National Aeronautics and
Space Administration

EXPLORE NASA AIRBORNE SCIENCE PROGRAM

2022 Earth Science Community Needs Assessment

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1. INTRODUCTION

The purpose of this report is to summarize and update known and projected aircraft capabilities needed by the NASA Earth Science Community. The primary objective of the NASA Airborne Science Program (ASP), managed under the Science Mission Directorate Earth Science Division, is to meet the needs of the NASA Earth Science community with respect to within atmosphere or sub-orbital measurements. Program objectives are driven primarily by Research and Analysis Program-funded projects that use airborne instruments in support of satellite calibration, algorithm or model validation, or multi-instrument, multi-vehicle missions to understand fundamental earth system processes. Prior to launch, many flight project develop airborne instruments that simulate intended measurements from orbit.

Over the past decade the NASA Earth Science community has consistently used more than 3000 science flight hours per year on a wide variety of aircraft. As new instruments are developed to support the next generation of satellite missions, some needs remain consistent, while others change. This report serves to document current NASA Airborne Science Program stakeholder needs and mission support requirements within the NASA Earth Science community for the use of aircraft and services provided by the NASA Airborne Science Program.

1.1 Objectives and Scope

This analysis of Program stakeholder needs is conducted approximately every 5 years and is the third internal ASP report. The intent of this report is to summarize the NASA Programs, Missions, and Projects for which there are clear requirements for airborne platforms, as well as documenting stated needs, or interest, from future stakeholders. The ultimate objective is to serve as a reference for NASA Earth Science leadership and the Airborne Science Program, to ensure that the right mix of aircraft is made available to the community and that investments are made in either acquisition or divestment, in order to maintain a balanced portfolio of capabilities to meet the majority of science needs over the next 5-10 years.

This report first addresses currently funded NASA Programs and Projects of record, and is intended to summarize current and anticipated needs for aircraft capabilities and payload accommodations. Special consideration is given to future needs described in the 2017 National Academies Decadal Survey pertaining to new observations and technology incubation studies.

Requirements for airborne observations originate from the following NASA Earth Science activities:

- NASA Earth observing satellite missions,
- Earth Science Research and Analysis data collections and field studies,
- Earth Science instrument / technology development

1.2 Approach to data collection

Data for this report have been collected through several means over the past 12 months and validated where possible by Program Managers and Program Scientists at NASA HQ.

Sources of information include but are not limited to:

- Interviews with Program Scientists through the semi-annual ASP 5-yr planning exercise
- A survey completed by principal investigators at the NASA Centers,
- Reviews of science mission planning documents,
- Requests for NASA ESD flight hours in the NASA Science Operations Flight Request System (SOFRS)
- Participation in science team meetings and community workshops
- Requests and early planning for Designated Observables missions, as defined by the NRC 2017 Decadal Survey.

From a NASA systems engineering standpoint, the term requirement carries with it many assumptions and so we attempt to make a distinction between true project requirements and needs or interests expressed by the NASA science community. Requirements for specific aircraft and modifications originate from the mass, volume, and power of the instrument as well as the specific vantage point needed to provide scientifically useful observations. From a NASA Programmatic perspective, Program requirements are those for which funding has been appropriated, approved, and distributed to projects whose goal can only be accomplished using a NASA aircraft. Within this report we try to only use the term “requirement” to indicate near term funded activities.

Whenever practical, when discussing needs with the science community the focus is on functional terms such as high altitude or heavy lift as general descriptors of requirements. It is inevitable that certain instruments or science communities are accustomed to using a given platform, but by understanding the underlying observing requirements, the Program is better able to characterize optimal measurements, as opposed to a subset of requirements that are met by what is available.

1.3 Report structure

The structure of this report is intended to provide an overview of current capabilities followed by projected science needs in order to enable awareness of gaps or a mismatch in capabilities. Current assets of the program are presented in Section 2, along with historical usage and community interest based on representative previous requests or workshop results. Section 3 presents the documented requests for aircraft based on data collection described above, including input provided through discussions with NASA Centers and the information they provided through a survey to their Earth Science principal investigators. Section 4 presents an overview of cross-cutting engineering capabilities and services provided by the Program and requirements to maintain and / or expand these services. Appendices include a 5-year plan broken out by both science focus area and aircraft, and a list of acronyms.

2. AIRBORNE SCIENCE PROGRAM PORTFOLIO OF ASSETS

2.1 Current NASA airborne science platforms

In describing science community needs for aircraft, it is important to begin with an overview of currently available, science-capable aircraft within NASA because in many ways the current operational aircraft reflect capabilities that have been retained and funded because of recurring project requirements.

Science aircraft have been modified in order to carry a wide variety of different kinds of payloads from downward or upward looking imagers or radiometers, to inlets for gas samplers, as well as external hard points for radar receiver/transmitters. The current fleet of modified NASA aircraft is listed in Table 1, along with their performance characteristics. These aircraft have also been equipped with onboard computers and antennae for purposes of handling aircraft data relevant to the payloads, and transmitting data to the ground for real time assessment.

The fleet of available aircraft spans several orders of magnitude in terms of available payload mass, provides measurements from the surface to 70,000ft, and has flight ranges that exceed 5000 nautical miles. Figures 1, 2, and 3 indicate the general characteristics of the NASA aircraft in altitude, endurance, range, and payload space. This includes both ASP supported and Center supported aircraft.

Figure 2 provides different ways of comparing and contrasting the various capabilities of the aircraft, as well as other science aircraft available at NASA Centers but not directly funded through the ASP.

Figure 1. NASA Earth Science Aircraft

Table 1. Airborne Science Aircraft and their characteristics

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	50,000	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	3,000
G-III	NASA-JSC	UAVSAR pod, Sonobuoy launch tube	7	2,610	45,000	460	3,000
G-III	NASA-LaRC	2 nadir ports	7	2,610	45,000	460	3,000
GV	NASA-JSC	2 nadir ports	12	8,000	51,000	500	5,500
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
WB-57	NASA-JSC	Nose cone, 12 ft of pallets for either 3 ft or 6 ft pallets, 2 Spearpods, 2 Superpods, 14 Wing Hatch Panels	6.5	8,800	>60,000	410	2,500
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	10	36,500	33,000	290	3,200
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	6	3,000	42,000	430	2,075
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 (2)	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

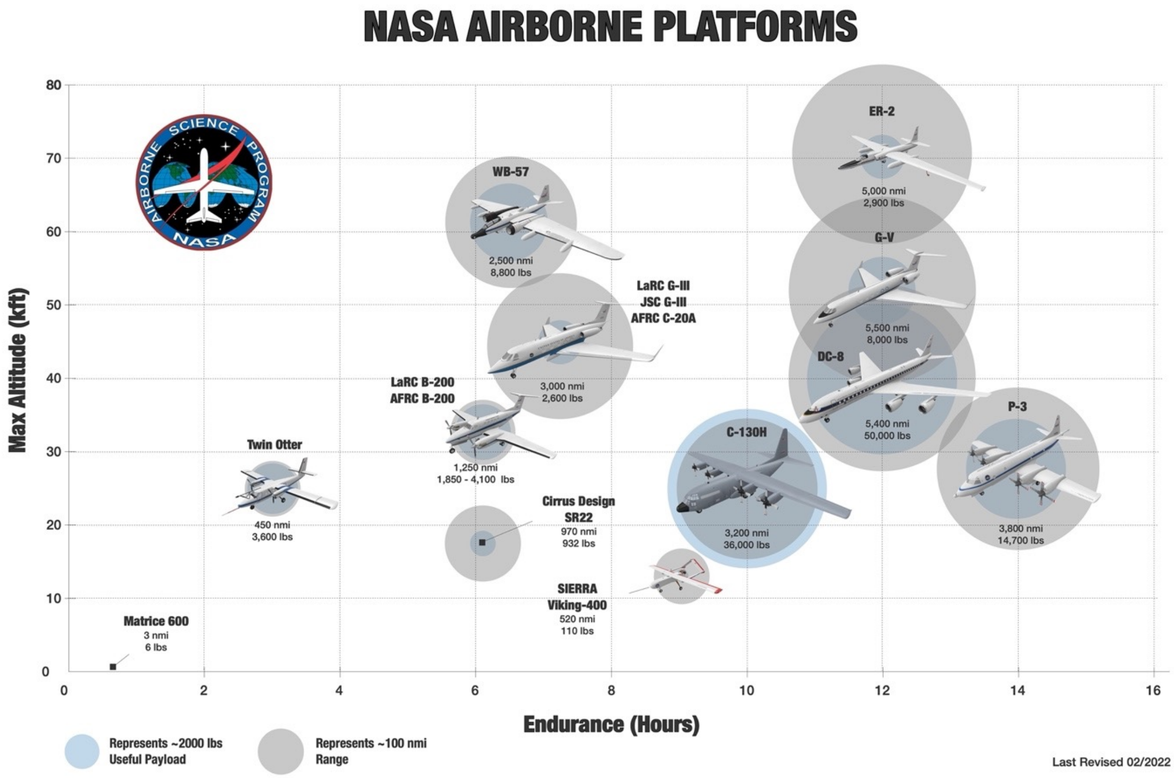

Figure 2. NASA Earth Science Aircraft capabilities in altitude and range and endurance

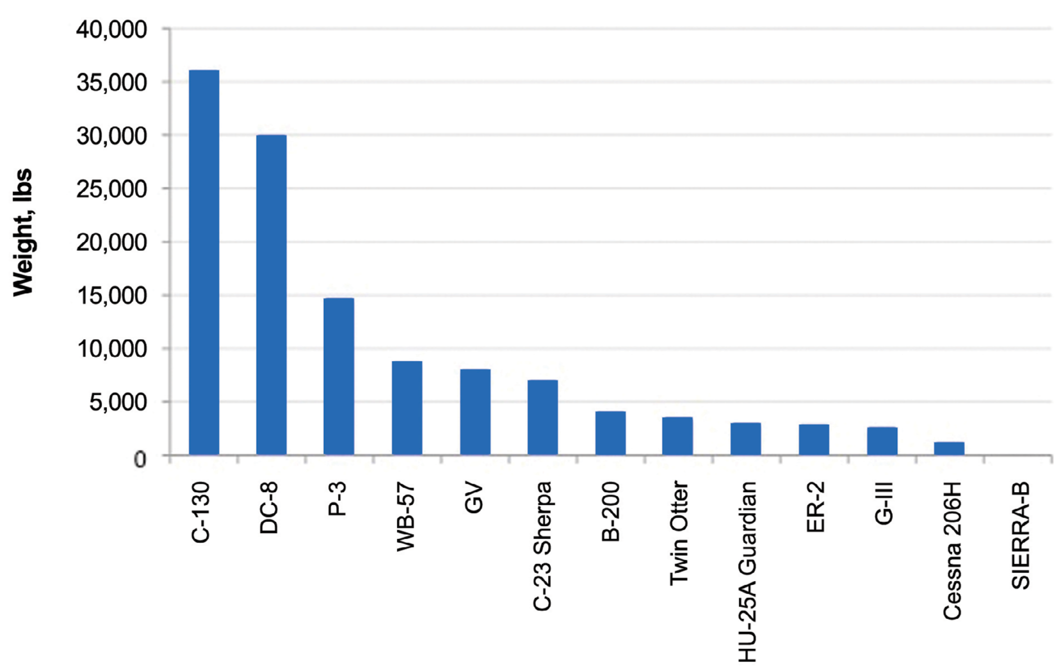

Figure 3. Useful Payload Weight of NASA aircraft

The NASA DC-8 Aircraft is a modified airliner that is used as a flying laboratory for carrying large arrays of science payloads in support of instrument development, satellite calibration, algorithm validation, as well as process studies critical for informing Earth system models. The DC-8 range, payload mass, volume and power, external ports and inlets, enable active, passive and in situ instruments to provide coincident measurements that cannot be achieved on any other aircraft in the world. For instrument and measurement development it continues to be important to have human attendants onboard to interpret data and make adjustments to instrumentation in order to achieve mission goals.

NASA's two ER-2 aircraft have been a foundational asset of the Airborne Science Program since the mid-1970's and continue to serve as a high-altitude medium lift platform for enabling simulating the orbital vantage point by being over 95-98% of the Earth's atmosphere. The aircraft each includes wing pods, a centerline pod, as well as nose and tail compartments. These aircraft are used to support atmospheric chemistry and dynamics, as testbed for new imagers and radar, as well as in support of R&A process studies.

The NASA G-III aircraft support the JPL UAVSAR Project, developed with ESTO and ASP funding, and are operated with funding from several R&A and ESSP Programs. The UAVSAR is flown in a centerline pod and the autopilot was specially modified to enable precise and accurate re-flights of previous data collection flight lines. Enabling repeat passes within a 10m tube enables interferometric products showing very slight changes in topography. Langley Research Center recently acquired a G-III and modified it to include 2 nadir viewing ports; has been called into service to fly the JPL PRISM instrument for the ESSP Earth Venture -3 mission S-MODE, among other missions.

The NASA GV aircraft is a shared venture between NASA Science and Human Spaceflight Directorates. For Science, it has been modified with 2 nadir ports and onboard electronics, which are used to support Earth Science remote sensing missions. It is available for science when not being used as a crew return vehicle for NASA astronauts returning from ISS. The GV has been of interest by NASA scientists and engineers for many years given the ability to carry both a LIDAR and remote sensing instruments with the speed, range, and altitude to make local to regional measurements.

The NASA P-3 is the other flying laboratory enabling multiple payloads with human attendants. While the range and endurance doesn't match the DC-8, the P-3 provides a low and slow alternative for in situ measurements and high-resolution remote sensing surveys using imager, LIDAR and RADAR (see, for example, Operation Ice Bridge and past Cryospheric Science missions). The P-3 also has the flexibility to operate out of remote locations, including Antarctica. With multiple nadir and zenith ports, the P-3 supports radiation and instrument development projects, and has the capability to deploy dropsondes, which is needed by the tropospheric chemistry and weather science community.

2.2 Aircraft payload accommodations and satellite communications

For aircraft to serve as platforms for instrument development and Earth observations, various modifications are needed, including nadir and zenith viewing ports, gas sampling inlets, internal and external mounting locations for instrument hardware, onboard computing, and telemetry, to name a few. The information provided previously in Table 1 summarizes the current payload accommodations available on NASA aircraft. Table 2 highlights those modifications and provides representative examples of the science enabled by them. In addition to payload accommodations, each aircraft provides some level of satellite communications (SatCom) for transmission of aircraft and science data. Information about the state variables measurements provided on selected aircraft is found in Table 3.

