National Aeronautics and Space Administration

EXPLORE

Science Mission Directorate
Airborne Science Program

2020
Annual Report

COVER IMAGE:

Background: View of Wake Island from the JSC G-III during SHARC. Photo credit: Kate Gunderson

Insert: LaRC UC-12B and HU-25A fly together during ACTIVATE. Photo credit: David C. Bowman

BACK COVER:

Top: AFRC C-20A and ER-2 flying at the Los Angeles County Air Show. Photo credit: Julie Davidovich

Center: JSC GV with Operation IceBridge payload: Photo credit: Jeremy Harbeck

Bottom: P-3 participating in IMPACTS mission. Photo credit: Joe Finion

National Aeronautics and Space Administration

EXPLORE

Science Mission Directorate

Airborne Science Program

2020

Annual Report

Figures and Tables

1. Leadership Comments

Bruce Tagg, Director of the Airborne Science Program.

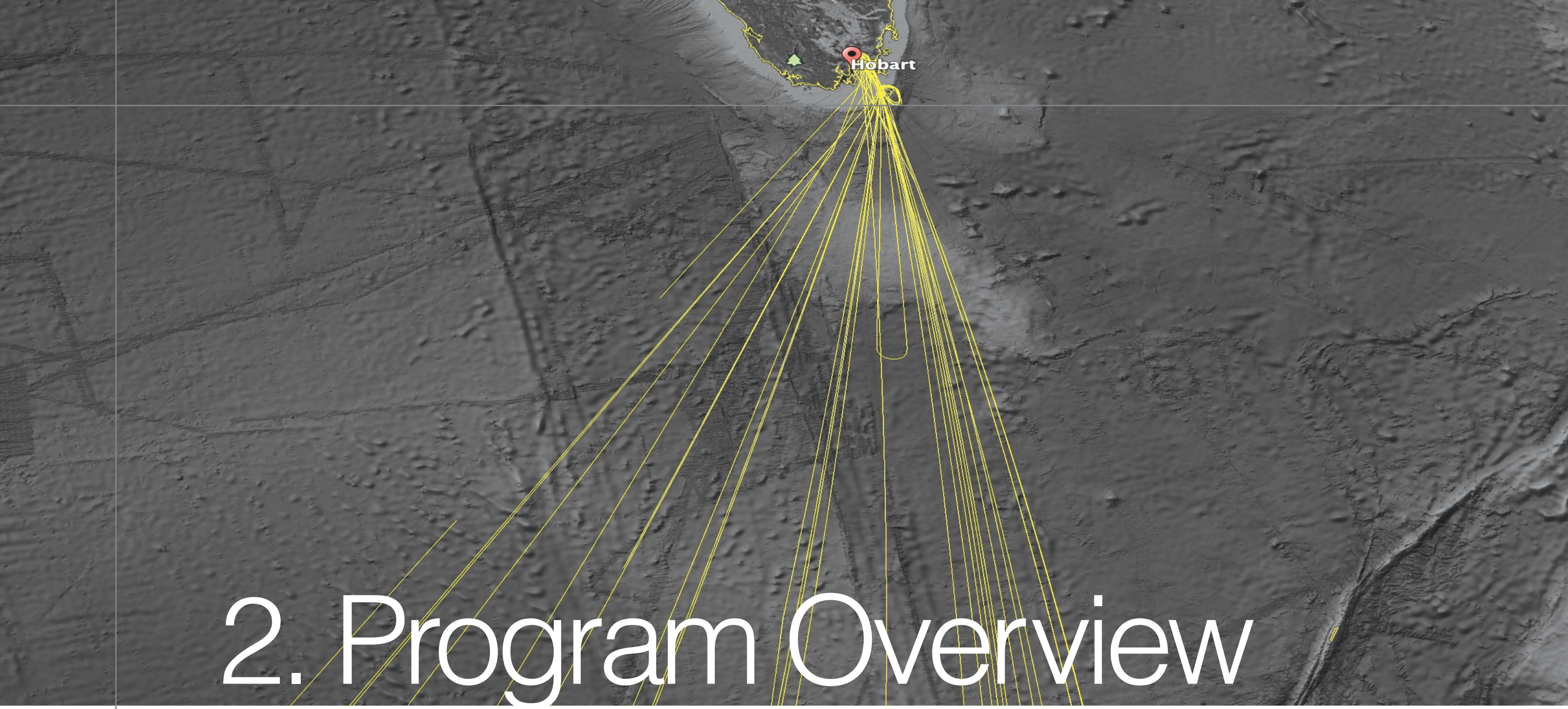
Thank you for taking the time to review highlights from our flight projects in Fiscal Year (FY) 2020. It is through challenging times that our persistent dedication to safety and mission success really make a difference – the commitment of our staff and the flight teams that strive to support critical Earth Science observations should make all of us proud this year.

In FY 2020, the NASA Airborne Science Program (ASP) supported several successful missions, including Oceans Melting Greenland (OMG), IMPACTS, ACTIVATE, SnowEx, and the final flights of Operation IceBridge, totaling more than 1600 Earth science flight hours. While the majority of these flights took place prior to the lockdowns that affected the Centers in March 2020, ongoing activities involving UAVSAR and the Western Diversity Time Series (WDTS) safely continued operating, while extending the important time series measurements in the western U.S. and contributing to time-sensitive events, such as the wildfire response. The Student Airborne Research Program (SARP) continued into its 12th year, with students participating in the program virtually. The students received a full research experience through hands on research at home and analysis of the wealth of SARP data available since 2009.

The science aircraft fleet continues to evolve, with the addition of a G-III at Langley Research Center (LaRC) initially deployed as a remote sensing platform with two nadir ports, similar to the GV at Johnson Space Center (JSC). New technology efforts were successful in achieving first flight of a next generation solar electric high altitude unmanned aircraft in partnership with NASA's Small Business Innovative Research (SBIR) Program, while in parallel the Program's cross-cutting engineering team began an effort to architect the next generation onboard information technology and satellite communications systems for our fleet of the future. And speaking of information technology (IT), the Program's Mission Tools Suite (MTS), which supports virtual mission participation, flight tracking, and data visualization, released Version 2.0. These tools increasingly enable us to improve the efficiency and effectiveness of every flight hour, while also enabling team members to participate safely from home.

I hope you enjoy catching up on the Airborne Science Program and NASA Earth Science through this Annual Report. It's truly an honor and pleasure to serve the Agency and our Nation with such an incredible group of people.

Bruce A. Tagg, Director
bruce.a.tagg@nasa.gov



2. Program Overview

The Airborne Science Program (ASP) is an important element of the NASA Science Mission Directorate (SMD) Earth Science Division (ESD) because of its involvement and support through the entire life cycle of Earth observing space missions. Aircraft modified with ports, inlets, IT, and communications systems support NASA Earth Science missions by:

- Providing a platform for testing future satellite or International Space Station (ISS) instruments;
- Conducting underfligths for calibration and validation of on-orbit missions;
- Simulating future satellite mission data for algorithms development with airborne prototype instruments;
- Supporting process studies to provide high-resolution temporal and spatial measurements of complex local processes, which can be coupled to global satellite observations for a better understanding of the complete Earth system;
- Leading workforce development through hands-on science and engineering opportunities.

The program accomplishes these goals by providing support of operations of mission critical, or core aircraft; engineering for instrument mechanical, electrical, and IT integration; and onboard data systems and communications capabilities. The Program also assists NASA Principal Investigators (PIs) with access to commercial aviation services and use of non-NASA aircraft and equipment for Earth Science, as needed.

Structure of the Program

The Program is administered through the NASA Science Mission Directorate (SMD) Earth Science Division (ESD), with oversight and close coordination from the Flight Projects and Research and Analysis (R&A) Programs (see Figure 1). Aircraft operations and science support responsibilities are distributed among the NASA centers where the aircraft are based, as shown in Figure 2.

New Program Deputies

Derek Rutovic was appointed Deputy Airborne Science Program Director, with a focus in Operations. Mr. Rutovic received his B.S. in Aerospace Engineering from Purdue University in 2004 and graduated as part of Class 143 from the United States Naval Test Pilot School in 2013. Prior to joining the ASP management team, he served in engineering and program management roles for the fleet of aircraft at the Johnson Space Center (JSC). Mr. Rutovic was the lead engineer for multiple aircraft modifications, including installation of the UAVSAR pod on the G-III, the Super Guppy

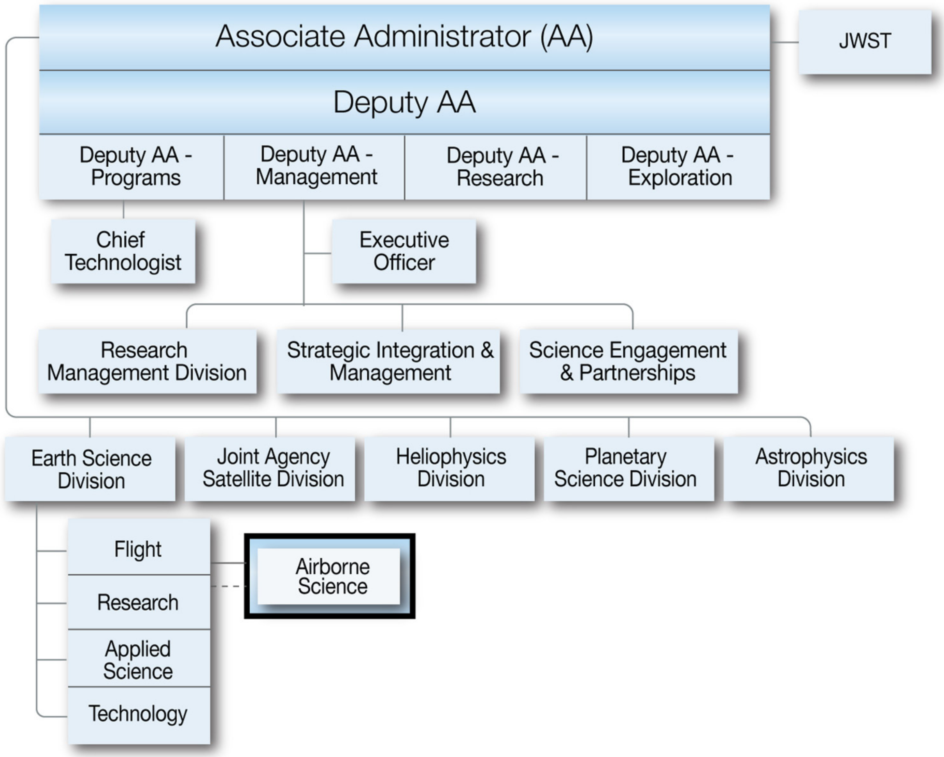


Figure 1. *Science Mission Directorate Organization Chart.*

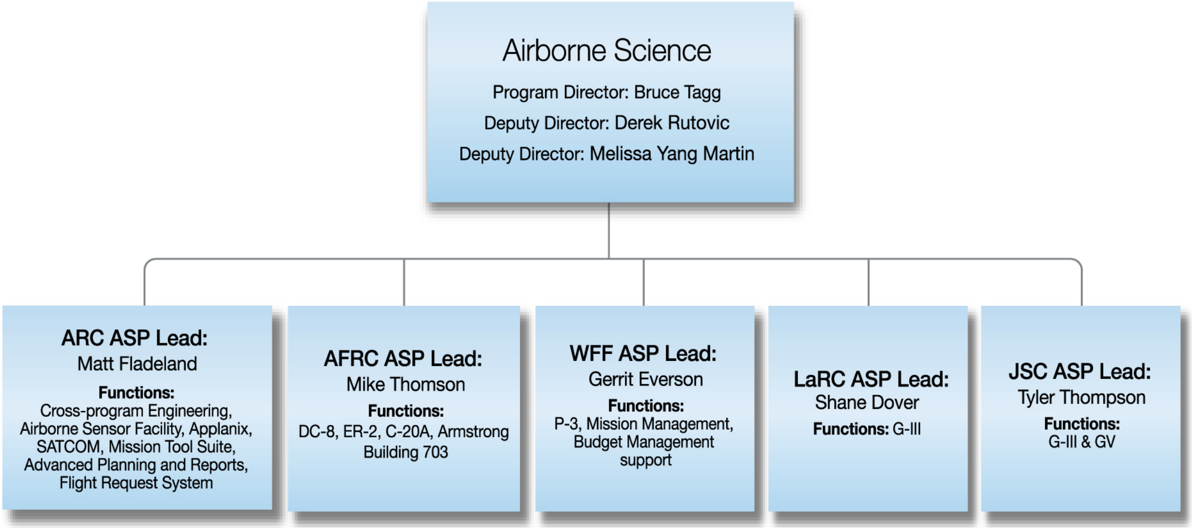


Figure 2. *Airborne Science Program Organization Chart.*

avionics upgrade, and the G-III Airborne Expendable Conductivity Temperature Depth (AXCTD) sonobuoy launch system installation. Since 2014, he has served as an aircraft program manager, at various times, for the G-III, GV, and WB-57F aircraft at JSC, responsible for ensuring success in meeting SMD, Human Exploration and Operations Mission Directorate (HEOMD), and Department of Defense (DoD) objectives. These program management efforts included development of the business plan, acquisition, and HEOMD/SMD partnership for the GV in 2016.

Melissa Yang Martin was appointed as Deputy Airborne Science Program Director, with a focus on Earth Science. She will split her time between supporting ASP and supporting the EVS program in the ESSP Program Office as Mission Manager. Dr. Yang Martin received her Ph.D. in analytical/atmospheric chemistry from the University of California, Irvine in 2009. From 2010 to 2015, she flew on several NASA-sponsored field campaigns as a research physical scientist at NASA Langley Research Center (LaRC), measuring CO2, CH4, CO, and H2O. Much of her research focused on the study of the carbon cycle, source-sink attribution and use of in situ data for satellite validation. In 2014, she went on detail as deputy project manager for the Radiation Budget Instrument. In November 2015, Dr. Yang Martin became Program Director of the National Suborbital Research Center (NSRC), responsible for science operations support for various NASA airborne research platforms, including the DC-8, P-3, and C-130, as well as management of the Student Airborne Research Program (SARP). She has also served as an interface to the scientific community.

Flight Request System and Flight Hours

The program's Science Operations Flight Request System (SOFRS) is a web-based tool used to track and facilitate the review and approval process for airborne science activities using ASP-supported aircraft, facility instruments, ASP science support assets, or any ESD-funded activities using aircraft. To schedule use of NASA SMD platforms and instrument assets, submit a Flight Request (FR) through SOFRS (https://airbornescience.nasa.gov/sofrs).

In FY2020, 158 Flight Requests (FR) were submitted for flight activities using at least one of the following ASP components: an ASP supported aircraft, ESD funding, an ASP facility instrument (AVIRIS-NG, AVIRIS-C, eMAS, LVIS, MASTER, NAST-I, and UAVSAR), and/or an ASP Science Support Asset (DMS and POS AV Applanix). A total of 36 FRs were completed, using 14 different aircraft. Of the remaining FRs, some were deferred, and the rest were canceled for a variety of reasons. The 36 completed FRs flew a total of 1743.9 flight hours. Table 1 shows the status of all flight requests and total flight hours flown by all aircraft, including "Other (non-NASA) Aircraft." Table 2 shows flight request status and total hours for the specific "Other (non-NASA) Aircraft" requested. Table 3 shows only ESD flight requests and flight hours flown by aircraft. Figure 3 is a histogram showing the history of total flight hours flown. Table 4 shows all SOFRS flight hours flown by funding source. Figure 4 shows the global reach of flight activities in 2020.

*How to read Table 1, 2, and 3 notes:

- The "Total FRs" column includes Flight Requests submitted for fiscal year FY20; these log numbers start with "20".
- The "Total FRs Approved" column includes Flight Requests that were approved but may or may not have flown during FY20.
- The "Total Partial FRs" column includes Flight Requests for which the total approved hours were not fully expended during FY20 and have been rolled over to the following year.
- The "Total FRs Completed" column includes only Flight Requests with the final status of "Completed".

The "Total Hours Flown" column includes all "Flight Hours Flown" for Flight Requests with a status of "Completed" or "Partial" for FY20.

Table 1. *FY20 flight request status and total hours flown by all aircraft. **

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
ASP Supported Aircraft					
DC-8[1] – AFRC[1]	11	0	0	0	0.0
ER-2 – AFRC[1]	22	8	2	4	122.9
Gulfstream C-20A (GIII) – AFRC[1]	15	11	5	1	81.8
Gulfstream III – JSC[1]	17	10	0	6	121.0
Gulfstream III – LaRC	3	2	0	0	0.0
Gulfstream V – JSC[1]	4	2	0	1	248.4
P-3 Orion – WFF[1]	15	3	0	2	109.5
Other NASA Aircraft					
B-200[2]	9	4	0	3	241.7
C-23 Sherpa - WFF[2]	1	0	0	0	0.0
Cessna 206H - LaRC[2]	2	2	0	0	0.0
Global Hawk - AFRC[2]	1	0	0	0	0.0
HU-25A Guardian – LaRC[2]	1	1	0	1	149.9
SIERRA – ARC[2]	2	0	0	0	0.0
Twin Otter – Any[2]	1	0	0	0	0.0
WB-57 – JSC[2]	3	1	0	0	0.0
Other (non-NASA) Aircraft[3]	51	20	1	18	668.7
TOTAL	**158**	**64**	**8**	**36**	**1743.9**

[1]ASP supported aircraft.

[2]These aircraft are NASA-owned, not subsidized by the Airborne Science Program.

[3]See Table 2.

Table 2. *FY20 flight request status and total hours flown by other (non-NASA) aircraft.*

Other (non-NASA) Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
A90 - Dynamic Aviation	6	4	1	3	118.4
Alphajet	2	0	0	0	0.0
B-200 - Dynamic Aviation	15	7	0	6	223.5
DC-3	2	1	0	1	134.8
Twin Otter CIRPAS	4	2	0	2	31.6
Twin Otter International	10	4	0	4	112.4
Aeroscout	1	0	0	0	0.0
B-200 - DOE	1	0	0	0	0.0
DHC-3T Twin Otter (Ultima Thule Outfitters)	1	1	0	1	48.0
Dynamic Aviation, King Air, via Quantum Spatial	1	0	0	0	0.0
ISRO King Air	1	0	0	0	0.0
Robinson R-44	1	0	0	0	0.0
SPEC Learjet	1	1	0	0	0.0
SuperSwift	1	0	0	0	0.0
UK Twin Otter	1	0	0	0	0.0
Vanilla Aircraft VA001	1	0	0	0	0.0
VT USL 26 Hexacopter	1	0	0	0	0.0
Zephyr-S	1	0	0	0	0.0
TOTAL	**51**	**20**	**1**	**17**	**668.7**

*Table 3. Summary of ESD funded FY20 Flight Request Status and Flight Hours Flown by Aircraft. **

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8[1] – AFRC[1]	11	0	0	0	0.0
ER-2 – AFRC[1]	14	8	2	4	122.9
Gulfstream C-20A (GIII) – AFRC[1]	13	11	5	1	81.8
Gulfstream III – JSC[1]	15	10	0	6	121.0
Gulfstream III – LaRC	2	1	0	0	0.0
Gulfstream V – JSC[1]	4	2	0	1	248.4
P-3 Orion – WFF[1]	13	3	0	2	109.5
Other NASA Aircraft					
B-200[2]	8	3	0	2	163.8
C-23 Sherpa - WFF[2]	1	0	0	0	0.0
Cessna 206H - LaRC[2]	1	1	0	0	0.0
Global Hawk - AFRC[2]	1	0	0	0	0.0
HU-25A Guardian – LaRC[2]	1	1	0	1	149.9
SIERRA – ARC[2]	1	0	0	0	0.0
Twin Otter – Any[2]	0	0	0	0	0.0
WB-57 – JSC[2]	3	1	0	0	0.0
Other (non-NASA) Aircraft[3]	43	17	0	15	616.7
TOTAL	**131**	**58**	**7**	**32**	**1614.0**

[1]ASP supported aircraft.

[2]These aircraft are NASA-owned, not subsidized by the Airborne Science Program.

[3]Other aircraft (*total hours*) are: A90 - Dynamic Aviation (*66.4h*), B-200 - Dynamic Aviation (*223.5*), DC-3 (*134.8h*), Twin Otter CIRPAS (*31.6h*), Twin Otter International (*112.4h*), and DHC-3T Twin Otter (Ultima Thule Outfitters) (*48h*).

