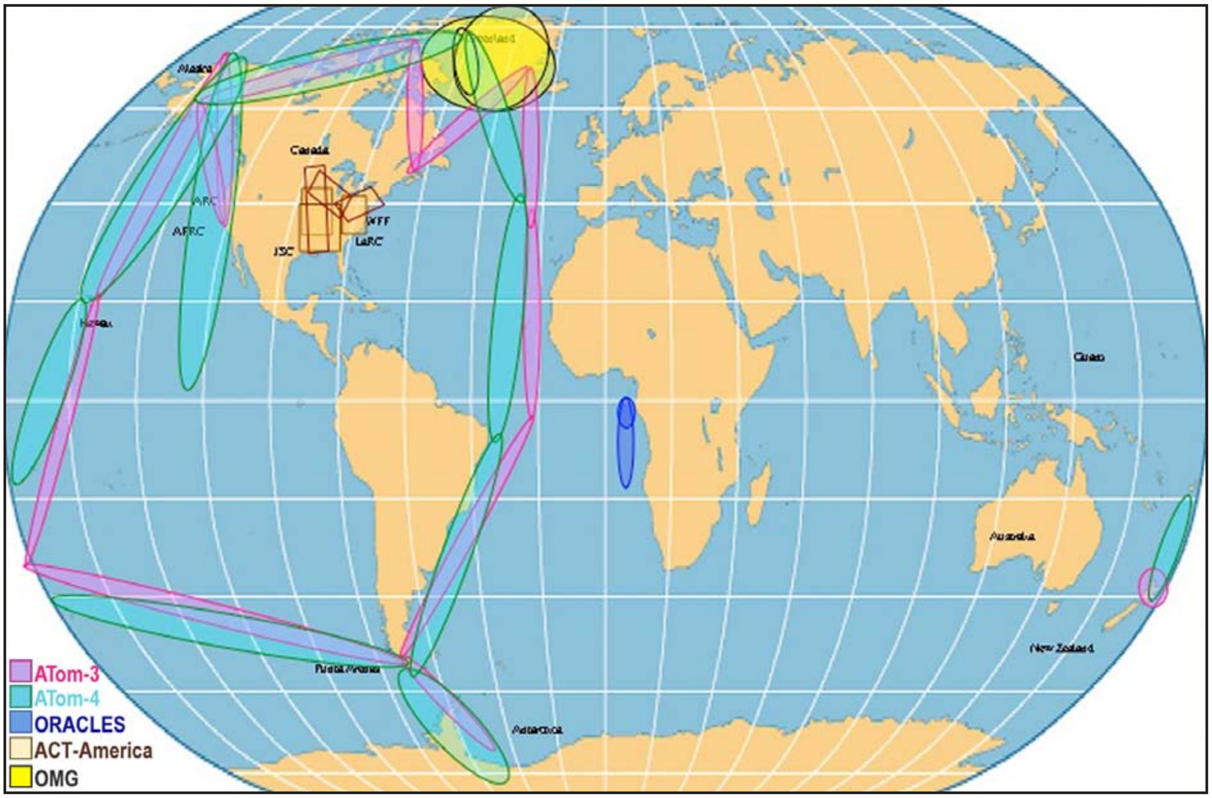


FIGURE 7 ***EVS-2 mission coverage in FY18.***

ATom

PI – Steve Wofsy (Harvard University)
Aircraft – DC-8

The Atmospheric Tomography (ATom) project successfully conducted the final of four planned global deployments in FY18, with the return of the NASA DC-8 to Armstrong Flight Research Center (AFRC) on May 21, 2018. Immediately after the final flight, the returning team celebrated the accomplishment with cake and sparkling wine in the B703 hangar. (Figure 8)

The third and fourth deployments featured new challenges — two unplanned and one planned — that the ATom team had to overcome. The first anomaly was the result of an aircraft communication system issue, which delayed the departure from AFRC to Anchorage by one day. The team shortened the planned two-day stopover in Anchorage by one day in order to get back on the original schedule. The second anomaly occurred due to bad weather on route to Thule, Greenland from Lajes AB, Portugal, which caused the aircrew to divert to Kangerlussuaq. Due to the short runway length at the Kangerlussuaq airport, the aircraft could not take off with sufficient fuel to get back to Anchorage, the next planned stopover location. After an overnight stay in Kangerlussuaq, the team flew to Bangor, Maine, spent the night, and then departed for Anchorage the following day, back on the original schedule and route. These rapid changes in international deployment locations and flight paths were carried out by the Earth Science Project Office (ESPO) logistics team within a few hours, an extraordinary accomplishment that saved the critical Arctic leg of mission four.

ATom-4 planning also relocated the tropical Atlantic site to Recife, Brazil, replacing Ascension Island as a stopover due to runway deterioration at Wideawake Field. The decision to use Recife caused a last-minute scramble to make all of the necessary arrangements, and raised security and diplomatic concerns, but in the end the stopover in Recife ultimately worked out very well.

FIGURE 8 ***NASA DC-8 and ATom-4 team on return to AFRC.***

Over the four deployments the ATom project accrued 437 flight hours, covering 320,000 km, executing 675 vertical profiles, 10 missed approaches, 10 eddy-flux maneuvers, 7 TCCON site over-flights and 3 over-flights of Antarctica.

“ATom was intended to probe the most remote parts of the atmosphere, to detect the subtle influence of pollution in the farthest reaches of the globe,” said lead PI Steven Wofsy. “We were astonished to find that human-caused pollution was anything but subtle in very remote places, especially the Arctic and Antarctic, and the tropical Atlantic. ATom showed that the most remote places in the atmosphere are commonly observed to be severely impacted by diverse sources of pollution.”

Michael J. Prather, the deputy lead PI, noted: “In ATom-4’s first 3 flights [PMD-equator-PMD-ANC-KOA] we passed through extensive air masses with strong, distinct chemical signatures of wildfires, industrial pollution, and stratospheric intrusions. These air masses were often folded and had sharp boundaries with what could be described as clean maritime air above and below. They were identifiable over thousands of km in the horizontal and 5 km [nearly a full-scale height] in the vertical.”

FIGURE 9 ***The ATom team flew over a streak of wildfires near Pyramid Lake in northwest Nevada.***

NAAMES

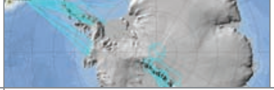
PI – Mike Behrenfeld (Oregon State University)
Aircraft – C-130

The North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) team completed its fourth and final deployment in spring 2018 with early results presented at the project science team meeting at Oregon State University in Corvallis, Oregon, on June 11-13. During the spring deployment, the R/V Atlantis explored a diversity of ocean ecosystem and associated atmospheric properties associated with the early phase of the annual plankton bloom, yielding many exciting measurements and results despite the aircraft maintenance setbacks that grounded the NASA C-130 in St. John's, Newfoundland. The scientific success of the spring campaign highlights the resiliency of the NAAMES sampling strategy that employs multiple complementary surface, airborne and spaceborne assets. Final data analyses and manuscript preparations are proceeding, but many "first glimpse" results were featured at the project science team meeting in June, where more than 80 team members from NASA and participating universities and organizations were in attendance presenting seven plenary talks, 16 interactive working breakout sessions and more than 50 science posters. Despite only finishing the fourth deployment as recently as April 2018, the NAAMES project has already garnered over 15 publications in high impact journals such as Nature Geosciences, Nature Microbiology, Nature Scientific Reports, PLOS ONE and others. A collection of NAAMES findings regarding plankton blooms is currently being prepared for a forthcoming special issue in the Frontiers collection of journals. NAAMES results and analyses were featured in a session entitled "Marine Aerosols, Trace Gases, and Clouds over the North Atlantic" that took place at the American Geophysical Union (AGU) Fall Meeting in Washington, D.C. in December and at a NASA Hyperwall talk. In February 2019 an additional session on blooms featuring many findings from NAAMES will occur during the Aquatic Sciences Meeting in San Juan, Puerto Rico. One of the major, early results from the NAAMES project is confirmation of the autumn-early winter initiation of the annual North Atlantic phytoplankton bloom that was hypothesized by Behrenfeld in 2010. Other emerging results on ocean-emitted trace gases and aerosols highlight the need for interdisciplinary science to tackle intractable problems related to our understanding of the Earth system.

ACT-America

PI – Ken Davis (Penn State University)
Aircraft – C-130, B-200/UC-12B

The Atmospheric Carbon and Transport – America (ACT-America) team completed its fourth atmospheric measurement campaign in May 2018. This investigation measures the sources of regional carbon dioxide, methane and other gases, and documents how weather systems transport these gases in the atmosphere. The research goal is to improve identi-



fication and prediction of carbon dioxide and methane sources and sinks using spaceborne, airborne and ground-based data over the eastern United States.

The spring field campaign was conducted between April 12 and May 20, 2018. The campaign used two instrumented NASA aircraft (Figure 10) to gather atmospheric measurements of greenhouse gases along with other trace gases and standard meteorological variables by operating out of LaRC; Wallops Flight Facility (WFF); Shreveport, Louisiana; and Lincoln, Nebraska. The LaRC B-200 aircraft (carrying in-situ sensors) collected 128.2 hours of data and the WFF C-130 aircraft (carrying in-situ and remote sensors) collected 103.2 hours of data during 26 research missions. These missions occurred over the U.S. South, Midwest, and Mid-Atlantic regions, as well as during transit flights between regions. In addition to the numerous level-leg flights, 334 quasi-vertical profiles of greenhouse gases and meteorological variables were made using spirals or on route ascents or descents with both the C-130 and B-200.

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, and the research flight days were classified into frontal, fair weather and Gulf inflow; some days were hybrids of these. Additionally, during five fair weather days, underflights of the Orbiting Carbon Observatory-2 (OCO-2) satellite were carried out to investigate the sensitivity of CO_2-column measurements from the OCO-2 to lower tropospheric CO_2 variability. The spring campaign included several sets of data that are unique to the ACT-America mission including: flying across the same stationary frontal boundary more than five times within a week over the Mid-Atlantic region, and flying across varying "greening" over both the South and Mid-Atlantic regions in which spring had arrived in the South and Mid-Atlantic, but not the Midwest. The longest ACT-America flight to date lasted 9.2 hours and crossed 10 states between South Dakota and the Gulf of Mexico. All the measurements collected during the campaign will be used to improve numerical models of greenhouse gas fluxes and atmospheric transport, one of the most compelling issues in carbon cycle science. ACT-America will conclude with its fifth campaign in the summer of 2019.

FIGURE 10 ***C-130 and B-200 with ACT-America teams.***

ORACLES

PI – Paquita Zuidema (U Miami) and Robert Wood (U Washington)
Aircraft – P-3 Orion

In early November 2018, the Observations of Aerosols Above CLouds and their InteractionS (ORACLES) team completed its third and final airborne science deployment; this was the second deployment based in the small island nation of São Tomé (the first deployment was based in Namibia in 2016). The overall goal of the ORACLES project is to study the interactions between clouds and biomass burning aerosols. São Tomé is located at the northern edge of the annual biomass burning aerosol plume that originates on the African continent.

Southern Africa produces between one-third and one-half of the Earth's biomass burning aerosol particles, yet the fate of these particles and their influence on regional and global climate is poorly understood and, therefore, poorly represented in models. ORACLES has input from teams with both regional and process modeling components. The data collected will be used to reduce uncertainty in both regional and global forecasts. The purpose of the three ORACLES airborne campaigns was to capture the seasonal cycle of absorbing aerosol radiative forcing and absorbing aerosol-cloud interactions, with the following overarching goals:

- Characterize the absorbing aerosol and cloud conditions and its variability over the southeast Atlantic from August through October, the main months in which substantial biomass burning aerosol is advected westward off of continental Africa.
- Determine the impact of African biomass burning aerosols on cloud properties and the radiation balance over the South Atlantic, using state of the art in situ and remote sensing instruments to generate data sets that can also be used to verify and refine current and future observation methods.
- Acquire a process-level understanding of aerosol-cloud-radiation interactions and resulting cloud adjustments that can be applied in global models.

The P-3 platform began ORACLES integration in early August, with only one minor payload change: the Photo Thermal Interferometer (PTI; Brookhaven National Lab) was once again included (it did not fly in 2017). After its on-time arrival on September 24, the P-3 flew a total of 13 science flights (~105 hours). Approximately one-half of the flights followed a north-south line directly into the heart of the aerosol plume. (See Figure 11.) As in 2017, several flights were dedicated to sampling the same polluted air masses days apart, to gain information on aerosol aging. Two flights focused on radiation, and the remainder were comprehensive surveys of the aerosol plume and cloud deck.

For the 2018 campaign, Dr. Robert Wood and Dr. Paquita Zuidema stepped in to share PI duties, following the departure from NASA of former PI Dr. Jens Redemann. They guided the team through a very successful deployment phase wrap-up. Over the entire mission, ORACLES completed 56 science flights and 447 hours of science flight. The project achieved its baseline science requirements after flying for two weeks in 2018, achieving 9 consecutive weeks of flight coverage from August to October. The mission succeeded in acquiring detailed measurements of aerosol and cloud properties over an extended region of the Southeast Atlantic, where there is a dearth of measurements and major disagreements between modeled climate effects of biomass burning aerosol.

Science highlights include: (a) the first measurements showing aerosol chemical aging on timescales of 3-8 days, whereby organic carbon is removed leaving behind more strongly sunlight-absorbing black carbon cores; (b) new constraints on aerosol spectral absorption from remote sensing using novel radiation flight maneuvers; (c) data indicating that much of the biomass burning aerosol entrained into the boundary layer within the stratocumulus deck is removed by precipitation as the cloud deck moves equator-ward, with an associated decrease in the mean cloud droplet number concentration; and (d) first mapping of seasonal differences in the biomass burning aerosol plume and its vertical structure. In addition, ORACLES was the first mission to empirically investigate the effects of the relative placement

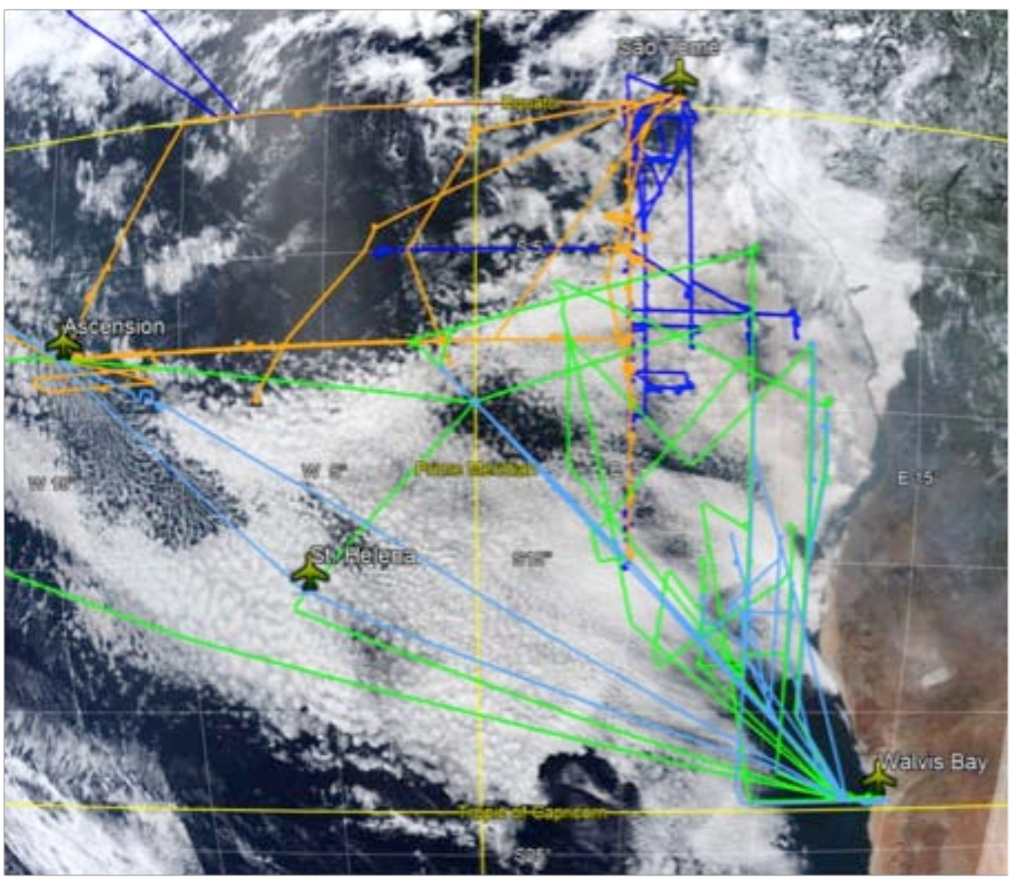


FIGURE 11 ***P-3 and ER-2 flight tracks from three ORACLES deployments, overlaid on a VIIRS true color image taken on Sept. 13, 2018, showing a typical cloud deck and overlying (brown color) aerosol layer. Flight tracks shown are from 2016 (P-3: light blue; ER-2: green), 2017 (orange) and 2018 (dark blue).***

of cloud probes with respect to the leading edge of the wing, collecting unique data that will affect all future cloud probe missions.

This was the second campaign in São Tomé for most of the aircraft, science and ESPO teams. The Portuguese language and the availability of quality infrastructure presented occasional challenges to the team. The airport and civil aviation organizations alleviated this through their support and local communities were very welcoming. The hotel staff proved to be extremely helpful in making connections outside the hospitality industry: shipping, customs, medical and governmental connections. Connections were established with the University of São Tomé and with the Meteorological officials at the airport, who assisted with forecasting local conditions. Weather conditions were expected to provide greater logistical challenges in 2018 than in 2017, due to the onset of the rainy season on the African continent to the east/northeast and associated squall lines that can reach São Tomé. However, the team quickly became adept at forecasting evolving local conditions and only one hour of flight time was lost due to bad weather.