Table 2. Aircraft payload accommodations, state variables and science applications

Aircraft	Payload accommodations and SatCom provisions	Science measurement or observation (examples)	Typical flight hrs / yr*
DC-8	4 nadir ports, 1 Zenith port, 14 additional view ports; Iridium and INMARSAT SatCom; Static Air Pressure, Total Air Temperature, Dew Point	Atmospheric Gas sampling, meteorological measurements, weather radar etc. Numerous simultaneous measurements	400
ER-2	Q-bay (2 nadir ports), nose (1 nadir port), wing pods (4 nadir, 3 zenith ports) centerline pod (1 nadir port); Iridium and INMARSAT SatCom	Cloud physics lidar, etc. Ideal for top of atmosphere / near space remote sensing (radiation, clouds) and instrument test	300
Gulfstream III (C-20A), Armstrong	UAVSAR pod: SAR instruments L-band, Ka-band, P-band	Vegetation, land and ice topography; soil moisture; Capable of interferometric SAR	250
G-III (JSC)	UAVSAR pod; dropsonde launch tube	SAR measurements; dropsonde measurements	250
G-III (LaRC)	2 nadir ports	Hyperspectral imagery	N/A
Gulfstream V	2 nadir ports; Iridium and INMARSAT SatCom	Passive and active imaging systems: ocean, ice, vegetation mapping	N/A
P-3	1 large and 3 small zenith ports, 3 fuselage nadir ports, 2 bomb bay nadir ports, 4 P-3 aircraft window ports, 3 DC-8 aircraft window ports, nose radome, aft tailcone, 10 wing mounting ports, dropsonde capable; Iridium and INMARSAT SatCom; Static Air Pressure, Total Air Temperature, Dew Point	Simultaneous sampling and remote sensing for clouds, weather, snow thickness, ice, and more	350
B-200	2 nadir ports, aft pressure dome with dropsonde tube, cargo door	Remote sensing for clouds, lidar, ocean measurements	200
Hu-25 Guardian/Falcon	1 nadir port, wing hard points, multiple crown probes	Clouds, weather, aerosols and particulates, remote sensing	50
WB-57	Nose cone, 12 ft of pallets, 2 superpods, 2 spearpods	Atmospheric chemistry and composition, in situ sampling	70

Over the past decade the Program has implemented standardized onboard data networks and standardized physical interfaces that allow various payloads to operate on more than one aircraft. These networks have enabled onboard instruments to obtain aircraft data in addition to enabling real time payload data to be sent to the ground or other aircraft during multi-aircraft campaigns. This enables adaption to changing conditions and optimizes data collection.

Table 3. State variables available on selected NASA aircraft

N817NA - DC8						
Variable	**Instrument**	**Precision**	**Accuracy (+/-)**	**Units**	**Variables derived from primary measurement**	**Source**
Static Air Pressure	Aircraft Data Computer	0.03	0.85 to 2.85	hPa	Static Air Temp, e, Relative Humidity	derived from platofrm ADC. RVSM 1999
Total Air Tempeature	Rosemount TAT probe	0.01	0.3	deg C	Static Air Temp	Dependent on probe type and restoration factor application
Dew Point	Edgetech Vigilant	0.1	0.2	deg C	e, mixing ratio, relative humidity	function of aircraft maneuvers and instrument cooling rate
Dew Point	Buck 1011 -C	0.1	0.1	deg C	e, mixing ratio, relative humidity	function of aircraft maneuvers and instrument cooling rate
N426NA - P3						
Variable	**Instrument**	**Precision**	**Accuracy (+/-)**	**Units**	**Variables derived from primary measurement**	**Source**
Static Air Pressure	Aircraft Data Computer	0.5	2.5 to 5.0	hPa	Static Air Temp, e, Relative Humidity	derived from platform ADC, function of aircraft maneuvers
Total Air Tempeature	Rosemount TAT probe	0.01	0.3	deg C	Static Air Temp	Dependent on probe type and restoration factor application
Dew Point	Edgetech Vigilant	0.1	0.2	deg C	e, mixing ratio, relative humidity	function of aircraft maneuvers and instrument cooling rate

2.3 Historical ASP fleet utilization

Figure 4 shows the total ASP-recorded flight hours since 2011. Figure 5 shows ESD flight hours for major NASA aircraft since 2013, where "B-200" includes NASA aircraft only – at LaRC and AFRC. Figure 6 shows the flight hours for NASA aircraft, non-NASA aircraft and the total.

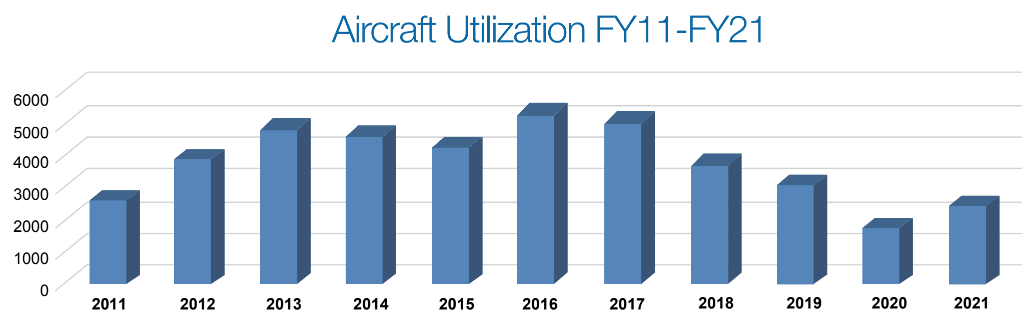

Figure 4. Airborne Science aircraft utilization

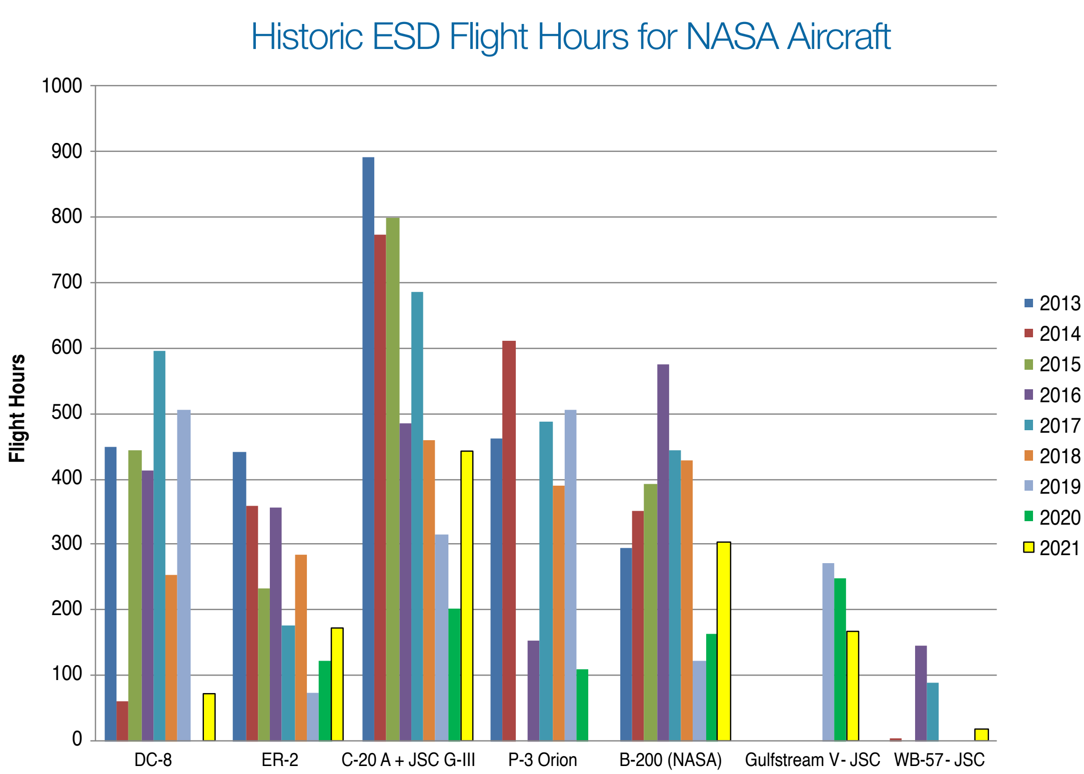

Figure 5. Historical ESD Flight Hours 2013-2021– NASA Aircraft

The usage across the fleet has been largely consistent over the past decade (until COVID), when taking into account maintenance down periods for the ER-2, P-3, and DC-8, and changes in platform availability because of funding (ER-2 and Sherpa). One pronounced recent trend is a significant increase in flight requests and flight hours for the B-200/Twin Otter class of aircraft, primarily because of lower costs to fly.

The Sherpa is currently in maintenance at WFF, having been modified to serve the ESSP EVS-1 CARVE project, as well as the NASA GSFC CARAFE project. There was significant interest at several NASA Centers to bring the aircraft back into service given its significant payload capability.

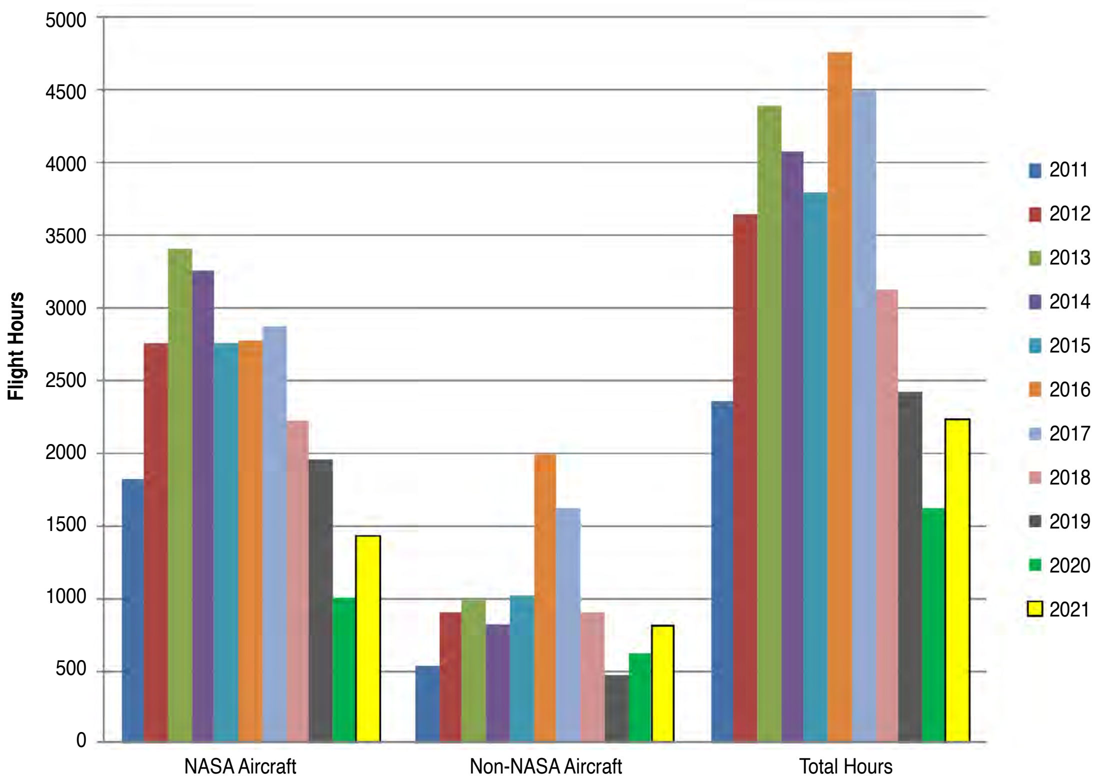

Figure 6. **ESD Flight Hours 2011-2021 – NASA and Non-NASA Aircraft**

2.4 Generalized aircraft capability needs based on previous use, previous requests and workshop input

It is possible to speculate on future needs for aircraft based on historical use and previous requests. In addition, various workshops over the years have collected input from scientists as to what capabilities they would like for their research. Some answers have pointed to futuristic performance and some are more tuned to available resources.

One way to quantify the flight regimes that are needed for NASA airborne science is to analyze proposals from NASA solicitations that focused on airborne data collection or instrument development. Figure 7 presents data from selected or proposed missions based on proposals and flight requests. To the extent possible, this data is based on peer reviewed proposals that rated Good to Excellent based on information from Program managers. This scatterplot of duration and altitude specifications does well to demonstrate why such a wide variety of aircraft are needed in order to serve Earth scientists and engineers as they develop, test, and use airborne payloads to collect observations.

The most recent round of Earth Venture Suborbital (EVS-3) proposals especially provide insight into the needs of the Earth Science community. There are several conclusions one can draw from this data including sustained need for observations at nearly every altitude as well as sustained need for high altitude, long endurance platforms. It is also notable that instrument development proposals typically fall into two categories: low altitude, short duration testing for early demonstration and high-altitude testing for instruments destined for the space environment and viewing conditions.

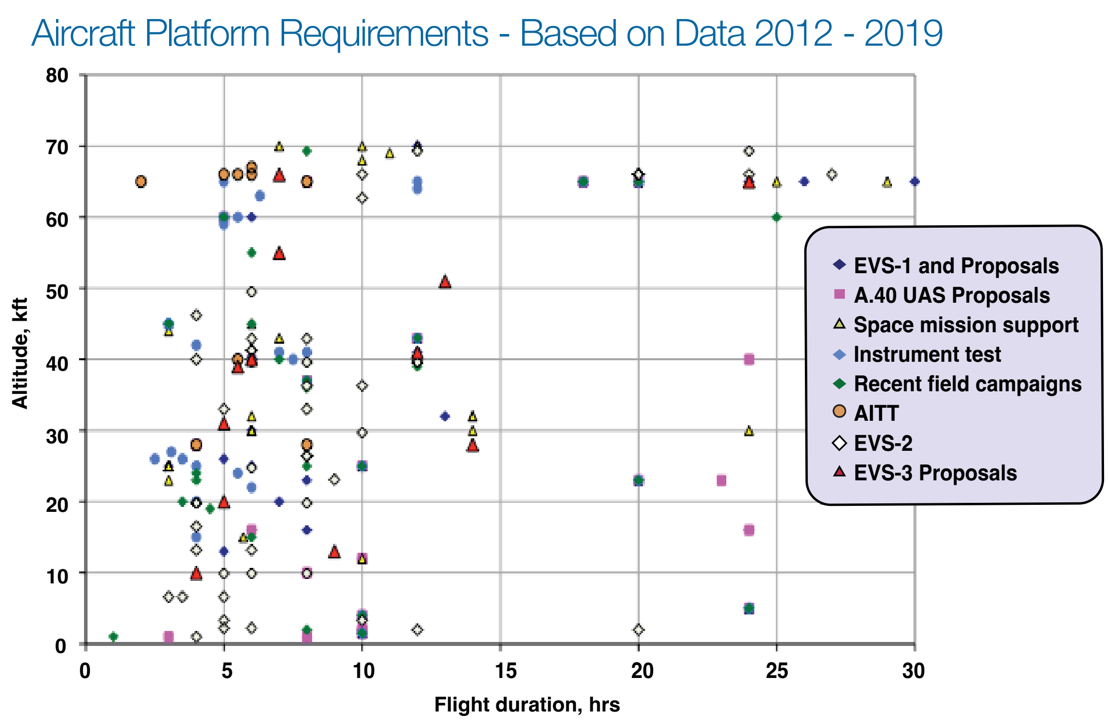

Figure 7. Aircraft performance specifications based on proposal requests

Past missions usefully illustrate how different science disciplines make use of various aircraft and their unique modifications. Table 4 presents selected recent large missions that carried multiple instruments across a variety of science disciplines in order to demonstrate how various aircraft with different capabilities are used singly or together to meet different science objectives. This clearly demonstrates a sustained need for larger aircraft to enable carrying many science payloads together in order to achieve mission goals. Figure 8 shows the comparison of instrument weights for various recent missions, suggesting which aircraft are most suitable for which areas of science. Clearly the Atmospheric Chemistry and Composition science campaigns have requirements for carrying many large payloads in order to achieve their science.

