NASA Airborne Science Program

2014 ANNUAL REPORT

(Front Cover: View from C-130 during ARISE)

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National Aeronautics and Space Administration

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LEADERSHIP COMMENTS

Bruce Tagg
Program Manager, Airborne Science Program

Welcome to the 2014 edition of the Airborne Science Program (ASP) Annual Report.

This year we again flew over 4,000 Earth Science flight hours and collected data from a variety of missions around the world. For the sixth time we flew the Arctic and Antarctic for Operation IceBridge, and we wrapped up the data collection for two of the five Earth Venture Suborbital-1 (EVS-1) investigations. It was a record year for multi-aircraft missions with DISCOVER-AQ (P-3, B-200, HU-25C and NSF/NCAR C-130), HS3 (Global Hawk, NOAA G-IV, and the WB-57), COMEX (CIRPAS Twin Otter, ER-2, Twin Otter International, Alpha Jet), and IPHEX (ER-2, UND Citation). As reported by airborne science investigators, twelve NASA Earth satellite missions were supported, including GPM and OCO-2 that launched this year. The DC-8 completed a major depot inspection that is expected to prolong its operational life another 10 years and the P-3 went in for re-winging that should extend its operational life by decades. We also took our newest (to us anyway) ASP aircraft addition, the WFF C-130, to the Arctic and Alaska for a sea ice and cloud interaction mission called ARISE.

The program's Mission Tool Suite for Education (MTSE) had another very busy year as well. MTSE allows students and teachers to track the progress of the ASP aircraft and provides a web portal through which classrooms can participate in live, online text chats with NASA scientists, educators and crew members during the missions. During FY2014, a total of 133 classrooms connected to ATTREX, HS3 and OIB mission teams through MTSE with a total of 3,127 K-12 students and their teachers participating. In the sixth ASP Student Airborne Research Program (SARP) class, thirty-two undergraduate students from a like number of colleges and universities graduated from an eight-week field experience designed to immerse them

ASP Vision

Building on our Airborne Science Program foundation, to continually improve our relevance and responsiveness to provide airborne access to the Earth Science community.

Program Mission Statement

ASP enables Earth Science researchers and scientists to improve society's understanding of Earth system science by providing a pre-eminent suite of airborne capabilities that meet NASA Earth science requirements. ASP accomplishes its mission by:

- Fostering a team of energetic, safety conscious, and customer-focused experts;
- Ensuring the capabilities it offers are safe, affordable, robust, modern, and meet the needs of the Earth science community;
- Continuously improving the relevance and responsiveness of airborne capabilities it makes available to the Earth Science community.

in NASA's Earth Science research and train the next generation of engineers and scientists.

For 2015, we look to conclude the remaining EVS-1 missions and start the five new EVS-2 missions. Operation IceBridge is expected to continue at its current pace through 2018. The year looks to continue support of NASA Earth Science space missions, both operational and in development, as well as ESTO technology maturation projects including HyTES, PRISM, and many others. We look forward to the return of the P-3 after re-winging, and inspiring the next generation of scientists and engineers with SARP and MTSE activities. As always, Randy and I hope you enjoy reading about the program and we look forward to a productive 2015.

PROGRAM OVERVIEW

ASP is an important element of the NASA Science Directorate and the Earth Science program.

ASP supports NASA Earth Science in the following capacities:

- Process studies
- Satellite mission instrument development, algorithm development and calibration and validation activities
- Instrument test
- Workforce development / next generation scientists

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

Structure of the Program

Figure 1 shows the role of the 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.

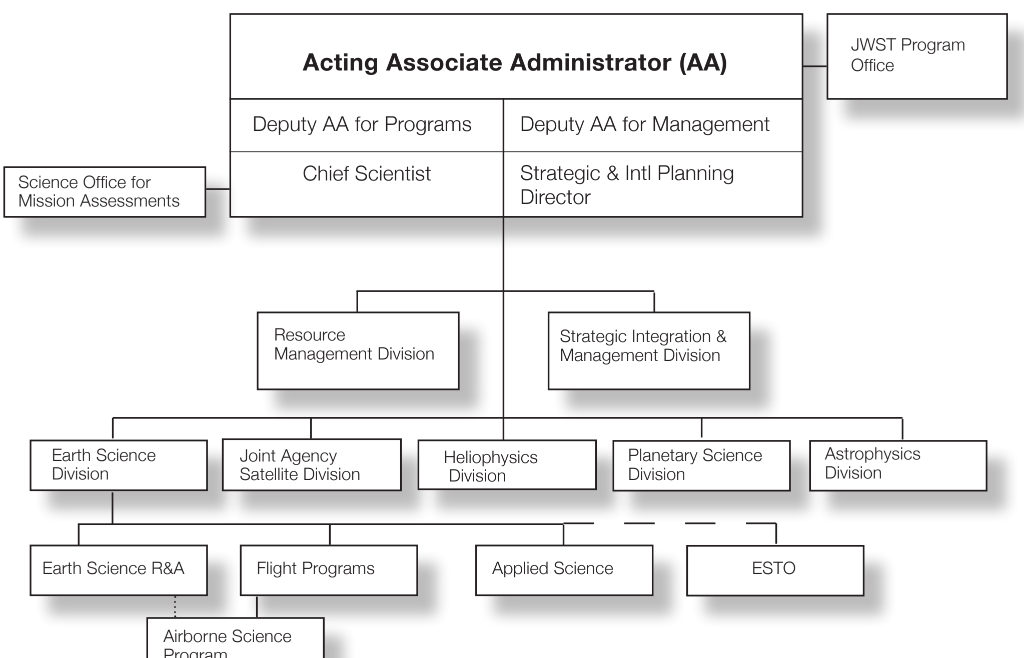


Fig. 1: SMD Organization Chart

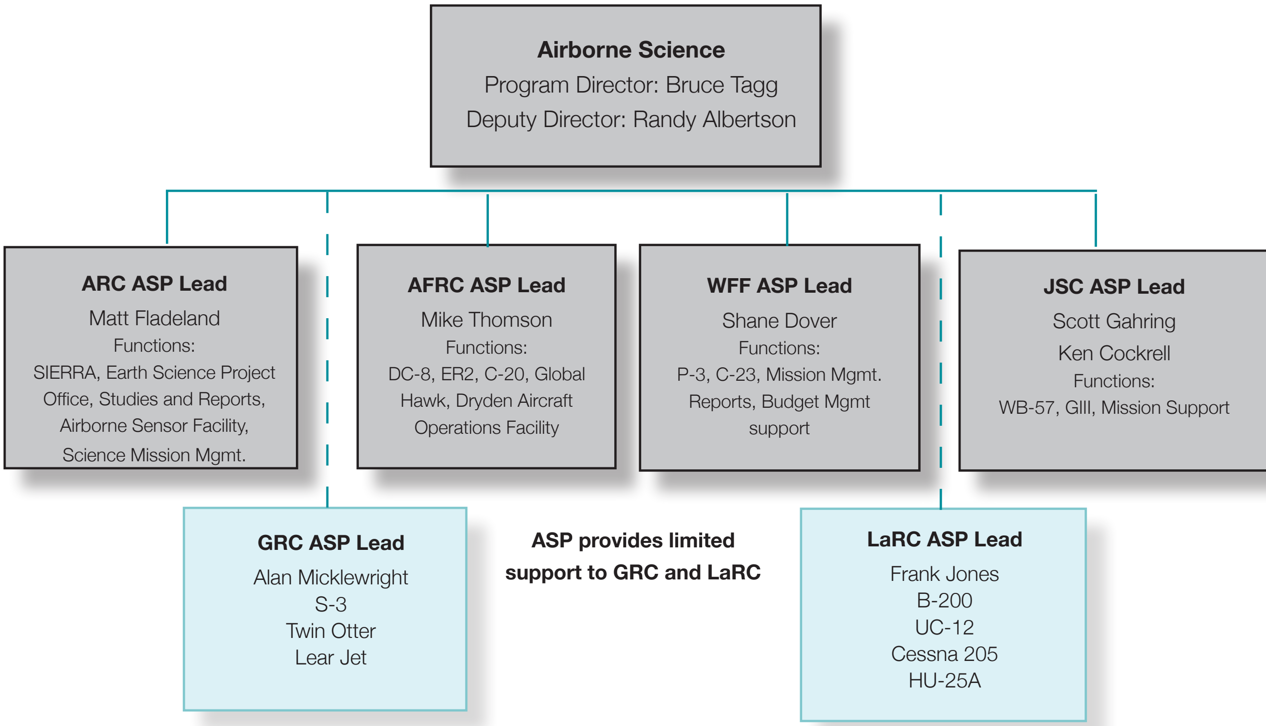


Fig. 2: Airborne Science Organization Chart

New Program Capabilities

The NASA Goddard Space Flight Center's Wallops Flight Facility activated a C-130 Hercules research aircraft in 2013, and it flew its first airborne science missions in 2014. The C-130 is a self-sufficient aircraft that can operate from short field civilian and military airports to remote areas of the world in support of scientific studies and other operations. The C-130 is a four-engine turboprop aircraft designed for maximum payload capacity. The C-130 has been extensively modified to support airborne science related activities.

Other acquisitions and upgrades in 2014 include delivery of Viking-400 UAS, a new SIERRA-B UAS airframe, INMARSAT capability on the ER-2 aircraft and extensive new functions of the Mission Tool Suite.

Fig. 3: C-130 in Alaska during ARISE mission

Flight Request System

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 system is also used to validate funding and confirm personnel resources to meet a request. The only way to schedule the use of NASA SMD platforms and instrument assets is to submit a Flight Request 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 2014, the focus was on creating additional reporting capabilities and on the continual refinement of the Flight Request System.

Fiscal Year 2014 Flight Requests

Several large campaigns were successfully conducted this year, including: ATTREX, HS3, and Operation ICE Bridge (OIB).

There were 206 Flight Requests submitted in 2014. A total of 89 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 15 Airborne Science supported aircraft and 11 “other” platforms. Together they flew a total of 4600 flight hours, as shown in Table 1.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hrs Flown
DC-8	8	6	0	5	88.8
ER-2	25	18	8	7	359.8
P-3	13	6	0	5	610.2
WB-57	9	7	2	5	46.1
Twin Otter	31	17	3	13	509.7
B-200	13	9	1	7	352.4
G-III Class	48	31	0	27	771.6
Global Hawk	7	3	0	3	444.7
C-130 Hercules	2	2	1	1	231.0
C-23 Sherpa	6	4	1	2	316.0
Dragon Eye	1	0	0	0	0.0
Falcon - HU-25	4	2	0	2	69.2
S-3 Viking	1	1	0	1	37.0
SIERRA	4	0	0	0	0.0
T-34	2	1	0	1	29.2
Other	32	16	1	11	734.4
TOTALS:	**206**	**123**	**17**	**89**	**4600.1**

Table 1: Summary of FY14 Flight Request Status and Flight Hours Flown by Aircraft

Notes on Tables 1 and 2:

- These totals are based on the Flight Request's log number, and therefore include Flight Requests whose log number starts with "14".
- The "Total FRs" column includes Flight Requests that were submitted and whose log number starts with "14".
- The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY14.
- The "Total Partial FRs" column includes Flight Requests in which the total approved hours were not fully expended during FY14 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 2014.
- Other aircraft include: Basler BT-67 (DC-3T), Alpha Jet, Twin Otter International, Contract Helicopter, Bussmann Helicopter, Piper Navajo, Cessna-208B, CIRPAS- Twin Otter, Cessna Citation, USDA-Cessna 206 and Learjet 25-Ice Niner.

Table 2 indicates the flights funded by NASA's Earth Science Division (ESD). Table 3 distinguishes between funding sources ESD, NASA Science Mission Directorate (SMD), and non-NASA funding.

Aircraft	Total ESD FRs	Total ESD FRs Approved	Partial ESD FRs	Total ESD FRs Completed	Total ESD Hours Flown
DC-8	5	4	0	4	61.7
ER-2	20	15	8	6	359.8
P-3	12	6	0	4	610.2
WB-57	2	2	1	1	4.4
Twin Otter	23	14	3	10	431.8
B-200	11	9	1	7	352.4
G-III Class	46	31	0	27	771.6
Global Hawk	7	3	0	3	444.7
C-130 Hercules	2	2	1	1	231.0
C-23 Sherpa	5	4	1	2	316.0
Dragon Eye	0	0	0	0	0.0
Falcon - HU-25	4	2	0	2	69.2
S-3 Viking	0	1	0	1	37.0
SIERRA	4	0	0	0	0.0
T-34	1	1	0	1	29.2
Other	20	11	1	7	457.3
TOTALS:	**158**	**103**	**16**	**74**	**4069.4**

*Table 2: Summary of ESD funded FY14 Flight Request Status and Flight Hours Flown by Aircraft**

Funded Flight Hours (Flown)

Fiscal Year	ESD 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
2013	4,392.4	88.7	129.6	93.5	124.9	4,829.1
2014	4,069.4	28.5	419.5	12.8	69.9	4,600.1

Table 3: Funded flight hours over the past 2 years.

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

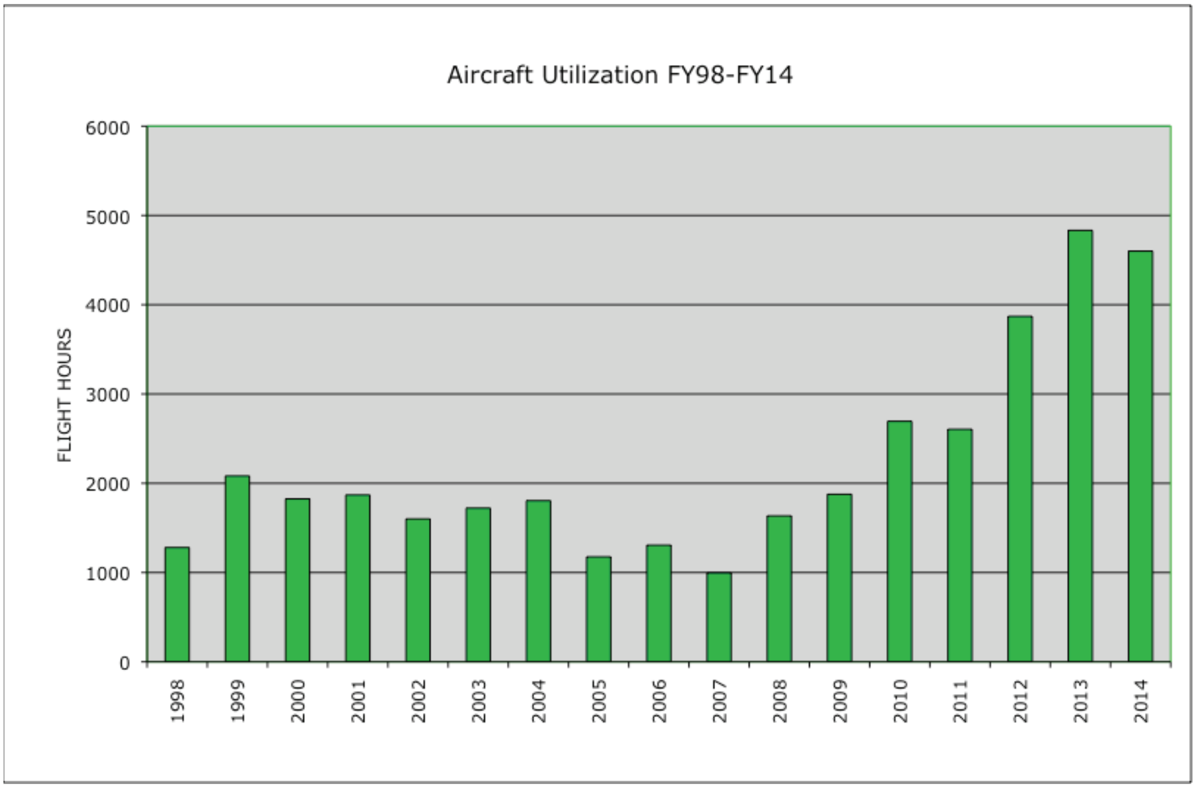


Fig. 4: ASP flight hours over the past 17 years

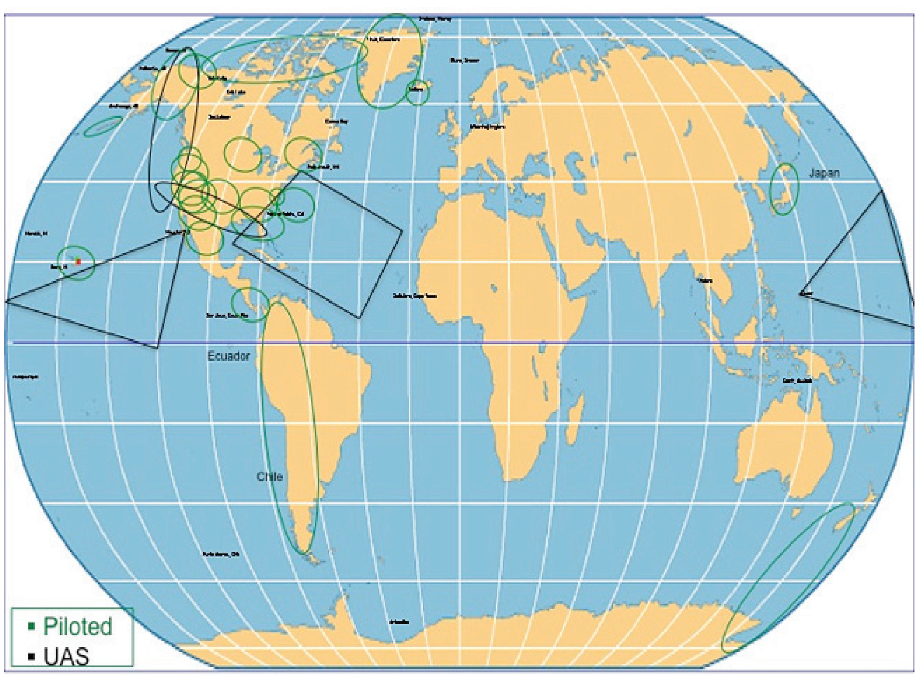
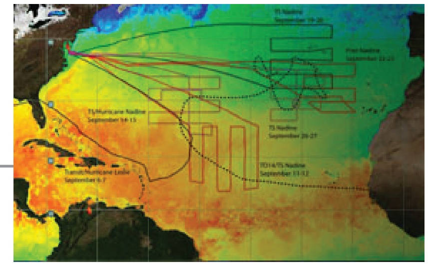


Fig. 5: Locations of airborne campaigns in FY2014

SCIENCE



The Airborne Science Program conducted over 4600 flight operation hours in support of NASA's Earth science missions during FY 2014.

NASA Airborne Science platforms were actively engaged in process studies, instrument flight-testing, and, especially, support for Earth Science space missions in all phases from definition to validation. Flight hours for the largest missions are shown in Table 4. Airborne activities provided cal/val data for recently launched GPM, OCO-2 and Landsat 8, while also providing algorithm data for the upcoming SMAP

Name	Aircraft	Location	Flight Hours
OIB	C-130, P-3	Greenland	547.3
UAVSAR	C-20A	Various	397.2
AirMOSS	G-III	Various	353.8
CARVE	Sherpa	Alaska	295.5
HS3 + HDESS	Global Hawk, WB-57	Atlantic	272.6
DISCOVER-AQ	B-200, P03, Hu-25	Colarado	265.0
G-LiHT Vegetation studies	Piper, Cessna, UC-12	Maine, NH, Alaska, LaRC	269.1
MRV* for EcoMarket Infrastructure	Piper, Cessna	Santa Rosa, CA	214.5
IPHEX	ER-2, UND Citation	Southeast US	175.8
ARISE	C-130	Alaska	158.5
Airborne Snow Observatory	Twin Otter	California, Colorado	154.0
ATTREX	Global Hawk	Guam	145.3
HyspIRI prep	ER-2	California	119.0
SABOR	B-200	Bermuda	92.5
MABEL	ER-2	Alaska	74.5
COMEX	Twin Otter	California	71.2
AJAX	Alpha-jet	California	69.9
CO2 Sounder/ASCENDS	DC-8	SW US	43.6
CALIPSO Validation	UC-12	Bermuda	37.6
AirSWOT	B-200	California	24.9
SARP	DC-8	California	17.1
ESTO	Various	Various	138.5

Table 4: Science Flight Statistics - Major Missions

*MRV=measurement, reporting and verification, an activity of NASA's Carbon Monitoring System.

and HyspIRI missions. The Airborne Science Program conducted over 40 missions and deployed field campaigns, utilizing more than 14 NASA-supported aircraft and UASs 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). The program also involved students in many activities, from student-led flight projects to graduate student researchers.

Major Mission highlights

Major accomplishments of the FY 2014 Airborne Science Program include airborne science again platforms supporting the Operation IceBridge and other arctic and snow-related missions the Earth Venture-1 (EV-1) Projects, cal/val for the recently launched GPM satellite and preparation for SMAP, ICESat-II, and HyspIRI and multiple uses of SAR imagery from the UAVSAR system on the Armstrong C20-A.

Operation Ice Bridge (OIB) and ARISE

Operation IceBridge is the largest airborne survey of the Earth's polar ice ever flown. It is yielding a three-dimensional view of the Arctic and Antarctic ice sheets, ice shelves and sea ice. These flights provide a yearly, multi-instrument look at the behavior of the polar ice sheets to determine their contributions to current and future global sea level rise and help understand the connections between changes in sea ice cover and the Earth system.

