AIRBORNE SCIENCE PROGRAM
2013 Annual Report

On the front cover: A view of the haze filling California's Central Valley looking north from NASA's ER-2 flying over Palmdale during a spring DISCOVER-AQ flight, concurrent with PODEX.

National Aeronautics and Space Administration

Airborne Science Program

2013 Annual Report

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In Memoriam

Gary Shelton

1941 - 2013

NASA's Airborne Science Program lost a pioneer and advocate on May 16th when Gary Shelton passed away at his home in Tucson, Arizona. Gary died from complications following Aortic Thoracic Aneurysm surgery. Gary's extended NASA family is saddened by his premature death.

Gary's career with NASA began in 1984 when he left a management position with the EPA in Las Vegas and joined the High Altitude Missions Branch at Ames Research Center. His responsibilities included oversight of the Applications Aircraft Data Facility and management of U-2 / ER-2 aircraft deployments. Gary was a very successful marketer for mapping programs supporting EPA, USFWS and USFS. NASA became the largest provider of aerial photography for the Forest Service for quite a while, covering many of the country's National Forests and the Appalachia's, including the gypsy moth mapping with the ER-2's specialized cameras. He knew more about aerial photography, from the technical to the business end, than anyone we've ever encountered. He set up a number of successful foreign deployments to difficult areas, including two to Brazil (SCAR-B in 1995 and TRMM in 1999) and the South African SAFARI in 2000. Gary had a knack for getting things done in third world countries. He always had a great way with people and personified the 'can-do' philosophy - the bigger the problem and the harder the challenge, the higher he rose to the occasion. During Gary's assignment at ARC, he was detailed to NASA Headquarters' Mission to Planet Earth. He worked with Applid Science and was also assigned as the acting Airborne Science Program Manager.

Gary moved with the Airborne Science aircraft to Dryden Flight Research Center in 1998 and ultimately became Director of the Dryden Airborne Science Program. Gary continued to support the Airborne Science Program in Washington, DC over the past decade under a contract with SAIC.

Gary was a remarkably accomplished individual who devoted his professional life to the goals of the American Society for Photogrammetry and Remote Sensing (ASPRS) for the betterment of the environment. He will be missed.

Steve Wegener

1946 - 2013

Our dear colleague Steve Wegener passed away peacefully in his sleep on Wednesday, August 14, 2013, in Fairbanks, Alaska, in the midst of an adventurous road trip, exploring the wild frontier of Alaska with two of his brothers. He had been in treatment for lung cancer for the last four years, throughout which his lust for life endured, and was expressed through abundant time with family, his ongoing environmental research, extensive travel, and his involvement in cancer treatment studies through UC Davis.

Steve settled in Menlo Park at the US Geological Survey in 1978, where he worked for many years until his career took him to the NASA/Ames Research Center. His work at NASA Ames was pioneering, as he tackled the new frontiers of high-altitude atmospheric research and later airborne science missions from Unmanned Aerial Vehicles (UAV). Although officially retired from NASA in 2004, he never left original research, continuing his work as a scientist at the Bay Area Environmental Research Institute and with his own consultancy, Wegener Airborne Science.

Adventures were always Steve's passion; throughout his life he traveled extensively both domestically and abroad. He never turned down an opportunity for a trip, large or small, and he enjoyed the travel preparations and reflecting afterwards with friends and family as much as the adventure itself. Steve's legacy is to live everyday to it's fullest, which he did right up until the end. He will forever be admired, missed and loved.

Leadership Comments

Welcome to another addition of the Airborne Science Annual Report and again I have to say a huge thank you to the people who make the program a success. We flew another record year with nearly 4400 science hours for the five missions of Earth Venture 1, instrument development, various satellite calibration, validation, and data collection activities, and for the first time ever, flying the P-3 from Antarctica for Operation IceBridge. To the Airborne Science team: we've fulfilled our job of supporting the Earth Science Division and NASA due to your hard work and dedication. There are too many people to name and most don't want the attention anyway so I'd like to personally thank the teams from Wallops, Ames, Dryden, Johnson, Glenn, and Langley. To our stackholders and community: thank you for your support and trusting us with your missions.

On a sad note, we lost two of Airborne Science's best this year with the passing of Steve Wegener and Gary Shelton. They were both long time members and supporters of Airborne Science and will be sorely missed. Gary used to run the program and oversaw the aircraft transition from Ames Research Center to Dryden while Steve was a scientist and pioneer in high-altitude atmospheric research and later airborne science missions from Unmanned Aerial Vehicles (UAV's).

Randy and I thank you for taking the time to read this year's annual report and hope that you find this edition informative and we look forward to another productive year in Earth Science data collection and discovery.

The 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.

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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.

Bruce Tagg and Randy Albertson
Airborne Science Program

Program Overview

The Airborne Science Program (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 (page 6) shows the components of the Airborne Science Program. The aircraft responsibilities are distributed among the NASA centers where the aircraft are housed.

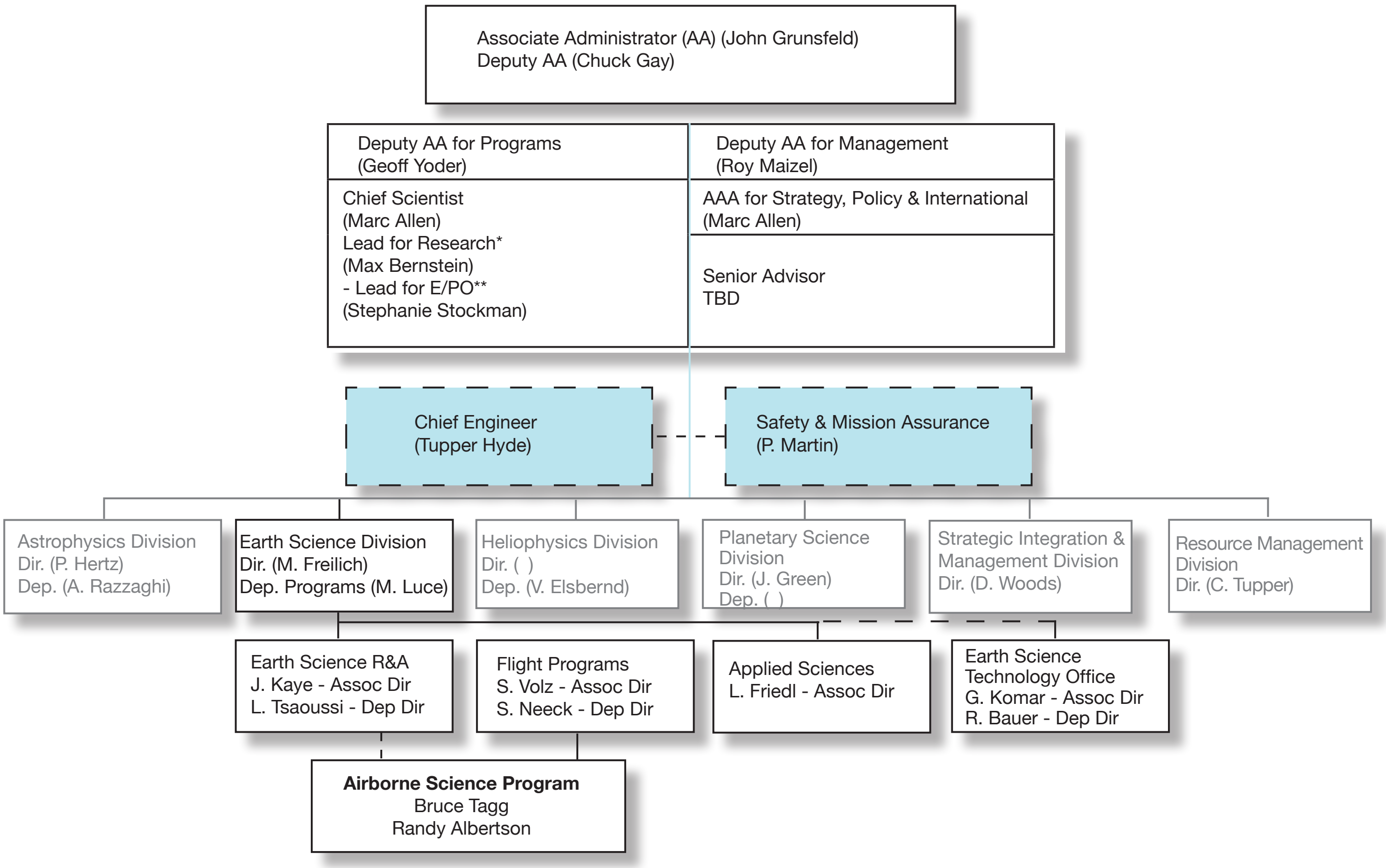


Figure 1. SMD Organization

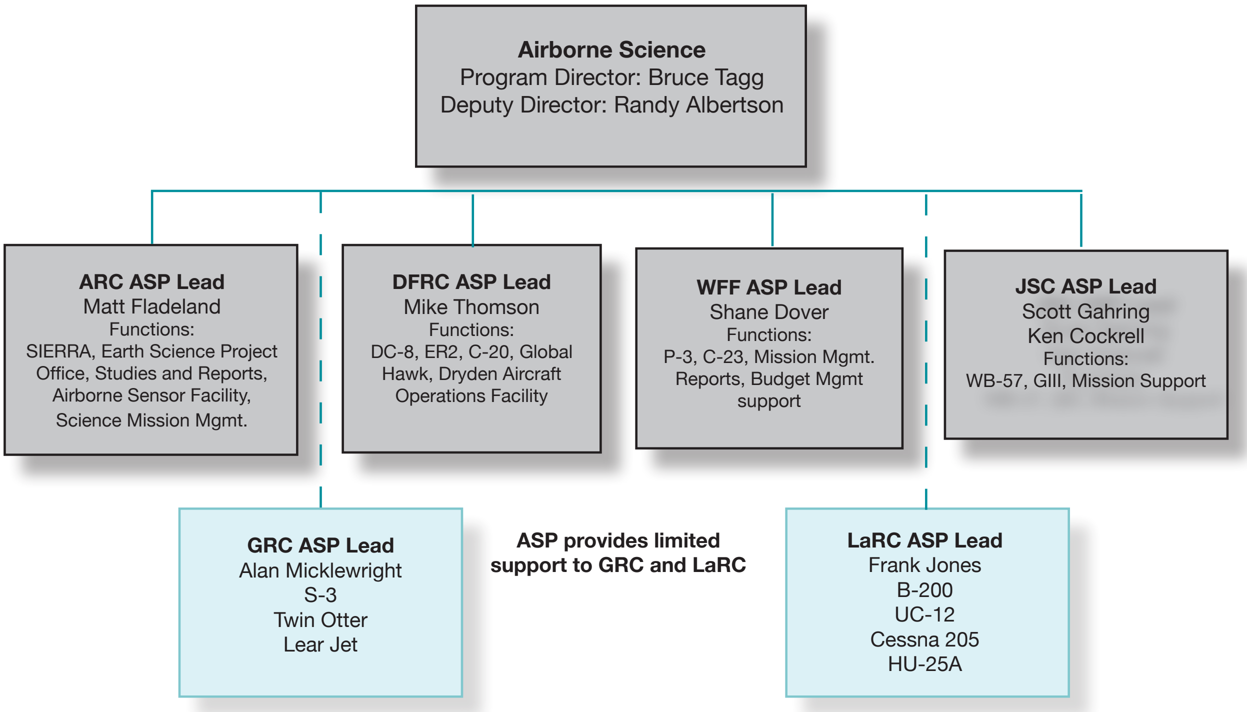


Figure 2. Airborne Science Organization Chart

FY2013 Major Improvements / Capability Additions

Several new capabilities were added to the Airborne Science Program in FY2013. The major addition is the Global Hawk Operations Center – East, established at Wallops Flight Facility initially to support the HS3 mission. Having Global Hawk operational capability on the east coast affords the opportunity for greater range and endurance for missions in the Atlantic. It also adds access to Greenland and that portion of the Arctic. A second Global Hawk landed at WFF in August 2013, as seen in Figure 3. This was the first time two Global Hawks were deployed concurrently.

Figure 3. Global Hawk 872 arrives at WFF.

An addition to the fleet is a C-130 aircraft, also at WFF, initially acquired to fulfill low-altitude, heavy-lift missions while the NASA P-3 is being rewinged. It also provides some airlift capability for NASA. Yet another improvement is the installation of Inmarsat satcom capability on the ER-2 aircraft, providing experimenters with real-time data access from these high flyers.

Flight Request System Summary

The Airborne Science Program maintains aircraft and sensor assets to support the Headquarters Science Mission Directorate (SMD). The flight request system manages and tracks the allocation of the ASP aircraft and facility sensors. The Science Operations Flight Request System (SOFRS) is a web-based database to facilitate the review and approval process for every airborne science mission using NASA SMD funds, personnel, instruments or aircraft. Requests for these assets and the scheduling of their use are accomplished through SOFRS. This system was designed to allow researchers that are funded by NASA or other agencies to have access to unique NASA aircraft, as well as commercial aircraft with which NASA has made contracting arrangements. The only way to schedule the use of NASA SMD platforms and instrument assets is to submit a Flight Request for approval through SOFRS (http://airbornescience.nasa.gov/).

The SOFRS team strives for continuous improvement by improving the interface with users and the data products. In 2013, the focus was on creating additional reports for HQ from the data collected in the Flight Request System and on making additions to the flight request form to collect additional data as requested.

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hrs Flown
DC-8	9	8	0	8	474.3
ER-2	28	19	6	9	566.8
P-3	9	6	0	4	462.3
WB-57	3	1	0	1	0.0
Twin Otter	20	10	0	10	297.6
B-200	13	6	1	5	295.9
G-III Class	43	36	2	30	890.5
Global Hawk	10	4	0	3	471.3
C-130 Hercules	1	1	1	0	47.5
C-23 Sherpa	3	2	1	1	320.1
Falcon - HU-25	2	1	0	1	31.9
Ikhana	7	0	0	0	0.0
SIERRA	8	2	0	2	5.8
T-34	1	1	0	1	35.1
Other	34	23	4	19	933.6
TOTALS:	**191**	**120**	**15**	**94**	**4832.7**

Table 1. Aircraft, Flight Requests, and Total Hours flown in FY13, NASA ESD hours were 4392.

NOTES:

- These totals are based on the flight request's log number, and therefore include all flight requests whose log number starts with "13".
- The "Total FRs" column includes all flight requests that were submitted and whose log number starts with "13".
- The "Total Approved" column includes flight requests that were set to a status of "Approved" at some point.
- The "Total 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 Open, Pending Safety Review, Approved, Completed or Partial for 2013.

- Other aircraft include: Basler BT-67 (DC-3T), PNNL G-1, Alphajet, JPL RC-UAV, BAT4, Twin Otter International, Piper Cherokee PA-32, Dragoneye, Contract Helicopter, Scaled Composites' PROTEUS, Vision II, UTSI Piper Navajo, BE-76 Beechcraft Duchess, Purdue University Airborne Laboratory for Atmospheric Research, XSCAV, Cessna-208B, DHC-3 Otter, Cessna CUMAV, Scan Eagle and Learjet 25-Ice Niner.

Flight Requests for 2013

Flight requests were submitted for 14 NASA-supported aircraft platforms and 19 other platforms and flew 4833 flight hours in all, as shown in Table 1. Several large campaigns were successfully conducted this year, including Earth Venture-1 (ATTREX, HS3, CARVE, Discover AQ, AirMOSS), SEAC4RS, Operation IceBridge, and more. Total flight hours for the past 16 years are shown in Figure 4. Locations of FY13 missions are shown in Figure 5. Note that ASP facilitated airborne experiments of numerous non-NASA aircraft.

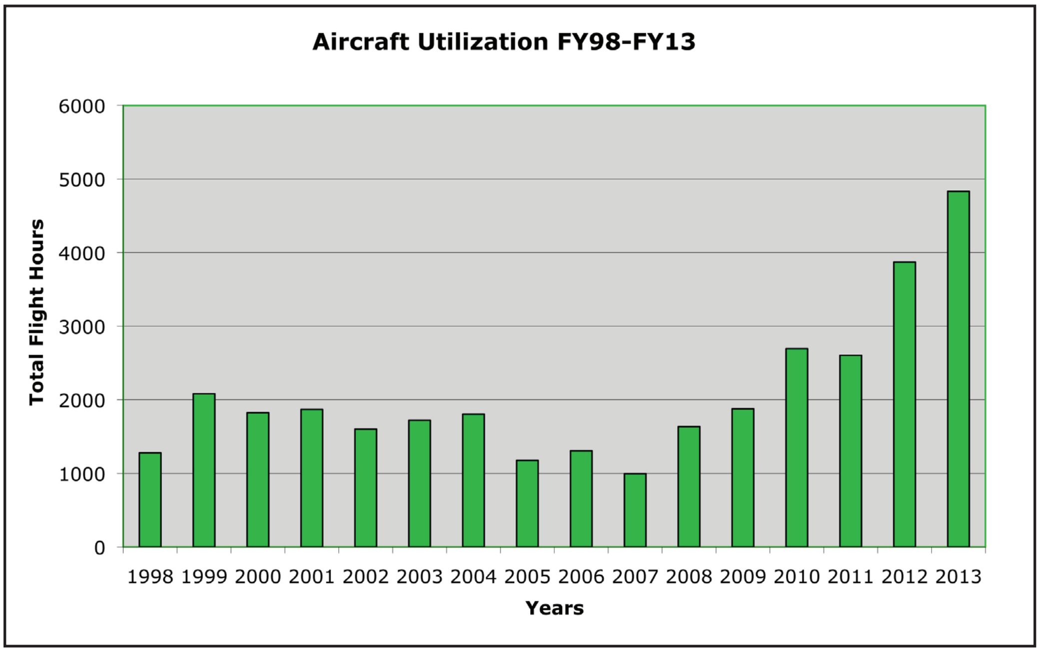


Figure 4. ASP science flight hours over the past 16 years. Totals include all hours tracked by SOFRS, including missions flown in support of other NASA directorates, other government organizations and some reimbursable requests.

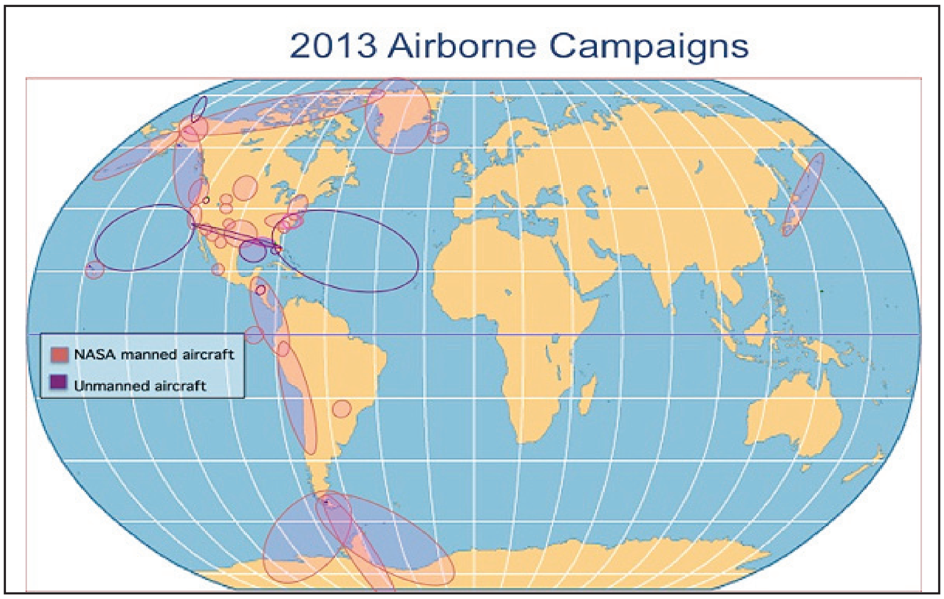


Figure 5. Locations of airborne campaigns in FY2013

Science

The Airborne Science Program conducted nearly 4400 science flight operation hours in support of NASA's Earth science missions during FY 2013.

NASA Airborne Science platforms were actively engaged in mission definition and development activities, including instrument development flights supporting future satellite mission definition (Ice, Cloud and Land Elevation Satellite – II and HyspIRI), gathering ice sheet observations as gap fillers (Operation IceBridge), and serving as technology test beds for Instrument Incubator Program (IIP) missions and satellite calibration and validation (SMAP, SWOT). 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). Flight hours for the largest missions are shown in Table 2. The program also involved students in many activities. In all, 209 undergraduate and 228 graduate students, representing 113 universities, directly participated in Airborne Science investigations and student-led flight projects.

Mission	Aircraft	Location	Flight hrs
Operation IceBridge	P-3, Single Otter, Falcon, DC-8	Arctic (Greenland), Alaska, Antarctic	513
UAVSAR	G-III/C-20	CONUS, Mexico, Central America, South America, Japan	339
AirMOSS	G-III	US, Canada, Mexico, Costa Rica	472
HS3	Global Hawk	Atlantic Ocean, Pacific Ocean	318
CARVE	Sherpa	Alaska	241
DISCOVER-AQ	P-3, B-200, Falcon	California, Texas	352
ATTREX	Global Hawk	DFRC / Pacific Ocean	153
SEAC4RS	ER-2, DC-8	Texas	408
HyspIRI Prep	ER-2	California	112
PODEX	ER-2, B-200, P-3	California	75
Airborne Snow Observatory	Twin Otter	California, Colorado	156
AmigaCarb	Piper Cherokee	US, Mexico	113

Table 2. Science Flight Statistics, Major Missions

Major Mission Highlights

Major accomplishments of the FY 2013 Airborne Science Program include airborne science platforms supporting the Operation IceBridge and the Earth Venture-1 (EV-1) Projects, preparation for upcoming satellite missions SMAP, IceSat-II, HyspIRI and SWOT and multiple uses of SAR imagery from the UAVSAR system on the DFRC C20-A.

Operation Ice Bridge (OIB)

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 connection changes in sea ice cover and the Earth system.

Operation IceBridge is critical to ensuring a sustained series of observations of the most dynamic portions of the great Greenland and Antarctic ice sheets.