Table 4. Large missions and the instruments they carry

Mission	Number of instruments (max)	Aircraft	Accommodations
Operation IceBridge	14	DC-8, P-3, C-130, G-V	Volume, nadir ports, launch tube
SEAC4RS	38	DC-8	Volume, multiple ports and probes
ATom	24	DC-8	Volume, multiple ports and probes
KORUS-AQ	24	DC-8	Volume, multiple ports and probes
FIREX-AQ	32	DC-8	Volume, multiple ports and probes
FIREX-AQ	7	ER-2	Altitude, multiple ports
CAMP2EX	13	P-3	Multiple ports, volume for radar
ORACLES	16	P-3	Multiple ports, volume for radar
DISCOVER-AQ	9	P-3	Volume, multiple ports
CPEX-AW	4	DC-8	Ports, launch tube, door for Lidar
POSIDON	9	WB-57	Volume, imaging ports, sampling ports
ACCLIP	15	WB-57	Altitude, Volume, imaging ports, sampling ports
CARVE	3	SHERPA	Volume, low and slow flight
NAAMES	6	C-130	Volume, zenith port
MACPEX	24	WB-57	Altitude, volume, multiple ports
IMPACTS	11	P-3	Heavy lift
	6	ER-2	Altitude, imaging and sampling ports
ARISE	5	C-130	Volume, zenith port
ACT-America	6	C-130	Volume, zenith port
ACT-America	4	UC-12	Imaging and sampling ports

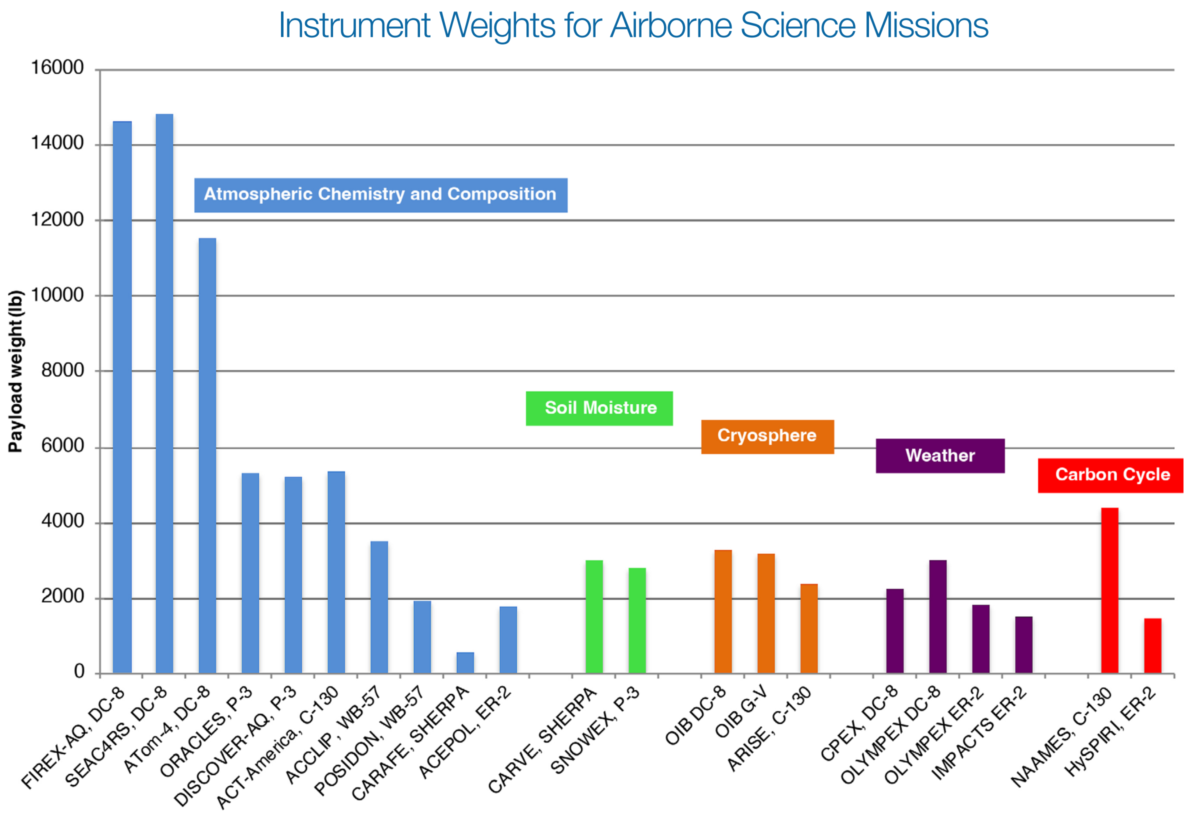

Figure 8. Payload Instrument weights for selected recent missions

3. SCIENCE NEEDS FOR AIRCRAFT IN SUPPORT OF NASA EARTH SCIENCE OBSERVATIONS

This section describes science needs and, in some cases, may list true Program or Project requirements, but this document does NOT attempt to provide an engineering document to formally describe the NASA SMD ESD Airborne Science Program requirements. The intent is to summarize science needs as opposed to formal requirements that flow down from observing system requirements to airborne instruments, to aircraft capability requirements. NASA Program and Project requirements are driven by the NASA Program Planning and Budget Execution process in coordination with OMB. Material provided here supports that yearly process and assists by validating priorities among the many and varied stakeholders that this Program supports.

From the 2017 Decadal Survey[1]:

> *"Investments in observations from space are considerably enhanced by complementary, and generally far less costly, observations from in situ, airborne, and other vantage points. These observations are used for a variety of purposes: (1) complementing space-based measurements within model data assimilation, (2) calibration/validation of space-based measurements, (3) algorithm development/ refinement, and (4) providing fine-scale complements to more coarse space-based measurements for process studies, and more. Sensors on commercial aircraft already provide important contributions to the global observing system, with significant opportunities for further contributions. New technologies and methodologies promise substantial advances in these areas. Drones can make airborne measurements far cheaper and more readily available than some ground-based observations or those from conventional aircraft. Their use for scientific campaigns is growing rapidly."*

The following section of the report presents airborne needs for current space missions and field campaigns, followed by needs for future campaigns. Embedded in this section are the inputs resulting from discussions and surveys of NASA Centers.

3.1 Science needs related to current Earth Science missions from Space: Extended and Operational Portfolio missions

Figures 9 and 10 show NASA's Earth Science fleet of space missions, both satellites and instruments on the International Space Station. These include operating missions in extended operations phase, primary operations, implementation phase and pre-formulation phase. Most of these missions either have or will have airborne science support in the following ways, as described above and here:

- Post-launch data product and algorithm validation through cal/val activities
- Pre-launch algorithm development through relevant data collection
- Pre-launch instrument development and test

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

- Process / field studies that provide supporting science understanding
- Field tests that parallel the mission measurements with improved temporal or spatial specificity or resolution
- Observation technique development
- Develop an early adopters community (i.e. user ready to ingest/use data once the spacecraft becomes operational)

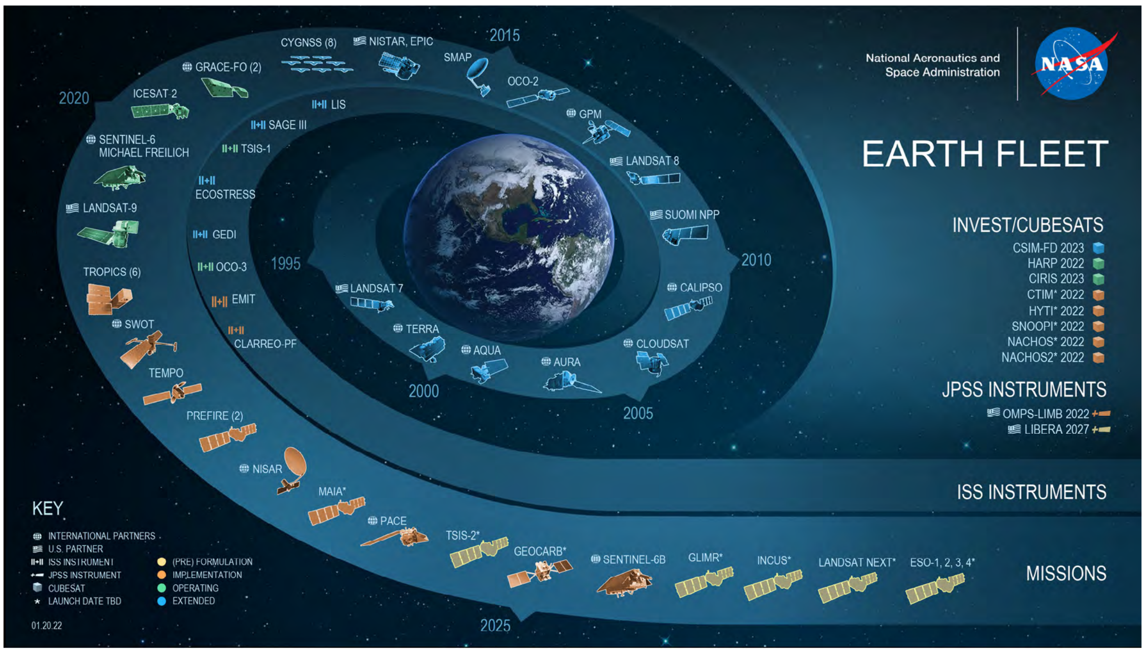

Figure 9. NASA Earth Science space missions

Table 5 lists airborne support for the operating missions in extended and primary operation and indicates how ASP activities and platforms have been supporting these missions. The Program and HQ Program Scientists generally assume that similar aircraft capabilities will continue to be needed to provide validation data or related data for these missions. Airborne support for these missions occurs occasionally, not routinely. For example, in 2019 and 2021 the GV flew LVIS instrument to collect data product validation data for the recently launched GEDI mission.

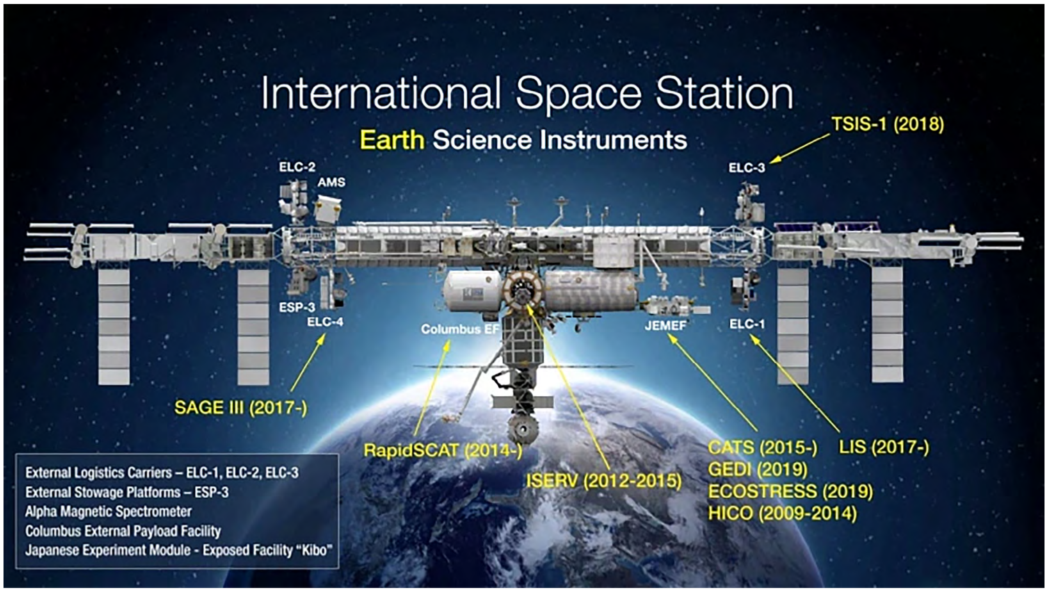

Figure 10. Earth Science supported on the ISS

Table 5. Airborne Science support for NASA Earth Science Space Missions in Extended and Primary Operations (active missions). The supporting aircraft have the capability to carry the supporting instrument and perform the supporting activities

Mission	POC	Satellite Instruments	Supporting/related aircraft instruments	Airborne Science supporting activities	Supporting Aircraft
Aura	Jucks	MLS, HIRDLS, OMI, TES	ASMLS; Discover-AQ, KORUS-AQ packages	Data product validation	ER-2, P-3, DC-8
Calipso Cloudsat	Considine	CALIOP, IIR, WFC, CPR	HSRL, HSRL-2, AMPR, CRS, CPL	Cal/val	B-200, UC-12, ER-2
Aqua / Terra	Jucks	MODIS, AMSR-E, ASTER, MISR, CERES	MAS, eMAS, MASTER, AVIRIS	Data product validation	ER-2, Twin Otter
GPM / Aeolus	McCarty	Microwave Imager, Doppler Precipitation Radar (DPR)	MPR, COSMIR, HIWRAP	Instrument calibration & Data product validation	ER-2, DC-8, Citation
Suomi-NPP	Lorenzoni	VIIRS, CrIS, ATMS, OMPS	NAST, S-HIS, eMAS, MASTER, AVIRIS	Instrument calibration & Data Product validation	P-3, Twin Otter, ER-2
SMAP	Entin	L-band radar, L-band radiometer	UAVSAR, PALS, SLAP	Instrument calibration & Data Product validation	G-III, P-3, B-200, DC-3
ICESat-2	Markus	5-beam laser mapper	LVIS, Ice Bridge suite	Instrument calibration & Data Product validation	G-V, P-3, DC-8
Landsat - 9	Margolis	Multi-spectral imager	AVIRIS-NG, AVIRIS classic, MASTER	Data Product validation	ER-2, B-200
ECOSTRESS (ISS)	Turner	High resolution multispectral thermal imaging spectrometer	HYTES, AVIRIS-ng	Data Product validation	B-200, ER-2, G-V
GEDI (ISS)	Margolis	Lidar	LVIS, G-LiHT	Data product validation	B-200, G-V, various

3.2 Science needs related to Earth Science focus areas / field campaigns

Most of the science needs outlined in this section of the report are cited from the Flight Request system summary of current missions and illustrated in the ASP 5-year plan (Appendix A). Some input from the NASA Center Survey activity is also included here. Current EVS-3 missions are described in the following section. Upcoming field campaigns and process studies are summarized in Table 6 below. For most of these missions the aircraft have been specified or indicated.