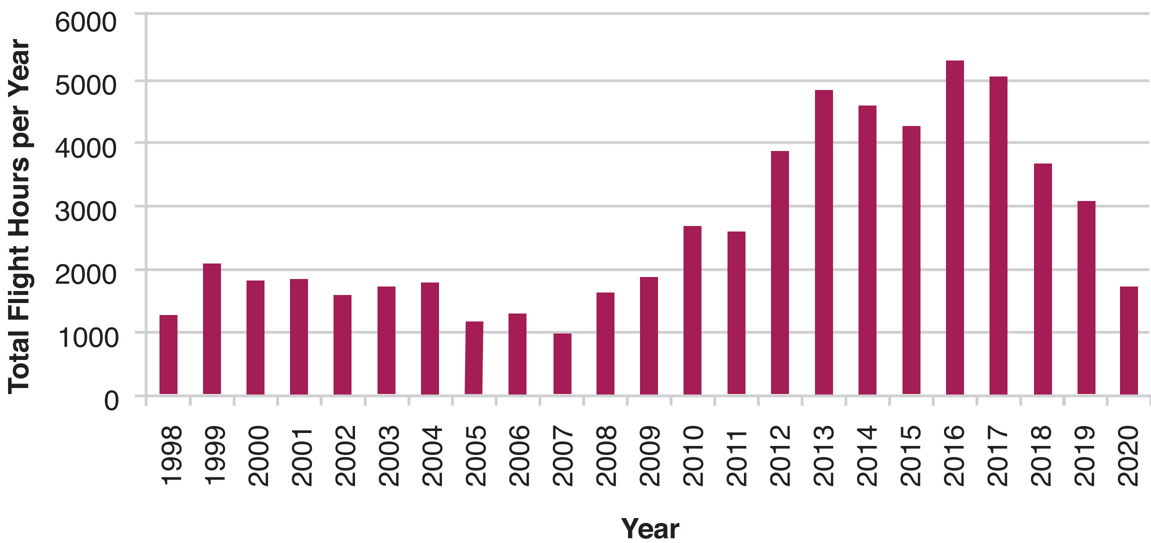


***Figure 3**. ASP Annual Flight Hours from FY98 through FY20.*

***Table 4.** All Flight Hours Flown by Funding Source.*

Fiscal Year	ESD	SMD (Non-ESD)**	Other NASA	Non-NASA	Funding Sources Not Listed in FR	Total Funded Flight Hours
2014	4069.4	28.5	419.5	12.8	69.9	4600.1
2015	3758.0	24.5	266.9	184.9	26.9	4261.2
2016	4752.1	16.6	285.6	260.5	0	5314.8
2017	4484.4	85.9	280.1	194.1	0	5044.5
2018	3125.8	6.4	451.5	103.6	1.2	3688.5
2019	2415.1	0.0	586.6	60.6	7.5	3069.8
2020	1614.0	0.0	129.9	0.0	0.0	1743.9

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

FY2020 Airborne Campaigns

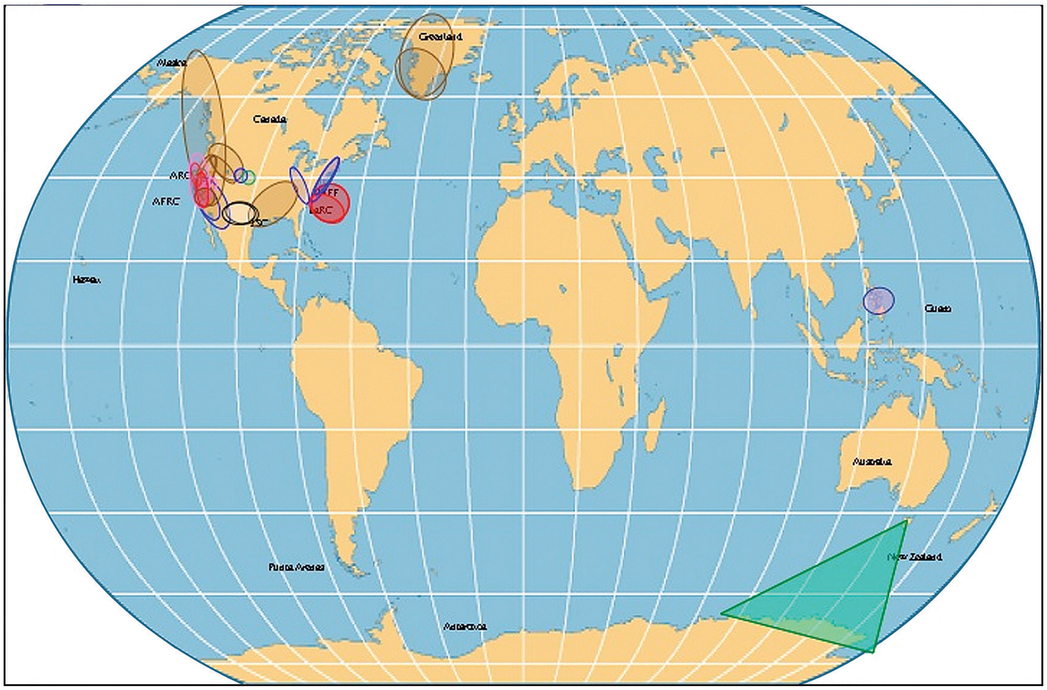


Figure 4a. *Locations of FY20 ASP campaigns.*

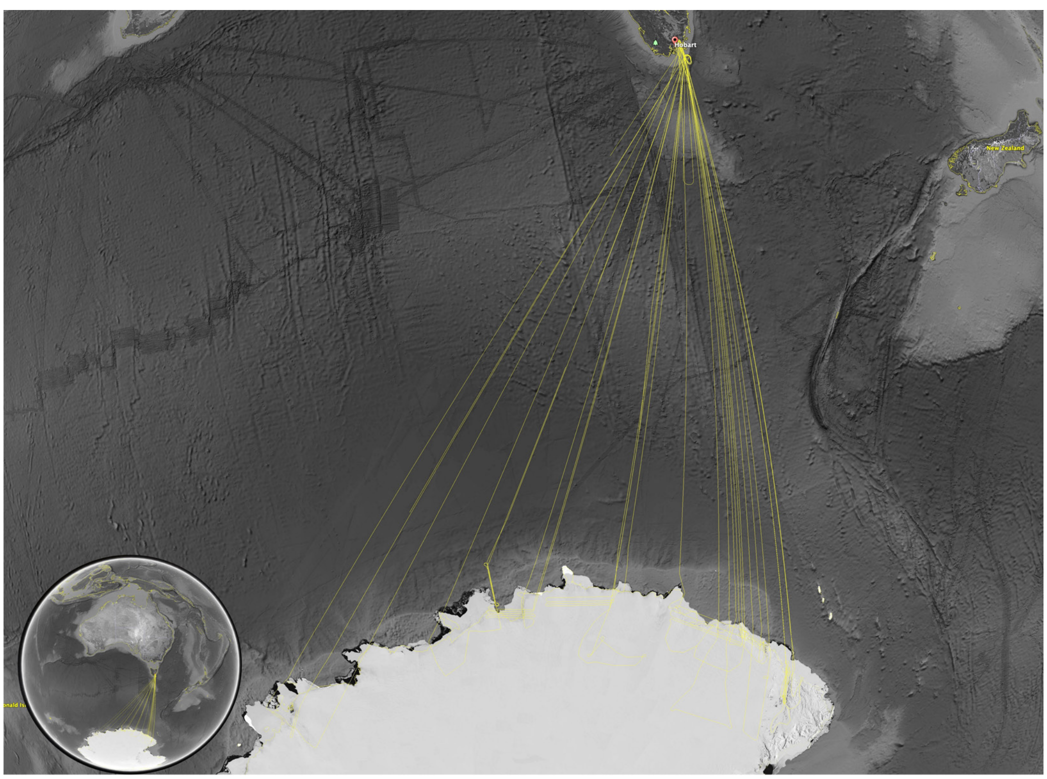
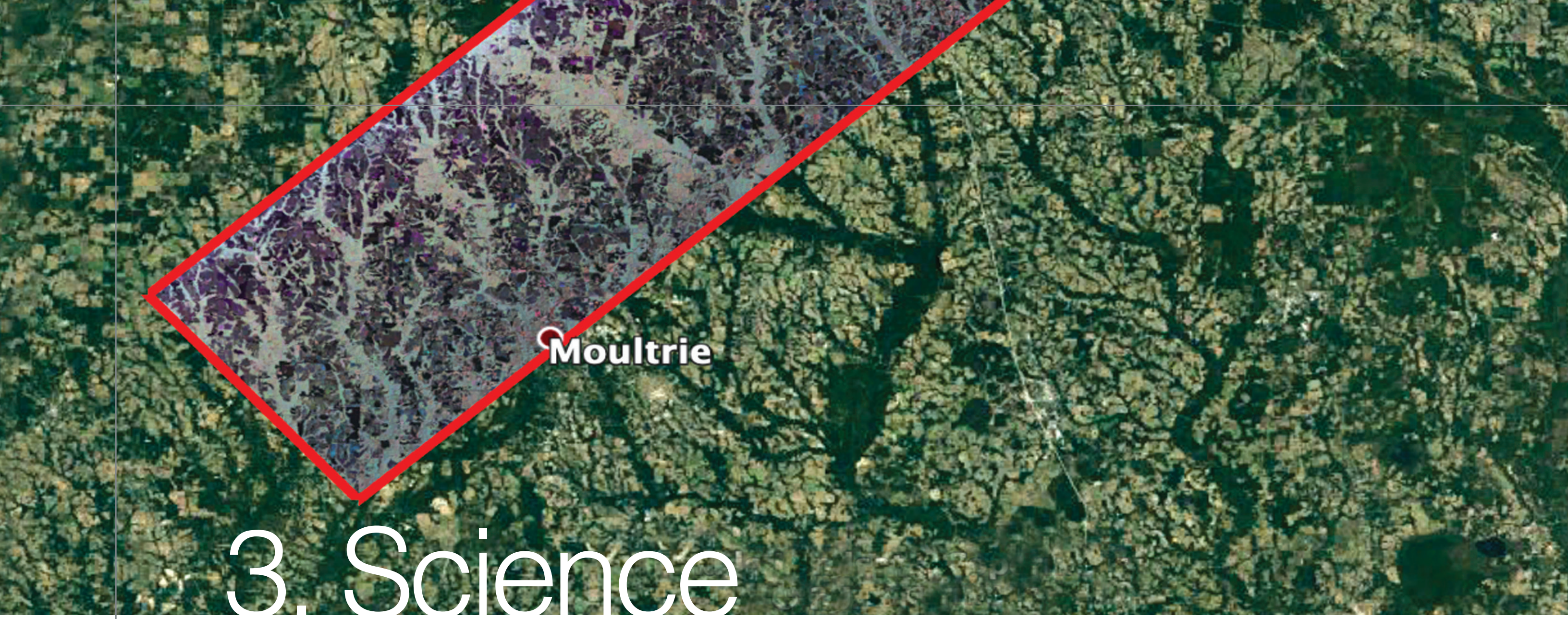


Figure 4b. *Detail of OIB Antarctica flight tracks of the GV, illustrating range of GV capabilities. Map created in Mission Tools Suite 2.0.* ***Credit:*** *Aaron Duley*



3. Science

Major Mission Highlights

Despite the unique safety and logistics challenges introduced by a global pandemic, in FY20 ASP conducted over 1600 flight operation hours in support of Earth science process studies, instrument flight-testing, and support for Earth Science space missions in all phases from definition to validation. Two of the five Earth Venture Suborbital-3 (EVS-3) missions, IMPACTS and ACTIVATE, were able to begin flight activities early in the calendar year. ACTIVATE was also able to return to flight in summer 2020. Operation IceBridge (OIB) completed activities in FY20, including GV deployment to Australia and a final Alaska mission. Table 5 shows flight hours for the largest campaigns.

***Table 5.** FY20 Major Science Campaigns.*

Campaign	Flight Hours	Location	Aircraft
ACTIVATE	288.2	Atlantic coast	Falcon, UC12-B
OIB – Antarctica – Fall 2019 (FY20)	248.4	East Antarctica	GV
OIB – Alaska	48.0	Alaska	Twin Otter
NASA Methane Survey	239.1	California, Texas	B-200
UAVSAR Combined Missions	198.4	CONUS	G-III
SNOWEX	159.8	Colorado, Idaho, California	G-III, B-200, Twin Otter
OMG	134.8	Greenland	Airtec DC-3
IMPACTS	123.9	Atlantic coast	P-3, ER-2
NISAR SAR Campaigns	75.7	Alaska, South-East U.S.	G-III
CAMP2EX	48.2	Philippines	P-3, SPEC Lear
G-LiHT Post-hurricane Recovery	38.0	Florida	A90
Western Diversity Time Series	29.0	California	ER-2

Earth Venture Suborbital

The Earth System Science Pathfinder (ESSP) Earth Venture Suborbital (EVS) projects are flagship equivalent $15-30M, 5-yr efforts that focus on the most compelling science questions where aircraft measurements are absolutely critical to resolving uncertainties. The single remaining EVS-2 mission, OMG, continued flight activities in 2020, while two of the new EVS-3 missions were able to begin flight operations. As detailed below, ACTIVATE successfully carried out a winter and summer series and IMPACTS completed a winter 2020 mission. Three other EVS-3 missions, DCOTSS, S-MODE, and Delta-X, will begin flight operations in 2021.

Aerosol Cloud Meteorology Interactions Over the western ATlantic Experiment (ACTIVATE)

PI – Armin Sorooshian, University of Arizona
Program – EVS-3
Aircraft – HU-25A, UC12-B
Payload Instruments: CVI, AC3, RSP, HSRL-2

Complex interactions between aerosols and clouds represent one of the largest sources of uncertainty when simulating climate processes. ACTIVATE is focused on studying these interactions over the Western North Atlantic Ocean (WNAO). Without aerosol particles, there cannot be cloud droplets, and the number and type of particles can have critical impacts on how clouds form and evolve. Clouds in turn have important impacts on aerosol particles, such as modifying their properties, redistributing them vertically, and removing them via precipitation scavenging. Advancing knowledge of aerosol-cloud interactions requires immense amounts of data collected under a variety of conditions to be able to disentangle the impacts of meteorology and aerosol particles on cloud behavior. To respond to this need, the ACTIVATE team made strategic design choices related to aircraft flight operations. Deploying the aircraft from NASA LaRC minimizes logistical and travel costs, increasing the number of flight hours. It also provides easy access to the wide range of meteorological and aerosol conditions (and thus cloud types) over the WNAO region, which is helpful for building statistics relevant to aerosol-cloud interactions.

ACTIVATE is acquiring for the first time detailed, simultaneous, and systematic measurements of aerosols and clouds from in situ and remote sensing instruments deployed on two coordinated aircraft over multiple years. The HU-25A Falcon flies underneath the UC-12B King Air to conduct in situ sampling of boundary layer clouds, such that ACTIVATE can measure clouds that range from stratiform to thicker cumulus clouds. The Falcon payload consists of instruments characterizing gases, aerosols, clouds, and meteorological state parameters and winds. Key measurement aspects are the duo of a counterflow virtual impactor (CVI) inlet that enables characterization of droplet residual particle properties when flying in cloud, and the Axial Cyclone Cloud water Collector (AC3) that collects cloud water samples for post-flight chemical analysis.

Flying well above the HU-25A at 8-10 km, the UC-12B instruments include the Research Scanning Polarimeter (RSP) and High Spectral Resolution Lidar (HSRL-2) to characterize aerosol and cloud properties from above. Dropsondes are also deployed from the UC-12B to measure profiles of atmospheric state parameters. ACTIVATE uses these advanced remote sensors to assess and advance aerosol and cloud retrieval capabilities to study aerosol-cloud interactions. The joint deployment of these remote sensors additionally helps assess current (e.g., CALIPSO) satellite measurements and can help the NASA Aerosol, Clouds, Convection, and Precipitation (ACCP)

Figure 5. *ACTIVATE scientists Ewan Crosbie (facing camera) talking to Michael Shook and Simon Kirschler after an ACTIVATE flight. Note the sampling probes on the top of the aircraft.* ***Photo credit:*** *Armin Sorooshian*

Study assess how such satellite and suborbital measurements can be used to address the National Academy of Science 2017 Decadal Survey recommendations.

During 2020, the two ACTIVATE aircraft flew together successfully for 35 total joint flights and demonstrated the effectiveness of the joint flight approach. In the winter deployment (ACTIVATE 1), 17 joint flights took place from February 14 – March 12, 2020, with five additional flights using only the HU-25A. The winter flights sampled cold air outbreak conditions, which are of special importance, as climate models struggle to simulate the postfrontal clouds associated with these conditions. The winter flights ended early due to operational restrictions imposed as a result of the COVID-19 pandemic. After extensive consultation with LaRC personnel, the ACTIVATE team developed a plan to safely proceed under a high level of caution to conduct summertime flights in August and September.

The summer deployment (ACTIVATE 2) consisted of 18 joint flights from August 13 – September 30, 2020. A major reason the second deployment was successful is because team members live near the base of operations at NASA LaRC. In addition, only a few team members are needed to operate the numerous instruments on these aircraft. While the pace of operations was reduced due to safety restrictions, the summer flights were successful in addressing the aerosol-cloud studies described earlier. The summer flights were marked by different cloud scenes, as compared to the winter campaign, which was part of the rationale to fly in different seasons. Biomass burning plumes from the extensive wildfires in the western U.S. were a common feature sampled during the summer flights. Some of these flights were coordinated with the ASTER and CALIPSO satellites, including some where smoke aerosols resided in the vertical column below the UC-12B King Air and CALIPSO. Early ACTIVATE results point

Figure 6. *ACTIVATE team photo in front of the HU-25A Falcon in the NASA Langley hangar during the first science team meeting.* ***Photo Credit:*** *Evan Horowitz*

to the broad range of cloud droplet number concentrations, spanning several orders of magnitude, which makes the dataset important to understanding the key fundamental drivers of this cloud microphysical variable, as well as other cloud characteristics, such as reflectivity and precipitation formation.

ACTIVATE team members include: University of Arizona, NASA LaRC, NASA GISS, Columbia University, Pacific Northwest National Laboratory (PNNL), College of William and Mary, German Aerospace Center (DLR), Rochester Institute of Technology, SciSpace LLC, NASA WFF, Yulista Holding LLC, and Bay Area Environmental Research Institute (BAERI).

Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS)

PI – Lynn McMurdie, University of Washington
Program – EVS-3
Aircraft – P-3, ER-2
Payload Instruments: CRS, HIWRAP, EXRAD, CoSMIR, AMPR, CPL, CDP, CAPS, HVPS, Nevzorov, Hawkeye, TAMMS, AVAPS, RICE

In winter 2020, IMPACTS flew two aircraft in a coordinated fashion to characterize snow band structure, understand the dynamical and microphysical mechanisms that produce the observed structures, and apply this understanding to improving remote sensing and modeling of snowfall. The ER-2 aircraft operated out of Hunter Airfield near Savannah, Georgia. It flew at a high altitude (~65k ft) above the storm systems and was equipped with passive and active remote sensing instruments similar to those flown on satellites. The ER-2 flew nine missions for a total of 62.6 hours. The P-3 operated out of its home base at Wallops Flight Facility (WFF) and was equipped with in situ microphysical and environmental instrumentation and dropsonde capability. The P-3 flew at a variety of altitudes (4-25k ft) within the storm systems depending on the depth of the cloud, height restrictions, and temperature structure as determined by the mission scientists. The P-3 flew ten missions for a total of 61.3 hours. Of these missions, five were coordinated flights where the two aircraft were no more than 10 minutes apart during straight flight legs.

IMPACTS sampled storms that occurred over Illinois, Indiana, North Carolina and offshore waters, New York, and New England (see Figure 7). The storms exhibited a wide-range of characteristic structures that contribute to snow bands, such as strong frontogenesis, elevated convection, weak and strong synoptic forcing, generating cells, and gravity waves. At least two flights were well coordinated with overpasses of the Global Precipitation Measurement (GPM) satellite.

IMPACTS conducted a wide range of media and outreach activities at Hunter Airfield and WFF. These included media days at each facility, multiple on-air interviews, media visits, and media fly-alongs on the P-3. During flights, students at multiple K-12 schools followed mission operations in real-time. The Program's Mission Tools Suite for Communications (MTS-C) website allowed students and teachers to track aircraft position and chat live with flight scientists in the operations center and onboard the aircraft.

The data collected during this first deployment is of high quality, with very few instrument issues. All data are available at NASA's Global Hydrology Resource Center (GHRC) Distributed Active Archive Center (DAAC) and the science team is conducting multiple lines of scientific inquiry addressing IMPACTS goals. Preliminary results were presented in two public seminars at the University of Washington, plus at the 2020 American Geophysical Union and 2021 American Meteorological Society meetings. Several scientific journal articles on results from this first deployment are currently in preparation.

The IMPACTS team includes: University of Washington, NASA GSFC, NASA ARC, BAERI, NC State, NASA LaRC, IM Systems Group, Inc, SUNY Stony Brook, University of Oklahoma, NOAA Earth System Research Laboratories (ESRL), University of Illinois (UI), Penn State, NASA JPL, National Centers for Environmental Prediction (NCEP), University of Maryland, Baltimore County (UMBC), Colorado State, NASA WFF, Brookhaven National Laboratory (BNL), NASA AFRC, University of Alabama in Huntsville, Universities Space Research Association (USRA), NASA MSFC, i3, Yulista Tactical Services (YTS), National Center for Atmospheric Research (NCAR), University of North Dakota (UND), University of Colorado, Boulder (CU Boulder).

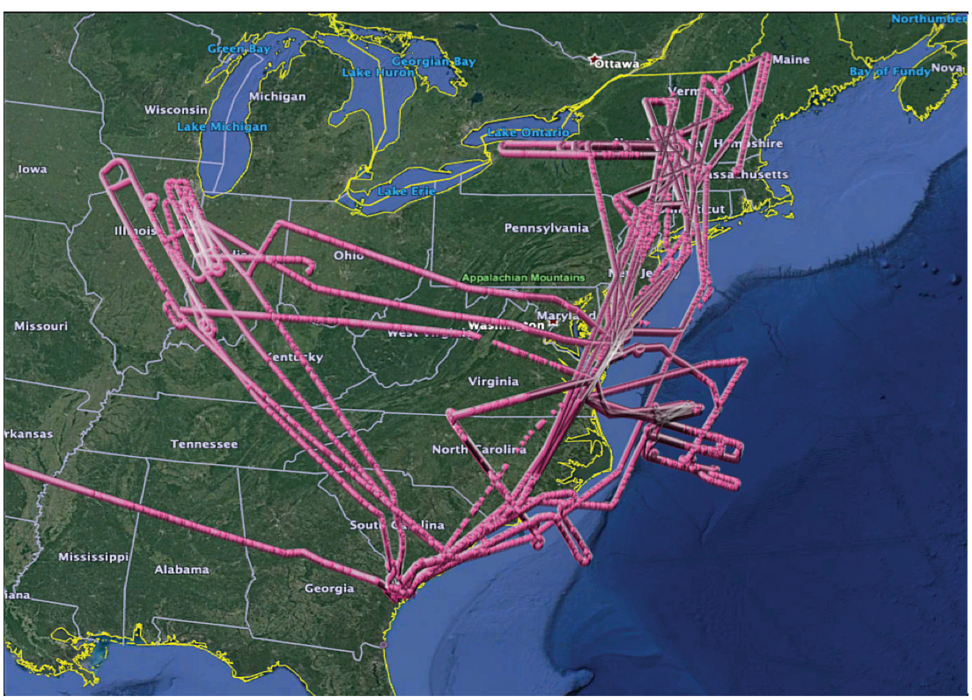


Figure 7. *Flight tracks during the IMPACTS 2020 deployment.*

Figure 8. *The IMPACTS science team.*

Oceans Melting Greenland (OMG)

PI – Josh Willis, JPL
Program – Earth Venture Suborbital-2
Aircraft – Basler DC-3
Payload: AXCTDs

The Oceans Melting Greenland (OMG) multi-year project seeks to understand how in-water and airborne measurements can improve estimates of glacial discharge from Greenland. The complicated geometry of the sea floor steers currents on the shelf and often determines whether Atlantic water can reach into the long narrow fjords and interact with coastal glaciers. Because knowledge of these pathways is a critical component of modeling the interaction between the oceans and ice sheet, OMG will facilitate improved measurements of the shape and depth of the sea floor in key regions. In 2020, OMG dropped 346 Airborne Expendable Conductivity Temperature Depth (AXCTD) sensors to measure ocean conditions (ocean salinity and temperature) on the shelf around Greenland, as shown in Figure 9. That is the highest number of AXCTD sensors the team has dropped in a single year, and it was accomplished in just under 3 weeks. In addition to the probes, OMG also deployed three iridium floats.

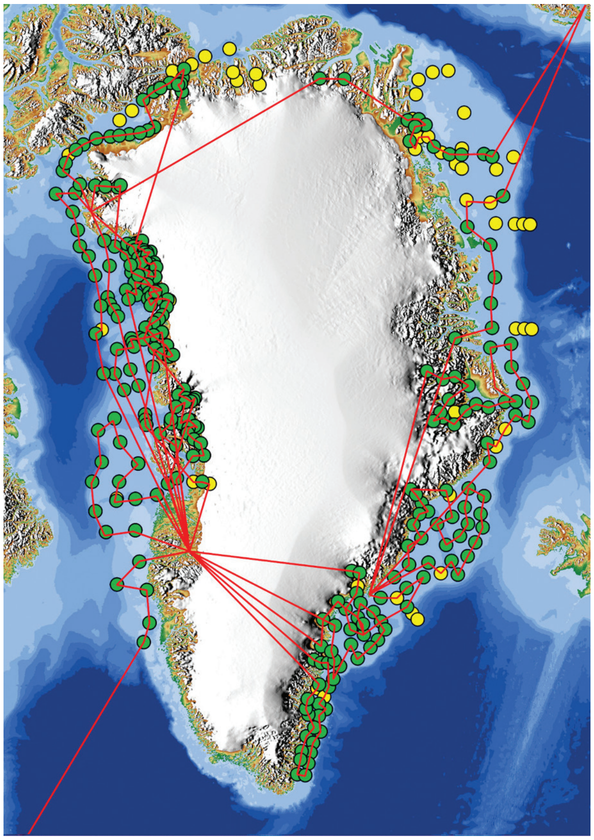


Figure 9. *In 2020, OMG performed an extensive survey of the oceans around Greenland. Yellow dots show planned drops, green dots show completed drops.*

The OMG science team spent a concentrated amount of time in Kangerlussuaq, in southwest Greenland. The team was able to work from that city while observing Greenland's strict quarantine rules because of support from the Kangerlussuaq International Science Support (KISS) team. KISS provided lodging that made it possible to isolate, without contact with locals, while providing access to the airplane. In an incredibly challenging year, the OMG team was only successful because of the hard work and help of many at JPL, NASA SMD, the U.S. State Department, and Canadian, Danish, Norwegian, and Greenlandic authorities.

