National Aeronautics and Space Administration

Science Mission Directorate
Airborne Science Program

2016 Annual Report

COVER IMAGE

Background on front and back cover: View of cloud layer from P-3 during ORACLES mission, looking toward Namibia coastline.

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1. Leadership Comments

Welcome to the 2016 edition of the Airborne Science Program's Annual Report. This year was the busiest year ever for the program with over 4,750 Earth Science Flight hours flown all over the world. We travelled the globe (literally) this year, as well as to the Arctic and Antarctic, throughout the US including Alaska and Hawaii, Korea, and to Africa (not once but twice!). The second round of six Earth Venture Suborbital missions (EVS-2) is in full implementation and we completed the eighth year of Operation IceBridge. The Program supported future satellite missions such as ACE, HyspIRI, NISAR and SWOT with preparatory missions, in addition to current operational missions such as GPM and SMAP. We supported a major field campaign to study air quality processes around the Korean peninsula and also completed the eighth year of the Student Airborne Research Program.

In addition to NASA aircraft operations, this year also marks a record for commercial aircraft usage, with over 1,700 Earth Science flight hours flown. We are also excited to announce that we have teamed up with the Human Exploration and Operations (HEO) Mission Directorate to provide a much needed long range business jet to the ASP inventory. The aircraft should be available for Earth Science missions in FY17.

Within the Program we've had some transitions of note this past year. Shane Dover moved from the Wallops Flight Facility to take a senior position at Langley and Werner Winz took over the Wallops operation. Rick Shetter retired and Melissa Yang-Martin took over as director of the National Suborbital Research Center (previously National Suborbital Education and Research Center). NSRC transitioned from the University of North Dakota to the Bay Area Environmental Research Institute. Earth Science Project Office previous Chief, Mike Craig, also retired. We wish each success in their new endeavors.

Randy and I hope you enjoy reading about all the great work as well as some of our new capabilities. We would like to also say a huge thank you to the dedicated people who make up the program for making this a record year. Please let us know what you think of the report and, as always, we welcome any and all feedback about the program.

Bruce Tagg, Director
Randy Albertson, Deputy Director

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 mission instrument development, algorithm development and calibration and validation activities
- Instrument testing and development
- Process studies to improve models of earth system elements
- Workforce development / next generation 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 ASP within SMD. Figure 2 shows the components of the program. The aircraft responsibilities are distributed among the NASA centers where the aircraft are based: Ames Research Center (ARC), Armstrong

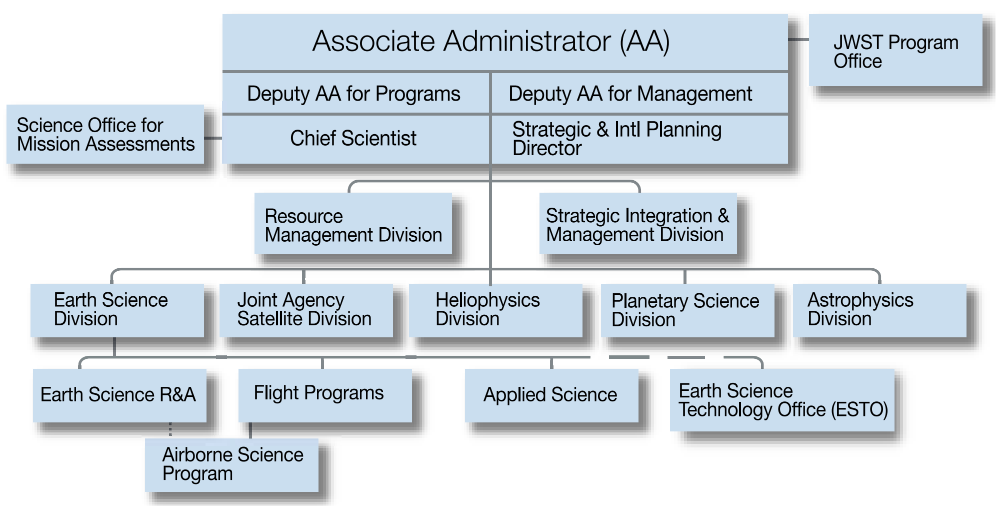
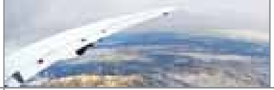


FIGURE 1 *Science Mission Directorate Organization Chart.*



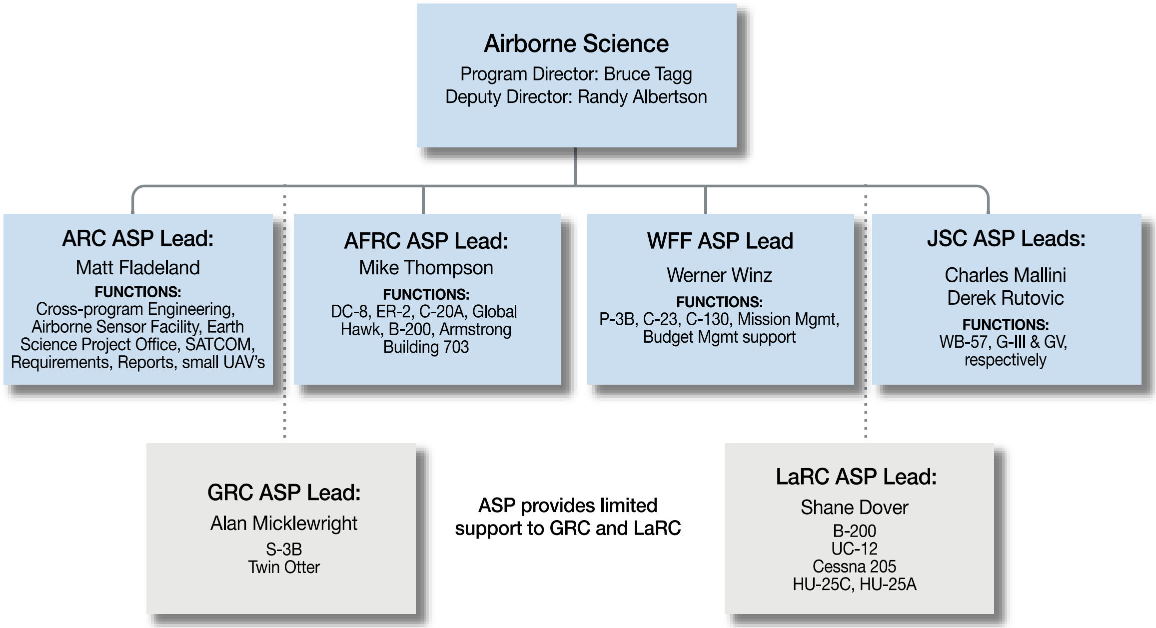


FIGURE 2 *Airborne Science Organization Chart.*

Flight Research Center (AFRC), Wallops Flight Facility (WFF), Johnson Space Center (JSC), Glenn Research Center (GRC), Langley Reserach Center (LaRC). **Note that all acronyms are defined in Appendix C.**

New Program Capabilities

2016 saw the return of the P-3 with new wings, ready for another two decades of science work. The second C-130 was also completely booked in 2016. A fully functional Ka-band SAR, complimentary to the L-band and P-band UAVSAR variants, became operational.

Coming in 2017 are a Gulfstream V (GV) platform at JSC and a replacement Global Hawk at AFRC.

Flight Request System and Flight Hours

The Science Operations Flight Request System (SOFRS) is a web-based tool used to track and facilitate the review and approval process for every airborne science mission using NASA SMD funds, instruments, personnel or aircraft. The only way to schedule the use of NASA SMD platforms and instrument assets is to submit a Flight Request (FR) for approval through SOFRS (https://airbornescience.nasa.gov/sofrs).

The SOFRS team strives for continuous improvement by refining the user interface and reports produced. There were 211 Flight Requests submitted in 2016 for missions with at least one of the following ASP components: an ASP supported aircraft, ESD funding, an ASP facility instrument (AVIRIS, MASTER, UAVSAR, and NAST-I), and/or an ASP Science Support Asset (DCS, DMS, and POS-AV). A total of 91 were completed, some were deferred and the rest were canceled for various reasons. Flight Requests were submitted for 38 aircraft. Together they flew a total of 5,314.8 flight hours. The details are listed in Tables 1 through 3 below. Locations of ASP activities in FY16 are indicated on the globe in Figure 4.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[1]	15	11	0	11	423.2
ER-2[1]	35	29	6	15	381.8
P-3[1]	16	3	0	1	155
Global Hawk[1]	4	2	1	1	242.8
C-20(G-III) AFRC[1]	31	23	4	13	272
WB-57[5]	5	5	1	4	146.8
Twin Otter[5]	9	4	1	2	291.2
C-130 Hercules[5]	8	3	0	3	325
C-23 Sherpa[5]	5	4	0	4	150.4
Dragon Eye[5]	1	1	1	0	3.1
Falcon - HU-25[5]	2	2	0	2	192.2
G-III - JSC[5]	25	20	4	10	227.7
Sierra[5]	5	0	0	0	0
B-200[5]	14	9	0	9	574
Other[1]	36	24	5	16	1929.6
TOTALS	**211**	**140**	**23**	**91**	**5314.8**

TABLE 1 *FY16 ASP-ESD Flight Request Status and Flight Hours Flown, by aircraft[4].*

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

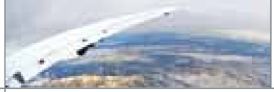
[2] ASP Science Support Assets include: DCS, DMS and POS-AV

[3] Current ASP Facility Instruments are: AVIRIS, MASTER, UAVSAR, and NAST-I

[4] "ASP Component" consist of flights including at least of one of the following: an ASP supported aircraft[1], ESD Funding, an ASP Facility Instrument[3], or an ASP Science Support Asset[2]

[5] These aircraft are NASA owned aircraft not subsidized by the Airborne Science Program

[6] Non-NASA contract aircraft include: DC-3, Bussmann Helicopter, King Air A90, King Air B200, Twin Otter, Piper Cherokee, G-V, and Tempest UAS



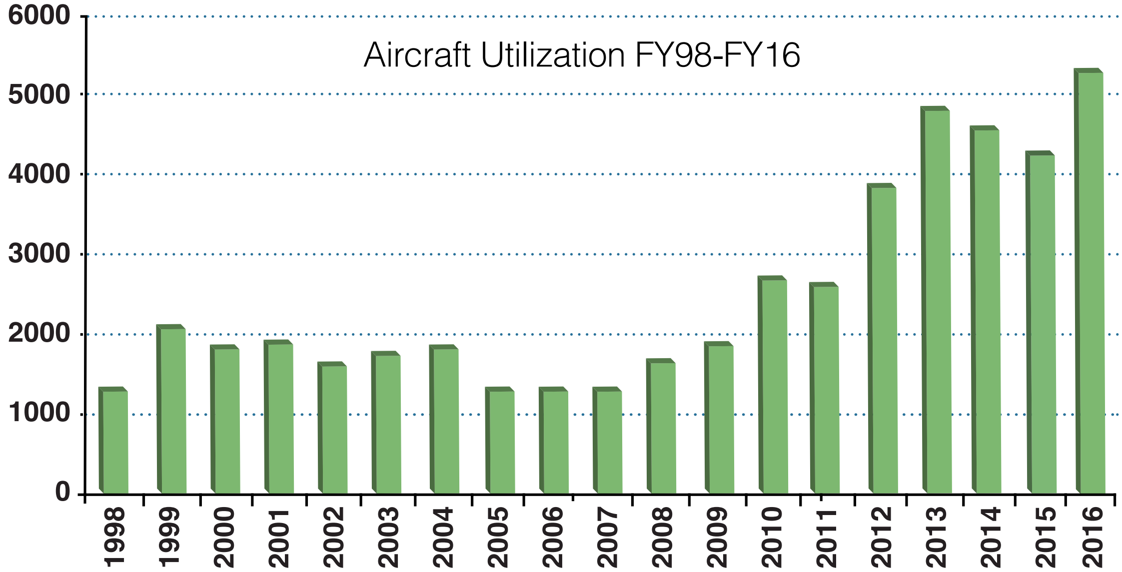


FIGURE 3 *ASP flight hours over past 19 years.*

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[2]	9	6	0	6	411.9
ER-2[2]	26	25	4	14	356.1
P-3[2]	13	3	0	1	155
Global Hawk[2]	1	0	0	0	0
C-20A (G-III) – AFRC[2]	27	21	3	12	258.2
WB-57[5]	5	5	1	4	146.8
Twin Otter5[5]	5	4	1	2	291.2
C-130 Hercules[5]	8	3	0	3	325
C-23 Sherpa[5]	4	3	0	3	107.6
Dragon Eye[5]	1	1	1	0	3.1
Falcon - HU-25[5]	2	2	0	2	192.2
G-III – JSC[5]	24	20	4	10	227.7
SIERRA[5]	3	0	0	0	0
B-200[5]	13	9	0	9	574
Other[6]	30	19	4	14	1703.3
TOTAL	**171**	**121**	**18**	**80**	**4752.1**

TABLE 2 *Summary of ESD funded FY16 Flight Request Status and Flight Hours Flown By Aircraft[1].*

[1] "ASP Component" consists of flights including at least of one of the following: an ASP supported aircraft[2], ESD Funding, an ASP Facility Instrument[3], or an ASP Science Support Asset[4]

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

[3] Current ASP Facility Instruments are: AVIRIS, MASTER, UAVSAR, and NAST-I

[4] ASP Science Support Assets include: DCS, DMS and POS-AV

[5] These aircraft are NASA owned aircraft not subsidized by the Airborne Science Program

[6] Non-NASA contract aircraft include: DC-3, Bussmann Helicopter, King Air A90, King Air B200, Twin Otter, Piper Cherokee,G-V, and Tempest UAS

***How to read Table 1 and Table 2**

- *These totals are based on the Flight Request's log number, and therefore include Flight Requests whose log number starts with "16".*
- *The "Total FRs" column includes Flight Requests that were submitted and whose log number starts with "16".*
- *The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY16.*
- *The "Total Partial FRs" column includes Flight Requests in which the total approved hours were not fully expended during FY16 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 2016.*

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	4,069.4	28.5	419.5	12.8	69.9	4,600.1
2015	3,758.0	24.5	266.9	184.9	26.9	4,261.2
2016	4752.1	16.6	285.6	260.5	0	5,314.8

TABLE 3 *Funded flight hours flown over the past 3 fiscal years.*

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

2016 Airborne Campaigns

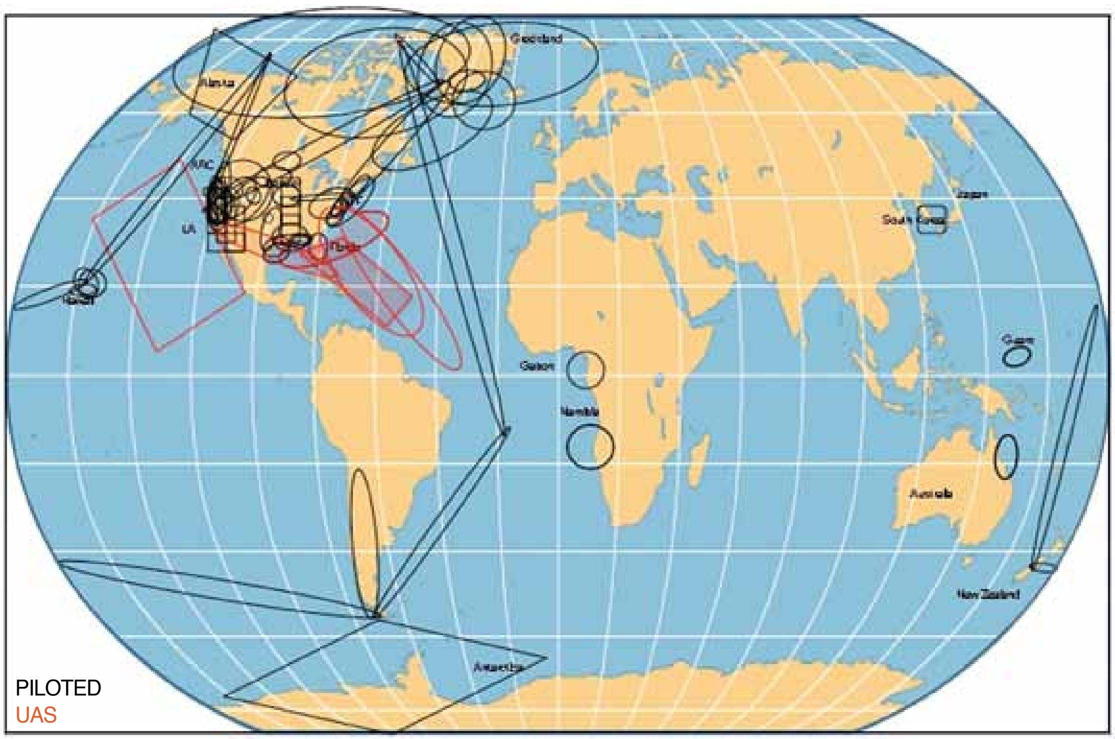


FIGURE 4 *Locations of ASP missions in 2016.*

3. Science

Major Mission Highlights

The Airborne Science Program conducted over 4700 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. Airborne activities provided cal/val data for the recently launched Global Precipitation Mission (GPM) while also providing sinulated data for ICESat-2 and NISAR algorithm development. The Program successfully concluded support for the first round of Earth Venture Suborbital missions while initiating EVS-2, the second round of Earth Venture Suborbital missions and also continued Operation IceBridge (OIB). Flight hours for the largest missions are shown in Table 4.

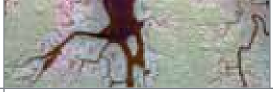
KORUS-AQ

The Korea-US Air Quality (KORUS-AQ) mission, a joint effort between NASA and Korea's National Institute of Environmental Research (NIER), was conducted in May and June of 2016. The study integrated observations from aircraft, ground sites, and satellites with air quality models to understand the factors controlling air quality and to determine how observations from the future constellation of geostationary air quality satellites can be best interpreted and used to inform air quality mitigation strategies. The air quality constellation will include satellites from both NASA (TEMPO) making observations over North America and South Korea (GEMS) making observations across Asia.

The mission employed three aircraft, each fulfilling a key role. NASA AFRC's DC-8 served as the primary aircraft for direct atmospheric sampling of gases and aerosols affecting air quality. It flew extensively across the Korean peninsula and surrounding waters at multiple altitudes providing information on the vertical distribution,

Mission	Aircraft	Flight Hours	Location
OMG	G-III, Single Otter	634.4	Greenland
OIB-Arctic/Antarctic	P-3(NOAA), GV, HU-25C, Heli	571.4	Greenland, Alaska, Canada, Chili, Antartica
AVIRIS-ng	B-200 (ISRO)	430.0	India
KORUS	DC-8, B-200	380.6	South Korea
ORACLES	P-3, ER-2	276.0	Namibia
Act-America	C-130, B-200	263.1	CONUS
Airborne Snow Observatory	A90	258.6	Colorado, California
SHOUT / El Nino Rapid Response	Global Hawk	242.8	Pacific Ocean; Atlantic Ocean, Gulf of Mexico, Caribbean Sea
GPM/OLYMPEX/RADEX	DC-8, UND Citation, ER-2	237.1	Washington state
AfriSAR	C-20A, B-200	181.2	Gabon, Africa
NAAMES	C-130	173.3	North Atlantic
California Methane Survey	B-200, Twin Otter	155.7	Southern California
SMAPVEX16	DC-3	132.3	Iowa; Canada
CARVE	Sherpa	107.6	Alaska
ATom	DC-8	107.5	Global
CORAL	G-IV	85.0	Hawaii; Australia
HyspIRI airborne	ER-2	64.8	California
AirSWOT	B-200	64.2	California, Louisiana, Alaska, Oregon
UAVSAR - Total L, P, Ka bands	C-20A, G-III	417.0	US, Greenland, Africa
Technology test and demonstration	ER-2, WB-57, TO, DC-8, B-200	263.0	California, multiple US locations

***TABLE 4** Major Science Missions in FY16.*



chemistry, and transport of pollutants. The DC-8 payload included 26 instruments, five of which were from Korean investigators.

Flying high overhead, NASA Langley's King Air remotely sensed conditions below the aircraft using NASA Goddard's Geostationary Trace gas and Aerosol Sensor Optimization (GEO-TASO) spectrometer, and Ball Aerospace's Multi-slit Optimized Spectrometer (MOS). As the airborne simulator for TEMPO, Geo-TASO provided observations replicating the type of data expected from future geostationary satellites.

Onboard Hanseo University's King Air, Korean scientists deployed an in situ payload to measure pollutants directly observable from space (ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and fine particles). This aircraft also hosted NASA Goddard's Compact Airborne Formaldehyde Experiment (CAFÉ). This smaller, more nimble aircraft was able to provide information on key pollutants in areas less accessible to the DC-8.

Flying from Osan Air Base in South Korea, these aircraft overflew a network of Korean ground sites spanning from the Seoul Metropolitan area to locations across the peninsula and nearby islands. These ground sites included intensive measurement sites hosting both Korean and U.S. researchers as well as the several hundred regulatory air quality monitoring sites. Additional observations over the water came from research vessels participating in a companion effort called the Korea-United States-Ocean Color (KORUS-OC) study. These observations provided key information on water quality as well as air quality and its effect on remote sensing of water conditions.

The multi-perspective observations provided by the aircraft and ground sites constitute the most complete characterization of air quality ever obtained. The observations of pollution under a wide range of conditions across urban, rural and coastal interfaces provide the basis for detailed analysis. Results will provide Korean colleagues at NIER with key information that will be useful to Korea's Ministry of the Environment for development of air quality mitigation strategies. Results will also lead to improved air quality models and readiness for observations from upcoming geostationary satellites.

FIGURE 5 *Members of the KORUS-AQ Science Team attending the Media Day at Osan Air Base are pictured above. In all, 300 people from five NASA centers and more than 10 US and 14 Korean research institutions participated in Operations at Osan AB.*

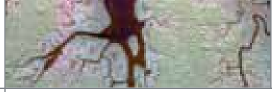
Operation IceBridge (OIB)

OIB finished up a successful year in the Arctic with a series of campaigns taking measurements of the Greenland ice sheet and Arctic sea ice. The traditional Arctic spring campaign was conducted in April and May 2016 in conjunction with the National Oceanographic and Atmospheric Administration (NOAA) using their P-3 hurricane hunter aircraft and the IceBridge suite of laser, radar, optical, and infrared instruments. The campaign conducted 16 science flights totaling 142 flight hours to continue the time series of measurements of ice thickness change to bridge the gap between the end of the ICESat laser altimetry mission and the upcoming launch of ICESat-2.

As a prelude to better understanding seasonal changes in the Earth's ice cover with the year-round measurements of ICESat-2, IceBridge undertook a new campaign this year to measure Arctic sea ice at the height of the melt season in July. The campaign was based out of Barrow, Alaska using the Langley Falcon equipped with a laser altimeter, and visible and infrared imagers. Spectacular views and measurements of sea ice melt ponds were acquired, and images and interview statements were used in a number of prominent media outlets such as the New York Times. The campaign was then relocated to Kangerlussuaq, Greenland in late August to conduct repeat surveys of lines flown earlier in the spring to assess the impact of the summer melt season on the Greenland ice sheet. In total, the summer campaign achieved 23 science flights totaling 109 hours.

In mid-September the Falcon transited from Kangerlussuaq to NASA AFRC to quickly transfer the IceBridge laser altimeter and thermal imager to the NASA DC-8 in preparation for the fall Antarctic campaign.

FIGURE 6 2016 OIB Arctic flight tracks.



OLYMPEX / RADEX

Clouds and precipitation were the focus of the Olympic Mountain Precipitation Experiment (OLYMPEX), a NASA-led field campaign coordinated with the University of Washington and conducted on the Olympic Peninsula from November 2015 through February 2016. The campaign combined the research interests of two NASA satellite missions: GPM that launched in 2014, and a RADar instrument EXperiment (RADEX) implemented as part of the Aerosol-Cloud-Ecosystems (ACE) mission, which is in formulation. The goal of the joint campaign was to collect detailed atmospheric measurements that will be used to evaluate how well these satellites measure aerosols, clouds, rainfall and snowfall from space, and to improve the algorithms that convert satellite measurements into useful products.

