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Suborbital Science Missions of the Future
Workshop Summary Report

Workshop July 10-12, 2004
Arlington, Virginia

Sponsored by NASA Science Mission Directorate
(formerly Office of Earth Science)

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Workshop Summary Report

1. Introduction

In July of 2004, the Suborbital Science office of NASA's Science Mission Directorate (formerly Office of Earth Science) hosted a workshop for members of the Earth science community to discuss advanced and future requirements for carrying out science experiments from aircraft or other suborbital platforms. The goal of the workshop was to develop innovative mission concepts and system requirements for each of six Earth science focus areas to guide new investments in suborbital systems development.

The workshop targeted potential new technology platforms, such as a new generation of uninhabited aerial vehicles. Thus, there was a focus on mission concepts that are not bound by the limitations that have traditionally constrained suborbital activities in the past (e.g., time a pilot can stay onboard an aircraft, pilot safety requirements, etc.). The outcomes point not only to the use of UAVs, but also smart sondes and other innovative technology.

This report covers only those topics that were discussed at the workshop, plus one subsequent meeting with atmospheric scientists who could not be present because of a mission occurring at the same time. Therefore, the outcomes reflect only those topics discussed by the scientists who participated. They may not be entirely comprehensive. Also, the topics were not prioritized (either during the workshop, or subsequently). Although the topics are likely to represent the most important issues facing the earth science community today, they were not screened against NASA's overall priorities.

2. Workshop Structure

The main objective over 2 – 1/2 days was to have the science community describe science missions they would like to carry out to answer their most critical science questions and to describe in as much detail as possible the flight and instrument capabilities that would be required to accomplish such missions. A professional facilitator – Cindy Zook – facilitated the sessions. The facilitator had helped design the workshop in advance and then led the major activities.

The six science focus themes of what was then called the Earth Science Enterprise formed the basis for the workshop structure. The schedule called for periods of time with all participants meeting together and other periods with theme area scientists meeting in breakout session rooms. Among the participants were engineers familiar with airborne science platforms and payload integration and operations. A total of 65 people attended the workshop. The list of participants is found in Appendix A.

The first morning began with plenary speakers from Aeronautics and Earth Science and from the program and project offices. Leaders of several directed studies that have been underway in parallel to the workshop effort also presented. The speakers and presentation titles were:

- **Cheryl Yuhas, Suborbital Science manager, HQ - Welcome**
- **Mike Luther, Science Mission Directorate, HQ – ESE Strategic Plan**
- **John Sharkey, Dryden Flight Research Center (for Victor Lebacqz) – Aeronautics Enterprise**
- **Steve Wegner, Ames Research Center – Introduction to Suborbital Science Missions of the Future and Directed Studies**
- **Matt Fladeland, Ames Research Center – Carbon Cycle Focus Area**
- **John Sonntag, Wallops Flight Facility – Applications of UAVs for Cryospheric Science**
- **Carol Raymond, JPL – UAVs in the NASA Earth Surface and Interiors Program**

These talks set the stage for the science groups to do their work. The six science teams were:

- **Atmospheric Composition and Chemistry**
- **Climate Variability and Change**
- **Water and Energy**
- **Carbon Cycle, Ecosystems and Biogeochemistry**
- **Weather**
- **Earth Surface and Interior Structure**

The teams completed several exercises: 1) to identify science questions, 2) to develop mission scenarios according to a template, 3) to summarize their most important needs going forward. The workshop package, including schedule and templates is shown in Appendix B.

The complete raw products, presentations and list of attendees of the workshop can be found at the Internet address listed below. These products are also being used to develop a rigorous Requirements Analysis for the Suborbital Systems program and serve as input to the Civil UAV Assessment.

http://geo.arc.nasa.gov/uav-suborbital/

3. Outcomes

The outcomes of the workshop were designed to influence future investment decisions in the Suborbital Science program. Following is a brief review of the science issues best addressed from suborbital platforms. The workshop was designed to obtain information that could be used to influence Suborbital Science Program decisions, particularly technology investments that would most directly benefit the Earth science research community.

3.1 Suborbital Science Uniqueness

Participants were asked to describe the advantage of using a suborbital platform to perform critical science missions. These advantages are sometimes due to a comparison with the limitations of manned flight, and sometimes due to a comparison with the limitations of satellite measurements. In general, the responses fall into two categories:
1) Measuring in locations that cannot be reached or maintained by either manned aircraft or satellite. (This includes the niche categories of "dull, dirty, and dangerous.")
2) Providing measurement products that are improved or unique compared with current measurements. These are generally characterized by temporal or spatial resolution.
Following are some of the responses, categorized as described above.

