Airborne Science Program

2010 report on Observations required to support the next generation of NASA Earth science satellites

National Aeronautics and Space Administration

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2010 Report on Airborne Observations required to support the next generation of NASA Earth science satellite missions

Susan Schoenung
Longitude 122 West, Inc.

Matt Fladeland
NASA Ames Research Center

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1 EXECUTIVE SUMMARY

This report presents a snapshot in time of known or projected requirements for support from the NASA Airborne Science Program (ASP) for upcoming Earth Science satellite missions. Those missions begin with Glory, scheduled to launch in early 2011, and proceed through the "Tier 3" Decadal Survey missions, which will launch sometime after 2020.

The types of support required by NASA Earth observing missions from ASP included instrument flight test and algorithm development before launch, and calibration of instruments and algorithm validation measurements post-launch in support of data product generation. In addition, the Program supports "gap filler" to acquire observations between satellite missions; Operation Ice Bridge is one example. Also, the ASP will continue to support other R&A projects, that may or may not use satellite data from these upcoming missions, to address fundamental science questions on Earth system phenomenon and processes. Figure 1 shows the preliminary platform requirements to support upcoming NASA Earth Science missions.

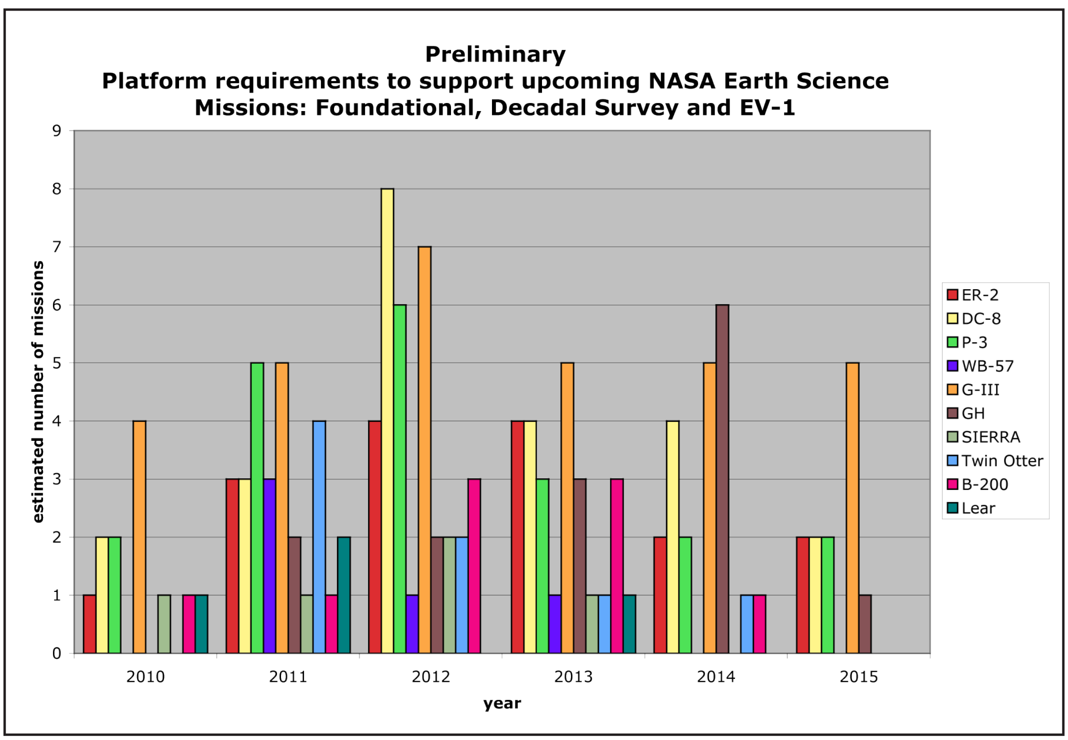

Fig. 1: Preliminary platform requirements.

The requirements described in this report were gathered from mission cal/val plans, discussions with instrument developers, science teams, and program and project scientists. Assuming funding is available, the Airborne Science Program is well positioned to meet the needs of these missions in most cases. High demand for several platforms, the G-III carrying UAVSAR in particular, may cause scheduling issues. In some cases, integration of new instruments may also challenge available resources, but should be doable with advance planning. Indeed, the major message of this report is that science teams need to make their plans and needs known as early as possible for a successful outcome.

There are also opportunities for airborne missions to support multiple tasks, where cross-cutting requirements have been identified. This occurs when common instruments are requested for similar types of measurements. Examples include the use of LVIS for ice topography measurements that could benefit both ICESat-2 and DESDynI, or the use of MASTER to support spectral imaging missions such as HyspIRI and NPP. These examples have not been discussed with the science teams. The GEO-CAPE and ACE teams have discussed their mutual interest in coastal ocean measurements.

Figure 2 illustrates the level of aircraft support that may be required over the next five years. Projections beyond such a timeframe are not useful given the lack of data on missions beyond that time horizon. Additionally, the figure provides a representative breakdown by mission. Note that many of the requirements are for flight testing of instruments developed under the Earth Science Technology Office.

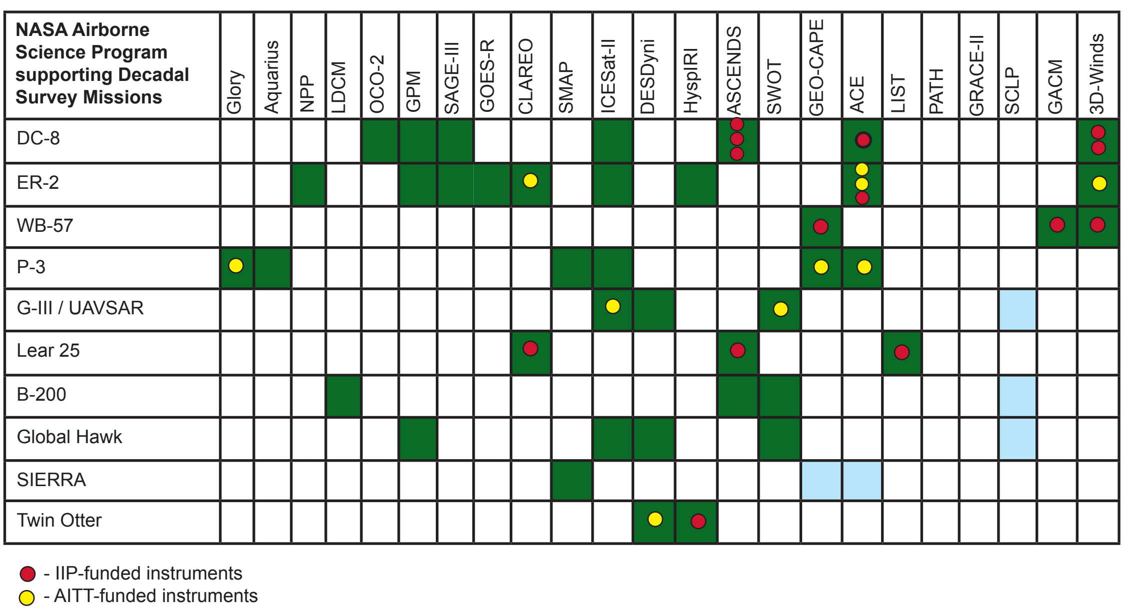

Fig. 2: Platform support for future missions. NASA's Earth Science Technology Office (ESTO) manages the Instrument Incubator Program (IIP) and Airborne Instrument Technology Transition (AITT) programs.

Table 1 summarizes what is currently known about Airborne Science support activities required for upcoming Flight Program missions. Table 1 and the preceding figures do not include requirements for upcoming field campaigns sponsored by the Research and Applications (R&A) program. (Acronyms are spelled out in Appendix 3.)

Table 1: Summary of Future Missions and ASP activities.

Mission	Estimated Launch Date	Program Executive	Program Scientist	Satellite Instruments	Supporting Airborne Instruments	Airborne Science Support Activities
Foundational Missions						
Glory	February 2011	Bretthauer	Maring	Aerosol Polarimeter (APS), Total Irradiance (TIM)	RSP, ATS, Nephalometers	Cal / val
Aquarius	April 2011	Ianson	Lindstrom	Radiometers, Scatterometer	PolSAT	Cal / val
NPP	September 2011	Carson	Wickland	VIIRS, CrIS, ATMS, OMPS	NAST, S-HIS, MAS, PSR, APMIR, MASTER, AVIRIS	Algorithm development, cal / val
LDCM	December 2012	Jarett	Wickland	Multi-band land imager	MAS, EMAS	Cal / val
OCO 2	February 2013	Ianson	Jucks	NIR spectrometer	ASCENDS test beds, in situ CO2	Algorithm development, Cal / val
GPM	July 2013	Neeck	Kakar	Microwave Imager (GMI), Doppler Precipitation Radar (DPR)	EDOP	Algorithm development: MC3E
						Algorithm development: COLDEX
						HMT
						NAMMA2
						Cal / val
SAGE-III	Mid 2013	Topiwala	Considine	Spectrometer	Multiple payloads	Algorithm development,
GRACE follow-on	Mid 2016	Neeck	LaBrecque	Inter-satellite ranging	N/A	N/A
GOES-R	October 2012	Topiwala	Bontempi	Advanced Baseline Imager (16 channels)	AVIRIS/MASTER	Algorithm development, Cal / val
Tier I Decadal Survey Missions						
SMAP	November 2014	Ianson	Entin	L-band radar, L-band radiometer	UAVSAR	CANEX Freeze-Thaw
					UAVSAR	CANEX10

Mission	Estimated Launch Date	Program Executive	Program Scientist	Satellite Instruments	Supporting Airborne Instruments	Airborne Science Support Activities
					PALS	instrument test
						SMAPVex 2012
						SMAPVex 2015
ICESat II	Late 2015	Slonaker	Wagner	Laser altimeter	LVIS	OIB
					ATM	OIB
					MABEL	instrument test
					SIMPL	Instrument test flight
					LVIS-GH	OIB
CLARREO-1	2017	Slonaker	Jucks	Solar radiometer, IR spectrometer, GPS RO	INFLAME	Algorithm development, cal/val
CLARREO-2	2020	Slonaker	Jucks	Solar radiometer, IR spectrometer, GPS RO	AITT instruments, far IR	Algorithm development, cal/val
DESDynI	2017	Dutta	LaBrecque	InSAR, LIDAR	Flash Lidar	instrument test flights
				InSAR, LIDAR	LVIS-GH	Instrument test flights
					UAVSAR	Algorithm development
Tier II Decadal Survey Missions						
SWOT	2020	Neeck	Lindstrom	Ka-band radar, C-band radar	KaSPAR, HAMSR	Cal / val
					AirSWOT	Algorithm development
ASCENDS	2019	Neeck	Jucks	CO2 Lidar	MFLL, CO2 Lidar Sounder, CO2 LAS	Instrument flight test
						A
						B
						C
					Broadband lidar	Instrument flight test
					ACCLAIM	Instrument flight test
						Cal / val
HyspIRI	>2020	Neeck	Turner	VIS-IR imaging spectrometer	HYTES	Instrument test
					EMAS	Instrument test
					Mineral and gas identifier	Instrument test

Mission	Estimated Launch Date	Program Executive	Program Scientist	Satellite Instruments	Supporting Airborne Instruments	Airborne Science Support Activities
PACE	2018	Neeck	Maring	Ocean radiometer (ORCA), OES	ORCA simulator	Air-ocean flux measurements
						Ship-based UAV
ACE	>2020	Neeck	Maring	Polarimeter, Lidar, cloud radar	Competing polarimeters	Instrument flight test (PODEX), cal / val
						CATS
						HSRL/DIAL
						HSRL & RSP
						MACPEX
						ACE-PEX 12
						PACE3E
						ACE-ALDEX13
						ACE-ALDEX15
GEO-CAPE	>2020	Neeck	Al-Saadi	Hyperspectral imagers	IIPFTS instruments	Algorithm development, instrument flight test
GEO-CAPE	>2020	Neeck	Al-Saadi	Hyperspectral imagers	PRISM	Instrument test
					PRISM	Instrument test
						Cal / val
Tier III Decadal Survey Missions						
SLCP	>2020	Neeck	Entin	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
LIST	.2020	Neeck	Dobson	LIDAR	Swath-mapping lidar (IIP)	Instrument flight test
					SIMPL	Algorithm development
GACM	>2020	Neeck	Jucks	UV spectrometer, IR spectrometer, Microwave limb sounder	Microwave limb soumder (IIP)	Instrument flight test
PATH	>2020	Neeck	Kakar	Microwave array spectrometer	MW array spectrometer	Instrument test flight
GRACE II	>2020	Neeck	LaBrecque	Microwave or laser ranging systems	Limb sounder	Instrument test flight
3-D WINDS	>2020	Neeck	Kakar	Lidar	DAWN-Air2	Instrument test flight
					TwiLiTE	Instrument test flight
					Coherent Doppler Lidar (AITT)	Instrument test flight

Mission	Estimated Launch Date	Program Executive	Program Scientist	Satellite Instruments	Supporting Airborne Instruments	Airborne Science Support Activities
EV-1 Missions						
Hurricane Sentinel	2010-2014	Avery	Maring		GRIP hurricane payload	Field campaign: supports PATH, ACE, 3-D Winds, GPM
DISCOVER-AQ	2010-2014	Avery	Maring		Column sampling, HSRL, ACAM	Air pollution: supports GEO-CAPE, ACE, GACM
CARVE	2010-2014	Avery	Maring		Surface carbon sampling; PALS, FTS, gas analyzer	Arctic climate change; supports SMAP, HsypIRI, DESDynI, ASCENDS, OCO reflight.
AirMOSS	2010-2014	Avery	Maring		Modified UAVSAR	Vegetation: supports SMAP, DESDynI
ATTREX	2010-2014	Avery	Maring		GLOPAC-type sampling payload	Strat/Trop chemistry and aerosols

2 INTRODUCTION

2.1 Purpose

This report presents the known and projected use of NASA's Airborne Science Program (ASP) assets to support the development and implementation of upcoming NASA Earth Science satellite missions, including both foundational and Decadal Survey recommended missions [1]. [1]

The report is a companion to, "NASA Earth Science Requirements for Suborbital Observations," a compendium of Airborne Science mission requirements, published in 2007 [2] with the primary objectives to:

- Define major requirements for airborne observations for all upcoming NASA Earth Science Division satellite missions.
- Provide an analysis of areas of common interest among missions and gaps in capabilities that threaten access to needed airborne observations.
- Assess needs against other ASP partners including R&A projects, ESSP EV-1, and ESTO technology development.