The OLYMPEX campaign included an intensive observations period with coordinated airborne and ground-based measurements from a wide variety of instruments. NASA's ER-2 flew at high altitude with a suite of instruments primarily focused on aerosols and clouds for RADEX: a suite of multi-frequency radars, a profiling lidar, a polarimeter; and a microwave radiometer completed the ER-2 instrument set. NASA's DC-8 also flew above the clouds but at a somewhat lower altitude with a suite of OLYMPEX precipitation instruments including multi-frequency radar and microwave radiometers as well as a dropsonde system to directly profile atmospheric winds, temperature and humidity. Flying through the clouds was the University of North Dakota's Cessna Citation aircraft equipped with an array of in situ instruments to measure water in all of its phases: as vapor, liquid droplets, and frozen particles. Flights were coordinated as dictated by the scientific objectives of the campaign, often with all three aircraft simultaneously observing the same volume of a storm (this was a first for GPM). On several occasions storms were observed by the aircraft in stacked patterns flown under the GPM satellite.

In addition to the aircraft platforms and instruments, OLYMPEX also deployed an extensive and extended set of ground-based observations. The US Park Service provided logistic support to help maintain the gauges during some of the extreme weather conditions observed during the campaign. Indeed, one of the gauges at the head of the Quinault River measured >10 feet of rain from November 2015 through February 2016!

A specific example of a well-coordinated airborne and ground data collection occurred directly under the GPM Core satellite on December 3, 2015 (Figure 7). For this cold-rain case, high altitude instruments on the ER-2 and DC-8 sampled in a near perfect altitude stack under the GPM Core satellite with the Citation aircraft profiling cloud microphysics directly underneath. All three aircraft and the GPM Core satellite traversed the broader coverage of OLYMPEX ground radars, which were performing a collection of range-height scans through the location of the aircraft and over the steep terrain.

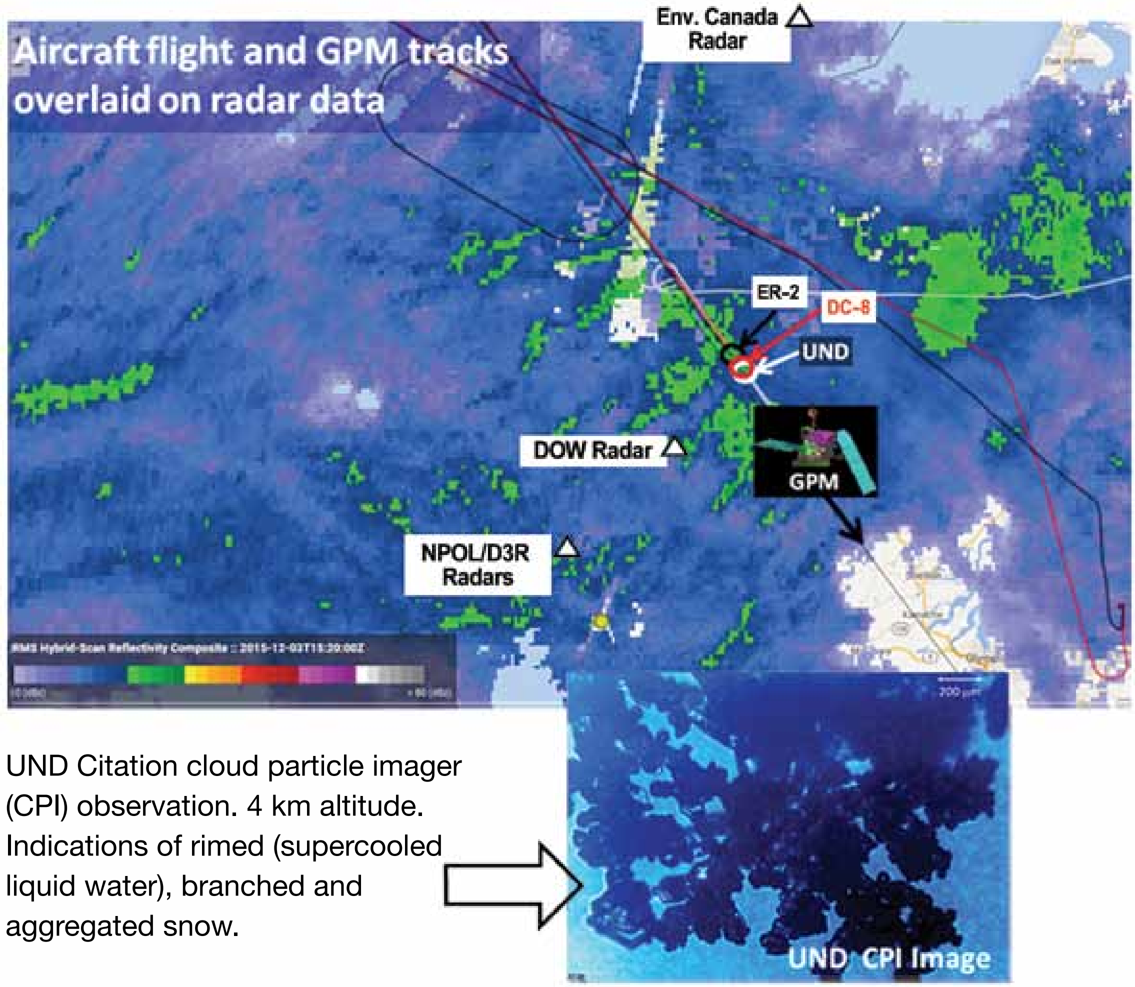
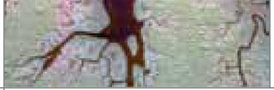


FIGURE 7 *December 3, 2015 mission. Left, background. Flight tracks from a triple aircraft stack flown under the GPM Core satellite nadir point overlaid on composite ground radar reflectivity. An image of a riming aggregate snowflake is shown from a UND Citation imaging probe flying in cloud at a height of ~4 - 5 km under the DC-8.*

Finally, the Airborne Snow Observatory (ASO), which consists of an imaging spectrometer and lidar, flew on a Twin Otter aircraft to measure snowpack depth over the Olympic Mountain domain. The ASO made "no-snow" flights over the Olympic Mountains during the summer of 2015, and then in late winter/early spring 2016 to estimate accumulated snowfall as part of the OLYMPEX campaign.

Earth Venture Suborbital

Earth Venture Suborbital (EVS), a program of the Earth Science Pathfinder Program, completed EV-1 (suborbital) projects in 2016, as EVS-2



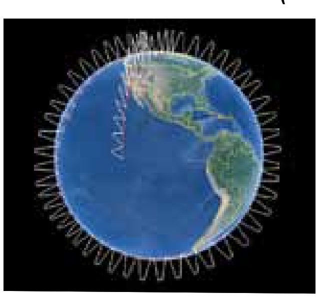
projects were fully under way. Completing activities in 2016 were CARVE and AirMOSS. The six EVS-2 missions, awarded in 2015 for activities over the years through 2019, are listed in Table 5. The map in Figure 8 shows the broad reach of these missions.

Mission	Location	Dates	Aircraft
ATom	Multiple – see map	2015 - 2018	DC-8
NAAMES	North Atlantic / Azores	2015 - 2018	C-130
ACT-America	Midwest – Eastern US	2015 - 2018	C-130, B-200
ORACLES	Coast of Africa / Namibia	2016, 2017, 2018	P-3, ER-2
OMG	Greenland	2015 - 2020	G-III, C-20A, Single Otter
CORAL	Indian and Pacific oceans, Caribbean	2016, 2017	G-IV

TABLE 5 *EVS-2 Locations, Schedules and Aircraft.*

FIGURE 8 *EVS-2 Mission Locations.*

ATMOSPHERIC TOMOGRAPHY MISSION (ATom) – HARVARD UNIVERSITY (STEVE WOFSY)



From July 29 through August 23, 2016, ATom successfully completed 11 science flights on an around-the-world journey on NASA's DC-8 flying laboratory. Starting in Palmdale, California, the team journeyed to Anchorage, Alaska; Kona, Hawaii; American Samoa; Christchurch, New Zealand; Punta Arenas, Chile; Ascension Island; Terceira Island, Portugal; Kangerlussuaq, Greeland; Minneapolis, Minnesota; and back to Palmdale. The science flights were on average between 8-9 hours in length with over 91 science flight hours total. Over the course of the campaign more than 130 climbs and descents were performed, giving the mission scientists a thorough characterization of all levels of the troposphere.

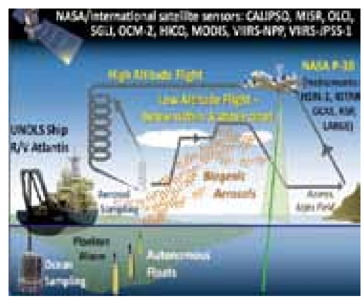
The main goal of ATom is to learn about how the most remote parts of the atmosphere are affected by pollutants emitted on land. Some stunningly dirty air was observed, even in the middle of the ocean, in the subtropics, and in the Arctic, with a lot of pollution coming from biomass fires. Clean air was also observed, especially in the Southern Pacific outside of New Zealand. However, even in the remote region of the Antarctic polar vortex, traces of pollution were detected.

ATom studies the movement and chemical processes that affect the top three greenhouse agents after carbon dioxide – methane, tropospheric ozone, and black carbon. This series of field campaigns will be the first time scientists will do a comprehensive survey of over 200 gases and aerosol particles all over the world. The majority of the air sampled will be over the Pacific and Atlantic oceans. This summer's trip was the first of four deployments, one in each season over the next three years.

***FIGURE 9** The ATom team back in Palmdale after completion of the first ATom field campaign.*

Data were collected that not only show where these hundreds of trace gases are hanging out and where they are going, but also how they interact with each other – creating new compounds or destroying others, like methane, and effectively removing them from the atmosphere. Taken together, the data will give the science community a better understanding of how these gases, many of which are pollutants, affect global climate change.

NORTH ATLANTIC AEROSOLS AND MARINE ECOSYSTEMS STUDY (NAAMES) – OREGON STATE UNIVERSITY (MIKE BEHRENFELD)



NAAMES is an interdisciplinary NASA Earth Venture Suborbital Program investigation resolving key processes controlling marine ecosystems and aerosols that are essential to our understanding of Earth system function and future change. The NAAMES investigation began in January 2015 and involves four field campaigns in the subarctic North Atlantic. The first of these campaigns was conducted in November 2015 and targeted a transition point in the annual cycle where phytoplankton biomass stops decreasing and the blooming phase is initiated. The November campaign also established a baseline low for atmospheric aerosols, against which aerosol levels measured during the other three campaigns will be compared. The second NAAMES campaign was conducted during May and June 2016. This second campaign also targeted a transition point in the annual cycle, but in this case corresponded to when phytoplankton biomass had reached its spring bloom climax and was beginning its declining phase. This campaign also documented aerosol properties during a period with strong contributions from ocean ecosystems.

NAAMES field campaigns consist of combined ship and aircraft field measurements that are aligned to specific events in the annual plankton cycle. Ship-based measurements are conducted on the UNOLS Atlantis research vessel and provide detailed characterization of plankton stocks, rate processes, and community composition. Ship measurements also characterize sea water volatile organic compounds, their processing by ocean ecosystems, and the concentrations and properties of gases and particles in the overlying atmosphere. These diverse data are extended over broader spatial scales through parallel airborne remote sensing measurements and in situ aerosol sampling that target ocean properties as well as the aerosols and clouds above. NAAMES science flights are based out of Saint Johns, Newfoundland, and are conducted on a NASA C-130 Hercules aircraft. Remote sensing instruments include the LaRC High Spectral Resolution Lidar (HSRL-1), the GISS Research Scanning Polarimeter (RSP), the GSFC Geo-CAPE Airborne Simulator (GCAS), and an AIMS multi-channel sun photometer. The airborne data crucially link local-scale processes and properties to the much larger scale of the satellite record (Figure 11 shows Atlantis and C-130 tracks during the NAAMES 2016 campaign). Integrating the NAAMES observations with state-of-the-art climate and ecosystems models enables the creation of a process-based foundation for resolving plankton dynamics in other ocean regions, accurately interpreting historical satellite records, and improving predictions of future change and their societal impacts.

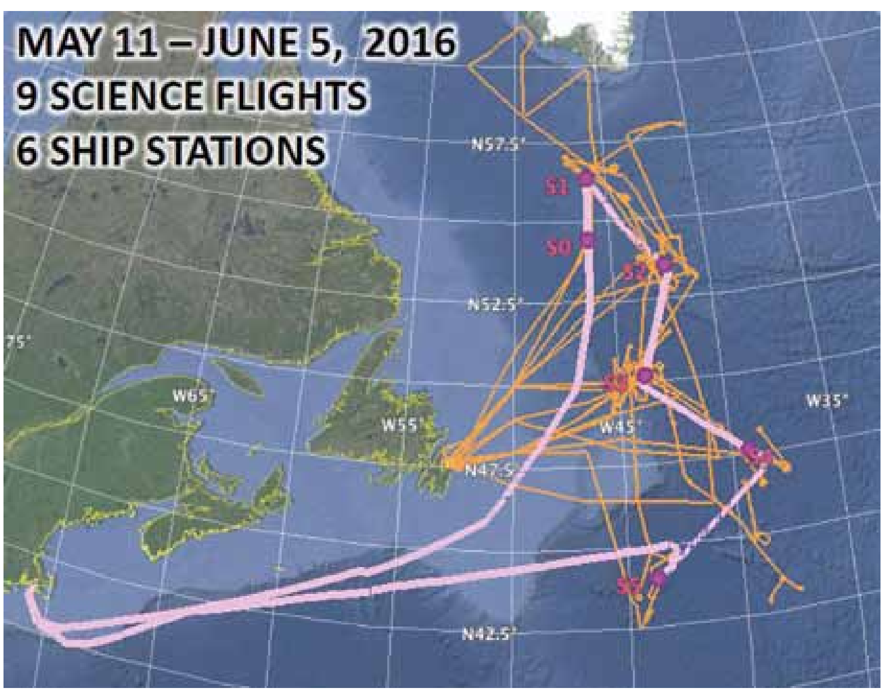


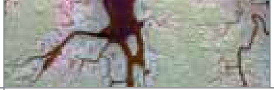
FIGURE 10 NAAMES 2016 science measurement tracks and intensive field sampling stations. *Heavy Pink Line = UNOLS Atlantis ship track. Thin Orange Line = C-130 Hercules science flight lines. Purple Dots = Intensive sampling stations (labeled S0 to S5).*

ATMOSPHERIC CARBON AND TRANSPORT (ACT)-AMERICA – PENN STATE UNIVERSITY (KENNETH DAVIS)

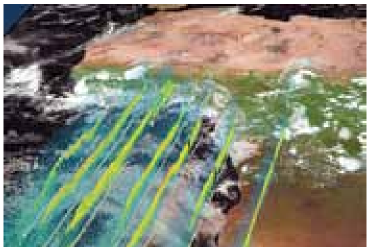
This investigation measures the sources of regional carbon dioxide, methane and other gases, and documents how weather systems transport these gases in the atmosphere. The research goal is to improve identification and prediction of carbon dioxide and methane sources and sinks using spaceborne, airborne and ground-based data over the eastern United States. Research flights use NASA's C-130 and UC-12 aircraft.

ACT-America concluded its first measurement campaign on August 29, 2016 after six weeks of science flights based out of LaRC, WFF, Lincoln, Nebraska, and Shreveport, Louisiana. The campaign gathered over 111 hours of data with in situ sensors on the LaRC B-200 aircraft and over 151 hours with in situ and remote sensors on the WFF C-130 aircraft. More than 270 vertical profiles of the atmosphere were collected between the two aircraft. Two of the more than 20 joint science flights were coordinated with overpasses of the Orbiting Carbon Observatory-2 (OCO-2) satellite. The team is now ramping up science analysis of the campaign data and preparing for the next campaign, scheduled to begin in January 2017. ACT-America includes significant contributions from LaRC personnel for aircraft operations, instrument operations, Atmospheric Vertical Observation of CO_2 in the Earth's Troposphere (AVOCET) and ASCENDS Carbonhawk Experiment Simulator (ACES) teams, and management.

FIGURE 11 *Langley B-200 and WFF C-130 paired for ACT-America flights.*



OBSERVATIONS OF AEROSOLS ABOVE CLOUDS AND THEIR INTERACTIONS (ORACLES) – ARC (JENS REDEMANN)



In late September 2016, the ORACLES team completed NASA's first airborne science deployment based in southern Africa in many years. The goal of the ORACLES project is to study the interactions between clouds and biomass burning aerosols.

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, immediately after its re-wing. The airfield in Namibia just finished a major improvement, with final recertification during the deployment. The ER-2 arrived in Walvis Bay in August 26, 2016, and the P-3 arrived the following day. Governmental delegations met both aircraft.

The P-3 flew a total of 15 science flights (115.2 hours), while the ER-2 flew a total of 12 science flights (97.3 hours) into and out of Walvis Bay. An unprecedented data set on aerosol and cloud microphysical properties was collected, revealing previously unconfirmed transport pathways and mixing into the Boundary Layer (BL) over the South East Atlantic Ocean, as well as radiative and microphysical interactions. Data analyses are only in their preliminary stage, but the aircraft sampled domains that were completely void of experimental data prior to ORACLES.

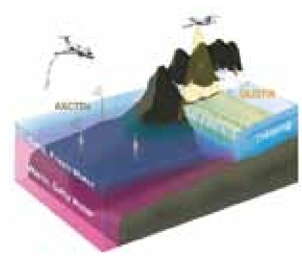
Flights were broadly divided into routine flights and target of opportunity flights. Routine flights followed the same northwestward initial flight line, so as to collect repeated measurements in the same location at a series of times and under varying conditions. The two aircraft together flew a total of 23 flights over the Atlantic Ocean in late August and September, with an attending team of over 100 persons. The instruments on the P-3 included HIGEAR and PDI (U Hawaii), APR-3 (JPL), RSP (GISS), 4STAR (ARC), SSFR (U Colorado), COMA (ARC) and a Suit of Cloud probes (U Illinois and UND). AMPR (MSFC), PTI (BNL), TAMMS (LaRC) and a water isotope probe (Oregon State) were added to enhance science return. The ER-2 payload included SSFR, HSRL-2, eMAS, RSP and AirMSPI. Many of the flights were coordinated, with the ER-2 flying high above the P-3 for portions of the day.

FIGURE 12 *P-3 and ER-2 flight tracks during the ORACLES-2016 deployment.*

ORACLES built on earlier relationships established during NASA's TRACE-A and SAFARI campaigns in the 90's and early 2000's. The Ministry of Higher Education, Training and Innovation served as the government host for the project and advocate to the Namibian Cabinet. The project team worked with the US Embassy to coordinate with the other ministries, including Environment & Tourism, Works & Transport, Fisheries, Presidential Affairs, and Safety & Security. The science team established new relationships with Namibian and southern African scientists from the Namibia University of Science & Technology, the University of Namibia, Gobabeb Training and Research Centre, and North West University

FIGURE 13 *Pilot Stu Broce with the Honorable Minister of Environment and Tourism, Phamba Shifeta.*

OCEANS MELTING GREENLAND (OMG) – JPL (JOSH WILLIS)



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 using aircraft including NASA's Gulfstream III. OMG flew three science flight missions in 2016: GLISTIN-A, AirGRAVITY and AXCTD.

GLISTIN-A Radar:

In March 2016, the JPL GLISTIN Radar was installed on JSC Gulfstream III (G-III). This Ka-band single-pass interferometer made high resolution, high precision elevation measurements of Greenland's coastal glaciers for the spring season. During the two-week March deployment, GLISTIN-A conducted eight glacier survey flights out of Kangerlussuaq (Sondrestrom Air Base), Keflavik (Iceland) and Thule Air Force Base. GLISTIN-A acquired 71.5 out of 82 planned flight lines over glaciers (87%), including all of the 16 high priority lines.

OMG's AirGRAVITY:

In 2016, OMG's airborne bathymetric survey was completed by OMG's contractor Sander Geophysics Ltd (SGL). The AirGRAVITY instrument, is a high precision airborne gravimeter producing a data set that was converted into a bathymetric data set. The AirGRAVITY instrument and aircraft are owned and operated by SGL.

SGL flew science missions over OMG's science area in the North West, North East and South East Greenland. SGL deployed from Kangerlussuaq, Keflavik, and Station Nord. SGL flew a total of 481 flight hours surveying more than 26,000 miles.

OMG's AXCTD:

In Spring of 2016, JSC installed an Airborne Expendable, Conductivity Temperature Depth (AXCTD) launch tube in the G-III. In June of 2016, OMG successfully launched four AXCTD probes into the Gulf of Mexico. The AXCTD probes acquire a Temperature and Salinity profile down to 1000 meters.

In September and October 2016, OMG deployed the AXCTD system to Greenland. OMG AXCTD launched 213 AXCTD probes around the perimeter of Greenland. The Gulfstream III deployed out of Kangerlussuaq, Thule Air Force Base, Svalbard (Norway) and Keflavik (Iceland). The G-III flew over 100 flight hours supporting OMG's AXCTD mission.

FIGURE 14 *Locations of AirGravity measurements.*

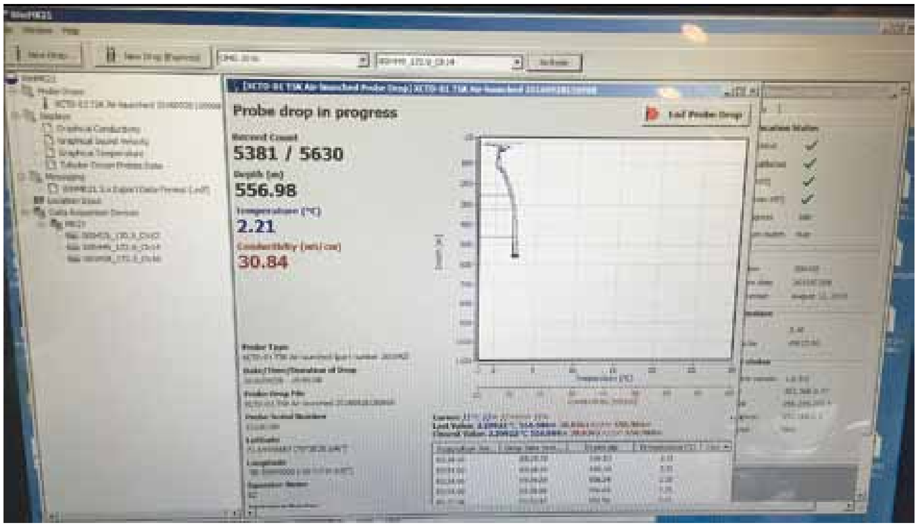


FIGURE 15 *OMG's AXCTD system acquiring data, North East of Nerlerit Inaat, Greenland.*

CORAL REEF AIRBORNE LABORATORY (CORAL) – BERMUDA INSTITUTE OF OCEAN SCIENCE, INC. (ERIC HOCHBERG)

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. CORAL flies PRISM, a new multispectral imager, on a contracted GIV aircraft.

In June 2016, in Hawaii, CORAL completed its Operational Readiness Test (ORT) and met all the criteria required for a successful field campaign, including coordinating efforts between airborne and in-water validation activities, completing multiple successful flight lines over target areas, and daily chain-of-communication protocols to ensure the seamless deployment of both airborne and in-water assets. Basically, the ORT was the "dress rehearsal" for the first full field campaign in the Great Barrier Reef.

CORAL then set up shop in Australia for a two-month investigation of the Great Barrier Reef, the world's largest reef ecosystem. A NASA airborne mission designed to transform our understanding of Earth's valuable and ecologically sensitive coral reefs, CORAL's three-year mission combines aerial surveys using PRISM, a state-of-the-art airborne imaging spectrometer technology developed by NASA's Jet Propulsion Laboratory, Pasadena, California, with in-water validation activities. The mission will provide critical data and new models for analyzing reef ecosystems from a new perspective. According to Principle Investigator Eric Hochberg "CORAL addresses an urgent need in the face of ongoing worldwide reef degradation, and also serves as a pathfinder for a future satellite mission to globally survey the world's reefs."