<u>Location or duration is a priority</u>

- Loitering capabilities
- Dangerous & Dirty plume measurements
- Not available from space platforms (in situ)
- Requires in situ sampling of clouds and aerosols.
- Requires coordinated, multilevel radiative flux measurements
- Requires following plume or other pollution events over long distances
- Resolution, time on station, adaptability to key climate event, ability to deploy drop-buoys in remote regions, unique ice volume and depth observations, detailed evolution of selected icebergs

<u>Product fidelity or resolution is a priority</u>

- High spatial and temporal resolution, overlap with and extension of satellite observations.
- The measurements aboard a suborbital system can be chosen to be much more comprehensive than the planned and operational satellite instruments.
- Improved targeting of atmospheric phenomena (e.g., Lagrangian sampling).
- Instruments can be calibrated in the air and on the ground pre and post-flight.
- Measurement flexibility and greater capability for instrument upgrades
- High frequency measurements to resolve temporal variation
- High resolution in space, time and spectra
- Provides capability to observe small amounts of aerosol over bright regions that satellites typically can't observe.

- Low altitude network of UAVs, can generate a very high resolution 3-D map under its footprint and along its flight path.

3.2 Mission Concepts and Analysis

The participants described a total of 33 different missions in various levels of detail. The raw descriptions can be found at the project website. All six science groups contributed mission concepts based on the template. (Several additional missions were later contributed from a follow-on session at the New Hampshire site of the INTEX mission.) These completed templates provide a wealth of information about the projected needs of the science community for airborne science. The titles of the missions are listed in Table 1.

Table 1. Mission Concepts Detailed during Workshop

#	Mission Title
	Atmospheric Composition and Chemistry
1	Clouds and Aerosols
2	Stratospheric Ozone
3	Tropospheric Ozone
4	Water Vapor and Total Water
	Tropospheric
5	Tracking long-distance pollution
6	Cloud Systems
7	Long time-scale vertical profiling
8	Global 3-D Species
9	Troposphere daugherships
	Climate Variability and Change
10	Aerosol, Cloud and Precipitation
11	Physical oceanography
12	Glacier and Ice Sheet Dynamics
13	Radiation
	Water and Energy Cycles
14	Cloud Properties
15	River Discharge
16	Snow-Liquid Water Equivalent
17	Soil Moisture and Freeze/Thaw States
	Carbon Cycle, Ecosystems and Biogeochemistry
18	Coastal Ocean Observations
19	Active Fire, Emissions and Plume Assessment
20	CO_2, O_2 and Trace Gas Flux Study
21	Vegetation Structure, Composition & Canopy Chemistry
	Weather
22	Cloud Microphysics / Properties
23	Extreme Weather

24	Forecast Initialization
25	Hurricane Genesis, Evolution and Landfall
	Earth Surface and Interior Structure
26	Surface Deformation
27	Ice Sheets
28	Surface Measurements using Imaging Spectroscopy
29	Topography using LIDAR
30	Gravitational Acceleration
31	International Polar Year
32	Magnetic Fields
33	Terrestrial reference frame stability

An illustration of the mission types described at the workshop is shown in Figure 1. The frequency of mission types is a result of the work of the participants but is not meant to suggest science priorities.