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 2017. Operation IceBridge is critical to ensuring a sustained series of observations of the most dynamic portions of the great Greenland and Antarctic ice sheets. Operation IceBridge is jointly sponsored by the Airborne Science Program and the Earth Science Directorate Cryosphere Program.

During FY2013, the Airborne Science Program conducted two major OIB campaigns including the fourth journey of the DC-8 to Antarctica and fifth season of P-3 and other aircraft in the Arctic. Together the OIB missions flew over 500 hours.

Antarctic Campaign: October-November 2012

The NASA DC-8 team and researchers supporting Operation IceBridge recently completed a five-week field campaign based out of Punta Arenas, Chile. This was the fourth year in a row that IceBridge researchers gathered information on Antarctic land based glaciers and sea ice using the DC-8. Antarctic weather is always challenging the team's ability to fly these missions at 1,500 ft AGL altitudes but this year's Antarctic weather presented sufficient opportunities to accomplish 16 science missions in 34 days as opposed to the planned 15 missions during 44 days.

During this year's Antarctic campaign IceBridge scientists added to existing sea ice elevation data in the Bellingshausen and Amundsen Sea areas on the west side of the Antarctic Peninsula and Weddell Sea on the east side of the peninsula. Antarctic ice sheet's altitudes, depths, and grounding lines were studied this year in areas that included the Foundation Ice Stream, Getz, Pine Island (and its expanding crack), Thwaites, Smith, Kohler, Ronnie, and Recovery glaciers. Flight lines for Antarctic missions are shown in Figure 6.

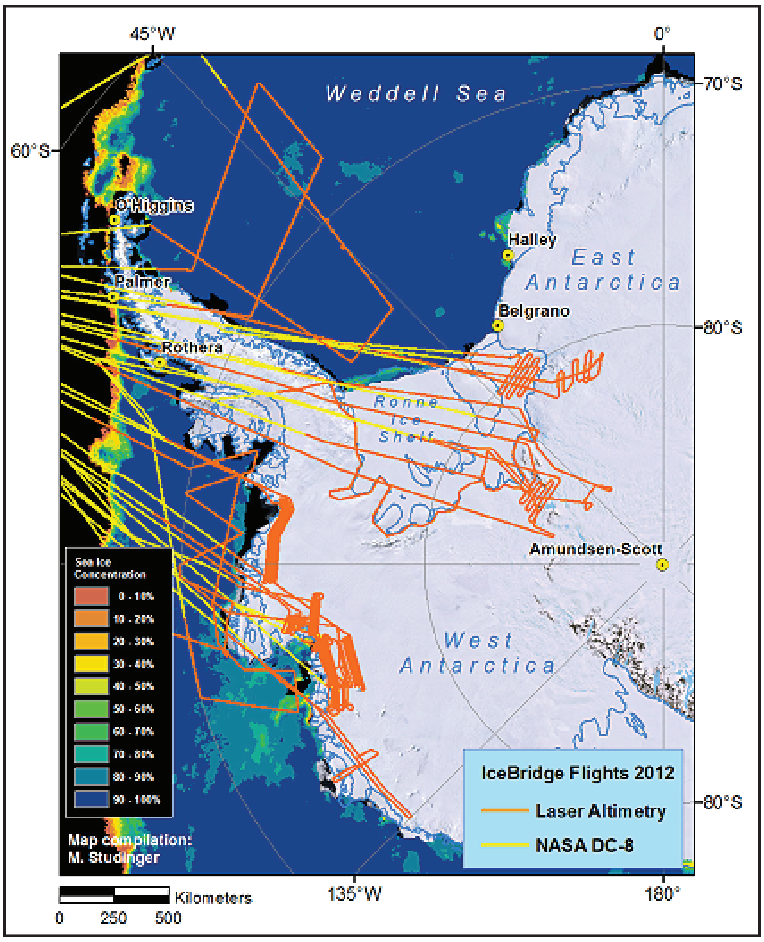


Figure 6. Flight lines for FY13 Antarctic mission (Fall 2012).

IceBridge also achieved key milestones in educational outreach and science diplomacy by providing flight opportunities to two Chilean teachers, personnel from the U.S. Embassy in Santiago (including U.S. Ambassador to Chile Alejandro Wolff), and researchers from the Chilean Antarctic Institute. U.S. classrooms from across the nation tied into many of the flights via Xchat where experimenters and flight crew answered numerous questions asked by the students in real-time using the DC-8's satellite communication system.

Airborne Topographic Mapper (ATM) Sigma Lidar was operated during most missions. New instruments (ATM3 and ATM4) were assessed for their ability to make surface altitude measurements during high altitude transit segments.

Arctic Campaign

From mid-March through early May 2013, Operation IceBridge (OIB) returned to the Arctic for a campaign of science flights out of bases in Thule and Kangerlussuaq, Greenland, and Fairbanks, Alaska. Researchers aboard NASA's P-3B airborne laboratory gathered data on sea ice, ice sheets and glaciers in and around Greenland, the Arctic Ocean and off the north coast of Alaska. Flight lines for the Arctic mission are shown in Figure 7.

During these flights, OIB measured changes in ice surface elevation, mapped bedrock beneath Greenland's ice sheet and glaciers, and produced a near real-time dataset of Arctic sea ice thickness. This new quick-look product uses data processing techniques developed last year and aims to provide researchers producing seasonal sea ice forecasts with more up-to-date initial conditions for use in computer models.

During the first few weeks of the campaign, OIB flew surveys of Arctic sea ice from Thule Air Base in northern Greenland and Fairbanks, Alaska. Arctic sea ice has been the subject of increasing attention, especially following a record-breaking 2012 annual minimum and the appearance of several large cracks in Arctic ice in February of this year.

This year marks the second time OIB has deployed in Fairbanks. The transits between Greenland and Alaska give researchers data on sea ice conditions across the entire Arctic Basin and the flights over the Beaufort and Chukchi seas provide the research community with data on changes in this economically important region.

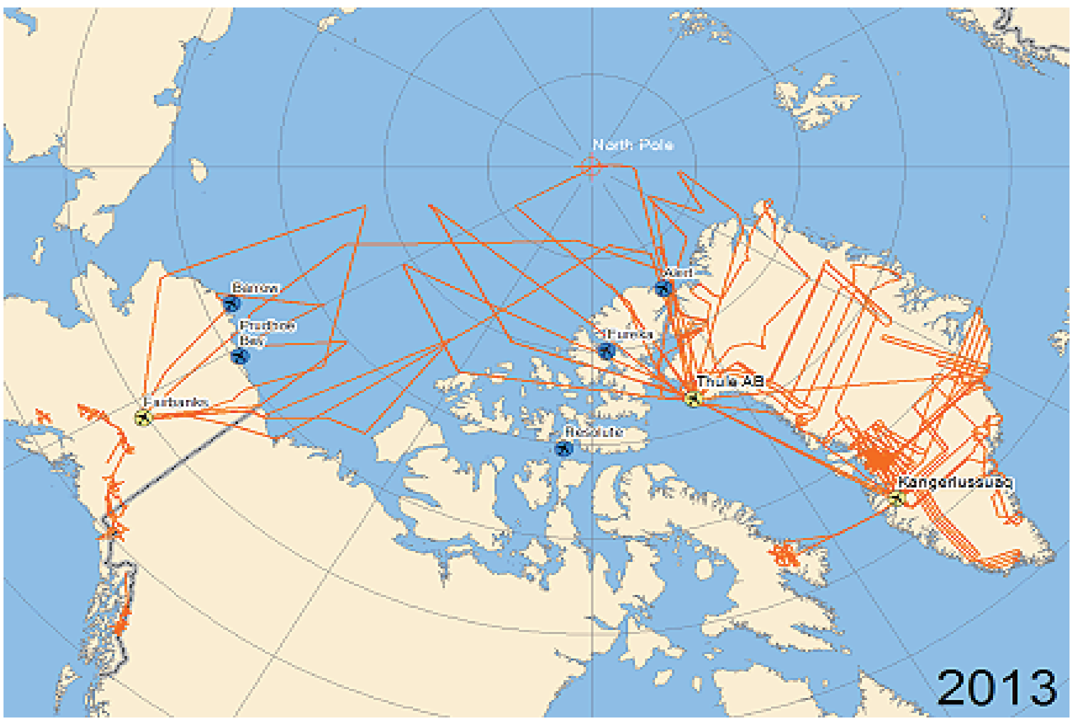


Figure 7. OIB 2013 Arctic flight lines. Orange lines indicate P-3 with ATM flying land ice.

After a few weeks of sea ice flights, the mission moved south to Kangerlussuaq where researchers carried out surveys of the ice sheet and important outlet glaciers in the southern half of Greenland. One of these areas, the Jakobshavn Glacier, is one of the fastest changing areas in Greenland, draining about 10 percent of the ice sheet.

While in Kangerlussuaq OIB also hosted three high school science teachers—one each from the U.S., Denmark and Greenland. For two weeks the teachers lived and worked alongside OIB researchers, gaining a special insight into polar science. The teachers will take these lessons back into the classroom and design new lessons and materials for their students.

OIB finished out the campaign with a return to Thule, completing the campaign's remaining high-priority sea ice flights and surveying key outlet glaciers in northern Greenland. These flights built on existing measurements from previous campaigns, filled in gaps in coverage and featured coordinated measurements with other research groups such as the European Space Agency's CryoSat-2 team.

In addition to giving teachers a behind-the-scenes look at science, IceBridge researchers also did live question and answer sessions with classrooms around the United States, reaching over 700 students. Using a custom web portal created by Airborne Science Program personnel at NASA Ames, classrooms were able to communicate through a text-based chat system via the P-3B's satellite communication system.

SEAC4RS

The Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS) mission was completed in 2013 and proved to be a great scientific success. Originally planned to take place in South East Asia, specifically Thailand, the mission moved its operations to Ellington Field, TX. With the NASA DC-8, ER-2 and the SPEC Inc. Learjet the mission flew a combined total of more then 411 flight hours during the six-week campaign. SEAC4RS flew3 days a week, week after week, and was very successful, meeting all science objectives but one. The mission had hoped to fly hurricanes in the Gulf of Mexico co-incident with the HS3 Global Hawks flying out of Wallops Flight Facility. All SEAC4RS aircraft were operationally flawless in all respects. There was just one weather issue that caused the ER-2 to scrub one flight mid-deployment.

There were numerous science objectives virtually equal in scientific importance to the SEAC4RS leadership. These ranged from flying the North American Monsoon in the early portion of the mission to investigations of biogenic emissions over the South East USA. Other primary objectives in the mission included sampling the boundary layer and convective weather, as well as wild fire smoke and a hurricane in the Gulf of Mexico. Most of the science flights were coordinated between the ER-2 and the DC-8. The Learjet joined the DC-8 primarily for the purpose of sampling and comparing in situ microphysics data from similar instruments onboard both aircraft. Flight lines for SEAC4RS on September 18 are shown in Figure 8.

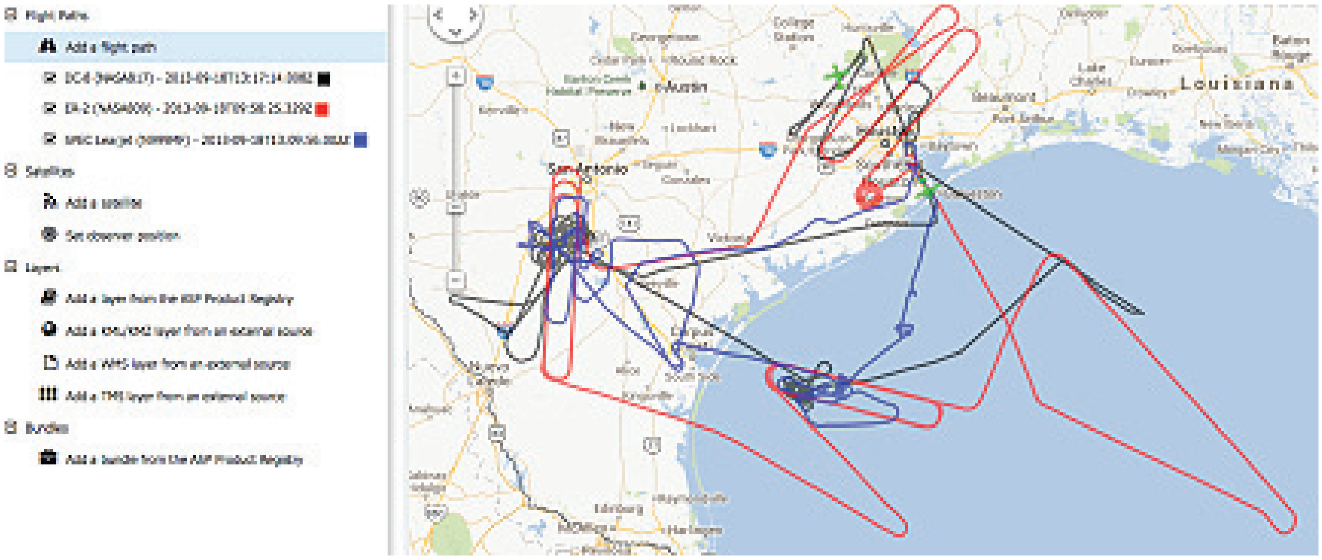


Figure 8. DC-8, ER-2 and SPEC Learjet flight tracks on 18 September 2013 (Shown on ASP flight tracker)

Flying out of Palmdale, prior to deploying to Ellington Field, the DC-8 and ER-2 performed coordinated science flights sampling wild fire smoke near the coast of the California / Oregon state border. On the transit flights to Ellington the two aircraft sampled the North American Monsoon over New Mexico and Arizona as well as Saharan Dust over the Gulf.

During the third week of the mission the DC-8 flew an overnight suitcase mission to Spokane, Washington to perform extended science operations over large wild fires adjacent to Boise, Idaho and downstream where the jet stream was pushing the smoke into Canada and the Midwest US. A photo of smoke from the Rim Fire in California was also captured from the DC-8. Finally, three aircraft continued to sample various chemistry and were able to catch one named tropical storm (Ingrid) in the Gulf of Mexico just before it turned into a Category 1 hurricane and made landfall in Mexico. (See Figure 9.)

SEAC4RS' vast data sets collected during the mission will be used for years to come to assist in producing effective forecast models related to a wide variety of atmospheric interactive systems.

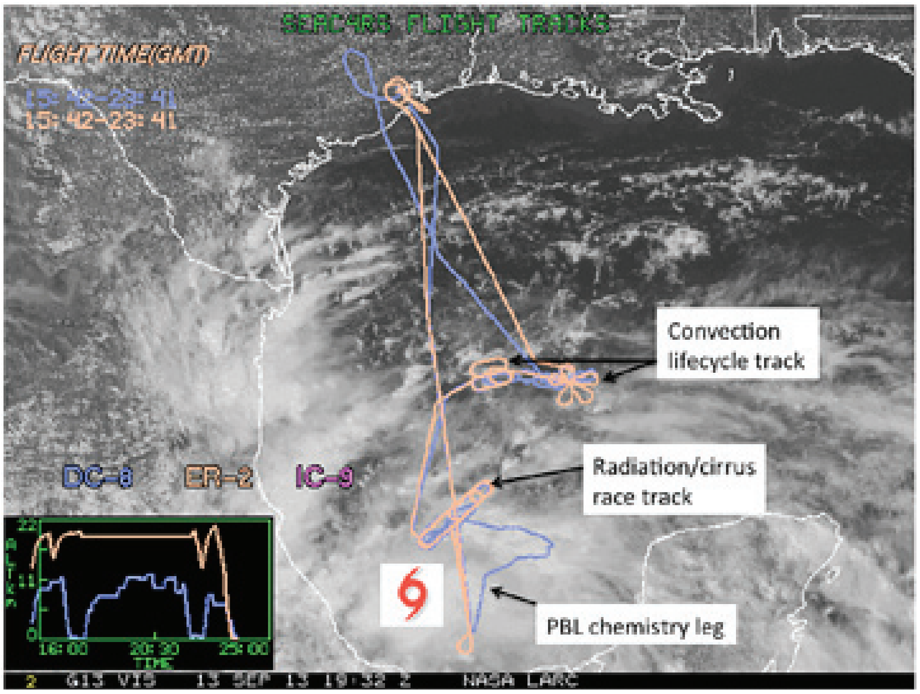


Figure 9. Tropical Storm Ingrid, Sept. 13, 2013.

Earth Venture-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, EV-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 2013, all five of the EV-1 missions moved into the second half of their flight missions.

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

The 2013 HS3 EV-1 campaign took place between Aug. 20-Sept. 23, 2013. HS3 used two of NASA's unmanned Global Hawk (GH) aircraft to study Atlantic hurricanes during the deployment at the Wallops Flight Facility. The mission's goal is to improve understanding of the processes that control hurricane formation and intensity change and to better determine the relative roles of the large-scale environment and smaller-scale processes in the inner-core region of storms (i.e., the eyewall and rainbands). One GH, designated the environmental (AV-6), is designed to sample temperature, humidity, winds, and Saharan dust in the storm environment while the other, designated the over-storm (AV-1), is focused on measuring winds and precipitation within the storm. Global Hawk AV-1 and AV-6 are also designated by their tail numbers #871 and #872, respectively.

HS3 conducted seven flights with the environmental GH and two with the over-storm GH. All HS3 flight lines are shown in Figure 10. The first flight (Aug. 20-21, AV-6) was over the remnants of Tropical Storm (TS) Erin, which had dissipated two days prior to flight. Power to the dropsonde system was lost shortly after getting on-station, but S-HIS and CPL obtained information on the movement of a major Saharan Air Layer (SAL) outbreak over the low-level remnants of Erin. On Aug. 24-25, AV-6 obtained detailed measurements of an intense SAL outbreak. The next four flights (3 with AV-6, 1 with AV-1) over the period of Aug. 29-Sept. 8 examined the pre-Gabrielle disturbance, its formation into a

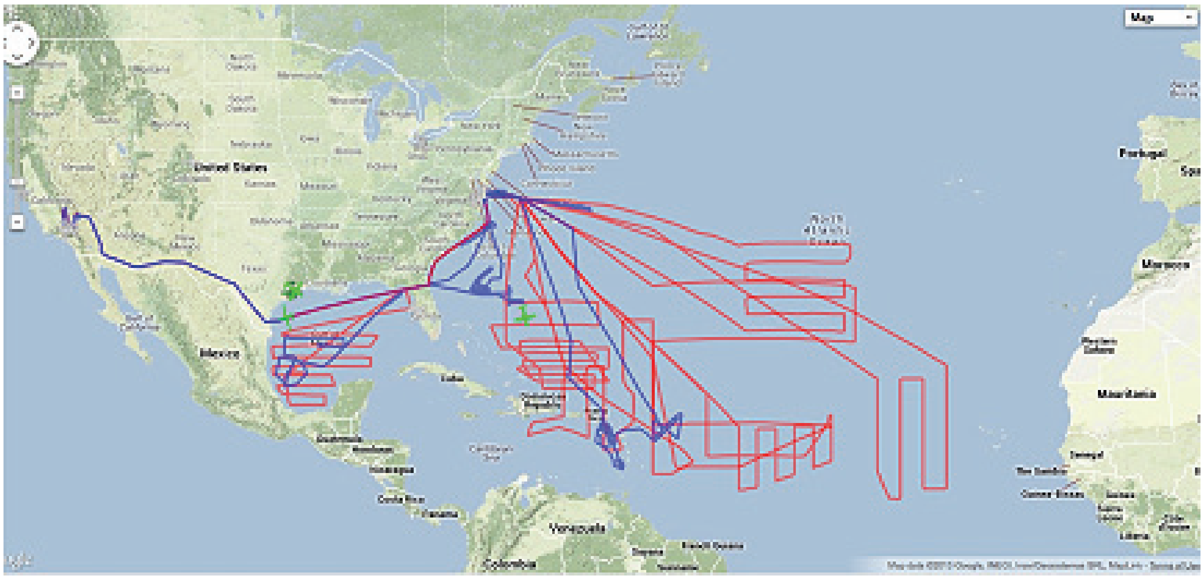


Figure 10. HS3 flight paths for 2013. (Red for AV-6 and blue for AV-1.)

TS, and its later potential for redevelopment. An AV-1 flight on Sept. 15-16 obtained two overpasses of Hurricane Ingrid in the Gulf of Mexico before cold fuel temperatures required a return to base. A Sept. 16-17 AV-6 flight examined the reformation of TS Humberto, revealing a hybrid tropical/extratropical storm structure. The final science flight, on Sept. 19-20, used AV-6 to examine the potential genesis of a disturbance in the Gulf of Mexico. While this storm failed to develop, the HS3 data should provide valuable information on the factors that prevented its genesis.

The HS3 team with both Global Hawks at WFF are shown in Figure 11. To support the 2013 HS3 mission, an independent Global Hawk Operations Center was installed at Wallops Flight Facility. A detailed description is included in the chapter on ASP infrastructure.

Figure 11. HS3 team with AV-1 and AV-6 at WFF.

The Carbon in Arctic Reservoirs Vulnerability Experiment (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 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 2013 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 Picarro real time gas analyzers (CH4, CO2, CO, H2O), a Fourier Transformation Spectrometer (FTS), two Programmable Flask Packages (PFP) and a FLIR (1024 x 1024) Thermal Infrared camera .

The CARVE aircraft was deployed to Fairbanks, Alaska from 2 April to 27 October 2013. During this entire period, once a month, for a two week period, the CARVE flight crew observed over various locations, including the North slope, Barrow, Prudhoe bay, Nome, Unalakleet, Innoko Valley, Minto Valley, Fort Yukon, Bethel, and Bettles. CARVE flight tracks are shown in Figure 12.

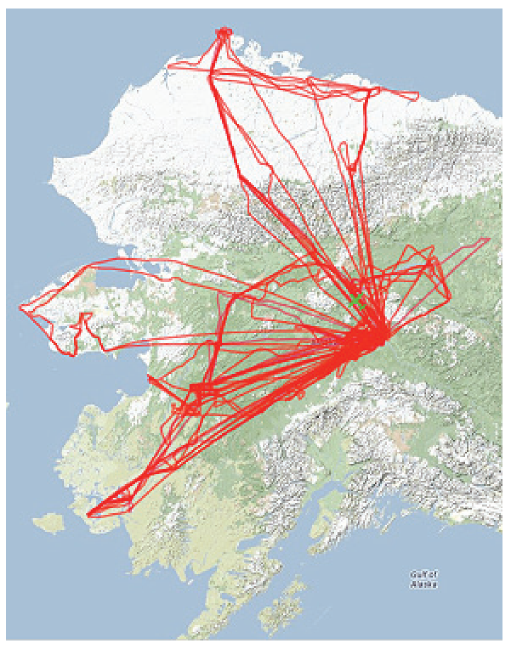


Figure 12. CARVE 2013 flight tracks of the C-23 Sherpa, radiating from Fairbanks, AK.

