National Aeronautics and
Space Administration

Science Mission Directorate

Airborne Science Program

2015 Annual Report









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1. Leadership Comments

Welcome to the FY2015 edition of the Airborne Science Program's Annual Report. This year we flew over 3,700 Earth Science flight hours and over 4,200 total flight hours again collecting data for a variety of missions around the world. The Arctic was a major ASP focus this year. We had several missions flying there, including AirSWOT, CARVE, Operation IceBridge, Polar Winds, SIMPL Greenland, and SNPP Arctic. It was also a unique year in that it was the first time we flew both the Arctic and Antarctic at the same time for Operation IceBridge. We had the C-130 up North, while we utilized NSF's GV to study Antarctica. This year we wrapped up the last of the Earth Venture Suborbital-1 investigations (i.e., AirMOSS and CARVE) and initiated six more EVS-2 investigations: ACT-America, ATom, CORAL, NAAMES, OMG, and ORACLES. In addition, this year we had several major campaigns in cooperation with other Agencies, including the PECAN mission with NSF, NOAA and DOE on the DC-8, as well as the NOAA SHOUT mission on the Global Hawk. We also continued the Student Airborne Research (SARP) Program, where we had another outstanding class with many going on to present their research at AGU. To learn more about each of these activities (and many more), please visit our website at (https://airbornescience.nasa.gov/).

As always, Randy and I hope you enjoy reading about the program and please let us know how we are doing.

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:

- Instrument concept development and testing
- Satellite data simulation, on-orbit calibration, and algorithm validation
- Process studies that improve earth system models
- Workforce development and training the next generation of Earth scientists

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

Structure of the Program

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

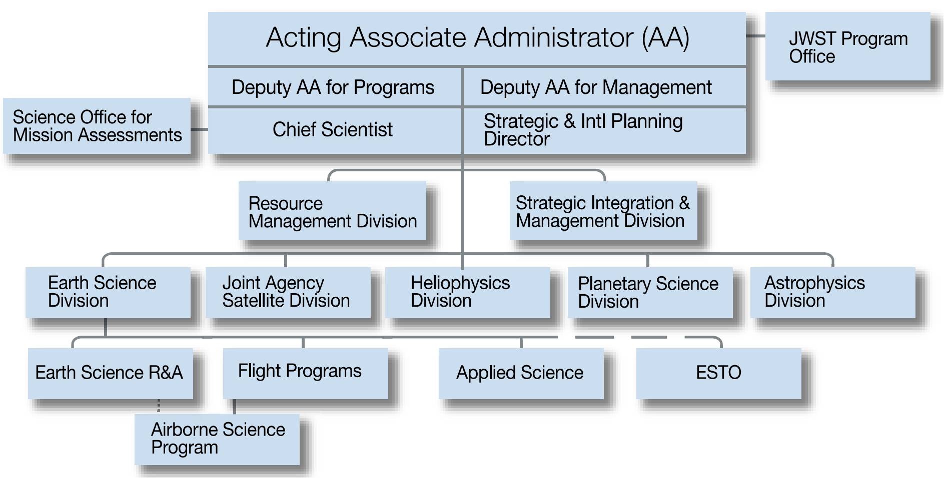


***FIGURE 1** Science Mission Directorate Organization Chart*

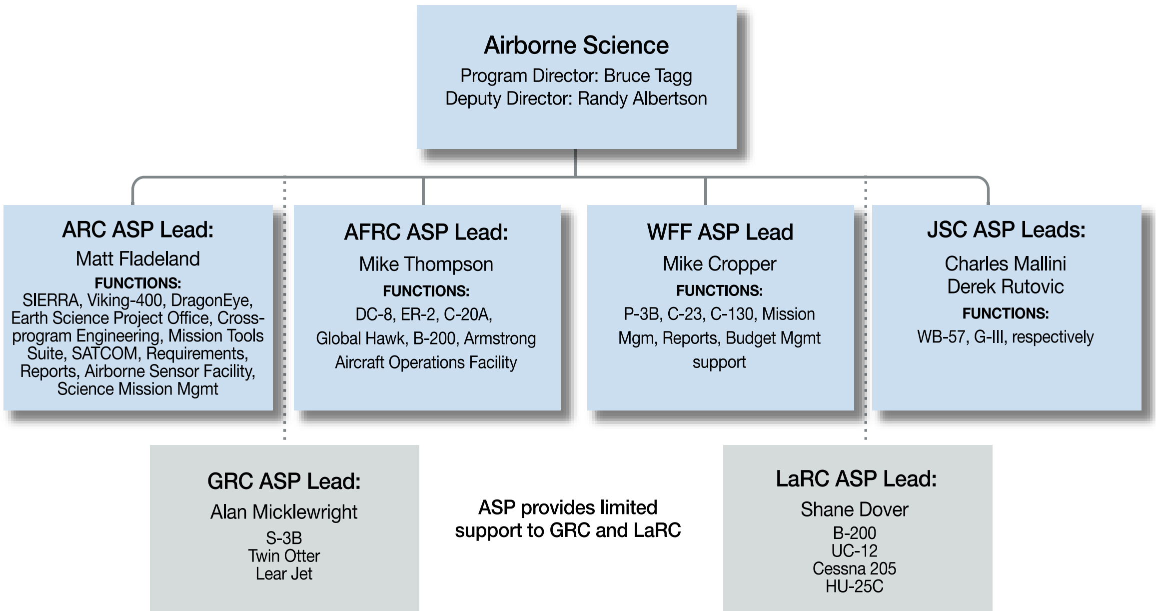


FIGURE 2 *Airborne Science Organization Chart*

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. In 2015, the focus was expanded to assist the HQ Aircraft Management Office with tracking non-SMD aircraft as well.

There were 210 Flight Requests submitted in 2015 for missions with at least one of the following components: an ASP supported aircraft[1], ESD funding, an ASP facility instrument, and/or an ASP Science Support Asset[2]. A total of 96 were completed, some were deferred and the rest were canceled depending upon the availability of resources at the time of the request. Flight Requests were submitted for 16 Airborne Science supported aircraft and 8 “other” platforms. Together they flew a total of 4,261 flight hours. The details are listed in Tables 1 through 3 below. Locations of ASP activities in FY15 are indicated on the globe in Figure 4.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[1]	17	13	2	11	541.8
ER-2[1]	34	23	9	11	365.7
P-3[1]	7	0	0	0	0
Global Hawk[1]	5	3	0	3	146.2
C-20(G-III) AFRC[1]	38	26	1	22	383.7
WB-57[5]	3	2	0	2	0
Twin Otter[5]	25	16	2	12	466.9
C-130 Hercules[5]	3	2	0	2	315.8
C-23 Sherpa[5]	9	5	3	1	424.2
Cessna 206[5]	1	1	0	1	8.8
Cirrus SR-22[5]	1	1	0	1	4.7
Dragon Eye[5]	1	1	1	0	5
Falcon - HU-25[5]	2	2	1	1	43.2
G-III - JSC[5]	10	6	3	3	414.9
Sierra[5]	4	0	0	0	0
B-200[5]	14	13	0	12	400.5
Other[1]	36	22	5	14	744.8
TOTALS	210	136	27	96	4266.2

***TABLE 1** FY15 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

ACRONYMS can be found in Appendix C

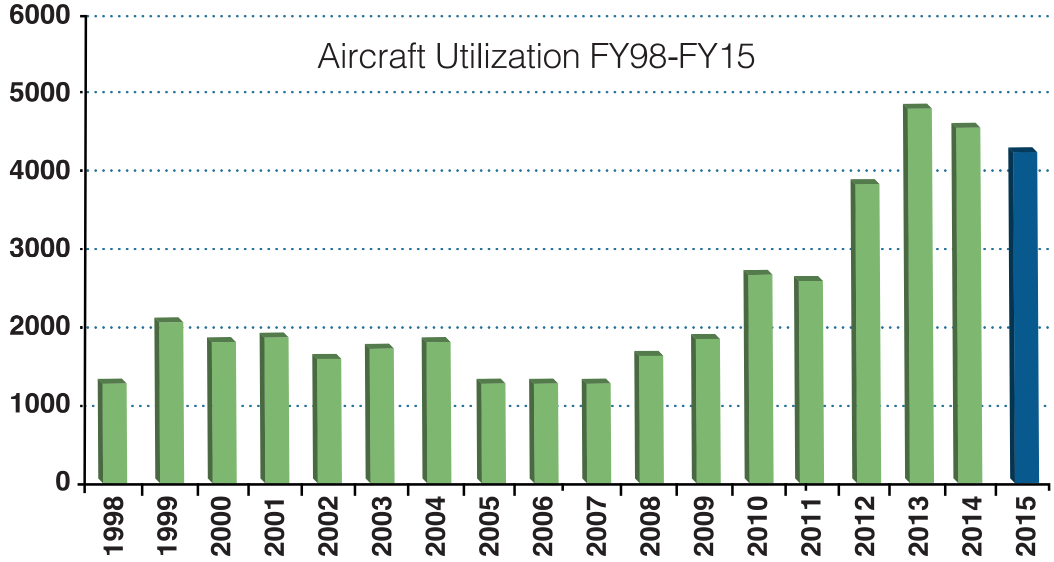


FIGURE 3 ASP flight hours over past 18 years

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[2]	9	6	0	6	442.4
ER-2[2]	22	17	9	5	229.9
P-3[2]	6	0	0	0	0.0
Global Hawk[2]	2	1	0	1	39.7
C-20A (G-III) – AFRC[2]	35	26	1	22	383.7
WB-57[5]	2	2	0	2	0.0
Twin Otter5[5]	21	15	2	11	436.0
C-130 Hercules[5]	3	2	0	2	315.8
C-23 Sherpa[5]	8	5	3	1	424.2
Cessna 206[5]	1	1	0	1	8.8
Cirrus SR-22[5]	0	0	0	0	0.0
Dragon Eye[5]	1	1	1	0	5.0
Falcon - HU-25[5]	1	1	1	0	32.6
G-III – JSC[5]	10	6	3	3	414.9
SIERRA[5]	3	0	0	0	0.0
B-200[5]	13	12	0	11	393.0
Other[6]	30	16	4	10	614.5
TOTAL	157	111	24	75	3740.5

***TABLE 2** Summary of ESD funded FY15 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 "15".*
- *The "Total FRs" column includes Flight Requests that were submitted and whose log number starts with "15".*
- *The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY15.*
- *The "Total Partial FRs" column includes Flight Requests in which the total approved hours were not fully expended during FY15 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 2015.*

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

*****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.***

2015 Airborne Campaigns

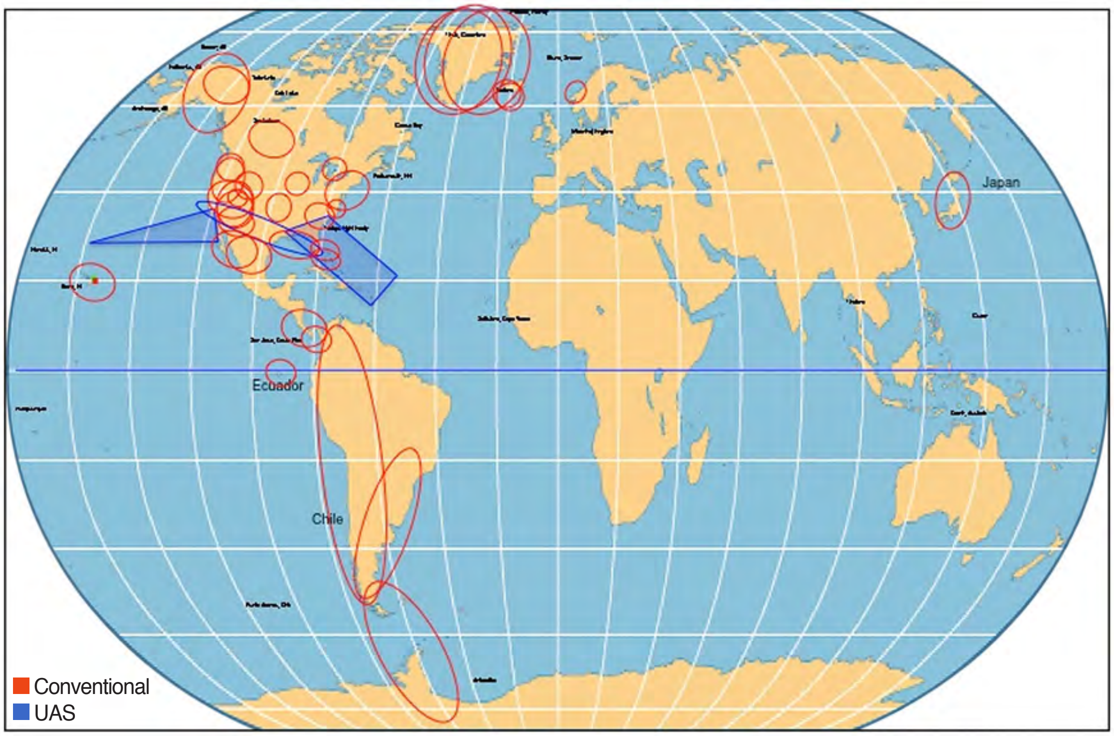
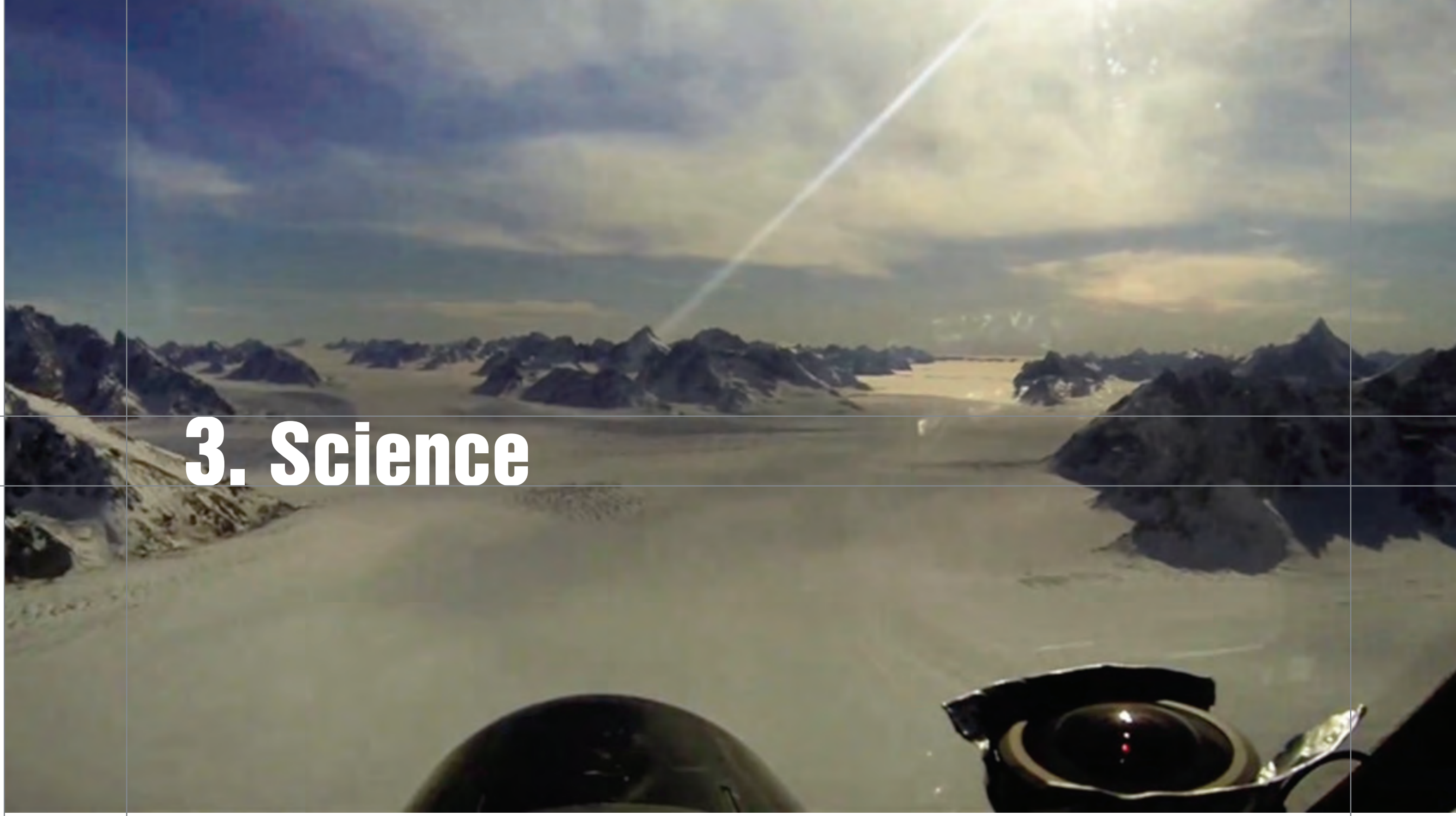


***FIGURE 4** Locations of ASP missions in 2015*



3. Science

Major Mission Highlights

The Airborne Science Program conducted over 4200 flight operation hours in support of process studies, instrument flight-testing, and, especially, support for Earth Science space missions in all phases from definition to validation. Airborne activities provided instrument calibration and data product validation for recently launched SMAP and CATS on the International Space Station, while also providing simulation data sets for algorithm development for the upcoming ICESat-2 and NISAR missions. The Program successfully concluded support for the first round of Earth Venture Suborbital missions while initiating the EVS-2, the second round of Earth Venture Suborbital missions and also continued Operation IceBridge (OIB).

The Airborne Science Program conducted nearly 80 missions and deployed field campaigns, utilizing more than 13 NASA-supported aircraft to support science and technology investigations across the six Earth science focus areas (Atmospheric Composition, Carbon Cycle and Ecosystems, Climate Variability and Change, Weather, Water and Energy Cycle, and Earth Surface and Interior). Flight hours for the largest missions are shown in Table 4. The program also involved students in many activities, from student-led flight projects to support for graduate student researchers.

FY2015 ASP Major Missions	Aircraft	Flight Hours	Location
Operation IceBridge (OIB)	C-130, DC-8, Falcon, B-200, GV	664.0	Greenland, Alaska, Chile, Antarctica
CARVE	Sherpa	424.2	Alaska
AirMOSS	G-III	398.2	9 North American biomes
UAVSAR	C-20A	349.5	Various (North, Central and South America, Japan, Iceland)
AVIRIS-ng	B-200/King Air/Twin Otter	305.9	Various (North America and Iceland)
Airborne Snow Observatory	A90 Dynamic Aviation	250.9	California, Colorado
AirSWOT	B-200	204.0	California, Oregon, Louisiana, Alaska, Canada
Polar Winds	DC-8, B-200	144.3	Iceland, Greenland
Chlorophyll Fluorescence	Twin Otter	118.1	CO, WI, CA, OK
SHOUT	Global Hawk, B-200, Cirrus R22	109.7	Atlantic ocean
HyspIRI prep	ER-2	99.5	California
HIWC	DC-8	87.3	Puerto Rico
SMAPVEX-15/ Rotating PALS	DC-3	82.0	California/Arizona
SIMPL Greenland	B-200	73.1	Greenland
Great Lakes Environmental Assessment	Twin Otter-GRC	70.6	Ohio
SNPP Arctic	ER-2	64.2	Iceland
PECAN	DC-8	56.7	Kansas
AJAX	AlphaJet	44.9	California
Cal-Water-2	ER-2	42.0	Sacramento
HyTES 2015	Twin Otter	40.6	CO, UT, NV, AZ, CA
WISE Patagonia	Other	40.0	Chile
ATTREX/CAST	Global Hawk	39.7	Pacific Ocean
Calipso-CATS	ER-2	32.7	California

***TABLE 4** Major Science Missions in FY15*

Operation Ice Bridge (OIB)

In 2015 IceBridge conducted four separate campaigns on four different aircraft to study the rapid and extensive changes presently taking place in the polar regions. The Arctic spring campaign was conducted using a C-130 aircraft logging 33 science flights (traveling a total distance equivalent to 36% of the distance to the moon) over Greenland and the Arctic Ocean. Highlights of the campaign included numerous international cooperative efforts such as an overflight of an ice-bound Norwegian ship, which served as the home base for a group of researchers taking ground measurements under the IceBridge flight track.

Other international efforts included the release of several quick look data sets to aid in the planning of Greenland field activities, as well as a data product to support seasonal sea ice forecasts of the Arctic Ocean. IceBridge also engaged in a broad level of outreach activities including hosting media personnel from the New York Times and National Geographic. IceBridge participated in a number of in-flight classroom chat sessions with students in grades 1-12 through an Iridium satellite data link, reaching 723 students in 11 states and three countries.

In the summer of 2015, IceBridge utilized a DHC-2 Single Otter aircraft carrying a laser altimeter for its Alaska campaign. The melting of Alaskan glaciers is contributing a substantial portion of the Earth's measured sea level rise, and these results from IceBridge work in Alaska were used during President Obama's speech at the recent Anchorage conference of ministers and officials from Arctic nations.

To wrap up the year, IceBridge conducted an exciting and historic first for the project in undertaking simultaneous collection of data from both the Arctic and Antarctic. Both surveys are from high altitude with the Arctic campaign utilizing a HU-25C Falcon aircraft and the Antarctic campaign utilizing an NCAR Gulfstream-V aircraft. These campaigns will build on the long-running time series of data collected from the mission.

***FIGURE 5** Greenland as viewed from the C-130 during IceBridge in May 2015.*

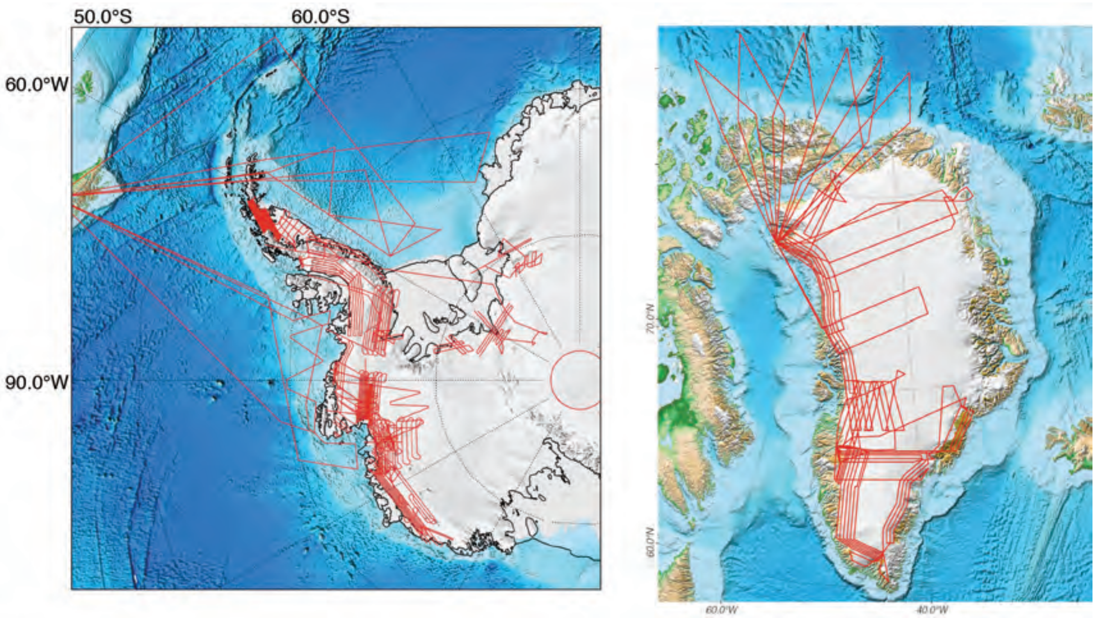


***FIGURE 6** IceBridge flight tracks over Antarctica and Arctic OIB science targets in 2015*

Polar Winds

Beginning in May, the DC-8 aircraft began a series of science flights based out of Keflavik Iceland, aimed at studying Arctic polar winds. The Polar-Winds mission was led by PI Michael Kavaya, with goals to provide current wind data for use in pre-existing weather models and to collect pre-launch calibration and validation data in support of the European Space Agency's (ESA) Atmospheric Dynamics Mission Aeolus satellite, or ADM-Aeolus. The DC-8 logged nearly 70 hours of flight time during Polar-Winds, returning from Iceland on May 28.

This airborne mission focused primarily on gathering wind data in the Arctic polar regions near Iceland and Greenland. This area is of particular interest to both NASA and ESA due to the continued rise in arctic temperatures and decrease in polar ice formation. The polar winds mission demonstrates the contribution of airborne Doppler wind lidars in improving our understanding of energy and atmospheric chemistry transport around the polar regions. The DC-8 aircraft carried two lidar instruments. The primary instrument mounted in the aircraft was the Doppler Aerosol WiNd Lidar (DAWN), managed by NASA's Langley Research Center in Hampton, Virginia. Also aboard is the Tropospheric Wind Lidar Technology Experiment (TWiLITE), managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland.