Mounted in the belly of a modified Tempus Solutions Gulfstream IV aircraft, the Portable Remote Imaging Spectrometer (PRISM) surveys reefs from an altitude of 28,000 feet (8,500 meters) to generate calibrated scientific data products. The aircraft was selected and specifically engineered so the PRISM instrument could be installed and operated from the plane while meeting strict requirements in terms of both airplane and instrument performance and preparedness (e.g., having on board systems that reduce the ambient temperature such that the PRISM instrument can stabilize prior to flight, etc.)

UAVSAR and AFRISAR 2016

The UAVSAR radar instruments are operated by the Jet Propulsion Laboratory (JPL). In 2016, UAVSAR's L-band radar, together with it's sibling instruments, the GLISTIN-A Ka-band radar and the AirMOSS P-band radar, supported 26 flight requests by conducting 57 flights aboard the NASA AFRC Gulfstream C-20A (NASA502) and 32 flights aboard the NASA JSC Gulfstream G-III (NASA2). This year, activities were more evenly spread across instruments with 455 lines collected with L-band, 204 flight lines collected with Ka-band, and 17 lines collected with P-band. The OMG mission accounted for the major increase in GLISTIN-A Ka-band radar demand with about 100 flight lines acquired for the mission. Overall, the UAVSAR team supported a broad community of scientists, as evidenced by the breakdown of flight lines across disciplines (see Figure 17).

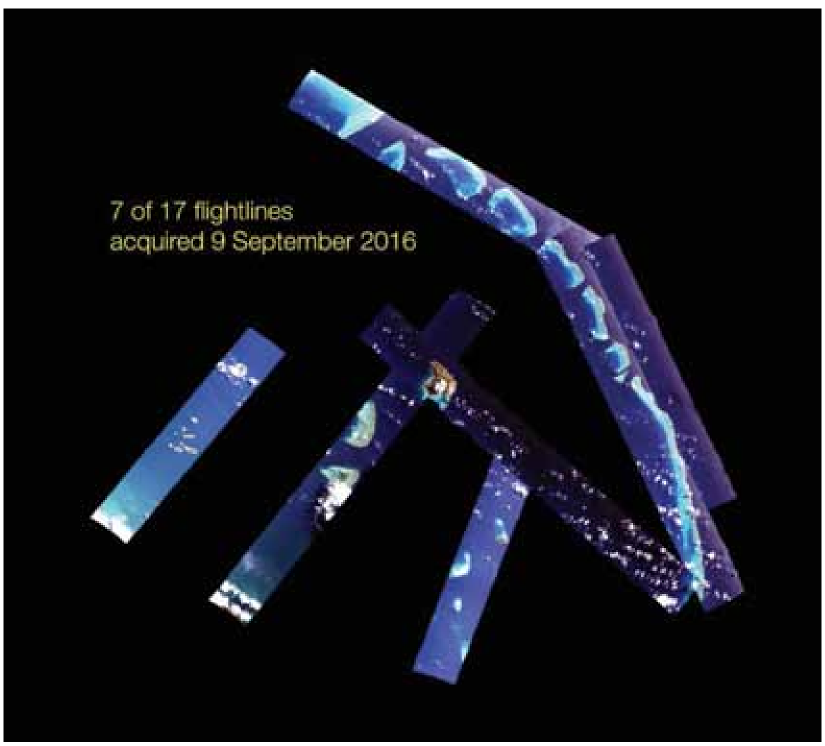


***FIGURE 16** Mosaic of PRISM data from the Great Barrier Reef.*

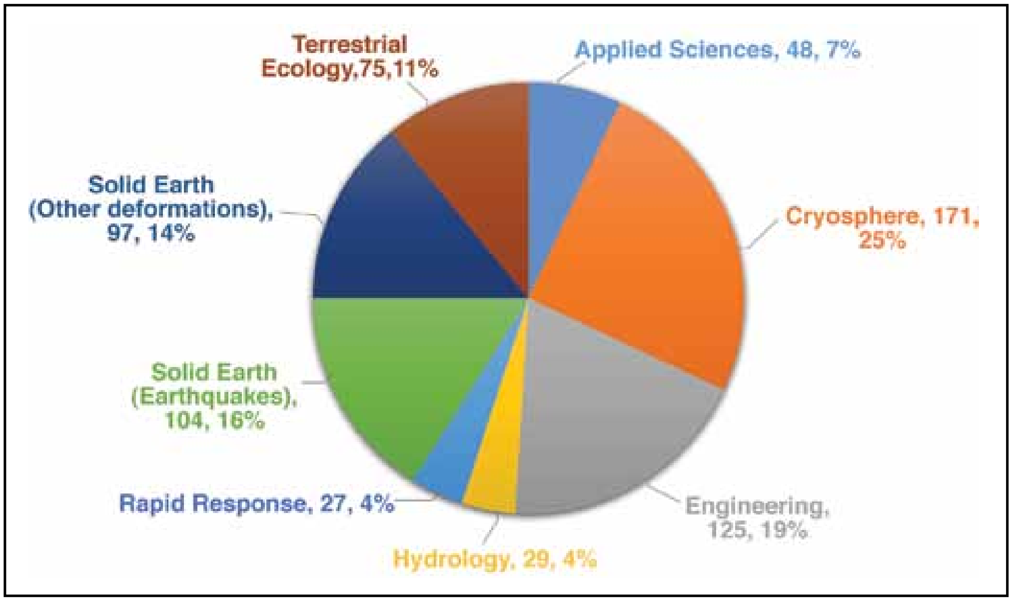


FIGURE 17 *Science and Application disciplines collecting UAVSAR data in FY16. The chart shows the number of flight lines per discipline, including P-, L-, and Ka-band instruments.*

The L-band facility instrument acquired a total of 9.78 TB of raw data, with 97.6% success in data acquisition. The production processing delivered 292 PolSAR science products, 161 requested InSAR pairs with average latency of 19 days, and 45 InSAR stacks with average latency of 31 days.

The UAVSAR team logged a total of 417 flight hours across the US, Mexico, Greenland, and Gabon, Africa. Images acquired during these deployments support new remote sensing algorithms that address significant knowledge gaps. Permafrost melting investigations were carried out in Alaska with both P- and L-band instruments. In February 2016, the UAVSAR team, aboard the C20-A aircraft, joined AfriSAR, a large collaborative effort with Goddard Soace Flight Center (GSFC), the Gabonese and European space agencies, to acquire data in Gabon. These data are currently being used to study tropical forest contributions to the carbon cycle. In parallel, the G-III crew flew to Greenland to support the EV-2 mission OMG, that aims at quantifying glacier melting and their contribution to sea level rise. In addition, continued observations over the Gulf Coast have shown sinking rates in the city of New Orleans.

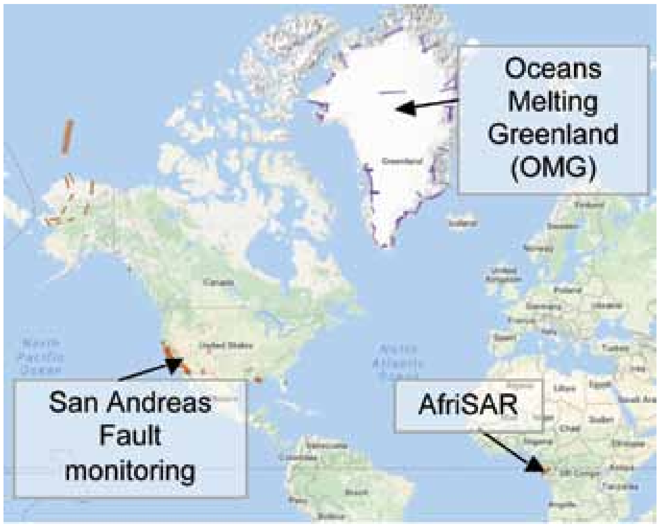
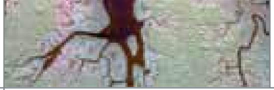


FIGURE 18 *Geographical extent of FY16 UAVSAR L-band flights and data acquisitions.*



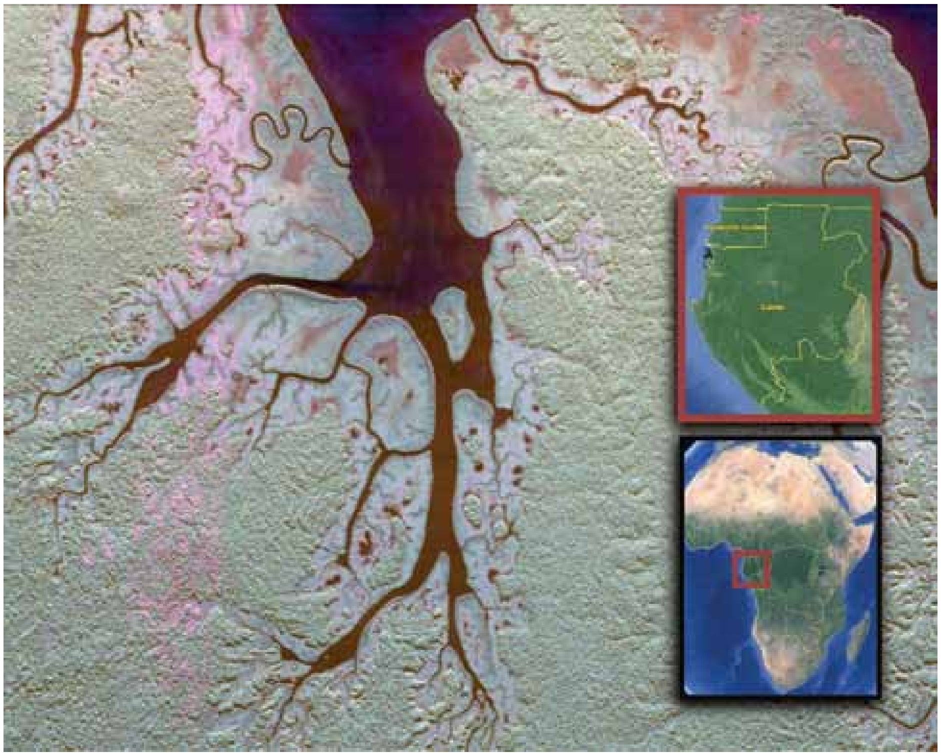


FIGURE 19 *UAVSAR L-band polarimetric image of Pongara National Park, Gabon, acquired during the AfriSAR deployment in February 2016. In this false color image, the contributions of 3 radar polarizations are displayed in red (HH), green (HV), and blue (VV). The interaction of the radar signal with tree trunks and canopies allows us to differentiate mangroves (purple-pink) from dry forests (green). Data can be found at: uavsar.jpl.nasa.gov/cgi-bin/data.pl*

VIRGAS

The Volcano Investigation Readiness and Gas-phase and Aerosol Sulfur (VIRGAS) mission on the JSC WB-57 aircraft took place in October 2015, with the first week for instrument integration and the second and third weeks for mission flights over Mexico and the Pacific off the coast of Mexico and Central America. The scientific payload consisted of five instruments: SO_2, Whole Air Sampler (WAS), H_2O, O_3, and Meteorological Measurement System (MMS). The VIRGAS payload was also flown in collaboration with the Office of Naval Research (ONR) Tropical Cyclone Intensity (TCI) experiment on three of their mission flights during the week of October 19-23, 2015.

Five science flights were successfully flown with a 3-hr test flight (ferry flight to Harlingen, TX) and a 1.5-hr aborted flight. In addition, the payload flew on the ONR TCI mission flights studying Hurricane Patricia (MMS three flights, O_3, SO_2 and H_2O two flights, and WAS one flight). Collaboration with the ONR TCI mission allowed the WB-57F to reach father south – 10.8°N from Harlingen, Texas instead of 18.5°N from Ellington Field. (See flight tracks in Figure 20.) ONR also contributed 18 dropsondes for one of the VIRGAS flights (VIRGAS flight #3). Total flight time was approximately 48 hrs.

FIGURE 20 *WB-57 Flight tracks during VIRGAS mission.*

The VIRGAS payload worked well overall during the mission. The NOAA SO_2 is a new instrument that had test flights in September as a piggy-back on four ONR TCI mission flights. A few minor problems were found and mitigated before the VIRGAS test flight. Another problem was observed during the VIRGAS test flight and fixed before the first science flight. The instrument performed very well on all subsequent flights, and achieved a lower detection limit of 2 ppt (10-s average) See Figure 21. The University of Miami (WAS), NOAA O_3 and NOAA H_2O insturments worked well throughout the mission. The MMS also participated in the VIRGAS and ONR TCI flights.

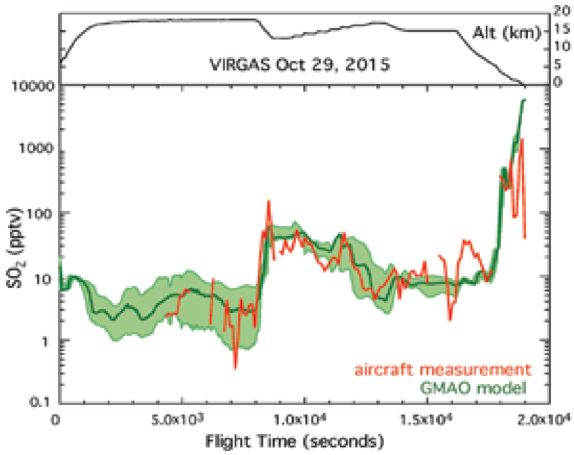


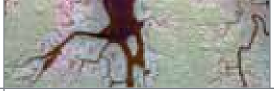
FIGURE 21 *WB-57F SO_2 measurements show good agreement with the GMAO model.*

AVIRIS and AVIRIS-NG 2016 Activities

In 2016, the Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) and the next generation instrument (AVIRIS-NG) flew a diverse set of science campaigns including surface spectroscopy and greenhouse gas studies. Operating since 1986, AVIRIS is an airborne imaging spectrometer that measures reflected solar radiation in the nadir viewing geometry from 400 to 2500 nm at 10 nm sampling. AVIRIS-NG became fully operational in 2015, offers 5 nm sampling, has flown on Twin Otter and King Air aircraft, and was integrated into the ER-2 in late 2016. The two instruments flew a total of over 500 hours in 2016.

In January and February of 2016, AVIRIS was deployed to quantitatively map methane emissions associated with an accidental release from the Aliso Canyon gas storage facility near Porter Ranch, California. Over multiple flight days, AVIRIS observed gas plumes extended many kilometers downwind of the main blowout. As part of this study, the Hyperion imaging spectrometer on board the EO-1 satellite also detected this event (Figure 22). The methane leak continued from 23 October 2015 until February 18, 2016 when the well was finally plugged.

As part of the Student Airborne Research Program (SARP), AVIRIS flew over burned regions from the Sherpa Fire in Santa Barbara County, California. This provided the opportunity for



students to evaluate impacts of the fire on watershed runoff and smoke on reflectance retrievals. In addition, students used 2016 data acquired for the HyspIRI Preparatory Airborne Campaigns to classify agriculture in the Central Valley, develop hyperspectral indices sensitive to changes in soil moisture, and evaluate hyperspectral indicators of conifer mortality due to beetles in the Sierra Nevada.

AVIRIS-NG was in India in early 2016 and completed a three-month airborne campaign (300 flight hours) collecting imaging spectroscopy measurements for 57 sites. These sites were selected to represent a diverse set of imaging spectroscopy datasets, including coastal zones, forests (including mangrove), exposed soils and mineralogy, agricultural, and urban areas. This project continues the collaboration between NASA and the Indian Space Research Organization (ISRO) (Figure 23).

There were a number of additional campaigns with AVIRIS-NG, including Wisconsin flights to study forest canopy chemistry. In addition, AVIRIS-NG flew with UAVSAR and ASO as part of a ground subsidence study in Louisiana. This study represents a pre-satellite test mission for NISAR, SWOT, and HyspIRI.

FIGURE 23 *ISRO and JPL team members in Coimbatore India.*

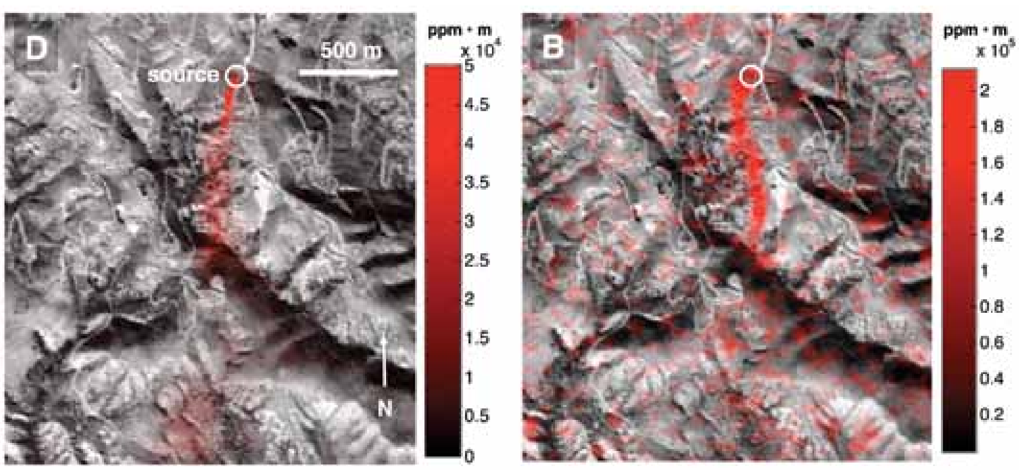


FIGURE 22 *Quantitative mapping of methane plume from Aliso Canyon blowout using AVIRIS on 12 January 2016, 20:25 UTC (left) and Hyperion on 1 January 2016, 16:39 UTC (right). From Thompson et al. (2016).*

Support to ESD Satellite Missions, including Decadal Survey Missions

A primary purpose of the Airborne Science Program is to support Earth Science space flight missions, usually satellite missions, but now also sensors flying on the International Space Station (ISS). This support includes airborne campaigns to collect data for algorithm development prior to launch, to test instrument concepts for satellite / ISS payloads or airborne simulators, and to provide data for calibration or validation of satellite algorithms, measurements or observations once in orbit. In 2016, ASP provided support to Earth Science missions as listed in Table 6. This included significant flight hours for upcoming Decadal Survey missions.

Satellite or space mission	ASP Mission	Aircraft	Flight hrs	Location	Purpose
Decadal Survey					
SMAP	SMAPVEX-16, SLAPEX-freeze//thaw, AirMOSS	DC-3; B-200; G-III	132.3	Iowa, Canada, Alaska	Cal/val
ICESat-2	Operation IceBridge	NOAA P-3, Falcon, GV	571.4	Greenland, Canada, Alaska	Precursor data set, data continuity
SWOT	AirSWOT; GLISTIN	B-200; G-III	74.8	California, Louisiana, Alaska, Oregon	Algorithm development
HyspIRI	HyspIRI airborne precursor; SARP	ER-2	64.8	6 boxes in California	Precursor data sets
NISAR	UAVSAR	C-20A	400	Numerous CONUS, Greenland, Africa	Precursor data sets
GEO-CAPE	KORUS	B-200	191.4	South Korea	Algorithm development
ASCENDS	ASCENDS-16	DC-8	9.4	California, Nevada	Instrument test
ACE	RADEX; ORACLES; SPEX Airborne	ER-2	194.7	Washinton, Namibia, California	Instrument test; data collection
PACE	PRISM AITT; ORCAS, SPEX Airborne	ER-2, NCAR GV	7.6	California	Precursor data set, polarimetry data
3-D Winds	ATHENA-OAWL	WB-57	38.5	Gulf coast	Instrument development
Other					
GPM	OLYMPEX / RADEX	ER-2, DC-8, UND Citatiion	237.1	Washington state	Cal/val
Suomi-NPP	VIRGAS	WB-57	31.9	Mexican coasts	Process development
CALIPSO	HSRL-2 flights	B-200	6.6	California	Instrument test / Validation
TEMPO	KORUS	DC-8	189.2	South Korea	Precursor data sets
OCO-2	ACT-America, ATom, ASCENDS-16, KORUS, AJAX	C-130, B-200, DC-8, AlphaJet	319.2	Global	Cal/val
AQUA / TERRA	KORUS, emas & HIS integration	ER-2	195.8	South Korea, California	Cal/val
AURA	KORUS, VIRGAS, ASMLS	DC-8; WB-57; ER-2	201.0	South Korea, Mexico	Cal/val
LANDSAT	AVIRIS underflights	ER-2	13.7	California	Cal/val
CRYOSAT-2	OIB, GLISTIN, Beaufort Sea UAVSAR	G-III, P-3, GV	47.2	Greenland, Alaska	Cal/val

***TABLE 6** Satellite / Space mission support.*

SMAPVEX-16

NASA's Soil Moisture Active Passive (SMAP) mission has been successfully providing global volumetric soil-moisture estimates for nearly a year and a half. Soil moisture information is provided by brightness temperature measurements from the passive radiometer instrument operating at L-band (1.4GHz). In order to validate and improve the retrieval model giving soil moisture estimates from SMAP brightness temperatures, the mission has a comprehensive calibration and validation (Cal/Val) ground-based network that provides sensor measurements over various soil-types and vegetation density.

The SMAP Validation Experiment 2016 (SMAPVEX16) airborne campaign was recently undertaken to satisfy multiple mission objectives. SMAPVEX-16 will provide measurements of cal/val sites at a much higher spatial resolution that will allow further investigation of anomalous SMAP retrievals. SMAPVEX-16 was performed over two cal/val domains (Iowa-IA and Manitoba-MB) that exhibited larger errors with respect to the passive soil moisture retrievals. These domains exhibit a variety of soil moisture and vegetation conditions. The higher spatial resolution data provided by an aircraft campaign also allows the evaluation of alternative disaggregation approaches from the current 36-km scale to a finer spatial scale.

The SMAPVEX-16 campaign was conducted from May 24 to August 16, 2016. Each domain was visited twice for a two-week period, providing data during different stages of crop growth. A total of 27 science flights and over 130 flight hours were conducted. The airborne grids were based on the SMAP grid dimensions (about 40 km by 30 km). SMAPVEX-16 was conducted with the JPL Passive Active L-band System (PALS) scanning instrument. The PALS instrument has features similar to the SMAP instrument. PALS was installed on a DC-3 aircraft owned and operated by Airborne Imaging, Inc. (see Figure 24).

Preliminary analysis shows that SMAPVEX-16 produced exceptional high-resolution soil-moisture change data within the experiment domains that correlate well with the SMAP measurements. Figure 25 shows two days of PALS brightness temperature on a grid over Carman, MB separated by three days after a wetting (rain) event.

FIGURE 24 *Airborne Imaging Inc. DC-3 with the PALS radome underneath the aircraft.*

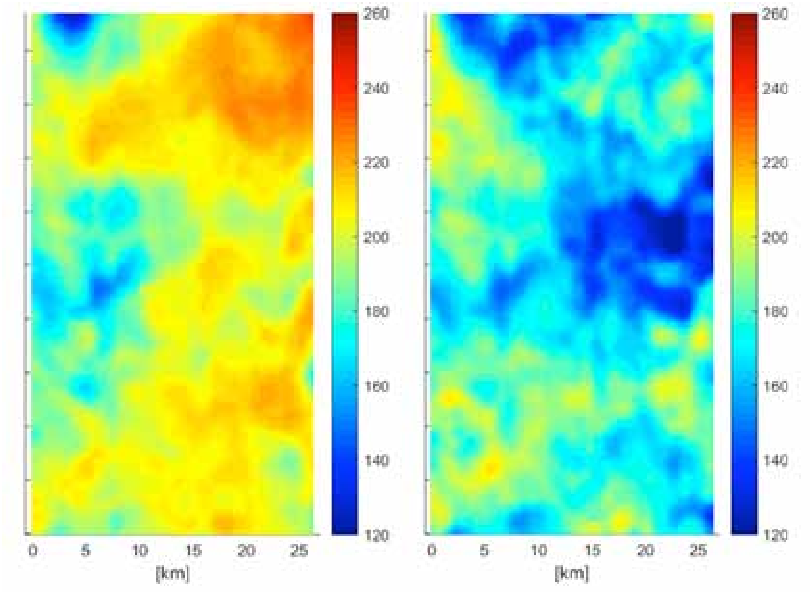


FIGURE 25 *A Horizontal polarization brightness temperature observed over the experimental domain in Carman, MB over a three-day gap (June 16 and June 19) with PALS. The units are in Kelvin.*

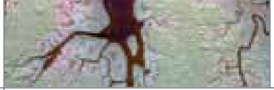
The spatially heterogeneous soil-type, vegetation and precipitation pattern impact the soil moisture retrieval by PALS and SMAP. The SMAP mission cal/val team is currently analyzing these effects.