Figure 13. CARVE exceeded its Program Level Requirements Threshold.

In 2013, CARVE achieved the following major milestones: all 2012 level -2 data was released to the public, CARVE flew over 260 Alaskan science flight hours - in 45 flight days, on July 6, 2013, CARVE exceeded it PLRA Threshold requirement of flying 320 science flight hours! Milestone was celebrated as shown in Figure 13.

CARVE is very close to the next major milestone, "PLRA Baseline requirement of 500 science flight hours in three years". Currently CARVE's combined science flight hours for 2012 and 2013 is 465 hours! CARVE team is looking forward to making these measurement again in Alaska in 2014 and 2015.

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

North American ecosystems are critical components of the global exchange of the greenhouse gas carbon dioxide and other gases within the atmosphere. To better understand the size of this exchange on a continental scale, the AirMOSS investigation addresses the uncertainties in existing estimates by measuring soil moisture in the root zone of representative regions of major North American ecosystems.

AirMoSS is flying a P-band synthetic aperture radar (SAR) on a Gulfstream-III aircraft operated by NASA's Johnson Space Center. The AirMOSS instrument is similar to the UAVSAR flown on the Dryden G-III aircraft, except it operates at a different wavelength (70 cm) compared to the L-band UAVSAR, which operates at 24 cm. The aircraft and instrument are shown in Figure 14.

The AirMOSS experiment is designed to minimize one of the largest components of uncertainty in net ecosystem exchange (NEE) of carbon by measuring root zone soil moisture (RZSM) and its spatial heterogeneity. The current knowledge of NEE for North America has large uncertainties. AirMOSS will reach its goals by providing high-resolution regional observations of RZSM over nine major North American biomes (shown in Figure 15), and feeding the information to hydrologic and ecosystem models for estimation of NEE.

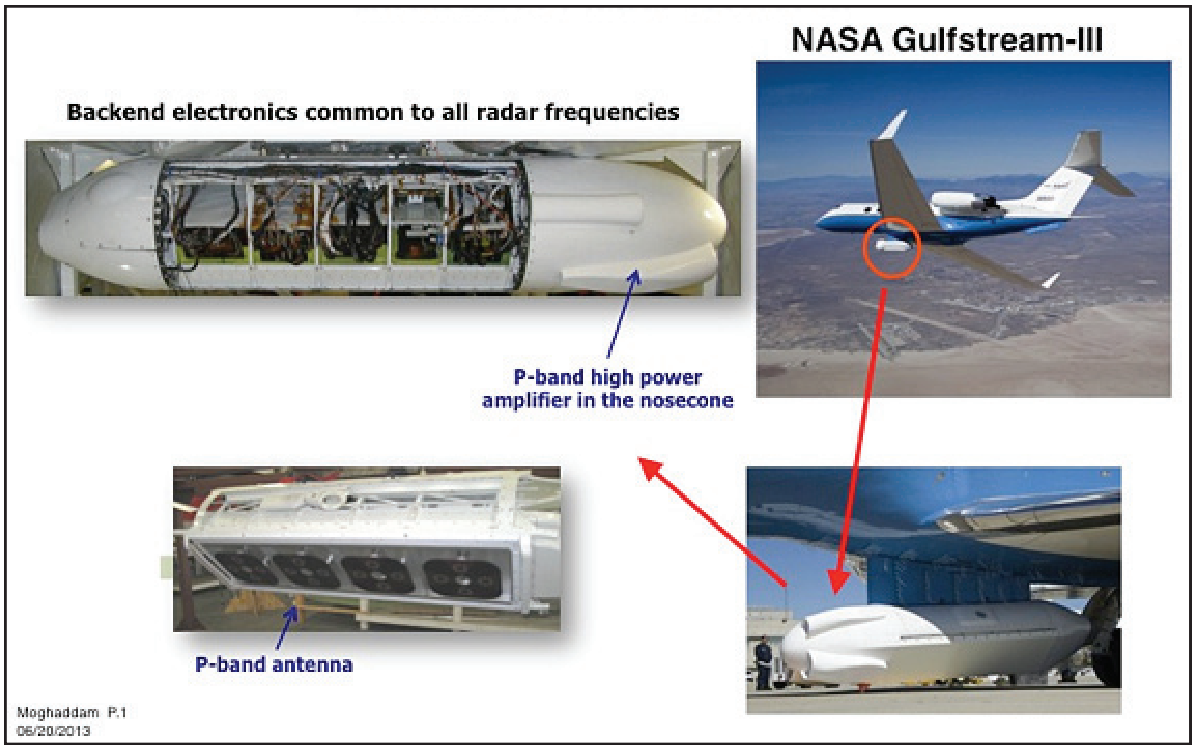


Figure 14. AirMOSS Flight System

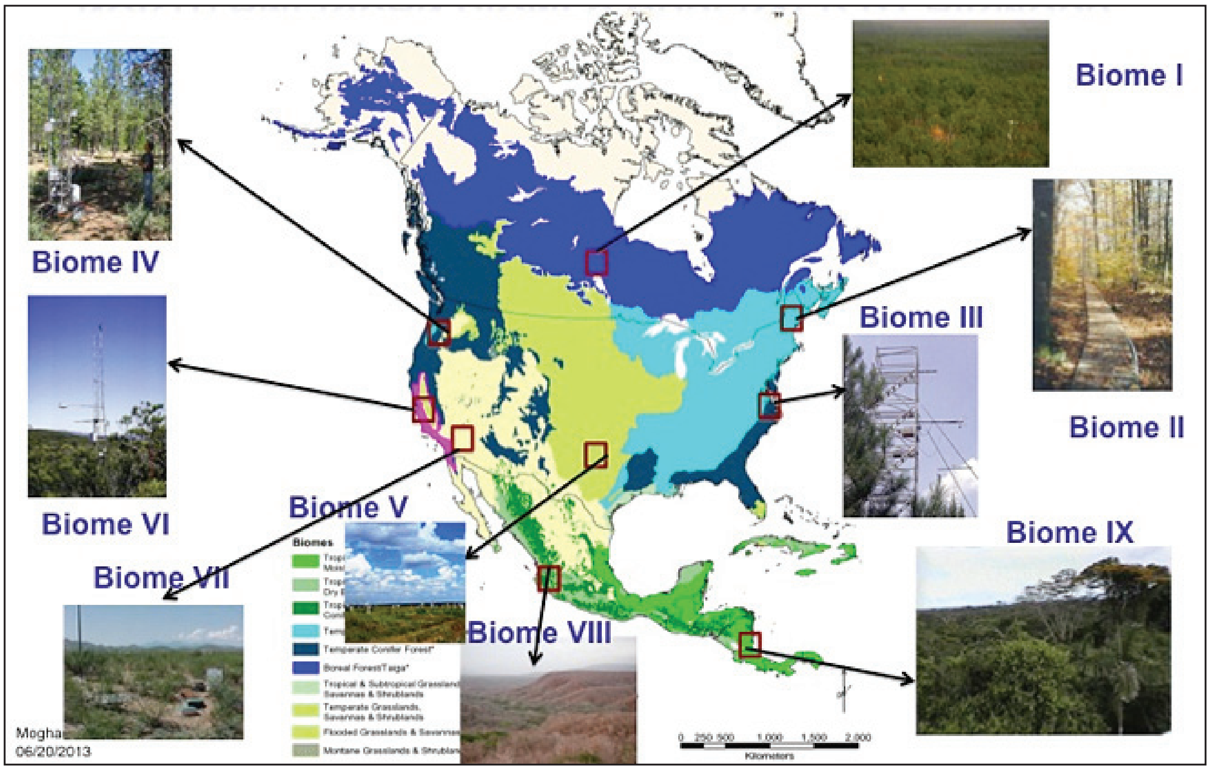


Figure 15. North American Biomes observed by AirMOSS.

Airborne Tropical Tropopause Experiment (ATTREX): 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, investigators will launch four airborne campaigns with NASA's Global Hawk Unmanned Aircraft Systems (UAS). The flights will study chemical and physical processes at different times of year from bases in California and Guam.

The Airborne Tropical TRopopause EXperiment (ATTREX), managed by NASA Ames Research Center, is an Earth Ventures mission focused on understanding the physical processes occurring in the tropical tropopause layer (TTL; ~14-19 km) and their impact on the Earth's climate. Air ascends into the stratosphere through the TTL, and therefore the composition of the TTL provides a boundary condition for the stratospheric composition. Thin cirrus clouds forming near the cold tropical tropopause limit the humidity of air entering the stratosphere. It has been shown that small changes in stratospheric humidity have large impacts on the Earth's radiation budget. ATTREX is providing high-resolution measurements of TTL composition, clouds, tracers, water vapor, and radiation using the long-duration, unmanned NASA Global Hawk. The overarching objectives of ATTREX are to improve our understanding of TTL processes and to improve their representation in climate models.

During February-March, 2013, the first ATTREX science flights were conducted out of Dryden Flight Research Center (DFRC) in southern California. The 24+ hour flights targeted the deep tropics over the central and eastern Pacific. The primary sampling strategy used involved profiling vertically through the TTL between about 45,000 and 60,000 feet. Over 100 TTL vertical profiles were obtained. Some of the flights were designed to survey the TTL composition versus latitude, including sampling deep into the southern hemisphere. Other flights targeted relatively recent detrainment from deep tropical convection. The numerous tracers measured on the vertical profiles will provide information about TTL dynamics, transport pathways, and transport time scales. Regions with anomalously cold tropopause temperatures and thin cirrus were targeted on multiple flights. These flights will provide case studies for evaluating how effectively the cirrus clouds freeze dry air ascending across the cold tropical tropopause. A combination of factors resulted in extremely cold tropopause temperature and low humidity during January-February, 2013. The in situ measurements provided by ATTREX will be combined with satellite measurements and modeling studies to understand the cold temperatures and dry conditions that prevailed in the 2013 winter. The ATTREX team is shown in Figure 16.

Figure 16. The 2013 ATTREX team.

Deriving Information on Surface Conditions from COlumn and VERtically Resolved Air Quality (DISCOVER-AQ): NASA LaRC

DISCOVER-AQ Activities in FY13 included two four-week deployments. The first was to California's Central Valley in January-February, and the second was to Houston, Texas in September. Both deployments were successful in terms of science, collaboration, and outreach activities.

During the deployment to California, DISCOVER-AQ collaborated with the PODEX mission, providing detailed aerosol measurements for polarimeters onboard the ER-2. In addition to the ten primary science flights, two additional flights directed to PODEX targets of interest were executed. Conditions were ideal, with two particulate matter (PM2.5) build ups occurring during the flight period. The first build up occurred over seven days, during which 5 flights were executed to examine a tripling in PM2.5 across the valley. Data for the California campaign have been archived and were made available to the public in late June. The data is being used not only by DISCOVER-AQ and PODEX scientists. EPA Region 9 (California) is also using the data to assess relocation of a PM2.5 monitor in the Bakersfield area.

The location of the Houston mission is shown in Figure 17. During the deployment to Houston, DISCOVER-AQ also collaborated with a ship working in the Gulf of Mexico to understand ocean color and atmospheric corrections affecting retrievals. In addition to the eight primary science flights, the King Air flew in support of the ship (sponsored by NASA's GEO-CAPE working group) on three occasions. Over the first six flights, significant cloudiness was encountered, with smoke from agricultural fires routinely observed above the surface and ozone levels that were moderately elevated, but not exceeding national air quality standards. During the final two flights, however, passage of a frontal system and clear skies led to the worst ozone exceedance recorded in Houston in the last six years. This demonstrated that sufficient emissions are present to quickly degrade air quality in

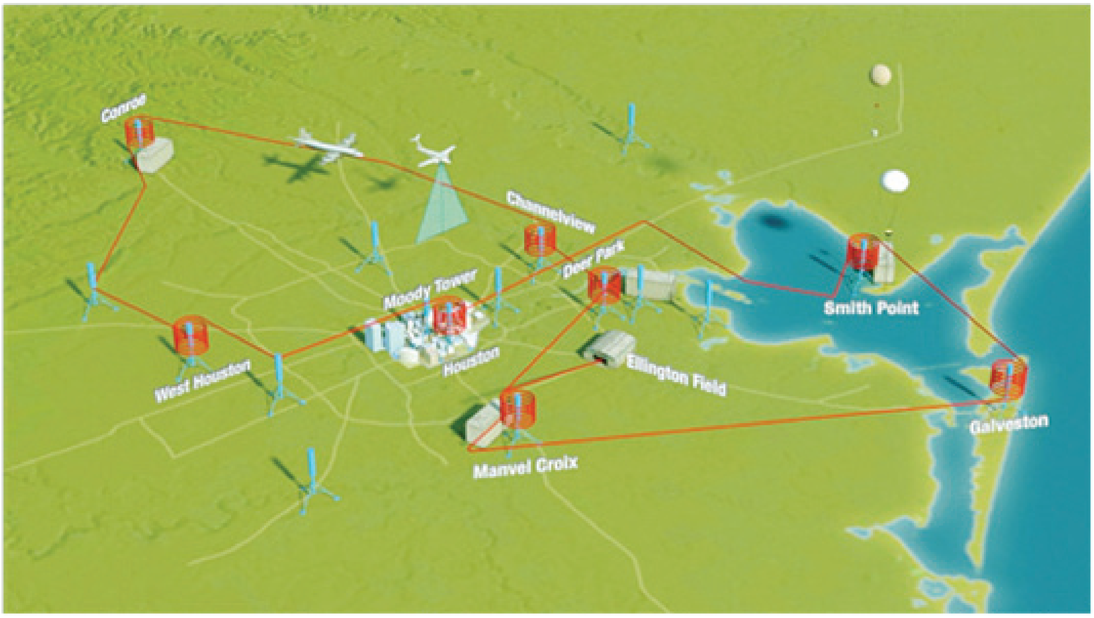


Figure 17. Schematic map of the DISCOVER-AQ 2013 Houston campaign area.

Houston under the right meteorological conditions. Houston also offered a new opportunity to test small sensors capable of monitoring ozone and nitrogen oxides. These sensors represent the first viable technology that could enable citizen scientists to monitor their own air quality. Sensors were deployed by both DISCOVER-AQ and partners at EPA. Sensors were distributed in a dense network through placement at schools in Houston's ship channel area where petrochemical activities and emissions are concentrated. This activity led to a high level of interest from local students who enjoyed chatting with the plane and having scientists visit their classrooms as they participated in the experiment by taking care of the sensors to keep them charged and placed outside each day. Two of the schools sent nearly 300 students to visit and tour the aircraft and mobile labs at Ellington Field.

During DISCOVER-AQ, the IIP-sponsored instrument GEO-TASO flew on the HU-25 Falcon for several flight days collecting aerosol and trace gas data relevant for the upcoming TEMPO and GEO-CAPE missions.

UAVSAR

The JPL UAVSAR, flying on NASA's C-20-A accounted for nearly 500 hours of science flight time in 2013.

UAVSAR is a reconfigurable, polarimetric L-band synthetic aperture radar (SAR), specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. Much of the work of the UAVSAR is supportive of the upcoming Earth Radar Mission, the radar portion of DESDynI, but most of the work in 2013 is also immediately relevant to terrestrial ecology, vegetation interests, soil moisture, and vulcanology, in addition to Earth Surface and Interior interests in land movements and faults.

Many of the missions were flown from the home base of the C20-A at the Dryden Aircraft Operations Facility (DAOF) in Palmdale, but there were also several deployments to other bases and international facilities, as shown in Table 3.

Location	Science	Flight hours
Alaska / Japan	Volcano studies	50.7
New Orleans (2 times)	Gulf coast studies	46.5
Costa Rica, Ecuador, and Chile (2 locations)	Vegetation and volcano studies	118.5
Alaska	Volcano studies	26.3
Hawaii	Volcano studies	29.7

Table 3. UAVSAR Deployments in 2013

UAVSAR Central and South America Deployment March 7 - April 4, 2013

The C-20A completed a 28-day deployment to Central & South America (March 7th - April 4th). The deployment contained 21 flights for 118.5 total hours, 8 logistics changes in 4 different countries. Science (Volcanoes, Glaciers, SMAP, Mangrove Mapping, Wetland Delineation, Levee, Subsidence, Vegetation, etc.) was collected over 13 different countries against 13 different Flight Requests. The Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR), developed and operated by NASA's JPL, collected 100% of the planned data lines. The mission was a complete success.

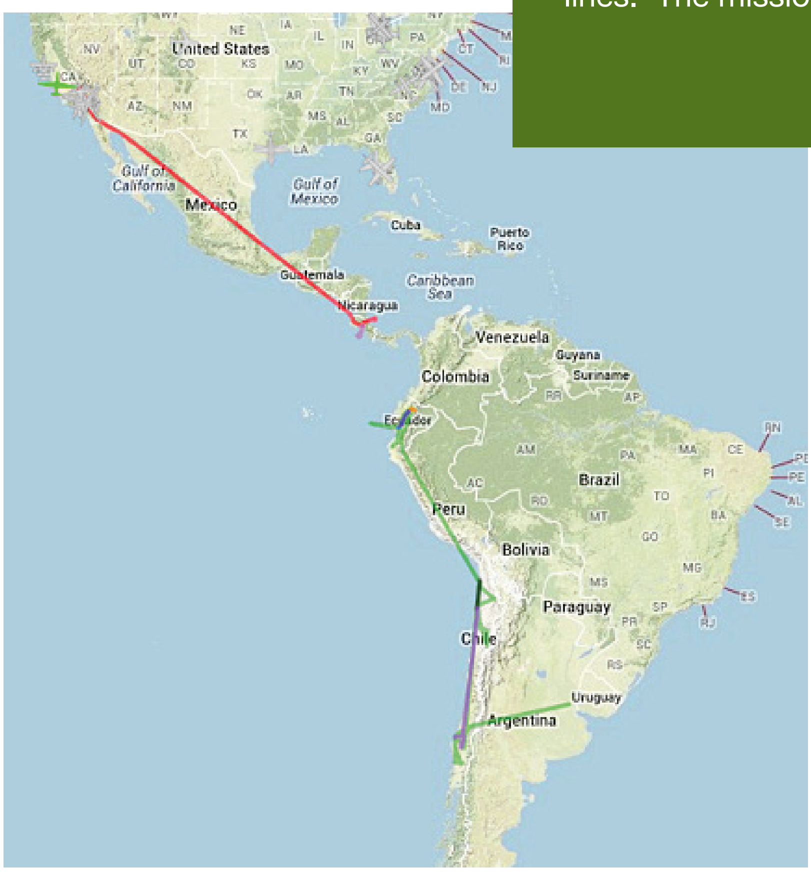


Figure 18. UAVSAR flight tracks for the Central and South American deployment.

Support to ESD Satellite Missions, including Decadal Survey Missions

One 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 measurements or observations once in orbit. In 2013, ASP provided support to the Earth Science missions listed in Table 4. This included significant flight hours for upcoming Decadal Survey missions.

Satellite	How supported	Flight hours
HyspIRI	AVIRIS and MASTER in HspIRI Prep studies; AVIRISng, PRISM, HYTES	228
ICESat - 2	Flights of MABEL and GLISTEN-A	57
SMAP	UAVSAR to Argentina cal/val site	31
ACE	PODEX	50
CALIPSO	HSRL & RSP / Calipso cal/val	58
SWOT	AirSWOT flights; Sacramento River	25
ASCENDS	CO2 instruments test flights	37
GEO-CAPE	GEO-TASO flights in conjunction with DISCOVER-AQ	32
ASTER	DragonEye flights in Costa Rica	3

Table 4. Efforts focused primarily to support ESD Satellite Missions, including Decadal Survey Missions.

HyspIRI Preparatory Airborne Studies

NASA Earth Science Division within the Science Mission Directorate selected proposals using airborne measurements resulting from airborne campaigns in FY2013 and FY2014. NASA plans to launch the Hyperspectral Infrared Imager (HyspIRI) satellite -- a mission recommended by the 2007 National Academy of Sciences Decadal Survey -- to determine the spectral and thermal characteristics of the world's ecosystems. Prior to flying the sensors in space, however, preparatory science investigations are underway using similar sensor technology installed on NASA's ER-2, a high-altitude aircraft based at NASA's Dryden Aircraft Operations Facility in Palmdale, Calif. For these campaigns, NASA flew the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER Airborne Simulator (MASTER) instruments on a NASA ER-2 aircraft to collect precursor datasets in advance of the HyspIRI mission. NASA solicited proposals using airborne data to address one, or more, science or applications research topic aligned with the science questions for the HyspIRI Mission. A goal of this solicitation was to generate important science and applications research results that are uniquely enabled by HyspIRI-type data, taking advantage of the contiguous spectroscopic measurements of the AVIRIS, the full suite of MASTER TIR bands, or combinations of measurements from both instruments. NASA received a total of 49 proposals and selected 14 for funding at this time. The total funding to be provided for these investigations is approximately $6.3 million over three years.

The HyspIRI Airborne Preparatory campaign is conducting three seasonal flights over large geographic regions of California for a minimum of two years. The HyspIRI Preparatory Airborne Science Team held a meeting in November 2012 at the University of California, Santa Barbara (UCSB). The fourteen Principal Investigators and their research groups attended the three-day meeting to develop the six study areas for flights over the 2013 and 2014 flight seasons. A wide range of investigations covered by the HyspIRI Preparatory Airborne team, including Atmospheric, Ecology, Forestry, Geography, Geology, and Oceanography. Also attending the UCSB meeting was the NASA Headquarters Program Manager Woody Turner, representatives from the HyspIRI Steering Committee, and NASA Dryden ER-2 team members. At the conclusion of the meeting the six study areas were defined, which included five "boxes" that simulated a potential HyspIRI image area and one "soda straw" that follows a potential HyspIRI satellite track. The boxes cover a wide geographical gradient that represents diverse ecological, geological, and oceanographic zones across the state of California and some of Nevada. Figure 19 shows the five boxes and the soda straw on a map of California. These sites are titled Tahoe, San Francisco Bay Area, Santa Barbara, Southern California, Yosemite/NEON, and the Soda Straw. The Santa Barbara Box is approximately 7,300 square miles, the Yosemite/NEON Box is approximately 6,800 square miles, the Tahoe Box is approximately 6,000 square miles, the Bay Area is approximately 13,000 square miles and the Southern California Box is approximately 15,000 square miles.