Data collected during Operation IceBridge helps scientists bridge the gap in polar observations between NASA's Ice, Cloud and Land Elevation Satellite (ICESat) -- which stopped collecting science data in 2009 after operating for twice its design lifetime-- and ICESat-2 planned for launch in 2018. Operation IceBridge is critical to ensuring a sustained series of observations of the most dynamic portions of the great Greenland and Antarctic ice sheets. The Airborne Science Program and the Earth Science Directorate Cryosphere Program jointly sponsor operation IceBridge.

During FY2014, the Airborne Science Program conducted two major OIB campaigns including the first ever landing of the P-3 at McMurdo Station in Antarctica,

Fig. 6: P-3 Orion at McMurdo Station for Operation IceBridge (Fall 2013)

and 6th season of P-3 and other aircraft in the arctic. See Figure 6. Together the IceBridge missions flew over 500 hours.

Operation IceBridge has developed into a major data mission, collecting more than 60 data products related to land and sea ice, in addition to snow, as illustrated in Figure 7.

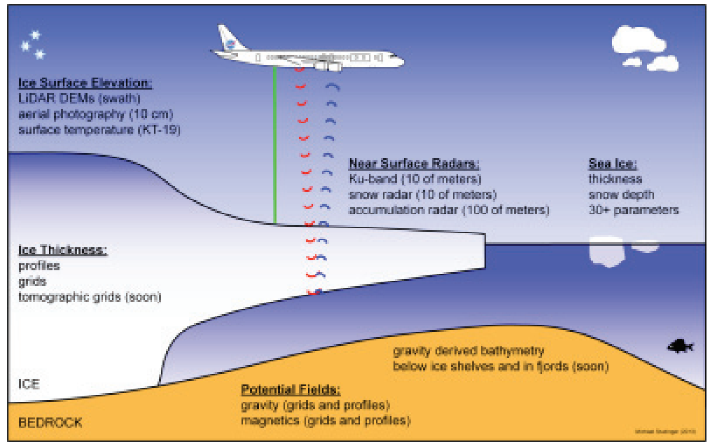


Fig. 7: IceBridge data products and how they are measured

OIB Antarctic Campaign: November 2013

The NASA P-3 Orion, based at the Wallops Flight Facility (WFF), deployed to McMurdo Station, Antarctica on November 11, 2013 for a 22-day mission in support of the Operation IceBridge (OIB) campaign. This deployment marked the first NASA aircraft to be based from the Antarctic continent and the first wheeled aircraft operation based from McMurdo Station. To reach McMurdo, the P-3 flew via New Zealand, rather than via south Chile, which is the route to the Antarctic Peninsula and Pine Island Glacier, as flown by the DC-8. Future missions will alternate deployment between Punta Arenas and McMurdo. See Figure 8.

Planning for the McMurdo campaign began a year and a half prior to deployment. WFF and OIB personnel worked closely with the National Science Foundation (NSF) and the U.S. Air Force (USAF) Air National Guard (ANG) 109th Airlift Wing Polar Operations Office located in Schenectady, NY. NSF and the USAF ANG personnel partnered with NASA to develop operational concepts, provided ice runway training opportunities, and supported site visits to McMurdo Station as well as

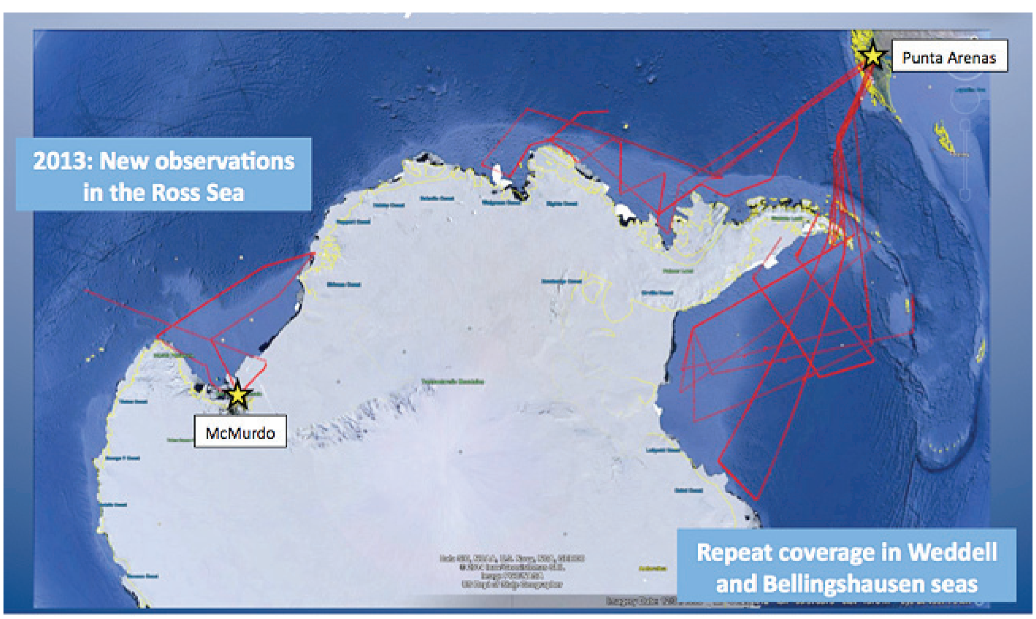


Fig. 8: Antarctic observation areas

logistical airlift and surface vessel support to and from Antarctica.

In preparation for deployment, an avionics upgrade was performed on the P-3 flight station to include new Flight Management Systems, Iridium satellite communication capability (text, data and voice), synthetic vision capability, installation of a Terrain Awareness Warning System (TAWS), and new flight displays. P-3 flight crews performed simulated ice runway training at the U.S. Navy P-3 simulator at NAS Jacksonville, FL as well as the 109th C-130 simulator at Tampa, FL.

WFF and the P-3 Orion supported 128.2 flight hours, flew 5 of the available 7 science flight days (two down days due to weather), and collected over 20,000 km of science data. The payload consisted of four radars from the University of Kansas, two LiDARs and a GPS navigation aid from the NASA Wallops Flight Facility, a Digital Camera System from the NASA Ames Research Center, and a gravimeter and magnetometer instrument managed by Columbia University. The mission demonstrated the feasibility of conducting NASA aircraft operations from the Antarctica continent and allowed data to be collected over longer durations and more area than previously accessible to other scientific research aircraft.

2014 IceBridge Arctic Campaign

From Mar. 12 to May 23, 2014, Operation IceBridge carried out its 2014 Arctic field campaign. Researchers flew aboard NASA's P-3 research aircraft out of bases in Thule and Kangerlussuaq, Greenland, and Fairbanks, Alaska, to study changes to land and sea ice in the Arctic. The mission also conducted a pair of flights designed to help verify future measurements from ICESat-2, which is slated to launch in 2017.

During this 11-week-long deployment, IceBridge collected data on changing ice surface elevation and ice thickness and measured snow depth on sea ice. Several of these surveys were repeats of flights from previous years. Repeating measurements from years to year means IceBridge is able to build a long-term time series of changes to polar ice, continuing a data record started by NASA's Ice, Cloud and Land Elevation Satellite, or ICESat.

The campaign started with flights over Arctic sea ice from Thule Air Base in northern Greenland, with a week-long temporary deployment to Fairbanks, Alaska. During these flights, IceBridge measured sea ice thickness and snow depth, producing a quick look dataset before the end of the campaign that would be of use to scientists making forecasts of summer sea ice melt. Several of IceBridge's sea ice flights were in coordination with other research groups, such as the European Space Agency's CryoVEx satellite validation team.

After several weeks in Thule, IceBridge headed south to Kangerlussuaq to study coastal glaciers in the southern half of the country. These flights included measurements of Jakobshavn Glacier, which drains more than seven percent of the Greenland Ice Sheet and is one of the fastest moving glaciers in the world.

While in Kangerlussuaq, IceBridge once again hosted high school science teachers from the United States, Greenland and Denmark, giving them a first-hand look at polar airborne research. In addition, the mission was visited by a crew from the Al Jazeera America television program TechKnow, who produced a half-hour episode about IceBridge.

IceBridge finished the campaign with a return to Thule. From there, IceBridge finished the campaign's remaining high-priority sea ice surveys and collected data on glaciers in northern Greenland. Arctic flight lines are shown in Figure 9.

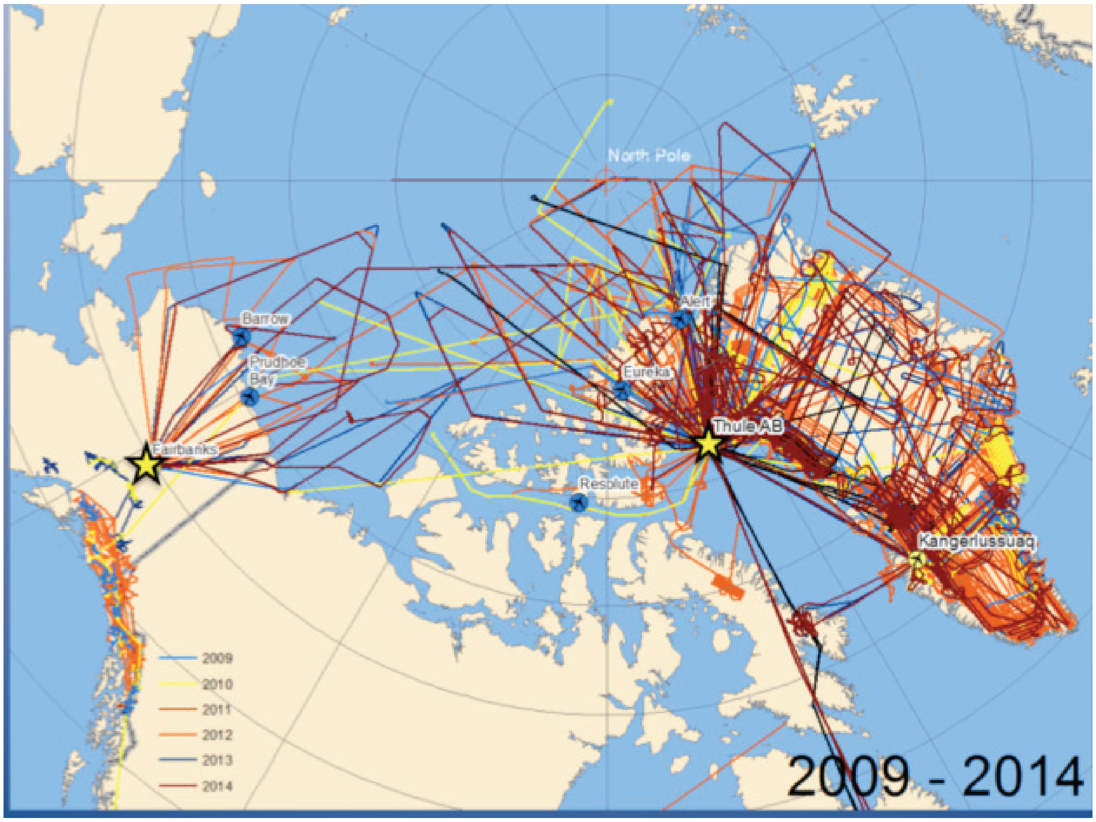


Fig. 9: Combined Arctic flight lines for 2009 through 2014 show extensive coverage.

ARISE (Arctic Radiation - IceBridge Sea and Ice Experiment)

The Arctic Radiation-IceBridge Sea and Ice Experiment. (ARISE) mission was a supplement to Operation IceBridge in 2014, making use of the newly instrumented C-130. ARISE also provided some preparation for the C-130, which will fly the spring 2015 IceBridge Arctic mission while the P-3 is being re-winged. ARISE featured a very broad instrument suite because of the spacious accommodations of the C-130. (See Figure 10.) The variety of instruments provided a large number of options for interesting science flights, but somewhat ironically, posed challenges as each instrument required different meteorological conditions, in conflict with each other.

Fig. 10: Inside the C-130 during ARISE.

ARISE was the first NASA airborne science mission of its kind, combining a unique instrument suite that would have been unlikely to fly together on the same airborne platform in missions past. New data sets are currently in the process of being studied and analyzed, and the ARISE science team will meet in June for their first post-mission science and data results workshop. A complete data set will be free and available for analysis in late Spring/early Fall of 2015 at NSIDC and the LaRC DAAC.

A few of ARISE's in-field accomplishments include:

- Conducting 17 Science flight (132 hours flown)
- Conducting 6 grid box experiments for CERES
- Conducting numerous sea-ice lines and Alaskan glaciers characterized for IceBridge
- Observing the sea-ice transition (melting early, then refreezing), and characterized by wide range of sea-ice conditions and associated cloud properties and radiative effects
- Observing that low clouds were geometrically and optically thin, often multi-layered with fog at the surface at times
- Conducting numerous focused low cloud radiative closure experiments
- Observing a significant amount of haze
- Conducting first ever melt season under-flight of Cryosat-2 with the LVIS laser altimeter (used for IceBridge objectives)
- Conducting calibration flight for radiometers including 4STAR, maneuvers to characterize airframe effects, and to calibrate the MET data system

A cloud flight line in Figure 11 highlights many features observed during ARISE.

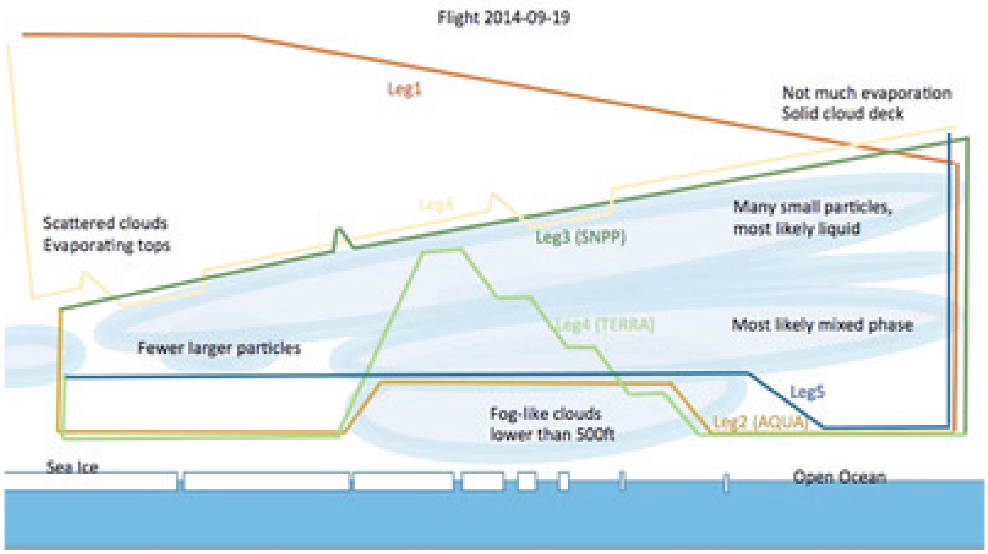


Fig. 11: ARISE cloud flight profile. Note the underpass of satellites AQUA, SNPP and TERRA.

Earth Venture Suborbital - 1

The Earth Science Division established Earth Venture (EV) as an element within the Earth System Science Pathfinder (ESSP) Program. The first project of the Earth Venture series, EVS-1, consists of a portfolio of five competitively selected suborbital Earth Science investigations to conduct innovative, integrated, hypothesis or scientific question-driven approaches to Earth system science. During FY 2014, all five of the EV-1 missions made significant progress and two – DISCOVER-AQ and HS3 – completed their airborne activities.

Hurricane and Severe Storm Sentinel (HS3) - NASA GSFC/ARC

The HS3 (Hurricane and Severe Storm Sentinel) Mission recently completed its third and final deployment at NASA's Wallops Flight Facility (WFF). A NASA Armstrong Flight Research Center (ARFC)-based Global Hawk deployed to WFF on August 26, 2014 and flew 10 science flights in the Atlantic before retuning to AFRC on September 30, 2014.

One goal of the science team was to learn more about rapid storm intensification by following severe storms through their entire life cycle, from inception to dissipation. HS3 was able to do just that, with four flights over Hurricane Edouard. All of the instruments on HS3's environmental Global Hawk (NASA 872, also known as AV-6), including the Scanning High-Resolution Interferometer Sounder (S-HIS), Cloud Physics Lidar (CPL) and Advanced Vertical Atmospheric Profiling System (AVAPS), performed well and collected data throughout the deployment. AVAPS dropped a total 649 sondes this year for a 3-year total of 1425.

The series of four flights covered almost the entire life cycle of the storm, beginning with Edouard as a newly formed tropical storm during the first flight. The second flight provided an opportunity to observe rapid intensification from a weak category 1 hurricane into a strong category 2. The third flight provided great data with some well-placed dropsondes in the eye and eye wall of the storm when it was near maximum intensity. The final flight provided sampling of a rapidly weakening hurricane.

Other areas of scientific interest that HS3 addressed during this deployment were the structure of the Saharan Air Layer (SAL) and its effects on storm formation, and the extra-tropical transition of a storm as it moved to higher latitudes. HS3 also included 2 flights to the Main Development Region (MDR) in the central Atlantic. (See Figure 12.) The MDR is the birthplace of many hurricanes, and an inter-comparison flight with a NOAA G-IV over the Gulf of Mexico. Additional highlights for this year included flights to three different named storms, Cristobal and Dolly, in addition to Edouard. A total of 10 science flights and 236 science hours were flown. That brings the three-year total for HS3 to 8 different named storms, 30 science flights and 642 hours flown.

Principal Investigator Scott Braun of NASA GSFC and Project Manager Marilyn Vasques of NASA ARC led the HS3 mission with collaborative efforts by nearly all the NASA centers, the National Oceanic and Atmospheric Administration, the National Center for Atmospheric Research, the Naval Research Laboratory, the Naval Postgraduate School, the University of Wisconsin, State University of New York at Albany, University of Utah, University of Maryland–Baltimore County, Penn State University and other organizations. Over 300 people made up the HS3 team and contributed to the success of the project.

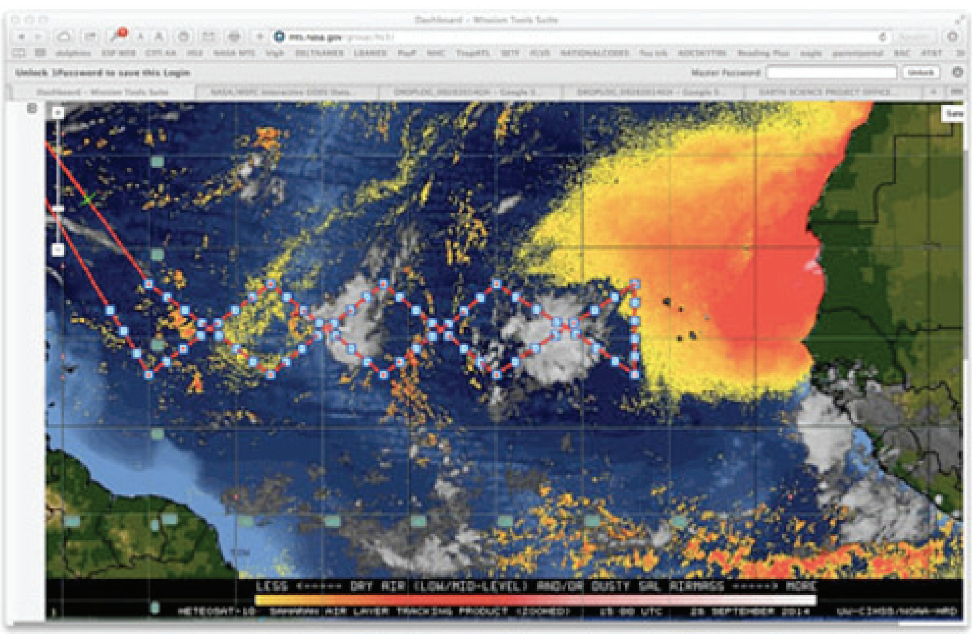


Fig. 12: The flight plan for HS3 Science Flight #10, flown September 28-29, into the main developmenmt region (MDR) where most Atlantic hurricanes form. Screenshot: NASA.

Carbon in Arctic Reservoirs Vulnerability Experiement (CARVE) - JPL

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) quantifies correlations between atmospheric and surface state variables for the Alaskan terrestrial ecosystems through intensive seasonal aircraft campaigns, ground-based observations, analysis and modeling sustained over its 5-year mission. The data will

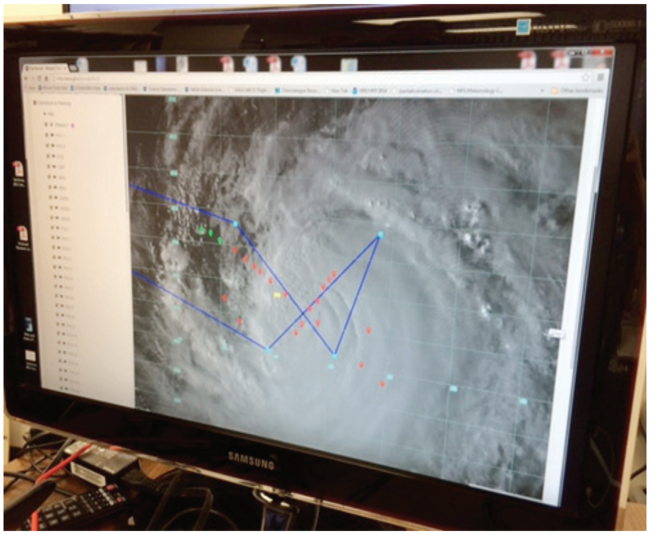


Fig. 13: Sonde drop and WB-57 flight tracks over hurricane Gonzalo.

be used in a multidisciplinary investigation to determine spatial and temporal patterns, sensitivity to change, and potential responses of Arctic carbon budgets to observed and projected climate change.