2.2 NASA Flight Programs

In order to study the Earth as a system and understand how it is changing, NASA develops and supports a constellation of Earth observing satellite missions that test new instruments and observing techniques and, when necessary, provide continuity of datasets for important environmental and climate data records. These missions provide Earth science researchers the data they require to address NASA's Earth science questions.

The Flight Programs element of the science mission directorate is responsible for providing engineering support and flight operations across the entire life of an Earth science satellite mission. This includes any airborne support required prior to, and following launch. NASA missions begin with a study phase during which the key science objectives of the mission are defined, requirements are developed and designs for spacecraft and instruments are analyzed. Following the study phase, missions enter a development phase

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[1] The "Decadal Survey" is the National Research Council Report "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," released 15 January 2007. It provides scientific goals, observation needs, applicable technologies, a program of recommended missions.

whereby all aspects of the mission are developed and tested to ensure they will meet the mission objectives. Operating missions are those missions that are currently active and providing science data to researchers. Operating missions may be in their primary operational phase or in an extended operational phase.

2.3 NASA Airborne Science Program

The ASP reports to the Earth Science Flight Programs Office and serves the Research and Analysis program of the Earth Science Division, within the Science Mission Directorate (SMD). ASP provides flight and airborne measurements in support of field science, algorithm development, instrument test, and satellite calibration and validation.

This report serves the NASA ASP by highlighting requirements that emphasize the need for sustained and augmented capabilities within the program. The Airborne Science Program has always provided both pre- and post-launch support to Earth science missions, most recently the elements of EOS and, specifically, the A-Train. In addition, ASP assets are used to develop the next generation of satellite instruments through ESTO and other technology programs.

Foundational missions, those developed following EOS and prior to the Decadal Survey, and scheduled for launch within the next two years, will make use of Airborne Science capabilities for instrument test and algorithm development. The capabilities of the ASP, both platforms and sensors, have been developed/modified, maintained and operated to meet those needs.

As the fifteen new Decadal Survey missions are now in the early stages of development, and the Earth Venture Program begins, it is appropriate for the ASP to evaluate the upcoming requirements for services and capabilities to support these missions. Specific questions include the availability of platforms to meet increased demand for flight hours or deployment to remote locations, and the capability of the platforms to be adapted for new instruments or payload suites. The interest in real time data and multiple, simultaneous sources of information feed the need for an improved networking capability, including suborbital and orbital data streams.

2.4 Approach

The approach to collecting and interpreting the needs for ASP assets has been primarily through conversation with potential users. Within the NASA SMD Earth Science Division, each new program has a Program Executive and a Program Scientist who interface with the Program Executive, and the science community interested in the mission. Those interviewed for this report included the above plus program managers, science team members, and field test planners. ASP personnel have also attended many mission planning and science team meetings and workshops, gathering information from presentations and discussions. For several missions, detailed field test plans have already been generated. For most of the missions, the support needs may not be explicit, but airborne requirements were discovered among the science plans.

For each mission described in this report, the following are presented:

- Responsible personnel (Program Executive, Program Scientist, Project Scientist)
- Mission description, including launch date and payload
- Relevant aircraft simulator or complementary instrumentation
- Known or potential Airborne Science support activities
- Schedule of ASP activities, if available
- Gap assessment

The final section of the report presents a cross-cutting view of the missions to highlight potential opportunities for technology or flight activity planning.

3 FOUNDATIONAL MISSIONS

“Foundational missions” are those under development or in implementation phase when the National Research Council (NRC) Decadal Survey recommendations were published in 2007. Since these will launch before the Decadal Survey missions, the Airborne Science Program has to know and consider the mission support requirements. At this time, since the payload instrumentation is established, most requirements are expected to be related to post-launch cal/val.

3.1 Glory

3.1.1 Points of contact

Program Executive: Joy Bretthauer, NASA HQ
Program Scientist: Hal Maring, NASA HQ
Project Scientist: Michael I. Mishchenko, NASA GSFC

3.1.2 Mission description

3.1.2.1 Objective

Glory will measure global aerosols and cloud liquid properties and total solar irradiance. This mission addresses a high priority objective of the U.S. Global Change Research Program.

3.1.2.2 Status and launch date

Glory is in the implementation phase and scheduled for launch in February 2011.

3.1.2.3 Payload instruments

The Glory payload consists of an Aerosol Polarimetry Sensor (APS), which will provide the retrieval of aerosol particle microphysical properties by inverting multiangle and multispectral radiance and polarization measurements, and a Total Solar Irradiance Monitor (TIM), which will measure the absorption and reflection of solar radiation by the Earth’s atmosphere, and determine the global average temperature of the Earth. Cloud Camera data will provide cross track coverage over a finite swath of aerosol load and fine mode fraction over the open ocean.

3.1.3 Instrument analogues

Likely airborne analogues include the Research Scanning Polarimeter (RSP) and aerosol sampling nephalometers.

3.1.4 Airborne science support activities

Airborne support for cal/val is possible, but nothing is currently scheduled.

3.1.5 Gap assessment

No gaps identified.

3.1.6 Cross-cutting requirements from other missions

None currently identified

3.2 Aquarius

3.2.1 Points of contact

Program Executive: Eric Ianson, NASA HQ
Program Scientist: Eric Lindstrom, NASA HQ
Project Scientist: Gary Lagerloef, NASA GSFC

3.2.2 Mission description

3.2.2.1 Objective

Aquarius will measure sea surface salinity and relate the observations to ocean circulation, global water cycle, and climate.

3.2.2.2 Status and launch date

Aquarius, an Earth System Science Pathfinder (ESSP) mission, is in the implementation phase, and scheduled for launch in June 2011.

3.2.2.3 Payload instruments

Aquarius is a joint project with the Argentine agency CONAE. The formal mission name is Aquarius / SAC-D. The primary payloads are described in Table 2. Additional instruments include infrared and visible cameras and a radio occulation sounder.

INSTRUMENT	OBJECTIVES	SPECIFICATIONS	RESOLUTION	AGENCY
AQUARIUS Radiometer % Scat-terometer	Sea Surface Salinity Soil Moisture	Integrated L-Band Radiometer (1.413 Ghz) & Scatterometer (1.26 Ghz) Swath: 390 km	Three beams: 76 x 94, 84 x 120, 96 x 156 km	NASA
MWR Microwave Radiometer	Precipitation, wind speed, sea ice con-centration	Bands: 23.8 Ghz V Pol. and 36.5 Ghz H and V Pol. Band width: 0.5 and 1 Ghz swath: 380 km	Sixteen beams < 54 km	CONAE

Table 2: Payloads for Aquarius.

3.2.3 Instrument analogues

Potential supporting airborne instruments are the JPL Polarimetric Scatterometer (PolSCAT) and various radiometers.

3.2.4 Airborne science support activities

In 2009, the Airborne Science program flew "HighWinds 09," a mission on the P-3 out of Goose Bay, Canada. The POLSCAT instrument was used to measure scattering from the ocean surface. Those measurements were used by the Aquarius science team to develop foundational algorithms for data product generation. It is probable that similar measurements may be required during the cal/val post-launch phase (~2011), although nothing is currently scheduled.

3.2.5 Gap assessment

If a mission similar to "HighWinds 09" is requested, both the aircraft and instrument should be available through a routine flight request.

3.2.6 Cross-cutting requirements from other missions

None currently identified, although data collected to support SMAP may benefit Aquarius cal/val at some stage.

3.3 NPOESS Preparatory Project (NPP)

3.3.1 Points of contact

Program Executive: Andrew Carson, NASA HQ
Program Scientist: Diane Wickland, NASA HQ
Project Scientist: James Gleason, NASA HQ
Atmosphere validation lead: David Starr, NASA GSFC

3.3.2 Mission description

The NPOESS Preparatory Project (NPP) is a joint mission with NOAA and the U.S. Department of Defense to extend key measurements in support of long-term monitoring of climate trends and global biological productivity. The original intent was to extend the measurement series initiated with EOS TERRA and AQUA by providing a bridge between NASA's EOS missions and the National Polar-orbiting Operational Environmental Satellite System (NPOESS). Even though the NPOESS program has been restructured, splitting the activities of NASA and the Defense Department, NPP is still scheduled to launch in October 2011. The mission objective remains the same: to provide continuity with NASA's Earth Observing System (EOS) satellites for climate observations and to provide the operational weather community with risk reduction for the next generation of weather satellites.

3.3.2.1 Objectives

The overall objective is to obtain and maintain the measurements listed in Table 3, where EDR = Environmental Data Records:

Table 3: NPP Measurements.

Name of Product	Group	Type
Imagery*	Imagery	EDR
Atmospheric Vertical Moisture Profile *	Atm. Sounding	EDR
Atmospheric Vertical Temperature Profile *	Atm. Sounding	EDR
Pressure Vertical Profile	Atm. Sounding	EDR
Clear Column Radiances	Atm. Sounding	SDR
Precipitable Water	Atmosphere	EDR
Suspended Matter	Atmosphere	EDR
Aerosol Optical Thickness	Aerosol	EDR
Aerosol Particle Size	Aerosol	EDR
Cloud Base Height	Cloud	EDR
Cloud Cover Layers	Cloud	EDR
Cloud Effective Particle Size	Cloud	EDR
Cloud Optical Thickness/Transmittance	Cloud	EDR
Cloud Top Height	Cloud	EDR
Cloud Top Pressure	Cloud	EDR
Active Fires	Land	Application
Albedo (Surface)	Land	EDR
Land Surface Temperature	Land	EDR
Soil Moisture	Land	EDR
Surface Type	Land	EDR
Vegetation Index	Land	EDR
Sea Surface Temperature *	Ocean	EDR
Ocean Color and Chlorophyll	Ocean	EDR
Net Heat Flux	Ocean	EDR
Sea Ice Characterization	Snow and Ice	EDR
Ice Surface Temperature	Snow and Ice	EDR
Snow Cover and Depth	Snow and Ice	EDR
Ozone Column	Atmosphere	EDR
Ozone Profile	Atmosphere	EDR

Instruments: See 3.3.2.3

CrIS/ATMS		VIIRS		CMPS		* **NPP primary EDRs**

3.3.2.2 Status and launch date

The NPP mission is in the implementation phase, with launch scheduled for October 2011.

3.3.2.3 Payload instruments

The payload suite consists of:

- The Cross-track Infrared Sounder (CrIS) combined with the Advanced Technology Microwave Sounder (ATMS) globally produces atmospheric temperature, moisture, and pressure profiles from space.

  Spectral Range:
  LWIR Band 650-1095 cm-1
  MWIR Band 1210-1750 cm-1
  SWIR Band 2155-2550 cm-1

- OMPS: Ozone Mapping and Profiler Suite
  Collects data to permit the calculation of the vertical and horizontal distribution of ozone in the Earth's atmosphere.

  Specifications:
  Nadir mapper 300 -380 nm
  Nadir profiler 250 –310 nm

- VIIRS: Visible/Infrared Imager/Radiometer Suite
  Collects visible and infrared radiometric data of the Earth's atmosphere, ocean, and land surfaces. Data types include atmospheric, clouds, Earth radiation budget, land/water and sea surface temperature, ocean color, and low light imagery.

  Specifications:
  Multiple VIS and IR channels between 0.3 and 14 microns
  Imagery Spatial Resolution: ~400m @ NADIR / 800m @ EOS

3.3.3 Instrument analogues

Airborne simulator instruments include a number of imagers, including: NAST-I, Scanning HIS, PSR, APMIR, MAS, eMAS, MASTER, and AMS.

3.3.4 Airborne science support activities

Cal / val activities are anticipated. VIIRS simulator instruments, particularly the eMAS and Airborne Modular Sensor, are suitable for complementary validation and field activities. No flight requests are currently pending for post-launch flights, but are anticipated, specifically through the ESD Carbon Cycle and Ecosystems (CCE) program.

Current discussion of validation field campaigns includes the following:

- Field data (airborne in-situ & remote sensing) to quantify error characteristics associated with atmospheric composition, such as absorbing aerosols and mixtures (aerosol models), and aerosol vertical distribution.

- Field data (airborne in-situ & remote sensing) to quantify error characteristics associated with high-impact, complex cloud scenes, especially multilayered clouds. Complex cloud scenes in heavy aerosol environment may also be a challenge.

Some suggested activities include:

FY12:

- Identify requirements for specific field campaign measurements
- Participate, highly leveraged, in PACE (major NASA NRL field experiment in SE Asia)

FY13-15:

- Participate in further field activities (small highly focused activities)

3.3.5 Gap assessment

No known gaps.

3.3.6 Cross-cutting requirements from other missions

Because of the spectral imagers required, it is possible that there may be collaboration with LDCM support activities.

3.4 Landsat Data Continuity Mission (LDCM)

3.4.1 Points of contact

Program Executive: David Jarrett, NASA HQ
Program Scientist: Diane Wickland, NASA HQ
Project Scientist: James Irons, NASA GSFC
Calibration/Validation leads: Brian Markham, NASA GSFC; and Jim Storey, USGS

3.4.2 Mission description

3.4.2.1 Objectives

Characterize and monitor land-cover use and change over time for global climate research, polar studies, land use and land cover change, and the impacts of natural events as well as human activities on the Earth’s surface.

Maintain data continuity with the Landsat system.

Extend the Landsat record of multi-spectral, global coverage of the land surface at a moderate resolution and seasonal basis.

3.4.2.2 Status and launch date

The LDCM mission is in implementation phase, with scheduled launch date of December 2012.

3.4.2.3 Payload instruments

LDCM will carry two instruments, the Operational Land Imager (OLI) and a Thermal InfraRed Sensor (TIRS). The characteristics of the multi-band OLI are listed in Table 4. The second sensor, the Thermal InfraRed Sensor, operates at 100 m wavelength. Its characteristics are shown in Table 4.

Table 4: Visible and Infrared bands of the Operational Land Imager (OLI).

