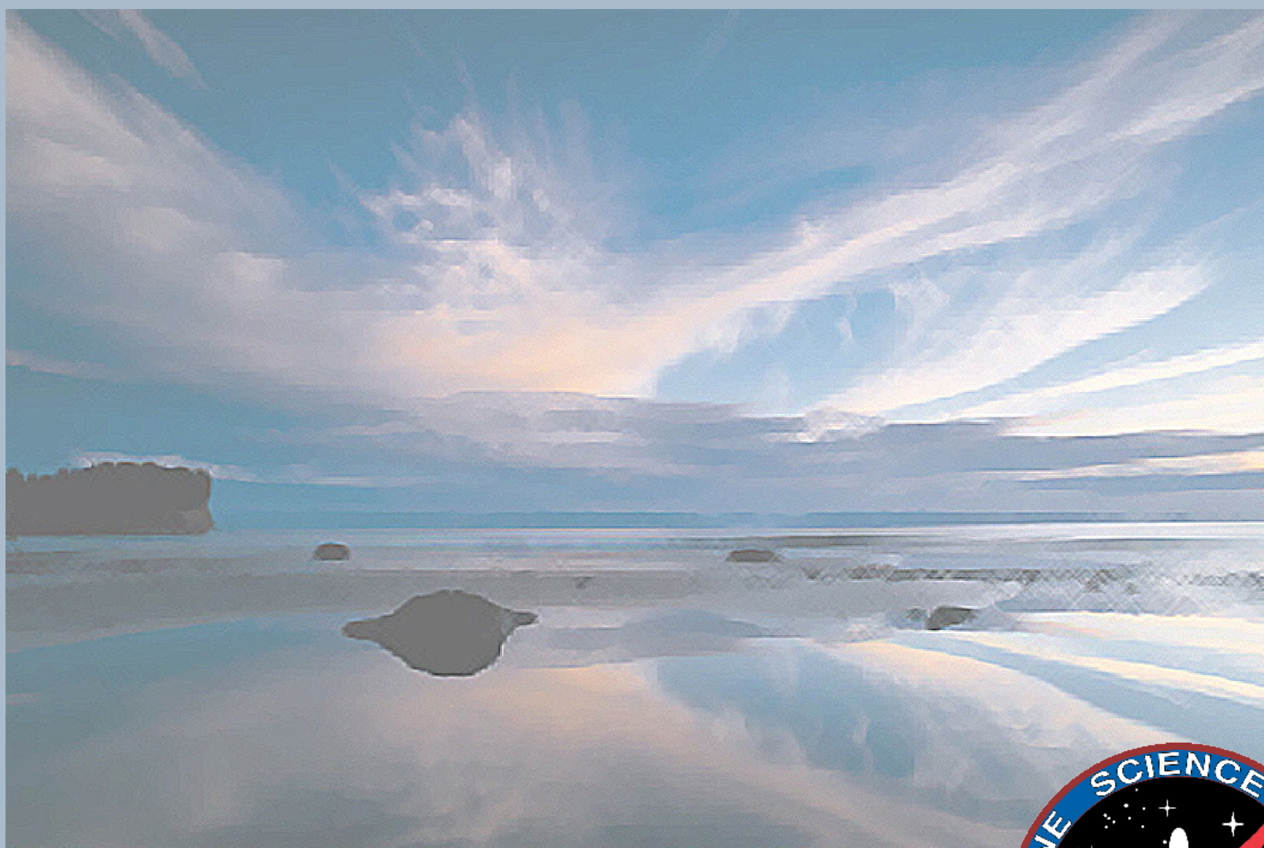
NASA Airborne Science Program Requirements



2013 Update

National Aeronautics and Space Administration

NASA Airborne Science Program Requirements

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Susan M. Schoenung
Longitude122 West, Inc.

Matthew M. Fladeland
NASA Ames Research Center

Abstract

Earth Science requirements for airborne capabilities vary dramatically with regard to aircraft flight regimes (altitude and range), duration, and payload carrying capacity, along with many operational characteristics. This report updates the known requirements for NASA Airborne Science support from several earlier reports. "2010 Report on Observations required to support the next generation of NASA Earth Science Satellites" was published in December 2010. "NASA Earth Science Requirements for Suborbital Observations" was published in June 2007. This report includes results from a survey of NASA Science Center requirements, along with other sources to update these reports in a combined product, documenting requirements for the next 5+ years and focusing on capability needs and gaps for the Airborne Science Program.

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Executive Summary

The NASA Airborne Science Program (ASP) serves the Earth Science community with a wide range of aircraft, instrument and mission support capabilities. To continue to meet the science community needs by maintaining, upgrading and investing in new assets, it is crucial to understand the requirements as far into the future as possible. This report presents our current understanding of the needs of the community, based on flight requests, discussions with Earth Science program scientists and scientists at the NASA science centers.

Current aircraft performance capabilities are represented in the Figures ES-1 and ES-2 below. The NASA ESD / ASP program-funded aircraft include the DC-8, P-3, two ER-2s, C-20 (Gulfstream-III), G-III (at JSC) and two Global Hawks. This requirements activity shows demand for all the ASP-funded aircraft and many others. Apparent gaps in platform capabilities are shown in Figure ES-3, based on activities underlying this report. This Executive Summary summarizes only briefly the platform needs. Details and other requirements, for instruments and mission support capabilities, are described in the main body of this report. {Note that this report does not include any requirements impacted by the results of the Earth Venture Suborbital-2 (EVS-2) solicitation.]

Figure ES-3 points out some gaps in the existing fleet. Table ES-1 explains the need behind each of these gaps. (In Figure ES-3, the terminology "core-funded" refers to the Earth Science Directorate subsidy to these assets in the ASP fleet. The JSC G-III aircraft is only subsidized through FY 2014.)

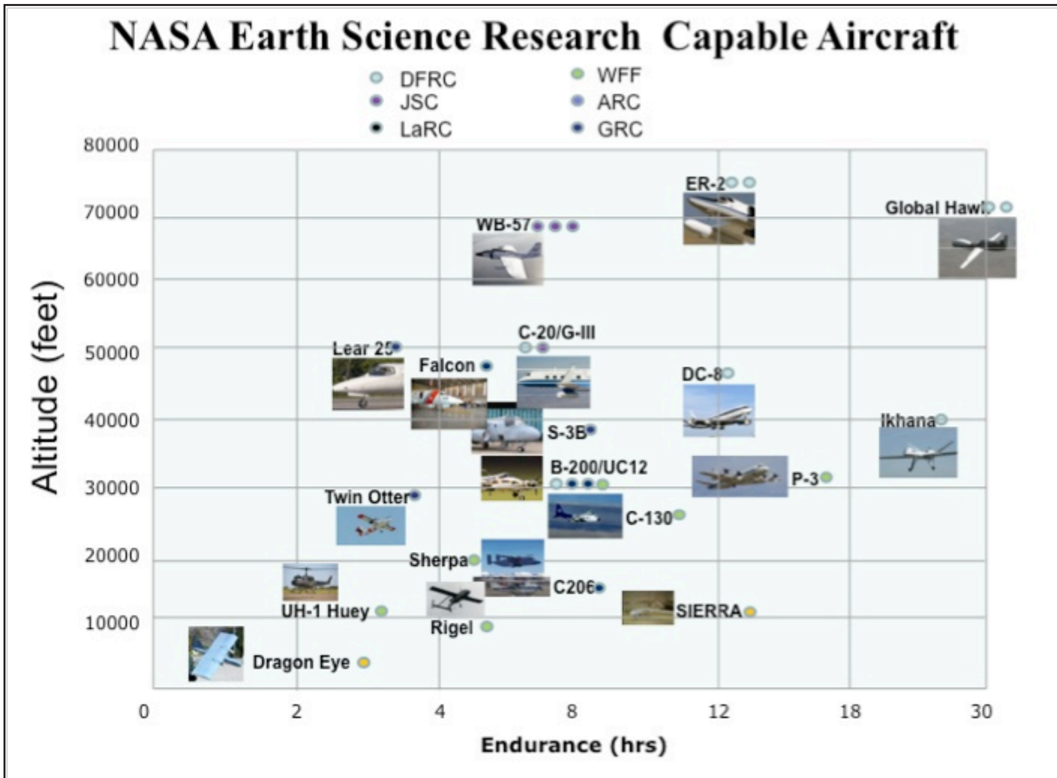


Figure ES-1: NASA Research Aircraft characterized by altitude and endurance capability.

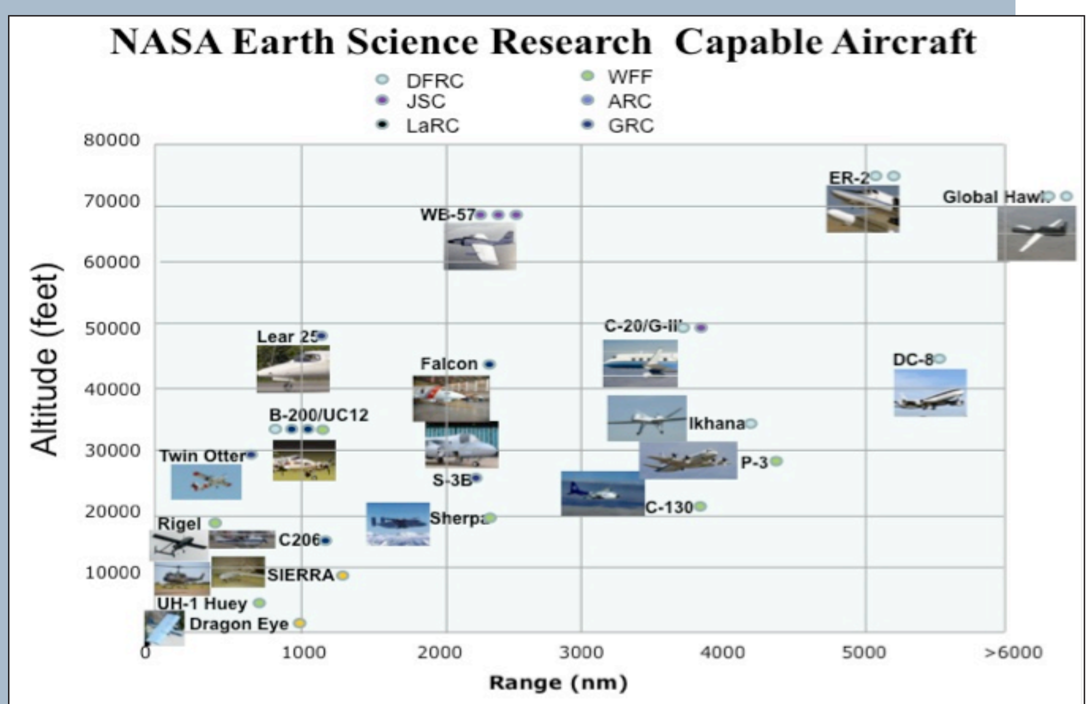


Figure ES-2: NASA Research Aircraft characterized by altitude and range capability.

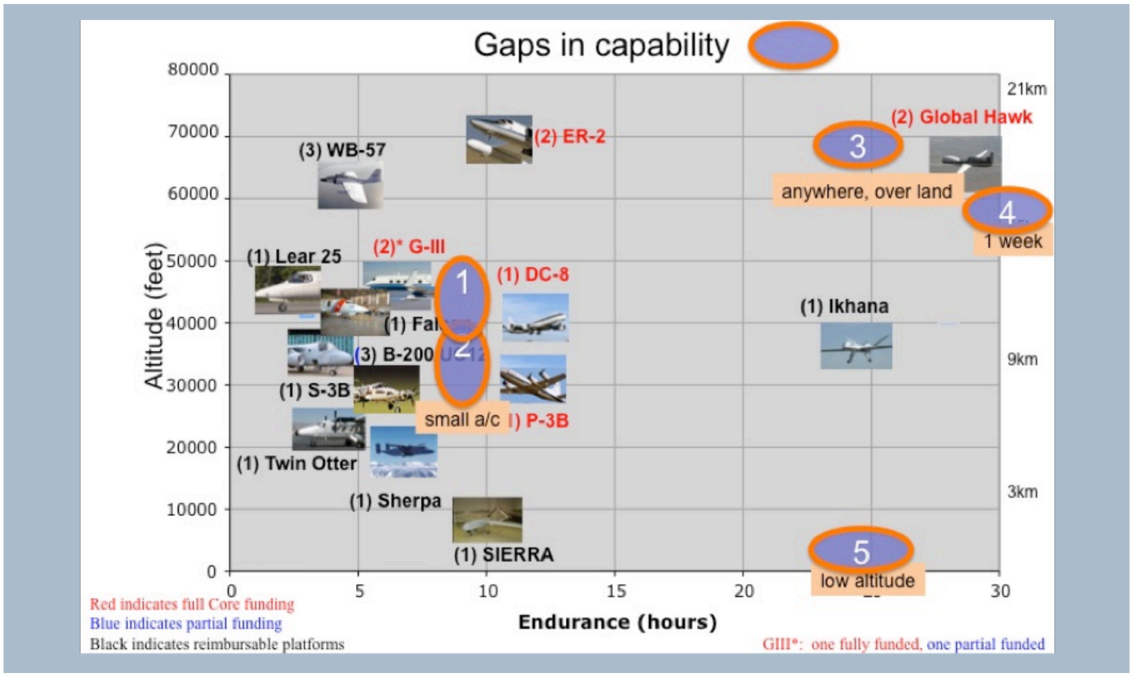


Figure ES-3 Summary of aircraft gaps as identified by NASA Science Center Survey

Table ES-1 Explanation of gaps indicated in Figure ES-3.

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

1. Introduction

Objectives and Background

The purpose of this report is to update known and projected capability requirements for the NASA Airborne Science Program (ASP). The ASP charter is to meet the airborne mission needs of the NASA Earth Science community. Previous reports have addressed the breadth and depth of needs so that capabilities can be available in the present and future. This report addresses the latest information based on discussions with Earth scientists in the NASA community, program scientists at NASA HQ, science teams for upcoming satellite missions, and science teams for upcoming field missions. It also draws on the data in the Science Operations Flight Request System (SOFRS), although flight requests tend to be more near-term and based on what's available.

One major objective has been to determine if the current make-up of the ASP aircraft fleet needs adjusting – adding or subtracting vehicles from the fleet. Another major objective is to identify mission support needs that require investment, as in integration infrastructure, data handling or communications systems. Science instrumentation / payload needs are noted in this report, where appropriate, but instrumentation development is not typically funded through the Airborne Science Program.

Scope

This report addresses the many capabilities of the Airborne Science Program that together provide science investigators with the performance, data and information needed for their missions. These include:

- Aircraft systems, both manned and unmanned, with a wide spectrum of flight altitudes, ranges, and speeds. Flight planning and deployment planning.
- Payload carrying capabilities, including weight and volume, power, environmental control, specialized access ports, windows and probes. Pods and dispensers.
- System integration of payload systems, multiple payloads, data and communication systems. Multi-platform mission coordination.
- Satellite science teams and presentation materials
- Mission tools, including real-time data access, communications, and mapping.
- Science support instrumentation and systems, such as cameras and inertial measurement units (IMUs)

In recent years, the mission tools have become nearly as important to the science community as the flight and payload characteristics of the ASP systems. The ability to observe, monitor and control aspects of the experiment in real-time and collaboratively greatly increases the science return from airborne missions.