SLAPex Freeze/Thaw

November 2015 saw the first campaign dedicated solely to observing frozen and thawed soil with active/passive microwave sensors as well as ground truth. The SLAPex Freeze/Thaw campaign was conducted with the Scanning L-band Active/Passive (SLAP) instrument developed at NASA GSFC flying on a B200 from NASA LaRC. Other participants included an international group of researchers and ground truth teams from Agriculture Canada, Environment Canada, University of Guelph, University of Sherbrooke, George Mason University, and City College of New York.

The SLAP instrument uses a thin directional array antenna and hardware adapted from the SMAP and Aquarius missions to mirror the scan geometry and data products of the SMAP satellite. With its unique low-profile design, it has flown over 30 flights on both the B200 and the UC-12B at NASA LaRC and can be easily adapted to a variety of other aircraft.

The region of study was coincident with the area used during SMAPVEX 2012. Just southwest of Winnipeg, Manitoba, the region is dominated by annual crops, grasslands/pasture, and some deciduous forests. During the November 2015 campaign, the post-harvest bare soil froze overnight into the early morning and thawed throughout the day. The NASA team flew a total of 22 flight hours over twelve science flights: six early morning flights during frozen soil conditions, and six afternoon flights during thawed soil conditions, while the ground truth teams measured soil properties like temperature, moisture, and roughness.



ASCENDS-16

The ASCENDS measurement team conducted a successful science campaign on the NASA DC-8 from Palmdale, California during February 2016. The objectives of the ASCENDS campaigns were to demonstrate accurate lidar remote sensing measurements of atmospheric CO_2 in the nadir column from the aircraft to the surface. The ASCENDS airborne campaigns allow assessing the performance of different lidar approaches in flights over the wide variety of surface and atmospheric conditions expected for the ASCENDS space mission.

The primary science instruments for the 2016 airborne campaign were the NASA GSFC CO2 Sounder lidar and LaRC's AVOCET CO_2 in-situ instrument. Since 2014, the CO2 Sounder team made several improvements to the lidar that improved the lidar's measurement precision by a factor of 3. The team also added a new capability by using 15 wavelengths to sample the CO_2 line, and an experimental mode with a second laser amplifier that allowed twice the laser power. Two other science instruments from NASA LaRC (the Diode Laser Hygrometer (DLH) and COLAS, instruments, led by Glenn Diskin) also flew as piggyback payloads.

The campaign flew its initial flight on February 10 over the California Central Valley and Edwards Air Force Base (AFB). The flight was 4.5 hours long and included several passes North-south over the Central Valley along with spiral-down maneuvers over Castle Airport and Edwards AFB. This flight allowed testing the new measurement modes of the lidar.

The campaign then conducted its second flight on February 11. The objectives were to measuring atmospheric column CO_2 from the aircraft over a cold and smooth snow surface. The capability to measure atmospheric CO_2 to snow surfaces is important to assess concentrations and fluxes during winter in the northern hemisphere. Such measurements are not available from passive CO_2 sensing satellites because the sun angles during the winter are low, and because the snow surfaces are dark in the infrared. The second flight targeted a widespread area of fresh cold snow in a high desert area near Elko, in the northeast corner of Nevada. The flight was six hours long and had six north-south passes over flat snow areas at altitudes from 8 to 12 km above sea level, as well as a spiral down maneuver over the Elko, Nevada airport.

All science instruments worked well during the campaign. Analysis of the measurements from the CO2 Sounder lidar showed accurate measurements over the snow fields at all sun angles and in darkness, and showed the best performance to date (random errors and biases < 1 ppm) made over Edwards AFB.

FIGURE 26 *Ground track for the second ASCENDS Flight over North Eastern Nevada.*

FIGURE 27 *Anand Ramanathan (standing) and Bill Hasselbrack (seated) of the CO2 Sounder team monitor the operation of the lidar during a flight.*

HyspIRI Preparatory Airborne Studies

During June 2016 the Hysperspectral Infrared Imager (HyspIRI) Airborne Preparatory Campaign conducted a single season of flights over the California and Nevada boxes. There are five boxes, and one simulated satellite track, which represent a seasonal collection for the campaign. The HyspIRI Airborne Preparatory Campaign was conducted from 2013 through 2015, and each year three seasons worth of collection over the five boxes (plus one satellite track line) were conducted. Due to the extreme drought in California, the SMD Earth Science Division funded a fourth year with one season's collection. The goal was to capture the end of the drought, and the return of the vegetation from the dry conditions.

The 2016 flights were again conducted on NASA AFRC ER-2 with the Classic Airborne Visible and Infrared Imaging Spectrometer (AVIRIS-C) and the MODIS ASTER Airborne Simulator (MASTER) from AFRC in Palmdale, California. The flights were also coordinated with the Student Airborne Research Program (SARP) so that they students could use the remote sensing data from AVIRIS-C and MASTER.

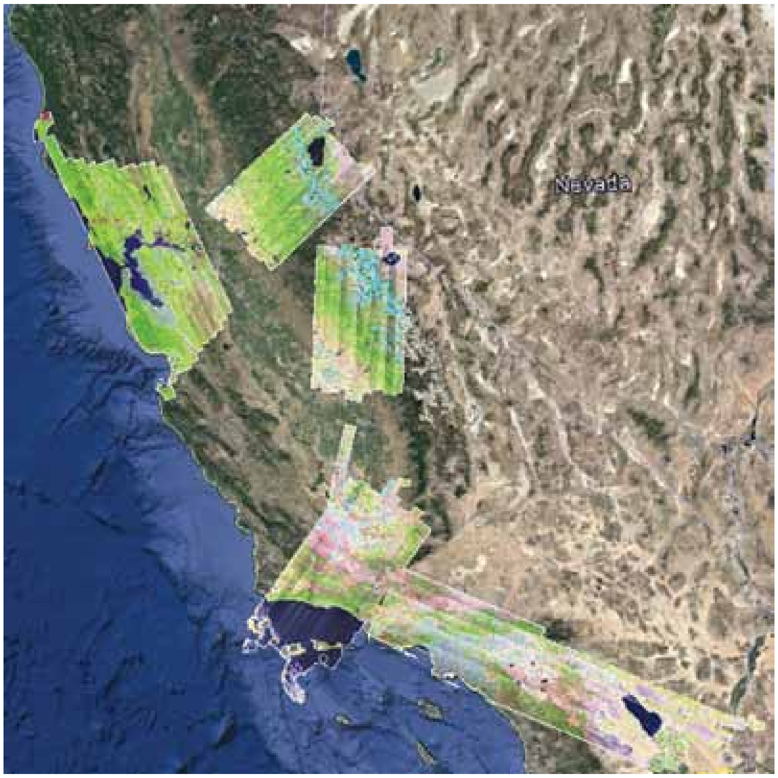


FIGURE 28 *A color-composite of AVIRIS flight lines from the 2016 summer seasonal HyspIRI data collection. The sites range across the state of California, clockwise from upper left: San Francisco Bay Area, Lake Tahoe, Central Sierra, Southern California, and Santa Barbara.*

AirSWOT

AirSWOT is a simulator instrument for the Surface Water and Ocean Topography (SWOT) satellite mission, which is currently in formulation. In FY16, AirSWOT conducted 17 flights in 64.2 flight hours. It successfully acquired 147 flight lines to support three flight requests and acquired over 17TB of raw radar data along with 6,541 IR camera images.

In February, there were five flights over the Gulf of Mexico. Three of the flights were under flights of the SARAL/Altika altimeter. Two flights were focused on observing a front in the waters of the Gulf in coordination with the MASS airborne laser altimeter (operated by Scripps/UCSD) and surface assets operated by CARTHE/LASER experiment. Figure 29 shows the flight region of AirSWOT in the Gulf of Mexico.

In March and April, AirSWOT flew over Mono Lake as well as nearby Grant and June Lakes to support SWOT mission to better understand the impact of topographic layover on phase/height and coherence measurements. We also collected IR camera data to aid in phenomenology studies. In addition, AirSWOT imaged Tuolumne River Basin area jointly with ASO and UAVSAR in a multi-aircraft mission to develop new approaches for measuring snow density, snow depth, and snow water equivalent (SWE) with radar remote sensing techniques. This development targets advancing the scientific potential of SWOT and NISAR, and providing the path to space for a global SWE measurement system. Field data were co-collected during each snow collection to assess snow condition, such as snow depth and snow density.

***FIGURE 29** Flight regions for AirSWOT in the Gulf of Mexico.*

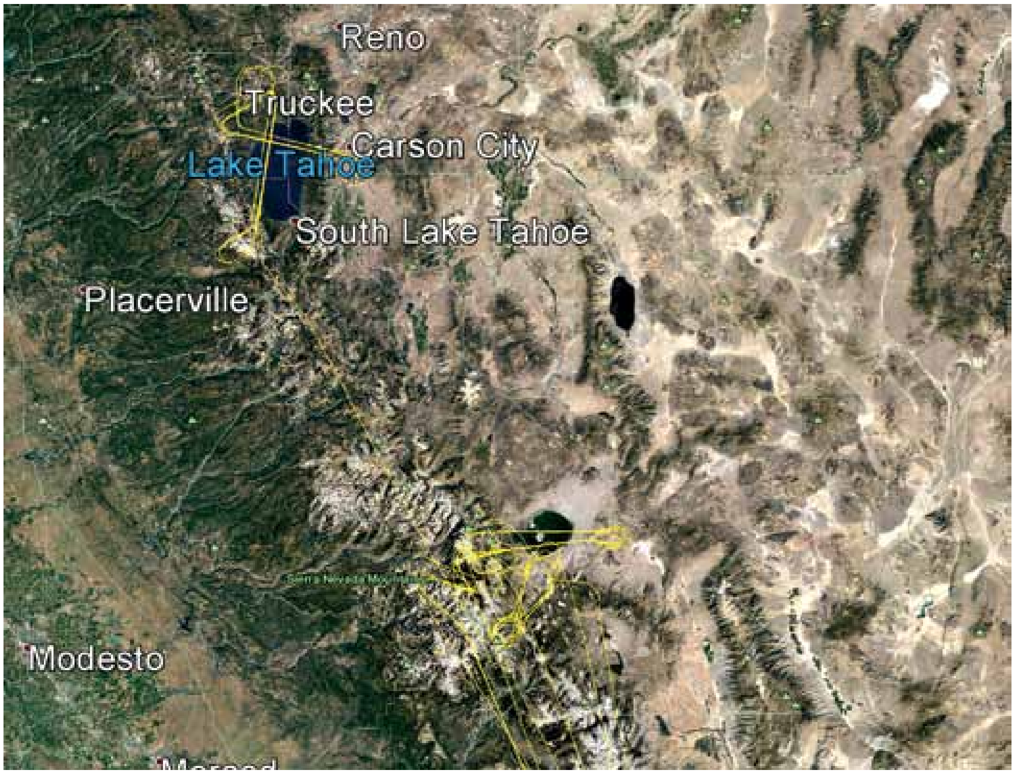
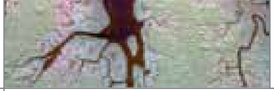


FIGURE 30 *Flight regions for AirSWOT over lakes and rivers in the SIERRA Nevada.*

NISAR

The NASA-ISRO (NISAR) mission, a joint mission between NASA and ISRO, is scheduled to launch in 2020. Using advanced radar imaging that will provide an unprecedented, detailed view of Earth, the NISAR satellite is designed to observe and make global integrated measurements of the causes and consequences of land surface changes related to some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes and landslides.

The most relevant airborne support for NISAR is JPL's L-band UAVSAR system. Currently, the L-band SAR flies most frequently on the AFRC C-20A (G-III) aircraft, but has also flown on the JSC G-III. In 2016, numerous UAVSAR geodesy missions were deemed to provide early data in support of NISAR, including the AfriSAR mission to Gabon. In 2017, participation of UAVSAR in the ABoVE mission will also contribute data relevant to planning for NISAR.



Support to Instrument Development

Another major element of the ASP program is the support of instrument development for Earth Science. Some instruments are developed specifically for airborne utilization, while many are developed as precursors or simulators for satellite instruments. In 2016, ASP aircraft flew all of the instruments listed in Table 7. Many of these instruments have been developed under sponsorship of NASA's Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP) and Airborne Instrument Technology Transition Program (AITT). ESTO demonstrates and provides technologies that can be reliably and confidently applied to a broad range of science measurements and missions. Through flexible, science-driven technology strategies and a competitive selection process, ESTO-funded technologies support numerous Earth and space science missions.

Many of the instruments developed under ESTO IIP funding require test flight in conjunction with ASP before moving to further maturation for space missions. A large number of other IIP-selected instruments are also scheduled for test flights in 2017 and 2018, as shown in the 5-year plan (Appendix B). Instruments selected in the IIP-2016 solicitation, along with instruments selected in the Sustainable Land Imaging and AITT-2016 solicitations, will be test flown in 2019 or 2020.

Several other instruments, not part of the ESTO program, were demonstrated and matured in 2017. These include AVIRIS-ng, CARAFE, and MALIBU.

Instrument	Sponsor	Aircraft	Flight Hours
	ESTO		
WISM	IIP	Twin Otter	9.7
EXRAD	IIP	ER-2	5.6
Methane Sounder	IIP	DC-8	5.4
ATHENA-OAWL	IIP	WB-57	38.5
AirMSPI	IIP	ER-2	15.2
HDSS	IIP	WB-57	15.8
Doppler Scatt	IIP	B-200	42.1
PRISM	AITT	ER-2	3.9
HSRL-2	AITT	ER-2	6.6
Fluorescence AITT	AITT	ER-2	7.3
	Other		
GSFC CO2 Sounder, LaRC AVOCET, LaRC DHL, COLAS	Upper Atmosphere Reserach Program	DC-8	9.4
AVIRIS-ng	Terrestrial Ecology	B-200	13.1
SPEX	SRON	ER-2	3.7
eMAS and HSI	Earth Observing System (EOS)	ER-2	6.4
CARAFE	GSFC	Sherpa	36.4
MALIBU	GSFC	Tempest UAV	1.9

TABLE 7 *Instrument development flights in FY16.*

CARbon Airborne Flux Experiment (CARAFE)

The CARbon Airborne Flux Experiment (CARAFE) was flown in September 2016 on the NASA LaRC C-23B Sherpa. The CARAFE objectives were to: 1) assemble a versatile, economical airborne system for quantifying greenhouse gas (GHG) sources/sinks over a spectrum of ecosystem states; 2) evaluate biophysical process models and parameterizations; and 3) validate top-level satellite flux products from OCO-2 and other missions. More specifically, we measured levels of carbon dioxide (CO_2), methane (CH_4), water (H_2O) and winds for the estimation of exchange rates (fluxes) of these gases between the atmosphere and the surface.

A total of nine CARAFE science flights were flown between September 7 and 26, 2016 from the NASA Wallops Flight Facility. The CARAFE payload included:

- *Los Gatos Research CH_4/H_2O and CO_2 integrated cavity optical spectroscopy (ICOS) analyzers, modified for airborne fluxes*
- *Picarro CO_2 cavity ringdown analyzer (accuracy standard)*
- *Laser open-path fast H_2O sensor (G. Diskin and J. DiGangi, NASA LaRC)*
- *Turbulent Air Motion Measurement System (TAMMS), air motion sensors, including pressure transducers, AoA, and TAT*
- *High-quality inertial navigation system for 3-D wind calculations*
- *Flir Camera, Vegetation Camera, and Nikon Camera*
- *Li-COR Photosynthetically Active Radiation (PAR) sensor*

The nine CARAFE flights had a total of 36.4 science flight hours (~4 hours per flight). Figure 31 shows these flights color-coded by date.

The first flight was specifically designed to test instrument systems performance, perform air motion calibration maneuvers, and characterize variations of mean fields and fluxes for GHGs, water, and heat at different altitudes over the relatively uniform Pocomoke forest region. Additional flights were designed to measure fluxes over the Pocomoke Forest and surrounding farms on the Eastern Shore of the DelMarVa Peninsula. These flights allowed comparisons of fluxes under slightly differing conditions, and allowed the science team to characterize the behavior of the boundary layer in this region. Another flight obtained fluxes over the relatively flat, extensive agricultural region across northern portion of the DelMarVa Peninsula. This flight was also coordinated with flux tower observations at the USDA Choptank and University of Delaware St. Jones Reserve sites. The latter provides H_2O, CH_4 and CO_2 tower fluxes and a test sample of flux over tidal marsh. Figure 32 shows flux estimates along the E-W track in this region. The H_2O flux is positive, while the CO_2 flux is negative as vegetation takes up CO_2. Substantial CH_4 fluxes were also observed over marshland at the far east and west ends of the track.

The final CARAFE flight was designed to measure fluxes over open ocean water, coastal areas, and Chesapeake Bay. CH_4 fluxes were near zero over the open water, an important flux null detection test. No major CH_4 enhancements were observed coming off the salt marsh regions, Bay water, or Chester during this flight. Overall the instrument payload performed extremely well, and the use of the C-23 Sherpa as a flux measurement system was proven.

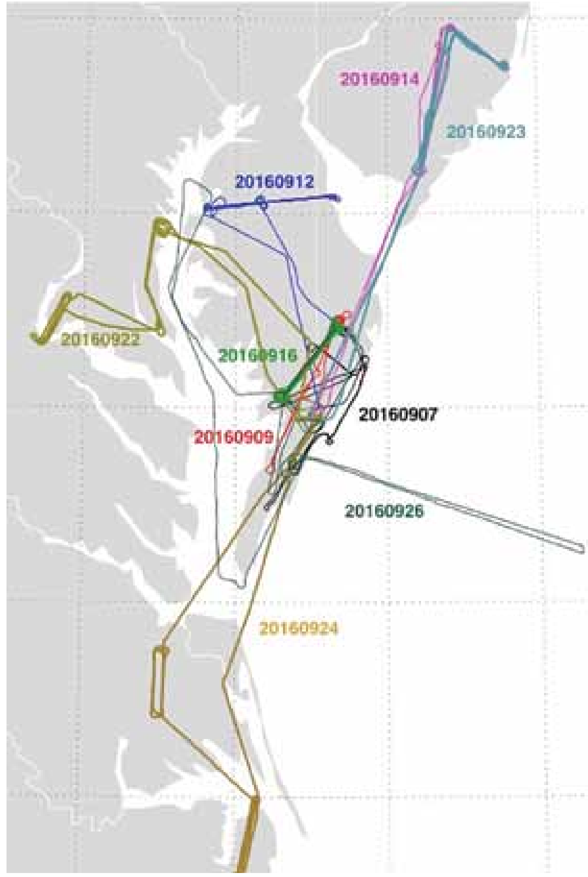


FIGURE 31 *CARAFE flight tracks for September 2016.*

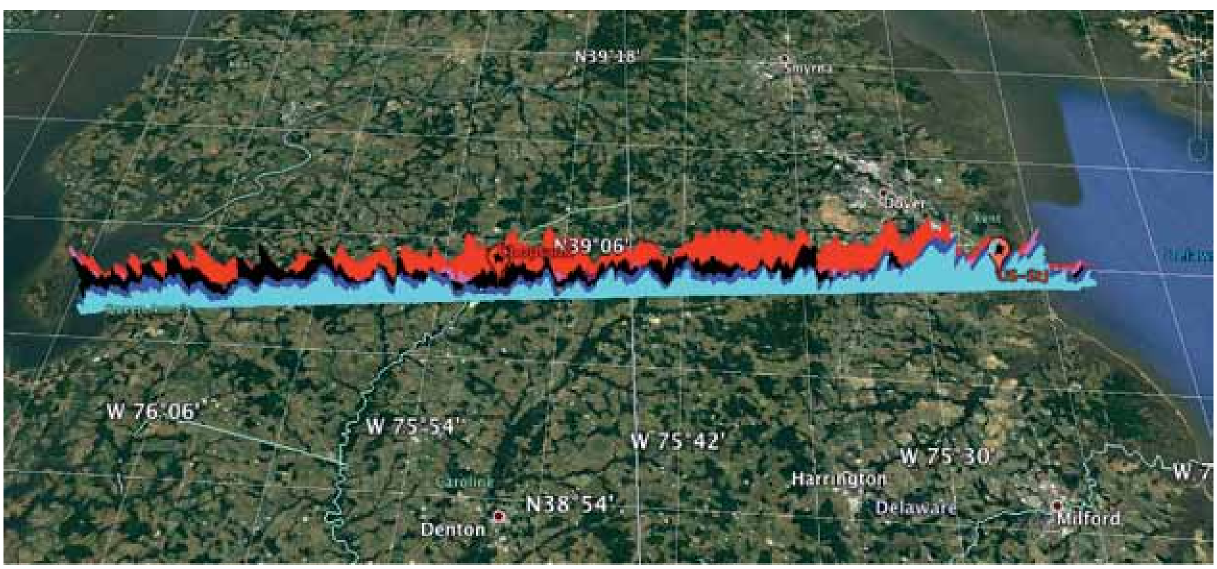


FIGURE 32 *Flux measurements from the CARAFE flight of Sept. 12, 2016 (see blue track in Figure 31). Temperature flux (red), CO_2 flux (black), LGR H_2O flux (blue), DLH H_2O flux (cyan), and CH_4 flux (magenta). The negative of the CO_2 flux is plotted because CO_2 is being taken up by the vegetation at this time of the year.*

2017 Upcoming Activities

ABoVE

A major upcoming mission in 2017 is the Arctic-Boreal Vulnerability Experiment (ABoVE). ABoVE is a NASA Terrestrial Ecology Program field campaign being conducted in Alaska and western Canada over the next decade. It is a diverse large-scale study of the impacts of environmental change on Arctic and Boreal terrestrial and freshwater ecosystems. Research will be based on analysis of data from airborne and spaceborne remote sensing data collection, as well as field-based observations. The first series of airborne activities is scheduled for early 2017 and includes six different aircraft carrying numerous instruments. The aircraft include: both NASA G-III aircraft, two B-200 aircraft, a Twin Otter, and a Mooney airplane. The ABoVE study domain is shown in Figure 29.