Band Number	Band Name	Min. Lower Band Edge (nm)	Max. Upper Band Edge (nm)	Ground Sampling Distance (m)
1	Coastal/Aerosol	433	453	28-30
2	Blue	450	515	28-30
3	Green	525	600	28-30
4	Red	630	680	28-30
5	NIR	845	885	28-30
6	SWIR 1	1560	1660	28-30
7	SWIR 2	2100	2300	28-30
8	Panchromatic	500	680	14-15
9	Cirrus	1360	1390	28-30

3.4.3 Instrument analogues

MAS, eMAS

3.4.4 Airborne science support activities

Post-launch cal/val activities are anticipated.

3.4.5 Gap assessment

The MAS and eMAS instruments should be available for scheduling. Aircraft availability will depend on schedule priorities.

3.4.6 Cross-cutting requirements from other missions

Because of the spectral imagers required, it is possible that there could be collaboration with NPP support activities.

3.5 OCO 2

3.5.1 Points of contact

Program Executive: Eric Ianson, NASA HQ
Program Scientist: Ken Jucks, NASA HQ
Project Scientist: Michael Gunson, JPL
Calibration/Validation leads: Paul Wennberg, JPL: Ross Salawitch, GSFC

3.5.2 Mission description

OCO-2 will collect high resolution measurements of CO_2, which in turn will provide the distribution of CO_2 over the entire globe. These measurements will be combined with data from the ground-based network to provide scientists with the information that they need to better understand the processes that regulate atmospheric CO_2 and its role in the carbon cycle. The on-board instrument will acquire the most precise measurements of atmospheric CO_2 ever made from space.

3.5.2.1 Objectives

Improve our understanding of the geographic distribution of CO_2 sources and sinks (surface fluxes) and the processes controlling their variability on seasonal time scales.

Validate a passive spectroscopic measurement approach and analysis concept that is well suited for future systematic CO_2 monitoring missions.

3.5.2.2 Status and launch date

OCO-2 has entered the tailored formulation phase, and will launch by February 2013.

3.5.2.3 Payload instruments

OCO-2 will carry a single instrument comprised of three high resolution grating spectrometers. Each spectrometer detects the intensity of radiation within a very specific narrow band at Near Infrared (NIR) wavelengths. Table 5 shows the spectral range and resolving power of the OCO spctrometer.

Table 5: Spectral Range and Resolving Power of OCO-2 spectrometer bands.

Spectral Range and Resolving Power of Bands:
Minimum Wavelength
O_2 A-Band: 0.758 μm
Weak CO_2: 1.594 μm
Strong CO_2: 2.042 μm
Maximum Wavelength
O_2 A-Band: 0.772 μm
Weak CO_2: 1.619 μm
Strong CO_2: 2.082 μm
Resolving Power ($\lambda/\Delta\lambda$)
O_2 A-Band: > 17.000
Weak CO_2: > 20.000
Strong CO_2: > 20.000

3.6 Global Precipitation Measurement (GPM)

3.6.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Ramesh Kakar, NASA HQ
Project Scientist: Arthur Hou, NASA GSFC
Ground Validation leads: Matt Schwaller and Walter Peterson, NASA GSFC
Algorithm team: Eric Stocker, NASA GSFC

3.6.2 Mission description

The Global Precipitation Measurement (GPM) Mission is an international partnership initiated by NASA and Japan Aerospace Exploration Agency (JAXA) to provide the next-generation precipitation observations from space. The GPM concept centers on the deployment of a Core Observatory carrying advanced active and passive microwave sensors in a non-Sun-synchronous orbit to serve as a physics observatory to gain insights into precipitation systems and as a calibration reference to unify and refine precipitation estimates from a constellation of research and operational satellites. NASA's plan includes the "Core" observatory and flight unit 2.

3.6.2.1 Objectives

- Provide measurements of microphysical properties and vertical structure information of precipitating systems using active remote-sensing techniques over a broad spectral range.
- Combine active and passive remote-sensing techniques to provide a calibration standard for unifying and improving global precipitation measurements by a constellation of research and operational microwave sensors.
- Measure snow and lighter rain rates through the use of high-frequency passive microwave radiometry.
- Improve passive microwave retrieval (PWR) algorithms over land.
- Improve precipitation measurements in mid- and high-latitudes during cold seasons.

3.6.2.2 Status and launch date

The GPM mission is currently in implementation phase. The Core Observatory will launch in July 2013, and the flight unit 2 low-inclination spacecraft will launch in November 2014.

3.6.2.3 Payload instruments

GPM will be pointing toward Earth to measure precipitation. It will be vital to control the attitude (or physical orientation) of the Core Spacecraft accurately, so that we can map exactly where the resulting data originates on Earth. The Core observatory is uniquely instrumented with a conically-scanning radiometer and a cross-track scanning radar.

+ GPM Microwave Imager (GMI)
+ Dual-frequency Precipitation Radar (DPR)

The well-calibrated GPM Microwave Imager (GMI) measurements and the well characterized scene obtained from the Dual-frequency Precipitation Radar (DPR) will combine to provide an excellent reference against which to calibrate other microwave radiometers in the GPM constellation when overlapping measurements of the same Earth scene are made.

3.6.3 Instrument analogues

ER-2 Doppler Radar (EDOP) and similar, advanced systems

3.6.4 Airborne science support activities

The GPM validation team has prepared a "Ground Validation Science Implementation Plan," which includes both surface and airborne measurements. A successful field campaign, the Canadian CloudSAT/CALIPSO Validation Programme (C3VP) was carried out in 2007. An upcoming campaign, the Mid-latitude Continental Convective Clouds Experiment (MC3E), joint with the DOE ARM program, is scheduled for 2011. This will involve the use of EDOP on the ER-2, and in situ sampling on an additional platform, for algorithm development. In 2012, additional measurements will be made from the DC-8 in an experiment staged in Canada called COLDEX. In summer 2013, the GPM NOAA/NASA team is planning an HMT experiment in North Carolina.

Post-launch, in 2013-2014, the first cal/val field campaign will fly the DC-8, ER-2 and Global Hawk, carrying instruments similar to those used in NAMMA in August 2006 (see Table 6). Finally, in 2015, another cal/val campaign using only the DC-8 will be launched.

Table 6: NAMMA DC-8 Instruments.

NAMMA DC-8 Instruments
2DS stereo probe
Dual-Frequency Airborne Preciptation Radar (APR-2)
Cloud Particle Imager: CPI
Cloud Aerosol and Precipitation Spectrometer: CAPS
Carbon mOnoxide By Attenuation of Laser Transmission: COBALT
Counterflow Virtual Impactor: CVI
Diode Laser Hygrometer: DLH
High Altitude Monolithic Microwave Integrated Circuit Sounding Radiometer: HAMSR
Langley Aerosol Research Group Experiment: LARGE
Lidar Atmospheric Sensing Experiment: LASE
Meteorological Measurement System: MMS
Real Time Mission Monitor: RTMM
Research Environment for Vehicle-Embedded Analysis on Linux: REVEAL

3.6.5 Gap assessment

The instruments required for GPM-related airborne measurements either exist or are being developed and tested under funded programs (e.g., IIP, AITT). Integration onto the platforms of choice may run into schedule conflicts during the proposed time frames.

3.6.6 Cross-cutting requirements from other missions

None clearly identified, although some data from GPM-related experiments may be of value for 3-D Winds.

3.7 SAGE-III

3.7.1 Points of contact

Program Executive: Nandkishore Topiwala, NASA HQ
Program Scientist: David Considine, NASA HQ
Project Scientist: Michael I. Mishchenko, NASA GSFC

3.7.2 Mission description

This instrument will fly on ISS. See http://science.nasa.gov/media/medialibrary/2010/07/01/climate_architecture.pdf for more information.

3.7.2.1 Objective

The SAGE III mission is an important part of NASA's Earth Observation System and is designed to fulfill the primary scientific objective of obtaining high quality, global measurements of key components of

Table 7: SAGE III Measurement Objectives.

SAGE III MEASUREMENT OBJECTIVES	
PRODUCT NAME	**VERTICAL COVERAGE**
Aerosol Extinction at 8 Wavelengths (solar)	0 - 40 km
Water Vapor (H2O) Concentration	0 - 50 km
Nitrogen Dioxide (NO2) Concentration and Slant Path Column Amount	10 - 50 km 10 - 50 km (slant path)
Nitrogen Trioxide (NO3) Concentration (lunar)	20 - 55 km
Ozone (O3) Concentration and Slant Path Column Amount	6 - 85 km 50 - 85 km (slant path)
Chlorine Dioxode (OCIO) Concentration (lunar)	15 - 25 km
Pressure Profile	0 - 85 km
Temerature Profile (solar)	0 - 85 km
Cloud Presence	6 - 30 km

atmospheric composition (see Table 7) and their long-term variability. These measurements are vital inputs to the global scientific community for improved understanding of climate, climate change, and human-induced ozone trends.

3.7.2.2 Status and launch date

SAGE III is in the implementation phase, with a recent announcement of a Mid-2013 launch.

3.7.2.3 Payload instruments

The SAGE III instrument is a grating spectrometer that measures ultraviolet/visible energy. It relies upon the flight-proven designs used in the Stratospheric Aerosol Measurement (SAM I) and first and second SAGE instruments.

3.7.3 Instrument analogues

Various Airborne spectrometers can be used to make supporting measurements for SAGE III.

3.7.4 Airborne science support activities

In 2000, the ASP flew the SAGE III Ozone Loss and Validation Experiment (SOLVE) mission in support of the current SAGE III operational satellite. This major mission made use of both the DC-8 and the ER-2, carrying a total of 34 instruments, as listed in Figures 4.a and 4.b (page 24).

3.7.5 Gap assessment

No cal/val plans for the new SAGE III mission have been provided at this time, but it is possible that a SOLVE-like mission may be desired at some point after launch. The schedules for the aircraft will need to be considered, as well as the current availability for both NASA facility and PI instruments.

3.7.6 Cross-cutting requirements from other missions

None currently identified.

3.8 GRACE follow-on

3.8.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: John LaBrecque, NASA HQ
Project Scientist: TBD

3.8.2 Mission description

The primary goal of the GRACE mission is to map variations in the Earth's gravity field. The GRACE mission has two identical spacecrafts flying about 220 kilometers apart in a polar orbit 500 kilometers above the Earth.

GRACE maps the Earth's gravity fields by making accurate measurements of the distance between the two satellites, using geodetic quality Global Positioning System (GPS) receivers and a microwave ranging system.

Table 8.a: SOLVE payload instruments on the DC-8.

SOLVE PAYLOAD: DC-8	
O3 / PMS	B. Anderson, LaRC
TOTCAP	Avallone, Colorado
FACS / NMASS	Reeves, Denver
LASE	Brownell, LaRC
UV DIAL	Browell, LaRC
ATHOS	Brune, Penn State
OC / Temp. Lidar	Burris, GSFC
Aerosol / Solar cam	Hostetler, LaRC
NO / NOy	Kondo, Nagoya (Japan)
ASUR	Kunzl, Bremen (Germany)
MTP	Mahoney, JPL
FTTR	Mankin, NCAR
H20	May, JPL
DACOM / NDIR	Sachse, LaRC
SAFS	Shetter, NCAR
CIO / BrO	Toohey, Colorado
CIMS	Viggiano, Phillips Lab

Table 8.b: SOLVE payload instruments on the ER-2.

SOLVE PAYLOAD: ER-2	
HOx / H2O	Anderson, Harvard
CIONO2	Anderson, Harvard
WAS - ATLAS	Atlas, Univ. Miami
MASP	Baumgardner, NCAR
MMS	Bui, ARC
ACATS	Elkins, NOAA
NO / NOy	Fahey, NOAA
Argus	Jost, ARC
MTP	Mahoney, JPL
H2O	May, JPL
CPFM	McElroy, AES (Canada)
O3	Richard, NOAA
ALIAS	Webster, JPL
CIMS	Wennberg, CalTech
FCAS / NMASS	Wilson, Denver
Impactor	Wilson, Denver U
CO2	Wofsy, Harvard

3.8.2.1 Objective

GRACE continuity

3.8.2.2 Status and launch date

Mid-2016

3.8.2.3 Payload instruments

The key science instrument for GRACE is the JPL K-Band Ranging (KBR) Instrument Assembly. Its components include the Ultra Stable Oscillator (USO), the microwave assembly, the horn, and the Instruments Processing Unit (IPU).

3.8.3 Airborne science support activities

None currently proposed or projected

3.8.4 Gap assessment and cross-cutting activities

NA

3.9 Geostationary Operational Environmental Satellite (GOES-R)

3.9.1 Points of contact

Program Executive: Nandkishore Topiwala, NASA HQ
Program Scientist: Paula Bontempi, NASA HQ
Project Scientist: Dennis Chesters, NASA GSFC

3.9.2 Mission description

The Geostationary Operational Environmental Satellite Program (GOES) is a joint effort of NASA and the National Oceanic and Atmospheric Administration (NOAA).

3.9.2.1 Objective

The GOES-R series of satellites will be comprised of improved spacecraft and instrument technologies that will result in more timely and accurate weather forecasts, and will improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.

3.9.2.2 Status and launch date

The first launch of the GOES-R series satellite is scheduled for 2015.

3.9.2.3 Payload instruments

The major instruments of the GOES-R System are: the Advanced Baseline Imager (ABI); the Hyperspectral Environmental Suite (HES); the Space Environment In-Situ Suite (SEISS), which includes a Magnetospheric Particle Sensor (MPS), an Energetic Heavy Ion Sensor (EHIS), and a Solar and Galactic Proton Sensor (SGPS); the Solar Imaging Suite (SIS), which includes the Solar X-Ray Imager (SXI), the

Current GOES (5 Channels)	Future GOES-R (16 Channels)
.64 µm	0.47 µm
3.8 µm	0.64 µm
6.19 µm	0.88 µm
11.3 µm	1.38 µm
13.3 µm	1.61 µm
	2.26 µm
	3.9 µm
	6.19 µm
	6.95 µm
	7.34 µm
	8.5 µm
	9.61 µm
	10.35 µm
	11.2 µm
	12.3 µm
	13.3 µm

Table 9: Imager channels on GOES-R.

Solar X-Ray Sensor (SXS), and the Extreme Ultraviolet Sensor (EUVS); the GEO Lightning Mapper (GLM); and the Magnetometer.

The Advanced baseline imager has 16 channels, as indicated in Table 9.

3.9.3 Instrument analogues

AVIRIS, MASTER.

3.9.4 Airborne science support activities

Algorithm development and cal/val for GOES-R are anticipated, with flights scheduled on the ER-2 beginning in 2010.