The 2014 CARVE instrument system includes CARVE's custom navigation and logging system, which time tags and geolocates data from the following probes and instruments: outside air temperature, relative humidity probes and ozone sensor, two Picarros real time gas analyzers which measures: Methane (CH4) Carbon dioxide (CO2), Carbon monoxide (CO) and water vapor (H2O), a Fourier Transformation Spectrometer (FTS), two Programmable Flask Packages (PFP) and a nadir looking, (1024 x 1024) Thermal Infrared camera.

The CARVE aircraft was deployed to Fairbanks, Alaska from May to November 2014. During this entire period, once a month, for a two week period, the CARVE flight crew observed enhanced CH4, and CO2 over various locations, including the North Slope, Barrow, Prudhoe bay, Nome, Unalakleet, Innoko, Minto Flats, Fort Yukon, Bethel, Bettles, Kotzebue, and Kuskokwin valley. Representative measurements are shown in Figure 14.

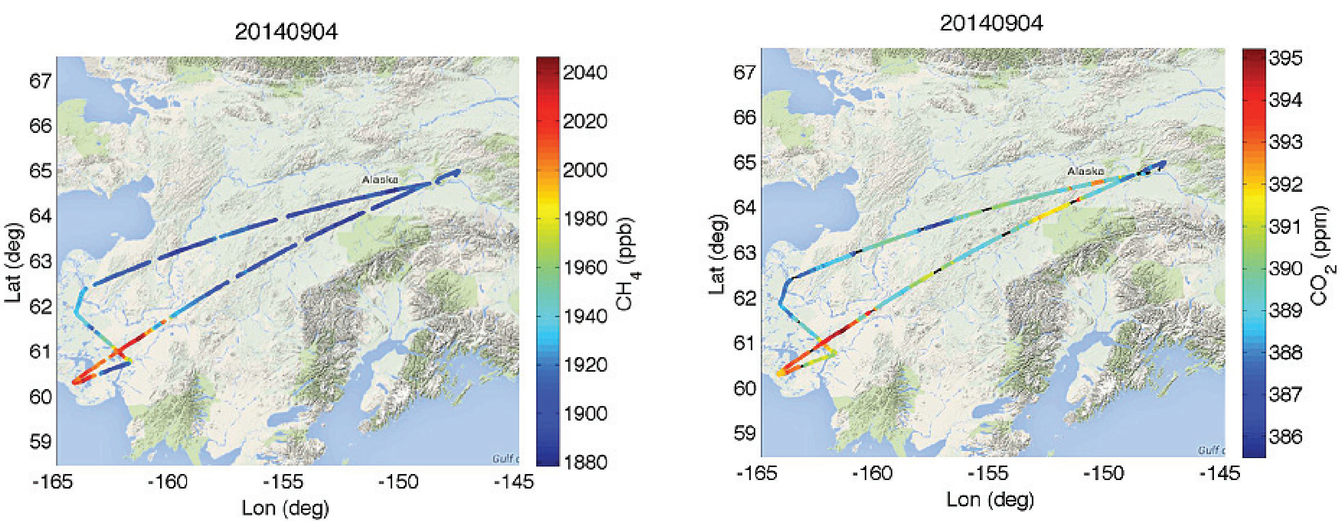


Fig. 14: CARVE observations of CH4 (top) and CO2 (bottom) along the 4 September 2014 flight to Bethel and the Yukon/ Kuskowim Delta. Enhanced CH4 and CO2 values were observed over a ~300 km region extending from the Lower Yukon River Valley to the Bering Sea. Data gaps are internal calibration periods.

In 2014, CARVE achieved the following major milestones: all 2013 level-2 data were released to the public, CARVE flew over 266 Alaskan science flight hours in 47 flight days, and on 29 May 2014 the CARVE team flew its 500th science flight hour, successfully completing its Program-Level Baseline Science Investigation Requirements. This is a major milestone for the CARVE team and for NASA's EV-1 program. CARVE achieved its 500 Science Flight hour goal, utilizing CARVE Science payload version 2.0, while maintaining a 100 % hardware dispatch rate from May 2012 to November 2014. Currently CARVE's combined science flight hours for 2012 to 2014 are 732 hours or 232 hours above Baseline. The CARVE team is looking forward to making these measurements again in Alaska in 2015.

Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) - JPL, USC

The Airborne Microwave Observatory of Subcanoy and Subsurface (AirMOSS) EV-1 mission completed its second full campaign year in October 2014. AirMOSS has flown well over 800 hours and more than 40 flight campaigns since August 2012. The P-band synthetic aperture radar (SAR), which is the principal instrument of the AirMOSS mission, operates in the 420-440 MHz band aboard the NASA Johnson Space Center Gulfstream 3 (G-3) airplane, and is used to retrieve maps of soil moisture profiles under the surface and under vegetation canopies. The flights are flown at 41,000 ft (12,5 km) altitude. The radar, built and operated by JPL, has a 2 kW transmitter to ensure high levels of signal-to-noise ratio are achieved for measuring backscattering cross sections. AirMOSS seeks to study how dynamics and heterogeneities of root zone soil moisture (RZSM) control ecosystem carbon fluxes in North America. The RZSM information is used in hydrologic and ecosystem process models to determine how much carbon North American ecosystems are sequestering and releasing, depending on the available water at their roots. The difference, also called the Net Ecosystem Exchange (NEE) of carbon into the atmosphere, is essential for a better understanding of global climate change.

Each flyover generates roughly half a million pixels of high-resolution digital imagery, with each pixel representing an area of 30 to 100 meters squared. For retrieving soil moisture profiles, these measurements are run through complex numerical algorithms, using computer clusters at NASA Ames and at the USC HPCC, providing the first temporally and spatially sustained direct observations of RZSM from a remote sensing observation. An example is shown in Figure 15. Hydrologic and ecosystem models then use these RZSM snapshots to simulate

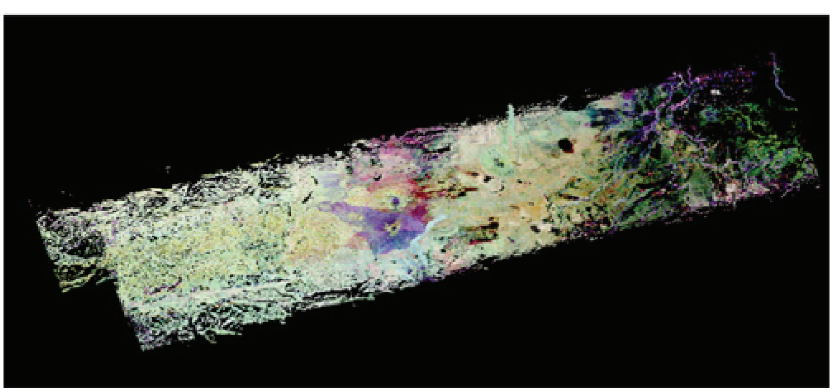


Fig. 15: Example of AirMOSS radar imagery taken at Metolius, OR. (Biome IV). Mosaic of 4 flight lines is shown as false-color overlay of HH/HV/VV in R/G/B/ channels.

hourly maps of soil moisture and NEE, and will ultimately provide an up-scaled estimate of NEE at the north American continental scale.

The campaign plan is designed to optimize seasonal coverage at the wide range of ecosystems in North America, while also ensuring that the G-3 primary Astronaut Direct Return Mission is intact. All of the AirMOSS imagery is available at the ASF DAAC, and the science products are available publicly at the USGS LP-DAAC.

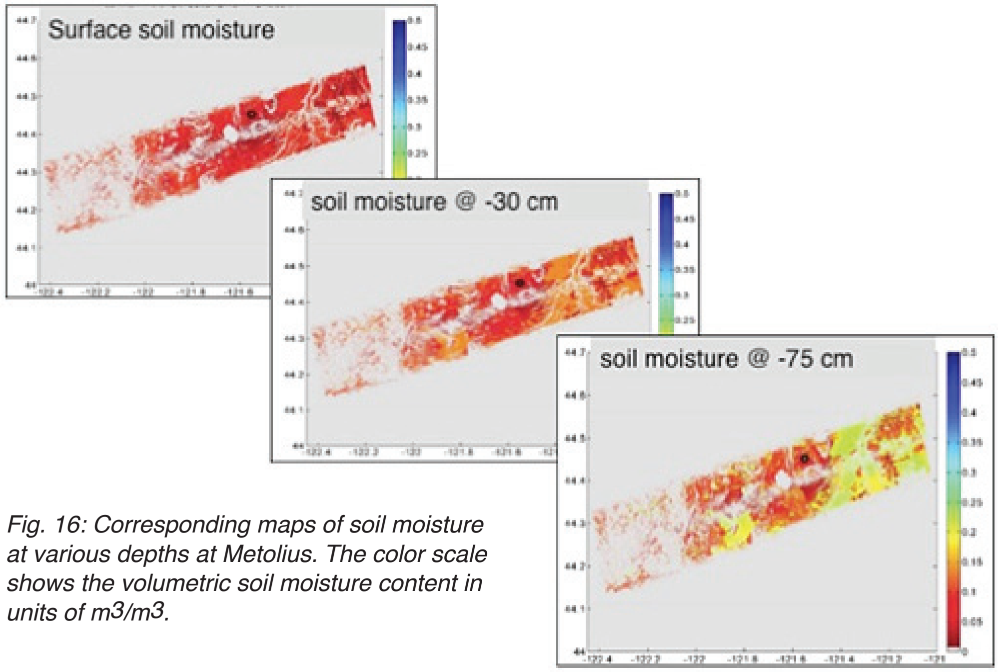


Fig. 16: Corresponding maps of soil moisture at various depths at Metolius. The color scale shows the volumetric soil moisture content in units of m3/m3.

AirMOSS, led by Mahta Moghaddam at University of Southern California, managed by Yunling Lou of JPL, and with flight operations based in JSC, is a multidisciplinary collaboration also involving the Massachusetts Institute of Technology, Harvard University, Purdue University, Oregon State University, NASA Goddard Space Flight Center, U.S. Department of Agriculture, and U.S. Geological Survey.

Airborne Tropical Tropopause Experiment (ATREX) - NASA/ARC

Water vapor in the stratosphere has a large impact on Earth's climate, the ozone layer and how much solar energy the Earth retains. To improve our understanding of the processes that control the flow of atmospheric gases into this region, ATTREX investigators have used the Global Hawk Unmanned Aircraft Systems (UAS) to study chemical and physical processes occurring in the tropical tropopause layer (TTL; ~14-19 km).

Science flights began on Feb. 13, 2014 from Andersen Air Force Base on Guam in the western Pacific region. Global Hawk was on a mission to track changes in the upper atmosphere and help researchers understand how these changes affect Earth's climate. The western Pacific region is critical for establishing the humidity of the air entering the stratosphere. ATTREX scientists installed 13 research instruments on NASA's Global

Hawk 872, also known as AV-6 (Air vehicle 6 is shown in Figure 17). Some of these instruments capture air samples while others use remote sensing to analyze clouds, temperature, water vapor, gases and solar radiation.

In 2014, ATTREX conducted seven long-duration science flights (Figure 18) totaling 121 hours, averaging more than 17 hours per flight. In order to acquire the needed measurements, the aircraft must fly vertical profiles, as shown in Figure 19. This year's flights bring the total hours flown in support of ATTREX to 297 hours since 2011. AV-6 returned to Armstrong Flight Research Center on March 14. ATTREX was coordinated with several other related missions, including NCAR's Convective Transport of Active Species in the Tropics (CONTRAST) and the UK-sponsored Coordinated Airborne Studies in the Tropics (CAST). In 2015, ATTREX will complete with a joint CAST mission out of Southern California. CAST is sponsored by the Natural Environment Research Council (NERC), the UK's leading public funder of environmental science.

The sampling strategy has primarily involved repeated ascents and descents through the depth of the TTL (about 13-19 km). Over 100 TTL profiles were obtained

Fig. 17: Global Hawk UAS AV-6 in Guam.

on each flight series. The ATTREX dataset includes TTL water vapor measurements with unprecedented accuracy, ice crystal size distributions and habits. The cloud and water measurements provide unique information about TTL cloud formation, the persistence of supersaturation with respect to ice, and dehydration. The plethora of tracers measured on the Global Hawk flights are providing unique information about TTL transport pathways and time scales. The meteorological measurements are revealing dynamical phenomena controlling the TTL thermal structure, and the radiation measurements are providing information about heating rates associated with TTL clouds and water vapor.

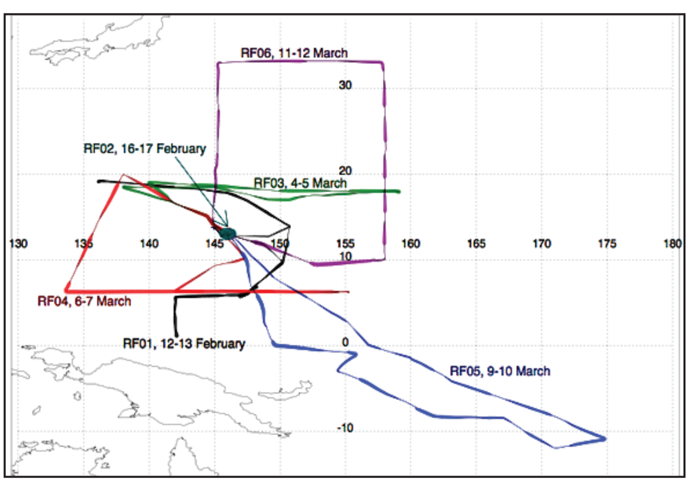


Fig. 18: ATTREX flights from Andersen AFB, Guam. Mission included six Guam local flights, 1.5 transits, 100 hours of TTL sampling, and 180 TTL vertical profiles..

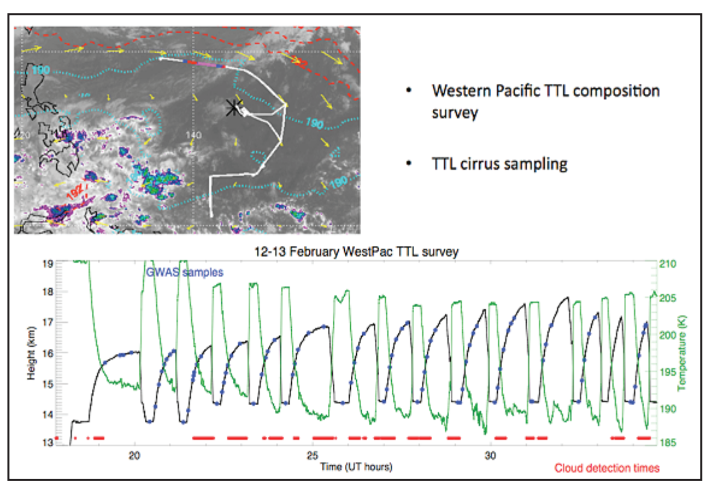


Fig. 19: ATTREX profiles.

Dr. Jensen and Project Manager Dave Jordan of Ames lead the ATTREX mission. It includes investigators from Ames and three other NASA facilities: Langley Research Center, Goddard Space Flight Center, and the Jet Propulsion Laboratory. The team also includes investigators from the National Oceanic and Atmospheric Administration, the National Center for Atmospheric Research, the University of California at Los Angeles, the University of Miami, the University of Heidelberg, and private industry.

Deriving Information on Surface Conditions from COlumn and VERtically Resolved Air Quality

DISCOVER-AQ recently completed its fourth and final deployment in a series of field studies to improve the interpretation of satellite observations to diagnose surface air quality. Conducted over Colorado's Northern Front Range/Denver Metropolitan Area in July and August 2014, this was the largest concentration of observations yet, as NASA's core DISCOVER-AQ team was joined by an impressive set of collaborators, in addition to longstanding partners from EPA and NOAA. Many of these collaborators were part of the Front Range Air Pollution and Photochemistry Experiment (FRAPPÉ) jointly sponsored by NCAR/NSF and the State of Colorado.

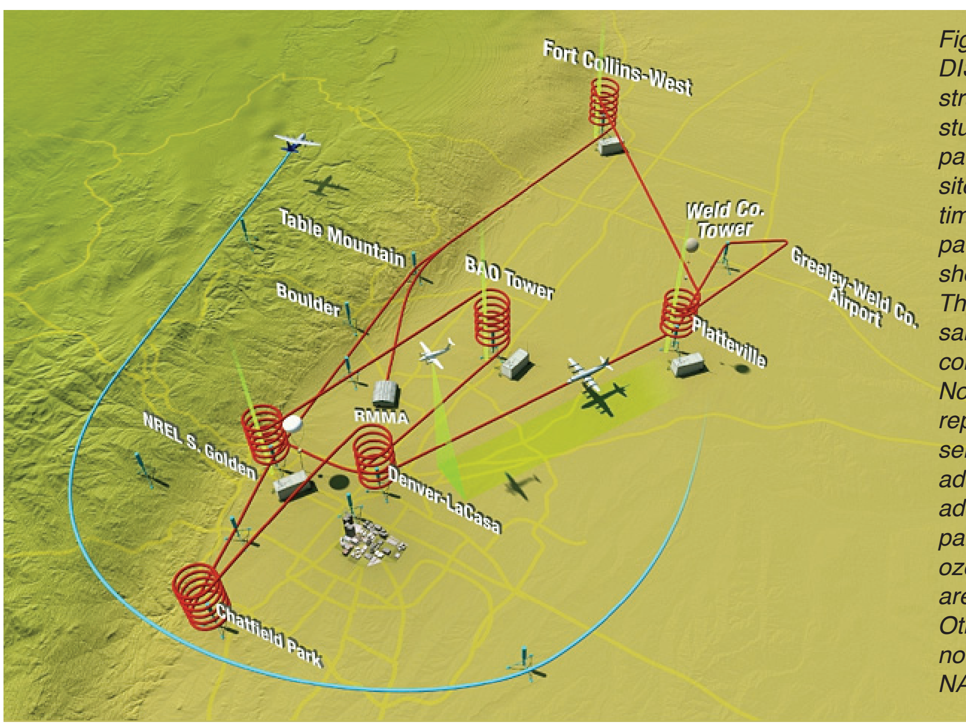


Fig. 20: This graphic depicts the DISCOVER-AQ/FRAPPÉ observing strategy employed during the Colorado study. The red line traces the P-3B flight path with recurring spirals over monitoring sites. This flight path is repeated three times on each flight day. The actual flight path for the higher flying King Air is not shown but closely follows that of the P-3B. The NSF C-130 shown over the mountains samples more freely and can explore conditions upwind and downwind of the Northern Front Range area. Tripod sensors represent locations of sun-tracking remote sensors. Trailers are shown at sites where additional in situ measurements were added to a monitoring location. Balloon pairs represent tethered balloon and ozonesonde operations. Lidar observations are shown as vertical traces in light green. Other activities, such as mobile labs are not represented. Image credit: Tim Marvel/ NASA

A total of four aircraft collected observations during joint flights over a network of surface sites across the region. NASA's P-3B from NASA Wallops Flight Facility and B-200 King Air from NASA Langley Research Center were the main platforms supporting DISCOVER-AQ. The P-3B provided in situ profiles of chemical species, aerosols and radiation over air quality ground monitoring sites and the B-200 provided remote sensing of gaseous and particulate pollution from high overhead.

The NCAR C-130 was fielded by the FRAPPÉ team to serve as a second in situ aircraft to map pollutant emission sources and chemistry and to sample more freely upwind and downwind of the DISCOVER-AQ study region. The overlap in payloads for the two in situ aircraft required one of the research flights to include a formation flight to compare the measurements on both aircraft. A second remote sensing aircraft, the NASA Langley HU-25C Falcon, was sponsored by NASA's GEO-CAPE science team. This plane joined the B-200 flying high overhead with GeoTASO onboard, a UV-spectrometer instrument developed at Ball Aerospace to demonstrate the technology that will be used in future geostationary satellite observations of air quality.

Beneath these four aircraft, the ground network was also populated with an unprecedented array of observations to augment the local air quality network maintained by the Colorado Department of Public Health and Environment. This included 10 lidars (measuring ozone, aerosols, and winds), 16 Pandora spectrometers for remote sensing of trace gases, 20 AERONET sunphotometers for aerosol remote sensing, 4 in situ trailers, 6 mobile labs, 2 tethered balloon operations, and instrumentation on a 300 meter tower at NOAA's Boulder Atmospheric Observatory. During the campaign, two flight days documented conditions for ozone that exceeded federal air quality standards. On many other days, ozone production was interrupted by afternoon storms, avoiding the potential for additional violations. Clearly identifiable chemical signatures associated with urban emissions, oil and gas exploration, and feedlot operations across the area will provide critical information on the contribution of these sources to local air quality conditions. More information on all of the DISCOVER-AQ deployments can be found on the project website at: http://discover-aq.larc.nasa.gov/

SABOR

A major collaboration of air and sea measurements took place this summer (July-August) in the Ship-Aircraft Bio-Optical Research (SABOR) mission. With funding provided by NASA's Ocean Biology and Biogeochemistry Program, the SABOR experiment brought together marine and atmospheric scientists to tackle the optical issues associated with satellite observations of phytoplankton. Flying on the NASA Langley UC-12B, the payload consisted of NASA Langley's High Spectral Resolution Lidar Version 1.1 (HSRL 1.1) and the Research Scanning Polarimeter (RSP) from the NASA Goddard Institute for Space Studies (GISS), with the goal of monitoring microscopic plants that form the base of the marine food chain.

