National Aeronautics and
Space Administration

Science Mission Directorate
Airborne Science Program

2017 Annual Report

COVER IMAGES

Background: Rain in the vicinity of Yellowknife, Northwest Territories, Canada, viewed from NASA AFRC B-200 during ABoVE.

Inset: NASA JSC G-3 carrying P-band SAR, NASA AFRC B-200 carrying AirSWOT and Dynamic Aviation B-200 carrying AVIRIS-NG are parked at Yellowknife during ABoVE.

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1. Leadership Comments

Welcome to the 2017 edition of the Airborne Science Program's (ASP) Annual Report. This year was another busy year for the program flying over 4,100 Earth Science flight hours for the Earth Science Dvision (ESD). We travelled the globe (again!) this year: from the Arctic to the Antarctic, throughout the U.S. including Alaska and Hawaii, and back to Africa (São Tomé this time). By our count, we flew some twenty-four science campaigns, from single sensor small aircraft missions to major multi-phase campaigns consisting of eight aircraft. Many campaigns had surface components consisting of flux towers, research vessels, or individuals gathering in situ data via diving in reefs, wading through Boreal wetlands, or tracking through snow. NASA research aircraft also supported disaster response efforts following hurricanes Harvey and Irma, as well as, remote imaging the debris field following a SpaceX launch mishap and follow-up observations of the Aliso Canyon gas storage facility after operations restarted. Additionally, the program's support for ongoing and upcoming satellite missions was extensive, including twenty-one satellite missions identified by airborne science mission Principal Investigators. The most heavily supported satellite missions were ICESat-2, NI-SAR, HyspIRI, OCO-2, LANDSAT, and components of EOS.

We have also adjusted our ASP supported aircraft. Due to budget realities, we will no longer support the C-130s at Wallops Flight Facility (WFF) and the Global Hawk at the Armstrong Flight Research Center (AFRC). We are however, continually searching for ways to provide capabilities that Earth Science needs. In the remote sensing area, we have two new platforms. The first platform is the Gulfstream V (G-V). In collaboration with the Human Exploration and Operations Mission Directorate, we acquired the G-V at Johnson Space Center (JSC) and began modifications. Although the modifications needed to make it a science platform are taking longer than we thought, we are making progress and are looking for its first ESD mission in late 2018. The second platform is a Gulfstream III (G-III). Langley Research Center (LaRC) acquired a G-III that they plan to modify with multiple ports for use by the science community. We also began making our ER-2's safer for the pilots by funding the Cabin Altitude Reduction Effort (CARE). As a result, we are temporarily flying only one ER-2 platform for a few years. The one currently being modified (#809) is scheduled to be back and ready for flight in August. Then #806 starts its CARE modifications. In addition, we are beginning studies for replacement aircraft including one for the DC-8. We'll need input from the science community to help define requirements for replacement aircraft.

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:

- Satellite data simulation, calibration, and data product validation
- Instrument testing and development
- In situ or high resolution data needed to resolve model uncertainties
- Workforce development and mentoring of the next generation of mission 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.

Structure of the Program

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

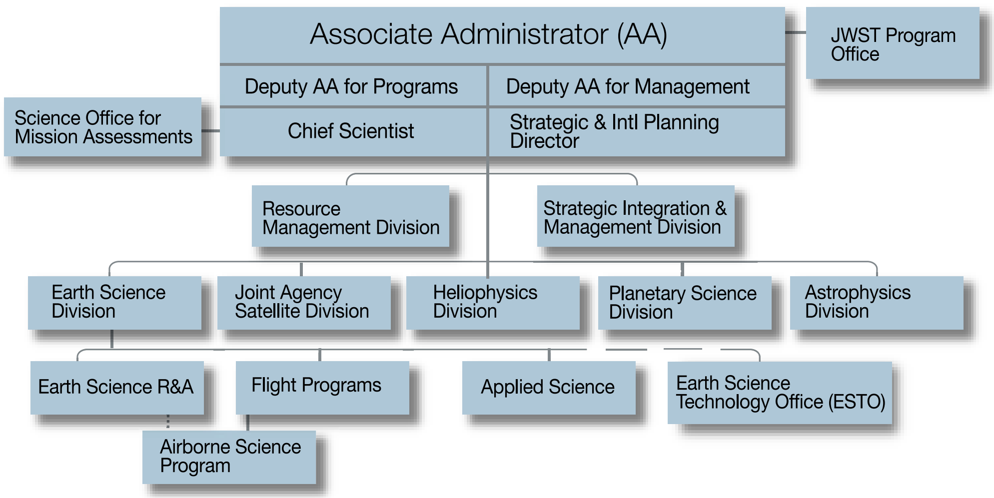


FIGURE 1 ***Science Mission Directorate Organization Chart.***

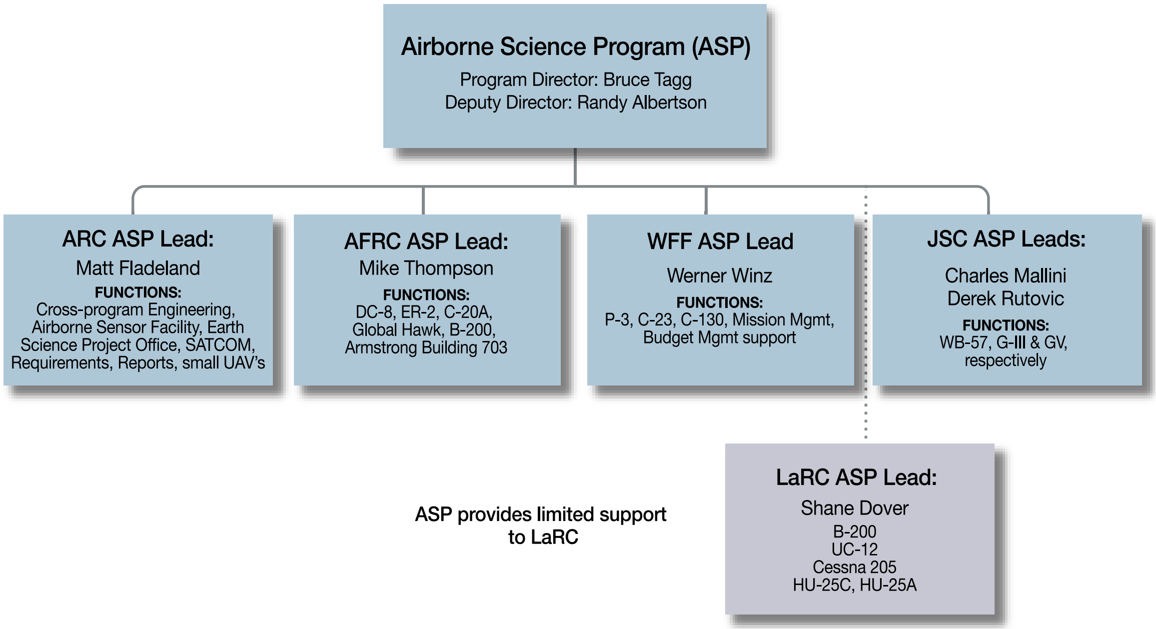


FIGURE 2 ***Airborne Science Organization Chart.***

New Program Capabilities

Coming in 2018 are two new science-capable platforms: A G-V at JSC and a new G-III at LaRC. The G-V will be a shared asset between SMD and Human Exploration and Operations, similar to the way the current JSC G-III is managed. The new G-III is being modified and operated by LaRC. In addition, the SIERRA-2 UAV at ARC will also be undertaking its first flight in FY18 and be available for science and UAS-related projects.

Flight Request System and Flight Hours

The ASP maintains science-capable aircraft and instrument assets for research use in support of NASA SMD. The Science Operations Flight Request System (SOFRS) is a web-based tool used to track and facilitate the review and approval process for airborne science missions using SMD funds, instruments, personnel or aircraft. The only way to schedule the use of NASA Earth Science 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 204 FRs submitted in 2017 for missions with at least one of the following ASP components: an ASP supported aircraft, ESD funding, an ASP facility instrument (AVIRIS –C, AVIRIS-NG, MASTER, eMAS, UAVSAR, LVIS and NAST-I), and/or an ASP Science Support Asset (DMS and POS-AV). A total of 93 FRs were completed, using 29 different aircraft. Of the remaining FRs, some were deferred and the rest were canceled for various reasons. The 93 completed FRs flew a total of 5044.5 flight hours, of which over 4100 hours were for Earth Science.

Table 1 shows all ASP-ESD FRs status and flight hours flown by aircraft. Table 2 shows a list of the "Other" Aircraft Flown. Table 3 shows only ESD FRs and flight hours flown by aircraft. Figure 3 is a histogram showing the 20 year history of flight hours usage. Table 4 shows all SOFRS flight hours flown over the past 4 fiscal years by funding source. Locations of ASP activities in FY17 are indicated on the globe in Figure 4.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[1]	15	6	0	6	595.8
ER-2[1]	42	24	2	17	309.1
P-3[1]	6	2	0	2	484.7
WB-57[2]	2	1	0	1	90.3
Twin Otter[2]	9	5	1	4	170
B-200[2]	11	7	1	6	443.7
Global Hawk[1]	6	3	0	2	159.1
T-34[2]	1	1	0	0	0
C-130 Hercules[2]	4	4	1	2	225.7
C-20A (G-III) - AFRC[1]	23	20	2	11	362
C-23 Sherpa[2]	4	3	0	3	94.8
Dragon Eye[2]	3	1	0	1	4.5
Falcon-HU-25[2]	1	1	0	1	39.5
G-III-JSC[2]	28	21	1	15	376.9
Ikhana[2]	1	0	0	0	0
SIERRA[2]	3	0	0	0	0
Other[3]	45	30	2	22	1688.4
TOTALS	**203**	**129**	**10**	**93**	**5044.5**

TABLE 1 ***FY17 ASP-ESD Flight Request Status and Total Flight Hours Flown, by aircraft*.***

[1]ASP Supported Aircraft include: DC-8, P-3, ER-2, C-20A, and the Global Hawk.

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

[3]Non-NASA contract aircraft include: A90 Dynamic Aviation, A90 King Air, Aeroscout, Alphajet, Aurora Centaur (DA-42) Aircraft, B-200 - King Air - Dynamic Aviation, BlackSwift Tempest; SuperSwift sUAS, Caravan, CIRPAS Twin Otter, Piper Cherokee/King Air, DA King Air, DC-3, DC-3 Bassler, Dragon Eye, Dynamic Aviation - King Air, Dynamic Aviation B-200T, JSC G-V, Kenn Borek Air LTD, King Air B-200, Mooney, NRL P-3, Tarot Hexacopter, Tempus G-IV, Twin Cessna 310J, Twin Otter – SGL, Twin Otter International, UAS.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
A90 Dynamic Aviation	5	5	0	5	307.5
Alphajet	1	1	1	0	12.5
CIRPAS Twin Otter	1	1	1	0	12.9
DC-3 Bassler	1	1	0	1	15.3
Dynamic Aviation King Air	6	6	0	6	465.6
Dynamic Aviation B-200 T	2	2	0	2	222.3
Mooney	1	1	0	1	316.7
NRL P-3	1	1	0	1	32.5
Piper Cherokee or King Air	1	1	0	1	316.7
Tempus G-IV	2	2	0	2	167.7
Twin Cessna 310J	1	1	0	1	32.4
Twin Otter International	1	1	0	1	7.3
UAS	1	1	0	1	3
TOTALS	**24**	**24**	**2**	**22**	**1688.4**

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

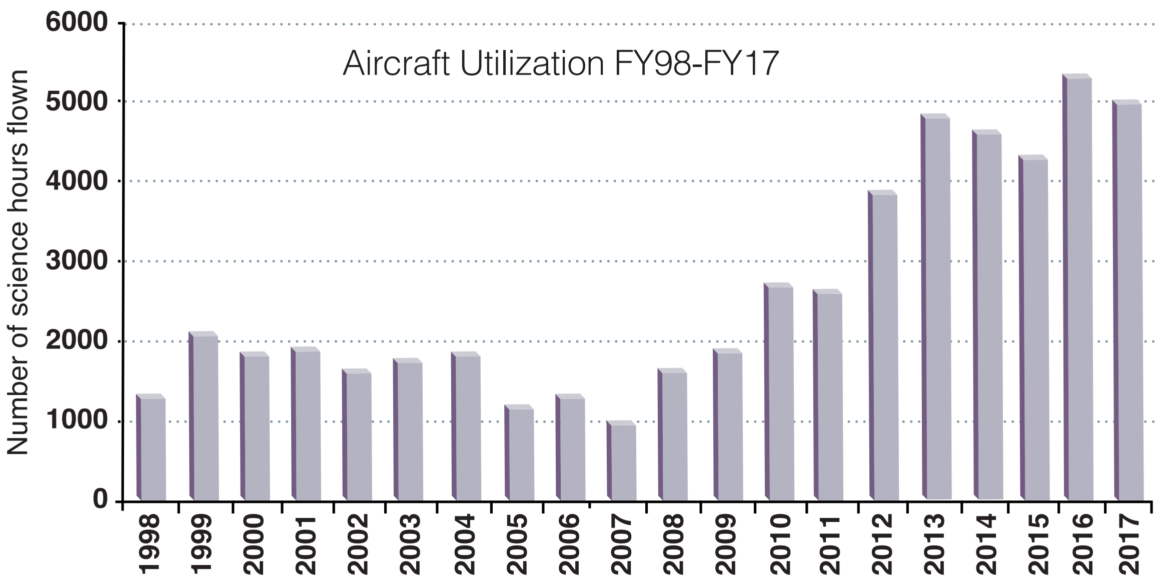


FIGURE 3 ***ASP flight hours over past 20 years.***

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[1]	7	5	0	5	595.8
ER-2[1]	27	19	1	13	177.4
P-3[1]	6	2	0	2	484.7
WB-57[2]	2	1	0	1	90.3
Twin Otter[2]	8	4	1	3	152.7
B-200[2]	9	7	1	6	443.7
Global Hawk[1]	1	0	0	0	0
T-34[2]	1	1	0	0	0
C-130 Hercules[2]	4	4	1	2	225.7
C-20A (G-III) - AFRC[1]	18	16	2	9	308.8
C-23 Sherpa[2]	4	3	0	3	94.8
Dragon Eye[2]	3	1	0	1	4.5
Falcon-HU-25[2]	1	1	0	1	39.5
G-III-JSC[2]	25	20	1	14	373.9
Ikhana[2]	1	0	0	0	0
SIERRA[2]	2	0	0	0	0
Other[3]	36	24	2	18	1492.6
TOTALS	**155**	**108**	**9**	**78**	**4484.4**

TABLE 3 ***Summary of ESD funded FY17 Flight Request Status and Flight Hours Flown by Aircraft*.***

[1]ASP Supported Aircraft include: DC-8, P-3, ER-2, C-20A, and the Global Hawk.

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

[3]Non-NASA contract aircraft include: A90 Dynamic Aviation, A90 King Air, Aeroscout, Alphajet, Aurora Centaur (DA-42) Aircraft, B-200 - King Air - Dynamic Aviation, BlackSwift Tempest; SuperSwift sUAS, Caravan, CIRPAS Twin Otter, Piper Cherokee/King Air, DA King Air, DC-3, DC-3 Bassler, Dragon Eye, Dynamic Aviation - King Air, Dynamic Aviation B-200T, JSC G-V, Kenn Borek Air LTD, King Air B-200, Mooney, NRL P-3, Tarot Hexacopter, Tempus G-IV, Twin Cessna 310J, Twin Otter–SGL, Twin Otter International, UAS.

***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 "17".
- The "Total FRs" column includes Flight Requests that were submitted and whose log number starts with "17".
- The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY17.
- The "Total Partial FRs" column includes Flight Requests in which the total approved hours were not fully expended during FY17 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 2017.

Fiscal Year	ESD Flight Flight Hours	SMD (Non-ESD) Flight Hours**	Other NASA Flight Hours	Non-NASA Flight Hours	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

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

2017 Airborne Campaigns

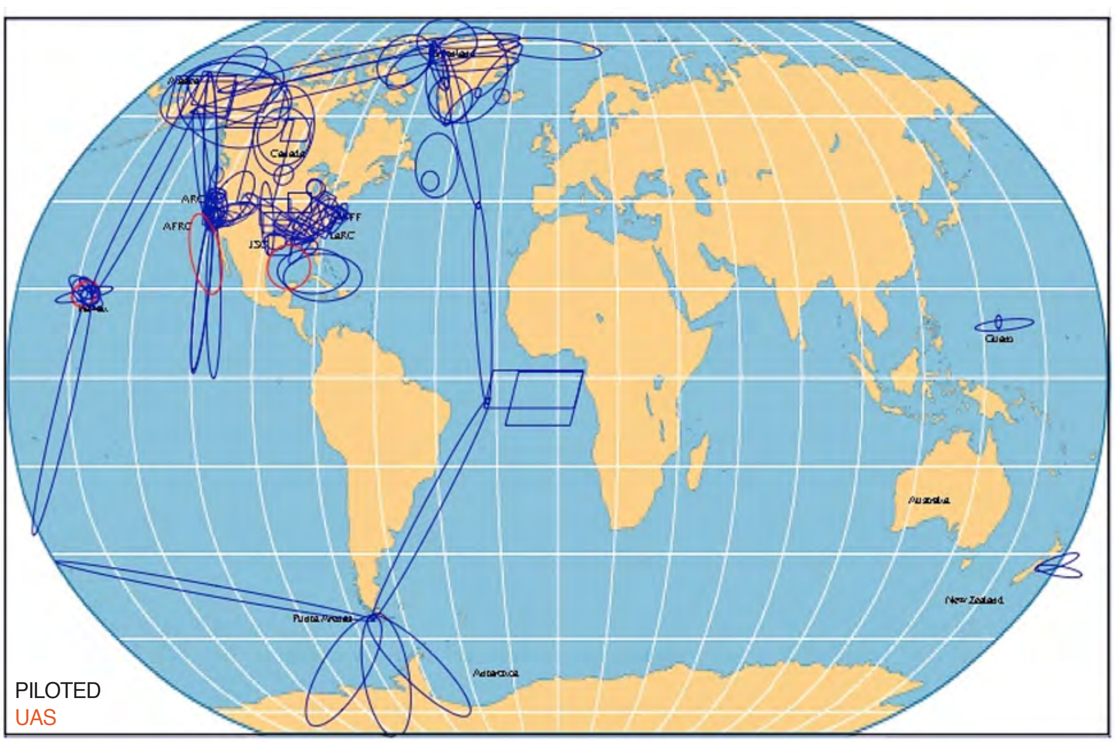
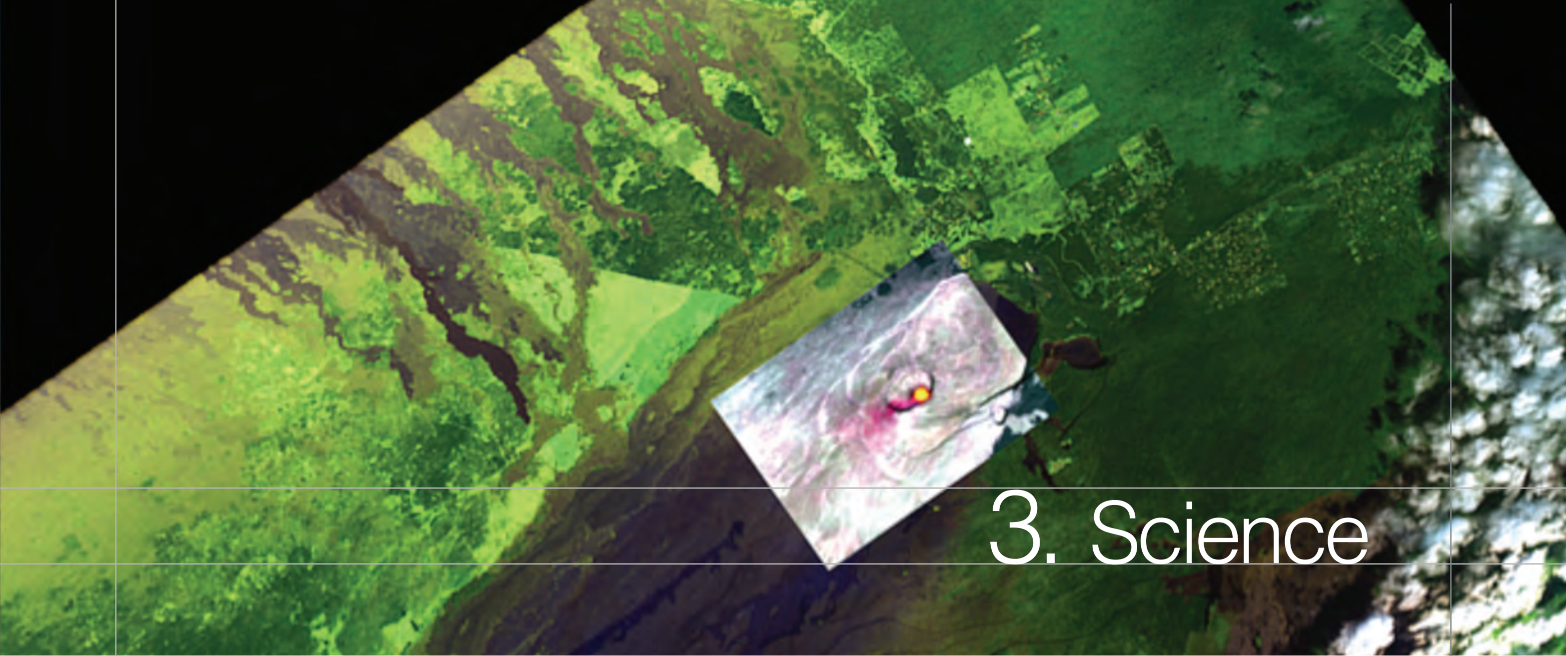


FIGURE 4 ***Locations of ASP missions in 2017.***



3. Science

Major Mission Highlights

The ASP conducted over 5000 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. A major new mission in 2017 was the Arctic Boreal Vulnerability Experiment (ABoVE) with multiple aircraft and field operations. All six Earth Venture Suborbital-2 (EVS-2) missions were supported in 2017 and 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
ABoVE (including AirSWOT)	G-III, C-20A, Twin Otter, B-200 (3), Moony	836.2	Alaska, Canada
OIB-Arctic	P-3, B200, HU24-Guardian	504.2	Greenland, Alaska, Norway
OIB-Antarctic	DC-8	306.9	Punta Arenas
Airborne Snow Observatory	A90	305.4	Colorado, California
ACT-America*	C-130, B-200	224.5	CONUS
OMG*	G-III, C-130	181.4	Greenland
ORACLES*	P-3	170.6	Sao Tome
CORAL*	G-IV	167.7	Hawaii; Australia, Guam, Palau
Lake Michigan Ozone Study	B-200	150.2	Madison, WI
ATom*	DC-8	128.5	Global
NAAMES*	C-130	107.2	North Atlantic
CPEX	DC-8	104.3	Caribbean
GOES-R Field Campaign	ER-2	103.9	Southwest, Central and Southeast US
G-LiHT	King Air	92.7	Everglades / Puerto Rico
Posidon	WB-57	90.3	Guam
HOPE / EPOCH	Global Hawk	85.9	Pacific Ocean; Gulf of Mexico
SnowEx	P-3 (NOAA), G-III, C-20A	74.9	Colorado
SHOUT	Global Hawk	73.2	Atlantic, Gulf of Mexico
HyspIRI	ER-2	65.3	Hawaii
ASCENDS Preparatory Campaign	DC-8	56.1	Alaska
UAVSAR - Total L, P, Ka bands	C-20A, G-III	670.4	US, Canada, Greenland, Iceland
Technology test and demonstration	ER-2, WB-57, TO, DC-8, B-200	175.1	California, multiple US locations

TABLE 5 ***Major Science Missions in FY17. *Indicates EVS-2 mission.***

Arctic Boreal Vulnerability Experiment (ABoVE) 2017

The ABoVE Airborne Campaign (AAC) was one of the largest airborne science experiments ever conducted by NASA's ESD. Funded by the Terrestrial Ecology Program, the AAC involved 10 aircraft in 20 deployments across more than 200 science flights, and surveyed over 4 million square kilometers in Alaska and northwestern Canada. Many of these flights were coordinated with same-day ground-based measurements to link field-based, process-level studies with geospatial data products derived from satellite remote sensing. A major goal of the 2017 campaign was to collect data that spanned the critical intermediate space and time scales that are essential for a comprehensive understanding of scaling issues across the ABoVE Study Domain and extrapolation to the pan-Arctic. The 2017 campaign provided unique opportunities to validate satellite and airborne remote sensing data for northern high latitude ecosystems. The science strategy coupled domain-wide sampling with L-band and P-band synthetic aperture radar (SAR), imaging spectroscopy (AVIRIS-NG), full waveform lidar (LVIS) and atmospheric carbon dioxide and methane (ArctiC-C) with more spatially and temporally focused studies using Ka-band SAR and solar induced chlorophyll fluorescence (CFIS).

Aircraft flown during ABoVE included both the AFRC C20-A and the JSC G-III, two Dynamic Aviation B-200s, a Twin Otter and a Mooney. The ABoVE aircraft flew a total of over nearly 1000 hours during the campaign.