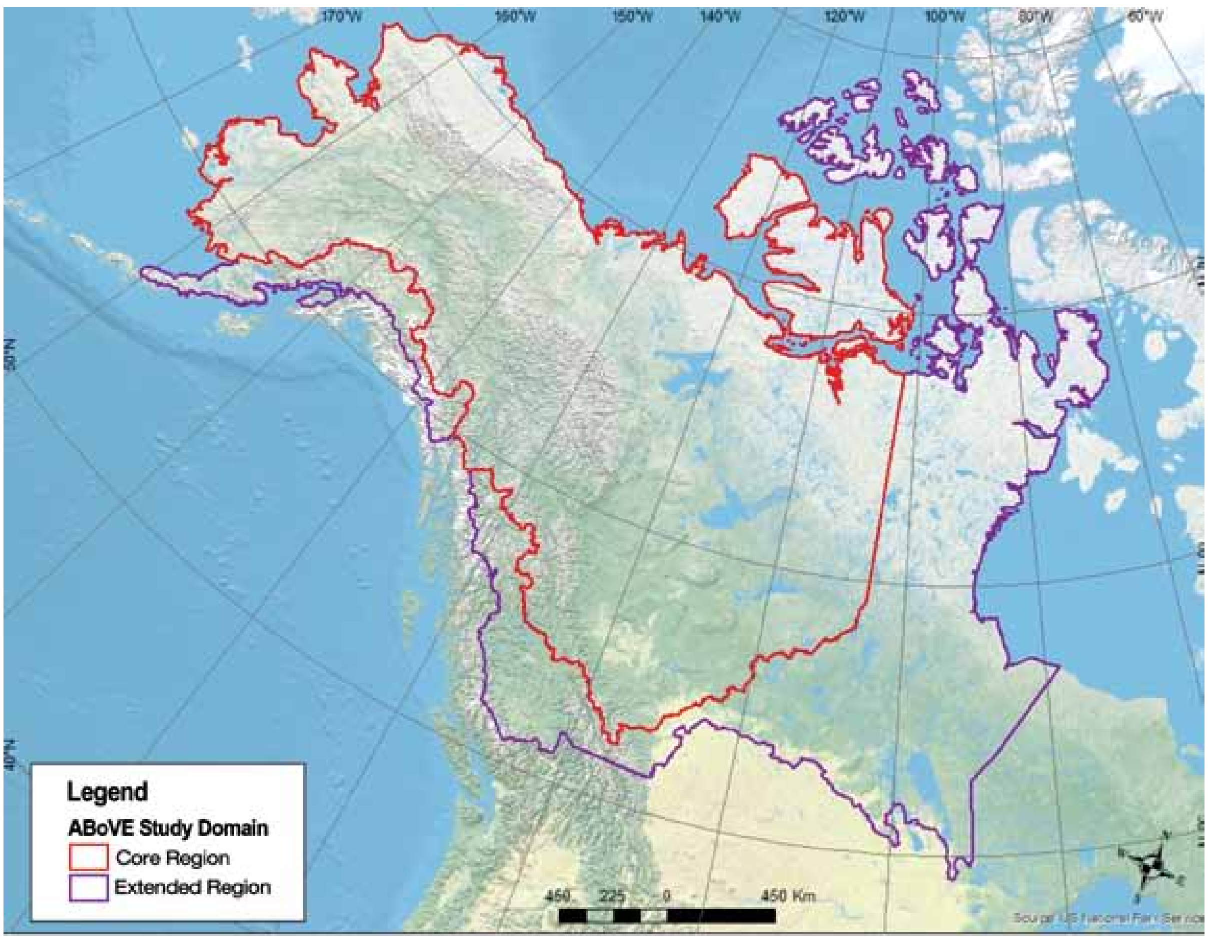


FIGURE 33 *ABoVE Study Domain.*

SNOWEX

SnowEx is a multi-year airborne snow campaign. The overarching question that SnowEx will address is: How much water is stored in Earth's terrestrial snow-covered regions? We will use a unique combination of sensors, including LiDAR, active and passive microwave, an imaging spectrometer and infrared sensors to determine the sensitivity and accuracy of different remote sensing techniques for measurement of snow water equivalent (SWE). Ground-based instruments, snow field measurements and modeling will all also be required to help address the science questions.

A large fraction of snow-covered lands are forested, however most remote sensing techniques have found forested areas challenging. But recent developments, like LiDAR, have opened up new possibilities. And even passive microwave has shown to have more promise in forested areas than previously thought. Since the SnowEx research community wants to fully understand the various techniques, focusing on the challenges presented by forests is the perfect opportunity to collect a unique dataset that will help address the science questions and enable snow mission design trade studies, which would otherwise be hard to justify.

"Winter 1" activities will take place from February 6-24, 2017. The full suite of sensors will fly in February 2017 to collect multi-sensor observations in dry snow conditions. The focus of Year 2 (FY18) will be analysis of Year 1 data and planning of future activities. Minor targeted additional observations might be undertaken to fill critical gaps needed for analysis.Further airborne and ground data collection would continue in 2019-2021. In Year 1, the SnowEx field and aircraft campaign will take place in Grand Mesa, Colorado, with a secondary site located at Senator Beck, Colorado.

Aircraft selected for SnowEx will be an NRL P-3 and UAVSAR on one of the G-III aircraft, and possibly others.

IIP and AITT

A number of Instrument Incubator Program (IIP) awarded instrument projects are scheduled for test flight in 2017. These include HAWK-OAWL, WISM, SoOP-AD, and ASMLS. These prepare for upcoming space missions.

Other major missions in 2016

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

Mission	Aircraft	Location
CPEX	DC-8	Caribbean
Operation IceBridge	P-3, DC-8	Antarctic, Arctic
HyspIRI Airborne - tropical	ER-2	Hawaii
CORAL	G-IV	Palau, Hawaii
ATom	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	South Atlantic, Namibia

TABLE 8 *Other major missions in 2017.*

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
	Global Hawk (2)	NASA-AFRC	30	1900	25,600	65,000	345	11,000	http://airbornescience.nasa.gov/aircraft/Global_Hawk
	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
	Gulfstream III (G-III)	NASA-JSC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_-_JSC
	Gulfstream V (G-V)	NASA-JSC	10	8,000	91,000	51,000	500	>5,000nm	
	HU-25C 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
	T-34C	NASA-GRC	3	100	4,400	25,000	150	700	http://airbornescience.nasa.gov/aircraft/T-34C
	Twin Otter	NASA-GRC	3	3,600	11,000	25,000	140	450	http://airbornescience.nasa.gov/aircraft/Twin_Otter_-_GRC
	UH-1	NASA-GSFC	2	3,880	9,040	12,000	108	275	https://airbornescience.nasa.gov/aircraft/UH-1_Huey
	Viking-400 (4)	NASA-ARC	11	100	520	15,000	60	600	https://airbornescience.nasa.gov/aircraft/Viking-400
	WB-57 (3)	NASA-ARC	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 science

***TABLE 9** Airborne Science Program aircraft and their performance capabilities.*

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 and can 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 9. The altitude / endurance characteristics are also shown in Figure 34. Two new catalog aircraft will be available for science in 2017: a GV operated by JSC, and a newly refurbished Global Hawk operated by AFRC. The characteristics of these aircraft are also included in Table 9.

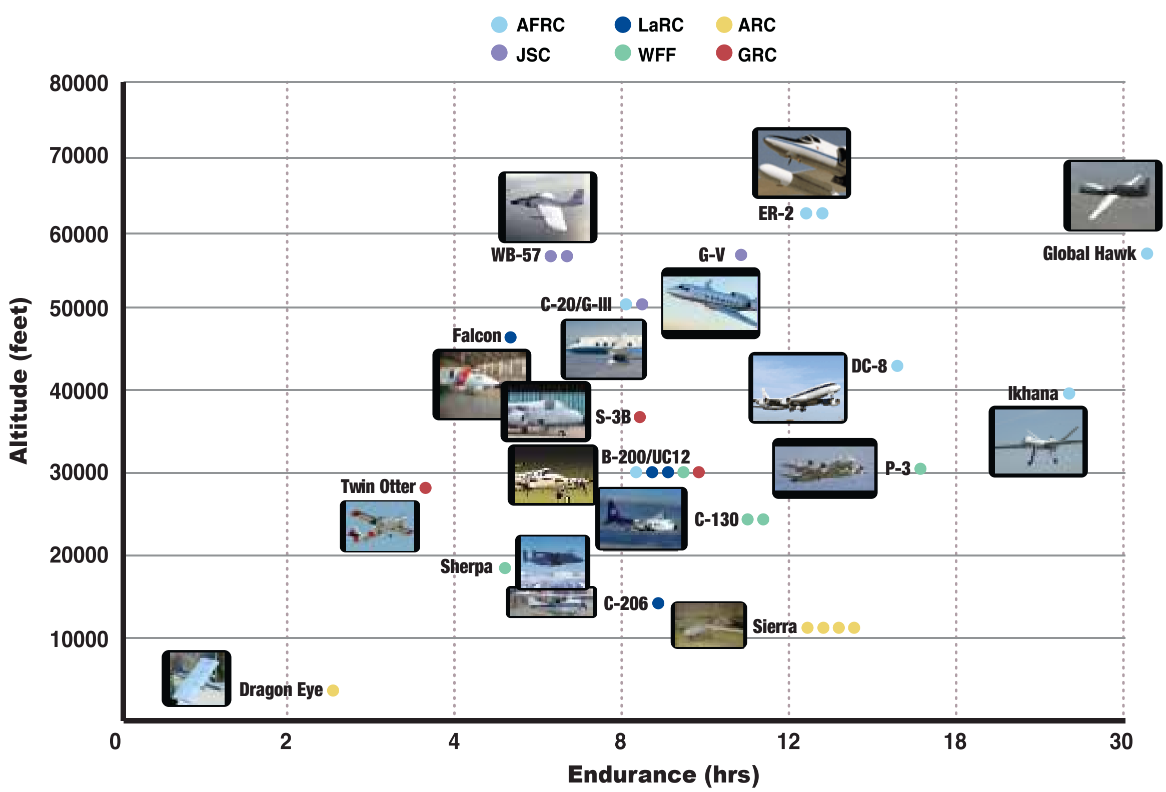


FIGURE 34 *NASA Aircraft showing altitude and endurance capabilities.*

ASP-Supported Aircraft

The five aircraft systems directly supported (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).

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 FY16: 417

DC-8 FY16 missions

Mission	Location	Science program area
KORUS-AQ	South Korea, Japan	Atmospheric Composition
GPM Olympex	Washington (state)	Weather
ATom-1	Global	Atmospheric Composition
SARP	California	Training
ASCENDS-16	California	Atmospheric Composition
Methane Sounder	California	Atmospheric Composition

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Modification	Impact
Controller-Pilot Data Link Communications (CPDLC) Upgrade	Extremely helpful for Oceanic ATC communication. Significant improvement in science gathering efficiency for oceanic operations for ATom vertical profiling.
TCAS v7.1 Upgrade	Meets December 2015 compliance requirement to operate in European controlled airspace. Enabled flight operations in the Azores (Portugal) for ATom.

FIGURE 35 *The NASA DC-8 launching from Ascension Island during the Summer 2016 ATom field campaign.*

WEBSITE: *http://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 FY16: 477

ER-2 FY16 missions

Mission	Location	Science program area
HyspIRI Airborne	California (6 boxes)	Carbon cycle
RADEX (Olympex) / EXRAD	Washington (state)	Weather
ORACLES	Namibia	Atmospheric Composition
HSRL-2 AITT	California	Atmospheric Composition
Aliso Canyon Methane	California	Atmospheric Composition
PRISM AITT	California	Carbon Cycle
Instruments (eMAS, AirMSPI-2, AVIRIS-ng)	California	Carbon cycle / Atmospheric Chemistry
Snow Research in Nevada	California	Water and Energy cycle
SPEX-Airborne	California	Atmospheric Composition
SARP	California	Training
Cosmic Dust	California	Space Science

***FIGURE 36** ER-2 aircraft, ER-2 pilot Greg Nelson, and Graduate students in Nambia during ORACLES.*

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:
Wing Training Edge Re-Wiring on #806. Replaced 1.2 miles of Kapton wiring during 600-hour inspection, improving reliability and safety.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
A cabin altitude reduction effort (CARE) will be performed on NASA #809 in FY17. A similar cabin altitude reduction effort will be performed on NASA #806 in FY18. Only one platform will be available during the consecutive period from June 2017 through March 2019.

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

P-3B Orion

OPERATING CENTER:

Goddard Space Flight Center's Wallops Flight Facility (WFF)

AIRCRAFT DESCRIPTION:

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

SCIENCE FLIGHT HOURS IN FY16: 155

MODIFICATIONS MADE IN FY14 AND IMPACTS ON PERFORMANCE AND SCIENCE:

The P-3 Orion returned to service from a 21 month re-wing modification in June 2016. The aircraft's wings, along with center wing box, horizontal stabilizer lower material and aft pressure bulkhead material were replaced. The replacement of these materials and structural components have extended the service life of the P-3 for another 20-25 years for NASA use. During the re-wing effort the aircraft's four P-3 fuselage bubble windows were replaced along with resurfacing of the cabin floor. Four wing pylons were also modified in FY16 to support canister type wing probes along with the installation of required data and power cables in the wings to support wing probes. Two canister wing probes can be installed on each of the four pylons. Additional pylons are available to support additional wing probes as needed.

SCIENCE MISSIONS IN FY16:

The P-3 participated in ORACLES, a major EVS-2 mission to Namibia.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

Routine calendar/flight hour based maintenance will be done throughout each year depending on mission schedule.

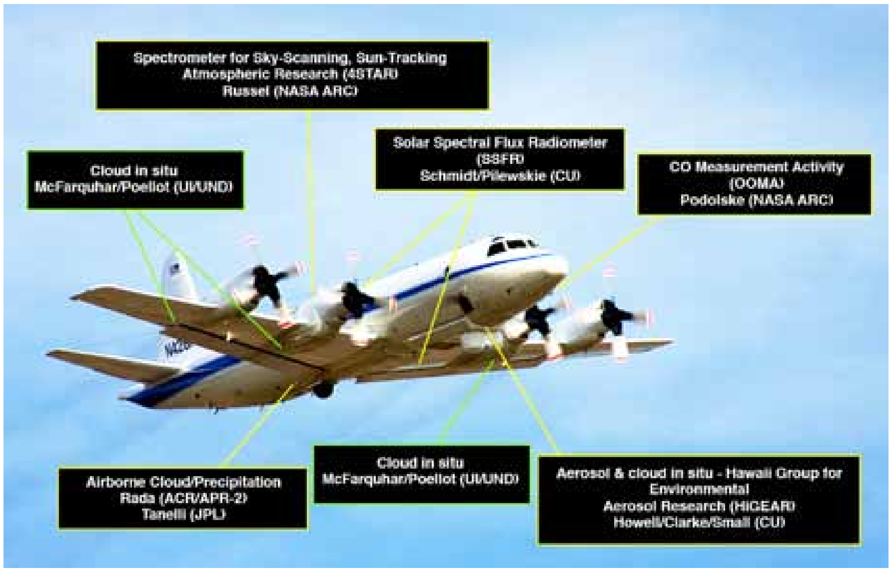


FIGURE 37
NASA P-3 flew the ORACLES mission in 2016.

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

C20-A (Armstrong G-III)

OPERATING CENTER:
Armstrong Flight Research Center

AIRCRAFT DESCRIPTION:
The Gulfstream III is a business jet with routine flight at 40,000 feet. Both the AFRC and JSC platforms have been structurally modified and instrumented to serve as multi-role cooperative platforms for the Earth science research community. Each can carry a payload pod for the three versions of JPL's UAVSAR instrument (L-band, P-band, Ka-band). The AFRC aircraft is one of the ASP-supported fleet, whereas the JSC G-III program support ended with the completion of the AirMOSS mission.

SCIENCE FLIGHT HOURS IN FY16: C-20A: 386.1

C20-A FY16 missions

Mission	Location	Science program area
AfriSAR	Gabon, Africa	Carbon cycle
UAVSAR (L-band)	CONUS, from Palmdale	Earth Surface and Interior
Gulf Coast subsidence	New Orleans	Earth Surface and Interior
SNOWEX GLISTIN	Colorada, from Palmdale	Water & Energy cycle
Alpine Glacier Mapping	Washington, Montana	Cryosphere
Space-X Debris Mapping	Florida	Geodetic Imaging Program

MODIFICATIONS MADE TO THE C20-A AIRCRAFT IN FY16: NONE

FIGURE 38 *C-20A (AFRC G-III) carrying UAVSAR in pod.*

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

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 either AFRC or WFF.

All of the science flight hours on NASA #872 in FY2016 were sponsored by NOAA for hurricane rapid response. NASA #874 will be ready for science in April 2017.

SCIENCE FLIGHT HOURS IN FY16: 243.

Global Hawk FY16 missions

Mission	Location	Science program area
El Nino Rapid Response	California	Weather
SHOUT Hurricane Rapid Response	Gulf of Mexico; Atlantic Ocean; Caribbean Sea	Weather

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Modification	Impact
Satellite communications link encryption circuits upgrade	Complies with new National Security Agency (NSA) policy. Allows for approved continued flight operations
Iridium ATC Communication Antenna Modification	Adds space in Zone 7 for payload installations.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS: None in FY16

FIGURE 39 *Global Hawk being towed back to WFF hangar following landing from first SHOUT mission after dawn on August 25, 2016.*

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

Other NASA Earth Science Aircraft

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

Aircraft	Operating Center
C-130 Hercules	WFF
B-200 King Air; UC-12B	LaRC, AFRC, WFF; can also be contracted through JPL
C-23 Sherpa	WFF
HU-25A Falcon / HU-25C Guardian	LaRC
G-III	JSC
G-V	JSC
Dragon Eye UAS	ARC
Ikhana UAS	AFRC
S-3B Viking	GRC
SIERRA UAS	ARC
T-34C	GRC
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 continue to fly them.

SCIENCE FLIGHT HOURS IN FY15: 325

C-130 FY16 missions

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

Aircraft	Modifications and Impacts
N439NA	Experimenter Power System was upgraded to support higher experimenter power load requirements. The aircraft is capable of supporting 115V 60Hz and 400Hz as well as 28VDC power. A new 55 inch nadir port plug and mounting structure was developed that supplies two unpressurized mounting locations as well as one 16 inch pressurized viewing aperture and two 8 inch pressurized viewing apertures. The right side rectangular fuselage window was modified to support easier installation of fuselage window probes via an adapter plate assembly. The flight station zenith port was structurally reinforced to support heavier zenith viewing installations and a wing tip pylon was installed on the left wing to support the installation of two canister type wing probes. The aircraft's nose radome was also modified along with installation of fuselage instrumentation to support measurement of finite winds and other atmospheric data products. The cargo pallet seat/rack installation system used on previous C-130 missions was discontinued in favor of new rack and seat mounts that provided greater cabin floor space for instrument racks as well as vibration isolation of the instrument rack structures.
N436NA	Modified to support 115V 60Hz and 400Hz along with 28VDC power via a new Experimenter Power System. The aircraft was modified to include three 16 inch aperture nadir ports and an Airborne Science Program Data System. A 20-person cabin interphone system, an experimenter Iridium phone and gas bottle mounting locations were installed in the cabin area along with galley and lavatory modifications. Two rectangular fuselage windows are available both capable of using the same window adapter assemble as the N439NA C-130. Instrument racks and seats mount to the cabin floor in the same manner as N439NA with instrument racks vibration isolated. The flight station of N436NA contains a similar style zenith port as the N439NA C-130. The N436NA flight station also contains an advanced C-130 glass cockpit providing increased capabilities to operate airborne science missions worldwide.

FIGURE 40
NASA C-130.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

A Programmed Depot Maintenance (PDM) is required for N439NA after June 30, 2018, requiring four to six months to complete. A PDM extension inspection is required for N436NA after January 10, 2018 requiring three to four months to complete. WFF is evaluating options to meet or extend this maintenance requirement in the most cost effective manner.

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

JSC G-III

OPERATING CENTER: **Johnson Space Center**

AIRCRAFT DESCRIPTION:

The Gulfstream III is a business jet with routine flight at 40,000 feet. Both the AFRC and JSC platforms have been structurally modified and instrumented to serve as multi-role cooperative platforms for the earth science research community. Each can carry a payload pod for the three various versions of JPL's UAVSAR instrument. The JSC G-III (N992NA) had opportunities to carry each SAR version at times during 2016.

SCIENCE FLIGHT HOURS IN FY16: 228

JSC G-III FY16 missions

Mission	Location	Science program area
Oceans Melting Greenland	Greenland, Iceland, Norway	Earth Venture Suborbital-2
Alaska Permafrost	Alaska	Water and Energy Cycle
Beaufort Sea Ice	Alaska	Cryosphere
Geodesy	California	Earth Surface and Interior
Red River mapping	North Dakota	Water and Energy Cycle
GLISTIN-A Sea Ice	Greenland, Top of the World	Cryosphere

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

TN992NA went through numerous maintenance activities this year to extend the life and use of the airplane. All major 72-month flight control maintenance was completed on the aircraft. For this, all of the flight controls were removed, inspected, and repaired as needed. In addition, the JSC team removed and replaced all of the bolts and bushings that are used to secure the vertical tail to the aircraft as part of a 144-month inspection. Normally, this requires the complete removal of the vertical tail from the airplane, but JSC installed six, Gulfstream-designed access panels for these bolts. JSC also completed the biennial RVSM certification for the aircraft, had engine hush kits installed to meet FAA-mandated noise requirements, and removed and replaced the right hand engine.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE JSC G-III::

a. N992NA will be painted in January 2017. The aircraft is currently overdue for a paint job.

b. The right hand engine will come due again in August 2018 and will need to be replaced again.

c. JSC is currently completing an in-house avionics upgrade design to support ADS-B and navigation requirements for worldwide operations. We anticipate modifying the airplane at the end of CY17.

FIGURE 41 *JSC G-3 launching a AXCTD probe (June 2016) South of Galveston. Photo taking from T-38.*

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

B-200 / UC-12

OPERATING CENTERS:

NASA LaRC operates 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. Wallops Flight Facility 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 six hours. Three NASA centers operate B-200 aircraft with varying modifications for science.

SCIENCE FLIGHT HOURS: 352.4

B-200 missions in FY15

Mission	Location	Science program area
ACT-America	NASA Langley; Lincoln, NE; Shreveport, LA	Atmospheric Composition
KORUS-AQ	South Korea	Atmospheric Composition
AfriSAR	Gabon, Africa	Carbon cycle
HSRF-2 / Ozone DIAL	NASA Langley	AITT / Atmospheric Composition
SLAPVEX Freeze/Thaw	Winnipeg, Canada	Water & Energy cycle
SoOP-AD	NASA Langley	ESTO IIP
AirSWOT	California	Water and energy

***FIGURE 42** LaRC B-200, along with C20-A in Gabon for AfriSAR mission.*

MODIFICATIONS MADE IN FY16 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Aircraft	Modification	Impact
N528	Installed ADS-B and upgraded avionics suite	Allows aircraft to operate in international airspace
N528	Acquired and utilized removable fuel ferry tanks for transit to/from South Korea (can also be installed on NASA 529)	Allows aircraft to deploy trans-Pacific
N529	Installed upgraded avionics suite	Allows aircraft to operate in international airspace

MODIFICATIONS AND MAINTENANCE FOR LARC B-200 AND UC-12 B

The LaRC UC-12B will have an autopilot installation and weather radar upgrade, in order to minimize avionics differences between LaRC aircraft, thus improving efficiency and interoperability.
It will also undergo corrosion repair. The LaRC B-200 will have an avionics and weather radar upgrade, again to minimize avionics differences between aircraft.

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.

WEBSITES:

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

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

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

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

C-23 Sherpa

OPERATING CENTER:
Wallops Flight Facility

AIRCRAFT DESCRIPTION:
The 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 FY16: 150

Sherpa FY16 missions

Mission	Location	Science program area
CARVE and CARVE-CAN	Alaska, Canada	Climate change
CARAFE	Wallops Island, VA	Atmospheric composition

FIGURE 43 *NASA's C-23 Sherpa flew the CARAFE and CARVE-Canada missions in FY2016.*

MODIFICATIONS MADE IN FY16 AND IMPACTS ON PERFORMANCE AND SCIENCE:
The C-23 nose radome was modified along with the installation of other fuselage instrumentation to support measurements of finite winds and other atmospheric data products. The aircraft was also modified to include infrastructure to support NASDAT and Applanix installations for future mission needs. completion of this maintenance the aircraft only requires standard annual maintenance each year (four to six weeks), which can be adjusted to meet mission needs.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
No major maintenance. Routine calendar/flight hour based maintenance will be done throughout each year depending on mission schedule.

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

HU-25C Guardian / Falcon

OPERATING CENTER:
Langley Research Center

AIRCRAFT DESCRIPTION:
The HU-25C Guardian is a modified twin-engine business jet based on the civilian Dassault FA-20G Falcon. The HU-25A is a modified 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 remaining OIB activities in 2016.