The OMG team worked with Kenn Borek Air LTD, a global leader in polar research scientific aviation, which provided a Basler DC3-TP for the airborne ocean survey. In total, OMG flew 135 hours in 24 days. This is the third year OMG has utilized a Basler DC3-TP, and the first working with Kenn Borek Air. The aircraft was well suited for the OMG Greenland survey given the speed, range, ability to operate from short gravel runways, and ample cabin space.

Having received permission to complete a no-cost extension of the project, OMG will return to Greenland one final time in 2021.

The End of an Era: Operation IceBridge's Last Campaigns and Close-out

PI – Joe Macgregor, GSFC
Program – Cryosphere
Aircraft – GV, Single Otter, Cessna 206
Payload Instruments: Laser altimeter, ARES, OIB package

In 2020, NASA's Operation IceBridge (OIB) completed some of its last Alaskan campaigns, having completed its final polar campaigns in 2019, and began mission close-out. (The final mission to Antarctica with the JSC GV aircraft is reported in detail in the 2019 Annual Report.) The Alaskan campaigns continued to innovate, deploying a new aircraft and new laser altimeter while mitigating COVID-19 risk during deployments at remote Alaskan outposts.

In May, OIB team members Chris Larsen, Martin Truffer, and Jack Holt organized the simultaneous deployment of two aircraft in Alaska to survey the changing elevation of major Alaskan glaciers. The first was the trusted DHC-3T Single Otter operated by Ultima Thule Outfitters, which was the platform for all previous OIB Alaska deployments. This platform included the venerable Riegl LMS-Q240i laser altimeter and the low-frequency Arizona Radio Echo Sounder (ARES) for measuring ice thickness. The second was a new platform, a lower-cost Cessna 206 operated by Keller Aviation, that deployed a new Riegl VQ-580ii laser altimeter, capable of higher-altitude ranging at an order of magnitude faster scanning rate at 100 kHz compared to the older Riegl (10 kHz). The campaigns were successful and completed a total of 137 science flight hours surveying the springtime state of Alaska's glaciers. In August, with COVID-19 risk increasing in Alaska, the OIB Alaska team opted to only fly the smaller Cessna and did so successfully for 70 science flight hours to measure summertime melt. As a consequence of the inability to fly the Single Otter in August 2020, OIB Alaska will undertake one final campaign to survey Alaskan glaciers in Spring 2021.

OIB Project Science Office priority in 2020 was ensuring remaining outstanding data products from previous years' campaigns were delivered to the National Snow and Ice Data Center and preparing the mission for a KDP-F and other close-out activities in 2021. The team drafted a manuscript summarizing OIB's scientific legacy, including the contributions of past and present members of the OIB leadership, science, and instrument teams. This provided an opportunity to review the mission by the numbers:

OIB Mission Statistics (2009–2020)	Totals (as of Jan 2021)
Campaigns	64
Aircraft	15
Science Flights	958
Science Flight Hours	4,856 hr
NASA and ESA Satellite Tracks Underflown	436,237 km
Instruments	32
Data Products	93
Data Volume Downloaded from NSIDC	348 TB
Scientific Articles Using OIB Data	635
K-12 Students Engaged Over X-chat	11,708
NASA Press Releases Mentioning OIB	130
YouTube Views of OIB Videos	9.3M
NASA Investment	$180.1M

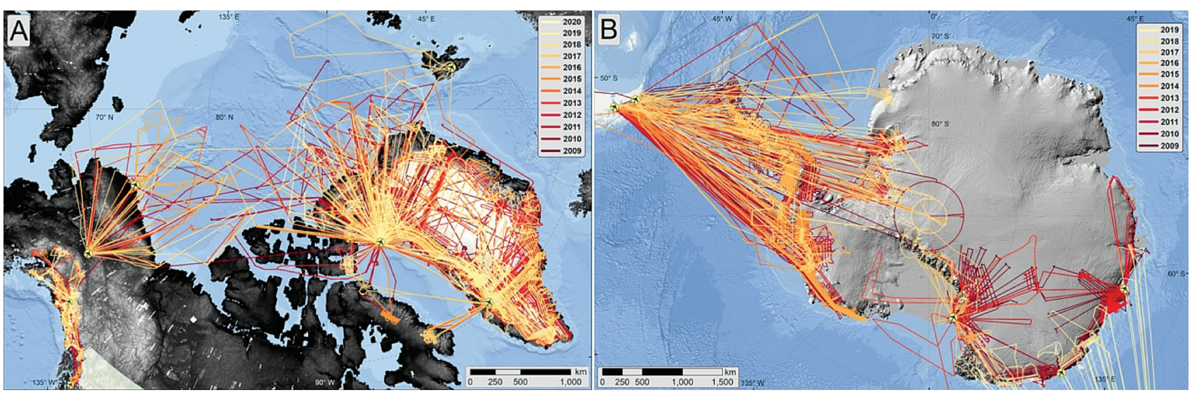


Figure 10. *All combined 2009-2020 OIB flight lines.* ***Image credit****: Jeremy Harbeck*

The combination of OIB's advanced instrument suite and breadth of surveys enabled numerous fundamental advances in our understanding of the Earth's cryosphere. For land ice, OIB dramatically improved knowledge of interannual outlet-glacier variability, ice-sheet and outlet-glacier thickness, snowfall rates on ice sheets, fjord and sub-ice-shelf bathymetry, and ice-sheet hydrology. Unanticipated discoveries included a reliable method for constraining the thickness within difficult-to-sound incised troughs beneath ice sheets, the extent of the firn aquifer within the Greenland Ice Sheet, the vulnerability of many Greenland and Antarctic outlet glaciers to ocean-driven melting at their grounding zones, and the dominance of surface-melt-driven mass loss of Alaskan glaciers. For sea ice, OIB significantly advanced our understanding of spatiotemporal variability in sea ice freeboard and its snow cover, especially through combined analysis of fine-resolution altimetry, visible imagery, and snow radar measurements of overlying snow thickness. Such analyses led to the unanticipated discovery of an interdecadal decrease in snow thickness on Arctic sea ice and numerous opportunities to validate sea ice freeboards from satellite radar altimetry.

While many of its datasets have yet to be fully explored, OIB's scientific legacy has already demonstrated the value of sustained investment in reliable airborne platforms, airborne instrument development, interagency and international collaboration, and open and rapid data access to advance our understanding of Earth's remote polar regions and their role in the Earth system. As mission close-out activities progress, the OIB team extends its thanks to the innumerable individuals in the NASA airborne science community who helped make this twelve-year mission a resounding success.

Summary of the OIB October 2019 (FY20) Antarctic mission on the GV aircraft:

- Flight hours: 248.4
- Science missions: 20
- Payload: Laser altimeters (ATM T-6, T-7), radar sounders (MCoRDS, Snow Radar) and nadir imagers (CAMBOT, FLIR, Headwall Nano-Hyperspec), a new MCoRDS design implemented in the aircraft belly, hybrid gravimeter (iMAR/DgS)

Figure 11. *The terminus of Johns Hopkins Glacier, Glacier Bay National Park, Alaska.* ***Photo credit:*** *Chris Larsen*

SnowEx

PI – Hans-Peter Marshall, Univ. Boise
Program – Terrestrial Hydrology
Aircraft – G-III, Twin Otter
Payload Instruments: UAVSAR, SWESARR, ASO package

NASA's SnowEx campaign is a multiyear effort using a variety of techniques to study snow characteristics. SnowEx is learning valuable information about how snow properties change by terrain and over time, as well as investigating the tools, datasets, and techniques NASA will need to observe and measure snow properties from space. Current satellite missions easily measure how much of the land is covered by snow. But no single satellite currently in orbit contains an instrument or collection of instruments designed to measure snow water equivalent (SWE) and/or the snow characteristics that may be used to calculate it.

For SnowEx 2020's intensive operating period, a grueling three weeks of data collection at one site, scientists from around the world traveled to Grand Mesa, Colorado. This is the world's largest mesa, or flat-topped mountain, and at 11,000 feet above sea level, winters are long and snow can be deep. Its high flat surface and variety of land cover — from wide-open meadows to dense forests — make it ideal for testing instruments across different conditions.

Platform Name	Center	Payload Accommodations	Duration (Hours)	Useful Payload (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)
ASP Supported Aircraft							
DC-8	NASA-AFRC	4 nadir ports, 1 zenith port, 14 additional view ports	12	30,000	41,000	450	5,400
ER-2 (2)	NASA-AFRC	Q-bay (2 nadir ports), nose (1 nadir port), wing pods (4 nadir, 3 zenith ports), centerline pod (1 nadir port)	12	2,900	>70.000	410	>5,000
G-III/C-20A	NASA-AFRC	UAVSAR pod	7	2,610	45,000	460	3,400
G-III	NASA-JSC	UAVSAR pod, Sonobuoy launch tube	7	2,610	45,000	460	3,400
G-III	NASA-LaRC	2 nadir ports	7	2,610	45,000	460	3,400
GV	NASA-JSC	2 nadir ports	12	8,000	51,000	500	>5,000
P-3	NASA-WFF	1 large and 3 small zenith ports, 3 fuselage nadir ports, 4 P-3 aircraft window ports, 3 DC-8 aircraft window ports, nose radome, aft tailcone, 10 wing mounting points, dropsonde capable	14	14,700	32,000	400	3,800
Other NASA Aircraft							
B-200 (UC-12B)	NASA-LaRC	2 nadir ports, 1 nose port, aft pressure dome with dropsonde tube, cargo door	6.2	4,100	31,000	260	1,250
B-200	NASA-AFRC	2 nadir ports	6	1,850	30,000	272	1,490
B-200	NASA-LaRC	2 nadir ports, wing tip pylons, zenith site for aerosol inlet, lateral ports	6.2	4,100	35,000	275	1,250
[illegible]	[illegible]	3 nadir ports, 1 zenith port, 2 rectangular [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 12. *Megan Mason, Chris Hiemstra, and Kate Hale (L-R) conducting fieldwork during the SnowEX campaign.* ***Photo credit:*** *Hans-Peter Marshall*

While the ground teams worked in the snow, airborne teams flew precision flight lines overhead carrying instrument combinations that made similar measurements: radar and lidar (light detection and ranging) for snow depth, microwave radar and radiometers for SWE, optical cameras to photograph the surface, infrared radiometers to measure surface temperature, and hyperspectral imagers to document snow cover and composition. The observations, instruments, and aircraft are listed in Table 6.

Table 6. *SnowEx airborne observations and instruments.*

NASA Airborne Observations		
Instrument	**Developer**	**Aircraft**
L-band InSAR, UAVSAR	JPL	JSC GIII
Active/Passive microwave, SWESARR • X-, dual Ku-band radar • X, K-, Ka-band radiometer	GSFC	NPS CIRPAS Twin Otter
Thermal IR	U. of Washington	NPS CIRPAS Twin Otter
Reigl 1560i Lidar, CASI hyperspectral	Quantum Spatial	Dynamic Aviation A90
Partner Airborne Observations		
FMCW Radar	U. of Alabama	TOI Twin Otter
Gamma Airborne Survey	NOAA NOHRSC	Twin Commander

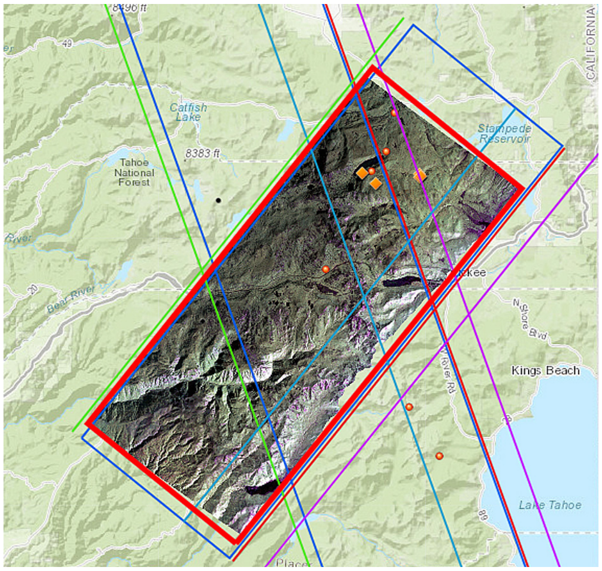


Figure 13. *Example UAVSAR imagery and flight lines during SnowEx.*

One of the seven instruments, Snow Water Equivalent Synthetic Aperture Radar and Radiometer (SWESARR), was developed and built at NASA GSFC. Another radar, the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR), is from NASA JPL. UAVSAR L-band images generated accurate snow accumulation maps. Figure 13 is an example of UAVSAR imagery and flightlines during SnowEx.

The teams also took advantage of overpasses by several satellites, including NASA's ICESat-2 and Terra and the European Space Agency's (ESA) Sentinel-1 missions, to collect additional data for comparison. On the ground, the team ran a range of computer models to compare with gathered data to see how they compared and might be combined for future analyses. Coordinating new and mature instruments across a variety of conditions and locations was challenging, according to PI Dr. Hans-Peter Marshall. "For a seasonal snow airborne campaign, SnowEx 2020 is unique in that we successfully flew so many instruments over the same location, coordinated with extensive field observations," he said. "Using those data sets together is going to be really exciting. It will take us a long way toward a better understanding of how to develop a global SWE product that combines data from multiple satellites, field data, and modeling." The science team is actively planning for the follow-on 2021 campaign.

Figure 14. *Carrying instruments similar to those used on the ground, this US Navy CIRPAS Twin Otter and other aircraft flew over the snow pits, taking similar measurements at the same time for calibration and comparison with ground data.* ***Photo credit:*** *Jessica Merzdorf*

Uninhabited Arial Vehicle Synthetic Aperture Radar (UAVSAR)

PI – Yunling Lou, JPL
Programs – Terrestrial Ecology, Water and Energy Cycle, Earth Surface and Interior
Aircraft – G-III (JSC), C20-A

During FY20, the UAVSAR project supported twelve Flight Requests and five Principal Investigators. Two, the Joint NASA and ISRO Airborne Campaign and NISAR AM/PM campaign, involved multi-disciplinary science teams from several U.S. institutions. The SnowEx mission described above involved a combination of aircraft and instruments, including the UAVSAR. The NASA AFRC G-III (NASA802) conducted 16 flights and collected 161 data lines, for a total of 82 hours. The NASA JSC G-III (NASA992) conducted 26 flights and collected 188 data lines, for a total of 121 hours. Besides the L-band radar, the team conducted one P-band engineering flight in March 2020 before pausing flight operations due to the pandemic shutdown.

The NextGen Airborne SAR Workshop was held in May 2020 to discuss science priorities, technology needs, and potential aircraft configurations for the next generation of airborne SAR instruments. Workshop participants included remote sensing researchers, airborne sciences experts, and NASA HQ program managers: https://uavsar.jpl.nasa.gov/science/workshops/nextGen2020.html.

More than 100 peer-reviewed papers utilizing UAVSAR data have been published in FY20. The number of publications is a testament to UAVSAR's high data product quality, as well as NASA's free and open data policy. Links to publications are available at: https://uavsar.jpl.nasa.gov/cgi-bin/publications.pl.

Much of the work of UAVSAR continues to support preparations for the launch of the NASA ISRO satellite NISAR. The UAVSAR team is using data collections from the UAVSAR AM/PM and Joint L-band/S-band campaigns to produce NISAR-

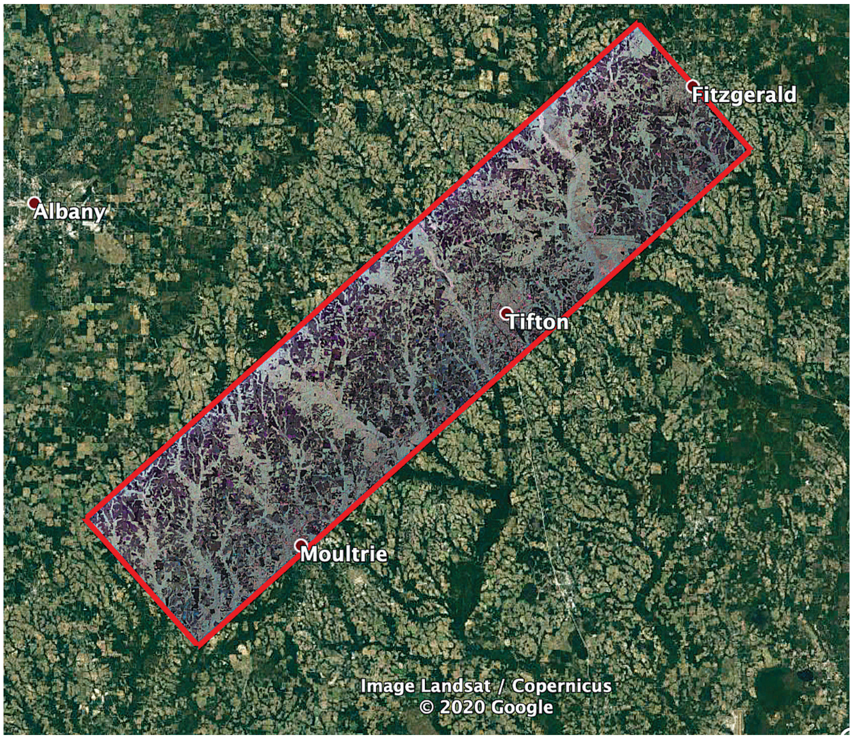


Figure 15. *UAVSAR image acquired during the AM/PM campaign in Tifton, GA shows a mix of forest (green) and agricultural zones (purple).*

simulated products supporting algorithm development. In October 2019, UAVSAR imaged sites in the southeastern U.S. as part of the UAVSAR AM/PM campaign. The resulting L-band observations support research on forests, wetlands, and agricultural zones. Sites were imaged with approximate 12-day intervals at 6 AM/6 PM following the planned NISAR observation plan. The JSC G-III flew these 41 flight lines.

The Joint NASA and ISRO Airborne Campaign was a collaborative effort between NASA and the Indian Space Research Organization (ISRO) to conduct observations in preparation for the NISAR instrument. A group of ten PIs designed observations to support studies on glaciers, sea ice, crop mapping, soil moisture, and vegetation. The ASAR instrument, flown aboard the AFRC G-III, was equipped with L- and S-band radars. In December 2019, observations were conducted over a broad range of study sites in the CONUS and Alaska. Results are available at: https://uavsar.jpl.nasa.gov/asar/.

The AFRC C-20A also conducted flights in Fall 2020 to image California's San Andreas Fault, extending L-band observations that date back to 2009. The imagery produced during the 2020 campaign provide baseline conditions for use in the event of a future earthquake.

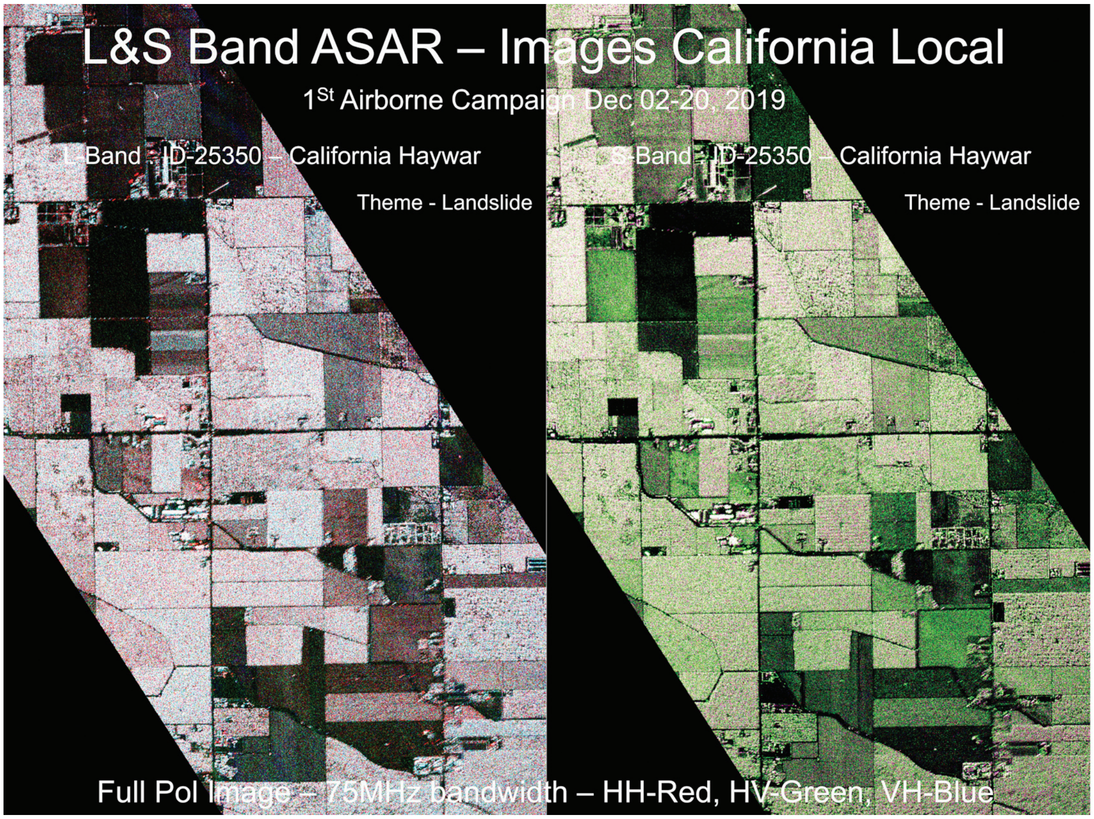


Figure 16. *ASAR dual-frequency observations (L- and S-band) over a landslide study site in California.*

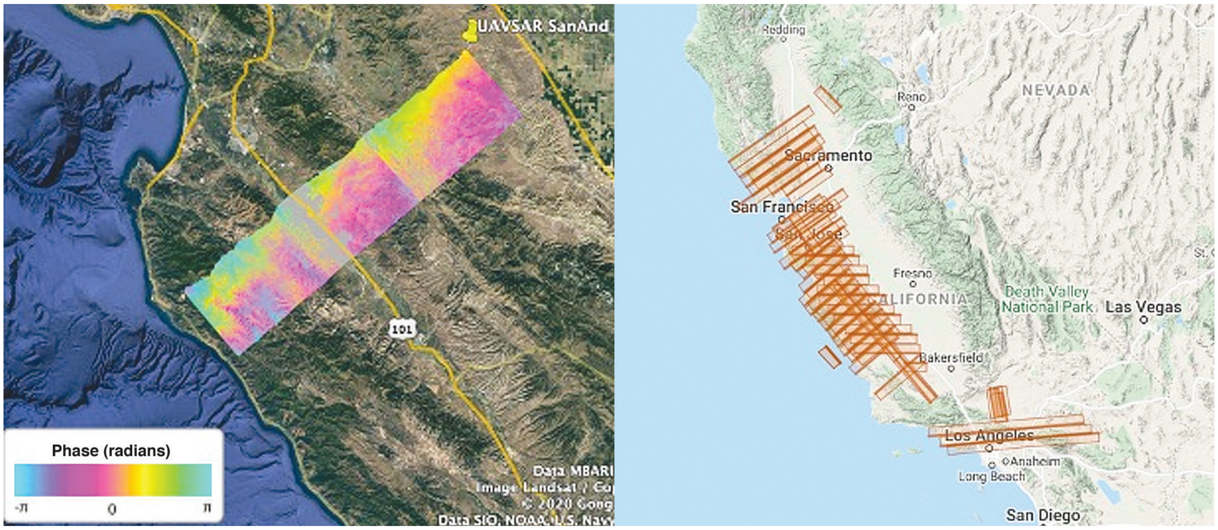


Figure 17a. *UAVSAR swaths covered a large portion of the San Andreas Fault in California.* ***Figure 17b:*** *UAVSAR observation pairs are used to generate images that point to sites with ground deformation.*

The UAVSAR/AFRC team imaged California wildfires in September 2020, including the CZU Lightning Complex Fire in Santa Cruz and Bobcat fire in southern California. The effort, led by NASA's Applied Sciences Program, resulted in damage proxy maps shared with stakeholders from Cal Fire and the California National Guard.