The National Science Foundation's Research Vessel "Endeavor", operated by the University of Rhode Island, was the floating laboratory that scientists used for the ocean-going portion of the SABOR field campaign. Scientists on the "Endeavor" studied ocean ecosystems from the Gulf of Maine to the Bahamas.

The airborne portion of the campaign consisted of a total of 30 flights, constituting 92.5 flight hours. The research flights were conducted from Pease Air Force Base (Portsmouth, NH), Bermuda, and NASA Langley. Flight operations from the Research Services Directorate at LaRC were able to support the mission with multiple flights per day and multiple days in a row.

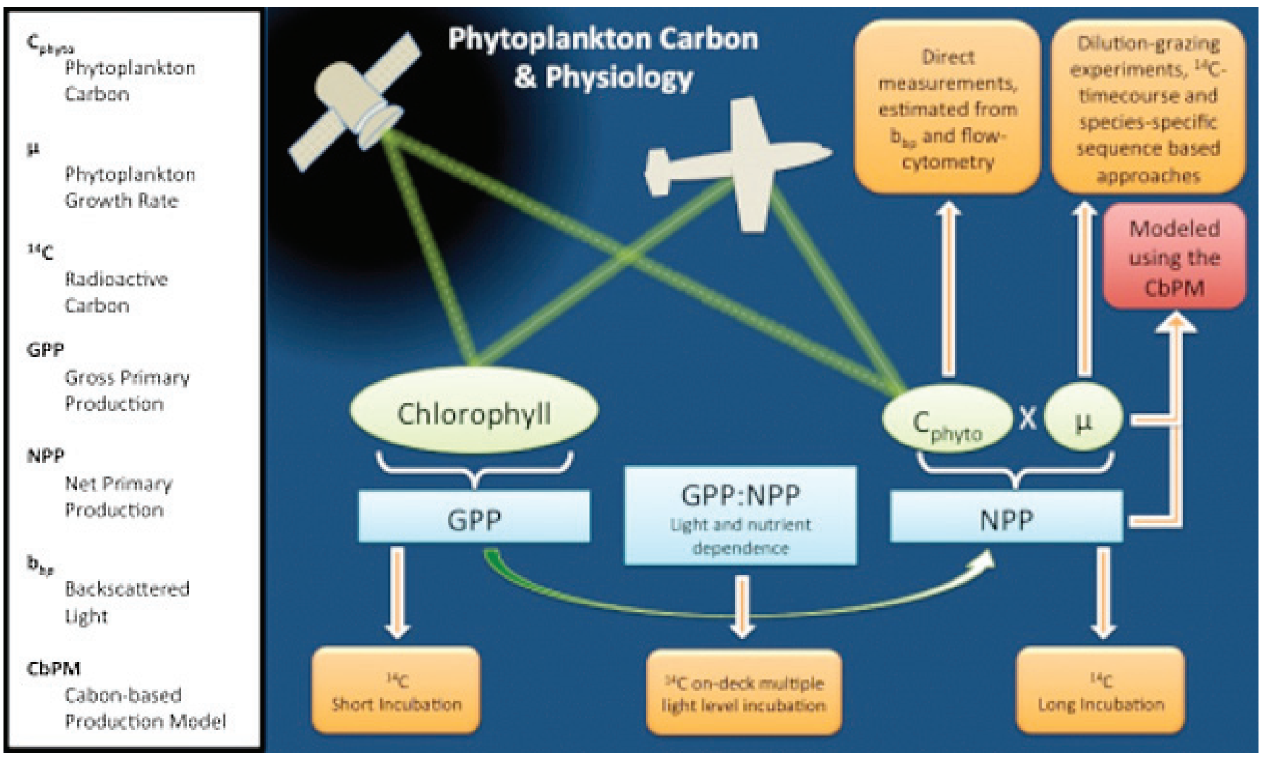


Fig. 21: SABOR Experiment concept showing the use of the UC-12B aircraft.

UAVSAR

The JPL UAVSAR, flying on NASA's C20-A, accounted for nearly 400 hours of science flight time in 2014.

UAVSAR is a reconfigurable, polarimetric L-band synthetic aperture radar (SAR), specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. Most of the work in 2014 is immediately relevant to terrestrial ecology, vegetation interests, soil moisture, and vulcanology, in addition to Earth Surface and Interior interests in land movements and faults. In addition, much of the work of the UAVSAR is supportive of the upcoming NASA-ISRO SAR (NISAR) mission.

Many of the missions were flown from the home base of the C20-A at the Palmdale Aircraft Operations Facility, but there were also several deployments to other bases and international facilities, as shown in Table 5.

Location	Science	Flight Hours
Hawaii / Japan	Volcano studies	53.7
New Orleans	Gulf coast studies	18.0
South America	Vegetation and Volcano studies	80.2
Iceland	Ice studies	46.6
Mexico	Land movement	25.2

Table 5: Major UAVSAR Deployments in 2014.

JPL's UAVSAR, flying on NASA Armstrong C-20A, surveyed fault displacements in the area of the August 24, 2014 Napa Valley earthquake. UAVSAR flew a five-hour data collection mission on August 29th. Collecting data shortly after the earthquake will be valuable to scientists as they compare with earlier, pre-earthquake data from the same area.

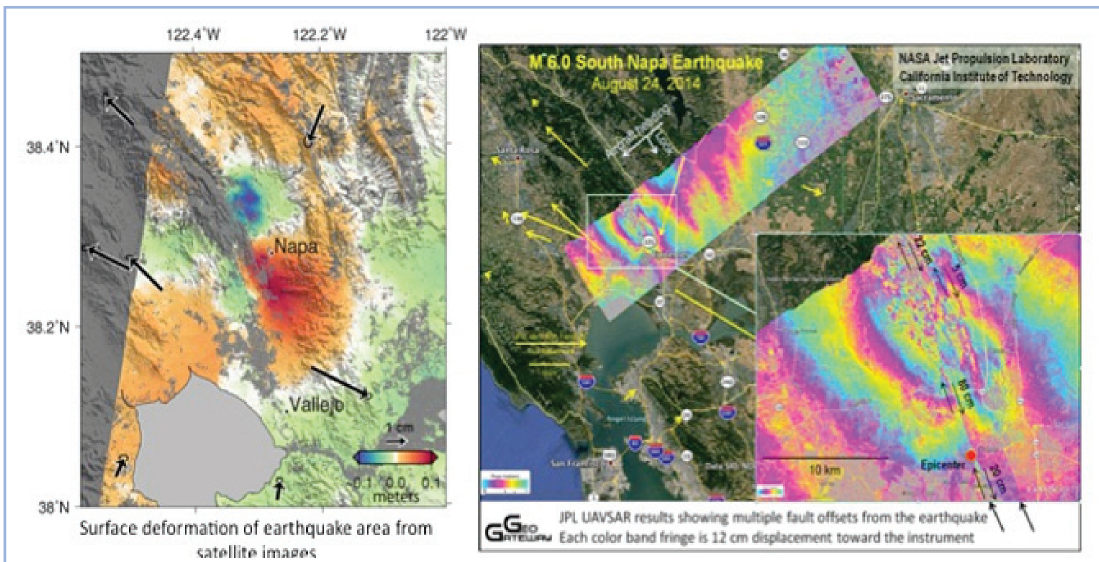


Fig. 22: Napa Earthquake region.

Support to ESD Satellite Missions, including Decadal Survey Missions

A primary purpose of the Airborne Science Program is to support Earth Science satellite missions. This support includes airborne campaigns to collect data for algorithm development prior to launch, to test instrument concepts for satellite payloads or airborne simulators, and to provide data for calibration or validation of satellite algorithms, measurements or observations once in orbit. In 2014, ASP provided support to Earth Science missions as listed in Table 6. This included significant flight hours for upcoming Decadal Survey missions.

Satellite	Campaign or Instrument	Flight Hours
ICESat-2	IceBridge, ARISE	705.8
ICESat-2	MABEL, Alaska	74.5
SMAP	UAVSAR, SLAP, AirMOSS	456.5
NISAR	UAVSAR missions	314.9
Landsat 8	G-LiHT, HyspIRI airborne	208.1
GPM	IPHEX Mission	175.8
GEO-CAPE	GEO-TASO, DISCOVER-AQ	157.0
OCO-2	CARVE, COMEX, AJAX, TCCON	141.2
CALIPSO	SABOR mission, HSRL cal/val	130.1
HyspIRI	HyspIRI Prep; AVIRIS & MASTER	129.1
ASCENDS	ASCENDS Accelerator, CarbonHawk	63.9
ACE / PACE	PRISM, EXRAD, AirMSPI testing	48.4
SWOT	AirSWOT, HAMMR	39.1
Suomi NPP	SNPP cal/val	4.6

Table 6: Support to ESD Satellite Missions, including Decadal Survey Missions

Integrated Precipitation and Hydrology Experiment (IPHEX)

The NASA Global Precipitation Measurement (GPM) Mission Integrated Precipitation and Hydrology Experiment (IPHEx) took place in the Appalachian Mountains of southwestern North Carolina from May 1 – June 15, 2014. Flight region is shown in Figure 23. GPM IPHEx partners included Duke University and the NOAA Hydrometeorological Testbed. Overarching campaign objectives included the improvement of satellite-based remote sensing algorithms of clouds and precipitation over mountainous terrain, and evaluation and further development of associated data products for use in hydrologic applications such as flood prediction.

To achieve these objectives an extensive set of airborne and ground-based instruments were deployed and operated under occasional overpasses of GPM constellation satellite platforms. Participating aircraft included the NASA ER-2 and University of North Dakota Citation. At high altitude, the ER-2 served as a "proxy" satellite platform carrying the AMPR and CoSMIR radiometers spanning frequencies from 10-183 GHz, and the CRS, HIWRAP, and EXRAD radars covering the W, Ka, Ku, and X bands. Indeed, IPHEx was the first NASA field effort to ever deploy and operate four cloud and precipitation radar frequencies from the same high-altitude airplane. The University of North Dakota Citation aircraft carried a suite of in situ cloud microphysics probes to sample cloud and precipitation processes within the field of view of ER-2 and ground-based instruments.

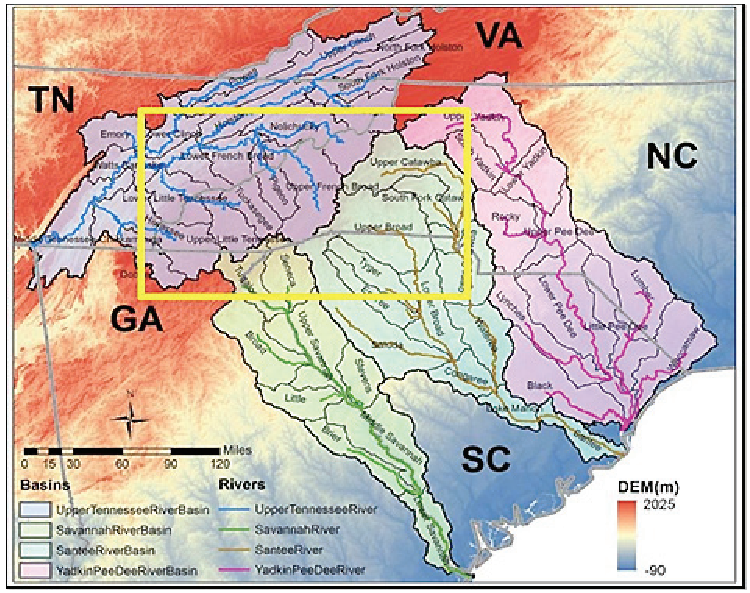


Fig. 23. Extended IPHEx domain showing the river basins under study. In clockwise direction: Upper Tennessee (purple, 56,573 km2), Yadkin-Peedee (pink, 46,310 km2), Catwaba-Santee (blue, 39,862 km2), and Savannah (green, 27,110 km2). The yellow rectangle denotes the Core Observing Area where ground validation efforts concentrated from May 1 to June 15, 2014.

At the ground, an extensive array of NASA and NOAA multi-parameter radars (NASA/WFF NPOL and D3R radars, NOAA NOXP radar), disdrometers, rain and stream gauge networks were deployed and operated on a 24/7 basis to complete observations of precipitation formation and movement through the coupled atmosphere-hydrologic system. IPHEx scientists successfully collected 113 hours of ER-2 and 78 hours of Citation airborne data and six full weeks of ground-based science data over a wide variety of storm types ranging from heavy raining mountain cloud systems that produced strong hydrologic response, severe hail storms, to smaller and more lightly raining maritime clouds. Collectively the IPHEx observations will provide a comprehensive view of orographic precipitation processes, what those processes actually "look like" as viewed from GPM spaceborne instrumentation, and subsequently how to better estimate precipitation rates over complex terrain.

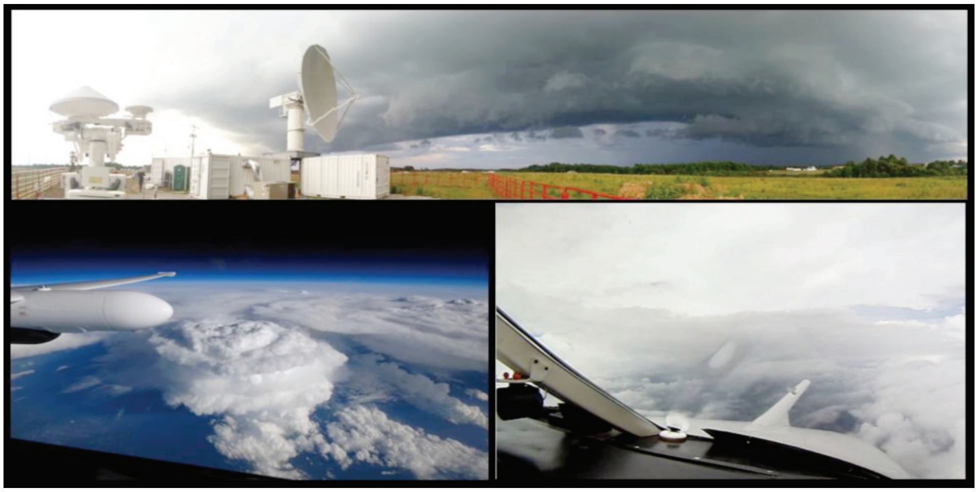


Fig. 24: (Top) NASA NPOL and D3R radars move to sample a strong storm. (Bottom left) ER-2 view of a severe storm sampled during a GPM overpass. (Bottom right) UND Citation penetrating complex strtiform cloud and precipitation layers.

HyspIRI Preparatory Airborne Studies

In 2013-2014, to support the development of the HyspIRI mission and to prepare the community for HyspIRI-enabled science and applications research, NASA is flying the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER Airborne Simulator (MASTER) instruments on the NASA high-altitude ER-2 aircraft to collect data sets for precursor science and applications research and to test the processing pipeline. The flights cover six large areas in California spanning a range of diverse environmental zones that capture significant climatic and ecological gradients. (See Figure 25.) The airborne data collection campaigns cover the designated areas at three separate seasons over two years in order to capture data from multiple seasons. The areas selected are of sufficient size to simulate HyspIRI data sets while also providing opportunities for a broad array of science and applications research relevant to this mission and

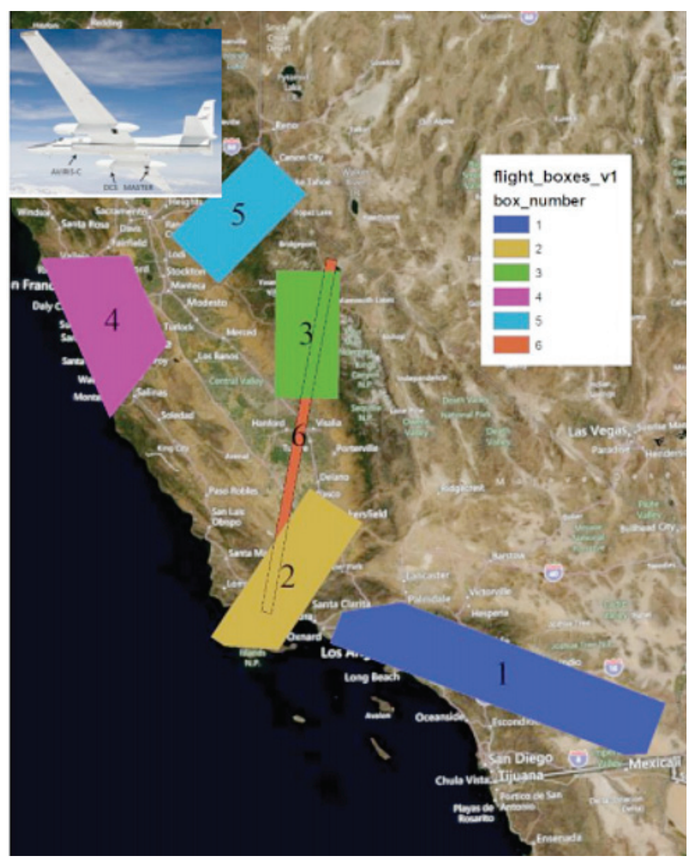


Fig. 25: Map of HyuspIRI Preparatory Airborne Study Flight Boxes in California and Nevada.

NASA's Earth Science program. Fourteen PI teams have been participating in the HyspIRI preparatory mission since 2013.

In 2014, the ER-2 flew a total of 135 flight hours with AVIRIS and MASTER to collect data over the HyspIRI study areas. Flights were conducted during three seasons. Several flight days included additional activities:

- flying Landsat lines in coordination with
- flying in coordination with the AVIRIS-ng on the Twin Otter for comparative measurements
- flying jointly with COMEX

MABEL Alaska 2014 Campaign

(July 10-Aug 1, 2014)

The Multi Altimeter Beam Experimental Lidar (MABEL) is a photon-counting lidar system employing up to 16 individual beams at 532nm and up to 8 individual beams at 1064nm to provide signal returns from several spots on the ground simultaneously. MABEL was designed to produce data similar in nature to that to be obtained by the ATLAS altimeter for the ICESat-2 mission (launch in 2017). The elevation data from MABEL is being used by the ICESat-2 science definition team to understand unique phenomena associated with photon-counting lidar data for mission-specific targets including sea ice, glaciers, snow fields, and vegetation canopies.

In July of 2014 MABEL collected approximately 70 hours of data from NASA's ER-2 high altitude aircraft over targets in Alaska and the Arctic Ocean from Alaska to the North Pole. Based near Fairbanks AK, MABEL was able to reach targets including sea ice near the North Pole, glaciers near Juneau AK, the Bagley Ice Fields and several G-LiHT lines flown nearby as part of a separate vegetation mission. Data collected

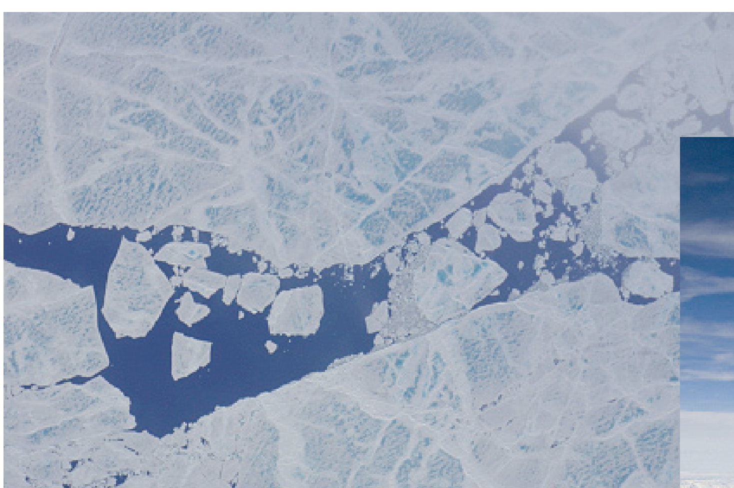


Fig. 26: Broken sea ice observed during MABEL flight

Fig. 27: In summer 2014, MABEL flew above Alaska and the Arctic Ocean on one of NASA's ER-2 high altitude aircraft.

will enable the ICESat-2 team to better develop their algorithms by including any potential unique effects from photon counting found in partially melted ice and snow targets, melt ponds, etc. Along with MABEL, supporting instruments providing information on the local atmospheric effects were flown: the Cloud Physics Lidar (CPL) and the Cloud Aerosol Transport System (CATS).

Figure 26 shows a region of broken sea ice very near the North Pole taken from an imaging CCD camera added to MABEL and used for the first time on this mission.

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 or UAS utilization, while many are developed as precursors or simulators for satellite instruments.

In 2014, ASP aircraft flew all of the instruments listed in Table 7. Many of these instruments have been developed under sponsorship of NASA's Earth Science Technology Office (ESTO).