These lidar instruments are supplemented with a dropsonde system, consisting of approximately 100 small tube-shaped instruments that will be dispensed from the aircraft inflight. The dropsondes are used to obtain vertical wind profiles to validate the lidar system data sets. The dropsondes also contain sensors that transmit and record information on air temperature and moisture.

***FIGURE 7** Preparing a dropsonde for release from the DC-8 during Polar Winds*

Also joining the airborne mission was the Dassault Falcon 20-E from the German Aerospace Center (DLR), which took measurements using the airborne prototype of the lidar instrument on ADM-Aeolus– the ALADIN airborne demonstrator (A2D) instrument, and a second Doppler wind lidar instrument. The two aircraft are shown in Figure 8.

***FIGURE 8** NASA DC-8, German Falcon, and the IceBridge team at Thule, Greenland*

The DAWN instrument had been test flown earlier in FY2015 on the Langley Beechcraft UC-12B Huron as the research aircraft. The primary objectives of that flight test effort in Greenland were: 1) to validate numerical model characterizations of airflow in the lower atmosphere and planetary boundary layer (PBL) over the open oceans, land, ice sheets and transition zones of the Arctic; and, 2) to practice for future efforts to provide calibration/validation of wind for the European Space Agency (ESA) ADM earth-orbiting direct detection wind lidar. The campaign consisted of a total of 30 flights/74.7 flight hours, including four local instrument check flights, two local research flights, six cross-country flights to reach Greenland and return, and 18 research flights in Greenland. The deployed research flights were conducted from Kangerlussuaq, Greenland between October 27, 2014 and November 13, 2014.

Earth Venture Suborbital

Earth Venture Suborbital (EVS), a program of the Earth Science Pathfinder Program, completed EVS-1 projects in 2015 (Table 5), just as EVS-2 projects were ramping up. Completing activities in 2015 were ATTREX, CARVE (Figure 9) and AirMOSS.

The ATTREX/CAST mission in early 2015 involved the United Kingdom National Environment Research Council's Coordinated Airborne Studies in the Tropics (CAST) program flying two instruments: the Aerosol Ice Interface Transition Spectrometer (AIITS) instrument providing unique information about cirrus ice crystal shapes, and the CAST GreenHouse gas Observations in the Stratosphere and Troposphere (GHOST) for measuring methane. In addition, six instruments from the Airborne Tropical TRopopause Experiment (ATTREX) were included in the Global Hawk payload, providing measurements of cloud properties, water vapor, meteorological conditions, and trace gases.

Just getting underway in FY2015 were EVS-2 missions North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) and Oceans Melting Greenland (OMG). The Atmospheric Tomography Mission (AToM) completed site visits and ActAmerica began assembling payloads. The latest addition to the EVS-2 awards is COral Reef Airborne Laboratory (CORAL). The goals and aircraft planned for all the EVS-2 missions are described separately beginning on page 29.

Mission	Aircraft	Hours	Location
ATTEX / CAST	Global Hawk	39.7	Southern California / Pacific Ocean
CARVE	Sherpa	424.2	Alaska
AirMOSS	G-III	398.2	9 North American biomes

***TABLE 5** EV-1 missions in 2015*

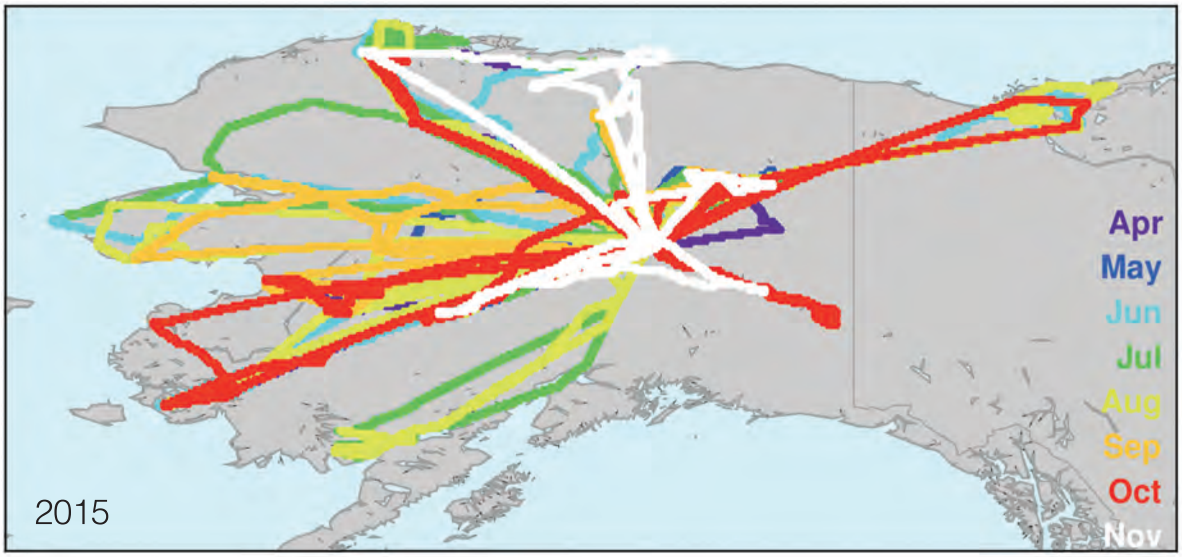


***FIGURE 9** CARVE Alaska flights in 2015. 2015 – CARVE is advancing our understanding of methane and other emissions from ecosystems, permafrost and lakes during different times of the year across Alaska*

UAVSAR Data Acquisition and Delivery Metrics for FY15

UAVSAR conducted 84 flights on the C20-A (NASA 502) for a total of 393 flight hours. The UAVSAR team collected a total of 687 flight lines, representing a 90% success rate in data acquisition/processing, to support 23 flight requests and acquisition of over 16TB of raw data. The production processing team delivered 856 InSAR pairs with an average latency of 9 days and 117 InSAR stacks (consisting of 1,141 scenes or data takes) with an average latency of 45 days. Major deployments and objectives during this one year period included: (1) volcanic deformation studies of Central and South America, (2) deformation associated with plate boundaries in California along the San Andreas, Hayward and associated faults in Baja California, (3) surface deformation associated with Gulf Coast subsidence, (4) surface deformation associated with levee conditions in the Sacramento and Mississippi deltas, (5) landslide mechanics study in Slumgullion, Colorado and Arizona (6) environmental impacts of the Gulf oil spill, (6) SMAP soil moisture cal/val in the Midwest and Argentina, (7) glacier study in Chile, (8) sediment transport and delta formation study at Wax Lake Delta in Louisiana, (9) temperate glacier study in Iceland, and (10) oil spill clean-up exercise in Norway to develop and validate a SAR-based capability to accurately measure oil volumetric fraction for future spill response. Locations of the data tracks are shown in Figure 10.

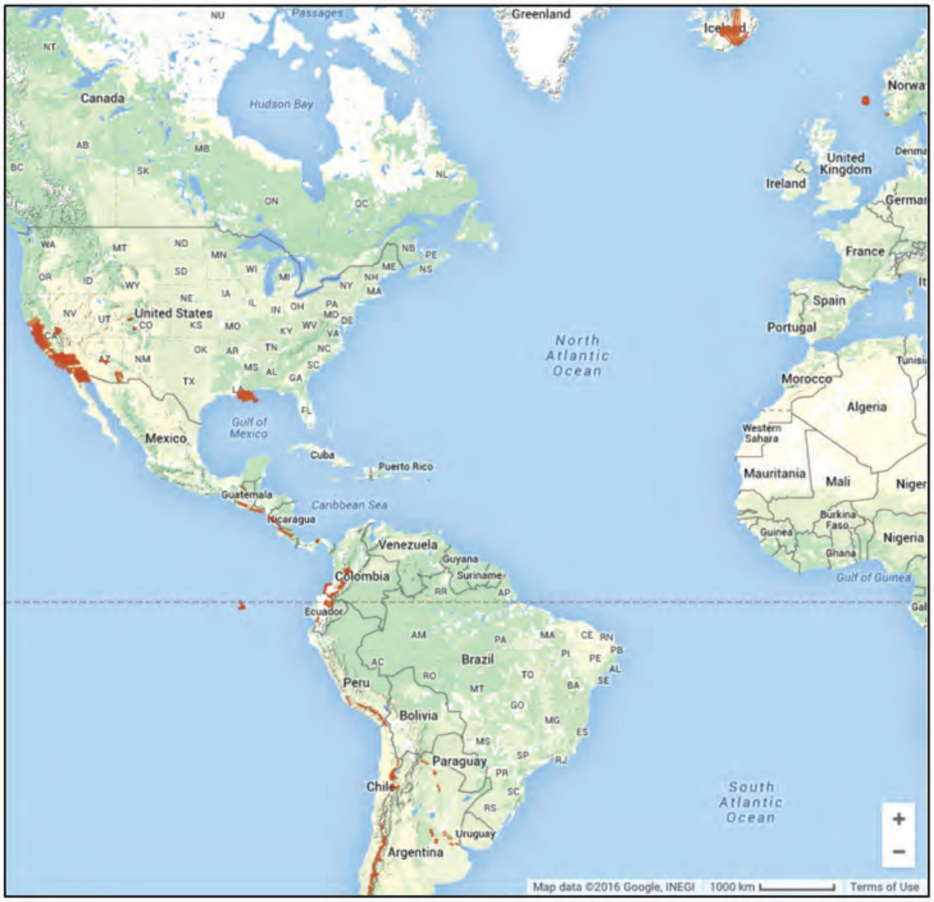


FIGURE 10 *Locations of UAVSAR data acquisitions in FY15 (orange flight tracks)*

The pie chart of UAVSAR data acquisitions by discipline (Figure 11) illustrates the diversity of UAVSAR applications. Excluding engineering flights, the project acquired data for 7 disciplines where solid earth (including earthquakes, volcanoes, and other deformations) accounts for 37% of the total data sets acquired.

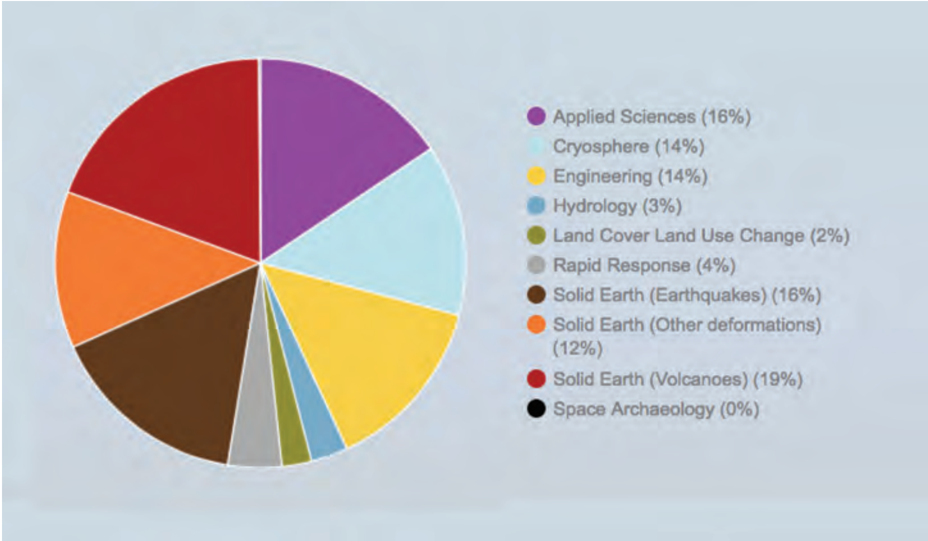


FIGURE 11 *Science and Applications disciplines collecting UAVSAR data in 2015*

Joint Gulf Coast Experiment

The Wax Lake Delta mission mentioned above featured concurrent UAVSAR and AirSWOT imaging of the Wax Lake Delta and the inland waters of the southeastern Louisiana gulf coast. UAVSAR on the NASA C20-A was used to measure shallow water bathymetry and water height change and AirSWOT on a NASA B-200 measured water surface height. The two planes are shown together in New Orleans in Figure 12. A screen shot from the C20-A is shown in Figure 13. The flight track map shows the science lines in green and 30 minutes of flight track history in red during the Joint experiment of the UAVSAR with AirSWOT to survey the delta growth/reduction under the rising tide conditions in gulf coast near New Orleans, LA.

***FIGURE 12** AFRC B-200 with AirSWOT and C20-A with UAVSAR in New Orleans*

***FIGURE 13** Screen shot showing flight tracks during joint Wax Delta mission*

Support to ESD Satellite Missions

A primary purpose of the Airborne Science Program is to support Earth Science space flight missions, including satellite missions, and now also missions flying on the International Space Station (ISS). This support includes airborne campaigns to collect data for algorithm development prior to launch, to test instrument concepts for satellite / ISS payloads or airborne simulators, and to provide data for calibration or validation of satellite algorithms, measurements or observations once in orbit. In 2015, 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-15	DC-3; C-20A, G-III	82.6	Arizona, Argentina	Cal/val
ICESat-2	SIMPL / AVIRIS-ng	2 B-200s	73.1	Greenland	Finalize instrument algorithms
ICESat-2	Operation IceBridge	C-130, DC-8, Falcon, B-200, GV	664	Greenland, Alaska, Chile, Antarctica	Build data base
SWOT	AirSWOT	B-200	204	California, Oregon, Louisiana, Alaska, Canada	Algorithm development
HyspIRI	HyspIRI airborne precursor	ER-2	99.5	6 Boxes in California	Precursor data sets
NISAR	UAVSAR volcanoes, ecosystems	C-20A	68.6	Various – N. and S. America	Precursor data sets
GEO-CAPE	GEO-TASO and GCAS	B-200	12.5	Virginia	Instrument development
ASCENDS	CarbonHawk	Falcon	10.6	California	Precursor data
ACE	EXRAD	ER-2	31.4	California	Instrument test
PACE	PRISM, G-LiHT	ER-2, Piper Cherokee	25	Florida	Color data
Other					
CATS (ISS)	CALIPSO-CATS	ER-2	32.7	California	Validation
CALIPSO	HSRL-2 flights	B-200	31.4	California	Equipment Test/ Validation
GEDI (ISS)	G-LiHT	Piper Cherokee	35	Bahamas, FL	Precursor data sets
OCO-2	Various, including AJAX	AlphaJet	44.9	California	Cal/val
AQUA	Numerous including COAST	Twin Otter	472	California	Cal/val
TERRA	Numerous including Snow Observatory	Twin Otter	250.9	Colorado California, Iceland	Data comparison
SNPP	SNPP Arctic	ER-2	64.2	Iceland	Cal/val
GOES	HIWC	DC-8	87.3	Florida, Caribbean	Cal/val

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

SMAPVEX-15

The SMAP mission, launched in 2015, carries both a radiometer and a radar for the measurement of soil moisture. The radiometer is up and operational. Unfortunately the radar experienced an anomaly in May 2015 and has not recovered. The initial cal/val plan for SMAP included both the JPL PALS instrument and the UAVSAR. Relevant UAVSAR data were collected in South America in April 2015, while elated P-band SAR data were collected as part of the AirMOSS mission in Arizona in August 2015.

The PALS instrument has flown previously on the WFF P-3 aircraft, but that aircraft was not available in 2015, so the major SMAPVEX-15 Field Campaign made use of a DC-3 aircraft operated by Airborne Imaging, Inc.

NASA's SMAP (Soil Moisture Active Passive) satellite observatory conducted a field experiment as part of its soil moisture data product validation program in southern Arizona on Aug. 2 - 18, 2015. The image in Figure 14 represents the distribution of soil moisture over the SMAPVEX15 (SMAP Validation Experiment 2015) experiment domain, as measured by the Passive Active L-band System (PALS) developed by NASA's Jet Propulsion Laboratory, Pasadena, California, which was installed onboard a DC-3 aircraft operated by Airborne Imaging, Inc. Blue and green colors denote wet conditions and dry conditions are marked by red and orange. The black lines show the nominal flight path of PALS.

The measurements show that on the first day, the domain surface was wet overall, but had mostly dried down by the second measurement day. On the third day, there was a mix of soil wetness. The heterogeneous soil moisture distribution over the domain is typical for the area during the North American Monsoon season and provides excellent conditions for SMAP soil moisture product validation and algorithm enhancement. The images are based on brightness temperature measured by the PALS instrument gridded on a grid with 0.6-mile (1-kilometer) pixel size. They do not yet compensate for surface characteristics, such as vegetation and topography. That work is currently in progress.

An alternative active-passive instrument, the GSFC SLAP instrument is also available for SMAP-relevant measurements. It flew test flights on the Langley B-200 in 2015.

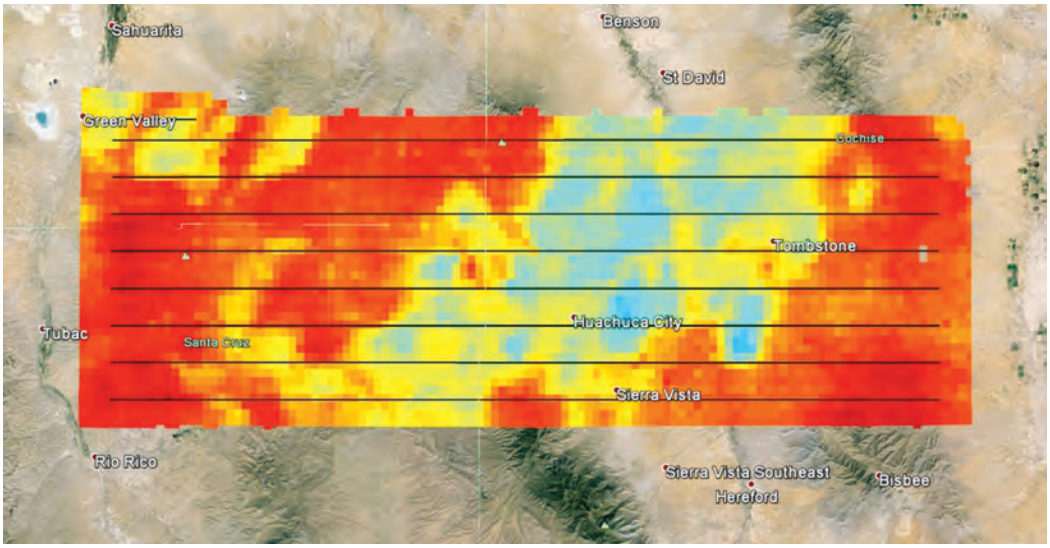
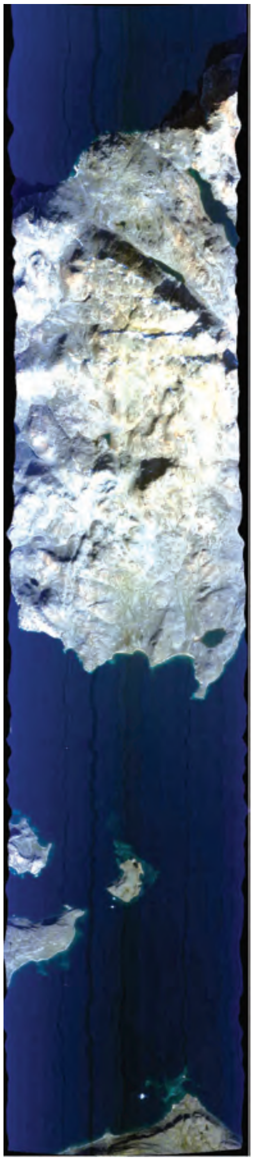


***FIGURE 14** PALS image from August 8, 2015*



ICESat-2 - SIMPL

Ice, Cloud, and land Elevation Satellite-2 (ICESat-2): Airborne efforts support geophysical algorithm development for the ICESat-2 payload. ICESat-2 will carry the Advanced Topographic Laser Altimeter System (ATLAS), which will be a six-beam photon-counting laser altimeter using 532-nm wavelength pulses.

To further refine the ICESat-2 geophysical algorithms, NASA recently conducted a coordinated airborne campaign designed with the primary goal of addressing how both green- and infrared-wavelength light beams are affected by water or melt on the ice surface, and with a secondary goal of determining how snow-grain size may affect the propagation of green-wavelength light. These science goals dictated the timing of the mission (August 2015) and the base of operation (Thule Air Base, Greenland).

To address the first science goal, NASA Goddard Space Flight Center's Slope Imaging Multi-polarization Photon-counting Lidar (SIMPL) was deployed on a NASA Langley Research Center B-200 King Air. To address the second science goal, NASA Jet Propulsion Laboratory's Airborne Visible/Infrared Imaging Spectrometer – Next Generation (AVIRIS-NG) was deployed on a B-200 King Air operated by Dynamic Aviation. Specific science targets to meet these goals included the dry interior of the Greenland ice sheet, melt ponds near the edge of the ice sheet, and melting sea ice in the Arctic Ocean. The mission, called SIMPL/ AVIRIS-NG Greenland 2015, conducted 9 coordinated science flights based out of Thule, for a total of 37 flight hours. The flight lines are shown in Figure 15. The total mission, including local data flights at NASA Langley and the transit flights to and from Greenland, required 73.1 flight hours on the NASA aircraft.

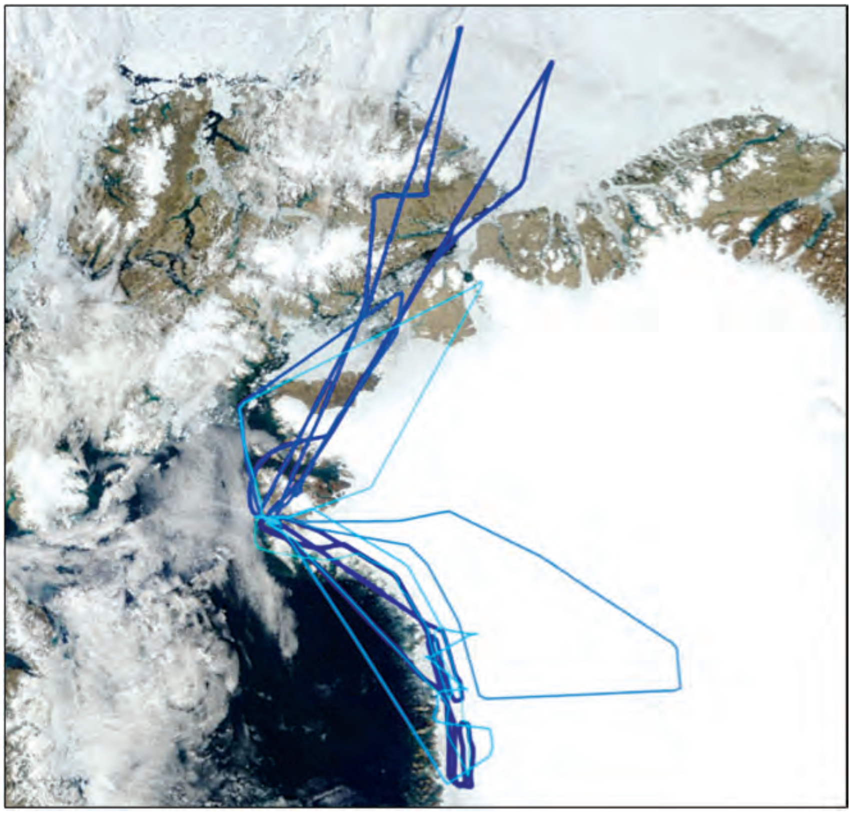


FIGURE 15 *Coordinated flight lines for the two B-200 aircraft during the SIMPL / AVIRIS-NG mission in Greenland.*

FIGURE 16 *The six regions in California imaged extensively during the HyspIRI Airborne Campaign*

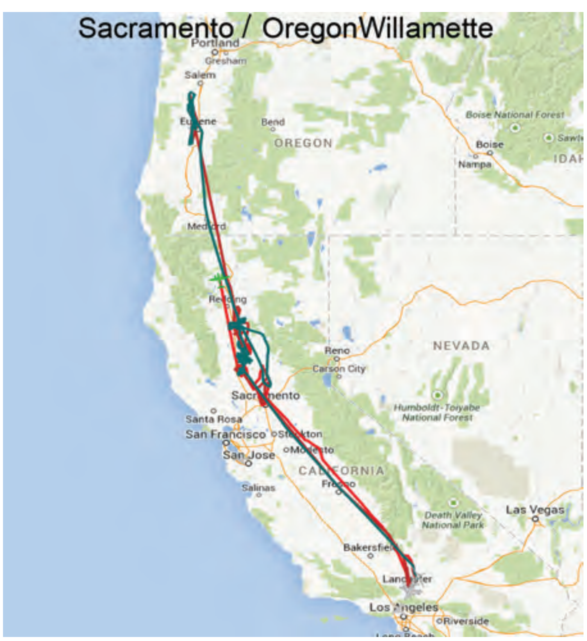
HyspIRI Preparatory Airborne Studies

In preparation for the Hyperspectral Infrared Investigations (HyspIRI) mission, NASA has undertaken a major campaign known alternatively as the HyspIRI precursor mission, the HyspIRI preparatory airborne mission and the "Multi-Season, Multi-Year Western U.S. NASA Remote Measurement Science Campaign." Six regions in California have been mapped in detail in 2013, 2014, and 2015 using the AVIRIS and MASTER instruments flying on an ER-2 aircraft. (The mission will move to Hawaii in 2016.) In 2015 a total of 10 individual campaigns and over 100 flight hours were conducted in support of HyspIRI preparation.