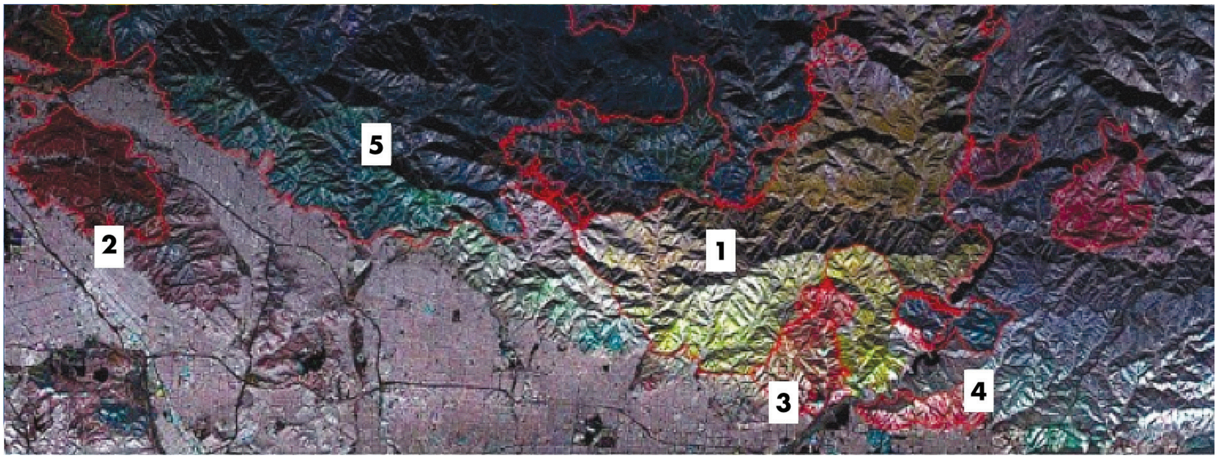


Figure 18. *An RGB color composite of three UAVSAR images acquired over the Angeles National Forest. Color intensity provides a proxy for vegetation material detected over three different years. Red = 2010; Green = 2017; Blue = 2020. Blue areas (2020) indicate vegetation regrowth over the Station Fire scar. Red sites areas (2010) reveal vegetation in 2010 that was burned before or in 2017. Forested areas recently impacted by the Bobcat fire appear in yellow, as the vegetation was present in 2010 and 2017 but not in 2020. Points: 1 - Bobcat (2020) 2 - La Tuna (2017) 3 - SG Complex (2016) 4 - Colby (2014) 5 - Station (2009)*

ASP Support to ESD Satellites and International Space Station Missions

The primary stakeholders in ASP are Earth Science space flight missions, including satellite missions and missions on the International Space Station (ISS). The Program provides platforms to collect data for algorithm development prior to launch, testing instrument concepts for satellite/ISS payloads or airborne simulators, and providing data for calibration or validation of satellite algorithms, measurements, or observations once in orbit. In FY20, ASP provided support to a number of Earth Science space missions (Table 7), including significant flight hours for the ICESat-2 mission.

Several FY20 airborne process missions collected data also valuable to future missions. Airborne campaigns are providing image data and instrument performance data to support SWOT, scheduled to launch in 2021, and NISAR, scheduled to launch in 2022. Future missions include Surface Biology and Geology (SBG), similar to the previous HyspIRI concept, which is supported by years of data now identified as the Western Diversity Time Series (WDTS). Continuation of this series is considered a priority in the Carbon Cycle and Ecosystems focus area and claimed hours on the ER-2 as soon as it was able to fly
in 2020.

Table 7. *Space missions supported by aircraft campaigns in FY20.*

Airborne Campaign	Space Mission Supported	Flight Hours	Location	Aircraft
OIB	ICESat-2	396.4	Antarctic, Alaska	GV, Twin Otter
ACTIVATE	Calipso	288.2	Atlantic Coast	UC-12B, HU-25A
NASA Methane Survey	OCO-2, OCO-3	239.1	California, Texas	B-200
UAVSAR Combined Missions	NISAR	198.4	CONUS, Alaska	G-III
SNOWEX	ICESat-2	159.8	Colorado	G-III, B-200, Twin Otter
IMPACTS	CloudSat, GOES-R, GPM	123.9	Atlantic Coast	P-3, ER-2
G-LiHT	Landsat 8	38.0	Alaska	A90
Western Diversity Time Series	SBG	29.0	California	ER-2
MURI	Landsat 8	27.5	California	ER-2
DopplerScatt	SWOT	25.5	California	B-200
Airborne Snow Observatory	Aqua, Terra, Landsat 8, SBG	23.7	California, Colorado	A-90
C-HARRIER	PACE	7.6	California	Twin Otter
eMAS/PICARD	Aqua, Terra	5.0	California	ER-2

Western Diversity Time Series (WDTS), Formerly HyspIRI Preparatory Mission

PI – Robert Green, JPL
Program – Terrestrial Hydrology, Biodiversity
Aircraft – ER-2
Payload Instruments: AVIRIS-NG, MASTER, HyTES, PICARD

The Western Diversity Time Series (WDTS) is the continuation of what was previously called HyspIRI Preparatory mission. The long-running time series has mapped six well-defined regions or "boxes" of California over multiple seasons; landscapes and vegetative conditions, building a database for the earlier proposed satellite mission HyspIRI. The ER-2 flies this mission, carrying various imaging instruments. Past missions have carried MASTER (a multispectral scanner), AVIRIS Classic (a visible to short wavelength infrared imaging spectrometer, and HyTES (a thermal infrared imaging spectrometer). More than 70 scientific articles have come from these measurements to date.

NASA's Earth Science Division has funded the continuation of these flights, as a unique science data set and for preparation of the new Decadal Survey mission Surface Biology and Geology (SBG).

In late September, the ER-2 (NASA809NA) was approved for return to flight status and began the new series. These 2020 flights carried a payload suite consisting of AVIRIS, MASTER, and HyTES, along with PICARD, a new instrument (a visible/SWIR spectrometer) that operates in pushbroom configuration. A total of 29 flight hours were completed in FY20, with additional hours scheduled in FY21.

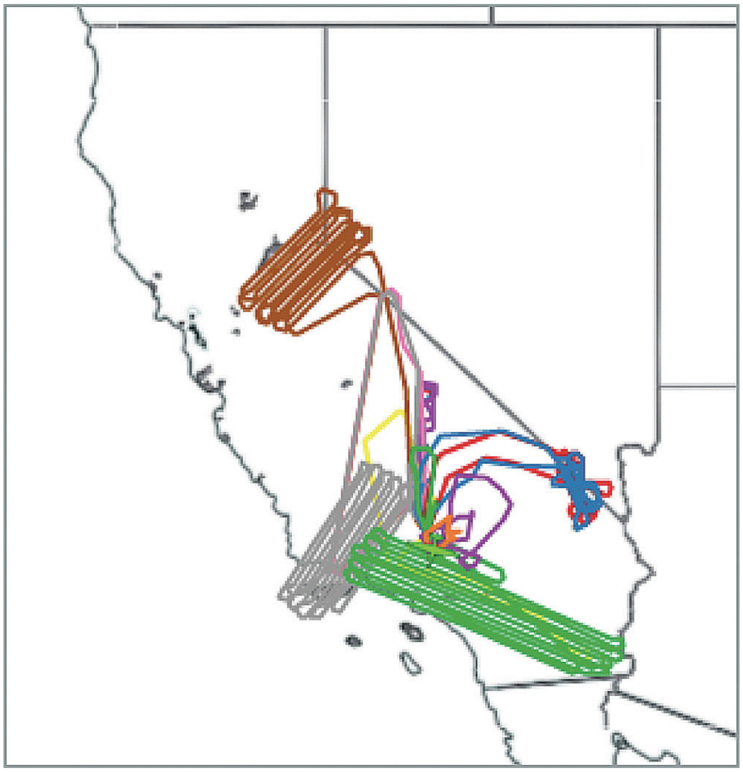


Figure 19. *ER-2 continues flights of California boxes for Western Diversity Time Series.*

ASP Support for Instrument Development

FY20 was another busy year in terms of new instrument development, including airborne support for the Earth Science Technology Office (ESTO). Some instruments are developed specifically for airborne utilization, while many are developed as precursors or simulators for satellite instruments. In 2020, ASP aircraft flew the instruments listed in Table 8. Many of these instruments have been developed under sponsorship of ESTO's Instrument Incubator Program (IIP) and Airborne Instrument Technology Transition Program (AITT). ESTO demonstrates and provides technologies that can be reliably and confidently applied to a broad range of science measurements and missions. Through flexible, science-driven technology strategies and a competitive selection process, ESTO-funded technologies support numerous Earth and space science missions.

Three projects are presented in additional detail. The Vapor-in-cloud Profiling Radar (VIPR) cloud radar has graduated from AITT and will transition to full operational use. Roscoe is an advanced version of the Cloud Physics Lidar (CPL) flown frequently in past atmospheric composition missions. The Multiband Radiometer (MURI) demonstrates that high-resolution imagery is possible using a low cost bolometer.

***Table 8.** Instrument development missions supported by airborne activities in FY2020.*

Mission	Flight Hours	Location	Aircraft
Vapor-in-cloud Profiling Radar (VIPR)	33.9	Colorado, California	Twin Otter
SWESARR	33.9	Colorado	Twin Otter
Multiband Radiometer (MURI)	27.5	California	Twin Otter
DopplerScatt	25.5	California	B-200
Roscoe Lidar	22.9	California	ER-2
AVIRIS-ng Calibration and Validation	12.2	California	B-200
air-LUSI	10.7	California	ER-2
C-HARRIER	7.6	California	Twin Otter
eMAS/PICARD/MASTER Integration	5.0	California	ER-2
Total Hours	**179.2**		

Multi-band Radiometer (MURI)

PI – Philip Ely, Leonardo DRS
Program – ESTO IIP
Aircraft – Twin Otter

Leonardo DRS' MURI, an Instrument Incubator Program (IIP) project, is a revolutionary way to do infrared imaging using existing sensor technology without the usual prerequisite "cooler," thus saving on size and power and avoiding potential obsolescence.

MURI (Figure 20) demonstrates that modern, low-cost, large-area microbolometer Focal Plane Arrays (FPAs) can support a multi-band infrared high resolution imaging radiometer suitable for Earth Science applications. The potential Earth Science applications for this technology are land surface climatology, geology and soils, measurement of soil moisture content, ecosystem dynamics, volcano and hazard monitoring, and methane detection.

Previously, in 2019, DRS completed instrument integration and test and conducted an airborne flight campaign that demonstrated excellent image quality with very good (<1%) radiometric accuracy and Noise Equivalent Delta Temperature (NEDT) sensitivity. In 2020, the MURI instrument was upgraded with bolometers

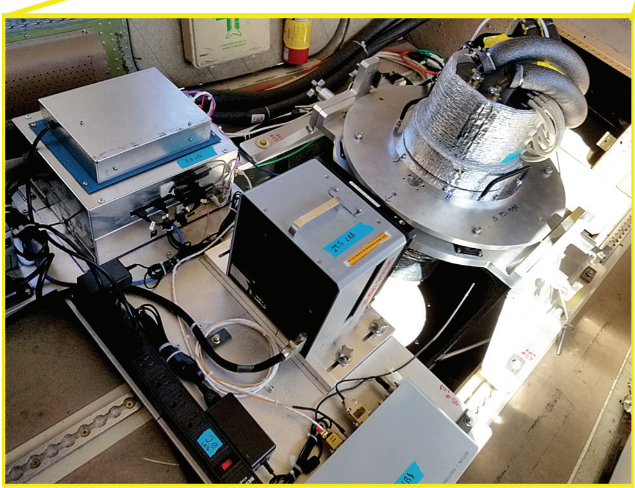


Figure 20. *The MURI instrument was installed in the Twin Otter aircraft for the 2020 airborne test campaign. Inset: MURI installed in the aircraft.*

that have a longer thermal time constant, which provides a 40% improvement in NEDT sensitivity. Despite the impact of COVID-19, the team was able to conduct a follow-up airborne test campaign to demonstrate improvements made to the instrument. The purpose of the 2020 airborne flight tests was to validate that the MURI backscan technique generates high quality imagery with better NETD using the longer time constant bolometer FPAs.

The 2019 and 2020 flight tests were coordinated with Landsat 8 overflights for comparison. Imagery was collected over Lake Tahoe buoys, Russel Ranch, Lake Isabella, Salton Sea buoys, SoCal Pacific Ocean NOAA buoys, Salton Sea shorelines and nearby targets, and other southern California targets. Initial data analysis from the 2020 airborne flight test indicates NETD achieved an improvement of more than 40%.

Current NEDT is better than 70 mK in the classical Landsat bands. Radiometric accuracy of better than 0.5% error (1σ) was demonstrated across five of the spectral bands. The figure compares MURI instrument radiance measured during the latest airborne demonstration to the predicted at-sensor radiance via forward modeling using ground-based measurements of the water bodies imaged (Lake Tahoe, Pacific Ocean, El Dorado Park). This graph demonstrates the high radiometric accuracy obtained across the five spectral bands.

Over the next several months, the DRS team will analyze the collected imagery with its partner, the Rochester Institute of Technology (RIT). RIT supported all airborne flight campaigns by collecting ground truth data against which the airborne data is validated. Figure 20 compares the emissivity vs wavelength of a scene with vegetation extracted from a FTIR ground truth instrument and the MURI instrument, showing good agreement.

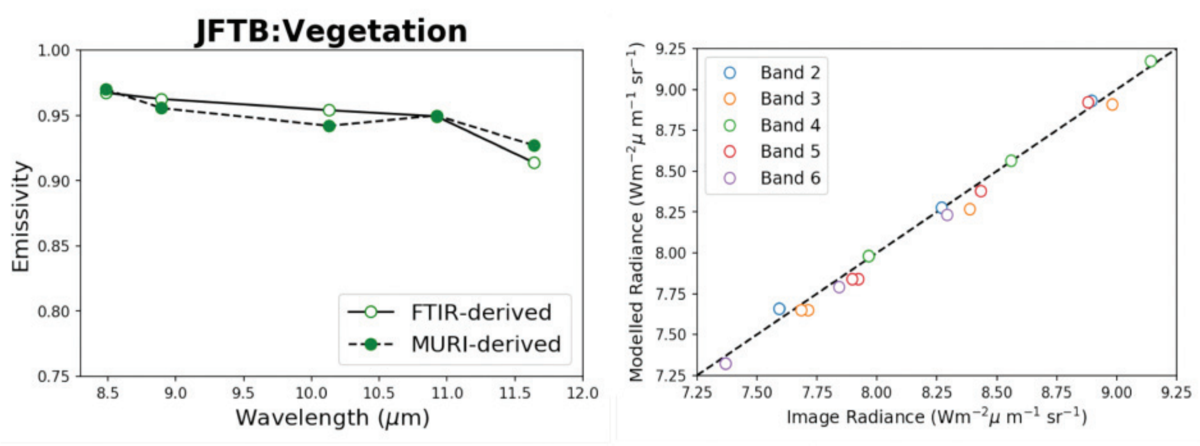


Figure 21. *MURI extracted airborne emissivity measurements vs. measured FTIR ground truth.*

Roscoe Lidar

PI – Matthew McGill, GSFC
Program – Atmospheric Radiation Science
Aircraft – ER-2

Roscoe (not an acronym) is a backscatter lidar similar to the long-standing GSFC instrument Cloud Physics Lidar (CPL; https://cpl.gsfc.nasa.gov). Roscoe is designed to operate simultaneously at 1064 and 355 nm, with depolarization measurement at both wavelengths. To avoid ever-increasing difficulties with airborne laser safety, Roscoe is intentionally designed without visible wavelengths.

As shown in Figure 22, to enable studies of tropospheric and stratospheric aerosols, Roscoe is designed to look upward and downward from an airborne platform. For tropospheric measurements, Roscoe's purpose is similar to that of the CPL: to provide measurements of cirrus, subvisual cirrus, and aerosols with high temporal and spatial resolution. For stratospheric measurements, Roscoe's depolarization measurement capability is essential for determination of stratospheric sulfate/ash layers.

Figure 23 shows the Roscoe package in flight configuration. Roscoe is designed to mount in an ER-2 forward superpod, and a superpod was specifically modified to incorporate an up-looking window. Like the CPL, Roscoe utilizes state-of-the-art technology with a high repetition rate, low pulse energy laser and photon-counting detection. Vertical resolution of the measurement is fixed at either 30 or 60 m; horizontal resolution can vary but is typically about 200 m.

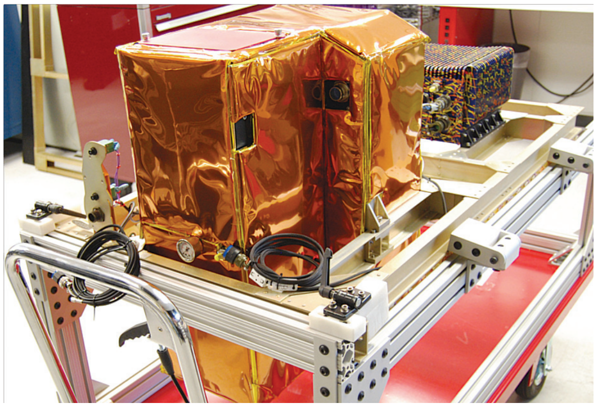


Figure 23. *Roscoe instrument in flight configuration.*

The fundamental Roscoe data product is a time-height cross-section image of the atmosphere, similar to CPL data products.

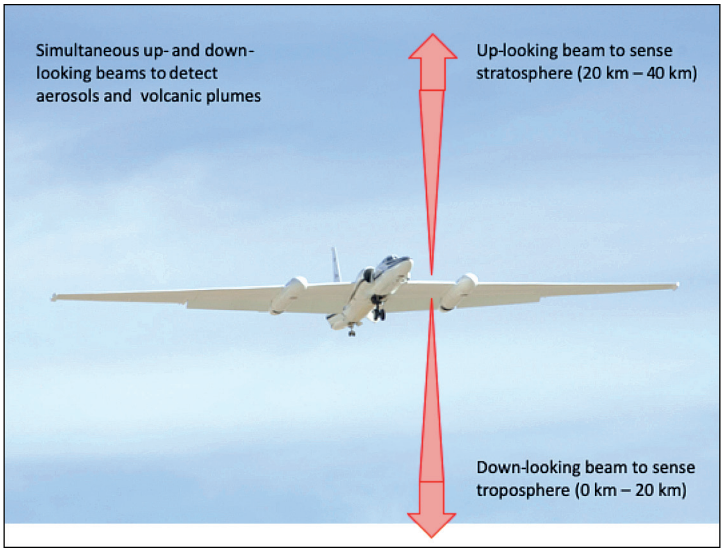


Figure 22. *The Roscoe instrument concept Is a simplified CPL design that looks upward and downward from the aircraft.*

Two engineering test flights were completed on October 21 and 23, 2019. Figure 24 shows initial Roscoe profiles compared with simultaneous CPL profiles. The first science deployment for Roscoe will be the ACCLIP campaign onboard the WB-57 aircraft. In addition to PI Matt McGill, other Roscoe team members include Dr. John Yorks, Mr. Stan Scott, Mr. Andrew Kupchock, and Mr. Patrick Selmer of GSFC.

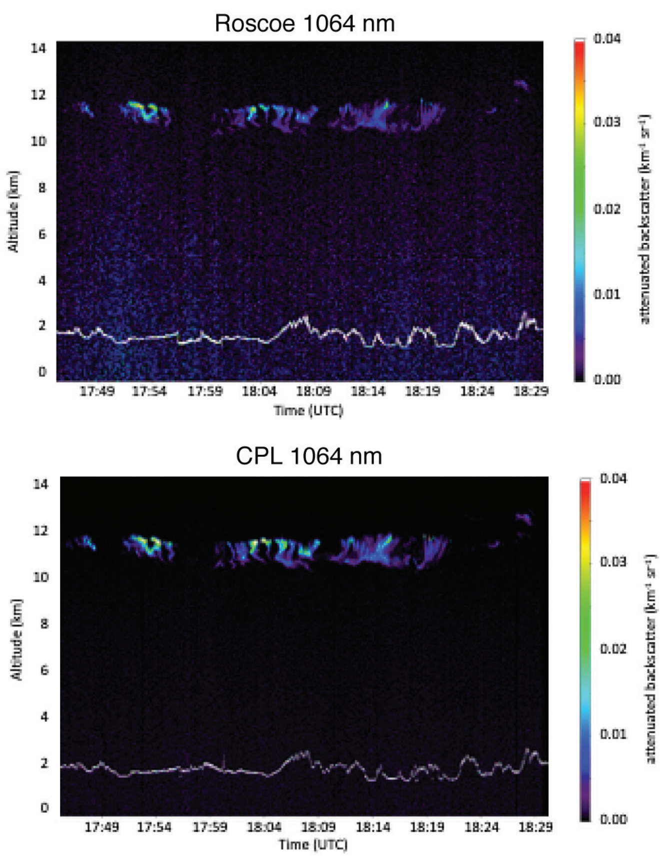


Figure 24. *Preliminary results show that Roscoe profiles closely mirror CPL.*

Vapor in-cloud Profiling Radar (VIPR)

PI – Matt Lebsock, JPL
Program – ESTO IIP
Aircraft – Twin Otter

JPL's VIPR instrument was successfully operated from an airborne platform for the first time in FY20, a major milestone for the IIP-16 project. VIPR was designed to demonstrate a new measurement capability of simultaneously measuring water vapor and ice content inside clouds with high precision and spatial resolution. The measurements fill a gap in the existing observing system, which struggles to profile water vapor within clouds. VIPR's observations address key unsolved science questions regarding the processes regulating cloud lifecycle and the transport of water vapor by convection.

Figure 25. *VIPR PI Matt Lebsock installing the instrument on the aircraft.*

Late in 2019, flights over a variety of ground and water targets as the aircraft plus instrument transited from Colorado to California revealed important characteristics of the G-band radar backscattering that are pertinent to over-cloud flights that then took place early in 2020. These include contrast between land and water, Doppler shift effects, and the variability of scattering based on beam pointing angle. During the

Figure 26. *Clouds measured by VIPR near the Santa Barbara coastline.*

January/February 2020 flights from California sites, VIPR took data over marine layer clouds along the coast of California from Santa Barbara to the San Francisco bay. VIPR flew 34 flight hours in FY20.

ASP Support to Applied Sciences

In 2020, as in previous years, several flight campaigns supported the NASA Applied Sciences Program or science goals of additional agencies. Of particular interest in 2020 was the opportunity for Airborne Science to work with the Disasters element of Applied Sciences to obtain fire-related imagery during late summer California wildfires. Table 9 lists these and other campaigns with user applications.

Fire Response – UAVSAR

PI – Yunling Lou, JPL
Program – Applied Sciences Disaster Program
Aircraft – C-20A
Payload Instrument: UAVSAR

As California experienced one of the worst wildfire seasons on record, NASA leveraged its resources to help. The AFRC C-20A aircraft took off from its base at AFRC Building 703 in Palmdale, California, carrying the UAVSAR instrument developed and operated by JPL. Attached to the bottom of the aircraft, the radar is flown repeatedly over an area to measure tiny changes in surface height with extreme accuracy. But the instrument is also highly ef-

Table 9. *Airborne science support to Applied Science goals.*

Mission	Flight Hours	Location	Aircraft
NASA Methane Survey	56.3	California	B-200
Fire Response - UAVSAR	18.3	southern San Francisco Bay area	G-III
Fire Response – Western Diversity Time Series piggyback	6.8	California	ER-2

fective at mapping burn scars, because radar signals bounce off vegetation in a different way than they do off bare, freshly burned ground. UAVSAR flights over burn areas produce observations that are ten-times higher resolution than satellites, meaning flights can be quickly tasked to target vulnerable burn scar areas after they are identified in satellite images. After vegetation is burned away, sloping hillsides and valleys can become susceptible to mudslides during winter rains, often months later. The researchers intend to produce data products that can be used to identify areas most at risk. This project was part of the ongoing effort by NASA's Applied Sciences Disaster Program in the Earth Sciences Division. As described in the UAVSAR section, fire areas of the CZU fire complex and Bobcat fire near JPL were imaged for a total of 18.3 flight hours.