Additional measurements were coordinated with the NEON Airborne Observing Platform, the ASCENDS instrument development suite, AirSWOT hydrology measurements and the ATom EVS-2 investigation.

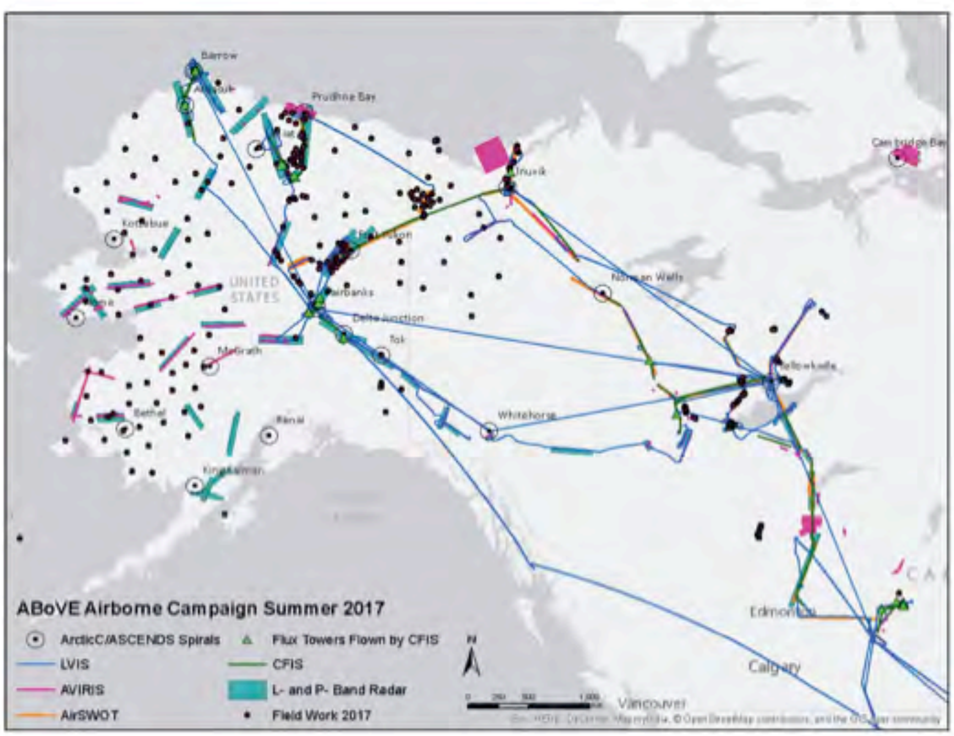


FIGURE 5 **Extent of the 2017 ABoVE Campaign, which occurred between April and October 2017.**

FIGURE 6 ***P-band SAR team with NASA C-20A during ABoVE August 2017 campaign in Fairbanks.***

Targets of science interest included the array of field sites operated by the ABoVE Science Team as well as the intensive sites operated by the following groups: DOE NGEE-Arctic team on the Seward Peninsula and in Barrow, NSF's LTER sites at Toolik Lake (North Slope) and Bonanza Creek (Interior Alaska), the Canadian Cold Regions Hydrology sites in the Arctic tundra near Trail Valley Creek NT, the interdisciplinary science stations at Daring Lake NT and Scotty Creek NT, the Government of the Northwest Territories Slave River/Slave Delta watershed time series, the Kluane Lake (YT) Research Station and numerous forest and fire disturbance plots maintained by the Alaskan and Canadian Forestry Services.

Operation Ice Bridge (OIB)

During FY17 OIB flew missions in both the Antarctic and the Arctic. The DC-8 flew 300 flight hours from Punta Arenas, while the P-3 flew early in 2017 to Greenland. For the spring melt, the HU-25A Guardian flew later to Greenland.

OIB wrapped up 2016 with a banner year surveying the Antarctic ice cover from the NASA DC-8. A total of 24 flights were flown which tied the previous record set for most flights during an Antarctic campaign. The campaign completed surveys of 22 out of the 25 highest priority science targets. The campaign also extended previous area covered flying surveys of new areas with rapid changes such as the Getz Ice Shelf and Ruppert Coast. Extensive new surveys in areas such as the Abbott Ice Shelf and Recovery Glacier were also undertaken. Lastly, the campaign continued the now 8-year time series of sea ice measurements in the Weddell and Bellingshausen Seas during a low year for Antarctic sea ice extent. In total, the campaign logged 292 research hours traveling 107,374 nm (equivalent to 5 times around the Earth and half the distance to the Moon).

In the spring, the OIB team was back aboard the NASA P-3 after a lengthy absence while the plane was fitted with new wings. Major improvements were made to the IceBridge instrument suite since it was previously onboard the P-3 in 2014, including upgraded laser, radar, and visible and infrared (IR) imagery instruments. The campaign conducted flights over Greenland and the Arctic Ocean, and then expanded coverage in the eastern Arctic through flights based out of Svalbard, Norway. Note in Figure 7 how the flights crossed the North Pole on the way to Canada.

The OIB Melt Season 2017 deployment to Thule Air Base, Greenland with the NASA LaRC HU-25A Guardian concluded on July 27, 2017. The main purpose of the mission was to survey sea ice under melting conditions to track thickness changes from the spring time period as well as collect data to determine the capability of a green laser to measure melt pond depth. The research payload consisted of the NASA WFF Airborne Topographic Mapper (ATM), and

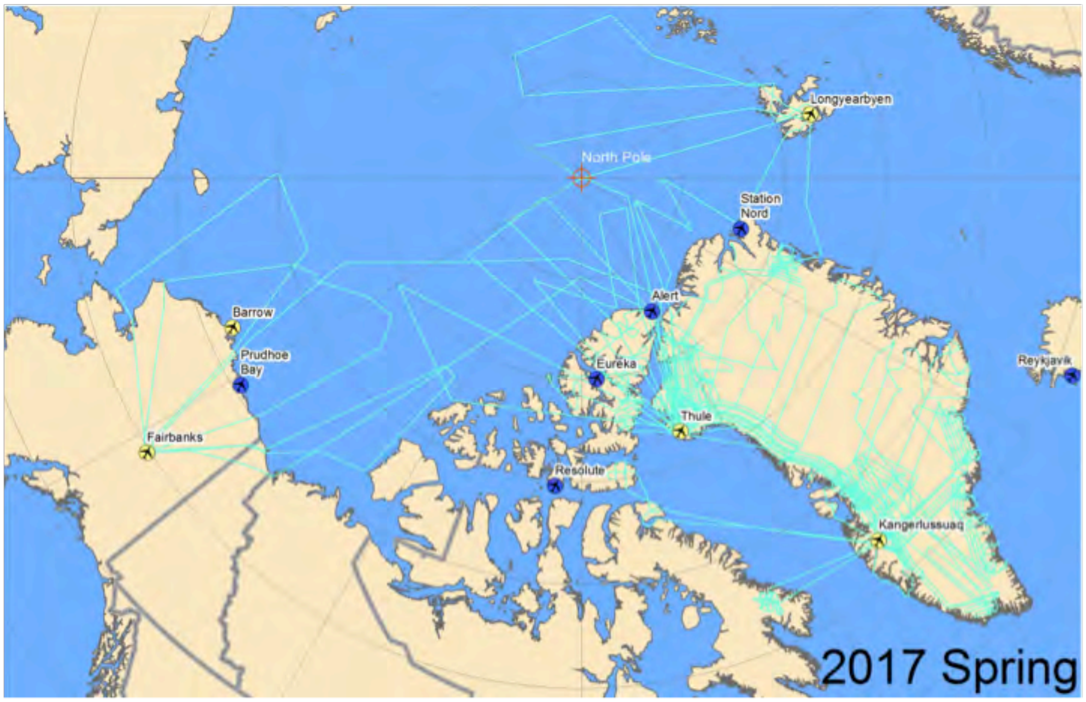


FIGURE 7 ***2017 OIB Arctic flight lines.***

the NASA Ames Research Center (ARC) Digital Mapping System (DMS). The deployment achieved all five of the planned flight profiles, including sea ice in the vicinity of Greenland and north of Ellesmere Island, and a land ice flight over supraglacial lakes near Hiawatha Glacier. A total of 12 sorties were flown using 39.5 flight hours. All research flights were conducted from Thule Air Base.

Earth Venture Suborbital – 2 (EVS-2)

The second round of EVS-2, missions were all fully under way during 2017. Earth Venture is an activity overseen by the Earth System Science Pathfinder (ESSP) office. One mission, CORAL, completed in 2017. The progress of the missions is listed in Table 6. The map in Figure 8 shows the broad reach of these missions during 2017.

Mission	Aircraft	Locations Flown	Status
ATom	DC-8	ATom-2 and ATom-3: Multiple locations – see map	ATom-4 will complete this mission in Spring 2018.
NAAMES	C-130	North Atlantic and off Greenland coast	NAAMES will complete with a March 2018 campaign.
ACT-America	C-130, B-200	Midwest, South, and Eastern US	ACT-America will fly again in Spring 2018 and complete in 2019.
ORACLES	P-3	Coast of Africa / São Tomé	ORACLES will complete in 2018 with a campaign returning to São Tomé
OMG	G-III, C-130	Greenland coast	OMG will fly GLISTIN again in 2018 and 2019, and complete with sonde drops in 2018, 2019 and 2020.
CORAL	G-IV	Great Barrier Reef, Palau, and the Mariana Islands.	CORAL completed in 2017 with final flights in Florida

TABLE 6 ***EVS-2 Mission Progress in FY17.***

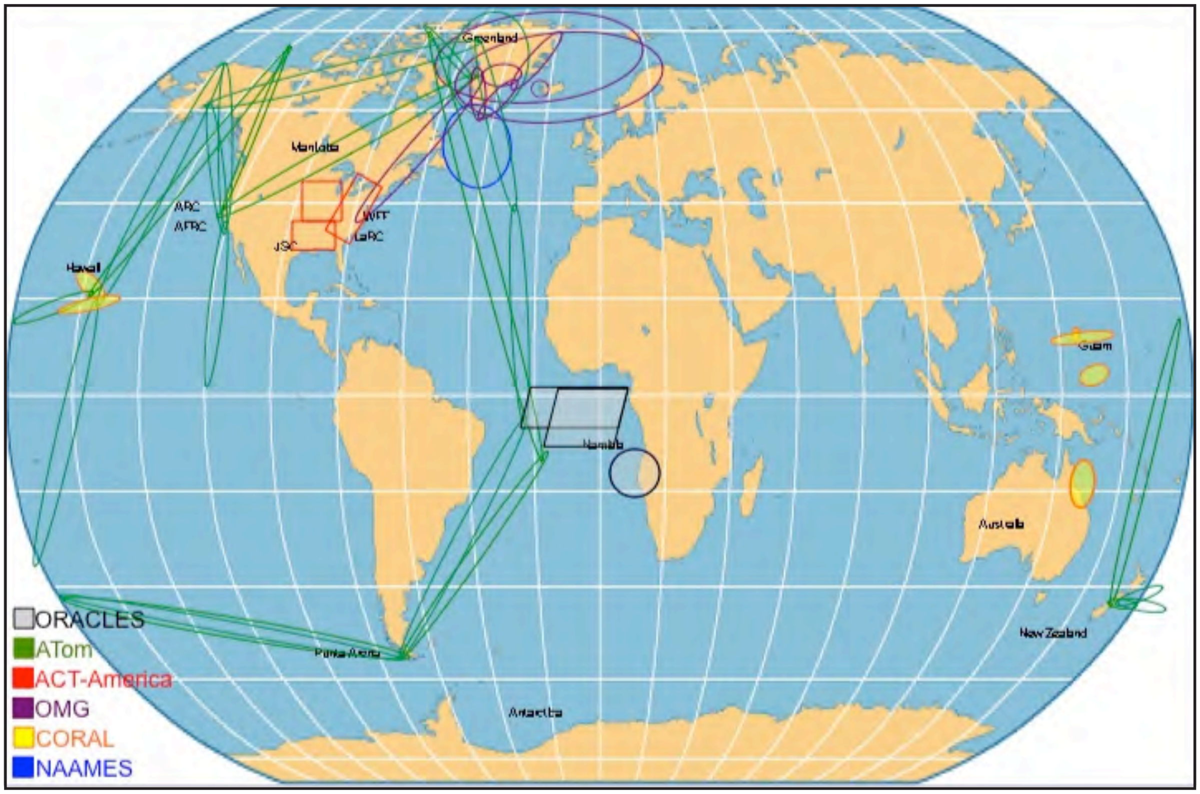
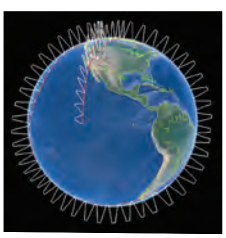


FIGURE 8 ***EVS-2 Mission coverage in FY17.***



Atmospheric Tomography Experiment (Atom) – PI: Steve Wofsy (Harvard University)

The Atmospheric Tomography (ATom) project successfully conducted the second and third of four planned global deployments in FY17. The ATom team is in the process of measuring more than 200 gases as well as airborne particles from NASA's DC-8 flying laboratory. In particular, they are interested in greenhouse gas pollutants such as methane and tropospheric ozone, and poorly understood particulates like black carbon. How these pollutants interact and move around the planet will help scientists better understand air pollution and climate change now and in the future. While flying, the DC-8 makes a nearly continuous series of gentle descents and ascents in order to capture the most chemically active part of the atmosphere, from the relatively warm humid air 500 ft above the ocean surface to the colder, dry air at a peak altitude of 35,000 feet, and everything in between.

The ATom-2 deployment began with installation of the 23-instrument suite on December 4th, 2016. The deployment got underway on January 26th and the aircraft left Palmdale bound for Anchorage on January 29th. The deployment proceeded, from Anchorage, with the planned

FIGURE 9 ***DC-8 Landing at Lajes Air Base in Terceira during ATom-2.***

stopovers in Kona, Fiji, Christchurch, Punta Arenas, Ascension Island, Terceira, Thule and Anchorage before returning to Palmdale on the 22nd of February. The deployment included approximately 107 science flight hours, 59 vertical profile maneuvers and 4 missed approaches.

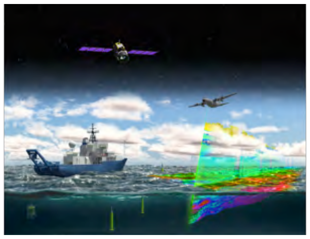
While the ATom-3 deployment began quite normally, with instrument installation on August 14th, a successful shakedown flight on September 12th and the completion of two science test flights, the team was informed in late August, less than a month before the deployment start date, that due to runway deterioration on Ascension Island the DC-8 would not be able to take-off from Ascension Island with sufficient fuel to reach Terceira, our next planned stopover location. It was determined that the next best alternative would be to land in Cabo Verde overnight and refuel the aircraft. The problems with this alternative included the High Threat Security Overseas (HTSOS) training requirement for aircraft passengers prior to arrival. They would also be required to have entry visas upon arrival. The Earth Science Project Office (ESPO) worked with the United States Embassy in Cabo Verde and got them to agree to waive the HTSOS training requirement due to the short time we would be Cabo Verde. Regarding the visas they said they could issue "Courtesy Visas" for everyone on the aircraft upon arrival. The runway situation on Ascension Island has ESPO investigating the possibility of using Recife, Brazil as a substitute for Ascension Island for the upcoming ATom-4 deployment (March, 2018).

After the new arrangements were set, the ATom-3 deployment got underway with a Palmdale/Palmdale flight south to the equator. Included in the ATom-3 deployment plan was an over-flight of Antarctica, originating from and ending in Punta Arenas. This flight was included to inves-

FIGURE 10 ***ATom-3 Science Team and crew back in Palmdale.***

tigate the polar vortex and ozone hole with an atmospheric chemistry instrument payload.

After leaving Punta Arenas, following the successful Antarctic flight, everything was proceeding along normally until the weather briefing the day before the scheduled departure from Terceira for Thule, Greenland. While the weather forecast looked good for the Thule arrival the planned Thule departure day weather looked as though there was the possibility that the aircraft would get stuck not being able to depart. The decision was made to go to Bangor, Maine instead of Thule. Due to quick logistical work by ESPO, everything ended up working out and the stopover in Bangor was successful. The ATom-3 deployment proceeded without any other anomalies. The aircraft returned to Palmdale on October 27th having completed 103.5 flight hours, 72.5 vertical profile maneuvers and 4 low approaches.



North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) – PI: Mike Behrenfeld (Oregon State University)

The NAAMES science team carried out the third of four, combined aircraft- and ship-based field campaigns from August 30th – September 24th, 2017. This deployment targeted the decelerating phase of the North Atlantic phytoplankton bloom as part of the overall project goals to understand the linkages between the North Atlantic Ocean ecosystem, atmospheric aerosols,

and clouds throughout the annual phytoplankton cycle. The initial deployment in November 2015 captured the seasonal baseline via a 26-day ship cruise and five, 10-hour research flights on a NASA C-130 aircraft. The May 2016 cruise captured the peak of biological activity and netted nine more research flights for the remote sensing and in situ measurement teams. Another 26 days of ship time and eight more science flights on the C-130 during September 2017 have now brought the number of observations out over the Atlantic to an unprecedented level.

As the team continues data analysis and processing activities on this important data set, new and important findings are beginning to emerge. Floats released during the first two NAAMES deployments have clearly documented the early winter initiation of the plankton bloom phase, upending traditional, decades-old theory on bloom dynamics. NAAMES-supported laboratory experiments have linked ocean bacterial metabolism to emissions of dimethylsulfide, which dominates biogenic aerosol releases from the oceans. Aerosol-cloud modeling of stacked flight sampling legs indicates that the sensitivity of clouds to aerosols is higher than suggested by previous modeling work. Meanwhile, satellite and airborne lidar observations continue to demonstrate the value of active remote sensing for combined ocean and atmospheric profiling in the cloudy mid- to high-latitude environments that challenge passive ocean color sensors.

The NAAMES team is currently gearing up for the final, springtime deployment that will take place in March, 2018, which will target the accelerating phase of the plankton cycle. At the conclusion of this five-year mission; NAAMES will provide a better understanding of the role that the coupled ocean-atmosphere system plays in Earth's changing climate.

FIGURE 11 ***NAAMES PI, Mike Behrenfeld, watches the NASA C-130 from the upper deck of the R/V Atlantis (left), while the scientists on the plane have a good view of the Atlantis rocking and rolling in the choppy North Atlantic Ocean (right).***

Atmospheric Carbon and Transport (ACT)-America – PI: Kenneth Davis (Penn State University)

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 identification and prediction of carbon dioxide and methane sources and sinks using spaceborne, airborne and ground-based data over the eastern U.S. Research flights use NASA's C-130 and B-200 aircraft.

ACT-America team completed their second and third atmospheric measurement campaigns during 2017. The winter field campaign was conducted between January 30 and March 10, 2017, and the fall field campaign occurred between October 2 and November 13. Both campaigns used two instrumented NASA aircraft to gather atmospheric measurements of greenhouse gases along with other trace gases and standard meteorological variables by operating out of LaRC, WFF, Shreveport, Louisiana, and Lincoln, Nebraska. The LaRC B-200 aircraft (carrying in-situ sensors) collected 209.0 hours of data and the WFF C-130 aircraft (carrying in-situ and remote sensors) collected 235.1 hours of data during 50 research missions. These mission occurred over the U.S. South, Mid-West, and Mid-Atlantic regions, and as well as during three transit flights between regions. In addition to the numerous level leg flights (Figure 12), more than 540 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 six fair weather days, underflights of the OCO-2 (Orbiting Carbon Observatory-2) satellite were carried out to investigate the sensitivity of CO_2-column measurements from the OCO-2 to lower tropospheric CO_2 variability. Airborne observations also sampled the atmospheric signatures of CO_2 and CH_4 fluxes around oil and gas extraction regions, urban centers, agricultural lands, and forests. We studied the distribution of greenhouse gases around several storms, often referred to as mid-latitude cyclones. In particular, front-relevant greenhouse gas structures in both boundary layer and lower free troposphere were also examined for two to three days in a row so that the impact of frontal propagation and associated greenhouse gas transport mechanisms could be revealed. 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 continue with its fourth campaign in the spring of 2018, scheduled to begin April 9, 2018. Ken Davis from Pennsylvania State University is the Principal Investigator (PI) for this mission.

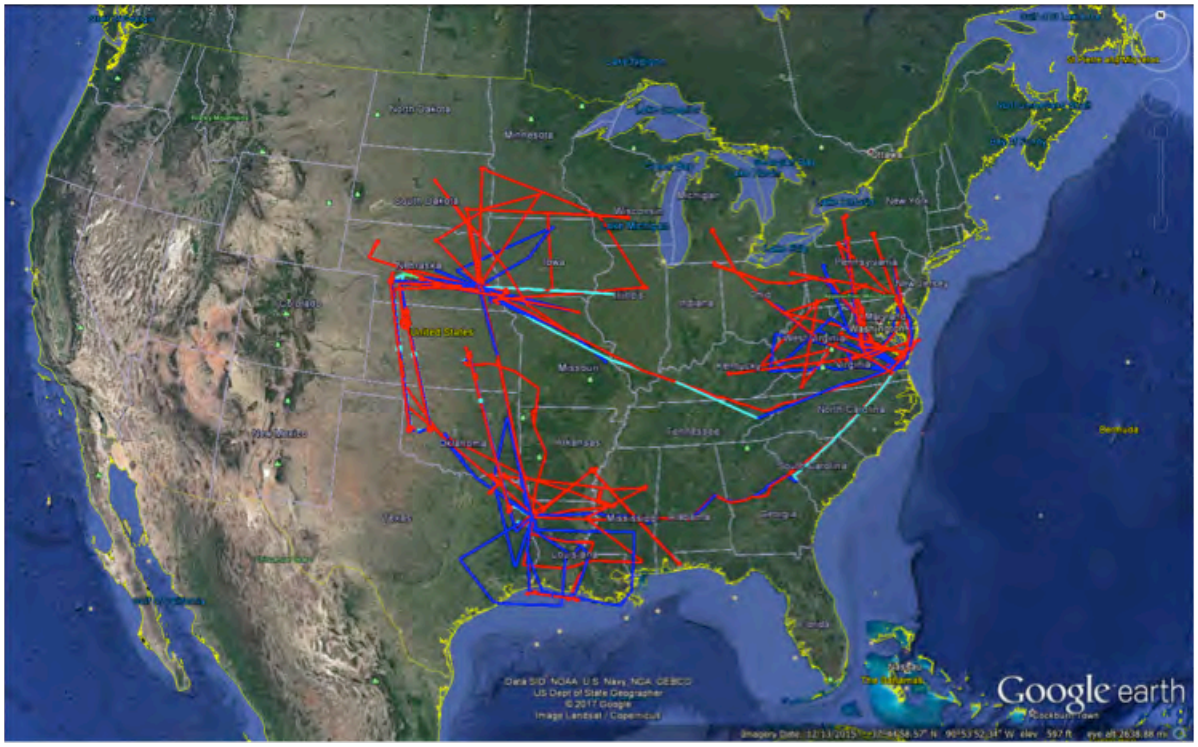
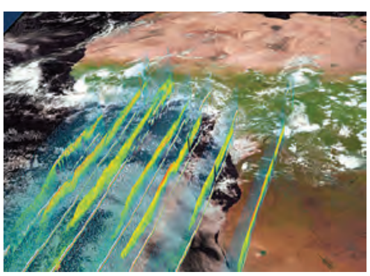


FIGURE 12 ***Tracks of B200 and C130 over the three ACT-America regions (Mid-Atlantic, Mid-West, and South) collecting high-resolution measurements during the Fall 2017 field campaign.***

Observations of Aerosols Above CLouds and their InteractionS (ORACLES) – PI: Jens Redemann (ARC)



In early September 2017, the ORACLES team completed its 2nd airborne science deployment based in Africa, this time from the small island nation of São Tomé. The goal of the ORACLES project is to study the interactions between clouds and biomass burning aerosols. São Tomé is located at the northern end of the annual aerosol plume that originates on the continent.

Southern Africa produces almost a third 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. 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 is to capture the seasonal cycle of aerosol-cloud interactions, with the following overarching goals:

- 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 June 2017, with several payload changes. AMPR, a 2016 addition, did not fly in 2017. HSRL-2, which flew on the ER-2 in 2016, was added to the P-3 payload. Filters were added to the inlet line of the HIGEAR suite, to collect particles for post-flight analysis. A duplicate cloud probe was flown for comparison, and a CVI inlet was added to the water isotope analysis system. The ESPO forward deployment team arrived at the airfield in São Tomé about 2 weeks before the scheduled arrival of the aircraft, to meet airfield officials, unpack shipments, prepare the lab and operations facilities, and arrange for immigration, transportation and handling of personnel, etc.