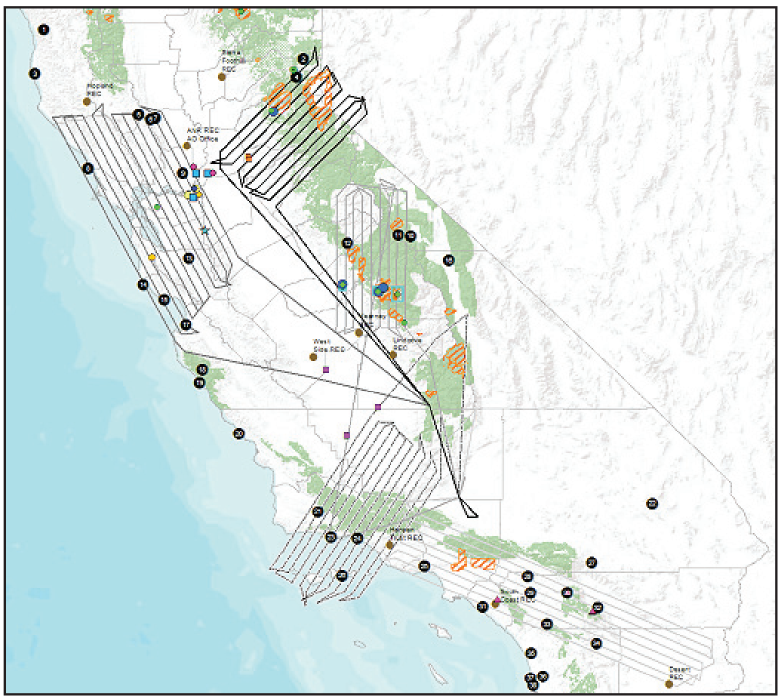


Figure 19. Map of HyspIRI Preparatory Airborne Study sites in California and Nevada.

ICESat-2

ASP flights also supported the upcoming ICESat-2 mission, by flying MABEL and GLISTEN-A.

Multiple Altimeter Beam Experimental Lidar (MABEL)

MABEL is the airborne simulator for the ICESat-2 ATLAS instrument. It flew on the Scaled Composites Proteus aircraft for the first time in 2013. (See Figure 20.) Instrument test flights took place in California, and then the aircraft moved from Mojave to LaRC. Deployment to Greenland had been planned, but all flights were staged out of Hampton, VA. September flights focused on collecting vegetation data, both day and night collections. The flight track for September 25 is shown in Figure 21.

Figure 20. MABEL instrument in Proteus pod.

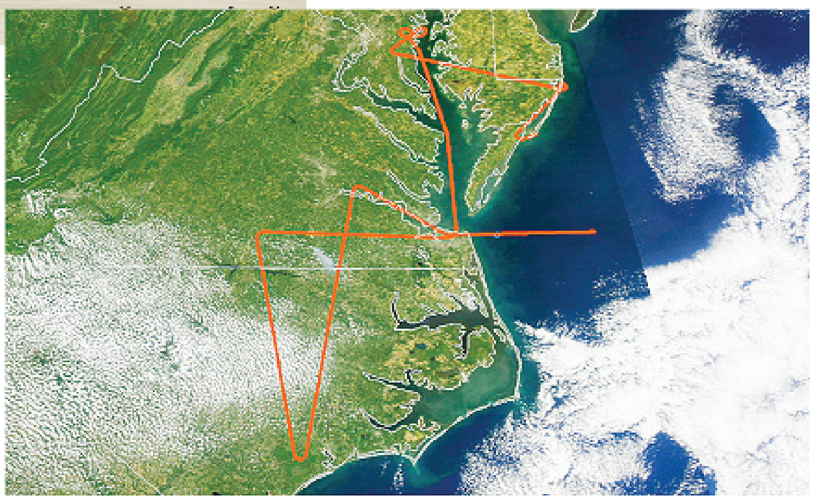


Figure 21. MABEL flight track on Proteus, September 25, 2013.

GLISTIN-A

The Airborne Glacier and Land Ice Surface Topography Interferometer (GLISTIN-A), developed by PI Delwyn Moller of Remote Sensing Solutions, is a swath-mapping Ka-band interferometer that has been configured for the UAVSAR pod. It flew in 2013 on the DFRC G-III and could also fly on the Global Hawk. The 2013 Alaska campaign had the following objectives:

1) Map glacial zones to demonstrate improved altimetric wide-swath mapping capability in the cryospheric environment;
2) Mapping tidal glaciers to support science rationale for a future operational concept;
3) First experimental mapping of sea-ice demonstrating free-board measurement viability;
4) Underfly CryoSAT II for satellite cal/val, and to quantify differential penetration; and
5) Along the way, ollect snow-cover DEM's at the SnowSTAR and Airborne Snow Observatory (ASO) Tuolumne campaign sites for snow inventory assessment.

The mission was able to accomplish these objectives, flying five glaciers in southern Alaska, an under flight of MODIS, an under flight of CryoSAT, and the first sea ice mapping in the Beaufort Sea, as shown in Figure 22.

- First data of its kind: 6 lines collected in total (16800 km2 mapped)
- Height accuracy ranges from 15cm near- to 1.5m far-range (3m x 3m posting).
- Near-nadir data is proof-of-concept to SWOT "secondary science" for sea-ice free-board measurement

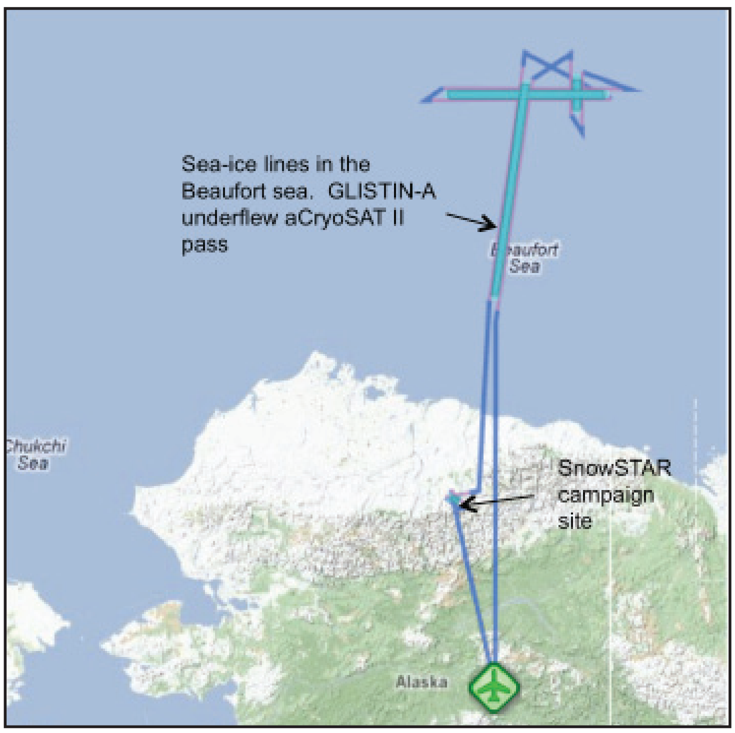


Figure 22. GLISTIN-A flight lines, May 2013.

PODEX

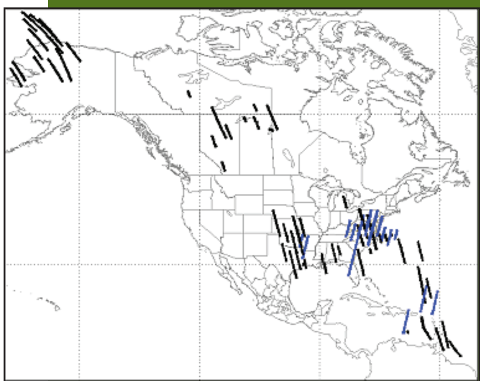
PODEX is the Polarimeter Definition Experiment. It supports the selection of a polarimeter for the Aerosol-Cloud-Ecosystem (ACE) mission, which is one of the Decadal Survey missions. It occurred from January 14 to February 6, 2013, from the Dryden Aircraft Operations Facility (DAOF) in Palmdale. The period was chosen such that PODEX could benefit from in-situ (P-3) and remote sensing (B-200) aerosol observations for DISCOVER-AQ that operated from DAOF during this time. The goal of PODEX was to acquire quality aerosol and cloud scenes to support algorithm development and maturation for three distinct airborne polarimeters that serve as early concepts for a polarimeter envisioned to fly on the Aerosols, Cloud and Ecosystem (ACE) mission in the next decade, i.e., a pre-formulation activity. The ER-2 payload included the three polarimeters: the Research Scanning Polarimeter (RSP, Brian Cairns/GISS), the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI, Dave Diner/JPL), and the Passive Aerosol and Cloud Suite (PACS, Vanderlei Martin/UMBC). (See Figure 23.) Also flown were the Cloud Physics Lidar (CPL, Matt McGill/GSFC) and the Autonomous Modular Sensor (AMS, Jeff Myers/Ames). AMS enables retrievals of cloud and aerosol to process MODIS data from Terra and Aqua while CPL, a CALIPSO simulator, provides definitive measurements of aerosol and cloud location in the vertical and an independent estimate of aerosol optical properties. Ten PODEX ER-2 missions were flown including 7 flights at least partially coordinated with DISCOVER-AQ over the San Joaquin Valley, 2 flights focused on stratus clouds over the ocean, 2 flights attempting clear scenes over the ocean and one flight focused on cirrus over the ocean. The San Joaquin Valley samples provided excellent aerosol targets (AOD ~ 0.1-0.25) over a variety of surface types (agricultural to urban) and brightness, including a case where the scene was somewhat obscured by cirrus. One stratocumulus case was excellent and well supported by the DISCOVER-AQ P-3.

Overall, PODEX acquired most of the desired scenes and conditions. The performance of the aircraft and crew was great, as was the cooperation with DISCOVER-AQ.

Figure 23. During a test phase for the PODEX experiment, engineers and the crew at Dryden Aircraft Operations Facility loaded the Research Scanning Polarimeter into the "superpod," for placement under the wing of the ER-2.

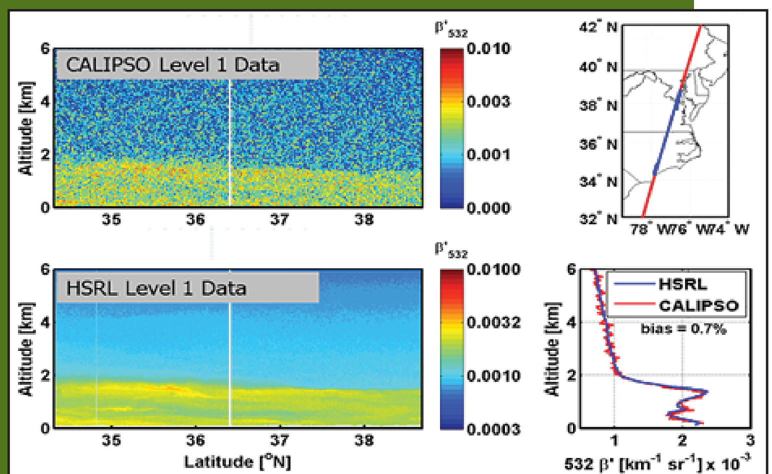
Support for CALIPSO 2006-2013

Between 2006 and the present the LaRC Airborne High Spectral Resolution Lidar Generation 1 (HSRL-1) instrument has flown 109 validation underflights of the CALIOP lidar on the CALIPSO satellite. These flights were conducted on the NASA Langley B-200 and UC-12 aircraft and acquired 151 hours of lidar data along the CALIPSO track, providing over 54,000 independent, co-located HSRL profiles for validation comparisons with CALIOP. The underflights cover a wide season and geographical range, which are highlighted in the first figure below. The daytime tracks are indicated in black (seventy five flights) and the nighttime flights in blue (thirty four flights).

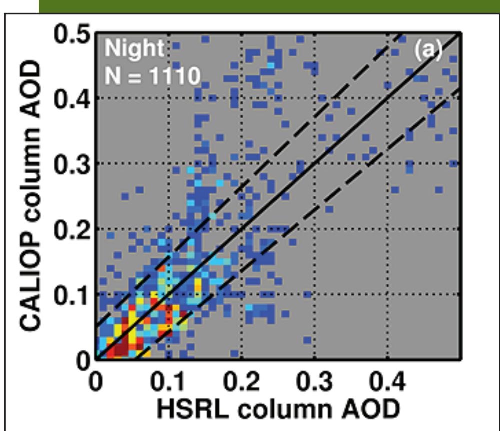


Underflights with a nadir-viewing lidar are critical for validation of CALIOP products. There are no passive radiometric or in situ instruments that provide comparable data on the fundamental measurement made by CALIOP: 180° backscatter from molecules and suspended particles (i.e., aerosol or cloud particles). Moreover, for assessment of this fundamental measurement and its calibration, the viewing geometry must be identical to that of the satellite, which requires viewing the atmosphere from above. Also, as CALIOP is a zero-swath, nadir-only instrument, acquiring sufficient statistics for validation requires sampling along the CALIOP track, as opposed to placing ground-based sensors at one location on the track. Additionally, CALIPSO is affected by solar background and both daytime and nighttime measurements are required the assessment of the CALIPSO data products with different levels of noise.

The figure also shows an example calibration comparison from the nighttime flight of 9 February 2009 (CALIPSO flight track in red, HSRL in blue). The color plots show the level 1 data from CALIPSO and HSRL. The warmer colors in these plots correspond to higher aerosol loading (in this case pollution and natural aerosol close to the ground) and the cooler colors indicate fewer aerosols (typical, but not always the case in the free troposphere). The line plot provides the average profile of the level 1 data products for each instrument and shows the excellent agreement between the two measurements.



The airborne HSRL-1 dataset is also used for validation of the CALIPSO level 2 geophysical products such as aerosol extinction and aerosol optical depth (AOD). These are key optical parameters that indicate aerosol loading and radiative effects and are used to understand the effect of aerosols on both health and climate. The high spectral resolution lidar technique employed on HSRL-1 differs from the standard backscatter technique used on CALIOP and provides an important benefit for level-2 validation as it provides a more direct measurement of the geophysical products retrieved from the CALIOP data. The seasonal and geographical range covered in this dataset allow the CALIOP level 2 retrievals to be assessed statistically, e.g., as a function of aerosol type and loading, in addition to profile-by-profile comparisons. This extensive validation record has been extremely valuable to the CALIPSO science team as they continue to refine retrieval algorithms and improve the quality of CALIOP level 2 data products. As with the level 1 validation, underflights along the CALIPSO ground track is the optimal way to acquire sufficient independent samples for meaningful validation comparisons. The figure to the left shows the resulting comparison of all nighttime level 2 AOD data from CALIPSO and HSRL, gridded to 5 km. The solid line is the one-to-one line representing perfect agreement between CALIPSO and HSRL and the dashed lines encompass 68% of the data. Deviations from this line are due to noise or systematic biases in CALIPSO and are studied in detail to improve the CALIPSO algorithms where possible.

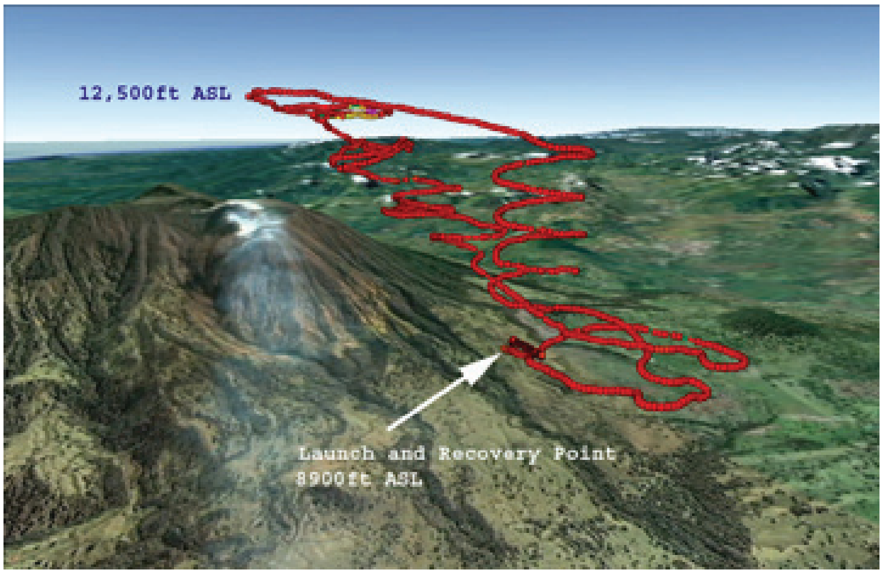


Contributed by Chris Hostetler and Ray Rogers

TERRA / ASTER

DragonEye UAS in Costa Rica in March 2013

DragonEye UAS flew in Costa Rica in March 2013 during a simultaneous flight of NASA's TERRA spacecraft. UAV payload included the standard military visible and infrared video cameras plus sulfur dioxide and particle sensors, and automatic atmospheric sampling bottles keyed to measure sulfur dioxide concentration. Flights ranged up to 12,500 feet ASL, more than 2,000 feet above the Turrialba summit as shown in Figure 24. Researchers operated the UAV, directing it into the volcanic plume to characterize its chemical and physical environment. This capability was especially important during simultaneous flights with the ASTER imaging radiometer, which was also measuring sulfur dioxide.



Figures 24. Flight lines of Dragon Eye UAS over the Turrialba Volcano, near San Jose, Costa Rica, to measure sulfur dioxide.

UAS-Enabled Earth Science

In 2013 all three projects selected in the ROSES 2011 A40 solicitation were completed. The missions were selected to test the utility of unmanned aerial vehicles (UAVs) for enabling science measurements. The project details are shown in Table 5.

Mission	PI / Institution	UAS	Study Location
Earthquake Hazards	Jonathan Glen / USGS	SIERRA	Surprise Valley, CA
		SWIFT / XCAV	Surprise Valley, CA
Sea Grass / Coral Reefs	Stan Herwitz / UAV Collaborative	Bat-4	Cedar Key, FL
		SIERRA, Vision	Key West, FL
MIZOPEX	James Maslanik / University of Colorado	Scan Eagle, CUMAV	Oliktok Point, AK
		SIERRA	Oliktok Point, AK

Table 5. UAS Enabled Earth Science missions

Earthquake Hazards

The "Long-term earthquake hazards and groundwater resources in a tectonically active region: Critical insights from UAS" project involved a collaboration of USGS, NASA-Ames, and Carnegie Mellon University researchers to design and implement a technique for collecting geophysical data more efficiently and effectively using unmanned aerial systems (UAS). This is an innovative use of UAS that has the potential to greatly increase the quality, quantity, and resolution of data collected while significantly reducing the costs and risks associated with manned surveys. The team chose to apply this technique in a geothermal area in Surprise Valley, CA to map faults and fractures in the sub-surface that may be controlling fluid circulation.

The primary goal of this project was to map paths for groundwater flow and characterize seismic hazard potential in Surprise Valley, CA by utilizing NASA's experimental UAS to collect high-resolution magnetic data along faults and fracture systems. This involved developing intelligent autonomous airborne technology capable of acquiring data in areas inaccessible to ground-based surveys, and performing prolonged operations in a low-altitude, low-speed flight regime that would otherwise poses risks to the pilot and crew.

Additional goals were: 1) testing different platforms to identify which had the optimal characteristics for performing aeromagnetic surveys, and 2) developing intelligent, payload- directed flight (PDF) control to enable the UAS to respond autonomously to sensor input, allowing it make real time flight modifications to focus on features of interest or to avoid hazards.

By the completion of the project the team had developed and tested 3 independent UAS (SIERRA, Swift, and XSCAV) and field deployed two of them. The first and primary science mission, flown with the SIERRA UAS in the summer of 2012, had far exceeded expectations in data return and quality such that the major geologic research goals had been met by the first year of the project. This mission also demonstrated that the SIERRA performed at levels comparable to that of high-resolution commercial surveys.

The second mission, flown with the XSCAV, shown in Figure 25, in the summer of 2013, resulted in the demonstration of a second platform, and significant progress in development of the PDF architecture and simulation testing of PDF control. However, before that mission was completed, the aircraft crashed during calibration flights on the third day of field deployment. As a result, the team was unable to field-demonstrate the PDF system. Nonetheless, the development, testing, and successful deployment of the XSCAV, development and ground testing of a third UAS (Swift), and development of the PDF flight control system, represent substantial steps toward providing the geoscience community with a relatively

Figure 25. The XSCAV UAS modified for Payload-Directed Flight.

low cost system for collecting high resolution geophysical data sets that are more complete and of higher quality than is presently possible with commercial surveys which are inflexible to modification to meet scientific objectives, and which pose risks to pilot and crew. The data collected during these missions have enabled the project to resolve geologic structures (i.e., to determine their geometry and extents) to an unprecedented degree.

Seagrass / Coral Reefs

Another of the projects selected, titled "High Resolution Assessment of Carbon Dynamics in Seagrass and Coral Reef Biomes," was led by Principal Investigator (PI) Stanley R. Herwitz, Ph.D., Director of the UAV Collaborative. The project was managed by Dr. Randy Berthold of NASA Ames.

The research goal of the NASA ROSES Seagrass/Coral Reef UAS Project involved testing the utility of UAS technology, particularly as it relates to assessments of change in seagrass and coral reef biomes. The team of investigators, completed experimental work in Florida in May. Detailed airborne and water-based datasets have been systematically collected from representative seagrass and coral reef sites on the Gulf Coast and in the Florida Keys. A total of 26 UAV flights involving 3 different UASs equipped with different multispectral and hyperspectral imaging payloads were completed in 2013.