Table 6. Upcoming Field Campaigns

Mission/ POC	Objective	Location	Date	Aircraft Instrumentation	Aircraft
ACCLIP / Maring, Jucks	Air pollution monitoring	Korea	2022	Similar to Korus-AQ package	WB-57
ABoVE / Margolis	Boreal land composition changes	Alaska, Canada	2022-23	UAVSAR, AVIRIS-ng, LVIS	G-III, B-200, G-V
SnowEx / Entin	Snow-water equivalent under various conditions	Colorado, Alaska	2022	UAVSAR	G-III
CPEX-CV / McCarty/Maring	Microphysics and deep convection	Cape Verde, Africa	2022	DAWN, APR-3, HALO, dropsondes	DC-8
BioScape / Turner	Vegetation biodiversity	South Africa	2024	HyTES, AVIRIS-ng, PRISM, LVIS	G-III (L), GV
Terrestrial ecology and earth surface topography / Bawden, Margolis	L-band SAR for solid earth and vegetation measurements	North America	Ongoing	UAVSAR	G-III
STAQS / Lefer	Air quality measurements	CA, New York	2023	GCAS, HSRL-2 AVIRIS-NG, HALO	GV, G-III
ARCSIX / Maring	Radiation and chemistry	Arctic	2024	Spectrometer, radiometer, aerosol counter, LVIS	GV, P-3
Asia-AQ / Lefer	Air quality measurements	4 Sites in SE Asia	2024	Similar to Korus-AQ package for air pollution	GV, DC-8
Africa-AQ / Lefer	Air pollution monitoring	Africa	TBD	Similar to Asia-AQ package	GV, DC-8
BLUEFLUX / Hibbard	Carbon Monitoring	Florida	2022,2023, 2024	Picarro	B-200
AEROMMA / Lefer	Air Quality	CA, NYC, OH	2023	Payload similar to FIREX-AQ	DC-8
PACE PAX / Lorenzoni	PACE cal/val	California coast	Fall 2024	eMAS; PRISM, AirHARP, SPEX Airborne, HSRL-2, RSP	ER-2
Arctic COLORS / Lorenzoni	Coastal impacts of climate change	Alaska	TBD	Imagery, aerosols (like SABOR); PRISM	Low-to-mid altitude with moderate payload; UAS measurements

3.3 Earth Venture - Suborbital

The Earth Venture Suborbital (EVS) missions have utilized, and will continue to utilize hundreds of flight hours on the ASP aircraft each year. Beginning with EVS-1 in 2012 and continuing through EVS-2 and now in EVS-3, the Program plays a significant role in this ongoing Earth System Science Pathfinder (ESSP) initiative.

Because the Earth Venture Suborbital series of mission is competitively selected, it is somewhat challenging to forecast aircraft usage by this major stakeholder Program. In general, the Program assumes that future EVS projects / proposals will likely request Program assets, but this is not required. We learn about the community needs for aircraft not only through the selected projects, but also from observing which aircraft have been proposed, even if not selected. Figure 11 illustrates both the broad range of aircraft proposed, but also the significant perceived usefulness of the major aircraft in the fleet: P-3, DC-8 and ER-2. Several non-NASA aircraft, Twin Otters and commercial King Airs, have also been requested to supplement the NASA fleet in those categories of aircraft. G-III/UAVSAR was selected for the EVS-3 mission Delta-X.

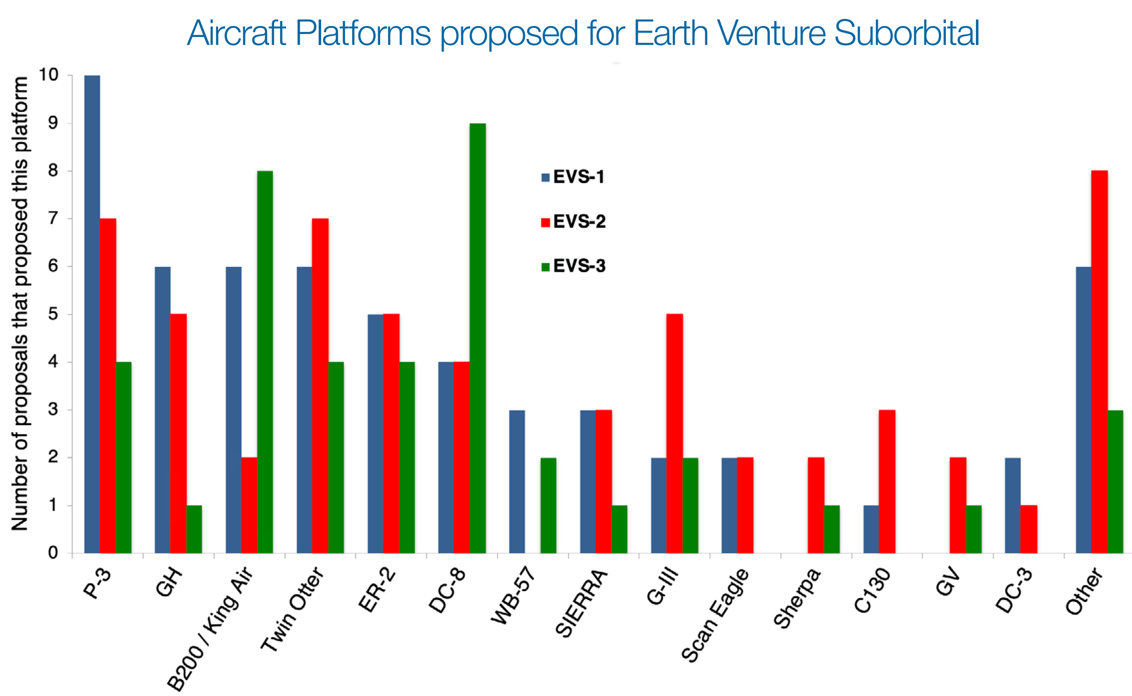

Figure 11. **Aircraft requested for Earth Venture Suborbital missions**

EVS-2 missions concluded in 2021, as shown in Table 7. As seen in the table, these missions employed not only NASA ASP-supported assets, but other aircraft as well. The aircraft are selected for their ability to perform the science operations, but also to maintain a balance of available aircraft within the fleet.

Table 7. Summary of EVS-2 flights, supporting aircraft, and status

Mission	Year	Aircraft
CORAL	Concluded in FY18	G-IV
ATom	Concluded in FY18	DC-8
ORACLES	Concluded in FY19	P-3. ER-2
NAAMES	Concluded in FY18	C-130
ACT-America	Concluded in FY19	C-130, B-200
Oceans Melting Greenland	Concluded in FY21	G-III, Basler DC-3

The five Earth Venture Suborbital-3 missions, deployment locations, nominal schedules and aircraft are listed in Table 8. Due to the operation stoppage during COVID-19, some schedules may slip later in time. Also, the solicitation for EVS-4 may be delayed from the approximate 2023 release.

Table 8. EVS-3 Aircraft Utilization

Mission	Location	Dates	Aircraft	Aircraft
IMPACTS	U.S. East Coast	2020-2023	P-3, ER-2	Weather instruments
DCOTSS	Based from Salinas, Kansas	2021-2022	ER-2	Trace gases
S-MODE	Pacific Ocean off Monterey, California	2021-2023	G-III, B-200	Wind radar, sea surface temp, height
ACTIVATE	Western North Atlantic	2020-2022	HU-25, B-200	Aerosol instruments
Delta-X	Mississippi River Delta	2021	G-III, B-200 (2)	AVIRIS-ng, AirSWOT, UAVSAR

The Aerosol Cloud Meteorology Interactions over the Western Atlantic (ACTIVATE) mission investigates how aerosol particles change cloud properties in ways that affect Earth's climate system with special attention paid to the marine boundary layer clouds over the western North Atlantic Ocean. The Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) investigates how strong summertime convective storms over North America can change the chemistry of the stratosphere. The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) will study the formation of snow bands during East Coast winter storms. The Delta-X project will investigate the natural processes that maintain and build land in a major river delta threatened by rising seas. Finally, the Submesoscale Ocean Dynamics and Vertical Transport (S-MODE) investigation will explore the potentially large influence that small- scale ocean eddies have on the exchange of heat between the ocean and atmosphere.

Taken together these missions do well to describe the varied requirements that this program must meet from low altitude to high altitude remote sensing with imagery and radar, to vertical profiles from the surface to the stratosphere for gas and physical measurements in the atmosphere. Each of these missions was made possible through the maturation of the primary science instruments on NASA aircraft and the validation of the parameters that they collect.

Some other implications from the EVS-3 proposals suggest the following:

- There is continued scientific interest in polar regions (Arctic, Greenland, Alaska, Antarctic)
- A strong interest continues in weather and atmospheric composition and chemistry.
- More than half of the mission concepts proposed call for multiple aircraft, some in stacked formation.

3.4 Science needs related to ongoing instrument development

The Airborne Science Program supports technology development, particularly flight-testing of new instruments and observational techniques, many of which are ultimately destined for space. Instrument test flights can be scheduled by investigators with support or funding from a variety of sponsors or agencies. Many are sponsored by NASA's Earth Science Technology Office (ESTO) [http://esto.nasa.gov]. While ESTO solicits, awards, and manages the technology development projects, investigators work with platform operators to schedule their instruments for integration and test. Near-term flight test plans are shown in Table 9. Some will be ESTO-supported and others are proposed or expect to be supported from other programs. Note that many instruments would like to fly on the ER-2.

Table 9. Instrument flight requests

Instrument	PI	Aircraft	Year
CAMLS / A-SMLS	Livesey	ER-2	2022
SHOW	Bourassa	ER-2	2022
AirMSPI-2	Diner	ER-2	2022
eMAS / PICARD validation	Jacobson	ER-2	2022
SoOpSAR	Yueh	TOIL	2022
GNSS RO/SF	JPL	B-200	2022
Air-MASTER	Sanchez- Barbetty	DC-8	2022
3D Cloud Scanner	Martins	ER-2	2022
Radar sounder	Cahill	P-3	2022
CHAPS Demonstrator	Schwartz	B-200	2022/23
Aerosol Wind Profiler	Marketon	G-III (LaRC)	2022
CoSSIR	Adams	ER-2	2022
KU Multi-channel snow radar	Paden	P-3	2022

Aircraft specifications for instrument development projects are determined by the observational requirements of the instrument and are usually dictated by a given flight altitude (e.g., ER-2 for high altitude) or the need to have engineers/scientists on-board. When possible, it is advantageous to fly multiple systems collocated on the same flight to provide complementary datasets or conduct inter-comparisons, in addition to reducing costs. Recent solicitations to support Sustainable Land Imaging and the PBL and STV Technology Incubator programs have also awarded several projects that will require airborne flight testing within the next few years. The schedules are not yet available. Several specifically call for the use of UAS, either HALE or small UAS.

The ESTO solicitation schedule for the Instrument Incubator Program and other activities can be found on the ESTO website [http://esto.nasa.gov]. A snapshot is shown here in Figure 12. Note the new opportunity for technology development in support of *Wildfire Science and Disaster Mitigation* (FireTech), with solicitations expected in 2023 and 2025.

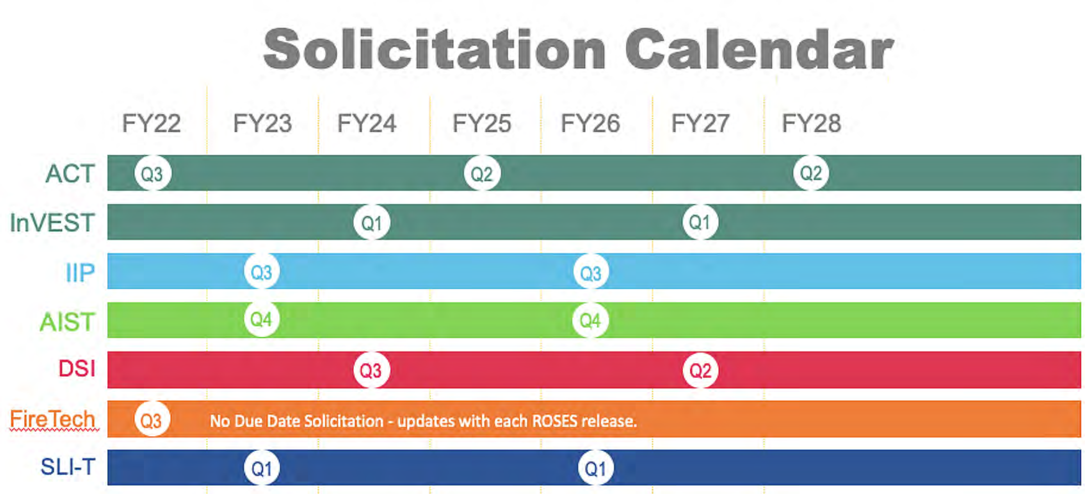

Figure 12. ESTO Solicitation Schedule

3.5 Science needs related to Future Earth Science missions from Space: Planned Launches

Out year planning for the Program is primarily based on planning for future space missions and how the Program capabilities may need to adjust to support those requirements. Figure 13 is a nominal ESD timeline of missions. Figure 13 shows upcoming missions relative to other airborne activities, including Earth Venture Suborbital, which often consumes many flight hours. Also shown are antici-pated technology development activities in advance of missions further in the future.

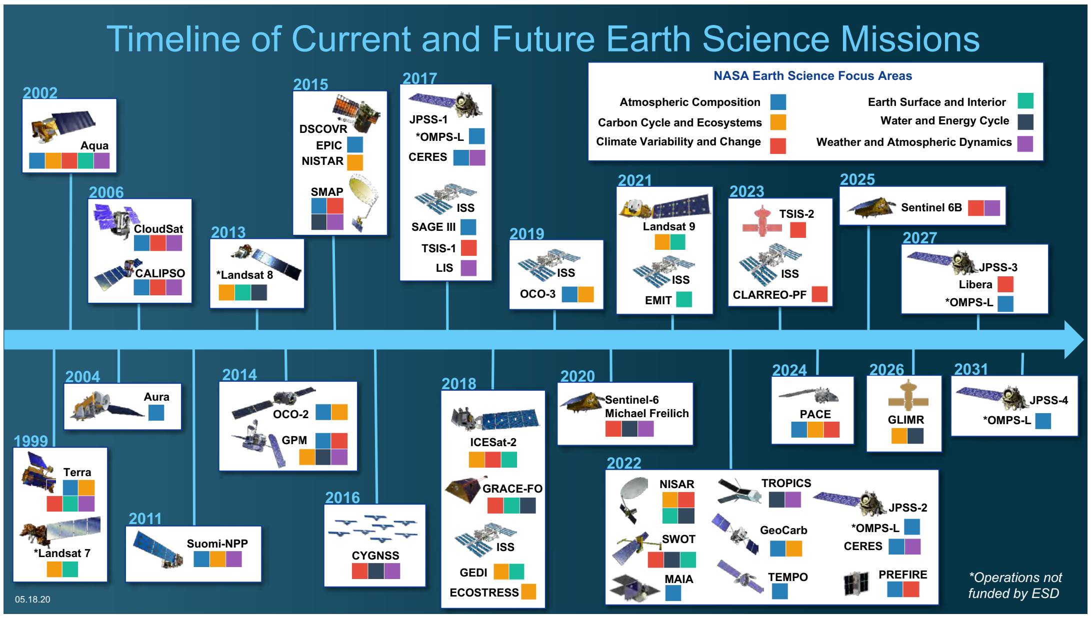

Figure 13. Nominal Timeline of Current and Future Earth Science Missions

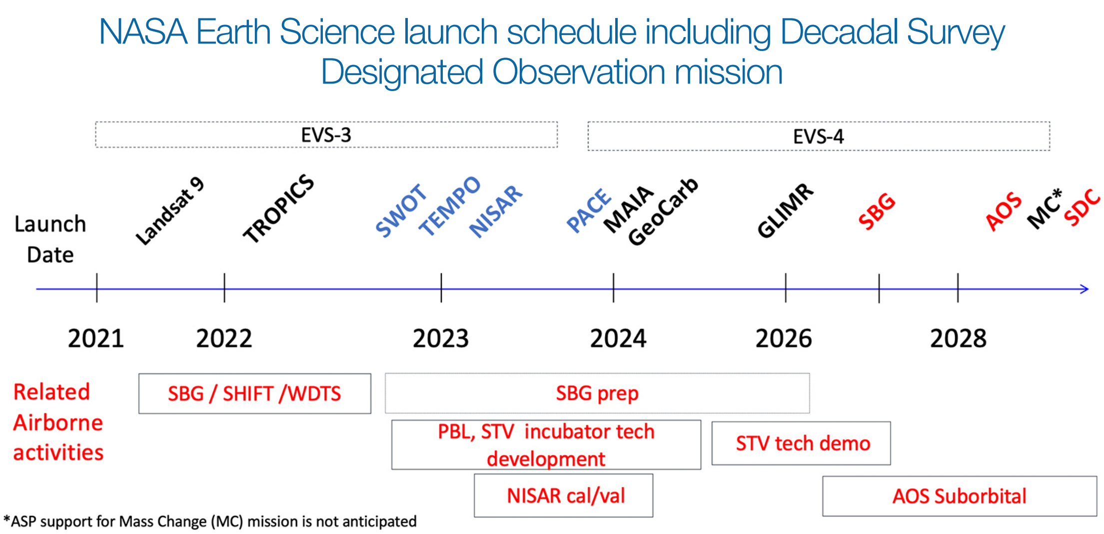

Figure 14. Approximate timeline of foreseeable future ESD missions and ASP support activities

Included in the timeline are not only planned satellite and ISS missions, but also several activities based on the 2017 Decadal Survey report. These are discussed further below. The approximate time frames of Earth-Venture Suborbital activities EVS-3 and EVS-4 are also shown. The EVS activities have employed a significant fraction of the airborne fleet in the past and are likely to do so again in the future, so it is useful to consider the time frame of those activities on the availability of aircraft.