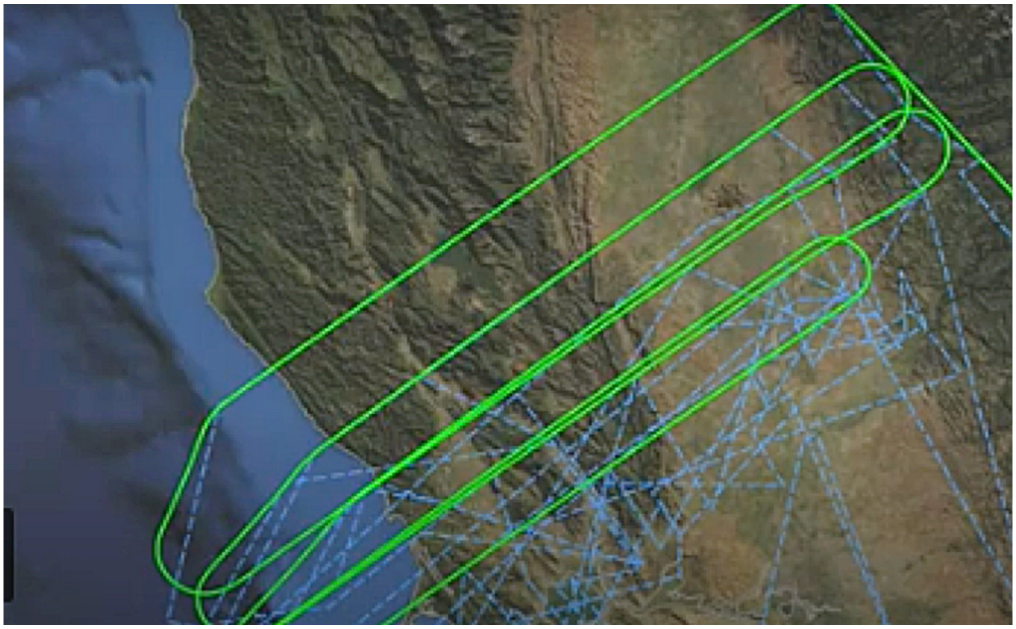


Figure 27. *UAVSAR flight tracks over the CZU fire south of San Francisco bay area.*

Figure 28. *The Bobcat fire was one of the fires imaged by the UAVSAR instrument in 2020.* ***Credit:*** *US Forest Service*

Fire Response – WDTS Piggyback

PI – Robert Green, JPL
Program – Terrestrial Ecology/Applied Sciences Disaster Program
Aircraft – C-20A
Payload Instruments: MASTER, AVIRIS

The MASTER and AVIRIS instruments imaged the Bobcat fire and several others in a piggyback activity on the Western Diversity Time Series flights. The fight track is shown in Figure 29.

Figure 29. *ER-2 flight over the Bobcat fire area with WDTS payload.*

Methane Emissions in the COVID Era

PI – Andrew Thorpe, JPL
Program – Research and Analysis Program
Aircraft – B-200
Payload Instrument: AVIRIS-NG

The COVID-19 pandemic is impacting key economic sectors and in turn emissions of methane and other pollutants. Conducting COVID-era airborne remote-sensing surveys of methane point source emissions using AVIRIS-NG across previously studied areas offers the potential to shed new light on some of the processes that influence the global methane budget. However, the health risks to flight crews first required development of a new safety plan including cleaning and mask protocols (Figure 30).

The flight campaign, spanning July through September 2020 and overseen by Dr. Eric Kort (University of Michigan), aimed to directly observe changes in California methane emissions due to COVID-19. This study benefited from analysis provided by an ongoing NASA Carbon Monitoring System project led by Riley Duren (University of Arizona) that uses airborne and satellite observations of methane emissions across multiple states. Acquisitions focused on the energy sector with additional flights for the agricultural and waste management sectors. Approximately half of the previous California Methane Survey sites were sampled (Duren et al., 2019) with multiple revisits to assess persistence.

While there were a few flights in the San Francisco bay area, most of the campaign targeted the Los Angeles basin and San Joaquin Valley. In Figure 31, the locations of observed methane plumes relative to the regions covered by AVIRIS-NG are shown for the southern San Joaquin Valley. Two plume images and associated emission estimates are shown for a power generating station and oil well source. Initial comparison with results from the 2016-2018 California Methane Survey (Duren et al., 2019) suggests a shift in emissions distribution. Data analysis is ongoing and will include a direct comparison of COVID methane results with California Methane Survey findings and comparison of methane point source emissions to regional emission estimates.

Additional flights were performed for sun glint acquisitions over the Coal Oil Point seep field to test methane retrievals over water as well as calibration and validation overflights at Ivanpah. As part of the Student Airborne Research Program (SARP), AVIRIS-NG flew over marine and terrestrial environments in Santa Barbara County. Data were also obtained for Dr. Katie Gold (Cornell University) over Sonoma, Tulare, and San Luis Obispo Counties to assess the impacts of vineyard management on vegetation health.

Figure 30. *2020 AVIRIS-NG flights required a COVID-19 safety plan that included a cleaning and mask protocol.*

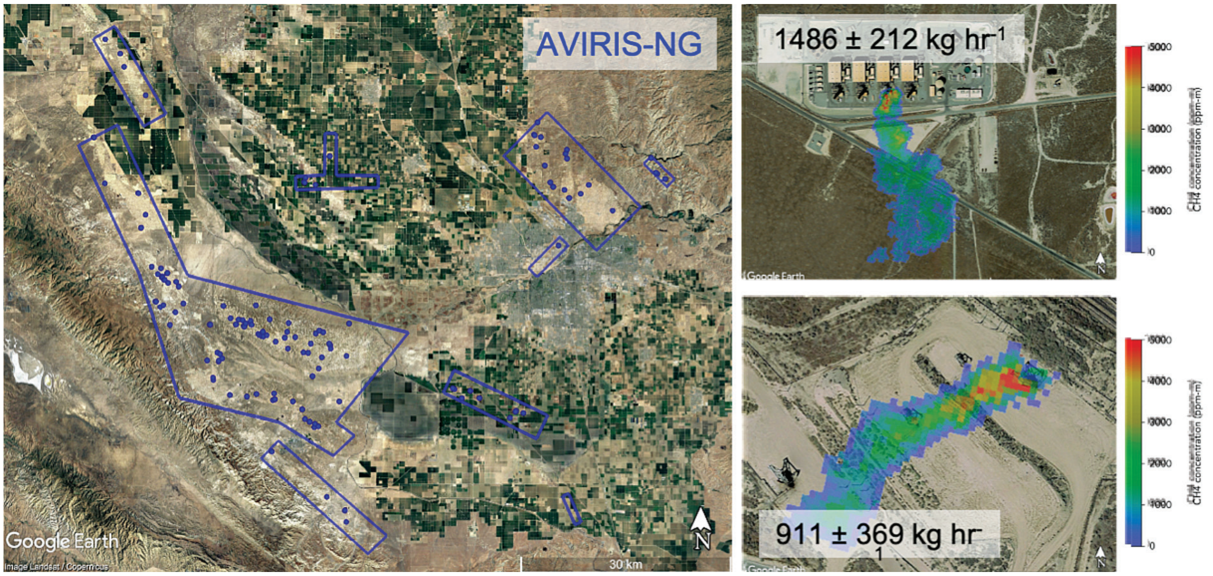


Figure 31. *AVIRIS-NG flights for the San Joaquin Valley showing the locations of observed methane plumes. Two plume images and associated emission estimates are shown for a power generating station and oil well source.*

Upcoming Activities

Major upcoming campaigns are listed in Table 10. The flight calendar for the Earth Venture Suborbital-3 (EVS-3) missions is shown in Figure 32. In addition, ASP plans to support instrument development, calibration and validation activities, and process studies for upcoming missions dedicated to the Designated Observables, Explorer, and Incubation missions described in the 2017 Decadal Survey.[1]

Table 10. *Planned major 2021 campaigns.*

Campaign	Aircraft	Location	Science Program
ACCLIP (Test Flights)	WB-57, NCAR GV	JSC	Atmospheric Composition
ACTIVATE	HU-25A, UC-12B	North Atlantic	EVS-3
CPEX-AW	DC-8	Caribbean	Weather
DCOTSS	ER-2	Central U.S.	EVS-3
DELTA-X	G-III, B-200 (2)	Mississippi River Delta	EVS-3
IMPACTS (Late Fall/Winter)	ER-2, P-3	U.S. East Coast	EVS-3
MOOSE-LISTOS	G-III	Detroit and NY areas	Air quality
OMG	DC-3; G-III	Greenland	EVS-2
S-MODE (Instrument Test Flights)	G-III, B-200, Twin Otter	California (Pacific Ocean)	EVS-3
SARP	DC-8	With CPEX-AW	R&A
SNOWEX	G-III, Twin Otter	Colorado, Alaska	Terrestrial Hydrology
TRACER-AQ	GV	Houston Area	Air quality
WDTS	ER-2	California	Carbon Cycle
LVIS/GEDI	GV	Texas	Carbon Cycle

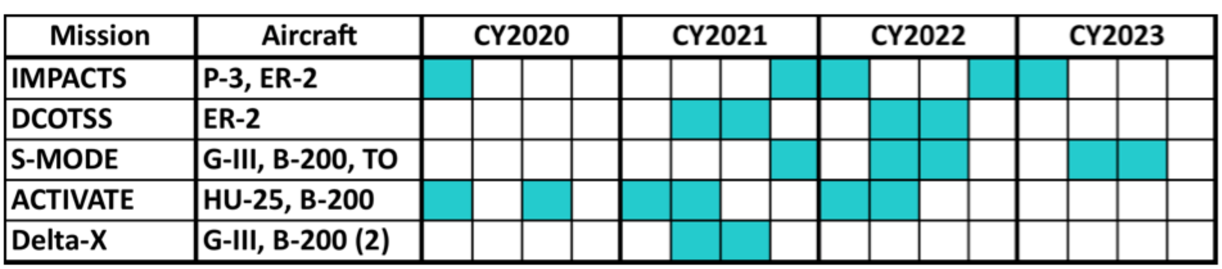


Figure 32. *EVS-3 missions, aircraft, and nominal flight schedules (CY).*

[1] Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from space (ESAS 2017)

4. Aircraft

NASA maintains and operates a fleet of highly modified aircraft unique in the world for their ability to support Earth observations. These aircraft are based at NASA Centers. ASP-supported aircraft have direct funding support from ASP for flight hours and personnel. Other NASA aircraft are also available for science missions. In addition, NASA missions employ commercial aviation services (CAS) under protocols established by NASA's Aircraft Office at Headquarters. More information about using these aircraft is provided on the ASP website at: airbornescience.nasa.gov. The annual "call letter," also available on the ASP web site, is an excellent source of information describing how to request airborne services.

FY2020 Fleet Highlights

The ASP fleet includes aircraft that can support low-and-slow flights to those capable of flying high and fast. The aircraft also have a wide

Table 11. *Enhancement modifications to ASP aircraft in FY20.*

Aircraft	Modification	Impact
Payload Enhancements		
ER-2	MVIS instrument added	Situational awareness during mission
P-3	Nadir port modifications Free fall chute	Payload interchangeability between P-3 nadir ports Sonobuoy and dropsonde capabilities
G-IIIs	Optical windows	Interchangeable windows between JSC, AFRC, and LaRC G-IIIs (6 total)
GV and LaRC G-III	Common installation hardware for science instrumentation fabricated and installed	Instruments operate on either aircraft (additional description in text)
LaRC UC-12B	Forward nose portal Dropsonde launcher installed	Forward looking camera Dropsonde capabilities
Aircraft Upgrades		
DC-8	Engines repaired	Return to science
ER-2	CARE modifications	Pilot health
GV	NextGen avionics upgrade	Worldwide operations
JSC G-III	NextGen avionics upgrade	Worldwide operations

variety of payload capacities. Multiple aircraft modifications and upgrades were completed to ASP platforms in FY20 that either enhance payload capability for the science community or help sustain the aircraft into the future.Highlights are listed in Table 11.

Also during FY20, work was performed toward the long-held aspiration of making aircraft in the fleet more interchangeable through common payload accommodation capabilities. Cooperative work is ongoing between JSC (GV) and LaRC (G-III) to prepare for future Airborne Science research. Both aircraft have already been modified to have dual nadir portals, as seen in Figure 33. The LaRC G-III also incorporates shutter doors for nadir portals, whereas the GV incorporates debris fences. Both teams have installed research power distribution systems, intercom communication systems, satellite communications, and NSRC's NASDAT in their aircraft. The engineering teams are jointly designing and fabricating common installation hardware for science instruments so that the instruments can be flown in either aircraft.

The centers have finalized or are in the process of completing several installation designs on the JSC GV and LaRC G-III aircraft, including for the following instruments:

- GCAS (GSFC's GeoCAPE Airborne Simulator (GCAS)
- LaRC's High Altitude Lidar Observatory (HALO)
- LaRC's High Spectral Resolution Lidar 2 (HSRL-2)
- Dropsonde/sonobuoy launcher (adapted from JSC G-III installation (N992NA))
- JPL's Portable Remote Imaging Spectrometer (PRISM)
- GSFC's Cloud Physics Lidar (CPL)
- JPL's Airborne Visible/Infrared Imaging Spectrometer-Next Generation (AVIRIS-NG)
- JPL's Hyperspectral Thermal Emission Spectrometer (HyTES)
- GSFC's Land, Vegetation and Ice Sensor (LVIS)
- Replacing aircraft passenger windows with UV transmissive optical windows

When this design work is completed, the instruments will be portable between aircraft, reducing integration time and costs to science teams. ASP will continue to encourage, work with, and support JSC and LaRC, as appropriate, with this integrated approach to instrument installation.

Figure 33. *NADIR ports on the JSC GV and LaRC G-III.*

ASP Fleet Summary Characteristics

Aircraft performance characteristics and payload accommodation summaries are listed in Table 12. Altitude/endurance characteristics are shown in Figure 34, with altitude/range provided in Figure 35. Figure 36 indicates range/payload performance for the aircraft.

Table 12. *Airborne science program aircraft and their performance capabilities.*

Platform Name	Center	Payload Accommodations	Duration (Hours)	Useful Payload (lbs)	Max Altitude (ft)	Airspeed (knots)	Range (Nmi)
ASP Supported Aircraft							
DC-8	NASA-AFRC	4 nadir ports, 1 zenith port, 14 additional view ports	12	30,000	41,000	450	5,400
ER-2 (2)	NASA-AFRC	Q-bay (2 nadir ports), nose (1 nadir port), wing pods (4 nadir, 3 zenith ports), centerline pod (1 nadir port)	12	2,900	>70.000	410	>5,000
G-III/C-20A	NASA-AFRC	UAVSAR pod	7	2,610	45,000	460	3,400
G-III	NASA-JSC	UAVSAR pod, Sonobuoy launch tube	7	2,610	45,000	460	3,400
G-III	NASA-LaRC	2 nadir ports	7	2,610	45,000	460	3,400
GV	NASA-JSC	2 nadir ports	12	8,000	51,000	500	>5,000
P-3	NASA-WFF	1 large and 3 small zenith ports, 3 fuselage nadir ports, 4 P-3 aircraft window ports, 3 DC-8 aircraft window ports, nose radome, aft tailcone, 10 wing mounting points, dropsonde capable	14	14,700	32,000	400	3,800
Other NASA Aircraft							
B-200 (UC-12B)	NASA-LaRC	2 nadir ports, 1 nose port, aft pressure dome with dropsonde tube, cargo door	6.2	4,100	31,000	260	1,250
B-200	NASA-AFRC	2 nadir ports	6	1,850	30,000	272	1,490
B-200	NASA-LaRC	2 nadir ports, wing tip pylons, zenith site for aerosol inlet, lateral ports	6.2	4,100	35,000	275	1,250
C-130	NASA-WFF	3 nadir ports, 1 zenith port, 2 rectangular windows, wing mount for instrument canisters, dropsonde capable, cargo carrying capable	12	36,500	33,000	290	3,000
Cessna 206H	NASA-WFF	Wing pod, belly pod, modified rear window for zenith ports	5.7	1,175	15,700	150	700
Dragon Eye (UAS)	NASA-ARC	*In situ* sampling ports	1	1	500+	34	3
HU-25A Guardian	NASA-LaRC	1 nadir port, wing hard points, crown probes	5	3,000	42,000	430	1,900
Matrice 600 (UAS)	NASA-ARC	Imager gimbal	1	6	8,000	35	3
SIERRA-B (UAS)	NASA-ARC	Interchangeable nose pod for remote sensing and sampling, 1 nadir port	10	100	12,000	60	600
WB-57 (3)	NASA-JSC	Nose cone, 12ft of pallets for either 3ft or 6ft pallets, 2 Spearpods, 2 Superpods, 14 Wing Hatch Panels	6.5	8,800	60,000+	410	2,500

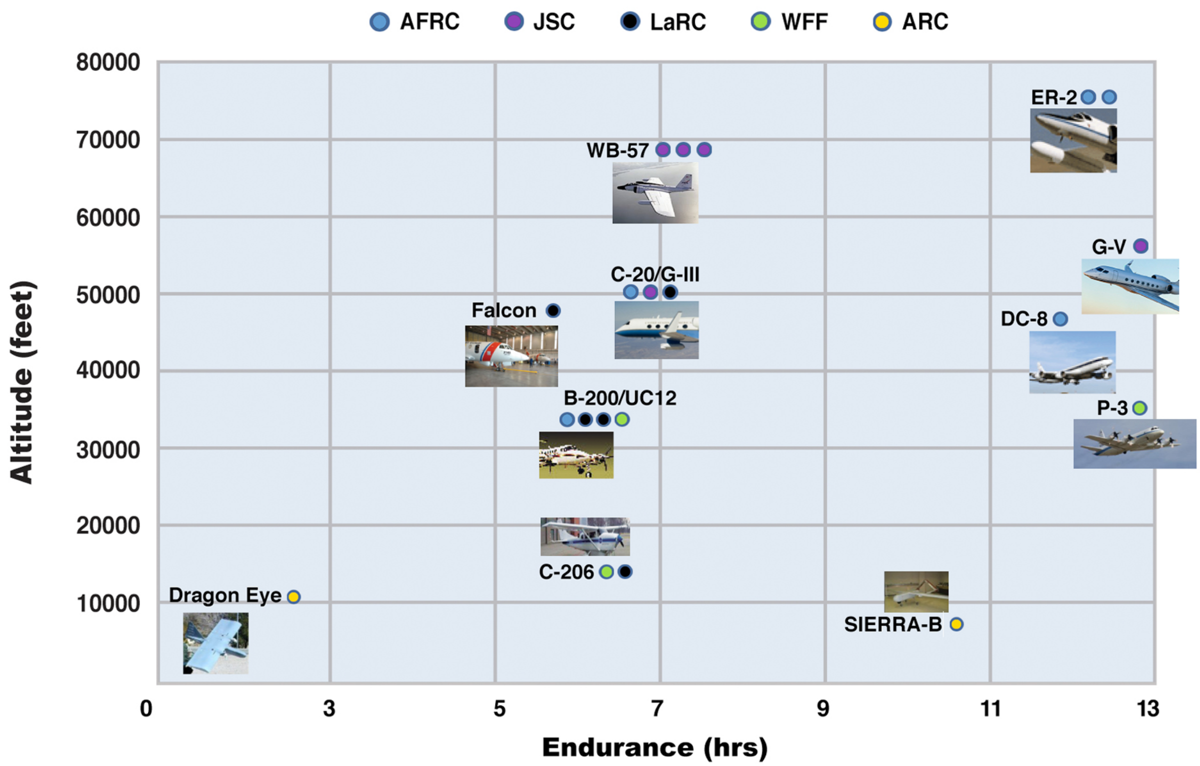


Figure 34. NASA Earth Science aircraft capabilities in altitude and endurance.

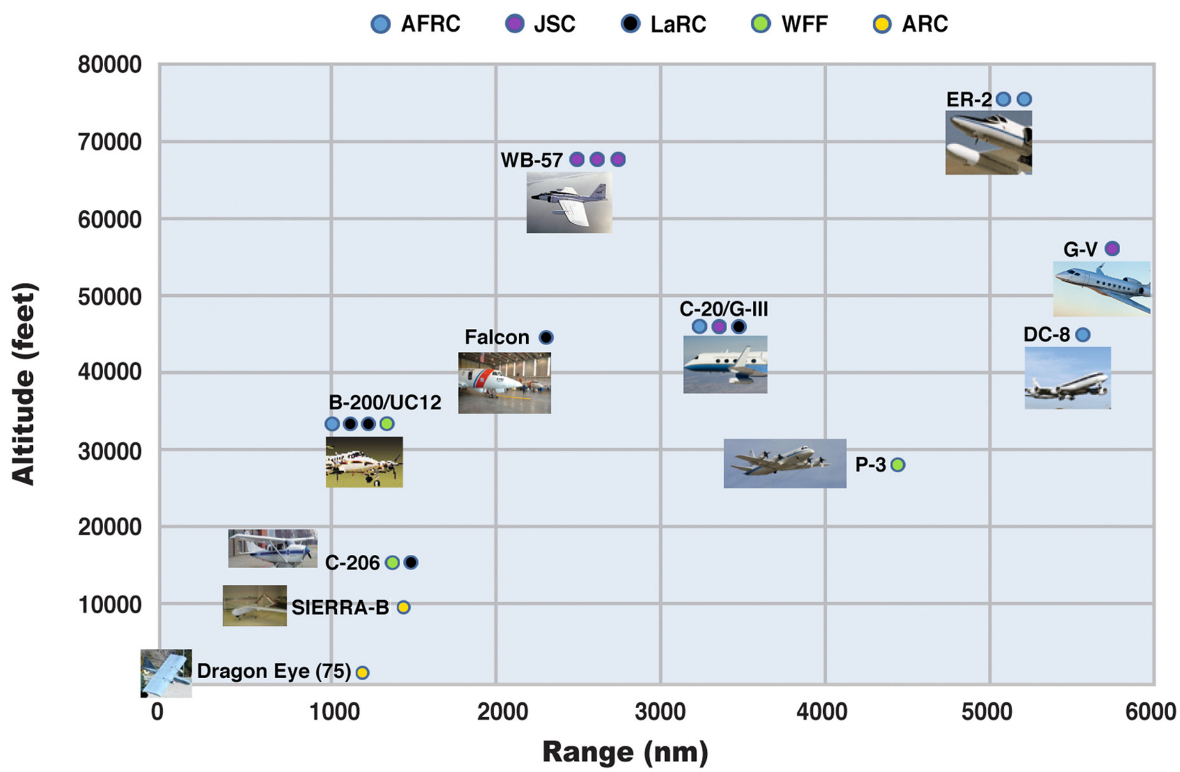


Figure 35. NASA Earth Science aircraft capabilities in altitude and range.