The airborne data collection effort has featured four UAS deployments. Deployment #1 in May 2012 featured the fixed-wing Bat-4 UAV operated by MLB Company. The Bat-4 was equipped with a Tetracam multispectral imaging system. Deployment #2 in October 2012 featured the fixed-wing SIERRA UAV operated by NASA Ames. Operating from the Key West Naval Air Station under an agreement with the U.S. Navy, the SIERRA acquired more than 320 gigabytes of data using a Galileo hyperspectral imaging system. Deployment #3 in November 2012 featured the Bat-4 equipped with the Tetracam operating in the area of Cedar Key north of Tampa.

Deployment #4 to the Florida Keys in May 2013 featured a jet-engine powered rotorcraft UAS named "Vision-II." This slow, low-flying platform, shown in Figure 26, was equipped with a downward-looking NovaSol hyperspectral sensor. Flight operations were carried out in two locations: one for the seagrass observations and a second, separate location for the coral reef observations. The seagrass measurements were conducted along the shoreline of Sugarloaf Key. Flight operations for the coral reef site were conducted from a floating barge strategically positioned offshore in the protected Cheeca Rocks marine sanctuary. (See Figure 27.) A total of 12 successful morning and afternoon takeoff and landing sequences of the Vision-II were conducted at these two sites, with each flight sequence being 30-40 minutes in duration. The Vision-II acquired more than 500 gigabytes of data using the NovaSol hyperspectral imaging system.

The research achievement was the collection of high-resolution airborne spectral data using UAV-based hyperspectral and multispectral sensors in synchrony with intensive field measurements used to characterize current biological conditions. Information that increases our understanding of the spatial distribution and vigor of seagrass and coral are of particular interest. Analysis of the extensive datasets collected during all the phases of this mission is currently in progress, with results expected for publication within the next year.

Figure 26. Vision II UAS carrying NovaSci hyperspectral imager.

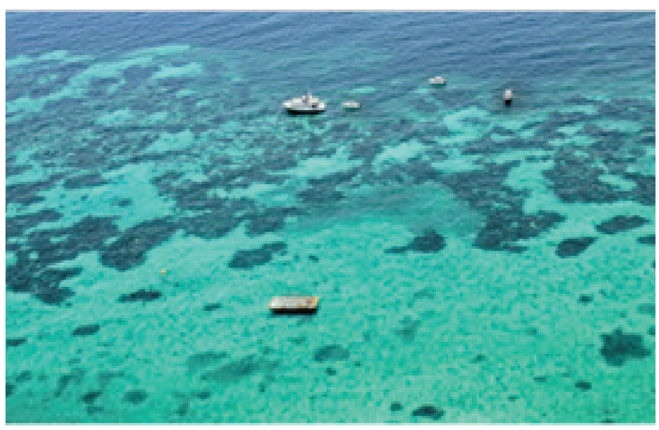


Figure 27. Aerial view of Cheeca Rocks reef, the barge serving as the UAV launch pad, and the project's associated research vessels.

MIZOPEX

The Marginal Ice Zone Ocean and Ice Observations and Processes Experiment (MIZOPEX) mission was completed in the summer of 2013.

MIZOPEX completed flights with 3 types of UAVs over the Alaskan Arctic Ocean in July-August 2013. The project goal was to assess the utility and challenges of using different classes of UAVs to characterize Arctic sea ice and ocean temperatures. The low-cost University of Colorado (CU) DataHawk was configured for water landing to collect insitu ocean temperatures, ScanEagles operated by University of Alaska – Fairbanks (UAF) obtained thermal and visible-band imagery and deployed miniaturized buoys to measure ocean subsurface temperature profiles, and the larger NASA SIERRA was fitted with multiple payloads that included radar, thermal imagers, lidar, cameras and energy- budget sensors.

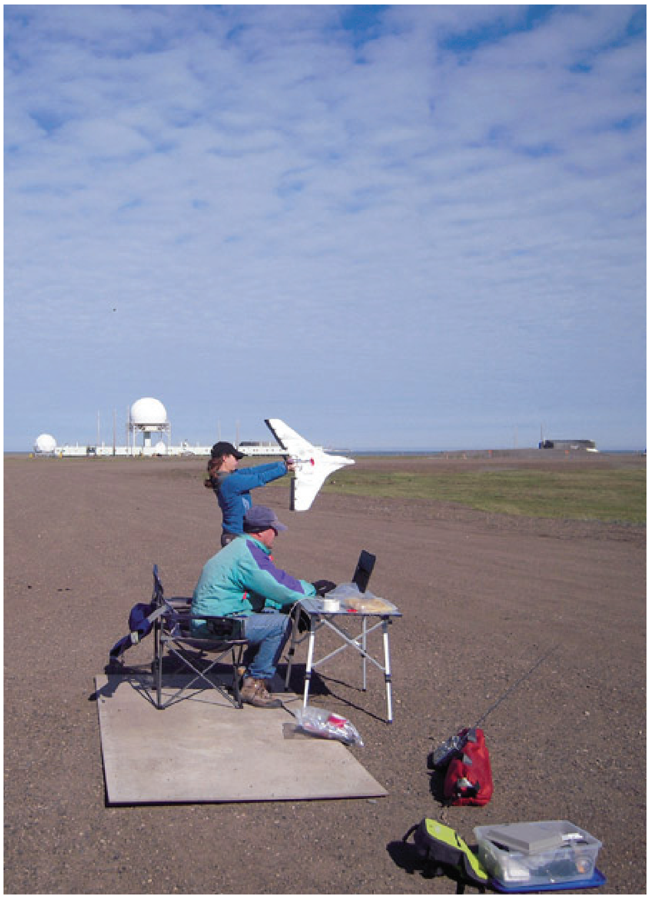


Figure 28. Pre-flight check of CU's DataHawk electric powered UAV. The USAF Oliktok Point facility is seen in the the background.

The mission was notable for exercising the first civilian FAA Certificate of Authorization (COA) to use ground radar as a sense-and-avoid method for transiting from restricted airspace into the National Airspace System. The COA also included a corridor, reaching from the Department of Energy facility at Oliktok Point, to international waters. In all, the project accomplished 23 flights using the 3 different UAVs. Unfortunately the SIERRA was lost during its second flight. The accident is under investigation.

Preliminary results show that the combination of remote sensing and MIZOPEX buoy measurements was able to measure the evolution of subsurface and surface ocean temperatures, while thermal imaging captured complex effects of melting floes on surrounding open-ocean temperatures. Deploying 2 ScanEagles at the same time proved to be an effective means of collecting coincident data with different payloads.

The MIZOPEX PI is Jim Maslanik from the University of Colorado. The mission was managed by Dr. Randy Berthold from Ames Research Center.

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 2013, ASP aircraft flew all of the instruments listed in Table 6. Many of these instruments have been developed under sponsorship of NASA's Earth Science Technology Office (ESTO).

Instrument	Sponsor	Aircraft	Flight Hours
4-Star / TCAP	Radiation Science Program	PNNL G-1	3.2
AirSWOT/KaSPAR	ESTO; Water & Energy	B-200 (D)	31.6
ASCENDS CO2 candidates	Atmospheric Composition	DC-8	37.3
AVIRIS ng	Terrestrial Ecology	Twin Otter	44.8
DAWN, DAWN-II	LaRC	B-200 (L)	45.8
eMAS	EOS	ER-2	6.3
ESFL	Earth Surface and Interior	Twin Otter	14.9
EXRAD	ESTO AITT	ER-2	12.1
GEO-TASO	ESTO	Falcon	31.9
GLISTIN-A	Earth surface and Interior Cryosphere	G-III (D)	30.7
HDSS	Radiation Science Program	DC-8	0.1
HSRL-1; RSP	ESTO; Earth Surface and Interior	P-3	58.3
HYTES	Terrestrial Ecology	Twin Otter	54.4
LVIS	ASP	C-130	5.7
MABEL	ICESat-2	Proteus	74.3
Polarimeters (PODEX)	Radiation Science Program	P-3, ER-2, B-200 (L)	74.4
SSFR	ESTO	ER-2	1.3
TOTAL:			**527.1**

Table 6. ASP Support to Instrument Development.

Upcoming Activities

In 2014, Operation IceBridge continues in Antarctica, Greenland and Alaska, with the P-3 landing at McMurdo in Antarctica. In FY14 a number of the Earth Venture-1 missions will complete the airborne portions of their programs. These include ATTREX, DISCOVER-AQ and HS3. ATTREX mission flies from Guam in 2014, the first non-CONUS deployment of the NASA Global Hawk. DISCOVER-AQ will continue in Colorado, and HS3 returns to the Atlantic. Both CARVE and AirMOSS continue in FY14 and FY15.

Earth Venture Suborbital-2 will begin with awards in 2014. Flight schedules and aircraft will depend on the selected projects.

Aircraft

NASA maintains a fleet of aircraft for scientific activities, primarily for Earth Science.

The Airborne Science program is responsible for monitoring the status of the aircraft, which are housed 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.

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	2	2,000	15,000	45,000	350	1,000	http://airbornescience.nasa.gov/aircraft/Learjet_25
	S-3B Viking	NASA/GRC	6	12,000	52,500	40,000	350	2,300	http://airbornescience.nasa.gov/aircraft/S-3B
	SIERRA	NASA-ARC	10	100	400	12,000	60	600	http://airbornescience.nasa.gov/platforms/aircraft/sierra.html
	T-34C	NASA-GRC	3	100	4,400	25,000	150	700	http://airbornescience.nasa.gov/aircraft/T-34C
	Twin Otter	NASA-GRC	3	3,600	11,000	25,000	140	450	http://airbornescience.nasa.gov/aircraft/Twin_Otter_-_GRC
	WB-57	NASA-JSC	6.5	8,800	72,000	60,000+	410	2,500	http://airbornescience.nasa.gov/aircraft/WB-57

Table 7. Airborne Science Program aircraft and their performance capabilities.

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 7. The altitude / endurance characteristics are also shown in Figure 29.

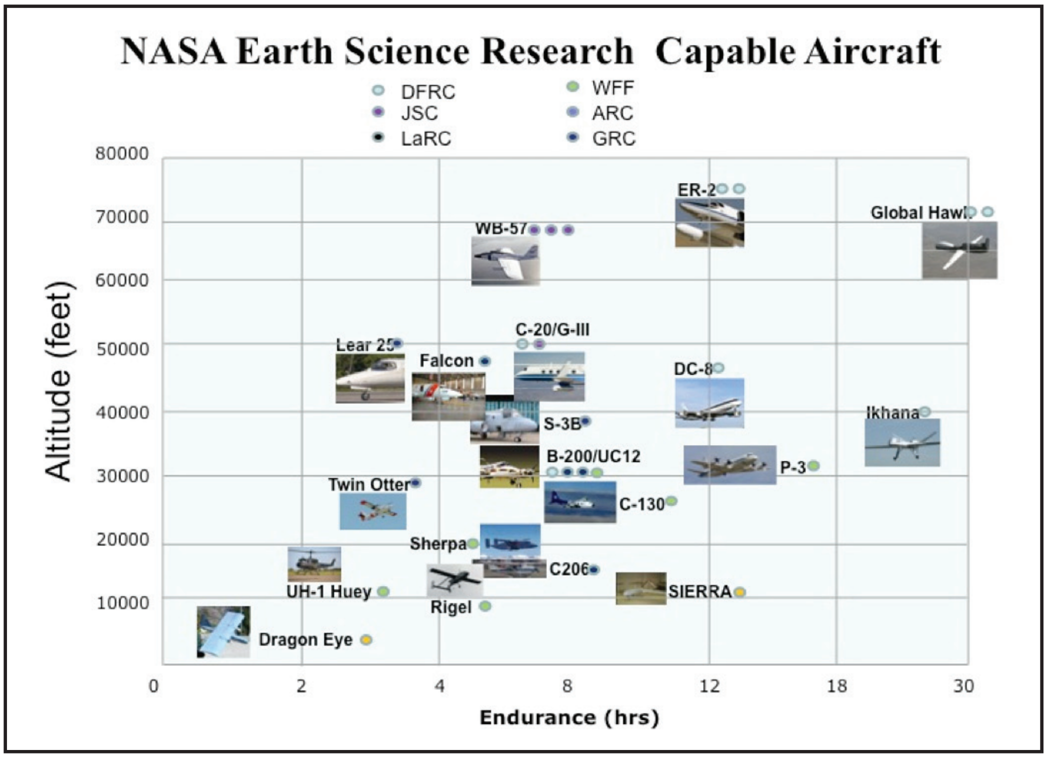


Figure 29. Flight characteristics of NASA aircraft.

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, JSC G-III, and (2) Global Hawk unmanned aircraft systems (UAS).

DC-8

The NASA DC-8 flying laboratory is a four-engine jet transport aircraft that has been highly modified to support the agency's Airborne Science mission. The aircraft, acquired in 1985, is 157 feet long with a 148-foot wingspan. With a range of 5,400 nautical miles, it can fly at altitudes from 1,000 to 42,000 feet for up to 12 hours, although most science missions average six to 10 hours. The DC-8 can carry 30,000 pounds of scientific instruments and equipment and can seat up to 45 experimenters and flight crew.

Figure 30. DC-8

The DC-8 incorporates a suite of sensors and data systems and provides services that can be tailored to specific missions or instruments. The DC-8 also has Iridium and Inmarsat satellite communications capability. Two Iridium-based communications systems, one for flight crew communications and one for science team communications, a multichannel system for upload of meteorological data, chat messaging, limited data telemetry and live Web page updates are available.

Figure 31. SEAC4RS End Of mission DC-8 Team Picture.

The NASA DC-8 flight operations are provided by NASA /Dryden Flight Research Center based out of the Dryden Aircraft Operations Facility in Palmdale, CA. The University of North Dakota National Suborbital Education and Research Center (NSERC) provides science mission operations including payload integration engineering, data display and satcom systems and support, and education and outreach for the program. University of California Santa Cruz also supports the DC-8 with engineering of optical windows, networks, and other activities.

DC-8 FY13 Activities

Flight hours in FY13	476.3 hrs
Missions and locations	• Operation IceBridge Antarctica; Puenta Arenas, Chile • ACCESS, Palmdale • ASCENDS 2013, Palmdale • SARP, Palmdale • SEAC4RS, Houston
Modifications and impacts	Controller-Pilot Data Link Commmunications (CPDLC) avionics installation complete through satellite link connectivity. This capability was originally implemented to support the planned SEAC4RS Southeast Asia missions. This system allows digital long-range communication with air traffic control and is soon to be a requirement around the globe as the Future Air Navigation System (FANS) is implemented. For the science teams it means quicker response times and a clearer means of communication for requesting real-time route and altitude changes even in oceanic areas where communicating these requests can be difficult.
Maintenance schedule	This year the DC-8 is moving to a new Low Utilization Maintenance Plan (LUMP) approach to performing maintenance. As the DC-8 comes out of its Heavy C Check in spring 2014 the DC-8 project will be able to map out planned calendar based inspection events looking more than 10 years out. This new maintenance plan will also support flexibility in moving inspection periods to allow maximum ability to support planned science missions
Website	http://airbornescience.nasa.gov/aircraft/DC-8

P-3 Orion

The NASA Goddard Space Flight Center's Wallops Flight Facility operates a P-3 Orion research aircraft to support airborne science research. Wallops Flight Facility has operated the P-3 since 1991 in support of a variety of scientific studies including ecology, meteorology, atmospheric chemistry, cryospheric research, oceanography, soil science, biology, and satellite calibration/validation. The P-3 is also used as a technology test bed for new airborne and satellite instrumentation. The P-3 is a self-sufficient global reaching aircraft that can operate from civilian and military airports to remote areas of the world in support of scientific studies.

Figure 32. P-3 Orion

P-3 Orion FY13 Activities

Flight hours in FY13	462.3 science hours, 494.2 SMD-funded hours
Missions and locations	• HSRL and RSP AITT Mission, Azores • DISCOVER-AQ California, Palmdale • PODEX, Palmdale • OIB Arctic, Thule and Kangerlussuaq, Greenland • DISCOVER-AQ Texas, Houston
Modifications and impacts	A new avionics package was installed in the aircraft in June 2013. The new system provides Iridium based voice, text, and weather graphics capability in the flight station; a Terrain Awareness Warning System; synthetic vision capability for use in low visibility situations; five new cockpit displays; and a new Flight Management System that allows for easier input of waypoints and flight lines. The installation of the new avionics systems also resulted in an increase of 200lbs to the P-3 payload capacity due to the removal of the original larger and previous avionics units.
Maintenance schedule	• Annual Maintenance: 12/9/13 – 1/30/14, September 2015, Fall 2016, Fall 2017, Fall 2018 for approximately 4 weeks (Fall 2016, 2017, and 2018 maintenance can moved to accommodate science missions) • Aircraft Re-Wing: 8/19/14 – 8/19/15
Website	http://airbornescience.nasa.gov/aircraft/P-3_Orion

The P-3 is a four-engine turboprop aircraft designed for endurance and range and is capable of long duration flights. The P-3 has been extensively modified to support airborne science related activities. Aircraft features include zenith ports, three nadir ports (aft of the wings), and eight P-3 and DC-8 style windows to mount experiments, a tail cone, nose radome and ten mounting locations on the wings. Most of the fuselage ports are contained within the pressurized cabin environment. The unpressurized bomb bay can be converted into experimenter ports via a custom fairing. This fairing creates two large nadir ports and several oblique ports for installation of large sensors and antennas.

A project data system is located on the aircraft and provides aircraft data and video throughout the cabin. This system is also connected to two satellite constellations and provides uplink/downlink capability, internet access, flight tracking, and instant messaging between other aircraft and ground assets. Several sensors are connected to the project data system to provide meteorological and aircraft positional data to experimenters. An engineering data system is also integrated into the aircraft along with an air data boom to gather pertinent flight test data to determine effects of installations on the aircraft's flight envelope.

ER-2

NASA operates two ER-2 aircraft as high altitude sensor platforms to collect remote sensing and in situ data on earth resources, atmospheric chemistry and dynamics, and oceanic processes. The aircraft also are used for electronic sensor research and development, satellite calibration and satellite data validation. Operating at 70,000 feet (21.3 km) the ER-2 acquires data above ninety-five percent of the Earth's atmosphere. The aircraft also yields an effective horizon of 300 miles (480 km) or greater at altitudes of 70,000 feet. Consequently, ER-2 sensors acquiring earth imagery or conducting atmospheric sounding replicate spatial, spectral and atmospheric characteristics of data collected by earth observing sensors aboard orbiting satellites.

Figure 33. ER-2

ER-2 FY13 Activities

Flight hours in FY13	480.5 science hours, 508.2 SMD-funded hours
Missions and locations	• PODEX, California • SEAC4RS, Houston • Wildland Fires and Emissions, California • SSFR instrument test, California • AVIRIS-Classic cal/val, California • eMAS integration and validation, California • EXRAD instrument test, California • Cosmic Dust, California • TWiLiTE HS3, California • NPP CfIMSS SDR validation, CA and Mexico • HyspIRI-preparatory mission, California
Modifications and impacts	Added Inmarsat antenna to TN 809 prior to SEAC4RS. This increased significantly the bandwidth for real-time downloading of science data, uploading commands to the science instruments, and monitoring and debugging science instrument issues.
Maintenance schedule	TN 809 - 600 hour inspection, Jan-Mar 2014 TN 806 - 600 hour inspection, Late CY2014
Website	http://airbornescience.nasa.gov/aircraft/ER-2

Figure 34. SEAC4RS end of mission ER-2 Team Picture.

G-III Class Aircraft

The Airborne Science Program supports two G-III class aircraft. Both the Dryden C20-A and JSC G-III are available and capable of offering the same performance for Earth Science.

Figure 35. C20-A with UAVSAR during South American Campaign.

The NASA C-20A (Gulfstream III) is a business jet that has been structurally modified and instrumented by NASA's Dryden Flight Research Center to serve as a multi-role cooperative research platform for the Earth science community and a variety of flight research customers. This particular aircraft, which carried the military designation of C-20A, was obtained from the U.S. Air Force in 2003.

NASA Dryden's G-III is equipped with a self-contained on-board Data Collection and Processing System (DCAPS). DCAPS is designed to allow easy upgrades, addition of add-on systems for expansion, and to operate in both autonomous and manual modes. The aircraft has been used extensively since 2005 to fly JPL's UAVSAR synthetic aperture radar system, which is carried in a pod under the aircraft. It has also carried a Ka-band radar and a P-band radar on some occasions.

Figure 36. JSC G-III carrying AirMOSS in SAR pod.

The Johnson Space Center's Gulfstream III (N992NA) is used to transport astronauts returning from Kazakhstan to Houston, Texas after completing missions aboard the International Space Station. In 2011-2012, the aircraft was extensively modified to accommodate the NASA Jet Propulsion Laboratory's P-band Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) instrument in a pod below the fuselage. The interior was also modified to include equipment racks and crew stations for the UAVSAR and Platform Precision Autopilot (PPA) operators. The P-band UAVSAR instrument is used to study North American root-zone soil moisture as part of the Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) project. AirMOSS is part of the NASA Earth Venture-1 (EV-1) program.

G-III Class FY13 Activities

Flight hours in FY13	890 hours
Missions and locations	• Alaska / Japan Deployment, 10 flights • Oklahoma / New Orlean Deployment, 7 flights • Kona Hawaii Deployment, 5 flights • Central and South America Deployment, 21 flights • Fairbanks Alaska deployment, 5 flights • Fairbanks Alaska Deployment, 5 flights • New Orleans Deployment, 3 flights • Local Flights out of Palmdale: California, Colorado and Mexico Science Flights, pplus engineering flights • AirMOSS, (Saskatchewan, Canada; Howland Forest, ME; Harvard Forest, MA; Duke Forest, NC; Metolius, OR; Marena, OK; Tonzi Ranch, CA; Walnut Gulch, AZ; Chamela, Mexico; La Selva, Costa Rica;
Modifications and impacts	There were no modifications to the C-20A in 2013. There were no modifications to the JSC G-III in 2013.
Maintenance schedule	C-20A • Ops 1&3 Checks: March 2014, 2016, 2018 • Ops 1&2 Checks: March 2015, 2017 • Maintenance Cards (48 Month, Cycle & Hour Cards): October 2014, 2015, 2016, 2017, 2018 JSC G-III Annual MX (6 weeks) each Dec-Jan. Both engines will complete engine calendar extension in CY14. Hush kit installation required by 31 Dec 15. In addition to the general maintenance periods, there is a dedicated six to eight week period for 72-month inspections due in early 2016.
Website	http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Dryden http://airbornescience.nasa.gov/aircraft/G-III_-_JSC

Global Hawk

Figure 37. Global Hawk.