Table 10 presents a summary of upcoming ESD satellite and instrument launches and indicates the aircraft likely to support related field measurements. Figure 15 shows the potential related airborne activity over the upcoming 5 years.

Table 10. Summary of Missions in Implementation and Pre-formulation Phases (Future)

Mission / (launch date) / POC	POC	Spacecraft Instruments	Supporting/ related aircraft instruments	Airborne Science supporting activities	Representative Supporting Aircraft
NISAR (2024)	Bawden	L-band SAR, S-band SAR	UAVSAR, ASAR	Algorithm development, Instrument calibration & Data product validation	G-III
PACE (2024)	Lorenzoni	Ocean Color Instrument (OCI); Polarimeter	OCI simulator, PRISM, HSRL	Algorithm development, Instrument calibration & Data Product validation	B-200, ER-2, G-III (PRISM)
SWOT (2022)	Shiffer	Ka-band radar, C-band radar	AirSWOT, MASS, DopplerScatt	Algorithm development, Instrument calibration & Data Product validation	G-V, B-200
TEMPO (2023)	Lefer	Geostationary ultraviolet visible spectrometer	GEO-TASO, GCAS	Instrument calibration & Data Product validation	UC-12, B-200
MAIA (2024)	ESTO, Maring	Air pollution particulate using twin camera radiometer and polarimeter	Air quality package	Instrument calibration & Data Product validation	ER-2, DC-8
TROPICS (2022)	ESTO	Microwave radiometers (3)	AMPR, HAMSR	Data product validation	DC-8, ER-2
GEOCARB (2024)	Jucks	Spectrometer	Picarro, CO_2/CH_4	Data product validation	Alphajet, profiling UAS
GLIMR (2026)	ESTO/ Entin, Lorenzoni	Hyperspectral imager	AVIRIS-ng, HyTES, PRISM	Instrument calibration & Data Product validation	G-III, G-V, B-200

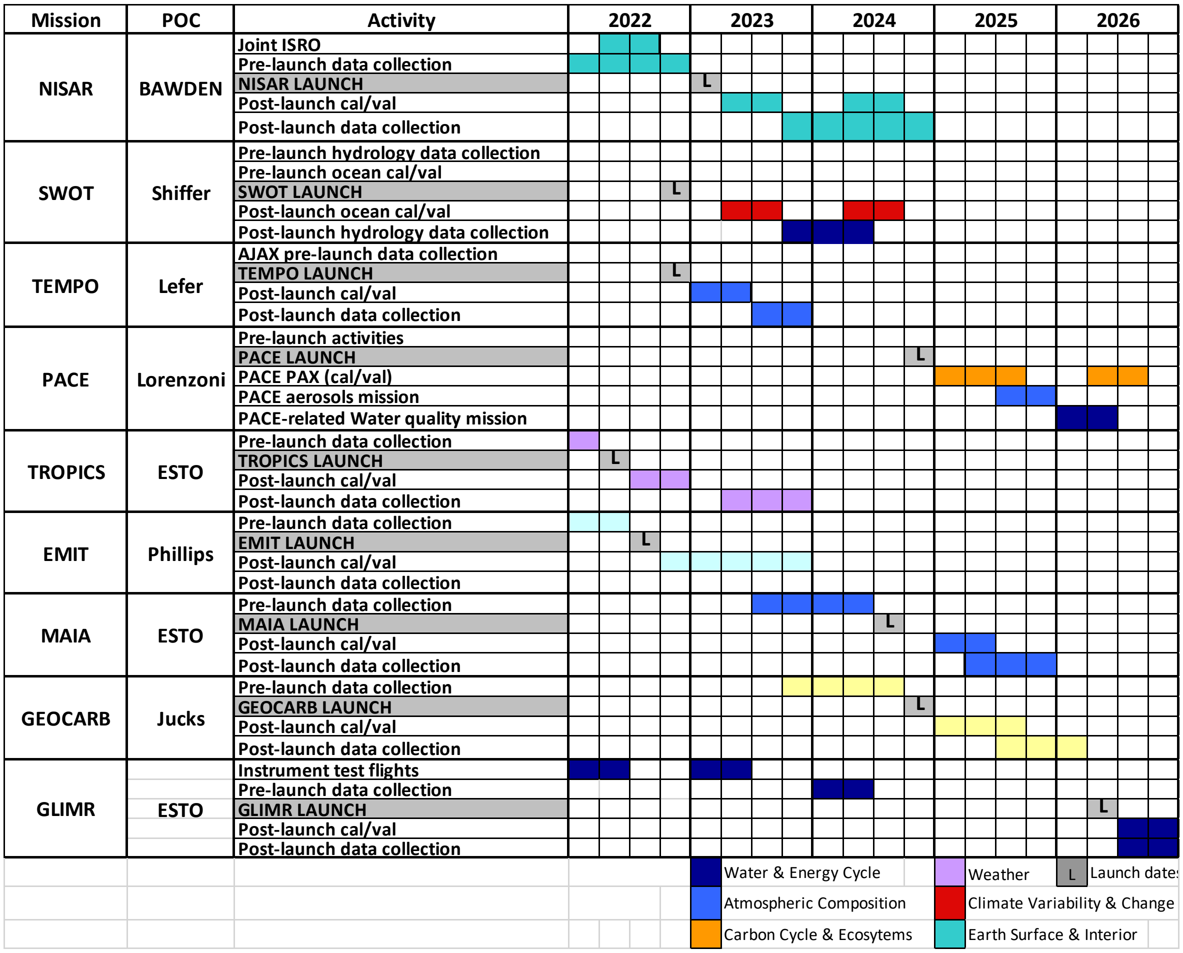

Figure 15. Projected schedule of airborne support for upcoming Earth Science satellite missions

3.6 Science needs related to Earth Science missions from Space: 2017 Decadal Survey

The latest Earth Science Decadal Survey from the National Research Council[2] has provided direction for NASA's Earth Science efforts on the basis of "Observing System Priorities." As shown in Figure 16, these are grouped into Designated Observables, Explorer, and Incubation categories. Each of these categories includes opportunities for airborne science. In fact, the report specifically states:

> *Optimal implementation of space-based observation depends on effectively integrating these measurements with measurements from suborbital missions and ground-based measurements and campaigns.*

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

Observing System Priorities

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar**		X	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar**		X	
Ocean Surface Winds & Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-	Radar scatterometer		X	
Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth & Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		X	
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation & forest degradation	Lidar**		X	
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height			X
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			X

** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables

Other ESAS 2017 Targeted Observables, not Allocated to a Flight Program Element	
Aquatic Biogeochemistry	**Radiance Intercalibration**
Magnetic Field Changes	**Sea Surface Salinity**

Figure 16. Observing system priorities outlined in the Decadal Survey

3.6.1 Designated Observables missions

The 2017 Decadal Survey did not describe missions, per se, as the 2007 report did, but rather presented the observations or measurements needed to answer science questions. The approach to providing those observations or measurements was left to NASA to develop. The major, most urgent needs are called out as "Designated Observables" or "DO"s. NASA has taken those five DOs and combined two together and study teams have prepared "architecture studies" to indentify alternative mission concepts for each one. They are now in various stages of pre-fomulation. The four potential future DO missions are listed below with the proposed measurement approach.

- Atmosphere Observation System (AOS). Previously called Aerosols-Clouds, Convection & Precipitation (ACCP) => Lidar, radar, polarization imaging radiometry
- Mass Change (MC) => Spacecraft ranging
- Surface Biology & Geology (SBG) => Hyperspectral visible, short-wave and thermal IR
- Surface Deformation & Change (SDC) => Interferometric SAR

With preformulation in process and the earliest potential launch date of 2026, the teams have already looked at possible airborne support needs, some in more depth than others. The AOS mission, in particular, already includes a suborbital element in its definition. Each team, as a minimum, has addressed a question of cal/val approaches. Table 11 lists the Designated Observables and some preliminary suggestions as to the airborne support needed. The Mass Change (MC) mission is not found in Table 11, as no airborne support for this activity is anticipated.

Table 11. Airborne Support to Designated Observables Missions

Mission	POC	Spacecraft measurement or Instruments	Supporting/ related aircraft instruments	Airborne Science supporting activities	Possible Aircraft
AOS	Maring	Lidar, radar, polarimeter, radiometer	Polarimeter, radiometer, lidar, radar	Algorithm development, Instrument calibration & Data product validation; **Suborbital component currently being defined.**	ER-2, DC-8
SBG	Turner	Hyperspectral visible, short-wave and thermal IR spectrometer (or) spectrometers	PRISM, HYTES, AVIRIS-ng, MASTER	Precursor data collection; Instrument calibration; Data Product validation	ER-2, G-V, G-III; commercial B-200
SDC	Bawden	Interferometric SAR	UAVSAR in multiple frequencies	Instrument calibration & Data Product validation	G-III, G-V

AOS

The Decadal Survey report suggests that for AOS, dedicated field campaigns that augment space-based observations will be needed to strengthen the quantification of the aerosol indirect forcing and thus the net anthropogenic forcing. "*Only a combination of platforms would resolve the roles of the naturally occurring and anthropogenic aerosols on clouds*."

On this basis, the AOS team has already begun the definition of a suborbital component. The related cal/val strategy is described as follows:

- Use approaches such as that used by GPM, CloudSat, CALIPSO
- NASA's airborne platform/instrument resources, with continuous evolution are expected to have a prominent role
- Coordinate with R&A future missions similar to CAMP2EX, SEAC4RS and OLYMPEX/RADEX, and upcoming missions, such as ARCSIX.

Based on this strategy, ASP can anticipate requests for multi-aircraft missions involving the ER-2 for radiation and cloud lidar and DC-8 for weather radar, for example.

SBG

The SBG mission is similar to the HyspIRI mission described in the 2007 Decadal Survey. Considerable preparation for that mission took place over the last years by way of the "HyspIRI prepatory" airborne series of flights over California and Hawaii. A large data set of different vegetation and topography types under different seasonal conditions has been developed and algorithm development for a space payload is underway. The significant data set will be part of the algorithm / data validation when SBG launches. NASA Earth Science has continued to fund data collection from these locations in a mission now called Western Diversity Time Series (WDTS). In addition, the SBG mission itself if funding in 2022 a multi-season data collection called the SBG High Frequency Time series (SHIFT). The current expectation is that SBG will be the first of the new Decadal Survey missions ready for launch, possibly by 2026.

The instruments that flew for HyspIRI prep have been MASTER, AVIRIS and HyTES, all on the ER-2. The current phase of WDTS uses the same aircraft and instruments. The use of AVIRIS-NG for SHIFT suggests significant future use of this instrument, which flies on a commercial B-200, not making use of the NASA fleet..

SDC

The SDC mission is similar to NISAR in that the primary measurement approach is via synthetic aperture radar (SAR). The SDC team has stated in their cal/val plan that they expect to use the **next generation** UAVSAR/AIRMOSS/GLISTIN with additional frequencies. Currently the instrument flies only in a pod on either the AFRC or JSC G-III aircraft. The capability may expand to other aircraft or configurations in the future as a result of the next generation SAR development work.

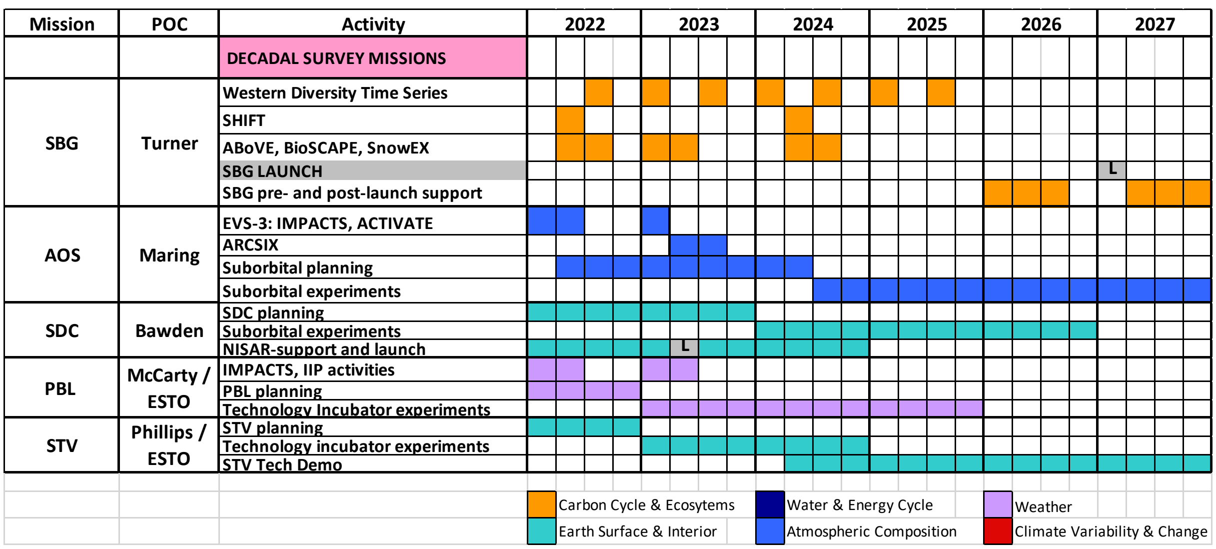


Figure 17. Projected ASP support for Decadal Survey activities

3.6.2 Support to Technology Incubation needs of Decadal Survey

The Decadal Survey Incubation program intends to accelerate the readiness of high-priority observables not yet feasible for cost-effective flight implementation. Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV) science goals call for exploring next-generation measurement approaches that could be ready for spaceborne implementation in 10+ years. The objective of selected incubation study teams is to identify methods and activities for improving the understanding of and advancing the maturity of the technologies applicable to PBL/STV and their associated science and applications priorities. The main deliverable produced by each study team is a white paper outlining potential future methods and activity areas, such as modeling and Observing System Simulations Experiments (OSSEs); field campaigns; and a range of potential observing system architectures utilizing emerging sensor and information technologies.