Approach to data collection

We have collected requirements information from many sources, including:

- Existing flight requests, aircraft flight schedules, 5-yr plan
- Historical documents – previous reports
- Recent science meeting proceedings and reports
- Interviews with program managers and program execs
- Interviews with principle investigators
- Satellite science teams and presentation materials
- Interagency science groups / documentation
- NASA Centers survey activity and requirements meeting

The last item refers to survey activity that occurred in late 2012 and a review meeting which took place on April 19, 2013. The results from this activity are highlighted in this report.

Previous work also forms the basis for this report, including

- "Suborbital Science Missions of the Future" workshop reports and documentation (2004)
- "NASA Earth Science for Suborbital Observations" (2007)
- "2010 report on Airborne Observations required to support the next generation of NASA Earth science satellites"
- Airborne Science Program Annual Reports

Report structure

The report is structured as follows. Section 2 summarizes the current assets of the program and includes a brief synopsis of past fleet utilization and requirements analysis efforts. (Detailed specifications of the current capabilities are included in Appendix A.) This hints toward anticipated future utilization. Section 3 presents known or projected requirements for Earth Science satellite missions, process studies and technology development. Section 4 summarizes the activity and results of the recent Science Center Survey initiative, including gaps and investments identified from that activity. Section 5 presents a synthesis, recommendations and conclusions. Appendix B contains the most recent ASP 5-year plan.

2. Airborne Science Program Portfolio of Assets

Current NASA Assets

Table 1 lists the current aircraft portfolio of the program. The science community also has access to numerous other platforms through cooperation with ICCAGRA, as discussed in Appendix A.

Table 1 Current ASP Platforms

Airborne Science Program Resources	Platform Name	Center	Duration (Hours)	Useful Payload (lbs.)	GTOW (lbs.)	Max Altitude (ft.)	Airspeed (knots)	Range (Nmi)	Internet and Document References
ASP Supported Aircraft*	DC-8	NASA-DFRC	12	30,000	340,000	41,000	450	5,400	http://airbornescience.nasa.gov/aircraft/DC-8
	ER-2 (2)	NASA-DFRC	12	2,900	40,000	>70,000	410	>5,000	http://airbornescience.nasa.gov/aircraft/ER-2
	Gulfstream III (G-III) (C-20A)	NASA-DFRC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Dryden
	Gulfstream III (G-III)	NASA-JSC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_-_JSC
	Global Hawk (2)	NASA-DFRC	30	1900	25,600	65,000	345	11,000	http://airbornescience.nasa.gov/aircraft/Global_Hawk
	P-3	NASA-WFF	14	14,700	135,000	32,000	400	3,800	http://airbornescience.nasa.gov/aircraft/P-3_Orion
Other NASA Aircraft	B-200 (UC-12B)	NASA-LARC	6.2	4,100	13,500	31,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_UC-12B_-_LARC
	B-200	NASA-DFRC	6	1,850	12,500	30,000	272	1,490	http://airbornescience.nasa.gov/aircraft/B-200_-_DFRC
	B-200	NASA-LARC	6.2	4,100	13,500	35,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	B-200 King Air	NASA-WFF	6.0	1,800	12,500	32,000	275	1,800	https://airbornescience.nasa.gov/aircraft/B-200_King_Air_-_WFF
	C-130	NASA-GSFC	10	36,500	155,000	33,000	290	1,050	https://airbornescience.nasa.gov/aircraft/C-130_Hercules
	C-23 Sherpa	NASA-WFF	6	7,000	27,100	20,000	190	1,000	http://airbornescience.nasa.gov/aircraft/C-23_Sherpa
	Cessna 206H	NASA-LARC	5.7	1,175	3,600	15,700	150	700	http://airbornescience.nasa.gov/aircraft/Cessna_206H
	Dragon Eye	NASA-ARC	1	1	6	500+	34	3	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	HU-25C Falcon	NASA-LARC	5	3,000	32,000	42,000	430	1,900	http://airbornescience.nasa.gov/aircraft/HU-25C_Falcon
	Ikhana	NASA-DFRC	24	2,000	10,000	40,000	171	3,500	http://airbornescience.nasa.gov/aircraft/Ikhana
	Learjet 25	NASA-GRC	2	2,000	15,000	45,000	350	1,000	http://airbornescience.nasa.gov/aircraft/Learjet_25
	S-3B Viking	NASA/GRC	6	12,000	52,500	40,000	350	2,300	http://airbornescience.nasa.gov/aircraft/S-3B
	SIERRA	NASA-ARC	10	100	400	12,000	60	600	http://airbornescience.nasa.gov/platforms/aircraft/sierra.html
	T-34C	NASA-GRC	3	100	4,400	25,000	150	700	http://airbornescience.nasa.gov/aircraft/T-34C
	Twin Otter	NASA-GRC	3	3,600	11,000	25,000	140	450	http://airbornescience.nasa.gov/aircraft/Twin_Otter_-_GRC
	UH-1	NASA-GSFC	2	3,880	9,040	12,000	108	275	https://airbornescience.nasa.gov/aircraft/UH-1_Huey
	WB-57 (3)	NASA-JSC	6.5	8,800	72,000	60,000+	410	2,500	http://airbornescience.nasa.gov/aircraft/WB-57

*ASP-supported means flight hours subsidized by NASA ESD. The JSC G-III is ASP-supported through FY14.

In addition to aircraft, the program maintains facility instrumentation, communications systems and data access and processing equipment. Furthermore, other program assets include important software systems: the ASP website, the Science Operations Flight Request System (SOFRS), and the Mission Tools Suite (MTS). All assets and capabilities of the Airborne Science Program are detailed in Appendix A.

Historical ASP Fleet Utilization and Requirements Analysis Activities

Historical data on aircraft flight hours can be used as a guide to future demand for the ASP fleet. Shown in Figure 1 are total program flight hours for the past 15 years. The total has grown significantly in recent years, especially with Operation IceBridge and Earth Venture-1 activities. This trend is expected to continue, especially with the recent release of the Earth Venture Suborbital-2 solicitation.

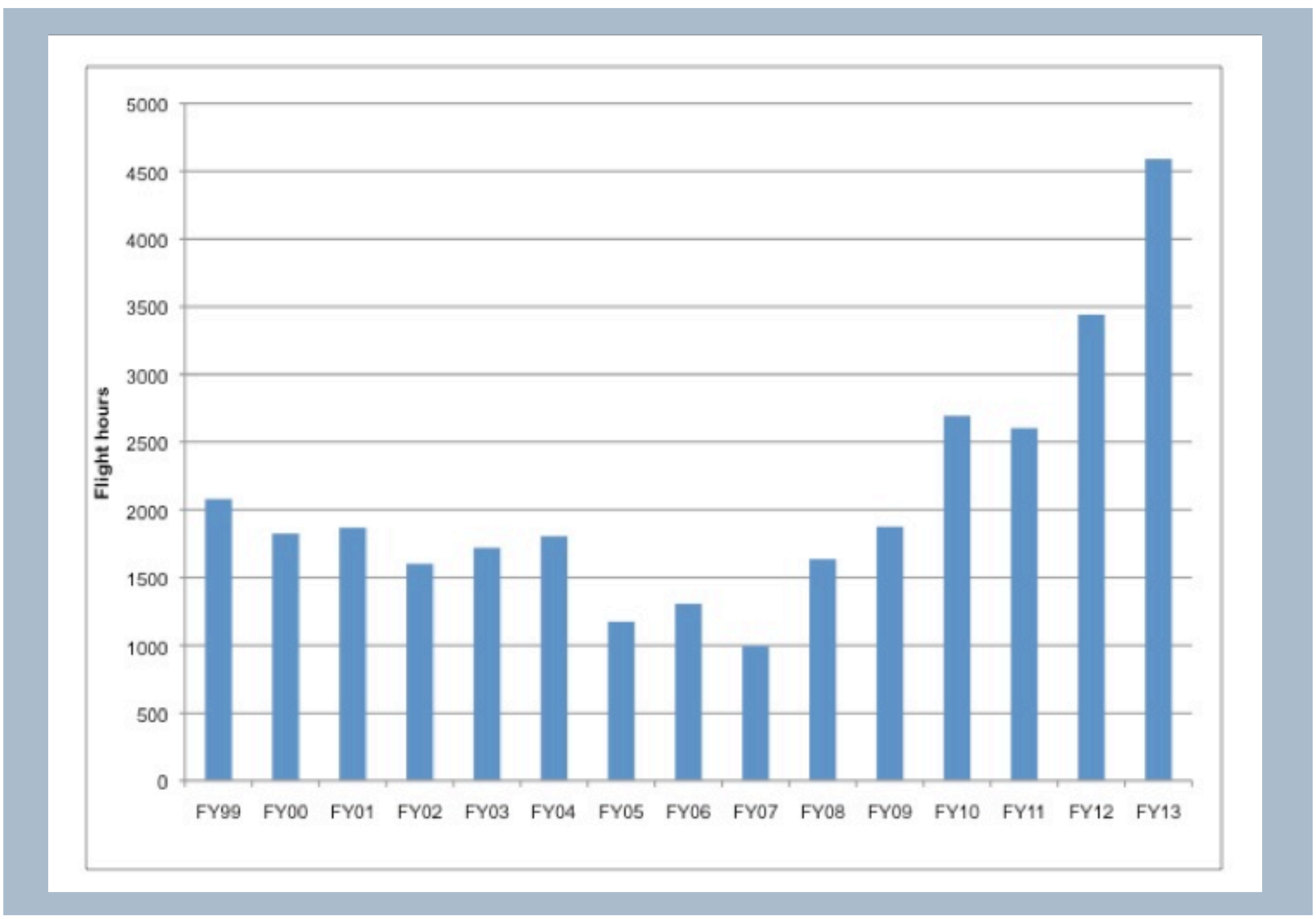


Figure 1 Airborne Science Flight hours. Hours in FY2013 exceed 4580.

Shown in Table 2 is the composition of the flight hours across the fleet for 2012. Table 3 shows historical data since 2006. Note that the majority of the flight hours are for the ASP program-supported aircraft, including especially the use of the Gulfstream – III carrying the UAVSAR instrument. This trend is anticipated to continue for the foreseeable future. A parallel trend is the steady use of other capability, readily available commercially or from other agency providers.

Table 2 Flight hours by aircraft in FY2012

Aircraft	Total FRs	Total Approved	Total Partial	Total Completed	Total Hours Flown
DC-8	10	7	0	4	533.1
ER-2	36	24	3	15	443.2
P-3	14	7	0	5	410.2
WB-57	5	3	0	3	29.7
Twin Otter	33	14	2	11	429.2
B-200	17	10	0	7	157.2
G-3	36	28	8	16	623.8
Global Hawk	3	2	1	1	219.8
C-23 Sherpa	1	1	0	1	257.9
Cessna 206	2	2	0	2	99.3
Falcon - HU-25	1	1	0	1	75.5
Ikhana	11	0	0	0	0.0
Learjet 25	1	1	0	0	0.0
S-3 Viking	1	0	0	0	0.0
SIERRA	33	2	1	1	31.6
T-34	1	1	0	1	37.6
Other	23	16	1	12	539.7
TOTALS:	**228**	**119**	**16**	**80**	**3887.8**

Table 3 Flight hours (per FY) for major Aircraft since 2006

Aircraft	2006	2007	2008	2009	2010	2011	2012	2013
DC-8	264	104.8	292.1	20.3	650.8	228.3	533.1	474.5
ER-2	168	190.4	148.9	150.7	188.8	143.7	443.2	566.8
P-3	123	250.9	201.4	216.1	112.1	533.3	410.2	462.3
G-III	-	0	155.9	526.0	278.8	448.4	623.8	890.5
Global Hawk	-	-	-	0	227.3	0	219.8	517.3
WB-57	122	83.8	11.3	44.5	40	79.7	29.7	0
B-200	157	55	415.7	331.8	274.6	304.5	157.2	258.3
Twin Otter	199	171.7	327.4	103.8	292.1	281.6	429.2	150.7
Sherpa	-	-	-	-	-	0-	257.9	320.1
SIERRA	-	-	0	76	10	17	31.6	5.8
Falcon	-	-	-	-	-	-	75.5	31.9
Cessna 206	-	-	0	41.0	18.3	87.2	99.3	0
C-130	-	-	-	-	-	-	-	2.0
T-34	-	-	0	26.4	73.7	0	37.6	35.1
Ikhana	-	79.1	54.5	0	0	0	0	0
Learjet 25	-	-	4.1	66.7	14.6	0	0	0
Aerosonde	74	11	23.5	0	-	-	-	-
Altair	73	98.4	-	-	-	-	-	-
Other	108	40.1	-	273.4	523.1	363.7	539.7	868.6
TOTALS:	**1288**	**996.1**	**1634.8**	**1876.7**	**2704.2**	**2605.4**	**3887.8**	**4583.9**

Past requirements analysis activities have been useful in providing guidance for the program. For example, the chart in Figure 2 was developed for the 2007 study. Note that many of the needs listed there have been met with new capabilities in recent years. Significantly, the Global Hawks provide long duration, long range flight at very high altitude. Also, precision location and navigation data are now available on all ASP-supported aircraft, allowing flight tracking during and after flight. On the other hand, some of these requirements are still unfulfilled, including routine access to the National Air Space for UAS, easy basing in remote areas, and payload-directed flight.

Sample priority matrix, from 2007 report

Platform Capabilities	Atm Comp - StratChem/ Rad; TropChem		Carbon Cycle		Climate, Cryosphere		Solid Earth		Water Cycle		Weather	
	5 year	10 year	5 year	10 year	5 year	10 year	5 year	10 year	5 year	10 year	5 year	10 year
Long Range (>5000nmi)	2; 2	1	3	2	1	0	1; 3	1; 1.5	3	2	2	1
Long Endurance (>12hrs)	2; 2	1	3	2	1	0	1; 3	1; 1.5	3	1	2	1
Base of operations in Remote Area	1; 3	1	1	1	1	0	1; 2	1; 2	1	1	2	2
Very high altitude (>60 ft)	1; 3	1	3	2	2	0	2; 1	2; 1	3	2	1	1
Very low altitude (<1000ft)	1; 1	1	2	2	2	0	3; 3	3; 3	2	1.5	2	1
Vertical Profiling	1; 1	1	1	1	3	0	3; 3	3; 3	2	1.5	2	2
Heavy lift/Multiple payloads	2; 1	2	1	1	1	0	3; 3	3; 3	3	2.5	2	1
All Weather Conditions	2; 2	2	3	3	1	0	1; 2	1; 2	3	2.5	1	1
Monitoring/control Multi-ship Operation; mother-daughter-ship	3; 3	2	3	3	0	0	2; 3	1; 2	3	1.5	2	2
Terrain Avoidance / terrain following	3; 3	3	2	2	1	0	3; 3	3; 3	2	1	3	3
Formation Flight / stacked, horizontal	2; 2	2	1	1	2	0	1; 2	1; 1	3	2	2	1
Precision Trajectories & Position/Nav data	3; 3	3	1	1	1	1	1; 1	1; 1	2	2	2	2
Payload-directed flight	3; 1	2	1	1	0	0	1; 1	1; 1	2	2	2	2
Quick deployment; event driven	3; 2	2	1	1	2	0	1; 1	1; 1	2	1.5	2	2
Expendable systems	3; 3	3	3	3	0	0	2; 3	2; 2	3	2	2	2
UAS access to airspace	1; 1	1	1	1	1	1	1; 2	1; 2	1	1	2	1

Legend: 1 is highest priority, 3 is lowest priority, 0 is no data

Figure 2 Requirements chart from 2007 study. Multiple values indicate input from more than one source in the program area. Red ☐ is highest priority. Yellow ☐ is medium priority. Grey ☐ is lowest priority. White ☐ is no data.