NASA's Dryden Flight Research Center operates two developmental-model Northrop Grumman Global Hawk unmanned aircraft for high-altitude, long-duration Earth science missions. Acquired from the U.S. Air Force, these autonomously flown aircraft are the first and sixth built under the original Global Hawk Advanced Concept Technology Demonstrator development program sponsored by the Defense Advanced Research Projects Agency. The ability of the Global Hawk to autonomously fly long distances, remain aloft for extended periods of time and carry large payloads brings a new capability to the science community for measuring, monitoring and observing remote locations of Earth not feasible or practical with piloted aircraft, most other robotic or remotely operated aircraft, or space satellites.

The aircraft's 11,000-nautical-mile range and 30-hour endurance, together with satellite and line-of-site communication links to the ground control station, allow for eventual worldwide operation. Dedicated satellite communication links provide researchers with direct access to their onboard instrument packages during missions. Researchers have the ability to monitor instrument function from the ground control station and evaluate selected data in real time.

The aircraft are operated in a time-share arrangement with Northrup Grumman that was negotiated as part of the original Space Act Agreement to bring the platforms to DFRC. This explains why the two aircraft are not available full time to the science community.

Global Hawk UAS FY13 Activities

Flight hours in FY13	481 hours
Missions and locations	• HS3, WFF • ATTREX, DFRC • LVIS, DFRC
Modifications and impacts	TN871 deployed for the first time in FY13 when it participated in the HS3 deployment at WFF. Also in FY13, the GHOC-East was completed and used for flight operations during HS3.
Maintenance schedule	TN871 • 75 cycle inspection, 6 weeks, FY15 • 2250 flight hour engine inspection, 6 weeks, FY16 • 75 cycle inspection, 6 weeks, FY18 TN872 • 2250 flight hour engine inspection, 6 weeks, FY14 • 75 cycle inspection, 6 weeks, FY16 • 4000 flight hour engine overhaul, 12 weeks, FY17 • 75 cycle inspection, 6 weeks, FY18
Website	http://airbornescience.nasa.gov/aircraft/Global_Hawk

Development and Operations of the GHOC-East at WFF

NASA's Wallops Flight Facility (WFF) and NASA's Dryden Flight Research Center (DFRC) along with ARC, have jointly developed the Global Hawk Operations Center – East (GHOC-E) located in Building D-1 at WFF. It includes a Flight Operations Room (FOR), where Global Hawk pilots and support staff control the flight of a NASA Global Hawk (GH) unmanned aerial vehicle (UAV) with flight durations of science missions up to 30 hours, and also a Payload Operations Room (POR), where up to 14 scientists control onboard payload instruments during each flight (See Figure 38). GHOC-E also consists of eight racks of electronic support equipment, various roof-mounted antennas, and a 4.9-meter diameter dish Ku-band satcom ground station.

GHOC-E is patterned after the existing GHOC-West located at DFRC, which has an identical console layout in the FOR and POR, and has the same systems configuration and capability. GHOC-E and GHOC-W are connected via a data link, which allows for the control of a GH to be transferred in flight between pilots at the two centers.

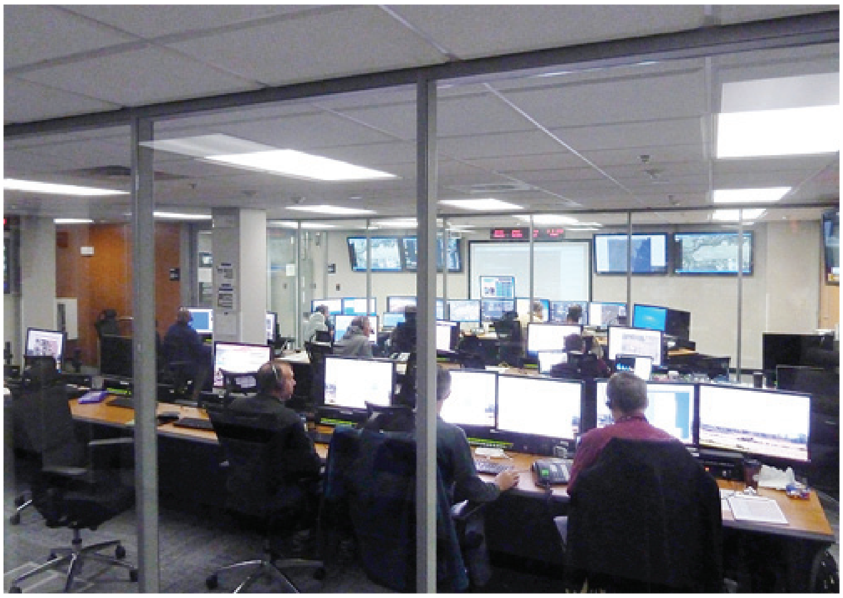


Figure 38. GHOC-East. Flight operations occupy the front portion of the control center, with experimenters monitoring and / or controlling their instruments from the rear portion.

Based on the operational experience at GHOC-W of supporting GH flights since October 2009, the design of GHOC-E was enhanced by increasing the floor space allocated for the FOR and the POR, adding a Pilot's Break Room, adding a larger visitor observation area, adding a support room for the technical staff, and adding a 10-seat conference room.

GHOC-E building renovation was completed by WFF in late April 2013 after a 4-month intensive construction effort, and DFRC then led the integration and test of the electronics into GHOC-E. As part of GHOC-E, WFF procured and installed a fixed 4.9-meter Ku-band satcom ground station at WFF to provide a data link for payload data and pilot voice communications with air traffic control. GHOC-E was certified as operational after a June 7, 2013 test when it successfully sent commands to Global Hawk 872 at DFRC's ramp and received status from that aircraft. GHOC-E was operationally used to support 12 GH science flights for the Hurricane and Severe Storm Sentinel (HS3) mission from WFF plus three ferry flights during the period of August 13, 2013 to September 26, 2013. GHOC-E will be used again to support HS3 flights in August and September 2014, and any future GH missions flown from WFF.

Other NASA Earth Science Aircraft

Other NASA aircraft, as described here and 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.

B-200 Class Aircraft

Three B-200 class aircraft are available for science. These include both a B-200 and a UC-12 operated by NASA LaRC and a B-200 operated by NASA DFRC. The performance envelopes and payload accommodations of the three aircraft are similar. WFF also maintains a B-200 for administration flights.

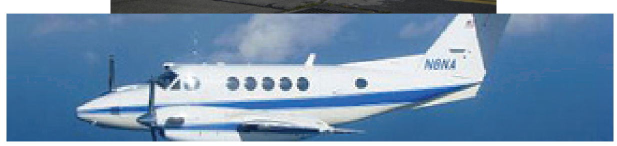


Figure 39. B-200 class Aircraft

Its payload capacity and flexibility make the B-200 class an excellent instrument test and operations platform. Among the instruments flown in 2013 were HSRL-2, DAWN and DAWN II, G-LiHT and AirSWOT.

B-200 Class FY13 Activities

Flight hours in FY13	307.5 hours
Missions and locations	• DAWN instrument test, Hampton, VA • DAWN II instrument test, Hampton, VA • G-LiHt + HyPlant, Hampton, VA • HSRL-2, Hampton, VA • DISCOVER-AQ, Palmdale, CA • DISCOVER-AQ, Houston, TX • AirSWOT, Edwards AFB, CA
Modifications and impacts	NASA Langley's Research Services Directorate (RSD) has acquired a Garmin GDL 39 portable ADS-B and GPS receiver, which can be installed in any of the LaRC science aircraft. This device enhances the ability of the pilot to fly precise flight lines. In preparation for a gross weight increase certification on the Dryden B-200, Dryden flight operations modified NASA 801 with winglets. The primary benefit of the winglets to science investigators will be NASA 801's gross weight increase configuration (i.e. full fuel load, experiment and crew) climb performance will be similar to its climb performance prior to gross weight increase operations.
Maintenance schedule	• LaRC B-200 phase inspection – July 1-31, 2014 • UC-12B Phase 3 and 4 inspections – Feb. 3-28, 2014
Websites	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC http://airbornescience.nasa.gov/aircraft/UC-12B http://airbornescience.nasa.gov/aircraft/B-200_-_DFRC

C-23 Sherpa

The NASA Goddard Space Flight Center's Wallops Flight Facility owns a C-23 Sherpa research aircraft available to support airborne science research. The C-23 is used to perform scientific research, provide logistics support on an as-needed basis to other airborne science missions, and can be used as a technology test bed for new airborne and satellite instrumentation. This aircraft is also available to support range surveillance and recovery operations as needed. The C-23 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.

Figure 40. C-23 Sherpa.

The C-23 is a two-engine turboprop aircraft designed to operate efficiently, under the most arduous conditions, in a wide range of mission configurations. The large square-section cargo hold, with excellent access at both ends (4 side fuselage doors and aft cargo ramp), and a 7000-pound payload, offers ready flexibility to perform a variety of missions. The aircraft also has 22 cabin windows as well as a nose cargo area available for installations.

C-23 Sherpa FY13 Activities

Flight hours in FY13	357.5 science hours, 445.5 SMD-funded hours
Missions and locations	• CARVE, Fairbanks, AK • Rocky Mountain Oilfield Testing Center mission, Casper, Wyoming
Modifications and impacts	A new 2-inch diameter nadir port was installed in the aircraft in the spring FY13 to support a new nadir viewing camera installation.
Maintenance schedule	Annual Maintenance: Fall each year for approximately 4 weeks (can be moved to accommodate science missions)
Websites	http://airbornescience.nasa.gov/aircraft/C-23_Sherpa

HU-25C Falcon

Operator: LaRC

The HU-25C is a modified business jet that has served as a search and rescue platform for the US Coast Guard since the 1980's. NASA LaRC acquired this aircraft in 2011 for service that provides a medium altitude, medium range platform for remote sensing instruments development and satellite support. Payload accommodations include a nadir camera port, large side looking search window ports, side looking radar hard points, and a drop hatch.

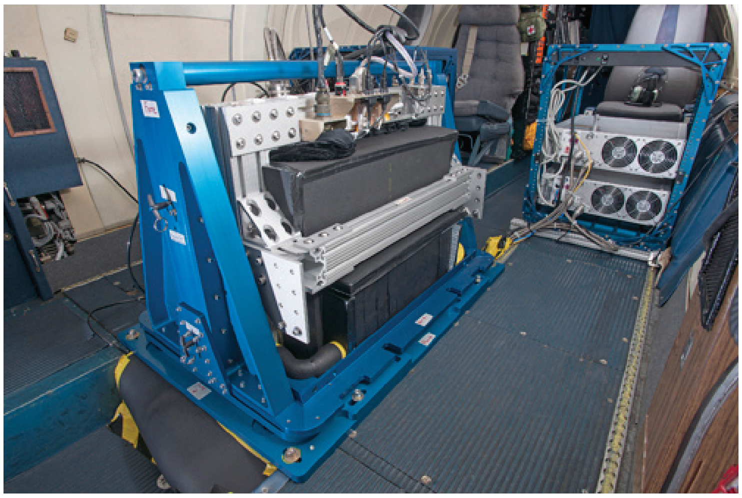


Figure 41. View of GEO-TASO instrument and left Welch rack from passenger door of NASA Langley HU-25C aircraft.

HU-25 Falcon FY13 Activities

Flight hours in FY13	33.4 hours
Missions and locations	• GEO-TASO instrument flights during DISCOVER-AQ Houston
Modifications and impacts	Two enhancements were made to the HU-25C Falcon aircraft in FY13. First, an avionics bus box was added to the ship's avionics system to provide researchers with access to many of the ship's avionics signals. In addition, the aircraft has been modified and certified for Reduced Vertical Separation Minima (RVSM), allowing the aircraft to routinely operate at altitudes above 28,000 ft worldwide.
Maintenance schedule	A Check – November 18- December 9, 2013 B Check – March 17 – April 11, 2014
Websites	http://airbornescience.nasa.gov/aircraft/HU-25C_Falcon

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. UAS missions are of particular value when long flight durations or range-measurement requirements preclude a human pilot or where remote or harsh conditions place pilots and high-value aircraft at risk. Designed by the U.S. Naval Research Laboratory and developed at NASA's Ames Research Center, the SIERRA is well suited for precise and accurate data collection missions because it is large enough to carry up to 100 pounds of scientific instruments for up to 600 miles yet small enough not to require a large runway or hangar.

Figure 42. The SIERRA UAS at Oliktok Point during MIZOPEX.

SIERRA FY13 Activities

Flight hours in FY13	20 hours
Missions and locations	• Seagrass and Coral Reefs, Key West, FL • MIZOPEX, Oliktok Point, AK
Modifications and impacts	One modification was made during 2013. At rectangular nadir view port was installed in the belly. There was no aerodynamic impact to the aircraft. This modification enhanced the ability to fly additional downward looking instruments. In 2013 two payloads were integrated and flown. Their only impact was to decrease maximum flight time from ten hours to under six. This impact was directly correlated to the weight of the payloads
Maintenance schedule	Maintenance schedule is determined by number of flight hours flown. Our policy is to perform an intensive inspection every 100 hours. Maintenance and repairs will be determined at the completion of each inspection or as issues arise. At the very least, in five years the SIERRA project will need at least two engine rebuilds per aircraft. Each rebuild will take approximately 40 man-hours.
Websites	http://airbornescience.nasa.gov/aircraft/SIERRA

The SIERRA Program, managed at NASA's Ames Research Center, is focused on providing end-to-end support for UAS flight missions in support of Earth science research and applications activities. The program has capabilities to support all phases of UAS missions, including experiment design, requirements definition, payload integration design and support, airworthiness and flight safety reviews, airspace access including COA development, deployment planning, mission planning and flight operations.

The final flight of SIERRA took place on July 26, 2013. While conducting a sea ice survey off the N. Slope of Alaska for the MIZOPEX mission, the SIERRA lost engine power and glided into the water approximately 40 miles north of Oliktok Point.

Fabrication of two stretch versions of SIERRA (aka Ship B) is underway. Ship B1 is scheduled to be completed by Oct 2014. Ship B2 is scheduled to be completed approximately 9 months later.

DragonEye UAS

The DragonEye 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.

Figures 43. NASA Dragon Eye UASs.

DragonEye UAS FY13 Activities

Flight hours in FY13	10 hours
Missions and locations	Costa Rica volcano sampling, Costa Rica
Modifications and impacts	DragonEye UAS were modified to carry sampling bottles.
Maintenance schedule	There is no maintenance schedule for the DragonEye UAS, as they are considered expendable.
Websites	http://airbornescience.nasa.gov/aircraft/Dragon_Eye

WB-57

Aircraft manager: NASA JSC

The NASA Johnson Space Center (JSC) in Houston, Texas is the home of the NASA WB-57 High Altitude Research Program. Three fully operational WB-57 aircraft are based near JSC at Ellington Field. The aircraft have been flying research missions from Ellington Field for 50 years, and continue to be an asset to the scientific community with professional, reliable, customer-oriented service designed to meet all scientific objectives.

Figures 44. NASA WB-57

The WB-57 is a mid-wing aircraft capable of operation for extended periods of time from sea level to altitudes well in excess of 60,000 feet. The WB-57 can fly for approximately 6.5 hours and has a range of approximately 2500 miles.

NASA currently operates three WB-57 aircraft – N926, N927 and N928.The big news in 2013 was increasing the fleet size from two to three aircraft with the completed regeneration of NASA 927, increasing the capability to support the airborne science community by 50%. First flight of the former USAF WB-57F 63-13295 was accomplished on 9 Aug 2013, more than 41 years after its last flight. All three aircraft were stripped and painted in FY13 for the first time in over a decade to aid corrosion control and extend fleet longevity. After extensive preparation, plans for the fleet in FY14 include upgrading ejection seats in 926 and 928 to ACES II (927 already complete), new canopies, new autopilot, and new navigation data system.

Still other NASA aircraft are available for science. They are listed below. More details on all these aircraft are available on the Airborne Science website: (http://airbornescience.nasa.gov/aircraft).

T-34 Turbomentor
Aircraft manager: NASA GRC

Twin Otter
Aircraft manager: NASA GRC

The Twin Otter, DHC-6, is a versatile aircraft capable of flying various mission profiles with an array of instruments. The aircraft has instrument mounts on both wings as well as numerous fuselage mounting points. It is an economical aircraft for missions flown below 20,000' at speeds of around 90 to 140 knots.

S-3B Viking
Aircraft manager: NASA GRC

Learjet 25 / Learjet 35
Aircraft manager: NASA GRC

A Learjet 35 (C-21) has been acquired by NASA GRC at no cost from the USAF to eventually replace the Learjet 25. It will provide greater payload and range/endurance capabilities.

Cessna 206H
Aircraft manager: NASA LaRC

An Aspen Avionics Evolution 1000 Primary Flight Display has been installed on the Cessna 206H aircraft, providing the pilot with a glass Electronic Flight Instrumentation System. The system provides a full-featured electronic Horizontal Situation Indicator (HSI) with moving map, thereby enhancing the ability of the pilot to fly precise flight lines.

Ikhana UAS
Aircraft manager: NASA LaRC

The Ikhana is a remotely piloted General Atomics Predator B that was acquired by NASA to serve as an aeronautical research aircraft and to serve the Earth Sciences community. The Ikhana measures 36 feet in length, and has a wingspan of 66 feet. It has a maximum takeoff weight of 10,500 pounds. The payload capability of Ikhana is 2000 plus pounds (external) and more than 800 pounds (internal). Where possible, sensor payloads are integrated into wing-mounted pods to minimize aircraft downtime and allow rapid reconfiguration. Ikhana can operate at altitudes from 500 feet to above 40,000 feet with endurances above 24 hours.

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 FY2013 Ames operated and partnered with commercial operators to fly 5 different types of Category 1-3 UAVs in support of NASA science.

The **SIERRA UAV** was assigned the MIZOPEX mission in January and the team was able to negotiate airspace, design and integrate 3 separate payload noses, and deploy successfully to Oliktok Point before the plane was lost on the first science flight. The accident is currently under investigation. Work had already begun on SIERRA-2 and delivery of the airframe modifications are expected in early FY2014 with flight tests 5-6 months later. Modifications will include a wet-wing with a larger dihedral angle and a new engine.

Ames supported the MIZOPEX mission by coordinating with the FAA, DOE, and USAF for access to airspace as well as airworthiness approvals for the University of Colorado DataHawk, and the University of Alaska Scan Eagle UAVs.

The **Dragon Eye UAVs** were acquired in FY2013 from the Marines via the General Services Administration in support of a JPL-led team working to validate NASA/JAXA ASTER satellite retrieval algorithms of sulfur dioxide over volcanic plumes. These 6lb electric UAVs are a good candidate for carrying the >1lb instrument into the plume for 1hr. In FY14 the Dragon Eye team is supporting PhD work in automated multi-aircraft controls to optimize in situ sampling as well as a project on rapid prototyping and 3D printing project aimed at improving payload or endurance capabilities.

Ames also partnered with the UAV Collaborative to support flight operations of the Vision II rotorcraft UAV for a NASA mission to image coral and sea grass off the coast of Florida. Ames worked closely with the FAA and Navy for access to airspace, provided airworthiness and flight readiness reviews for the team and provided a range safety officer during the deployment.

New Platforms

C-130 Hercules

The NASA Goddard Space Flight Center's Wallops Flight Facility activated a C-130 Hercules research aircraft in June 2013, to support airborne scientific research activities. The C-130 is used to perform scientific research, provide logistics support on an as-needed basis to other airborne science missions, and can be used as a technology test bed for new airborne and satellite instrumentation. This aircraft is also available to support range surveillance and recovery operations as needed. 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. The aircraft has two large nadir ports. One nadir port is approximately 55 inches in diameter (pressurized) and the other nadir port is approximately 24 inches in diameter (unpressurized). A large removable side fuselage plug exists on the port side of the aircraft just forward of the wings. An experimental power system is installed in the aircraft (115VAC 60Hz and 400Hz as well as 28VDC) as well as a variety of other small fuselage ports. The aircraft also is capable of carrying 5 cargo pallets that can be utilized to carry cargo or modified to support instrument racks and seats. The large rear cargo door allows for easy installation of large instruments and payloads. The aircraft is equipment with external fuel tanks to increase range and duration. The C-130 began upload in August and September 2013 to support the FY14 Land Vegetation and Ice Sensor (LVIS) mission to Greenland which began in October 2013.

Figure 45. The C-130 Hercules

Annual Maintenance: Fall each year for approximately 4 weeks (can be moved to accommodate science missions)

UH-1 Huey

The Goddard Space Flight Center's Wallops Flight Facility acquired a UH-1 Iroquois (aka "Huey") helicopter in August 2013. The UH-1 is a versatile helicopter capable of supporting airborne research, range surveillance, recovery operations, drop model testing, technology development, aerial photography and a variety of other customer requested flight activities. The NASA UH-1 is equipped with high skids to allow for large experiments to be mounted to the underside of the fuselage. The configurable interior with cargo mounting points allows for experimenter equipment to be mounted in numerous locations. Two large side fuselage sliding doors allow for easy loading of cargo and personnel and provide an excellent viewing capability to the exterior of the aircraft.

Figure 46. The UH-1 Huey

Viking UAS

NASA is in the process of acquiring several Viking UAS for operation by ARC and WFF. These UAS are similar in size to the SIERRA and could carry out similar remote sensing and sampling missions.

Aircraft Cross Cutting Support and IT Infrastructure

Aircraft support for science 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.

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 8) 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, and one ER-2, aircraft; with installations on the WB-57F and the second ER-2 scheduled in 2014.