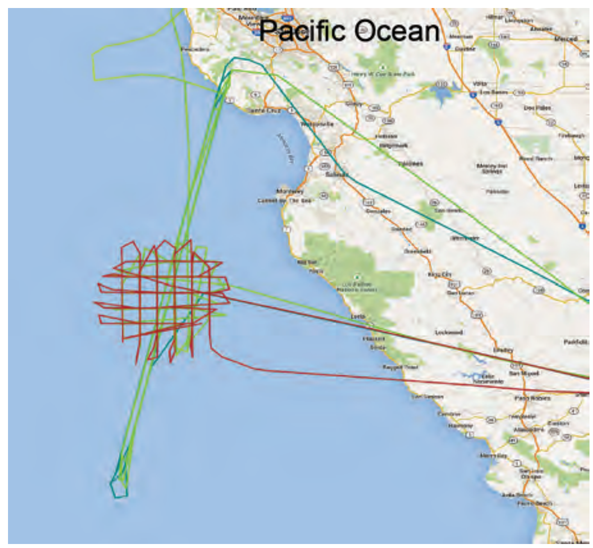
AirSWOT

During FY15, the AirSWOT instrument had a very busy season, flying a total of 180 hours aboard the NASA801 B200 aircraft. This included engineering flights over our Rosamond lake calibration site, Tahoe calibration site and Piute Ponds wetlands as well as four separate experiment campaigns involving collaboration with universities and other government agencies.

River Campaign: During March 2015, AirSWOT made three two-day trips to Eugene, OR. On each trip, data was collected over the Sacramento and Willamette Rivers. Teams from USGS and University of Oregon collected measurements of river surface heights and hydraulic pressures. Data from this campaign will be used to study radar phenomenological effects that cause errors in height measurements and also to validate retrievals of river height and slope measurements.



Ocean Campaign: During April 2015, AirSWOT collected data off of the California coast near Monterrey. This campaign was coordinated with overpasses of the AltiKa ocean altimeter as well as an airborne LIDAR and surface assets including two ships deploying instrumentation. The experiment campaign was intended to support the validation of AirSWOT measurement capabilities for support of the SWOT mission.



Mississippi Campaign: Four data collection flights were performed over the Wax Lake Delta and Atchaflaya Wetlands, near New Orleans Louisiana. Data were collected at varying points over the tidal cycles. These data will be used both for SWOT mission studies and to aid development of numerical models of river delta development. More information about this campaign, which took place jointly with the C20-A carrying UAVSAR is found on page 17.

Alaska Campaign: In its longest campaign to date, AirSWOT deployed to Fairbanks, Alaska for twenty-two days. Seventeen data collection flights were conducted over the Tanana and Yukon Rivers and Yukon Flats. Ground teams from UNC and UCLA collected in-situ data on the river, lakes and wetlands. Data from this experiment will be used to validate AirSWOT hydrological measurements in complex, arctic environments.

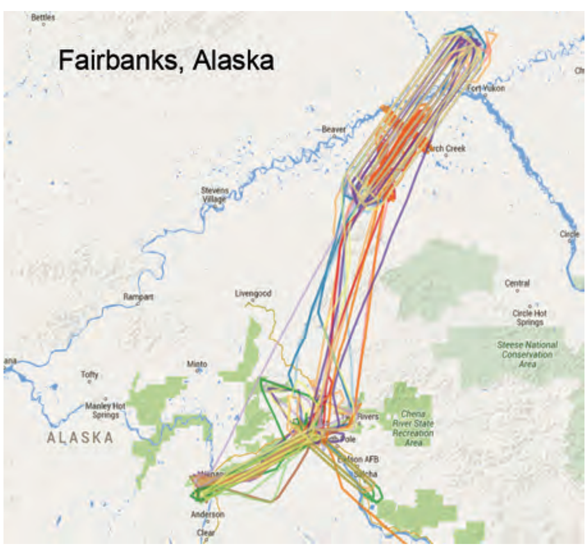


***FIGURE 17** 2015 AirSWOT flights*

NISAR

The NASA-ISRO (NISAR) mission is scheduled to launch in 2020. NASA has partnered with ISRO to meet science requirements called for by the 2007 Decadel Survey DESDynI mission concept.

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 land-slides.

The most relevant airborne support for NISAR is JPL's UAVSAR. Currently, the UAVSAR flies most frequently on the Armstrong C-20A (G-III) aircraft. In 2015, four UAVSAR missions, most notably in South and Central America, were deemed to provide early data in support of NIS-AR. Significantly more UAVSAR activity related directly to algorithm development for NISAR is scheduled in 2016.

GEO-CAPE

NASA LaRC completed the science research flight campaign on the Langley B-200 Aircraft for two NASA Goddard instruments: the Geo-stationary Trace gas and Aerosol Optimization (GEO-TASO) instrument; and, the GeoCAPE Airborne Simulator (GCAS). The instruments were flown on the NASA Langley B200 King Air, utilizing its two nadir ports. The campaign, which concluded on July 10, 2015, consisted of a total of four flights, constituting 12.5 flight hours. The research flights were conducted from NASA Langley with overflights of a NOAA research vessel cruising off the coast of Virginia. All flight science objectives were met on schedule. Download of the two instruments has been completed and the instruments have been returned to NASA Goddard. Funding was provided by the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) Program, Earth Science Division, Science Mission Directorate, NASA Headquarters. The Principal Investigator was Scott Janz, NASA Goddard.

CALIPSO / CATS

During August 2015 the NASA ER-2 was used to fly the Cloud Physics Lidar (CPL) for validation of the CALIPSO satellite and the Cloud-Aerosol Transport System (CATS) instrument on the International Space Station (ISS). These flights

***FIGURE 18** Installing the CPL and CATS simulator on the ER-2*

also afforded an opportunity to further test the new Airborne Cloud-Aerosol Transport System (ACATS) simulator instrument. Obtaining an accurate assessment of cloud and aerosol properties and their transport remain a major challenge in understanding and predicting the climate system. The CATS, CPL, and ACATS data products have a wide range of applications to significant climate system issues, such as examining cirrus optical properties, assessing dust and smoke transport, and investigating cloud-aerosol interactions.

On all of the flights, underpasses of the CALIPSO satellite were the primary target, focusing on complex scenes of cirrus clouds and smoke from forest fires in the Pacific Northwest. On most of the flights it was also possible to intercept the ISS track for further validation of the CATS sensor. Preliminary examination shows good agreement between CATS and ACATS data sets. Figure 19 is a data image showing CPL, ACATS, CATS-ISS, and CALIPSO data from the same flight. The left panels show the CALIPSO and CPL data from the CALIPSO underpass. The right-hand panels show the CPL, ACATS, and CATS data from the ISS underpass track.

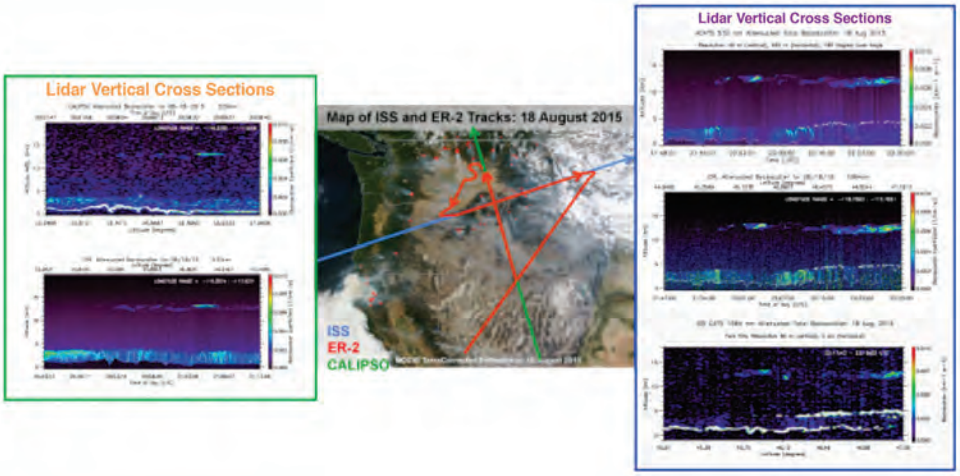


***FIGURE 19** Data image showing CPL, ACATS, CATS-ISS and CALIPSO data from the same flight*

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 2015, ASP aircraft flew all of the instruments listed in Table 6. 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 flights in conjunction with the Airborne Science Program before moving to further maturation for space missions. In FY15 flight-testing was provided for instruments as listed in Table 7. The WISM, HAMMR and Methane Sounder instruments are all in development related to Decadal Survey missions. A large number of other IIP-selected instruments are also scheduled for test flights in 2016 and 2017, as shown in the 5-year plan (Appendix B).

Instrument	Sponsor	Aircraft	Flight Hours
	ESTO		
WISM	IIP	Twin Otter	9.4
MOS Ocean Color Sensor	IIP	Twin Otter	24.3
HAMMR	IIP	Twin Otter	32
Methane Sounder	IIP	DC-8	6.7
Soil moisture mapping small UAS	IIP	Tempest UAS	1.1
Intelligent Payload Module	AIST	Cessna, Helicopter	19.1
EXRAD	AITT	ER-2	5.6
	Other		
HSRL-2	Calipso	ER-2	31.4
AirSWOT	SWOT	B-200	28.1
CarbonHawk (ACES)	LaRC	Falcon	10.6
AVIRIS-ng	Turner	B-200	48.4
Chlorophyll Fluorescence	Jucks	Twin Otter	118.1
TWiLiTE	Kakar	DC-8	3.7
eMAS and HSI	Platnik	ER-2	5.5

***TABLE 7** Instrument development flights in FY15*

New Instruments

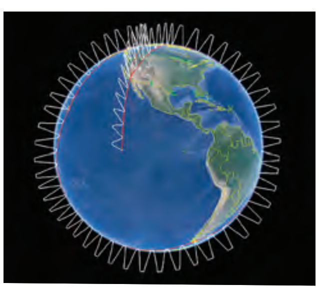
A number of new passive optical imaging and spectrographic instruments have been under development for the past few years and reached mission-ready status in 2015. These include the AVIRIS-next generation (AVIRIS-NG), Hyperspectral Thermal Emission Spectrometer (HyTES), Portable Remote Imaging SpectroMeter (PRISM), and the enhanced MODIS airborne simulator (eMAS). Status and activities for these instruments are described in Section 7.

2016 Upcoming Activities

Earth Venture Suborbital – 2 (EVS-2)

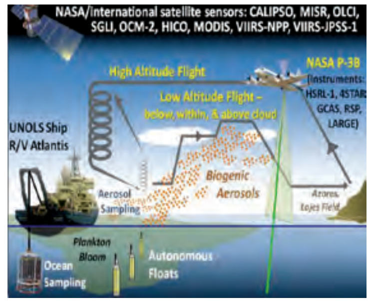
Six new Earth Venture – Suborbital missions were awarded in 2015 for activities over the years through 2019. The missions are listed below. The aircraft requirements are listed in Table 8. The map in Figure 20 shows the broad reach of these missions.

ATMOSPHERIC TOMOGRAPHY EXPERIMENT (ATOM) – HARVARD UNIVERSITY (STEVE WOFSY)



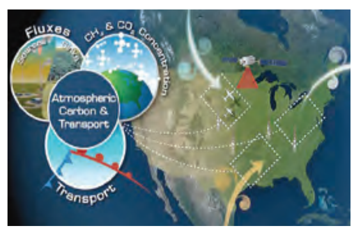
This investigation will study the impact of human-produced air pollution on certain greenhouse gases. Airborne instruments will look at how atmospheric chemistry is transformed by air pollutants and at the impact of methane and ozone, which affect climate. Flights of NASA's DC-8 will originate in Palmdale, California, fly north to the Western Arctic, south to the South Pacific, east to the Atlantic, north to Greenland, and return to California across North America.

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



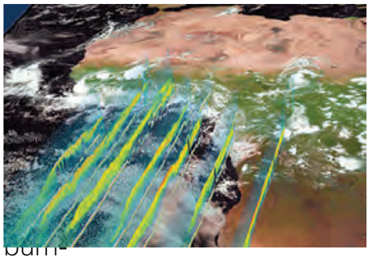
This investigation will improve predictions of how ocean ecosystems would change with ocean warming. The mission will study the annual life cycle of phytoplankton and the impact small airborne particles derived from marine organisms have on climate in the North Atlantic. The large annual phytoplankton bloom in this region may influence the Earth's energy budget. Research flights on NASA's C-130 aircraft will be coordinated with a (UNOLS) research vessel.

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



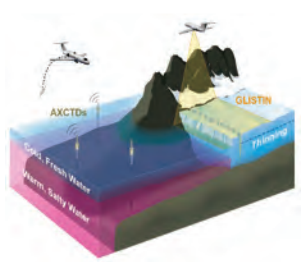
This investigation will quantify the sources of regional carbon dioxide, methane and other gases, and document how weather systems transport these gases in the atmosphere. The research goal is to improve identification and prediction of carbon dioxide and methane sources and sinks using spaceborne, airborne and ground-based data over the eastern United States.

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



Oracles will probe how smoke particles from massive burning in Africa influence cloud cover over the Atlantic. Particles from this seasonal burning that are lofted into the mid-troposphere and transported westward over the southeast Atlantic interact with permanent stratocumulus "climate radiators," which are critical to the regional and global climate system. NASA aircraft, including the P-3 and ER-2, will fly this mission out of Walvis Bay, Namibia.

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 propertied around Greenland, will be taken from ships and the air using several aircraft. NASA aircraft supporting this mission include both Gulfstream III aircraft.

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

This investigation will provide 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 will make 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 8 campaigns across 10 coral reef regions in the Indian, Pacific, and Atlantic Ocean. CORAL will fly PRISM, a new multispectral imager, on the NASA ER-2 aircraft over a 3-year period.

Mission	Location	Dates (see 5-year plan)	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
CORAL	Indian and Pacific oceans, Caribbean	2015 - 2018	ER-2, GV

***TABLE 8** EVS-2 Locations, Schedules and Aircraft*

***FIGURE 20** EVS-2 Mission Locations*

Other major missions in 2016

Mission	Aircraft	Location
OLYMPEX	DC-8, ER-2, B-200	Puget sound area
KORUS-AQ	DC-8, B-200	Korea
SMAPVEX-16	DC-3	Iowa
Operation IceBridge	C-130, DC-8	Antarctic, Arctic
HyspIRI Airborne	ER-2	Hawaii

***TABLE 9** Other major missions in 2016*

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	2,550	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_-_Dryden
	Global Hawk	NASA-AFRC	26	1,500	26,750	65,000	335	9,000	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	5	2,000	13,500	28,000	220	1,000	http://airbornescience.nasa.gov-/aircraft/B-200_UC-12B_-_LARC
	B-200	NASA-AFRC	5	1,700	13,420	28,000	270	1,400	http://airbornescience.nasa.gov-/aircraft/B-200_-_DFRC
	B-200	NASA-LARC	5	2,000	13,500	28,000	220	1,000	http://airbornescience.nasa.gov-/aircraft/B-200_-_LARC
	B-200 King Air	NASA-WFF	6.0	1,800	12,500	28,000	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	646	3,600	10,000	150	700	http://airbornescience.nasa.gov-/aircraft/Cessna_206H
	Cirrus SR22	NASA-LARC	6.1	932	3,400	10,000	175	970	http://airbornescience.nasa.gov-/aircraft/Cirrus_Design_SR22
	Dragon Eye	NASA-ARC	<1	1	6	1000	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
	HU-25C Falcon	NASA-LARC	4.5	2,000	32,000	36,000	350	1,600	http://airbornescience.nasa.gov-/aircraft/HU-25C_Falcon
	Ikhana	NASA-AFRC	20	2,000	10,500	45,000	171	3,000	http://airbornescience.nasa.gov-/aircraft/Ikhana
	Learjet 25	NASA-GRC	2	2,000	15,000	45,000	350	1,000	http://airbornescience.nasa.gov-/aircraft/Learjet_25
	Learjet 35	NASA-GRC	4	4,200	19,600	45,000	350	2,300	
	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	500	http://airbornescience.nasa.gov-/aircraft/T-34C
	Twin Otter	NASA-GRC	3	3,000	11,000	25,000	140	450	http://airbornescience.nasa.gov-/aircraft/Twin_Otter_-_GRC
	UH-1	NASA-WFF	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-JSC	6.5	8,800	72,000	60,000+	410	2,500	http://airbornescience.nasa.gov-/aircraft/WB-57

__TABLE 10__ Airborne Science Program aircraft and their performance capabilities

NASA maintains and operates a fleet of highly modified aircraft unique in the world for their ability to support earth observations. The aircraft are based at various NASA Centers. Some of the platforms have direct support from ASP for flight hours and personnel. These are the "ASP-supported Aircraft."

NASA catalog aircraft are also available for science missions. More information about using the aircraft can be found on the ASP website at airbornescience.nasa.gov. The annual “call letter” is an excellent source of information 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 10. The altitude / endurance characteristics are also shown in Figure 21.

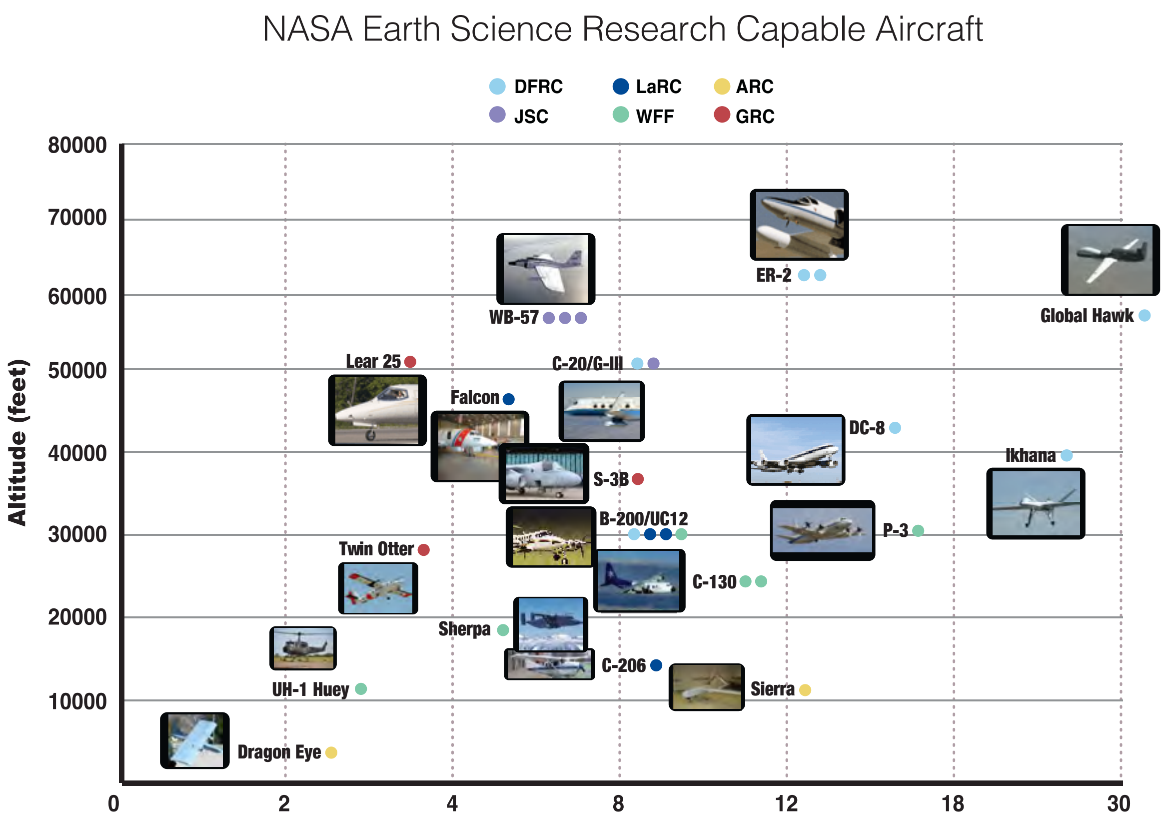


FIGURE 21 NASA Aircraft showing altitude and endurance capabilities

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 FY15: 539.3

Following a major upgrade in 2014, the DC-8 was back in service in 2015, with activities as listed below.

DC-8 FY15 missions

Mission	Location	Science program area
Operation IceBridge	Antarctica	Cryosphere
TWiLiTE / dropsondes validation	California	Weather
Polar Winds	Iceland	Weather
SARP	California	Training
PECAN	South Dakota, Oklahoma	Weather
HIWC	Florida, Gulf of Mexico	Weather
Methane Sounder / COSS	California	Atmospheric Composition

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Modification	Impact
LN-92 INS Upgraded	Better supportability and interface with Honeywell RDR-4000 weather RADAR
Honeywell RDR-4000 Wx RADAR	Required for HIWC mission and on indefinite loan from LaRC

FIGURE 22 *NASA DC-8 aircraft takes off from its base of operations in Palmdale, California for Polar Winds mission*

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 FY15: 342.3

ER-2 FY15 missions

Mission	Location	Science program area
HyspIRI Airborne	California (6 boxes)	Carbon cycle
CalWater-2	California	Applied Science
CPL / ACATS	California	Atmospheric Composition
HSRL-2	California	Atmospheric Composition
SNPP	Iceland	EOS
Rad-X underflight	California	
Photovoltaic / Solar Cell Science	California	Atmospheric Chemistry
Red Wildcat	California	Lockheed Reimbursable
Cosmic Dust	California	

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE: NONE

FIGURE 23
ER-2 aircraft

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
A cabin altitude reduction effort 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 October 2016 through September 2018.

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.

MODIFICATIONS MADE IN FY14 AND IMPACTS ON PERFORMANCE AND SCIENCE:

The P-3 Orion began the re-wing process in August 2014. This process includes removing the existing set of wings and replacing with a new set of wings along with replacement of material in the horizontal stabilizers and aft pressure bulkhead. Once completed in Spring 2016, the P-3 Orion's fatigue life limits will be reset and the aircraft will be available for NASA missions for another 20-30 years.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

Aircraft unavailable due to re-wing until June 2016.

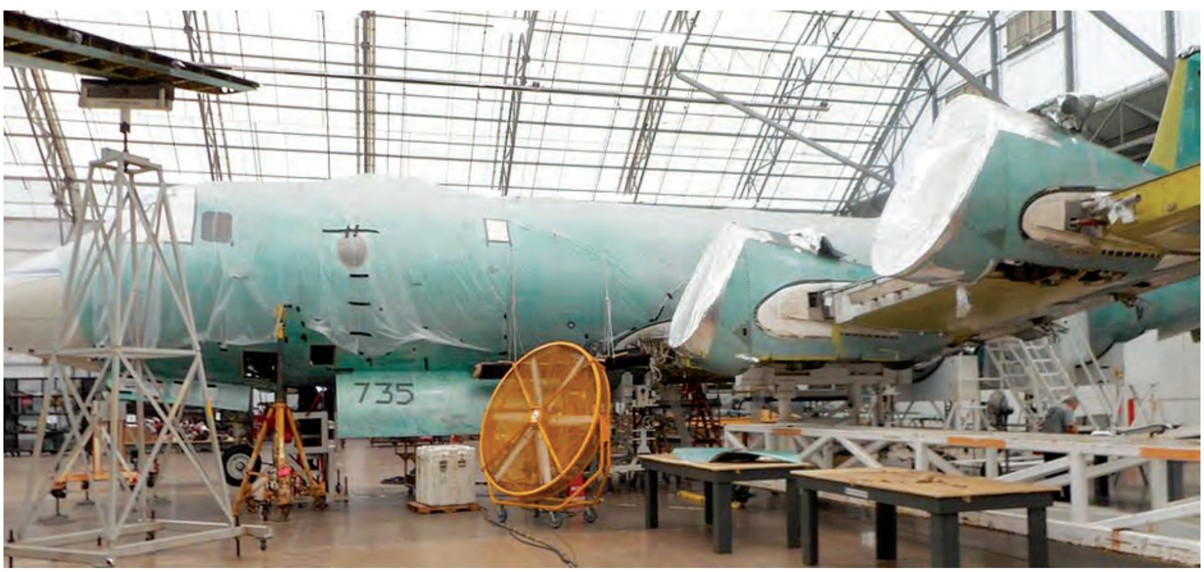


***FIGURE 24** P-3B Orion in Rewing Process*

***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 different versions of JPL's UAVSAR instrument. The Armstrong aircraft is part of the ASP-supported fleet, whereas the JSC G-III program support ended with the completion of the AirMOSS mission.