3. Requirements for Earth Science

Given the fleet of platforms and their capabilities as described previously, the question to the scientist is: does this range of capabilities meet your science needs? Since NASA Earth Science covers many topics, the range of observation and measurement requirements is also very broad. From past, current and future requirements activities, it is possible to describe and draw the general science regimes for airborne performance. The spectrum covers a wide range of altitude, duration, range and payload capability. Figure 3 is a science overlay in altitude – endurance space, based on ten years of combined data points from science community studies, including the "Suborbital Science Missions of the Future." Figure 4 is based on more recent input.

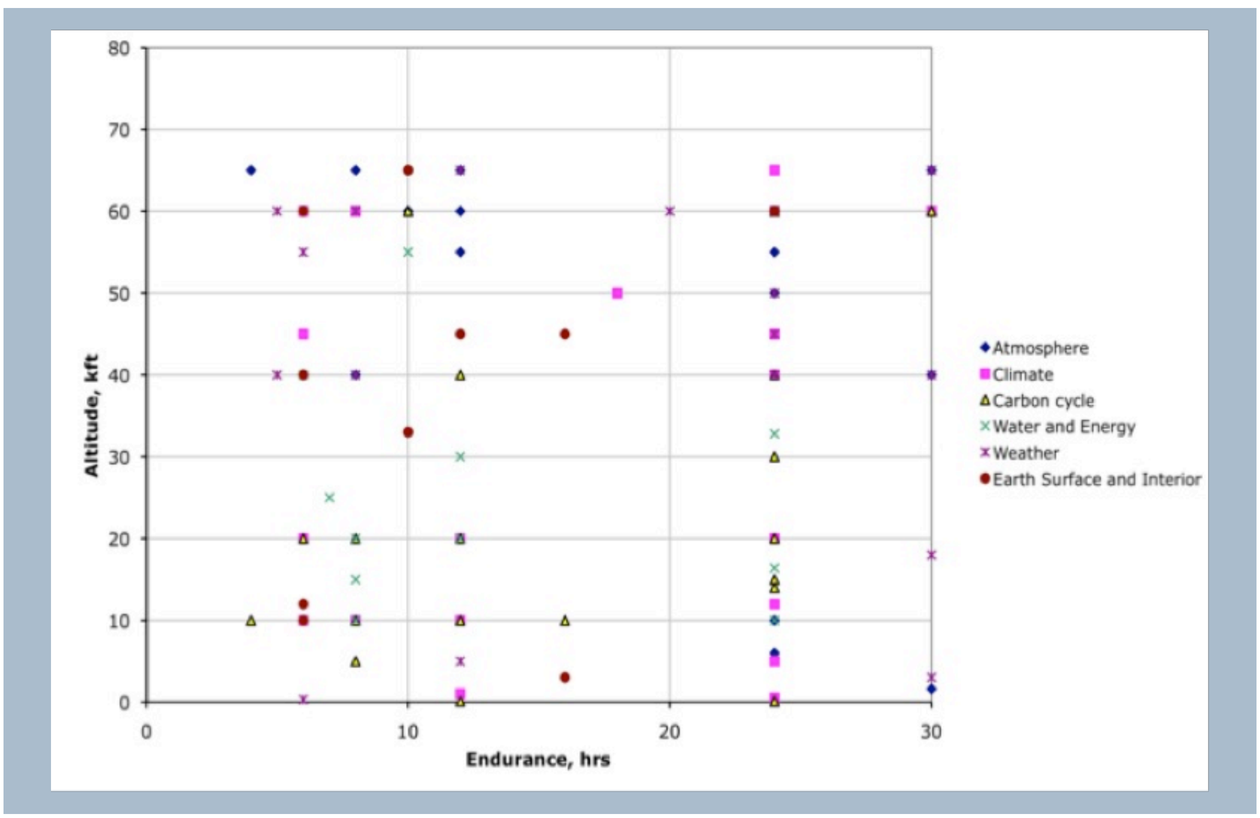


Figure 3 Science overlay - requirements in altitude-duration space for Earth Science focus areas. (Data from ASP science database.)

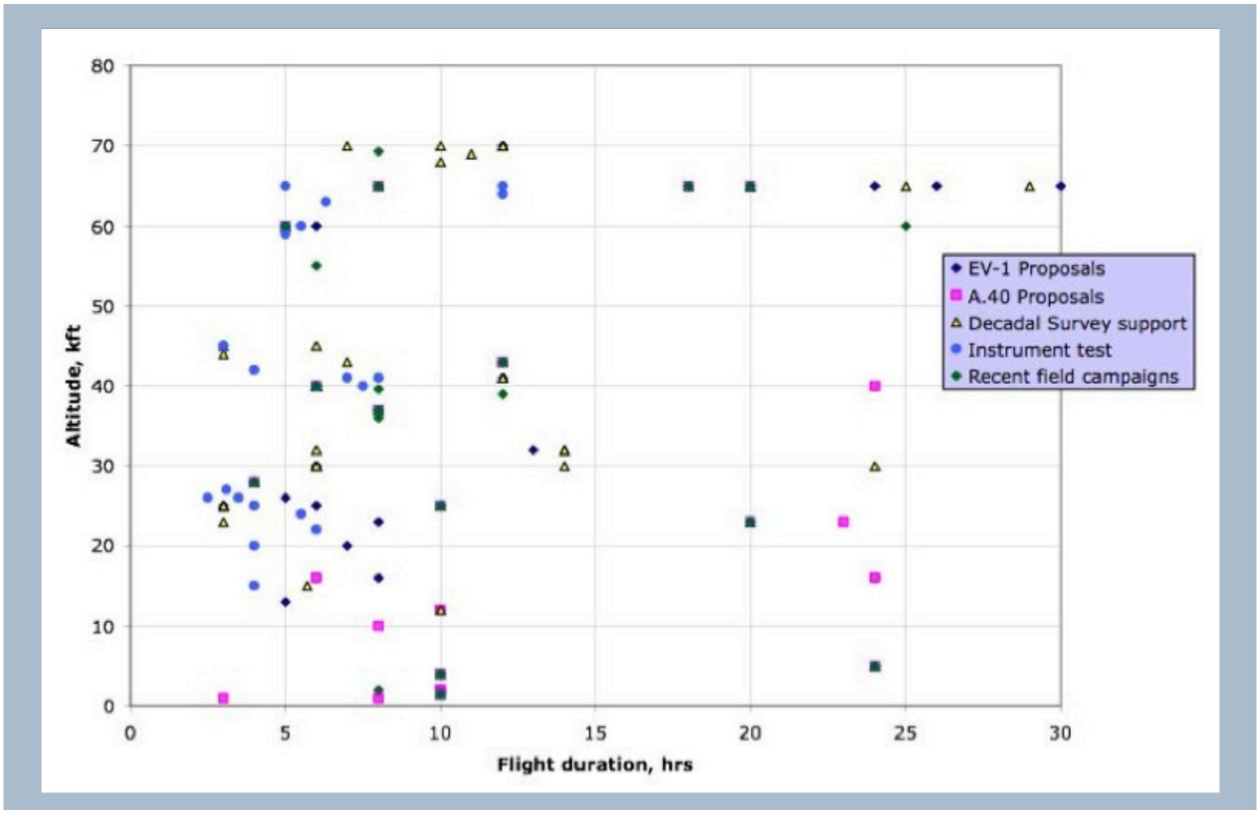


Figure 4 Derived requirements from recent studies

Definitions and Requirements

This section describes the science regimes and the science motivation for platform performance. In general, a balanced portfolio of low, medium, and high altitude aircraft will be needed to operate, test and evaluate advanced instruments and mission design concepts.

Very High Altitude (>60,000 ft) High Altitude (>50,000 ft) - Enables testing instrument retrievals and assessment. High-altitude, multi-payload, stable flight platform (e.g., ER-2, WB-57) for precise satellite under flights

Mid Altitude (20,000 – 45,000 ft) – Medium- to large-size aircraft are cost effective, capable platforms for correlative studies with ground sensors, low aircraft and satellites. Long-duration, long-range, mid-altitude aircraft (e.g., P-3, DC-8) to deploy in situ, LIDAR and polarimeter instruments for atmosphere and ocean/atmosphere interface studies, with both profiling and constant altitude legs

Low Altitude (<20,000 ft), Very low altitude (<5000 ft) - small to mid-size aircraft (e.g., B-200) for deploying in situ and remote sensors to validate retrievals

High altitude flight is required for simulation of satellite / space missions because the observations are made from above most of the atmosphere and line of sight or column lengths are long. Furthermore, the environmental conditions simulate space if the payload is not in a controlled space. High altitude is also desirable for atmospheric measurements at the tropopause and in the stratosphere.

Additional reasons for flying high:

- Reach the very important upper troposphere/ lower stratosphere boundary (UTLS)
- Fly over cloud tops and over a greater depth of the cloud
- Simulate space environmental conditions
- Simulate column seen from space
- Simulate area coverage seen from space
- For a given instrument, swath width scales linearly with altitude (AGL) and pixel resolution scales inversely
- Air traffic control regulations change at higher altitudes (usually more lenient)

It is still not possible to completely sample the troposphere (45-50 kft) with in situ sensors on board a single aircraft without compromising on either payload or ceiling. In general, longer-duration, longer-range, higher-altitude, more cost-effective aircraft are needed.

Heavy lift above 40 kft to reach the tropopause is of huge value. Heavy lift is defined as the ability to carry as many as 12 different payload instruments and can weigh from 2000 to 6000 lbs. Medium lift above 27 kft and for long duration (8 hr) is also needed. Medium lift is defined as the ability to carry up to 6 different payload instruments and can weigh from 200 to 600 lbs.

Additional reasons for long duration:

- Diurnal (24 hrs) and longer continuous measurements are needed
- Range to remote locations often requires long duration flight if there will be time to take data. Especially needed is long-range capability to make measurements over the polar regions.

Flying laboratory at mid-altitude

The research community still mostly requires scientists onboard. This is important for research, technology development & testing, and generally more cost effective than investing in autonomy for research operations.

Interdisciplinary focus of the science requires more complex payloads, so heavy lift is still a premium (20+ instruments), although there are still questions that can be investigated with a medium sized payload (e.g., 5-10 instruments).

Low altitude / long endurance

Low altitude flights are especially useful for some land surface measurements, canopy measurements, and ocean measurements. Pixel size or other measurement resolution improves with closeness to the surface. Often the regions of interest are remote - a far distance from the aircraft base and so long range is required. For some measurements, long endurance is desirable for mapping large areas without returning to base.

Requirements related to Earth Science focus areas field and process studies

Most of the requirements 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. (http://airbornescience.nasa.gov/sofrs/) Referring to the 5-year plan in the Appendix, upcoming process studies in each of the six Earth Science program areas are summarized in Table 4 below. Near-term requirements for completing EV-1 projects are listed in Table 5.

Table 4 Upcoming Science Program process studies and supporting aircraft

Science Focus Area	Mission	Year	Aircraft
Atmospheric Chemistry and Composition	Atmospheric Composition Campaign (SEAC4RS-like)	2016 2019	DC-8, ER-2 DC-8, ER-2
Carbon cycle and Terrestrial Ecology	ABoVE Ecosystem Structure	2015 + 2014 +	Sherpa G-III
Cryosphere	Iceland Glaciers	2014	G-III
Water and Energy Cycle	Airborne Snow Observatory Snow field campaign	2013, 14 2015, 16	Twin Otter DC-8, P-3
Earth Surface and Interior	UAVSAR faults and landslides Volcanic plumes	2014 + 2014, 15	G-III Small UAS
Weather	Atmospheric Dynamics Mission	2015	DC-8

Table 5 Remaining EV-1 flights and supporting aircraft

Mission	Year	Aircraft
ATTREX	2014	Global Hawk
CARVE	2015, 15	Sherpa
DISCOVER-AQ	2014	P-3, B-200
HS3	2014	(2) Global Hawk
AirMOSS	2014, 15	JSC G-III

Requirements related to NASA Satellite Missions

The NASA Earth Science community depends for a majority of Earth Science studies on data from Earth-orbiting satellites. The Airborne Science Program supports Earth Science satellite missions in a variety of ways:

- algorithm development prior to launch
- instrument test during the mission development phase
- calibration and validation after launch
- field tests that parallel the mission measurements with improved temporal or spatial specificity or resolution
- observation technique development

A significant portion of ASP missions support or complement satellite missions. One representative example is the annual CALIPSO cal/val mission, on going since 2006. CALIPSO, along with CloudSat provide aerosol and cloud data from space. In 2008, the "Caribbean Validation Mission" used data from the High Spectral Resolution LIDAR (HSRL) flying on the LaRC B-200 to verify the true effectiveness of new daytime calibration algorithms being applied to data from the CALIOP LIDAR on the CALIPSO satellite. In 2009, a series of flights of the HSRL on the LaRC B-200 was flown to verify that the calibration of the CALIOP LIDAR on CALIPSO before and after a laser transmitter switch was made. The data from the HSRL flights proved conclusively that the calibration of the satellite instrument was not affected by the change in lasers. In 2011, HSRL participated in MACPEX, again providing cal/val data for CALIOP. In 2012, a new version of the HSRL, along with the Research Scanning Polarimeter (RSP) from NASA GISS, returned to the Caribbean for more CALIOP cal/val measurements. In 2013, HSRL participated in DISCOVER-AQ.

Many other ASP flight experiments support satellites in the A-Train, including AQUA, AURA, TERRA and TRMM. The Atmospheric Composition and Chemistry focus area uses field data to complement composition measurements from space, while the Weather focus area relies on measurements in severe storms to complement wind and precipitation observations. In support of ASTER and MODIS imaging products, the MASTER and MAS instruments, flying on the ER-2 and other aircraft, act as satellite simulators for numerous terrestrial ecology, fire and land use / land change studies. The current suite of Earth Science satellites is shown in Figure 5.

A current major development phase for NASA Earth Science is the preparation to fly satellite missions proposed by the National Research Council's Decadal Survey.[1] The proposed mission set is shown in Figure 6. These "Decadal Survey missions" are driving much of the current requirements not only for Airborne Science, but also for the Earth Science Technology Office (ESTO) programs. (http://esto.nasa.gov). A recent hour-tally of support from ASP to Decadal Survey missions is shown in Figure 7. These are self-reported indications from the Principle Investigators, as to which missions their science supports.