OMG

PI – Josh Willis (JPL)
Aircraft – G-III, Basler/DC-3

The objective of Oceans Melting Greenland (OMG) is to investigate the role of warmer, saltier Atlantic subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise by observing changes in glacier melting where ice contacts seawater.

OMG carried out its third surveys of both the oceans and the ice in 2018. With 25 feet of potential sea level rise locked away in the Greenland Ice sheet, this study will help understand 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 2018: “GLISTIN-A” and “AXCTD”.

In March 2018, JPL’s Glacier and Land Ice Surface Topography Interferometer (GLISTIN-A) radar was installed on the JSC G-III. The GLISTIN-A, single-pass interferometer, made high-resolution, high-precision elevation measurements (yearly campaign three of four) 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 2018, OMG installed JPL’s Airborne Expendable, Conductivity Temperature Depth (AXCTD) system into a DC-3TP owned by Airtec. AXCTD probes are dropped from the aircraft into the ocean to measure ocean temperature and salinity on the ocean shelf. Because the aircraft was able to land on smaller, gravel runways, the crew and aircraft were able to stay in Greenland throughout the entire trip, removing the need to transit from Iceland, Svalbard or Canada, as in previous years. The aircraft deployed to Kulusuk in southeast Greenland for about one week, followed by one day in east Greenland before finishing the survey from Thule Air Base in Northwest Greenland. OMG deployed 239 AXCTD probes in Greenland this year and reached several fjords in north Greenland that were too choked with ice for data collection in previous years. This was campaign three of five. Figure 12 shows the many locations of the sonde drops.

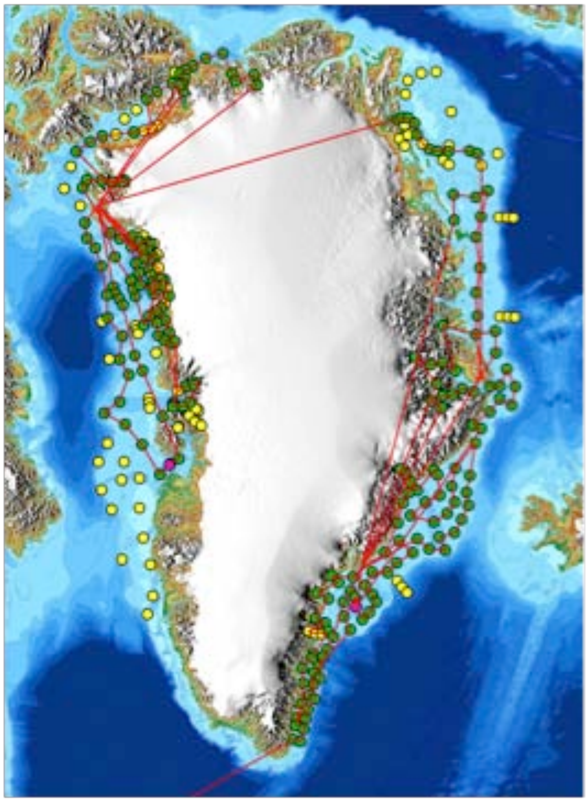


FIGURE 12 ***2018 AXCTD survey of the oceans around Greenland. Yellow dots show planned drops, green dots show completed drops. The two purple drops show the locations of the Alamo Probe drops. Unfortunately, the Alamo Probes failed after launch and did not return any data this year.***

HyTES / HyspIRI

PI – Simon Hook, JPL
Program – Terrestrial Ecology
Aircraft – ER-2

Since 2013, the continuing flights to record vegetation conditions in California and Hawaii have collected data as precursors to a satellite mission carrying a hyperspectral sensor. Known as “HyspIRI prep” throughout the last decade, these data sets are not only invaluable for the eventual satellite comparison, but also provide important data on changing environmental conditions, especially in California. Previous year missions have relied primarily on the MASTER and AVIRIS instruments for multispectral measurements.

In January 2018 the instrument suite on the ER-2 aircraft was expanded to include the Hyperspectral Thermal Emission Spectrometer (HyTES) and the Portable Remote Imaging Spectrometer (PRISM), both developed by JPL. The 2018 payload provided simultaneous passive optical imaging from ultraviolet through infrared, perhaps the most extensive spectral coverage to date from any ER-2 campaign.

The ER-2 returned to Marine Corps Base Hawaii for flights over the erupting Kilauea volcano and Hawaiian coral reefs. The HYTES image (Figure 13) of the SO_2 plume from Pu’u ‘O’o was acquired on January 18. The second image has been enhanced to highlight SO_2 in the plume. The ER-2 flew nearly 60 hours in Hawaii during a one-month mission.

Back in California, the HyspIRI prep team completed the 2018 observations of 6 regions, including the HyTES payload, during nearly 120 hours of flight. Flight boxes are shown in Figure 14. Beginning in 2019, the California flight boxes will continue in preparation of for the Surface Biology and Geology (SBG) mission, which is currently in the definition stage. SBG is expected to be similar to what was proposed for HyspIRI.

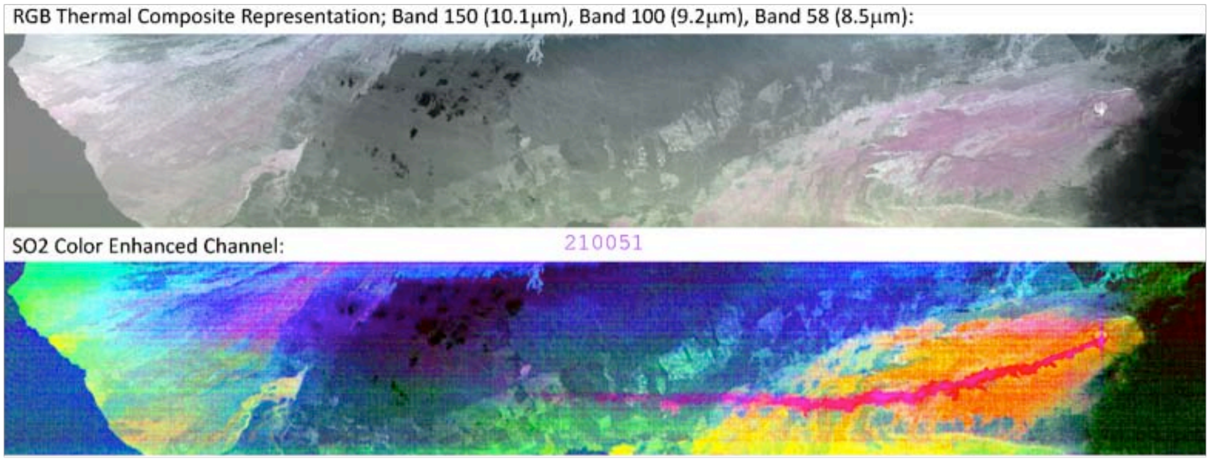


FIGURE 13 ***HyTES images from Hawaii: the HYTES image of the SO_2 plume from Pu'u 'O'o. The second image has been enhanced to highlight SO_2 in the plume.***

UAVSAR Data Acquisition and Delivery Metrics for FY18

PI – Yunling Lou
Program – Earth Surface and Interior
Aircraft – G-III

During FY18, the UAVSAR project supported 16 flight requests and 12 principal investigators. The AFRC C-20A (NASA502) executed 43 science / engineering flights for a total of 207 flight hours. The JSC G-III (NASA992) conducted 35 science / engineering flights totaling 152 flight hours. During this period, 720 flight lines were collected. In 2018, all three radars flew with the following statistics: L-band flew 47 flights, Ka-band flew 25 flights and P-band flew 6 flights.

A breakdown of flight lines per discipline in Figure 15 shows the broad range of scientific studies that were supported by the UAVSAR instrument suite.

The L-band radar acquired a total of 10 TB of raw data with 96% success rate in data acquisition. JPL delivered 359 PolSAR science products, 134 requested InSAR pairs, and 48 requested InSAR stacks. L-band imagery from the

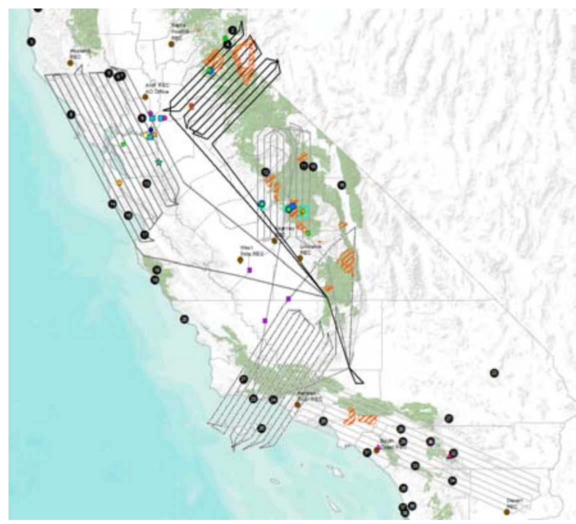
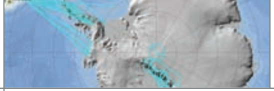


FIGURE 14 ***HyspIRI flight boxes were flown multiple seasons in 2013, 2014 and 2015, and single seasons in 2016, 2017 and 2018.***

ABoVE mison is shown in Figure 16. The P-band radar acquired a total of 1.2 TB of raw data with 78% success rate in data acquisition, and delivered 55 PolSAR science products. Finally, the Ka-band radar acquired a total of 6 TB of raw data with 96% success rate in data acquisition, and delivered 124 TopSAR science products.

The JSC G-III supported eight flights in Hawaii to produce high-resolution topographic maps



with the UAVSAR Ka-band instrument. The team imaged the Kilauea volcano during its eruption to generate lava volume estimates, as lava flowed from the caldera towards farms and residential areas. JPL and the U.S. Geological Survey (USGS) scientists are developing new approaches to measure lava flows with remote sensing, with the goal of improving volcanic models. Flights were conducted in May and June as well as September, at the tail end of the eruption.

In September 2018, the AFRC C20-A conducted six flights to image areas impacted by Hurricane Florence with the L-band instrument. The objective of the experiment was to observe the flood water cresting and receding over floodplain sites identified by stakeholders from the Federal Emergency Management Agency (FEMA). False-color polarimetric quick-look images were delivered post-flight and posted at the NASA Disasters data portal. UAVSAR images filled gaps between radar satellite coverage overpasses so flood responders could determine and predict where neighborhoods and key facilities were impacted by flood waves. UAVSAR data can be downloaded by visiting this page: http://uavsar.jpl.nasa.gov/cgi-bin/data.pl.

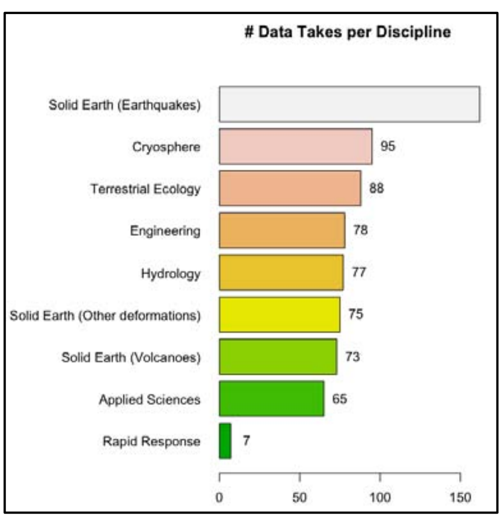


FIGURE 15 ***Range of discipline supported by UAVSAR projects.***

FIGURE 16 ***UAVSAR false-color polarimetric image showing the Mackenzie River Delta (light green) near Inuvik, Canada. Image acquired in August 2018. Polarization: HH HV VV.***

Arctic Boreal Vulnerability Experiment (ABoVE)

PI – Charles Miller, JPL
Program – Terrestrial Ecology
Aircraft – G-III, B-200, A-90

NASA conducted flights as part of the ABoVE mission in 2018 using AVIRIS-ng, L-band SAR (UAVSAR) and G-LiHT. Coordinated flights and ground validation were conducted with the German Aerospace Center (DLR). Targets of interest included field sites occupied by the ABoVE Science Team as well as the intensive sites operated by the DOE NGEE-Arctic on the Seward Peninsula and in Barrow, NSF sites at Toolik Lake (Arctic/North Slope) and Bonanza Creek (Boreal/Interior Alaska), the Canadian Cold Regions

Hydrology sites in the Arctic tundra near Trail Valley Creek Northwest Territories (NT), the interdisciplinary science station at Scotty Creek NT, the Government of the Northwest Territories Slave River/Slave Delta watershed time series, the Kluane Lake Yukon Territory (YT) Research Station, and numerous forest and fire disturbance plots maintained by the National Park Service, and the U.S. and Canadian Forestry Services.

NASA conducted AVIRIS-ng flights during July 21 through August 18, 2018. The primary mission goal was to obtain imagery over areas that were not imaged in 2017 due to weather conditions. Some flights were flown in “methane mode” over regions known or suspected to have high methane emissions. AVIRIS-ng data sets were collected as shown in Figure 17.

NASA conducted L-Band SAR (UAVSAR) flights during August 18-31, repeating lines flown during the 2017 campaign to establish a multi-year time series. Sites included the Boreal Ecosystem Research and Monitoring Sites (BERMS) site in Saskatchewan, the Peace-Athabascan Delta, road-accessible sites near Yellowknife and Inuvik, and a subset of sites in Alaska and Yukon that were of greatest interest to the SAR Working Group. New flight lines were planned and executed in coordination with the German Aerospace Center (DLR). The BERMS site was flown in TomoSAR mode.

The DLR flew their F-SAR instrument over regions of the ABoVE domain in the Northwest Territories and Saskatchewan in August 2018. DLR and ABoVE will share airborne and ground validation data from the coordinated collections at the BERMS in Saskatchewan and at the Baker Creek watershed near Yellowknife, NT. G-LiHT conducted flights for ABoVE from July 13 to15. The A90 aircraft flew to the Tanana Valley to update data collected during the 2014 G-LiHT flights over forests that have since burned, and over Cold Regions Research and Engineering Laboratory (CRREL) permafrost transects. The A90 also flew ABoVE requests in 2018 over Creamery Field near Fairbanks and Yukon Flats near Ft. Yukon. Weather did not permit collections over Delta Junction sites in 2018, but these may be attempted in 2019.

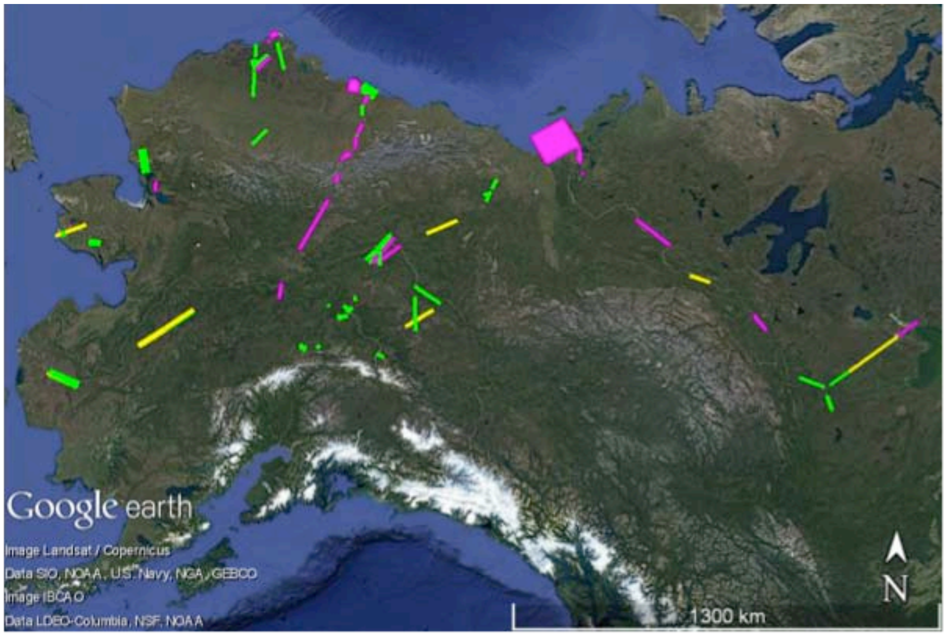
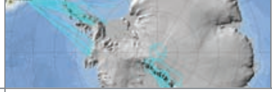


FIGURE 17 ***AVIRIS-ng datasets collected during ABoVE 2018. Green lines indicate flight lines sucessfully collected; yellow lines may be obscured by clouds; magenta lines were planned but not collected due to weather.***



Disaster Response

Several missions flown during 2018 can be considered disaster response missions of opportunity. These were useful for providing post-event data. Some activities are sponsored by the Applied Science Program.

Kilauea Eruption Response

PI: Paul Lundgren
Program: Earth Surface and Interior
Aircraft: G-III

The G-III carrying GLISTIN-A flew multiple flight lines over the Kilauea volcano in Hawaii to map the evolving topography caused by lava flows and crater collapse.