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-57F, DFRC B200	Airborne Sensor Facility/ARC
DMS (Digital Mapping System) 21 MP natural color cameras	DC-8, P-3B	Airborne Sensor Facility/ARC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/ precision IMU	DC-8, ER-2, P-3B, B200	Airborne Sensor Facility/ARC
POS AV 610 (4) Applanix Position and Orientation Systems DGPS w/ precision IMU	DC-8, P-3B	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
HDVIS High Definition Time-lapse Video Systems	Global Hawk UAS	Airborne Sensor Facility/ARC
Low Light 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, D1 5nm)	Twin Otter	JPL/JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, D110nm)	ER-2, Twin Otter	JPL/JPL
UAV_SAR Polarimetric L-band synthetic aperture radar, capable of Differential interferometry	C-20/G-III/GH	JPL/JPL
NAST-I Infrared imaging interferometer (3.5 – 16μm range)	ER-2	U Wisconsin/LaRC

Table 8. Facility Equipment and Communications capabilities

NASA Airborne Science Data and Telemetry System

The NASDAT provides experiments:

- Navigation and Aircraft data isolated from the aircraft bus
- Time (as accurate as possible)
- Baseline SatCom, Network, & Sensor-Web Communication
- Legacy interfaces from Navigation Recorder: RS-232, RS-422, ARINC-429, Synchro, IRIG-B
- Recorded cockpit switch states on manned aircraft
- Extreme durability, able to operate for 10+ years and withstand harsh environments

Figure 47. NASA Airborne Science Data and Telemetry System

Satellite Communications Systems

Several types of airborne satellite communications systems are currently operational on the core science platforms, as listed in Table 9. 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 these have a relatively low data rate, unlike the larger systems, they operate at high polar latitudes and are light weight and inexpensive to operate.

Sat-Com System Type/Data Rate (nominal)	Supported Platforms	Support group/location
Ku-Band (single channel) / > 1 Mb/sec	Global Hawk & Ikhana UAS; WB-57	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, others	Airborne Sensor Facility, NSERC /ARC

Table 9. Satellite Communications systems on ASP aircraft

Mission Tools

The primary objectives of the Mission Tools Suite (MTS) are to (a) support tactical decision-making and distributed team situational awareness during a flight; (b) to facilitate team communication and collaboration throughout the mission lifecycle; and (c) to both consume and produce visualization products that can be viewed in conjunction with the real-time position of aircraft and airborne instrument status data. Taken together, the MTS supports tactical decision-making by aggregating disparate information sources into a cohesive common operating picture. The MTS is comprised of individual tools that attempt to mesh real time aircraft and instrument status, current satellite and model products, together with tools for team communication and collaboration as well as tools to support tactical mission planning. MTS represents the ground element of the NASA SensorNet project, which is developing the airborne networking infrastructure to enable satellite communication of aircraft parameter and instrument data during flight missions. 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.

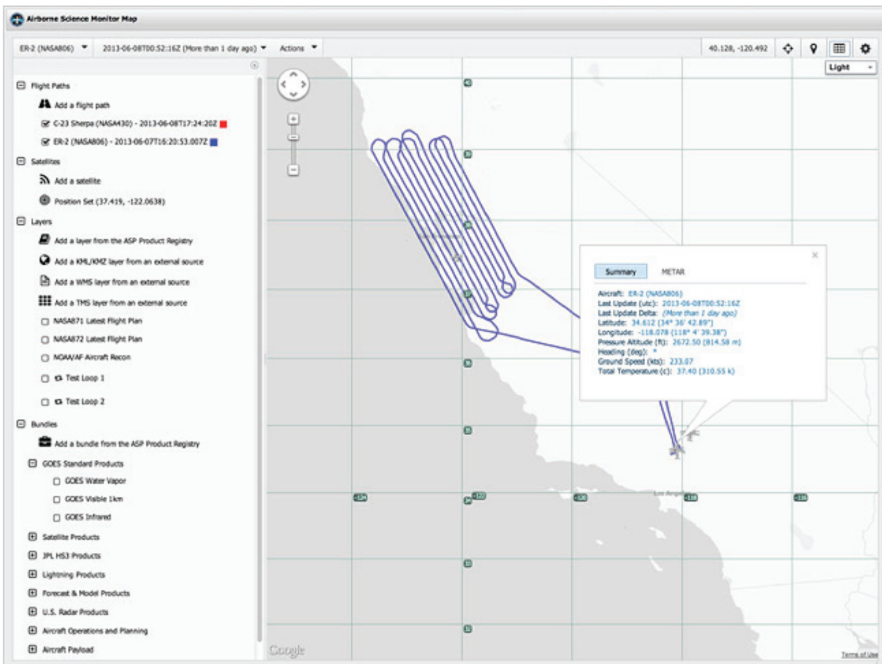


Figure 48. MTS Flight tracking screen

Prior year accomplishments included operational mission support roles for the Hurricane and Severe Storm Sentinel (HS3) campaign, where the MTS was used to assist multi-agency support flight activities among NASA, NOAA and the Air Force, the Airborne Tropical Tropopause Experiment (ATTREX), the Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS) campaign, and support for the Marginal Ice Zone Observations and Processes Experiment (MIZOPEX).

In addition to operational support, the MTS for Education site (MTSE) and Airborne Science public tracker was also used as a platform to provide education and public outreach activities for Operation Ice Bridge (OIB) and DISCOVER-AQ.

Numerous features have been added to the MTS over the past year. Some highlights include satellite pass prediction, support for the WMTS standard with easy access to MODIS imagery from the Global Imagery Browse Services provided by the NASA Earth Observing System Data and Information System, GeoJSON overlay support, services to support product loops and third-party display of forecast and model products, a simple line and waypoint tool with flexible import/export capability, new customized base maps including a base map detailing Global Flight Information Regions, usability improvements for adding previous flight tracks, a revamped Instrument Display for viewing instrument status packets, simplified access to project and aircraft specific social media, flight reports, and aircraft scheduling, and a bot and history service for the Chat tool. Additional information about other features/capabilities can be found at the MTS website.

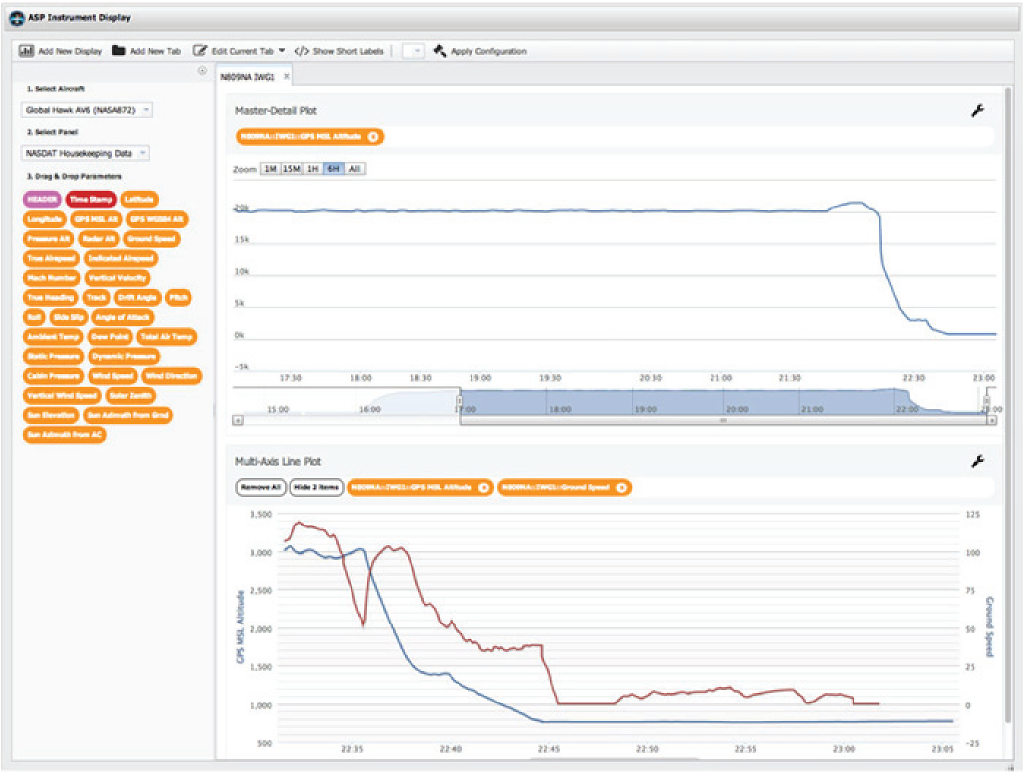


Figure 49. Data tracker.

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 Facililty (ASF), University of California, Santa Cruz at Ames Research Center.

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 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 and P-3B aircraft. A high speed data network (both wired and wireless) is maintained on the aircraft so on board investigators have access to display data available on the aircraft. Video, aircraft parameter, and facility instrument data are recorded, quality controlled, and final data are posted on the science mission and Airborne Science Program data archives. Sat-com 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 sat-com systems. The ASF personnel also support the ER-2 program, providing payload integration suport as required.

Strategic 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 processing, IT mission tools, and new platforms

Requirements Update

ASP personnel monitor upcoming science missions for potential airborne needs to support Earth Science and Earth Science space missions in the following ways:

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

ASP personnel participated in science team meetings and program reviews in 2013 to describe ASP capabilities and collect requirements information.

In 2013, the Program completed a formal update of the ASP requirements report. Input to the activity was requested from each of the NASA science centers (GSFC, LaRC, MSFC, ARC, and JPL) in the form of a survey. An ASP Requirements meeting was held with Science Center and R&A program staff in spring 2013. Major new needs suggested for the program are indicated in Figure 50 and summarized in Table 10.

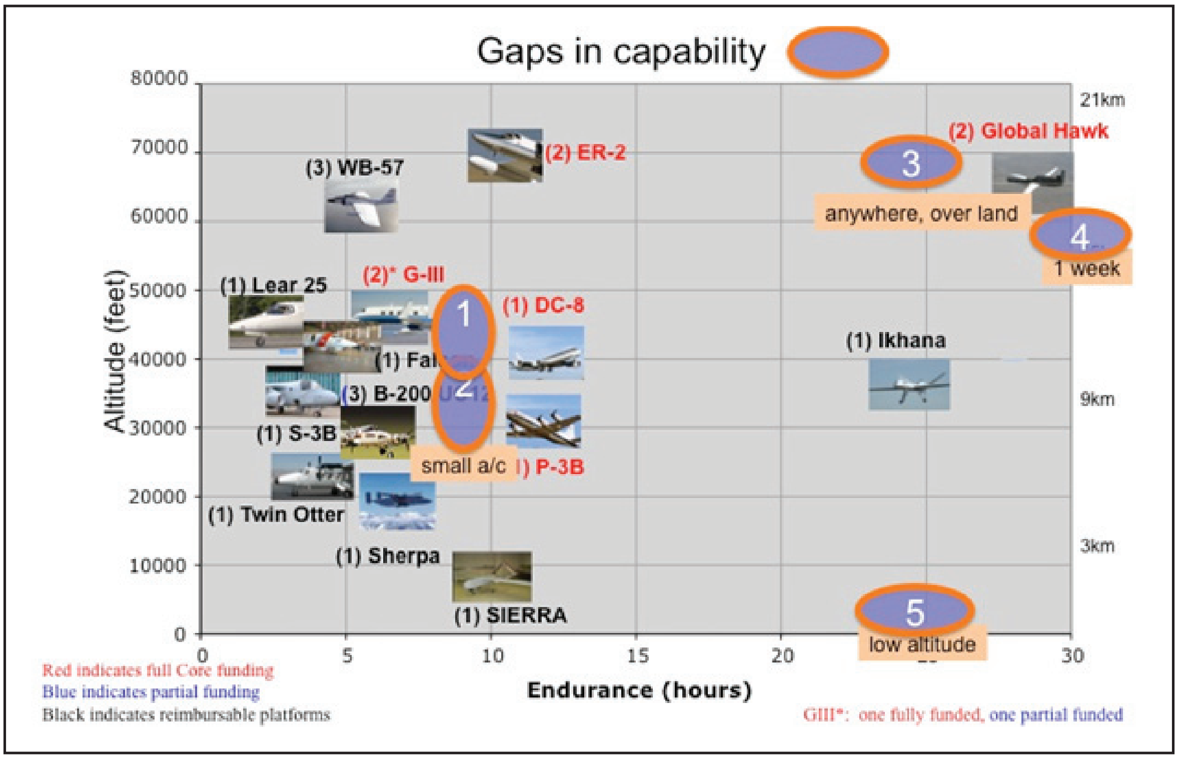


Figure 50. Summary of aircraft gaps as identified by NASA Science Center Survey

Gap	Performance Need	Science Rationale	Possible Solution
1. Flight altitude to 50kft, 8 hr duration, moderate payload	Similar to DC-8 flight regime, including nadir ports, but something smaller and less expensive	Lidar systems for weather and terrain mapping, but not full size laboratory.	Gulfstream V
2. Flight altitude 25 to 35 kft, 8 hr duration, small to moderate payload	Similar to King Air (B-200), but with longer duration	In situ sampling and ocean color both want 8 hrs, but flight characteristics and cost of B-200.	King Air B-350; possible business jet
3. Very high altitude (65+kft), long duration (24 hrs), fly anywhere	Similar flight regime as Global Hawk, ideally higher, not constrained to over ocean	Ability to see the evolution of atmospheric transport processes during a 24-hour period	Continue UAS in the NAS work; possible new aircraft
4. Very long endurance (~week)	Above weather and traffic with ability to follow event	Ability to monitor or track fire or pollutant plume, storm development	Aerial refueling, airship or balloon; new aircraft
5. Low altitude, long duration (or long range to target), where the target is remote or there are basing constraints	100 – 200 ft over water, stable flight; over land with auto pilot	Radiation science over the ocean; carbon flux measurement; coral or ocean color imaging	Long duration, low altitude UAS (OR ship launch)

Table 10. Explanation of gaps indicated in Figure 50.

Participation in other science team meetings and program reviews in 2013 to describe ASP capabilities and collect requirements information are listed in Table 11.

Activity
ASP 5-yr Schedule Forecast Meeting at HQ
Participation in NOAA River Observing workshop (telecon)
Member of Terrestrial Ecology Airborne Science Working Group (Intermediate participation in HyspIRI Science team and Steering Group monthly telecons)
Review of ESTO project requirements
Participation in OIB science team meeting
Participation 2012 HyspIRI Products Symposium
Participation in “International Workshop on Greenhouse Gas Measurements from Space” (OCO-2 and ASCENDS)
Decadal Survey Pre-formulation review
SMAP 3rd Cal/Val workshop

Table 11. Activities to support ASP requirements information gathering.

5-Year Plan

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

Education and Outreach and Partnerships

Student Airborne Research Program 2013

The fifth annual NASA Student Airborne Research Program (SARP) took place June 8-August 2, 2013 at the NASA Dryden Aircraft Operations Facility and the University of California, Irvine. The program was designed to expose advanced undergraduates majoring in the sciences, mathematics, and engineering to all aspects of a NASA Airborne Science research campaign.

The thirty-one students represented thirty-one different colleges and universities from across the United States. The program began at the Dryden Aircraft Operations Facility with introductory lectures by university faculty members, NASA scientists, and NASA program managers designed to prepare students for their flights on the DC-8. The students then participated in instrument integration and flight planning. Each student had the opportunity to fly at least three times on the DC-8. Students in the remote sensing of the ocean and land groups took ground-truth validation measurements from a research vessel in the Santa Barbara Channel and from a forest in the Sierra Nevada Mountains during a DC-8 overflight.

After the DC-8 flights, the students returned to UC Irvine for six weeks of data analysis and interpretation. The program culminated with the students' formal presentations of their results and conclusions. Eleven students submitted first-author conference abstracts on their SARP research to the American Geophysical Union Fall Meeting in San Francisco.

Figure 51. SARP students, mentors, and faculty pose by the DC-8 at the NASA Dryden Aircraft Operations Facility, 2013.

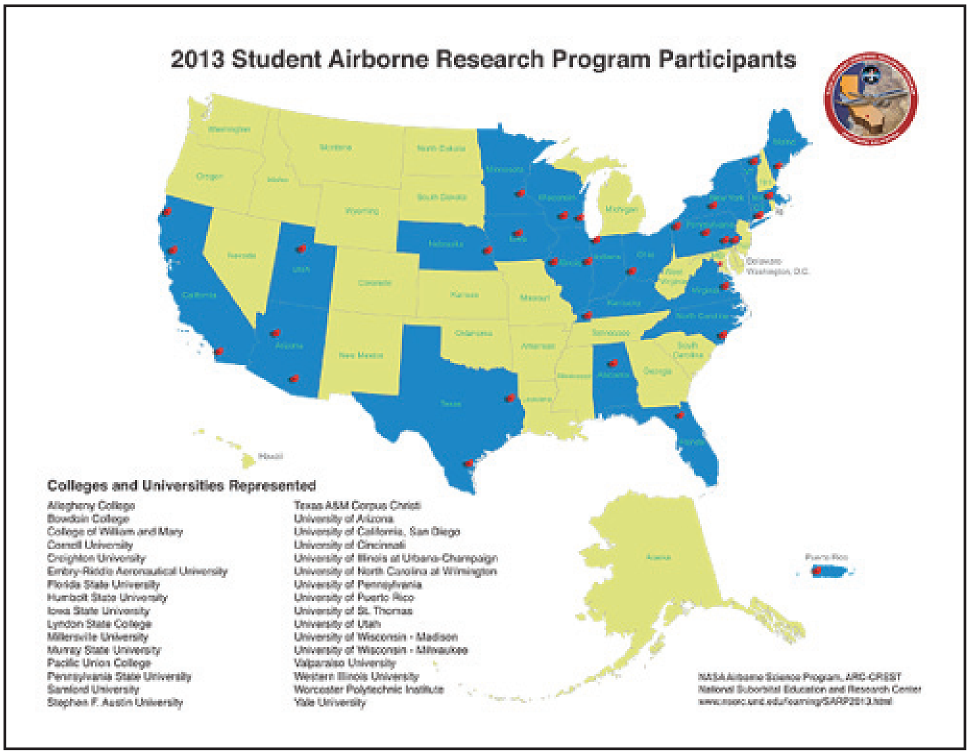


Figure 52. Colleges and Universities represented in SARP 2012.

FY2013 Mission Tools Suite for Education

A number of missions (OIB 2012 Antarctica, DISCOVER-AQ 2013 California, ATTREX 2013, OIB 2013 Greenland, HS3 2013 and DISCOVER-AQ 2013 Texas) used the Airborne Science Program's Mission Tools Suite for Education (MTSE) to reach K-12 teachers and students directly in their 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 FY2013, 4815 K-12 students and their teachers participated in live chats with mission personnel.

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 (Current record: 352 students in 15 classrooms during one ATTREX flight)

  – Chat scheduling and organization coordinated before and during the flights by NSERC

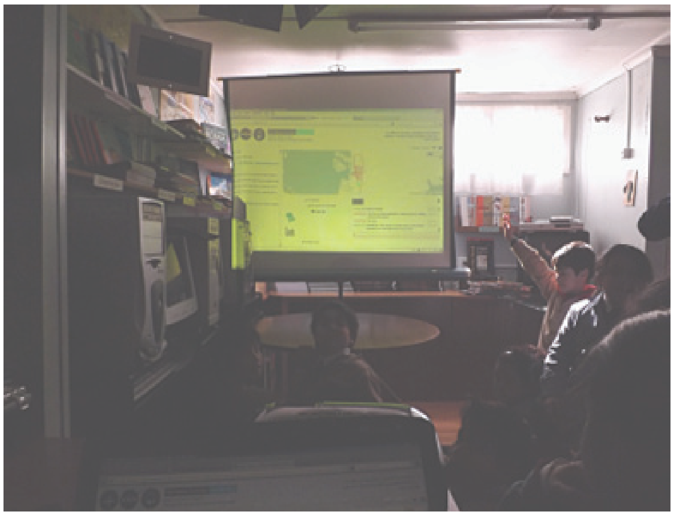


Figure 53 (left). Middle school students in Punta Arenas, Chile connect with the IceBridge mission in Greenland (right) using the Mission Tools Suite for Education (MTSE) website projected in their classroom (April 4, 2013).

DISCOVER-AQ Outreach

Education outreach during DISCOVER-AQ was highly successful, with a media day that included teacher visits and classes chatting with scientists on the P-3B. The students from the AP Environmental Science class at Kingsburg High School, located along the flight track, greeted the aircraft by holding hands to form an ozone molecule in the courtyard and were captured on the nadir video camera. These students also produced a video of their work (including interaction with DISCOVER-AQ) that won the GLOBE student video competition that year.

Figure 54. (above): DISCOVER-AQ Scientists Sally Pusede and Kaitlin Duffey from UC Berkeley chat directly with students while flying on the P-3B.

Figure 55. (right): Two fifth grade students from Houston's Deer Park Independent School District get a taste of what it is like to work on the NASA P-3B.

UAVSAR South American Mission

Ambassador of the United States of America, Adam Namm, along with the students who were awarded scholarships in the program "College Horizons" of the Centro Ecuatoriano Norteamericano visited the crew of a scientific mission of the National Aeronautics and Space Administration (NASA). The mission is capturing aerial radar images of volcanoes, glaciers and wetlands for geological and environmental studies. The aim of the tour is to obtain interferograms or maps of the surface of the forest areas and geological formations to detect changes in natural structures or deformations in the Earth's crust. The regional mission, authorized by the Government of Ecuador and coordinated with the authorities of the Ecuadorian Air Force, of the Directorate General of Civil Aviation and the Galapagos National Park, was scheduled from March through April 3, 2013, and includes similar activities in Honduras, Guatemala, El Salvador, Costa Rica, Nicaragua, Columbia, Peru, Chile, Argentina and Bolivia.

Figure 56. Scholars in the "College Horizons" program, along with Ambassador Namm, visit the NASA C20-A in Guayaquil during the UAVSAR South American mission in March 2013.

Partnerships

The Airborne Science Program, through its field centers, continued to maintain a significant and growing collaboration with the National Oceanic and Atmospheric Administration (NOAA).