1 NRC Decadal Survey: "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," released 15 January 2007.

Figure 5 Current Earth Science Satellite Missions

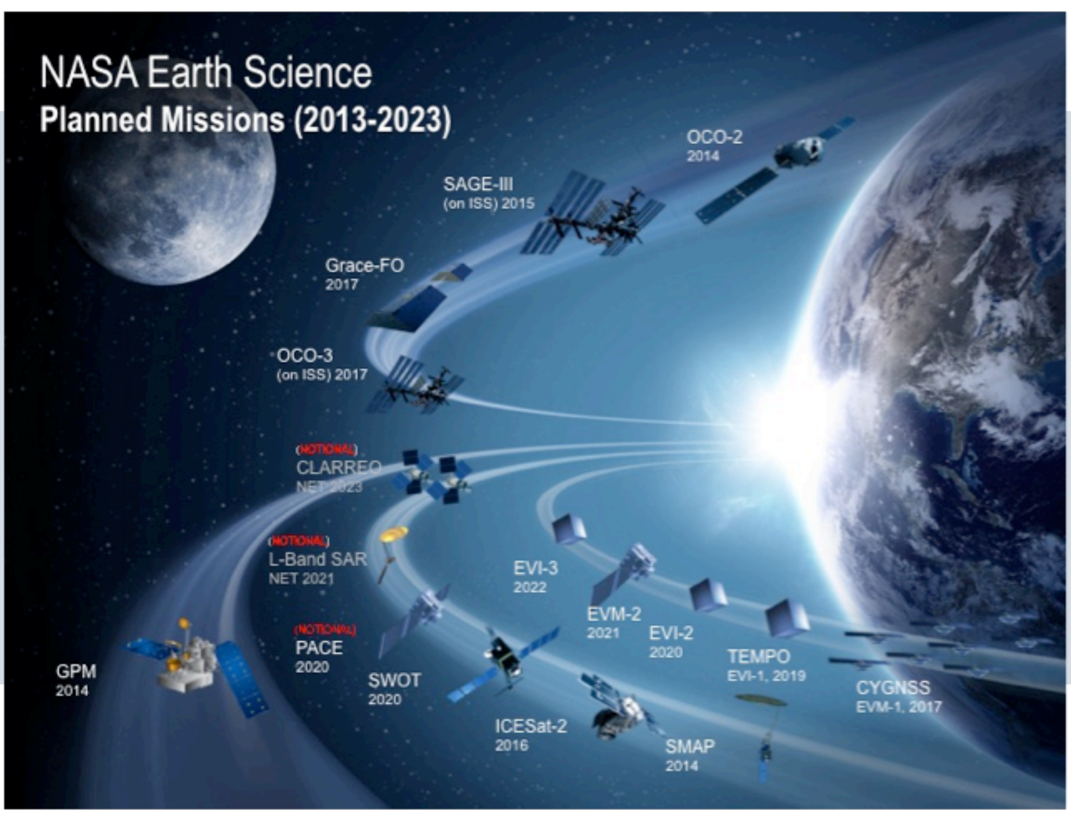


Figure 6 Orbits and Launch Dates for Future Earth Science Satellite Missions

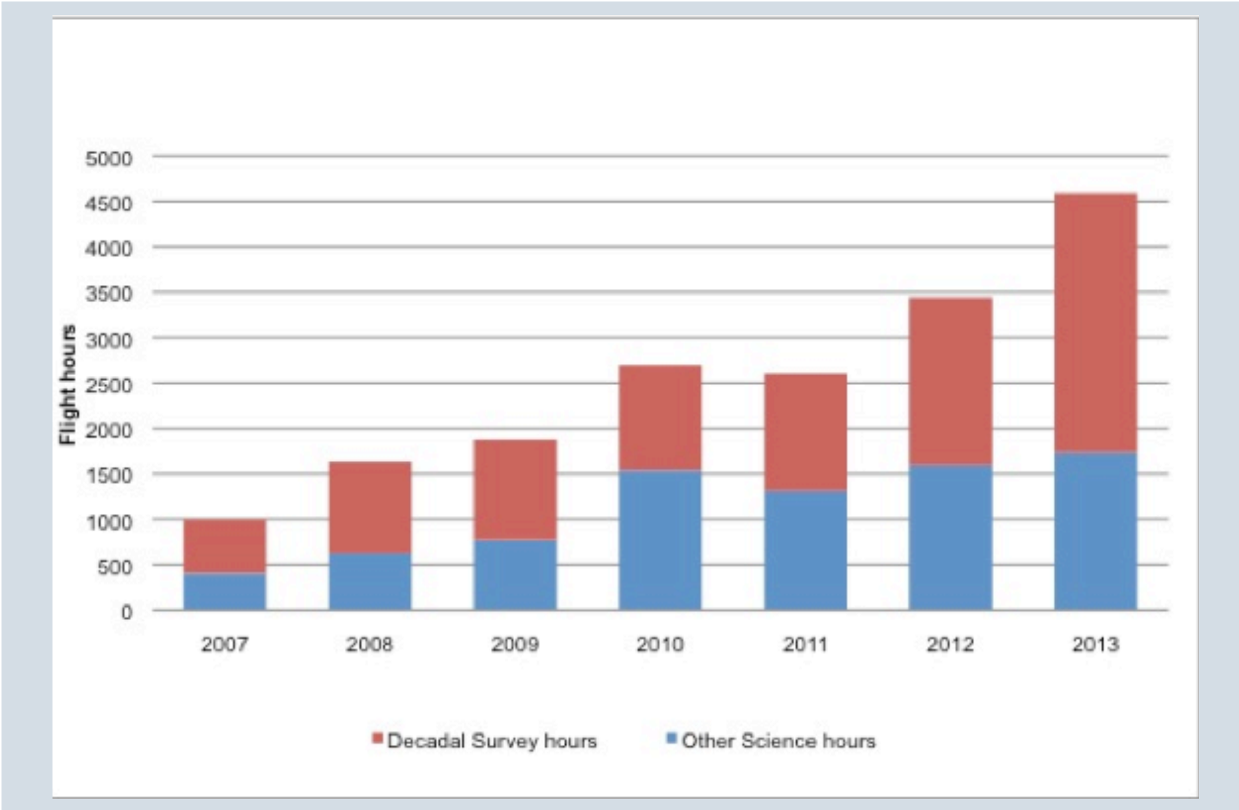


Figure 7 Airborne flight hours in support of Decadal Survey mission preparations. (Self-reported by principle investigators.)

Table 6 lists upcoming foundational and Decadal Survey missions and summarizes current and potential future plans for ASP support. Since many of these missions are scheduled for launch after 2020, the requirements are expected to grow.

Table 6 Decadal survey and foundational missions and anticipated ASP support.

Mission	Satellite Instruments	Supporting Airborne Instruments	Airborne Science Supported Activities	Aircraft
Foundational Missions				
OCO 2	NIR spectrometer	Picarro CO2/CH4	Algorithm development, cal/val	SIERRA, Alphajet
GPM	Microwave Imager, Doppler Precipitation Radar (DPR)	AMPR, COSMIR, HIWRAP	Algorithm development, cal/val	ER-2, DC-8
GRACE Follow-on	Advanced laser range-finding interferometer		Operation IceBridge	P-3
GOES-R	Advanced Baseline Imager (16 channels)	AVIRIS/MASTER	Algorithm development, cal/val	ER-2
Decadal Survey Tier I Missions				
SMAP	L-band radar, L-band radiometer	UAVSAR, PALS	SMAPVEX 2015	G-III, Twin Otter, P-3
ICESat II	Laser altimeter	LVIS/ATM/MABEL; GLISTEN	Operation IceBridge	DC-8, P-3, DH-3, ER-2, C-130, GH
DESDynI (L-band Radar)	InSAR, LIDAR	UAVSAR	Algorithm development	G-III, GH
Decadal Survey Tier II Missions				
SWOT	Kaband radar, C-band radar	KaSPAR, HAMSR, AirSWOT	Cal/val	GH, B-200
ASCENDS	CO2 LIDAR	CO2 lasers	Instrument flight test	DC-8, B-200, TO
HyspIRI	VIS-IR imaging spectrometer	AVIRIS, MASTER, AVIRIS-ng, HYTES	Instrument test, algorithm development	ER-2, Twin Otter
PACE	Ocean radiometer (ORCA), OES	ORCA simulator; PRISM; HSRL	Instrument test; field test	Twin Otter; B-200
ACE	Polarimeter, LIDAR, cloud radar	Competing polarimeters, HSRL-2, EXRAD	Instrument flight test; cal/val	ER-2 / P-3 / B-200
GEO-CAPE	Hyperspectral imagers	GEO-TASO; Pan-FTS, PRISM	Algorithm development, instrument flight test	Falcon, Twin Otter, ER-2
Decadal Survey Tier III Missions				
SCLP	Ku- and X-band radars, K- and Ka-band radiometers	X-band phased array (IIP), K- and Ka-band radars	Instrument flight test, radiometers on GH	B-200, GH
LIST	LIDAR	Swath-mapping LIDAR (IIP)	Instrument flight test	Lear 25
GACM	UV spectrometer, IR spectrometer, Microwave limb sounder	Microwave limb sounder (IIP)	Instrument flight test	WB-57
PATH	Microwave array spectrometer	MW array spectrometer	Instrument flight test	Twin Otter, P-3
GRACE II	Microwave or laser ranging systems	Limb sounder	Instrument flight test	P-3
3-D WINDS	LIDAR	DAWN-Air2, TwiLiTE, Coherent Doppler LIDAR (AITT)	Instrument flight test	DC-8, WB-57
New Operating Missions				
Aquarius	Radiometers, Scatterometer	UAVSAR, radiometers	Cal/val	G-III, SIERRA
NPP	VIIRS, CrIS, ATMS, OMPS	NAST, S-HIS, eMAS, PSR, APMIR, MASTER, AVIRIS	Cal/val	P-3, Twin Otter, ER-2
LDCM	Spectrometer	AVIRIS, AVIRIS-ng, LVIS, UAVSAR, G-LIGT; spectrometer	Cal/val	ER-2, G-III, Twin Otter, DC-8, P-3

Near-term missions with specific airborne plans

Listed below are some upcoming Earth observation satellite missions and supporting airborne activities. These are derived directly form flight requests or documented plans, and do not reflect longer terms concepts under consideration by science teams. It would be useful to the Airborne Science Program for each satellite mission team to include formal airborne support planning, especially for algorithm development, calibration and post-launch validation, in their Key Decision Point (KDP) activities. It has also been recommended that the current ASP planning approach be supplemented by one or more workshops dedicated to this issue in 2014.

GPM

An intensive precipitation field campaign supported by the GPM mission will be conducted during the spring/summer of 2014 in conjunction with NOAA's Hydrometeorological Test Bed (HMT). The ER-2 aircraft campaign will be coordinated with ground-based observations and with cloud in-situ measurements conducted with the University of North Dakota Citation aircraft. Use the NASA ER-2 as a platform for collection of microwave radiometer and radar remote sensing data that simulate the observations planned for NASA's GPM spaceflight mission.

SMAP

SMAP is currently scheduled to launch in October 2014. A cal/val plan has been devised for the early post-launch period in 2015, called SMAPVEX 2015. Prior to SMAPVEX 2015, the SMAP program is actively preparing for that time by collecting and analyzing UAVSAR and PALS data. Either or both the P-3 or Twin Otter will also support SMAPVEX 15.

ICESAT-2

ICESAT-2 preparation is primarily through the activities of Operation IceBridge and data collection using MABEL, the new ICESAT-2 simulator. MABEL has flown on the ER-2 and is currently flying on the Scaled Composites Proteus. OIB is scheduled to continue through 2016, as launch is currently scheduled for mid-July 2016. Another instrument, GLISTEN-A, also supports ICESAT-2 and is being modified to fly on Global Hawk (GLISTEN-H).

SWOT

The airborne simulator for SWOT, called AirSWOT, has been flight tested on a B-200, but a higher altitude aircraft is desirable. AirSWOT measurements also support Aquarius.

PACE

The ocean color instrument for the PACE satellite (called OCI) will require not only pre-launch calibration, but also post-launch validation. Field studies are anticipated. Aircraft carrying AVIRIS, CASI or similar instruments are assumed to participate in PACE, just as in ACE. A detailed schedule has not yet been developed, but will be similar to that previously developed for ACE. A field experiment using both HSRL and PRISM is also scheduled to begin in 2014.

HyspIRI

HyspIRI preparation flights are taking place in 2013 and also planned for 2014. In this program, both the AVIRIS and MASTER instruments are flying on the ER-2, performing mapping in California to provide pre-launch data for data processing development. Other potential instruments include AVIRIS-ng, PRISM and HyTES, as precursors to HyspIRI.

ACSENDS

Preparation for the ASCENDS mission is focused on understanding the characteristics of several candidate CO2 sensors. A series of experiments on board the DC-8 have carried three different instruments over calibrated sites to assess performance. Future flights are also planned.

The Next Decadal Survey

The next NRC Decadal Survey for Earth Science is expected in early 2017. Plans are already underway for accepting input from the science community and forming working groups. The 2007 recommendations for satellite missions were ambitious and costs were underestimated. It is likely that some of the same observations and measurements will again be recommended, since many of the science needs are still pressing. An emphasis on climate should be expected, given that the “2010 NASA Response to Climate Plan” identified new climate measurements, even beyond those in the 2007 decadal survey.[2] Airborne Science support will still be needed, and possibly with more urgency to cover the time gaps till new missions can be launched.

[2] “Responding to the Challenge of Climate and Environmental Change: NASA’s Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space.” June 2010

Requirements related to instrument development

The Airborne Science Program supports technology development, particularly flight test of new instruments, many of which are ultimately destined for space. Instrument test flights can be scheduled by science 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 technology development projects, investigators work with ASP platform operators to schedule their instruments for integration and test. ESTO is currently completing the 2013 Instrument Incubator Program (IIP) solicitation with awards to be announced in early CY2014, which will likely result in some flight requirements in the 2015-2017 timeframe. Awards from the 2012 Airborne Instrument Technology Transition (AITT) solicitation have not been announced and therefore are not included in the schedule presented here. Near-term flight tests are shown in Figure 8. Some will be ESTO-supported and others are proposed (shown in yellow) or will be supported from other programs.