Research, development and any ensuing flight-testing will be managed through the ESTO Program through a newly developed Decadal Survey Incubator element. Table 12 lists the possible airborne activities in support of the PBL and STV technology incubation efforts. Science focus area managers have indicated that any flight-testing might begin in the 2023 time frame, as indicated previously in Figure 14.

Table 12. Airborne Support to Technology Incubators

Mission	POC	Spacecraft measurement or Instruments	Supporting/ related aircraft instruments	Airborne Science supporting activities	Possible Aircraft
Planetary Boundary Layer (PBL)	McCarty	Temperature / humidity / wind measurements to determine PBL heights	Test versions	Technology development, suborbital observations	DC-8, B-200, P-3, GV
Surface Topography and Vegetation (STV)	Phillips	Lidar, SAR	Test versions, simulator versions	Technology development, similar but higher resolution airborne measurements	G-III, GV

PBL

The PBL white paper includes the following text:

- *"There is a pressing need to fly the instruments that comprise the proposed spaceborne architecture together on a common aircraft platform along with dropsondes to generate multisensory datasets with sufficient in-situ validation data to develop and test synergistic algorithms."*
- *The ESTO DSI solicitation for period FY23 – FY25 will likely call for DC-8 or P-3 to carry multiple instruments along with dropsonde capability. (High altitude not required.) Representative payloads may include lidars, IR and MW sounders*

Planetary Boundry Layer (PBL) Incubator

Program Scientist:

Launch date: TBD > next Decadal

Science objectives / observational goals

Variable	Horizontal resolution	Vertical resolution	Temporal resolution	Accuracy
Water vapor	0.1-100 km	0.1-1 km	Minutes to monthly	10%
Temperature				1K
PBL height		N/A		100 m

Expected satellite components: DAR, DIAL, RO, IR, MW

Requirements for airborne incubator: measurement capabilities and platform compatibility for TRL≥6 instruments.

Relevant airborne requirements from PBL incubator study:

- PBL is from 1 – 5 km
- Airborne remote sensing that provides synergies with space-based observations.
- "There is a pressing need to fly the instruments that comprise the proposed spaceborne architecture **together on a common aircraft platform** along ***with dropsondes*** to generate multisensory datasets with sufficient in-situ validation data to develop and test synergistic algorithms."

Aircraft Calendar

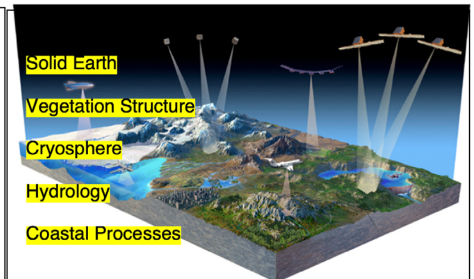
- 2022-22 ACTIVATE on HU-25A and B-200
- 2022 CPEX-CV on DC-8
- 2022 IIP, AITT ABLE on B-220
- 2023 IIP Placeholders on ER-2
- ESTO DSI solicitation for period FY23 – FY25 will likely call for DC-8 or P-3 to carry multiple instruments along **with dropsonde capability.** (High altitude not required.) Representative payloads may include lidars, IR and MW sounders
- Relevant AOS suborbital activities will complement
- Complementary approaches to diurnal cycle measurements my require long-duration suborbital.

STV

For STV, the biggest issue is the timing, capability and compatibility of the next generation SAR with current platforms. The second biggest need is for capable HALE aircraft for long duration observation of surface events.

Surface Topography and Vegetation (STV) Incubator

- Program Scientist: Ben Phillips
- Launch date: TBD >next Decadal
- Science objective: A common measurement of surface topography and vegetation structure to address numerous processes related to 5 Earth science disciplines, bound together by information systems.
- Candidate architecture: multiple platforms and sensors on orbital and suborbital assets
- Candidate payloads: Lidar, radar, stereo photogrammetry
- Relevant aircraft instruments: SAR, LVIS, GLiHT, lidars, spectrometers



Past and planned airborne support:

- SAR topography data and repeat pass from UAVSAR is relevant; also LVIS and multi-return lidar for vegetation structure
- Suborbital platforms, such as HALE UAS, are high priority and could provide experimental proof-of-concept
- The architecture envisions multiple types of platforms with multiple types of payloads.
- **Issues:** compatibility of next generation SAR with current platforms; maturity of both the technology and airspace integration needed for HALE.

Related Aircraft Calendar

- 2021 + Ongoing UAVSAR activities on G-III
- ESTO Decadal Survey Incubator (DSI) solicitation for period FY23 – FY25 to **miniaturize** instruments for UAS
- 2021-2 GLiHT activities on CAS; LVIS ongoing collections
- 2022 + Stated desire for HALE workshop and demonstration
- ~2025 STV Tech Demo
- Future next gen SAR in 100's hours / year

3.6.3 Support for Explorer missions described in the Decadal Survey

NASA ESD will begin soliciting and funding science teams to identify and define activities toward the development of "Explorer" missions described in the Decadal Survey. This may generate demand for airborne service late in this decade. As seen in Figure 18, these missions relate most to SBG and AOS, which are already using airborne services.

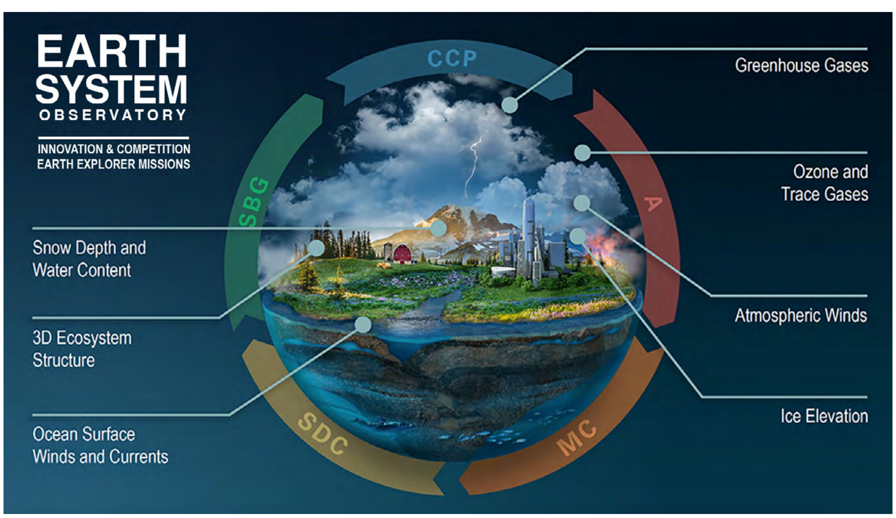


Figure 18. Decadal Survey Explorer Missions

3.7 Science needs based on FY 2020 NASA Center Survey and Discussions

Scientists and engineers at NASA Centers are key stakeholders of the NASA SMD Airborne Science Program. The Airborne Science Program provides managerial and financial support to Centers in the operations of science aircraft, while also providing direct technical support to scientists and engineers who are actively using aircraft to support NASA missions. To ensure that the Program core aircraft fleet, payload accommodations, and future investments are aligned with the science needs at the Centers, the Airborne Science Program periodically solicits inputs from the Centers as to their current and future needs for aviation services.

3.7.1 Process

This section summarizes requirements that were communicated to Program representatives in late 2019-early through winter 2020. ASP staff visited GSFC, LARC, ARC, JPL, in addition to supporting a telecon with MSFC. Each visit consisted of meetings with Center Earth Science management, a presentation to staff providing an overview of the Program, new developments, as well as a description of the requirements solicitation process. A survey was also provided to managers and staff. Here we summarize findings from these meetings in order to ensure that these requirements are captured by the Program for purposes of strategic planning and program execution.

Science areas addressed by the scientists include Atmospheric Composition and Chemistry, Weather, Cryosphere, Terrestrial Ecology, Aerosols and Clouds, Precipitation, Marine Habitat, and Coastal Regions, Soil Moisture, Oceanography, Salinity, and Earth Surface and Interior.

Respondents were asked to address the following questions, identifying the science area of interest:

1) What a/c do you use and want to continue to use?
2) What a/c capabilities are needed that are not available?
3) What payload accommodations (or combined a/c + payload accommodations) are needed that are not currently available?
4) What are the added benefits of the new capabilities? What impact would there be if these new capabilities don't materialize?
5) What upcoming campaigns or missions are planned or anticipated?
6) Describe a notional mission concept and the related airborne requirements.
7) How important is payload data telemetry during a mission?
8) What tools are useful for planning airborne science missions?
9) What new sensors are planned or desired to service your science community? What existing instruments will be in operations over the next 5-10 years?

Where practical, we wanted to understand capabilities required (altitude, suration, range, payload weight, etc.) rather than specific aircraft. However, for the near term, aircraft-specific requirements are needed as well.

3.7.2 Summary of Results

Aiircraft:

All currently ASP-supported aircraft are in routine use and continued use is projected and desired. Gaps in the fleet include:

- Aircraft capable of supporting large instruments needing access to doors or large ports. Aircraft with suitable capability, used in the past, have included Twin Otter, DC-3/Basler, and Sherpa.
- Storm-penetrating aircraft.
- Another G-V, dedicated to science. This would clear the calendar of astronaut return missions.
- King Air 350ER or inexpensive aircraft with longer range and more schedule availability than LARC/AFRC B-200; although not a gap in the fleet, the cost of the currently un-supported B-200s is too expensive.

Aircraft accommodations or payload support needed:

- Dropsonde capability from long-range aircraft, e.g., G-V
- Aircraft modifications or aircraft with two nadir ports AND radar support
- Zenith port(s) on the G-V (or other)
- Forward and nadir cameras on ER-2 with real-time data downlink
- A new, advanced replacement for UAVSAR and its 3 frequency versions.

Other:

- Real-time data is desired for many instruments – action may be to educate scientists on what is available and how to request it
- Suggestion to make AirSWOT a facility instrument
- Single-pass interferometry in demand – how to modify a/c to do this?
- Suggestion to base P-3 and Sherpa on West Coast

Figure 19 shows the aircraft requested for continued use. Figure 20 shows the noted gaps in payload / range space where another aircraft might be useful.

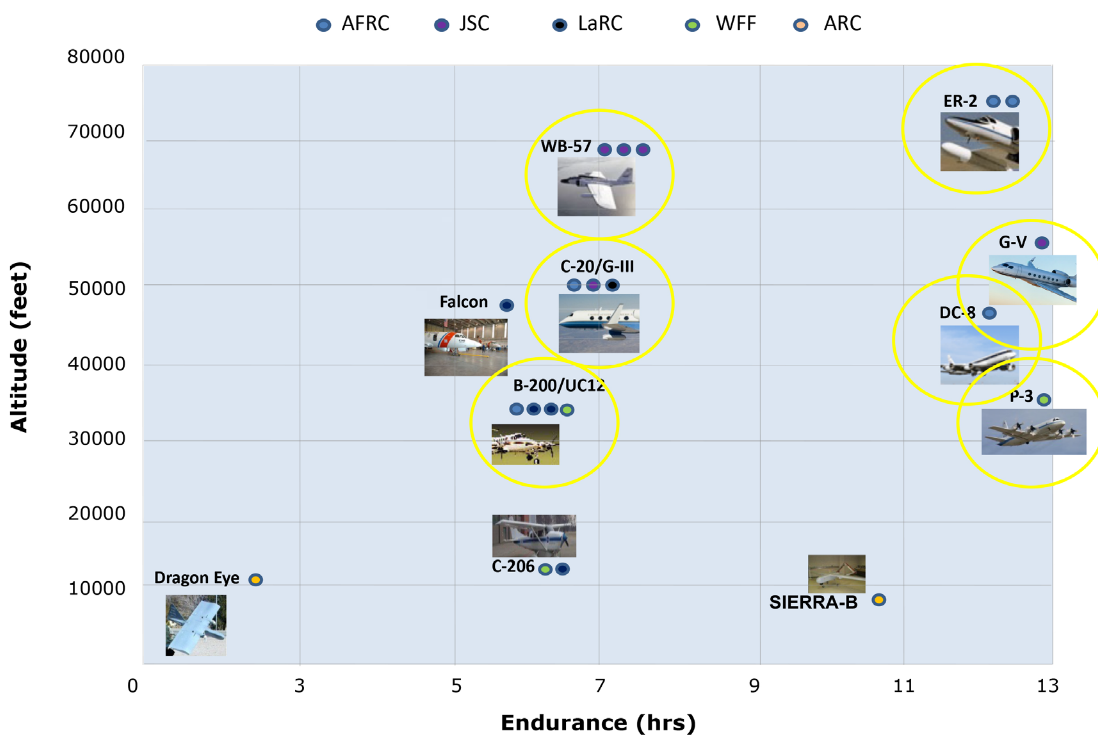


Figure 19. NASA Aircraft indicated for continued use by Center scientists

Figure 20. Gaps in the fleet for longer endurance with payload capability

3.7.3 Discussions with Scientists at Centers – Highlighted needs by Aircraft

DC-8:

DC-8 will be needed (or similar capability) for all foreseeable future. The primary users are Atmospheric Composition and Chemistry in particular, and Atmospheric Dynamics (Weather). The DC-8 is requested because of the large payload mass and volume to enable simultaneous measurements of multiple species in the same air sample. For weather, the DC-8 all weather capability is needed to carry multiple large radar instruments into storms.

ER-2:

The ER-2 is needed for missions that require remote sensing from above clouds or in combination with in situ measurements (multi-aircraft with DC-8 or P-3). The ER-2 has been the central aircraft for HyspIRI Prep, flying the AVIRIS and MASTER instruments. These California flights continue as predecessors to the Designated Observable mission Surface Biology and Geology (SBG). The ER-2 is also needed to test fly instruments destined for space missions. The high altitude reach of the aircraft above more than 98% of the atmosphere is a close simulation of the space environment. An issue has been that the ER-2 is not available enough for testing all the instruments under development for space (satellites and ISS)

P-3:

The P-3 is ideal for large payloads and relatively slow flight. It was the workhorse for Operation IceBridge in the Arctic and Antarctic. More cryospheric science work is planned in support of ICESAT-2 and to support process studies. P-3 is the ideal platform for DopplerScat and AirSWOT, but is not available. P-3 has been requested for SNOWEX, but again is not available. For these two activities, the P-3 would be a good fit for the hydrology instrumentation, such as PALS, SWESARR. Some alternatives to the WFF P-3 include the NRL or NOAA research P-3s, G-III + Twin Otter/Sherpa.

G-III:

Both the AFRC C-20A and JSC G-III are used and needed to give regular access to the 3 versions of the “UAVSAR” – L-band, Ka-band and P-band, which are in high demand. Along with other instruments, ABoVE has flown and will continue to fly L-band and P-band. All activities preparing for the launch of NISAR make use of the G-III for L-band data sets, and now include the ISRO S-band SAR. The aircraft are workhorses for terrestrial ecology, terrestrial hydrology, earth surface and interior and rapid response. The newly available LaRC G-III has nadir ports. Scientists are requesting zenith ports and dropsonde capability as well.