SCIENCE FLIGHT HOURS IN FY16: 190

HU-25C and HU-25A FY16 missions

Mission	Location	Science program area
OIB Greenland	Thule & Kangerlussuaq, Greenland	Cryosphere
OIB Alaska	Pt. Barrow	Cryosphere

MODIFICATIONS MADE IN FY16 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Aircraft	Modification	Impact
HU-25A	Transferred aircraft from flyable storage to active status	Allows HU-25A to be used as complete in situ sampling platform or as a remote sensing platform
HU-25A	Completed Reduced Vertical Separation Minima (RVSM) calibration flights	Allows aircraft to routinely file for flight operations above FL280 and to operate internationally

FIGURE 44 *HU-25A participated in OIB in FY16.*

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
The HU-25A will undergo an aircraft corrosion control inspection and will be given a NASA-standard external paint job. A+ checks and engine change will occur in early 2017.

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

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 FY16: 247

WB-57 FY16 missions

Mission	Location	Science program area
POSIDON	Ellington Field (Guam in FY17)	Atmospheric Composition
Cosmic Dust Collector	Ellington Field	Space Science
Instrument tests (OAWL, HIRAD, HDSS)	Ellington Field	Weather
Tropical Cycle Intensity (TCI) I and TCI II	Warner-Robins	Weather
VIRGAS	Harlington, across Mexico to Pacific Ocean	Atmospheric Composition

FIGURE 45
WB-57.

MODIFICATIONS MADE IN FY16 AND IMPACTS ON PERFORMANCE AND SCIENCE:
During FY16 all aircraft were configured with the upgraded payload GPS to allow payloads to receive data above 60,000 feet. Also, the navigation data recorder software was modified to interface with the Mission Tools Suite (MTS), providing NASDAT-like features for scientists who are accustomed to having this information when flying on other platforms. In addition, in-house refurbishment of canopy pumps provided increased understanding, reliability and serviceability of this unique system.

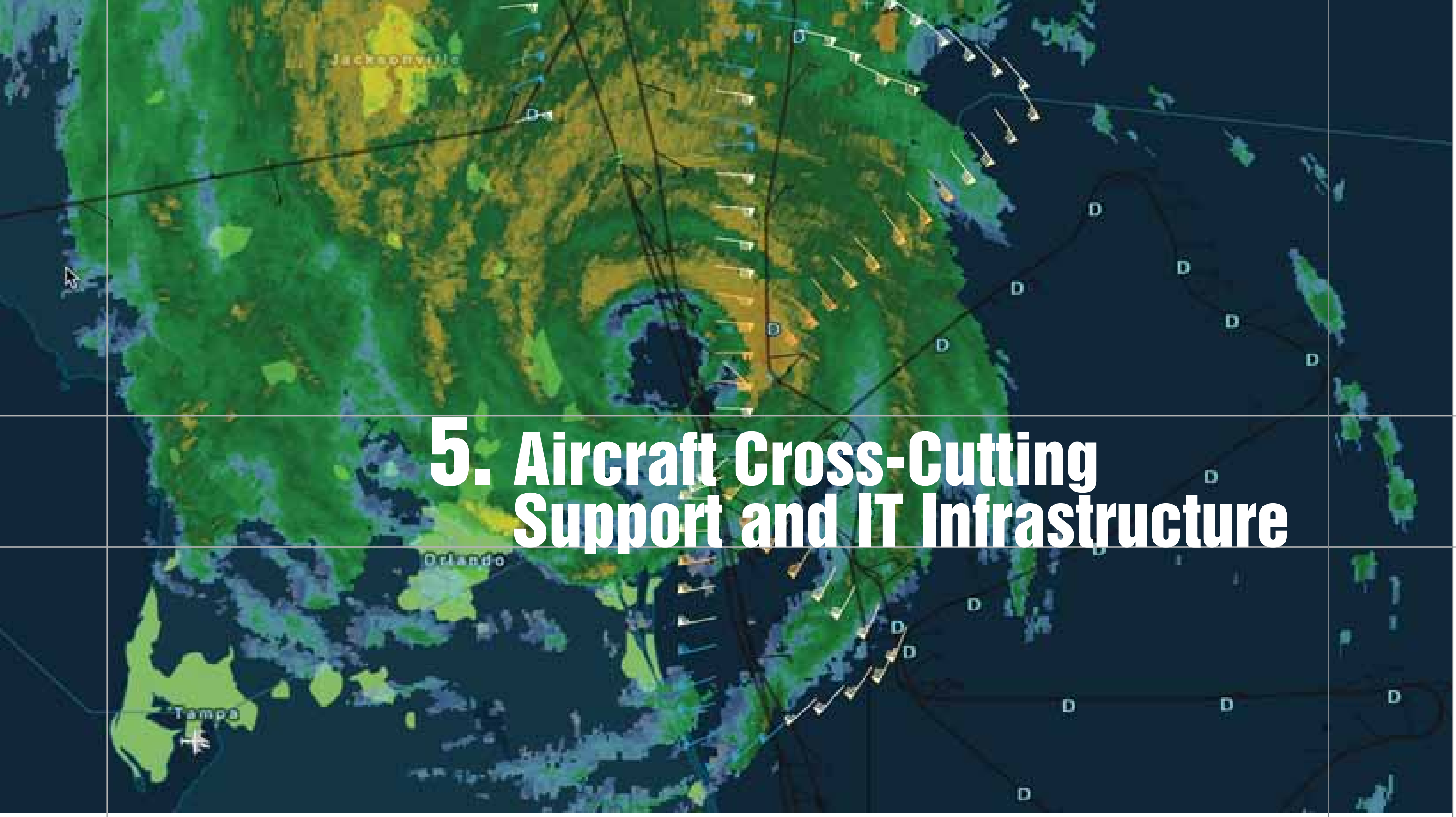
Aircraft	Modifications and Impacts
N926	The Autopilot System Upgrade improved the reliability and functionality of the previous autopilot system, eliminating obsolete components. The autopilot system integrated with the Flight Management System has the benefit of precise flight paths which provides opportunities for tailored mission flight plans for scientific uses. N926 is the final aircraft to receive this upgrade. The Communications System Upgrade replaced the obsolete, analog system with a configurable digital audio system and noise cancelling to improve the communications abilities of the aircrew with each other and outside the cockpit. Payload customers benefit because the system interfaces can be used to connect special payload voice radios, and payload caution and warning can be integrated into the aircraft audio system. N926 is the final aircraft to receive this upgrade. The installation of the new navigation data recorder system replaced the larger, obsolete navigation data recorder and increased the functionality allowing improved data collection for payloads while preserving the support of legacy sensor systems. N926 is the final aircraft to receive this upgrade.
N436NA	The addition of auxiliary static ports enables payloads that are installed in the radome to have access to a static port. N927 is the final aircraft to have this modification, which was necessary to support POSIDON instrument MMS. The addition of a Ku Spread Spectrum (KuSS) transmit enable switch allows KuSS to be tested on the ground and eliminate the need for a weight on wheels jumper. N927 is the first aircraft to receive this modification. The addition of the Network Time Protocol System allows millisecond precision time synchronization with GPS satellites which is highly desired by payloads and also benefits our nav data recorder. N927 is the second aircraft to receive this modification. The N927 specific modification of the left and right spear pod pylons allows N927 to carry the spear pods for greater payload capabilities. The satellite phone ring indicator makes it easier for the aircrew to recognize calls during suited flights. N927 is the first aircraft to receive this modification. Wiring was installed to allow the navigation data recorder to record pneumatic pump activity enabling troubleshooting of the system. N927 is the first aircraft to receive this mod.
N928	The modification of the aft transition allows components to be installed in this area increasing payload capabilities. N928 is the final aircraft to receive this modification.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

Beyond 2016

N927 will receive a Superpod/Spearpod/Wing Pylon structural modification in TBD year. The aircraft was delivered to NASA with inadequate pod interfaces. The modification will correct that deficiency thus providing additional science capability on this aircraft.

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



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.

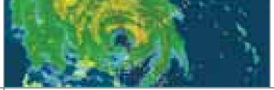
Cross-cutting support for ASP missions is managed at Ames Research Center and is supported by the University of California Santa Cruz Airborne Sensor Facility (ASF) and the National Suborbital Research Center (NSRC). Specific activities include providing facility instruments, satellite telemetry and mission tools data services, and assistance with payload integration engineering.

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

ASP Facility Science Infrastructure

Facility Instrumentation

The Airborne Science Program provides a suite of facility instrumentation and data communications systems for community use by approved NASA investigators. Currently available ASP instrumentation (listed in Table 10) includes stand-alone precision navigation systems, and a suite of digital tracking cameras and video systems. Real-time data communications capabilities, which differ from platform to platform, are also described below, and are integral to a wider Sensor Network architecture. In addition, ESD, through the Research and Analysis 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.

Sensor Network IT Infrastructure

A state-of-the-art real-time data communications network has been implemented across the ASP core platforms. Utilizing onboard Ethernet networks linked through airborne satellite communications systems to the web-based Mission Tools Suite, 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 Telecom-

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	ARC / NSRC
DMS (Digital Mapping System) 21 MP natural color cameras	All ASP Platforms	ARC / NSRC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/ precision IMU	All ASP Platforms	3 at ARC / NSRC
POS AV 610 (2) Applanix Position and Orientation Systems DGPS w/ precision IMU	All ASP Platforms	2 at ARC / NSRC 2 at WFF
Hygrometers	DC-8, P-3, C-130	ARC / NSRC
IR surface temperature instruments	DC-8, P-3, C-130	ARC / NSRC
Forward and Nadir HD Video Systems	DC-8, P-3, C-130	ARC / NSRC
Static air temperature instruments	DC-8, P-3, C-130	ARC / 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	ARC / NSRC
Enhanced MAS (MODIS Airborne Simulator) 38 ch multispectral scanner	ER-2	ARC / NSRC
PICARD (Pushbroom Imager for Cloud and Aerosol R&D) 400 – 2450nm range, DL 10nm	ER-2	ARC / NSRC
AVIRIS-ng Imaging Spectrometer (380 - 2510nm range, Dl 5nm)	Twin Otter, B-200	JPL
PRISM (Portable Remote Imaging SpectroMeter) (350 - 1050nm range, Dl 3.5nm)	Twin Otter, ER-2	JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, Dl 10nm)	ER-2, Twin Otter	JPL
UAVSAR Polarimetric L-band synthetic aperture radar, capable of Differential interferometry	G-3/C-20, Global Hawk	JPL
NAST-I Infrared imaging interferometer (3.5 – 16mm range)	ER-2	LaRC

TABLE 10 *Facility Equipment.*

munication Systems (IWGADTS). The Sensor Network architecture includes standardized electrical interfaces for payload instruments, using a common Experimenter Interface Panel (EIP); and an airborne network server and satellite communications gateway known as the NASA Airborne Science Data and Telemetry system (NASDAT). These capabilities are now operational, as indicated in Table 11.

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. High bandwidth Ku- and Ka-Band systems, which use large steerable dish antennas, are installed on the Global Hawk and Ikhana unmanned aerial system (UAS), and the WB-57F. 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.

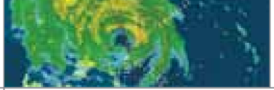
Payload Management

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

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

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 / ASF
Iridium (1 – 4 channel systems) / 2.8 Kb/sec per channel	All ASP Platforms	ASF / NSRC

TABLE 11 *Satellite Communications systems on ASP aircraft.*



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, and the standardized EIPs; 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

The NASA Airborne Science Mission Tools Suite (MTS) is the ASP's decisional support and situational awareness system used to assist with the execution of airborne missions. The primary objectives of the MTS are (a) to support tactical decision-making and distributed team situational awareness during a flight; (b) to facilitate team communication and collaboration throughout the mission lifecycle; and (c) to both consume and produce visualization products that can be viewed in conjunction with the real-time position of aircraft and airborne instrument status data. Taken together, the intent of the system is to encourage more responsive and collaborative measurements between instruments on multiple aircraft, satellites, and on the surface in order to increase the scientific value of the measurements, and improve the efficiency and effectiveness of flight missions.

2016 was an extraordinarily busy time for the MTS team as we have participated in supporting multiple missions across the globe. We have been pleased to hear from users how the MTS has helped to mitigate operational challenges. Whether one is following a flight from a university, NASA Center, hotel, living room, or coffee shop, the MTS has been central to lowering the barriers to distributed team participation, simplifying the process for showing and displaying mission products, and providing new avenues for ingesting and disseminating data from new research platforms.

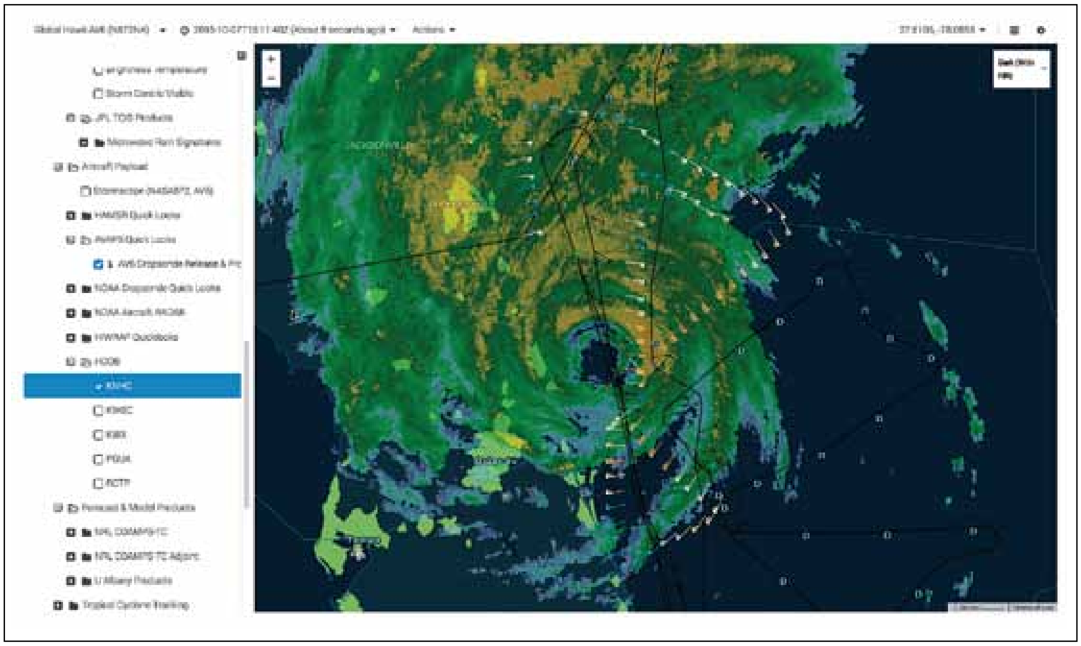
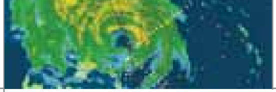


FIGURE 46 *Screenshot of the MTS monitor interface during the 2016 SHOUT Science Flight #8 on October 7, 2016. Screenshot shows the Global Hawk along with dropsonde locations over Hurricane Matthew as it nears landfall along the Florida coast.*

Complementing mission support activities, the MTS team has rolled out a number of minor enhancements and new capabilities in the past several months to meet the operational needs of different campaigns. Some changes are visible in the MTS client, providing a new capability or augmenting an existing function. Other changes involve enhancements to existing web service endpoints. With each passing mission, iterative improvements in the system equates to baseline capabilities for future missions whilst promoting system stability and reliability.

A major effort to highlight is the migration from an old external consumer interface for data obtained by the Federal Aviation Administration (FAA) to a modern system for accessing publically available FAA data products. The FAA's System Wide Management Interface (SWIM) provides business services that have broad applicability for airborne science projects operating in the airspace. The screenshot below shows data from the SWIM Traffic Flow Management (TFM) service. MTS users can add this view by right clicking on the map > choosing "Show Nearby" > "Flights" from the pop-up menu. This visualization provides a useful way of observing IFR flights in the airspace, but more importantly, the same data can be used to track flights without a native SATCOM capability.



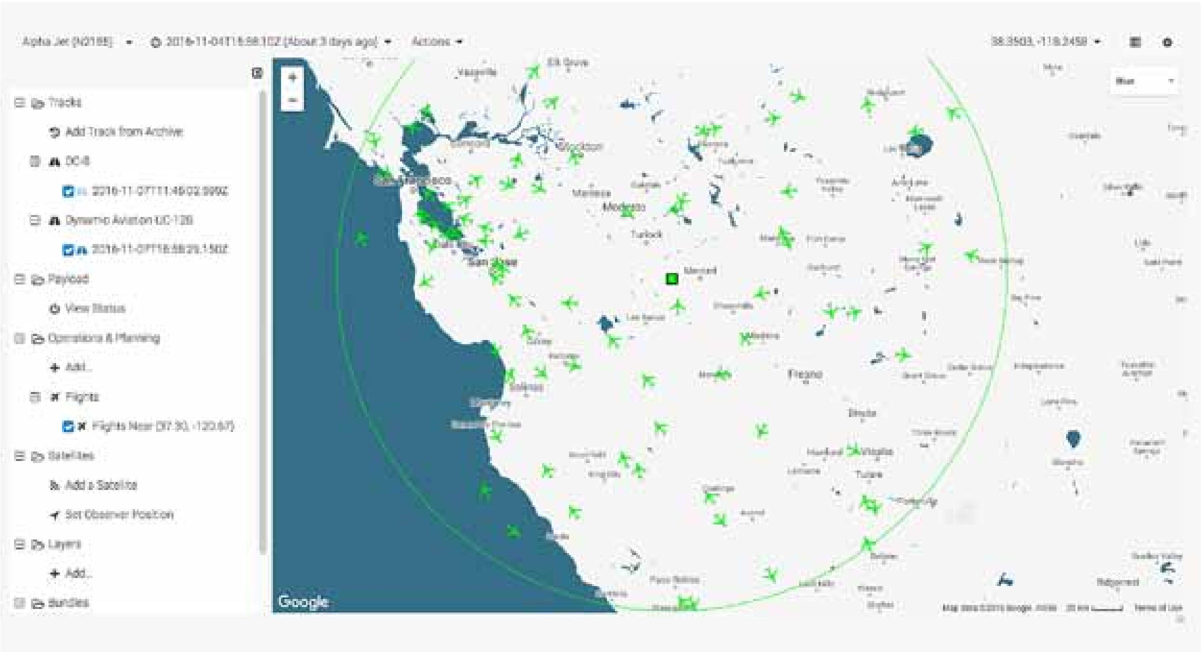


FIGURE 47 *The MTS monitor clients continues to integrate data sources available from the FAA's SWIM external consumer interface. The screenshot demonstrates data consumed from the Traffic Flow Management (TFM) service, which is a replacement of the now deprecated Aircraft Situation Display to Industry (ASDI), and the manifestation of that data visualized in the MTS monitor. TFM provides tracking of aircraft operating under IFR in the US and Canadian national airspace.*

While much work remains to provide outlets for SWIM-related products our current focus is on making the various integrated weather products available in the MTS. Once complete, all FAA SWIM functionality will be accessible via the MTS bot, providing a central location for any FAA-related information.

Lastly, the MTS team is also in the planning stages of providing a extensive redesign on the various client tools (e.g., chat, payload monitoring, image display, monitor). The major objective is to provide better unification and to address many of the suggestions and feedback we have received over the past several years. The redesign will introduce some new and exciting capabilities from sharable layers, multi-room chat monitoring, real-time 3-D visualization, and better support across device form factors.

The MTS is a resource available to any size mission where NASA airborne assets are utilized. For questions about the tool, please contact Aaron R. Duley aaron.r.duley@nasa.gov or visit the website at http://mts.nasa.gov. To view the public tracker, visit the ASP website and click on the Asset Tracker link, or visit http://airborne-science.nasa.gov/tracker.

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 anaging 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 ISS, 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 2017 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 2016 to describe ASP capabilities and collect requirements information are listed in Table 12.

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 2016 PARCA / OIB workshop
Participation in 2016 NASA SMAP cal/val meeting
Participation in 2016 AGU Ocean Sciences Meeting
Participation in 2016 Ocean Carbon and Geochemisty Workshop
Participation in 2016 HyspIRI Science and Applications Workshop
Participation in 2016 AGU Fall meeting

TABLE 12 *Activities to support ASP requirements information gathering.*

7. Education, Training, Outreach and Partnerships

Student Airborne Research Program 2016

The eighth annual NASA Student Airborne Research Program (SARP) took place June 12 through August 5, 2016, 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 2016 participants came from 32 different colleges and universities in 23 states (Figure 48). They were competitively

2016 Student Airborne Research Program Participants

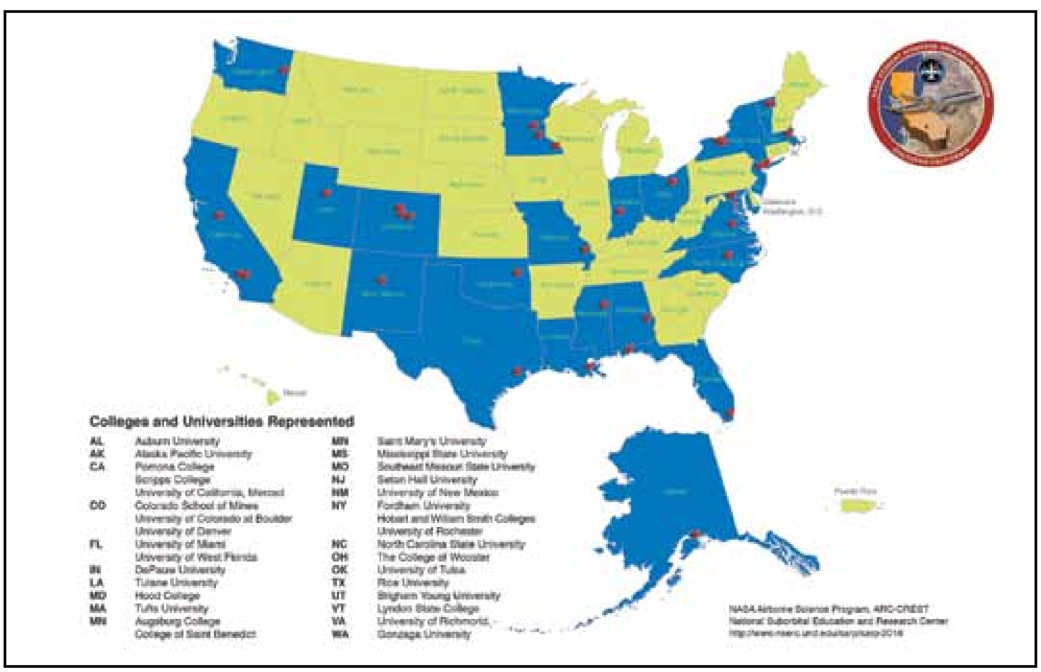


FIGURE 48 *Map showing locations of students participating in SARP 2016.*

selected based on their outstanding academic performance, future career plans, and interest in Earth system science.

Students assisted in the operation of over 20 different instruments onboard the DC-8. These instruments were previously used to collect air quality data over South Korea as part of the Korea U.S. Air Quality mission (KORUS-AQ) in the weeks before the start of SARP. Two SARP alumni, Benjamin Nault (SARP 2010) and Tamara Sparks (SARP 2012), were KORUS-AQ instrument scientists. For the SARP flights, the DC-8 aircraft overflew dairies, oil fields and crops in the San Joaquin Valley, parts of Los Angeles, and the Santa Barbara Channel at altitudes as low as 1,000 feet. The students also used remote-sensing data collected by instruments onboard the ER-2 to study the response to drought on vegetation and changes in the ocean biology along the California coast. In addition to airborne data collection, students also took measurements at field sites near Santa Barbara and California's Central Valley.

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

FIGURE 49 *The 32 SARP participants pose in front of the DC-8 at NASA Armstrong Hangar 703.*

FIGURE 50 *Students prepared signs to welcome the KORUS-AQ team back from Korea before their own research fights on the DC-8.*

SARP participants flew onboard the DC-8 on two flights (June 17 and 18, 2016). They assisted in the operation of the KORUS-AQ air quality, aerosol, and gas instruments onboard the DC-8 including taking Whole Air Samples during planned missed-approaches at several California airports and during low altitude passes of the Santa Barbara Channel and California Central Valley. Flight 1 focused on the air quality in the Los Angeles and Santa Barbara areas with ten planned missed-approaches at Southen California airports to acquire vertical profiles of pollution in the LA Basin. Flight 2 focused on air quality in Central California and included low (~1000 ft) flying through the Central Valley, a planned missed-approach at Bakersfield Airport, and a spiral over the TCCON site at Edwards. Both flights also included sampling the smoke plume of the Sherpa Fire that was burning near Santa Barbara.