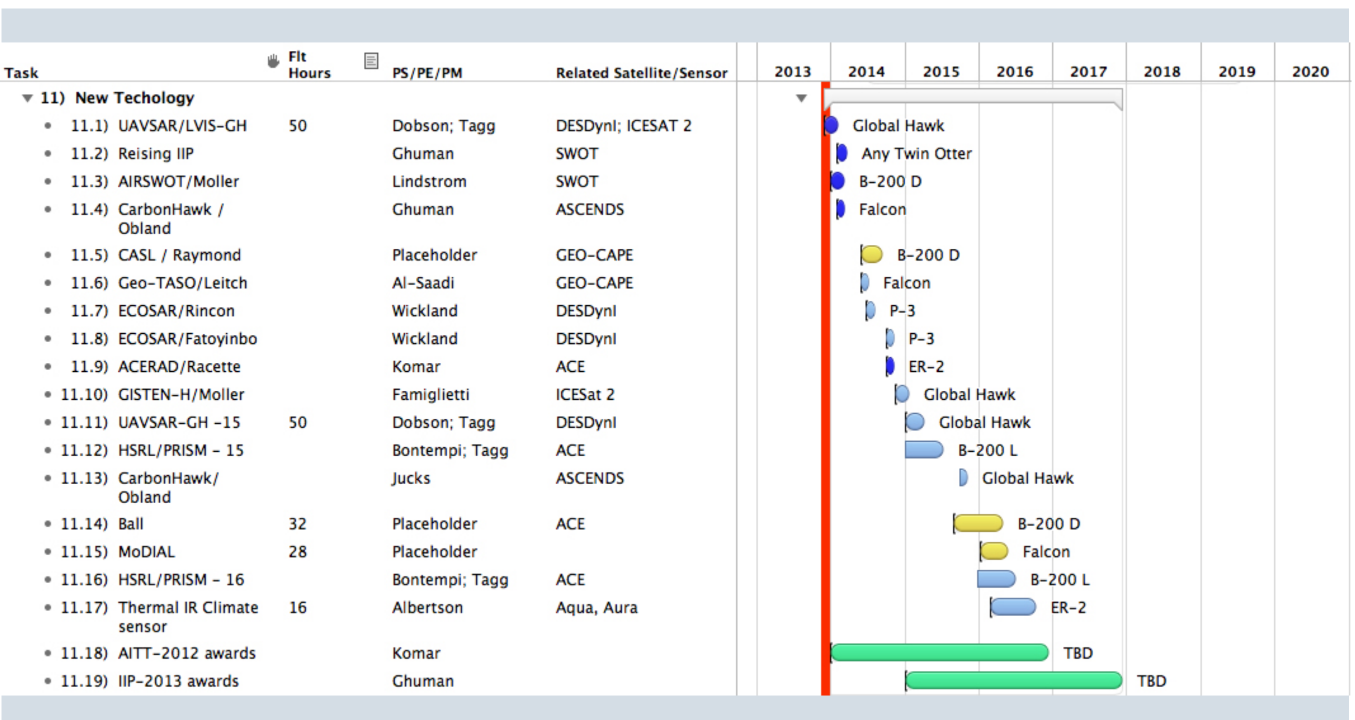


Figure 8 Current technology development flight plans

For the most part, the flight requirements for instrument test are determined by altitude (e.g. ER-2 or WB-57 for high altitude) or location of an airborne asset at or near the PI's location (e.g., LARC B-200 for LaRC investigators). In some ideal cases, several instruments are flown together. An example is the LVIS and UAVSAR together on the Global Hawk. Another possibility is a future opportunity to fly HYTES and AVIRIS-ng together on the G-III, if windows can be appropriately located on the G-III.

Telemetry and Mission Tools Requirements

Airborne science is not just about flying airplanes carrying science payloads. It is important in planning and carrying out the science missions to make use of advanced flight planning and tracking tools, real-time data access and processing, and on-board navigation and inertial position monitoring. This requires real-time telemetry of data from both the aircraft and the science instruments. The telemetry and facility instruments available within the Airborne Science Program are described in Appendix A.

In addition, scientists on the ground need situational awareness with regard to weather conditions and other environmental factors in the vicinity of the aircraft in flight. The last few years have brought significant capability to the Airborne Science Program under the umbrella of the Mission Tools Suite. Current functions are listed in Table 7. Scientists have expressed interest in additional functionality, primarily in terms of path planning coordinated with related Earth Science satellites. Some requests are listed in Table 8.

Table 7 Functions of the Mission Tools Suite

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

Table 8 Additional capabilities requested by science community

MTS Functions
• Visualization of satellite swath during overpass • Mission playback capability • Need tools for estimating the time required for a given flight leg, together with overlays of satellite imagery or numerical model output. • A tool to plan payloads would be useful. Something that would estimate whether a user-defined payload can fit in a weight, volume and CG envelope of a given platform. • A method of storing, integrating, and processing data similar to the "Field Catalog" developed at NCAR would be very useful for complex NASA airborne missions • When we talk about multiple aircraft, we need more sophisticated, automated flight scheduling/planning software.

4. Input from Center Requirements Survey and ASP Requirements Meeting

Process

During the fall of 2012, each of the NASA Science Centers was sent a survey to describe as quantitatively as possible, the science requirements for airborne science capabilities. The survey results were iterated several times to clarify some answers. In April 2013, an ASP web meeting was held to review the survey results and discuss the needs with the ASP program and NASA Earth Science program managers, including the Research and Analysis director.

The NASA Centers surveyed and prime respondents are listed in Table 9. Input was collected from multiple sources and scientists within each Center.

Table 9 NASA Centers surveyed and respondents

Center	Respondents
Ames	Steve Hipskind
Goddard	Paul Newman, Matt McGill, Lisa Callahan
JPL	Gary Lau, Mike Gunson, Bill Mateer
LaRC	Bruce Doddridge
MSFC	Michael Goodman

In the pages of requirements delivered, the areas addressed included:

- Decadal Survey satellite missions
- Other satellite missions
- Science focus and process study areas
- Earth Venture
- Technology demonstration
- Applications
- General aircraft and program needs

Respondents were asked to address the following questions:

1. What are the current capabilities within ASP that your community relies upon and will continue to rely upon for the foreseeable future?
2. What capabilities are lacking and in need of development (platforms, sensors, telemetry, data systems, mission management)? What is the time frame?

3. What are the added benefits of the new capabilities? What impact would there be if these new capabilities don't materialize?
4. What major missions/campaigns are planned over the next 5 years? 10 years?
5. Please describe 4-5 notional mission concepts that represent the breadth of science desired. What Earth Science program focus areas do these concepts represent?
6. How important is payload data telemetry during a mission?
7. What tools would be useful for planning airborne science missions?
8. 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 rather than specific aircraft, but particularly in the near term, aircraft-specific requirements are needed as well.

Additional questions were added later to address specific issues about extreme altitude and endurance. All teams provided answers to these additional questions.

- Why is higher altitude needed for some science? Why is 65,000 ft better than 50,000 ft? Why is 50,000 ft better than 40,000 ft.? Please articulate.
- Why is longer flight duration needed for some science? Why is 24 hours better than 12? Why is 8 hours better than 4 or 5? Please articulate.

Results

The matrix of survey results and Center presentations are available on the airborne science website. [airbornescience.nasa.gov] Following are some highlights.

The highest priority needs:

- Keep DC-8. The laboratory capability is especially needed for atmospheric science missions.
- Keep ER-2. The high altitude capability is needed for both process studies above most of the atmosphere and instrument development for satellite missions. The WB-57 is also available for high altitude science flights. JSC operates three WB-57 aircraft which could be employed for airborne science.
- Keep GH – make it less expensive and easier to use. The very long endurance of the Global Hawk is needed for weather, diurnal investigations and long-range missions.
- Add longer endurance capability in the 35,000 – 40,000 ft regime (size like B-200, but less expensive than the DC-8.). <u>The ideal capability is not currently included in the ASP fleet</u>.

Figure 9 shows flight regime results in altitude-endurance space from the answers to the surveys. Figure 10 indicates which current platforms are needed in the future. Some of the most frequently noted needs are listed in Table 10. (In Figure 10, the terminology "core-funded" refers to the Earth Science Directorate subsidy to these assets in the ASP fleet. The JSC G-III aircraft is only subsidized through FY 2014.)

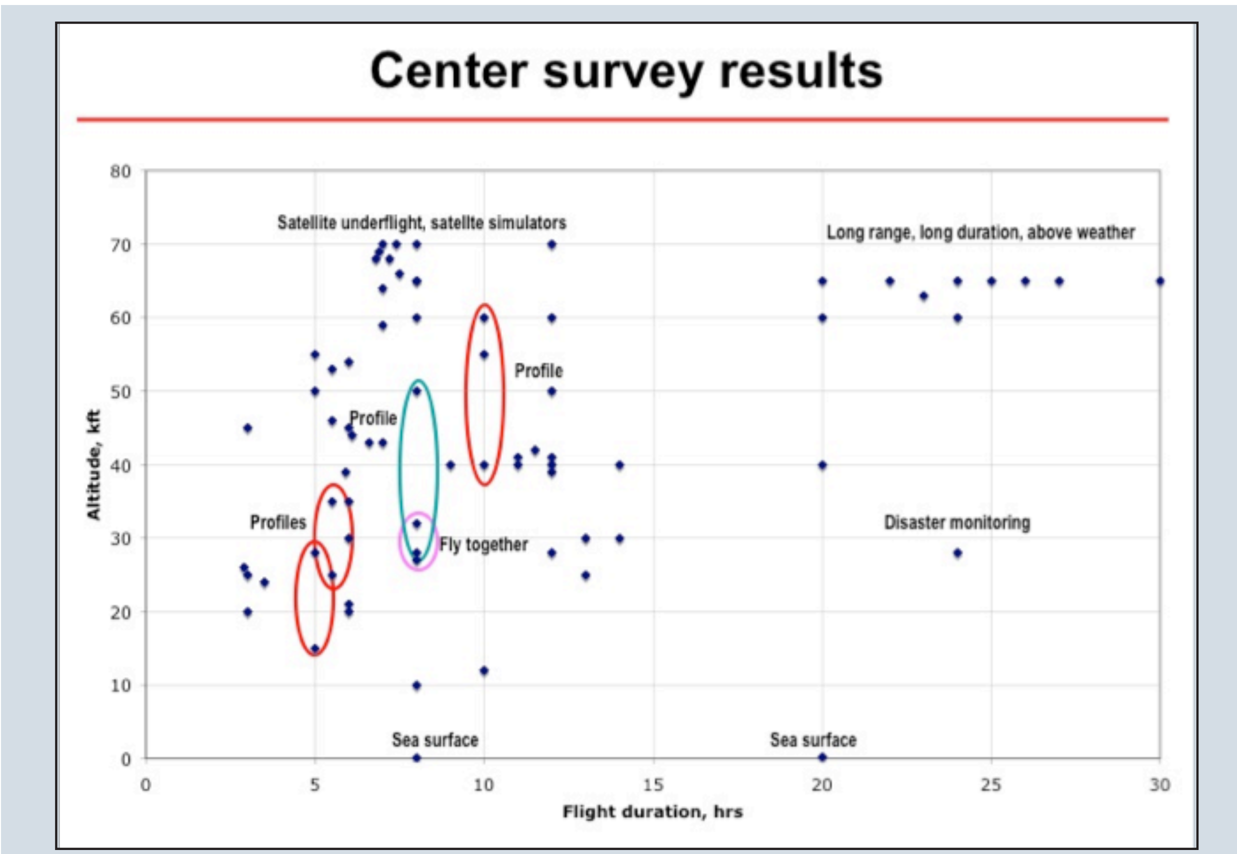


Figure 9 Flight regime requirement space indicated in Center survey results

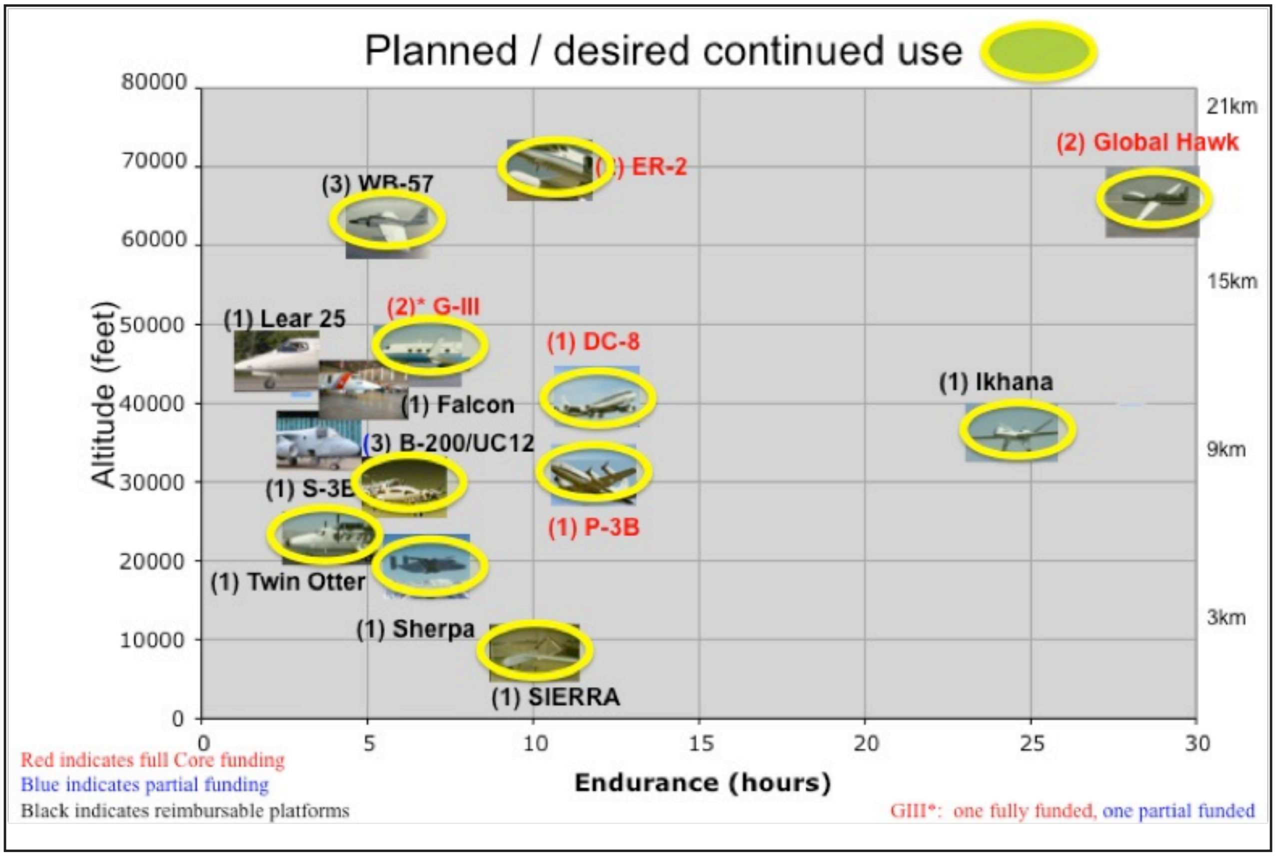


Figure 10 Specific requirements for continued use of NASA aircraft indicated in Center survey results.

Table 10 Comments noted during requirements analysis process

Platform needs	We need G-III – like capability on the East Coast. (To support terrestrial and eco-system science without having long distance flights from California.) Note that the JSC G-III is based in Houston and can serve the East Coast.
	We currently have medium duration (4 hr) for small payloads. *"We need longer duration (8 hr) without having to use a larger, more expensive platform."*
	Heavy lift ABOVE 40 kft to reach tropopause (for trop/strat science) Note that WB-57 can meet this need.
	24+ hours at 65,000 ft with scientists on board
	Long-range capability to make measurements over the polar regions. (CO2 measurements to support ASCENDS)
	Growing demand for low-altitude observation, especially for surface and ocean carbon fluxes, ice and snow measurements.
	Vertical profiles spanning the troposphere for studies of strat / trop species transport.
	Radiation Sciences Program and Atmospheric Dynamics Program would like an aircraft with ability to carry investigators and sensors into convective clouds in the icing region. Note that S-B3 aircraft could be used to meet this requirement, depending on altitude required.
Specific to UAS	– UAS access to more of the NAS, not just over oceans. – Ability (and permission) to fly 2 Global Hawks at one time. – High altitude long duration UAS to demonstrate space capability. – UAS (or other) with even longer observational periods – up to a week or more. – Increased use of small UAVs for science and application areas.
	For LIDAR development, testing and inter-comparisons: aircraft with two large nadir ports, power for two LIDAR systems, large access doors, available GPS antenna, *with flight hour cost below the DC-8.*
	Ability to fly AVIRIS / AVIRIS-ng in conjunction with other instruments: HYTES, PRISM, UAVSAR (Could be done with G-III modifications.)
Mission tools	Increased bandwidth for downloading of near real time airborne instrument observations to scientists at field operations center or home institution
	Cost estimating tools

Requirements Meeting discussion outcomes

Following are some quotes from the requirements meeting, with attribution.