G-V:

The G-V has been used to support SWOT cal/val (carrying MASS), GEDI cal/val (carrying LVIS), Operation IceBridge (carrying OIB suite). The long distance / long duration capability is in demand for remote sensing missions. Scientists have asked for zenith ports, in-situ sampling capability, and dropsonde launching capability.

Table 13 lists missions that Center scientists consider planned or anticipated, the likely or specified aircraft and the likely or specified instruments. This list matches well with the plans heard from the Program Scientists in their planning.

Table 13. Planned or Likely missions described during the Center Survey

Focus Areas	Mission	Time frame (if noted)	Aircraft (specified or likely)	Instrument (if noted)
AC	ACCLIP	2020	WB-57	Several in situ
AC, W	ACTIVATE	2020-2022	B200, Falcon	LIDAR, in situ
AC, W	DCOTTS	2020-2021	ER-2	Several in situ
AC, W	ACCP suborbital component	pre- and post-launch	ER-2 (aerosols), P-3, DC-8	ORACLES, SEAC4RS payloads
AC	Air Quality (like KORUS)	2022	DC-8	Several in situ
AC, W	Joint with TRACER (DOE/ARM) TRACER-AQ	2021 (ARM site)	B-200, G-III, G-V	HSRL, GCAS
AC, CVC, W	ARCSIX (ARISE II)	2021	P-3, ER-2	LVIS, 4-Star, Radiometers
OBB, AC, CVC	PACE cal/val	2023	B-200, ER-2, UAS	AVIRIS-NG
AC	TROPOMI/TEMPO cal/val	2022-2024	DC-8	
AC, CVC	TEMPO validation – East coast and West coast	2022-2023	Cessna 182 or 206	Formaldehyde, NO_2, ozone, GEO TASO, headwall imaging spectrometer, HSRL-2
AC, W	like CAMP2EX	NA	P-3 or equivalent	multi-instrument package
TE, WEC, CVC	AboVE	2020, 2021, 2022	G-III	AVIRIS-NG; LVIS
TE	GEDI cal/val	2021?	G-V	LVIS
TE	South Africa campaign (like BioSCape)	2021	G-III, G-V	PRISM, LVIS, AVIRIS-NG, HyTES
TE, CVC, ESI	G-LiHT with USFS	2020-2028	Cessna or other	G-LiHT
TE	DELTA-X	2020	G-III, B-200 (2)	UAVSAR, AVIRIS-NG
TE, ESI, WEC	NISAR cal/val	2020 – 2023	G-III	L-band SAR, ASAR
TE, ESI	Western Diversity Time Series	2020, 2021, 2022	ER-2	AVIRIS, MASTER, HYTES, PRISM
TE	SBG Pathfinder	2022-2024	ER-2	AVIRIS, MASTER, HYTES, PRISM
TE, OBB, WEC	Arctic COLORS	2022, 2023	G-III, B-200	AVIRIS-ng. G-LiHT
OBB	Coral Studies / NEMO0net	2021	UAS	FluidCam / MIDAR
WEC	SMAPVEX	2021, 2022	DC-3	PALS
WEC, CVC	High Latitude Salinity campaign	Mission In development	G-III, P-3	L-band SAR or combined passive-active L-band radar
WEC, CVC, TE	SNOWEX	2020-2022	G-III, CAS	SWESARR
CVC	OMG- surveys	2020, 2021	P-3, Basler,G-III, G-V	Dropsonses
CVC	GLISTIN-A campaign in development	2022	G-III	GLISTIN-A
CVC, cryo	American Ice	2022	P-3	Snow radar, lidar
CVC, ESI, W	Joint with THINICE (NSF)	2021 (Arctic)	GV	TBD
CVC	S-MODE	2020-2021	B-200, G-III	PRISM, several
CVC	SWOT hydrology cal/val	2020-2021	B-200	AirSWOT
W	IMPACTS	2020-2022	ER-2, P-3	Radar, LIDAR, in situ
W	CPEX-AW	2021	DC-8	DAWN, HALO, APR3, dropsonde
W	Aeolus cal/val	2022	DC-8, P-3	DAWN, HALO, APR3, dropsonde
W	ER-2 convection and/or similar to OLYMPEX with 2 a/c	NA	ER-2, DC-8, P-3	AMPR, COSMIR, HIWRAP, CRS, XRAD
W	Severe storm sentinel	2021	ER-2	HIWRAP, HAMSR, HIRAD
W	Intense Convection and Severe Weather	NA	2 aircraft	HIWRAP, HAMSR, HIRAD
ESI	UAVSAR, HRT, SWIR	NA	G-III, B-200	SAR versions, SWIR
ESI	UAS Fault Line missions	2022-2022	UAS	SAR
ESI	STV Technology Incubator	TBD (2022)	TBD	TBD

Other future mission concepts noted by the science community as part of the Center Survey are listed in Table 14. The desire to continue studies of the Arctic and Antarctic is notable.

Table 14. Future mission concepts as noted by Center scientists

Focus Area	Payload accommodations and SatCom provisions	Science measurement or observation (examples)
AC, W	Combined mission to measure aerosols, clouds and gases (like ACCP, plus gas composition)	Aircraft with capability to carry multiple sensors.
AC, W	Cal/val of upcoming atmospheric sounder satellite mission; in situ vertical profiles of atmospheric constituents and meteorology for transport models	Vertical profiling aircraft carrying atmospheric chemistry payload
W, AC	Fixed-wing UAS capability to sample clouds at 2-3km (up to 10,000 ft)	Medium altitude UAS with cloud sampling payload
TE, AC	UAS vertical profiles of meteorology, methane and CO2. Coordinated with major field mission, such as AboVE.	Low altitude UAS with met and gas sensor, vertical profiling capability
TE	Like DELTA-X (multi sensors, multi a/c) at other delta locations	Multi-aircraft with hydrology and land imaging payloads
TE, WC	Like AboVE at other locations: combined terrestrial ecology and hydrology experiments using radar, lidar and imaging spectroscopy.	Multi-aircraft carrying radar, lidar, imaging spectroscopy
TE, WC	12-day repeat pass in wetland inundation areas (SAR)	SAR-carrying aircraft
Cryo	Ongoing requirement for lidar, radar, and EO/IR over poles. Similar aero-geophysical flight and payload requirements as OIB	Capability to fly OIB payload over poles (range and payload accommodations)
Cryo	Ice grounding-line mission in Antarctica	Capability to fly ice instruments to edges of Antarctica
Ocean, Cryo	Antarctic and Arctic oceans for physical and biological oceanography	Capability to fly oceanography payload over poles
W, Ocean	Planetary boundary layer (weather) mission on G-V with multiple instruments, flight over oceans and tropics *(Note this is a Decadal Survey Incubation Recommendation)*	G-V carrying planetary boundary layer (weather) payload
W, AC	Fixed-wing UAS capability to sample clouds at 2-3km (up to 10,000 ft)	Medium altitude UAS with cloud sampling payload
W, ESI	OLYMPEX-like mission with multiple a/c to study convective processes with topography within frontal systems.	Multi-aircraft: weather capable with radar volume; lidar or other topography from high altitude
ESI	SUAS for site specific high resolution imagery for fault mapping and instrument development	Small UAS with high resolution imaging payload

4. CROSS-CUTTING SUPPORT AND MISSION TOOLS

Telemetry (Satcom for aircraft performance and science data) and instrumentation infrastructure assets and capabilities are described in Appendix A, section A.3. For the foreseeable future, all facility instruments and Satcom capabilities are needed by the science community and will be maintained.

Mission planning tools are typically used by the aircraft operators, often in coordination with the scientists planning a mission. In some science campaigns, the science team makes use of a dditional planning tools to prepare for missions requiring specific weather conditions, satellite overpass or cooperation with other agencies or entities.

The Airborne Science Program does not on its own operate or make available flight planning tools. However, the Mission Tool Suite can be used to explore data layers available from other sources, such as weather or satellite orbit data. Several requests have come from Center scientists for either general or specific planning tools to be made available from the Program. (See Center Survey results.)

The Mission Tool Suite (MTS) is a powerful capability for real-time tracking, not only of flight tracks, but many other parameters and layers. The most recent version also makes available many types of post-mission data. The MTS team is open to requests from science investigators for either specific or general additional data streams during a mission. The major functions of the MTS are listed in Table 15.

Table 15. MTS Capabilities

MTS Functions
• Remotely monitor real-time aircraft location • View current and archived aircraft flight tracks • Add information overlays from a curated product registry • Customize user workspaces • Communication and collaboration tools • Integrated IRC (Internet relay chat) client supporting multiuser and person-to-person private chat • Remotely monitor real-time instrument engineering data • Plotting and graphing • Map projections that serve polar missions (e.g., polar stereographic) • Automatic ground overlay re-projection • A capable user interface that simplifies the process of simultaneously monitoring tracked assets across different products stacks • Product video playback • Multi-channel chat • Two-factor authentication for non-NASA users • Integration with the ASP calendar to automatically tag telemetry and other stored data for post-mission reports and visualization

During the Center Survey discussions, and in the survey results, several requests specific to the functions of the MTS were shared. These included the following:

- Ability to display weather models in Mission Tools – Perhaps the GMAO products initially. Total cloud, high cloud, medium cloud and low cloud.
- NASA MTS would benefit from continued investment to improve speed and functionality, and to reduce its current unwieldiness. Making MTS more accessible to mobile platforms would also be beneficial
- MTS: Desire to archive the real-time data for mission playback. Maybe in version 2.

5. CONCLUSIONS

Across all Earth science stakeholders who were contacted during this survey, there exists a strong, continued need for NASA Science aircraft. New satellites under development have a variety of airborne instruments that are or will soon be used to develop new data products, and the Earth Venture Suborbital Program and Research and Analysis Programs represent a sustained need for the core aircraft

The Program will continue to fly UAVSAR (or an updated SAR payload) for NISAR validation, indicating sustained need for business class jets such as the G-III and GV. Both SWOT and PACE will make use of airborne measurements for calibration and validation using a variety of active and passive optical instruments.

The Designated Observables satellite missions recommended by the National Academies have significant need for aircraft both for technology development and algorithm refinement for data products. AOS has a defined suborbital team to plan their use of aircraft and SBG has been building a long-term time series through the Western Diversity Time Series to refine imaging spectroscopy.

Missions in the technology incubator category, including STV and PBL, have expressed a need for instrument development using aircraft in addition to needing aircraft measurements for calibration, similar to OIB for ICESAT, or LVIS for GEDI.

With increased cadence of the instrument incubator program we see sustained need for ER-2 and Commercial Aviation Services (CAS) for instrument testing and maturation.

ER-2 continues to be important for technology development (Table 9, pg 28), process studies, and satellite support. Delays of several years for short instrument test flights are becoming more common because of maintenance delays. The Program should consider funding operations for 2 concurrent aircraft. This could be accomplished through contracts to LM or hiring additional mechanics and pilots at AFRC.

CAS continue to provide support for light aircraft with medium range requirements and this requirement is stable to growing, but largely reflects continued interest in AVIRIS-NG.

Following is a summary of the major survey and discussion input comments from our visits with NASA Center scientists.

Aircraft:

All currently ASP-supported aircraft are in routine use and continued use is projected and desired.

Gaps in the fleet include:

- Aircraft capable of supporting large instruments needing access to doors or large ports. Aircraft with suitable capability, used in the past, have included Twin Otter, DC-3/Basler, and Sherpa.
- Storm-penetrating aircraft for observing processes in severe storms, fire and volcanic plumes.
- Concerns were voiced about the availability of the ER-2 and G-V. Suggestions of having another GV dedicated to science and going back to 2 concurrently operational ER-2s.
- King Air 350ER or inexpensive aircraft with longer range and more schedule availability than LARC/AFRC B-200; although not a gap in the fleet, the cost of the currently un-supported B-200s is too expensive.

Aircraft accommodations or payload support needed:

- Strong need for dropsonde capability from long-range aircraft, e.g., G-V
- Aircraft modifications or aircraft with two nadir ports AND radar support
- Zenith port(s) on the G-V (or other)
- Forward and nadir cameras on ER-2 with real-time data downlink
- A new, advanced replacement for UAVSAR and its 3 frequency versions.

Other:

- Real-time data is desired for many instruments
- Suggestion to make AirSWOT a facility instrument
- Single-pass interferometry in demand – how to modify a/c to do this?
- Suggestion by JPL researchers to rotate P-3 and Sherpa to West Coast

APPENDIX A. 5-YEAR PLAN

Atmospheric Composition and Chemistry

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	Platform
1) Atmospheric Composition and Chemistry				
1.1) SABRE		Jucks		WB-57
1.2) ACCLIP	140	Jucks	AURA	WB-57
1.3) TEMPO LAUNCH		Lefer	TEMPO	
1.4) AEROMMA	200	Lefer	GOER-R, TEMPO, SNPP	DC-8
1.5) GOTHAMM-AQ	80	Lefer EPA	TEMPO	G-III (2)
1.6) STAQS	100	Lefer	TEMPO, Sentinel 5P	NASA GV
1.7) ARCSIX	300	Maring/Markus	ICESat-2	NASA GV; DC-8
1.8) Asia-AQ (4SE Asia locations)	150	Lefer / Jucks	GEMS, TROPOMI	DC-8; NASA GV
1.9) PACE LAUNCH		Lorenzoni	PACE	
1.10) PACE PAX	100	Lorenzoni, Maring	PACE	ER-2
1.11) MAIA LAUNCH		Lefer	MAIA	
1.12) GEOCarb LAUNCH		Jucks	GEOCarb	
1.13) GEOCarb cal/val (AJAX?)	??	Jucks	GEOCarb	TBD
1.14) Africa-AQ	150	Lefer		NASA GV; DC-8

Weaather and Atmospheric Dynamics

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	Platform
6) Weather and Atmospheric Dynamics				
6.1) CPEX-CV	100	McCarty	ADM / GPM	DC-8
6.2) GOES-R cal/val	100	McCarty	GOES-R	ER-2
6.3) Planetary Boundary Layer technology and characterization experiments		ESTO	PBL incubator	DC-8; Any Twin Otter
6.4) AOS Suborbital prep		Maring	AOS	TBD

Carbon Cycle and Ecosystems

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	Platform
2) Carbon Cycle & Ecosystems Science				
2.1) UAVSAR-TE-22	20	Bawden/Margolis	NISAR	G-III
2.2) SHIFTS	20	Turner	SBG	Other B-200
2.3) BLUEFLIX (CMS)	150	Hibbard		Other B-200
2.4) AVIRIS-NG-22	20	Turner/Margolis	SBG	Other B-200
2.5) LVIS-GEDI -22		GSFC	GEDI	NASA GV
2.6) G-LiHT Sensor fusion	TBD	Margolis	Landsat 8	A90
2.7) ABoVE - 2022	30	Margolis	NISAR, OCO-2, ICESat 2	G-III; Other B-200
2.8) Western Diversity Time Series - 22	30	Turner	SBG	ER-2
2.9) Air-LUSI	6	Lorenzoni		ER-2
2.10) NISAR LAUNCH			NISAR	
2.11) UAVSAR-TE-23	20	Bawden/Margolis	NISAR	G-III
2.12) BLUEFLIX (CMS) - 23	150	Hibbard		Other B-200
2.13) AVIRIS-23	20	Turner/Margolis	SBG	Other B-200
2.14) ABoVE - 2023	30	Margolis	NISAR, OCO-2, ICESat2	G-III
2.15) LVIS-GEDI -23		Margolis	GEDI	NASA GV
2.16) Western Diversity Time Series - 23	30	Turner	SBG	ER-2
2.17) BioSCape	250	Turner	SBG, BioMASS	NASA GV; G-III (2)
2.18) SHIFTS - repeat	20	Turner	SBG	Other B-200
2.19) BLUEFLIX (CMS) - 24	150	Hibbard		Other B-200
2.20) STV demo - forest topography		Margolis/Phillips	STV	G-III
2.22) PACE LAUNCH			PACE	
2.23) PACE PAX		Lorenzoni	PACE	G-III (2)
2.24) SBG Pathfinder	30	Turner	SBG	TBD
2.25) Arctic COLORS	100	Lorenzoni		TBD
2.26) GLIMR cal/val		Lorenzoni	GLIMR	TBD