3.9.5 Gap assessment

The instruments are available, pending scheduling, and have flown on the ER-2.

3.9.6 Cross-cutting requirements from other missions

Support for GOES-R will be on a cost-reimbursable basis, so no collaborative activities are foreseen.

4 DECADAL SURVEY TIER I MISSIONS

4.1 SMAP (Soil Moisture Active Passive)

4.1.1 Points of contact

Program Executive: Eric Ianson, NASA HQ
Program Scientist: Jared Entin, NASA HQ
Project Scientists: Eni Njoku, JPL, Peggy O'Neill, GSFC
Cal/val Lead: Tom Jackson, USDA

4.1.2 Mission description: objectives and instruments

SMAP will measure soil moisture in support of understanding of Earth's water and energy cycles. Both active and passive remote sensors are included in the satellite payload. The instrument is designed to make coincident measurements of surface emission and backscatter, with the ability to sense the soil conditions through moderate vegetation cover.

The science goal is to combine the attributes of the radar and radiometer observations in terms of their spatial resolution and sensitivity to soil moisture, surface roughness, and vegetation.

The SMAP instrument architecture incorporates an L-band radar and an L-band radiometer that share a single feedhorn and parabolic mesh reflector. The reflector is offset from nadir and rotates about the nadir axis at 14.6 rpm, providing a conically scanning antenna beam with a surface incidence angle of approximately 40°. The reflector has a diameter of 6 m, providing a radiometer footprint of 40 km. The real-aperture radar footprint is 30 km, defined by the two-way antenna beam width.

4.1.3 Mission schedule

SMAP is in Phase B status.
Estimated launch date: November 2014

4.1.4 Instrument analogues

The SMAP science team anticipates flying SMAP simulators over the next 5 years in support of algorithm development cal/val work. The flights include radiometers and radars. Representative instruments are PALS and UAVSAR.

There has also been some discussion of CO_2 measurements in northern latitudes, but no specific analogue instruments have been proposed.

PALS
The Passive/Active L-/S-band (PALS) microwave instrument was developed by the Jet Propulsion Laboratory (JPL) to investigate the synergism of radiometer and radar measurements for soil moisture remote sensing. It has flown successfully on a number of science missions and is a desirable payload for SMAP field experiments.

UAVSAR
UAVSAR, a reconfigurable, polarimetric L-band synthetic aperture radar (SAR), is specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. It has flown successfully in 2009 for ice mapping in Greenland and Iceland and in the CANEX mission in Canada / Alaska in early 2010. It is also a desirable payload for SMAP field experiments, although the repeat pass capability of the G-III is not required.

4.1.5 Cal/val and field test

A cal/val plan is being developed for the project that addresses both pre- and post-launch requirements identified by the SMAP project and Science Definition Team (SDT). The objective of SMAP cal/val is to calibrate and validate Level 1 through Level 4 algorithms and products relative to the mission requirements. Elements of the cal/val plan will include in situ, tower and aircraft simulators, satellite observations, model and surrogate variables, and field campaigns.

Pre-launch cal/val is focused on validating that there are means in place to fulfill the mission objectives. In particular:

- Identified activities that will improve algorithms and products
- Establish infrastructure necessary for post-launch calibration and validation

Post-launch cal/val is focused on validating that the science products meet their quantified requirements, and on improving the algorithms and quality of products over the mission life.

4.1.6 Preliminary field plans and schedule overview

Flight of Opportunity – Antarctica Dome C: radiometer measurements from DC-8 as part of Operation Ice Bridge.

The CanEX soil moisture experiment in early 2010 was a highly successful use of the UAV-SAR, which will be sought again in 2011 for CanEx freeze-thaw. PALS is planned as a cal/val simulator and will have a check flight on the P-3 in late 2010.

A detailed field campaign schedule is in development. Draft plans are shown in the Figure 6 (page 30). Other, complementary launches, SMOS, Aquarius, and GCOM-W are also indicated. Note that focused campaigns continue through 2015.

4.1.7 Gap assessment

The aircraft and payload support required for SMAP exist. UAVSAR scheduling is a potential issue.

4.1.8 Cross-cutting requirements from other missions

None currently identified, although data collected to support SMAP may benefit the later missions SWOT and SLCP.

Year/ Quarter	1	2	3	4
2008			SMAPVEX08	
2009				SMOS
2010		SMAPEx	SMAPEx CanEx-SM	Aquarius SMAPEx PALS Check
2011				GCOM-W CanEx-FT
2012			SAOCOM SMAPVEX12	
2013				
2014				SMAP
2015		SMAPVEX15	SMAPVEX15	SMAPVEX15
Satellite launch in red.				

Table 10: SMAP Major Field Campaigns.

- SMAPVEX08
  - High priority design/algorithm issues
- SMAPEx (Australia)
  - 4 one-week campaigns to span four seasons
  - Aircraft Radar/Radiometer
- CanEx-SM (Canada)
  - Two-week soil moisture campaign
  - Aircraft Radar/Radiometer
- CanEx-FT (Canada)
  - Two-week freeze/thaw campaign
  - Aircraft Radar Radiometer
- PALS Check
  - New configuration tests on P-3
  - RFI studies
- SMAPVEX12
  - Major hydrology campaign
  - Long duration
  - Aircraft Radar/Radiometer
- SMAPVEX15
  - Extended campaign for both SM - and FT
  - Long duration
  - Aircraft Radar/Radiometer

4.2 ICESAT II (Ice, Cloud, and Land Elevation Satellite II)

4.2.1 Points of contact

Program Executive: Richard Slonaker, NASA HQ
Program Scientist: Tom Wagner, NASA HQ
Project Scientist: Thorsten Markus, NASA GSFC

4.2.2 Mission description

The objectives of ICESat II are:

- Measuring ice sheet mass balance, cloud and aerosol heights.
- Measure land topography and vegetation characteristics.
- Provide multi-year elevation data needed to determine ice sheet mass balance.
- Provide cloud property information, especially for stratospheric clouds common over polar areas.
- Provide topography and vegetation data around the globe, in addition to the polar-specific coverage over the Earth's ice sheets.

4.2.3 Mission schedule

ICESat II is currently in Phase A.

Estimated launch date: Late 2015

4.2.4 Payload Instrument

Laser altimeter, similar to ICESat. However, in contrast to the ICESat design, ICESat-2 will use a micropulse multi-beam approach. This provides dense cross-track sampling to resolve surface slope on an orbit basis. The sensor will have a high pulse repetition rate of approximately 10 kHz, which generates dense along-track sampling of about 70 cm. This concept has advantages over ICESat of improved elevation estimates over high slope areas and very rough (e.g. crevassed) areas and improved lead detection for sea ice freeboard estimates.

4.2.5 Instrument analogues

Airborne analogues include those being used in Operation Ice Bridge:

ATM – the Airborne Topographic Mapper, the legacy instrument for ice mapping.

LVIS – the Laser Vegetation Imaging Sensor, a mature instrument capable of higher altitude.

PARIS - Pathfinder Airborne Radar Ice Sounder, a new system being used in Operation Ice Bridge.

SIMPL - Slope Imaging Multi-polarization Photon-counting Lidar, an IIP pathfinder instrument simulator for ICESat - 2.

In addition, a new instrument developed at NASA Goddard, the Multiple Altimeter Beam Experimental Lidar (MABEL) instrument, is performing as a simulator instrument, flying on the ER-2. Preliminary flights in 2010 will be followed by additional flights in 2011.

4.2.6 Flights requested: “Operation Ice Bridge”

The schedule for Operation Ice Bridge is shown in Figure 6.

More details can be found in the ICESat Gap Filler report. [4]

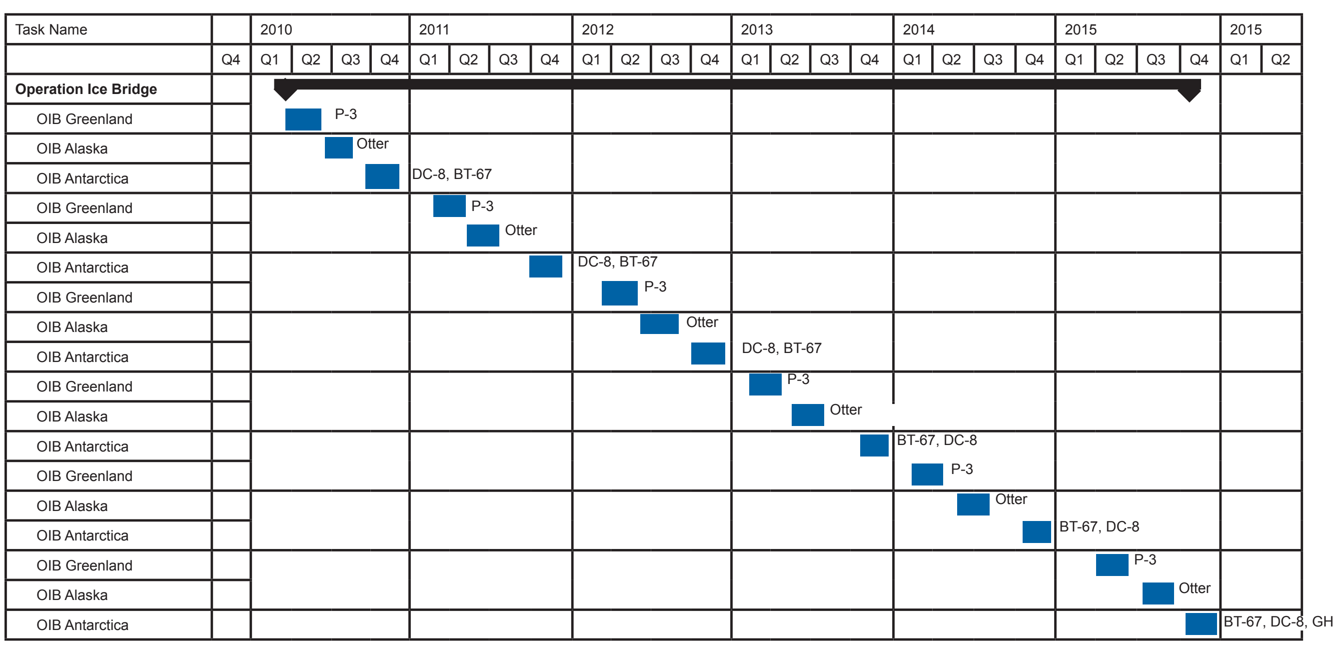


Fig. 6: Schedule for Operation Ice Bridge.

Besides the P-3, DC-8 and Global Hawk, currently identified for Ice Bridge missions, other airborne support for ICESat II could be provided using a Twin Otter, DC-8, or DHC-3.

4.2.7 ASP Gap Assessment

The aircraft support required for ICESat II and Ice Bridge exist. Potential schedule conflicts will need to be resolved. Global Hawk capability could increase Antarctic range.

4.2.8 Cross-cutting requirements from other missions

Lidar experiments for ICESat-2 support could be aligned with experiments supporting DESDynI. The LVIS instrument is identified for both, and there are some regions of common interest.

4.3 DESDynI (Deformation, Ecosystem Structure and Dynamics of Ice)

4.3.1 Points of contact

Program Executive: Sanghamitta Dutta, NASA HQ
Program Scientist: John LeBrecque, NASA HQ
Chief Scientist: Bo-Wen Shen, NASA GSFC
Cal/val Lead: Forrest Hall, NASA GSFC

4.3.2 Mission description

DESDynI is a dedicated InSAR and LIDAR mission optimized for studying hazards and global environmental change.

Mission objectives:

- Determine the likelihood of earthquakes, volcanic eruptions, and landslides.
- Predict the response of ice sheets to climate change and impact on the sea level.
- Characterize the effects of changing climate and land use on species habitats and carbon budget.
- Monitor the migration of fluids associated with hydrocarbon production and groundwater resources.

4.3.3 Mission schedule

DESDynI is currently in pre-Phase A. Estimated launch date: 2017

4.3.3.1 Payload instruments

The current plan for DESDynI is to fly the payload on two separate satellites. The sensors are: 1) an L-band Interferometric Synthetic Aperture Radar (InSAR) system with multiple polarization; and, 2) a multiple beam lidar operating in the infrared (~ 1064 nm) with ~ 25 m spatial resolution and 1 m vertical accuracy.

Separating the two sensors provides an opportunity for each to use the most optimum pointing vector and orbit characteristics.

4.3.4 Instrument analogues

For DESDynI field campaigns, the following instruments and activities are anticipated:

LVIS has been and will continue to be used for vegetation measurements related to algorithm development.

UAVSAR has been and will continue to be used for topography measurements needed for corrections to the vegetation data and for solid earth deformation

ESFL, the steerable flash lidar (Ball Aerospace), is designed to support DESDynI by making forest carbon measurement. With AITT funding, it will be flight tested on a Twin Otter in 2011.

4.3.5 Preliminary field plans and schedule overview

Many scheduled G-III / UAVSAR flight hours support data collection for DESDynI algorithm development.

4.3.6 ASP Gap Assessment

The aircraft and payload support required for DESDynI exist. LVIS can fly on a number of aircraft; the Twin Otter is currently identified. UAVSAR flies only on the G-III, although there are plans to make UAVSAR compatible with other aircraft, particularly the Global Hawk. Hence, UAVSAR scheduling is a potential issue.

4.3.7 Cross-cutting requirements from other missions

Missions using the UAVSAR on the G-III are, or could be, scheduled to include both repeat-pass Earth surface experiments, as well as simpler SAR experiments. There is also potential for flights of the LVIS instrument to support both ICESat-2 and DESDynI objectives.

4.4 CLARREO (Climate Absolute Radiance and Refractivity Observatory)

4.4.1 Points of contact

Program Executive: Richard Slonaker, NASA HQ
Program Scientist: Ken Jucks, NASA HQ
Chief Scientist: David Young, NASA LaRC

4.4.2 Mission description

The CLARREO imperative is to:

- Initiate an unprecedented, high accuracy record of climate change that is tested, trusted and necessary for sound policy decisions.
- Establish a record of direct observables with high accuracy and information content necessary to detect long-term climate change trends and to test and systematically improve climate predictions.
- Observe System Internationale traceable, spectrally-resolved radiance and atmospheric refractivity with the accuracy and sampling required to assess and predict the impact of changes in climate forcing variables on climate change.