- ***"This is NASA. If anyone should be getting to the extreme edges of the envelope, it is NASA."*** (This comment was made especially with respect to very high altitude and very long endurance.) – Woody Turner
- "We need the last 10,000 ft." (Also regarding high altitude, above 60,000 ft.) – Jack Kaye
- "As we look ahead to the Decadal Survey missions, we need to know what they need." – Jack Kaye
- Out-year missions should be "community-originated and community-developed campaigns, not directed from HQ." – Diane Wickland, explaining that future campaigns are not directed from program managers and that's why they can't tell us what is coming very far out in time.
- "There is an emerging role for aircraft platforms to bridge the gap to upcoming satellites." – Steve Hipskind
- The response to recent (AITT) and near-term solicitations (e.g., EVS-2) will determine a portion of future demand.
- "We are under-investing in instruments." – George Kumar

Investment targets discussion came to the following conclusions:

- Keep the DC-8? Yes
- Re-wing the P-3? Yes
- Keep two ER-2s? Not decided
- Keep one (or two) Global Hawks? Wait and see.
- Would the best a/c investment be a business jet or a King Air 350?
- Encourage use of the WB-57s by returning them to the ASP-supported, subsidized fleet.
- An aircraft with something like the DC-8 altitude and range, but smaller & cheaper to fly (would greatly enhance turnaround).

- Comment: "We've looked at NASA aircraft vs. contract aircraft. The BPA didn't work."

5. Synthesis and Gap Analysis: Recommendations and Conclusions

This section addresses the gaps identified in the current ASP fleet of aircraft and includes suggestions for addressing those needs. This section also looks forward to the sources for future flight requests and how those might lead to future requirements. Recommendations and conclusions close this section.

Gap Analysis

Figure 11 points out some gaps identified in the existing fleet as a result of the Center Survey and requirements activity. Table 11 explains the need behind each of these gaps. (In Figure 11, the terminology "core-funded" refers to the Earth Science Directorate subsidy to these assets in the ASP fleet. The JSC G-III aircraft is only subsidized through FY 2014.)

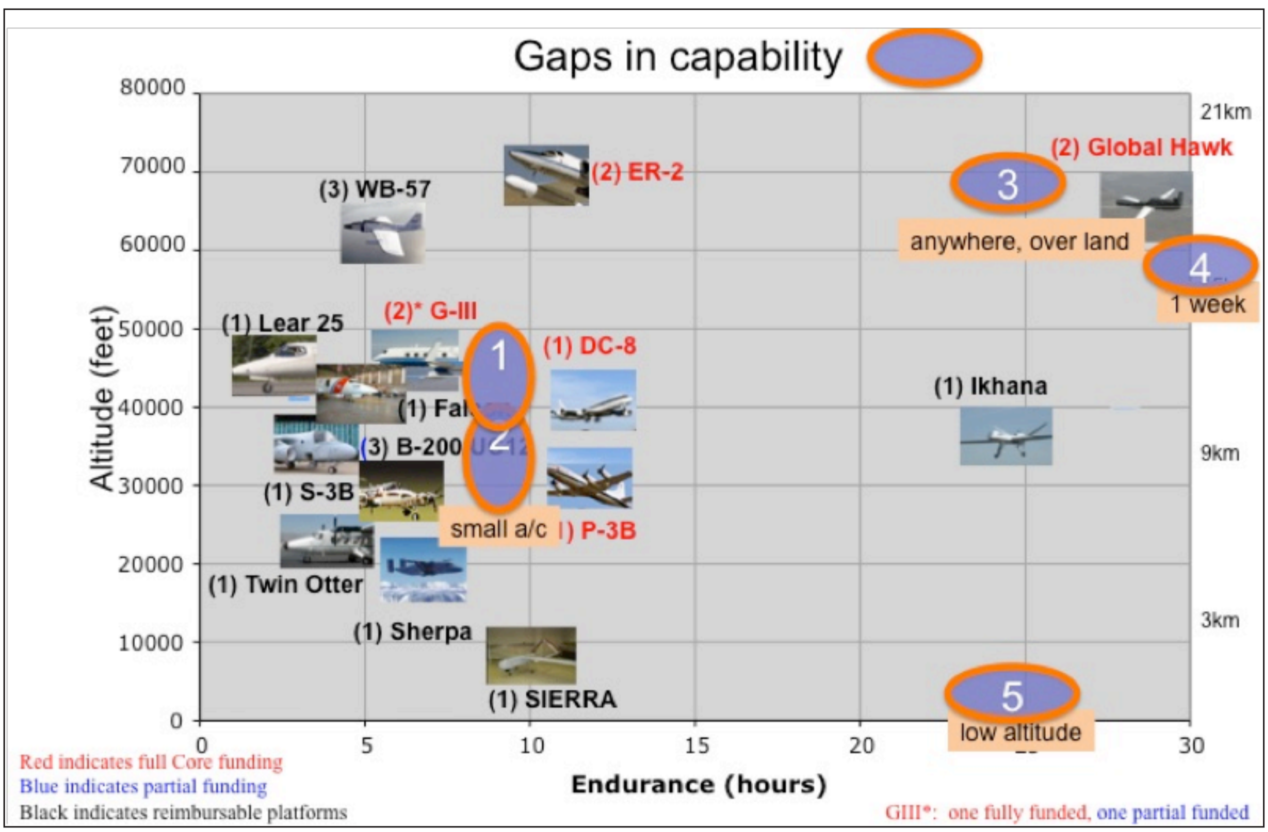


Figure 11 Gaps in the existing fleet suggested by Center survey results

Table 11 Explanation of the gaps shown in Figure 11

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

Tracking down and predicting the requirements

The science questions that drive future Earth Science missions, in space, in the air, on the Earth Surface and below are articulated in the Earth Science plan and NASA Climate Change Plan. Airborne Science capabilities are driven by the need for measurements and observations both near and far, and from all regions of Earth. Sometimes it is difficult to see specific needs very far ahead. Programmatically, the next 5 years will see flight requests based on Earth Science satellite missions, field studies, technology development, many of them based on various NASA solicitations. The solicitations come out of science focus area programs, ESTO, satellite mission science teams and the Earth Science Pathfinder Program (ESSP), which manages Earth Venture. On the other hand, it is not difficult to imagine what the needs might be, given that the science questions are fairly well articulated, even if they evolve over time.

One place to look for requirements is to project the recent past into the near future. If, for example, Earth Venture Suborbital–2 fields proposals similar to those in EV-1, it is possible to anticipate ASP-related needs or demands, based on the earlier program. Figure 12 shows the platforms proposed for EV-1.

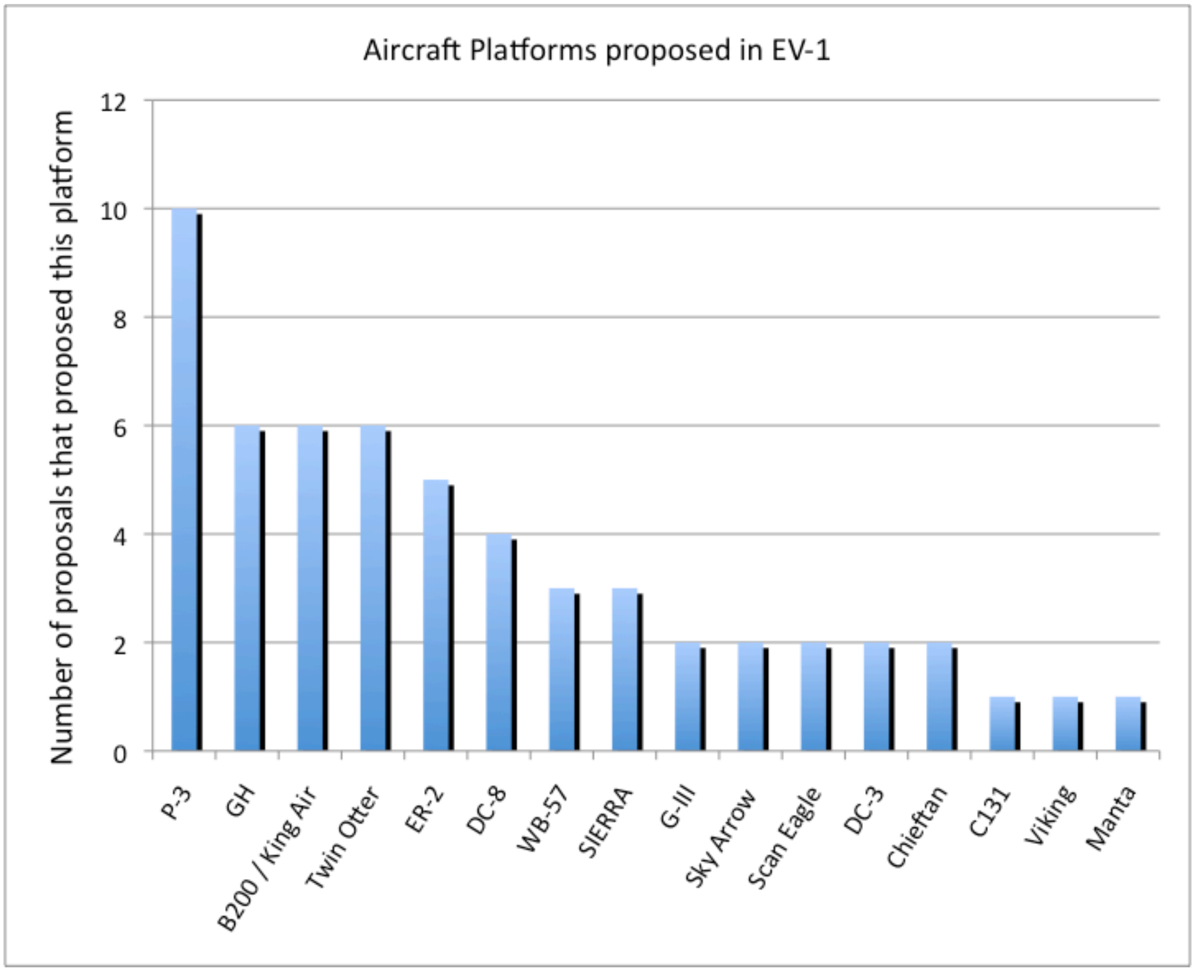


Figure 12 Aircraft platforms proposed for EV-1

What are we learning from EV-1 that applies to future ASP requirements?

- Needed another UAVSAR and a/c to carry it
- Needed another, more suitable a/c for PALS
- Airspace coordination skills are important, for both manned aircraft and UAS
- Science personnel can be limited, as well as a/c, payload, comm., etc personnel
- Integrating multiple instruments is a significant challenge
- Accessing polar regions is a particular challenge, but important and not to be avoided
- Foreign basing is also a challenge that requires early planning

Specific to UAS, it is also possible to predict some demand for UAS based on the proposals submitted to the UAS-enabled Earth Science call. The science and vehicles proposed for the 2010 A.40 call are shown in Figure 13. Based on the ongoing activities of UAS selected projects, several lessons for the future include:

- There is a need for long-range UAS capabilities, long endurance, both low and high altitude
- Requirement for communications in the Arctic
- Pod design for UAS, especially Ikhana
- Common data systems, which can be used on various aircraft and allow for comparison
- Even greater instrument due diligence is needed during the proposal review, to ensure performance as advertised

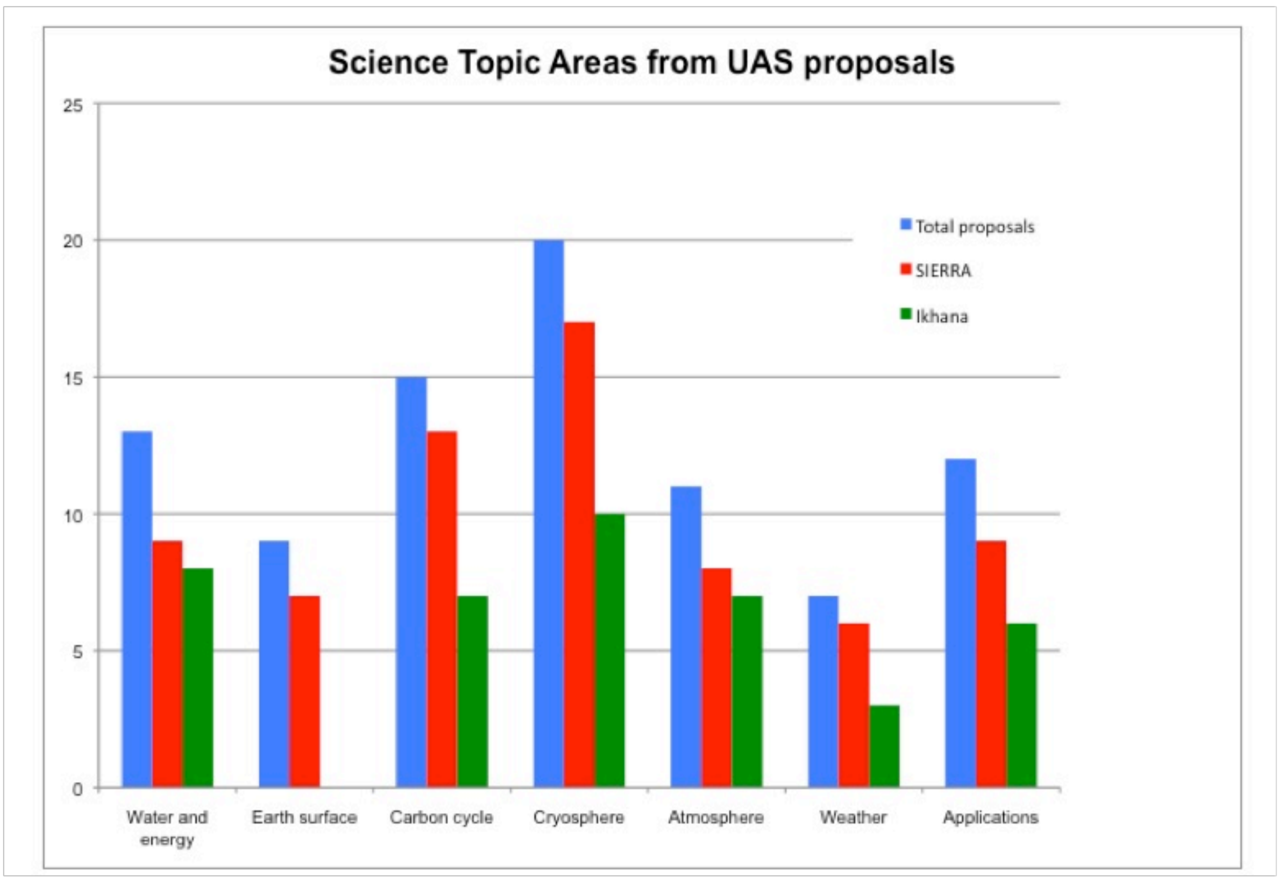


Figure 13 Vehicles and Science proposed for UAS-Enabled Earth Science: Note that each proposal required two or more UAS.