Instrument	Sponsor	Aircraft	Flight Hours
CO2 sounder	ESTO	DC-8	43.6
UAVSAR	ESTO	Global Hawk	26.8
2-micron IPDA Lidar	ESTO	B-200	24.9
CarbonHawk	ESTO	HU-25C	20.3
HAMMR	ESTO	Twin Otter	14.2
EXRAD	ESTO	ER-2	5.9
Intelligent Payload Monitor	ESTO	Hellicopter	2.8
AVIRIS-ng	TE	Twin Otter	38.0
PRISM	OBB	Twin Otter	71.4
HyTES	R&A	Twin Otter	48.2
SLAP	Entin	UC-12B	43.1
eMAS, SHIS	EOS	ER-2	6.0
HDSS	NRL	WB-57	12.8
OCS-ICOS	ARC	WB-57	5.1
Ice Penetrating Radar	Planetary Science	BT-67	13.6
TOTAL			**376.7**

Table 7: ASP Support to Instrument Development

ASCENDS

The 2014 ASCENDS airborne campaign utilized the NASA DC-8 based out of Palmdale, CA. The campaign started on August 8 and completed successfully on September 3rd. The five science flights measured column CO2 absorption and range from the aircraft to ground with three different lidar candidates for the ASCENDS mission. Flights have successfully measured column CO2 over forests in California, around an urban area, and over various vegetation cover types in Iowa at both dusk and dawn. The lidar approach allows measurements under these conditions that are difficult for passive sensors. Two flights targeted under flights of the OCO-2 satellite, one in north western Nevada, and the other in the central valley of California. These will allow inter-comparisons once the respective data sets are processed. Participants in the campaign include the AVOCET team and MFFL lidar team from LaRC, the CO2 Sounder team from GSFC, and the LAS lidar team from JPL

Fig. 28 – (Left) Graham Allan supporting ground testing of the lidar. (Right) Wallace Harrison (rear), and Bill Hasselbrack and Stewart Wu operating the CO2 Sounder lidar on the DC-8.

Geostationary Trace gas and Aerosol Sensor Optimiztion (GEO-TASO) instrument

The ESTO-funded Geo-TASO airborne sensor (Figure 29) is an airborne spectrometer flying on the NASA Langley Research Center HU-25C Falcon. The sensor system advances retrieval algorithm development and mission readiness for the upcoming TEMPO and GEMS air quality measurement space missions. GeoTASO stands for Geostationary Trace gas and Aerosol Sensor Optimization. Its main objective is to assess and improve the performance of the full sensor-algorithm system. The UV-Visible multi-order spectrometer gives high spectral and spatial resolution measurements that feed both trace gas and aerosol retrieval algorithms to test algorithm performance with real-world scene data. Flying on the

Falcon at 32 kft provides a space-like vantage point of the atmosphere's boundary layer where the air quality measurements are needed. Figure 30 shows the sensor on the Falcon.

Fig. 29: GEO-TASO on the HU-25C.

CarbonHawk

Another instrument, the ASCENDS CarbonHawk Experiment Simulator (ACES), is an intensity-modulated continuous-wave lidar system recently developed at NASA Langley Research Center (LaRC) that seeks to advance technologies and techniques critical to measuring atmospheric column CO2 mixing ratios.

Fig. 30: ASCENDS Carbon Hawk Experiment on the HU-25C.

Full instrument development concluded in the spring of 2014 after 3.5 years of effort funded by LaRC and NASA's Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP). Following ground tests of the instrument, ACES successfully completed its first test flights in July 2014, flying six times (17.4 hours) with the NASA Langley HU-25C Falcon as the sampling platform. (Figure 30) The research flights were conducted from the LaRC Flight Research Hangar and recorded data at multiple altitudes over land and ocean surfaces with and without intervening clouds, which are all important situations to understand for future space-based measurements. Measurements of CO2 were simultaneously gathered in situ on the aircraft to validate the ACES measurements.

Upcoming Activities

In FY15 three Earth Venture-1 missions will complete the airborne portions of their programs. These include ATTREX, AirMOSS and CARVE. The final ATTREX campaign will be joint with the UK Natural Environment Research Council. In 2015, Operation IceBridge continues in the Arctic with the C-130, while the DC-8 returns to Antarctica. The five new Earth Venture Suborbital (EVS-2) projects will begin their 5-year programs in late 2015 (Figure 31).

Fig. 31: Map of new EVS-2 mission locations

Aircraft

NASA maintains a fleet of aircraft for scientific activities, primarily for Earth Science. 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 8. The altitude / endurance characteristics are also shown in Figure 32.

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-DFRC	12	30,000	340,000	41,000	450	5,400	http://airbornescience.nasa.gov/aircraft/DC-8
	ER-2	NASA-DFRC	12	2,900	40,000	>70,000	410	>5,000	http://airbornescience.nasa.gov/aircraft/ER-2
	Gulfstream III (G-III) (C-20A)	NASA-DFRC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Dryden
	Gulfstream III (G-III)	NASA-JSC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_-_JSC
	Global Hawk	NASA-DFRC	30	1900	25,600	65,000	345	11,000	http://airbornescience.nasa.gov/aircraft/Global_Hawk
	P-3B	NASA-WFF	14	14,700	135,000	32,000	400	3,800	http://airbornescience.nasa.gov/aircraft/P-3_Orion
Other NASA Aircraft	B-200 (UC-12B)	NASA-LARC	6.2	4,100	13,500	31,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_UC-12B_-_LARC
	B-200	NASA-DFRC	6	1,850	12,500	30,000	272	1,490	http://airbornescience.nasa.gov/aircraft/B-200_-_DFRC
	B-200	NASA-ARC/DOE	6.75	2,000	14,000	32,000	250	1,883	http://airbornescience.nasa.gov/aircraft/B-200_-_DOE
	B-200	NASA-LARC	6.2	4,100	13,500	35,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	C-23 Sherpa	NASA-WFF	6	7,000	27,100	20,000	190	1,000	http://airbornescience.nasa.gov/aircraft/C-23_Sherpa
	Cessna 206H	NASA-LARC	5.7	1,175	3,600	15,700	150	700	http://airbornescience.nasa.gov/aircraft/Cessna_206H
	Dragon Eye	NASA-ARC	1	1	6	500+	34	3	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	HU-25C Falcon	NASA-LARC	5	3,000	32,000	42,000	430	1,900	http://airbornescience.nasa.gov/aircraft/HU-25C_Falcon
	Ikhana	NASA-DFRC	24	2,000	10,000	40,000	171	3,500	http://airbornescience.nasa.gov/aircraft/Ikhana
	Learjet 25	NASA-GRC	3	3,200	1,500	45,000	350	1,200	http://airbornescience.nasa.gov/aircraft/Learjet_25
	S-3B Viking	NASA/GRC	6	12,000	52,500	40,000	450	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	500	4,400	25,000	75	700	http://airbornescience.nasa.gov/aircraft/T-34C
	Twin Otter	NASA-GRC	3	3,600	11,000	25,000	140	450	http://airbornescience.nasa.gov/aircraft/Twin_Otter_-_GRC
	WB-57	NASA-JSC	6	6,000	63,000	60,000+	410	2,500	http://airbornescience.nasa.gov/aircraft/WB-57

Table 8: Airborne Science Program aircraft and their performance capabilities

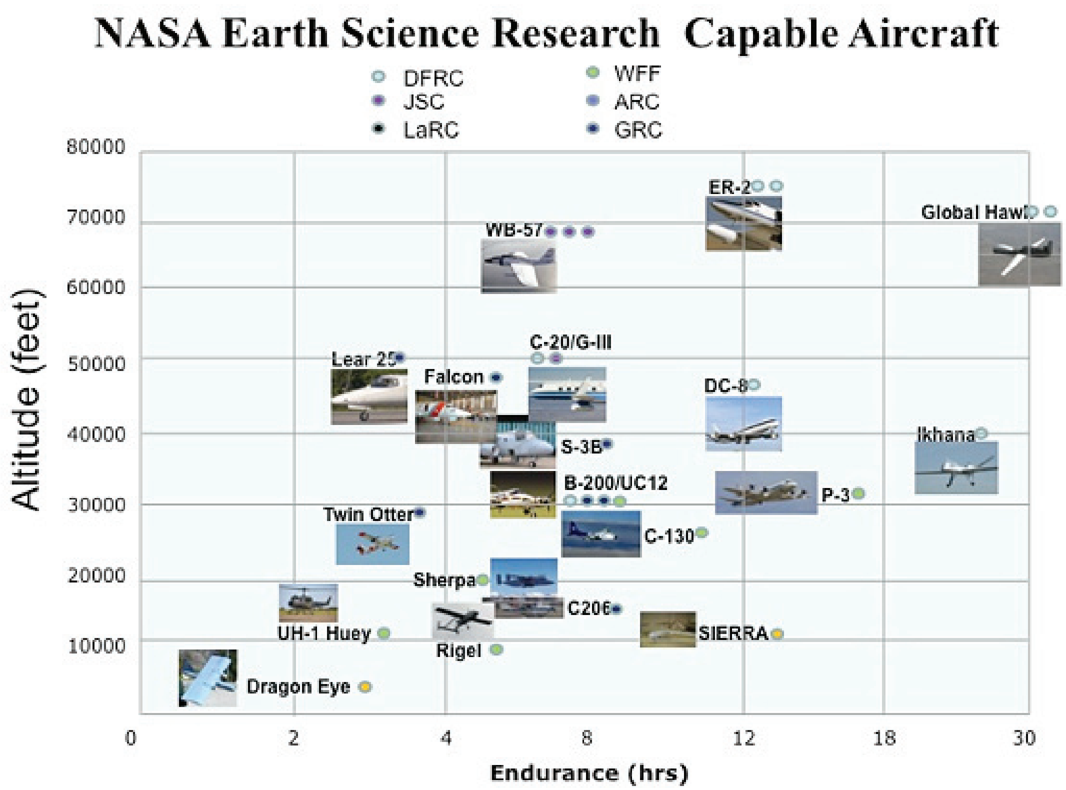


Fig. 32: Flight characteristics of NASA aircraft

ASP-Supported Aircraft

The six aircraft 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, JSC G-III, and (2) Global Hawk unmanned aircraft systems (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: 60.7

Fig. 33: Stewart Wu (GSFC) stands watch during ground-based laser testing outside hangar 703 of NASA Armstrong's Science Aircraft and Integration Facility in Palmdale, CA. The laser beam in emitted nadir from the DC-8 aircraft and is redirected by the circular mirror atop the blue box. These tests ensure alignment of the transmit beam and receiver optics before the rigors of flight.

Mission	Location	Flight Hours
SARP	California	Training
ASCENDS accelerator	California	Atmospheric Composition and Chemistry

DC-8 FY14 missions

Significant upcoming maintenance periods:
Due to the incorporation of the new Low Utilization Maintenance Program (LUMP), there are no long-term maintenance periods planned for this aircraft. All planned maintenance will be accomplished around science activities keeping the aircraft highly available to science.

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

Modifications made in FY14 and impacts on performance and science:

Modification	Impact
Iridium multi-channel modems upgrade.	Better reliability in providing science satellite communications capability.
Data servers update	Better reliability and capacity upgrade to servers for science data handling
Upgrades to cabin ethernet switches	Better reliability for science data handling
Updated cabin emergency escape lighting	Meets escape lighting standards at far less cost than maintaining original system and with higher system reliability
Established Low Utilization Maintenance Program (LUMP)	Incorporated into Heavy Check that provides more efficient process for maintaining the DC-8 based on how it is utilized. Reduces overall maintenance costs and makes the aircraft more available to support science operations.
Landing gear wheels antiskid valves upgrade.	Enhances flight operations safety, maintainability, and reliability.

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: 360.3

Fig. 34: The ER-2 crew rolls the aircraft's nose, containing MABEL, away from its body, so engineers can work on the instrument. (Credit: Kate Ramsayer, NASA)

Modifications made in FY14 and impacts on performance and science:
Inmarsat satellite communication systems became operational on both aircraft in FY14. This provides higher-bandwidth downlink and uplink capability for the science teams.

Significant upcoming maintenance periods:
A cabin altitude reduction effort will be performed on NASA #806 during August 2015 through April 2016. A similar cabin altitude reduction effort will be performed on NASA #809 from May 2016 through January 2017. Only one platform will be available during the consecutive period from August 2015 through January 2017.

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

Mission	Location	Science program area
IPHEX	Georgia	Weather
ACOCO	California	Water and Energy
HyspIRI prep	California	Terrestrial Ecology
AVIRIS Cal	California	Carbon Cycle
eMAS	California	EOS
RADEX-14	California	Radiation Science Program
MABEL	Alaska	Cryosphere
Landsat 8	California	Terrestrial Ecology
Ocean Aerosol	California	Radiation Science Program

ER-2 FY14 missions

P-3 Orion

Operating center: Goddard Space Flight Center's Wallops Flight Facility (WFF)

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

Science flight hours: 610.2

Fig. 35: NASA P-3B as viewed from the cockpit of the NCAR C-130 during a joint flight to compare observations. (Credit: Patrick J. Reddy)

Mission	Location	Science program area
Operation IceBridge: Antarctica	McMurdo Station, Antarctica	Cryosphere
Operation IceBridge: Arctic	Thule and Kangarlussuaq, Greenland	Cryosphere
DISCOVER-AQ	Colorado	Atmospheric Composition and Chemistry

P-3FY14 missions

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 August 2015 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 and other maintenance until April 2016.

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

G-III Class Aircraft

Operating centers: C20-A Armstrong Flight Research Center, G-III 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 various versions of JPL's UAVSAR instrument.

Science flight hours: C20-A: 397.2; JSC G-II: 369.2

Fig. 36: G-III carrying SAR pod

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
AirMOSS	AZ, CA, OK, OR, ME, MA, NC, Canada, Mexico, Costa Rica	Water and Energy Cycle
AirMOSS Alaska Permafrost	Alaska	Water and Energy Cycle

G-III FY14 missions

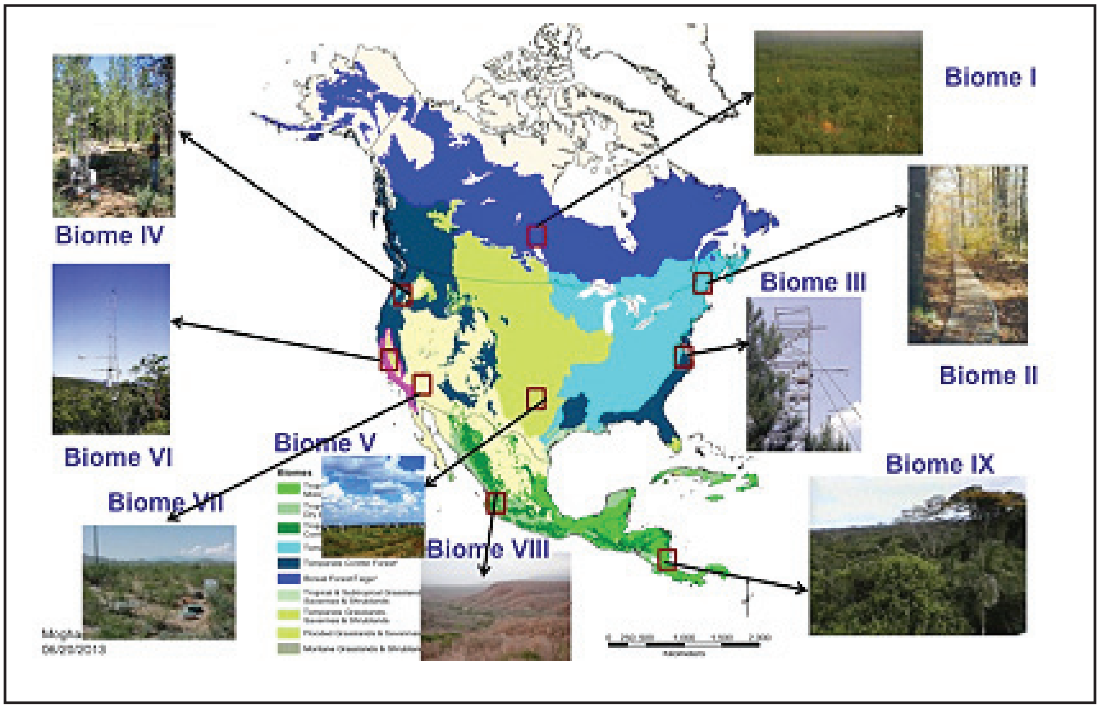


Fig. 37: Regions of North and Central America flown by G-III for AirMOSS

Modifications made in FY14 and impacts on performance and science: None

Significant upcoming maintenance periods:
In addition to routine maintenance in 2015, the C20-A will be down from July 7 – August 31, 2015 to replace engines and to perform a cockpit upgrade.

The JSC aircraft is in Maintenance from November 2014 through January 2015. Both engines completed engine calendar extension in 2014. Engine husk kit installation will be complete by Jan 2015, which will reduce engine noise and allow greater operational flexibility.

Websites: http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Armstrong
https://airbornescience.nasa.gov/aircraft/G-III_-_JSC

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 two Global Hawks can be operated from either AFRC or WFF.

Science flight hours: 444.7

Significant upcoming maintenance periods: None in FY15

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

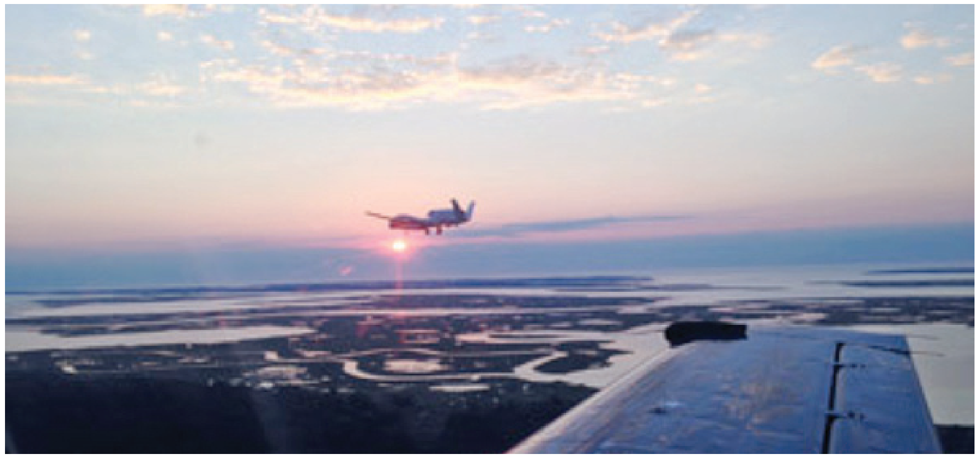


Fig. 38: NASA Global Hawk 872 lands at WFF just after sunrise on September 29 during HS3, as viewed from the T-34 chase aircraft (Credit: NASA)

Mission	Location	Science program area
UAVSAR	California	ESTO
ATTREX	Guam	Atmospheric Composition and Chemistry; Atmospheric Dynamics
HS3	WFF	Weather

Global Hawk FY14 missions

Modification	Impact
Wing rack installation	Provides ability to support external wing-mounted instruments
Low resolution camera upgrades	Improved picture quality
High definition daylight camera Installation	Provides real-time views of weather phenomena to adjust flight paths

Modifications made in FY14 and impacts on performance and science:

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
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

Table 9: Other NASA Earth Science Aircraft

C-130 Class Aircraft

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. One has been extensively modified to support airborne science-related activities. The second is currently being modified to support future airborne science research needs. A third C-130 may be brought up in 2015.

Science flight hours: 231

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

C-130 FY14 missions

Fig. 39: ARISE Team with C-130

Modifications made in FY14 and impacts on performance and science:
FY14 marked the first science mission flights for the NASA C-130. The existing 55” diameter nadir port was divided into two 16” diameter and two 8” diameter nadir ports to support multiple science instruments simultaneously. Two zenith ports were created in the flight station. Portable GPS units were added to the flight station to allow for precision flight lines to be flown by the pilots. An Airborne Science Program data system, cabin interphone, and Iridium phone were added to provide flight data and improve internal and external communications for the experimenters. Cargo pallets were modified to support instrument racks and seats to allow for quick installation and removal of science equipment from the cabin. A lavatory and galley pallet was also manufactured to improve in-flight comfort. The experimenter power load center was modified to increase power output to each of the experimenter stations.

Significant upcoming maintenance periods:
NASA#426 begins modifications January 2015

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

B-200 Class Aircraft

Operating centers: Langley Research Center, Armstrong Flight Research Center

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.

NASA Langley Research Center operates both a conventional B-200 and a UC-12 (military version). Both have been extensively modified for remote sensing

Fig. 40: (Left) LaRC UC-12 during SABOR; (Right) AFRC B-200 flying AirSWOT

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.

Science flight hours: 352.4

Modifications made in FY14 and impacts on performance and science:
The LaRC UC-12B received upgraded ship's starter generators from 250 A to 300 A, thereby increasing research power capacity by a factor of two, from 4200 to 8400 W @28 VDC. The aircraft is not presently wired to harness all that power, but will be when additional contactors, fuses and wiring are added. This upgrade doubles the amount of research power available.