After its arrival on August 9, the P-3 flew a total of 13 science flights for a total of 112 hours. Approximately one-half of the flights followed a north-south line directly into the heart of the aerosol plume. A new feature in 2017 were flights dedicated to re-sampling the same pol-

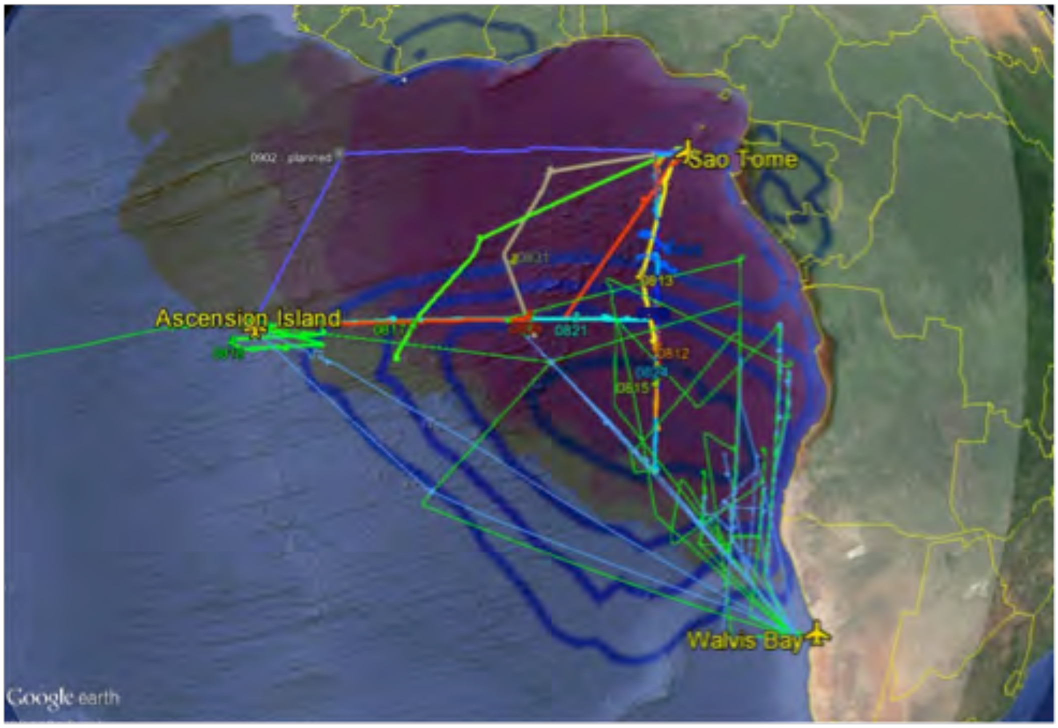


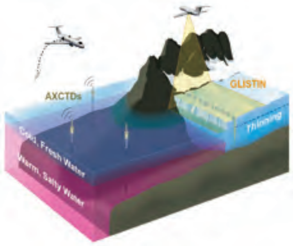
FIGURE 13 ***P-3 and ER-2 flight tracks from both the ORACLES-2016 and -2017 deployments, overlaid on a contour map of the average aerosol plume in August.***

FIGURE 14 ***P-3 on approach to São Tomé International Airport on arrival day, August 9, 2017.***

luted air masses one or two days later, providing new information on aerosol aging. A further important feature of the 2017 deployment was a flight to Ascension Island, followed by a coordinated flight with a complementary UK aircraft campaign. Data from the UK BAE-146 are being used for inter-comparisons to provide an objective assessment of instrument performance from both planes. All of these flights, along with the two transit flights, mean that ORACLES-2017 sampled extensively along the aerosol flow path, as well as at the northern edge of the low cloud deck where deeper clouds are more likely to interact with the aerosol plume.

This was the first 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. But the airport and civil aviation organizations were very supportive 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. Science connections were established with the University of São Tomé and with the Meteorological officials at the airport. Television and press personnel interviewed team members and shared the project's goals and progress with the community. The team accomplished 13 flights in this first campaign in a new location, collecting very unique science data, and with this experience, they are well prepared to return to São Tomé in 2018.

Oceans Melting Greenland (OMG) – PI: Josh Willis (JPL)



The objective of 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. Measurements of the ocean bottom, as well as seawater around Greenland, are being taken from ships and the air. OMG flew two science flight missions in 2017: "GLISTIN-A" and "AXCTD".

OMG's GLISTIN-A Radar Mission #2:
In March 2017, 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 #2 of 4) of Greenland's coastal glaciers. During the 24 day March deployment, GLISTIN-A conducted glacier survey flights out of Kangerlussuaq (Sondrestrom Air Base), Keflavik (Iceland) and Thule Air Base (Greenland). GLISTIN-A acquired 82 out of 82 planned OMG science flight lines.

FIGURE 15 ***C-130 launching an AXCTD test probe during OMG (October 2017) North East of WFF. Photo taken from LaRC G-III chase aircraft.***

OMG's AXCTD Mission #2:
In late September and early October 2017, OMG installed JPL's Airborne Expendable, Conductivity Temperature Depth (AXCTD) system into NASA's WFF C-130 aircraft. AXCTD probes are dropped from the aircraft into the ocean to measure ocean temperature and salinity on the ocean shelf. After successful C-130 AXCTD test drops off the Virginia coasts, the C-130 was declared operational and deployed to Keflavik, Iceland.

Over the next three days, OMG deployed over 118 AXCTDS probes in Greenland's Eastern waters from Keflavik deployment base. On the fourth day, OMG's C-130 deployed to Thule, Greenland. A few days later, due to an approaching winter storm, the OMG C-130 departed Thule and recovered at Goose Bay, Canada. Between Thule and Goose Bay western deployment bases, OMG C-130 dropped 121 AXCTDs probes and one Alamo probe in Greenland's western waters. On October 24, after a total of 13 deployment days, OMG declared mission success and returned back to NASA WFF. This was OMG's AXCTD yearly campaign #2 of 5.

COral Reef Airborne Laboratory (CORAL) – PI: Eric Hochberg (Bermuda Institute of Ocean)

This investigation provides critical data and new models needed to analyze the status of coral reefs and to predict their future, especially under scenarios of predicted environmental change. CORAL is making high density observations for a large sample of reefs (~8% of global reef areas) that occur across a broad range of environmental conditions, implemented in eight campaigns across 10 coral reef regions in the Indian, Pacific, and Atlantic Ocean. The airborne portions of the field campaigns were conducted aboard a Tempus Applied Solutions Gulfstream-IV (G-IV) aircraft outfitted with the JPL-developed Portable Remote Imaging Spectrometer (PRISM) instrument—a combination spectrometer and radiometer developed specifically for coastal ocean science applications.

From June 2016 through May 2017 CORAL conducted intensive field campaigns in four representative reef areas across the globe: the main Hawaiian Islands, the Great Barrier Reef, Palau, and the Mariana Islands. Field campaigns comprised two unique, but complementary, aspects: 1) airborne remote sensing activities, and 2) in-water validation activities to collect measurements of reef benthic cover, water column optical properties, and reef biogeochemistry used to validate CORAL data products.

Highlights of the field campaigns included coordination with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) research vessel "Investigator" during the Great Barrier Reef campaign. This resulted in concomitant in-water optical measurements and overflight data. In addition, a plan was formulated and successfully implemented to use remaining flight hours for airborne data collection over reef tracts in the Florida Keys, representing the first CORAL data set from the Atlantic Ocean.

Beginning with the Operations Readiness Test (ORT) conducted June 2016 in Hawaii, and ending with the two-day Florida campaign, a total of

355 flight lines were acquired with a total image area of 94,495 square kilometers. The ORT and four major field campaigns resulted in a more than 800 distinct in-situ measurements: benthic cover surveys at 311 locations, reef metabolism measurements at 49 locations, and optics measurements at 443 locations.

Following the conclusion of the field campaigns, and closing out 2017, CORAL scientists began synthesizing data to refine algorithms and begin the development of models that will be used to estimate reef condition and forecast reef response.

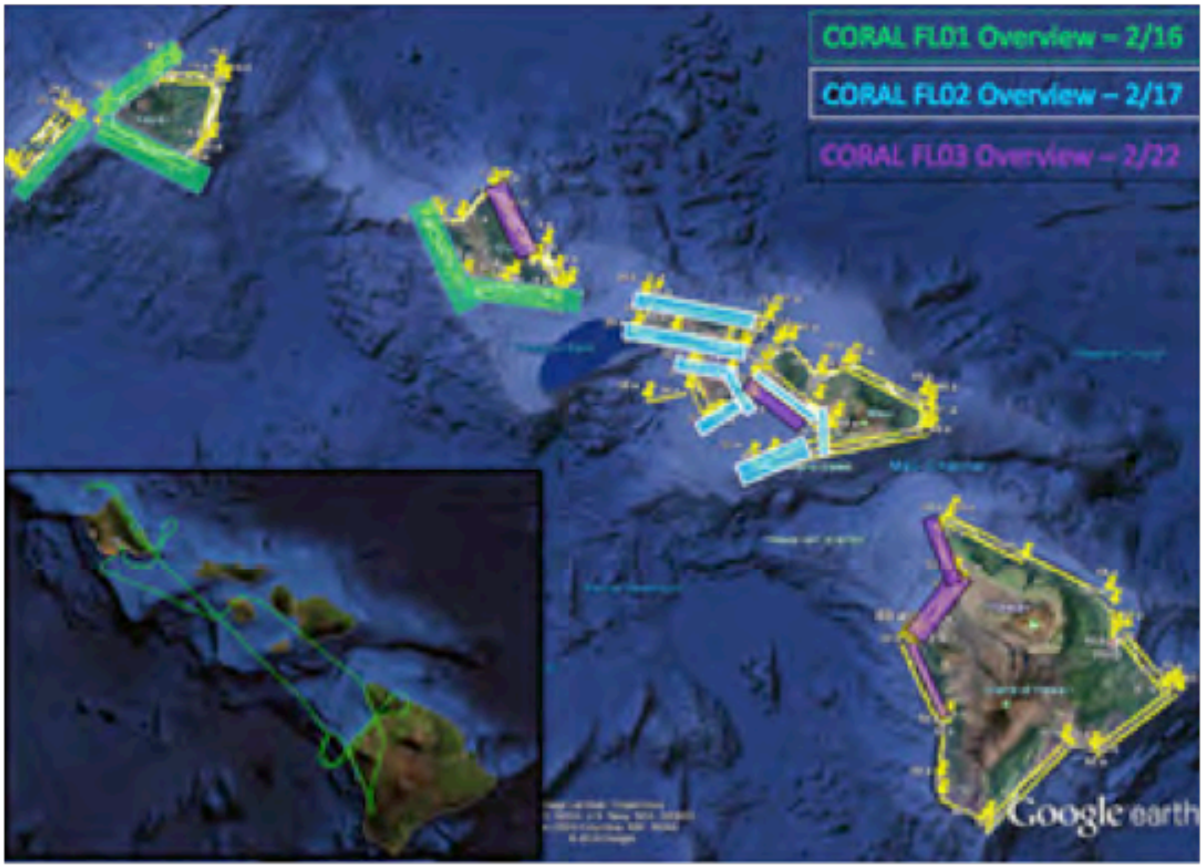


FIGURE 16 ***CORAL data collection paths using PRISM.***

Convective Processes Experiment (CPEX)

The Convective Processes Experiment (CPEX) campaign used NASA's DC-8 airborne laboratory to record the entire evolution of convective storms, from birth to decay. The DC-8 was outfitted with five complementary research instruments designed and developed at NASA. The plane also carried dropsondes that were dropped from the plane to make measurements as they fall. Working together, the instruments collected detailed data on wind, temperature and humidity in the air below the plane during the birth, growth and decay of convective clouds -- clouds formed by warm, moist air rising off the subtropical waters around Florida. "To understand what makes a thunderstorm form and grow, we need field campaigns. We need to fly to where the storms are, look at them and their environment in detail, and measure all the important features at the same time," said Bjorn Lambrigtsen of JPL, a member of the CPEX science team.

The five NASA instruments flew together as a group for the first time:

- DAWN, the Doppler Aerosol Wind Lidar,
- APR-2, the Airborne Second-Generation Precipitation Radar,
- HAMSR, the High Altitude MMIC (Monolithic Microwave integrated Circuit) Sounding Radiometer;
- MTHP, the Microwave Temperature and Humidity Profiler
- MASC, the Microwave Atmospheric Sounder for Cubesats.

The mission took place from mid-May through the end of June. Flying from Fort Lauderdale, Florida, the DC-8 logged a total of 104 hours during CPEX. Fight tracks for the mission are shown below. The mission succeeded in sampling all the conditions hoped for, including tropical storm Cindy on June 20-21. Some of the box patterns were partly for science and partly for critical evaluation of the DAWN wind lidar, one of the critical instruments contributing to many of the scientific objectives.

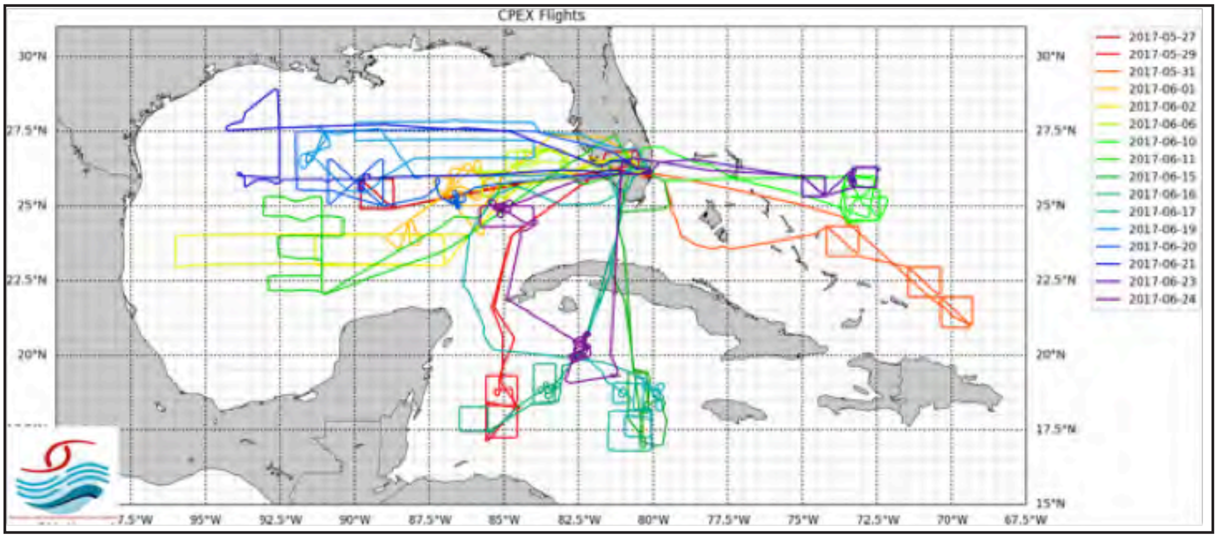


FIGURE 17 ***CPEX flight tracks by date.***

HyspIRI Preparatory Campaign - Hawaii

Over the past four years, NASA has flown a series of research flights over California, carrying airborne prototypes of instruments in preparation for a future satellite mission called the Hyperspectral Infrared Imager (HyspIRI), now in the conceptual design phase. During winter 2017, a NASA-led science team flew off in search of a new landscape, exploring Kilauea volcano on the island of Hawaii, and the adjacent volcano Mauna Loa from the air, ground and space. Their goal: to better understand volcanic processes and hazards.

The HyspIRI Hawaii campaign concluded after six weeks of data collection. The ER-2, based at Marine Corps Base Hawaii (MCBH) – Kaneohe Bay on Oahu, flew 18 science missions. Two of the missions included transit flights from Palmdale to the MCBH and return to Palmdale. The transit flights included obtaining science data over the Mauna Loa and Kilauea volcanoes, as well as the coral reefs of Gardner Pinnacles and Nihau. The ER-2 airplane flew a total of 65.3 hours during the 18 missions.

The ER-2 carried AVIRIS-classic and MASTER. A weather requirement of no more than 25 percent cloud coverage was required at the target. Working within these cloud constraints was a challenge, but despite challenging weather in Hawaii, the airborne campaign was quite successful with multiple images obtained of most of the coral reef and volcano phenomena targeted for observation. In addition to volcano imaging, monitoring of miles of coral reefs was undertaken using these sensors that provide better

FIGURE 18 ***ER-2 at Kaneohe Bay during the HyspIRI Hawaii campaign.***

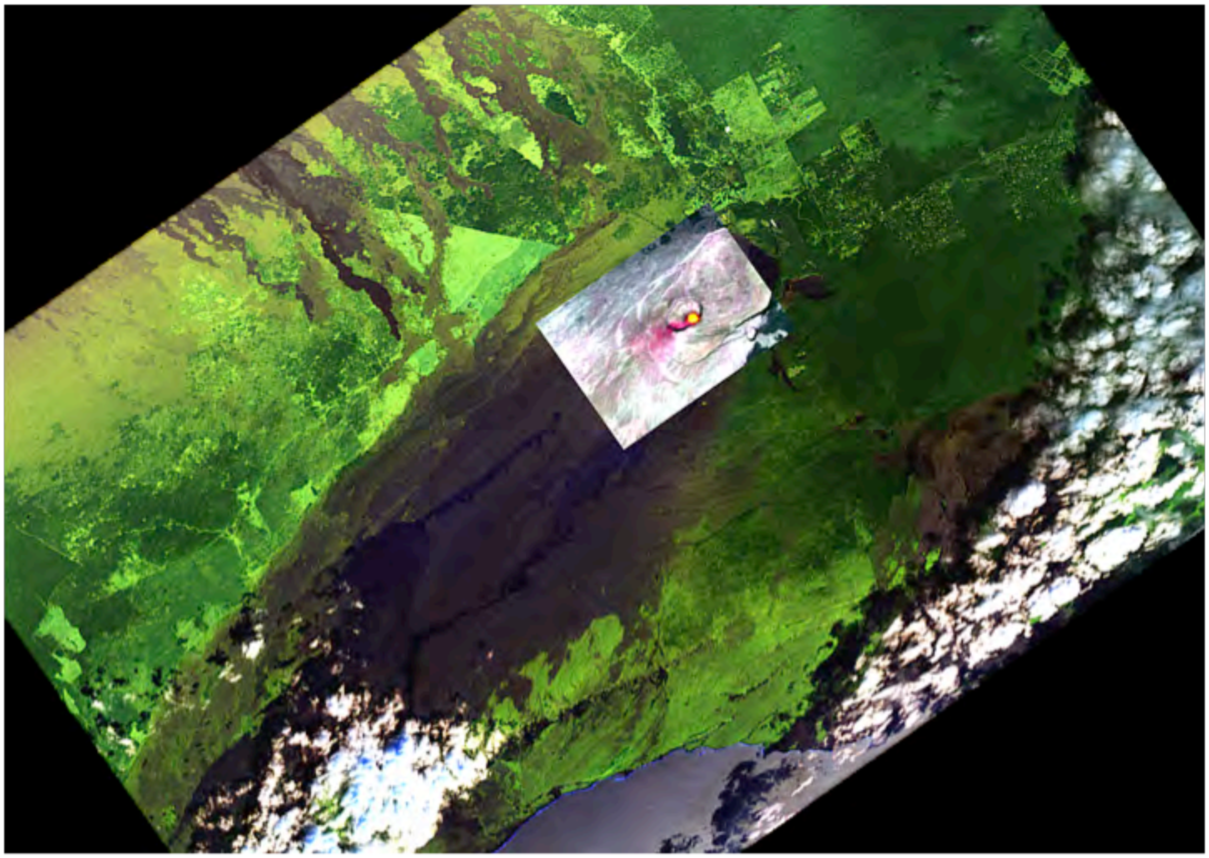


FIGURE 19 ***Composite MASTER image of Kilauea crater, overlaid on WorldView data image.***

spatial and spectral resolution than currently available from NASA satellite systems.

The MASTER image in Figure 19 of Hawaii Volcanoes National Park is a color composite of shortwave and thermal infrared bands. It highlights Kilauea's lava lake as well as the sulphur dioxide plume (portrayed in pink).

UAVSAR in 2017

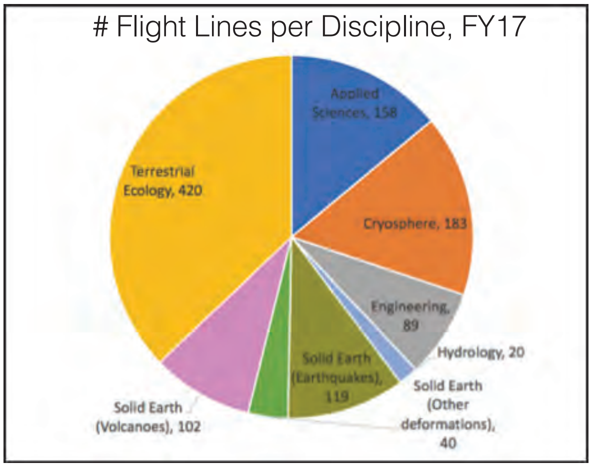
In 2017 the UAVSAR project supported 27 flight requests and 19 PIs, conducting 57 science flights with AFRC G-III and 42 science flights with the JSC G-III.

Most flights used the L-band instrument but this year has seen an increase in the demand for P-band data (Figure 20) due to the ABoVE mission. The number of Ka-band flight lines was comparable to FY16 but flight requests included two new investigators to study volcano topography change and snow volume change. A breakdown of flight lines per discipline underscores the broad range of scientific studies that were supported by the UAVSAR instrument suite (Figure 20).

The L-band radar acquired a total of 15 TB of raw data with 94% success in data acquisition. The production processing team delivered 555 PolSAR science products, 220 requested InSAR pairs with average latency of 16 days, and 26 InSAR stacks with average latency of 29 days. For P-band radar, we acquired a total of 7 TB of raw data with 91% success in data acquisition. The production processing team delivered 169 PolSAR science products. UAVSAR data can be downloaded at: http://uavsar.jpl.nasa.gov/cgi-bin/data.pl.

The crew flew in the U.S., Canada, and Greenland: 326 and 344 hours were logged by AFRC and JSC centers, respectively. This year's activities included complex experiments that required coordination with ground crews and other airborne science instruments:

- The SnowEX deployment took place in Colorado with the goal of mapping changes in snow depth. The experiment integrated UAVSAR, field measurements, and lidar data before and after snowfall events.



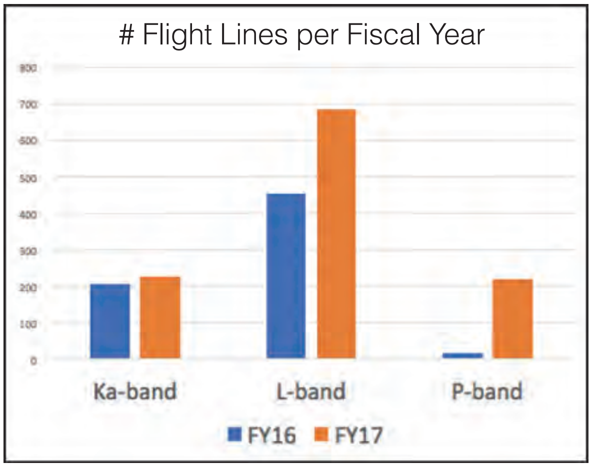


Figure 20 ***Left:*** **Science and Application disciplines supported by UAVSAR observations in FY17. The chart shows the number of flight lines per discipline, including P-, L-, and Ka-band instruments.** ***Right:*** **comparison of number of flight lines per instrument between FY16 and FY17.**

- In Louisiana, the Wax Lake Delta experiment characterized water and sediment levels with lidar, UAVSAR, AirSWOT, and AVIRIS. In this case, observations had to be carefully planned to sample high- and low-tide events, and to overlap with boat teams conducting in-situ measurements.

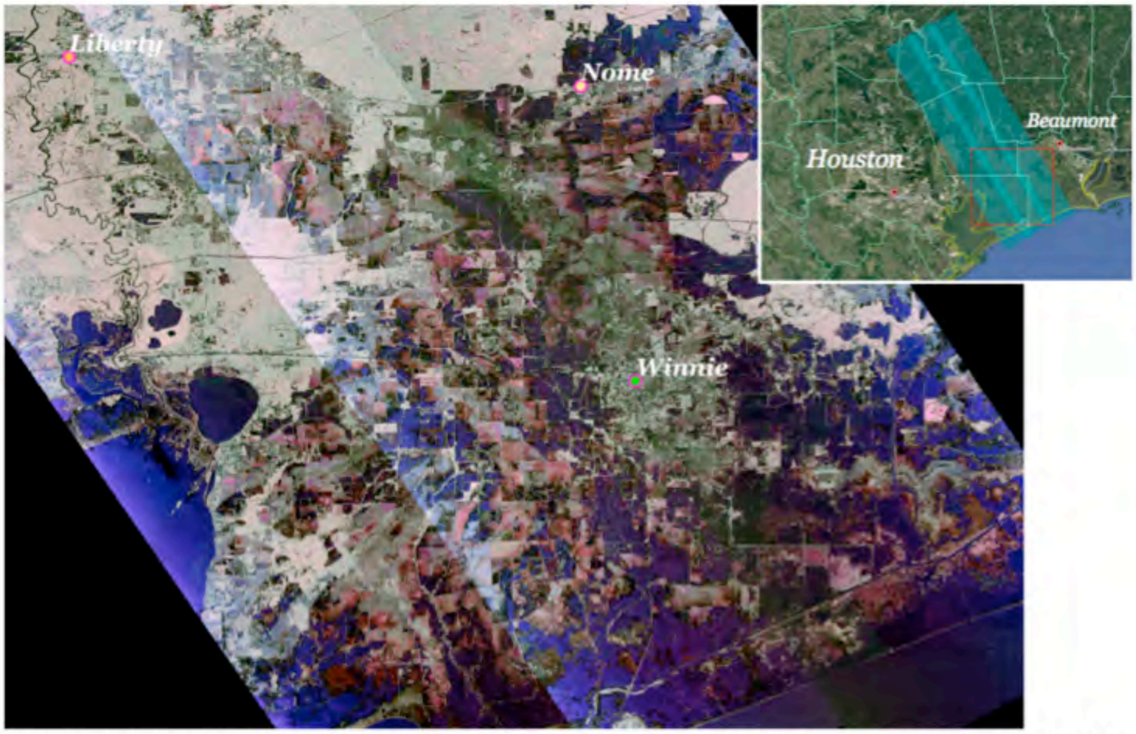
- The Ka-band instrument was used to produce high-resolution topographic maps of Hawaii's Big Island. These data will be integrated with maps of gas emissions and surface temperature from USGS ground stations and optical airborne observations.