In addition to the DC-8 flights, AVIRIS and MASTER data was also acquired for SARP by the NASA ER-2 on June 17 near Santa Barbara.

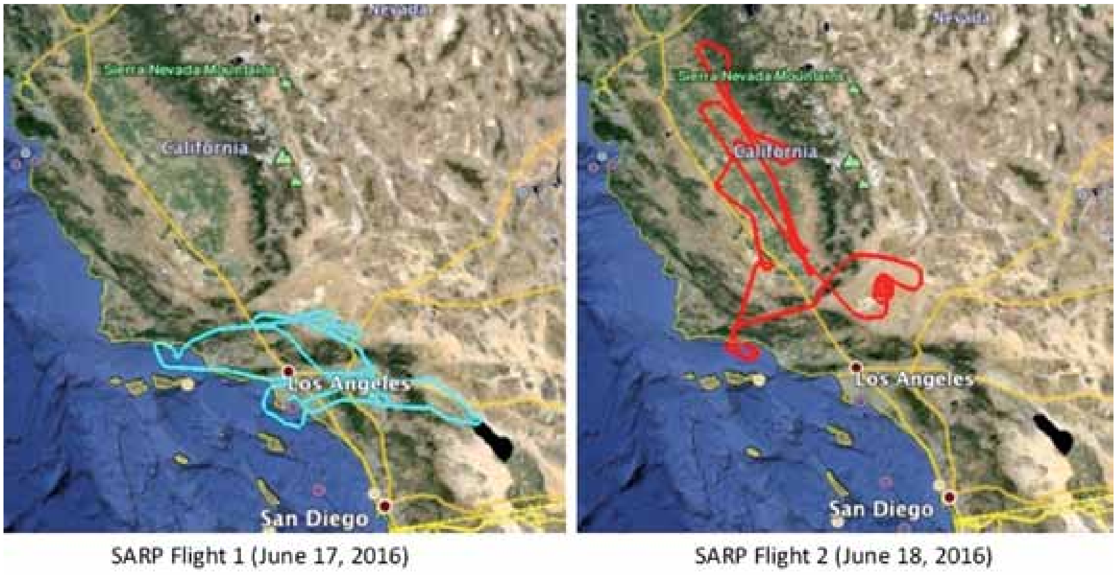


FIGURE 51 *ER-2 Flights for HyspIRI prep that also provided data for SARP.*

Appendix A:
Airborne Science Program History - Steve Hipskind

Steve Hipskind
Division Chief, Ames Research Center Earth Science Division

Introduction

Steve Hipskind's career spanned 40 years, almost all of which was connected to airborne science: first as a researcher, then project manager of large, international field campaigns and finally spending the last 10 years of his NASA tenure as a senior executive and division chief of the Ames Research Center Earth Science Division. Steve earned both a bachelor's and master's degree at the University of Virginia in Environmental Science. Steve's career began as a support scientist at the National Center for Atmospheric Research (NCAR) in Boulder, CO in 1975. Steve fulfilled an agreement with his professors to return to UVa to pursue a PhD, where he participated in a summer field experiment studying acid rain in Virginia thunderstorms using a specially equipped NCAR Queenair. Steve left the PhD program before finishing to take a research associate position at Oregon State University with Dr. Edwin Danielsen. When Dr. Danielsen was offered a branch chief position at NASA Ames Research Center, he asked Steve to follow him there. Steve was at Ames from 1980 until his retirement in 2015, over which time the airborne science program saw many changes, which are discussed below from Steve's perspective.

Steve's Interview

(Steve was interviewed by Jim Wegener, Matt Fladeland, Randy Albertson and Susan Schoenung during the Fall AGU Conference in 2014 and 2015):

My discussion will focus primarily on atmospheric chemistry and dynamics and the in situ observation capabilities of the NASA aircraft. John Arvesen and Jeff Myers had done a nice job in previous interviews (found in previous Airborne Science Program annual reports) of speaking to the development of remote sensing capabilities.

Like many people my age, growing up I could not get enough of the undersea world of Jacques Cousteau. I had lived through the Sputnik launch and stayed up late to watch the lunar landing in the summer of 1969. But the space program was the farthest thing from my mind as I contemplated a career of science and adventure in oceanography. It is therefore with some irony that I spent 35 of my 40-year career working at NASA.

I switched from oceanography to atmospheric science in graduate school, influenced by my thesis advisor Dr. Carl Aspliden, a Swede, who left a promising career running a bar in Nairobi, Kenya, to study meteorology at Florida State University (FSU). I studied synoptic meteorology under Bob Simpson, of Saffir-Simpson fame. Simpson just recently passed away in 2014 at the age of 102, after having delivered the keynote talk to the annual Hurricanes and Tropical Meteorology Conference at age 100. Simpson had just retired as director of the National Hurricane Center and took the position at UVa in 1974, with wife Joanne Simpson. Joanne, of course, went on to a long career at NASA Goddard, leading TRMM, the Tropical Rainfall Measurement Mission, among many other accomplishments. Mike Garstang, a South African, who had also studied at FSU, was on my thesis committee and helped me land a position with Dr. Ed Zipser and the GATE group at NCAR in 1975. I spent many long hours at the Mesa Lab in the shadow of the Flatirons doing quality control, processing and analysis of the aircraft data from the GATE experiment. GATE (the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment), conducted in the tropical eastern Atlantic in 1974 with aircraft based in Dakar, Senagal. It remains the largest international field program that I am aware of. GATE had participation from 72 nations, 40 ships and 13 aircraft from 4 different countries, Brazil, France, U.K., U.S.A. and U.S.S.R! I didn't know until many years later that John Arvesen, who ran the ER-2 program at NASA Ames, also participated in GATE with the Ames CV-990 aircraft.

I met Ed Danielsen while working at NCAR and took a position with him when he moved to Oregon State University with the Atmospheric Science Department. Ed had a long history of using aircraft for research dating back to the 1950's and 60's, using the high altitude WB-57 aircraft, funded by the Atomic Energy Commission, to study nuclear fallout from atmospheric bomb tests. His work completely overturned the conventional wisdom, which at the time held that stratospheric residence times were months to years. The U.S. was still conducting atmospheric nuclear bomb tests up to the early 1960's, with the assumption that the fall-out would be rendered harmless before reaching the surface. Ed theorized that tropopause fold events could drive stratosphere to troposphere transport in hours, not months or years. Though his ideas were extremely controversial at the time, he was able to prove their validity using aircraft observations.

Before leaving Oregon State, Ed began working with NASA Ames Research Center on two U-2 missions to Panama first in 1979 and again in 1980, continuing his studies of stratosphere-troposphere transport. He was offered the branch chief position of the Theoretical Studies Branch at Ames in 1979 and asked me to join him. Ed was hired by then Division Chief Dale Compton, who would become the Ames Center Director in 1989. I started my Ames career on cooperative agreement with San Jose State University in 1980.

Through the 1980's, Ed worked collaboratively with researchers at Ames and across the community to develop state-of-the-art, in situ sensors for observing atmospheric chemistry and dynamics. He worked closely with Ames management under Center Director Bill Ballhouse and with Shelby Tilford at HQ. Art Schmeltekopf and his team at the NOAA Aeronomy Lab in Boulder, CO, which included David Fahey, Mike Proffitt and Ken Kelly, were major partners, as was Chuck Wilson at University of Denver. Ed also worked with researchers and engineers at NASA Langley on fast response measurements for Ames' large, mid-altitude aircraft, the CV-990. Gerry Gregory and Glen Sachse at Langley were building key ozone and carbon monoxide instruments, respectively.

Ed's visionary work developing new airborne sensors culminated in the Stratosphere Troposphere Exchange Project (STEP). We conducted a mid-latitude STEP campaign based at NASA Ames in 1984, which included the U-2 and CV-990 aircraft. In preparation for the STEP tropical mission in 1987, we conducted a unique calibration experiment for the newly developed Ames Meteorological Measurement System (MMS). Danielsen, Steve Gaines and I workied with MMS PI Stan Scott, his new assistant Paul Bui and scientific balloon veterans Tommy Thompson and Wink Winkler from the NOAA Aeronomy Lab. We launched balloons with state-of-the-art radiosondes at the Crows Landing Facility in the California Central Valley. The ER-2 launched from Ames and flew spirals around the balloon from near the surface into the stratosphere. We were also able to track both balloon and aircraft with high precision, cold-war-vintage Nike tracking radars. This experiment launched for me a strong working relationship with researchers at NOAA that lasted essentially for the rest of my career.

We conducted the STEP deployment to Darwin, Australia with the ER-2 in early 1987. Phil Russell was the STEP Project Manager and Estelle Condon with the Deputy Project Manager. Danielsen was the Project Scientist. John Arvesen was managing the High Altitude (ER-2) program at Ames. Marty Knutson, who had brought the original U-2's to Ames in the early 1970's, also flew the first ER-2 to Ames, with great fanfare, and white scarf flowing, in 1981. Marty had moved up to be the Aircraft Operations Director, as well as site manager for Dryden, which was then under Ames management.

STEP was conducted in collaboration with two other large missions: EMEX, the Equatorial Mesoscale Experiment, led by Peter Webster, then at Penn State, Ed Zipser, NCAR, and Bob Houze, University of Washington, and AMEX, the Australian Mesoscale Experiment, led by Greg Holland, NCAR and previously Australian Bureau of Meteorology. Aircraft included, in addition to the NASA ER-2, the NOAA P3, the NCAR Electra and CSIRO (Commonwealth Scientific and Industrial Organization) F27.

Even while we were conducting the STEP mission, preparations were underway to mount an ambitious field campaign to Punta Arenas, Chile to observe the newly discovered Ozone Hole over Antarctica. The Airborne Antarctic Ozone Expedition (AAOE) greatly challenged NASA's ability to conduct an international mission to a remote part of the planet with very demanding operating conditions. The Ozone Hole was the most visible international environmental issue of the day. The mission got intense coverage from every corner of the globe. The pilots, led by Chief Pilot Ron Williams and Arvesen's Deputy, Jim Barrilleaux, were, rightfully, hailed as heroes, literally risking their lives to return the data so critical to the future survival of the planet. Adrian Tuck, who had just come to the NOAA Aeronomy Lab from the UK Met Office, was the project scientist, with Brian Toon, who was still at Ames, as the Deputy. Estelle Condon was the project manager. Bob Watson, then head of the Upper Atmosphere Research Program, was the HQ program manager. Because of its investments made during the 1980s, including the new CIO instrument by Jim Anderson at Harvard, NASA had the only platform and instrument suite on the planet capable of making the critical direct measurements into the polar stratosphere.

In 1988 Estelle Condon hired me to become her Deputy Project Manager for the first Arctic ozone mission. Estelle had a major impact on the Airborne program, gaining international recognition for her management of AAOE and many of the follow-on ozone missions. She went on to leadership positions at NASA Ames, eventually becoming inducted into the Ames Hall of Fame. I owe much of whatever success that I have had to Estelle. She was an incredible mentor, pushing me to take on roles beyond my comfort zone.

Over the next decade the ozone missions dominated the NASA Airborne Science program, but with significant efforts in tropospheric air pollution studies, hurricane observations and TRMM satellite validation. The Atmospheric Effects of Aviation also started during this time. We did the Airborne Arctic Stratospheric Expedition (AASE) in 1989 with the ER-2 and DC-8 based at Stavanger, Norway. The second Arctic mission, AASE II, followed in 1991, flying out of Fairbanks, Alaska and Bangor, Maine. Adrian Tuck was the Project Scientist for AASE, and Jim Anderson for AASE II. Jim Huning was managing the Airborne Science Program (ASP) at NASA HQ through all of the ozone missions into the late-1990's. Mike Kurylo had taken over the Upper Atmospheric Research Program.

There is a photo in the 2007 Airborne Science Program Annual Report in Barney Nolan's interview that showed a U-2 in 1960 parked at a Dryden hangar with the NASA logo as a cover for its real purpose. Considering that photo, there is an interesting anecdote from the AASE II mission. While the ER-2 was based in the hangar in Bangor, we were asked to host a transiting military U-2 (TR-1). Other than seeing the U-2 painted black, it would have been largely a non-incident, had someone not decided to paint a large, foot-tall red NASA stencil on the tail of the TR-1 overnight, looking surprisingly like the 1960 photo. When people arrived early in the morning there was mirth and merriment on the faces of the NASA team – less so from our Air Force guests. No culprit was ever identified.

In the early 1990's the aircraft industry was interested in re-examining supersonic transport. NASA was asked to look at the technology and potential environmental impacts. The Earth Science Division at NASA HQ was asked make a scientific assessment of the latter. Michael Prather came to NASA HQ to manage the science program with Howard Wesoky providing funding and oversight from Aeronautics. Originally focused on high-speed, stratospheric aircraft, it was expanded to include subsonic aircraft and put under the umbrella AEAP – Atmospheric Effects of Aviation Program. Under that program, we conducted the first dedicated mission, SPADE (Stratospheric Photochemistry, Aerosols and Dynamics Expedition), from NASA Ames in 1992. Steve Wofsy of Harvard was the Project Scientist and I assumed the reins as Project Manager. In 1994 ASHOE-MAESA (Airborne Southern Hemisphere Experiment-Measurements for Assessing the Effects of Stratospheric Aircraft) was conducted as a combined AEAP/polar ozone mission. It employed the ER-2 based primarily in Christchurch, New Zealand, and included data flights over the tropics on the transit to and from New Zealand. Adrian Tuck was Project Scientist for ASHOE, Bill Brune for MAESA.

One of the remarkable accomplishments of the ASHOE-MAESA mission was the first ever, direct observation in the stratosphere of the exhaust emissions from a supersonic aircraft. We had learned that an Air France Concorde would be landing in Christchurch during an around-the-world junket. Howard Wesoky made contacts with Air France, and through a lot of scrambling, genuine interest and collaboration from Air France, ONERA (Office National d'Etudes et Recherches Aerospatiales) and the Concorde captain, we were able to vector the (subsonic) ER-2 into the exhaust plume of the Concorde as it made its way from Fiji into Christchurch at Mach 2. Our luck was greatly enhanced by the air traffic controller in Wellington, who had military intercept experience and who kept in close contact with ER-2 pilot Jim Barrilleaux. In one of my more memorable moments, David Fahey, Bill Brune and I met the Air France captain on landing in Christchurch. He invited us onto the Concorde for a personal tour and we took turns sitting in the driver's seat.

The POLARIS (Photochemstry of Ozone Loss in the Arctic Region in Summer) mission was conducted in 1997 out of Fairbanks, Alaska. The SONNEX (NASA SASS Ozone and Nitrogen Oxide Experiment) mission deployed to Shannon, Ireland was a DC-8 AEAP mission. POLARIS and SONNEX, both in 1997, were the last missions conducted from NASA Ames.

As people familiar with the program well know, the aircraft were "consolidated" to NASA Dryden that year, though the appropriations language included specific exclusion of aircraft from "East of the Mississippi" – i.e., NASA Wallops and NASA Johnson. There was plenty of speculation, but the real reasons for the decision will likely be buried with the people that made them. I don't think anyone disputes that there was not a lot of

ER-2 alongside the Concorde supersonic jet in Christchurch, New Zealand.

love lost between then NASA administrator Dan Goldin and Ames Center Director Dale Compton and Aircraft Operations manager Warren Hall. I, along with Adrian Tuck, Steve Wofsy and others, were asked to participate in the science white-wash - I mean science impact assessment - of the move. The HQ Earth Science Division did specifically decree that the Ames project management office, ESPO, would continue to manage the large airborne field campaigns.

NASA had pioneered the use of UAV's for airborne research. Jim Anderson along with Aurora Flight Sciences founder, John Langford, were early advocates for a high altitude, long duration aircraft that could operate out of and over Antarctica to continue monitoring of the Ozone Hole. NASA convened a workshop in Truckee, California, in 1989 to explore the development and utilization of UAV's for Earth Science. If you look at the ASHOE-MAESA mission logo, indeed, you will see the Aurora Perseus aircraft, which was funded by AEAP and was a planned participant in the campaign. Alas, Perseus met an untimely end in the Mojave Desert before it could be deployed.

NASA implemented a unique NASA-industry partnership with the ERAST (Environmental Research Aircraft and Sensor Technology) program, which aimed to develop new platforms and also invest in miniaturization of science instrumentation. Steve Wegener had a large hand in funding several important instruments across the community during this period. Cheryl Yuhas was managing the ASP in 2002 when two UAV demonstration missions were selected specifically to utilize platforms developed under ERAST. The MSFC ACES (Altus Cumulus Electrification Study) Mission, PI Rich Blakeslee, operated out of Naval Air Station Key West. The COFFEE Project utilized the AeroEnvironment Pathfinder-Plus solar-powered aircraft for coffee harvest optimization in Kauai, Hawaii, with PI Stan Herwitz from Clark University. Payload components for the COFFEE mission were designed by engineers at ARC, Steve Dunagan and Don Sullivan.

I remember meeting for lunch at Ming's restaurant in Palo Alto with Greg Holland, NCAR, and Tad McGeer, founder of In Situ, sometime in the early 1990's. They were excited about Tad's new concept, a "flying radiosonde". They planned to put meteorological sensors on a UAV to fill in the gaps in the global radiosonde network, which were limited to land-based balloon launches. They named their system Aerosonde. Fast forward to 1998; Aerosonde was the first UAV to make an ocean crossing, flying over the north Atlantic from Newfoundland to Scotland. In another first in 2001, Aerosonde, with PI Judy Curry, participated in the CAMEX-4 campaign, becoming the first scientific mission to mix a UAV with conventional aircraft. Ames managed the CAMEX-4 mission – one of a series of hurricane missions under HQ Program Manager Ramesh Kakar. Robbie Hood, who went on to lead NOAA's UAV effort, was the PI, then at MSFC. Based in Jacksonville, Florida, CAMEX-4 also happened to be where President George W. Bush was visiting at the time of the 9/11 attack. All CAMEX personnel were asked to leave the housing facilities at Jacksonville NAS. Several of our folks ended up driving across country to return home, when all commercial aviation was shut down.

In 2003 Vince Ambrosia, NASA Ames, was funded to conduct the WRAP (Wildfire Research

Steve briefing California Governor Arnold Swarzenegger on WRAP mission.

and Applications Partnership) mission under the REASON program. Utilizing the Dryden-based Ikhana UAV, Ambrosia built a strong partnership with the U.S. Forest Service, CalFIRE and others to demonstrate the power of UAV's in providing quick response observations of the movement and intensity of large western wildfires. Ambrosia and the WRAP team had many firsts including the first ever UAV flights over the entire western U.S. with flight durations of over 20 hours. The WRAP mission garnered many national awards and drew the attention of then governor Arnold Schwarzenegger, who, along with the CalFIRE Chief Del Walters, visited the Ames campus in 2008 to praise the WRAP accomplishments.

I continued to manage field campaigns into the early 2000's, but was gradually phasing out of project management to focus on line management at Ames, first as the Atmospheric Chemistry and Dynamics Branch Chief, beginning in 1997, then as Division Chief starting in 2004. One of the best decisions I ever made was to promote Mike Craig into increasing roles with Earth Science Project Office. He first worked with me during the 1992 SPADE mission as the Instrument manager, a role he played again in the 1994 ASHOE/MAESA mission. Mike was my deputy for the POLARIS mission in 1997, where his negotiation skills so impressed Program Manager Mike Kurylo, that Kurylo said that he wanted Mike to negotiate his next house purchase. Mike Craig has gone on to manage dozens of missions. With his unique-in-the-world technical and personal skills, Mike has been referred to by HQ Program Managers as a "National Resource". Indeed, because of his expertise, he was asked by HQ to run the technical review of the first two Earth Venture Airborne Mission proposal reviews. Another of Mike's strengths is his ability to identify talent and provide mentorship. Although Mike, too, retired from NASA – in 2016 – he left a strong team under the leadership of Marilyn Vasquez.

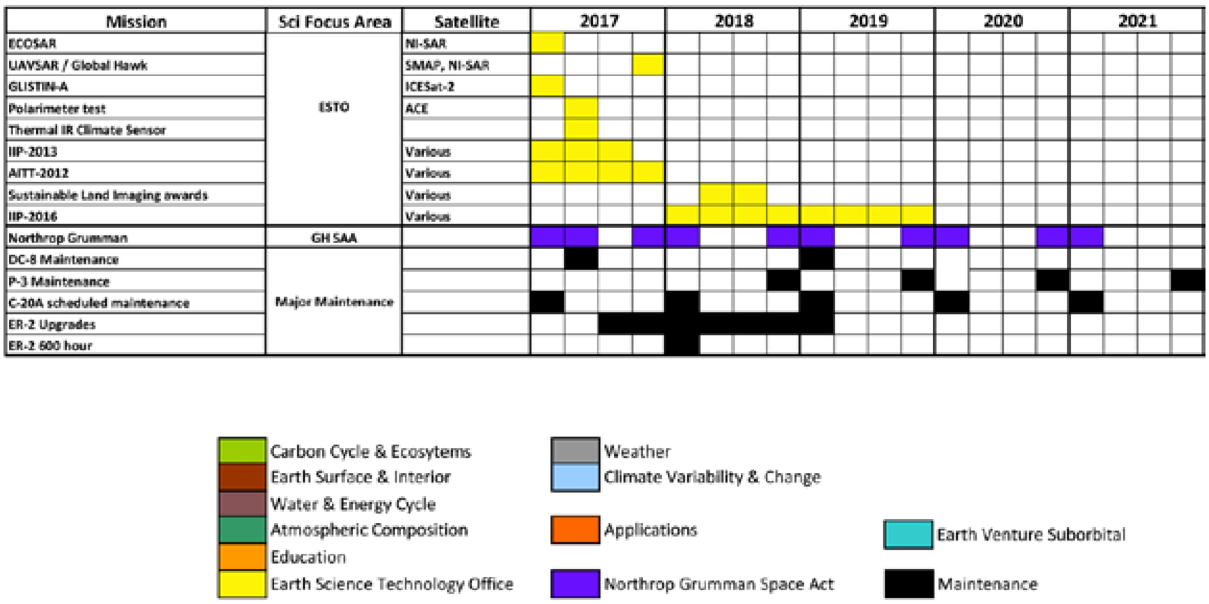
Matt Fladeland came to Ames in 2002 after completing a Presidential Management Internship at NASA HQ. I asked Matt to manage our newly created Airborne Science Office at Ames in 2005. Matt was given the task by then ASP manager Cheryl Yuhas to poll the community and create a science requirements document for the airborne program. This important report, "Suborbital Science Missions of the Future" was also co-authored by Steve Wegener and Susan Schoenung. It was Matt Fladeland who pulled the cryosphere community together and wrote the proposal for an airborne mission to bridge the gap created with the loss of ICESat satellite mission in 2009 and the expected launch of ICESat II in 2015. Matt's proposal became the hugely successful 5-year Operation Ice Bridge program, which has now been extended beyond its initial 5 years. Now Airborne Science director at Ames, Matt led the development of the Mission Tools Suite, which greatly enhances the planning and execution of NASA's airborne missions. Matt works closely with the HQ ASP managers, from Cheryl Yuhas, to Andy Roberts and Bruce Tagg to assure that the program is meeting the science requirements. He also works closely with HQ and with the ESPO to manage the ASP web site and the Flight Request System.