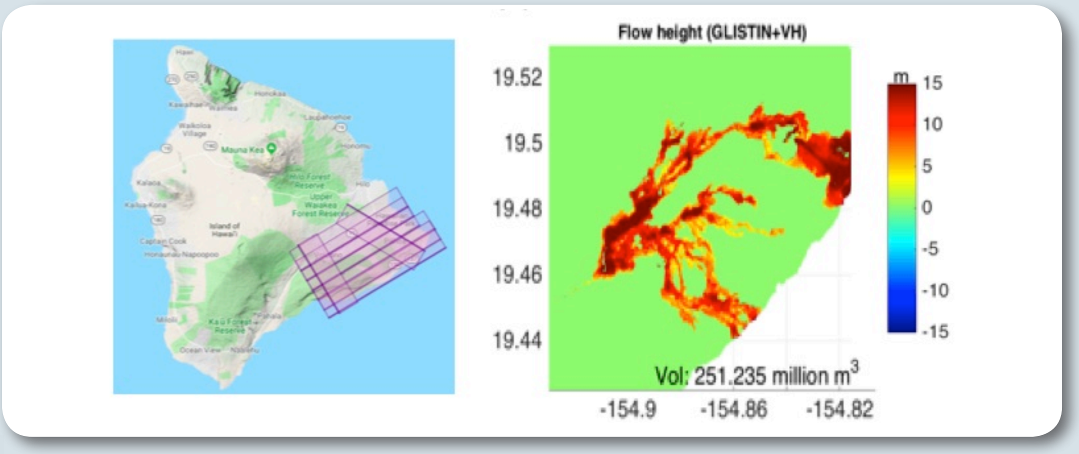


FIGURE 18 ***GLISITN-A flight lines in Hawaii and corresponding lava map.***

Post-Hurricane Vegetation Monitoring

PI: Bruce Cook
Program: Terrestrial Ecology Rapid Response
Aircraft: A90

G-LiHT returned to South Florida and Puerto Rico to survey post hurricane recovery from Hurricanes Irma and Maria.

FIGURE 19 ***Puerto Rico G-LiHT phase one aerial RGB imagery.***

Hurricane Florence Damage Assessment

PI: Yunling Lou
Program: Applied Science Disasters
Aircraft: C-20A

The C-20A carrying UAVSAR (L-band) obtained SAR imagery of flooding and damage following the deluge produced by Hurricane Florence in North Carolina.

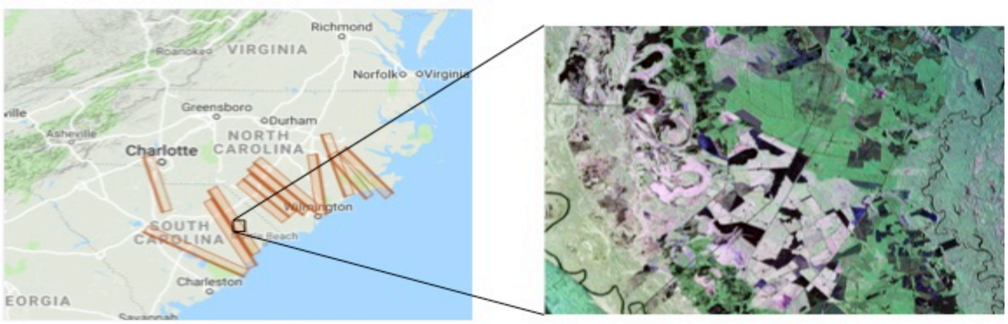


FIGURE 20 ***UAVSAR false color polarimetric image over the Pee Dee River. Colors refer to polarization.***

Thomas Fire Damage Assessment

PI: Rob Green
Program: ESD Research & Analysis
Aircraft: ER-2

The ER-2 flew MASTER over the fire scar caused by the massive Thomas Fire in Southern California.

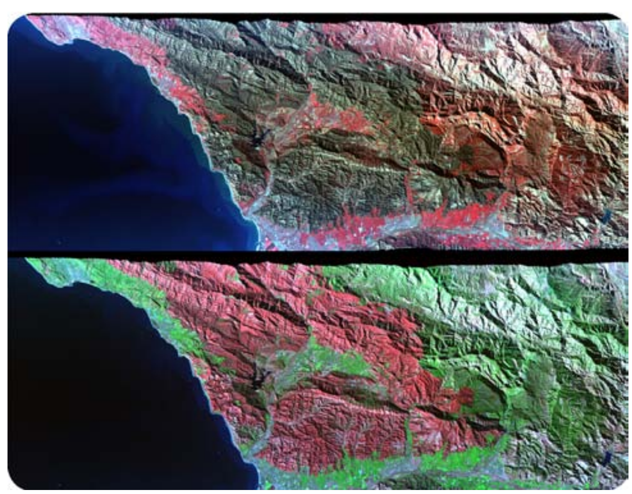
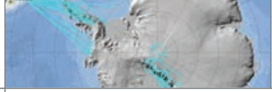


FIGURE 21 ***The upper image is the standard Color Infrared (CIR) composite; the lower is the Burned Area Emergency Response (BAER) composite, as used by the USFS.***



Support to ESD Satellite Missions, including 2007 Decadal Survey Missions

A primary purpose of the Airborne Science Program is to support Earth Science space flight missions, including satellite missions and missions flying on the International Space Station (ISS). This support includes airborne campaigns to collect data for algorithm development prior to launch, to test instrument concepts for satellite and ISS payloads or airborne simulators, and to provide data for calibration or validation of satellite algorithms, measurements or observations once in orbit. In 2018, ASP provided support to Earth Science missions as listed in Table 7. This included significant flight hours for several missions, especially

Satellite or space mission	ASP Mission	Aircraft	Flight hrs	Location	Purpose
2007 Decadal Survey					
ICESat-2	Operation IceBridge	P-3,B200, DC-8, Basler	567.6	Greenland, Alaska, Antarctica	Build data base
NISAR	ABoVE, UAVSAR	C-20A, G-III	152	California, Colorado, Alaska	Precursor data sets
HyspIRI	HyspIRI Hawaii, California; HyTES, ABoVE (AVIRIS-ng)	ER-2; A90	315.9	Hawaii; 3 boxes in California; Alaska / Canada	Precursor data sets; instrument development
ACE	ORACLES	P-3	181.0	São Tomé	Aerosol data collection
GEO-CAPE	Long Island Sound Ozone Study	B-200, Guardian	123.5	Long Island Sound	Precursor data sets
SWOT	DopplerScatt	B-200	60.1	Gulf of Mexico, Pacific ocean	Instrument development
SMAP	AirMOSS Alaska Permafrost	G-III	30	Alaska	Hydrologic data
Other					
OCO-2	ACT-America, ATom, ABoVE, AJAX, SARP	C-130, B-200, Alphajet DC-8	730	Global	Cal/val
CRYOSAT-2	OIB	P-3, DC-8, Basler	567.6	Greenland, Alaska, Antarctica	Build data base
LANDSAT	ASO	A90	245.7	California, Colorado	Cal/val
TEMPO	Long Island Sound Ozone Study; AVIRIS-ng	B-200; Guardian; B-200	167.9	Long Island Sound; California	Precursor data sets
TROPOMI	Long Island Sound Ozone Study	B-200; Guardian	123.5	Long Island Sound	Precursor data sets
SENTINEL 3B	AVIRIS-ng (Europe)	B-200	90.5	Switzerland	Precursor data sets
AURA	SARP	Sherpa	45.3	California	Cal/val
CALIPSO	ACEPOL	ER-2	40	California	Instrument Validation; algorithm validation
CATS-ISS	CAMAL	ER-2	10.5	California	Instrument test
Suomi-NPP	Air-HARP, air-LUSI	ER-2	9.8	California	Polarization, irradiance
AQUA / TERRA	eMAS, PICARD integration	ER-2	6.8	California	Cal/val

TABLE 7 ***Satellite / Space Mission Support.***

ICESat-2, which launched in 2018. GEDI and ECOSTRESS also launched in 2018.

In 2018, some airborne process missions also collected data that will be valuable for future missions. TEMPO is scheduled to launch as early as 2019, and NISAR and SWOT are expected to launch in 2021. Future missions include a HyspIRI-like mission, now identified as Surface Biology and Geology (SBG). In addition, missions that collected CO_2 measurements are relevant to OCO-2, Suomi-NPP, and future missions to measure greenhouse gases.

Two airborne missions described below are the Long Island Sound Tropspheric Ozone Study (LISTOS) that supports TEMPO and TROPOMI, and Aerosol Characterization from Polarimeter and Lidar (ACEPOL), which flew a variety of polarimeters in support of CALIPSO and in advance of NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission.

LISTOS

PI – Jay Al-Saadi, LaRC
Program – Tropospheric Chemistry
Aircraft – Guardian, B-200

The summer 2018 Long Island Sound Tropospheric Ozone Study (LISTOS) was designed to improve the understanding and forecasting of poor air quality associated with high surface ozone concentrations in the Long Island Sound region. It was conducted with several federal, regional, state, local and university partners. NASA's involvement included extensive airborne remote sensing measurements, deployment and operation of two ground-based ozone lidar systems, ozone sonde launches, and support of a ground-based network of NASA-developed Pandora remote sensing instruments. Partners provided continuous forecasting and analysis support, airborne in-situ measurements, and extensive measurements from ground sites, two mobile labs, and two ships.

A goal of NASA's involvement in LISTOS is improving the ability of the public to use air quality information from satellites, in particular the upcoming measurements from the Tropospheric Emissions: Monitoring Pollution (TEMPO) mission. The NASA LISTOS flights used two instruments that are airborne simulators for TEMPO: the GEO-CAPE Airborne Simulator (GCAS) and the Geostationary Trace Gas and Aerosol Sensor Optimization (GeoTASO). Funding from NASA's GEO-CAPE Mission Study supported the LISTOS flights. A unique aspect of the LISTOS campaign was the ability to make measurements through the entire summer. By basing from LaRC and having flexibility to use either GCAS or GeoTASO on multiple aircraft, the team was able to conduct 30 flights totaling 140 flight hours during 15 sampling days from mid-June through mid-September while adapting to other scheduled usage of LaRC aircraft. This flexibility allowed a wide range of weather conditions to be sampled through the summer, including classic heat waves resulting in unhealthy ozone throughout the region, other weather patterns resulting in more localized high ozone and relatively clean background conditions.

LISTOS measurements are also being used to help with validation of data products from the new TROPOspheric Monitoring Instrument (TROPOMI) on the European Space Agency Sentinel-5 Precursor satellite launched last fall. While TROPOMI provides air quality measurements with a factor of 10 improvement in spatial resolution over previous satellites, its observations from low Earth orbit occur only once each

FIGURE 22 ***NASA Goddard's Peter Pantina, left, and Langley's Laura Judd make final checks of the GEO-TASO instrument on the HU-25A aircraft before a flight.***

day. Geostationary TEMPO observations will provide hourly measurements through the day at similar spatial resolution to TROPOMI. The airborne GCAS and GeoTASO observations mapped the LISTOS domain up to four times per day, providing researchers and air quality managers with TEMPO-like data so they can improve preparations for using TEMPO data.

Phase 1 of LISTOS, during June, used GeoTASO on the LaRC HU-25A Guardian aircraft. In addition to mapping the LISTOS domain, the range of the Guardian allowed these flights to also map pollutants in the Baltimore area in support of NASA's OWLETS-2 air quality campaign (PI – Hanisco). Phase 2, July through early September, used GCAS on the LaRC B-200 King Air aircraft. In addition to GCAS, the capability of the B-200 also allowed inclusion of the new High Altitude Lidar Observatory (HALO) instrument (IIP project, PI – Nehrir) to provide information on aerosol vertical distribution and the mixing depth of pollutants. This information, critical for accurately inferring surface concentrations from the satellite remote sensing measurements, is also especially helpful for analysis of air quality events in coastal regions, such as Long Island Sound. Phase 3 of LISTOS, which completed in September, flew the B-200 with GeoTASO and a new Multi-axis Optical Airborne Tracker (MOAT). MOAT allows improved GeoTASO zenith measurements, providing data very useful for ongoing testing of new TEMPO algorithms for retrieving ozone vertical profile in the troposphere.

ACEPOL

PI – Felix Seidel
Program – Upper Atmosphere Radiation Program
Aircraft – ER-2

The ER-2 flight campaign called Aerosol Characterization from Polarimeter and Lidar (ACEPOL) sought to test capabilities of several proposed instruments for the Aerosol-Cloud-Ecosystem (ACE) mission, a 2007 Decadal Survey mission in pre-formulation phase. The new 2017 Decadal Survey replaces ACE with a similar mission called Aerosols and Clouds, Convection and Precipitation (ACCP). In addition, the NASA PACE mission will measure aerosols and needs similar instruments. The ACEPOL mission flew nine flights in November 2017 observing targets including California's Central Valley and the Pacific Ocean, and as far east as Arizona, where the team observed smoke from controlled forest fires near Flagstaff.

The ER-2's payload included four airborne polarimeters (AirHARP, AirMSPI, AirSPEX and RSP) and two lidar instruments (CPL and HSRL-2). Each of the polarimeters used different techniques and angles to measure and record data. The instruments also differed from one another in size and power. From an engineering perspective, the ultimate goal of the ACEPOL mission was to better understand how those overall differences translate into data collection.

The combination of the polarimeter and lidar instruments, along with ground-based data from stationary air quality measurement stations provide scientists with a more complete picture of the three-dimensional distribution of aerosols in Earth's atmosphere. Utilizing a variety of different approaches for collecting data also enables scientists to differentiate various types of aerosols (e.g., smoke, dust, pollution) and clouds (cirrus, stratus, etc.).

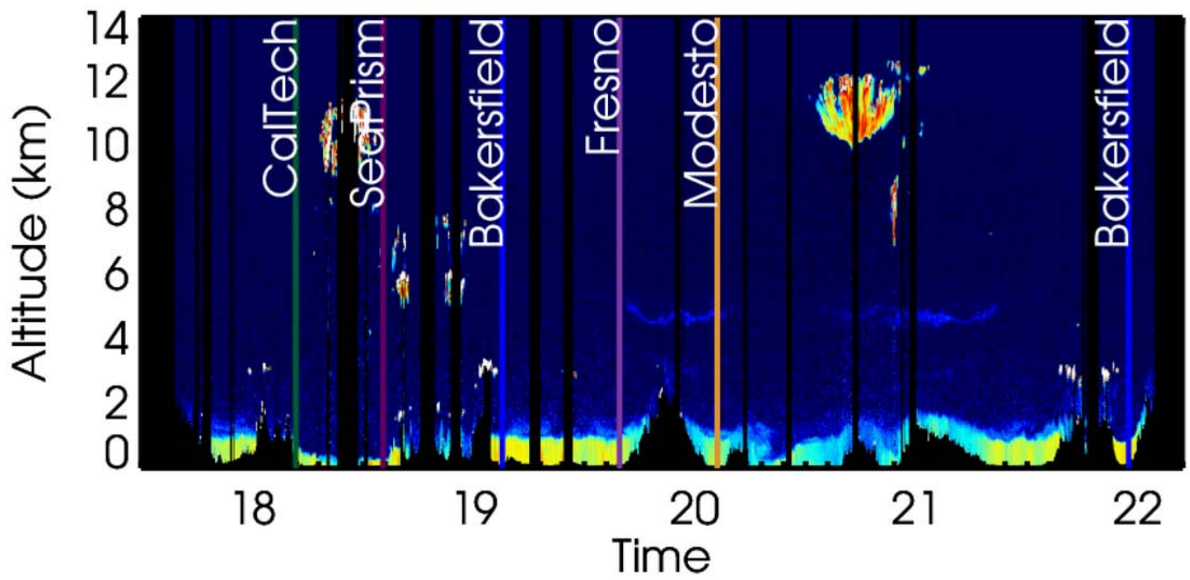
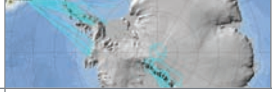


FIGURE 23 ***HSRL-2 preliminary data from the ER-2 ACEPOL flight on Nov. 7 showing the structure of aerosol and clouds in the atmosphere along the flight track. The ground is black, dark blue indicates clear air and white indicates water clouds. Transparent cirrus clouds high in the atmosphere show up in yellow and orange. Yellow, green and blue at lower altitudes indicate aerosols.***



The ER-2, based at AFRC, was chosen because its high altitude flight regime provides a vantage point and conditions similar to space. By flying these instruments on an aircraft before the expense of launching them into space, scientists and engineers can make adjustments to the hardware and data retrieval algorithms. The aircraft test phase in sensor development is helpful for ensuring instruments are collecting both accurate and useful data prior to the time the final version of the sensors makes its trip into space.

In addition to testing capabilities of new sensors, ACEPOL flights provided calibration and evaluation data for NASA's CALIPSO satellite lidar by staging satellite underpasses as part of their flight plans. In addition to comparisons with CALIPSO, ACEPOL also contributes to the development of future satellite missions including the European Space Agency's EarthCare, the European Organization for the Exploitation of Meteorological Satellites METOP-SG , and NASA's MAIA and PACE programs.

The ACEPOL mission involved partnership between multiple NASA centers, including LaRC, GSFC, JPL and the Goddard Institute for Space Studies. The mission also included international partnership with the Netherlands Institute for Space Research, which flew the AirSPEX instrument on board the ER-2 for the second time.

Support to Instrument Development

Another major element of the ASP program is the support of instrument development for Earth Science. Some instruments are developed specifically for airborne utilization, while many are developed as precursors or simulators for satellite instruments. In 2018, ASP aircraft flew all of the instruments listed in Table 8. 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.

A large number of other IIP-selected instruments are also scheduled for test flights in 2019 and 2020, as shown in the 5-year plan (Appendix A).

Instrument	Sponsor	Aircraft	Flight Hours
Doppler Scatt	IIP/SWOT	B-200	60.1
MISTIC Winds	IIP	ER-2	19.8
HALO	IIP	B-200	18.4
C-HARRIER	AITT	Twin Otter	3.7
Triple-pulsed IPDA 2-micron lidar	IIP	B-200	15.4
CAMAL	GSFC	ER-2	10.6
Air-HARP	IIP	ER-2	5.6
air-LUSI	AITT	ER-2	4.2
HAVHM	IIP	DC-3	5.5
Total flight hours			143.3

TABLE 8 ***Instrument Development Flights in FY18.***

AITT Progress

The AITT program is designed to fund maturation of newly developed aircraft instruments, such as prototypes developed through the ESTO IIP program. The program provides campaign-ready airborne instrumentation that can participate in field experiments, evaluate new satellite instrument concepts, and provide calibration and validation of satellite instruments. Past examples are the 4STAR radiometer, PRISM and the 3-frequency weather radar.