Through memorandums of agreement, NASA and NOAA have been collaborating in aircraft operations, primarily training and using NOAA pilots. In FY13, NOAA augmented NASA P-3 and C-23 flight crews in implementing Operation IceBridge and Carbon in Arctic Reserves Vulnerability Experiment missions. NASA and NOAA have also been collaborating 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. Captain Phil Hall returned to new NOAA duties and was replaced by Lt Commander Jonathan Neuhous as the embedded NOAA GH liaison.

Figure 57. Forecast team briefs GH pilots on mission plan. Standing from left to right are Herman Posada (NASA), Jon Neuhaus (NOAA), Phil Eastman (NOAA) and Phil Hall (NOAA).

Appendix A

Historical Perspective: Cheryl Yuhas

Cheryl Yuhas, currently a Program Executive in the Science Mission Directorate at NASA Headquarters, was manager of the Suborbital Science Program from 1998 until 2006. The program name changed to Airborne Science in 2007.

Cheryl arrived at NASA Headquarters as a detailee from the Mission-to-Planet-Earth Program Office at NASA Goddard Space Flight Center. By 2000, she had the job officially. Cheryl reported to Jack Kaye, head of Research and Analysis for Earth Science. In the beginning she relied on Jim Huning, former director, for corporate memory. Randy Albertson also served throughout Cheryl's time, both formally and informally as deputy, and more corporate memory. (Mission-to-Planet-Earth became Earth Science Enterprise in 1998.)

During her tenure, the program went through several transitions. Consolidation of the fleet at NASA Dryden had occurred and funding for the platforms there was relatively stable. The Airborne Sensor Facility at Ames was supported by EOS. Other parts of the program were not as well supported. When Cheryl took over the program, it needed requirements, rationale and vision. She set out to provide that.

A major theme during this time period was how to maintain operations through a tight budget period. Cheryl focused on sharing resources with other agencies and bringing industry and other entities to the table to provide access for the science community. Through the concept of "One NASA," the NASA Centers were to share not only physical assets, but personnel and skills. In an effort to create a Suborbital Science team, she held quarterly team meetings at the various participating centers, thus exposing personnel not only to the facilities at Dryden, Wallops, Johnson, Ames and NSERC, but also to each other.

Another major development was the introduction of unmanned aerial systems (UAS) to the program and to science users. Code A (Aeronautics) had been supporting technology development through the Environmental Research and Sensor Technology (ERAST) program, and now it was time to put that technology to work for science.

Cheryl sponsored the Unmanned Aerial Vehicle Science Demonstration Project (UAV-SDP) a ground-breaking science demonstration of UAVs over the period 2000-2002. One project, the Altus Cumulus Electrification Science (ACES) mission by NASA MSFC scientists made use of the General Atomics Altus flying from Key West, and sharing facilities with CRYSTAL-FACE. The other, the COFFEE mission, flew the solar-powered AeroVironment Pathfinder Plus in Hawaii. These were PI-led missions, in which the proposer could decide which UAV he wanted to fly.

"Our flight demonstrated the viability of this type of UAV for practical applications," said Cheryl Yuhas, Suborbital Airborne Sciences program manager. "NASA is committed to taking new technologies, developed for Earth Science research, and showing their practical applications -- integrating our technologies into decision-support systems that provide a return on the taxpayers' investment," she said. "This type of aerial platform will ultimately allow for accurate and timely Earth observations over large regions for extended periods of time. They also provide for the efficient return of payloads to Earth at the end of an observation period -- something not possible when using satellites."

For a period of time, there was a budget line for UAV Science, separate from the budget for Airborne Science. Cheryl used this to also determine requirements for UAS missions. The "Suborbital Science Missions of the Future" activity, along with the Civil UAS Assessment activity helped inform not only requirements for UAS capabilities, but overall capabilities for the Suborbital Science Program. Some insights included the need for real-time data, both navigational and scientific, from airborne platforms, both manned and unmanned.

In addition to implementing traceability for aircraft requirements, Cheryl set out to establish methodology for use of the aircraft and supporting instruments, develop common interfaces to make the platforms more interchangeable for the scientists, and requested standardized handbooks for all the systems.

This was the period of "As only NASA can," and in that spirit, Cheryl and her program set out to develop new technology for the science community. NASA considered moving all four major platforms (DC-8, P3-B and two ER-2s) to outside parties. Only the DC-8 moved to North Dakota, and later returned to Dryden. Experiments in various "business plans" for operations and mission management led to varying results.

Other challenges during this period included responding to commercial pressure from commercial remote sensing operators not to compete with industry, internal pressure from NASA Aircraft Management to reduce costs (the program budget was reduced by 30% in 2004) and minimize infrastructure, and more internal pressure from the Applications program to rely on satellite data rather than aircraft data.

To address the pressure for new technology, under the Earth Science Capability Demonstration (ESCD) program, NASA developed specifications for both the Altair and Ikhana UAS. These were employed in several early missions, including the highly successful Western States Fire Mission, demonstrating long-duration flight, the new multispectral Airborne Modular Sensor, real-time data processing and real-time data download.

Cheryl was also a big believer in partnership with other agencies. She participated regularly in meetings of Interagency Coordinating Committee for Airborne Geoscience Research and Applications (ICCAGRA) and the University-National Oceanographic Laboratory System (UNOLS) Scientific Committee for Oceanographic Aircraft Research. She initiated a joint Memorandum of Understanding with NOAA and the Department of Energy. That partnership is still active today.

Improvements to the aircraft fleet were limited during Cheryl's tenure due to budget constraints and maintenance issues (such as the DC8 engine replacement needed due to volcanic ash contamination). She introduced procurement vehicles that made it easier for researchers to get access to non-core aircraft like the commercial Twin Otters, brought the WB-57's into the program, and supported the development of real-time mission monitors and onboard science data systems to enhance campaign planning.

Other major airborne missions that occurred during Cheryl's time as Manager:

CAMEX
CRYSTAL-FACE
SOLVE and SOLVE II
AVE, PAVE and CR-AVE
NAMMA

Cheryl left the Suborbital Science Program in 2006. She was succeeded by Andrew Roberts, WB-57 pilot and a long-time participant in the program. Although no longer manager, Cheryl played a role in addressing the 2008 request by Congress to conduct a review of the suborbital mission capabilities of NASA. "The act expresses the sense of Congress that suborbital flight activities, including the use of sounding rockets, aircraft, and high-altitude balloons, and suborbital reusable launch vehicles, offer valuable opportunities to advance science, train the next generation of scientists and engineers, and provide opportunities for participants in the programs to acquire skills in systems engineering and systems integration that are critical to maintaining the nation's leadership in space programs. Further, the act finds it in the national interest to expand the size of NASA's suborbital research program and to consider it for increased funding." This resulted in the 2010 report ""Revitalizing NASA's Suborbital Program: Advancing Science, Driving Innovation, and Developing Workforce."

Cheryl holds a degree in physics from the University of Michigan.

Appendix B

5-Year Plan

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
1) Atmospheric Composition and Chemistry				
1.1) Calipso validation	35	Considine	Calispso	B-200 L
1.2) 4-Star test	15	Maring	NPP, GEO-CAPE	P-3
1.3) ASCENDS Technology acceleration		Ghuman/Komar	ASCENDS	DC-8
1.4) RADEX-14	15	Maring	ACE	ER-2
1.5) Atmo.Chem.Mission		Jucks	OCO-2	DC-8; ER-2
1.6) Atmospheric composition Northwest Pacific	174	Pszenny	Geo-Cape, A-Train, NPP	DC-8
1.7) Radiation science experiment		Maring		P-3
1.8) Atmospheric Composition Campaign	150/ac	Jucks; Maring	NPP, A-Train, Terra	DC-8; ER-2

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
2) Carbon Cycle & Ecosystems				
2.1) AVIRIS & MASTER HyspIRI prep	100	Turner/Neeck	HyspIRI	ER-2
2.2) AVIRIS Classic /AK	30	Wickland; Tagg	HyspIRI	ER-2
2.3) AVIRISng	95	Wickland	HypsIRI	Any Twin Otter
2.4) Coral Biodiversity	22	Turner	PACE, HyspIRI	ER-2; Twin Otter GRC
2.5) Land management / veg (AVIRISng)	24	Wickland	HyspIRI	Any Twin Otter
2.6) HSRL-O88	40	Bontempi	PACE	B-200 L
2.7) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI	G-III
2.8) Forest responses		Wickland		ER-2
2.9) Ecosystem Change (Cook GLiHT)	100	Wickland	LDCM	Piper Cherokee
2.10) Carbon monitoring (AVIRISng)	37	Wickland	DESDynI	DC-8
2.11) Florida Everglades				ER-2
2.12) AVIRIS & MASTER HyspIRI prep	100	Turner/Neeck	HyspIRI	ER-2
2.13) CCE Field Campaign ABoVE	100	Wickland		Sherpa
2.14) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI	G-III
2.15) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI	G-III
2.16) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI	G-III
2.17) HySPICE		Bontempi	HyspIRI	ER-2
2.18) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI	G-III

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013	2014	2015	2016	2017	2018	2019	2020
3) Cryospheric Science											
3.1) OIB Greenland 2014	300	Wagner; Tagg	ICESat 2		P-3						
3.2) OIB Iceland 2014	30	Wagner	ICESat 2		G-III						
3.3) OIB Alaska 2014		Wagner	ICESat 2		Single Otter						
3.4) LVIS Greenland					Falcon						
3.5) MABEL Alaska					ER-2						
3.6) OIB Antarctica 2014	250	Wagner; Tagg	ICESat 2		DC-8						
3.7) OIB Greenland 2015	300	Wagner; Tagg	ICESAT 2			C-130					
3.8) OIB Iceland 2015	35	Wagner	ICESat 2			G-III					
3.9) OIB Alaska 2015		Wagner	ICESat 2			Single Otter					
3.10) MIZOPEX follow-on	30	Wagner				SIERRA					
3.11) OIB Antarctica 2015	250	Wagner; Tagg	ICESat 2			DC-8; P-3					
3.12) OIB Greenland 2016	300	Wagner; Tagg	ICESAT 2				P-3				
3.13) OIB Iceland 2016	35	Wagner	ICESat 2				G-III				
3.14) OIB Alaska 2016		Wagner					Single Otter				
3.15) OIB Antarctica 2016	250	Wagner; Tagg	ICESat 2				DC-8; P-3				
3.16) UAVSAR Greenland or Iceland	35	Wagner						G-III			
3.17) OIB Greenland 2017	300	Wagner, Tagg	ICESat 2					P-3			
3.18) OIB Antarctica 2017	250	Wagner, Tagg	ICESat 2					DC-8			
3.19) UAVSAR Greenland or Iceland	35								G-III		
3.20) OIB Greenland 2018	300	Wagner, Tagg	ICESat 2						P-3		
3.21) OIB Antarctica 2018	250	Wagner, Tagg							DC-8		

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013	2014	2015	2016	2017	2018	2019	2020
4) Water and Energy Cycle											
4.1) Moller - AIRSWOT	112	Entin, Lindstrom	SWOT		B-200 D						
4.2) SMAPVEX 14 (piggyback)	15	Entin	SMAP		G-III						
4.3) Airborne Snow Observatory (Painter)	32	Entin, Dorn	HyspIRI		Any Twin Otter						
4.4) Coastal Airborne In-Situ Radiometers		Entin	PACE		ER-2						
4.5) Coastal Airborne In-Situ Radiometers		Bontempi, Entin	PACE			P-3					
4.6) Snow Field Campaign-15	20	Entin				DC-8					
4.7) Water quality field campaign	30	Entin, Turner	HyspIRI, ACE			TBD					
4.8) SMAPVEX-15	30	Entin	SMAP			G-III; Any Twin Otter					
4.9) Arctic Hydrology 138001		Entin	SWOT			B-200 D					
4.10) 4Star upgrade	8	Entin				DC-8; P-3					
4.11) Snow Field Campaign- 16	50	Entin					DC-8; P-3				
4.12) SMAPVEX-16 cal/val	50	Entin	SMAP				P-3				
4.13) SMAP cal/val	20	Entin	SMAP				G-III				
4.14) RZSM - ESA Collaboration OR	30	Entin	ESA BIOMASS				G-III (2)				
4.15) SMAP cal/val	20	Entin	SMAP					G-III			
4.16) RZSM - ESA Collaboration	30	Entin	ESA BIOMASS					G-III (2)			

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013 2014 2015 2016 2017 2018 2019 2020
5) Earth Surface & Interior				
5.1) UAVSAR – 14	290	Dobson; Tagg	DESDynI	G-III
5.2) UAVSAR – 15	290	Dobson; Tagg	DESDynI	G-III
5.3) Costa Rica – volcanic plumes	10	LaBrecque	HyspIRI / ASTER	DragonEye
5.4) UAVSAR – 16	290	Dobson; Tagg	DESDynI	G-III
5.5) UAVSAR – 17	290	Dobson; Tagg	DESDynI	G-III
5.6) UAVSAR – 18	290	Dobson; Tagg	DESDynI	G-III
6) Weather				
6.1) GPM-IPHEX (GPM)	86	Kakar; Neeck	GPM	UND Citation; ER-2
6.2) Atmospheric Dynamics mission Antarctica piggback		Kakar; Neeck		DC-8
6.3) RADEX-15	100	Maring	GPM	DC-8
6.4) OLYMPEX (GPM c/v)	100	Kakar, Neeck	GPM	DC-8; UND Citation
6.5) GOES-R cal/val			GOES-R	ER-2
6.6) GOES-R cal/val			GOES-R	ER-2
7) Applications				
7.1) CA-DWR w UAVSAR	60	Friedl; Dobson		G-III
7.2) Precision Ag	9	Doorn	HyspIRI	ER-2
7.3) Airborne Snow Observatory (Painter)	32	Entin, Dorn	HyspIRI	Any Twin Otter
7.4) Wildfire	50	Lindsay	Terra, Aqua	B-200 D
8) Earth Venture 1				
8.1) ATTREX-14	200	Jucks, Tagg		Global Hawk
8.2) AirMOSS – 14	326	Entin; Tagg	SMAP	G-III (2)
8.3) CARVE – 14	336	Wickland; Tagg		Sherpa
8.4) DISCOVR-AQ – 14	100	Maring, Tagg	GEO-CAPE	B-200 L; P-3
8.5) HS3 – 14	327	Kakar; Tagg		Global Hawk
8.6) AirMOSS – 15	300	Entin; Tagg	SMAP	G-III (2)
8.7) CARVE – 15	336	Wickland; Tagg		Sherpa
12) EVS-2				

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013 2014 2015 2016 2017 2018 2019 2020
9) Education				
9.1) SARP 2014	14	Kaye; Tagg		P-3
9.2) SARP 2015	14	Kaye; Tagg		DC-8
9.3) SARP 2016	14	Kaye; Tagg		DC-8
9.4) SARP 2017	14	Kaye; Tagg		DC-8
9.5) SARP 2018	14	Kaye; Tagg		DC-8
9.6) SARP 2019	14			DC-8
10) New Techology				
10.1) Reising IIP		Ghuman	SWOT	Any Twin Otter
10.2) CarbonHawk / Obland		Ghuman	ASCENDS	Falcon
10.3) HyTES	65	Kaye	HyspIRI	Any Twin Otter
10.4) HSRL-2	15	Trepte	ACE	B-200 L
10.5) Geo-TASO/Leitch		Al-Saadi	GEO-CAPE	Any Twin Otter
10.6) ECOSAR/Rincon		Wickland	DESDynI	P-3
10.7) CO2 Laser sounder /ASCENDS		Ghuman	ASCENDS	DC-8
10.8) ECOSAR/Fatoyinbo		Wickland	DESDynI	P-3
10.9) Wright – IIP	10	ESTO	HyspIRI	SIERRA
10.10) ACERAD/Racette		Komar	ACE	ER-2
10.11) GISTEN-H/Moller		Famiglietti	ICESat 2	Global Hawk
10.12) UAVSAR-GH -15	50	Dobson; Tagg	DESDynI	Global Hawk
10.13) CarbonHawk/ Obland		Jucks	ASCENDS	Global Hawk
10.14) Thermal IR Climate sensor	16	Albertson	Aqua, Aura	ER-2
10.15) Klein-IIP	140	ESTO	GPM, GCOM-W1	SIERRA; Ikhana
10.16) Polarimeter test	30	Buckner		Any Twin Otter
10.17) RLINFS test	7	Buckner		DC-8
10.18) AITT-2012 awards		Komar		TBD
10.19) IIP-2013 Awards		Komar		TBD
11) Maintenance schedules / platform unavailable				
11.1) DC-8 Maintenance		DFRC		DC-8
11.2) P-3B ReWing		WFF		P-3

Appendix C

Acronyms

AA	Associate Administrator
ACCESS	Advancing Collaborative Connections for Earth System Science
ACE	Aerosol-Cloud-Ecosystem
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AirMSPI	Airborne Multiangle SpectroPolarimetric Imager
AirSWOT	Air Surface Water and Ocean Totpography
AITT	Airborne Instrument Technology Transition
AMIGACarb	AMerican Icesat Glas Assessment of Carbon
AMS	Autonomous Modular Sensor
ASCENDS	Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASO	Airborne Snow Observatory
ASP	Airborne Science Program
ASPRS	Aviation Safety Reporting System
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATLAS	Atmospheric Laboratory of Applications and Science
ATM	Airborne Topographic Mapper
ATTREX	The Airborne Tropical TRopopause EXperiment
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BGAN	Broadband Global Area Network
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CARVE	The Carbon in Arctic Reservoirs Vulnerability Experiment
CH_4	methane
CO	carbon
CO_2	carbon dioxide
COA	Certificate of Authorization

CONUS	Continental United States
CPDLC	Controller-Pilot Data Link Commmunications
DAOF	Dryden Aircraft Operations Facility
DAWN, DAWN-II	Doppler Aerosol Wind
DCAPS	Data Collection and Processing System
DCS	Digital Camera System
DEM	Digital Elevation Model
DESDynI	Deformation, Ecosystem Structure and Dynamics of Ice
DFRC	Dryden Flight Research Center
DISCOVER-AQ	Electronically Steerable Flash Lidar
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)
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
ESTO	Earth Science Technology Office
EV, EV-1	Earth Venture, Earth Venture-1
EXRAD	ER-2 X-band Radar
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FLIR	Forward Looking Infrared
FOR	Flight Operations Room
FTS	Fourier Transformation Spectrometer
G-LiHT	Goddard’s Lidar, Hyperspectral and Thermal Imager
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GeoJSON	Geo JavaScript Object Notation
GH	Global Hawk
GHOC; GHOC-E	Global Hawk Operations Center; GHOC-East
GISS	Goddard Institute for Space Studies

GRC	Glenn Research Center
GLISTEN-A	The Airborne Glacier and Land Ice Surface Topography Interferometer
GSFC	Goddard Space Flight Center
H2O	water
HDSS	High Definition Sounding System
HQ	Headquarters
HS3	Hurricane and Severe Storm Sentinel
HSI	Horizontal Situation Indicator
HSRL	High Spectral Resolution Lidar
HyspIRI	Hyperspectral Infrared Imager
HYTES	Hyperspectral Thermal Emission Spectrometer
ICCAGRA	Interagency Coordinating Committee for Airborne Geoscience Research and Applications
ICESat	Ice, Cloud, and land Elevation Satellite
IIP	Instrument Incubator Program
IRIS	Interface Region Imaging Spectrograph
IWGADTS	Interagency Working Group for Airborne Data and Telecommunication Systems
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JSC	NASA Johnson Space Center
LaRC	Langley Research Center
LUMP	Low Utilization Maintenance Plan
LVIS	Land Vegetation and Ice Sensor
MABEL	Multiple Altimeter Beam Experimental Lidar
MASTER	MODIS/ASTER Airborne Simulator
MIZOPEX	The Marginal Ice Zone Ocean and Ice Observations and Processes Experiment
MODIS	Moderate Resolution Imaging Spectroradiometer
MSFC	Marshall Space Flight Center
MTS; MTS-E	Mission Tools Suite; Mission Tools Suite for Education

MX	Maintenance
NAMMA	NASA African Monsoon Multidisciplinary Analyses
NASDAT	NASA Airborne Science Data and Telemetry
NAST-I; NAST-M	NPOESS Airborne Sounding Testbed-Interferometer; Microwave Sounder
NEE	net ecosystem carbon exchange
NEON	National Ecological Observatory Network
NOAA	National Oceanographic and Atmospheric Administration
NSERC	National Suborbital Education and Research Center
OCO-2	Orbiting Carbon Observatory - 2
OIB	Operation Ice Bridge
PACS	Passive Aerosol and Cloud Suite
PDF	Payload- directed flight
PFP	Programmable Flask Packages
PI	Principal Investigator
PLRA	Program Level Requirements Assessment
PNNL	Pacific Northwest National Laboratory
PODEX	Polarimeter Definition Experiment
POR	Payload Operations Room
PRISM	Portable Remote Imaging Spectrometer
RSP	Research Scanning Polarimeter
RVSM	Reduced Vertical Separation Minima
RZSM	Root Zone Soil Moisture
SAFARI	Southern African Regional Science Initiative
SAIC	Science Applications International Corporation
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
S-HIS	Scanning High-resolution Interferometer Sounder
SIERRA	Sensor Integrated Environmental Remote Research Aircraft

SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SOFRS	Science Operations Flight Request System
SOLVE, SOLVE II	SAGE III Ozone Loss and Validation Experiment
SSFR	Solar Spectral Flux Radiometer
SWOT	Surface Water Ocean Topography
TCAP	Two-Column Aerosol Project
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TIR	Thermal Infrared Radiometer
TN	Tail number
TRMM	Tropical Rainfall Measuring Mission
TS	Tropical Storm
TTL	Tropical Tropopause Layer
TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UAF	University of Alaska - Fairbanks
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCSB	University of California, Santa Barbara
UCSC	University of California, Santa Cruz
UMBC	University of Maryland Baltimore County
USAF	U.S. Air Force
USC	University of Southern California
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
WFF	Wallops Flight Facility
XSCAV	eXperimental Sensor-Controller Aerial Vehicle

On the back cover: Helheim Fjord in eastern Greenland seen from the NASA P-3B on the April 5, 2013 OIB survey flight. Helheim Glacier, one of the largest in Greenland, drains into the ocean through this fjord. Credit: NASA / Jim Yungel

AIRBORNE SCIENCE PROGRAM
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