SCIENCE FLIGHT HOURS IN FY15: C20-A: 386.1

G-III FY15 missions

Mission	Location	Science program area
UAVSAR	AZ, CA, CO, HI, LA, WY, Japan, South America, Mexico	Earth surface and interior
UAVSAR	Iceland, South America	Cryosphere
UAVSAR	CONUS, South America	Water and energy cycle
UAVSAR	South America	Carbon cycle/Terrestrial ecology
UAVSAR	California	Applied science

MODIFICATIONS MADE TO THE C20-A AIRCRAFT IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Modification	Impact
Installed 2 Mid-Life Engines	Provides 4,000 hours or 9 years of flight
Repaired ALL Fuel Tanks	Leak proof for the remaining life (4000 hours) of the vehicle

***FIGURE 25** C20-A (Armstrong G-III) carrying UAVSAR for New Orleans mission in 2015*

***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.

Aircraft number N871 was retired from operation in 2015 due to electrical problems. All of the science flight hours were on N872.

SCIENCE FLIGHT HOURS IN FY15: 137.2

Global Hawk FY15 missions

Mission	Location	Science program area
ATTREX / CAST	California	Earth Venture, Atmospheric Composition, Atmospheric Dynamics
NOAA SHOUT	Gulf of Mexico; Atlantic Ocean	Weather

FIGURE 26 *NASA Global Hawk shown with the CAST AIITS and ATTREX Hawkeye instruments on the wing pylons.*

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE: NONE
A decision to bring up a new Global Hawk (N874) will be made in early 2016.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS: None in FY16

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

Other NASA Earth Science Aircraft

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

Aircraft	Operating Center
C-130 Hercules	WFF
B-200 King Air; UC-12B	LaRC, AFRC, WFF
C-23 Sherpa	WFF
HU-25C Falcon	LaRC
G-III	JSC
Dragon Eye UAS	ARC
Ikhana UAS	AFRC
Learjet 25	GRC
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 keep them.

SCIENCE FLIGHT HOURS IN FY15: 320.3

C-130 ARISE - Arctic Radiation IceBridge Sea and Ice Experiment (ARISE); Fairbanks, Alaska; 18.7 hours in FY15 (mission overlapped FY14 and FY15, 140.3 flight hours flown in FY14)

C-130 OIB Arctic – Operation IceBridge (OIB) – Arctic; Thule, Greenland; Fairbanks, Alaska; Kangerlussuaq, Greenland; 297.6 flight hours

C-130 Hercules missions

Mission	Location	Science program area
Operation IceBridge	Thule and Kangerlussuaq, Greenland; Fairbanks, Alaska	Cryosphere
ARISE	Fairbanks, Alaska	Cryosphere

FIGURE 27 NASA C-130 parked outside the Thule aircraft hangar

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

Several permanent upgrades were made to the C-130 aircraft (N439NA) in FY15 in order to support FY16 Earth Venture missions. A new experimenter power system was added to the aircraft capable of supplying a larger quantity of 115VAC 60Hz/400Hz as well as 28VDC. A new generic window frame was added to the right side window to allow for easier installation of fuselage window probes. A C-23 Sherpa lavatory was also repurposed into a new C-130 lavatory that mounts to the cargo ramp area. A new wing pylon was installed on the left wing tip that allows for two canister type wing probes to be flown on the aircraft as well as a radome modification to install five pressure ports for detailed wind measurements. The typical rack/seat cargo pallet cabin layout design has been changed to allow mounting of racks and seats directly to the cabin floor. This provides greater cabin floor space to mount more experimenter racks and seats in the cabin as opposed to the previous mounting design.

C-130 Hercules N436: The C-130 Hercules (N436NA) departed WFF on 6/27/15 for aircraft modifications to support FY16 Earth Venture missions. Engineering and permanent modifications are underway to install a 115VAC 60Hz/400Hz and 28VDC experimenter power system, three 16 inch diameter nadir ports, a window frame for mounting fuselage probes, a 20 person cabin interphone system, an Iridium phone, an Airborne Science data system, and a lavatory/galley area. This C-130 will utilize the new experimenter rack and seat layout as developed for the C-130 N439NA in FY15.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

C-130 Hercules N439 – The C-130 Hercules, N439NA, will undergo annual maintenance and corrosion inspections 12/7/15 – 1/29/16. The corrosion inspections will extend the need for a phase depot maintenance cycle until FY18. Standard annual maintenance periods are required in 2016 and 2017 (4-6 weeks) and can be adjusted to meet mission needs.

C-130 Hercules N436 – The C-130 Hercules, N436NA, is undergoing annual maintenance as part of the airborne research modification effort. The aircraft is scheduled to return to WFF early spring 2016. The aircraft only requires standard annual maintenance each year (4-6 weeks), which can be adjusted to meet mission needs.

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.

SCIENCE FLIGHT HOURS IN FY15: 414.9

G-III FY15 missions

Mission	Location	Science program area
AirMOSS	AZ, CA, OK, OR, ME, MA, NC, Canada, Mexico, Costa Rica	Water and Energy Cycle
AirMOSS Alaska Permafrost	Alaska	Water and Energy Cycle

MODIFICATIONS MADE TO THE JSC G-III AIRCRAFT IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

The JSC team completed an effort to reassemble, inspect, and provide airworthiness certification of UAVSAR pod S/N 003 to support the GLISTIN-A Ka-band radar. In addition, the radar was integrated and flown on the aircraft for the first time ever in July 2015. This effort was completed to prepare both the radar and the aircraft to support the EVS-2 Oceans Melting Greenland (OMG) project beginning in March 2016.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE JSC G-III:

a. The aircraft will be inducted to MP Aero at Van Nuys airport on 4 JAN 2016 to have hush kits installed to meet FAA stage III noise compliance regulations. Modification is expected to last through 5 FEB 2016.

b. The aircraft has 72 month inspections due in the middle of 2016. The program is currently discussing the schedule implementation of this maintenance.

c. The aircraft paint job has been deferred for a few years given the pace of flying associated with the AirMOSS program and the need to complete other maintenance requirements during down times. The program is planning to paint the aircraft during the winter of 2016 – 2017 with the downtime between scheduled missions. Anticipated downtime is 30 – 45 days.

d. The right engine will need to be replaced by August 2018. The program has two options to support this requirement: 1) Overhaul spare engine 2) Purchase engine that has time/calendar remaining. Either way, the program will have an engine available during the summer of 2018 such that an engine change can be efficiently scheduled. The aircraft will be down for two weeks for the engine change.

e. The program is actively working on the engineering design and development of an upgrade to support upcoming FAA and European avionics equipment and capability mandates for the end of 2018. This effort was initiated early such that the modification could be broken down in steps: steps that can be completed in parallel with the normal course of aircraft maintenance while still meeting the 2018 deadline

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

B-200 / UC-12

NASA Langley Research Center operates both a conventional B-200 and a UC-12 (military version). Both have been extensively modified for remote sensing research. NASA Armstrong 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 6 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
AirSWOT	California, Oregon, Alaska, Canada, Louisiana, Gulf of Mexico, Texas	Water and energy; Ocean science
DAWN Polar Winds	Greenland	Atmospheric Dynamics
SLAPVEX DelMarVA	LaRC	Water and energy
G-LiHT	LaRC	Ecosystem science
GEO-TASO and GCAS	LaRC	Atmospheric Composition and Chemistry; Instrument comparison
SIMPL	Greenland	ICESat-2 algorithm development

***FIGURE 28** LaRC B-200 in Thule, Greenland for SIMPL / AVIRIS-NG mission*

SIGNIFICANT MAINTENANCE FOR AFRC B-200:
The AFRC B-200 was in phase maintenance from July 1 through August 31, 2015. Future maintenance will depend on flight hours.

MODIFICATIONS AND MAINTENANCE FOR LARC B-200 AND UC-12 B
The ship's starter generators on the LaRC B-200 aircraft was upgraded to match the corresponding upgrades on the UC-12B aircraft. No other significant modifications were made on the LaRC aircraft in FY15. However, significant mods are planned for FY16. ADS-B capability and avionics mods necessary for overseas deployments of the UC-12B are being installed prior to the KORUS-AQ deployment to South Korea in April 2016.

Radio upgrades are being made to the B-200 to allow it to deploy through Europe and Africa. This work will be completed prior to the AfriSAR deployment to Gabon in February 2016. Following the Gabon deployment, the ADS-B mods and avionics mods made to the UC-12B also will be installed in the LaRC B200, preferably before the ACT-America mission in July 2016. Also following AfriSAR, the landing gear on the B-200 will be rebuilt and both of the engines will be replaced. These are normal time-compliance maintenance actions. These tasks will be completed prior to ACT-America.

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 FY15: 487.8

B-200 missions in FY15

Mission	Location	Science program area
CARVE	Alaska, Canada, MegaCities (Bakersfield)	Climate change

***FIGURE 29** Alaska Governor Bill Walker visited the CARVE plane in Fairbanks on August 5, 2015*

***FIGURE 30** Sherpa heading out for the final CARVE flights*

MODIFICATIONS MADE IN FY14 AND IMPACTS ON PERFORMANCE AND SCIENCE: NONE

Significant upcoming maintenance periods: The C-23 Sherpa is undergoing A, B, C and D maintenance checks 12/14/15 to 2/17/16. Upon completion of this maintenance the aircraft only requires standard annual maintenance each year (4-6 weeks), which can be adjusted to meet mission needs.

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. NASA acquired this aircraft to provide a medium altitude, medium range platform for remote sensing instruments and satellite support.

SCIENCE FLIGHT HOURS IN FY15: 32.6

HU-25C FY15 missions

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

***FIGURE 31** HU-25C participated in OIB in FY15*

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:
No modifications were made to the HU-25C in FY15. However, a new addition to the LaRC fleet, a Dassault HU-25A Guardian, is being prepared for flight, with all of the required avionics upgrades necessary for overseas deployments, including Reduced Vertical Separation Minima (RVSM) certification. This aircraft is planned as a supplement or replacement for the existing HU-25C aircraft, depending on research demand. The plan is to have the HU-25A aircraft available for research in the Summer of 2016.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:
Avionics upgrades to the HU-25C aircraft will occur as cost and schedule permit to bring the aircraft into compliance with the new ATC requirements from Europe. No significant schedule interruption is expected.

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

WB-57

OPERATING CENTER:
Wallops Flight Facility

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 FY15: 0

FIGURE 32 *WB-57 in Florida for HDSS mission*

MODIFICATIONS MADE IN FY15 AND IMPACTS ON PERFORMANCE AND SCIENCE:

- **WB-57 Navigation Data System Upgrade (N927, N928):**
  The new navigation data system offers a multitude of improvements over previous versions. These include limited NASA Mission Tools Suite (MTS) integration (provides real-time aircraft state information), Ethernet-based on-aircraft housekeeping data (IWG1 format as is done with NASDAT), analog recording capability, expanded discrete I/O capability, upgraded processing power, and a much more flexible programming interface that allows tailoring the system to payload-specific needs.

- **WB-57 Autopilot Upgrade:**
  The WB-57 was upgraded to a digitally-controlled automatic pilot system. Availability of a functional autopilot is required for altitudes above 50,000 feet and with the upgrades to

the autopilot system, this upgrade, by design, has increased the reliability of the overall system to result in increased mission support for high altitude flights. The new system also provides many pilot assisting enhancements such as flight director guidance, altitude capture, Indicated Air Speed and Mach target control, as well as aural autopilot disengage tones. The autopilot system integrated with the flight management system has the added benefit of precise flight paths, which provides opportunities for tailored mission flight patterns for numerous scientific uses. Enhancements to the autopilot system have also resulted in increased accuracy in the various autopilot modes. This upgrade has addressed several required system improvements needed to meet RVSM certification with efforts currently underway to gain RVSM approval.

- **WB-57 Audio System Upgrade (N926, N927, N928):**

  The WB-57 was upgraded to a digitally-controlled and software-configurable audio system. Payload customers benefit from the new system by having several audio interfaces available. The interfaces can be used to connect special payload voice radios, as well as to integrate payload caution and warning with the aircraft audio system.

  Aircrew benefit from this upgrade by having numerous options available for noise mitigation and increased audio clarity. As of now, the WB-57 aircrew utilizes both custom molded and foam Communication Earplugs (CEPs), as well as active noise reduction (ANR) in the low altitude flight helmet configuration.

SIGNIFICANT UPCOMING MAINTENANCE PERIODS:

2016

i. N926 will receive the Nav Data system upgrade in February/March 2016.

ii. All three aircraft will be scheduled for payload bay mounting rail replacements throughout 2016. The aircraft will have identical payload bay mounting interfaces at the completion of this effort, vastly improving the interoperability across all three aircraft.

iii. All three aircraft will be scheduled for Sensor Equipment Operator (SEO) cockpit monitor upgrades throughout 2016. The new monitors will provide a state-of-the-art, more reliable system for the SEO's to interact with the payloads and communicate (via chat) with science personnel on the ground.

Beyond 2016

iv. 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***

The NASA ASP Small Unmanned Systems Projects

The goal of the NASA Ames Small UAS (SUAS) project is to develop and demonstrate new opportunities for small, low-cost, yet high-quality science observations with an emphasis on environments where traditional aircraft are not well suited. This project has acquired, modified and operated the mid-sized SIERRA UAV and the Dragon Eye UAV and have successfully transitioned these platforms to the new Ames Aircraft Management Office where they continue to be available for SMD and ARMD research. Eight Viking-400 UAS have also been acquired, with plans to share activities between Ames and Wallops Flight Facility.

In FY15 the SUAS team completed assembly and ground testing of the second SIERRA UAV (seen in Figure 33) to replace the capabilities lost during the MIZOPEX mission in 2013. The payload for the CARTA/Salton Sea mission, which consists of a mass spectrometer and MEMS electro-chemical gas sensor, has been successfully integrated and ground tested and is awaiting flight testing. The SIERRA team also collaborated with the Ames SmallSat office to mature the X-cube concept to develop a modular payload integration rack for cubesats to test imaging payloads and for zero-g simulation.

The Dragon Eye team continued to build out the fleet of modified aircraft for the CARTA/Salton Sea mission that involves replacing the autopilot and adding direct pilot controls.

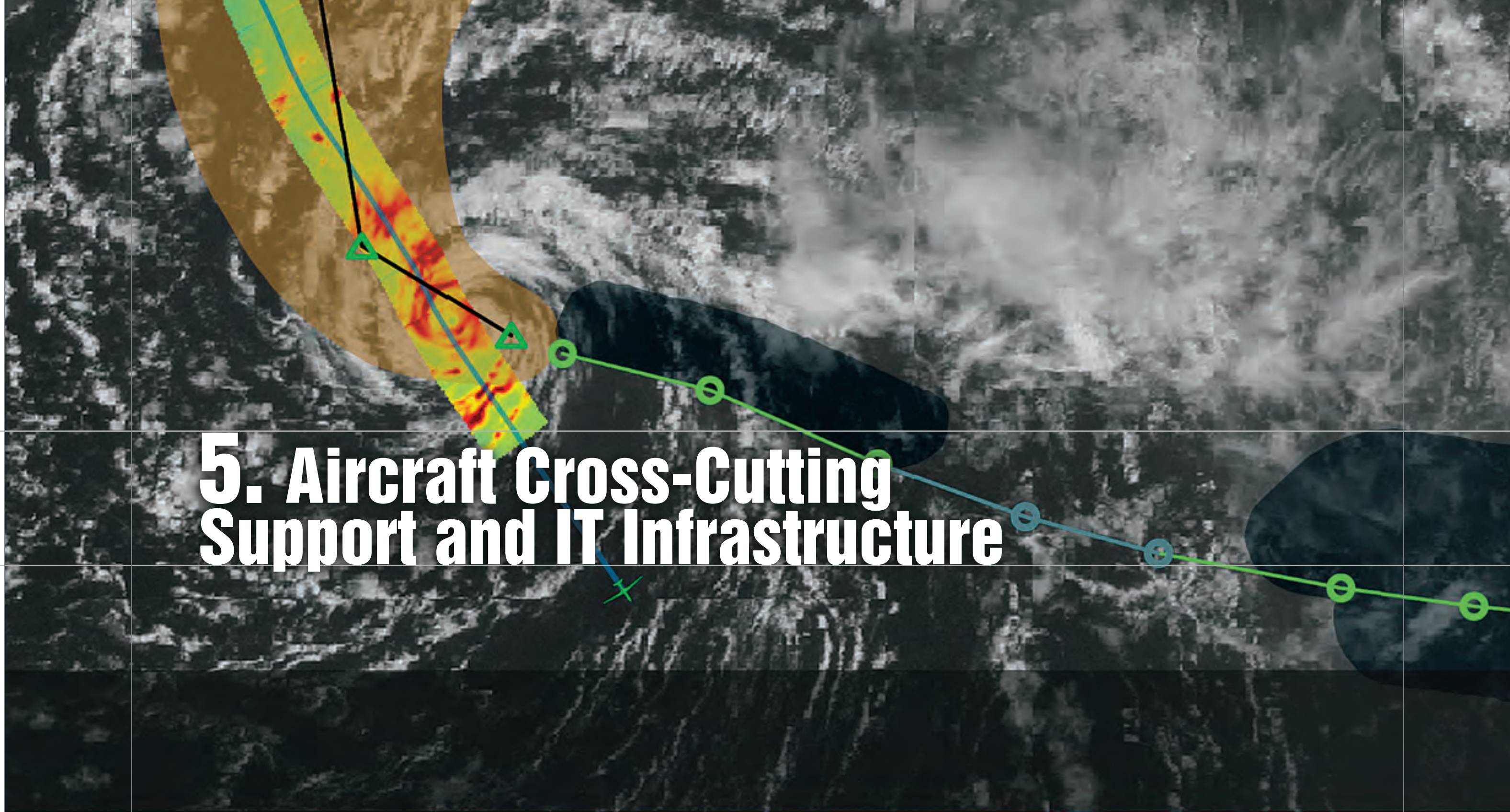
The team collaborated with Kim Sorensen, a PhD researcher from NTSU, to apply anti-ice coating to the Dragon Eye towards wind tunnel and flight-testing in FY2016. The team also assisted in supporting the NASA ARMD Unmanned aircraft Traffic Management (UTM) program. Use of the SMD-developed and tested systems enabled them to accelerate their development, which will

***FIGURE 33** SIERRA UAS. Ship-B has increased endurance and payload-carrying capability*

ultimately benefit SMD through streamlined procedures for integration into the National Airspace System. Shown in Figure 34 is the SUAS team partnering with the UTM team in test flight of the DragonEye.

The Ames SUAS team initiated several partnerships within the Department of Interior to assist them in making SUAS operational for their various missions while the Ames Aircraft Management Office has been assisting them with airworthiness reviews of new systems they are purchasing. The team is working with USGS researchers at the Volcano Observatories to modify Raven and Falcon SUAS for volcanic gas monitoring in addition to supporting integration work on wildlife tracking and telemetry systems.

FIGURE 34 *ESD ASP SUAS team partnering with ARMD UTM team for DragonEye test flights*



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 University of North Dakota National Suborbital Education and Research Center (NSERC). 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, the NASA Earth Science Division, 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, and the Ames and Langley Research Centers. The Ames

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 Airborne Science Program 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 Work-

Airborne Science Program Facility Equipment		
Instrument / Description	Supported Platforms	Support group / location
DCS (Digital Camera System) 16 MP color infrared cameras	DC-8, ER-2, Twin Otter, WB-57, B200	Airborne Sensor Facility / ARC
DMS (Digital Mapping System) 21 MP natural color cameras	All ASP Platforms	Airborne Sensor Facility / ARC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/ precision IMU	All ASP Platforms	3 at Airborne Sensor Facility / ARC
POS AV 610 (2) Applanix Position and Orientation Systems DGPS w/ precision IMU	All ASP Platforms	2 at Airborne Sensor Facility / ARC 2 at WFF
Hygrometers	DC-8, P-3, C-130	NSERC
IR surface temperature instruments	DC-8, P-3, C-130	NSERC
Forward and Nadir HD Video Systems	DC-8, P-3, C-130	NSERC
Static air temperature instruments	DC-8, P-3, C-130	NSERC
HDVIS High Def Time-lapse Video System	Global Hawk UAS	AFRC
LowLight VIS Low Light Time-lapse Video System	Global Hawk UAS	AFRC
EOS and R&A Program Facility Instruments		
Instrument / Description	Supported Platforms	Support group / location
MASTER (MODIS/ASTER Airborne Simulator) 50 ch multispectral line scanner V/SWIR-MW/LWIR	B200, DC-8, ER-2, P-3, WB-57	Airborne Sensor Facility / ARC
Enhanced MAS (MODIS Airborne Simulator) 38 ch multispectral scanner	ER-2	Airborne Sensor Facility / ARC
PICARD (Pushbroom Imager for Cloud and Aerosol R&D) 400 – 2450nm range, DL 10nm	ER-2	Airborne Sensor Facility / ARC
AVIRIS-ng Imaging Spectrometer (380 - 2510nm range, DI 5nm)	Twin Otter, B-200	JPL
PRISM (Portable Remote Imaging SpectroMeter) (350 - 1050nm range, DI 3.5nm)	Twin Otter, ER-2	JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, DI 10nm)	ER-2, Twin Otter	JPL
UAVSAR Polarimetric L-band synthetic aperture radar, capable of Differential interferometry	G-3/C-20, Global Hawk	JPL
NAST-I Infrared imaging interferometer (3.5 – 16mm range)	ER-2	LaRC

***TABLE 11** Facility Equipment*

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

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 UAS, and the WB-57F. Inmarsat BGAN (Broadband Global Area Network) 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 light weight and inexpensive to operate.

Payload Management

The Airborne Science Program provides a variety of engineering support services to instrument teams across all of the program platforms. These include mechanical engineering, electrical and network interface support, and general consulting on the operational issues associated with specific aircraft. The services are provided jointly by personnel from the National Suborbital Education and Research Center (NSERC), University of North Dakota at the NASA Palmdale facility; and the Airborne Sensor Facility (ASF), University of California, Santa Cruz at Ames Research Center and Palmdale.

NSERC staff provides instrument integration services for the NASA DC-8 aircraft. Instrument investigators provide a Payload Information

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	NSERC / AFRC / JSC
Inmarsat BGAN (two channel systems) / 432 Kb/sec per channel	DC-8, WB-57, P-3, S-3B, DFRC B200, ER-2	NSERC/Airborne Sensor Facility
Iridium (1 – 4 channel systems) / 2.8 Kb/sec per channel	All ASP Platforms	Airborne Sensor Facility, NSERC

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

Form that includes instrument requirements for space, power, aircraft data, and location of the instruments and any applicable inlet or window access needs. The staff then uses the provided information to complete engineering design and analysis of instrument and probe installations on the aircraft and wiring data and display feeds to instrument operators.

NSERC 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 Airborne Science Program 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. NSERC engineers also work with investigators to send appropriate data up to and down from the aircraft to allow for real time situational awareness to scientists on the ground and in flight.

Along with general payload engineering services, the ASF designs and builds custom flight hardware for the ASP real-time Sensor Network, e.g. the NASDAT (network host and navigation data server), and the standardized Experiment Interface Panels; as well as payload data systems for the Global Hawk, including the Telemetry Link Module and the MPCS (Master Power Control System.) Together with NSERC, 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 Mission Tools Suite (MTS) is a decision-support product from the Airborne Science Program that provides a set of core capabilities for planning and executing airborne campaigns. In addition to web-based communication and collaboration tools such as document sharing and mission chat, the MTS supports a multitude of features (Figure 35) such as tactical mission monitoring, mission planning, real time position and instrument status, access to low latency satellite, radar, and other meteorological and mission products. A primary goal of the MTS is to improve distributed team situational awareness and to improve the overall efficiency and effectiveness of flight missions for both single and multi-asset campaigns.