4.4.3 Mission schedule

CLARREO is currently in Pre-phase A. It passed Mission Concept Review (MCR), November 17, 2010. CLARREO-1 will launch in 2017 and CLARREO-2 in 2020.

4.4.3.1 Payload instruments

Spectral reflected solar and emitted infrared radiances and Global Positioning System (GPS) Radio Occultation refractivities measured by CLARREO will be used to detect climate trends and to test, validate, and improve climate prediction models.

The CLARREO mission is currently envisioned to consist of two duplicate observatories each carrying a payload of one infrared instrument suite, one reflected solar instrument suite and a Global Navigation Satellite System Radio Occultation (GNSS-RO) instrument system.

The CLARREO Payload Elements include:

- A “Reflected Solar (RS) Suite” consisting of three pushbroom hyperspectral grating imagers covering 320-2300 nanometers combined into a single instrument package and pointed by a two-axis gimbal.
- An “Infrared (IR) Suite” consisting of a Fourier Transform Spectrometer (FTS) covering 5-50 microns (2000-200 cm-1) and an on-orbit calibration and verification system.
- A “ Global Navigation Satellite System–Radio Occultation (GNSS-RO)” receiver capable of RO measurements using GPS, GLONASS, and Galileo navigation systems.

4.4.4 Instrument analogues

One IIP-sponsored instrument, Marty Mlynczak’s INFLAME experiment has been flight tested and is ready for further application in algorithm development. The University of Colorado / LASP radiometer and University of Wisconsin IR calibration system.

4.4.5 Preliminary field plans and schedule overview

Most of the proposed satellite instruments have heritage and will not need flight tests for technology readiness advancement. However, the proposed *systems* will need demonstration. Suggestions were made for system tests at very high altitude, for example, on a balloon, or on a aircraft, most likely the DC-8. The data collection and management portions of the system will also need testing on an aircraft. Satellite overpass may be desired for calibration. A likely date for such testing would be 2011. The points of contact for overall discussion would be David Young at LaRC. A concept for CLARREO calibrated measurements is shown in Figure 7.

Specific PI’s will be:

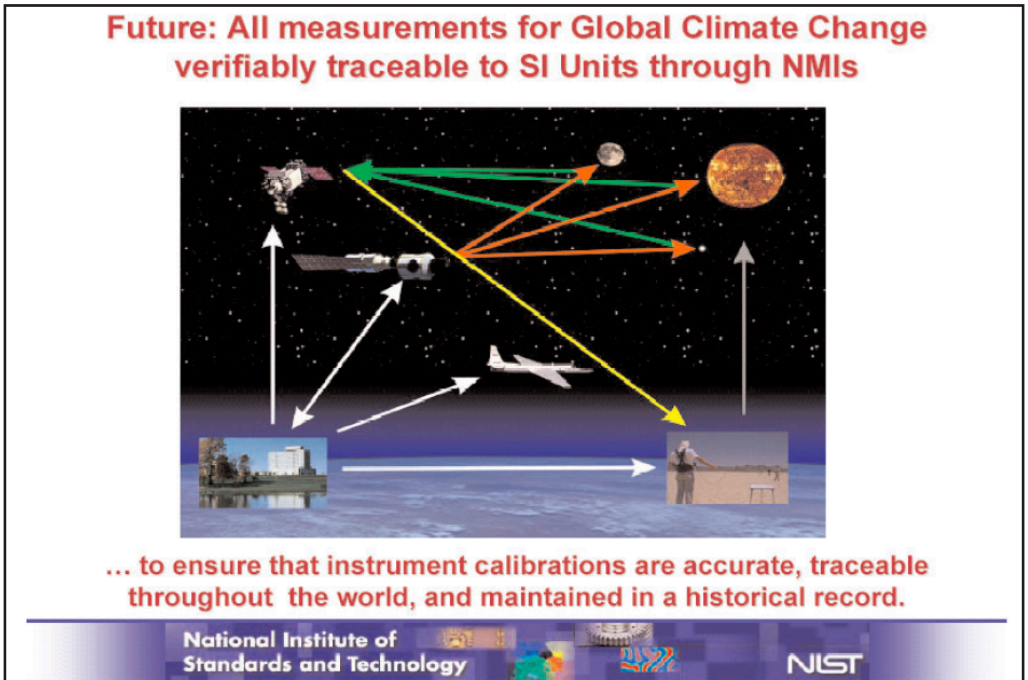
- Marty Mlynczak (LaRC) for the Far-IR system
- Hank Revercomb (UW) for IR testing with coordinated overpasses
- Kurt Thome (GSFC) for the solar instrument system
- Andrew Lacis (GISS), if a polarimeter such as the APS is selected for the mission

4.4.6 ASP Gap Assessment

The aircraft and payload support required for CLARREO exist. Since high altitude is desired, there may be some schedule conflicts with other high-altitude aircraft.

4.4.7 Cross-cutting requirements from other missions

None currently identified.



Note: NMI = National Metrology Institute

Fig. 7: Concept for CLARREO calibrated measurements.

5 DECADAL SURVEY TIER II MISSIONS

5.1 SWOT (Surface Water Ocean Topography)

5.1.1 Points of contact

Program Scientist: Eric Lindstrom, NASA HQ
Chief Scientist: Parag Vaze, JPL
U.S. science lead for hydrology: Doug Alsdorf, Ohio State University;
Airborne simulator developer: Delwyn Moller, Remote Sensing Solutions

5.1.2 Mission description

SWOT will combine the concepts of WaTER (Water and Terrestrial Elevation Recovery) and the Hydrosphere Mapper missions into a single mission to address the objectives of both land hydrology and oceanography.

5.1.3 Mission schedule

SWOT is currently in pre-phase A, with launch scheduled for 2020.

5.1.4 Payload instruments

The Ka-band Radar Interferometer (KaRIN) instrument makes this mission possible. As indicated in Figure 8, KaRIN contains two Ka-band SAR antennae at opposite ends of a 10-meter boom with both antennae transmitting and receiving the emitted radar pulses along both sides of the orbital track. Look

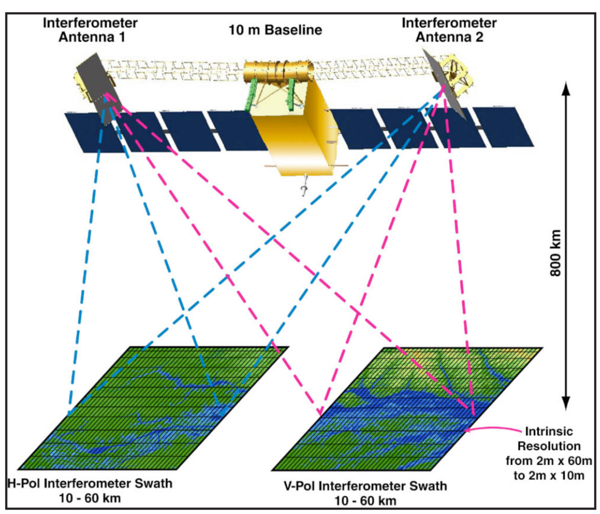


Fig. 8: Ka-band wide swath radar

angles are limited to less than 4.5° providing a 120-km wide swath. The 200-MHz bandwidth achieves cross-track ground resolutions varying from about 10 m in the far swath to about 60 m in the near swath. A resolution of about 2 meters in the along track direction is derived by means of synthetic aperture processing.

5.1.5 Instrument analogues and flight plans

The Airborne Glacier and Land Ice Surface Topography Interferometer (GLISTEN-A), recently funded by an AITT award is a follow-on to the Ka-band version of UAVSAR flown on the G-III to Greenland in 2009. Flight test is expected in mid-2012. This pod-based instrument could fly on either the G-III or Global Hawk for algorithm development.

The most relevant simulator to the SWOT Ka-band wide swath radar (KaRIN) is the Ka-band SWOT Phenomenology Airborne Radar (KaSPAR) system. AirSWOT is the KaSPAR radar itself (Ka-band interferometer also, but nadir and near-nadir viewing and with more bandwidth and more baselines).

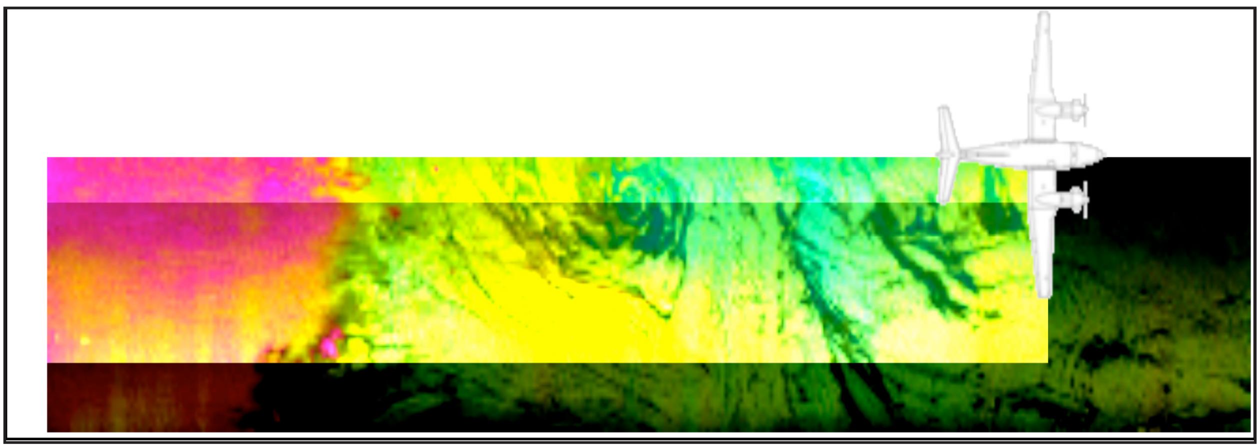


Fig. 9: Ka-SPAR concept.

KaSPAR will not be pod-based and is completely independent of UAVSAR. Development of the AirSWOT is currently SBIR-funded and does not include flight integration and test. If funding is found, flight tests of the AirSWOT instrument would be initially on the DFRC B-200 in early 2012.

Eventually developers would like to put KaSPAR on the Global Hawk as a high-altitude simulator for algorithm development and cal/val. The KaSPAR observation concept is shown in Figure 9.

5.1.6 ASP Gap Assessment

The aircraft support required for GLISTIN-A and KaSPAR / AirSWOT requires negotiation for integration into the desired platforms.

5.1.7 Cross-cutting requirements from other missions

None currently identified, although data collected to support SMAP, Aquarius or the ocean portions of ACE may benefit SWOT.

5.2 HyspIRI (Hyperspectral Infrared Imager)

5.2.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Woody Turner, NASA HQ
Science Leads: Rob Green, Simon Hook, JPL

5.2.2 Mission description

The objectives of the HyspIRI mission are to:

- Study the processes that indicate volcanic eruption.
- Analyze the nutrients and water status of vegetation.
- Examine soil type and health.
- Use spectra to identify locations of natural sources.
- Study deforestation and changes in vegetation type.
- Provide early warning of droughts.
- Improve exploration for natural resources.
- Forecast likelihood of volcanic eruptions and landslides.

5.2.3 Mission schedule

HyspIRI is currently in pre-Phase A. Estimated launch date: 2020

5.2.4 Payload instruments

- Visible short-wave infrared (VSWIR) imaging spectrometer.
- Multispectral thermal infrared (TIR) scanner.

5.2.5 Instrument analogues and preliminary airborne plans

The primary instrument to fly on HyspIRI is a hyperspectral spectrometer. Common analog instruments previously flown on aircraft are MASTER and AVIRIS.

Plans include late 2011: MASTER, AVIRIS on ER-2.

ESTO has supported the development of instruments suitable for HyspIRI with identified instrument test flights in 2011. These are:

- Hyperspectral Thermal Emission Spectrometer (HyTES). The airborne hyperspectral thermal imager called HyTES will be flight tested in support of HyspIRI mission. It is expected to be available for routine use in 2011.
- Mineral and gas identification spectrometer.

5.2.6 ASP Gap Assessment

The aircraft and payload support required for HyspIRI exists, but there could be schedule issues for AVIRIS, MASTER and the aircraft they fly on.

5.2.7 Cross-cutting requirements from other missions

Because of the common requirements for spectral imagers, it may be possible to support HyspIRI and NPP or LDCM concurrently.

5.3 ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons)

5.3.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Ken Jucks, NASA HQ
Science Lead: TBD

5.3.2 Mission description

Mission objectives:

- Measure the number density of Carbon Dioxide (CO_2) in the column of air beneath the aircraft.
- Measure length of the column using a laser altimeter.
- Measure ambient air pressure and temperature.

5.3.3 Mission schedule

ASCENDS is currently in pre-Phase A. Estimated launch 2019.

5.3.4 Payload instruments

The satellite will carry a multifrequency laser, with primary objective to measure CO2. Measurements of oxygen are also planned.

5.3.5 Instrument analogues

To support the development of the payload and algorithms, the ASCENDS science team has been test flying several candidate CO2 instruments. These include:

- Browell (LaRC), Modulated CW Fiber Laser-Lidar Suite
- Abshire (GSFC), CO2 Laser Sounder
- Spiers (JPL), Airborne 2 micron Laser Absorption Spectrometer

5.3.6 Preliminary field plans and schedule overview

Summer 2009: The three instruments were flown on independent aircraft, but simultaneously over the Oklahoma ARM site.

Summer 2010: All three instruments were flown together on the DC-8 on local flights from Palmdale over various land and ocean surfaces and on a long-range flight over the Oklahoma ARM site.

Summer 2011: Flight tests are planned for the three instruments over various land and cloud features not previously investigated; in the presence of significant CO2 variability in the lower troposphere; and in the presence of thin cirrus and low-altitude scattered clouds. There is a possibility that the Heaps broad-band lidar will also be flown during this campaign.

Any pre-or post-launch airborne activities in support of OCO-2 will also support ASCENDS either directly or indirectly.

5.3.7 ASP Gap Assessment

The aircraft and payload support required for ASCENDS exist.

5.3.8 Cross-cutting requirements from other missions

Algorithm development and other support for ASCENDS could benefit OCO-2.