Mission	Location	Science program area
AirSWOT	California	Water and energy; Ocean science
SABOR	LaRC; Bermuda; Portsmouth, NH	Ocean Biology and Biochemistry
SLAP	LaRC	Water and energy
G-LiHT and HyPlant	LaRC	Technology
CALIPSO Cal/Val	LaRC and Bermuda	Atmospheric Composition and Chemistry
2-micron IPDA Lidar	LaRC	ESTO
DISCOVER-AQ	Colorado	Radiation Science Program

B-200 FY14 missions

Fig. 41: On the UC-12B during SABOR

Significant upcoming maintenance periods:
The AFRC B-200 will be in phase maintenance from November 25, 2014 through February 25, 2015. The ship's starter generators on the LaRC B-200 aircraft will be upgraded to match the corresponding upgrades on the UC-12B aircraft on a non-interference basis (sometime in FY15).

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: 316

Mission	Locartion	Science program
CARVE	Alaska, Canada	Climate change

Sherpa FY14 missions

Modifications made in FY14 and impacts on performance and science: None

Significant upcoming maintenance periods: None

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

Fig. 42: Sherpa heading out for CARVE mission

HU-25C Falcon / Guardian

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: 70.2

Fig. 43: HU-25C engaged in both Discover-AQ and ACES in 2014

Mission	Locartion	Science program
ASCENDS CarbonHawk Experiment Simulator (ACES)	LaRC	ESTO
GEO-TASO with DISCOVER-AQ	Colorado	ESTO

HU-25C FY14 missions

Modifications made in FY14 and impacts on performance and science:
Installed data and power wiring to left wing pylon station. This allows atmospheric probes to be flown on both under-wing pylons.

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: Johnson Space Center

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

Fig. 44: WB-57 in Florida for HS3 / HDSS mission

Science flight hours: 46.1

Mission	Locartion	Science program
HDSS / Tropical Cyclone Intensity Program	TX	Weather
Propulsive Decelerator Technologies Project	FL	Technology
HS3	TX	Weather
OCS-1COS	TX	Atmospheric Chemistry
Cosmic Dust	TX	Technology

WB-57 FY14 missions

Modifications made in FY14 and impacts on performance and science:
The WB-57 fleet completed upgrade to ACES II ejection seats this year, enhancing safety, reliability, sustainability, and crew comfort over the legacy ESCAPAC ejection seats. FY14 also saw new canopies for all three aircraft, and flight testing of a new digital autopilot conducted on NASA 927. Once testing is complete in early FY15, the other two aircraft will be retrofitted with the new digital autopilot. This will make a significant improvement to reliability and sustainability, as the legacy MC-1 autopilot is the most common maintenance/logistics issue with the aircraft. Similarly, a new communications system was tested on NASA 927 this year and will be retrofitted to the other two aircraft in FY15, enhancing communications quality and system sustainability. Additional plans for the fleet in FY15 include a re-engining study to enhance aircraft performance and fuel economy, a complete upgrade to the SEO suite in the rear cockpit, new standardized pallet bay rails, and a new navigation data system.

Significant upcoming maintenance periods:
NASA 926 due for 12-week Major Inspection beginning in March 2015.

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

The NASA ASP Small Unmanned Systems Projects

Small and Medium Class UAVs are flown by Ames Research Center with an overarching goal of demonstrating and exploiting small-scale, sometimes expendable aircraft for science. In FY2014 Ames continued activities with several UAVs in support of NASA science.

SIERRA UAS

The Sensor Integrated Environmental Remote Research Aircraft (SIERRA) is a medium-class, unmanned aircraft system (UAS) that can perform remote sensing and atmospheric sampling missions in isolated and often inaccessible regions, such as over mountain ranges, the open ocean, or the Arctic/Antarctic.

A new SIERRA-B (Scientific Instrumentation Evaluation Remote Research Aircraft-B) is under development with the final assembly almost completed by the end of 2014. (See Figure 45.) The upgraded SIERRA CAT III UAS will provide approximately 80-100 lbs of payload capability to researchers. The SIERRA-B adds enhanced capabilities including a longer carbon composite fuselage and bigger center wing tank for increased range, a fuel-injected Zanzottera engine for better fuel efficiency, changed angle of incidence providing less drag, enhanced structural and vehicle analysis and testing for greater reliability, more electrical power for investigators, and enhanced DGPS capabilities. A new mini-NASDAT (NASA Airborne Science Data And Telemetry) system will provide additional capabilities for investigators. A flight scheduled for the fall of 2015 is currently in planning to utilize the SIERRA UAS in conjunction with the DragonEyes as a platform to perform instrumented atmospheric sampling with SO_2 sensors and mass spectrometry of emissions from the Salton Sea mud pots.

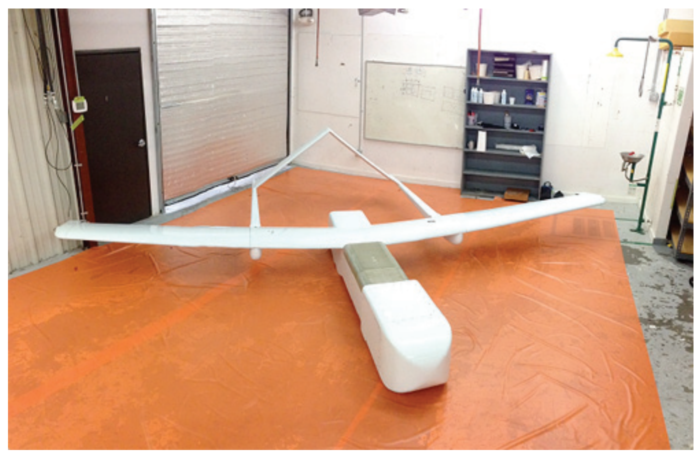


Fig. 45: SIERRA-B Carbon Composite Fuselage/Wings/ Empennage manufactured in Mojave and ready for component installation.

DragonEye UAS

The DragonEye (Figure 46) is a small (6 lb) UAS developed originally by the Naval Research Laboratory and later optimized for mass production by AeroVironment. These dual electric engine aircraft are used for local area remote sensing and in situ gas sampling. 70 units were obtained from the Marine Corp in 2013.

Fig. 46: DragonEye UAS

FY14	Dragon Eye
flight hours	7.3
locations	Three series of test flights @ Site 300 (Lawrence Livermore Lab); 3 series of test flights at Moffett Field with Autopilot equipped DE's; 1 series test flights at Crows Landing of 2 versions of the stretch wing DE variant known as Franken Eye
upgrades / modifications	Commercial Autopilot (revisions A & B) check out and flight control tuning; 2 versions of the stretch wing DE variant known as Franken Eye built and flight tested; 1 version of Ardupliot (revision C) built and flight tested; 6 more rev C variants in production for use in FY15; de-icing equipped DE prototype development initiated with completion expected Mar 2015;3D printing of wing sections successfully proven
planned maintenance	Ongoing efforts to replace military autopilots and radio hardware in stock DE's with equivalent COTS products; each aircraft takes about 5 days to convert;

DragonEye Activity in FY14

Viking-400

A total of eight Viking-400 CAT III UAS were transferred to Ames Research Center from the DoD for research purposes. Authorization was provided to bring 4 of the Vikings up to flight status. Current plans are to modify the Viking engine ignition system and autopilot to match the SIERRA-B configuration with initial flight testing in 2015. Two aircraft will be operated by Ames Research Center and the other 2 will be operated in partnership by Goddard Space Flight Center's Wallops Flight Facility. One of the Viking-400 was put on display at the NASA ARC 75th anniversary open house. (See Figure 47.)

Fig. 47: Viking-400 on display at Ames 75th anniversary open house

A number of partnerships were formed in 2014 and ongoing including: Building a partnership with NAVAIR China Lake for use of their TigerShark UAS with a payload capability of 50 lbs and 10 hour endurance, supporting a Norwegian PhD candidate doing deicing research using previous UAS test data from cold condition flights and future piggyback flights on the UASs, supported an SBIR Phase III partnership with GSE Inc. and Aerojet Rocketdyne for development of a unique 38HP engine providing enhanced performance over existing 2-stroke engines for testing on the SIERRA-B/Viking vehicles.

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 and University of North Dakota 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 is being progressively 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 Working Group for Airborne Data and Telecommunication Systems (IWGADTS.) The Sensor Network architecture includes standardized electrical interfaces for payload instruments, using a common Experimenter Interface Panel; and an airborne network server and satellite communications gateway known as the NASDAT (NASA Airborne Science Data and Telemetry system) These capabilities are now operational on the Global Hawk UAS, DC-8, P-3B, both ER-2s, and one WB-57F.

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	DC-8, P-3	Airborne Sensor Facility / ARC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/ precision IMU	DC-8, ER-2, P-3, B200	Airborne Sensor Facility / ARC
POS AV 610 (2) Applanix Position and Orientation Systems DGPS w/ precision IMU	DC-8, P-3	2 at Airborne Sensor Facility / ARC 2 at WFF
DyNAMITE (Day/Night Airborne Motion Imagery for Terrestrial Environments) Full Color High Definition and Mid-Wave IR High Resolution Full Motion Video System	WB-57	JSC
Hygrometers	DC-8, P-3, C-130	Airborne Sensor Facility / ARC
IR surface temperature instruments	DC-8, P-3, C-130	Airborne Sensor Facility / ARC
High-speed 3D winds and aircraft attitude instruments	DC-8, P-3, C-130	Airborne Sensor Facility / ARC
Static air temperature instruments	DC-8, P-3, C-130	Airborne Sensor Facility / ARC
HDVIS High Def Time-lapse Video System	Global Hawk UAS	Airborne Sensor Facility / ARC
LowLight VIS Low Light Time-lapse Video System	Global Hawk UAS	Airborne Sensor Facility / ARC
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 + VSWIR imaging spectrometer	ER-2	Airborne Sensor Facility / ARC
AVIRIS-ng Imaging Spectrometer (380 - 2510nm range, Dl 5nm)	Twin Otter	JPL / JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, Dl 10nm)	ER-2, Twin Otter	JPL / JPL
UAV-SAR Polarimetric L-band synthetic aperture radar, capable of Differential interferometry	ER-2, Twin Otter	JPL / JPL
NAST-I Infrared imaging interferometer (3.5 – 16mm range)	ER-2	U Wisconsin / LaRC

Table 10: Facility equipment

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 (Table 11). 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.New Inmarsat BGAN (Broadband Global Area Network) multi-channel systems, using electronically-steered flat panel antennas, are now installed 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 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

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 / DFRC / JSC
Inmarsat BGAN (two channel systems) / 432 Kb/sec per channel	DC-8, WB-57, P-3, S-3B, DFRC B200, ER-2, Global Hawk	Airborne Sensor Facility / DFRC
Iridium (1 – 4 channel systems) / 2.8 Kb/sec per channel	Global Hawk, DC-8, P-3, ER-2, WB-57, G-III, SIERRA, C-130, others	Airborne Sensor Facility, NSERC /ARC

Table 11: Satellite Communications systems on ASP aircraft

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 utilization of airborne assets to conduct Earth Science research provide unique opportunities to better understand our Planet and the environmental systems that impact our lives. Earth Science research in the airborne domain requires the collective contribution of many individuals, and this orchestration requires solutions that can quickly propagate the current mission context and constraints to help participants operate independently yet be in-the-loop to enable fast and efficient decision making. A consequence to the contrary may result in increased monetary costs and, more importantly, lost opportunities for observing rare natural phenomena. To this end, the primary objectives of the Mission Tools Suite (MTS) are (a) to support tactical decision-making and distributed team situational awareness during a flight; (b) to facilitate team communication and collaboration throughout the mission lifecycle; and (c) to both consume and produce visualization products that can be viewed in conjunction with the real-time position of aircraft and airborne instrument status data. The many aspects of MTS are shown in Figure 48.

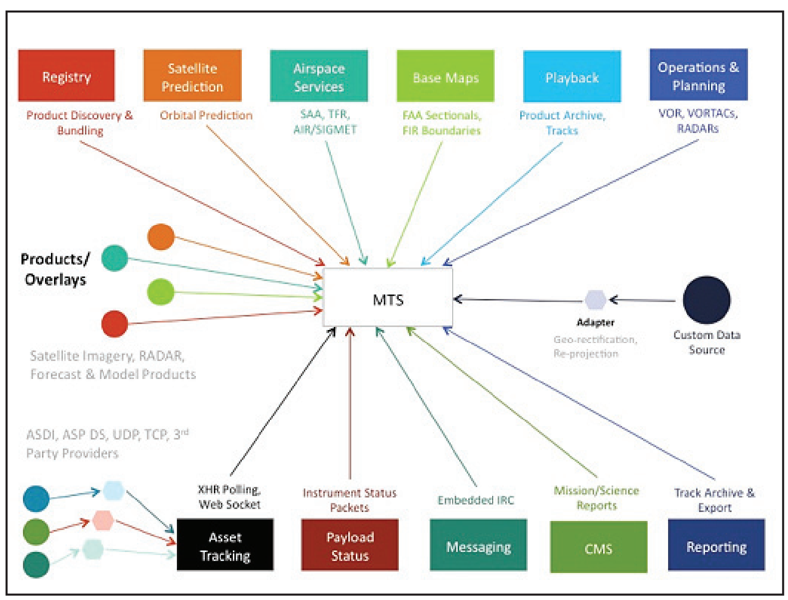


Fig. 48: The many functions of MTS

MTS represents the ground complement to the NASA SensorNet project, which is developing the airborne networking infrastructure to enable satellite communication of aircraft parameter and instrument data during flight missions. Taken together, the intent of the system is to encourage more responsive and collaborative measurements between instruments on multiple aircraft, satellites, and on the surface in order to increase the scientific value of the measurements, and improve the efficiency and effectiveness of flight missions. To that end, Dr. Aaron Duley has been presenting the use and utility of MTS to various constituencies. An example of his presentation opening is shown in Figure 49.

2014 MTS accomplishments include:

- a number of important architectural, performance, and end-user enhancements to the software,
- the addition of mobile-friendly tracking option,
- an improved platform for public education and outreach through the Mission Tools for Education (MTSE) initiative,
- a host of customized instrument, satellite, and other data product visualizations to support real-time mission activities,

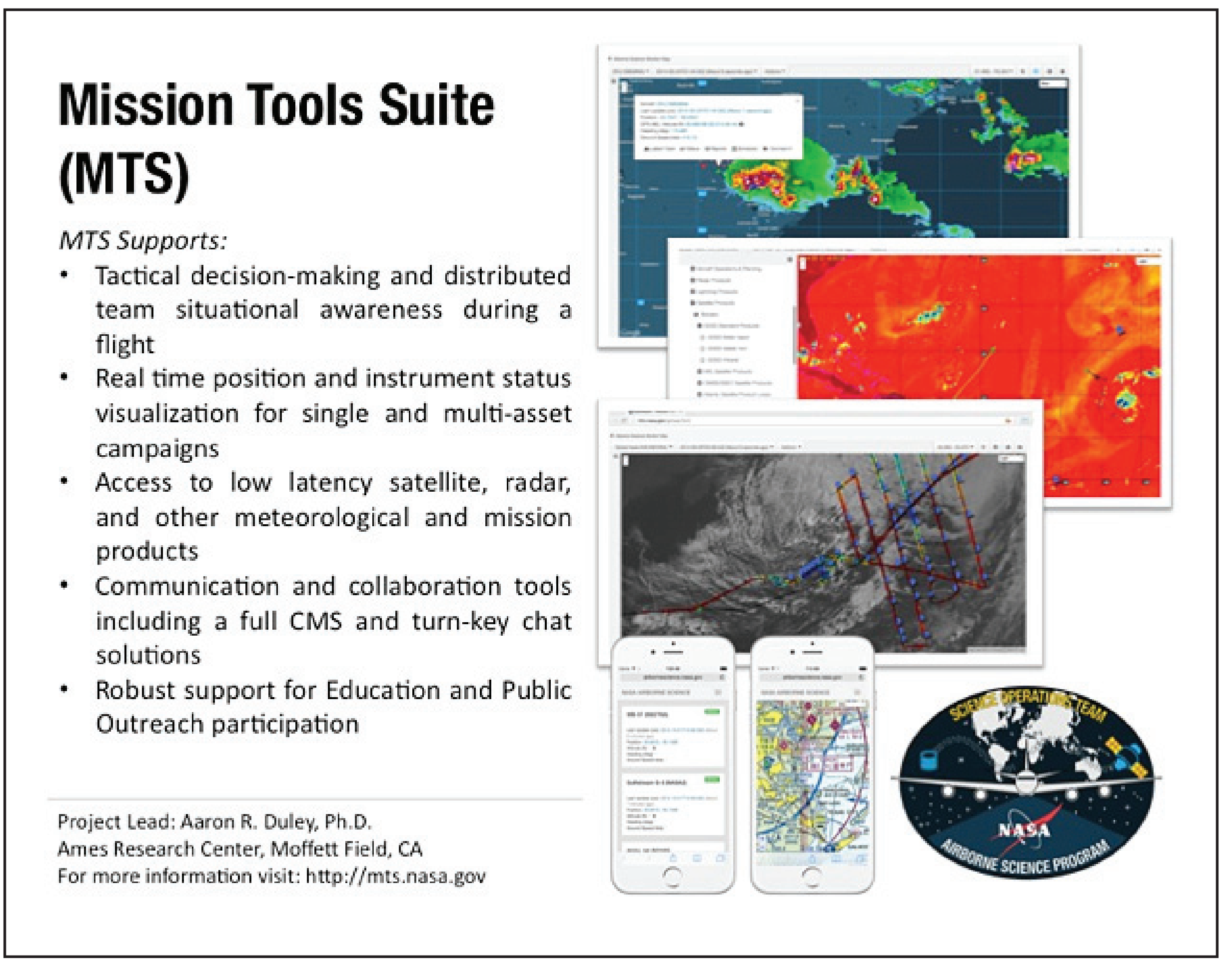
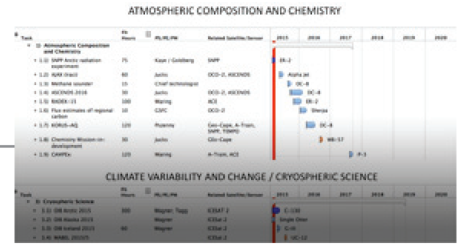


Fig. 49: Presenting the MTS to new users

- the management and dissemination of low-cost tracking solutions supporting multi-asset tracking and mission situational awareness,
- widespread use of the Airborne Science Program's public asset tracker, mobile tracker, MTS, and MTSE.

MTS supported the following projects: Hurricane and Severe Storm Sentinel (HS3), Airborne Tropical Tropopause Experiment (ATTREX), Integrated Precipitation and Hydrology EXperiment (IPHEX), Ship-Aircraft Bio-Optical Research (SABOR), Tropical Cyclone Initiative/HS3, CO2 and Methane Experiment (COMEX), Arctic Radiation - IceBridge Sea & Ice Experiment (ARISE), Operation Ice Bridge (OIB), Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE). Looking forward into FY15, the MTS team plans to continue its operational support role and will feature the next major software release.

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

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

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

In recent years, much attention has been focused on planning for the “Decadal Survey” missions defined in the 2007 NRC report. The first up will be SMAP and IceSAT-2. 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.

Upcoming new space missions are planned for the International Space Station, several small sats, and collaborations with ESA and other space agencies. Several airborne experiments have already been identified to support these activities. Furthermore, the next NRC Decadal Survey for Earth Science is expected in 2017 and new airborne support missions should be anticipated.

Participation in science team meetings and program reviews in 2014 to describe ASP capabilities and collect requirements information are listed in Table 12.

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 2014 ESTO review Forum
Participation in 2014 NASA SMAP cal/val meeting
Participation in 2014 NASA SWOT science team meeting
Participation in 2014 PARCA meeting
Participation in 2014 OBB AVIRIS-ng update
Planning for the next Decadal Survey – Atmospheric Composition and Chemistry mission at ARC
Presentation at 2014 IGARRS meeting

Table 12: Activities to support ASP requirements information gathering

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.

Education, Training, Outreach and Partnerships

Student Airborne Research Program 2014

Thirty-two undergraduate students from a like number of colleges and universities participated in an eight-week NASA Airborne Science Program field experience designed to train and inspire future scientists by immersing them in the agency's Earth Science research. The students are shown in Figure 50. The locations of their colleges are shown in Figure 51.

Flying aboard NASA's DC-8 airborne laboratory, students measured pollution, aerosols, and air quality in the Los Angeles basin and California's central valley. They also used remote sensing instruments to study forest ecology in the Sierra Nevada and ocean biology along the California coast.

NASA's Student Airborne Research Program (SARP) provides a unique opportunity for undergraduate students majoring in the sciences, mathematics and engineering to participate in all aspects of a NASA Airborne Science research campaign. 2014 was the 6th summer the program has been offered.

SARP began June 16, 2014 at NASA Armstrong Flight Research Center's facility in Palmdale, California, with lectures by university faculty members, NASA scientists and NASA program managers. The students flew aboard the DC-8 on five flights during the week of June 23. They acquired multi-spectral images of kelp beds in the Santa Barbara Channel and of forests in the Sierra Nevada.

In addition, the students flew over dairies and oil fields in the San Joaquin Valley, parts of the Los Angeles basin and the Salton Sea at altitudes as low as 1,000 feet in order to collect air samples, measure aerosols and air quality. During the final flight, half of the students were in the field taking ground validation or complementary measurements while the DC-8 flew overhead.