Field Campaign Participation in FY15 included:

- *Ship-Aircraft Bio-Optical Research, NASA (SABOR; 2014)*
- *Arctic Radiation - IceBridge Sea & Ice Experiment, NASA (ARISE, 2014)*
- *Precipitation, Aerosols, and Pacific Atmospheric Rivers Experiment, NOAA/NASA (CalWater2, 2015)*
- *Sensing Hazards with Operational Unmanned Technology, NOAA/NASA (SHOUT, 2015)*
- *Tropical Cyclone Initiative (TCI, 2015)*
- *North Atlantic and Marine Ecosystems Study, (NAAMES, 2015)*
- *Volcano-plume Investigation Readiness and Gas-phase and Aerosol Sulfur (VIRGAS, 2015)*
- *Olympic Mountains Experiment (OLYMPEX, 2015)*

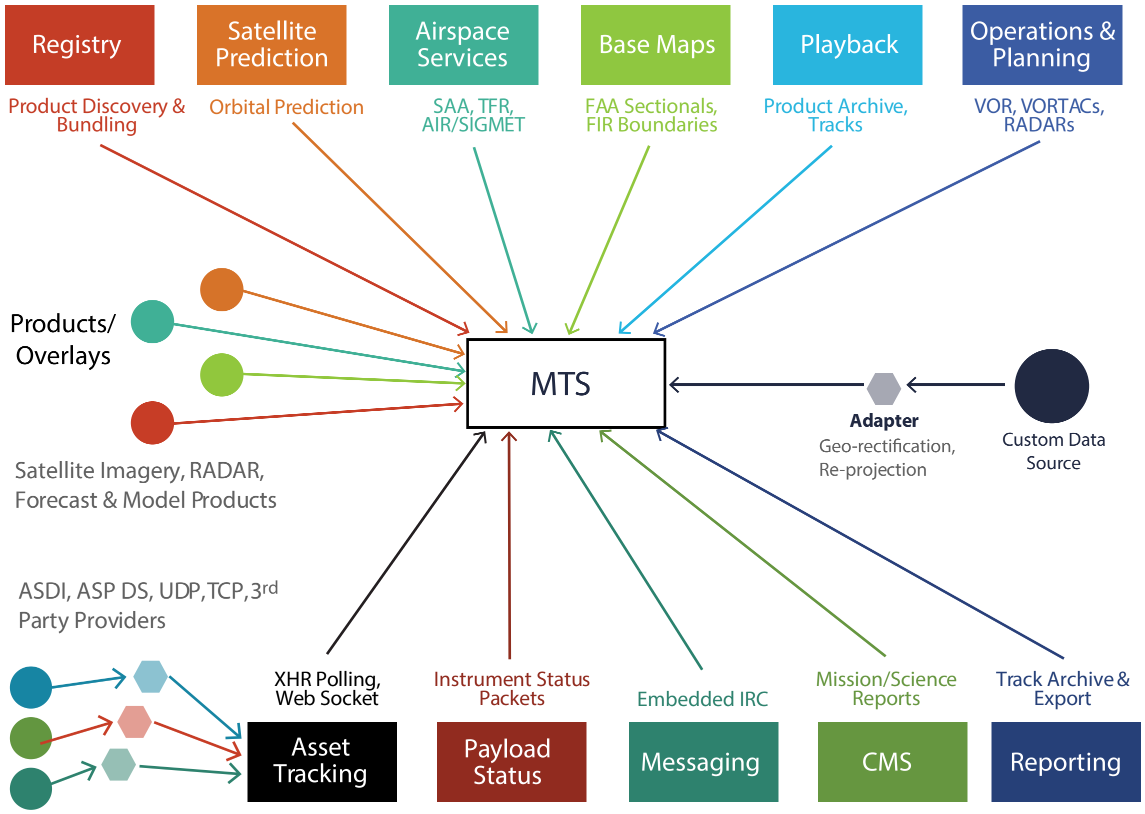


***FIGURE 35** The mission tool suite is designed to incorporate numerous inputs of interest to the science investigators. The center box shows the user interface. The outer boxes show various MTS modules, each of which are outputs to the web.*

For each release since 2011 (see Figure 36), the system's development priorities have been shaped largely from community feedback and have followed a similar cycle. That is, as new capabilities are requested and completed, existing capabilities are carefully reviewed, refined, consolidated, and in some cases removed entirely. The iterative nature of development has been successful to distill a host of functionality common across multiple stakeholders and airborne missions as a whole. As each campaign yields its own set of challenges and solutions, those capabilities are both refined and generalized for use by subsequent campaigns. A screen shot with both flight track and underlying storm features from the 2015 SHOUT mission is shown in Figure 37. Specifically, Figure 37 shows NASA Global Hawk (N872NA) flight over Tropical Storm Fred SHOUT mission. The aircraft had just passed over the storm center at approximately 59,000 ft. The storm center is located about 2,050 nautical miles southeast of Wallops Flight Facility (WFF).

To date the MTS has been used in various capacity for over 20 different campaigns and the system now includes hundreds of features that span nearly second resolution of status on some platform aircraft, layer management and simplified product access and project distribution, tools for tactical operations, simple integrated tools for satellite prediction, unified payload monitoring and plotting, and a diverse set of airspace products. Since 2014, the asset tracker has been available in a mobile version.

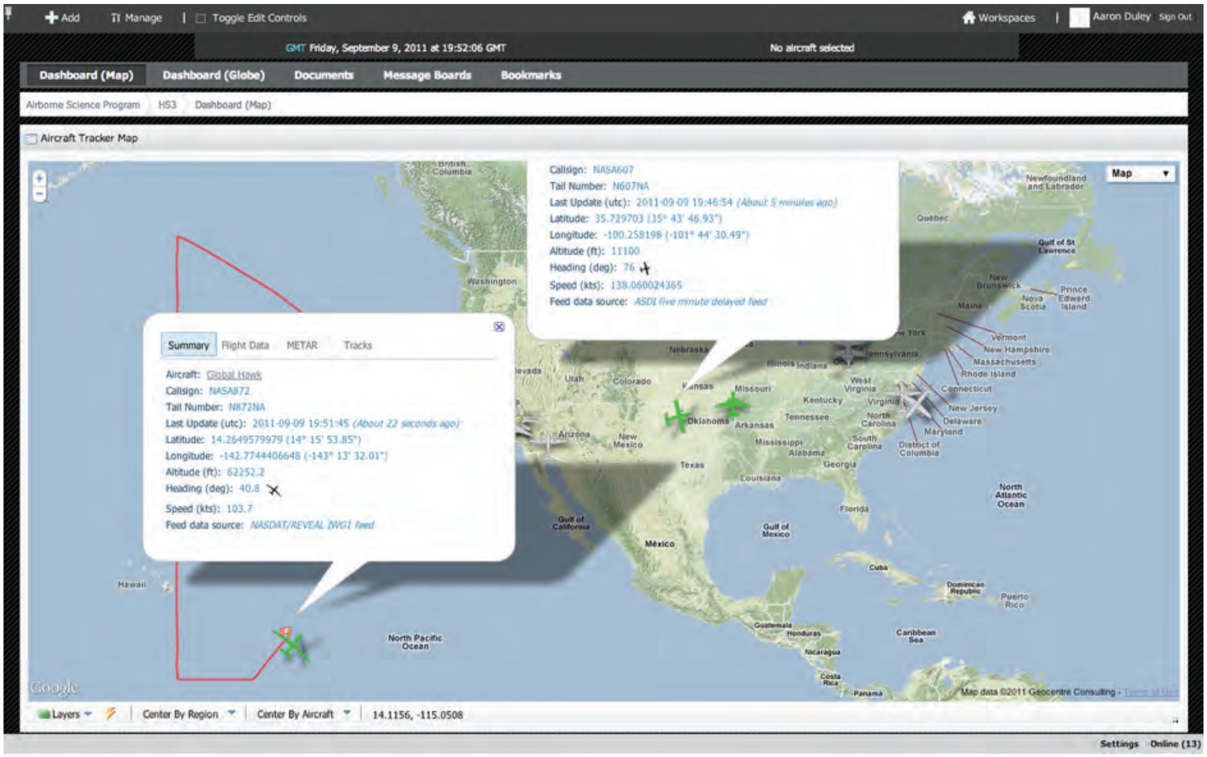


FIGURE 36 Screenshot of the first MTS version (09/08/2011)

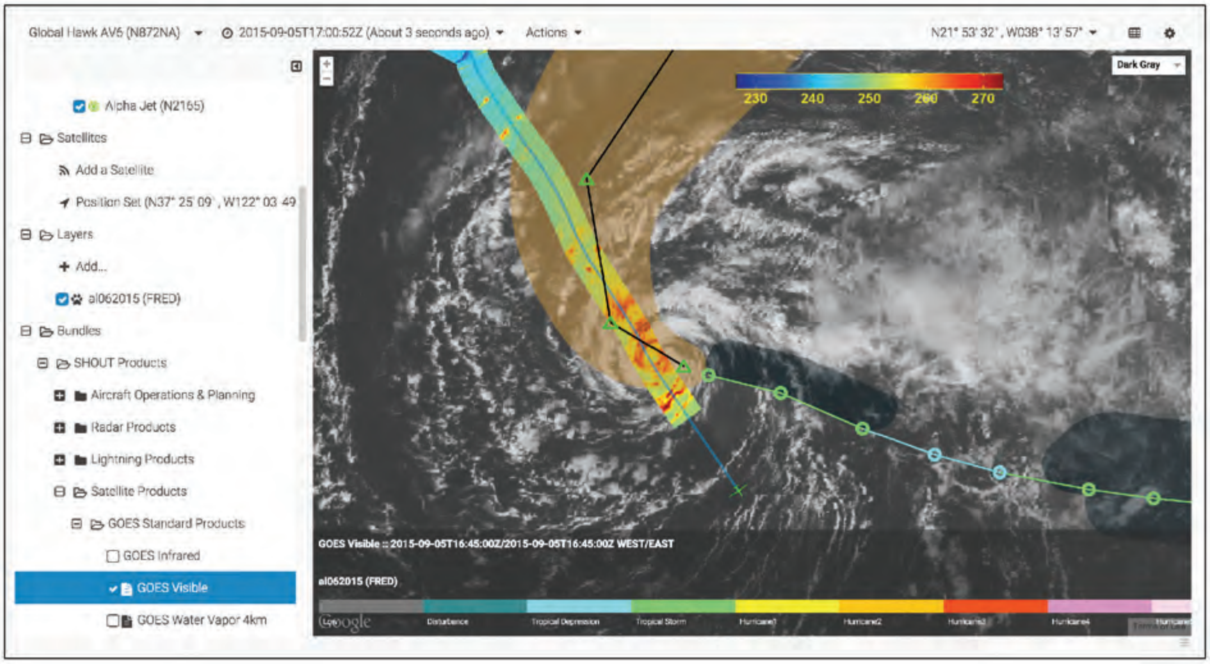


FIGURE 37 Screenshot (09/05/2015) showing NASA Global Hawk (N872) flight over Tropical Storm Fred during the SHOUT mission.

Specific MTS Improvements in FY15 include:

Data Source Ingest and Visualization

- Shapefiles produced by the National Hurricane Center (NHC) for tracked storms track, track prediction and wind radii available within the tool.
- Added drifter tracking and visualization support.
- Added float tracking and visualization support.
- Added the ability to directly display both EPSG:4326 and EPSG:3857 images. EPSG:4326 is the image projection used in Google Earth and is the standard projection for KML/KMZ referenced images. EPSG:3857 is a Web Mercator projection used frequently in web-based mapping tools such as Google Maps, Open Layers and Leaflet. The ability to add either projection can be done directly with the need to first wrap in a KML or first requiring re-projection.
- Created an FTP KML and Image proxy service. It is very common for mission support teams to produce a satellite, forecast or some other modeling product, but not necessarily have the capability to serve that product via HTTP(s). The FTP proxy can then make those products available via an HTTP endpoint without needing to first copy that image to another server.
- Added direct access to products available from the Global Imagery Browsing Service (GIBS).
- Added quick access to airspace, administrative, and other mission-relevant features. Access to METARs, State, County Boundaries, Airspace Fixes and Navigational Aids.
- Improvements to valid time and color scale display for RADAR and 1km GOES products.

Tactical Planning

- Added a time-based range ring capability. Range rings typically involve placing a statically sized ring centered at some position or asset. Time-based range rings permit the user to attach a range ring to an asset and the size of that ring will be dynamically changed based up the ground speed of the asset and the desired time base for the ring (e.g., 30 minutes).
- Added dynamic sector visualization. This permits the ability to quick draw sector azimuths from a centralized point. Used for planning flight lines along some route.

Performance and Optimization

- Decreased end-to-end asset update real-time update rate by up to 10 seconds in some cases. Decreased end-to-end updates improve asset position accuracy which in turn is helpful for tactical decision-making (e.g., dropsonde release).
- Significantly improved application memory consumption and performance. Optimizations include running regular track optimizations both on track load and during mission monitoring.
- Track waypoint inclusion is now optional and not loaded by default.
- Revamped public/mobile tracker which is now responsive to client screen size and can be used from handhelds to the desktop.

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 Airborne Science Website and click on the Asset Tracker link, or visit http://airbornescience.nasa.gov/tracker.

6. New Instruments

A number of new passive optical imaging and spectrographic instruments have been under development for the past few years and reached mission-ready status in 2015. These include the AVIRIS-next generation (AVIRIS-NG), Hyperspectral Thermal Emission Spectrometer (HyTES), Portable Remote Imaging SpectroMeter (PRISM), and the enhanced MODIS airborne simulator (eMAS). Status and activities for these instruments are described below. In addition, the Digital Mapping System (DMS) camera has been very busy. It is also presented in this section.

AVIRIS-NG

The Airborne Visible-Infrared Imaging Spectrometer - Next Generation (AVIRIS-NG) has been developed to provide continued access to high signal-to-noise ratio imaging spectroscopy measurements in the solar reflected spectral range. AVIRIS-NG is expected to replace the AVIRIS-Classic instrument that has been flying since 1986.

AVIRIS-NG measures the wavelength range from 380 nm to 2510 nm with 5 nm sampling. Spectra are measured as images with 600 cross-track elements and spatial sampling from 0.3 m to 4.0 m when flown on a Twin Otter platform. In the near future, AVIRIS-NG is anticipated to fly on a high altitude platform (NASA's ER-2). AVIRIS-NG has better than 95% cross-track spectral uniformity and >= 95% spectral IFOV uniformity.

AVIRIS-NG became fully operational for science in 2015, including methane measurement campaigns in California, Louisiana and in the Four Corners region; and vegetation structure mapping in California, Idaho, and Wisconsin. In

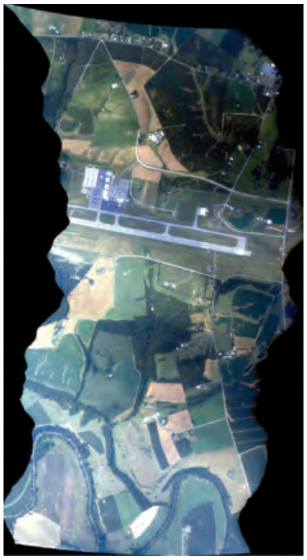


***FIGURE 38** AVIRIS-NG orthorectified image*

a significant science opportunity, AVIRIS-NG flew in Greenland on a B-200 aircraft in conjunction with the SIMPL instrument on a companion B-200 to collect algorithm data for ICESat-2. This mission is described separately in Section 3.2.

PRISM

In 2015, the Portable Remote Imaging SpectroMeter (PRISM) completed a reconfiguration for operation on the ER-2, funded through the ESTO AITT program. Software, power and electronics control systems were reconfigured for automated operation as well as operation in the ER-2 nose environment. After installation, two test flights were undertaken in October 2015. The first flight was to assess operation and confirm data integrity, and the second to demonstrate full operation and science-grade data collection. During the second flight, data were collected over calibration sites in Ivanpah Playa and Santa Monica Bay. Simultaneous in-situ data were collected at both sites, and there was also a Landsat overpass over Santa Monica. The instrument was then returned to JPL to start preparation for the NSF/NASA ORCAS campaign. The flights demonstrated successful operation of all systems and PRISM data agreed to within 1% with in situ calibration. Radiance and reflectance data have been posted on the publicly accessible PRISM website. Science products from the Santa Monica flight are under development and preliminary data indicate good agreement between Landsat and PRISM Chlorophyll-a predictions.

__FIGURE 39__ PRISM installation in the ER-2 nose

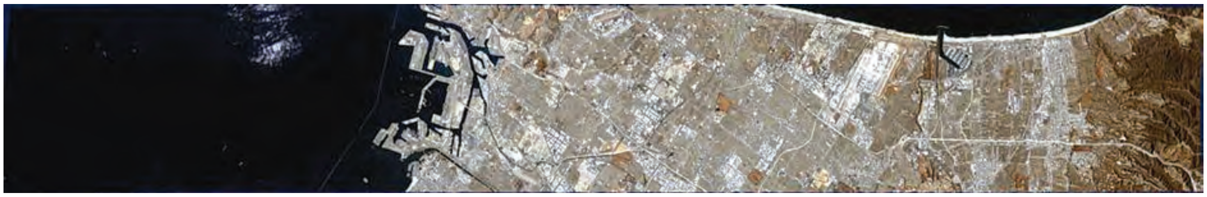


__FIGURE 40__ PRISM flight line over the Los Angeles and Santa Monica Bay area

HyTES Science in FY2015

The HyTES instrument measures Thermal Infrared radiance in 256 spectral bands between 7.5 and 12 um, with 512 pixels across-track. Due to its high spatial and spectral resolution, the HyTES instrument has a wide range of applications. Radiance observations can be processed to retrieve surface temperature and emissivity, geologic mapping and trace gas detection.

Prior to FY15, HyTES had flown an engineering campaign and two Science campaigns. Much of the emphasis was on relatively high altitude (10,000 ft above ground level) mapping of rock, soil and water targets for surface temperature retrieval and spectral identification of minerals. Campaigns in June 2013 and July 2014 demonstrated the additional capability of trace-gas detection and plume mapping while flying at lower altitudes (1500 to 3000 ft AGL). Methane, SO_2 and Ammonia detections were all demonstrated.

The FY2015 flights had a much stronger emphasis on trace-gas detection. HyTES collaborated with CARVE and AVIRIS-ng in Methane experiments in Bakersfield in Feb and late-April and participated with AVIRIS-ng in a large NOAA and NASA Methane campaign in the Four Corners Region in Early April, 2015. (Figure 41) For that campaign, NASA provided 2 aircraft and ground teams to complement a number of NOAA assets. HyTES flew on contracted Twin Otters from Twin Otter International with a total of 87.9 flight hours between the 2 campaigns.

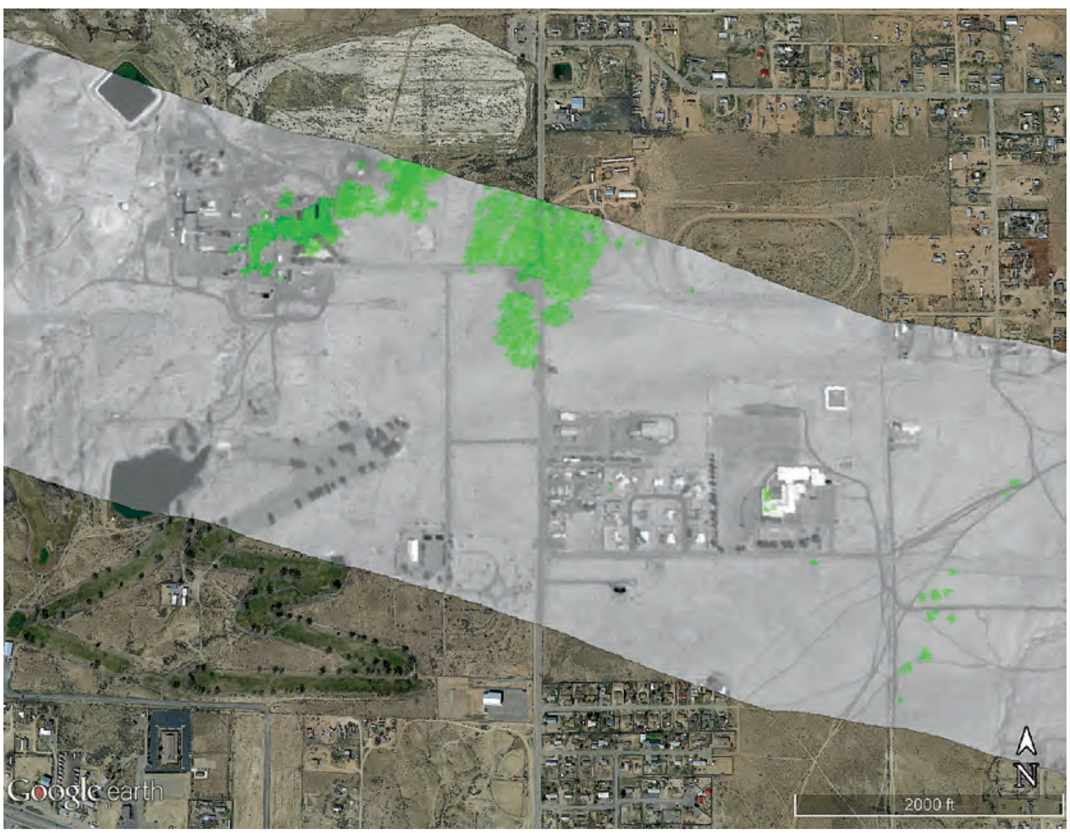


***FIGURE 41** HyTES methane retrieval from Four Corners campaign in April 2015. Methane plumes are green.*

High altitude observations were also made in FY2015, primarily over arid geologic areas. Much of the instrument work in 2015 involved preparation for future high-altitude use on the ER-2, but improvements were also made to the focus and alignment of the instrument as well as algorithms for gas detection, geo-location and atmospheric correction. The HyTES website was also updated and users can now order from all of the campaigns to date.

FIGURE 42 *HyTES on Twin Otter and CARVE on the Serpa in hangar Bakersfield Methane Campaign*

eMAS

The Enhanced MODIS Airborne Simulator (eMAS) is an airborne scanning spectrometer that acquires high spatial resolution imagery of cloud and surface features from its vantage point on-board a NASA ER-2 high-altitude research aircraft. Data acquired by the eMAS are helping to define, develop, test, and refine algorithms for the Moderate Resolution Imaging Spectoradiometer (MODIS), a key sensor of NASA's Earth Observing System (EOS) that flies on the AQUA and TERRA satellites. The MODIS program emphasizes the use of remotely sensed data to monitor variation in environmental conditions for assessing global climate change.

The eMAS instrument is maintained and operated by the Airborne Sensor Facility (ASF) at NASA Ames Research Center in Mountain View, California, under the oversight of the EOS Project Science Office at NASA Goddard. Instrument scheduling is coordinated by the ASF, with formal arrangements made via the NASA Airborne Science Program flight request system. The images in Figure 43 depict cloud-top temperature and various micro-physical properties.

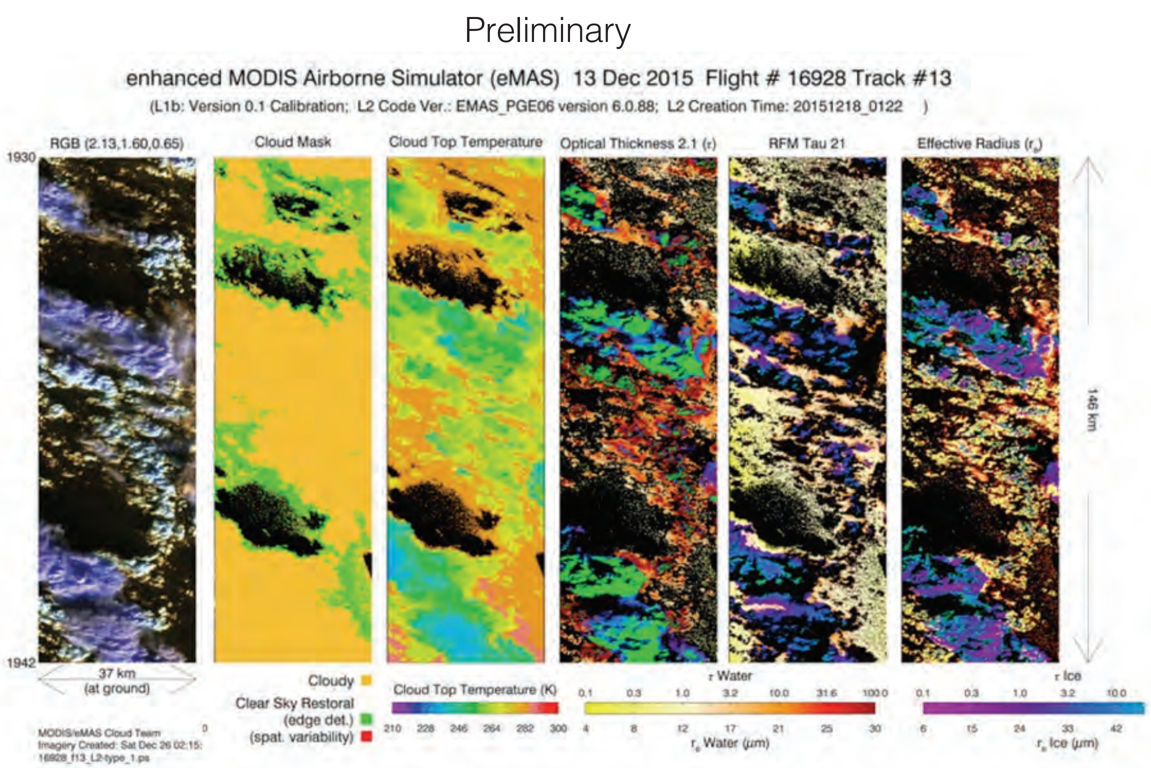


***FIGURE 43** Example eMAS Level-2 products, courtesy of the GSFC MODIS Atmospheres team*

FIGURE 44 *A DMS mosaic of the Petermann Glacier*

Digital Mapping System Camera

The Digital Mapping System (DMS) is an airborne digital camera that acquires high resolution natural color and panchromatic imagery from low and medium altitude research aircraft. This year over 900,000 frames of DMS camera data were collected on four deployments to the Arctic and Antarctic, using four different aircraft. Each camera frame was geo-rectified using data from an Applanix POS-AV system, together with custom software developed at the Ames UARC. Figure 44 is a reduced-resolution DMS image mosaic of an area in Greenland (it was also posted as a NASA "Image of Day"). The mosaic is composed of six images collected on 10/6/2015, of a rocky area immediately north of Petermann Glacier, with the edge of the glacier at the top of the image. Several frozen progracial lakes are apparent in the image, and all show some windblown snow cover. The lake at top left also has some small icebergs, calved from the Petermann margin, floating in it."