In FY18, three instruments began, continued, or completed their transition to more capable missions or higher altitude aircraft, making them more useful for some types of missions.

Air-LUSI

PI – Kevin Turpie, UMBC
Program – AITT
Aircraft – ER-2

The objective of airborne LUnar Spectral Irradiance (air-LUSI) mission is to provide NASA a capability to measure exo-atmospheric lunar spectral irradiance with unprecedented accuracy. Careful characterization of the Moon from above the atmosphere will make it a stable and consistent SI-traceable absolute calibration reference. This could revolutionize lunar calibration for some Earth observing satellites and would be especially beneficial to ocean color missions, such as the upcoming PACE and JPSS (VIIRS) missions, and retrospectively for the SeaWiFS, EOS (MODIS), and S-NPP (VIIRS) data records.

Air-LUSI approaches this characterization by taking lunar spectral irradiance measurements at high-altitude on the ER-2 aircraft. This is accomplished with a non-imaging telescope to collect moonlight, which is passed to a NIST-calibrated spectrometer (called the IRradiance Instrument Subsystem or IRIS) via fiber optics. The spectrometer and an on-board validation reference are hermetically sealed in an enclosure made of two solid blocks of aluminum, keeping the spectrometer and reference at constant sea-level pressure and 20°C during the high altitude flight. The Autonomous, Robotic TElescope Mount Instrument Subsystem (ARTEMIS) keeps the telescope pointed at the Moon using a camera to track the sky in front of the telescope. (See Figure 24.)

After a year of design and development, air-LUSI executed its first test flight at AFRC on August 1 and 2 between the hours of 3 a.m. and 5 a.m. The results exceed expectations. During its test flights, the ARTEMIS subsystem kept the IRIS telescope locked onto the Moon to within 0.1° on average and the IRIS enclosure kept the spectrometer and validation reference solidly at sea-level pressure and 20°C. The measurements recorded during these flights showed very high signal-to-noise ratio and sensitivity to the lunar spectrum. The air-LUSI team is now analyzing this and the engineering data and preparing for their demonstration flights early in 2019.

FIGURE 24 ***Air-LUSI IRIS telescope on ARTEMIS mount in ER-2 wing pod tail.***

C-HARRIER

PI – Liane Guild, ARC
Program – AITT
Aircraft – CIRPAS Twin Otter

The C-HARRIER (Coastal High Acquisition Rate Radiometers for Innovative Environmental Research) project continued development in 2018. The radiometer instrument system is aligned with present and next-generation satellite bio-optical observations for coastal and ocean biology water quality research, and it utilizes advanced airborne microradiometer technology, which will support new satellite-based algorithms and observations for NASA's Ocean Biology and Biogeochemistry research program in Earth Science. C-HARRIER flew in October on the Navy's CIRPAS Twin Otter to collect data for water quality and aerosol optical depth of Southern California, Monterey Bay and Lake Tahoe sites. (See Figure 25.) The instruments include the ARC C-AIR radiometer and 3STAR sun tracking radiometer (sun photometer) and GSFC C-AERO radiometers.

DopplerScatt

PI – Dragna Perkovic-Martin, JPL
Program – AITT
Aircraft – B-200

JPL's DopplerScatt instrument, designed to measure ocean surface currents, has graduated from IIP to AITT and now on to collaborative science measurements. Two missions were carried out in 2018, one in the Gulf of Mexico in March, and the second in the Pacific in August. In the first mission, JPL, in collaboration with Chevron, was benchmarking DopplerScatt's surface current measurements against ground-truth data from Chevron. DopplerScatt conducted survey flights March 23-29 over the Gulf of Mexico, while the Loop Current is active in the far north of the Gulf near New Orleans. The flights were conducted over areas where Chevron already measures surface currents with assets such as drifters, acoustic Doppler current profilers (ADCPs) and ROCIS (an airborne optical imager). The collaboration and deployment specifics were worked out efficiently and

FIGURE 25 ***Test flight on the CIRPAS Twin Otter over Moss Landing and coastal Monterey Bay. CIRPAS meteorology probes can be seen on the wing tip supporting the science data collection.***

DopplerScatt team members deployed to the field on March 23 and executed four flights between March 24 and March 27.

During the deployment, DopplerScatt trialed a new real-time processor and real-time map display as part of the AITT milestone verification. These new features enabled situational awareness of operators and faster quick-look ground post-processing.

DopplerScatt surface current estimates are being compared to the in-situ data provided by Chevron as well as to the ROCIS sensor data. The ROCIS data is of particular interest, as it is the first comparison of current measurements at the very surface of the water (top few millimeters as opposed to slightly deeper currents measured by other sensors). Strong loop currents can pose safety risks to offshore operations. DopplerScatt's estimates of surface currents could be used to inform offshore operations. This deployment was a huge team effort including teams from AFRC, Chevron and DopplerScatt/JPL.

For the August mission, the DopplerScatt team collaborated with Florida State University, University of Washington and Scripps Institute of Oceanography, in a deployment to the Pacific (Southwest of the San Francisco Bay) to observe submesoscale processes. DopplerScatt conducted survey flights August 20-24 over the area where novel ultra-thin drifters were deployed by the FSU and UW from the research vessel Shana Rae.

DopplerScatt team members and a summer student deployed in the field on August 20 and executed five flights between August 20 and 24 with flying 2 sorties on August 24. During the deployment DopplerScatt collected data continuously during the flights. The winds were low (1-3 m/s) until August 24 when they picked up to ~ 6m/s in the afternoon. DopplerScatt surface current estimates will now be compared to the in-situ data provided by the FSU and UW. DopplerScatt is planned to be used in early SWOT pre-cursor cal/val missions.

FIGURE 26 ***The AFRC B-200 flew DopplerScatt on multiple missions in 2018.***

Upcoming Missions

Major upcoming missions are described below and listed in Table 9.

Mission	Aircraft	Location
CAMP²EX	P-3	Philippines
FIREX-AQ	DC-8	Idaho, Kansas
Operation IceBridge	DC-8, P-3	Antarctic, Arctic
ACT-America	B-200, C-130	Midwest, South U.S.
OMG	C-20A, G-III, DC-3	Greenland
SWOT cal/val experiment	G-V	Pacific off San Francisco

TABLE 9 ***Major Missions Upcoming in 2019.***

Cloud and Aerosol Monsoonal Processes - Philippines Experiment (CAMP²EX)

The science objectives of CAMP²Ex are:
1. Determine the extent to which aerosol particles are responsible for modulating warm and mixed phase precipitation in tropical environments. 2. Understand how the presence of aerosol particles, and the resulting increase in cloud droplet number, changes the heat budget in convective clouds, and whether this change controls which clouds grow into large thunderstorms. 3. Characterize the aerosol lifecycle in the Southwest Monsoon, recognizing that aerosol induced changes in clouds and precipitation may very well feed back into aerosol production, transport and removal.

The mission will deploy an instrumented P-3 from Cebu, Philippines and fly inside the Philippines flight information region (FIR) with possible flights to Singapore. The payload includes APR-2, LARGE, HSRL, 4STAR, BBR, SSFR and Cloud Polarimeter. This mission is scheduled for July-August 2019.

FIREX-AQ

FIREX-AQ is a mission sponsored by NASA's Atmospheric Composition and Chemistry program. It will fly in summer 2019 on the DC-8, based first out of Boise, Idaho, and later out of Salinas, Kansas, so as to reach multiple regions of the U.S. where fires may be burning. The DC-8 will carry a complete chemistry payload, similar to SEAC⁴RS, which flew in 2013. It will also carry the MASTER thermal NASA imager. This is a joint mission with NOAA's FASMEE mission, which will be sampling additional chemistry from a Citation at more limited range.

FIREX-AQ will investigate both wild and prescribed burn fires. The overarching objective of FIREX-AQ is to provide measurements of trace gas and aerosol emissions in great detail, relate them to the fuel and fire conditions at the point of emission, characterize the conditions relating to plume rise, follow plumes downwind to understand the chemical transformation and air quality impacts, and assess the efficacy of satellite detections for estimating the emissions from sampled fires.

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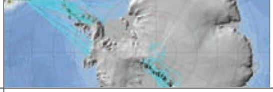


Technology Demonstrations

A number of instruments under development, including Instrument Incubator Program (IIP) projects are scheduled for initial or continued test flights in 2019. These include the following:

- SRI CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD) on SIERRA-B.
- Compact Midwave Imaging System on LaRC G-III.
- Development and Demonstration of an Airborne Differential Absorption Radar for Humidity Sounding Inside Clouds on a Twin Otter.
- Upgrade of AirMSPI-2 to operational readiness for scientific field campaigns on ER-2.
- Air-LUSI on ER-2.

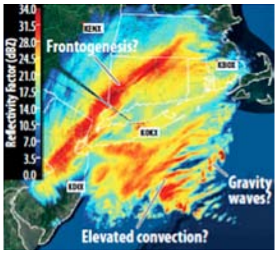
These and other missions are indicated on the 5-year plan in Appendix A.

Earth Venture Suborbital-3 (EVS-3)

Five new NASA Earth Science campaigns will take to the field starting in late 2019 to investigate a range of pressing research questions, from what drives intense East Coast snowfall events to the impact of small-scale ocean currents on global climate. These studies will explore important, but not-well-understood, aspects of Earth system processes and were competitively selected as part of NASA's Earth Venture-class program. This is NASA's third series of Earth Venture suborbital investigations, which are regularly solicited, sustained observation projects first recommended by the National Research Council in 2007. According to Jack Kaye, associate director for ESD research, these innovative investigations tackle difficult scientific questions that require detailed, targeted field observations combined with data collected by our fleet of Earth-observing satellites.

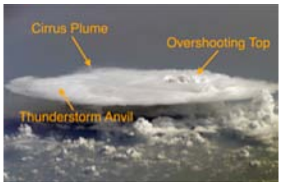
The five newly selected Earth Venture investigations are:

IMPACTS: Investigation of Microphysics and Precipitation for Coast-Threatening Snowstorms



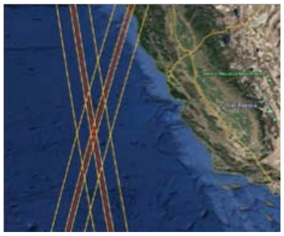
Lynn McMurdie of the University of Washington will lead the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms project to study the formation of snow bands in East Coast winter storms. Better understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall will help improve forecasts of these extreme weather events. This study will involve flights of NASA's ER-2 and P-3 research aircraft over the northeastern United States.

DCOTSS: Dynamics and Chemistry of the Summer Stratosphere



Kenneth Bowman of Texas A&M University will lead the Dynamics and Chemistry of the Summer Stratosphere project to investigate how strong summertime convective storms over North America can change the chemistry of the stratosphere. These storms regularly penetrate deep into the lower stratosphere, carrying pollutants that can change the chemical composition of this atmospheric layer, including ozone levels. Flights of NASA's ER-2 high-altitude aircraft will be based in Salina, Kansas.

S-MODE: Submesoscale Ocean Dynamics and Vertical Transport



Thomas Farrar of Woods Hole Oceanographic Institute will lead the 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. The project will collect a benchmark data set of climate and biological variables in the upper ocean that influence this exchange. Measurements will be collected by research aircraft and shipborne instruments 200 miles off the coast of San Francisco, in the vicinity of the SWOT cross-over tracks.

ACTIVATE: Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment

Armin Sorooshian of the University of Arizona will lead the Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment to identify 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 that have a critical role in our planet's energy balance. Two NASA research aircraft, an HU-25 Falcon and a B-200 King Air, will fly from NASA's Langley Research Center in Hampton, Virginia, to gather measurements from above, below and within.

Delta-X

Marc Simard of NASA's Jet Propulsion Laboratory in Pasadena, California, will lead the Delta-X investigation to better understand the natural processes that maintain and build land in major river deltas threatened by rising seas. The project will improve models that predict loss of coastal land from sea level rise by improving estimates of how deltas add land—a process that involves trapping sediments and creating organic soils as plants grow. Delta-X will focus on the Mississippi River Delta using instruments on three NASA research aircraft.

A total of six NASA centers and 27 educational institutions are participating in these five Earth Venture projects. The five-year investigations were selected from 30 proposals. The Delta-X project is funded at a total cost of no more than $15 million; each of the other projects is funded at no more than $30 million. The tentative flight schedule is shown in Figure 27.

Mission	Aircraft	CY2019				CY2020				CY2021				CY2022			
IMPACTS	P-3, ER-2				■	■			■	■			■	■			
DCOTSS	ER-2					■		■			■	■					
S-MODE	G-V, B-200						■				■	■					
ACTIVATE	HU-25, B-200					■	■			■	■			■	■		
Delta-X	G-III, B-200(2)						■	■		■			■		■	■	

FIGURE 27 ***EVS-3 Missions, aircraft and tentative flight schedules.***

4. Aircraft

Airborne Science Program Resources	Platform Name	Center	Duration (Hours)	Useful Payload (lbs)	GTOW (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)	Internet and Document References
ASP Supported Aircraft*	DC-8	NASA-AFRC	12	30,000	340,000	41,000	450	5,400	http://airbornescience.nasa.gov/aircraft/DC-8
	ER-2 (2)	NASA-AFRC	12	2,900	40,000	>70,000	410	>5,000	http://airbornescience.nasa.gov/aircraft/ER-2
	Gulfstream III (G-III)(C-20A)	NASA-AFRC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Armstrong
	Gulfstream III (G-III)	NASA-JSC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_-_JSC
	Gulfstream V (G-V)	NASA-JSC	10	8,000	91,000	51,000	500	>5,000	http://airbornescience.nasa.gov/aircraft/Gulfstream_V
	P-3	NASA-WFF	14	14,700	135,000	32,000	400	3,800	http://airbornescience.nasa.gov/aircraft/P-3_Orion
Other NASA Aircraft	B-200 (UC-12B)	NASA-LARC	6.2	4,100	13,500	31,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_UC-12B_-_LARC
	B-200	NASA-AFRC	6	1,850	12,500	30,000	272	1,490	http://airbornescience.nasa.gov/aircraft/B-200_-_AFRC
	B-200	NASA-LARC	6.2	4,100	13,500	35,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	B-200 King Air	NASA-WFF	6	1,800	12,500	32,000	275	1,800	https://airbornescience.nasa.gov/aircraft/B-200_King_Air_-_WFF
	C-130	NASA-WFF	12	36,500	155,000	33,000	290	3,000	https://airbornescience.nasa.gov/aircraft/C-130_Hercules
	Cessna 206H	NASA-LARC	5.7	1,175	3,600	15,700	150	700	http://airbornescience.nasa.gov/aircraft/Cessna_206H
	Cirrus SR22	NASA-LARC	6.1	932	3,400	10,000	150	700	http://airbornescience.nasa.gov/aircraft/Cirrus_Design_SR22
	Dragon Eye	NASA-ARC	1	1	6	500+	34	3	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	Gulfstream III (G-III)	NASA-LARC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_-_LARC
	HU-25A Falcon	NASA-LARC	5	3,000	32,000	42,000	430	1,900	http://airbornescience.nasa.gov/aircraft/HU-25A_Falcon
	SIERRA-B	NASA-ARC	10	100	400	12,000	60	600	http://airbornescience.nasa.gov/platforms/aircraft/sierra.html
	Twin Otter	NASA-GRC	3	3,600	11,000	25,000	140	450	http://airbornescience.nasa.gov/aircraft/Twin_Otter_-_GRC
	WB-57 (3)	NASA-JSC	6.5	8,800	72,000	60,000+	410	2,500	http://airbornescience.nasa.gov/aircraft/WB-57

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

NASA maintains and operates a fleet of highly modified aircraft unique in the world for their ability to support Earth observations. The aircraft are based at various NASA centers.

Some of the platforms have direct support from ASP for flight hours and personnel. These are the "ASP-supported Aircraft."

Other NASA aircraft are also available for science missions. In addition, NASA missions employ commercial air services (CAS) under protocols established by NASA's Aircraft Office at Headquarters.

More information about using the aircraft can be found on the ASP website at airbornescience.nasa.gov. The annual "call letter" is an excellent source of information on how to request airborne services. This letter can also be found on the website.

The capabilities of the ASP fleet range from low and slow to high and fast, with a wide variety of payload capacities. The aircraft and their performance characteristics are listed in Table 10. The altitude / endurance characteristics are also shown in Figure 28; altitude/range in Figure 29.