5.4 GEO-CAPE (Geostationary Coastal and Air Pollution Events)

5.4.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Jay Al-Saadi, NASA HQ
Science Leads: Annemarie Elderling, JPL; Laura Iraci, NASA ARC

5.4.2 Mission description

Mission objectives:

- Identification of human versus natural sources of aerosols and ozone precursors.
- Dynamics of coastal ecosystems, river plumes, and tidal fronts.
- Observation of air pollution transport in North, Central, and South America.
- Prediction of track of oil spills, fires, and releases from natural disasters.
- Detection and tracking of waterborne hazardous materials.
- Measure coastal health.
- Forecasts of air quality.

5.4.3 Mission schedule

GEOCAPE is currently in pre-Phase A. Estimated launch date: 2013.

5.4.4 Instruments & analogues

High and low spatial resolution hyperspectral imagers will fly on the satellite. Analogues include AVIRIS and TIMS.

ESTO-sponsored instruments to be tested include:

- Panchromatic Fourier Transform Spectrometer (PanFTS)
- Tropospheric Infrared Mapping Spectrometer (TIMS)
- Wide Field Imaging Spectrometer (WIFS)

5.4.5 Preliminary field plans and schedule overview

Fall 2010: Fourier transform spectrometer (FTS) simulator to fly on the WB-57 out of Houston to image the shipping area to the coast.

2010-2011: DC-8 atmospheric sampling from ocean to coast; possible joint mission with ACE.

5.4.6 ASP Gap Assessment

TBD

5.4.7 Cross-cutting requirements from other missions

A joint mission with ACE to collect ocean / coast data could benefit both missions.

5.5 ACE (Aerosol - Cloud – Ecosystems)

5.5.1 Points of contact

Program Exexutive: Steve Neeck, NASA HQ
Program Scientist: Hal Maring, NASA HQ
Cal/val Lead for aerosols: Jens Redemann, NASA ARC
Cal/val Lead for oceanography: Chuck McClain, NASA GSFC

5.5.2 Mission description

Mission objectives:

- Cloud and aerosol height.
- Organic material in surface ocean layers.
- Aerosol and cloud types and properties.
- Improved climate models.
- Prediction of local climate change.
- Measure ocean productivity and health.
- Air-quality models and forecasts.

5.5.3 Mission schedule

ACE is currently in pre-Phase A. Pre-ACE (PACE) is scheduled for launch in 2017, ACE is scheduled for launch in the post 2020 time-frame

Figure 10 illustrates the mission concept for Pre-ACE and ACE.

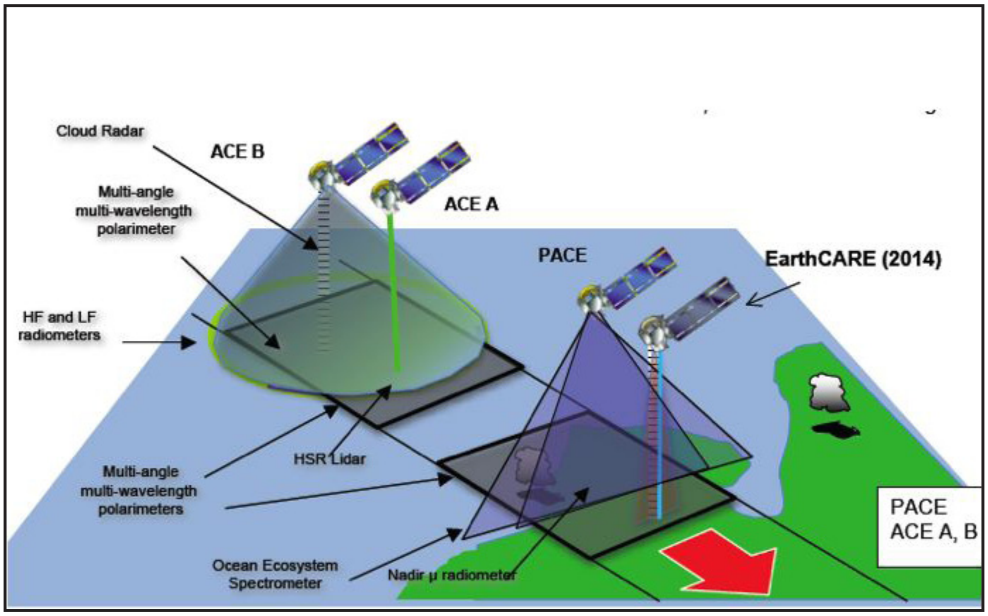


Fig. 10: ACE and Pre-ACE concepts.

5.5.4 Payload instruments

ACE Payload currently considers the following instruments candidates:

- Lidar for assessing aersol/cloud heights and aerosol properties. (TRL 4-6)
- Dual frequency cloud radar for cloud properties and precipitation. (TRL 4-6)
- Multi-angle, swath polarimeter for imaging aersol and clouds. (TRL 4-60
- Ocean color radiometer for ocean ecosystems. (TRL 5)
- IR imager for cloud temperatures and heights. (TRL 6)
- High frequency microwave radiometer for cloud ice measurements. (TRL 6)
- Low frequency microwave radiometer for precipitation measurements. (TRL 6)
- Microwave temperature/humidity sounder. (ATMS, TRL 9)

5.5.5 Instruments analogues

Several polarimeter instruments are candidates for ACE, including RSP, AirMSPI, PACS /OMI.

5.5.6 Preliminary field plans and schedule overview

A characterization experiment to compare three alternative polarimeter concepts will be flown in summer 2011. The polarimeters on the ER-2 will overfly P-3 with upward-looking radiometer. This is the ACE Polarimeter Definition Experiment (PODEX).

- Dave Diner (JPL) is PI for the AirMSPI instrument.
- Vanderlei Martins (U. Maryland) is PI for the Passive Aerosol and Cloud Suite (PACS).
- Brian Cairns (Columbia U./ GISS) is PI for the Research Scanning Polarimeter (RSP) instrument.

Each instrument is in various stages with respect to being able to fly on the ER-2, and all will need to fly together. Finally, there is to be a coordinated under-flight of the P-3 during this experiment. Jens Redemann, who leads the field studies team for ACE aerosols, is the point of contact for the flight request. An illustration of the experiment is shown in Figure 11.

The overall field campaign schedule is shown in Figure 12. The dates may vary, but the level of desired activity is constant.

The ACE team is interested in flying a low-altitude UAS for chemistry measurements at the ocean surface in conjunction with other ship-board and buoy measurements. Currently, there is no chemistry imperative, and hence, no funding in the ACE program for this type of measurement. However, it would be a good collaboration with GEO-CAPE ocean requirements.

5.5.7 ASP Gap Assessment

The aircraft and sensors for the early measurements exist. A UAS ocean surface experiment will require development of sensors and control system.

5.5.8 Cross-cutting requirements from other missions

A joint mission with ACE to collect ocean / coast data could benefit both missions.

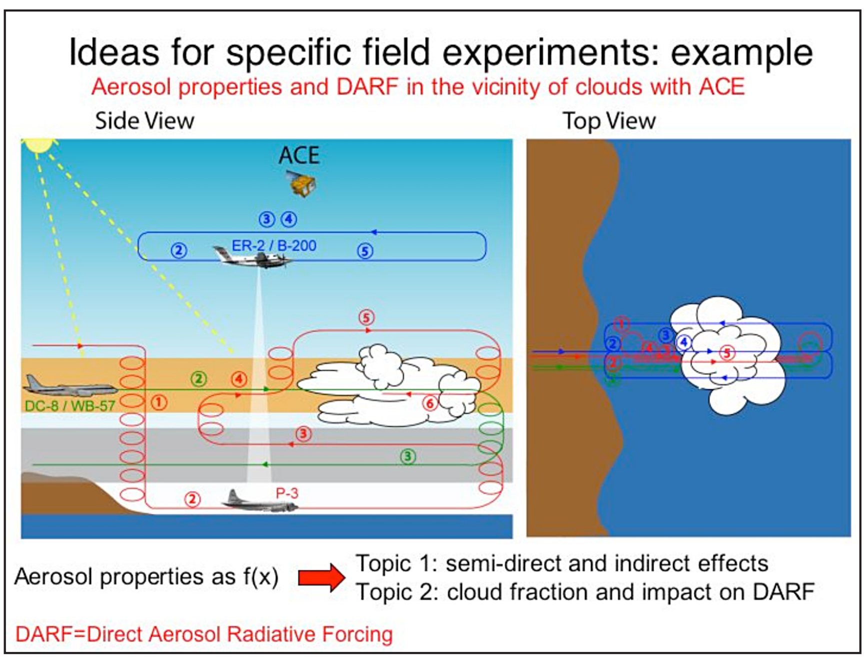


Fig. 11: Concept for ACE algorithm development mission.

ACE Major Suborbital Field Campaigns

Year/Qtr	1	2	3	4
2010		MACPEX	ACE-PoDEX10	
2011			PACE	
2012			ACE-PEX 12	ACE-ALDEX13B
2013		ACE-ALDEX13A		
2014				
2015				
2016				
2017	ACE-launch	ACE-VEX17A	ACE-SVEX17	ACE-VEX17B
2018	ACE-SVEX18A	ACE-VEX18A	ACE-SVEX18B	ACE-VEX18A
2019	ACE-SVEX19A	ACE-VEX19B	ACE-SVEX19B	ACE-VEX19B

Science focus: Aerosols Clouds Ocean Ecosystems

- MACPEX
  - Mid-latitude Airborne Cirus Properties Experiment
  - WB-57, Houston, TX
- ACE- PoDEX10
Polarmeter Definition Experiment
  - High priority design/algorithm issues
  - ER-2 + P-3B, Wallops or Dryden
- PACE - Pacific Atmospheric Composition, Cloud, and Climate Experiment
  - Instrument design, combination algorithm issues specific to ACE science question
  - DC-8, ER-2, SE Asia
  - ACE-PEX12 (ACE Precursor Experiment)
  - Study aerosol properties near clouds and DARF as function of distance from clouds
  - ER-2, P-3B, + in-situ a/c Wallops?
  - ACE- ALDEX
  - Algorithm Development Experiment to support multi-sensor algorithm development
  - ER-2 + P-3B, Wallops or Dryden
- ACE- VEX17-19 (Validation Experiment)
  - ACE product and algorithm validation
- ACE- SEVEX17-19 (Science and Validation Exp.)
  - ACE product and algorithm validation
  - Suborbital measurements as necessitated by ACE science questions requirements

Fig. 12: Schedule of ACE.

6 DECADAL SURVEY TIER III MISSION SUPPORT

All Tier 3 missions are in early planning stages, pre-Phase A.

Tier 3 Missions launch dates	
Mission	**Launch Date**
LIST	>2020
PATH	>2020
GACM	>2020
SCLP	>2020
GRACE-II	>2020
3-D Winds	>2020

6.1 LiST (Lidar Surface Topography)

6.1.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Craig Dobson, NASA HQ
Project Scientist: TBD

6.1.2 Mission description

Mission objectives: Land surface topography for hazards and water runoff.

6.1.3 Instrument & analogues

Laser Altimeter.

ESTO-sponsored instruments to be tested include: Swath-mapping lidar (Yu).

6.1.4 Preliminary flight plans and schedule overview

Flight test of lidar in 2012 time frame.

6.2 PATH (Precision and All-weather Temperature and Humidity)

6.2.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Ramesh Kakar, NASA HQ
Project Scientist: TBD

6.2.2 Mission description

Mission objectives: High frequency, all-weather temperature and humidity soundings for weather forecasting and SST.

6.2.3 Instrument & analogues

Microwave array spectrometer.

6.2.4 Preliminary field plans and schedule overview

TBD.

6.3 GACM (Global Atmospheric Composition Mission)

6.3.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Ken Jucks, NASA HQ
Science Lead: L. Watkins, NASA GSFC

6.3.2 Mission description

Mission objectives: Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction.

6.3.3 Instruments & analogues

- UV spectrometer
- IR spectrometer
- Microwave limb sounder

ESTO-sponsored instruments to be tested include microwave limb sounder for atmospheric composition (Stek).

6.3.4 Preliminary field plans and schedule overview

Flight test of limb sounder in 2012 time frame.

6.4 SCLP (Snow and Cold Land Processes)

6.4.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Jared Entin, NASA HQ
Project Scientist: TBD

6.4.2 Mission description

Mission objectives: Snow accumulation for fresh water availability.

6.4.3 Instruments & analogues

Ku and X-band radars
K and Ka-band radiometers

ESTO-sponsored instruments to be tested include: X-band phased array for snow-water equivalent measurements.

6.4.4 Preliminary flight plans and schedule overview

Flight test of KaSPAR (SWOT instrument) is possible in support of SCLP.
Flight test of the X-band array in the 2013 time frame. Both are being designed for Global Hawk.

6.5 GRACE-II (Gravity Recovery and Climate Experiment-II)

6.5.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: John Lebrecque, NASA HQ
Project scientist: TBD

6.5.2 Mission description

Mission objectives: High temporal resolution gravity fields for tracking large-scale water movement.

6.5.3 Instruments & analogues

Microwave or laser ranging system.

6.5.4 Preliminary field plans and schedule overview

Just as the GRACE follow-on may not have any airborne requirements, GRACE-II may also not have any airborne support requirements.

6.6 3-D Winds (Three-Dimensional Tropospheric Winds from Space-based Lidar)

6.6.1 Points of contact

Program Executive: Steve Neeck, NASA HQ
Program Scientist: Ramesh Kakar, NASA HQ
Project Scientist: TBD

6.6.2 Mission description

Mission objectives: Tropospheric winds for weather forecasting and pollution transport.

6.6.3 Instrument analogues

Doppler Lidar.

ESTO-sponsored instruments to be tested include:

- TWiLiTE (Gentry)
- Coherent Doppler Lidar (Diner)

6.6.4 Preliminary field plans and schedule overview

Summer 2010: Simultaneous flight of two AITT instruments on DC-8.

6.6.5 ASP Gap Assessment

The DC-8 integration is understood. The schedule may require negotiation.

6.7 TIER 3 Missions Summary

A summary of support for Tier 3 missions is shown in Figure 13.