7. Advanced Planning

7. Advanced Planning

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

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

Strategic planning in the program is focused on the following areas:

- *ASP-supported (core) Aircraft – maintenance, upgrades, determining future composition of the fleet*
- *Observatory management - improved tools for managing assets and requirements while improving the service to science investigators*
- *New Technology – bringing new technologies to observational challenges including application of advanced telemetry systems, on-board data processing, IT mission tools, and new platforms*
- *Education opportunities*

Requirements Update

In 2015, an updated Requirements Report was published. It can be found on the Program website under "Documents."

The primary findings of this requirements survey are:

- *There are clear requirements for all aircraft currently in the core fleet given currently funded* *instrument development, satellite missions, R&A research, and the Earth Venture line of missions.*

- *All satellite missions currently in formulation have plans to use aircraft during one or more phases of their development and operations.*
- *Requirements for medium altitude- medium payload, business-class jet or Super King Air aircraft have increased and represent a gap in the current fleet, forcing projects to rely on less capable aircraft, or other agency aircraft.*
- *There are no platforms capable of providing low altitude long endurance measurements required for ocean and land surface fluxes and radiation measurements.*
- *There is a continued call from the science community for high altitude long endurance platforms for providing geostationary-like measurements in addition to providing diurnal measurements of atmospheric phenomenon.*

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.

New space missions on for the International Space Station, several small sats, and collaborations with ESA and other space agencies. 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 2015 to describe ASP capabilities and collect requirements information are listed in Table 13.

5-yr plan

A five-year plan is also maintained by the Program for out-year planning and scheduling. A graphical copy is shown in Appendix 2, depicting plans by science area and aircraft platform. Significant maintenance periods for the various aircraft are also indicated.

***TABLE 13** Activities to support ASP requirements information gathering*

Activity
Applied Science Decadal Survey Mission update – ASP presentation
Member of Terrestrial Ecology Airborne Science Working Group (Intermediate participation in HyspIRI Science team and Steering Group monthly telecons)
Participation in 2015 ESTO review Forum
Participation in 2015 NASA SMAP cal/val meeting
Participation in 2015 NASA SWOT science team meeting
Participation in 2015 GEO-CAPE community meeting
Participation in 2015 OBB planning meeting
Participation in 2015 NISAR Applications workshop
Participation in 2015 CCE Community workshop
Presentation at 2015 AUVSI Conference and ISRSE Conference

8. Education, Training, Outreach and Partnerships

Student Airborne Research Program 2015

The seventh annual NASA Student Airborne Research Program (SARP) took place June 14-August 7 at the NASA Armstrong Flight Research Center and the University of California, Irvine. The program was designed to expose advanced undergraduates majoring in the sciences, mathematics, and engineering to all aspects of a NASA Airborne Science research campaign.

The thirty-two students represented thirty-two different colleges and universities from twenty-one states and Puerto Rico. The program

2015 Student Airborne Research Program Participants

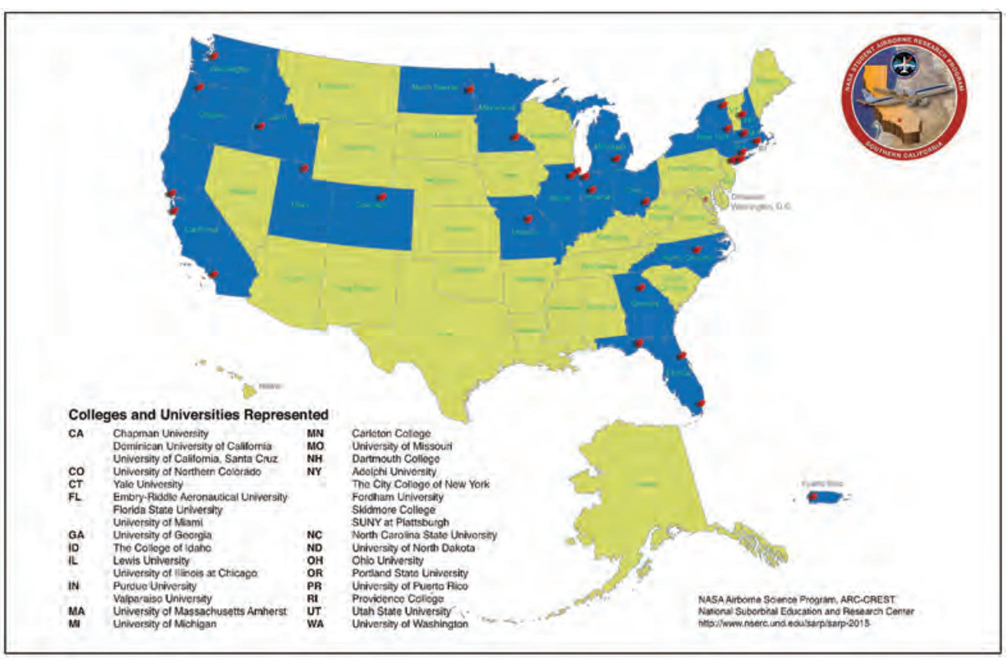


FIGURE 45 Map showing locations of students participating in SARP 2015

began at the Armstrong Flight Research Center in Palmdale, CA with introductory lectures by university faculty members, NASA scientists, and NASA program managers designed to prepare students for their flights on the DC-8. The students then participated in instrument integration and flight planning. Each student had the opportunity to fly at least two times on the DC-8. Students in the remote sensing of the ocean and land groups took ground-truth validation measurements from a research vessel in the Santa Barbara Channel and from a forest in the Sierra Nevada Mountains during a DC-8 overflight. After the DC-8 flights, the students returned to UC Irvine for six weeks of data analysis and interpretation. The program culminated with the students' formal presentations of their results and conclusions. Twelve students submitted first-author conference abstracts on their SARP research to the American Geophysical Union Fall Meeting in San Francisco.

***FIGURE 46** SARP 2015 participants pose in front of the NASA DC-8 on June 23, 2015*

Appendix A:

Airborne Science History Project: Andrew Roberts

Andrew Roberts was Director of the Airborne Science Program from 2007 through 2009. During his tenure as Director, he instituted this project to collect the history of NASA's Airborne Science Program and, especially, the people who have contributed to its success.

A pilot, an engineer, a manager, and a Director, Andy played many roles in airborne science until he retired from NASA in 2009. He has returned on occasion to advise, help in proposal reviews, and preparation of program materials.

Andy was interviewed in 2014 by Jim Weber and this section reports portions of that conversation, where Andy reviewed his career in (somewhat) chronological order.

1973

I went to Foothill College initially when I graduated from high school, right near Ames Research Center. I lived in Palo Alto and I was taking a pilot ground school class from my professor Betty Hicks. She recommended me to a work-study program in the flight operations radio room over at NASA Ames Research Center, which started my NASA career. In this position, I was able to observe and participate in a lot of the development of the earlier years of the Airborne Science Program, and I was able to be there when they were first flying the Learjet with the infrared telescope in it. I was sitting there one night with the scientist who just completed a flight, and what was really cool was the scientist was looking at the data and said, "You know, I think there is sulfuric acid on the outer atmosphere of Venus." And sure enough—

I thought, "This is really neat, this Airborne Science stuff." Then I was helping out with the Convair 990 and getting those missions set up, while we were having the first test flights of Kuiper, once it came back down and landed after the telescope door got stuck because of it whistling like blowing on the top of an opened coke bottle. Kuiper was doing its first test flights then, so it was a great year to be involved with all this.

While I was there in the work-study program the ER-2s had just showed up. They were called the U2s. I was getting to see all this stuff that was cranking up in the Airborne Science world, and so it really put the bug in my system.

We had the Learjets, the STOL aircraft, the C8, the XV-15, which was the predecessor to the Osprey. The Cessna 310 I got to fly in along with the Learjet. Much more impressive than the Cessna's and Pipers I was flying in, which I started doing in high school.

While I was working in the radio room at Ames, one P-3 was landing, another aircraft was positioning to takeoff off, so the Moffett tower controller didn't obviously really listen to the confirmation by the 990 crew on the runway switch to the right runway he issued them in error, but he confirmed the switch most likely without realizing what he confirmed. Then the 990 lined up on the right runway per the new instruction; there was already a P3 on short final for the right runway. The 990 being a little faster and a bit higher, the 990 couldn't see the P3, because it was lower, the 990 moved up on the P-3. The nose-wheel of the Convair 990 went into the top of the tail of the P3. This pushed the P3 nose up, stalled it, which in turn pushed the nose of the Convair 990 up and stalled both planes, they went down on top of the each other. We had about 43 folk's sign up to fly as observers including me, but the day before and that morning most folks cancelled except for 9, I had too much to get done so I cancelled also. This was '73, April 12th to be precise. I then participated in the rescue and recovery all in the 990 perished. My first loss of colleagues in an aviation accident.

After this year at Foothill, I got an ROTC scholarship to Purdue, where I went to study Aeronautical Engineering. During the summer, I came back as a civil service intern to ARC and worked in Al Worden's mission analysis division aka MAD. Al Worden was one of the Apollo 15 astronauts that moved to Ames. So that was pretty neat, and he brought the T-38 with him when he came to Ames. That's how Ames got a T-38 (which I got to fly years later).

1977

Well, moving ahead. After Purdue, in 1977, I had about a year or so, before I could go to flight training with the Air Force. Ames hired me back as a wind tunnel test engineer for the unitaries, the 14 and 12 foot wind tunnels.

I was part of the AD-1 (Ames-Dryden 1) program. It was a scissor-wing aircraft. That was my first real project. I also tested the space shuttle. In fact, it was kind of interesting. This was in '77 - before the shuttle was going to be dropped off the back of the 747, I was busy in the 12 foot wind tunnel determining the stability and control, drag and lift coefficient numbers on different space shuttle configurations, and we had something really advanced for that day and age. We had a terminal in my control room, and there was a mirror terminal at Johnson Space Center, where they were getting all our coefficient derivatives and applying the numbers to figure out where to drop the shuttle off from the 747, so that it made the runway and not over or undershoot it. If you dropped it too far back, it wasn't going to make it. If you dropped it too close, it was going to overshoot. You had to make sure you did all that right.

Normally after a wind tunnel test, we take all the data and we check all the calibration constants to make sure that those are all correct. And typically there's a couple errors in them, and then we recalculate the whole test before we put out the final report where all the data is. I ran into one of the old engineers there and saying, "I can't believe they're going to go drop this thing tomorrow. I haven't had a chance to even check the calibrations on all the sensors." Then he said, "You should have been here for Apollo." The Apollo astronauts never knew how little checking was done or maybe they did. The culture was different back then.

There was a computer network set up between Johnson and Ames though. This was '77, so we were all amazed. It was tied to our super computer, the IBM 360 there in Ames. This was a high-tech sensor-net system. It pre-dates the internet by like 15 years. I don't know how they did it, because all I know is they had a mirror terminal, and I'm assuming it must have been over the phone lines, but I don't know what they used to do it. They did not have SatCom, it was all land lines or microwave.

There's no propulsion on the space shuttle for the approach and landing, it was a glider that flew like a brick. But the astronaut pilots had a lot of experience. Some of them had experience because of the lifting body days. A number of the Dryden test crews developed the lifting bodies and the concept for bringing those things to a landing.

I remember the simulator at ARC that was used to train the test crews was a large landscaped model. They had that big model with farmland, airport, hills, cities and towns, there was a camera that would fly around it. And there were a few crashes I saw into the landscape. In the model on the floor, where the camera didn't stop in time before it hit some of the hills.

1978

After the year at ARC, I was pretty lucky, I guess somebody at NASA thought I was doing a decent job and they put me on what they call the Military Furlough status. So, I went off to flight school with the Air Force in 1978, where I would pick up a six-year commitment. I didn't realize how lucky I was at the time to have gotten that status, but what Ames did for the whole period of time I was in the military, they maintained a Civil Service slot for me in their system, because I was filling that slot, even though I was in the military.

Those were the good old days before full cost accounting. When the facilities and personnel and travel and everything came out of what they call Resource and Program Management. They still were tying up a slot they couldn't use for someone else, and they held it for me the whole time. So when I started into the military, one day I was paid by NASA, the next day I was paid by the Air Force. Then when I left the Air Force, the next day I was paid by NASA. So I never had an interruption in the paycheck.

Right. After I graduated, I went to NASA as a wind tunnel test engineer, set up to go to flight school. Went to flight school, was on NASA's military furlough. -- I wanted to go to air defense command, but they were shutting the air defense command down, so I was looking around to see what airplanes I wanted to fly. I picked the C-141, because I knew if I got the L-300 rating on my FAA certificate (L-300 is the civilian designation for the C-141), I could fly the Kuiper because the Kuiper was the only L-300 in existence. And I knew I was going back to NASA, so it made sense. Plus, I liked the mission that the military airlift command guys had. Out gallivanting around the planet with just your crew.

Kuiper was an L-300. It was actually built for the French, and when we had problems with De Gaulle, Congress stopped the sale of the C-141 with the French, so then Lockheed had an extra plane lying around and got the FAA to designate it as a L-300 for commercial work. They were trying to do something with it and they couldn't, so eventually they had NASA picking it up. They gave it to us. Maybe for a dollar. I'm not sure. We always called it a C-141, because most of us that were flying it had C-141 experience and it looked like one. Same engines, same flight control system, same electronics.

While in the Air Force, soon after I was fully qualified in the 141 and with my L-300 on my FAA pilot's license, there was this new program called ENJJPT, which is Euro-NATO Joint Jet Pilot Training, where it was all fighter flying. I thought, "I got my L-300 rating, and I've got four more years that I have to spend in the Air Force," so I volunteered to join the ENJJPT program. The idea was we trained the U.S. and NATO fighter pilots to be able to fly together in case of a World War III situation.

1981

That was '81 to '85, I was at Sheppard Air Force Base working with all the Europeans, and that was a great deal. My officemate was a Norwegian, my boss was a Brit, whose boss was from Belgium. We were all intermixed, and I took over the advanced aerodynamics program where I wrote the textbook that everybody at ENJJPT used for the advance aerodynamics course.

I was flying T-38's, primarily. It's more of a tactics thing, what we were doing with that program. Get the guys involved in common tactics. Because the problem is every country had their own training programs and when you try to get them to fly together. They didn't have a basis to work with. We gave everybody - all the NATO fighter pilots - a basis to work with. And so that way it would be easier to fly in joint operations--that was just a great program. We would jump each other in the air at times, simulate air-to-air combat and we would get to do things that you could never do at normal Air Force training, because it was run by a European Steering Committee and they were a lot more aggressive in their training than Americans were. Everybody got to exchange their ideas, and we would fight each other. I have a Portuguese pilot's flight jacket, because I beat him in a simulated air-to-air combat, and we had Norwegian observers as the neutral parties. We'd go out and teach each other ways that we would do our fighting. Occasionally we'd get to meet eastern bloc pilots, and we'd pick their brains.

1985

In 1985 I came back to NASA -- after all my adventure in the military, I came back to Ames as a research engineer in the wind tunnels, because that's where my slot was held. But immediately they picked me up as a support pilot on the flight line.

This is '85. Jim Martin who is running the NASA ARC flight operations then invited me to join his reserve unit, the C-141 unit at Travis. So, I was able to keep my 141 skills up and fly the Kuiper, along with several of the other airplanes. I flew the T-38, because obviously I had a lot of hours with the 38 at that point, and had a great time doing that. While my work in the wind tunnel had me helping to come up with some of the concepts for the telescope opening airflow issues with Dr. Bill Rose on the future SOFIA, at that point we were wind tunnel testing the SOFIA concept, then later did some actual flight-testing of the concepts on Kuiper. I was also working on the advance turbo fan or turbo prop engines, which were the high-speed supersonic propeller tip concepts, they're real efficient and the technology is being applied to modern turboprops. I was named for a Collier Trophy

as part of the team that developed these concepts. I got a Collier Trophy out of that, which is maintained at the Smithsonian. I also picked up a patent on a new flow through wind-tunnel balance. We developed a balance for wind tunnel models that could actually run air through it, power air motors which ran propulsion systems on the model in the wind tunnel while making aerodynamic force measurements.

The other thing I was doing at the time to keep me ultimately involved in the airborne science community, I was the chief aerodynamist on the new DC-8 from 1986-1989. This was for all the external mods we were putting on it. I had one interesting issue that came up. We were putting some CAPS probes on the DC-8 near the outer edge of the wing, and we figured out, by doing some CFD analysis with the McDonald Douglas aerodynamics folks, coming to the conclusion that we needed at least three diameters separation between the two probe cylinders, so we didn't produce a shock wave induced separation, because airflow would go sonic in between the probes. The project engineer didn't like that. He wanted to get them closer together because of the structural requirements. Aerodynamically, we said, "No, that's as close as we can get them together." We were in a big final design review -- we had all the government, contractors, and sub-contractors there. There must have been about 60 of us sitting in this room. They were showing all the mods they were making to the DC-8 and they get to this point where they showed the probes again, and I looked at that and I said, "That looks like it's closer than three diameters." They said, "Yeah, it's about two diameters apart." I said, "It's not going to work guys." I said, "Well, "Did you clear this with aerodynamics?" He said, "Oh, yeah. Aero's agreed to this." I said, "Bring Mark up here. I want him to explain to me how this is going to work." I stopped the whole design review. Mark, the McDonald Douglas aerodynamist, comes walking up, who I had been working with, and we've been working pretty closely together. I go, "Mark, have you ever seen this before?" And he goes, "No, I have never seen that before."

Earl Peterson was running the DC-8 program was there and his group. They determined it was the McDonald Douglas project manager trying to force that mod. Because his structural guy said it had to be this close and he obviously didn't come back to aero to figure out anyway that we could work this out. After we bring the whole thing to a stop, in the end it goes to three diameters. Because aerodynamically, we could prove that it just wasn't going to work at 2 diameters.

1989

I was always staying in touch with the basic program and being involved in some way or another, because it always interested me, by working on airplanes, flying them, and doing projects. While I'm sitting there in the wind tunnel, John Arvesen comes up and says he just heard that I'm a pilot and I'm an engineer, and he needs a chief engineer on the ER-2.

He wants somebody with a strong operational background rather than just getting a basic aerodynamic or aerospace engineer. I said, "That sounds great." This was 1989. We had three ER-2's, and each one of them was different. After I joined the High Altitude Mission Branch I discovered, you could not move an experiment from one airplane to the other, it would take weeks, because you had to rewire the other airplane to accept the payload.

1990's

I led the building of the experimenter interface panels. That's what got the standardization thing started. But then we had to get each airplane re-engined. So we rewired all the airplanes, put in the interface panels, started standard systems -- and that's where we went from about $100,000 per integration down to $15,000 or $20,000 per integration. By just standardizing the experimenter interface and communizing the 3 ER-2's. I wasn't looking for 100% solution or that we never have to rewire an airplane. But for maybe 95% of the instruments, if they can fit into this system, that'll take care of it.

I'm the guy that brought ER-2 Lockheed engineering up to Ames, because I had to go down to Southern California to the skunk works to see the engineering work-- this was kind of fun being in the Skunkworks regularly. I ended up in a meeting with Ben Rich, who was running the Skunk Works at the time, I said to him, "We can't continue to have our engineering staff at Burbank, designing systems that were putting on ER-2's up at Ames. We needed them up at Ames so they can walk to the airplane and actually measure the aircraft.

MTP (JPL instrument) was a good example of this. The MTP instrument wouldn't fit in the inlet cheek where we had placed it, because the drawings that they had on the airplane were a little different than what we actually had, so we would have to go back to Burbank and redo it several times. I just said, "This is crazy. We don't just need a liaison engineer. We need a bona fide engineer right by the airplane since at any given time we had 30+ engineering activities ongoing. We need at least one mechanical and one electrical and Ben agreed. But it was kind of neat, I got to sit there with Ben Rich and all these notable senior aviation guys. On his table he had this little airplane that I used to help out when I would do some classified missions in the Air Force that model was black and had a diamond shape to it. It was called the F-117. The existence of the F-117 is out in the open nowadays. But when this model was sitting at his desk it wasn't and I said, "How come you have that on your desk?" He says, "Oh, that's just some model that I found in a Japanese magazine."

So he put it on his desk, "This is just a model I bought." But he said (because he knew I was an aerodynamicist), "Why do you think we designed this with this faceted shape?" I said," Well obviously for the radar suppression." He said, "Yeah, but if you look at modern-day stealth airplanes, you don't have any of that classic flat panel shape anymore." I go, "Yeah, that's true." He says, "Well, the reason was because back then we only had slide rules and we had to calculate aero forces using flat plate aerodynamics."

While being the chief engineer of the ER-2 I was still continuing the support flight ops as a pilot. These are the 1990's. I got rid of the INS that they had in the U-2, and put in the LTN-92 into the ER-2 so we could have a civilian interface instead of the military 1553 data bus. I ended up being able to argue for the new engines, which was a $13 million operation, and convinced Jim Huning (Airborne Science director at NASA HQ) to support me.

When I got the engineering moved up to Ames, Huning thought I was crazy. Here is this upstart kid and I'm asking him for money. I'm this new guy on the block and I'm saying, "I'm moving engineering up to Ames, and I need half a million bucks to set up my engineering office with the CAD machines and all that." He finds the money for me, -- because I told him, "I'm going to save you a lot of money in integration for the scientists, we're going to be able reduce the cost by commonality, and by having local engineering."

The other thing I got to set up was, I had machinist that I used when I was in the wind tunnels, and I hired him for-- I think it was about $25,000 a year. Because I was having a problem with the Ames Machine Shop, and getting them to give priority to our stuff. I may have had 100 scientists, on travel, out there waiting for a mission to get off. I would give the machine shop a job, and they would sit there and say, “Well, we’ll get to it when we get to it.” I said, “But I need this tomorrow.” “Oh no, you can’t have it tomorrow. You’ll get to have it in a week or two, or whatever,” and I had to go up and down the halls at Building 200 (Center Director’s office). I ended up getting what I needed, because I was making a bit of a stink. But I got tired of that, and I had to do it every time. And it couldn’t be an emergency every time. So I hired this guy part time - Dan Rathermel - and he was a machinist, and I told the machine shop, “You can have him work on whatever you want, but the day I walk in, he drops whatever he’s doing and he does only what I want him to do.” I probably used him about a third of the time I was paying for him or a quarter, because he did a lot with the interface panels for the science payloads. He saved so many missions that if one time a year he came to the rescue with something, he was worth the whole year worth in pay. Because of all the scientists we had sitting around waiting for a flight to happen. At the time I was still flying the Kuiper and had quite a few good adventures down in the southern hemisphere, both with the Kuiper and with the ER-2 program. One on the ER- 2 was that we were on a mission called TOGA COARE out of Townsville, Australia, and the ER-2 had a sump-tank that had failed and was leaking. The problem was we couldn’t fly the airplane and the only way to get the sump tank out was to take the engine out the airplane. The only way to take the engine out of the airplane is just split the airplane in half and pull it apart. I was able to convince Jim Huning again, up at

headquarters, because I realized, every flight equated to approximately half a million dollars in the science budget, losing the science data and the scientist livelihood – for about a hundred thousand dollars we shipped all the equipment from Ames that it would take us to split the airplane apart and replace the sump tank by putting the equipment on an Evergreen 747, down to Sydney and then I had arranged the RAAF - the Royal Australian Air Force. C-130 to bring the equipment to us in Townsville—By having them fly from Townsville down to Sydney, meet the 747 there; get the parts on it; fly the C-130 back up to Townsville and in five days from the time we had a problem we had the airplane back in service.