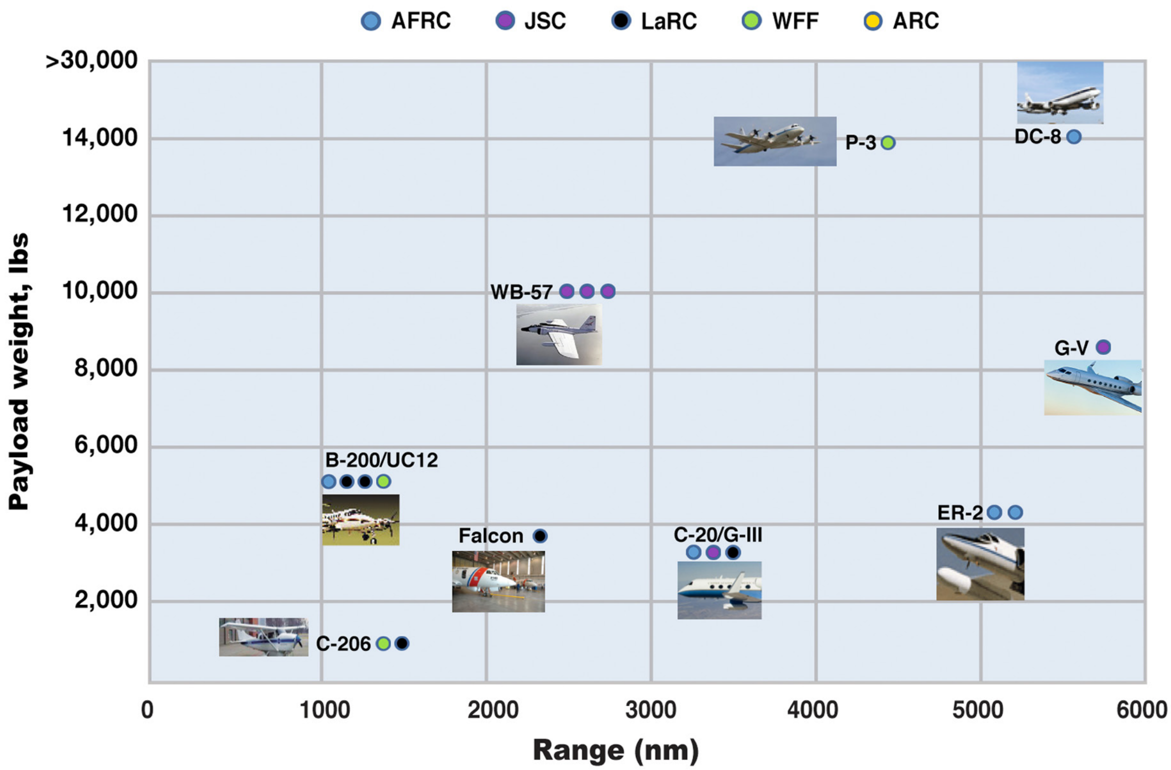


Figure 36. *NASA Earth Science aircraft capabilities in payload weight and range.*

ASP-Supported Aircraft

The eight aircraft systems ASP directly supported (subsidized flight hours) in FY20 are the DC-8 flying laboratory, two ER-2 high altitude aircraft, P-3, C-20A (G-III), JSC G-III, and JSC GV. Beginning in FY20, ASP also provided flight hour support to the new LaRC G-III.

DC-8

Operating Center:
Armstrong Flight Research Center (AFRC)

Aircraft Description:
The DC-8 airborne laboratory is a four-engine jet aircraft with a range in excess of 5,000 nm, a ceiling of 41,000 ft, and an experiment payload of 30,000 pounds (13,600 kg). This aircraft, extensively modified as a flying laboratory, is operated for the benefit of airborne science researchers.

FY20 Science Flight Hours: 0

FY20 Modifications and Impacts on Performance/Science:
After FIREX-AQ in FY19, engine inspection identified damage to all four engines. Repairs to five engines (including a spare) have been in process at an off-site vendor. Two engines were completed in FY20. The remainder will be completed in early FY21. An up-to-date calendar of maintenance plans will be posted on the ASP website platform calendar.

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

Figure 37. *DC-8 Flying Laboratory.*

ER-2

Operating Center:
Armstrong Flight Research Center (AFRC)

Aircraft Description:
The ER-2 is a civilian version of the Air Force's U2-S reconnaissance platform. NASA operates two ER-2 aircraft. These high-altitude aircraft are used as platforms for investigations at the edge of space.

FY20 Science Flight Hours: 122.9

ER-2 FY20 Missions

Mission	Location	Science Program Area
Roscoe	California	Atmospheric Composition
PICARD	California	Terrestrial Ecology
AirLUSI	California	Airborne Instrument Technology Transition
IMPACTS	Eastern U.S.	Atmospheric Composition
HyspIRI/WDTS	California	Terrestrial Ecology/Biodiversity

FY20 Modifications and Impacts on Performance and Science:

The Cockpit Altitude Reduction Effort (CARE) modifications to ER-2 TN809 and ER-2 TN806 will enhance pilot safety by increasing cockpit pressure, reducing effective cockpit altitude from 29,000 feet to 15,000 feet when the aircraft is operating at its cruise altitude of 65,000 feet. Lowering the effective cockpit altitude reduces chance of decompression sickness, which can have short- and long-term effects on the pilot.

Figure 38. *The ER-2, based in Savannah, Georgia for IMPACTS, made the local news.*

ER-2 TN806 received the CARE Modification from Lockheed-Martin in November 2018 through May 2019, at which time AFRC began final re-assembly in May 2019.

Following a 6-month work stoppage due to COVID-19 response, re-assembly work was restarted and is scheduled to be completed by the end of FY21, along with the ADS-B out upgrade.

ER-2 TN809 will need to undergo a 600-hour scheduled maintenance inspection and ADS-B out upgrade as well, with an expected completion by the second quarter of FY22.

Both aircraft will continue routine maintenance every 200 and 600 flight hours, respectively. A 200-hour maintenance takes 2-3 weeks to complete; a 600-hour maintenance takes 3-4 months.

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

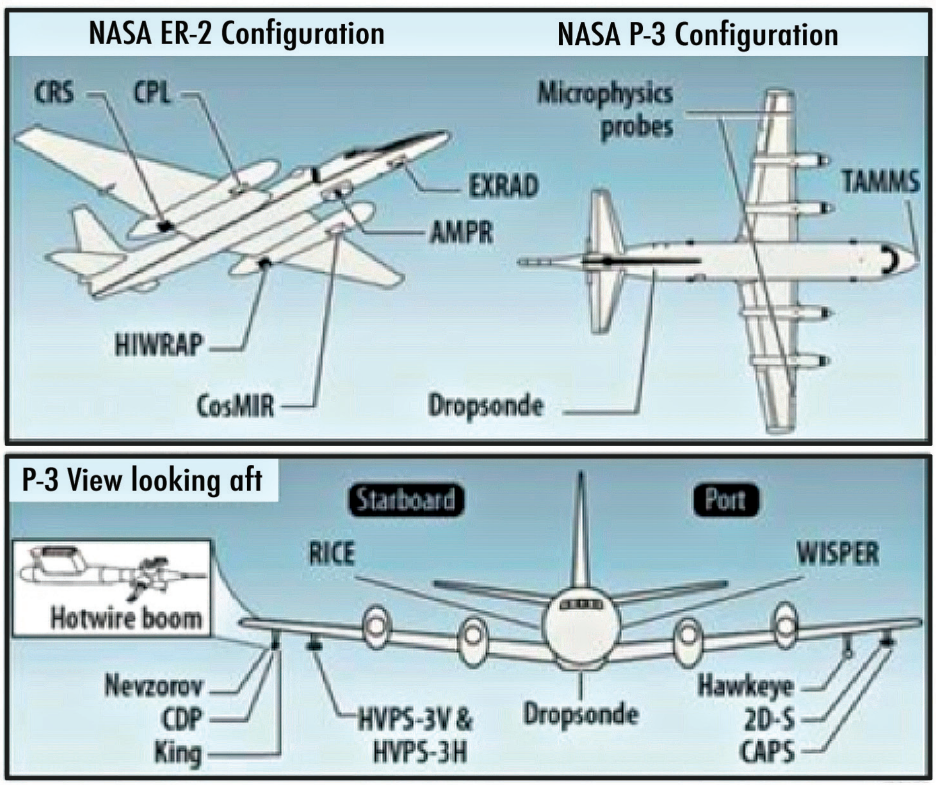


Figure 39. *The NASA ER-2 and P-3 fly together for IMPACTS.*

Gulfstream III (G-III)

NASA ASP supports three G-III aircraft for Earth Science: one at AFRC, one at JSC, and as of 2020, one at LaRC. The G-III is a business jet with routine flight at 40,000 feet. The AFRC and JSC platforms have been structurally modified and instrumented to carry the payload pod for the three versions of JPL's UAVSAR instrument (L-band, P-band, Ka-band). The LaRC G-III does not carry the pod. Features specific to each aircraft, along with science activities undertaken in FY20, are described below.

C-20A (AFRC G-III)

Operating Center:
Armstrong Flight Research Center (AFRC)

FY20 Science Flight Hours: 81.8

C-20A (G-III) FY20 Missions

Mission	Location	Science Program Area
NASA/ISRO L-band/S-band (ASAR)	Alaska/Oregon	Earth Surface and Interior
SNOWEX	Colorado, Idaho, California	Water and Energy Cycle
Imaging Near-fault Deformation in Central and Northern California	California	Earth Surface and Interior
UAVSAR L-band Engineering	California	Earth Surface and Interior
UAVSAR P-band Engineering	California	Earth Surface and Interior
Disaster Response/Wildfires	California	Earth Surface and Interior/ Applied Science

FY20 Modifications and Impacts on Performance and Science:

C-20A is in good flying condition and Ops 1 and 3 maintenance was performed in January through March 2020. The team also completed flight hours/cycle maintenance throughout summer 2020. The C-20A maintenance schedule is updated on the ASP website.

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

Figure 40 The AFRC C-20A, carrying a UAVSAR pod, en route to wildfire response in California.

JSC G-III

Operating Center:
Johnson Space Center (JSC)

Aircraft Description:
The JSC G-III carried L-band and P-band versions of the SAR in 2020.

FY20 Science Flight Hours: 121.0

JSC G-III FY20 Missions

Mission	Location	Science program area
SnowEx	California, Colorado, Idaho	Water and Energy Cycle
NISAR AM/PM	Southeast U.S.	Terrestrial Ecology
Engineering/Calibration	California	Earth Surface and Interior
Eel River	California	Earth Surface and Interior
Landslides	Colorado	Earth Surface and Interior
Sierra Nevada Faults	California	Earth Surface and Interior

FY20 Modifications and Impacts on Performance and Science:

The JSC G-III underwent a Next-gen Avionics upgrade, which included ADS-C, FANS 1/A+, and CPDLC. Like the GV modifications, these upgrades meet airspace equipment mandates, allowing the GIII to continue worldwide operations.

JSC adapted an AFRC G-III design for side optical windows and built four new window frames for ASP use. Different material types for the windows are available via a development effort. As an example, acrylic material capable of passing ultraviolet light was purchased for the Hayabusa2 imaging mission.

Significant Upcoming Maintenance Periods:

- Late summer 2021 (~3 weeks) – Engine Swap and other scheduled maintenance

Website:

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

Figure 41. *The JSC G-III showing the UAVSAR pod.*

LaRC G-III

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The Gulfstream III (a former U.S. Air Force C-20B) aircraft became available for NASA science during FY20. Eventually, this aircraft (NASA 520) will replace the LaRC Dassault HU-25A Guardian aircraft (NASA 524) for airborne science. The nadir portals (each 18.16 in. x 18.16 in. with external shutters) allow the aircraft to support Earth science sensors. The G-III can be equipped with pressure domes over the portals so instruments can be flown open to the atmosphere. Six Researcher Interface Panels are being installed in the passenger cabin, which will accommodate up to ten researchers. The research system will also accommodate the NASA Airborne Science Data and Telemetry (NASDAT) system. The G-III aircraft has an advertised range of 3750 nm. Expected duration is 7.5 hours and the maximum mission altitude is 45,000 ft.

First Missions (FY20):
The LaRC G-III became a participant in the SHARC mission in late 2020, flying to Australia, along with the JSC G-III, to image re-entry of the Japanese Hayabusa2 asteroid sample. The first Earth Science mission with this aircraft will be delayed flights of an IIP project, the Compact Midwave Imaging System (CMIS), for the Applied Physics Laboratory, Johns Hopkins University. The CMIS suite will be installed in the aft nadir portal and use four custom-made optical panels.

Website:
https://airbornescience.nasa.gov/aircraft/Gulfstream_III_-_LaRC

Figure 42. *The NASA LaRC G-III (N520NA) team in Adelaide for SHARC. (Health safety protocols were followed, allowing this team without masks.)*

Gulfstream G-V

Operating Center:
Johnson Space Center (JSC)

Aircraft Description:
The Gulfstream V (GV) is a long-range, large business jet aircraft built by Gulfstream Aerospace, derived from the Gulfstream IV. It flies up to Mach 0.885, at up to 51,000 feet, and has a range of 5,000 nautical miles. JSC procured the GV in 2016 as part of a shared usage agreement between the ISS Program and NASA ESD. The ISS program uses the GV for Crew Return missions and ESD uses it to support airborne science missions in remote locations around the world. With significant accommodations for science payloads, the GV made its first science campaign to Antarctica in November 2019 (FY20).

FY20 Science Flight Hours: 248.4

G-V FY20 Missions

Mission	Location	Science program area
OIB	Australia	Cryosphere

FY20 Modifications and Impacts on Performance and Science:

Next-gen avionics upgrade: ADS-B v2 Out, ADS-C, FANS 1/A+, CPDLC, FMS software upgrade. These upgrades meet airspace equipment mandates to allow the aircraft to continue operation in a variety of airspace worldwide.

Significant Upcoming Maintenance Periods:

- Ongoing (expected mid-March 2021 ETIC) – Display upgrade, engine overhaul, horizontal stabilizer corrosion repair
- Display upgrade mitigates part obsolescence and sustainment issues and maintains the GV's Honeywell avionics protection plan coverage

Website:
http://airbornescience.nasa.gov/aircraft/GV_-_JSC

Figure 43. *The OIB GV team at the airport in Hobart, Tasmania.* ***Photo credit:*** *John Sonntag*

P-3 Orion

Operating Center:
Wallops Flight Facility (WFF)

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

FY20 Science Flight Hours: 109.5

P-3 Orion FY20 Missions

Mission	Location	Science Program Area
CAMP2EX	Philippines	Atmospheric Composition
IMPACTS	Eastern U.S.	Atmospheric Composition

FY20 Modifications and Impacts on Performance and Science:

The P-3 Orion is currently ready to support flight operations. The P-3's main and nose landing gear were replaced during summer 2020 and upgrades to the nadir #2 port were completed. The nadir #2 port modifications were to enlarge the aperture to 31" x 21" and to make the port aperture match the nadir #1 port. These rectangular openings allow for installation of flat cover plates that can be modified for a variety of window sizes, including multiple windows on a single cover plate. Cover plates are interchangeable between the two ports.

Also in 2020, a removable free fall chute design was completed for the nadir #2 port. The unpressurized free fall chute allows dropsondes

Figure 44. *The P-3 landing at WFF in snowstorm during IMPACTS.* ***Photo credit:*** *Dan Chirica*

and sonobuoys up to 5.5” in diameter to be deployed from the aircraft.

FY20 also saw the first use of Computational Fluid Dynamics (CFD) in design and development of large external P-3 installations. The use of CFD for large installations, such as wing pylons and canister instruments, will enable a better understanding of aircraft performance characteristics as well as aircraft flow during science data collection.

Significant Upcoming Maintenance Periods:

- Phased Depot Maintenance – mid-2022, 6-8 months (The WFF Aircraft Office is investigating a Conditions Based Maintenance (CBM) program for future use. If CBM is implemented, this PDM may be cancelled.)
- Landing Gear Overhaul – March 2025, 1-2 months (Date may change as a result of CBM.)
- Annual Maintenance – 2020-2025, 4-6 weeks annually (This maintenance can be scheduled to support mission needs; duration may change due to CBM.)

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

Other NASA Earth Science Aircraft

Other NASA aircraft, as described here, on the Airborne Science website, and in the annual ASP Call Letter, are platforms operated by NASA centers. Although not subsidized by the ASP program, these aircraft are also modified to support Earth-observing payloads. These aircraft are available for science through direct coordination with the operating center.

Table 13. *Other NASA aircraft available for Earth Science missions.*

Aircraft	Operating Center
AlphaJet	Under agreement with ARC
B-200 King Air; UC-12B	LaRC, AFRC, WFF, or contracted
C-130 Hercules	WFF
Cessna 206H	LaRC
HU-25A Falcon / HU-25C Guardian	LaRC
SIERRA-B	ARC
Small UAS	AFRC, ARC, LaRC, JPL
Twin Otter	GRC or contracted
Viking-400 UAS (in development)	ARC, LaRC
WB-57	JSC

B-200 / UC-12

Operating Center:
Langley Research Center (LaRC), Armstrong Flight Research Center (AFRC)

Aircraft Description:
LaRC operates a conventional B-200 and a UC-12B (military version). Each has been extensively modified for remote sensing research. AFRC operates a Super King Air B-200 that has been modified for downward looking payloads. The Beechcraft B-200 King Air is a twin-turboprop aircraft capable of mid-altitude flight (>30,000 ft) with up to 1000 pounds of payload for up to 6 hours. The three B-200 aircraft have varying modifications to support science.

FY20 Science Flight Hours: 98.9

B-200 FY20 Missions

Mission	Location	Science Program Area
ACTIVATE	ACTIVATE	Atmospheric Dynamics
DopplerScatt	DopplerScatt	Terrestrial Hydrology

FY20 Modifications and Impacts on Performance and Science:

- Installed a portal on the top of the nose ahead of the windshield on the UC-12B (NASA 528)
- Installed a dropsonde launcher on the UC-12B (NASA 528) for upcoming EVS-3 mission ACTIVATE; this can also be installed on the B-200 (NASA 529)

Significant Upcoming Maintenance Periods:
Each aircraft undergoes phase inspections as a function of flight hours or elapsed time. A typical phase inspection has a duration of 4 weeks. Phase inspections occur as necessary, based on aircraft use.

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

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

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

HU-25A Falcon/Guardian

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The HU-25C and HU-25A Falcons are modified twin-engine business jets based on the civilian Dassault FA-20G Falcon. The HU-25C completed an OIB mission early in FY16 and has been placed into flyable storage. The HU-25A replacement is now in active service.

FY20 Science Flight Hours: 129.3

HU-25A FY20 Missions

Mission	Location	Science Program Area
ACTIVATE	NASA LaRC – Atlantic Ocean	Atmospheric Composition

FY20 Modifications and Impacts on Performance and Science:

None.

Significant Upcoming Maintenance Periods:
Maintenance is a function of number of flight hours flown.

Website:

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

Figure 45. *The HU-25A and UC-12B outside of the NASA LaRC aircraft hangar during ACTIVATE.*
Photo credit: *David C. Bowman*

WB-57 High Altitude Aircraft

Operating Center:
Johnson Space Center (JSC)

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

FY20 Modifications and Impacts on Performance and Science:

None; the aircraft team is preparing to support the test flights for the ACCLIP mission beginning in FY21.

Website:

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

Figure 46. *The WB-57 is in preparation for Asian summer monsoon Chemical and Climate Impact Project (ACCLIP) flights in FY21.*

CESSNA 206H

Operating Center:
Langley Research Center (LaRC)

Aircraft Description:
The NASA LaRC Cessna 206H is an all-metal, six-seat, high-wing, single-engine general aviation airplane equipped with tricycle landing gear and is designed for general utility purposes. The aircraft was acquired by NASA in 2001 to provide a low-cost research platform for advanced pilot displays and to serve as a platform for atmospheric science instruments. Up to 300 pounds can be carried in the Cessna production belly cargo pod and 100 pounds in a custom-designed pod that attaches to the right wing strut. The aircraft is equipped with NASA LaRC's General Aviation Baseline Research System, which includes GPS, Air Data, Attitudes and Heading Reference System (ADAHRS), out-the-window video and a Researcher Workstation.

FY20 Science Flight Hours: Cessna 206H flew chase missions for ACITVATE to observe dropsonde activity.

FY20 Modifications and Impacts on Performance and Science:
None.

Website:

http://airbornescience.nasa.gov/aircraft/Cessna_206H

SIERRA-B UAS

Operating Center:
Ames Research Center (ARC)

Aircraft Description:
The Sensor Integrated Environmental Remote Research Aircraft (SIERRA)-B aircraft is a high wing, 480 pound gross weight monoplane (UAS Class III) with twin tail booms and inverted V-tail. It 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 ARC, the SIERRA-B is well suited for precise and accurate data collection missions because it is large enough to carry up to 100 pounds of scientific instruments and fly up to 12,000 feet, yet is small enough not to require a large runway or hangar. The SIERRA-B Program, managed at ARC, 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.

FY20 Science Flight Hours: 6

FY20 Modifications and Impacts on Performance and Science:
None.

Significant Upcoming Maintenance Periods:
Maintenance is a function of number of flight hours flown.

Website:
http://airbornescience.nasa.gov/aircraft/SIERRA_-_ARC

Figure 47. *SIERRA UAS*

5. Aircraft Cross-Cutting Support and IT Infrastructure

Aircraft support entails aircraft facility instrument operations and management, engineering support for payload integration, flight planning and mission management tools, flight navigation data hardware and software support, and flight data archiving and distribution.

Cross-cutting support for ASP missions is managed at ARC and supported by the Universities Space Research Association (USRA) Airborne Sensor Facility (ASF) and Bay Area Environmental Research Institute (BAERI) National Suborbital Research Center (NSRC). Specific activities include providing facility instruments, satellite communications, mission tools data services, and assistance with payload integration engineering.

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

ASP Facility Science Infrastructure

Facility Instrumentation

The ASP provides a suite of facility instrumentation and data communications systems for community use by approved NASA investigators. Currently available ASP instrumentation (Table 10) includes standalone precision navigation systems, a suite of digital tracking cameras and video systems, and various air data measurement instruments. Real-time data communications capabilities, which differ from platform to platform, are also described below, and are integral to a wider Sensor Network architecture. In addition, ESD, through the Research and Analysis (R&A) Program and EOS Project Science Office, maintains a suite of advanced imaging systems that are made available to support multidisciplinary research applications. These are supported at various NASA field centers, including JPL, ARC, and LaRC. The ASF also maintains a spectral and radiometric instrument calibration facility, which supports the wider NASA airborne remote sensing community. Access to any of these assets is initiated through the ASP Flight Request process (see page 4).

Sensor Network IT Infrastructure

A state-of-the-art real-time data communications network has been implemented across the ASP core platforms. Utilizing onboard Ethernet networks linked through airborne satellite communications systems to the web-based MTS, the sensor network is intended to maximize the science return from 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 (EIP); an airborne network server and satellite communications gateway known as the NASA Airborne Science Data and Telemetry (NASDAT) system; and a web-based application programming interface (API) for interfacing to customer software and other agencies. These capabilities are now operational, as indicated in Table 14.