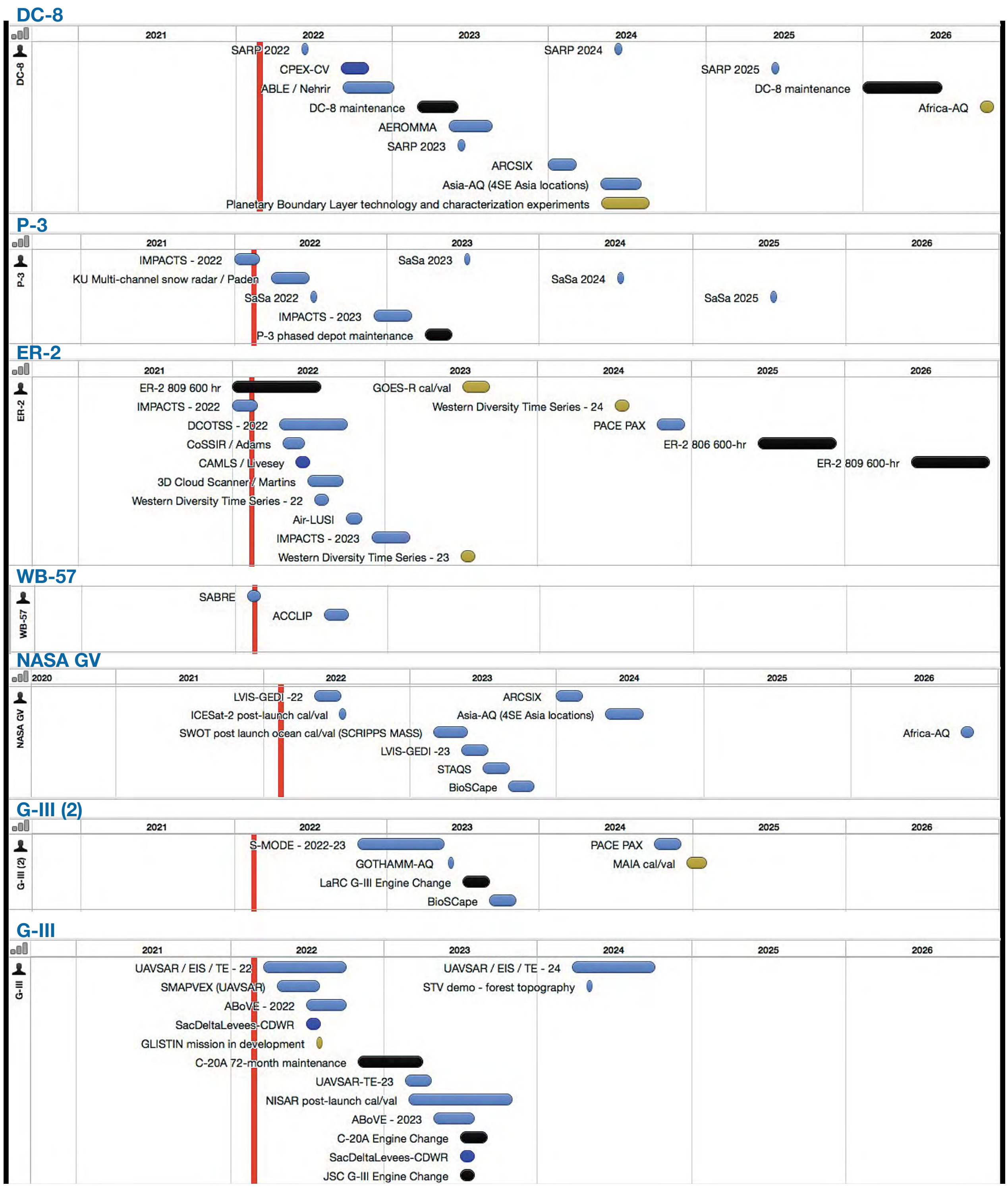
Climate Variability and Change (Cryosphere and Physical Oceanography)

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
3) Climate Variability and Change / Cryospheric Science				
3.1) ICESat-2 post-launch cal/val	50	Markus	ICESat 2	NASA GV
3.2) Arctic Salinity mission SASSIE	60	Shiffer	SMAP	DC-3
3.3) SWOT Launch			SWOT	
3.4) NISAR LAUNCH		Bawden	NISAR	
3.5) SWOT post launch ocean cal/val (SCRIPPS MASS)	120	Shiffer	SWOT	NASA GV
3.6) SWOT post-launch hydrology cal/val (AirSWOT)	120	Shiffer	SWOT	B-200 D
4) Water and Energy Cycle				
4.1) SoOpSAR SNOW	40	Entin		Any Twin Otter
4.2) SMAPVEX (PALS)	100	Entin / Bawden	SMAP	DC-3
4.3) SMAPVEX (UAVSAR)		Bawden	NISAR	G-III
4.4) SnowEX - 23	75	Entin	GCOM-W1, GPM, SBG	Other B-200
4.5) SWOT Launch			SWOT	
4.6) SWOT post-launch hydrology cal/val (AirSWOT)	120	Shiffer/Entin	SWOT	B-200 D
4.7) SLAP support for PBL		Entin	PBL	Other B-200
4.8) PACE LAUNCH			PACE	
4.9) PACE-coastal water quality mission		Entin/Lorenzoni	PACE	TBD

Earth Surface and Interior

Title	Flt Hours	PS/PE/PM	Related Satellite/Sensor	
5) Earth Surface & Interior				
5.1) UAVSAR / EIS / TE - 22	150	Bawden; Phillips	NISAR	G-III
5.2) UAV demo - mission in development		Phillips		TBD
5.3) GLISTIN mission in development		Bawden		G-III
5.4) NISAR LAUNCH			NISAR	
5.5) NISAR post-launch cal/val	100	Bawden	NISAR	G-III
5.6) STV Tech Demo		Phillips	STV	TBD
5.7) UAVSAR / EIS / TE - 24	150	Bawden; Phillips	NISAR	G-III

5-year plan by Aircraft



APPENDIX B. ACRONYMS

ABoVE	The Arctic-Boreal Vulnerability Experiment
ACCLIP	Asian summer monsoon Chemical and Climate Impact Project
ACCP	Aerosols-Clouds, Convection and Precipitation
ACT-America	Atmospheric Carbon and Transport-America
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
AEROMMA	Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas
AFRC	Armstrong Flight Research Center
AirHARP	Airborne Hyper-Angular Rainbow Polarimeter
Air-MASTER	Airborne Multi-Application SmallSat Tri-band Radar
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AirMSPI	Airborne Multiangle SpectroPolarimetric Imager
AirSWOT	Airborne Surface Water and Ocean Topography
AITT	Airborne Instrument Technology Transition
AMPR	Advanced Microwave Precipitation Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AOS	Atmosphere Observing System
ARC	Ames Research Center
ARCSIX	Arctic Radiation and Chemistry Experiment
ARCTIC COLORS	Arctic – Coastal Land Ocean Interactions
ARMD	Aeronautics Research Mission Directorate
ARISE	Arctic Radiation - IceBridge Sea & Ice Experiment
ASAR	Airborne SAR (S-band)
ASMLS	Airborne Scanning Microwave Limb Sounder
ASP	Airborne Science Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMS	Advanced Technology Microwave Sounder
ATom	Atmospheric Tomography Experiment
AVIRIS-ng	Airborne Visible / Infrared Imaging Spectrometer-next generation
AVIRIS	Airborne Visible / Infrared Imaging Spectrometer
BioSCAPE	Biodiversity: Marine, Freshwater, and Terrestrial Biodiversity Survey of the Cape

BLUFLUX	Blue Carbon Prototype Products for Mangrove Methane and Carbon Dioxide Fluxes
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMLS	Compact Adaptable Microwave Limb Sounder
CAMP2Ex	Cloud-Aerosol-Monsoon Processes-Philippines Experiment
CARAFE	CARbon Airborne Flux Experiment
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CAS	Commercial Aviation Services
CERES	Clouds and the Earth's Radiant Energy System
CHAPS-D	Compact Hyperspectral Air Pollution Sensor - Demonstrator
CMIS	Compact Midwave Imaging System
CORAL	Coral Reef Airborne Laboratory
CoSSIR	Compact Scanning Submillimeter-wave Imaging Radiometer
COSMIR	Conical Scanning Millimeter-wave Imaging Radiometer
COVID	Coronavirus Disease
CPEX-AW	Convective Processes Experiment – Aerosols and Winds
CPEX-CV	Convective Processes Experiment – Cabo Verde
CPL	Cloud Physics Lidar
CPR	Cloud Profiling Radar
CrIS	Cross-track Infrared Sounder
DAWN	Doppler Aerosol WiNd
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DISCOVER-AQ	Deriving Information on Surface Conditions from column and vertically resolved observations relevant to Air Quality
DO	Designated Observable
DPR	Dual- frequency Precipitation Radar
ECOSTRESS	ECOSTRESS = Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
eMAS	enhanced MODIS airborne simulator
EO/IR	Electro-optic / Infrared

ESD	Earth Science Directorate
ESSP	Earth Science Pathfinder Program
ESTO	Earth Science Technology Office
EVS	Earth Venture Suborbital
FIREX-AQ	Fire Influence on Regional to Global Environments and Air Quality
G-III	Gulfstream 3
G-LiHT	Goddard's Lidar, Hyperspectral and Thermal
GCAS	GEO-CAPE Airborne Simulator
GEDI	Global Ecosystem Dynamics Investigation
GEOCarb	Geostationary Carbon Observatory
GEO-TASO	Geostationary Trace gas and Aerosol Sensor Optimization
GLIMR	Geosynchronous Littoral Imaging and Monitoring Radiometer
GLISTIN	Glacier and Ice Surface Topography Interferometer
GNSS	Global Navigation Satellite System
GOTHAMM	Greater New York Oxidant, Tropospheric Halogens, and Aerosol Measurements and Modeling
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
GV	Gulfstream 5
HALE	High Altitude Long Endurance
HALO	High Altitude Lidar Observatory
HIRDLS	High resolution dynamics limb sounder
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HQ	Headquarters
HRT	High Resolution Tracker
HSRL	High Spectral Resolution Lidar
HyspIRI	Hyperspectral Infrared Imager
HyTES	Hyperspectral Thermal Emission Spectrometer
ICCAGRA	Interagency Coordinating Committee for Airborne Geoscience Research and Applications
IIP	Instrument Incubator Program
IIR	Imaging Infrared Radiometer
IMPACTS	Investigation of Microphysics and Precipitation for Coast-Threatening Snowstorms

InSAR	Interferometric synthetic aperture radar
ISRO	Indian Space Research Organization
ISS	International Space Station
JPL	Jet Propulsion Laboratory
KaSPAR	Ka-band SWOT Phenomenology Airborne Radar
KORUS	Korea - US
LaRC	Langley Research Center
LVIS	Laser Vegetation Imaging Sensor
MACPEX	Mid-latitude Airborne Cirrus Properties Experiment
MAIA	Multi-Angle Imager for Aerosols
MASS	Modular Aerial Sensing System
MAS	MODIS Airborne Simulator
MASTER	MODIS/ASTER Airborne Simulator
MC	Mass Change
MIDAR	Multispectral Imaging, Detection and Active Reflectance
MISR	Multi-angle Imaging SpectroRadiometer
MLS	Microwave limb sounder
MODIS	Moderate-Resolution Imaging Spectroradiometer
MSFC	Marshall Space Flight Center
MTS	Mission Tool Suite
NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NASA	National Aeronautics and Space Admisitration
NAST	NPOESS Airborne Sounder Testbed
NCAR	National Center for Atmospheric Research
NIR	Near Infrared
NISAR	NASA-ISRO SAR
NOAA	National Oceanic and Atmospheric Administration
NPP	National Polar-orbiting Partnership
NSF	National Science Foundation
OCI	Ocean Color Instrument
OCO	Orbiting Carbon Observatory
OIB	Operation IceBridge

OLYMPEX	Olympic Mountains Experiment
OMB	Office of Management and Budget
OMG	Ocean Melting Greenland
OMI	Ozone monitoring instrument
OMPS	Ozone Mapper and Profiler Suite
ORACLES	Observations of Aerosols Above Clouds and their Interactions
OSSE	Observing System Simulation Experiment
PACE	Phytoplankton-Aerosol-Cloud-Ecosystem
PALS	Passive Active L-and S-band Sensor
PBL	Planetary Boundary Layer
PICARD	Pushbroom Imager for Cloud and Aerosol Research and Development
PRISM	Portable Remote Imaging Spectrometer
R&A	Research and Analysis
RADEX	Radar Definition Experiment
RSP	Research Scanning Polarimeter
SABOR	Ship-Aircraft Bio-Optical Research
SAR	Synthetic Aperture Radar
SatCom	Satellite Communications
SBG	Surface Biology and Geology
SDC	Surface Deformation and Change
SEAC4RS	Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys
SHIFT	SBG High Frequency Time series
S-HIS	Scanning High-resolution Interferometer Sounderr
SHOW	Spatial Heterodyne Observation of Water
SIERRA	Sensor Integrated Environmental Remote Research Aircraft
SLAP	Scanning L-band Active Passive
SLI	Sustained Land Imaging
S-MODE	Submesoscale Ocean Dynamics and Vertical Transport
SMAP	Soil Moisture Active Passive
SMAPVEX	SMAP Validation Experiment
SMD	Science Mission Directorate

SNOWEX	Snow Experiment
SOFRS	Science Operations Flight Request System
SoOpSAR	Signal of Opportunity SAR
SOFRS	Science Operations Flight Request System
STAQS	Synergistic TEMPO Air Quality Science
STV	Surface Topography and Vegetation
SUAS	Small UAS
SWESARR	Snow Water Equivalent SAR and Radiometer
SWIR	Short wave / IR
SWOT	Surface Water and Ocean Topography
TBD	To be determined
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TES	Tropospheric emission spectrometer
TRACER-AQ	Tracking Aerosol Convection Interactions Experiment – Air Quality
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TROPOMI	TROPOspheric Monitoring Instrument
UAS	Unmanned Aircraft System; Uncrewed Aircraft System
UAVSAR	Unmanned Aerial Vehicle Synthetic Aperture Radar
VIIRS	Visible Infrared Imager Radiometer Suite
WDTS	Western Diversity Time Series
WFC	Wide Field Camera
WFF	Wallops Flight Facility

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