- The JSC team continues to support OMG and conducted its second survey of Greenland glaciers this year.

- During the ABoVE experiment, permafrost sites in Alaska and Canada were imaged before ground thaw and after maximum thawing in order to upscale point measurements on permafrost behavior.

- In Hawaii, flights carrying the L-band instrument covered all times of day. The goal was to capture short-term variation in air moisture in order to model its impact on radar-derived estimates of volcanic deformation.

The UAVSAR team also supported a rapid response flood event following Hurricane Harvey in September 2017. The team conducted one flight on each of four days from Austin, Texas to observe the floodwater cresting and receding along four rivers in greater Houston and east Texas. Single polarization channel quick-look images were delivered post-flight to emergency response staff at the Texas State Operations Center in Austin. 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. Overall, the team was able to balance local science with complex, multi-instrument deployments to deliver data for cutting edge science studies. Figure 21 is a mosaic image of three UAVSAR swaths acquired August 31, 2017. The city of Winnie on the Texas coast is surrounded by water-saturated and flooded land following the passage of Hurricane Harvey. Colors are based on the Pauli decomposition algorithm where red, green and blue represent the following polarization components: |HH – VV|, |HV|, and |HH + VV|, respectively. As a result, predominantly surface-scattering objects such as open water or inundated land have bluish-purple tones, double bounce reflections, as from human-made structures and flooded vegetation, are reddish in coloration and volume-scatterers such as vegetation show up as green. Black pixels are regions with weak radar backscattering or no data. Inset shows swath coverage and image context between the cities of Houston and Beaumont.



Mosaic image of three UAVSAR swaths acquired August 31, 2017. The city of Winnie on the Texas coast is surrounded by water-saturated and flooded land following the passage of Hurricane Harvey. Colors are based on the Pauli decomposition algorithm where red, green and blue represent IHH – VVI, IHVI, and IHH + VVI, respectively. As a result, predominantly surface-scattering objects such as open water or inundated land have bluish-purple tones, double bounce reflections, as from human-made structures and flooded vegetation, are reddish in coloration and volume-scatterers such as vegetation show up as green. Black pixels are regions with weak radar backscattering or no data. Inset shows swath coverage and image context between the cities of Houston and Beaumont.

FIGURE 21 ***Mosaic image of three UAVSAR swaths acquired August 31, 2017.***

East Pacific Origins and Characteristics of Hurricanes (EPOCH)

The EPOCH project concluded its month-long airborne science campaign at the end of August 2017. The primary science goal of the project is to advance understanding of hurricane genesis and rapid intensification by analyzing observational data obtained by overflying developing storms.The project used the Global Hawk aircraft due to its ability to fly 24+ hour continuous missions, as well as its capability to reach storms in all three regions: the East Pacific, the Gulf of Mexico, and the Atlantic. This project was led by NASA, but received substantial contributions from NOAA.

The Global Hawk aircraft carried three primary instruments: the ER-2 X-band radar (EXRAD), the High Altitude Monolithic Microwave Integrated Circuit Sounding Radiometer (HAMSR), and the Advanced Vertical Atmospheric Profiling System (AVAPS). EXRAD is a high-power airborne Doppler radar developed by the Goddard Space Flight Center. It has flown in three prior field campaigns in the nose of an ER-2, but had never been integrated or flown on the Global Hawk before. HAMSR is a microwave atmospheric sounder designed and built by JPL. AVAPS,

developed by the National Center for Atmospheric Research (NCAR), is a dropsonde delivery system designed for the Global Hawk aircraft. It can hold up to 90 dropsondes per flight. These sondes provide high vertical resolution measurements of temperature, pressure, relative humidity, wind speed and direction in real-time.

The flight campaign began August 1 and conducted three science flights. The first occurred on August 8-9 and was able to capture intensification of Tropical Storm Franklin in the Gulf of Mexico. For the first time, dropsonde data were transmitted and assimilated in real-time into NOAA's Global Forecast System. The second flight occurred on August 23-24 and captured intensification of Tropical Storm Harvey to a hurricane. This storm had record-breaking impacts to coastal Texas and Louisiana due to the extensive flooding. The Global Hawk flight track and dropsonde release locations are shown in Figure 22. The final flight occurred on August 30-31 and captured the genesis of Tropical Storm Lidia in the Pacific. Each of the three science flights had duration greater than 20 hours. Total mission flight time was 86 hours.

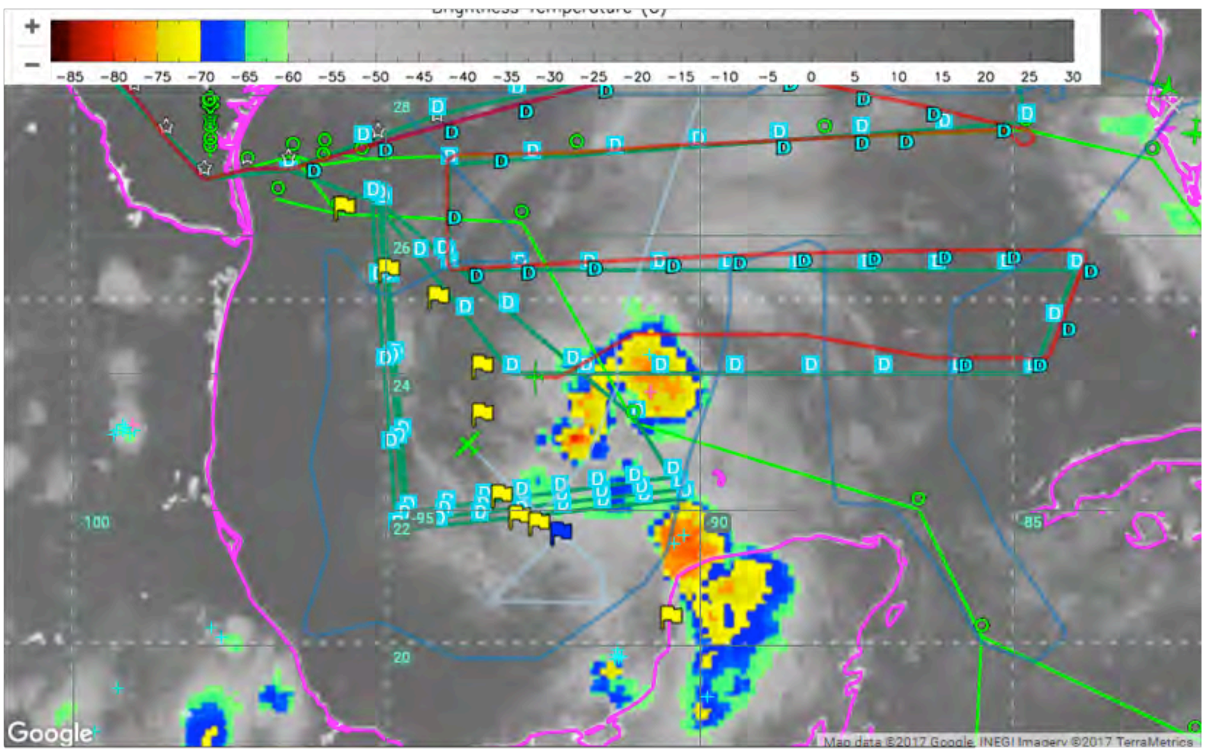


FIGURE 22 ***Global Hawk flight track and location of dropsonde releases over Hurricane Harvey during the EPOCH mission. In all, 80 dropsondes were dropped off the Texas coast.***

SnowEx

SnowEx is a multi-year airborne snow campaign supported by NASA's Terrestrial Hydrology Program with the primary goal of addressing the question: How much water is stored in Earth's terrestrial seasonally snow-covered regions? Year 1 (2016-17) focused on the distribution of snow-water equivalent (SWE) and the snow energy balance in a forested environment. The year 1 primary site was Grand Mesa and the secondary site was the Senator Beck Basin, both in western, Colorado, USA. Nine sensors on five aircraft made observations using a broad suite of airborne sensors including active and passive microwave, and active and passive optical/infrared/thermal sensing techniques to determine the sensitivity and accuracy of potential satellite remote sensing techniques, along with models, to measure snow under a range of forest conditions. The main winter campaign took place February 5-26, 2017. In addition to the airborne component, SnowEx included an extensive range of ground truth measurements—in-situ samples, snow pits, ground based remote sensing measurements, terrestrial lidar scans, and other sophisticated new techniques—made by nearly 100 participants from North America and Europe.

The snow community consensus is that a multi-sensor approach is needed to adequately address global snow, combined with modeling and data assimilation. What remains at issue, then, is how best to combine and use the various sensors in an optimal way. That requires field measurements, and SnowEx was designed to do exactly that.

A list of the nine sensors is as follows. All are from NASA unless otherwise noted.

- Radar (volume scattering): European Space Agency's (ESA) SnowSAR, operated by Meta-Sensing
- Lidar & hyperspectral imager: Airborne Snow Observatory (ASO from JPL)
- Bi-directional Reflectance Function (BRDF): the Cloud Absorption Radiometer (CAR from GSFC)
- Thermal Infrared imager (QWIP from GSFC)
- Thermal infrared non-imager from U. Washington
- Video camera from GSFC

The ASO suite flew on a King Air from Dynamic Aviation, and the other sensors flew on a Naval Research Laboratory (NRL) P-3.

In addition, two NASA radars flew on the JSC and AFRC G-III aircraft to test more experimental retrieval techniques:

- InSAR altimetry: GLISTIN-A
- Radar phase delay: UAVSAR

And the new WISM SAR and passive microwave system (Harris Corp) flew on a Twin Otter from Twin Otter International.

The February campaign was successful despite unusually warm/wet conditions (challenging for microwave sensors), clouds (challenging for optical sensors), record high snow amounts, extremely strong winds aloft on multiple days, and

having only a year to prepare everything. The unique SnowEx Year 1 dataset will answer key questions for developing future snow mission concepts and form a powerful legacy science dataset for years to come.

FIGURE 23 ***The view of the Senator Beck, Colorado site for SnowEx.***

FIGURE 24 ***NRL P-3 (VXS-1 squadron, Pax River) deployed at Peterson AFB for SnowEx. Visible are NASA P-3's nose housing CAR and the tail & nadir housings for the SnowSAR.***

Airborne Snow Observatory

The Airborne Snow Observatory (ASO) is an airborne platform designed to measure snow depth and snow albedo at high spatial resolution (3m) in mountainous terrain. These measurements are then inverted using modeled snow density estimates, that are guided by in situ measurements, for retrieval SWE at 50-meter spatial resolution. When integrated over entire watersheds, the ASO SWE products provide our most accurate estimations of snow water resources in complex terrain. In 2017, ASO expanded operations throughout the Sierra Nevada mountains in California and southwest Colorado. New survey areas included the San Joaquin River Basin and the North Fork of the Kings River, along with baseline collections over the American River and the Feather River in preparation for further expansion of snow survey coverage in 2018. The instruments (Riegl Q1560 Lidar and CASI 1500 Spectrometer) were installed on a Dynamic Aviation King Air A90, which flew 80 survey days, 119 individual basin surveys, and over 307 hours of flight time. The 2017 snow season in California was one of the largest seasons on record and ASO maintained monthly aerial surveys from 21,500 ft. mean sea level (MSL) over eight individual watersheds until the snow finally melted in mid-August. The basin-integrated SWE estimates derived from these surveys were provided within 1-3 days to local water authorities, including our collaborators and partial funding source, the California Department of Water Resources. In Colorado, ASO was a strong participant in the February 2017 NASA SnowEx campaign, with five surveys of the Grand Mesa and Senator Beck study areas conducted at low-flight altitude (13,500 ft. MSL) and very high spatial resolution. The science-driven SnowEx surveys were synchronized with overpasses by several other airborne sensors, including another JPL instrument GLISTIN-A, which is a Ka-band interferometer.

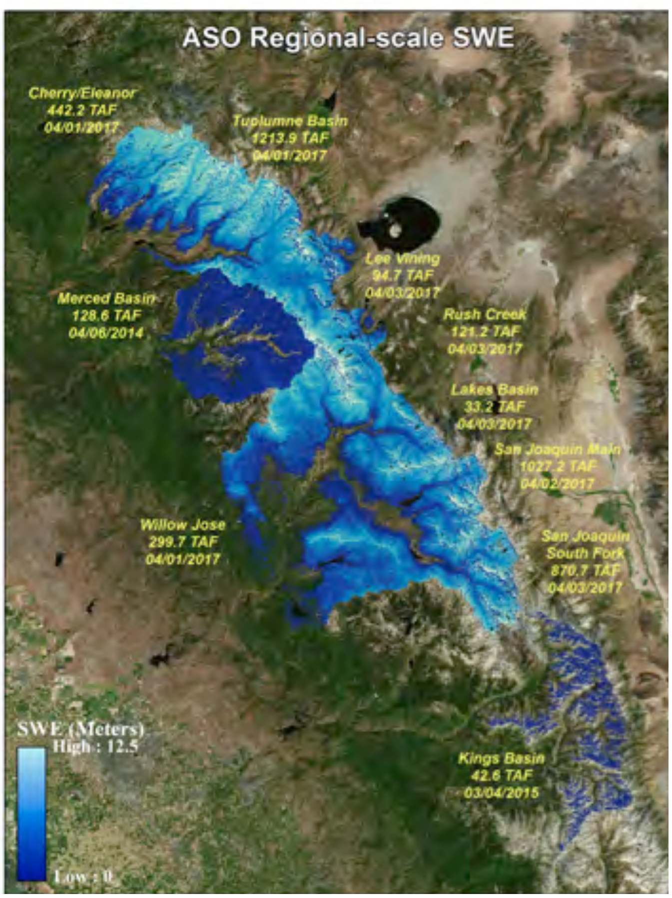


FIGURE 25 ***Snow water equivalent map of California based on the 2017 Airborne Snow Observatory measurements.***

A map of regional-scale SWE in Figure 25 was developed from the ASO 50m SWE products that shows the spatial coverage of the ASO 2017 snow surveys throughout California. Lighter blue shading reflects larger SWE depths than pixels shaded with darker blue and the yellow text reports the basin-integrated snow water volume estimates in units that are most common with water managers (TAF=thousand acre-ft). Note: the Merced Basin and Kings Basin retrievals shown were collected during the much lower snow years of 2014 and 2015 respectively and are included for spatial completeness.

G-LiHT

Scientists at NASA Goddard have been studying tropical, mid-latitude and boreal forest biomes with the next generation Goddard's Lidar, Hyperspectral and Thermal (G-LiHT) multi-sensor airborne imaging system. The system was completely upgraded during the past winter and used to collect more than 300 science flight hours from Puerto Rico to Maine during 2017. G-LiHT was designed and assembled for the purpose of collecting coincident, fine spatial resolution (1-meter) image data that is needed for many ecological studies and demonstrating the benefits of multi-sensor data fusion. G-LiHT simultaneously maps the composition, structure, and function of terrestrial ecosystems.

The 2017 campaign season began in March with flights in tropical forests of Puerto Rico and coastal ecosystems in south Florida. Data were collected for NASA's Fluorescence Airborne Experiment (FLARE) using FIREFLY, a newly designed spectrometer for measuring solar-induced fluorescence from chlorophyll that was also integrated into the G-LiHT system. FLARE supports ongoing collaboration between NASA and ESA on the Fluorescence Explorer (FLEX) satellite mission, which will be used to retrieve Solar-Induced Fluorescence (SIF) emitted from vegetation as a measure of photosynthetic activity, an indicator of stress. FLARE was designed to advance instrument and measurement techniques; provide data for development of retrieval algorithms; provide calibration and validation data for different biomes and times of the day; and advance the science basis for interpreting SIF retrievals. Figure 26 shows the extend of the 2017 Puerto Rico campaign that combined FLARE with the U.S. Department of Energy's Next Generation Ecosystem Experiment in the Tropics (NGEE-Tropics).

G-LiHT data were also acquired in coastal ecosystems of south Florida to observe and predict peat collapse in coastal wetlands for projects

FIGURE 26 ***The extent of the March 2017 Puerto Rico Airborne-Ground field campaign.***

funded by NASA's New Investigator and Carbon Cycle Science programs. G-LiHT airborne data is being combined with ground and space-based remote sensing data to quantify and predict rates of change, identify areas vulnerable to collapse, and model changes in regional carbon and water cycling to inform protection and restoration efforts in the Florida Everglades.

During September 2017, Hurricane Irma impacted this same area of Florida. Strong winds in excess of 225 km per hour and a 3-meter storm surge impacted the southern Florida Gulf Coast, resulting in extensive damages to coastal and inland ecosystems. G-LiHT was funded under a NASA Rapid Response and Novel Research in Earth Science project to return to south Florida in December 2017 and repeated the data acquisition to assess the extent of mangrove defoliation and mortality, coastal erosion and sedimentation associated with the event, and to determine whether this would affect regrowth and alter the reliance and vulnerability of coastal regions to future storms.

Other G-LiHT activities in 2017 included partnering with the U.S. Forest Service to conduct Forest Health Surveys and with the University of Maine's School of Forest Resources to collect the area of an entire Landsat scene (180 × 190 km) from a previous NASA Carbon Monitoring System project. The demand for G-LiHT data for Earth Science studies remains strong, and 2018 campaigns are planned for Alaska and New England.

GOES-R cal/val

To ensure the data quality of the National Oceanic and Atmospheric Administration's (NOAA) next generation Geostationary Operational Environmental Satellite (GOES-R series) Earth observing optical sensors, a post-launch validation field campaign was developed. Field campaigns are considered best practice and essential for collecting reference data that can be directly related to satellite observations. This is of heightened importance for GOES-R as entirely new instruments on the GOES-R series include the much improved imager whose last significant capability update was 22 years ago in the GOES I-M series, and a first of its kind operational lightning mapper in geostationary orbit. The GOES-R field campaign focused on post-launch validation of the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM) L1b & L2+ products. The campaign conducted March – May 2017 provided collection of reference data to validate the post-launch performance of these systems as part of a comprehensive post-launch validation strategy for each instrument and product algorithms.

The GOES-R field campaign was a roughly nine week campaign of data collection (~100 flight hours) using the NASA high altitude ER-2 platform, integrated with a host of both passive and active sensors coordinated with ground based, near surface, and satellite reference data over several Earth targets in support of the validation of L1b & L2+ products. The ER-2 mission set was executed in a two phased approach: Phase 1 – ER-2 based out of Palmdale, CA (March 21- April 11, 2017) with ABI validation missions as the primary focus for best access to desert validation targets; Phase 2 – ER-2 based out of Warner Robins Air Force Base with GLM validation missions as the primary focus for best access to lightning producing storms over both land and ocean (April 13 to May 17, 2017). The GOES-R satellite was located at its checkout location of 89.5 W during the entire campaign.

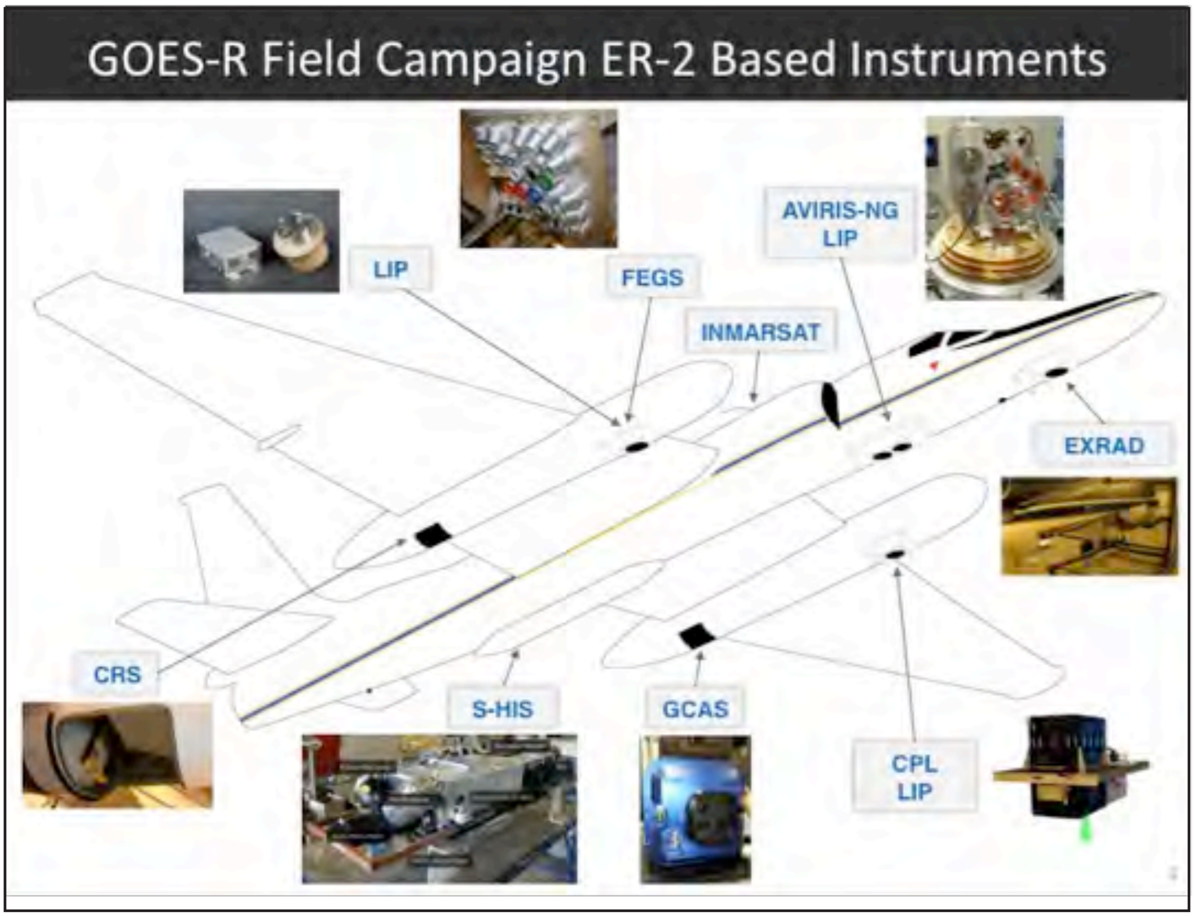


FIGURE 27 ***GOES-16 Field Campaign ER-2 Based Instruments: Next-Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRISng) & AVIRIS-Classic (AVIRISc); Scanning High-resolution Interferometer Sounder (S-HIS); Fly's Eye GLM Simulator (FEGS); Lightning Instrument Package (LIP); Cloud Physics Lidar (CPL); Cloud Radar System (CRS); ER-2 X-band Doppler Radar; GeoCAPE Airborne Simulator (GCAS).***

Support to ESD Satellite Missions, including Decadal Survey Missions

A primary purpose of the ASP is to provide platforms for instruments that support on-orbit or future Earth Science Satellite and International Space Station (ISS) missions. This support includes airborne campaigns to collect data for algorithm development prior to launch, to test instrument concepts for satellite / ISS payloads or airborne simulators, and to provide data for calibration or validation of satellite algorithms, measurements or observations

Satellite or space mission	ASP Mission	Aircraft	Flight hrs	Location	Purpose
Decadal Survey					
ICESat-2	Operation IceBridge, ABoVE (portions), SNOWEX	P-3, Guardian, B200, DC-8, G-III, C20-A	1088.4	Greenland, Alaska, Norway, Antarctica	Build data base
NI-SAR	ABoVE, SNOWEX, ESI	C-20A, G-III	401.7	California, Colorado, Alaska	Precursor data sets
HyspIRI	HyspIRI Hawaii, California; SARP, HyTES, ASO	ER-2; A90	265.5	Hawaii; 3 boxes in California; California ASO	Precursor data sets; instrument development
ACE	ORACLES; Lake Michigan Ozone Study, C-HARRIER	ER-2; B-200; Twin Otter	181.0	Namibia, Lake Michigan; California	Aerosol data characterization
GEO-CAPE	Lake Michigan Ozone Study, C-HARRIER	B-200, Twin Otter	166.0	US	Precursor data sets; instrument development
3-D Winds	CPEX	DC-8	104.3	Caribbean	Precursor data collection
SWOT	AirSWOT, GLISTIN	B-200; G-III	97.1	Alaska, North Dakota	Algorithm development
ASCENDS	ASCENDS-17 (ABoVE); AJAX	DC-8; AlphaJet	68.6	Alaska; California	Instrument development; precursor data
SMAP	AirMOSS Alaska Permafrost; Red River flood mapping	G-III	42.9	Alaska	Hydrologic data
Other					
OCO-2	ACT-America, ATom, ASCENDS-17, ABoVE (CFIS); AJAX, Carbon Monitoring Flux	C-130, B-200, DC-8, AlphaJet; Sherpa; Twin Otter	578.7	Global	Cal/val
LANDSAT	FLARE; HyspIRI Airborne; ASO; C-HARRIER	ER-2; A90; Twin Otter	388.20	California; Florida, Puerto Rico, Colorado	Cal/val
AQUA / TERRA	ASO, SARP, C-HARRIER	A90, ER-2; Twin Otter	208.5	California, Colorado	Cal/val
TEMPO	Lake Michigan Ozone Study; SARP	B-200; Sherpa	195.5	Lake Michigan; California	Precursor data sets
GPM	SNOWEX, EPOCH	P-3; Global Hawk	118.4	Colorado, Gulf of Mexico; Pacific	Algorithm Validation
GOES-R	GOES-R cal/val; Fly's Eye; GCAS	ER-2	111.8	CONUS	Cal/val; instrument test
CYGNSS	EPOCH	Global Hawk	85.9	Gulf of Mexico, Pacific	Cal/val
CALIPSO	CALIPSO-CATS Validation; SARP	ER-2; Sherpa	47.6	California	Instrument Validation; algorithm validation
CRYOSAT-2 / EnviSat	OIB, GLISTIN, Beaufort Sea UAVSAR	G-III, P-3, GV	47.2	Greenland, Alaska	Cal/val
AURA	SARP	Sherpa	45.3	California	Cal/val
GCOM W1	SNOWEX; Red River	P-3; G-III; U Alaska UAS	40.5	Colorado, North Dakota, Alaska	Cal/val
Suomi-NPP	C-HARRIER	Twin Otter	12.9	California	Radiation validation

TABLE 7 ***ASP support to Earth Science space missions, both on-orbit and in development, including those recommended by the National Academies Decadal Survey for Earth Science.***

once in orbit. In 2017, ASP provided support to Earth Science missions as listed in Table 7. This included significant flight hours for upcoming Decadal Survey missions, especially ICESat-2, which will launch in 2018. NI-SAR is also expected to launch in late 2018 or early 2019.