Parting Thoughts:

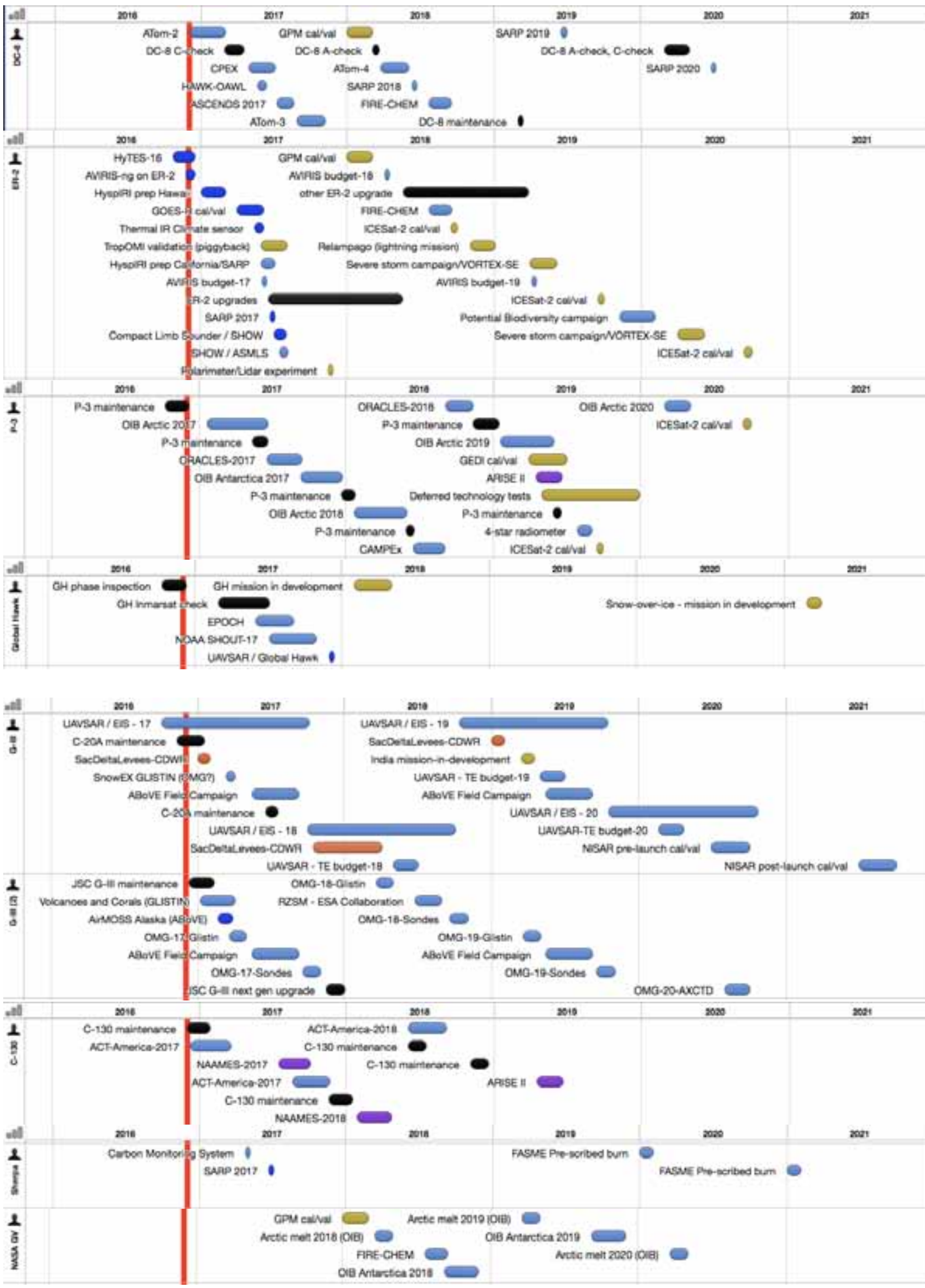
There is no more powerful example of the scope of the NASA Earth Science program and the power of the airborne program than the 1987 AAOE mission. NASA had the TOMS instrument on the Nimbus 7 spacecraft, which could observe global atmospheric ozone and map the extent of the Ozone Hole, but it was only when combined with the airborne program and the detailed process observations, that the science community could diagnose the CAUSE of the Ozone Hole. By any objective measure NASA through the decades, starting in the mid-1960's, and through the visionary efforts of NASA managers, science leaders and the aircraft operators, has built the largest, most scientifically diverse and capable airborne science program in the world. As seen in the recommendations from NASA's first Earth Science Decadal Survey, the Earth Science community sees the NASA ASP as an absolutely critical element in the effort to understand Earth System Science. I would offer that the ASP has touched more researchers across the Earth Science community, and has led to more publications and more PhD's than any other single NASA program.

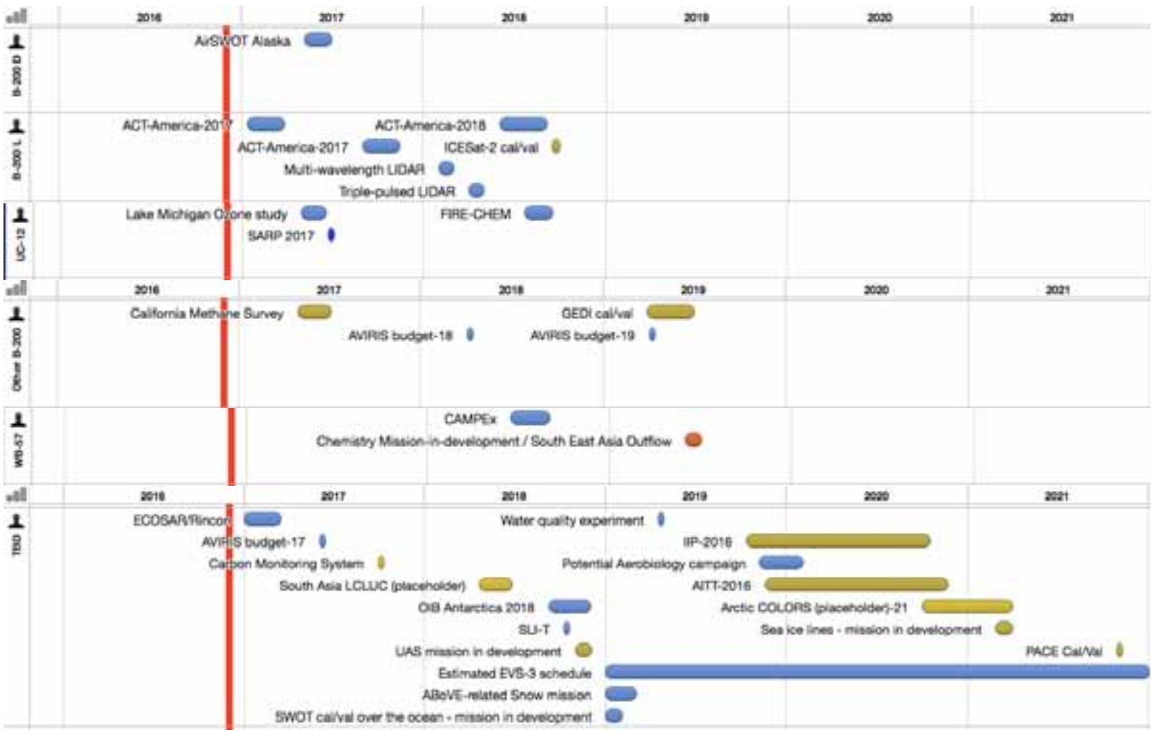
Appendix B:
5-Year Plan by Science Area

Mission	Sci Focus Area	Satellite	2017	2018	2019	2020	2021
UAVSAR-Terrestrial Ecology	Carbon Cycle & Ecosytems	NI-SAR					
HyspIRI Prep		HyspIRI					
AVIRIS - budget							
GEDI cal/val		GEDI					
Terrestrial Ecology							
Carbon Monitoring System/CARAFE		OCO-2					
ABoVE							
Arctic Colors							
Potential Biodiversity campaign							
Potential Aerobiology campaign							
NISAR cal/va/		NISAR					
PACE Cal/val		PACE					
PRISM experiments		HyspIRI					
UAVSAR	Earth Surface & Interior	NI-SAR					
Salton Sea - mud pots		TERRA/ASTER					
Volcanoes and Corals (GLISTIN)		HyspIRI					
Volcanoes and Corals		HyspIRI					
India mission-in-development		NISAR					
OIB / Arctic Melt	Climate Variability & Change	ICESat-2					
UAVSAR Grnl/Iceland		ICESat-2					
UAS mission-in-development							
ARISE II		ICESat-2					
Sea ice Lines - mission in development							
Snow-over-ice lines - mission in development							
ICESat-2 c al/val		ICESat-2					
Convective Processes Experiment (CPEx)	Weather	ADM/GPM					
GPM cal/val		GPM					
NOAA SHOUT							
EPOCH		Cygness / GPM					
HIWC-II							
Severe storms / VORTEX-SE							
GOES-R cal/val		GOES-R					
GH mission in development							
AirSWOT	Water & Energy Cycle	SWOT					
Airborne Snow Observatory		HyspIRI, Aqua, Terra, Landsat					
AirMOSS Arctic Permafrost		SMAP					
Red River mapping							
SNOW-SAR (ESA)							
SWOT cal/val over ocean (mission in development)		SWOT					
Water quality mission							
SMAPVEX-19 / SMAP cal/val		SMAP					
Root Zone Soil Moisture		ESA BIOMASS					
SnowEX							
ASCENDS 2017	Atmospheric Composition and Chemistry	ASCENDS					
Lake Michigan Ozone study		OCO-2					
California Methane Survey							
AJAX		OCO-2					
TropOMI validation		Sentinel-5					
Polarimeter / Lidar experiment		PACE, ACE					
ARISE II							
SHOW /ASMLS							
FIRE-CHEM		HyspIRI;GEO-CAPE, TEMPO, GOES R, CALIPSO					
FASME							
CAMPEx		Aqua, Calipso, ACE					
Atm Chem (mission in development)		OCO-2					
CA-DWR	Applications						
California Methane Survey							
Airborne Snow Observatory		HyspIRI					
ATom	EVS-2						
NAAMES							
ORACLES							
OMG							
ACT-America							
CORAL							
Earth Venture Suborbital - 3	EVS-3						
SARP	Education						
HSRL-2		ACE					
4-star Radiometer/deferred P-3		ACE/NPP/GEO-CAPE					


Mission
Sci Focus Area
Satellite
2017
2018
2019
2020
2021
ECOSAR
UAVSAR / Global Hawk
GLISTIN-A
Polarimeter test
Thermal IR Climate Sensor
IIP-2013
AITT-2012
Sustainable Land Imaging awards
IIP-2016
ESTO
NI-SAR
SMAP, NI-SAR
ICESat-2
ACE
Various
Various
Various
Various
Northrop Grumman
GH SAA
DC-8 Maintenance
P-3 Maintenance
C-20A scheduled maintenance
ER-2 Upgrades
ER-2 600 hour
Major Maintenance
Carbon Cycle & Ecosytems
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 Aircraft




2016
2017
2018
2019
2020
2021
AirSWOT Alaska
ACT-America-2017
ACT-America-2018
ACT-America-2017
ICESat-2 cal/val
Multi-wavelength LIDAR
Triple-pulsed LIDAR
Lake Michigan Ozone study
FIRE-CHEM
SARP 2017
California Methane Survey
GEDI cal/val
AVIRIS budget-18
AVIRIS budget-19
CAMPEx
Chemistry Mission-in-development / South East Asia Outflow
ECOSAR/Rincon
Water quality experiment
AVIRIS budget-17
IIP-2016
Carbon Monitoring System
Potential Aerobiology campaign
South Asia LCLUC (placeholder)
AITT-2016
OIB Antarctica 2018
Arctic COLORS (placeholder)-21
SLI-T
Sea ice lines - mission in development
UAS mission in development
PACE Cal/Val
Estimated EVS-3 schedule
ABoVE-related Snow mission
SWOT cal/val over the ocean - mission in development

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE DC-8

DC-8 Aircraft Maintenance (FY17-21)

Est Date	Length	Project	Aircraft
March/April 2017	45 Days	1A,2A,3A,1C Check Maintenance/Engine Inspection	DC-8
Aug-2017	1 week	1A Check Maintenance	DC-8
Mar-2018	12 days	1A, 2A, 4A, 8A Maintenance	DC-8
Sep-2018	1 week	1A,3A Check Maintenance	DC-8
Mar-2019	2 week	1A, 2A Maintenance	DC-8
Sep-2019	1 week	1A Maintenance	DC-8
Mar-2020	45 days	1A,2A,3A,4A,1C,2C Maintenance & landing gear swap	DC-8
Sep-2020	1 week	1A Maintenance	DC-8
Mar-2021	2 week	1A, 2A Maintenance	DC-8
Sep-2021	1 week	1A,3A Check Maintenance	DC-8

SDC-8 AIRCRAFT MAINTENANCE (FY17-21)

ER-2 Aircraft Maintenance (FY17-21)

Est Date	Length	Project	Aircraft
Oct-2016	10 days	Canopy Replacement	ER-2 (809)
Nov-2016	10 days	200 Hour Mx	ER-2 (806)
Jan-2017	10 days	200 Hour Mx	ER-2 (809)
May-2017	10 days	200 Hour Mx	ER-2 (806)
June 2017 – Apr 2018	11 Months	CARE Modification	ER-2 (809)
Aug-2018	10 days	200 Hour Mx	ER-2 (809)
Dec 2017 – Feb 2018	3 Months	600 Hour Mx	ER-2 (806)
May 2018 – Mar 2019	11 Months	CARE Modification	ER-2 (806)
Apr-2020	10 days	200 Hour Mx	ER-2 (806)
Jun-2020	10 days	200 Hour Mx	ER-2 (809)
May-2021	10 days	200 Hour Mx	ER-2 (806)
Jul-2021	10 days	200 Hour Mx	ER-2 (809)

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE C20-A

C-20 Aircraft Maintenance (FY17-21)

Est Date	Length	Project	Aircraft
Nov 2016 – Jan 2017	7 weeks	72 Month Inspection / Ops 1&2 Maintenance	C-20
Jun/Jul 2017	3 weeks	Cycles/Flight Hours Maintenance Cards	C-20
Feb-2018	5 weeks	Ops 1&3 Maintenance	C-20
Jun/Jul 2018	3 weeks	Cycles/Flight Hours Maintenance Cards	C-20
Feb-2019	5 weeks	Ops 1&2 Maintenance	C-20
Jun/Jul 2019	3 weeks	Cycles/Flight Hours Maintenance Cards	C-20
Feb-2020	5 weeks	Ops 1&3 Maintenance	C-20
Jun/Jul 2020	3 weeks	Cycles/Flight Hours Maintenance Cards	C-20
Feb-2021	5 weeks	Ops 1&2 Maintenance	C-20
Jun/Jul 2021	3 weeks	Cycles/Flight Hours Maintenance Cards	C-20

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE GLOBAL HAWK

Global Hawk Aircraft Maintenance (FY17-21)

Est Date	Length	Project	Aircraft
Nov 2016 – Jan 2017	60 days	Phase Inspection	GH (872)
Jun/Jul 2017	120 days	INMARSAT Install and Checkout	GH (872), Control Rooms
Feb-2018	Block 10 (TN 874 Ready for Science)		GH (874)
Jun/Jul 2018	3 days	Install new blow-down bottles	GH (874)
Feb-2019	10 days	GHOC East and GHMOF computer upgrades	Control Rooms
Jun/Jul 2019	3 days	150 hour engine fuel nozzle overhaul	GH (874)
Feb-2020	3 days	150 hour engine fuel nozzle overhaul	GH (874)
Jun/Jul 2020	3 days	150 hour engine fuel nozzle overhaul	GH (874)
Feb-2021	3 days	1000 hour engine fuel nozzle overhaul	GH (872)
Jun/Jul 2021	3 days	150 hour engine fuel nozzle overhaul	GH (874)

Appendix C: Acronyms

A

AA	Associate Administrator
ABoVE	Arctic-Boreal Vulnerability Experiment
ACE	Aerosols Clouds Ecosystems
ACES	ASCENDS CarbonHawk Experiment Simulator
ACT-America	Atmospheric Carbon and Transport-America
ADS-B	Automatic dependent surveillance – broadcast
AFRC	Armstrong Flight Research Center
AGL	Above Ground Level
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
APR-3	Airborne Third Generation Precipitation Radar
ARC	Ames Research Center
ARMD	Aeronautics Research Mission Directorate
ASCENDS	Active Sensing of CO_2 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
ATHENA-OAWL	Atmospheric Transport, Hurricanes, and Extratropical Numerical weAther prediction with the Optical Autocovariance Wind Lidar
ATM	Airborne Topographic Mapper
ATom	Atmospheric Tomography Mission
AVIRIS, AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation
AVOCET	Atmospheric Vertical Observation of CO_2 in the Earth's Troposphere
AXCTD	Airborne Expendable Conductivity Temperature Depth

B

BGAN	Broadband Global Area Network
BNL	Brookhaven National Laboratory
BL	Boundary Layer

C

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAFé	Compact Airborne Formaldahyde Experiment
Cal/val	Calibration / Validation
CARAFE	CARbon Airborne Flux Experiment
CARE	Cabin Altitude Reduction Effort
CARTHE/ LASER	Consortium for Advanced Research on the Transport of Hydrocarbon in the Environment / LAgrangian Submesoscale ExpeRiment
CARVE	The Carbon in Arctic Reservoirs Vulnerability Experiment
CCE	Carbon Cycle and Ecosystems
CIRES	Cooperative Institute for Research in Environmental Sciences
CH_4	methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Authorization
COLAS	CO_2 laser absorption spectrometer
COMA	CO measurement activity
CONUS	Continental United States
CORAL	Coral Reef Airborne Laboratory
CPDLC	Controller-Pilot Data link Communications
CPI	Cloud Particle Imager

D

DCS	Digital Camera System
DLH	Diode Laser Hygrometer
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)

E

eMAS	Enhanced MODIS Airborne Simulator
EOS	Earth Observing System
ESA	European Space Agency
ESD	Earth Science Division
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
EV, EV-1, EVS-2	Earth Venture, Earth Venture-1, Earth Venture Suborbital-2
EXRAD	ER-2 X-band Radar

F

4Star	Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research
FAA	Federal Aviation Administration
FR	Flight Request

G

GCAS	GeoCAPE Airborne Simulator
GEMS	Geostationary Environmental Monitoring Satellite
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GeoTASO	Geostationary Trace gas and Aerosol Sensor Optimization
GH	Global Hawk
GISS	Goddard Institute for Space Studies
GLISTIN-A	Glacier and Ice Surface Topography Interferometer - Airborne
GMAO	Global Monitoring and Assimilation Organization
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
HDSS	High Definition Sounding System

HDVIS	High Definition Time-lapse Video System
HiGEAR	Hawaii Group for Environmental Aerosol Research
HIRAD	Hurricane Imaging Radiometer
HIWC	High Ice Water Content
HQ	Headquarters
HSI	Hyperspectral Imaging instrument
HSRL	High Spectral Resolution Lidar
HyspIRI	Hyperspectral Infrared Imager
HyTES	Hyperspectral Thermal Emission Spectrometer

I

ICESat	Ice, Cloud, and land Elevation Satellite
IIP	Instrument Incubator Program
InSAR	Interferometric Synthetic Aperture Radar
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-AQ	Korea-US Air Quality
KORUS-OC	Korea-US Ocean Color
KuSS	Ku Spread Spectrum

L

LaRC	Langley Research Center
LiDAR	Light Detection and Ranging

M

MALIBU	Multiangle Imaging Bidirectional Reflectance Distribution Function small Unmanned Aerial system
MAS	MODIS Airborne Simulator
MASS	Modular Aerial Sensing System
MASTER	MODIS/ASTER Airborne Simulator
MMS	Meteorological measurement system
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Modular Optoelectronic Scanner
MPCS	Master Power Control System
MSFC	Marshall Space Flight Center
MTS	Mission Tools Suite
MX	Maintenance

N

NAAMES	North Atlantic Aerosols and Marine EcosystemsStudy
NASDAT	NASA Airborne Science Data and Telemetry
NAST-I	National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed - Interferometer
NIER	National Institute of Environmental Research (NIER)
NISAR	
NASA-ISRO SAR	
NCAR	National Center for Atmospheric Research
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council
NSA	National Security Agency
NSF	National Science Foundation
NSRC	National Suborbital Research Center

O

OBB	Ocean Biology and Biogeochemistry
OCO-2	Orbiting Carbon Observatory - 2

OIB	Operation Ice Bridge
OLYMPEX	Olympic Mountain Experiment
OMG	Oceans Melting Greenland
ONR	Office of Naval Research
ORACLES	Observations of Aerosols Above CLouds and their InteractionS
ORCAS	O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study
ORT	Operational Readiness Test

P

PACE	Plankton, Cloud, and ocean Ecosystem
PALS	Passive Active L- and S-Band Sensor
PDM	Programmed Depot Maintenance
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol R&D
PolSAR	Polarimetric SAR
POS	Position and Orientation Systems
PRISM	Portable Remote Imaging Spectrometer
POSIDON	Pacific Oxidants, Sulfur, Ice, Dehydration, and cONvection

R

RADEX	RADar Experiment
RSP	Research Scanning Polarimeter
RVSM	Reduced Vertical Separation Minima
RZSM	Root Zone Soil Moisture

S

SAFARI	Southern African Regional Science Initiative
SARAL/Altika	Satellite with ARgos and ALtiKa (Ka-band altimeter)
SAR	Synthetic aperture radar
SARP	Student Airborne Research Program
SEO	Sensor equipment operator

SGL	Sander Geophysics Ltd
SHOUT	Sensing Hazards with Operational Unmanned Technology
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SLAP	Scanning L- band Active Passive
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
SoOP-AD	Signals of Opportunity Airborne Demonstrator
SPEX	Spectropolarimeter for Planetary EXploration
SRON	Netherlands Institute for Space Research
SSFR	Solar Spectral Flux Radiometer
SUAS	Small UAS
SWIM	System Wide Management Interface
SWOT	Surface Water and Ocean Topography

T

TAMMS	Turbulent Air Motion Measurement System
TB	Terra bytes
TCAS	Traffic Collision Avoidance System
TCI	Tropical Cyclone Initiative
TEMPO	Tropospheric Emissions: Monitoring Pollution
TFM	Traffic Flow Management
TIR	Thermal Infrared Radiometer
TRACE-A	Transport and Atmospheric Chemistry near the Equator-Atlantic

U

UARC	University Affiliated Research Center
UARP	Upper Atmosphere Research Program
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles

UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCSD	University of California San Diego
UND	University of North Dakota
UNOLS	University-National Oceanographic Laboratory System
USGS	U.S. Geological Survey

V

VIRGAS	Volcano-plume Investigation Readiness and Gas-phase and Aerosol Sulfur

W

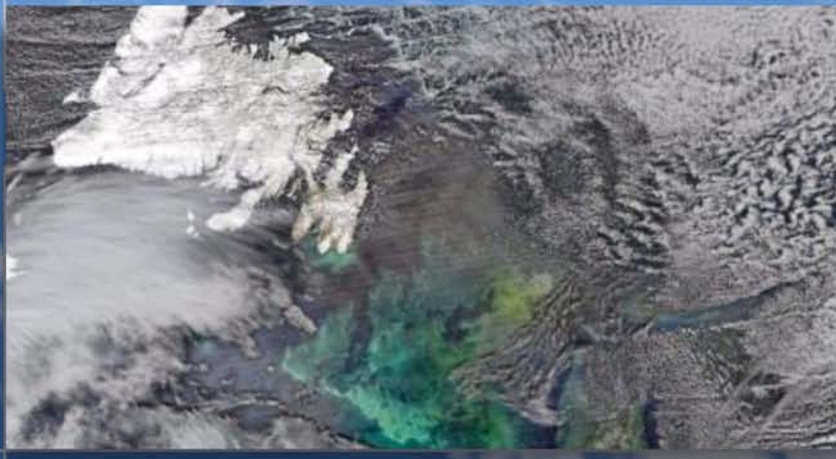
WAS	Whole Air Sampler
WFF	Wallops Flight Facility
WISM	Wideband Instrument for Snow Measurements
Wx	Weather

BACK COVER FIGURES

Upper: Part of Australia's Great Barrier Reef, one of many reefs that the CORAL mission is studying.

Middle: A view of the Kona coast during ATom. Hawaii is one stop on the ATom mission.

Lower: Phytoplankton blooming off the Grand Banks of Newfoundland, an area scientists are studying during the NAAMES mission.



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