Looking ahead

Based on known and planned solicitations and activities, the Airborne Science Program can look ahead and prepare for flight requests, as suggested in Table 11.

Table 12 Flight requests anticipated based on the following solicitations

Solicitation	Proposals due and/or awards expected
AITT 2012	Awards late 2013
Earth Venture Suborbital - 2	January 2014/June 2014
ROSES 2013, Terrestrial Ecology	Awards January 2014
ROSES 2013, Carbon cycle science	Proposals due July 30, 2013; Awards January 2014
PACE Science Team	Solicitation 2014

Cal/val plans for upcoming satellite missions ICESat-2 and SWOT are also forthcoming. Finally, the NASA Climate Response Plan calls for an emphasis on continuity of climate-related measurements and ASP capabilities may be required to fill gaps while awaiting satellite launch for some upcoming missions. An example is the L-band radar mission (the radar portion of DESDynI), which may imply even more need for the UAVSAR system on the G-III.

Conclusions and Recommendations

Requirements for Airborne Science Program capabilities are found not only in the official Flight Requests (SOFRS), but also through upcoming mission planning activities, technology development, and discussions with NASA Earth Science program managers and the scientific community. Based on FY 12 data included in this report, more than 50% of science flight hour needs are met using ASP-supported aircraft and more than 85% using NASA-affiliated aircraft. In recent years, the number of flight hours has continued to increase, especially by providing service for Operation IceBridge and the Earth Venture – 1 projects.

While specific requirements are difficult to project far into the future because of the nature of the NASA solicitation and award process, it is clear that ASP capabilities will be needed in both the near and far term future for satellite support, process studies, instrument test and known solicitations, such as EVS-2. The full spectrum of fleet capabilities is required, especially at the far edges of the altitude, endurance and payload-carrying envelopes. New capabilities are also required, especially for 8-hr duration flight over the entire altitude profile from 25,000 to 50,000 feet, but with perhaps smaller and less expensive systems.

The mission tools and communications and data management capabilities which have been developed in the past few years are being utilized with ever greater frequency and utility, so much so that there is now demand for even greater functionality and speed.

Suggestions and requests for new or improved capabilities are included in this report and follow-up on specific requirements is recommended. Beyond investment targets for hardware and software, are several suggestions for improved program processes. These include:

- Requesting an airborne planning element in all satellite mission programs, as early as KDP-A.
- A cost calculator for the various aircraft and support instrumentation, including integration estimates, for scientists to use in proposal planning.
- Routine updates to Flight Requests in SOFRS when flight dates change.

Appendix A.
Assets and capabilities of the Airborne Science Program

This Appendix contains a detailed description of the ASP program capabilities.. More information can be found on the ASP website at http://airbornescience.nasa.gov.

Table A1 Current NASA Aircraft Platforms

Airborne Science Program Resources	Platform Name	Center	Duration (Hours)	Useful Payload (lbs.)	GTOW (lbs.)	Max Altitude (ft.)	Airspeed (knots)	Range (Nmi)	Internet and Document References
ASP Supported Aircraft	DC-8	NASA-DFRC	12	30,000	340,000	41,000	450	5,400	http://airbornescience.nasa.gov/aircraft/DC-8
	ER-2	NASA-DFRC	12	2,900	40,000	>70,000	410	>5,000	http://airbornescience.nasa.gov/aircraft/ER-2
	Gulfstream III (G-III) (C-20A)	NASA-DFRC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_C-20A_-_Dryden
	Gulfstream III (G-III)	NASA-JSC	7	2,610	69,700	45,000	460	3,400	http://airbornescience.nasa.gov/aircraft/G-III_-_JSC
	Global Hawk	NASA-DFRC	30	1900	25,600	65,000	345	11,000	http://airbornescience.nasa.gov/aircraft/Global_Hawk
	P-3B	NASA-WFF	14	14,700	135,000	32,000	400	3,800	http://airbornescience.nasa.gov/aircraft/P-3_Orion
Other NASA Aircraft	B-200 (UC-12B)	NASA-LARC	6.2	4,100	13,500	31,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_UC-12B_-_LARC
	B-200	NASA-DFRC	6	1,850	12,500	30,000	272	1,490	http://airbornescience.nasa.gov/aircraft/B-200_-_DFRC
	B-200	NASA-ARC/ DOE	6.75	2,000	14,000	32,000	250	1,883	http://airbornescience.nasa.gov/aircraft/B-200_-_DOE
	B-200	NASA-LARC	6.2	4,100	13,500	35,000	260	1,250	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	C-23 Sherpa	NASA-WFF	6	7,000	27,100	20,000	190	1,000	http://airbornescience.nasa.gov/aircraft/C-23_Sherpa
	Cessna 206H	NASA-LARC	5.7	1,175	3,600	15,700	150	700	http://airbornescience.nasa.gov/aircraft/Cessna_206H
	Dragon Eye	NASA-ARC	1	1	6	500+	34	3	http://airbornescience.nasa.gov/aircraft/B-200_-_LARC
	HU-25C Falcon	NASA-LARC	5	3,000	32,000	42,000	430	1,900	http://airbornescience.nasa.gov/aircraft/HU-25C_Falcon
	Ikhana	NASA-DFRC	24	2,000	10,000	40,000	171	3,500	http://airbornescience.nasa.gov/aircraft/Ikhana
	Learjet 25	NASA-GRC	2	2,000	15,000	45,000	350	1,000	http://airbornescience.nasa.gov/aircraft/Learjet_25
	S-3B Viking	NASA/GRC	6	12,000	52,500	40,000	350	2,300	http://airbornescience.nasa.gov/aircraft/S-3B
	SIERRA	NASA-ARC	10	100	400	12,000	60	600	http://airbornescience.nasa.gov/platforms/aircraft/sierra.html
	T-34C	NASA-GRC	3	100	4,400	25,000	150	700	http://airbornescience.nasa.gov/aircraft/T-34C
	Twin Otter	NASA-GRC	3	3,600	11,000	25,000	140	450	http://airbornescience.nasa.gov/aircraft/Twin_Otter_-_GRC
	WB-57	NASA-JSC	6.5	8,800	72,000	60,000+	410	2,500	http://airbornescience.nasa.gov/aircraft/WB-57

Figure A1 below shows the range of aircraft capabilities in altitude – endurance space. Not all these platforms are subsidized by the Earth Science Division. See Table A1 for the lists of those aircraft which are and are not ASP-supported. Figure A2 shows the same aircraft in altitude – range space. Figure A3 shows all aircraft in the combined Interagency Coordinating Committee for Airborne Geoscience Research and Applications (ICCAGRA) fleet available for Earth Science.

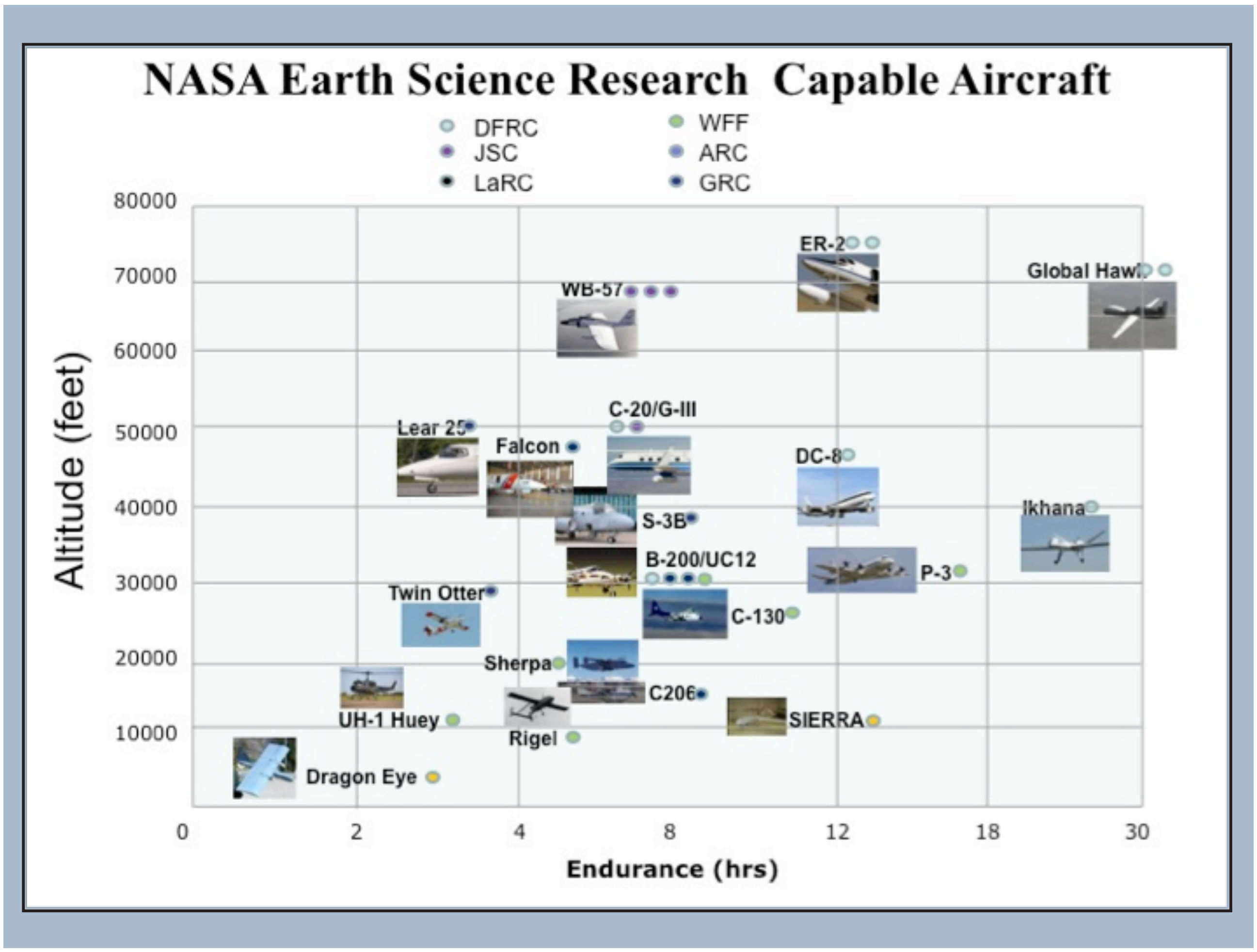


Figure A1 ASP platform capabilities in altitude and duration - all available aircraft.

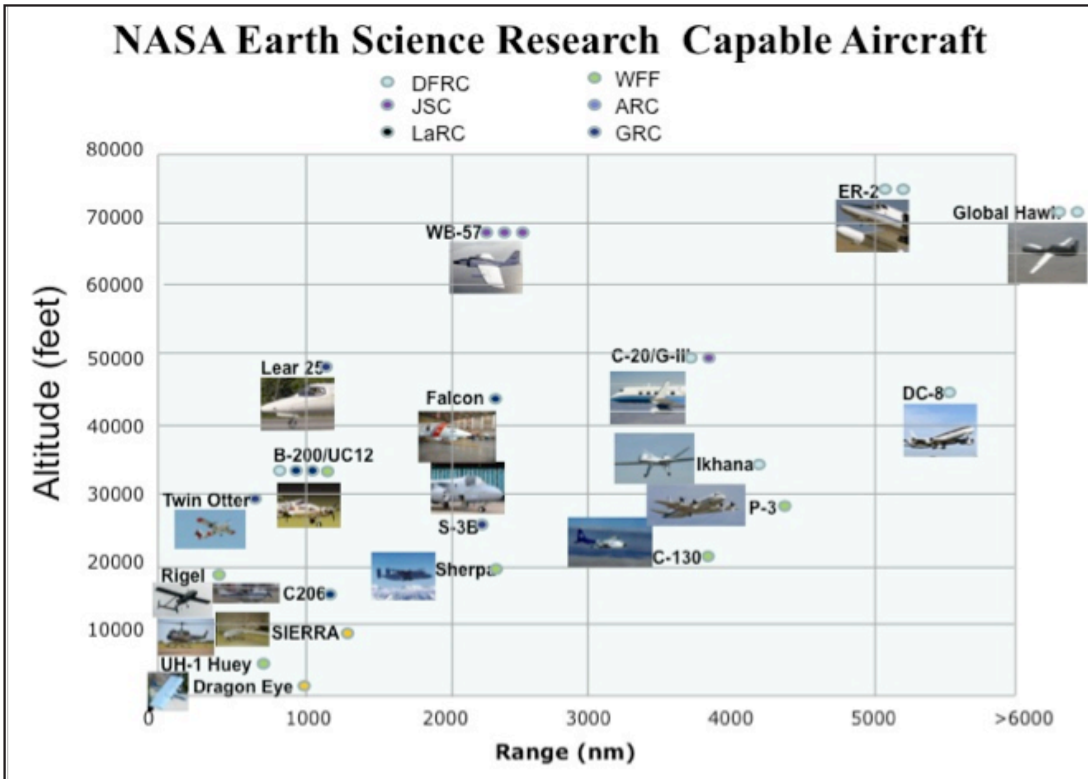


Figure A2 ASP platform capabilities in altitude and range - all available aircraft.