In 2017, some airborne process missions also collected data that will be valuable for future missions. Several process studies this year directly contributed to the ongoing validation of OCO-2 and Suomi-NPP through coincident in situ measurements of chemical species including CO_2. Flights of AVIRIS and MASTER provided new datasets for evaluating future applications of HyspIRI-like data for coastal resource mapping, volcanic morphology and emissions.

Support to Instrument Development

Another major element of the ASP program is the support of instrument development for Earth Science. Aircraft provide an important testbed for evaluating the performance of future spaceflight payloads in addition to enabling intercomparisons between different techniques. Some instruments are developed specifically for airborne utilization, while many are developed as precursors or simulators for satellite instruments. In 2017, 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 2018 and

Instrument	Sponsor	Aircraft	Flight Hours
Doppler Scatt	IIP	B-200	64.8
Signals of Opportunity Airborne Demonstrator	IIP	B-200	28.6
UWBRAD	IIP	DC-3	15.3
C-HARRIER	AITT	Twin Otter	12.9
SHOW	CSA	ER-2	11.6
CAFÉ	AITT	ER-2	7.3
WISM	IIP	Twin Otter	7.3
AVIRIS-ng	ESD	ER-2	6.9
Fly's Eye GLM Simulator	NOAA	ER-2	5.4
MISTIC Winds	IIP	ER-2	5.1
HyTES	AITT	ER-2	4.0
AirMOSS as an Ice Sounder	JPL	G-III	3.0
GEO-CAPE Airborne Simulator (GCAS)	GEO-CAPE	ER-2	2.9

TABLE 8 ***Instrument development flights in FY17.***

2019, as shown in the 5-year plan (Appendix B). Several other instruments, not part of the ESTO program, were demonstrated and matured in 2017. These include AirMOSS and GCAS.

AITT Progress

The AITT program is designed to provide opportunities for airborne instruments initiated under the ESTO IIP program to graduate to new aircraft platforms or mature into more comprehensive instrument payloads. 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 FY17, three instruments began their transition to more capable payloads or higher altitude aircraft, making them more useful for some types of missions.

Compact Airborne Formaldehyde Experiment (CAFÉ)

One project is the CAFÉ, with PI Thomas F. Hanisco of NASA Goddard Space Flight Center. The test flights of the CAFÉ were designed to demonstrate the capability of the new in situ formaldehyde instrument to operate at the low temperature and pressure environment in the ER-2 wing-pod at high altitude. The measurement of formaldehyde in the lower stratosphere will demonstrate the capability to measure the abundance of formaldehyde below 100 ppt using a new inlet. This is the first high-altitude in situ formaldehyde instrument. The test flights establish the capability to provide calibration and validation of current (Aura-OMI) and future (TEMPO, TropOMI, GEO-CAPE) satellite observations of formaldehyde.

These are test flights to demonstrate capability at altitudes between 14 and 20 km. The flight profiles needed are basic ascent-cruise-dive-cruise-descent patterns. The summer months are preferable to access the higher concentrations of formaldehyde found in the summer months. Otherwise, the flight requirements are flexible and can be met with shared (piggy-back) other instruments.

The instrument uses laser induced fluorescence to obtain the high detection sensitivity and fast time response needed for airborne measurements. The fluorescence technique uses a new non-resonant detection that takes advantage of compact industrial lasers to minimize size and power requirements and enhance ruggedness and reliability. The instrument is designed for autonomous operation in flight and requires minimal support between flights. An inlet mounted in the free stream is needed to sample ambient air. Recent aircraft campaigns include KORUS (2015), SARP (2017), and ATom (2017). The CAFÉ instrument can fly on pressurized or unpressurized aircraft. The instrument is shown in Figure 28.

Compact Airborne Formaldehyde Experiment

Size	8 U
Weight	27 kg
Power	< 600 W
Precision	50 pptv/s
Accuracy	10% +/-50 pptv
Data rate	1 s
Altitude	0 – 70+ kft

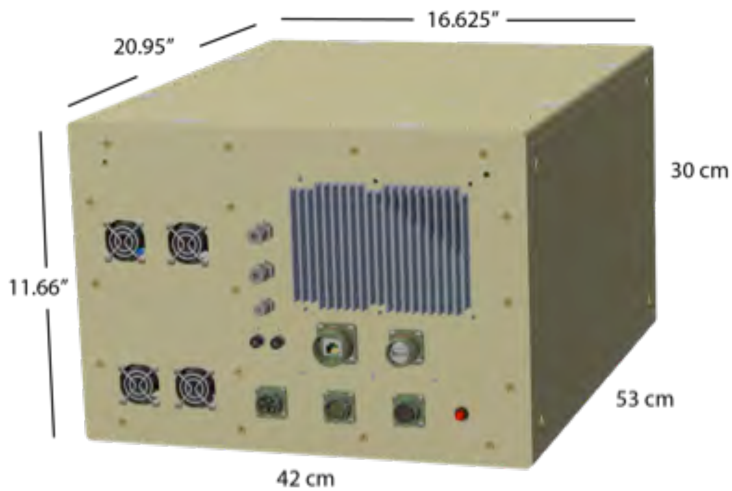


FIGURE 28 ***Compact Airborne Formaldehyde instrument.***

C-HARRIER

The C-HARRIER (Coastal High Acquisition Rate Radiometers for Innovative Environmental Research) team designed, developed, and tested a state of the art coastal and inland waters airborne calibration, validation, and research (CVR) system over coastal San Francisco and Monterey Bay Area waters and inland lakes. The radiometer instrument system is aligned with present and next-generation satellite bio-optical observations for coastal and ocean biology water quality research and utilizes advanced airborne microradiometer technology. The September 2017 airborne demonstration mission resulted in unprecedented bio-optical observations of the San Francisco Bay Delta, Monterey Bay, Pinto Lake, and Lake Tahoe relevant for water quality research of coastal ocean and inland waters, and associated ecosystems that will support new satellite-based algorithms and observations for NASA's Ocean Biology and Biogeochemistry research program in Earth Science.

The C-HARRIER team proposed to design and certify a multi-sensor system incorporating Biospherical Instruments (BSI) microradiometer instrumentation that was developed for NASA Ames (C-AIR) and NASA Goddard (C-AERO), and then integrate and test the system on an aircraft within the first four months of the two year project. Historically, instruments of this type have major limitations such as slow data rates and inadequate signal to noise with measurements saturating when encountering sunlight or sun glint over water. This compromised the use and integrity of the water bio-optical observation data. The BSI microradiometers have a high data rate (15 Hz) and ten decades of dynamic range. The team is well known by the community for their use of remote sensing in the coastal and ocean zones and has used their experience with other systems to drive requirements and specifications for the new system. The team took advantage of a prior Science Innovation Fund investment by ARC to not only add the design of the NASA Goddard Compact-Airborne Environmental Radiometers for Oceanography (C-AERO) to the airborne system, but also to enhance the spectral range (19 channels each spanning 320–1,640 nm) for C-AIR to match C-AERO. The integrated system is shown in Figure 29. The successful design, development and airborne testing through C-HARRIER establishes the path forward to next integrate the radiometer technology in a sun photometer configuration advancing a new state of the art system that will provide the marine and freshwater community a unique opportunity for coupled aquatics-atmospheric observations in coastal and inland waters.

The microradiometer system specifications are designed to match legacy and next-generation satellites used in existing algorithms to produce ocean color products and support water quality research. These products and algorithms are important in the assessment of phytoplankton (and harmful algal bloom) species composition, and shallow water community composition. The new system has unprecedented signal to noise and provides high fidelity optical property measurements at the land-ocean boundary, including radiometrically shallow aquatic ecosystems, across a heretofore rarely achieved spectral range (UV to SWIR). These attributes are critical for answering science questions in spectrally diverse coastal waters and supporting next generation coupled ocean-atmospheric satellite missions relevant to NASA's Carbon Cycle and Ecosystems Earth science focus area. Further, this airborne capability supports the Water and Energy Cycle, Climate Variability and Change, and Atmospheric Composition focus areas.

The team completed the system development and integration within schedule and budget and flew a full mission collecting a unique data set over the SF Bay Delta, Monterey Bay, Pinto Lake and Lake Tahoe. The flights provided proof-of-concept for the C-AIR/C-AERO system that will ultimately benefit future NASA aquatics airborne campaigns and cal/val of NASA airborne and satellite sensors. This success is a testament to the innovative design, teamwork and initiative of the team.

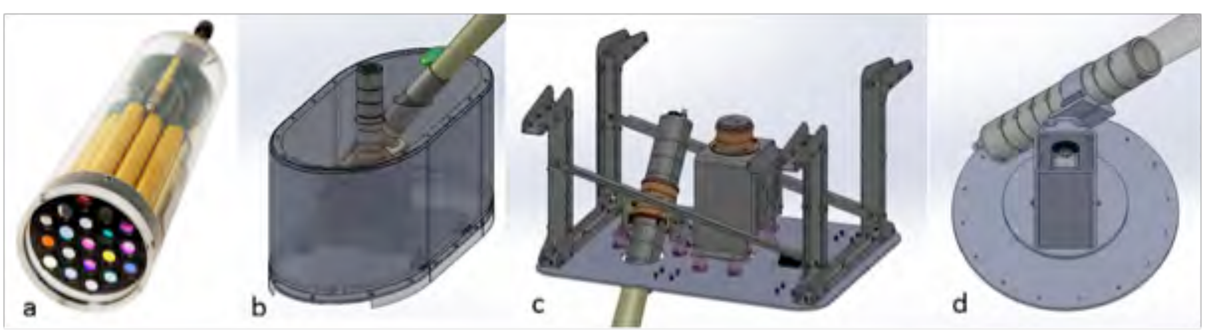


FIGURE 29 ***a) C-AIR or C-AERO radiometer (shown in a clear plastic housing for demonstration purposes), b) integration of C-AERO global irradiance and sky radiance in fairing mount, c) C-AERO total radiance and C-AIR nadir radiance in nadir port, and d) C-AIR sky radiance, or 3STAR, for sun tracking from the zenith port. 3STAR is C-AIR sky radiance in sun tracking installation.***

HyTES

The Hyperspectral Thermal Emission Spectrometer (HyTES) instrument had its first science flights on the Twin Otter in 2013 and since that time has been gradually improved to increase performance and reliability and has also been modified to enable it to fly on the ER-2 platform. Between the two platforms, HyTES can acquire data with pixel sizes from 1.5- to 34-meters, suitable for a wide variety of science studies. The low altitude data have been primarily used for trace gas retrievals of methane and ammonia and the data can be used to trace a gas plume back to its source. Flights have only just begun on the ER-2 high altitude platform and there are plans for a campaign to Hawaii in early 2018 to acquire data for volcano studies, in particular, measurements of SO2. The goal of the AITT task to enable HyTES to acquire thermal infrared measurements with a range of pixel sizes for scientific studies by utilizing both ER-2 platform and Twin Otter platforms has now been accomplished. An additional benefit of the ER-2 platform is that HyTES is able to fly together with PRISM, AVIRIS and MASTER enabling visible through thermal infrared spectroscopy studies.

During FY2017 all the hardware and software modifications required for operation on the ER-2 were completed. Modifications included a completely redesigned external enclosure, a new data system, fiber-optic data readout and a push-button operation capability for ER-2 use. A new operations concept involving removal of the scan-head from the plane between flights was also developed. Initial test flights in Dec 2016 and Jan 2017 revealed the need to further protect the instrument from the extremely low temperature environment of the ER-2 superpod aft-body. Heaters and additional insulation were added and a successful engineering flight was conducted on Oct 13, 2017. (See Figure 30.)

All modifications required to fly the new HyTES enclosure on the Twin Otter were completed in May 2017 and successful flights were made over gas-retrieval targets in June 2017.

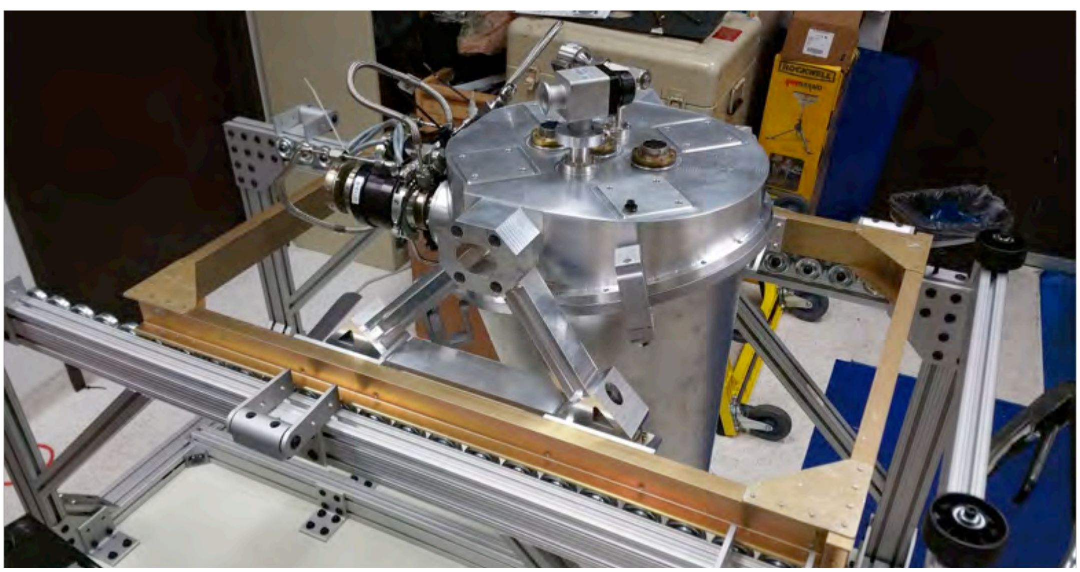


FIGURE 30 ***New HyTES enclosure mounted in ER-2 installation rail.***

2018 Upcoming Activities – Major missions

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

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 feedback into aerosol production, transport and removal.

The mission will deploy an instrumented P3-B 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 2018.

High Ice Water Concentration (HIWC) Radar - II (HIWC-II)

A second round of the HIWC mission is planned for 2018, to continue the success of that weather study.

Long Island Ozone Study

The Lake Mission Ozone Study, completed in 2017, provided important data for the study of air pollution from a major urban area (Chicago / Milwaukee). The 2018 Long Island study will similarly measure air pollution from the New York area.

Mission	Aircraft	Location
CAMP2EX	P-3	Philippines
HIWC-II	DC-8	Caribbean
Long Island Ozone Study	B-200	Long Island, NY
Operation IceBridge	P-3, DC-8	Antarctic, Arctic
HyspIRI HyTES Hawaii	ER-2	Hawaii
ATom-4	DC-8	Global
ACT-America	B-200, C-130	Midwest, South US
NAAMES	C-130	North Atlantic
OMG	C-20A, G-III	Greenland
ORACLES	P-3	Equatorial Atlantic, Sao Tome

TABLE 9 ***Major missions upcoming in 2018.***

Technology Demonstrations

A number of instruments under development, including Instrument Incubator Program (IIP) projects and AITT demonstrations are scheduled for test flight in 2018. These include the following:

- BlackSwift Technologies CCRPP (an L-band radiometer)
- SRI CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD)
- Airborne tropospheric ammonia instrument for satellite validation in FIRE-CHEM
- High Altitude Lidar Observatory (HALO)
- High Accuracy Vector Helium Magnetometer (HAVHM)
- Compact Adaptable Microwave Limb Sounder
- HAWC-OAWL Validation
- Doppler Scatt Improvements

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

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 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	6.0	1,800	12,500	32,000	275	1,800	https://airbornescience.nasa.gov/aircraft/B-200_King_Air_-_WFF
	C-130 (2)	NASA-WFF	12	36,500	155,000	33,000	290	3,000	https://airbornescience.nasa.gov/aircraft/C-130_Hercules
	C-23 Sherpa	NASA-WFF	6	7,000	27,100	20,000	190	1,000	http://airbornescience.nasa.gov/aircraft/C-23_Sherpa
	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
	Global Hawk	NASA-AFRC	30	1,900	25,600	65,000	345	11,000	http://airbornescience.nasa.gov/aircraft/Global_Hawk
	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 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
	Ikhana	NASA-ARFC	24	2,000	10,000	40,000	171	3,500	http://airbornescience.nasa.gov/aircraft/Ikhana
	S-3B Viking	NASA-GRC	6	12,000	52,500	40,000	350	2,300	http://airbornescience.nasa.gov/aircraft/S-3B
	SIERRA	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
	Viking-400 (4)	NASA-ARC	11	100	520	15,000	60	600	https://airbornescience.nasa.gov/aircraft/Viking-400
	WB-57 (3)	NASA-JSC	6.5	8,800	72,000	60,000+	410	2,500	http://airbornescience.nasa.gov/aircraft/WB-57

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." NASA catalog aircraft are also available for

TABLE 10 ***Airborne Science Program aircraft and their performance capabilities.***

science missions. 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 31; altitude/range in Figure 32.

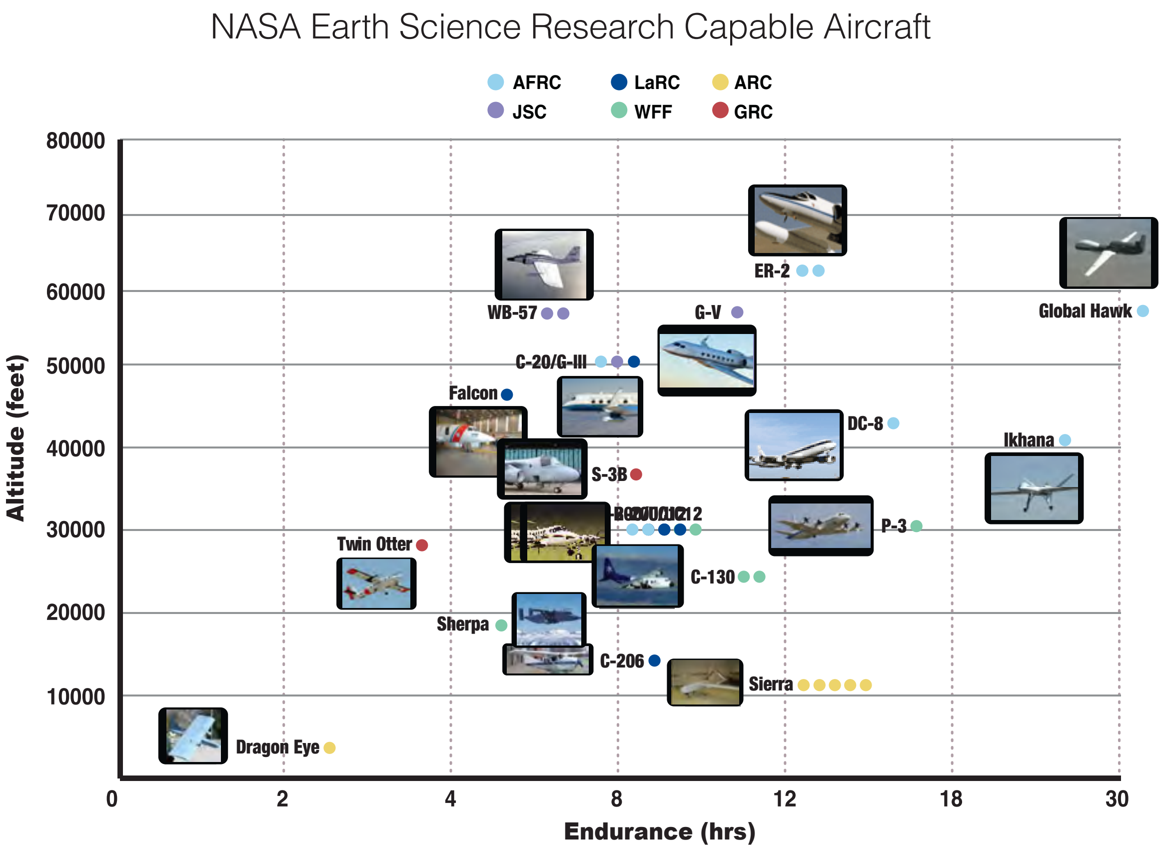


FIGURE 31 ***NASA Aircraft showing altitude and endurance capabilities.***

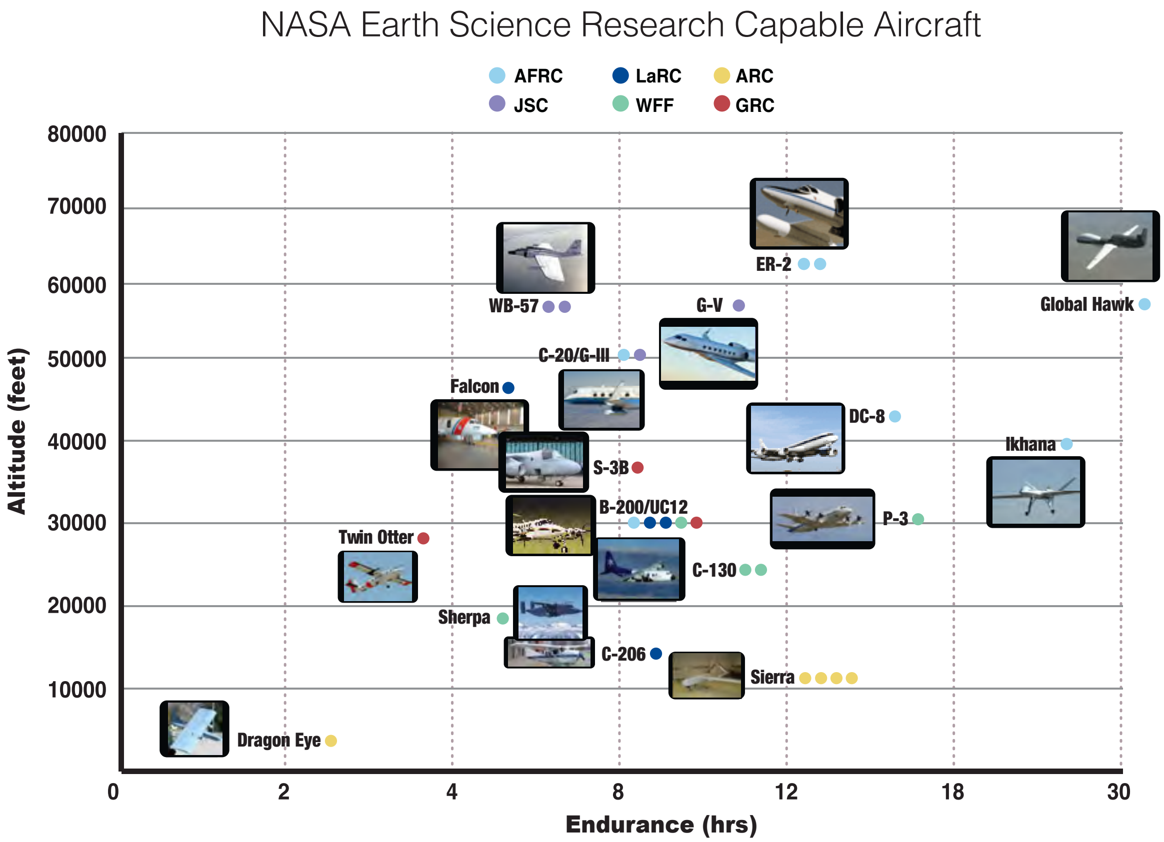


FIGURE 32 ***NASA Aircraft showing altitude and range capabilities.***

New Program Capabilities

Coming in 2018 are two new science-capable platforms: a G-V at JSC and a new G-III at LaRC.