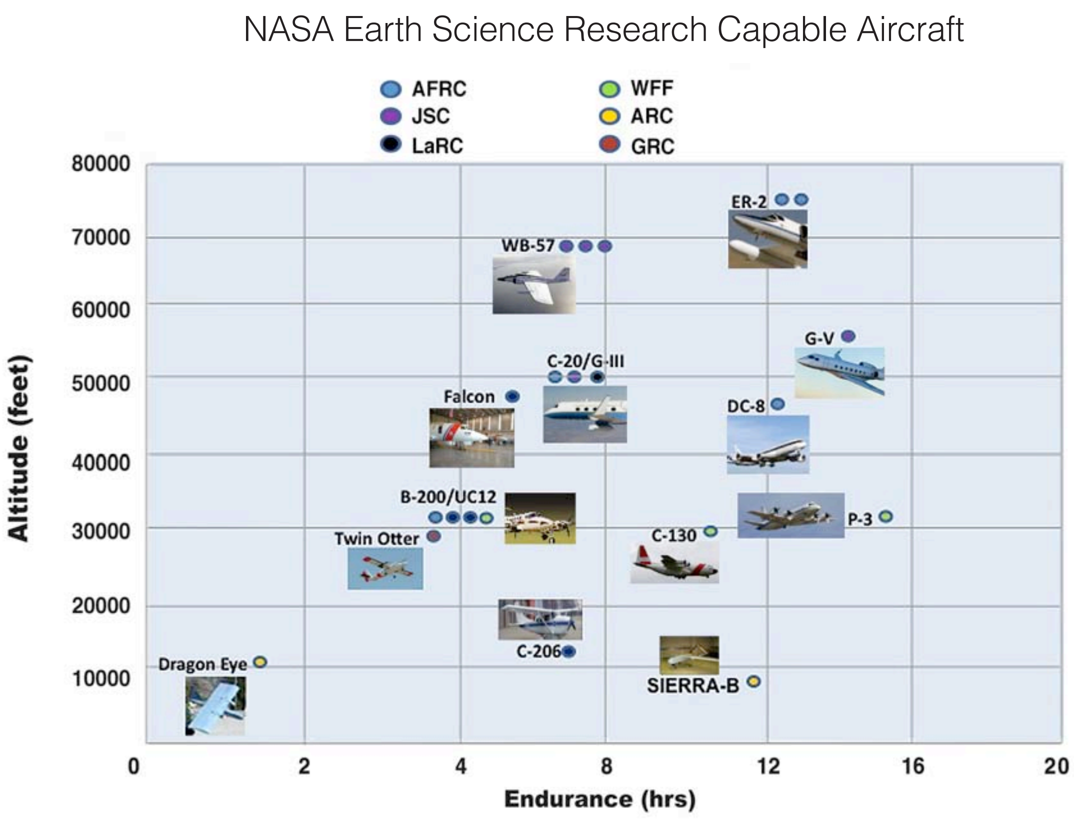


FIGURE 28 ***NASA Aircraft showing altitude and endurance capabilities.***

NASA Earth Science Research Capable Aircraft

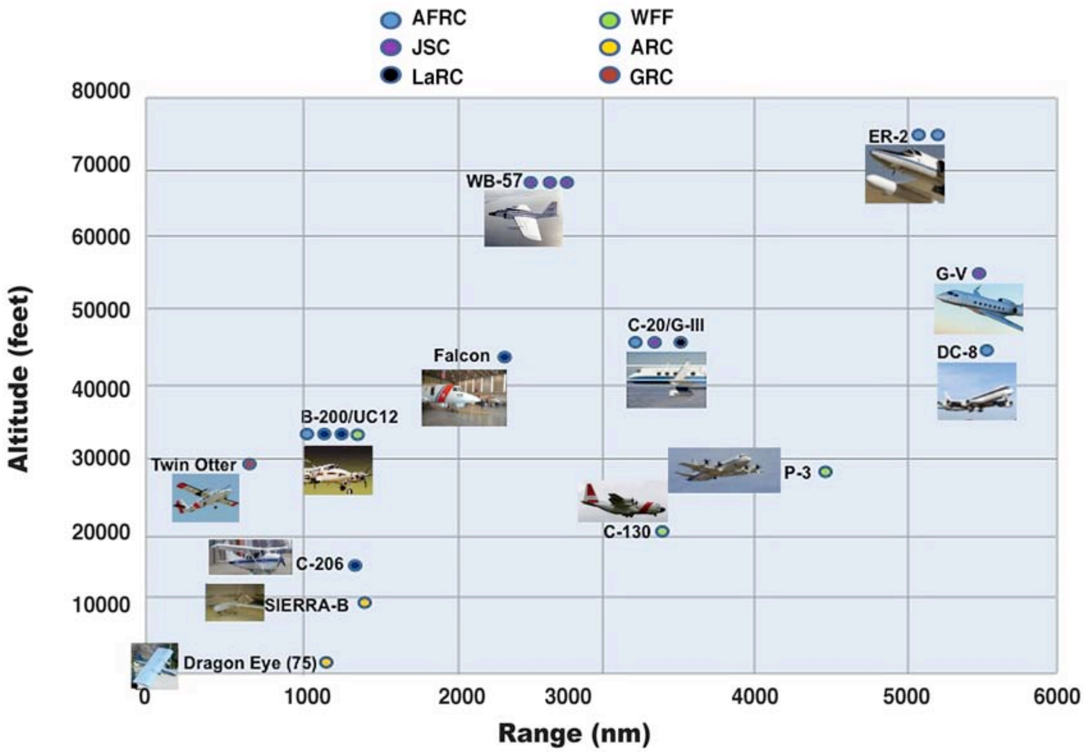


FIGURE 29 ***NASA Aircraft showing altitude and range capabilities.***

New Program Capabilities

Two new science-capable platforms are now included on the aircraft schedule: a G-V at JSC and a new G-III at LaRC.

ASP-Supported Aircraft

The seven aircraft systems directly supported in 2018 (subsidized flight hours) by the Airborne Science Program are the DC-8 flying laboratory, (2) ER-2 high altitude aircraft, P-3 Orion, C-20A (G-III), the JSC G-III and the JSC G-V.

DC-8 Airborne Laboratory

OPERATING CENTER:
Armstrong Flight Research Center

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

SCIENCE FLIGHT HOURS IN FY18: 279

DC-8 FY18 Missions

Mission	Location	Science program area
ATom-3 and ATom-4	Global	Atmospheric Composition
NDMAX-ECLIF	Germany	Atmospheric Composition
HIWC-II	Caribbean and Gulf of Mexico, Pacific Ocean	Aeronautics
OIB pre-Antarctica	Palmdale	Cryosphere

MODIFICATIONS MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE:
DC-8 had no major modifications in FY18.

WEBSITE: *airbornescience.nasa.gov/aircraft/DC-8*

FIGURE 30 ***The DC-8 was filled with instruments during ATom.***

ER-2

OPERATING CENTER:
Armstrong Flight Research Center

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

SCIENCE FLIGHT HOURS IN FY18: 279.5

ER-2 FY18 Missions

Mission	Location	Science program area
ACEPOL	Palmdale	Atmospheric Composition
Air-LUSI	Palmdale	ESTO
MARBLE	Palmdale	Education
Cosmic Dust	Palmdale	Science
MISTiC Winds	Palmdale	ESTO
HyspIRI HyTES Hawaii Campaign (H3C)	Hawaii	Carbon Cycle and Ecosystems
eMAS/PICARD/MASTER	Palmdale	EOS
CAMAL	Palmdale	Atmospheric Composition
HyTES SoCal	Palmdale	Carbon Cycle and Ecosystems
SARP	Palmdale	Atmospheric Composition
Thomas Fire	Palmdale	Disaster Response / Applied Science
HyspIRI CA	Palmdale	Carbon Cycle and Ecosystems

MODIFICATIONS MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE:
ER-2 809 is currently being reintegrated after undergoing Cabin Altitude Reduction Effort (CARE) modification to structurally modify NASA ER-2 aircraft to reduce cockpit cabin altitude from 29,000 to 15,000 feet when the aircraft is cruising at 65,000 feet. This is to reduce likelihood of decompression sickness, fatigue and risk of permanent neurological injury. A similar cabin altitude reduction effort will be performed on NASA #806 in FY19.

WEBSITE: *airbornescience.nasa.gov/aircraft/ER-2*

FIGURE 31 ***NASA ER-2 flew HyTES in Hawaii in 2018.***

P-3 Orion

OPERATING CENTER:
WGoddard Space Flight Center's 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 P-3 has been extensively modified to support airborne science-related payloads and activities.

SCIENCE FLIGHT HOURS IN FY18: 390.0

P-3 Orion FY18 Missions

Mission	Location	Science program area
ORACLES	São Tomé, Africa	Atmospheric Composition
OIB-Arctic	Greenland; Alaska	Cryosphere
OIB- Antarctic	Ushuaia, Argentina	Cryosphere

MODIFICATIONS MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE:
Nadir Port #3 was modified to include a new 16-inch diameter aperture glass window interface and the addition of three 5-inch diameter ports on the nadir plate. Custom Nadir Port #3 cover plates can be manufactured to support a variety of science instrument needs for this port location.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
- 6-8 week annual maintenance period each year that can be adjusted to meet mission needs.
- Landing gear gear change October – early Novermber 2019 (2-3 month effort)
- Phased Depot Maintenance (PDM) 2021 (4-6 month effort)

WEBSITE: *airbornescience.nasa.gov/aircraft/P-3_Orion*

FIGURE 32 ***P-3 on the apron of the São Tomé airport, early one October 2018 morning.***

C20-A (Armstrong G-III)

OPERATING CENTER:
Armstrong Flight Research Center

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 aircraft are part of the ASP-supported fleet. Beginning in 2019, a third G-III will be available at LaRC.

SCIENCE FLIGHT HOURS IN FY18: C-20A: 241.6

C20-A (G-III) FY18 Missions

Mission	Location	Science program area
Transoceanic Aerobiology Biodiversity Study (TABS)	California	Carbon Cycle and Ecosystems
GOLauncher1 Inert Test Article Envelope Clearance	California	Research
SIF Aerobiology	California	Carbon Cycle and Ecosystems
Environmental controls on landslide motion revealed by InSAR and pixel offset tracking	Colorado	Earth Surface and Interior
SacDelta Levees - CDWR-2	California	Earth Surface and Interior / Applied Science
Plate Boundary UAVSAR	California	Earth Surface and Interior
Imaging near-fault deformation in central and northern California	California	Earth Surface and Interior
UAVSAR L-band Engineering	California	Earth Surface and Interior
Temporal and Spatial Variability of Floodplain Currents by In-Situ Observations, Radar Interferometry and Numerical Simulations	South Carolina	Carbon Cycle and Ecosystems
ABoVE L-band continuation flights	Canada, Alaska	Carbon Cycle and Ecosystems
NASA/DLR cross-calibration experiments in Canada	Canada	Earth Surface and Interior
Hurricane response	Carolinas	Applied Science

MODIFICATIONS MADE TO THE C20-A AIRCRAFT IN FY18:
In FY18 the only modification was the addition of an air data probe located on the left side of the jet, which is for the collection of aerobiological particles during flight.

WEBSITE: *airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Armstrong*

FIGURE 33 ***During ABoVE, the UAVSAR team met with Canadian students in Yellowknife.***

JSC G-III

OPERATING CENTER: **Johnson Space Center**

AIRCRAFT DESCRIPTION:

The JSC G-III (N992NA) had opportunities to carry each SAR version at times during 2018.

SCIENCE FLIGHT HOURS IN FY18: 224.0

JSC G-III FY18 Missions

Mission	Location	Science program area
Sierra Nevada	California	Water and Energy Cycle
Alaska Permafrost	Alaska	Water and Energy Cycle
Landslide Mapping	Washington Alaska	Earth Surface and Interior
Engineering Flights	California	Earth Surface and Interior
OMG	Greenland, Iceland	Cryosphere
SacDelta	California	Carbon Cycle
Fault Deformation	California	Earth Surface and Interior
Volcano Topography	Hawaii	Earth Surface and Interior

MODIFICATIONS MADE TO THE JSC G-III AIRCRAFT IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE:

JSC purchased a parts aircraft in FY18 to reduce the long-term maintenance costs associated with engine overhaul and repair. Over $2 million worth of engine maintenance was coming due in the next several years, but JSC was able to purchase an entire airplane with two good engines for $550K. Even though the utilization of the engines alone covers the cost of the parts aircraft, other components have been cannibalized to fix both the G-III and the G-V. The right engine was changed in August 2018.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE JSC G-III:

December 2018 - January 2019:

- Left engine change
- NextGen avionics upgrade: mandated upgrade to communication and navigation equipment for world-wide operations.

WEBSITE: *airbornescience.nasa.gov/aircraft/G-III_-_JSC*

FIGURE 34 ***Flight crew for the spring ice survey at Thule Air Base, including pilots, mechanics, radar engineers and the lead scientist in front of NASAs Gulfstream III.***

New JSC G-V Aircraft (N95NA)

The G-V spent the month of January 2018 in Longview, Texas at Aerosmith Aviation and received a new coat of paint. The new paint job is instrumental in preventing structural corrosion and damage to maintain the long term health of the aircraft. The paint job was original to the aircraft and not a NASA livery.

JSC completed the following work in FY18 to prepare the aircraft as a platform for the airborne science community.

- Relocated the radar altimeter, VHF and DME antennas on the bottom of the aircraft to provide the fuselage "real estate" for the nadir portal installation.
- Modified the forward cabin floor structure to support airborne science payloads. (Without this modification, the sensors and instruments would not have a clear field of view from the cabin to the nadir portals.)
- Installed seat track throughout the cabin so that payload equipment and racks can be installed anywhere in the G-V.
- Completed the design, analysis and fabrication of the two equipment racks that provide the power and data interface between the aircraft and science equipment.
- Completed the design and analysis of a generic window pack assembly that interfaces with the nadir portals. The pack incorporates a single pane window that is similar in design and stress criteria to other airborne science platforms. Even though the cabin pressure differential is higher on the G-V than these aircraft, the overall design approach is consistent with the P-3 and DC-8 with the goal of minimizing the effort to transfer payloads between aircraft.
- Wrote the statement of work and awarded contract to install nadir portals on the G-V.
- The G-V has its first approved flight request (195001). The JSC team is working with Scripps Institution of Oceanography and JPL on the design and integration of the payload into the G-V. First flights are in early 2019.

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FIGURE 35 ***NASA G-V with JSC Aircraft Team.***

New LaRC G-III Aircraft

The G-III (C-20B) aircraft will replace NASA Langley's existing Dassault HU-25A Guardian aircraft for airborne science as soon as practical. An engine hush kit has already been installed, enabling the G-III aircraft to be Stage III noise compliant. This modification allows the aircraft to deploy nationwide and worldwide without requiring engine noise waivers. In addition, two nadir portals are being installed under contract. The nadir portals (each 18.16-inch x 18.16-inch with external shutters) will allow the aircraft to install Earth science sensors, as is currently possible with the center's two B-200 King Air aircraft and the HU-25A aircraft. The aircraft can be equipped with pressure domes over the portals such that instruments can be flown open to the atmosphere. A total of six Researcher Interface Panels are planned for the passenger cabin, which will accommodate up to 10 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. versus 1800 nm. for the HU-25A aircraft. The expected duration will increase from 4.5 hours to about 7.5 hours, and the realistic mission altitude will increase to 45,000 feet from 36,000 feet. Discussions with researchers at LaRC, GSFC and the Johns Hopkins University are underway regarding installation of research systems in the summer of 2019. The goal is to have the LaRC G-III aircraft ready for research at LaRC in the spring of 2019.

FIGURE 36 ***NASA 520, a new G-III at LaRC.***

Other NASA Earth Science Aircraft

Other NASA aircraft, as described here, on the ASP website and in the annual ASP Call Letter, are those platforms operated by NASA centers, but not subsidized by the ASP program. These are available for science through direct coordination with the operating center.

Aircraft	Operating Center
C-130 Hercules	WFF
B-200 King Air; UC-12B	LaRC, AFRC, WFF; can also be contracted through JPL
HU-25A Falcon / HU-25C Guardian	LaRC
Dragon Eye UAS	ARC
SIERRA-B UAS	ARC
Twin Otter	GRC, also can be contracted through JPL
WB-57	JSC
AlphaJet	Can be accessed through ARC

C-130 Hercules

OPERATING CENTER: **Wallops Flight Facility**

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. After completion of ACT-America in 2019, a business case will need to be developed to keep operating the remaining aircraft.

SCIENCE FLIGHT HOURS IN FY18: 310.5

C-130 FY18 Missions

Mission	Location	Science program area
NAAMES	St. John's, Newfoundland, Canada	Carbon Cycle and Ecosystems
ACT-America	Wallops Island, Virginia; Lincoln, Nebraska; Shreveport, Louisiana	Atmospheric Composition

MODIFICATIONS MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE: None

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

- N436: 6-8 week annual maintenance period each year that can be adjusted to meet mission needs.
- A Phased Depot Maintenance (PDM) extension. inspection is required for N436 in spring 2020 requiring 3-4 months to complete.
- N436: Landing gear overhaul Fall 2021 (2-3 month effort).

WEBSITE: *airbornescience.nasa.gov/aircraft/C-130_Hercules*

FIGURE 37 ***In the cockpit of the C-130 during ACT-America.***

B-200 / UC-12

OPERATING CENTERS:

NASA LaRC operates both a conventional B-200 and a UC-12B (military version). Both have been extensively modified for remote sensing research. NASA AFRC also operates a Super King Air B-200, which has been modified for downward looking payloads. WFF operates a B-200 primarily for mission management operations.

AIRCRAFT DESCRIPTION:

The Beechcraft B-200 King Air is a twin-turboprop aircraft capable of mid-altitude flight (>30,000 feet) with up to 1,000 pounds of payload for up to 6 hours. Three NASA centers operate B-200 aircraft with varying modifications for science.

SCIENCE FLIGHT HOURS IN FY18: 446.2

B-200 Missions in FY18

Mission	Location	Science program area
ACT-America	NASA LaRC; Lincoln, Nebraska; Shreveport, Louisiana	Atmospheric Composition
Long Island Sound Tropospheric Ozone mission	NASA LaRC; Baltimore; Long Island Sound	Atmospheric Composition
IPDA	NASA LaRC	ESTO IIP
HALO	NASA LaRC	ESTO IIP
DopplerScatt	EAFB; New Orleans; San Jose, California	AITT

MODIFICATIONS ON LARC B-200 AND UC-12B MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE: None

MODIFICATIONS ON AFRC B-200 MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE:
Completed floor access panel and pressure switch modification, which improves maintenance and flight safety.