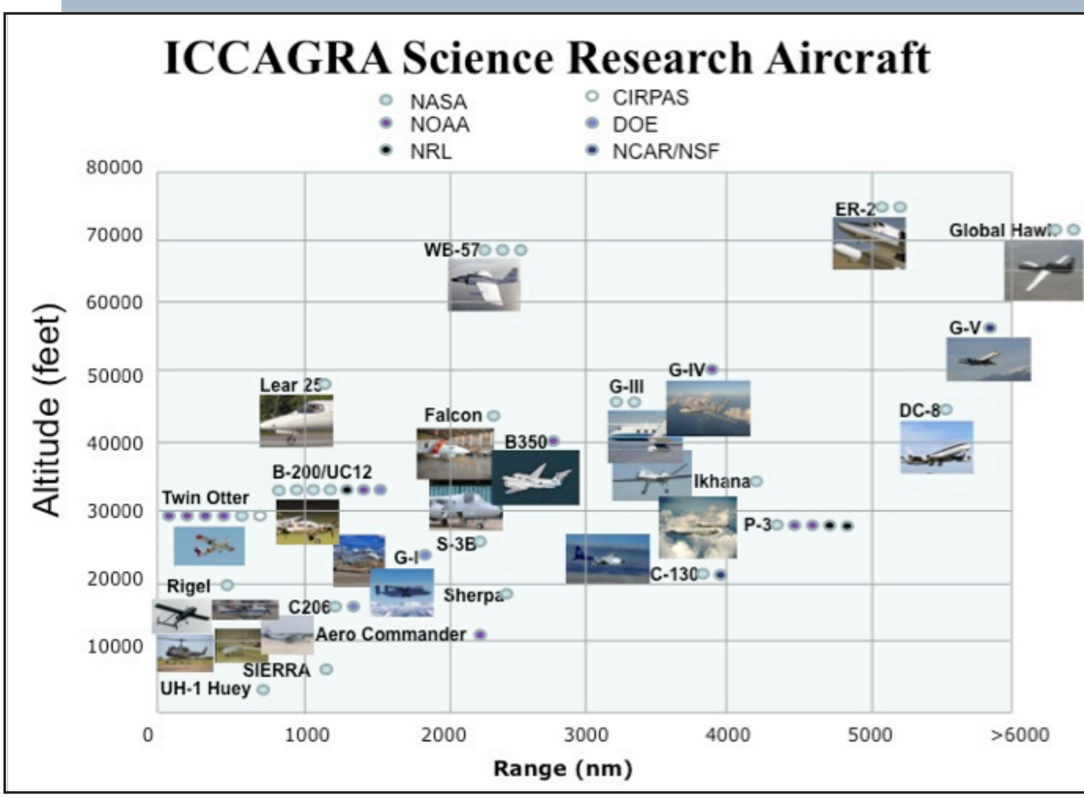


Figure A3 All ICCAGRA aircraft are also available fo Earth Science research

Table A2 Facility Equipment and Communications capabilities

Airborne Science Program Facility Equipment		
Instrument / Description	**Supported Platforms**	**Support group / location**
DCS (Digital Camera System) 16 MP color infrared cameras	DC-8, ER-2, Twin Otter, WB-57, B200	Airborne Sensor Facility / ARC
DMS (Digital Mapping System) 21 MP natural color cameras	DC-8, P-3	Airborne Sensor Facility / ARC
POS AV 510 (3) Applanix Position and Orientation Systems DGPS w/ precision IMU	DC-8, ER-2, P-3, B200	Airborne Sensor Facility / ARC
POS AV 610 (2) Applanix Position and Orientation Systems DGPS w/ precision IMU	DC-8, P-3	2 at Airborne Sensor Facility / ARC 2 at WFF
DyNAMITE (Day/Night Airborne Motion Imagery for Terrestrial Environments) Full Color High Definition and Mid-Wave IR High Resolution Full Motion Video System	WB-57	JSC
HDVIS High Def Time-lapse Video System	Global Hawk UAS	Airborne Sensor Facility / ARC
LowLight VIS Low Light Time-lapse Video System	Global Hawk UAS	Airborne Sensor Facility / ARC
EOS and R&A Program Facility Instruments		
Instrument / Description	**Supported Platforms**	**Support group / location**
MASTER (MODIS/ASTER Airborne Simulator) 50 ch multispectral line scanner V/SWIR-MW/LWIR	B200, DC-8, ER-2, P-3, WB-57	Airborne Sensor Facility / ARC
Enhanced MAS (MODIS Airborne Simulator) 38 ch multispectral scanner + VSWIR imaging spectrometer	ER-2	Airborne Sensor Facility / ARC
AVIRIS-ng Imaging Spectrometer (380 - 2510nm range, Dl 5nm)	Twin Otter	JPL / JPL
AVIRIS Classic Imaging Spectrometer (400 – 2500nm range, Dl 10nm)	ER-2, Twin Otter	JPL / JPL
UAV_SAR Polarimetric L-band synthetic aperture radar, capable of Differential interferometry	ER-2, Twin Otter	JPL / JPL
NAST-I Infrared imaging interferometer (3.5 – 16mm range)	ER-2	U Wisconsin / LaRC
Satellite Communications systems on ASP aircraft		
Sat-Com System Type/Data Rate (nominal)	**Supported Platforms**	**Support group / location**
Ku-Band (single channel) / > 1 Mb/sec	Global Hawk & Ikhana UAS; WB-57	NSERC / DFRC / JSC
Inmarsat BGAN (two channel systems) / 432 Kb/sec per channel	DC-8, WB-57, P-3, S-3B, DFRC B200, ER-2, Global Hawk	Airborne Sensor Facility / DFRC
Iridium (1 – 4 channel systems) / 2.8 Kb/sec per channel	Global Hawk, DC-8, P-3, ER-2, WB-57, G-III, SIERRA, others	Airborne Sensor Facility, NSERC /ARC

Table A3 Functions of the Mission Tool Suite

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

Appendix B. ASP 5-Year Plan

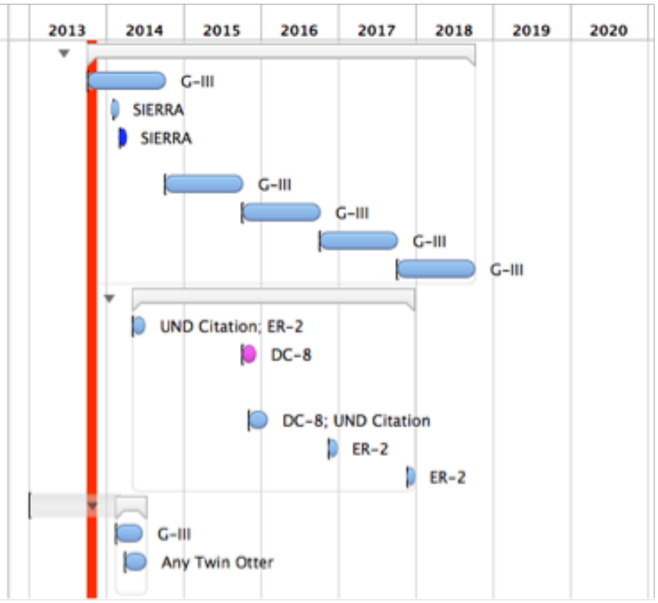
Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013	2014	2015	2016	2017	2018	2019	2020
1) Atmospheric Composition and Chemistry											
1.1) M3SCAPE	160/ 340	Maring	SMAP, DESDynI, ICESAT-2		G-III; Sherpa						
1.2) 4-Star test	15	Maring	NPP, GEO-CAPE		P-3						
1.3) ASCENDS Technology acceleration		Ghuman/Komar	ASCENDS		DC-8						
1.4) RADEX	50	Maring	ACE			ER-2					
1.5) ORACLES	120	Maring	ACE			ER-2; P-3					
1.6) Atmo.Chem.Mission		Jucks	OCO2			DC-8; ER-2					
1.7) Atmospheric Composition Campaign	150/ac	Jucks; Maring	NPP, A-Train, Terra				DC-8; ER-2				
1.8) SnowMASS	150	Maring					P-3				
1.9) SnowMASS	150	Maring						P-3			
1.10) SnowMASS	150	Maring							P-3		
1.11) SnowMASS	150	Maring								P-3	
1.12) Atmospheric Composition Campaign	150/ac	Jucks; Maring	NPP, A-Train, Terra							DC-8; ER-2	

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013	2014	2015	2016	2017	2018	2019	2020
2) Carbon Cycle & Ecosystems											
2.1) OCEANia (Guild)	9	Bontempi		Any Twin Otter							
2.2) PRISM		Bontempi	HyspIRI, GEO-CAPE		Any Twin Otter						
2.3) AVIRIS & MASTER HyspIRI prep	100	Turner/Neeck	HyspIRI		ER-2						
2.4) AVIRIS Classic /AK	30	Wickland; Tagg	HyspIRI		ER-2						
2.5) AVIRISng	95	Wickland	HypsIRI		Any Twin Otter						
2.6) Coral Biodiversity	22	Turner	PACE, HyspIRI		ER-2; Twin Otter GRC						
2.7) Land management / veg studies (AVIRISng)	24	Wickland	HyspIRI		Any Twin Otter						
2.8) HSRL-OBB		Bontempi	PACE		B-200 L						
2.9) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI		G-III						
2.10) Forest responses		Wickland			ER-2						
2.11) Ecosystem Change (Cook GLiHT)	100	Wickland	LDCM		Piper Cherokee						
2.12) Carbon monitoring (AVIRISng)	37	Wickland	DESDynI		DC-8						
2.13) Florida Everglades					ER-2						
2.14) CCE Field Campaign ABoVE	100	Wickland				Sherpa					
2.15) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI			G-III					
2.16) UAVSAR - Ecosystem Structure	20	Wickland	DESDynI				G-III				
2.17) UAVSAR -	20	Wickland	DESDynI					G-III			

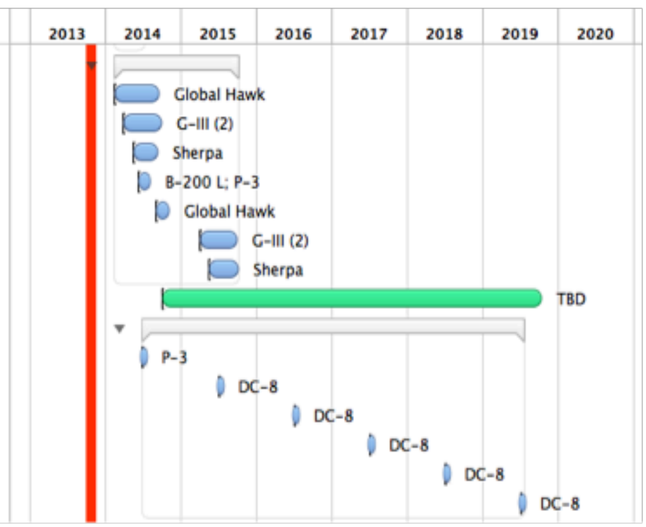
Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013 2014 2015 2016 2017 2018 2019 2020
3) Cryospheric Science				
3.1) OIB Antarctica 2013	250	Wagner; Tagg	ICESAT 2	P-3
3.2) OIB Greenland 2014	300	Wagner; Tagg	ICESat 2	P-3
3.3) OIB Iceland 2014	30	Wagner		G-III
3.4) OIB Alaska 2014				Single Otter
3.5) OIB Antarctica 2014	250	Wagner; Tagg	ICESat 2	DC-8
3.6) OIB Greenland 2015	300	Wagner; Tagg	ICESAT 2	TBD
3.7) OIB Iceland 2015	35	Wagner		G-III
3.8) OIB Alaska 2015				Single Otter
3.9) OIB Antarctica 2015	250	Wagner; Tagg	ICESat 2	DC-8; P-3
3.10) OIB Greenland 2016	300	Wagner; Tagg	ICESAT 2	P-3
3.11) OIB Iceland 2016	35	Wagner		G-III
3.12) OIB Alaska 2016				Single Otter
3.13) Microwave Scanning radiometer	70	Wagner	GPM	Ikhana; P-3; SIERRA
3.14) OIB Antarctica 2016	250	Wagner; Tagg	ICESat 2	DC-8; P-3
3.15) UAVSAR Greenland or Iceland	35			G-III
3.16) UAVSAR Greenland or Iceland	35			G-III

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013 2014 2015 2016 2017 2018 2019 2020
4) Water and Energy Cycle				
4.1) Moller - AIRSWOT	112	Entin, Lindstrom	SWOT	B-200 D
4.2) Airborne Snow Observatory (Painter)	32	Entin, Dorn	HyspIRI	Any Twin Otter
4.3) Coastal Airborne In-Situ Radiometers		Entin	PACE	ER-2
4.4) Coastal Airborne In-Situ Radiometers		Bontempi, Entin	PACE	P-3
4.5) Snow Field Campaign-15	20	Entin		DC-8
4.6) Water quality field campaign	30	Entin, Turner	HyspIRI, ACE	TBD
4.7) 4Star upgrade	8	Entin		DC-8; P-3
4.8) Arctic Hydrology 13B001		Entin	SWOT	B-200 D
4.9) SMAPVEX-15	30	Entin	SMAP	G-III; Any Twin Otter
4.10) Snow Field Campaign- 16	50	Entin		DC-8; P-3
4.11) SMAPVEX-16 cal/val	50	Entin	SMAP	P-3
4.12) SMAP cal/val	20	Entin	SMAP	G-III
4.13) SMAP cal/val	20	Entin	SMAP	G-III
4.14) RZSM - ESA Collaboration OR	30	Entin	ESA BIOMASS	G-III (2)
4.15) RZSM - ESA Collaboration	30	Entin	ESA BIOMASS	G-III (2)

Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor
5) **Earth Surface & Interior**			
5.1) UAVSAR - 14	290	Dobson; Tagg	DESDynI
5.2) NZ volcano	20		
5.3) Costa Rica - volcanic plumes	30	LaBrecque	HyspIRI / ASTER
5.4) UAVSAR - 15	290	Dobson; Tagg	DESDynI
5.5) UAVSAR - 16	290	Dobson; Tagg	DESDynI
5.6) UAVSAR - 17	290	Dobson; Tagg	DESDynI
5.7) UAVSAR - 18	290	Dobson; Tagg	DESDynI
6) **Weather**			
6.1) GPM-HMT (GPM)	86	Kakar; Neeck	GPM
6.2) Atmospheric Dynamics mission (Antarctica)		Kakar; Neeck	
6.3) OLYMPEX (GPM c/v)	100	Kakar, Neeck	GPM
6.4) GOES-R cal/val			GOES-R
6.5) GOES-R cal/val			GOES-R
7) **Applications**			
7.1) CA-DWR w UAVSAR	60	Friedl; Dobson	
7.2) Airborne Snow Observatory (Painter)	32	Entin, Dorn	HyspIRI



Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor
8) **Earth Venture 1**			
8.1) ATTREX-14	200	Jucks, Tagg	
8.2) AirMOSS - 14	326	Entin; Tagg	SMAP
8.3) CARVE - 14	336	Wickland; Tagg	
8.4) DISCOVR-AQ - 14	100	Maring, Tagg	GEO-CAPE
8.5) HS3 - 14	327	Kakar; Tagg	
8.6) AirMOSS - 15	300	Entin; Tagg	SMAP
8.7) CARVE - 15	336	Wickland; Tagg	
9) Earth Venture EVS-2		Maring; Tagg	
10) **Education**			
10.1) SARP 2014	14	Kaye; Tagg	
10.2) SARP 2015	14	Kaye; Tagg	
10.3) SARP 2016	14	Kaye; Tagg	
10.4) SARP 2017	14	Kaye; Tagg	
10.5) SARP 2018	14	Kaye; Tagg	
10.6) SARP 2019	14		



Task	Flt Hours	PS/PE/PM	Related Satellite/Sensor	2013–2017
11) New Techology				
• 11.1) UAVSAR/LVIS-GH	50	Dobson; Tagg	DESDynI; ICESAT 2	Global Hawk
• 11.2) Reising IIP		Komar	SWOT	Any Twin Otter
• 11.3) Moller - AIRSWOT		SBIR	SWOT	B-200 D
• 11.4) Obland/ CarbonHawk		Komar	ASCENDS	Falcon
• 11.5) CASL (AITT)		ESTO	GEO-CAPE	B-200 D
• 11.6) Geo-TASO/Leitch		Komar	GEO-CAPE	Falcon
• 11.7) ECO-SAR (Rincon)		Komar	DESDynI	P-3
• 11.8) ECO-SAR		Komar	DESDynI	P-3
• 11.9) Racette - ACERAD		Komar	ACE	ER-2
• 11.10) Moller - GISTENH		AITT	ICESat 2	Global Hawk
• 11.11) UAVSAR-GH -15	50	Dobson; Tagg	DESDynI	Global Hawk
• 11.12) HSRL/PRISM - 15		Bontempi; Tagg	ACE	B-200 L
• 11.13) Ball SP-IIP	32	ESTO	ACE	B-200 D
• 11.14) Obland/ CarbonHawk		Komar	ASCENDS	Global Hawk
• 11.15) MoDIAL		ESTO		Falcon
• 11.16) HSRL/PRISM - 16		Bontempi; Tagg	ACE	B-200 L
• 11.17) Thermal IR Climate sensor	16	Albertson	Aqua, Aura	ER-2
• 11.18) 2013 AITT awards		Komar		TBD