ASP-Supported Aircraft

The five aircraft systems directly supported in 2017(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), and one Global Hawk unmanned aircraft system (UAS). Beginning in FY18, the JSC G-V is ASP-supported, and the Global Hawk is not.

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 nmi, a ceiling of 41,000 ft 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 FY17: 595.6

DC-8 FY17 Missions

Mission	Location	Science program area
ATom-2 and ATom-3	Global	Atmospheric Composition
CPEX	Ft. Lauderdate, FL	Weather
ATom-1	Global	Atmospheric Composition
OIB Antactica	Punta Arenas, Chile	Cryosphere
ASCENDS-17	Fairbanks, AK	Atmospheric Composition

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

DC-8 had no major modifications in FY17.

FIGURE 33 ***NASA DC-8 and CPEX science team on May 27, 2017, Fort Lauderdale, FL.***

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

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 FY17: 275.7

ER-2 FY17 Missions

Mission	Location	Science program area
ORACLES	Namibia, Africa	Atmospheric Composition
FEGS	Palmdale	Weather
CAFÉ	Palmdale	ESTO
MASTER	Palmdale	Carbon Cycle
HyTES AITT	Palmdale	ESTO
HyspIRI Tropics	Hawaii	Carbon Cycle
AVIRIS-NG	Palmdale	Carbon cycle
CA Methane Survey	Palmdale	Applied Science
GOES-R	Georgia	Weather
MiSTIC Winds	Palmdale	ESTO
HyspIRI CA	Palmdale	Carbon Cycle

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:
ER-2 809 is currently 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 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 FY18-19. Only one platform will be available during the consecutive period from June 2017 through August 2019.

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

FIGURE 34 ***NASA ER-2 Preparing for GOES-16 Cal/Val mission.***

P-3B Orion

OPERATING CENTER:
Wallops Flight Facility

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

SCIENCE FLIGHT HOURS IN FY17: 484.7

P-3 Orion FY17 Missions

Mission	Location	Science program area
ORACLES	Sao Tome, Africa	Atmospheric Composition
OIB-Arctic	Thule and Kangarlussauq, Greenland; Fairbanks, AK; Svalbard, Norway	Cryosphere

MODIFICATIONS MADE IN FY17 AND IMPACTS ON PERFORMANCE AND SCIENCE:
A modified wing pylon was created that extends two canister style mounted wing probes beyond the leading edge of the P-3 wing. This pylon can mount on any outboard wing station on the P-3. Three additional standard P-3 pylons were converted to science pylons with the addition of two canister mount locations on each pylon. Standard pylons can be mounted on any P-3 wing station location.

Two nadir #3 port plugs were designed and manufactured for the P-3. One plug contains one 16" diameter aperture along with three small apertures for camera installations or other small science instruments. The second plug contains one 16" diameter aperture.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
- 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)

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

FIGURE 35
The NASA P-3 aircraft on the ground in São Tomé. The Research Scanning Polarimeter (RSP) is located in the "bomb bay," in the fuselage just forward of the engines.

C20-A (Armstrong G-III)

OPERATING CENTER:
Armstrong Flight Research Center

AIRCRAFT DESCRIPTION:
TThe 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). The Armstrong aircraft is part of the ASP-supported fleet, whereas the JSC G-III program support ended with the completion of the AirMOSS mission.

SCIENCE FLIGHT HOURS IN FY17: C-20A: 362.0

C20-A (G-III) FY17 Missions

Mission	Location	Science program area
ABoVE	Canada / Alaska	Carbon cycle
Land-Sea Continuum	New Orleans	Earth Surface and Interior
Plate Boundary and Earthquake Faulting	California	Earth Surface and Interior
Hawaiian Tropospheric Variations	Hawaii	Atmospheric Composition
Sacramento Delta Levees Imaging	California	Earth Surface and Interior / Applied Science
Imaging near-fault Deformation	California	Earth Surface and Interior
Programmable Autopilot	California	Aeronautics
UAVSAR L-Band Engineering / SnowEX	California	Water and Energy cycle
Environmental Controls on Landslide Motion	California / Colorado	Earth Surface and Interior
NISAR Snow Hydrology Application Development	Colorado	Water and Energy cycle
NISAR Repeat Observations (12 days)	Colorado	Earth Surface and Interior
Sacramento Delta and California Aqueduct Imaging	California	Earth Surface and Interior
Hurricane Harvey Disaster Relief	Austin, Texas	Applied Science

MODIFICATIONS MADE TO THE C20-A AIRCRAFT IN FY17: None

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

FIGURE 36 ***During ABoVE, the Alaska Satellite Facility User Working Group visited the UAVSAR plane (C-20A) and crew.***

Global Hawk

OPERATING CENTER:
Armstrong Flight Research Center

AIRCRAFT DESCRIPTION:
The Global Hawk is a high-altitude long-endurance Unmanned Aircraft System. With capability to fly more than 24 hours at altitudes up to 65,000 ft, the Global Hawk is ideal for long duration science missions. NASA's Global Hawk can be operated from AFRC, WFF or Marine Base Kaneohe Bay, Hawaii.

SCIENCE FLIGHT HOURS IN FY17: 81.1

Global Hawk FY17 Missions

Mission	Location	Science program area
HOPE EPOCH	Flights out of EAFB to Pacific, Gulf of Mexico, & Atlantic regions	Weather

MODIFICATIONS MADE IN FY17 AND IMPACTS ON PERFORMANCE AND SCIENCE:

- INMARSAT command and control system upgraded due to decommissioning of previous satellite system. This upgrade was required to keep the aircraft operational.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS: None in FY18

WEBSITE: *airbornescience.nasa.gov/aircraft/Global_Hawk*

FIGURE 37 ***Global Hawk in Hawaii, its most recent deployment base.***

New JSC G-V Aircraft (N95NA)

JSC has been working in earnest to modify the newly acquired G-V to be capable of supporting airborne science missions. During FY17, JSC completed the following.

i. GPS and Iridium antenna installations (7 total). These installations provide all necessary RF interfaces for payloads, allowing a polar (Iridium only, aft GPS antenna) or non-polar (Inmarsat, forward GPS antenna) configuration to minimize aircraft interference in either case. Additionally, the GPS antennas feature GLONASS band coverage and front end filtering to further reduce the effects of L-band interference generated by the aircraft.

ii. Power system modifications required to support power/control racks and experimenter racks. Includes provisions to use full aircraft generating capacity, including in-flight use of Auxiliary Power Unit (APU). Easy integration of additional non-standard power formats has been made practical with high current interfaces throughout the cabin.

iii. Network modifications required to support power/control racks and experimenter racks
1. Fiber optic and copper network cable installations. Allows first cabin-wide 10 Gigabit network within the NASA ASP.
2. GPS provisions for positioning and time synchronization, including Precision Time Protocol (PTP V2/IEEE 1588-2008)
3. NASDAT and Iridium phone provisions (antenna cabling, network and ARINC 429).

iv. Cockpit kill switch installation to allow safe deactivation of payload systems in the event of an emergency.

v. Forward lavatory and vacuum drain removal. This allows easy rack installation and removal and removes one obstacle for the future installation of nadir optical viewports.

FIGURE 38 ***G-V sircraft at JSC.***

New LaRC G-III Aircraft

LaRC has acquired three surplus USAF C-20B G-III aircraft; one aircraft will be prepared for science research. This aircraft will allow science instruments to be flown further, higher, faster and longer than is now possible with the existing HU-25A and King Air aircraft.

Plans for the G-III include:

- Complete NASA acceptance inspection in 1QFY18
- Install engine hush kits in 2QFY18
- Install pair of nadir portals during FY18 along with research power distribution system. Goal is to have the aircraft operational in Fall 2018.

Other NASA Earth Science Aircraft

Other NASA aircraft, as listed here, on the Airborne Science 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
C-23 Sherpa	WFF
HU-25A Falcon / HU-25C Guardian	LaRC
G-III	JSC
G-V	JSC
Dragon Eye UAS	ARC
Ikhana UAS	AFRC
SIERRA UAS	ARC
Twin Otter	GRC, also can be contracted through JPL
Viking-400 UAS	ARC
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. They are currently dedicated to the EVS-2 missions NAAMES and ACT-America. After those missions, a business case will need to be developed to keep them.

SCIENCE FLIGHT HOURS IN FY17: 225.7

C-130 FY17 Missions

Mission	Location	Science program area
NAAMES	St. John's, Newfoundland, Canada	Carbon Cycle
ACT-America	Wallops Island, VA; Lincoln, NE; Shreveport, LA	Atmospheric Composition

MODIFICATIONS MADE IN FY17 AND IMPACTS ON PERFORMANCE AND SCIENCE: None

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

- N439 & N436: 6-8 week annual maintenance period each year that can be adjusted to meet mission needs.
- A Phased Depot Maintenance (PDM) is required for N439NA after June 30, 2018 requiring 4-6 months to complete. A PDM extension inspection is required for N436NA 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 39 ***Inside the C-130 cargo area during NAAMES. Wires, conduits and specialized hardware take up nearly every inch of the cabin area.***

JSC G-III

OPERATING CENTER: **Johnson Space Center**

AIRCRAFT DESCRIPTION:

The G-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 various versions of JPL's UAVSAR instrument. The JSC G-III had opportunities to carry each SAR version at times during 2016.

SCIENCE FLIGHT HOURS IN FY17: 376.9

JSC G-III FY17 Missions

Mission	Location	Science program area
ABoVE	Canada, Alaska	Carbon Cycle
Taylor Oil Spill	Gulf of Mexico	Earth Surface and Interior
Sierra Nevada	California	Water and Energy Cycle
Red River Mapping	North Dakota	Water and Energy Cycle
Coastal Storm Modeling	California	Earth Surface and Interior
SnowEx	Colorado	Water and Energy Cycle
OMG	Greenland, Iceland	Cryosphere
SacDelta	California	Earth Surface and Interior
Landslide Mapping	California	Earth Surface and Interior
Volcano Topography	Hawaii	Earth Surface and Interior
OIB Sea Ice	Greenland	Cryosphere
Ice Sounder Experiment	California	Applied Science

MODIFICATIONS MADE TO THE JSC G-III AIRCRAFT IN FY16 AND IMPACTS ON PERFORMANCE AND SCIENCE:

JSC completed two major maintenance/overhaul activities on the G-III in FY17. First, the aircraft spent the month of January 2017 in Longview, TX at Aerosmith Aviation and received a complete new coat of paint. The paint job on the aircraft was overdue, and the new paint job is instrumental in preventing structural corrosion and damage to maintain the long term health of the aircraft.

JSC completed an in-house design and aircraft modification to meet upcoming, stringent federal and international requirements to upgrade navigation and communication avionics on the aircraft. Even though the requirements are not fully in effect until 2020, JSC completed the modification early to provide more straightforward flight planning with ATC for science missions in and around Greenland.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE JSC G-III:

The right engine on the G-III times out in August of 2018 and must be replaced. JSC is currently working a procurement to purchase a "parts aircraft" that would be used to supply engines for the G-III. The left engine will need to be replaced in the 2020/2021 timeframe, depending on flight hours flown.

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

FIGURE 40 ***JSC G-3 with GLISTIN-A radar, landing at Thule Air Base, Greenland during OMG.***

B-200 / UC-12

OPERATING CENTERS:

NASA LaRC, AFRC, and WFF operate both a conventional B-200 and a UC-12 (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 ft) with up to 1000 pounds of payload for up to 6 hours. Three NASA centers operate B-200 aircraft with varying modifications for science.

SCIENCE FLIGHT HOURS IN FY17: 309.9

B-200 Missions in FY17

Mission	Location	Science program area
ACT-America	NASA Langley; Lincoln, NE; Shreveport, LA	Atmospheric Composition
Lake Michigan Ozone Study (LMOS)	Madison, WI	Atmospheric Composition
Signals of Opportunity	Lawton/Ft. Sill, OK	ESTO IIP
SARP	Palmdale	Atmospheric Composition
ABoVE	Alaska	Water and Energy Cycle
AirSWOT	North Dakota	Water and Energy Cycle

MODIFICATIONS MADE IN FY17 AND IMPACTS ON PERFORMANCE AND SCIENCE: None

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

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE JSC B-200:

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.

FIGURE 41 ***The ACT-America deployment team in Shreveport, Louisiana, with both the B-200 and C-130 aircraft during the 2017 Fall campaign.***

C-23 Sherpa

OPERATING CENTER:
Wallops Flight Facility

AIRCRAFT DESCRIPTION:
TThe C-23 Sherpa is a two-engine turboprop aircraft designed to operate efficiently under the most arduous conditions, in a wide range of mission configurations. The C-23 is a self-sufficient aircraft that can operate from short field civilian and military airports in support of scientific studies.

SCIENCE FLIGHT HOURS IN FY17: 94.8

Sherpa FY17 Missions

Mission	Location	Science program area
CARAFE	Wallops Island, VA	Atmospheric composition
SARP	Palmdale, CA	Atmospheric composition
OWLETS	Wallops Island, VA	Atmospheric composition

MODIFICATIONS MADE IN FY17 AND IMPACTS ON PERFORMANCE AND SCIENCE:
A C-23 cabin window was structurally strengthened to support air sampling probes and other window mounted installations.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
- *4-6 week annual maintenance period each year that can be adjusted to meet mission needs (this includes A-D checks as needed).*

WEBSITE: *airbornescience.nasa.gov/aircraft/C-23_Sherpa*

FIGURE 42 ***NASA's C-23 Sherpa participated in SARP in 2017.***

HU-25A Guardian

OPERATING CENTER:

Langley Research Center

AIRCRAFT DESCRIPTION:

TThe 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 was transferred from flyable storage to active status for the OIB activities in 2016 and 2017.

SCIENCE FLIGHT HOURS IN FY17: 35.8

HU-25A FY17 Missions

Mission	Location	Science program area
OIB Greenland	Thule & Kangerlussuaq, Greenland	Cryosphere

MODIFICATIONS MADE IN FY17 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 43 ***HU-25A participated in OIB in FY17.***

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 8800 pounds of payload. JSC maintains three WB-57 aircraft.

SCIENCE FLIGHT HOURS IN FY17: 90.3

WB-57 FY17 Missions

Mission	Location	Science program area
POSIDON	Ellington Field, TX; Guam	Atmospheric Composition
Solar Eclipse	Ellington Field, TX	SMD Heliophysics

MODIFICATIONS MADE IN FY17 AND IMPACTS ON PERFORMANCE AND SCIENCE:
SEO monitors were upgraded to high definition on all three aircraft. This improves the visual displays for the pilots.

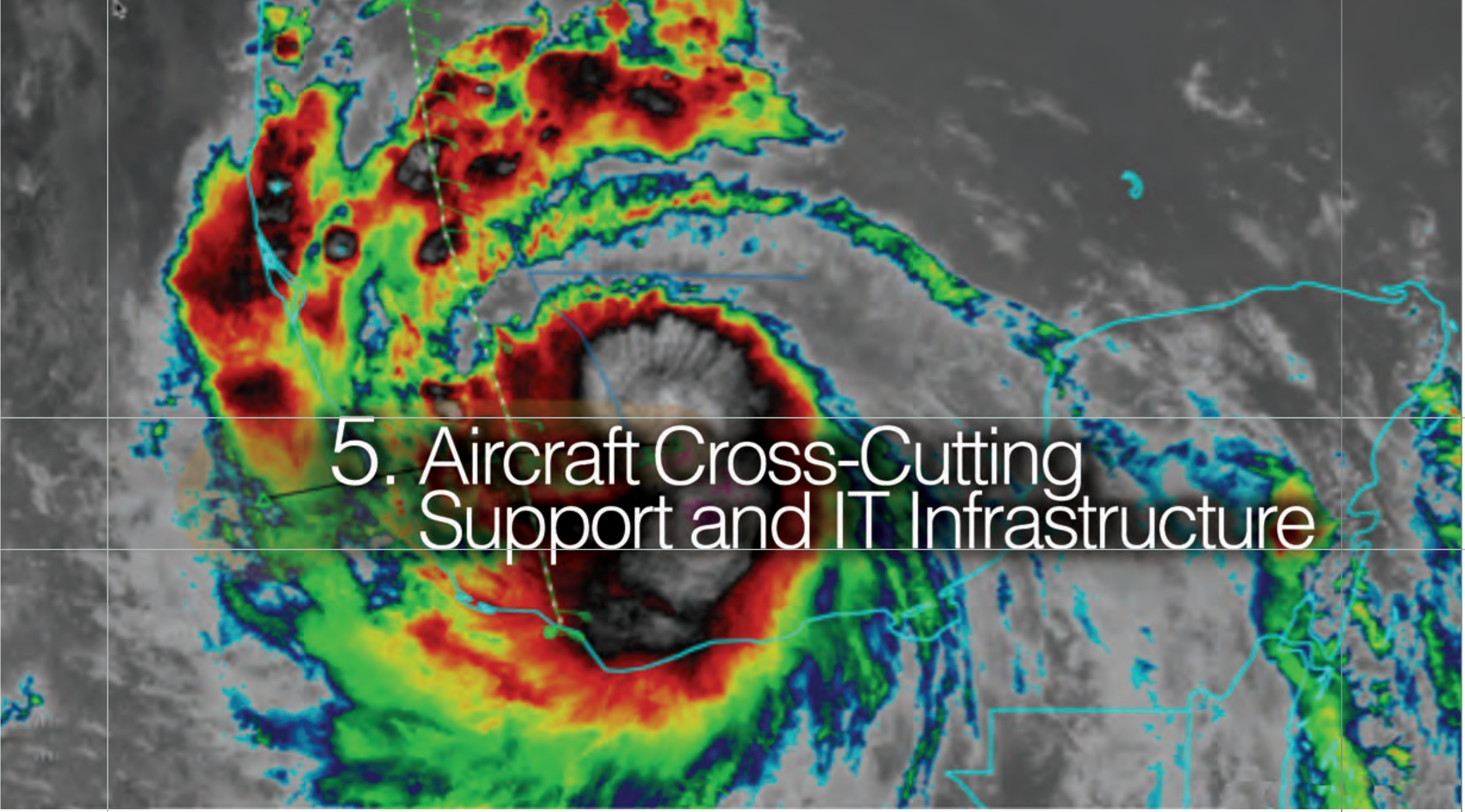
SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
N926:
- Minor phase inspection planned 3/20/19 – 5/15/19
- Major phase inspection planned 3/20/20 – 7/20/20
- Minor phase inspection planned 6/20/21 – 8/20/21

N927:
- Major phase inspection planned 8/29/18 – 12/20/18
- Minor phase inspection planned 12/20/19 – 3/20/19
- Major phase inspection planned 3/20/20 – 7/20/20

N928:
- Minor phase inspection planned 7/01/19 – 9/01/19
- Major phase inspection planned 9/01/20 – 1/20/21
- Minor phase inspection planned 1/20/22 – 3/20/22

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

FIGURE 44 *WB-57 flew POSIDON in FY17.*



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.

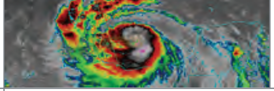
Cross-cutting support for ASP missions is managed at ARC and is supported by the University of California Santa Cruz Airborne Sensor Facility (ASF) and the National Suborbital Research Center (NSRC). Specific activities include providing facility instruments, satellite telemetry and mission tools data 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&D) 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**
DCS (Digital Camera System)* 16 MP color infrared cameras	DC-8, ER-2, Twin Otter, WB-57, B200	Airborne Sensor Facility / ARC
DMS (Digital Mapping System) 21 MP natural color cameras	All ASP Platforms	Airborne Sensor Facility / ARC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/ precision IMU	All ASP Platforms	3 at Airborne Sensor Facility / ARC
POS AV 610 (2) Applanix Position and Orientation Systems	All ASP Platforms	2 at Airborne Sensor Facility / ARC 2 at WFF
DGPS w/ precision IMU 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
Radar Altimeter	DC-8, P-3, C-130	NSRC
Forward and Nadir 4K Video Systems	DC-8, P-3, C-130	NSRC
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	Airborne Sensor Facility / ARC
Enhanced MAS (MODIS Airborne Simulator) 38 ch multispectral scanner	ER-2	Airborne Sensor Facility / ARC
PICARD (Pushbroom Imager for Cloud and Aerosol R&D) 400 – 2450nm range, DL 10nm	ER-2	Airborne Sensor Facility / ARC
AVIRIS-ng Imaging Spectrometer (380 - 2510nm range, DI 5nm)	Twin Otter, B-200	JPL
PRISM (Portable Remote Imaging SpectroMeter) (350 - 1050nm range, DI 3.5nm)	Twin Otter, ER-2	JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, DI 10nm)	ER-2, Twin Otter	JPL
UAVSAR Polarimetric L-band synthetic aperture radar, capable of Differential interferometry	G-3/C-20A, Global Hawk	JPL
NAST-I Infrared imaging interferometer (3.5 – 16mm range)	ER-2	LaRC

TABLE 11 ***Facility Equipment. *DSC not supported by ASP beginning in FY18.***

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; and an airborne network server and satellite communications gateway known as the NASA Airborne Science Data and Telemetry (NASDAT) system.

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, & 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

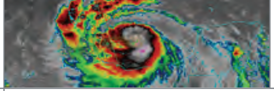
Several types of airborne satellite communications systems are currently operational on the core science platforms as listed in Table 12. High bandwidth Ku- and Ka-Band systems, which use large steerable dish antennas, are installed on the Global Hawk and Ikhana UAS, and the WB-57. Inmarsat Broadband Global Area Network (BGAN) multi-channel systems, using electronically-steered flat panel antennas, are available on many of the core aircraft. Data-enabled Iridium satellite phone modems are also in use on most of the science platforms as well. Although Iridium has a relatively low data rate, unlike the larger systems, it operates at high polar latitudes and is lightweight and inexpensive to operate.

Payload Management

The Airborne Science Program 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 Ames Research Center and Palmdale.

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, DFRC B200, ER-2	NSRC/Airborne Sensor Facility
Iridium (1 – 4 channel systems) / 2.8 Kb/sec per channel	All ASP Platforms	Airborne Sensor Facility, NSRC

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



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 provided information 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-3B, and C-130 aircraft. A high speed data network (both wired and wireless) is maintained on each of the aircraft so on board investigators have access to display data available on the aircraft. Video, aircraft state parameters, and permanent facility instrument data are recorded, quality controlled, and posted on the science mission and ASP data archives. Satcom services are provided with multichannel Iridium and high bandwidth INMARSAT services. These services allow for real time chat with scientists on the ground and other aircraft. NSRC engineers also work with investigators to send appropriate data up to and down from the aircraft to allow for real time situational awareness to scientists on the ground and in flight.

Along with general payload engineering services, the ASF designs and builds custom flight hardware for the ASP real-time Sensor Network, 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 (MPCS). Together with NSRC, they also support payload IT operations on the Global Hawks, as well as other aircraft equipped with payload satcom systems. The ASF personnel also support the ER-2 program, providing payload integration support as required.

Mission Tool Suite

MTS is ASP's decisional support and situational awareness system used to assist with the execution of airborne missions. The primary objectives of the MST 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.

The MST has continued to improve the infrastructure and tools to support the ASP's cross-cutting infrastructure capabilities. Once again, the MTS team has been privileged to support numerous missions this year. From these experiences we continue to grow and evolve our Program's cross-cutting capabilities to better support the next iteration of program customers.

Complementing mission support activities, the MTS team has rolled out a number of enhancements and new capabilities in the past several months to meet the operational needs of different campaigns. Here are some highlights:

A track reporting tool was released to simply the downloading of tracks for asset's monitored by MTS. The tool is available at the following URL: https://mts.nasa.gov/report-service. The reporting tool simplifies downloading and visualizing a large number of tracks to be used for program and other reporting requirements.