FIGURE 38 ***The AFRC B-200 flew DopplerScatt on multiple missions in 2018.***

MAINTENANCE FOR LARC B-200 AND UC-12B

Each LaRC 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 when necessary based on aircraft usage.

MAINTENANCE FOR AFRC B-200

Notional: Phase inspection are scheduled every 200 flight hours or 1 year (whichever comes first).

B-200 ***WEBSITES:***

airbornescience.nasa.gov/aircraft/B200_-_LARC
airbornescience.nasa.gov/aircraft/B-200_UC-12B_-_LARC
airbornescience.nasa.gov/aircraft/B200_-_AFRC
airbornescience.nasa.gov/aircraft/B-200_King_Air_-_WFF

HU-25A Guardian

OPERATING CENTER:

Langley Research Center

AIRCRAFT DESCRIPTION:

The HU-25C and HU-25A Falcon and Guardian 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.

SCIENCE FLIGHT HOURS IN FY18: 24.8

HU-25A FY18 Missions

Mission	Location	Science program area
Long Island Sound Tropospheric Ozone mission	NASA LaRC; Baltimore; Long Island Sound	Atmospheric Chemistry

MODIFICATIONS MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE: None

WEBSITE: *airbornescience.nasa.gov/aircraft/HU-25C_Guardian*

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

Maintenance is a function of number of flight hours flown.

FIGURE 39 ***HU-25A participated in LISTOS in FY18.***

WB-57

OPERATING CENTER:
Johnson Space Center

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 both navigational equipment and controls for the operation of the payloads located throughout the aircraft. The WB-57 can carry up to 8,800 pounds of payload. JSC maintains three WB-57 aircraft.

SCIENCE FLIGHT HOURS IN FY18: 0

MODIFICATIONS MADE IN FY18 AND IMPACTS ON PERFORMANCE AND SCIENCE: None

WEBSITE: *airbornescience.nasa.gov/aircraft/WB-57*

FIGURE 40 *WB-57.*

Non-NASA Commercial Aviation Services (CAS) Oversight and Management

NASA Earth Science investigators not only rely on NASA's highly capable and specialized aircraft, but also on science-capable aircraft from the commercial sector. This year alone, NASA-sponsored scientists flew missions supporting Operation IceBridge using a contracted Basler BT-67 in Antarctica and contracted King Air A-90s flew missions for the JPL Airborne Snow Observatory over the Sierra Nevada range in California and the GSFC G-LiHT in California, Florida and Puerto Rico. The EVS-2 Oceans Melting Greenland mission used a commercial DC-3 in Greenland and the ABoVE and AVIRIS teams used contracted Super King Air B200s in Alaska, Canada and Europe. Since 2010, each year the use of NASA Airborne Science Program aircraft has exceeded the average annual flight hours flown over the previous decade. Also in this time frame, the use of contracted aircraft has increased from below 20% of NASA Earth science funded flight hours to 35%. Where appropriate, the Airborne Science Program supports the use of contract aircraft, currently called Commercial Aviation Services, or CAS. NASA does not have the aircraft or other aviation resources the science community needs to accomplish all its missions, especially lower cost, small general aviation-like aircraft. Acquiring these readily available aircraft, on an as-needed basis, just makes more sense versus covering the full cost of ownership and operations.

NASA, as with all federal government agencies, has policies and procedures in place to help ensure that only reputable and capable contract companies and aircraft were procured to meet the needs of the mission. The procedures were usually split between the contracting office and an aircraft operations organization. The contracting office wrote the proposal and wrote and negotiated the contract. The aircraft operations organization determined the fitness of the aircraft provider usually through a review process. In recent years there have been substantial changes to the policies and rules NASA has instituted to acquire and manage the types of services mentioned above, such as requiring service providers to be FAA Part 135 compliant. Because CAS has become so critical to many of our stakeholders, the Program asked the NASA Aircraft Management Division to provide an overview of NASA's current CAS policies and expectations. It's important that Program stakeholders have a solid understanding of NASA's requirements and expectations.

What is CAS?

In general, commercial aviation services (CAS) are full-service contract agreements through which an executive agency acquires aircraft and related aviation services, including unmanned aircraft systems (UAS) and drones. Typically, these agreements come in the form of an aircraft charter under an exclusive use arrangement to perform a specific government function. In most cases these full-service agreements are contracts or subcontracts with commercial vendors but, in some cases, CAS can also be conducted through grants with non-commercial entities. In all cases the CAS entity operates and maintains the aircraft performing the government function.

NASA uses CAS to supplement NASA's own aircraft capabilities. NASA's use of CAS includes conducting science and aeronautics research and to support human exploration of space. In FY17 NASA spent approximately $6 million to fly over 1,600 flight hours using CAS. NASA's CAS utilization has climbed steadily in the last five years to account for almost 35% of all NASA aircraft flight hours flown in support of NASA mission requirements.

What is the Policy?

The Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB) have pointed out that safety of CAS flight operations is incumbent on the federal agency that has the mission responsibility. In 2017 NASA implemented significant changes in our oversight and management of CAS operations with an update to the NASA Aircraft Operations Management Manual. As a federal agency, which conducts almost all of our missions using NASA's public use authority, NASA has operational control of all public aircraft missions flown for NASA. This public aircraft authority is defined in the U.S. Code with additional guidance in federal regulations. These regulations require NASA to ensure the airworthiness and safe operations of all government aircraft operations to include CAS through NASA's management and oversight programs.

NASA's CAS oversight responsibility begins with planning for the use of aircraft to support NASA programs and projects. This ensures NASA's world-class performance and safety standards are built into the Requests for Proposals (RFPs) process. Then, NASA's center flight operations works with programs and projects in selecting qualified vendors that are capable of and committed to meeting NASA's high quality and safety standards. NASA's oversight continues throughout the performance of the contract, often with NASA instruments or personnel flying on board the contracted aircraft.

When NASA's people and equipment are exposed to flight risks, our aircraft operations managers have a responsibility to partner with the program and project managers and be the gatekeepers of NASA's safety requirements. To mitigate any safety risks of CAS flights, NASA has required CAS operators to implement higher standards, such as Federal Aviation Regulation (FAR) Part 135 requirements for CAS flight operations. In addition, all aircraft and aircraft modifications have to go through a NASA airworthiness review process and receive either a Certificate of Airworthiness or Statement of Airworthiness issued by a NASA center airworthiness technical authority, depending on the complexly of the aircraft modification.

NASA's oversight responsibilities include initial contractor reviews prior to contract award, surveillance during the contract period of performance, and appropriate close-out responsibilities. A surveillance plan (which includes mandatory inspection points and witnessing select processes but does not typically require continuous onsite oversight) is implemented for all CAS contracts due to the critical and complex nature of CAS operations as defined by NASA safety policies. CAS contracts cite and allow NASA access to all maintenance and flight operations performed under a NASA contract regardless of prime contractor or subcontractor status. This surveillance also includes inspections of all CAS operators, aircraft, pilots, and maintainers.

Why is CAS important to the Airborne Science Program and ESD community?

Safety oversight and management of CAS remains a critical area of attention for NASA. NASA's risk exposure to CAS has significantly increased as NASA increases its reliance on vendor provided flight services. Even though the increased use of CAS has brought a significant burden of safety oversight, NASA's aviation community is proactively addressing these challenges to ensure that NASA program and project managers are able to acquire CAS in an expedient manner to meet mission requirements.

As evident from past contractor performance there have been a few occasions where programs have experienced design, quality, cost and workmanship deficiencies that have had an impact on the success of these missions. NASA's safety oversight role in CAS has, therefore, been improved. While NASA's operates a large fleet of research aircraft, CAS allows NASA to tap into vast commercial resources to fulfill unique agency missions as needed. CAS has been, and will continue to be, indispensable in supplementing NASA's own aircraft capabilities. CAS is a significant element of NASA's aviation capability in carrying out the agency's various missions.

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 and is supported by the University of California Santa Cruz 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.

Further 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 11) 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 com-

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
POS 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 (ER-2 MVIS in 2019)	DC-8, P-3, C-130, ER-2	NSRC; ASF (ER-2)
Total Air Temperature probes	DC-8, P-3, C-130	NSRC
HDVIS High Def Time-lapse Video System	Global Hawk UAS	AFRC
LowLight VIS Low Light Time-lapse Video System	Global Hawk UAS	AFRC
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, Global Hawk	JPL
NAST-I Infrared imaging interferometer (3.5 – 16mm range)	ER-2	LaRC

TABLE 11 ***Facility Equipment.***

munications 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.

NASA Airborne Science Data and Telemetry (NASDAT) System

The NASDAT provides experiments with:

- Platform navigation and air data
- Highly accurate time-stamping
- Baseline Satcom, Ethernet network and Sensor-Web communications
- Legacy navigation interfaces for the ER-2 (RS-232, RS-422, ARINC-429, Synchro, IRIG-B)
- Recorded cockpit switch states on 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-57F. INMARSAT Broadband Global Area Network (BGAN) multi-channel systems, using electronically-steered flat panel antennas, are available on many of the NASA 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.

Sat-Com System Type / Data Rate (nominal)	Supported Platforms	Support group / location
Ku-band (single channel) / > 1 Mb/sec	Global Hawk & Ikhana UAS; WB-57	NSRC; AFRC; JSC
Inmarsat BGAN (two channel systems) / 432 Kb/sec per channel	DC-8, WB-57, P-3, S-3B, AFRC B200, ER-2,	NSRC; ASF
Iridium (1 – 4 channel systems) / 9.6 Kb/sec (four channel NASDAT system)	Most ASP Platforms	ASF; NSRC

TABLE 12 ***Satellite Communications Systems on ASP aircraft.***

Payload Management

ASP provides a variety of engineering support services to instrument teams across all of the program platforms. These include mechanical engineering, electrical and network interface support, and general consulting on the operational issues associated with specific aircraft. The services are provided jointly by personnel from NSRC at NASA's Palmdale facility and ASF at ARC and Palmdale.

NSRC staff provides instrument integration services for the NASA DC-8 aircraft. Instrument investigators provide a Payload Information Form that includes instrument requirements for space, power, aircraft data and location of the instruments, and any applicable inlet or window access needs. The staff then uses the information provided to complete engineering design and analysis of instrument and probe installations on the aircraft, and wiring data and display feeds to instrument operators.

NSRC also provides data display, aircraft video, facility instruments and satcom services on the DC-8, P-3, and C-130 aircraft. A high-speed data network (both wired and wireless) is maintained on each of the aircraft so onboard 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, e.g. the NASDAT (network host and navigation data server), and the standardized Experiment Interface Panels; as well as payload data systems for the Global Hawk, including the Telemetry Link Module and the Master Power Control System (MCPS). Together with NSRC, they also support payload IT operations on other aircraft equipped with payload satcom systems. The 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 Mission Tools Suite (MTS) is ASP's decisional support and situational awareness system used to assist with the execution of airborne missions (http://mts.nasa.gov). The primary objectives of the MTS are a.) to support tactical decision-making and distributed team situational awareness during a flight; b.) to facilitate team communication and collaboration throughout the mission lifecycle; and c.) to both consume and produce visualization products that can be viewed in conjunction with the real-time position of aircraft and airborne instrument status data. Taken together, the intent of the system is to encourage more responsive and collaborative measurements between instruments on multiple aircraft, satellites, and on the surface in order to increase the scientific value of the measurements, and improve the efficiency and effectiveness of flight missions.

In addition to supporting flight and program activities over this past year, the team has been focused on a top-to-bottom redesign of the MTS system. This new system should be ready for beta-testing by program stakeholders later in 2019 and operational early in FY20. For users, the new system will streamline functionality in order to improve application memory, performance and overall usability. Those features that are most relevant to mission execution should become easier to use for new users and more powerful for users that have used the system in the past (see Figure 41).

The next MTS release will be important in a few different ways. Some highlights include support for map projections that will better serve polar missions (e.g., polar stereographic), automatic ground overlay reprojection, a more capable user interface that will simplify the process of simultaneously monitoring tracked assets across different products stacks (see Figure 42), product video playback, and multi-channel chat. The overhaul will also make it easier for the cross-cutting infrastructure team to manage the application, be more responsive to new IT security directives, including two-factor authentication for non-NASA users, and allow integration with the ASP calendar to automatically tag telemetry and other stored data for post-mission reports and visualization. Taken together, the next release will be a major step forward for program stakeholders.

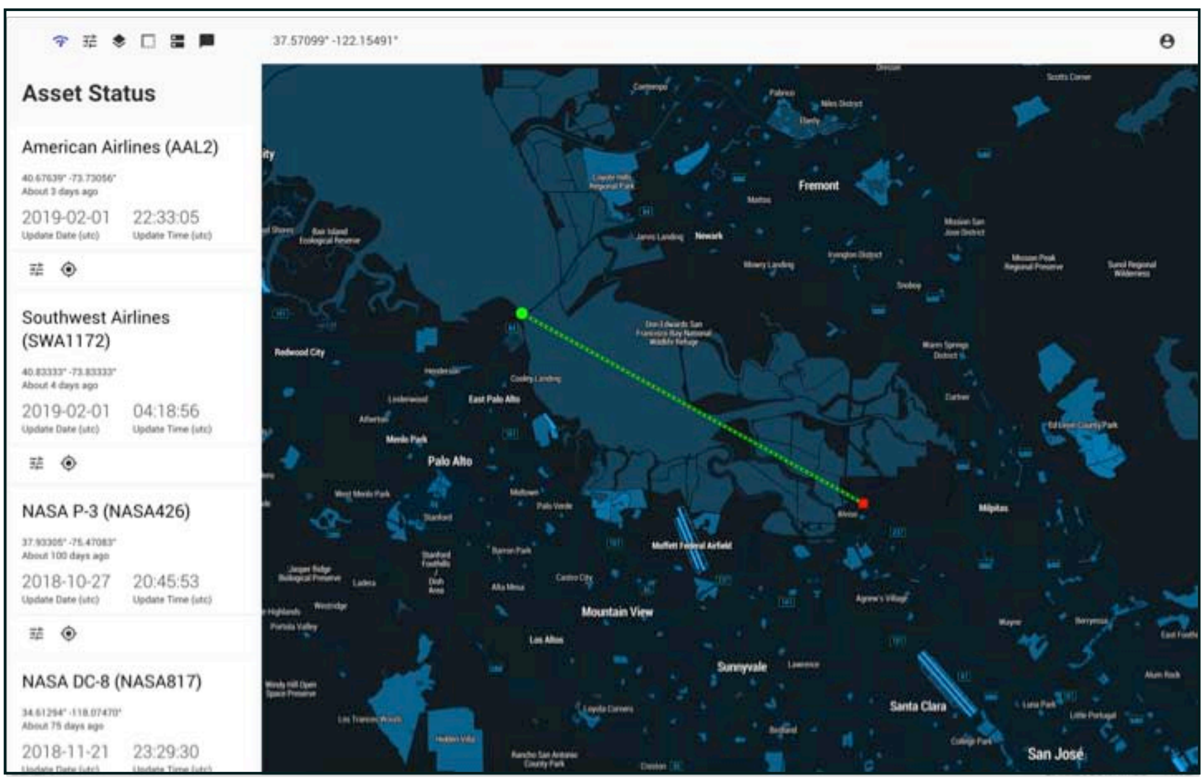


FIGURE 41 ***The new MTS user interface showing the Asset Status telemetry displays.***

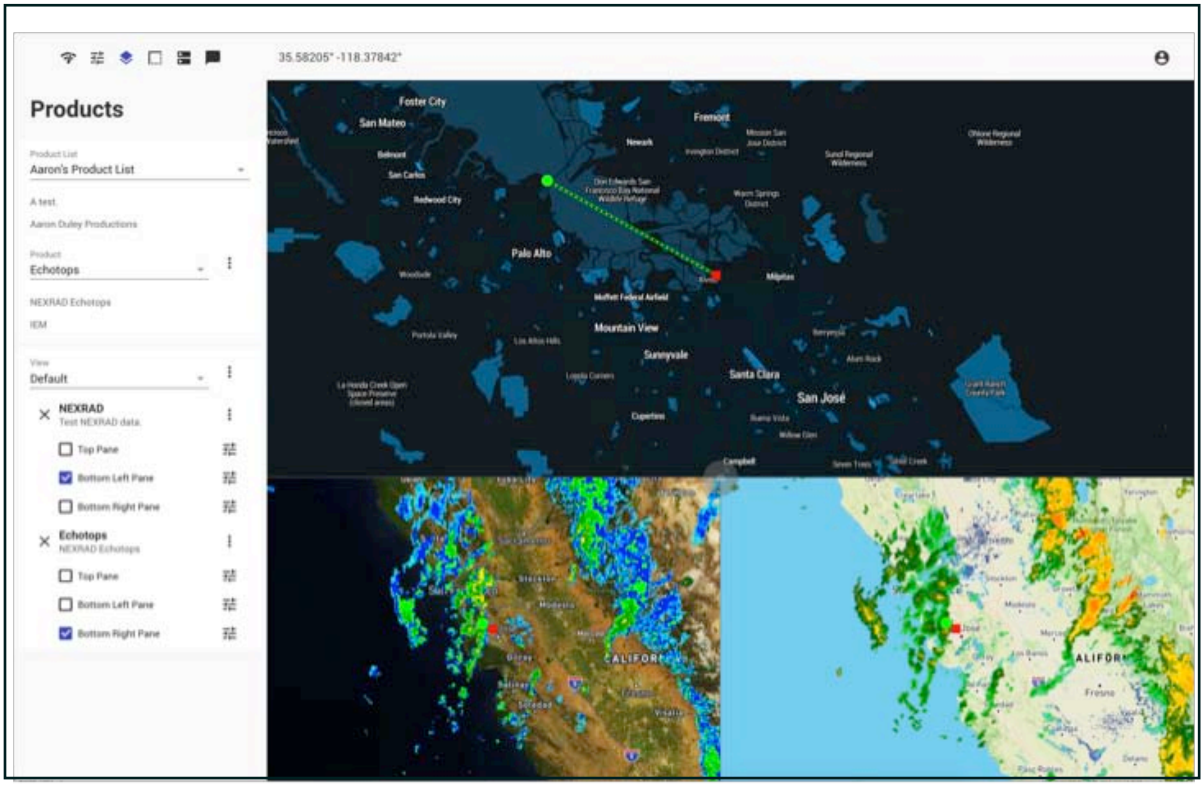


FIGURE 42 ***The MTS product interface. The product interface has been greatly simplified and users can now view different product stacks simultaneously within the same window.***

In concert with other activities, the team has also been hard at work to advance access to high-quality digital models of program assets (see Figures 43 and 44). 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 a number of freely available 3D models that include: C-20 (with/without UAVSAR), DC-8, P-3, Global Hawk, G-5, Twin Otter, WB-57, ER-2, B-200s (LaRC, AFRC), SIERRA-B, and the C-130.