When people forget how much money people are spending to make these missions happen, having people sitting around not getting the data that they need should not ever be acceptable.

There was another similar situation: one of my first deployments I was in Bangor, Maine with the ER-2 in February where the ER-2 can’t taxi on icy surfaces. There I was and the problem was, the Bangor airport, they could clear the runway, but every night the taxiways would get frozen over and they said “If you can get to the runway you’re okay.” I asked, “Is there any way if we spray de-icing fluid on the taxiways?” “Well, we don’t have a system to do that.”

The airport donated a flatbed truck and I went and ordered up an agricultural sprayer. Like a pesticide sprayer -- the only way you could control the disbursement is you control the speed of how fast you moved the truck. It had to be driven at 15mph, from our calculation. You wanted a certain amount of fluid on the taxiway. There was a fixed distribution rate and so we figured out how fast to drive it for whatever setting we had, and they just had to drive at that speed around the airport. All this was done within a week. It was Estelle Condon, the chief scientist for the mission, who gave me $50,000 to get the deicing or this agricultural sprayer. And we put it on the truck and within a week we had it all done right there in the field and we're spraying the taxi route for the ER-2 so that they can go out in the morning and fly. It was just this idea that you can't just sit around and wait for stuff to happen on normal process when so much money is at stake.

While I was chief engineer one of the things that interrupted my time there was a little thing called Desert Storm. They called me back to active duty in 1990. But even during that time, when I would get a little bit of time off from the war preparations, I'd come over to Ames and then get back in the war. On these brief respites from the war I worked on the re-engine and LTN 92 integration to the ER-2, so that the scientists could get the nav data on the AIRC 429 system rather than a 1553 data-bus.

I was in Desert Storm from-- combination of Desert Shield and Desert Storm starting in September '90 to July '91, and I had a couple of interesting things happen there. I was flying the C-141.

It started while flying the Kuiper when I was in Hawaii for NASA doing a deployment on astronomical observations. I saw the message light on my phone in the hotel room in Hawaii, and Lucy was with me at the time, and we decided we ought to go to dinner before I check that message because we knew we were in danger of getting activated, and I wasn't going to check any messages. After we went to dinner and the evening entertainment, I finally checked my voicemail message of the hotel, it asked me to call the squadron up, where I got a personal invitation from President Bush to join the war effort and to report in 24 hours.

The interesting thing was my chief pilot at NASA, was also the chief pilot of my reserve unit, so I said "Well, if you can wait three days for me to show up," because I'm supposed to show up the next day as soon as possible, "I can fly the Kuiper back. Otherwise, you'll have to fly another pilot out to fly the Kuiper back home. And he said, "Yeah, we'll put you on a later crew heading out to the desert." He was able to arrange for me to have a few more days in Hawaii before I had to head to the war. But, even while I was at the war, there were times I'd be back home because I would fly too many hours that I was burnt out of being able to continue flying, so I'd get to come home for a bit, and I stopped in at NASA and continued to work on the ER-2 modifications that we were working on at the time. Even got back for my son's birth just before hostilities began, my first flight when I got back in the field is when the war started – must have been waiting for me!

We were flying out of Travis in California, and flew, typically, to the East Coast, then we'd load up the aircraft, go to Europe. Then, over from Europe, we'd get into Saudi or Kuwait. I ended up flying a combination of about 50 combat support and actual combat missions. The last part of it was they had us still activated in June, and I went off to the Philippines for what they called the Inter-theater Deployment, and that was before Pinatubo blew. So every day, before we would launch out of the Clark Air Force Base near Manila. They would brief us on the status of the volcano because they knew it was about to blow. And two weeks after we left it actually blew, and that shut down that base permanently.

1992

When I got back from the USAF, we finished the engine upgrade and new nav systems on the ER-2. Got back to doing deployments with the ER-2, continued to upgrade the systems and standardized the 3 aircraft. As chief engineer of the ER-2, I led development of a lot of the standardized formats and the new user's guide or workbook, which has pretty much become a standard for all the Airborne Science aircraft now. Then, like I said, just continued to do quite a few interesting missions, got down to Brazil, over to Fiji, Australia, etc.

There were four civil servants that pretty much ran the program. There was John Arvesen who was the branch chief. I was the chief engineer. Gary Shelton was the mission coordinator, and Jim Barrieux was the chief pilot. Between the four of us, we had an organization of about 100 people. Jim covered the maintenance and the flight ops. I covered all the aircraft modifications and airworthiness activities, and Gary was the primary mission coordinator and planner.

Between us, I thought we had a pretty gang-buster program, and then the really bad part came up with Goldin wanting to shut down the Ames Research Center flight ops and USAF requesting their loaned aircraft back. I ended up getting the job of writing the letter when the Air Force. I had to write the letter to say, "We're happy to return it," which we really weren't. And the Air Force was actually hoping we would fight it because they were trying to use that to help them with their justification to restart the U-2 line because they wanted to get some more U-2s. But by then, also the Global Hawks were starting to be conceived, developed and built; the U-2 program was trying to get out ahead of that.

Huning was still at headquarters at that time and was trying to help keep Ames in play, but the winds at the headquarters with Goldin's directives where that everything gets consolidated in Dryden. Senator Mikulski came in and said, "Anything east of the Mississippi won't be consolidated," and Abbey came in and said, "JSC won't be consolidated." So the only place that was left was Ames and Dryden, and the congressional and senators in California really didn't care whether we-- or where we moved.

NASA moved the planes to Dryden. What happened was they came up and offered us jobs at Dryden – when I was talked to about how much they needed me to come down with the airplane. I was told, "Oh that flying thing that you do, I don't think we can do that at Dryden." That was the first turn off, and then the next thing he told me was - my present GS level which I was a 14 at the time and was told, "We're kind of a flat organization, and we don't really see that that job needs to be a 14, but you'll have safe pay for a couple of years." And I said, "I don't think that sounds too good, and Ames offered me a GS-15 position working on aviation safety," so I stayed at Ames. My boss at that time was Santiago who became the CIO of NASA at some point. But, very soon thereafter Johnson offered me a position as an instructor and research pilot. So I went up to my new boss in the Aviation Safety Organization and said, "I really hate to tell you this, but I think I'm going to take this other position." He says, "Yeah, Roberts, it's really a tough decision. Work on a desk, or fly jets. Work on a desk, or do acrobatics. Work on a desk, or fly WB-57s." He says, "I don't see that that's too tough of a decision."

1998

I was an instructor to the Astronaut Corps. That was our primary job and test pilot to checking out the aircraft with the modifications. The first job is to fly the T-38s, and because I have been a previous instructor in the Air Force in the 38s, it was an easy transition to get back to instructing in the 38s. And then, I started flying the Gulfstream, and then they put me in the WB-57. While I was a T-38 instructor, a project pilot on the G159, and then on the WB-57, I was the program manager, and a pilot on all three aircraft. This was started in '98 when I moved to Johnson. By 2000, I was flying the WB-57 and managing the program.

Then the Costa Rica operation came about, I was visiting headquarters working on the WB-57 program and talking to some of the science folks that needed to do tropical atmospheric observations and they said, "We really need to get to Central America." I think it was Hal Maring that probably told me that. I can't remember for sure. So I was looking at it and Howard Air force Base in Panama was shutting down which was what we used to use for Central America operations. Shortly thereafter I was flying a T-38 with Franklin Chang Diaz—the astronaut originally from Costa Rica. I didn't put two and two together. He was just another astronaut that I was flying with. We were just talking while we were up there and I said, "I really need to find a place in Central America to operate the WB-57. Do you have any good ideas?" And he says, "Well, how about Costa Rica?" So Franklin Chang turns out to be a real hero in that country because when he was growing up, he said, "I'm going to be an astronaut," and everybody says, "You can't. You're from Costa Rica." Well, Franklin Chang became a US citizen and became an astronaut. He and I hit it off pretty good. He also knew the president and the ministers and the head of their science organizations. So when I went down there, I got treated like royalty. We ended up working with the Costa Ricans. I actually brought down Adrian Tuck, Jim Anderson, somebody else, I think it might have been Jim Huning or Hal Maring. I brought those three down and to help convince them of the science need for operations. The Costa Ricans actually built us a hangar at their main airport there in San Jose. For about ten years, we pretty much did what we said, we flew down there every year. In fact, airplanes are still flying down from NASA and NSF.

While we were in Costa Rica we supported them hosting an ISRSE conference and talking to Jim Weber, (the interviewer) and some of the other old guys that we really didn't have any ways to capture the pretty rich history that the Airborne Science Program enjoys. That's going to end up going away and all that knowledge and all those experiences would be lost if we didn't have a way to capture it. So that's where the bright idea of really needing someone to start a history program. At that time, I wasn't running the Airborne Science Program so we couldn't start the history activity.

In fact, in Costa Rica I had my last WB-57 flight in early 2006. That was kind of an interesting flight because the winds were supposed to go out of limits while we were airborne but then be back in limits by the time I got back. And then, we were coming down and the winds were basically gusting in and out of limits, we were getting gusts of up to 40 knots and varying wind directions at the same time. It wasn't even steady. As I was coming in, I did a fly-by because it was my last WB-57 flight. And as I doing the fly-by, and

I'm bouncing all around, I'm sitting there thinking I can do one approach here, but I'm getting low on fuel, and I've got to go to Liberia (Liberia is another airstrip up on the Pacific Coast.) … That was my alternate and I'm thinking, "Here's my last flight on the WB-57, and I'm going to have to end up diverting." What a way to end it. But the winds behaved on that approach enough to land.

2006

In 2006, I ran the SOFIA platform, and what happened there was it was stuck in Waco because they were doing the modification work there at Waco, and then they were also doing what they call a D-check or a pretty extensive overhaul on the jet. And it had been there for ten years; pretty much people tried to make it a retirement program for the L-3Com guys, and NASA was dumping something like a million a week into the program. I got there, and first thing I did was I walked around the airplane, and I saw them closing a panel. I went up to one of the inspectors and said, "I see you're closing that panel. Is everything in there completed" because there's about 100 little screws that all have to be torqued properly, and it takes a bit of time to close it and open it. The inspector says, "Yep." I ask "Does that mean everything in there is ready for flight?" They go, "Yep. All the work is done, so we're getting it ready for flight." I said, "Great!"

The next day I come in because every morning my routine was to walk around the airplane, see what progress have been made. I saw the panel open, and I go up and I say, "Why is that panel open? You closed it yesterday and said everything was ready for flight." He said, "Oh, we have to do the airworthiness directive on it." I asked, "The FAA just issue on an 18-year-old SP - special purpose - 747 an airworthiness directive last night?" The inspector responds "Oh, no." I ask "When did you know about it?" He says "Oh, it's been on schedule to have that work done for years." And I said, "But yesterday you said it was ready for flight." "Well, yeah, the work we had to do for the modification was all done, and now that's ready for flight, but now we have to do the airworthiness directive." So I grabbed all the inspectors and pull them into a room and said, "This ain't going to happen anymore. You're not spending two hours closing a panel, and then another hour opening a panel, just because you're changing the work activity. If you got temporary work to do or temporarily closing a panel, put one or two, four bolts in it or something like that. But don't put the 100 in there and get them all properly torqued." Within six months, we had the airplane flying.

My job was to get it out of Waco and get it flying. During that time aircraft home base changed, instead of having it go to Ames, the decision became to move it to Dryden, so there was a lot of work on the Dryden side to do to get it ready to accept that airplane. The other big thing was we were running two airworthiness systems on the SOFIA. We were doing the NASA airworthiness process, and we were doing the FAA airworthiness process. We were probably spending a good 100,000 bucks a week trying to manage both airworthiness process. I went ahead and killed the FAA process which scared the heck out of the scientists because they were saying that they wouldn't be able to fly as crew members or have teachers on there, and I explained, "No, NASA has a way to do that. You can't fly as a passenger on the airplane, but you can fly as an observer."

During that time frame, when I had finished the SOFIA activity and got it into flying status, I got offered the deputy director position at Dryden in

Flight Ops and to work out there. That's important because I became a detailee from Dryden from that position. But at the same time, Cheryl Yuhas was having some issues with the DC-8 and getting it pulled out of the North Dakota's cooperative agreement which NASA and UND had set up. She got a new position, and they needed someone to take over the Airborne Science Program. I was considered for that and then picked up to run the Airborne Science Program.

2007

Mary Cleave hired me for that position. Actually, Ted Hammer was my boss. It was kind of interesting, my headquarter supervision was from Ted Hammer. My money came from Jack Kaye, who runs the research and analysis section, and my performance appraisals were written at Dryden by Dave Wright, since I was a detailee. My duty station was permanently moved to headquarters, so we moved the family.

Just a side note in May 2007 I retired from the USAF as a full Colonel where I commanded the Reserve forces at Arnold Engineering and Development Center. The retirement party was at the Jack Daniels Distillery. What a sendoff it was!

I was now the Airborne Science Program director, so I had the actual authority to actually make a few decisions. Not too many, but they gave me some latitude. I said, "We ought to get this historical program going." That was 2007. We built up our national interagency and international collaborations.

A few of the things that we got going while I was at headquarters, I was there from 2007 through 2009, and those were pretty monumental years. We took our budget and basically tripled it. We established the Palmdale facility because NASA had a problem with airplanes that didn't have hangars. There were a lot of naysayers, in the end it got approved. We got the DC-8 back under Dryden Operational Control and maintained the North Dakota activity for mission science operations.

We established Operation Ice Bridge under the airborne program and also established the EVS opportunities. Got the PRISM instrument development started and help get the AITT program going with the NOVICE mission on the WB-57. Also we participated on the FAA UAS aviation rulemaking committee as a voting member. Expanded the unmanned aircraft utilization for science programs plus supported an FTE in the FAA UAS office which paid many dividends in getting the FAA to approve our science use of the national airspace.

We got the Global Hawks at NASA started. We got standardization systems working between the different centers such as beyond line of sight systems, sensor to aircraft interfaces, mission tools, SOFRs started. Much of this was due to a strong airborne requirements document, which ARC generated. The requirements document took the national science objectives determined what observations in the atmosphere were needed and thus showing what platforms the ASP should support based on the national needs.

The other big program that we got started was the Student Airborne Research Program (SARP), which has turned out to be a major success. We flew that with the DC8 and we used the P-3.

It turns out in the airborne science business, the 800 lbs. gorilla is the NASA Airborne Science

Program. This unique set of aircraft which NASA supports allows many national science objectives to be realized using high altitude, long duration and large and small flying platforms.

Basically, they were good years, then all of a sudden, to everyone's surprise—

I got offered a position with Northrop Grumman to start up an operation in the combat zones that we were involved with to save a bunch of our people. It was at least a month warning that I gave people, but it came as a shock to everyone in the program. But it was important work that we did. My retirement from NASA was effective in July of 2009.

2009

What we (Northrup Grumman) did was we set up what was called BACN, Battlefield Airborne Communications Node, and what NASA had done in the past was help them develop and demonstrate that capability. So they knew of my involvement with being able to setup successful operations and modifications. NG wanted somebody because it was going from the demonstration phase to real operations, and they were putting four Global Expresses and four Global Hawks together with this system to fly in the combat zones. And it was actually the number one JUON, which is Joint Urgent Operational Need, in the country. The development of these aircraft and going into operations, we were told basically to run like a pack of dogs were chasing us, and that the Secretary of Defense was personally getting briefed every week on our progress. The users of the system said our system was as important as bacon, beans and bullets. Because they wouldn't go out on ground operations unless they knew we were airborne and covering them.

2013

I retired from Northrop Grumman in 2013. Since then, I've been asked to help out with NOAA, NSF and with NASA in several different areas and still helping to do the international coordination for Airborne Science Programs, supporting the WB-57 and mission development work and helping NOAA transition their Global Hawk demo operations to full-fledged weather operations. With NSF I am supporting the severe storm penetrating aircraft development.

Unfortunately, I've come down with Parkinson's, so my plans to do my flying when I retired has fizzled away. That's the one negative that I've had to cope with in what has been an exciting, adventure-filled and magical career where my family, friends and colleagues have made it a wonderful ride, which is continuing.

Final words from Jim Weber: "Since I see Andy pretty often, I can say that the Parkinson's might have slowed him down a little bit, but it hasn't changed him a whole lot. So, Andy, thanks a lot."

Appendix B:
5-yr plan and Aircraft Maintenance Schedules

5-year Plan (as of February 2016)

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
1) Atmospheric Composition and Chemistry				
1.1) ASCENDS 2016	30	Jucks	OCO-2, ASCENDS	DC-8
1.2) KORUS-AQ	120	Lefer	Geo-Cape, A-Train, SNPP, TEMPO	DC-8
1.3) KORUS-OC	200	Lefer	Geo-Cape, OCO-2	B-200 L
1.4) CARAFE	10	GSFC	OCO-2	Sherpa
1.5) AJAX	70	Jucks	OCO-2	Alpha Jet
1.6) SHOW	20	Jucks		ER-2
1.7) ASCENDS 2017	40	Jucks	OCO-2, ASCENDS	DC-8
1.8) CAMPEx	120	Maring	A-Train, ACE	P-3; WB-57
1.9) FIRE-CHEM	150	Lefer	A-Train, ISS	DC-8
1.10) Chemistry Mission-in-development	30	Jucks		WB-57

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
2) Carbon Cycle & Ecosystems Science				
2.1) ORCAS (PRISM piggyback)	98	Bontempi		NSF GV
2.2) Asian Environments	360	Kaye	NISAR	Other
2.3) AfriSAR	130	Hibbard	ESA BIOMASS	B-200 L; G-III (2)
2.4) UAVSAR - Terrestrial Ecology	20	Margolis	NISAR	G-III
2.5) Carbon Monitoring System		Hibbard/Jucks		Any Twin Otter
2.6) HyspIRI prep California	10	Turner	ECOSTRESS	ER-2
2.7) Sacto/SJ river invasive species	36	Hibbard		Other
2.8) HyspIRI prep tropical	40	Turner	HyspIRI	ER-2
2.9) LIDAR / spectrometer (mission in development)		CCE		ER-2; G-III (2)
2.10) ABoVE Field Campaign	100	Margolis		TBD
2.11) UAVSAR - Terrestrial Ecology	20	CCE	NISAR	G-III
2.12) EXPORTS (placeholder)		Bontempi		ER-2
2.13) South Asia LCLUC (placeholder)		Gutman	Landsat, NISAR	TBD
2.14) UAVSAR - Terrestrial Ecology	20	CCE	NISAR	G-III
2.15) UAVSAR - Terrestrial Ecology	20	CCE	NISAR	G-III
2.16) NISAR cal/val		CCE	NISAR	G-III
2.17) Arctic COLORS (placeholder)		Bontempi		TBD

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
3) Cryospheric Science				
3.1) OIB Arctic 2016	125	Wagner; Tagg	ICESAT 2	Other
3.2) OIB Alaska 2016		Wagner	ICESat 2	Single Otter
3.3) GLISTIN-A	24	Wagner	ICESat2, SWOT	G-III
3.4) OIB Arctic 2016	250	Wagner; Tagg	ICESat 2	Falcon
3.5) OIB Antarctica 2016	250	Wagner; Tagg	ICESat 2	DC-8
3.6) OIB Arctic 2017	300	Wagner, Tagg	ICESat 2	P-3
3.7) OIB Antarctica 2017	250	Wagner, Tagg	ICESat 2	P-3
3.8) OIB Arctic 2018	300	Wagner, Tagg	ICESat 2	P-3
3.9) OIB Antarctica	250	Wagner, Tagg	ICESat 2	P-3 or DC-8
3.10) ICESat-2 cal/val	100	Thurston	ICESat 2	ER-2; B-200 L
3.11) OIB Arctic 2019	250	Wagner, Tagg	ICESat 2	P-3
3.12) ICESat-2 cal/val	100	Thurston	ICESat 2	ER-2; P-3
3.13) ICESat-2 cal/val	100	Thurston	ICESat 2	ER-2; P-3

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015 2016 2017 2018 2019 2020 2021
4) Water and Energy Cycle				
4.1) AirSWOT Gulf Coast	20	Entin		B-200 D
4.2) AirMOSS Alaska	20	Entin	SMAP	G-III; G-III (2)
4.3) SMAPVEX-16	60	SMAP program	SMAP	DC-3
4.4) Airborne Snow Observatory	50	Entin		A90
4.5) SnowEX - 17		Entin		TBD
4.6) SLAP Freeze/Thaw-2	68	Entin		B-200 L
4.7) AirSWOT Canada	20	Entin		B-200 D
4.8) RZSM - ESA Collaboration	30	Entin	ESA BIOMASS	G-III (2)
4.9) Airborne Snow Observatory	50	Entin		A90
4.10) SnowEX - 18		Entin		TBD
4.11) SLAP Freeze/Thaw-2	68	Entin		B-200 L
4.12) Airborne Snow Observatory	50	Entin		A90
4.13) SnowEX - 19		Entin		TBD

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015 2016 2017 2018 2019 2020 2021
5) Earth Surface & Interior				
5.1) UAVSAR - 16	290	Dobson; Tagg	NISAR	G-III
5.2) Salton Sea mud pots	10	Phillips	HyspIRI / ASTER	SIERRA; DragonEye
5.3) Volcanoes and Corals		Turner, Dobson		SIERRA
5.4) UAVSAR - 17	290	Dobson; Tagg	NISAR	G-III
5.5) UAVSAR - 18	290	Dobson; Tagg	NISARI	G-III
5.6) UAVSAR - 19	290	Dobson; Tagg	NISAR	G-III
5.7) UAVSAR - 20	290	Dobson; Tagg	NISAR	G-III
5.8) NISAR cal/val		Dobson	NISAR	G-III
6) Weather				
6.1) NOAA Winter Experiments	268	Hood		Global Hawk
6.2) NOAA SHOUT-16	268	Hood		Global Hawk
6.3) Tropical Cyclone Intensity	60	NRL	TRMM, GPM	WB-57
6.4) GOES-R cal/val	100	Kakar	GOES-R	ER-2
6.5) Tropical Winds	67	Kakar	ADM / GPM	DC-8
6.6) GPM cal/val		Schwaller	GPM	DC-8; UND Citation; ER-2

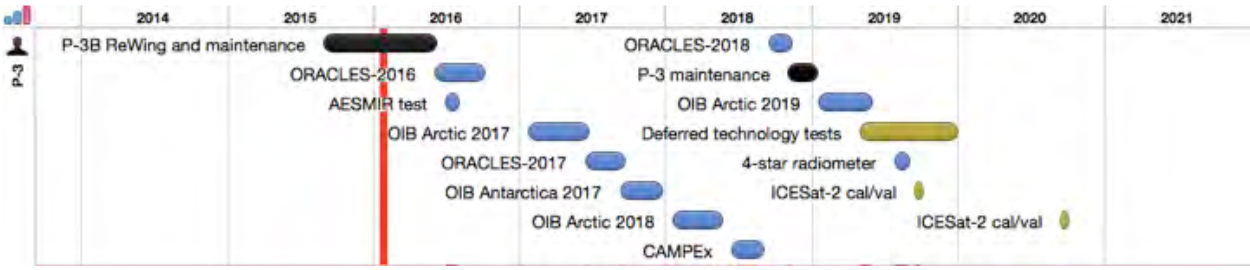
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015 2016 2017 2018 2019 2020 2021
6) Weather				
6.1) NOAA Winter Experiments	268	Hood		Global Hawk
6.2) NOAA SHOUT-16	268	Hood		Global Hawk
6.3) GOES-R cal/val	100	Kakar	GOES-R	ER-2
6.4) Tropical Winds	67	Kakar	ADM / GPM	DC-8
6.5) GPM cal/val		Schwaller	GPM	DC-8; UND Citation; ER-2
6.6) GH mission in development		Kakar		Global Hawk