The MTS team has developed an assortment of 3D models that can be used for program visualization and analysis activities. The models include the ASP core platform aircraft, and will soon include other commonly used program assets. Contact the MTS team if you are interested

FIGURE 45 ***3D-Models of the NASA Airborne Science Program aircraft available in a variety of formats to support mission visualizations and analysis.***

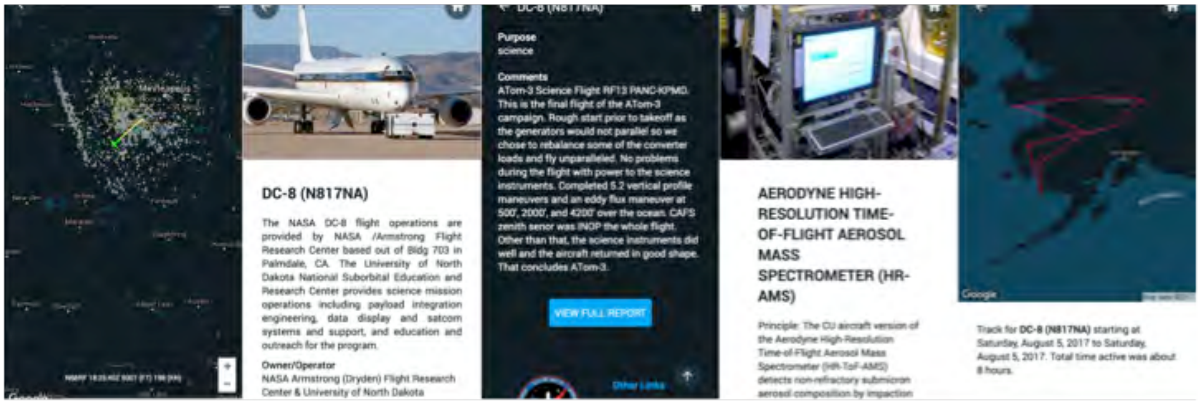


FIGURE 46 ***The Airborne Science Program Asset Tracker.***

in using a model and we can export the model to a desired format.

2017 marked the completion of our FAA System Wide Information Management (SWIM) integration work. Much of the data provided via SWIM will serve as the backbone for a suite of automated services that will be available to MTS users. The FAA's SWIM provides business services that have broad applicability for airborne science projects operating in the airspace.

The asset tracker (Figure 46) was rewritten from the ground-up to accommodate a variety of devices and form factors. The asset tracker can be used to quickly obtain an asset's status, details, schedule, including recent flight reports and tracks. The tracker is often the general public's first view into program activities, and attempts to connect a user not only to the program's aircraft, but also the instrumentation that drives the science.

Behind the scenes, the MTS team has been working on what will be the next generation monitoring and situational awareness system for the ASP. While the system has been enhanced over the past several years, the web technology space has vastly changed, and in turn, so has our ability to deliver many new capabilities that are currently in work. In addition to vastly improved tooling, collaboration will be a major focus of the next MTS release. It is evident that improved distributed situational awareness is key for many MTS customers.

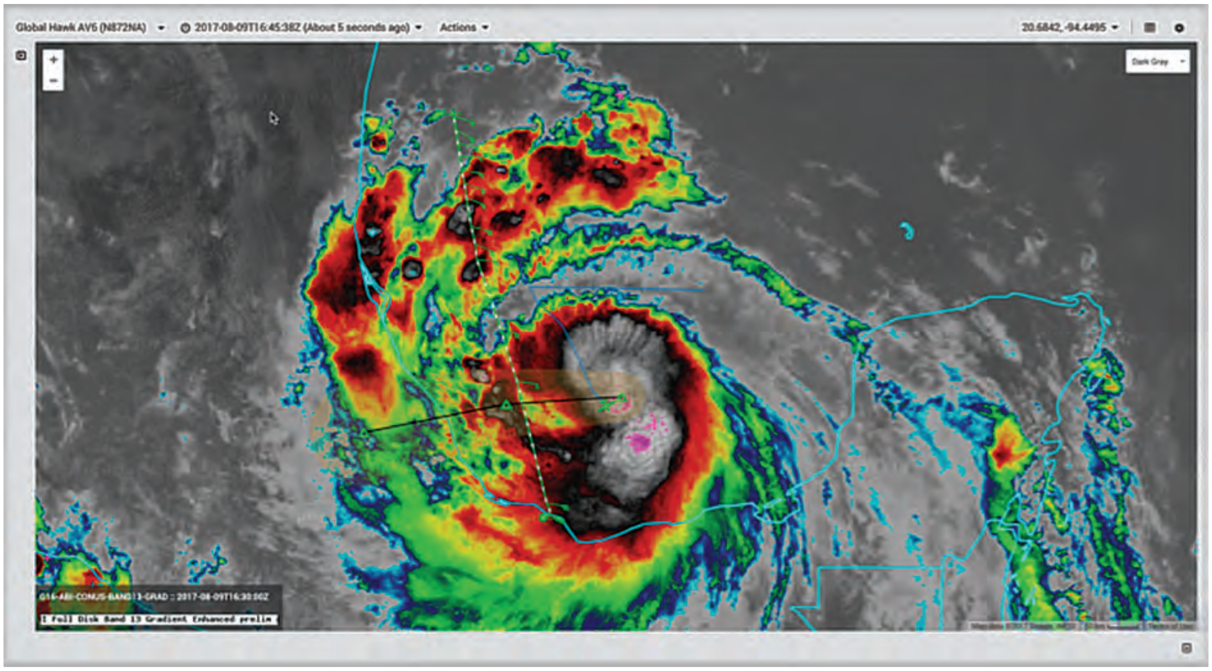


FIGURE 47 ***Screenshot from MTS showing experimental GOES-16 product used during the HOPE-EPOCH mission.***

6. Advanced Planning

6. Advanced Planning

The Airborne Science Program 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 meeting 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-yr schedule update, and through ongoing discussions with Mission and Program managers and scientists. Strategic planning in the program 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. However, ASP also supports existing space missions (e.g., A-Train satellites), as well as recently launched "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 International Space Station, several small sats, and collaborations with ESA and other space agencies are upcoming. Several airborne experiments are already supporting these activities. Furthermore, the next NRC Decadal Survey for Earth Science is expected in 2018 and new airborne support missions are anticipated, based on preliminary white papers prepared by the science community.

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

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

Participation in science team meetings and program reviews in 2017 to describe ASP capabilities and collect requirements information are listed in Table 13.

5-yr plan

A five-year plan is also maintained by the Program for out-year planning and scheduling. A graphical copy is shown in Appendix B, 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 December 2016 ABoVE Airborne Planning meeting
Participation in 2017 PARCA / OIB workshop
Participation in 2017 ATRAIN Symposium
Participation in 2017 IGARSS conference
Participation in 2017 ESTO Forum
Participation in 2016, 2017 AGU Fall meeting

TABLE 13 ***FY17 activities to support ASP requirements information gathering.***

7. Education and Outreach

Student Airborne Research Program 2017

The ninth annual NASA Student Airborne Research Program (SARP) took place June 12 through August 5, 2017, at the NASA AFRC and the University of California, Irvine. SARP provides a unique opportunity for undergraduate students majoring in science, mathematics or engineering fields to participate in a NASA airborne science research campaign. The 32 SARP 2017 participants came from 32 different colleges and universities in 23 states (Figure 48). 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 C-23 Sherpa, 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 Sherpa aircraft overflew dairies, oil fields and crops in the San Joaquin Valley in addition to parts of Los Angeles at altitudes as low as 1,000 feet to collect data.

Twelve students also flew on the NASA LaRC UC-12B King-Air. The King-Air flew much higher at 28,000 feet to remotely sense atmospheric gases. In addition, students used ocean and land remote sensing data collected for them over Santa Barbara by the NASA ER-2. 2017 was the first time that three aircraft were airborne simultaneously collecting data for SARP as well as the first time that the Sherpa and King Air flew as part of the program. In addition to airborne data collection, students also took measurements at field sites near Santa Barbara and at Joshua Tree and Sequoia National parks. The final six weeks of the program took place at the University of California Irvine where students analyzed and interpreted data col-

Student Airborne Research Program Class of 2017

Augustana College
Barnard College
Brown University
California Polytechnic State University
Colorado College
George Mason University
Hendrix College
Knox College
Mississippi State University
North Central College
North Park University
Northern Arizona University
Pennsylvania State University
Prairie View A&M University
Rice University
Saint Mary's College/University of Notre Dame
Smith College
Temple University
The College of Idaho
Towson University
Tufts University
University of Alaska, Fairbanks
University of California Davis
University of Houston
University of Maryland, Baltimore County
University of New Mexico
University of North Carolina at Charlotte
University of North Florida
University of Rochester
University of South Carolina
University of Utah

FIGURE 48 ***Map showing locations of the 2017 SARP students' colleges and universities.***

FIGURE 49 ***The SARP 2017 student participants, graduate student mentors, faculty advisors and pilots posed for a photo in front of the NASA Armstrong Hangar on Thursday, June 22, 2017, in Palmdale, CA.***

lected 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 aircraft and satellite missions. Nine students presented first-author conference posters or papers on the results of their SARP research at the American Geophysical Union Fall Meeting in New Orleans in December.

FIGURE 50 ***On June 26, 2017, the NASA ER-2, UC-12B King Air, and C-23 Sherpa were all airborne at the same time collecting data for SARP in Southern California.***

Appendices

Appendix A:

Historical Perspective: George Postell

Introduction

George Postell worked for NASA's Wallops Aircraft Office from 1988 until his retirement as Aircraft Office Chief in 2011. He was interviewed for this article during the 2016 Fall AGU meeting.

George Postell Interview

Jim Webber: I am here with the usual cast of characters: Matt Fladeland, Randy Albertson, and Susan Schoenung. We're interviewing George Postell today. George worked at the NASA Wallops Aircraft Office from 1988 until his retirement in 2011. So just like we normally do, we'll try to get started by asking what you did before you came to NASA, how you got into NASA. And then talk about some of the key people you worked with and key events that took place.

George Postell: The Wallops Flight Operations has been around since 1969. I showed up in 1988, nineteen years into its history. Upon my arrival, the Aircraft Operation was very healthy, supporting a diverse customer base among several NASA Centers. We were flying the NP-3 Orion, L-188 Electra, SC-7 Sky Van, T-39 Sabre liner, and a UH-1 Huey. These aircraft were flying range support and Airborne Science. In addition, we were flying a B-200 Super King Air in a Mission Management role, supporting Goddard and Headquarters flying NASA managers to various locations in the eastern half of the U.S. My tenure amounted to over half of the organizations 42-year history when I retired. I was a Naval Aviator, like most other pilots before me, former P-3 pilots, since the P-3 was then and remains our busiest aircraft. The Aircraft Operation was started by the then Director of the Wallops Flight Facility, Dr. Robert Krieger. He assigned retired Navy Captain Don Feller to head up the operation. His right hand man, Curt Allen, was also a retired Navy pilot. After Don Feller left, the lone Air Force (F-86) pilot, Dave Roberts, snuck in from NASA HQ to be in charge. Dave Roberts was running the program when I was hired by John Riley and Curt Allen. By the time I arrived in 1988, the organization had morphed from exclusively range support, which was mostly radar surveillance, telemetry, and mid air payload recovery services, to supporting other launch ranges, including the Air Force Test Range that controlled launch operations from Kennedy Space Center, and a variety of Airborne Science programs. The operation was pretty much underwritten by the range, though support had begun to shift to airborne science. At that time, the shift away from Range Support towards Airborne Science was well under way. We were supporting a diverse customer base that included scientists at Wallops, Langley, Goddard, and anyone else whose instrument needed a ride on the aircraft. The ER-2 would visit on a regular basis to Wallops during those years, and to a lessor extent, a WB-57 out of Johnson Space Center.

There was a lot of history in this group, for example Curt Allen flew the president of South Korea out of Seoul, Korea when the North Koreans invaded South Korea in 1950. Other key managers during my time were two non-pilots in charge, Roger Navarro, and Ed Melson. Then John Riley took over. Upon his retirement in 2001, I was selected as the Office Chief, where I remained for about 10 years until my retirement. Here's some history from the early days of the Airborne Science side. It began with Joe McGoogan. Joe set up the first Airborne Science program at Wallops in the mid-70s. He hired a scientist named Arnold Torres who eventually succeeded Joe as the Wallops Director. Arnold was a scientist and flew on the Wallops aircraft earlier in his career. He was the selection official, who was supported by Cheryl Yuhas, which resulted in my hiring as Chief years later. After Dr. Torres, came Dr. John Campbell, who led Wallops until the current Director, William Wrobel relieved him. I came in at the end of what I call the early days, and rode out the "dark years" wherein we almost ceased flight operations, and stayed around for the beginning of the recent resurgence.

Randy Albertson: I remember Torres' name…

George Postell: Probably because Arnold became the Director at Wallops. The aircraft were brought to Wallops to support the rocket range, and with the excess capacity, we started to do remote sensing, primarily with cameras in the beginning. Over the years, our sideline job flying Airborne Science became in time our only job. At that time the sounding rocket program and balloon program were much larger activities at Wallops.

But back to how I came to join the NASA Wallops Flight Facility.

Randy Albertson: So you were telling us about some of the guys who hired you and some people who came in with changes of administration, things like that. You mentioned a couple of names of people that you'd worked for or with.

George Postell: I came to the program in the usual way, being recruited from a U.S. Navy Reserve P-3 squadron, VP-66, as was also the case with John Riley. Then as now, we were a P-3 centric operation. At that time our workhorse aircraft included NASA 428, the NP-3. This aircraft was half Electra and half P-3, and was the proof-of-concept aircraft Lockheed proposed to be the follow on to the Navy P-2 Neptune aircraft. We mounted a large surveillance radar under the bomb bay and flew range support, and also science depending on the science needs at the time. We got the aircraft from Johnson Space Center, who was doing Earth Science on it as well. So I was hired into the program to fly and train crews on the NP-3, as I had 11 years active duty on the P-3 when hired. My fondest memories were working with a terrific team of NASA and contract professionals. On the science side, we were generally known as the Wallops Airborne Science Program, which was created by then Director of the Wallops Flight Facility, Joe McGoogan. Most of your readers may not know, until 1986, Wallops was a stand-alone Flight Center, pretty much exclusively supporting the sounding rocket launch operations. Early aircraft support services were obtained using a Lockheed contract. Contractors were flown on Lockheed Constellations out of New York to provide the rocket launch support services. Joe decided to provide the surveillance activities in-house. About the same time, Joe also created an Earth Science group at Wallops. Early key players included Frank Hogue and Bob Swift who flew the Airborne Oceanic Lidar (AOL) on the NP-3. I remember piloting a month long mission between the U.S. coast, the Azores, Ireland, Iceland, and back to the U.S. coast, all at 500 feet above the water! Meanwhile, the rocket launch support also included a mid-air payload recovery capability, first done by the Shorts SC-7 aircraft. Its replacement aircraft was a C-130, which gave us a higher weight payload recovery capability than that of the much smaller SC-7. Though the mid-air recovery capability was put on hold, the Shuttle Microwave Scattered Beam Landing system, which had flown on our P-3, went to the C-130. This aircraft was much more suitable with its large ramp door, as opposed to uploading everything through the P-3 27-inch wide door, which remains a limitation of the P-3. The C-130 also supported several Airborne Science program missions as a cargo hauler, and instrument platform.

When I came to NASA, each aircraft operation acted independently from one another. Each center worked its own flight requests, charging rates, and stand-alone activities within the center. Synergy became the concept of the day. For example, we flew passengers in the Mission Management role, funded by Goddard and Langley. This provided the pilots with invaluable instrument currency (pilot proficiency hours), to support flying the larger science aircraft. The other aircraft were underwritten by the rocket program, which allowed us to support all sorts of customers. We were also able to include some support of the private sector, which we could do with our unique instruments, charging those customers direct costs only. The key to efficiency in any aircraft operation is full utilization of the aircraft. For example, the C-130 would support the range with surveillance, the Shuttle Program calibrating the STS landings systems in Europe

Pacific Exploratory Mission (PEM) -Tropics A, August-September 1996.

Africa, White Sands and Dryden, Earth Science by flying science payloads, and providing cargo support for missions such as PEM Tropics, all in the same year or two. PEM Tropics was one of my favorite missions. The team is shown in the photo below. Some of the participants were Jim Hoell (PI), Doug Davis, D.J.Jacob, M. O. Rodgers, R.E. Newell, H.E. Fuelberg, R.J.McNeal, J.L. Raper, R.J. Bendura, and David Pierce (Wallops Mission Manager).

At that time, we had little if any interaction with the Headquarters Airborne Science Program, which we called Code Y. We supported the Airborne Science Branch at Wallops, with early members being Frank Hogue, and Goddard scientists such as Jack Bufton and Jim Garvin. We also supported on the L-188 Electra, the Global Troposphere Experiment (GTE) managed out of Langley. This experiment had a major payload and conducted most missions over the South American rain forest. By then, we were in the early-to-mid 90's, and we were financially healthy, due to the aircraft fixed cost being covered by the Rocket Program. We were servicing science "customers" including Wallops Airborne Science (the Airborne Oceanographic Lidar and the Airborne Terrain Mapping (ATM) laser run by Bill Krabil), Goddard's Jack Bufton's and Jim Garvin's instruments, Shuttle launch operations, and support of the Shuttle Microwave Scattered Beam Landing Systems. Those were fun missions for me - there was no such thing as a routine STS launch. Roger Navarro, who managed the airborne missions at Wallops, tells me he didn't even talk regularly with the HQ Science Program during those days. We at times had more business directly from the principle investigators than we could support. We had built the capability, and the users came. At the risk of missing the mention of key people at Wallops, our success was due to a few people doing heavy lifting in the areas of structural engineering (Doug Young and later Mike Cropper), and Mission Management (Dave Pierce, and Pete Bradfield, then later Anthony Guillory), who were the primary contacts to NASA Headquarters.

It was during this time that Headquarters began to invest more and more into the Wallops Aircraft Program. Jim Huning began supporting us at about $1 million a year, which was the largest block of support money we ever received from one source. By this time the NP-3 had been replaced by the current P-3, NASA 426 in 1991. But the implementation of full cost accounting in the late 1990s all but killed off our diversity of funding sources, which almost ended the flight program in the early 2000s. After Jim Huning came Gary Shelton, then Sherwin Beck and Cheryl Yuhas. Cheryl was followed by Andy Roberts, and finally Bruce Tagg. Randy Albertson filled in several times acting on several occasions. I very much enjoyed working with them all, in spite of what would characterize as the dark days when it appeared NASA was going out of the Airborne Science platform business, at least with regard to our own aircraft at Wallops.

During the Dan Goldin administration (1992-2001), NASA decided to consolidate aircraft operations at the Dryden Flight Research Center (now named Armstrong Flight Research Center). It was unclear which aircraft would make the move to Dryden, beyond the P-3, which was then in high demand. I remember a transition team from Dryden meeting at Wallops to discuss the impending transition, which felt like an estate sale of sorts. Only a very few of our staff had any intention to participate in the move, and our users were concerned if their platforms would make the move. This was a chaotic time for our staff and customers to say the least. This consolidation initiative was blocked by Maryland's Senator Mikulski, who wrote into the NASA appropriations budget that no aircraft base could be moved essentially west of the Mississippi River. While the Wallops flight program was saved, more and more control over the aircraft shifted to NASA Headquarters, which was in process of divesting itself away from aging aircraft such as the DC-8 and P-3.

Advanced ground based radars, and less expensive flight services from commercial sources, took away the funding at Wallops to maintain the fleet of aircraft. This shifted the funding burden solely to Airborne Science, which prohibited any funding to be spent on other aircraft such as the C-130, F-27, UH-1, or the T-39, which were donated to other activities outside of NASA.

Also during the Goldin years, we were directed to transfer operations flown on the NASA fleet to commercial sources. Since the heavy lift operations flown on the larger aircraft such as the DC-8, P-3, and ER-2s, were mostly not available in the commercial sector, we searched for agencies or groups who could operate these aircraft. We explored having the Navy operate the P-3, the Air Force the ER-2s, and we did transfer the DC-8 to the University of North Dakota through a Cooperative Agreement.

What seemed to be an unthinkable proposal, in my opinion, the University of North Dakota Cooperative Agreement, was accomplished safely and mostly successful. Many, of course, would not agree with me on the level of success of this effort. I enjoyed working with key personnel to include pilots such as Bill Brockett, maintenance from Steve Davis, and engineering support from a number of folks at Dryden such as Ron Wilcox. At UND, George Sielsdad and Rick Shetter were key on the science side, and Al Palmer's flight ops folks were also terrific. Geary Tiffany's support as Chair of the Intercenter Aircraft Operations Panel was also instrumental in getting the project off the ground.

Missions flown on smaller aircraft, such as our F-27 and T-39 aircraft were transitioned to commercial aircraft, called the Catalogue, which were more available than was the case with heavy lift. One of the most successful commercial providers was Twin Otter, who provided excellent support for years. We at Wallops provided Safety Reviews for the Catalogue program, during which we parked our smaller aircraft, leaving us with only the P-3 and B-200. Those were the darkest years, as we were down to the P-3, which needed new wings we couldn't afford, and the King Air, whose Mission Management (executive transport) program was about to be terminated by then NASA Director Griffin. Staff-wise, we were down to Rich Rogers and I as the only NASA pilots, and a hand full of contractors to keep our two planes maintained. There was much darkness and little light in our tunnel in those days.

With a change in senior leadership at NASA Headquarters came a reversal of most of the above-listed key policy events. Andy Roberts was implementing the reversal of the pendulum as Operation IceBridge came our way, and other long-term programs such as Earth Venture. We were well on our way to recovery when I retired, turning over the helm to Shane Dover. I like to say my greatest accomplishment in my career was retiring to allow the high energy Shane Dover to lead the Wallops Aircraft Office resurgence, which he did for a few years. These saw NASA's Global Hawk operations open a second deployment location at Wallops and flight ops for the first time out of McMurdo in Antarctica with our P-3. Since my retirement, the P-3 received new wings, and the fleet has expanded beyond even the early "good ole years". Pretty much all the original mission aircraft have been replaced with two C-130s, and a Sherpa C-23.

Wrap Up

For me, working at NASA, was the perfect situation, the perfect occupation. What I miss most in retirement are the people who kept the aircraft in the air, and the scientists who trusted us to take them where they needed to go. During the lean years we relied on a very limited number of people doing many jobs. Guys like John Doyle loaded the sensors on board the aircraft, prepared the aircraft for each mission, flew as flight engineer on the mission, repaired anything that broke during the flight, post-flighted the aircraft after the mission, repaired what broke after post flight, such as changing a tire on an open ramp at -25 degrees, then got up the next day to do it all over again for up to two weeks straight. Pilot Mike Singer was and continues to be the primary P-3 Captain on the P-3, who has more "there I was" stories than anyone else I know. Key participants who still are with the program include: pilot Rich Rogers, and engineer Mike Cropper, who is now Airborne Science lead at Wallops. There are too many to name them all, but I will mention our contract managers, Bob Gidge, Gary Richardson, Larry White, and Steve Bildman. Retired pilot Virgil Rabine, was the lead Captain for many years flying every thing we had, whose shoes were later filled by Mike Singer mentioned above. Pilot Willie Dykes also supported the program in fine fashion for many years flying pretty much every aircraft we flew.

Our key customers during my years included Frank Hogue, Bob Swift, Jack Bufton, Jim Garvin, Bill Krabil, Steve DinNardo, and more recently, Michael Studinger (with Operation IceBridge). I can't imagine a better team; I thoroughly enjoyed working with each of them. I will never forget flying Jim Garvin over Iceland over twenty years ago. He had more enthusiasm than any five people I know or have known.

So here I am six years into retirement with nothing but fond memories of my time at NASA.From time to time, I'm doing "real jobs" for the first time in my life, mostly related in the world of real estate, sales, house flipping, and small time development projects. My time at NASA I regard as an adventure, rather then work. For those 23 years, I am forever grateful.

Postscript

The photo to the left shows the one of two C-54 aircraft from the start of the Wallops Flight Operation. I am told these aircraft participated in the Berlin Airlift.