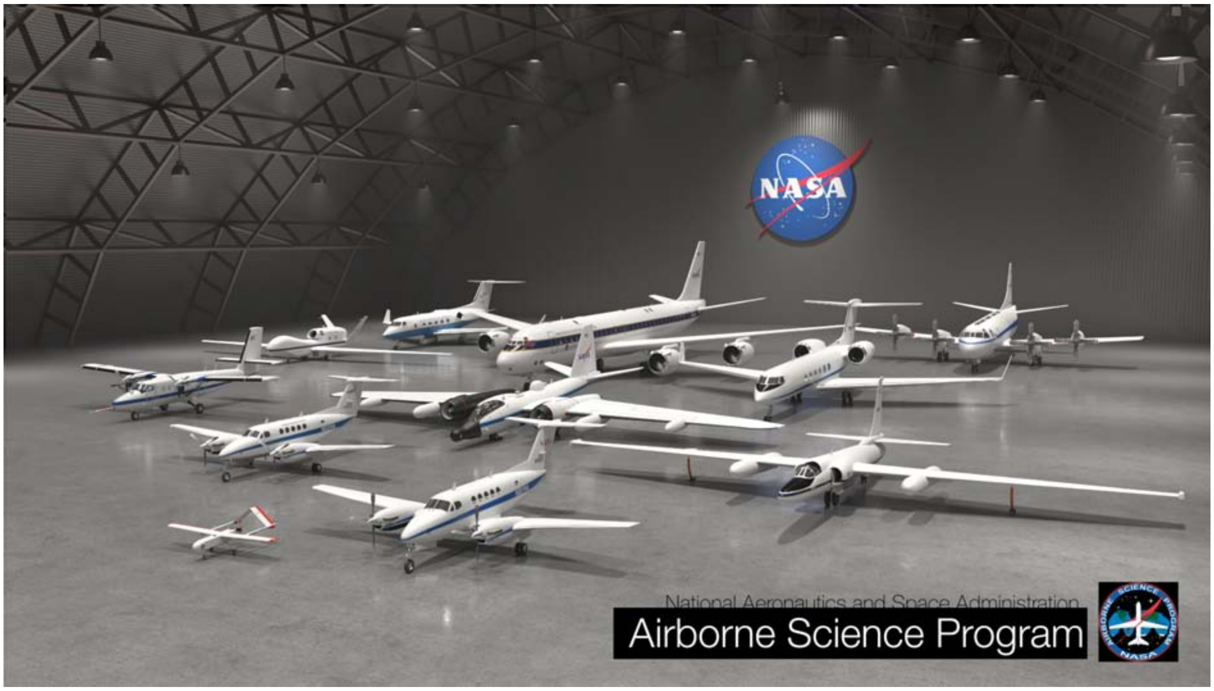


FIGURE 43 **Freely available 3-D models include: C-20 (with/without UAVSAR), DC-8, P-3, Global Hawk, G-5, Twin Otter, WB-57, ER-2, B-200s (LaRC, AFRC), SIERRA-B, C-130.**

FIGURE 44 **Example rendering of the ER-2. The model can be further customized to accommodate missions, generating outreach materials of aircraft instrumentation.**

6. Advanced Planning

The ASP maintains and operates a diverse fleet of aircraft, people and infrastructure that support a diverse and evolving stakeholder community. ASP leadership conduct a yearly strategic planning activity in order 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.

Requirements for Program assets are collected and communicated through the program flight request system (http://airbornescience.nasa.gov/sofrs), the annual 5-year schedule update, and through ongoing discussions with mission and program managers and scientists.

Strategic planning in ASP is focused on the following areas:

- ASP-supported (core) aircraft – maintenance, upgrades, determining future composition of the fleet
- 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
- Education opportunities

Requirements Update

In recent years, much attention has been focused on planning for the "Decadal Survey" missions defined in the 2007 NRC report. This has included SMAP and IceSAT-2. Next will be SWOT and NISAR, and then PACE. However, ASP also supports 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. The Program continues to document and update science impacts that have resulted from airborne support of space missions.

New space missions on the ISS, several small sats, and collaborations with ESA and other space agencies are upcoming. Several airborne experiments are already supporting these activities. Furthermore, the new 2017 NRC Decadal Survey for Earth Science has recommended new space missions such that new airborne support missions are anticipated. ASP personnel are planning an update of the “Requirements Report” in 2019, given the information in the 2017 Decadal Survey, the outcomes of the EVS-3 selections, new ESTO IIP and AITT selections and new input from the science community.

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

- Algorithm development
- Instrument testing
- Calibration and validation activities.

Participation in science team meetings and program reviews in 2018 to describe ASP capabilities and collect requirements information are listed in Table 13.

5-year plan

A five-year plan is also maintained by the Program for out-year planning and scheduling. A graphical copy is shown in Appendix A, depicting plans by science area and aircraft platform. Significant maintenance periods for the various aircraft are also indicated.

Activity
Member of Terrestrial Ecology Airborne Science Working Group (Intermediate participation in HyspIRI Science team and Steering Group monthly telecons)
Participation in 2018 HyspIRI close-out meeting
Participation in 2018 PARCA / OIB workshop
Participation in 2018 SWOT Science Team meeting
Participation in 2018 Ocean Sciences Meeting
Participation in 2018 ESTO Forum
Participation in 2018 AGU Fall meeting

TABLE 13 ***Activities to Support ASP Requirements Information Gathering.***

7. Education and Outreach

Student Airborne Research Program 2017

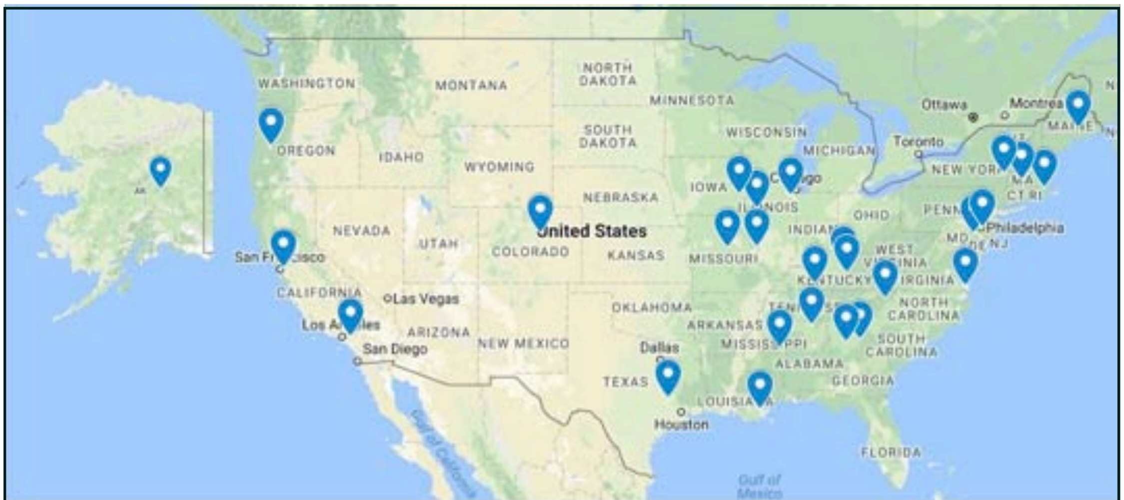
The 10th annual NASA Student Airborne Research Program (SARP) took place June 17-Aug. 10 at AFRC and the University of California-Irvine. SARP provides a unique opportunity for rising senior undergraduate students majoring in science, mathematics or engineering fields to participate in a NASA Airborne Science research campaign. SARP's goal 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 had their first hands-on research experience during this program.

The 28 SARP 2018 participants came from 28 different colleges and universities in 20 states. Figure 38 indicates the home institutions of the 2018 student participants. They were competitively selected based on their outstanding academic performance, future career plans, and interest in Earth system science.

All students flew onboard the NASA DC-8, where they assisted in the operation of instruments that sampled and measured atmospheric gases and assessed air quality in the Los Angeles Basin and in California's Central Valley. The DC-8 overflew dairies, oil fields and crops in the San Joaquin Valley in addition to parts of Los Angeles and the Salton Sea at altitudes as low as 1,000 feet to collect data. Students also used ocean and land remote sensing data collected for them over Santa Barbara by the NASA ER-2. In addition to airborne data collection, students took measurements at field sites near Santa Barbara, the Salton Sea and Sequoia National Park.

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 2018 American Geophysical Union (AGU) Fall Meeting.

NASA Student Airborne Research Progem 2018 Colleges & Universities



Appalachian State University	Pomona College	University of Delaware
Berea College	Principia College	University of Denver
Bridgewater State University	Rensselaer Polytechnic Institute	University of Iowa
Emory University	Temple University	University of Kentucky
Knox College	Texas A&M University	University of Maine
Lewis University	Tulane University	University of Massachusetts Amherst
Mills College	University of Alabama in Huntsville	University of Missouri
Mississippi State University	University of Alaska Fairbanks	University of Oregon
Old Dominion University	University of California, Berkeley	Western Kentucky University
Piedmont College		

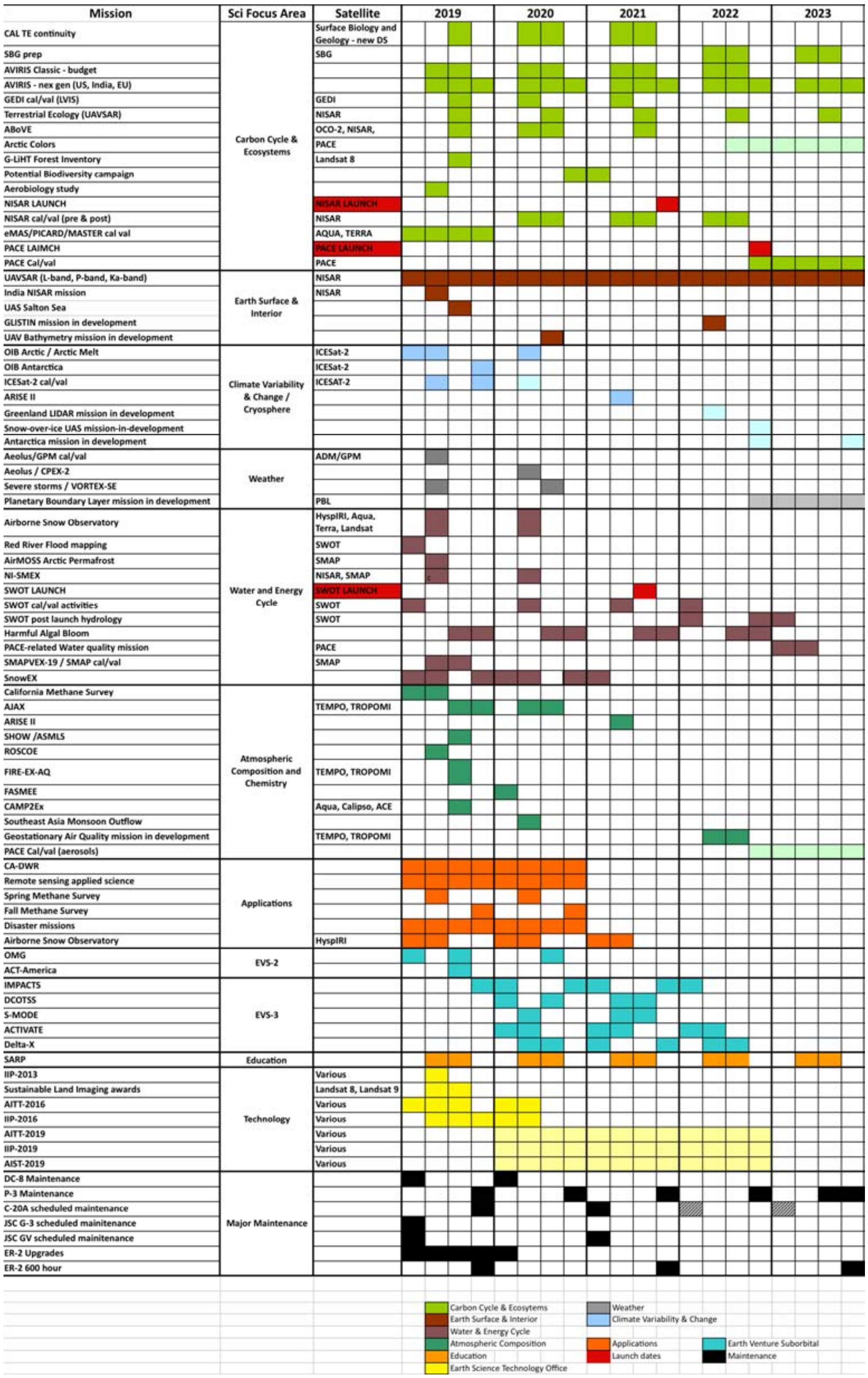
FIGURE 45 ***Map showing locations of the 2018 SARP students' colleges and universities.***

FIGURE 46 ***The SARP 2018 student participants with the DC-8 at AFRC.***

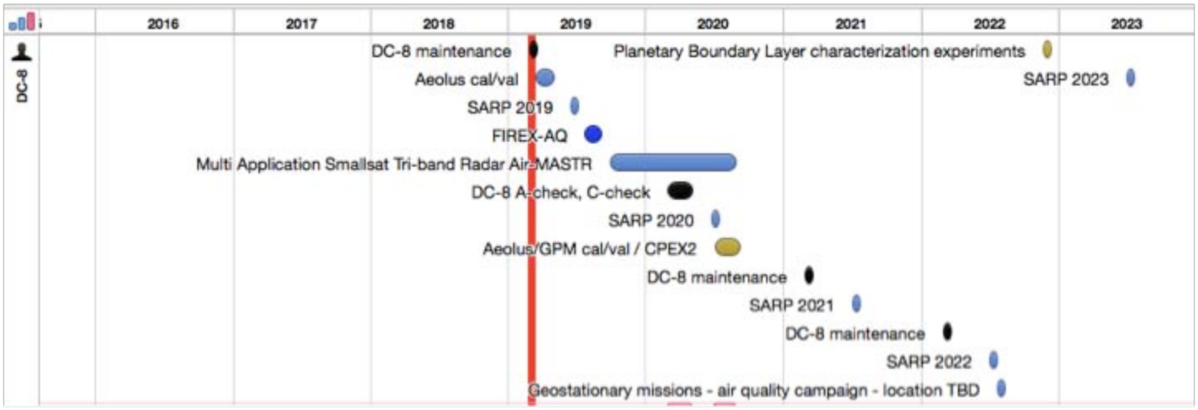
Appendices

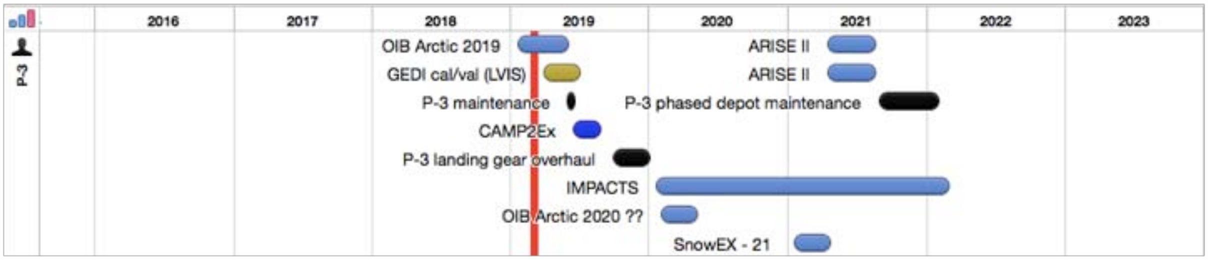
Appendix A: 5-Year Plan

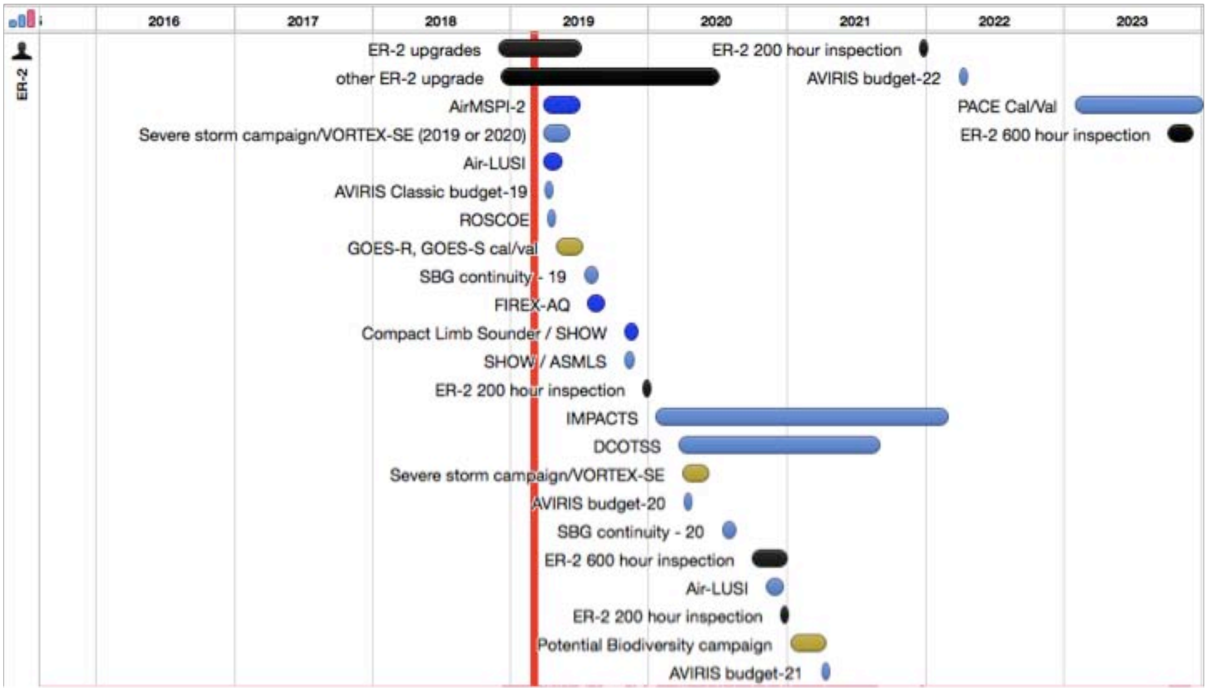
5-year Plan by Science Area
5-year Plan by Major Aircraft
Maintenance Schedules for selected Aircraft