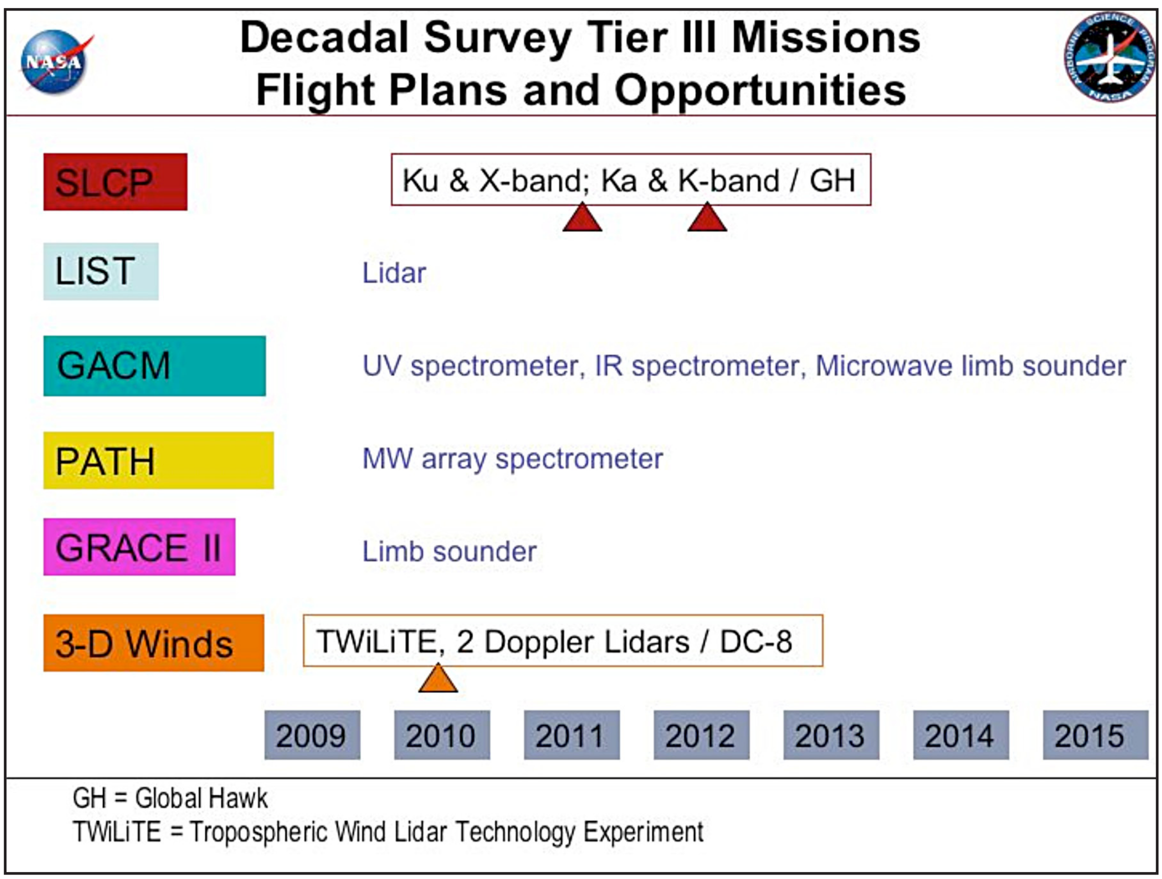


Fig. 13: Tier III missions.

7 Synthesis and Recommendations

7.1 Cross-cutting requirements and gaps

At this early stage in the development of field test and cal/val plans for Decadal Survey missions, it appears that the Airborne Science Program is well positioned to meet the needs of most mission teams. Because of EV-1 requirements for Global Hawk, and Operation Ice Bridge requirements for the P-3 and DC-8, scheduling of these aircraft must be considered as far in advance as possible.

For the sake of the aircraft scheduling and cost savings to the PIs, it would be beneficial, where possible, for an airborne mission to be designed to meet the requirements of more than one DS Mission team. Some overlap exists, for example, between the needs of the ACE mission and the GEO-CAPE mission.

The sensor and science support teams are also sufficiently flexible to meet the potential needs, except for UAVSAR. For that instrument schedule conflicts already exist.

7.2 Recommendations

1. Continue plans to build another UAVSAR and make it available on an additional platform.

2. Work with the mission science teams to refine airborne requirements and mission overlaps to maximize use of airborne resources.

8 References

[1] NRC Report, “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,” 15 January 2007.

[2] “NASA Earth Science Requirements for Suborbital Observations,” available at http://airbornescience.nasa.gov.

[3] NPR 7120.5D (NASA Space Flight Program and Project Management Requirements).

[4] “A summary and analysis of options for collecting ICESat-like data from aircraft through 2014,” NASA internal report, April 2009.

Appendix A: The Airborne Science Program

A.1 Airborne Science Program – types of support

The overall objectives of the NASA's Airborne Science Program are:

- **Satellite Calibration and Validation:** Provide platforms to enable essential calibration measurements for the Earth observing satellites, and the validation of data retrieval algorithms.

- **New Sensor Development:** Provide sub-orbital flight opportunities to test and refine new instrument technologies/algorithms, and reduce risk prior to committing sensors for launch into space.

- **Process Studies:** Obtain high-resolution temporal and spatial measurements of complex local processes that can be coupled to global satellite observations for a better understanding of the complete Earth system.

- **Development of Next-Generation Scientists and Engineers:** Foster the development of our future workforce with the hands-on involvement of graduate students and young scientists/engineers in all aspects of ongoing Earth science investigations.

Considering those program objectives, ASP can support the Decadal Survey missions in a number of ways including instrument flight testing, support for field studies to aid collection of data for pre-launch algorithm development, field campaigns to support satellite calibration and validation activities post-launch, and scientific process studies both large and small.

A.2 Instrument testing

NASA's Airborne Science Program has long provided test platforms for instruments that simulate those planned for satellite use. These analog instruments include the Thematic Mapper Simulator used in the 1970s to prepare for and validate Landsat datasets, through to the MODIS and ASTER simulators that continue to fly on the ER-2 and Twin Otter in support of the Aqua and Terra missions.

High altitude aircraft, in particular, can provide environments similar to space conditions for testing observations and also instrument output.

Recent awards from the Earth Science Technology Office (ESTO) were focused on technology developments for Decadal Survey missions, as indicted by stars in in Table A.1 (page 54).

A.3 Calibration/validation

The calibration & validation (cal/val) of data from satellite payloads plays a critical role in ensuring that high quality data products are generated and archived to meet science mission goals and objectives. Calibration typically refers to the use of airborne instruments for characterizing the on-orbit condition of space instruments while validation refers to the set of measurements that are used to determine the precision and accuracy of algorithms employed to interpret the data.

2007 Instrument Incubator Awards versus Decadal Survey Missions	CLARREO	SMAP	ICESat II	DESDynI	HyspIRI	ASCENDS	SWOT	GEO-CAPE	ACE	LIST	PATH	GRACE-II	SCLP	GACM	3D-Winds	CLARREO-NOAA	GPSRO	XOVWM
Abshire/GSFC-column CO2, lidar						★												
Diner/JPL-aerosols and clouds, polarimetric imager									★									
Durden/JPL -clouds and precipitation, profiling radar									■									
Folkner/JPL-time-varying gravity, laser frequency stabilization												■						
Fu/JPL-surface water and ocean topography, interferometric SAR							■											
Grund/Ball-tropospheric winds, Doppler lidar															★			
Hackwell/Aerospace-mineral and gas, TIR spectrometer					★													
Heaps/GSFC-column CO2, lidar						★												
Hook/JPL-mineral/water resources, hyperspectral TIR spectrometer					★													
Kavaya/LaRC-tropospheric winds, Doppler lidar															★			
Kopp/CU-radiation balance, UV-SWIR hyperspectral imager	■																	
Lambrigtsen/JPL-T, water vapor, precipitation; microwave sounder											■							
McClain/GSFC-ocean color, UV-SWIR radiometer									■									
Mlynczak/LaRC-radiation balance far-IR spectrometer	■																	
Neil/LaRC-boundary laser CO, gas correlation radiometer								■										
Papapolymerou/GT-snow-water equivalent, X-band phased array													★					
Revercomb/UWM-radiation balance, SI-traceable IR calibration	■																	
Sander/JPL-air pollution and coastal imaging, panchromatic FTS								■										
Stek/JPL-atmospheric composition, microwave limb sounder														★				
Weimer/Ball-vegetation canopy, steerable lidar				★														
Yu/GSFC-topography and vegetation structure, swath-mapping lidar										★								

Table A.1: IIP Instruments supporting Decadal Survey Missions; red stars indicate instruments requiring test flights.

The Airborne Science Program has played a major role in the calibration of data from NASA satellites and also the validation of results. It is anticipated that aircraft field missions will support many of the Decadal Survey missions, especially in the early years of those missions.

A.4 Process studies

In addition to the other types of airborne missions that are directly tied to satellite missions, ASP operates major field campaigns or process studies relevant to the critical science questions raised by the Earth Science focus areas. These studies complement data acquisition from space by providing measurements at spatial or temporal scales not achieved from satellite measurements. In addition, in situ measurements are used to provide measurements that cannot be made from space in order to develop or validate new models of atmospheric phenomenon and processes.

A.5 Airborne Science Program – capabilities to support upcoming satellite missions

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
Core Aircraft	ER-2	NASA-DFRC	12	2,900	40,000	>70,000	410	>5,000	http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/
	WB-57	NASA-JSC	6.5	8,000	72,000	65,000	410	2,500	http://jsc-aircraft-ops.jsc.nasa.gov/wb57/
	DC-8	NASA-DFRC	12	30,000	340,000	41,000	450	5,400	http:///.nasa.gov/centers/dryden/research/AirSci/DC-8/
	P-3B	NASA-WFF	12	16,000	135,000	30,000	330	3,800	http://wacop/wff.nasa.gov
	Gulfstream III (G-III) (mil: C-20A)	NASA-DFRC	7	2,610	45,000	45,000	459	3,400	http://airbornescience.nasa.gov/platforms/aircraft/g3.html
NASA Catalog Aircraft	King Air B-200 AND UC-12B	NASA-LARC	6.2	4,100	12,500	35,000	260	1250	http://airbornescience.nasa.gov/platforms/aircraft/b-200.html
	DHC-6 Twin Otter	NASA-GRC	3.5	3,600	11,000	25,000	100-140	420	http://www.grc.nasa.gov/WWW/AircraftOps/
	Learjet 25	NASA-GRC	3	3,200	15,000	45,000	350(.81 Mach)	1,100	http://www.grc.nasa.gov/WWW/AircraftOps/
	S-3B Viking	NASA/GRC	6	12,000	52,500	40,000	120-420	2,300	http://www.grc.nasa.gov/WWW/AircraftOps/
	Ikhana (Predator-B)	NASA-DFRC	30	3,000	10,000	52,000	171	3,500	http://airbornescience.nasa.gov/platforms/aircraft/predator-b.html
New Technology	Global Hawk	NASA-DFRC	30	1500	26,750	65,000	335	10,000	http://airbornescience.nasa.gov/platforms/aircraft/globalhawk.html
	SIERRA	NASA-ARC	11	100	445	12,000	60	550	http://airbornescience.nasa.gov/platforms/aircraft/sierra.html

Table A.2: ASP Fleet.

A.6 Aircraft

NASA's Airborne Science Program operates a fleet of core aircraft and contracts for additional "catalog" aircraft services. The platform capabilities are listed in Table A.2. Information about all the aircraft can be found on the Airborne Science Program website at http://airbornescience.nasa.gov.

The ASP fleet has operated from bases all over the world. Figure A.3 indicates mission locations in 2008.

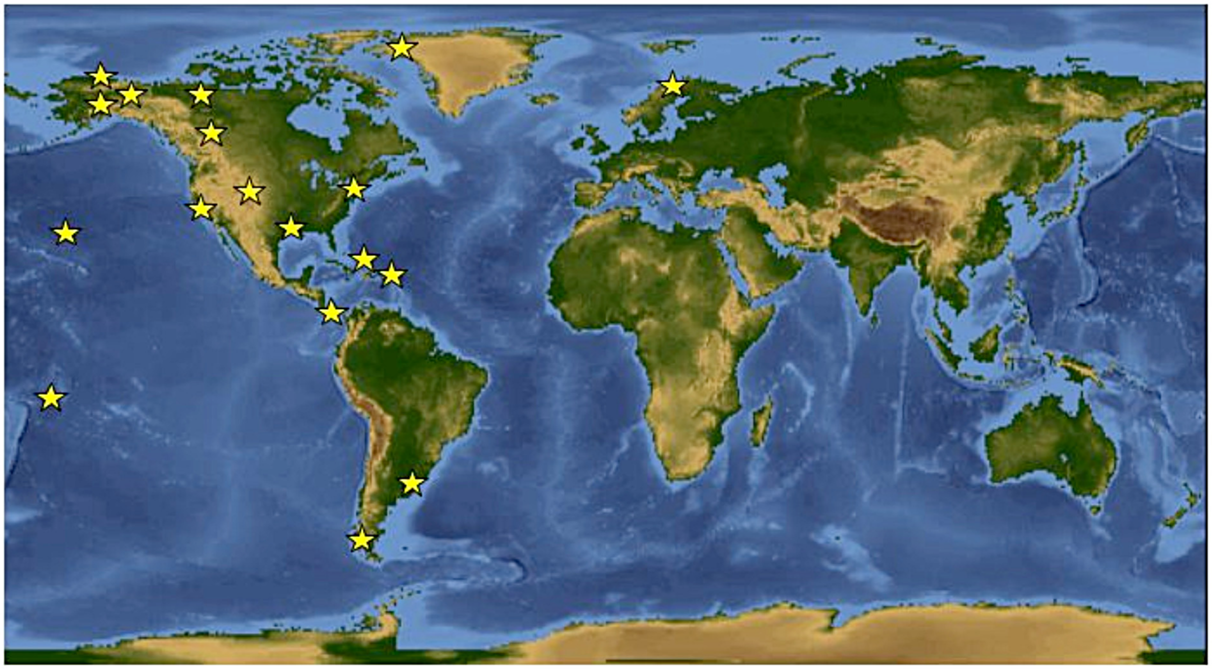


Fig. A.3: 2008 NASA Airborne Science Mission Locations.

A.7 Payloads and Accommodations

The ASP can arrange for the use of several NASA facility sensors operated by JPL and the Ames Airborne Sensor Facility (ASF.) Funding for the use of these systems is either on a cost-reimbursable basis, or by prior arrangement with a NASA Program Manager. Table A.3 lists facility instruments.

The ASP has also integrated and flown numerous PI-developed payloads, including both remote sensing and in situ sampling instruments, and provides integration services for new systems as well. The ASP platforms are equipped with windows, ports, and other accommodations for custom instruments.

Table A.3: NASA ASP Facility Instruments.