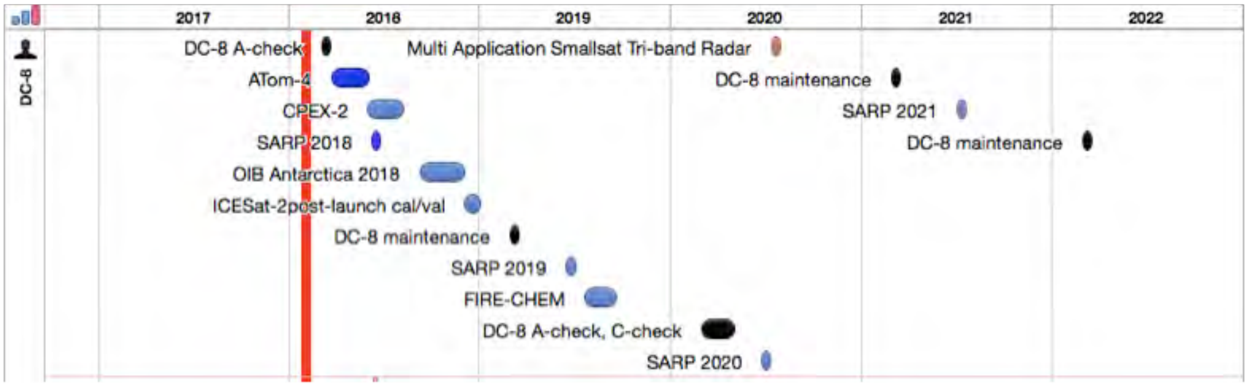
Appendix B: 5-year Plan by Science Area
5-year Plan by Major Aircraft
Maintenance Schedules for selected Aircraft

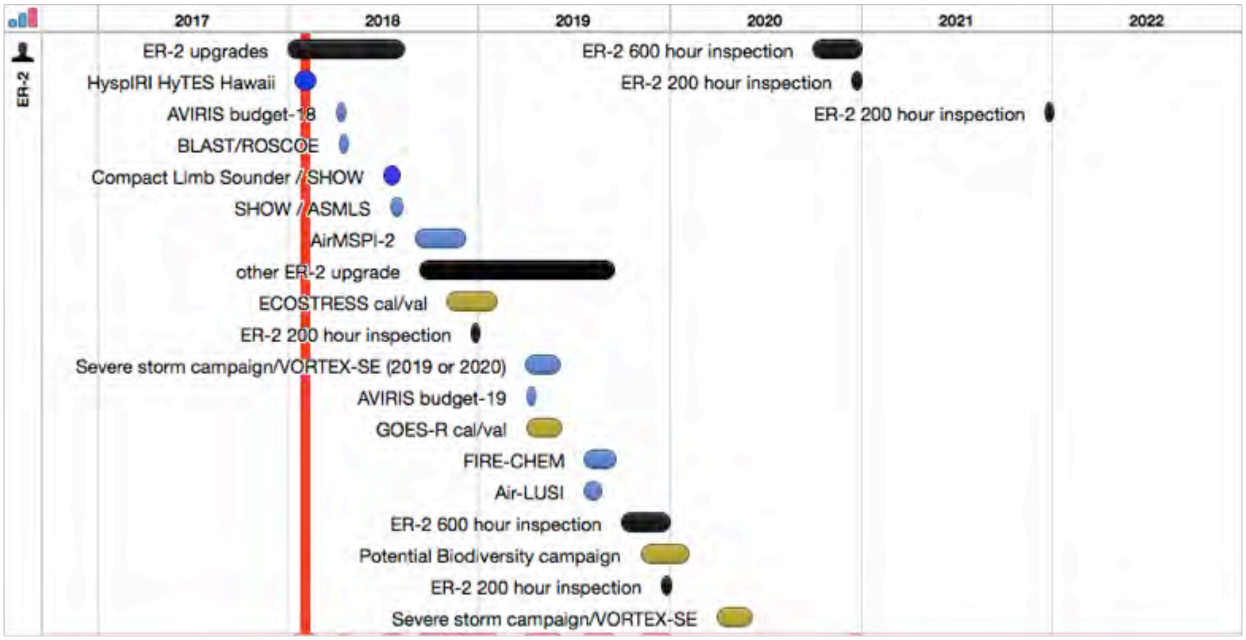
5-year Plan by Science Area

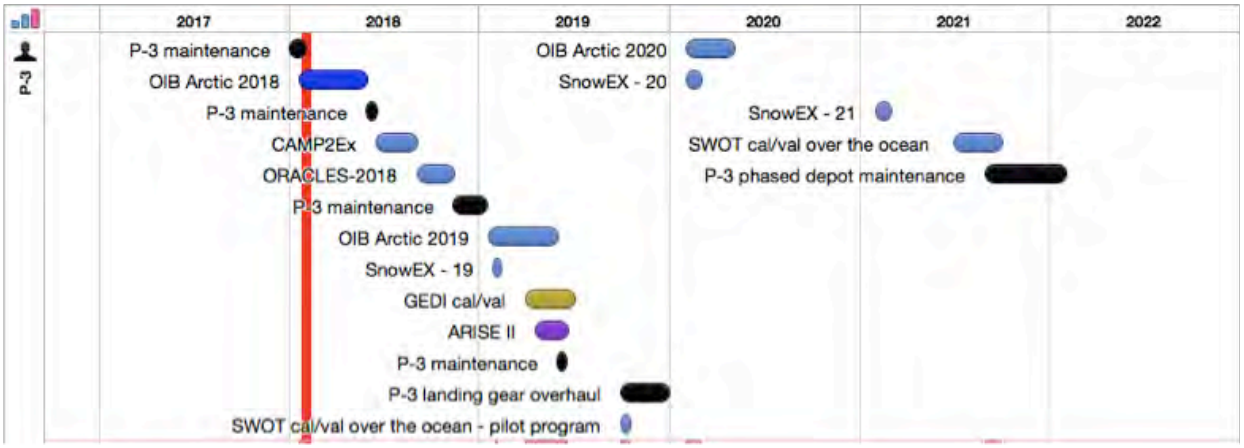
Mission	Sci Focus Area	Satellite	2018	2019	2020	2021	2022
UAVSAR Terrestrial Ecology	Carbon Cycle & Ecosystems	NI-SAR					
HyspIRI Prep		HyspIRI					
HyspIRI HyTES Hawaii		HyspIRI					
AVIRIS - budget							
ECOSTRESS cal/val		ECOSTRESS					
GEDI cal/val		GEDI					
Terrestrial Ecology (UAVSAR)							
Carbon Monitoring System/CARAFE		OCO-2					
ABoVE		OCO-2, NISAR,					
Arctic Colors							
Potential Biodiversity campaign							
Aerobiology study							
NISAR cal/val		NISAR					
eMAS/PICARD/MASTER cal val		AQUA, TERRA					
PACE Cal/val		PACE					
UAVSAR	Earth Surface & Interior	NI-SAR					
India NISAR mission		NISAR					
OIB Arctic / Arctic Melt	Climate Variability & Change / Cryosphere	ICESat-2					
OIB Antarctica		ICESat-2					
Snow-over-ice UAS mission-in-developmen							
ARISE II		ICESat-2					
ICESat-2 c al/val		ICESat-2					
Convective Processes Experiment (CPEx2)	Weather	ADM/GPM					
GPM cal/val		GPM					
HIWC-II							
Severe storms / VORTEX-SE							
GOES-R cal/val		GOES-R					
GH mission in development							
Airborne Snow Observatory	Water and Energy Cycle	HyspIRI, Aqua, Terra, Landsat					
Red River Flood mapping		SWOT					
AirMOSS Arctic Permafrost		SMAP					
NISAR/SMAP CTSM complement		NISAR, SMAP					
SWOT cal/val		SWOT					
Water quality mission							
SMAPVEX-19 / SMAP cal/val		SMAP					
Root Zone Soil Moisture		ESA BIOMASS					
SnowEX							
Long Island Sound Ozone study	Atmospheric Composition and Chemistry	TEMPO, TROPOMI					
California Methane Survey							
AJAX		OCO-2					
ARISE II							
SHOW /ASMLS							
CAMAL / BLAST Lidar test flights		CATS-ISS					
BLAST / ROSCOE Lidar test flights							
FIRE-CHEM		HyspIRI;GEO-CAPE, TEMPO, GOES R, CALIPSO					
FASME							
CAMP2Ex		Aqua, Calipso, ACE					
Atm Chem (mission in development)		OCO-2					
CA-DWR	Applications						
Remote sensing applied science							
Disaster missions							
Airborne Snow Observatory		HyspIRI					
AToM	EVS-2						
NAAMES							
ORACLES							
OMG							
ACT-America							
Earth Venture Suborbital - 3	EVS-3						
SARP	Education						
UAVSAR / Global Hawk	Technology	SMAP, NI-SAR					
IIP-2013		Various					
UAS-based spectral monitoring							
Sustainable Land Imaging awards		Various					
AITT-2016		Various					
IIP-2016		Various					
Northrop Grumman	GH SAA						
DC-8 Maintenance	Major Maintenance						
P-3 Maintenance							
C-20A scheduled maintenance							
ER-2 Upgrades							
ER-2 600 hour							

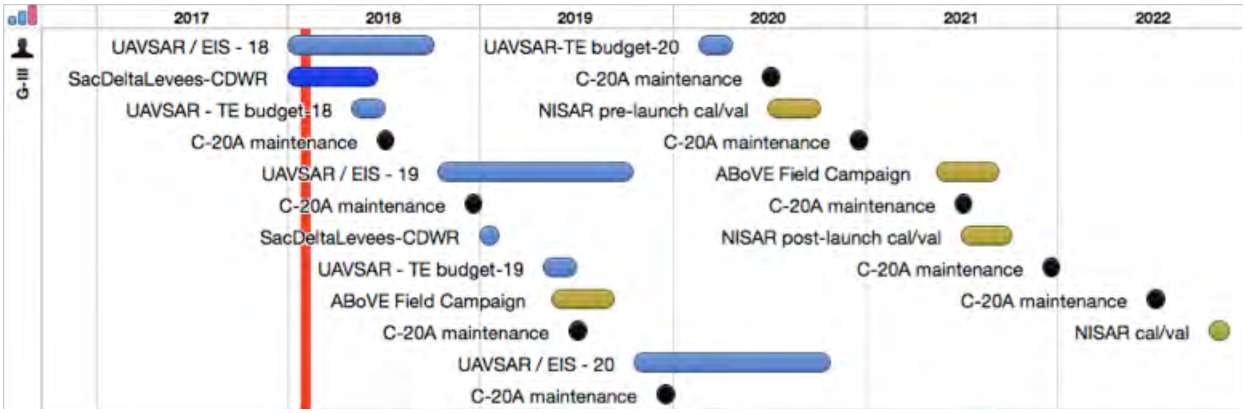
Carbon Cycle & Ecosystems
Earth Surface & Interior
Water & Energy Cycle
Atmospheric Composition
Education
Earth Science Technology Office
Weather
Climate Variability & Change
Applications
Northrop Grumman Space Act
Earth Venture Suborbital
Maintenance

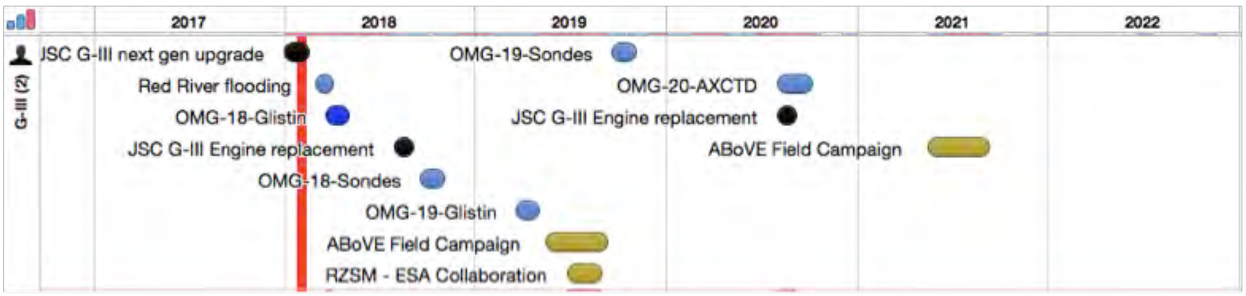
5-year Plan by Major Aircraft

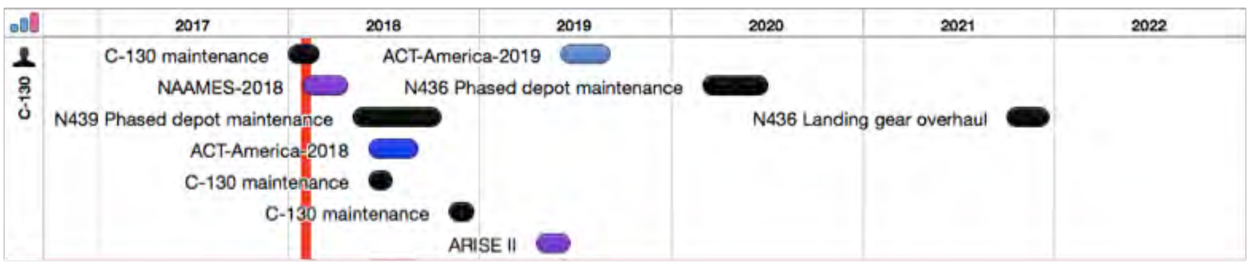







2017
2018
2019
2020
2021
2022
G-III
UAVSAR / EIS - 18
SacDeltaLevees-CDWR
UAVSAR - TE budget-18
C-20A maintenance
UAVSAR / EIS - 19
C-20A maintenance
SacDeltaLevees-CDWR
UAVSAR - TE budget-19
ABoVE Field Campaign
C-20A maintenance
UAVSAR / EIS - 20
C-20A maintenance
UAVSAR-TE budget-20
C-20A maintenance
NISAR pre-launch cal/val
C-20A maintenance
ABoVE Field Campaign
C-20A maintenance
NISAR post-launch cal/val
C-20A maintenance
C-20A maintenance
NISAR cal/val


2017
2018
2019
2020
2021
2022
G-III (2)
JSC G-III next gen upgrade
Red River flooding
OMG-18-Glistin
JSC G-III Engine replacement
OMG-18-Sondes
OMG-19-Glistin
ABoVE Field Campaign
RZSM - ESA Collaboration
OMG-19-Sondes
OMG-20-AXCTD
JSC G-III Engine replacement
ABoVE Field Campaign


2017
2018
2019
2020
2021
2022
C-130
C-130 maintenance
NAAMES-2018
N439 Phased depot maintenance
ACT-America-2018
C-130 maintenance
C-130 maintenance
ARISE II
ACT-America-2019
N436 Phased depot maintenance
N436 Landing gear overhaul


2017
2018
2019
2020
2021
2022
Global Hawk
UAVSAR / Global Hawk
Snow-over-ice UAS mission in development

Maintenance Schedules for Selected Aircraft

ER-2

FY	ER-2	Type of Maintenance	Timeframe
FY18	809	CARE	Oct 17 - Aug 18
FY18	806	CARE	Sep 18
FY19	806	CARE	Oct 18 - Sep 19
FY19	809	200-Hour Inspection	2 weeks
FY20	806	200-Hour Inspection	2 weeks
FY20	809	600-Hour Inspection	3 months
FY21	806	600-Hour Inspection	3 months
FY21	809	200-Hour Inspection	2 weeks
FY22	806	200-Hour Inspection	2 weeks
FY22	809	200-Hour Inspection	2 weeks

DC-8

Est Date	Length	Type of Maintenance
Mar-18	3 weeks	1A, 2A, 4A, 8A Maintenance
Sep-18	1 week	1A,3A Check Maintenance
Mar-19	2 week	1A, 2A Maintenance
Sep-19	1 week	1A Maintenance
Mar-20	2 months	1A,2A,3A,4A,1C,2C Maintenance & swap landing gear
Sep-20	1 week	1A Maintenance
Mar-21	2 week	1A, 2A Maintenance
Sep-21	1 week	1A,3A Check Maintenance
Mar-22	3 weeks	1A, 2A, 4A, 8A Maintenance
Sep-22	1 week	1A

C20-A

Est Date	Length	Type of Maintenance
FY18 – Dec	4 weeks	Ops #1 Maintenance
FY18 – Jun	4 weeks	Ops #3 Maintenance
FY19 – Nov	4 weeks	Cockpit Upgrade (Tentative)
FY19 - Dec	4 weeks	Ops #1 Maintenance
FY19 – June	4 weeks	Ops #2 Maintenance
FY20 – Dec	4 weeks	Ops #1 Maintenance
FY20 – Jun	4 weeks	Ops #3 Maintenance
FY21 - Dec	4 weeks	Ops #1 Maintenance
FY21 – June	4 weeks	Ops #2 Maintenance
FY22 – Dec	4 weeks	Ops #1 Maintenance
FY22 – Jun	4 weeks	Ops #3 Maintenance

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)

Appendix C: Acronyms

A

AA	Associate Administrator
AAC	ABoVE Airborne Campaign
ABI	Advanced Baseline Imager
ABoVE	Arctic-Boreal Vulnerability Experiment
ACE	Aerosols Clouds Ecosystems
ACT-America	Atmospheric Carbon and Transport-America
ADS-B	Automatic dependent surveillance – broadcast
AFRC	Armstrong Flight Research Center
AGU	American Geophysical Union
AirMSPI	Airborne Multi-angle SpectroPolarimeter Imager
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AITT	Airborne Instrument Technology Transition
AJAX	Alpha Jet Airborne Experiment
AMPR	Advanced Microwave Precipitation Radiometer
APU	Auxiliary Power Unit
APR-2	Airborne Second Generation Precipitation Radar
ARC	Ames Research Center
ARINC	Aeronautical Radio, Incorporated
ARMD	Aeronautics Research Mission Directorate
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
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
AVAPS	Airborne Vertical Atmosphere Profiling System
AVIRIS, AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation
AXCTD	Airborne Expendable Conductivity Temperature Depth

B

BBR	Broadband Radiometers
BGAN	Broadband Global Area Network
BRDF	Bi-directional Reflectance Function
BSI	Bio-spherical Instruments

C

C-HARRIER	Coastal High Acquisition Rate Radiometers for Innovative Environmental Research
CAFé	Compact Airborne Formaldahyde Experiment
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
Cal/val	Calibration / Validation
$CAMP^2EX$	Cloud and Aerosol Monsoonal Processes - Philippines Experiment
CARAFE	CARbon Airborne Flux Experiment
CAR	Cloud Absorption Radiometer
CARE	Cabin Altitude Reduction Effort
CCE	Carbon Cycle and Ecosystems
CCRPP	Civilian Commercialization Readiness Pilot Program
CFIS	Solar-induced chlorophyll fluorescence
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
COLAS	CO2 laser absorption spectrometer
CONUS	Continental United States
CORAL	Coral Reef Airborne Laboratory
CPDLC	Controller-Pilot Data link Communications
CPEX	Convective Processes Experiment
CPI	Cloud Particle Imager
CPL	Cloud Physics Lidar

CRS	Cloud Radar System
CSIRO	Commonwealth Scientific and Industrial Research Organization
CVI	counterflow virtual impactor
CVR	calibration, validation, and research

D

DAWN	Doppler Aerosol Wind Lidar
DCS	Digital Camera System
DLH	Diode Laser Hygrometer
DLR	German Space Agency
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)

E

eMAS	Enhanced MODIS Airborne Simulator
EPOCH	Eastern Pacific Origins and Characteristics of Hurricanes
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, EV-2, EVS-3	Earth Venture, Earth Venture-2, Earth Venture Suborbital-3
EXRAD	ER-2 X-band Radar

F

4Star	Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research
FAA	Federal Aviation Administration
FEGS	Fly's Eye GLM Simulator
FIRE-CHEM	Fire Impacts on Regional Emissions and Chemistry
FLARE	Fluorescence Airborne Experiment
FLEX	FLuorescence EXplorer
FR	Flight Request

G

GCAS	GeoCAPE Airborne Simulator
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GH	Global Hawk
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal
GLM	Geostationary Lightning Mapper
GLISTIN-A	Glacier and Ice Surface Topography Interferometer - Airborne
GOES	Geostationary Operational Environmental Satellite
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center

H

H_2O	Water
HALO	High Altitude Lidar Observatory
HAMSR	High Altitude Monolithic Microwave integrated Circuit (MMIC) Sounding Radiometer
HAVHM	High Accuracy Vector Helium Magnetometer
HAWC-OAWL	HSRL for Aerosols Winds and Clouds - Optical Autocovariance Wind Lidar
HDVIS	High Definition Time-lapse Video System
HiGEAR	Hawaii Group for Environmental Aerosol Research
HIWC	High Ice Water Content
HOPE	Hands On Project Experience
HSRL	High Spectral Resolution Lidar
HTSOS	High Threat Security Overseas
HyspIRI	Hyperspectral Infrared Imager
HyTES	Hyperspectral Thermal Emission Spectrometer

I

ICESat	Ice, Cloud, and land Elevation Satellite
ICCAGRA	Interagency Coordinating Committee for Airborne Geosciences Research and Applications
IEEE	Institute for Electrical and Electronics Engineers

IIP	Instrument Incubator Program
InSAR	Interferometric Synthetic Aperture Radar
IR	Infrared
IRIG-B	Inter-range instrumentation group - B
ISAF	In situ airborne fomaldahye
ISRO	Indian Space Research Organization
ISS	International Space Station
IWGADTS	Interagency Working Group for Airborne Data and Telecommunication Systems

J

JPL	Jet Propulsion Laboratory
JSC	NASA Johnson Space Center
JWST	James Webb Space Telescopt

K

KORUS	Korea-US

L

L1, L2	Level 1, Level 2
LARGE	Langley Aerosol Research Group Experiment
LaRC	Langley Research Center
LiDAR	Light Detection and Ranging
LIOS	Long Island Ozone Study
LMOS	Lake Michigan Ozone Study
LTER	Long-term Ecological Research
LVIS	Land, Vegetation, and Ice Sensor

M

MASC	Microwave Atmospheric Sounder for Cubesats
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
MCBH	Marine Corps Base Hawaii

MSL	Mean sea level
MMS	Meteorological measurement system
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Modular Optoelectronic Scanner
MPCS	Master Power Control System
MSFC	Marshall Space Flight Center
MTHP	Microwave Temperature and Humidity Profiler
MTS	Mission Tools Suite
MX	Maintenance

N

NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NASDAT	NASA Airborne Science Data and Telemetry
NAST-I	National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed - Interferometer
NISAR	NASA-ISRO SAR
NCAR	National Center for Atmospheric Research
NEON	National Ecological Observation Network
NGEE	Next generation ecological experiment
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSRC	National Suborbital Research Center
NT	Northwest Territories

O

OCO-2	Orbiting Carbon Observatory - 2
OIB	Operation Ice Bridge
OMG	Oceans Melting Greenland
ORACLES	Observations of Aerosols Above CLouds and their InteractionS
ORNL	Oak Ridge National Laboratory

ORT	Operational Readiness Test
OWLETS	Ozone Water-Land Environmental Transition Study

P

PACE	Plankton, Cloud, and ocean Ecosystem
PDM	Programmed Depot Maintenance
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol R&D
PolSAR	Polarimetric SAR
POS	Position and Orientation Systems
ppt	Parts per trillion
PRISM	Portable Remote Imaging Spectrometer
POSIDON	Pacific Oxidants, Sulfur, Ice, Dehydration, and cONvection

Q

QWIP	Quantum Well Infrared Photodetector

R

R&A	Research and Analysis
RSP	Research Scanning Polarimeter
R/V	Research Vessel
RZSM	Root Zone Soil Moisture

S

SAR	synthetic aperture radar
SARP	Student Airborne Research Program
SEO	sensor equipment operator
SHIS	Scanning High-resolution Interferometer Sounder
SHOUT	Sensing Hazards with Operational Unmanned Technology
SHOW	Spatial Heterodyne Observation of Water
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
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

SUAS Small UAS

SWE Snow water equivalent

SWIM System Wide Management Interface

SWIR Short wave infrared

SWOT Surface Water and Ocean Topography

T

TB Terra bytes

TEMPO Tropospheric Emissions: Monitoring Pollution

U

UARC University Affiliated Research Center

UAS Unmanned Aircraft Systems

UAV Unmanned Aerial Vehicles

UAVSAR Uninhabited Aerial Vehicle Synthetic Aperture Radar

UK United Kingdom

UND University of North Dakota

USGS U.S. Geological Survey

UV Ultraviolet

UWBRAD Ultra-Wideband Software-Defined Microwave. Radiometer

W

WFF Wallops Flight Facility

WISM Wideband Instrument for Snow Measurements

Wx Weather

Y

YT Yukon Territory

BACK COVER FIGURES

Top: The immense glass windshield on the C-130 affords a panoramic view of the North Atlantic during NAAMES.

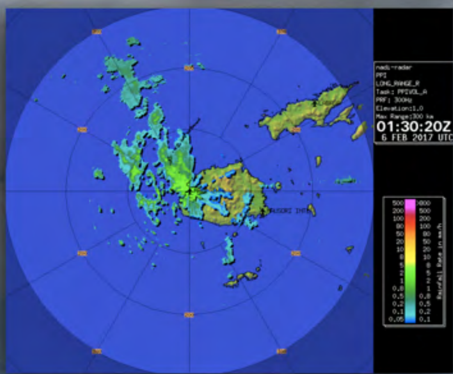
Second Row Left: Rainfall view from DC-8 en-route to New Zealand during ATom-2.

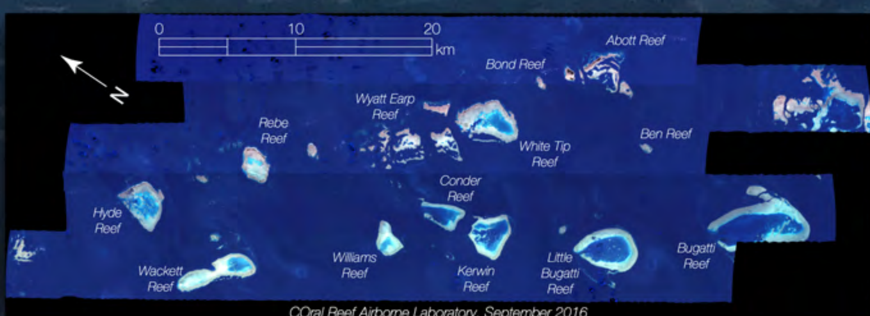
Second Row Right: C-130 flying over Milne Land, Eastern Greenland during OMG.

Third Row Left: Fields of green are an ever-present during ACT-America flights.

Third Row Right: Shadow of the P-3 and Sun's glory photographed from the nadir port during ORACLES.

Bottom: Great Barrier Reef – Pompey Sector was studied during CORAL.





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