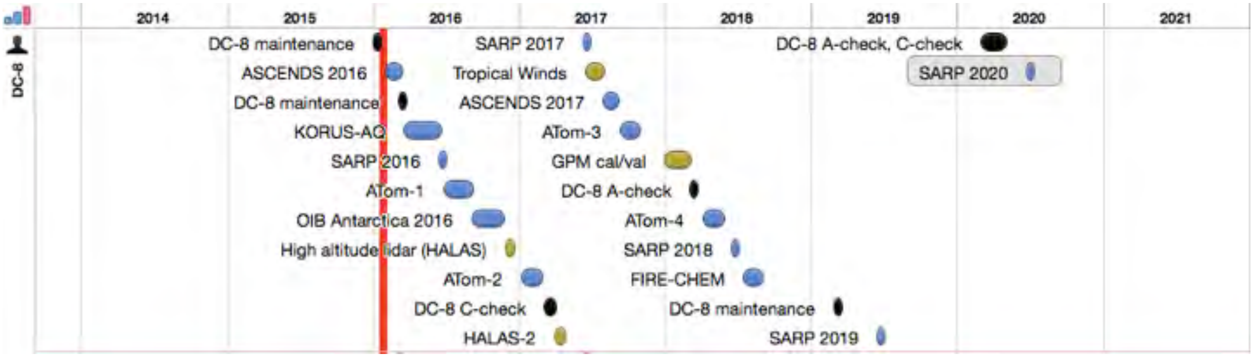
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015 2016 2017 2018 2019 20
7) EVS-2				
7.1) NAAMES-2016				C-130
7.2) NAAMES-2017				C-130
7.3) NAAMES-2018				C-130
7.4) ORACLES-2016	120	Maring	ACE	P-3; ER-2
7.5) ORACLES-2017	120	Maring	ACE	P-3
7.6) ORACLES-2018	120	Maring	ACE	P-3
7.7) ACT-America-2016	620	Jucks	OCO-2	C-130
7.8) ACT-America-2016		Jucks	OCO-2	B-200 L
7.9) ACT-America-2017	620	Jucks	OCO-2	C-130
7.10) ACT-America-2017		Jucks	OCO-2	B-200 L
7.11) ACT-America-2017	620	Jucks	OCO-2	C-130
7.12) ACT-America-2017		Jucks	OCO-2	B-200 L
7.13) ACT-America-2018	620	Jucks	OCO-2	C-130
7.14) ACT-America-2018		Jucks	OCO-2	B-200 L
7.15) ATom-1	120	Maring	OCO-2	DC-8
7.16) ATom-2	120	Maring	OCO-2	DC-8
7.17) ATom-3	120	Maring	OCO-2	DC-8
7.18) ATom-4	120	Maring	OCO-2	DC-8

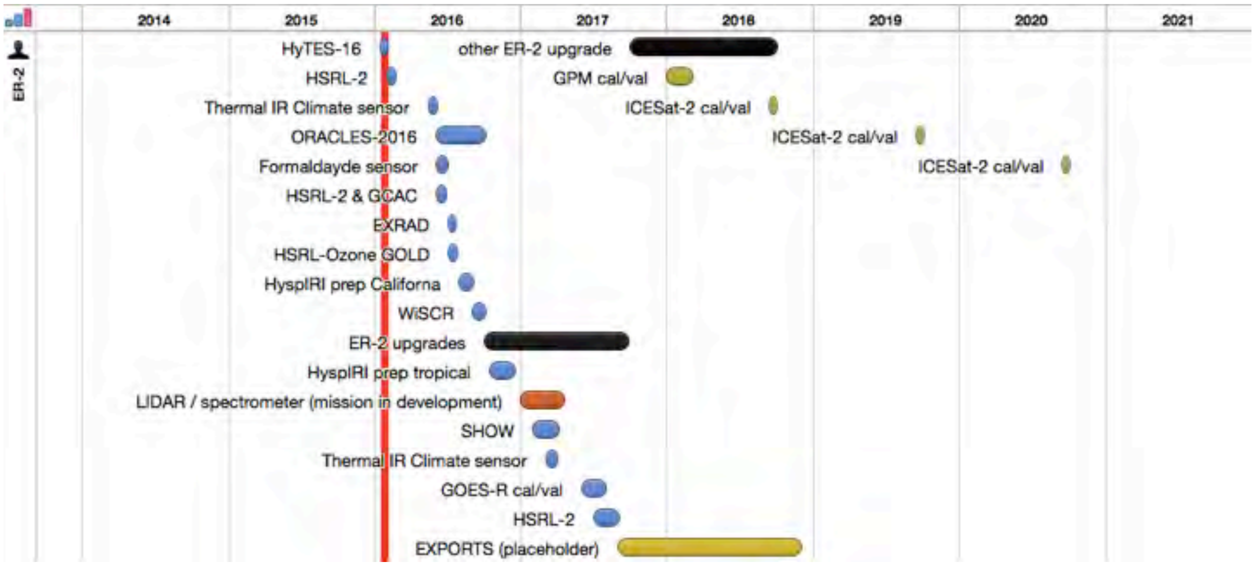
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
8) New Techology				
8.1) HyTES-16	10	AITT		ER-2
8.2) WISM (3 periods)	12	IIP		Any Twin Otter
8.3) ECOSAR/Rincon	18	IIP		TBD
8.4) HSRL-Ozone GOLD (check)	15	AITT		B-200 L
8.5) HSRL-2				ER-2
8.6) ATHENA-OAWL	30	IIP		WB-57
8.7) Thermal IR Climate sensor				ER-2
8.8) Formaldayde sensor	10	AITT		ER-2
8.9) UWBRAD		IIP		Any Twin Otter
8.10) HSRL-2 & GCAC				ER-2
8.11) EXRAD	18	ESTO AITT		ER-2
8.12) HSRL-Ozone GOLD	15	AITT		ER-2
8.13) Multi-wavelength LIDAR		IIP		B-200 L
8.14) WiSCR	18	IIP		ER-2
8.15) MISTIC Winds		IIP		Other
8.16) DopplerScatt		IIP		Other
8.17) SoOp-AD		IIP		B-200 L
8.18) Triple-pulsed LIDAR		IIP		B-200 L
8.19) HSRL-2		AITT		ER-2
8.20) Compact Limb Sounder		IIP		WB-57
8.21) UAVSAR / Global Hawk	17	ESTO ACT	SMAP, NISAR	Global Hawk
8.22) Next round IIP/AITT		IIP/AITT		TBD
8.23) Deferred technology tests				P-3

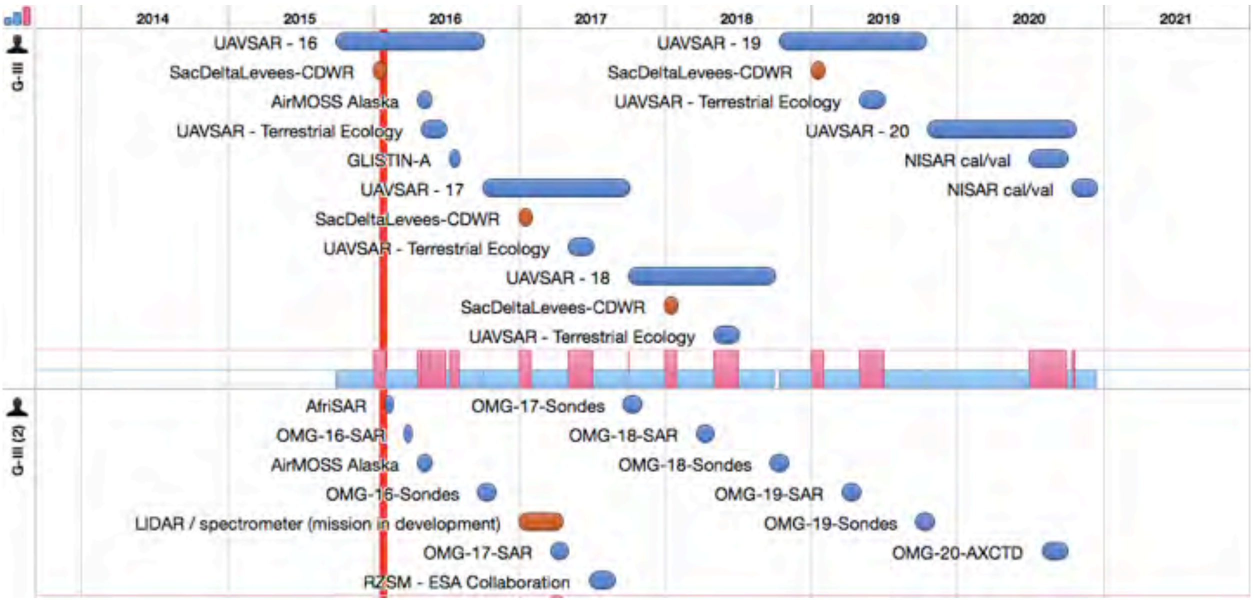
Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
9) Applications				
9.1) SacDeltaLevees-CDWR	32	Dobson		G-III
9.2) Cal Methane Survey	200	JPL		Any Twin Otter
9.3) SacDeltaLevees-CDWR	32	Dobson		G-III
9.4) SacDeltaLevees-CDWR	32	Dobson		G-III
9.5) SacDeltaLevees-CDWR	32	Dobson		G-III
10) Education				
10.1) SARP 2016	14	Kaye; Tagg		DC-8
10.2) SARP 2017	14	Kaye; Tagg		DC-8
10.3) SARP 2018	14	Kaye; Tagg		DC-8
10.4) SARP 2019	14	Kaye, Tagg		DC-8
10.5) SARP 2020	14	Kaye, Tagg		DC-3

5-yr Aircraft Schedules

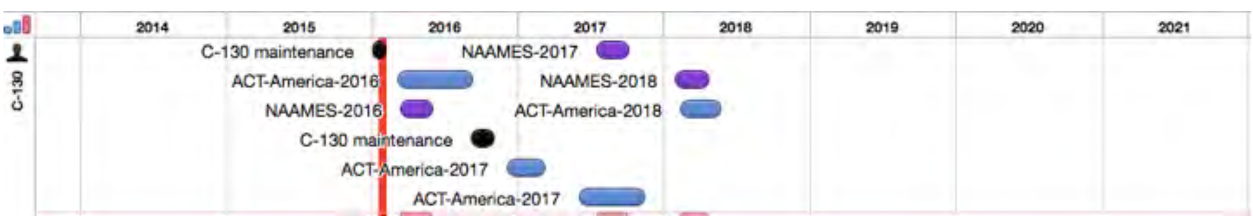







2014
2015
2016
2017
2018
2019
2020
2021
G-III
UAVSAR - 16
SacDeltaLevees-CDWR
AirMOSS Alaska
UAVSAR - Terrestrial Ecology
GLISTIN-A
UAVSAR - 17
SacDeltaLevees-CDWR
UAVSAR - Terrestrial Ecology
UAVSAR - 18
SacDeltaLevees-CDWR
UAVSAR - Terrestrial Ecology
UAVSAR - 19
SacDeltaLevees-CDWR
UAVSAR - Terrestrial Ecology
UAVSAR - 20
NISAR cal/val
NISAR cal/val
G-III (2)
AfriSAR
OMG-16-SAR
AirMOSS Alaska
OMG-16-Sondes
LIDAR / spectrometer (mission in development)
OMG-17-SAR
RZSM - ESA Collaboration
OMG-17-Sondes
OMG-18-SAR
OMG-18-Sondes
OMG-19-SAR
OMG-19-Sondes
OMG-20-AXCTD


2014
2015
2016
2017
2018
2019
2020
2021
Global Hawk
Global Hawk repair
NOAA Winter Experiments
NOAA SHOUT-16
UAVSAR / Global Hawk


2014
2015
2016
2017
2018
2019
2020
2021
C-130
C-130 maintenance
ACT-America-2016
NAAMES-2016
C-130 maintenance
ACT-America-2017
ACT-America-2017
NAAMES-2017
NAAMES-2018
ACT-America-2018


2014
2015
2016
2017
2018
2019
2020
2021
WB-57
ATHENA-OAWL
Tropical Cyclone Intensity
Compact Limb Sounder
CAMPEx
Chemistry Mission-in-development

5-yr Maintenance Schedule

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE DC-8

FY16	FY17	FY18	FY19	FY20	Maintenance
Dec 28 2015-Jan 14 2016					Fuel Tank Maintenance
Mar 7-18 2016					1A,2A,4A Check Maintenance
Sep 5-9 2016					1A Check Maintenance
	Mar 6-31 2017				1C Check Maintenance
	Sep 4-17 2017				1A Check Maintenance
		Mar 5-16 2018			1A,2A,4A&8A Check Maintenance
		Sep 3-7 2018			1A,3A Check Maintenance
			Mar 4-8 2019		1A,2A Check Maintenance
			Sep 2-6 2019		1A Check Maintenance
				Mar 2-5 2020	1A,2A,3A,4A,1C,2C Check Maintenance
				Aug 31-Sep 4 2020	1A Check Maintenance

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE ER-2

Aircraft	FY16	FY17	FY18	FY19	FY20	Maintenance
ER-2 806	Oct 2015-Jan 2016			3 Months		600-Flight Hour Maintenance
ER-2 806		2 Months			1 Month	200-Flight Hour Inspections
ER-2 806			12 Months			Cabin Altitude Reduction Effort
ER-2 809		12 Months				Cabin Altitude Reduction Effort
ER-2 809			2 Months		1 Month	200-Flight Hour Inspections
ER-2 809				3 Months		600-Flight Hour Maintenance

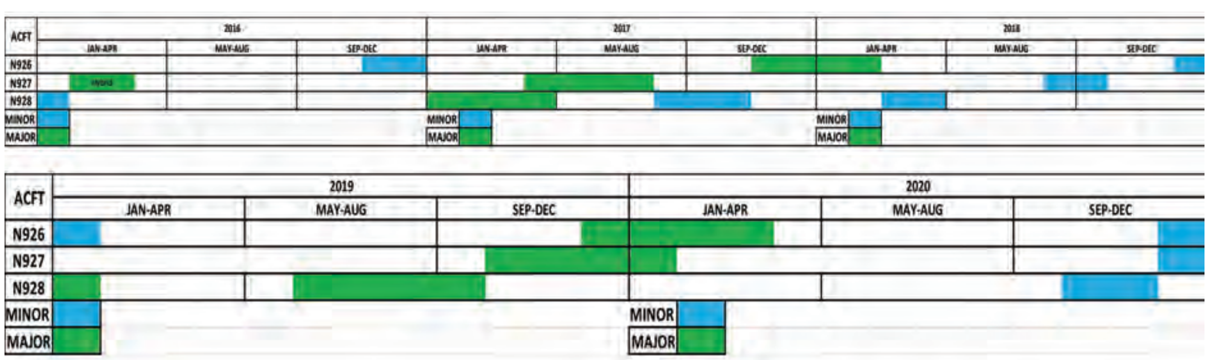
SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE C20-A

FY16	FY17	FY18	FY19	FY20	Maintenance
April-May '16 (5 Weeks)	Jan-Feb '17 (5 Weeks)	Jan-Feb '18 (5 Weeks)	Jan-Feb '19 (5 Weeks)	Jan-Feb '20 (5 Weeks)	Ops 1&3 (Odd Years) / Ops 1&2 (Even Years), Yearly Maintenance Cards based on Flight Hours & Landings (Cycles)
Jul-Aug 16 (5 Weeks)	Aug-Sept '17 (5 Weeks)	Jul-Aug '18 (5 Weeks)	Jul-Aug '19 (5 Weeks)	Jul-Aug '20 (5 Weeks)	FY16 Additional Tasks: Cockpit Upgrade
	Jun-July '17 (8 Weeks)				72-Month Inspection

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE GLOBAL HAWK

Aircraft	FY16	FY17	FY18	FY19	FY20	Maintenance
GH 872		6 Weeks				75-Cycle Inspection
GH 872				6 Weeks		2250-Flight Hour Engine Inspection
GH 872		2 Weeks				INMARSAT system upgrade required by 12/31/2016
GH 874						Initial service early FY17 with all inspections brought up to date during conversion period in FY16
GH 874		2 Weeks				INMARSAT system upgrade required by 12/31/2016
GH 874				6 Weeks		75-Cycle Inspection

SIGNIFICANT UPCOMING MAINTENANCE PERIODS FOR THE WB-57



Appendix C: Acronyms

A

ACATS	Airborne Cloud-Aerosol Transport System
ACE	Aerosols Clouds Ecosystems
ACES	ASCENDS CarbonHawk Experiment Simulator
ACT-America	Atmospheric Carbon and Transport-America
ADM	Atmospheric Dynamics Mission
AFRC	Armstrong Flight Research Center
AGL	Above Ground Level
AGU	American Geophysical Union
AIITS	Aerosol Ice Interface Transition Spectrometer
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AJAX	Alpha Jet Airborne Experiment
ARC	Ames Research Center
ARISE	Arctic Radiation-IceBridge Sea and Ice Experiment
ARMD	Aeronautics Research Mission Directorate
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASF	Airborne Sensor Facility
ASP	Airborne Science Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATC	Air Traffic Control
ATM	Airborne Topographic Mapper
ATom	Atmospheric Tomography Mission
ATTREX	The Airborne Tropical TRopopause EXperiment
AUVSI	Association for Unmanned Vehicle Systems International
AVIRIS, AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation

B

BGAN	Broadband Global Area Network

C

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CARTA	Costa Rica Airborne Research and Technology
CARVE	The Carbon in Arctic Reservoirs Vulnerability Experiment
CAST	Coordinated Airborne Studies in the Tropics
CATS	Cloud Aerosol Transport System
CCE	Carbon Cycle and Ecosystems
CERES	Clouds and the Earth's Radiant Energy System
CH4	methane
CO	Carbon monoxide
CO2	Carbon dioxide
COA	Certificate of Authorization
CONUS	Continental United States
CORAL	Coral Reef Airborne Laboratory
COSS	Celestial Objects Sighting System
CPL	Cloud Physics Lidar
CRS	Cloud Radar System

D

DAWN	Doppler Aerosol WiNd Lidar
DCS	Digital Camera System
DFRC	Dryden Flight Research Center
DLR	German Aerospace Research Agency
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

FAA	Federal Aviation Administration
FR	Flight Request
FTS	Fourier Transformation Spectrometer

G

GCAS	GeoCAPE Airborne Simulator
GEDI	Global Ecosystem Dynamics Investigation
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GeoTASO	Geostationary Trace gas and Aerosol Sensor Optimization
GH	Global Hawk
GHOST	Green House gas Observations in the Stratosphere and Troposphere
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal Imager
GOES	Geostationary Operational Environmental Satellite
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center

H

H2O	water
HAMMR	High-frequency Airborne Microwave and Millimeter-wave Radiometer
HDSS	High Definition Sounding System
HDVIS	High Definition Time-lapse Video System
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

K

KORUS-AQ	Air Quality Field Study in Korea

L

LaRC	Langley Research Center
LiDAR	Light Detection and Ranging
LVIS	Land Vegetation Imaging Sensor

M

MABEL	Multiple Altimeter Beam Experimental Lidar
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
MEMS	Microelectromechanical systems
MIZOPEX	The Marginal Ice Zone Ocean and Ice Observations and Processes Experiment
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 Atlan*tic Aerosols and Marine Ecosystems Study*
NASDAT	NASA Airborne Science Data and Telemetry
NAST-I	National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed - Interferometer
NCAR	National Center for Atmospheric Research
NOAA	National Oceanographic and Atmospheric Administration
NSF	National Science Foundation
NSERC	National Suborbital Education and 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
ORACLES	Observations of Aerosols Above CLouds and their InteractionS
ORCAS	O22/N22 Ratio and CO22 Airborne Southern Ocean Study

P

PACE	Pre-Aerosol, Clouds, and ocean Ecosystem
PALS	Passive Active L- and S-Band Sensor
PECAN	Plains Elevated Convection at Night
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol R&D
POS	Position and Orientation Systems
PRISM	Portable Remote Imaging Spectrometer

R

RVSM	Reduced Vertical Separation Minima
RZSM	Root Zone Soil Moisture

S

SABOR	Ship-Aircraft Bio-Optical Research
SAR	synthetic aperture radar
SARP	Student Airborne Research Program
SEO	sensor equipment operator
SHOUT	Sensing Hazards with Operational Unmanned Technology
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SIMPL	Slope Imaging Multi-polarization Photon-counting Lidar
SLAP	Scanning L- band Active Passive
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SNPP	Suomi National Polar-orbiting Partnership
SO2	Sulfur dioxide
SOFRS	Science Operations Flight Request System
SUAS	Small UAS
SWOT	Surface Water and Ocean Topography

T

TCI	Tropical Cyclone Initiative
TIR	Thermal Infrared Radiometer
TWiLITE	Tropospheric Wind Lidar Technology Experiment

U

UARC	University Affiliated Research Center
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
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

WFF Wallops Flight Facility

WISE Wide-field Infrared Survey Explorer

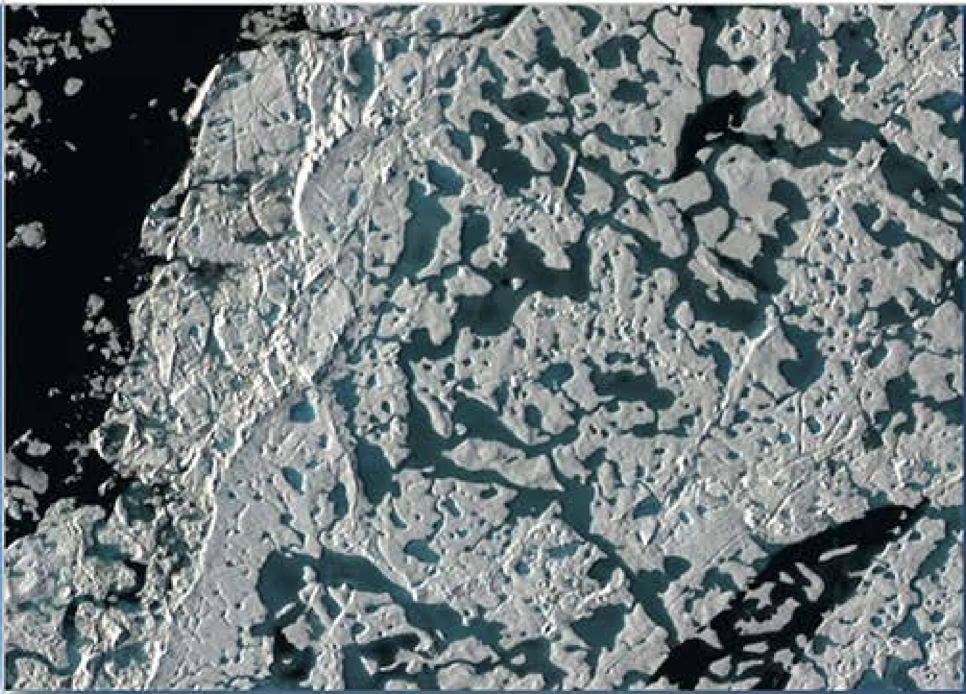
WISM Wideband Instrument for Snow Measurements

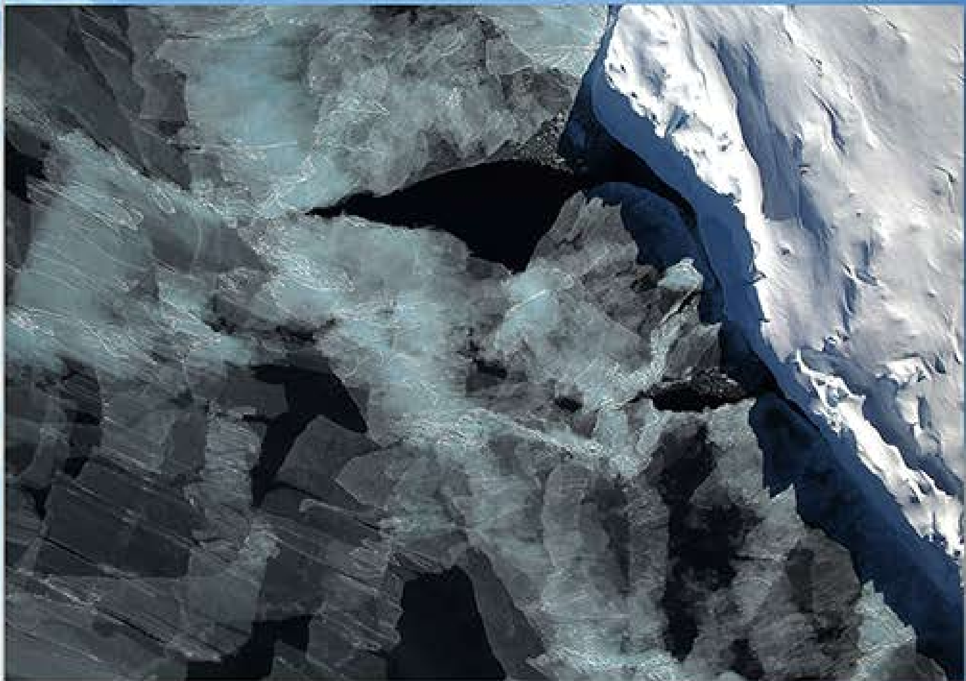
Wx Weather

BACK COVER FIGURES

Upper: Sea Ice Observed during SIMPL / AVIRIS-NG mission in Greenland in 2015

Lower: Sea ice in the Bellingshausen Sea seen by the Digital Mapping System instrument during the 2014 Antarctic campaign of Operation IceBridge.





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