The final six weeks of the program took place at the University of California, Irvine where students analyzed and interpreted the data they collected from science instruments on the aircraft. At the conclusion of the program, the students each delivered final presentations about their results and conclusions in front of an audience of NASA scientists and administrators, university faculty members and their fellow SARP students. Eight students will present their SARP research projects at the 2014 Fall AGU Meeting in San Francisco.

SARP is managed by NASA's Ames Research Center at Moffett Field, California, through the National Suborbital Education and Research Center (NSERC) at the University of North Dakota. As part of the Ames Cooperative for Research in Earth Science and Technology, NSERC receives funding and support from NASA's Earth Science Division.

Fig. 50: SARP 2014 participants pose in front of the NASA DC-8 on June 20, 2014. (Photo: NASA)

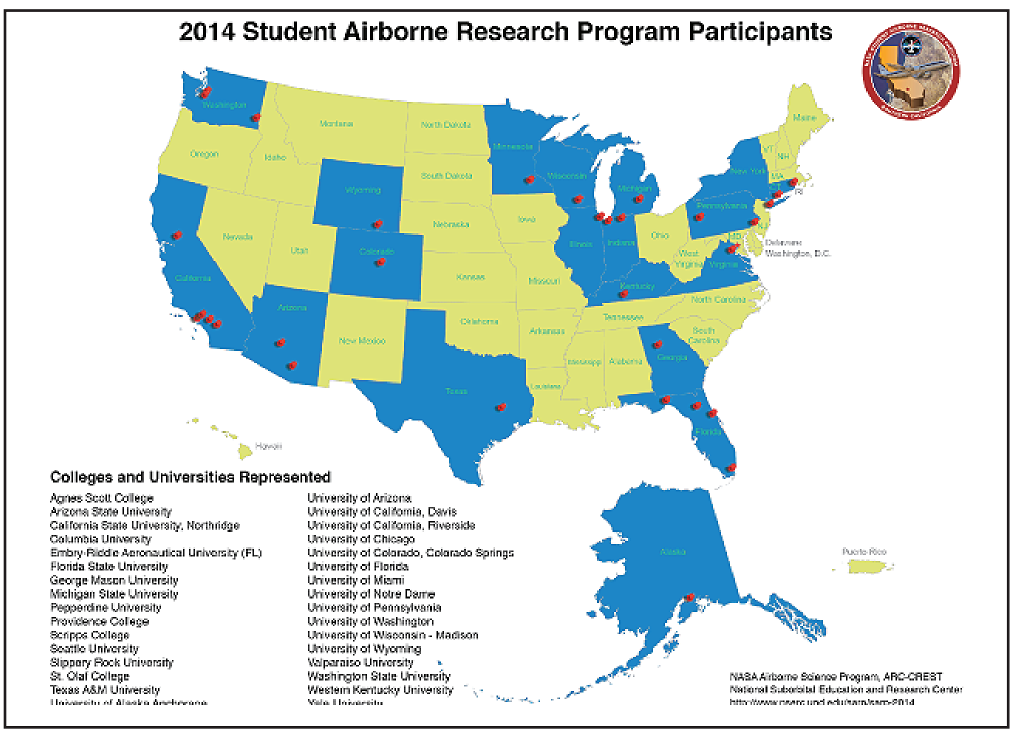


Fig. 51: Colleges and universities represented in SARP 2014

Mission Tools Suite for Education (MTSE)

A number of Airborne Science Program missions (OIB 2013 Antarctica, ATTREX 2014, OIB 2014 Greenland, and HS3 2014) used the NASA Mission Tools Suite for Education (MTSE) to directly connect to K-12 classrooms.

The MTSE website allows students and teachers to track the progress of the ASP aircraft and provides a portal through which classrooms can participate in live, online text chats with NASA scientists, educators and crew members during the missions. During FY2014, a total of 133 classrooms connected to ATTREX, HS3 and OIB through MTSE with a total of 3,127 K-12 students and their teachers (Figure 53).

MTS for Education Website Features:

- Live flight following: Students and teachers can track the position of ASP aircraft on a map (2D or 3D) in real-time
- Live camera feeds from the aircraft (on select missions)
- Real-time satellite data products
- Environmental data from the aircraft: Allows students to plot aircraft altitude, speed, temperature, wind speed, etc in real-time
- Live text chats between classrooms and mission scientists, pilots, and others onboard the aircraft or on the ground
    - Students and teachers can ask questions directly through the website with login information provided to them
    - Multiple classrooms can log in during the same flight
    - Chat scheduling and organization coordinated before and during the flights by NSERC

Fig. 52: Fifth grade students in Sanger, CA and their teacher, Janell Miller, during an online chat with OIB personnel on April 9, 2014.

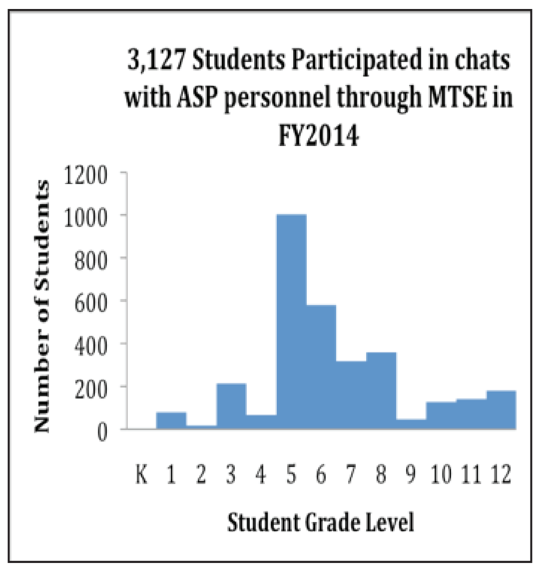


Fig. 53: Student participation

Ms. Miller has connected these students to OIB 2013 in McMurdo, ATTREX 2014 in Guam, and OIB 2014 in Greenland. Before connecting with OIB in Greenland she commented: "My class is so excited for this next adventure! Thank you so much for the opportunity this year. My students will remember this for the rest of their lives. We chatted with NASA at the South Pole, Equator, and soon the North Pole!"

Figure 54 shows 6th graders and their teacher, Nichol Anderson, participating in an online chat from their classroom at Central Elementary in Tioga, North Dakota with scientists onboard the P-3 aircraft over Greenland (5/12/2014).

Fig. 54: Top left: 6th grade teacher Nichol Anderson introduces the NASA Mission Tools Suite for Education (MTSE). Bottom left: Tioga, ND 6th grad students view a live online chat while the NASA p-3 flies over Greenland.

Top right: 32 Central Elementary 6th graders and their teacher pose with the MTSE flight tracker. Bottom right: Tioga, ND 6th grade students point at the NASA P-3 flight path over Greenland.

Additional outreach is part of most major ASP missions. For example, a media/education day for HS3 was held on September 11 with presentations of the project and tours of the aircraft and operations center. (See Figure 55.)

Figure 54. Twenty-one educators visited NASA Wallops Flight Facility on 9/11/14 to learn about the HS3 mission, tour the Global Hawk, the Global Hawk Operations Center and meet with HS3 mission personnel.

Partnerships

The Airborne Science Program, through its field centers, continued to maintain a significant and growing collabo¬ration with the National Oceanic and Atmospheric Administration (NOAA).
Through memorandums of agreement, NASA and NOAA have been collaborating in aircraft operations, primar¬ily training and using NOAA pilots. NOAA pilot Lt Commander Jon Neuhaus augmented NASA B200 pilots flying AirSWOT engineering missions. NASA and NOAA also collaborated in nearly all aspects of the Global Hawk unmanned aircraft system project and its associated missions, Hurricane and Severe Storm Sentinel and Airborne Tropical Tropopause Experiment. Lt Commander Jonathan Neuhaus continued as the embedded NOAA GH liaison.

The Airborne Science Program also remained active in the Interagency Coordinating Committee on Airborne Geoscience Research and Applications (ICCAGRA) representing NASA. Other ICCAGRA organizations include NOAA, National Science Foundation, Department of Energy, US Geological Survey, US Forest Service, Naval Research Laboratory, and Office of Naval Research along with participation from the National Center for Atmospheric Research, National Suborbital Education and Research Center and Center for Interdisciplinary Remotely-Piloted Aircraft Studies. ICCAGRA's role is to share information about activities and capabilities and facilitate collaboration between members. Examples of the collaboration this past year included the integration of NRL supported new dropsonde technology on the WB-57 and flying a coordinated mission with NOAA. NASA assumed the chairmanship of ICCAGRA this year.

The Airborne Science Program has also re-initiated contact with the European Fleet for Airborne Research (EUFAR), also in coordination with ICCAGRA, to look into future collaboration opportunities. A collaborative airborne science mission took place in Guam this year during ATTREX between the United Kingdom's National Environmental Council Bae-146 and NASA GH. Also participating was NSF's G-V, HIAPER.

Appendix A

Historical Perspective: Jeffrey Myers

Jeff Myers is the manager of the Airborne Sensor Facility (ASF) at NASA Ames Research Center, which provides remote sensing and payload engineering services for the NASA Airborne Science Program and the EOS Project Science Office. The ASF supports facility sensors, instrument and payload systems development, and sensor calibration. The ASF is operated under contract to the University of California-Santa Cruz.

The following is based on an interview which took place during the Fall 2012 AGU conference held in San Francisco, California.

Jeff Myers in 1985

I started at Ames in October of 1976, fresh out of UC-Berkeley. I was working toward an aviation A&P mechanics license in high school before I decided to go to Berkeley, earning a bachelor's degree in Physical Geography. (The A&P experience would later come in handy, when I started working around aircraft.) I came to Ames in 1976 to analyze lunar photography from the Apollo program. While two astronauts were on the moon's surface, a third crew member was running large-format mapping cameras on the orbiting Service Module. They acquired many spectacular rolls of 5-inch stereo film of the surface of the moon. Because I'd studied aerial photography at Berkeley under Bob Caldwell in the Forestry Department, the lunar mapping job was a natural fit.

The NASA U-2 program that was then at Ames ran mostly cameras, until John Arvesen, who was a scientist associated with the program, developed a thermal infrared scanner to fly on that aircraft. It was a surplus HRB-454 film-recording line scanner of the type that the Air Force had used in Vietnam. John converted it to record on an analog tape recorder instead of 70mm film, and he needed somebody to help him with the data processing. It was a two-channel system, with a broadband visible band in addition to the one in the thermal infrared, and somehow

I volunteered to help, actually knowing nothing about electronic data, and having no idea what I was getting into. At that time, there was a data facility, the precursor to the Airborne Sensor Facility, called the U-2 Operational Support Section. It was geared to film processing because the NASA U-2Cs were flying mainly cameras, supporting early earth science remote sensing research and laying the groundwork for the Landsat program.

Electromagnetic Systems Laboratory (ESL) was subcontracted to run the U-2 OSS by the Lockheed Skunk Works, which ran the U-2 program for NASA, from aircraft maintenance and camera technicians, through the pilots. (The one exception was Marty Knutson, who ran the overall program for NASA and was, of course, a pilot.) There were literally miles of optical film going through that lab, but they needed someone to process the infrared imagery, so they hired me.

The analog flight tapes from the HRB-454 had to be first digitized, which was done in a vault over at ESL, before they could be put into a computer compatible form. The scanner flew in the Q-Bay of the old C-model U-2 and collected some of the first thermal infrared data ever seen by the earth science community. The early flights revealed some really interesting things, including cold water upwelling off the Pacific coast and a forest fire in Sequoia National Park. Heavy smoke obscured the park in the visible band, but the fire perimeter itself was clearly apparent in the IR band. It was one of the early examples of IR fire mapping from a civilian aircraft and people were very excited about the possibilities.

The HRB-454 was replaced with an all-digital AADS-1260 multispectral scanner from Daedalus Enterprises in 1979, and John figured out that we could hook the scanner output to a 915-megahertz transmitter on the plane, and broadcast the data in real time, line-of-sight. They put a 30-watt transmitter in the back of the plane and started flying. We wanted to see how far we could go and still get the data signal. The link sustained a megabit-per-second and worked out to a 400-mile radius from Ames: not too bad even by today's standards. We had put a big antenna on the roof of the building that we could spin using a Radio Shack TV antenna rotor to follow the aircraft as best we could. We couldn't see it but we vaguely knew its location. It was definitely a human in-the-loop tracking system. We later moved the antenna to a nearby mountain top for better reception. It was a pretty good system and the forestry people were quite excited to see it in action. Broadcasting with 30 watts over southern California did cause a few problems though, and I believe we accidentally jammed a Navy cruise missile test on San Clemente Island. We were on an authorized frequency, but John somehow managed to keep the peace, and the system went on to fly over multiple fires in California.

In July of 1981, the first ER-2, NASA 706, was delivered to Moffett Field. There was a big ceremony and a VIP tour of the data facility. I spent 10 minutes showing Kelly Johnson [renowned aeronautical engineer] some of our growing collection of thermal imagery. He looked at color IR photography of California, as well. I think he was pleased to see some U-2 data that wasn't of a missile silo somewhere.

In the early 1980s, NASA started to conceive of the Thematic Mapper instrument for the next generation of Landsat. The U-2Cs had enabled the simulation of the early Landsat Multi-Spectral System with multispectral cameras, so it was the logical platform for this new project. Ames contracted with Daedalus Enterprises in Ann Arbor, MI (a spin-off from the old Willow Run Labs) to build the airborne Thematic Mapper Simulator (TMS.) This new system had modular spectrometers that included one for ocean color imaging (the AOCI) and one for weather satellite simulation (the MAMS.) The new system was delivered in 1983, with first flights on the new ER-2. (NASA also acquired a TM simulator called the NS-001 that flew on the JSC C-130B, and later came to Ames with the aircraft's transfer.) During the ER-2 TMS's first flight down the central Sierra we noticed that all the snow appeared black in the new shortwave IR bands. No one was very familiar with this spectral region at the time. Clouds were white, and everything else looked like it should, but the snow was black in this solar-reflective band. Was there a problem with this channel, or a problem with the digitizer? John called Vince Salomonson, who was one of the chief scientists at Goddard's Earth Sciences. After thinking it over, Vince called back and said that indeed, snow should be black in this spectral region because of the size and geometry of the ice crystals relative to those wavelengths. These SWIR bands later proved useful for distinguishing between snow and cloud, a continual problem in remote sensing. The TMS was also connected to the ER-2's transmitter and it was used to map the gigantic Yellowstone fires of 1988 in real-time, with a ground station, staffed by the data facility, located in the park headquarters.

By now I started going to Alaska every summer to be the TMS technician and data analyst. I would preflight the instrument in the morning, pouring the liquid nitrogen into the dewars, and then take the tapes off the plane and into hangar to analyze them at day's end. They were operating from what they called the Russian Hangar at Eielson AFB, near Fairbanks. It was a decrepit old hangar at the far end of the field that had been used to ferry Lend-Lease airplanes to the USSR in World War II. There had been little maintainance since then. Over the course of nine summers, the NASA U-2Cs and ER-2s imaged nearly the entire state of Alaska. The hardest area to cover was the Aleutians because of nearly constant cloud-cover. Also, the aircraft operated out of King Salmon in the south for aseveral summers trying to image those last sections of land, as well as the Aleutians and the panhandle. All of the Alaska photography and digital scanner data are archived at the EROS data center in Anchorage and Sioux Falls, SD. They represent a unique cloud-free data set to this day.

Aerial photography remained a big part of the program and the sensor facility cataloged and distributed all of it. For years the NASA U-2s were the biggest provider of aerial photography for the U. S. Forest Service, covering the national forests, and helping to track the Gypsy Moth infestations in the Appalachians. This resulted in literally miles of 9" and 5" color film. Gary Shelton had joined the project and was actively marketing the program, resulting in the loan of a third ER-2 (NASA 708) from the Air Force to accommodate all the flight requests. Besides supporting several classified instrument development projects, the ER-2s also flew the National Wetlands Inventory for USGS and the EPA, another big program that included TMS digital data.

In 1982 the C-130B arrived at Ames from Johnson Space Center, together with some Zeiss cameras, a low-altitude TM simulator (the NS-001,) and a new instrument called TIMS that JPL and NASA SSC had acquired. TIMS was a six-channel thermal IR imager, and Anne Kahle at JPL was the PI. It was probably the first multispectral thermal sensor that wasn't classified. The Sensor Facility was responsible for the data from these systems, as well. The C-130 flew a lot of NASA earth science missions for geologic mapping and forestry studies and we processed all the data. One of the instruments flown on the C-130 was the JPL Airborne Imaging Spectrometer (AIS), the precursor to AVIRIS. Because we were set up to decommutate the big 1" 14-track PCM data tapes that recorded its data, we performed some of the data reduction for that, as well.

These were busy years, with two deployments a year to Wallops alone, just to cover east coast requirements. Gary Shelton was very instrumental in keeping the ER-2s booked-up, as he seemed to know everybody in the government aerial business.

In 1989, when I became manager, the Airborne Sensor Facility produced more and more digital imagery and less film. Simultaneously, NASA was developing the Earth Observing System (EOS). Michael King and Jim Spinhirne at Goddard were interested in having an airborne MODIS instrument on the ER-2. Led by John Arvesen, with Michael as the science PI, and working with Daedalus, they developed a conversion of the TMS into the MODIS Airborne Simulator (MAS.) Mainly supporting the MODIS science team at Goddard, the MAS would go on to participate in over 30 major science field campaigns, from 1991 to the present, in locations ranging from Brazil to Alaska, and Australia to South Africa. It would become the mainstay of the facility sensor systems operated by the ASF. The MASTER instrument (the MODIS/ASTER Airborne Simulator) was subsequently developed with Daedalus, along the same design, to serve the ASTER science community. It started operations in 1998, flying on both the ER-2 and a variety of lower-altitude NASA aircraft. Over the years, the multi-spectral IR and VSWIR data from these two instruments has been heavily utilized by various research disciplines in the NASA Earth Science Division. When the science aircraft relocated to Dryden (now Armstrong) in late 1997, the ASF transferred several technicians and engineers there to support daily flight operations for the facility instruments. The main engineering and data processing functions remained at Ames. Besides the instrument operations, the ASF was increasingly tasked with other engineering support for the Airborne Science Program, largely because of their group of highly experienced engineers. This included the development of a standardized Experiment Interface Panel, to ease the integration of instruments across multiple platforms, and the development of a new navigation data recorder and network server to be called the NASDAT.

In 2005 the ASF was tasked with building up a science sensor for the new Altair/Predator-B UAS at Dryden. This led to the conversion of the old TMS into the Autonomous Modular Sensor system (AMS) that later flew on the Ikhana UAS. Leveraging lessons-learned from the earlier STARLink TDRSS system on the ER-2, it incorporated onboard data processing and real-time data networking that was particularly useful for forest fire mapping. The AMS was the core sensor for the highly successful Western States Fire Missions, before its eventual transfer to the U.S. Forest Service for their operational use.

The real-time data systems design work for the AMS project would become the basis for the payload systems later developed by the ASF for the larger Global Hawk UAS. This required networking multiple sensors with instrument teams on the ground, as well as providing command and control mechanisms, to maximize the science return from these very expensive and complex missions. The real-time sensor networking concepts developed for the Global Hawk in turn led to extending the capability to the other principle science aircraft in the ASP fleet, including the DC-8, P-3B, and ER-2, as sat-com systems became available on those platforms. The software for these extended sensor networks was jointly developed with UND-NSERC and other Ames engineers, including Don Sullivan at Ames. The end result has been to greatly enhance the effectiveness of the science platforms, especially during large multiple aircraft campaigns. Putting real-time science data and situational awareness into the hands of the investigators has now become a de facto requirement for many of the PIs.

Over the years, the ASF, together with their partners at UND-NSERC, has become a valuable engineering resource to the instrument community, partly because the staff has accumulated decades of practical experience in the design and operations of airborne science instrumentation.

Jeff concluded the interview with these remarks: "There is a core of dedicated people in the program that really just love what they're doing. I couldn't imagine a better job for myself. I could not have invented this job if I had thought of it years ago. The satisfaction in the end is when you see some of the really important science that is made possible by the program and all of its great people, some of which we're seeing here today at the AGU Conference, and that makes it all seem incredibly worthwhile."