Sensor	Flies on
AVIRIS (Airborne Visible and Infrared Imaging Spectrometer - JPL)	ER-2, WB-57, Twin Otter
MODIS Airborne Simulator (MAS)	ER-2
MASTER (MODIS/ASTER Airborne Simulator)	ER-2, B-200, WB-57, DC-8
Autonomous Modular Sensor (AMS)	Ikhana, Global Hawk
UAV-SAR (UAV-Synthetic Aperture Radar - JPL)	G-III
Science Support Systems	
Digital Cirrus Camera (DCS) and Georectification of DCS Imagery	ER-2, WB-57, Twin Otter
Applanix Position and Orientation System for Airborne Vehicles (POS AV)	B-200, WB-57, DC-8, Ikhana, Global Hawk

A.8 Data Handling

Generally, payloads flown on NASA aircraft have their own data recorders for storing science data. Information on aircraft position, roll/pitch/yaw, and other aircraft parameters are stored on flight data recorders that can then be accessed by the instrument PIs for data processing. ASP is in the early stages of building a new generation of flight data recorders and experiement interface panels to standardize these subsystems across the core fleet of aircraft. Investments are also being made to enable high bandwidth telemetry using satellite links where near real time data is desirable whether for checking on instrument health or for responsive flight re-tasking during a given flight.

A.9 Mission Planning and Cross-cutting Capabilities

ASP offers mission planning through the platform provider teams the Earth Science Program Office (ESPO). ASP also offers visualization capabilities for mission scientists to track their experiments.

ASP missions have the capability to meet many additional science needs, including:

- Carrying multiple payloads.
- Coordinating multiple platforms.
- Flying vertical profiles or stacked platforms.
- Long distances or long duration.
- Under-flight of satellite overpasses.
- Real-time data accessibility.
- Portability and integration of payloads between platforms.

Appendix B: Decadal Survey Missions

B.1 Master Schedule

The Tier 1 and Tier 2 missions appear on the master schedule below in Table B.1.

Table B.1: Status of New Generation Missions.

Project Life Cycle						
Project Pre-Formulation	Project Formulation		**Approval**	Project Implementation		
Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
NASA: DESDynI CLARREO SWOT ASCENDS ACE GEO	**NASA:** ICESat-2 **SAGE III**	**NASA:** SMAP **OCO-2** Venture EV-1	**NASA:** NPP Glory Aquarius GPM LDCM		**NASA Prime:** Aura OSTM **NASA Extended:** Aqua Terra TRMM Jason EO-1 QuikSCAT SORCE Acrimsat CALIPSO CloudSat GRACE	

The Tier 3 missions are not yet on the master schedule. These are:

- LIST (Lidar Surface Topography)
- PATH (Precision and all-weather temperature and humidity)
- GACM (Global Atmospheric Composition Mission)
- SCLP (Snow and Cold Land Processes)
- GRACE-II (Gravity Recovery and Climate Experiment-II
- 3-D Winds (Three-Dimensional Tropospheric Winds from Space-based Lidar)

B.2 Mission Terminology: Key Decision Points

In preparing to launch the Decadal Survey missions, each must go through all the following steps of the NASA project life cycle, shown in Figure B.1. (See NPR 7120.5D [3]). All the missions start in “pre-Phase

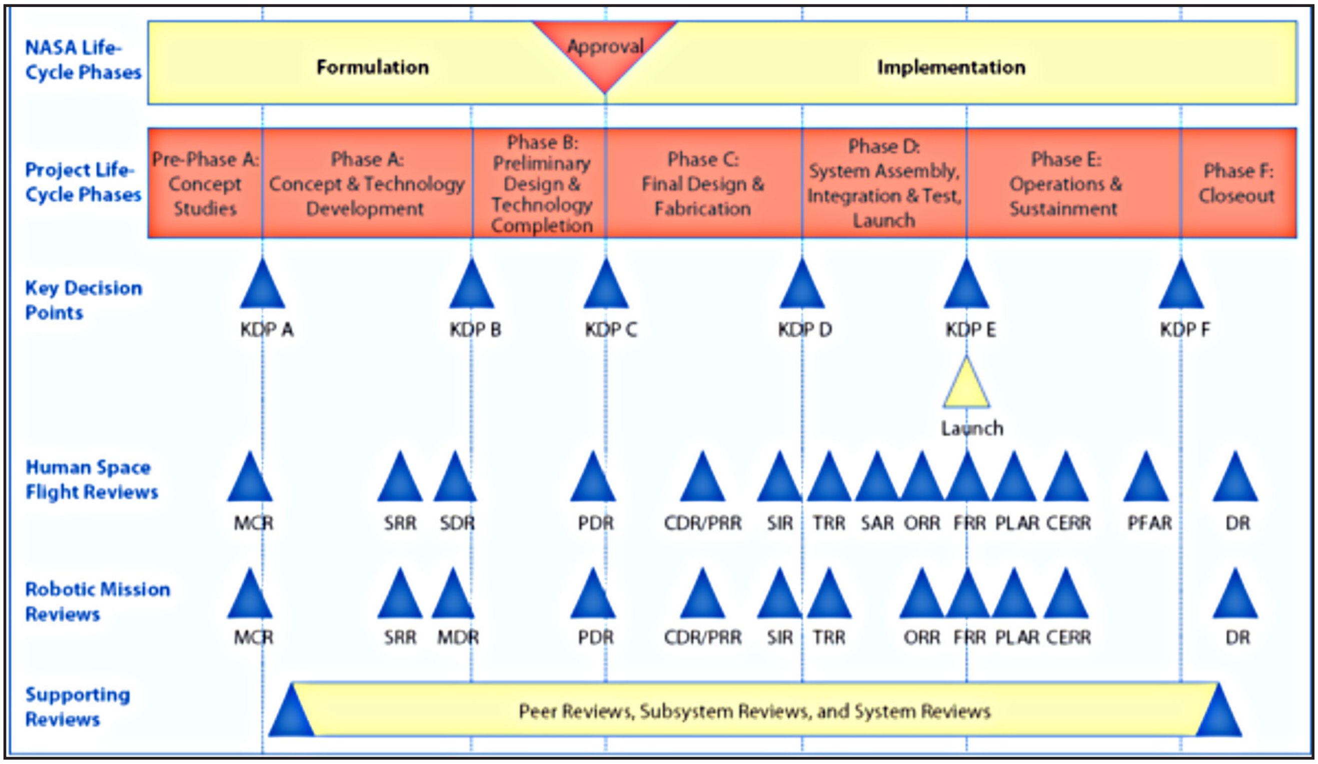


Fig. B.1: NASA project life cycle.

A" as concept studies. To reach "Phase A," where formal Science Definition Teams (SDT) are formed and funding becomes available for activities in addition to studies, the project must pass through "Key Decision Point – KDP" A. This means passing a Mission Concept Review (MCR). SMAP passed MCR in 2008 is in Phase A. The remaining Tier 1 missions are expected to pass MCR in 2009. Until then, all missions are "pre-Phase A."

The mission study process leading to MCR involves the following activities:

- Conduct studies and analyses to derive the Level 1 requirements (Science, engineering, cost and schedule).
- Complete an analysis of alternatives resulting in a conceptual design, and conduct Mission Concept Review.
- Prepare for approval all documents required in NPR 7120.5D (NASA Space Flight Program and Project Management Requirements).

Appendix C: Acronyms

ACE:	Aerosol – Cloud – Ecosystems
ACCLAIM:	Advanced CO_2 and Climate LAser International Mission
AITT:	Airborne Instrument Technology Transition
AMS:	Autonomous Modular Sensor
APMIR:	Airborne polarimetric microwave imaging radiometer
APS:	Aerosol Polarimetry Sensor
ASCENDS:	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
ASTER:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMS:	Advanced Technology Microwave Sounder
ATS:	Applications Technology Satellite
AVIRIS:	Airborne Visible/Infrared Imaging Spectrometer
CAMEX:	Convection and Moisture Experiment
CLARREO:	Climate Absolute Radiance and Refractivity Observatory
CrIS:	Cross-track Infrared Sounder
DESDynI:	Deformation, Ecosystem Structure and Dynamics of Ice
DPR:	Dual-frequency Precipitation Radar
EOS:	Earth Observation System
ESTO:	Earth Science and Technology Office
FTS:	Fourier Transform Spectrometer
GACM:	Global Atmospheric Composition Mission
GEO-CAPE:	Geostationary Coastal and Air Pollution Events
GMI:	GPM Microwave Imager
GPM:	Global Precipitation Measurement
GRACE:	Gravity Recovery and Climate Experiment
HAMSR:	High Altitude MMIC Sounding Radiometer
HyspIRI:	Hyperspectral Infrared Imager
ICESat:	Ice, Cloud, and Land Elevation Satellite II
IIP:	Instrument Incubator Program
JAXA:	Japanese Aerospace Exploration Agency
KaSPAR:	Ka-band SWOT Phenomenology Airborne Radar

LAS:	Laser Absorption Spectrometer
LDCM:	Landsat Data Continuity Mission
LIST:	Lidar Surface Topography
LVIS:	Laser Vegetation Imaging Sensor
MABEL:	Multiple Altimeter Beam Experimental Lidar
MAS:	MODIS Airborne Simulator
MASTER:	MODIS/ASTER Airborne Simulator
MFLL:	Multifrequency Fiber Laser Lidar
MMIC:	Monolithic microwave integrated circuit
MODIS:	Moderate Resolution Imaging Spectroradiometer
NAMMA:	NASA African Monsoon Multidisciplinary Analysis
NAST:	NPOESS Aircraft Sounder Testbed
NPOESS:	National Polar-orbiting Operational Environmental Satellite System
NPP:	NPOESS Prepatory Project
OCO:	Orbiting Carbon Observatory
OES:	Ocean Ecosystem Spectrometer
OMPS:	Ozone Mapping and Profiler Suite
ORCA:	Ocean Radiometer for Carbon Assessment
PACE:	Pre-ACE
PALS:	Passive/Active L- and S-band Sensor
PARIS:	Pathfinder Airborne Radar Ice Sounder
PATH:	Precision and All-weather Temperature and Humidity
PODEX:	Polarimeter definition experiment
PolSCAT:	Polarimetric Scatterometer
PSR:	Polarimetric Scanning Radiometer
RSP:	Research Scanning Polarimeter
SAGE III:	Stratospheric Aerosol and Gas Experiment III
SAR:	Synthetic Aperture Radar
S-HIS:	Scanning High Resolution Interferometric Sounder
SIMPL:	Slope Imaging Multi-polarization Photon-counting Lidar
SLCP:	Snow and Cold Land Processes
SMAP:	Soil Moisture Active Passive
SOLVE:	SAGE III Ozone Loss and Validation Experiment
SWOT:	Surface Water and Ocean Topography
TIM:	Total Irradiance Monitor
UAVSAR:	Unmanned Aerial Vehicle Synthetic Aperture Radar Visible/Infrared Imager/ Radiometer Suite

Appendix D: Program Executives and Scientists

Mission	Program Executive	email address	Program Scientist	email address
Foundational Missions				
Glory	Bretthauer	Joy.W.Bretthauer@nasa.gov	Maring	hal.maring@nasa.gov
Aquarius	Eric Ianson	eianson@nasa.gov	Lindstrom	eric.j.lindstrom@nasa.gov
NPP	Carson	andrew.s.carson@nasa.gov	Wickland	diane.e.wickland@nasa.gov
LDCM	Jarrett	David.B.Jarrett@nasa.gov	Wickland	diane.e.wickland@nasa.gov
OCO 2	Ianson	eianson@nasa.gov	Jucks	kenneth.w.jucks@nasa.gov
GPM	Neeck	steven.neeck@nasa.gov	Kakar	ramesh.kakar@nasa.gov
SAGE-III	Topiwala	Nandkishore.N.Topiwala@nasa.gov	Considine	david.b.considine@nasa.gov
GRACE follow on	Neeck	steven.neeck@nasa.gov	LaBrecque	John.LaBrecque@nasa.gov
GOES-R	Topiwala	Nandkishore.N.Topiwala@nasa.gov	Bontempi	paula.s.bontempi@nasa.gov
Decadal Survey Tier 1 Missions				
SMAP	Ianson	eianson@nasa.gov	Entin	Jared.K.Entin@nasa.gov
ICESat II	Slonaker	Richard.Slonaker@nasa.gov	Wagner	thomas.wagner@nasa.gov
CLARREO-1	Slonaker	Richard.Slonaker@nasa.gov	Jucks	kenneth.w.jucks@nasa.gov
CLARREO-2	Slonaker	Richard.Slonaker@nasa.gov	Jucks	kenneth.w.jucks@nasa.gov
DESDynI	Dutta	Sanghamitra.b.Dutta@nasa.gov	LaBrecque	John.LaBrecque@nasa.gov
Decadal Survey Tier II Missions				
SWOT	Neeck	steven.neeck@nasa.gov	Lindstrom	eric.j.lindstrom@nasa.gov
ASCENDS	Neeck	steven.neeck@nasa.gov	Jucks	kenneth.w.jucks@nasa.gov
HyspIRI	Neeck	steven.neeck@nasa.gov	Turner	woody.turner@nasa.gov
PACE	Neeck	steven.neeck@nasa.gov	Maring	hal.maring@nasa.gov
ACE	Neeck	steven.neeck@nasa.gov	Maring	hal.maring@nasa.gov
GEO-CAPE	Neeck	steven.neeck@nasa.gov	Al-Saadi	j.a.al-saadi@nasa.gov

Mission	Program Executive	email address	Program Scientist	email address
Decadal Survey Tier III Missions				
SLCP	Neeck	steven.neeck@nasa.gov	Entin	Jared.K.Entin@nasa.gov
LIST	Neeck	steven.neeck@nasa.gov	Dobson	craig.dobson@nasa.gov
GACM	Neeck	steven.neeck@nasa.gov	Jucks	kenneth.w.jucks@nasa.gov
PATH	Neeck	steven.neeck@nasa.gov	Kakar	ramesh.k.kakar@nasa.gov
GRACE II	Neeck	steven.neeck@nasa.gov	LaBrecque	John.LaBrecque@nasa.gov
3-D WINDS	Neeck	steven.neeck@nasa.gov	Maring	hal.maring@nasa.gov
Earth Venture - 1 missions	Avery	Melody.A.Avery@nasa.gov	Maring	hal.maring@nasa.gov