Table 14. *Facility equipment.*

Airborne Science Program Facility Equipment		
Instrument / Description	**Supported Platforms**	**Support Group**
Digital Mapping System (DMS), 21 MP Natural Color Cameras	Most ASP Platforms	ASF/ARC
POS AV 510 (3) Applanix Position and Orientation Systems, DGPS w/Precision IMU	All ASP Platforms	3 at ASF/ARC
POS AV 610 (2) Applanix Position and Orientation Systems, DGPS w/Precision IMU	All ASP Platforms	2 at ASF/ARC 2 at WFF
Dew Point Hygrometers	DC-8, P-3, C-130	NSRC
IR Surface Temperature Pyrometers	DC-8, P-3, C-130	NSRC
LN-251 Embedded GPS/INS Position and Orientation System	DC-8, P-3, C-130	NSRC
Combined Altitude Radar Altimeter	DC-8, C-130	NSRC
Forward and Nadir 4K Video Systems	DC-8, P-3, C-130	NSRC
Total Air Temperature Probes	DC-8, P-3, C-130	NSRC
Ice Detector	DC-8	NSRC
MVIS 4K Video Camera (nadir)	ER-2	ASF
FLIR Vue Pro R 640 IR Camera (45 and nadir)	DC-8	NSRC
45 HD Video Camera	DC-8	NSRC
EOS and R&A Program Facility Instruments		
Instrument / Description	**Supported Platforms**	**Support Group**
MODIS/ASTER Airborne Simulator (MASTER) 50 ch Multispectral Line Scanner V/SWIR-MW/LWIR	B200, DC-8, ER-2, P-3, WB-57	ASF/ARC
Enhanced MODIS Airborne Simulator (MAS) 38 ch Multispectral Scanner	ER-2	ASF/ARC
Pushbroom Imager for Cloud and Aerosol R&D (PICARD) 400 2450 nm range, DI 10 nm	ER-2	ASF/ARC
AVIRIS-ng Imaging Spectrometer (380 2510 nm range, DI 5 nm)	Twin Otter, B200	JPL
Portable Remote Imaging SpectroMeter (PRISM) (350 1050 nm range, DI 3.5 nm)	Twin Otter, ER-2, GV, LaRC G-III	JPL
AVIRIS Classic Imaging Spectrometer (400 2500 nm range, DI 10 nm)	ER-2, Twin Otter	JPL
UAVSAR Polarimetric L-band Synthetic Aperture Radar, Capable of Differential Interferometry	G-III/C-20	JPL
NAST-I Infrared Imaging Interferometer (3.5 16 mm range)	ER-2, DC-8	LaRC

NASA Airborne Science Data and Telemetry (NASDAT) System

The NASDAT provides experiments with: :

- Platform navigation and air data
- Highly accurate time-stamping
- Baseline Satcom, Ethernet network, and Sensor-Web communications
- Legacy navigation interfaces for the ER-2 (RS-232, RS-422, ARINC-429, Synchro, IRIG-B)
- Recorded cockpit switch states on the ER-2 and WB-57 aircraft
- Optional mass storage for payload data

In FY20, the Program kicked off an effort to architect the next generation of onboard information technology in support of science payloads. One of the goals of this effort is to investigate more modular, upgradeable systems that will enable incremental improvements as sub-system element improvements become available.

Satellite Communications Systems

Several types of airborne satellite communications systems are currently operational on the core science platforms. High bandwidth Ku- and Ka-band systems, which use large steerable dish antennas, are installed on the WB-57. Inmarsat Broadband Global Area Network (BGAN) multi-channel systems, using electronically-steered flat panel antennas, are available on many of the ASP core and other NASA aircraft. Data-enabled Iridium satellite phone modems are also in use on most of the science platforms. Although Iridium has a relatively low data rate, unlike the larger systems it operates at high polar latitudes and is lightweight and inexpensive to operate. Satcom capabilities are listed in Table 15.

Payload Management

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

NSRC staff provides science instrument integration services for the NASA DC-8 and P-3 aircraft. Instrument investigators provide a Payload Information Form that includes basic instrument requirements for space, power, aircraft data, location of the instruments, and any applicable inlet or window access needs. The staff then uses this, along with additional solicited information, to complete engineering design and analysis of new instrument and probe installations on the aircraft, and wiring data and display feeds

Table 15. *Satellite communications systems on ASP aircraft.*

Satcom System Type/Data Rate/Nominal	Supported Platforms	Support Group
Ku-Band (1 channel system) / > 1 Mb/sec	WB-57	NSRC; AFRC; JSC
Inmarsat BGAN (2 channel systems) / 432 Kb/sec per channel	DC-8, WB-57, P-3, AFRC B200, ER-2, GV, HU-25A	NSRC; ASF
Iridium (1–4 channel systems) / 9.6 Kb/sec (4 channel NASDAT system)	Most ASP Platforms	ASF; NSRC

to instrument operators. As availability permits, crosscutting instrument integration support has also been supplied intermittently on additional ASP aircraft.

NSRC also provides full-featured data display, aircraft video, facility instrument, and satcom services on the DC-8, P-3, and C-130 aircraft. A high-speed data network (wired and wireless) is maintained on each of the aircraft to provide on-board investigators access to display data available on the aircraft. Video, aircraft state parameters, and permanent facility instrument data are recorded, quality-controlled, and posted to the science mission and ASP data archives. Satcom services are provided with multichannel Iridium and high bandwidth Inmarsat services. These services allow for real time chat with scientists on the ground and other aircraft. NSRC engineers also work with investigators to send appropriate data up to and down from the aircraft to allow for real time situational awareness to scientists on the ground and in flight. Subsets of these systems are provided on several other ASP aircraft, including the ER-2, G-III, GV, UC-12B, and HU-25A.

Along with general payload engineering services, the Ames crosscutting team designs and builds custom flight hardware for the ASP real-time sensor network (i.e., network host and navigation data server (NASDAT)) and standardized EIPs. ASF personnel also support the ER-2 program, providing payload integration and field operations support, as required for the real-time sensor network and the MVIS video system.

Figure 48**. JPL's David Austerberry on board NASA AFRC C-20A aircraft during a UAVSAR P-band engineering flight. Scientists on board have internet access to real time data.* ***Photo credit: *Carla Thomas*

6. New Technology Development

ASP focuses technology investments in areas that can contribute directly to bringing new or improved capabilities to the Earth Science. One focus is on onboard equipment to facilitate relay of real time data to our payload operators and scientists, as well as enabling distributed teams to participate virtually in flight missions from the comfort of the home or office. An update of the Mission Tool Suite (MTS) was completed in 2020, providing significant new features for users (see MTS v2 below). The Program is also pursuing a new strategy for enabling more customizable, reconfigurable, and easier to upgrade IT systems for serving as onboard networks and for supporting the next generation of SATCOM systems such as Iridium NEXT and STARLINK. The Program is also exploring the use of a new generation of High Altitude Long Endurance (HALE) aircraft similar to those explored decades ago during the ERAST Program, but with significantly more capabilities given breakthroughs in battery chemistry and light weight materials. A new High Altitude Long Endurance (HALE) UAS development supported through NASA's SBIR program has accomplished first flight and landed its first customer.

Mission Tool Suite Version 2

The Airborne Science Mission Tools Suite (MTS) is a decisional support and situational awareness system used to assist with the execution of airborne missions. The system's primary purpose is to provide a central interface for program asset tracking, reporting, and onboard instrument telemetry, including access to land- and space-based observations to support mission operational objectives. The intent of the system is to encourage more responsive and collaborative measurements among instruments on multiple aircraft, satellites, and the surface to increase the scientific value of the measurements.

After nearly two years of effort, the next generation MTS is now available (Figure 48). (With MTSv2 online, the first generation of MTS has been decommissioned and is no longer available.) MTSv2 is a complete rework of the initial system, providing new capabilities for telemetry visualization and multi-projection support, including new tools to simplify product search, discovery, and management. The new system has been reworked from the ground up to take full advantage of lessons learned through nearly a decade of mission operations support. A fully redesigned user interface centralizes common display enhancements (e.g., range rings, wind vectors) and allows greater customization based on the user's mission role and preferences. The new system is available at https://mts2.nasa.gov. Affiliation with an airborne mission or

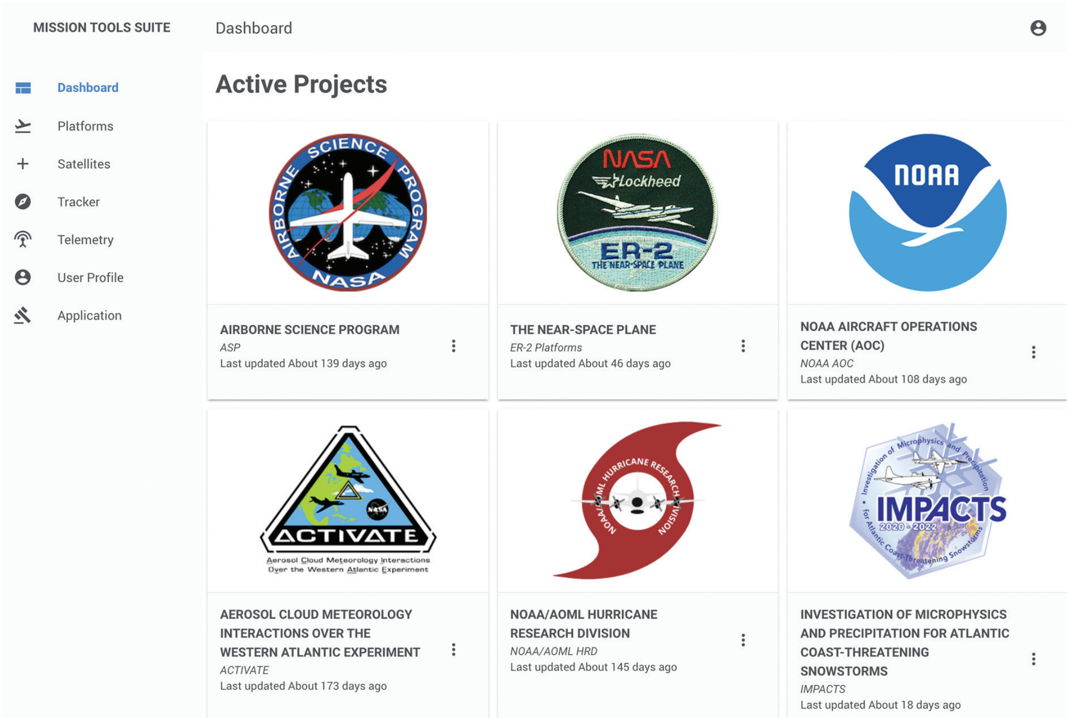


Figure 49. *The MTSv2 splash page.*

associated platform is required to access the new system. Original MTS credentials do not work with the new system. Previous users can revalidate access directly with mission management or with their project's mission liaison office.

MTS team provides free access to high-quality digital models of program assets (see Figure 49). These models can be previewed on the updated ASP public tracker website at https://airbornescienc.nasa.gov/tracker. Three-dimensional (3D) models are useful for aircraft visualization, public education and outreach, and are the foundation for providing next generation interfaces that will include augmented- and virtual-reality displays.

Figure 50. *The Mission Tool Suite provides 3D models of ASP aircraft.*

The program now has the capability to generate 3D renderings of single or multiple platforms operating n 3D realistic terrains. Additional information is available on the Airborne Science Program website or contact Aaron Duley (aaron.r.duley@nasa.gov).

Next Generation onboard Internet Technology and Satellite Communications

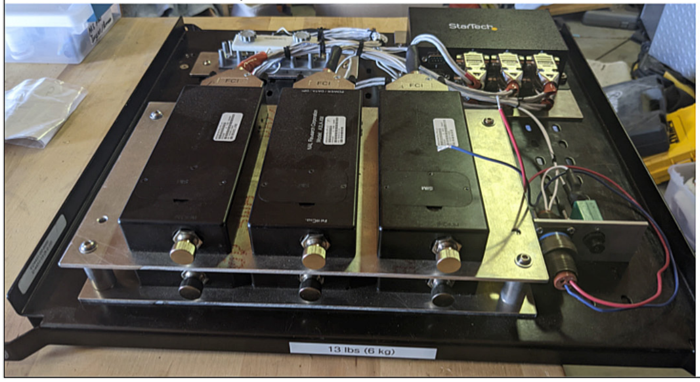
For more than a decade, the NASA Airborne Science Data and Telemetry (NASDAT) airborne servers, associated peripherals, and underpinning software, have provided an advanced level of data handling to and from aircraft and payloads, as well as providing real time data feeds through Iridium or Inmarsat services. In FY20 the Program stood up a small team to begin developing the next generation of payload auxiliaries and services that will enable modular upgrades and scalability based on current and projected project requirements and platform capabilities. An early demonstration of this took place on the JSC G-III during the SHARC mission, where the team demonstrated a 6-channel Iridium system that takes advantage of MultiPath Transmission Control Protocol (MPTCP) architecture for assuring reliable connectivity. The MPTCP software was developed at NASA GRC with ESTO funding. Figure 50 summarizes the success of that Multi-link demonstration. This new technology initiative will also explore the ability to incorporate IridiumNEXT, Inmarsat Global Express, and Starlink services for global coverage. The ultimate goal of this effort is to define an architecture and series of hardware and software standards to continue the NASDAT legacy of providing best available airborne IT and communications services to our stakeholders.

SHARC 6-Channel Iridium System with MPTCP

Rapidly developed from on hand components to meet the requirements of the SHARC campaign, the 6-channel system consists of

- 1 Adlink Industrial PC
- 1 8 port serial Adapter
- 6 A3LA-XM Modems.

Channel bonding is accomplished using the MPTCP software developed at NASA GRC.



Performance vs 4 channel MLPPP

Theoretical Performance:

- 9600 bps vs 14400 bps

Observed Sustained TCP Performance:

- 900-1000 bps vs 1500 bps

Observed Stability Improvement

- IRC from Hawaii to Wake Island: 0 service interruptions vs 25
- Adequate to install and configure DHCP server remotely to meet late JSC Requirement.

Figure 51. *Summary of NextGen multi-channel communications demonstration on the JSC G-III.*

New UAS technology

ASP is funding a project at ARC to evaluate and demonstrate the use of HALE UAS platforms and consider how they might contribute to future NASA earth observing architectures. The goals are to determine what new science might be achieved from these systems and to track system development. In particular, the project will identify opportunities for partnering on flight demonstrations or payload accommodation characterization flights to reduce risk and further mature these systems for eventual NASA science missions.

Several science focus areas have expressed strong interest in the additional vantage point and endurance that can provide unique and useful measurements. This follows the long history at NASA of research, development and deployment of HALE UAS.

An outcome of this new effort has been the successful first flight of a NASA SBIR project with Swift Engineering (San Clemente, California). Swift's 72-foot solar-powered HALE weighs less than 180 pounds and is designed to fly for 30 days at 65,000ft with a 15-22lb payload. Despite its wide wing- span, Swift's HALE is similar in size to a small general aviation (GA) aircraft but at a fraction of a GA's weight. Compared to the NASA ER-2, which operates at a maximum altitude of 70,000 feet and can carry a 2,600-pound payload for missions over 10 hours, the Swift HALE UAS is capable of flying lightweight payloads for days and weeks on end.

The first payload demonstration of this aircraft, being funded jointly by USFS Aviation and NASA SBIR, will be to fly several FLIR cameras (3-5micron and 8-12micron) to evaluate the

Figure 52. *The SWIFT Engineering HALE UAS completed a first test flight in New Mexico in 2020.*

ability to image, process, and telemeter fire location and perimeter date over a week or more of continuous flight. NASA matching funding will explore integration of payloads to support radiation measurements, magnetic fields, and imaging spectroscopy, in coordination with several NASA, DOE, and USGS teams. NASA Earth Science has worked closely with the ARC Safety Office to develop an Interagency Agreement to enable this office to support USFS with Airworthiness and Flight Safety Reviews, as well as Certificate of Authorization (COA) development. The flights are scheduled to take place in June 2021.

The payload mass and volume on this aircraft is also ideal for a 2u cubesat. Once the USFS flight is complete NASA will have the opportunity to fly an additional NASA payload for a flight demonstration. A process is being developed to vet and ultimately select for flight-testing various candidate payloads. In support of “SBG science”, for example, a number of COTS imaging spectrometers in the VIS-NIR are being evaluated. USGS has recently purchased a Hyspex Mjolnir system for evaluation and testing, which might be a good candidate.

This and other new generation UAS will have limited access to the airspace in the near term until the NASA ARMD Upper-E Traffic Management (ETM) project has developed a more automated way for handling Upper E airspace requests. Swift and other UAS companies have been introduced to the ETM team to ensure science conops are figured into their system requirements. For the upcoming Swift Engineering flight, a COA in development would allow flight from SpacePort America to the Gila National Forest in New Mexico. In discussions with the FAA it also seems quite feasible to transit along the border to the Pacific to conduct flights offshore for coastal surveys. Once UAS prove themselves with hundreds of incident free flight hours it will be much easier to gain access over CONUS targets through the existing COA process.

7. Advanced Planning

The Airborne Science Program (ASP) maintains and operates a diverse fleet of aircraft and infrastructure that support a varied and evolving stakeholder community. ASP leadership conducts a yearly strategic planning activity 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 through formal meetings to discuss lessons learned following all major campaigns.

ASP asset and service requirements are collected and communicated through the program flight request system (http://airbornescience.nasa.gov/sofrs), annual 5-year schedule update, and ongoing discussions with Mission and Program managers and scientists.

ASP strategic planning is focused on:

- ASP-supported (Core) Aircraft – maintenance, upgrades, determining future composition of the fleet
- Cross-cutting Infrastructure Support – support for ASP-supported and other NASA aircraft (e.g., providing tracking tools for all Earth science missions)
- Observatory Management – improved tools for managing assets and requirements while improving the service to science investigators
- New Technology – bringing new technologies to observational challenges, including application of advanced telemetry systems, on-board data processing, IT mission tools, and new platforms
- Educational Opportunities

Needs Assessment Update

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

- Algorithm development
- Instrument test
- Calibration and validation activities
- Process studies

In recent years, much attention has been focused on planning for satellite and ISS Earth Science mission, such as those previously defined in the 2007 NRC Decadal Survey report. This has included ICESat-2, soon-to-be-launched SWOT and NISAR, and the upcoming PACE mission. The Designated Observable missions under development on the basis of the more recent 2017 NRC Decadal Survey are now driving the future needs for airborne support.

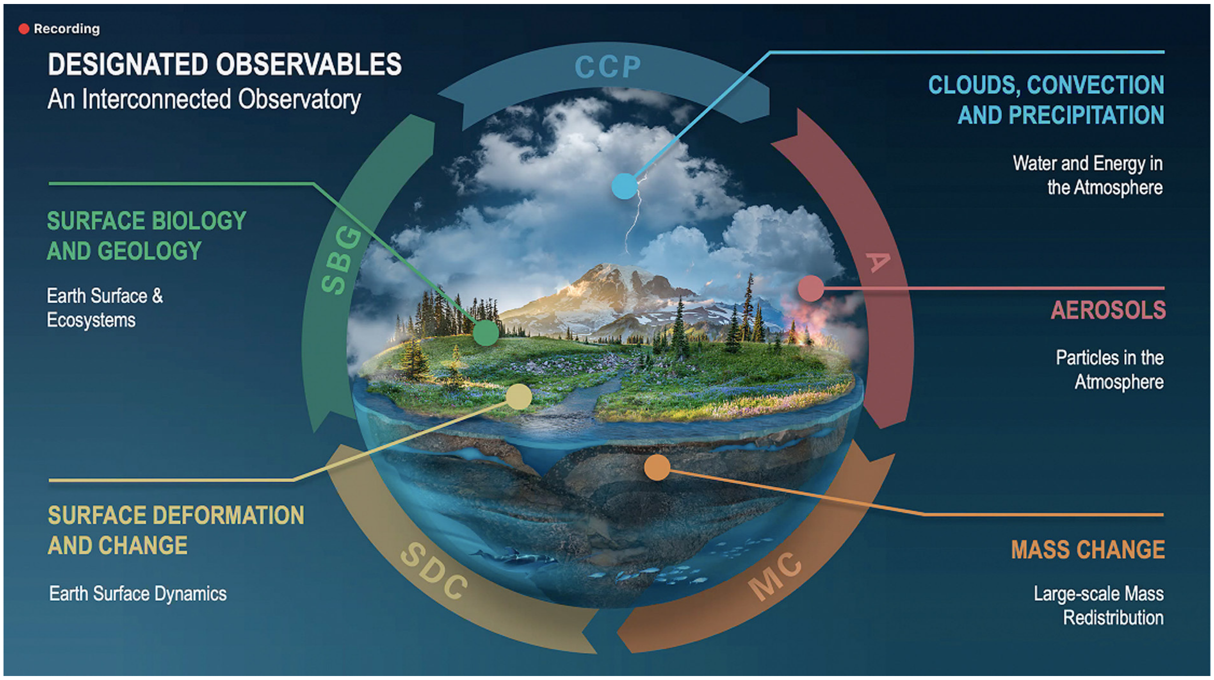


Figure 53. *The Designated Observable missions will need airborne support.*

The ACCP mission, for example, has a mandatory suborbital component to complement the space observations. The SBG mission will make use of airborne data for algorithm development, similar to the earlier precursor work for HysPIRI.

The updated ASP Needs Assessment report is currently in draft form and focuses on those future missions.

ASP also continues to support existing space missions (e.g., A-Train satellites), as well as other "foundational" missions, such as GPM, OCO-2, and Suomi NPP. Once launched, these missions require mandatory cal/val, often making use of airborne capabilities. New space missions on the International Space Station, several small satellites, and collaborations with ESA and other space agencies are also targets for airborne support.

Participation in science team meetings and program reviews by ASP personnel in 2020 to collect requirements information are listed in Table 16 on page 68.

Table 16. Activities supporting ASP requirements information gathering.

Activity
Participation in 2020 PARCA/OIB Workshop
Remote participation in ESTO Forum
Remote participation in Ocean Color workshop/Paula Bontempi farewell seminar
Remote participation in 2020 NextGen SAR workshop
Remote participation in STV Community workshop
Remote participation in National Academies Future Airborne Platforms workshop. *Videos available at: https://www.nationalacademies.org/event/07-29-2020/future-use-of-nasa-airborne-platforms-to-advance-earth-science-priorities-virtual-community-workshop-sessions*
Remote participation in PACE Applications Workshop
Remote participation in ACCP Community Forum; ACCP-GPM workshop
Remote participation in SBG Community workshop
Remote participation in SDC Study Update session
Remote participation in SMD Town Hall
Remote participation in 4th Federal UAS workshop
Remote participation in Fall Tactical Fire Remote Sensing Advisory Committee meeting ECOSTRESS Science Team meeting
Remote participation in AGU Town Halls, science sessions, and poster sessions

Five-year Plan

The ASP Program maintains a 5-year plan for out-year planning and scheduling. Significant maintenance periods for the various aircraft are indicated. A copy in Appendix A depicts plans by science area and aircraft platform. The 5-year plan is also available on the ASP website. A snapshot of potential flight campaigns for the Decadal Survey Designated Observable and Incubator mission is shown in Figure 53.

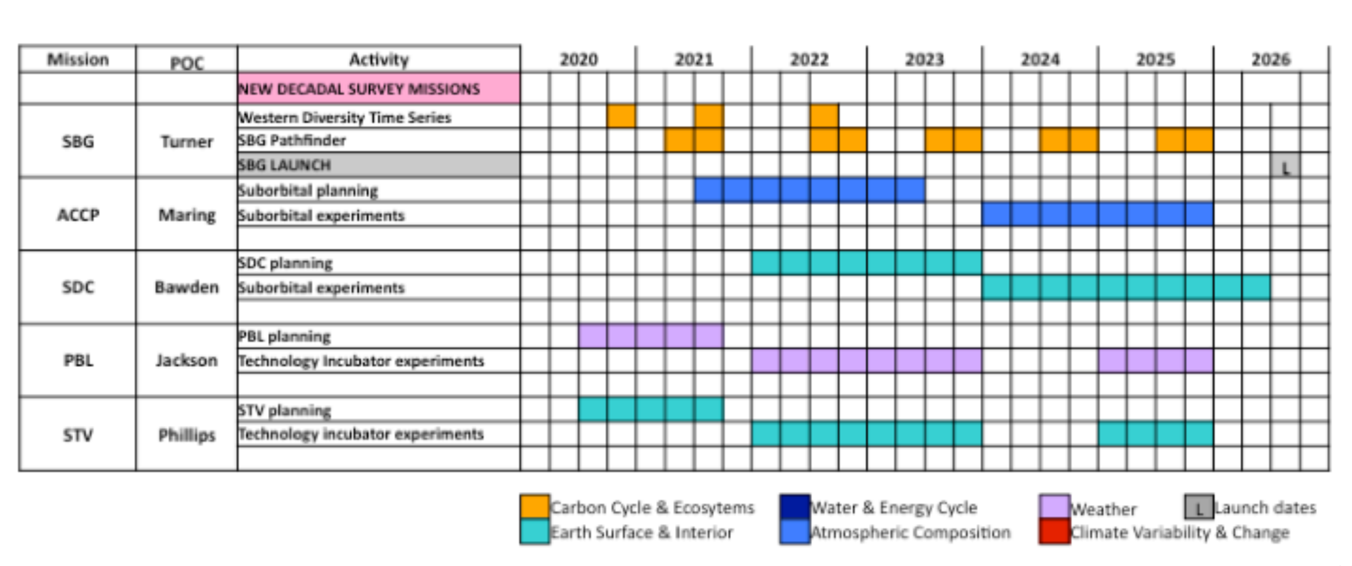


Figure 54. *Forecasted ASP support for 2017 Decadal Survey identified missions.*

8. Education, Training, Outreach, and Partnerships

Student Airborne Research Program 2020

The 12th annual NASA Student Airborne Research Program (SARP) took place online from June 15-August 7, 2020 . Every summer since 2009, SARP has competitively selected a group of ~30 undergraduate STEM majors from across the U.S. for a summer internship experience in NASA Earth Science research that included flights on a NASA research aircraft. This year, with COVID-19 travel and social distancing restrictions in place, SARP was grounded, but the internship continued with new at-home data collection and analysis.