Appendix B: Five-Year Plan

ATMOSPHERIC COMPOSITION AND CHEMISTRY

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015	2016	2017	2018	2019	2020
1) Atmospheric Composition and Chemistry									
1.1) SNPP Arctic radiation experiment	75	Kaye / Goldberg	SNPP	ER-2					
1.2) AJAX (Iraci)	60	Jucks	OCO-2, ASCENDS	Alpha Jet					
1.3) Methane sounder	15	Chief technologist		DC-8					
1.4) ASCENDS 2016	30	Jucks	OCO-2, ASCENDS	DC-8					
1.5) RADEX-15	100	Maring	ACE	ER-2					
1.6) Flux estimates of regional carbon	10	GSFC	OCO-2		Sherpa				
1.7) KORUS-AQ	120	Pszenny	Geo-Cape, A-Train, SNPP, TEMPO		DC-8				
1.8) Chemistry Mission-in-development	30	Jucks	GEo-Cape		WB-57				
1.9) CAMPEx	120	Maring	A-Train, ACE			P-3			

CLIMATE VARIABILITY AND CHANGE / CRYOSPHERIC SCIENCE

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015	2016	2017	2018	2019	2020
3) Cryospheric Science									
3.1) OIB Arctic 2015	300	Wagner; Tagg	ICESAT 2	C-130					
3.2) OIB Alaska 2015		Wagner	ICESat 2	Single Otter					
3.3) OIB Iceland 2015	60	Wagner	ICESat 2	G-III					
3.4) MABEL 2015(?)			ICESat 2	UC-12					
3.5) OIB Antarctica 2015	250	Wagner; Tagg	ICESat 2	C-130					
3.6) OIB Arctic 2016	300	Wagner; Tagg	ICESAT 2		C-130				
3.7) OIB Alaska 2016		Wagner	ICESat 2		Single Otter				
3.8) OIB Antarctica 2016	250	Wagner; Tagg	ICESat 2		DC-8				
3.9) OIB Arctic 2017	300	Wagner, Tagg	ICESat 2			P-3			
3.10) OIB Antarctica 2017	250	Wagner, Tagg	ICESat 2			P-3			
3.11) UAVSAR Greenland?	50	Wagner					G-III		
3.12) OIB Arctic 2018	300	Wagner, Tagg	ICESat 2				P-3		
3.13) UAVSAR Greenland?	50	Wagner						G-III	
3.14) OIB Arctic 2019	250	Wagner, Tagg	ICESat 2					P-3	

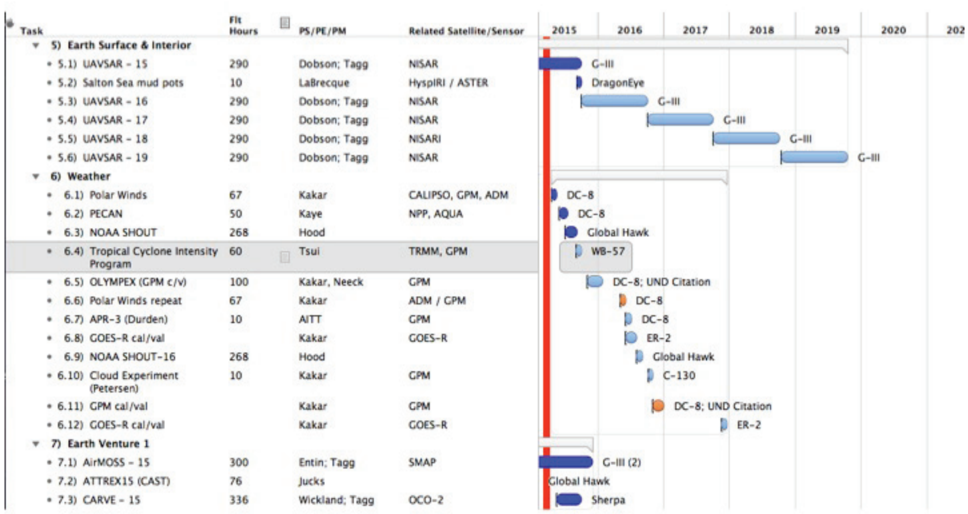
CARBON CYCLE AND ECOSYSTEM SCIENCE

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015	2016	2017	2018	2019	2020
2) Carbon Cycle & Ecosystems Science									
2.1) HyTES-15	50	Kaye		Any Twin Otter					
2.2) AVIRIS & MASTER HyspIRI prep	100	Turner/Neeck	HyspIRI	ER-2					
2.3) AVIRIS-ng (various)		Turner	HyspIRI	Any Twin Otter					
2.4) Carbon Monitoring System (placeholder)		Wickland		Any Twin Otter					
2.5) UAVSAR - Terrestrial Ecology	20	Wickland	NISAR		G-III				
2.6) HyspIRI prep Volcano mission		Turner	HyspIRI		ER-2				
2.7) EXPORT (placeholder)		Bontempi			TBD				
2.8) LIDAR / P-band SAR (mission in development)		Wickland				ER-2; G-III (2)			
2.9) CCE Field Campaign ABoVE	100	Kasischke							She
2.10) UAVSAR - Terrestrial Ecology	20	Wickland	NISAR			G-III			
2.11) UAVSAR - Terrestrial Ecology	20	Wickland	NISAR				G-III		
2.12) Arctic COLORS (placeholder)		Bontempi					TBD		
2.13) UAVSAR - Terrestrial Ecology	20	Wickland	NISAR					G-III	

WATER AND ENERGY CYCLE

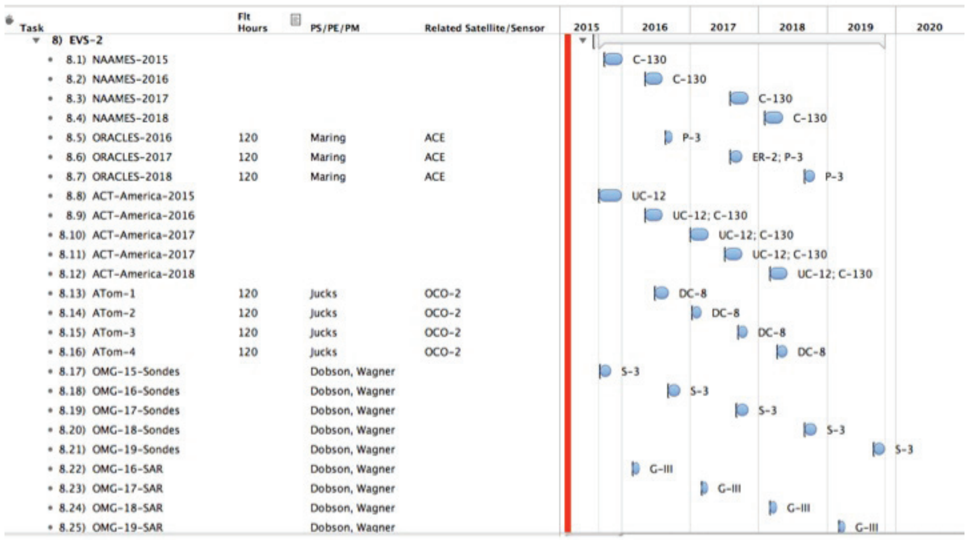
Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015 2016 2017 2018 2019 2020
4) Water and Energy Cycle				
4.1) Rotating PALS Engineering Demo	4	SMAP program	SMAP	DC-3
4.2) AIRSWOT	75	Entin, Lindstrom	SWOT	B-200 D
4.3) AirMOSS Alaska	20	Entin	SMAP	G-III (2)
4.4) Airborne Snow Observatory	50	Entin		A90
4.5) AIRSWOT / UAVSAR Wax Lake Delta	75	Entin	SWOT	B-200 D; G-III
4.6) AIRSWOT	75	Entin	SWOT	B-200 D
4.7) SLAP		Entin	SMAP	B-200 L
4.8) SMAPVEX-15-PALS	50	Entin	SMAP	Any Twin Otter
4.9) SMAP UAVSAR-15	30	SMAP program	SMAP	G-III
4.10) AirMOSS Alaska	20	Entin	SMAP	G-III (2)
4.11) Airborne Snow Observatory	50	Entin		A90
4.12) AirMOSS Alaska	20	Entin	SMAP	G-III (2)
4.13) Snow transects (in development)		Entin	SMAP	TBD
4.14) AirMOSS Alaska	20	Entin	SMAP	G-III (2)
4.15) SMAPVEX-16-RPALS	70	SMAP program	SMAP	P-3
4.16) SMAPVEX-16	60	SMAP program	SMAP	Any Twin Otter
4.17) SMAP UAVSAR-16	30	SMAP program	SMAP	G-III
4.18) Snow field campaign (CLPX-like)		Entin		Any Twin Otter
4.19) RZSM - ESA Collaboration	30	Entin	ESA BIOMASS	G-III (2)
4.20) SMAP UAVSAR-17	30	SMAP program	SMAP	G-III
4.21) SMAP UAVSAR-18	30	SMAP program	SMAP	G-III

EARTH SURFACE AND INTERIOR
WEATHER
EARTH VENTURE (SUBORBITAL) - 1



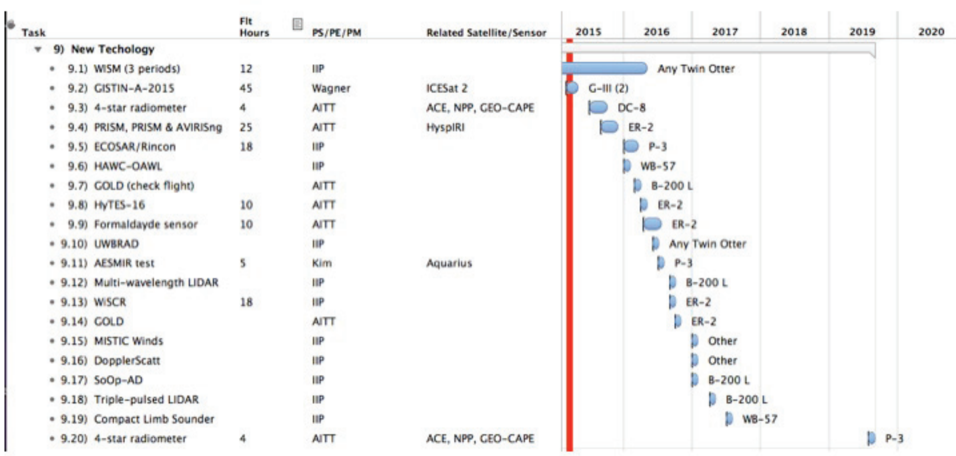
Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2015 2016 2017 2018 2019 2020 202
5) Earth Surface & Interior				
5.1) UAVSAR - 15	290	Dobson; Tagg	NISAR	G-III
5.2) Salton Sea mud pots	10	LaBrecque	HyspIRI / ASTER	DragonEye
5.3) UAVSAR - 16	290	Dobson; Tagg	NISAR	G-III
5.4) UAVSAR - 17	290	Dobson; Tagg	NISAR	G-III
5.5) UAVSAR - 18	290	Dobson; Tagg	NISARI	G-III
5.6) UAVSAR - 19	290	Dobson; Tagg	NISAR	G-III
6) Weather				
6.1) Polar Winds	67	Kakar	CALIPSO, GPM, ADM	DC-8
6.2) PECAN	50	Kaye	NPP, AQUA	DC-8
6.3) NOAA SHOUT	268	Hood		Global Hawk
6.4) Tropical Cyclone Intensity Program	60	Tsui	TRMM, GPM	WB-57
6.5) OLYMPEX (GPM c/v)	100	Kakar, Neeck	GPM	DC-8; UND Citation
6.6) Polar Winds repeat	67	Kakar	ADM / GPM	DC-8
6.7) APR-3 (Durden)	10	AITT	GPM	DC-8
6.8) GOES-R cal/val		Kakar	GOES-R	ER-2
6.9) NOAA SHOUT-16	268	Hood		Global Hawk
6.10) Cloud Experiment (Petersen)	10	Kakar	GPM	C-130
6.11) GPM cal/val		Kakar	GPM	DC-8; UND Citation
6.12) GOES-R cal/val		Kakar	GOES-R	ER-2
7) Earth Venture 1				
7.1) AirMOSS - 15	300	Entin; Tagg	SMAP	G-III (2)
7.2) ATTREX15 (CAST)	76	Jucks		Global Hawk
7.3) CARVE - 15	336	Wickland; Tagg	OCO-2	Sherpa

EARTH VENTURE SUBORBITAL - 2



Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
8) EVS-2				
8.1) NAAMES-2015				C-130
8.2) NAAMES-2016				C-130
8.3) NAAMES-2017				C-130
8.4) NAAMES-2018				C-130
8.5) ORACLES-2016	120	Maring	ACE	P-3
8.6) ORACLES-2017	120	Maring	ACE	ER-2; P-3
8.7) ORACLES-2018	120	Maring	ACE	P-3
8.8) ACT-America-2015				UC-12
8.9) ACT-America-2016				UC-12; C-130
8.10) ACT-America-2017				UC-12; C-130
8.11) ACT-America-2017				UC-12; C-130
8.12) ACT-America-2018				UC-12; C-130
8.13) ATom-1	120	Jucks	OCO-2	DC-8
8.14) ATom-2	120	Jucks	OCO-2	DC-8
8.15) ATom-3	120	Jucks	OCO-2	DC-8
8.16) ATom-4	120	Jucks	OCO-2	DC-8
8.17) OMG-15-Sondes		Dobson, Wagner		S-3
8.18) OMG-16-Sondes		Dobson, Wagner		S-3
8.19) OMG-17-Sondes		Dobson, Wagner		S-3
8.20) OMG-18-Sondes		Dobson, Wagner		S-3
8.21) OMG-19-Sondes		Dobson, Wagner		S-3
8.22) OMG-16-SAR		Dobson, Wagner		G-III
8.23) OMG-17-SAR		Dobson, Wagner		G-III
8.24) OMG-18-SAR		Dobson, Wagner		G-III
8.25) OMG-19-SAR		Dobson, Wagner		G-III

NEW TECHNOLOGY DEVELOPMENT

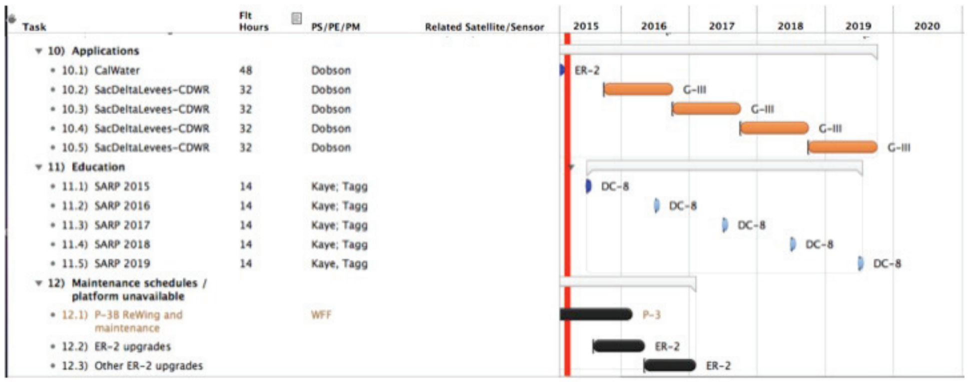


Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
9) New Techology				
9.1) WISM (3 periods)	12	IIP		Any Twin Otter
9.2) GISTIN-A-2015	45	Wagner	ICESat 2	G-III (2)
9.3) 4-star radiometer	4	AITT	ACE, NPP, GEO-CAPE	DC-8
9.4) PRISM, PRISM & AVIRISng	25	AITT	HyspIRI	ER-2
9.5) ECOSAR/Rincon	18	IIP		P-3
9.6) HAWC-OAWL		IIP		WB-57
9.7) GOLD (check flight)		AITT		B-200 L
9.8) HyTES-16	10	AITT		ER-2
9.9) Formaldayde sensor	10	AITT		ER-2
9.10) UWBRAD		IIP		Any Twin Otter
9.11) AESMIR test	5	Kim	Aquarius	P-3
9.12) Multi-wavelength LIDAR		IIP		B-200 L
9.13) WiSCR	18	IIP		ER-2
9.14) GOLD		AITT		ER-2
9.15) MISTIC Winds		IIP		Other
9.16) DopplerScatt		IIP		Other
9.17) SoOp-AD		IIP		B-200 L
9.18) Triple-pulsed LIDAR		IIP		B-200 L
9.19) Compact Limb Sounder		IIP		WB-57
9.20) 4-star radiometer	4	AITT	ACE, NPP, GEO-CAPE	P-3

APPLICATIONS

EDUCATION AND TRAINING

MAJOR MAINTENANCE



Appendix C: Acronyms

4STAR	Spectrometers for Sky-Scanning, Sun-Tracking Atmospheric Research

A

ACES	ASCENDS CarbonHawk Experiment Simulator
ACOCO	Atmospheric Correction Over Coastal Oceans
AFRC	Armstrong Flight Research Center
AERONET	Aerosol Robotic Network
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AMIGACarb	AMerican Icesat Glas Assessment of Carbon
AMPR	Airborne Microwave Radiometer
AMS	Autonomous Modular Sensor
ANG	Air National Guard
ARC	Ames Research Center
ARRISE	Arctic Radiation-IceBridge Sea and Ice Experiment
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASP	Airborne Science Program
ASPRS	Aviation Safety Reporting System
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATM	Airborne Topographic Mapper
ATTREX	The Airborne Tropical TRopopause EXperiment
AVAPS	Advanced Vertical Atmospheric Profiling System
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AVOCET	Atmospheric Vertical Observation of CO2 in the Earth's Troposphere

B

BGAN	Broadband Global Area Network

C

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CARVE	The Carbon in Arctic Reservoirs Vulnerability Experiment
CAST	Coordinated Airborne Studies in the Tropics
CATS	Cloud Aerosol Transport System
CCD	Charge-coupled device
CERES	Clouds and the Earth's Radiant Energy System
CH_4	methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Authorization
CONUS	Continental United States
CONTRAST	Convective Transport of Active Species in the Tropics
CoSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
CPDLC	Controller-Pilot Data Link Commmunications
CPL	Cloud Physics Lidar
CRS	Cloud Radar System

D

DAOF	Dryden Aircraft Operations Facility
DCS	Digital Camera System
DFRC	Dryden Flight Research Center
DISCOVER-AQ	Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)
DyNAMITE	Day/Night Airborne Motion Imagery for Terrestrial Environments

E

eMAS	Enhanced MODIS Airborne Simulator
EOS	Earth Observing System
EPA	Environmental Protection Agency
ERAST	Environmental Research and Sensor Technology
ESD	Earth Science Division
ESFL	Electronically Steerable Flash Lidar
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
FRAPPE	Front Range Air Pollution and Photochemistry Experiment
FTS	Fourier Transformation Spectrometer

G

GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GeoTASO	Geostationary Trace gas and Aerosol Sensor Optimization
GEMS	Geostationary Environment Monitoring Spectrometer
GH	Global Hawk
GISS	Goddard Institute for Space Studies
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal Imager
GPS	Global Positioning System
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center

H

H2O	water
HDSS	High Definition Sounding System
HDVIS	High Definition Time-lapse Video System
HiWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HQ	Headquarters
HS3	Hurricane and Severe Storm Sentinel
HSRL	High Spectral Resolution Lidar
HyspIRI	Hyperspectral Infrared Imager
HyTES	Hyperspectral Thermal Emission Spectrometer

I

ICCAGRA	Interagency Coordinating Committee for Airborne Geoscience Research and Applications
ICESat	Ice, Cloud, and land Elevation Satellite
IGARSS	International Geoscience and Remote Sensing Symposium
IIP	Instrument Incubator Program
IPDA	integrated path differential absorption
IPHEX	Integrated Precipitation and Hydrology Experiment
IRIS	Interface Region Imaging Spectrograph
IWGADTS	Interagency Working Group for Airborne Data and Telecommunication Systems

J

JPL	Jet Propulsion Laboratory
JSC	NASA Johnson Space Center

L

LaRC	Langley Research Center
LiDAR	Ligh Detection and Ranging
LP-DAAC	Land Vegetation and Ice Sensor

LUMP	Low Utilization Maintenance Plan

M

MABEL	Multiple Altimeter Beam Experimental Lidar
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
MFFL	Multi-Functional Fiber Laser
MIZOPEX	The Marginal Ice Zone Ocean and Ice Observations and Processes Experiment
MODIS	Moderate Resolution Imaging Spectroradiometer
MPCS	Master Power Control System
MSFC	Marshall Space Flight Center
MTS; MTS-E	Mission Tools Suite; Mission Tools Suite for Education
MX	Maintenance

N

NAMMA	NASA African Monsoon Multidisciplinary Analyses
NASDAT	NASA Airborne Science Data and Telemetry
NAVAIR	Naval Air Systems Command
NCAR	National Center for Atmospheric Research
NEE	net ecosystem carbon exchange
NISAR	NASA-ISRO SAR
NOAA	National Oceanographic and Atmospheric Administration
NSF	National Science Foundation
NSERC	National Suborbital Education and Research Center

O

OCO-2	Orbiting Carbon Observatory - 2
OIB	Operation Ice Bridge

P

PARCA	Program for Arctic Regional Climate Assessment
PFP	Programmable Flask Packages
PI	Principal Investigator
PNNL	Pacific Northwest National Laboratory
POS	Position and Orientation Systems
PRISM	Portable Remote Imaging Spectrometer

R

RADEX-14	Radiation Experiment-14
RSP	Research Scanning Polarimeter
RZSM	Root Zone Soil Moisture

S

SABOR	Ship-Aircraft Bio-Optical Research
SAL	Saharan Air Layer
SAR	synthetic aperture radar
SARP	Student Airborne Research Program
SCAR-B	Smoke/Sulfates, Clouds and Radiation-Brazil
SEAC4RS	Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys
SEO	sensor equipment operator
S-HIS	Scanning High-resolution Interferometer Sounder
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SLAP	Scanning L-band Active Passive
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SO_2	Sulfur dioxide
SOFRS	Science Operations Flight Request System

T

TAWS	Terrain Awareness Warning System
TIR	Thermal Infrared Radiometer
TRMM	Tropical Rainfall Measuring Mission
TTL	Tropical Tropopause Layer

U

UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UND	University of North Dakota
USAF	U.S. Air Force
USC	University of Southern California
USFS	U.S. Forest Service

W

WFF	Wallops Flight Facility

X

XSCAV	eXperimental Sensor-Controlled Aerial Vehicle

DC-8 over Palmdale, California

P-3 arriving at Thule AFB, Greenland

Global Hawk leaving the hangar in Guam