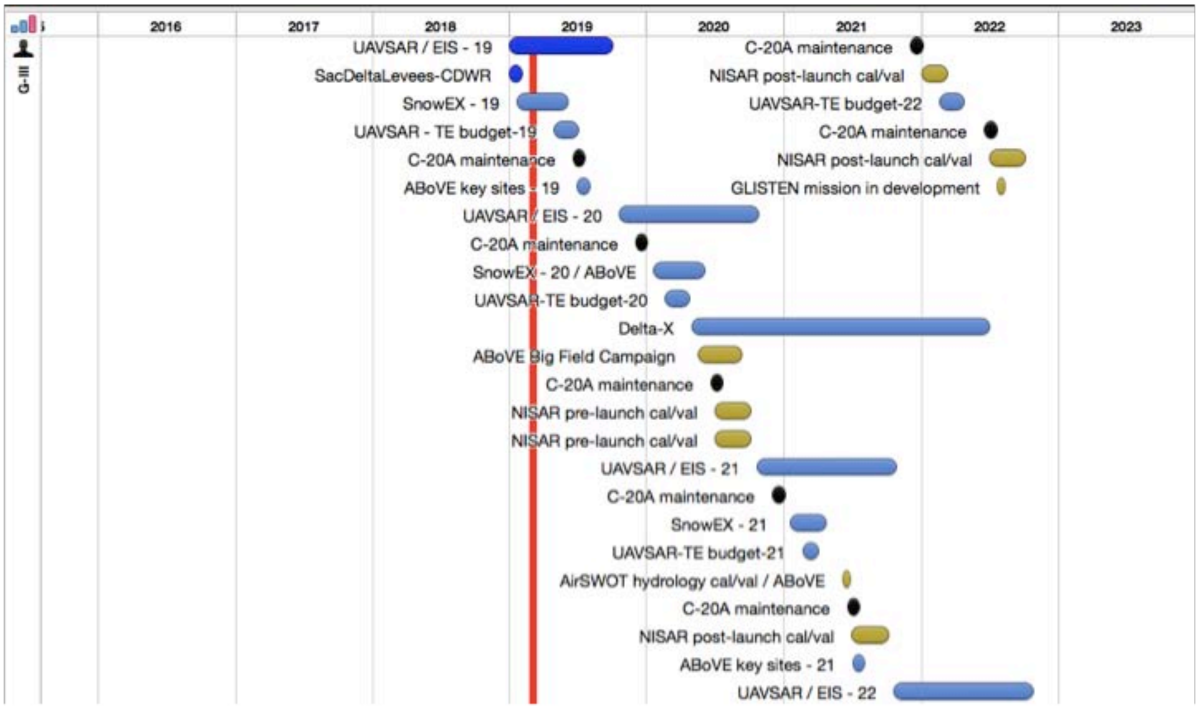


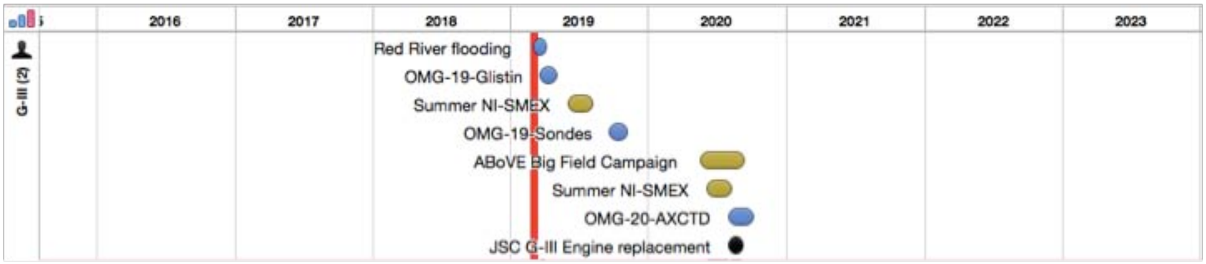
5-year Plan by Major Aircraft

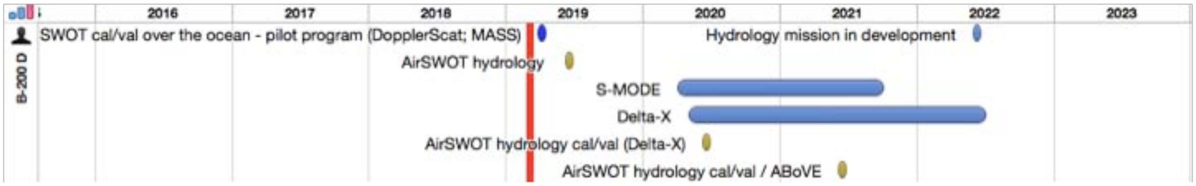







2016
2017
2018
2019
2020
2021
2022
2023
G-III
UAVSAR / EIS - 19
SacDeltaLevees-CDWR
SnowEX - 19
UAVSAR - TE budget-19
C-20A maintenance
ABoVE key sites - 19
UAVSAR / EIS - 20
C-20A maintenance
SnowEX - 20 / ABoVE
UAVSAR-TE budget-20
Delta-X
ABoVE Big Field Campaign
C-20A maintenance
NISAR pre-launch cal/val
NISAR pre-launch cal/val
UAVSAR / EIS - 21
C-20A maintenance
SnowEX - 21
UAVSAR-TE budget-21
AirSWOT hydrology cal/val / ABoVE
C-20A maintenance
NISAR post-launch cal/val
ABoVE key sites - 21
UAVSAR / EIS - 22
C-20A maintenance
NISAR post-launch cal/val
UAVSAR-TE budget-22
C-20A maintenance
NISAR post-launch cal/val
GLISTEN mission in development


2016
2017
2018
2019
2020
2021
2022
2023
G-III (2)
Red River flooding
OMG-19-Glistin
Summer NI-SMEX
OMG-19-Sondes
ABoVE Big Field Campaign
Summer NI-SMEX
OMG-20-AXCTD
JSC G-III Engine replacement


2016
2017
2018
2019
2020
2021
2022
2023
B-200 D
SWOT cal/val over the ocean - pilot program (DopplerScat; MASS)
Hydrology mission in development
AirSWOT hydrology
S-MODE
Delta-X
AirSWOT hydrology cal/val (Delta-X)
AirSWOT hydrology cal/val / ABoVE

Maintenance Schedules for Selected Aircraft

ER-2

FY	ER-2	Type of Maintenance	Timeframe
FY19	809	CARE	Present – April, 2019
FY19	80T6	CARE Modification	Present – April, 2019
FY19 & FY20	806	CARE Re-assembly	Apr 2019 – April 2020
FY19	809	200-Hour Inspection	2 weeks
FY20	809	200-Hour Inspection	2 weeks
FY21	809	600-Hour Inspection	3 months
FY21	809	200-Hour Inspection	2 weeks
FY21	806	200-Hour Inspection	2 weeks
FY22	809	200-Hour Inspection	2 weeks
FY22	806	200-Hour Inspection	2 weeks
FY23	809	600-Hour Inspection	3 months
FY23	806	600-Hour Inspection	3 months

DC-8

Estimated Dates	Maintenance Activity
Jan 28 – Mar 24, 2019	Cabin O2 system rebuild, LTN-92 full utilization implementation, and forebody bracket repairs, and 1A & 2A Maintenance
Sept 23 – 27, 2019	1A Maintenance
Mar 2 – Apr 30, 2020	1A, 2A, 3A, 4A, 1C, & 2C Maintenance & Landing Gear Swap (off-site maintenance)
Aug 31 – Sept 4, 2020	1A Maintenance
Mar 8 – 18, 2021	1A & 2A Maintenance
Sept 7 – 10, 2021	1A & 3A Maintenance
Mar 7 – 25, 2022	1A, 2A, 4A & 8A Maintenance
Sept 6 – 9, 2022	1A Maintenance
Mar 6 – May 5, 2023	1A, 2A, 3A, C1 & C3 Maintenance
Sept 4 – 7, 2023	1A Maintenance

C20-A

Est Date	Length	Type of Maintenance
FY19 – Nov	4 weeks	Cockpit Upgrade (Tentative)
FY19 – Dec	4 weeks	Ops #1 and #2 Maintenance
FY19 – June	4 weeks	Flight Hours / Cycle – Maintenance Cards
FY20 – Dec	5 weeks	Ops #1 and #3 Maintenance
FY20 – Jun	4 weeks	Flight Hours / Cycle – Maintenance Cards
FY21 – Dec	5 weeks	Ops #1 and #2 Maintenance
FY21 – June	4 weeks	Flight Hours / Cycle – Maintenance Cards
FY22 – Dec	5 weeks	Ops #1 and #3 Maintenance
FY22 – Jun	4 weeks	Flight Hours / Cycle – Maintenance Cards
FY23 – Dec	5 weeks	Ops #1 and #3 Maintenance
FY23 – Jun	4 weeks	Flight Hours / Cycle – Maintenance Cards

P-3 Orion

- 6-8 week annual maintenance period each year that can be adjusted to meet mission needs.
- Landing gear overhaul - fall 2019 (2-3 month effort)
- Phased Depot Maintenance 2021 (4-6 month effort)

AFRC B-200 (NASA 801)

Notional: Phase inspections are scheduled every 200 flight hours or 1 year (whichever comes first).

- Phase 3 & 4, Jan. 2019 – March 2019
- Phase 1 & 2, Jan. 2020 – March 2020
- Phase 3 & 4, Jan. 2021 – March 2021
- Phase 1 & 2, Jan. 2022 – March 2022
- Phase 3 & 4, Jan. 2023 – March 2023

Appendix B: Acronyms

A

AA	Associate Administrator
AAC	ABoVE Airborne Campaign
ABoVE	Arctic-Boreal Vulnerability Experiment
ACCP	Aerosols and Clouds, Convections and Precipitation
ACE	Aerosols Clouds Ecosystems
ACEPOL	Aerosol Characterization from Polarimeter and Lidar
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ACT-America	Atmospheric Carbon and Transport-America
ADCP	Acoustic Doppler Current Profilers
ADS-B	Automatic Dependent Surveillance – Broadcast
AFRC	Armstrong Flight Research Center
AGU	American Geophysical Union
Air-HARP	Airborne Hyper-Angular Rainbow Polarimeter
Air-LUSI	Airborne Lunar Spectral Irradiance
AirMSPI	Airborne Multi-angle SpectroPolarimeter Imager
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AirSPEX	Airborne Multi-angular Spectro-Polarimeter from SRON (Netherlands)
AITT	Airborne Instrument Technology Transition
AJAX	Alpha Jet Airborne Experiment
AMPR	Advanced Microwave Precipitation Radiometer
ANC	Anchorage International Airport
APU	Auxiliary Power Unit
APR-2	Airborne Second Generation Precipitation Radar
ARC	Ames Research Center
ARINC	Aeronautical Radio, Incorporated
ARMD	Aeronautics Research Mission Directorate
ARTEMIS	Autonomous, Robotic TElescope Mount Instrument Subsystem
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
ATom	Atmospheric Tomography Mission
AVIRIS, AVIRIS-ng	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation
AXCTD	Airborne Expendable Conductivity Temperature Depth

B

BAER	Burned Area Emergency Response
BBR	Broadband Radiometers
BERMS	Boreal Ecosystem Research and Monitoring Sites
BGAN	Broadband Global Area Network

C

C-AERO	Compact Airborne Environmental Radiometer
C-AIR	Coastal Airborne In-situ Radiometer
C-HARRIER	Coastal High Acquisition Rate Radiometers for Innovative Environmental Research
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
Cal/val	Calibration / Validation
CAMAL	Cloud-Aerosol Multi-Angle Lidar
CAMP^{2}EX	Cloud and Aerosol Monsoonal Processes - Philippines Experiment
CARE	Cabin Altitude Reduction Effort
CCE	Carbon Cycle and Ecosystems
CDWR	California Department of Water Resources
CIRES-IDD	CubeSat Imaging Radar for Earth Science - Instrument Development and Demonstration
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
CH_4	methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Authorization
CONUS	Continental United States

CPL	Cloud Physics Lidar
CRREL	Cold Regions Research and Engineering Laboratory
CY	Calendar Year

D

DC3	Deep Convection Clouds and Chemistry
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DISCOVER-AQ	Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DLR	German Space Agency
DME	Distance Measuring Equipment
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)

E

EAFB	Edwards Air Force Base
eMAS	Enhanced MODIS Airborne Simulator
EOS	Earth Observing System
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
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FASMEE	Fire and Smoke Model Evaluation Experiment
FIREX-AQ	Fire Impacts on Regional Emissions and Chemistry Experiment - Air Quality
FEMA	Federal Emergency Management Agency
FR	Flight Request
FSU	Florida State University
FY	Fiscal Year

G

GCAS	Geo-CAPE Airborne Simulator
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal
GLISTIN-A	Glacier and Ice Surface Topography Interferometer - Airborne
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	Glenn Research Center
GRIP	Genesis and Rapid Intensification Processes
GSFC	Goddard Space Flight Center

H

H_2O	Water
HALO	High Altitude Lidar Observatory
HAVHM	High Accuracy Vector Helium Magnetometer
HDVIS	High Definition Time-lapse Video System
HIWC	High Ice Water Content
HSRL	High Spectral Resolution Lidar
HS3	Hurricane and Severe Storm Sentinel
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

JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JWST	James Webb Space Telescope

K

KOA	Kona (Hawaii) International Airport
KORUS; KORUS-AQ	Korea-US; KORUS-Air Quality

L

LARGE	Langley Aerosol Research Group Experiment
LaRC	Langley Research Center
LiDAR	Light Detection and Ranging
LISTOS	Long Island Sound Tropospheric Ozone Study
LMOS	Lake Michigan Ozone Study
LVIS	Land, Vegetation, and Ice Sensor

M

MAIA	Multi-Angle Imager for Aerosols
MARBLE	Millimeter Radar for Learning and Education
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
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
NDMAX-ECLIF	NASA/DLR Multidisciplinary Airborne Experiment-Emissions and Climate Impact of Alternative Fuel
NGEE	Next generation ecological experiment
NISAR	NASA-ISRO SAR
NIST	National Institute of Standards and Technology
NOAA	National Oceanographic and Atmospheric Administration
NPP	National Polar-orbiting Partnership
NRC	National Research Council
NSF	National Science Foundation
NSRC	National Suborbital Research Center
NT	Northwest Territories
NTSB	National Transportation Safety Board

O

OCO-2	Orbiting Carbon Observatory-2
OIB	Operation Ice Bridge
OMG	Oceans Melting Greenland
ORACLES	Observations of Aerosols Above CLouds and their InteractionS
OWLETS	Ozone Water-Land Environmental Transition Study

P

PACE	Plankton, Cloud, and ocean Ecosystem
PARCA	Program for Arctic Regional Climate Assessment
PDM	Phased Depot Maintenance
PECAN	Plains Elevated Convection at Night
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol R&D
PMD	Palmdale Airport
PLOS ONE	Public Library of Science Open Access Journal
POS	Position and Orientation Systems
PRISM	Portable Remote Imaging Spectrometer

R

R&A	Research and Analysis
RGB	Red Green Blue
ROCIS	Remote Ocean Current Imaging System
RSP	Research Scanning Polarimeter

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
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SEAC^{4}RS	Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys
SEO	Sensor Equipment Operator
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SIF	Solar-Induced Fluorescence
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SnowEx	Snow Experiment
SNPP	Suomi National Polar-orbiting Partnership
SO^2	Sulfur Dioxide
SOFRS	Science Operations Flight Request System
SSFR	Solar Spectral Flux Radiometer
STEM	Science Technology Engineering and Math
SWIR	Short Wave Infrared
SWOT	Surface Water and Ocean Topography

T

TABS	Transoceanic Aerobiology Biodiversity Study
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
TB	Terra Bytes
TCCON	Total Carbon Column Observing Network
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
UW	University of Washington

V

VHF	Very High Frequency
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPR	Vapor In-cloud Profiling Radar

W

WFF	Wallops Flight Facility

Y

YT	Yukon Territory

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NP-2019-04-02-ARC