Air sample canisters were mailed to SARP participants in April, before the official start of the program in June, so students could sample

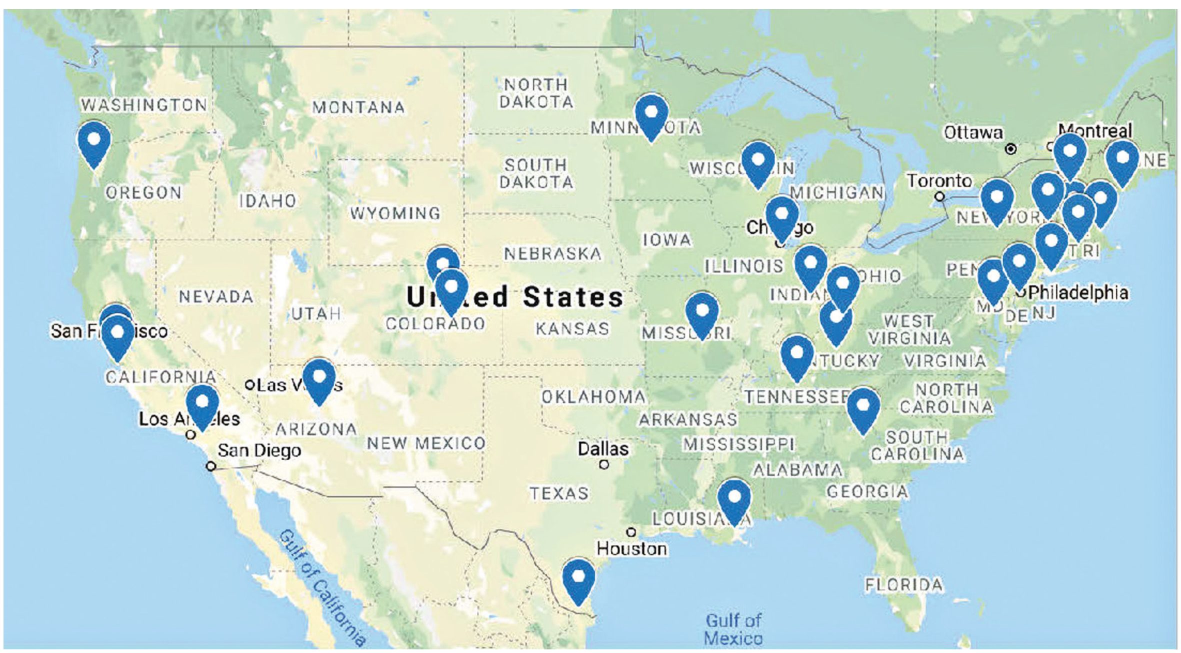
Figure 55. *The SARP intern class of 2020 participated in the program online.*

the air at the peak of stay-at-home orders while emissions were likely lowest, in late April. As states begin the gradual process of re-opening in the spring/summer, SARP participants continued to take air samples near their homes, allowing them to track any changes in emissions. Once SARP participants collected all their air samples, they mailed the canisters back to the UC Irvine laboratory, where the samples are being analyzed for nearly 100 compounds, including greenhouse gases such as methane and carbon dioxide, vehicular exhaust gases, and gases related to industrial activities.

The majority of the internship was spent developing individual research projects using the SARP airborne datasets from the past 11 summers, as well as data from other NASA airborne, satellite, and ground stations. A team of faculty advisors, NASA scientists, and graduate student research mentors supported the internship students.

At the conclusion of the program, students delivered a 12-minute AGU conference-style oral presentation on their individual research project. NASA scientists and administrators and SARP alumni and university faculty members attended the online presentations.

SARP 2020 Colleges & Universities



Adelphi University
Amherst College
Bowdoin College
Butler University
Centre College
Colorado School of Mines
Cornell University
Harvard University
Johns Hopkins University
Missouri University of Science and Technology
Northern Arizona University
Northern Kentucky University
Norwich University
Oregon State University
Pomona College
Ripon College
Saint Johns University
Stanford University
Swarthmore College
Tulane University
University of Albany
University of California, Santa Cruz
University of Chicago
University of Colorado Colorado Springs
University of Connecticut
University of Georgia
University of Texas Rio Grande Valley
Vanderbilt University

Figure 56. *Map showing locations of the 2020 SARP students.*

Appendices

Appendix A

5-year Plan

Mission	Sci Focus Area	Satellite	2021	2022	2023	2024	2025
Western Diversity Time Series	Carbon Cycle & Ecosystems	Surface Biology and Geology					
SBG pathfinder		SBG					
AVIRIS Classic - budget							
AVIRIS - nex gen (US, India, EU)		NISAR					
GEDI cal/val (LVIS)		GEDI					
Terrestrial Ecology (UAVSAR)		NISAR					
ABoVE		OCO-2, NISAR,					
Joint ESA forest campaign		ESA BIOMASS					
BioSCape		NISAR					
G-LiHT-sensor fusion for Disaster impact and Forest Inventory		Landsat 8					
NISAR LAUNCH		NISAR LAUNCH					
NISAR cal/val (pre & post)		NISAR					
OBB activities		PACE					
Arctic Colors		PACE					
PACE LAUNCH		PACE LAUNCH					
PACE Cal/val		PACE					
UAVSAR (L-band, P-band, Ka-band)	Earth Surface & Interior	NISAR					
India NISAR mission		NISAR					
NISAR L+S cal/val California		NISAR					
NISAR cal/val (pre & post)		NISAR					
NISAR LAUNCH		NISAR LAUNCH					
Surface Topography and Vegetation Tech Incubation		STV					
UAV mission in development							
OIB Alaska	Climate Variability & Change / Cryosphere	ICESat-2					
ICESat-2 cal/val		ICESAT-2					
NISAR LAUNCH		NISAR LAUNCH					
Vanilla Ice UAS mission							
KU snow radar							
ARCSIX		ICESat-2					
SWOT LAUNCH		SWOT LAUNCH					
SWOT ocean cal/val activities		SWOT					
SWOT hydrology cal/val		SWOT					
Aeolus/GPM cal/val; GOES-r cal/val	Weather	ADM/GPM					
CPEX-AW		ADM/GPM					
Severe storm VORTEX-SE		GOES-R, GPM					
ACCP Suborbital pathfinder		ACCP					
Planetary Boundary Layer technology incubation		PBL					
Airborne Snow Observatory	Water and Energy Cycle	HyspIRI, Aqua, Terra, Landsat					
AirMOSS Arctic Permafrost		SMAP					
SNOWEX		SMAP					
SWOT hydrology cal/val		SWOT					
SWOT LAUNCH		SWOT LAUNCH					
SWOT ocean cal/val activities		SWOT					
SWOT post launch hydrology		SWOT					
Harmful Algal Bloom							
PACE-related Water quality mission		PACE					
SMAPVEX-21 / SMAPVEX-22		SMAP					
Sea Surface salinity mission in development		SMAP					
California Methane Survey	Atmospheric Composition and Chemistry						
AJAX		TEMPO, TROPOMI					
ARCSIX							
MOOSE-LISTOS		TEMPO, TROPOMI					
SHOW /CAMLS							
TRACER-AQ							
ACCLIP							
ACCP Suborbital pathfinder		ACCP					
ASIA-AQ		GEMS					
PACE LAUNCH		PACE LAUNCH					
PACE Cal/val (aerosols)							
CA-DWR	Applications						
Remote sensing applied science							
Spring/Fall Methane Survey							
Disaster missions							
Airborne Snow Observatory		HyspIRI, Aqua, Terra, Landsat					
OMG	EVS-2						
IMPACTS	EVS-3 (nominal schedules)						
DCOTSS							
S-MODE							
ACTIVATE							
Delta-X							
EVS-4	EVS-4						
SARP	Education						
AITT-2016	Instrument Technology	Various					
AITT-2019		Various					
IIP-2019		Various					
AIST-2019		Various					
DSI-2021		STV, PBL					

Legend:

Carbon Cycle & Ecosytems	Weather	Earth Venture Suborbital
Earth Surface & Interior	Climate Variability & Change	Maintenance
Water & Energy Cycle	Education	Applications
Atmospheric Composition	Earth Science Technology Office	Launch dates

Appendix B

Acronyms

A

AA	Associate Administrator
ABoVE	Arctic-Boreal Vulnerability Experiment
AC3	Axial Cyclone Cloud water Collector
ACCP	Aerosols and Clouds, Convections and Precipitation
ACCLIP	Asian summer monsoon Chemical and Climate Impact Project
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAHRS	Attitudes and Heading Reference System
ADS-B	Automatic dependent surveillance – broadcast
AFRC	Armstrong Flight Research Center
AGU	American Geophysical Union
AirLUSI	Airborne Lunar Spectral Irradiance
AITT	Airborne Instrument Technology Transition
AJAX	Alpha Jet Airborne Experiment
AMPR	Advanced Microwave Precipitation Radiometer
API	Application Programming Interface
ARC	Ames Research Center
ARES	Arizona Radio Echo Sounder
ARINC	Aeronautical Radio, Incorporated
ARMD	Aeronautics Research Mission Directorate
ASAR	Airborne Synthetic Aperture Radar
ASF	Airborne Sensor Facility
ASO	Airborne Snow Observatory
ASP	Airborne Science Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATM	Airborne Topographic Mapper
AVAPS	Advanced Vertical Atmospheric Profiling System
AVIRIS, AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer, AVIRIS-next generation
AXCTD	Airborne Expendable Conductivity Temperature Depth

B

BAERI	Bay Area Environmental Research Institute
BGAN	Broadband Global Area Network
BNL	Brookhaven National Laboratory

C

CC-HARRIER	Coastal High Acquisition Rate Radiometers for Innovative Environmental Research
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
Cal/val	Calibration / Validation
CAMBOT	Continuous Airborne Mapping by Optical Translator
CAMP2EX	Cloud and Aerosol Monsoonal Processes - Philippines Experiment
CAPS	Cloud, Aerosol, and Precipitation Spectrometer
CARE	Cabin Altitude Reduction Effort
CAS	Commercial Aviation Services
CBM	Conditions-Based Maintenance
CCE	Carbon Cycle and Ecosystems
CDP	Cloud Droplet Probe
CFD	Computational Fluid Dynamics
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
CH4	methane
CMIS	Compact Midwave Imaging System
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Authorization
CONUS	Continental US
COSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
CPDLC	Controller Pilot Data Link Communications
COVID	Coronavirus Disease
CPEX-AW	Convective Processes Experiment – Aerosols & Winds
CRS	Cloud Radar System
CVI	Counterflow Virtual Impactor
CY	Calendar Year
CZU	San Mateo and Santa Cruz Unit (CalFire)

D

DAAC	Distributed Active Archive Center
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DGPS	Differential GPS
DHCP	Dynamic Host Configuration Protocol
DLR	German Aeronautics and Space Agency
DMS	Digital Mapping System
DOE	Department of Energy (U.S.)

E

ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
eMAS	Enhanced MODIS Airborne Simulator
EOS	Earth Observing System
ERAST	Environmental Research and Airborne Sensor Technology
ESA	European Space Agency
ESD	Earth Science Division
ESPO	Earth Science Project Office
ESRL	Earth System Research Laboratories
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
ETIC	Estimated Time For Completion
ETM	Upper-E Traffic Management
EV, EVS-2, EVS-3	Earth Venture, Earth Venture Suborbital-2, Earth Venture Suborbital-3

F

FANS	Future Air Navigation System
FIREX-AQ	Fire Impacts on Regional Emissions and Chemistry Experiment – Air Quality
FLIR	Forward Looking Infrared
FMCW	Frequency Modulated Continuous Wave Snow Thickness Radar
FMS	Flight Management System
FPA	Focal Plane Array
FR	Flight Request
FY	Fiscal Year

G

GCAS	GeoCAPE Airborne Simulator
GEO-CAPE	GEOstationary Coastal and Air Pollution Events
GEDI	Global Ecosystem Dynamics Investigation
GHRC	Global Hydrology Research Center
GISS	Goddard Institute for Space Studies
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal
GOES-R	Geostationary Operational Environmental Satellite - R
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center

H

H_2O	Water
HALE	High altitude long endurance
HALO	High Altitude Lidar Observatory
HDVIS	High Definition Time-lapse Video System
HEOMD	Human Exploration and Operations Mission Directorate
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HSRL	High Spectral Resolution Lidar
HVPS	High Volume Precipitation Spectrometer
HyspIRI	Hyperspectral Infrared Imager
HyTES	Hyperspectral Thermal Emission Spectrometer

I

ICESat	ICESat Ice, Cloud, and land Elevation Satellite
IIP	Instrument Incubator Program
IMPACTS	Investigation of Microphysics and Precipitation for Coast-Threatening Snowstorms
InSAR	Interferometric Synthetic Aperture Radar
IR	Infrared
IRC	Internet relay chat

IRIG-B	Inter-range instrumentation group - B
ISRO	Indian Space Research Organization
ISS	International Space Station
IT	Internet technology
IWGADTS	Interagency Working Group for Airborne Data and Telecommunication Systems

J

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

K

K-12	Kindergarten – 12th grade
KDP	Key Decision Point

L

LaRC	Langley Research Center
LiDAR	Light Detection and Ranging
LISTOS	Long Island Sound Tropospheric Ozone Study
LVIS	Land, Vegetation, and Ice Sensor

M

MAIA	Multi-Angle Imager for Aerosols
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
MCoRDS	Multichannel Coherent Radar Depth Sounder
MODIS	Moderate Resolution Imaging Spectroradiometer
MOOSE	Michigan Ontario Ozone Source Experiment
MSFC	Marshall Space Flight Center
MTS	Mission Tools Suite
MURI	Multi-band Radiometer
MVIS	Miniature Video Imaging System

N

NASDAT	NASA Airborne Science Data and Telemetry
NAST-I	National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed - Interferometer
NEDT	Noise Equivalent Delta Temperature
NISAR	NASA-ISRO SAR
NOAA	National Oceanographic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NPP	National Polar-orbiting Partnership
NPS	Naval Postgraduate School
NRC	National Research Council
NSRC	National Suborbital Research Center

O

OCO-2	Orbiting Carbon Observatory - 2
OIB	Operation Ice Bridge
OMG	Oceans Melting Greenland

P

PACE	PACE Plankton, Cloud, and ocean Ecosystem
PARCA	Program for Arctic Regional Climate Assessment
PBL	Planetary Boundary Layer
PDM	Programmed Depot Maintenance
PI	Principal Investigator
PICARD	Pushbroom Imager for Cloud and Aerosol R&D
PIF	Payload Information Form
PMD	Palmdale Airport
PNNL	Pacific Northwest National Laboratory
POC	Point of Contact
POS	Position and Orientation Systems
PRISM	Portable Remote Imaging Spectrometer

Q

R

R&A	Research and Analysis
RGB	Red Green Blue
RICE	Rosemount Icing Detector
RIT	Rochester Institute of Technology
RSP	Research Scanning Polarimeter

S

S-MODE	S-MODE Submesoscale Ocean Dynamics and Vertical Transport
SAR	Synthetic Aperture Radar
SARP	Student Airborne Research Program
SatCom	Satellite Communications
SBG	Surface Biology and Geology
SBIR	Small Business Innovative Research
SDC	Surface Deformation and Change
SEO	sensor equipment operator
SHARC	SCIFLI Hayabusa 2 Airborne Re-entry Observation Campaign
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SI	International System of Units
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SnowEx	Snow Experiment
SNPP	Suomi National Polar-orbiting Partnership
SOFRS	Science Operations Flight Request System
SPEC	Stratton Park Engineering Company
STEM	Science Technology Engineering and Math
STV	Surface Topography and Vegetation
SWE	Snow Water Equivalent
SWESARR	SWE Synthetic Aperture Radar and Radiometer

SWIR	Short wave infrared
SWOT	Surface Water and Ocean Topography

T

TB	Terra bytes
TEMPO	Tropospheric Emissions: Monitoring Pollution
TRACER-AQ	Tracking Aerosol Convection Interactions Experiment – Air Quality
TROPOMI	Tropospheric Monitoring Instrument
TOI	Twin Otter International

U

UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UV	Ultra-violet

V

VHF	Very High Frequency
VIPR	Vapor in-cloud Profiling Radar

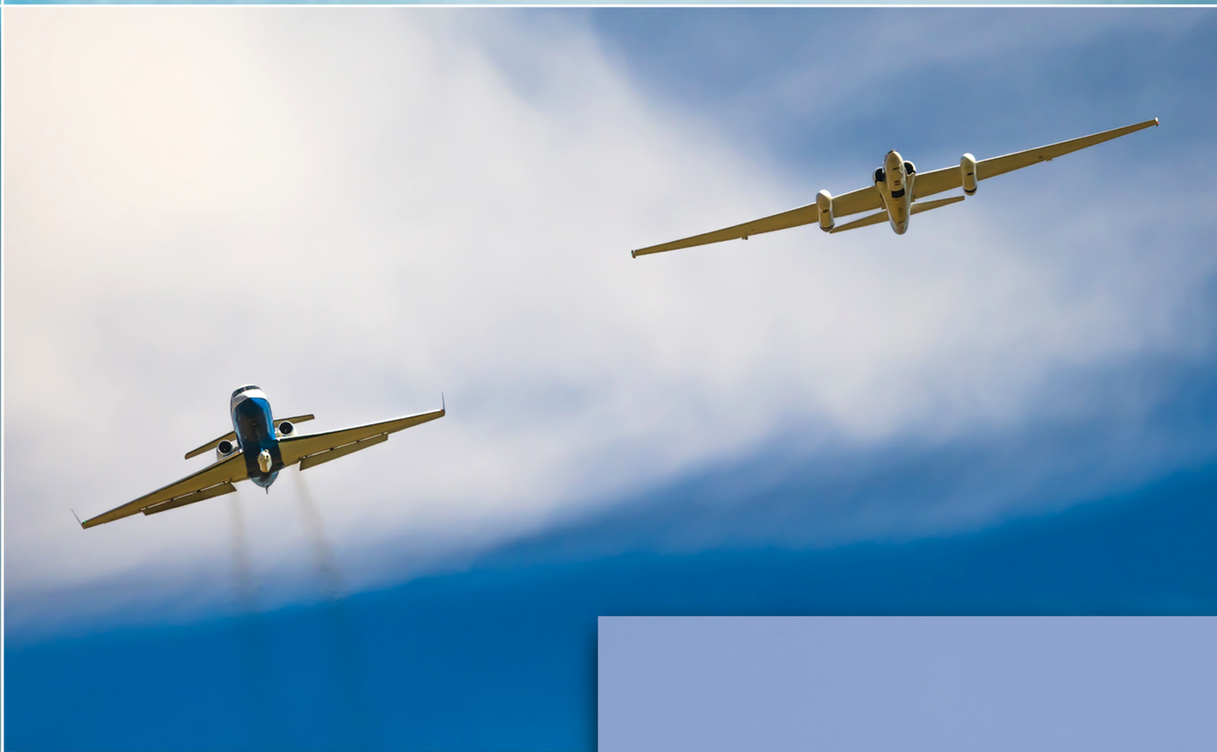
W

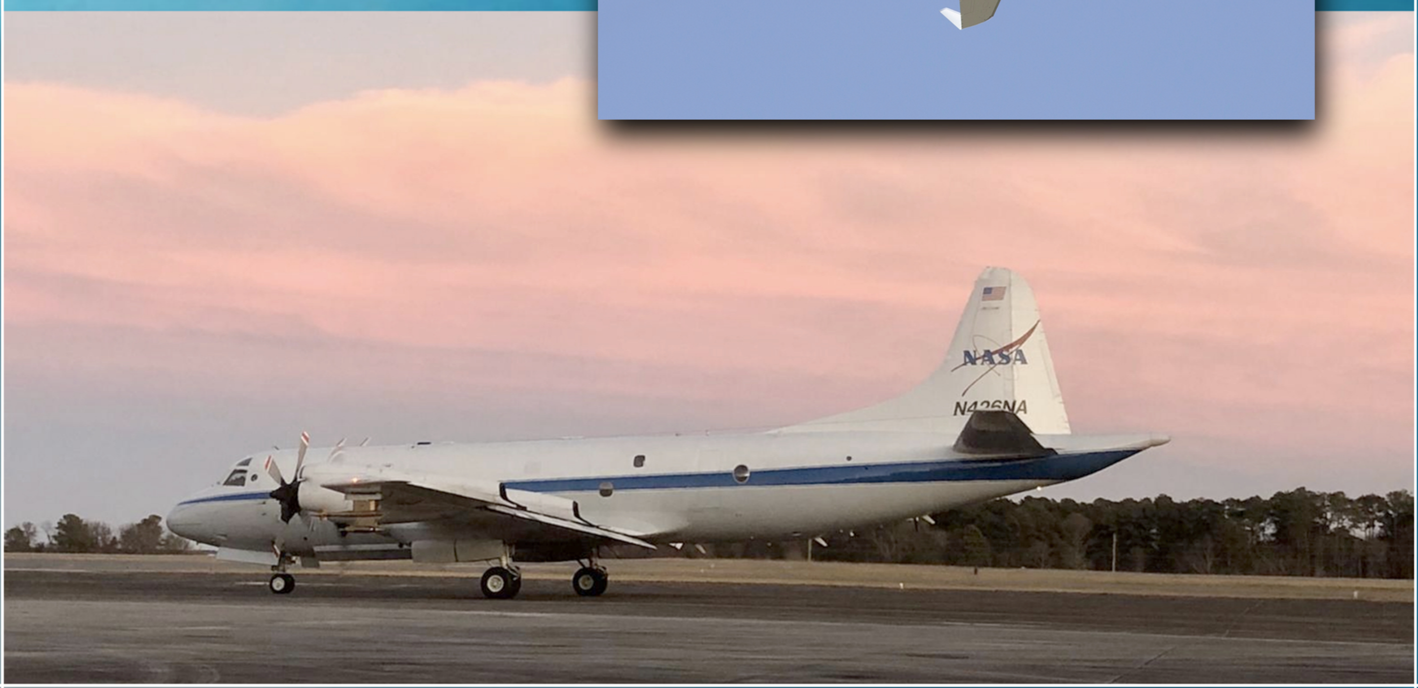
WDTS	Western Diversity Time Series
WFF	Wallops Flight Facility
WISPER	Water Isotope System for Precipitation and Entrainment Research
WNAO	Western North Atlantic Ocean

X

Y

Z





National Aeronautics and Space Administration

NASA Ames Research Center
Moffett Field, CA 94035

www.nasa.gov

NP-2021-04-01-ARC