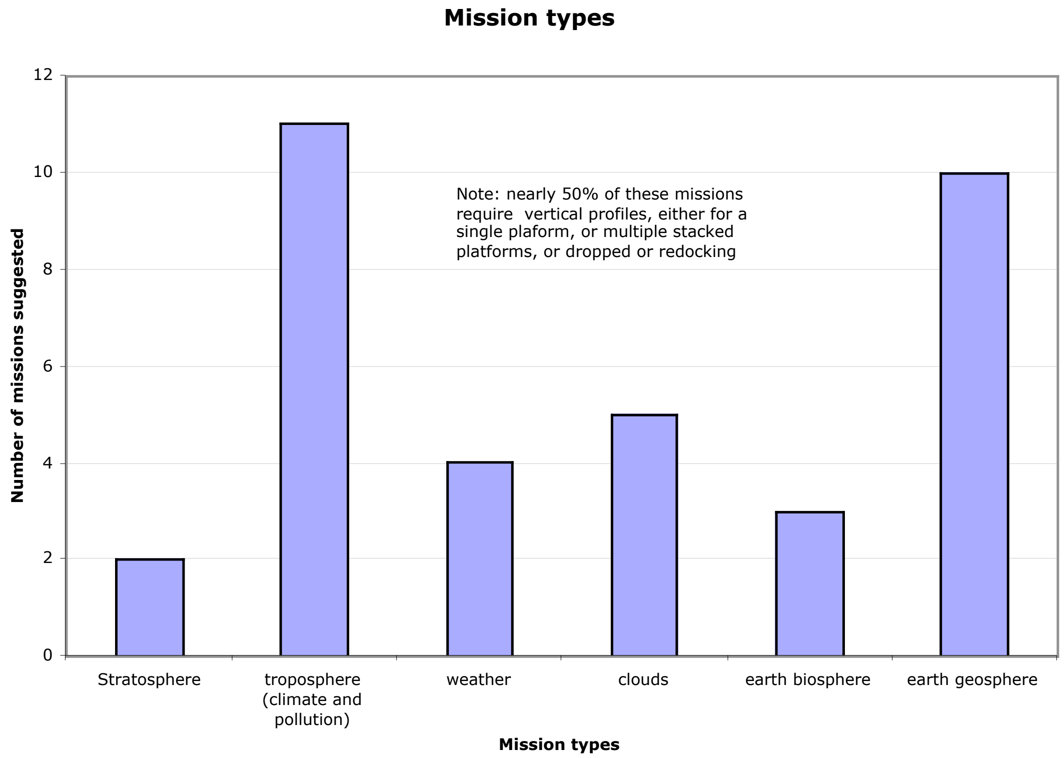

Figure 1. Mission types, categorized by what the scientists want to measure.

The locations of the concept missions were truly global. The map in Figure 2 indicates nominally the locations of the tropospheric missions described at the workshop. A full set of mission maps has been proposed as part of another Suborbital Science activity called Requirements Analysis.

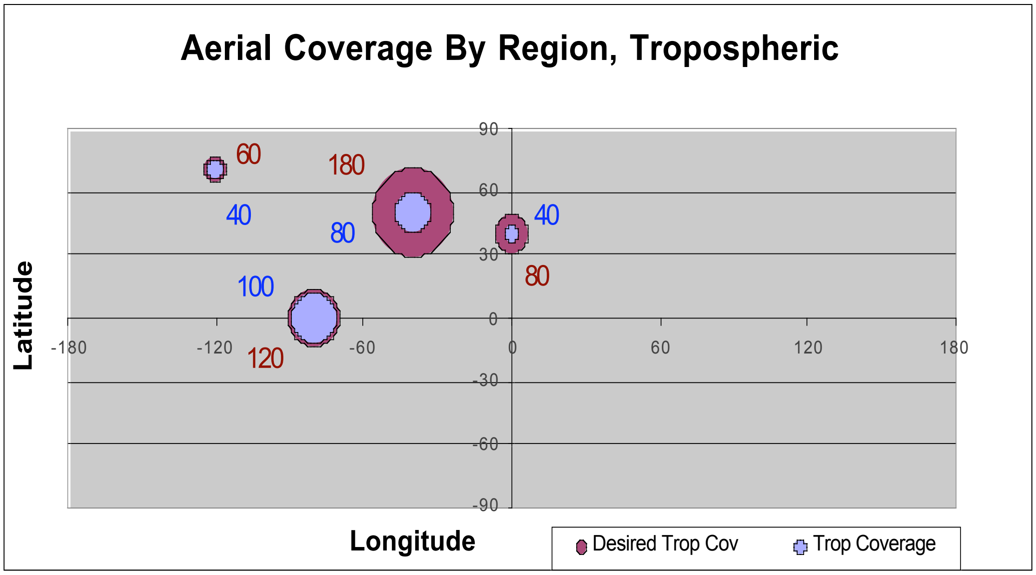

Figure 2: Global location of tropospheric missions (example from Suborbital Science Requirements Analysis project)

Platform Requirements

The platform requirements, in terms of altitude, endurance, range and payload-carrying capability are indicated graphically in Figures 3 through 6. Figures 3a, 3b, and 3c all illustrate the altitude and endurance requirements on a semi-logarithmic scale because of the broad endurance requirements. Figure 3a indicates the corresponding missions. Figure 3b overlays some platform developments under considerations by NASA's Aeronautics Research Mission Directorate Vehicle Systems Program, and Figure 3c presents the raw data from the workshop. Some general things to note:

- There is a very broad spectrum of requirements in each of these parameters.
- There are extreme requirements for endurance and range. The range requirement is sometimes influenced by basing assumptions, i.e., if the platform could be based any where, the range requirements might be less. Alternatively, if the bases are limited, the range requirements are greater.
- Both very high-flying and very low-flying platforms are described. Also, there is a significant need for vertical profiling, either by a single platform flying at a wide range of altitude, or multiple platforms. Clearly a portfolio of capabilities is required.
- In Figures 3, 4, and 5a, there are multiple altitude points indicated for some missions which require stacked platforms taking simultaneous measurements.
- Figure 6 shows the number of platforms called for by the various mission concepts. More than half of the sample missions call for more than one platform flying simultaneously.

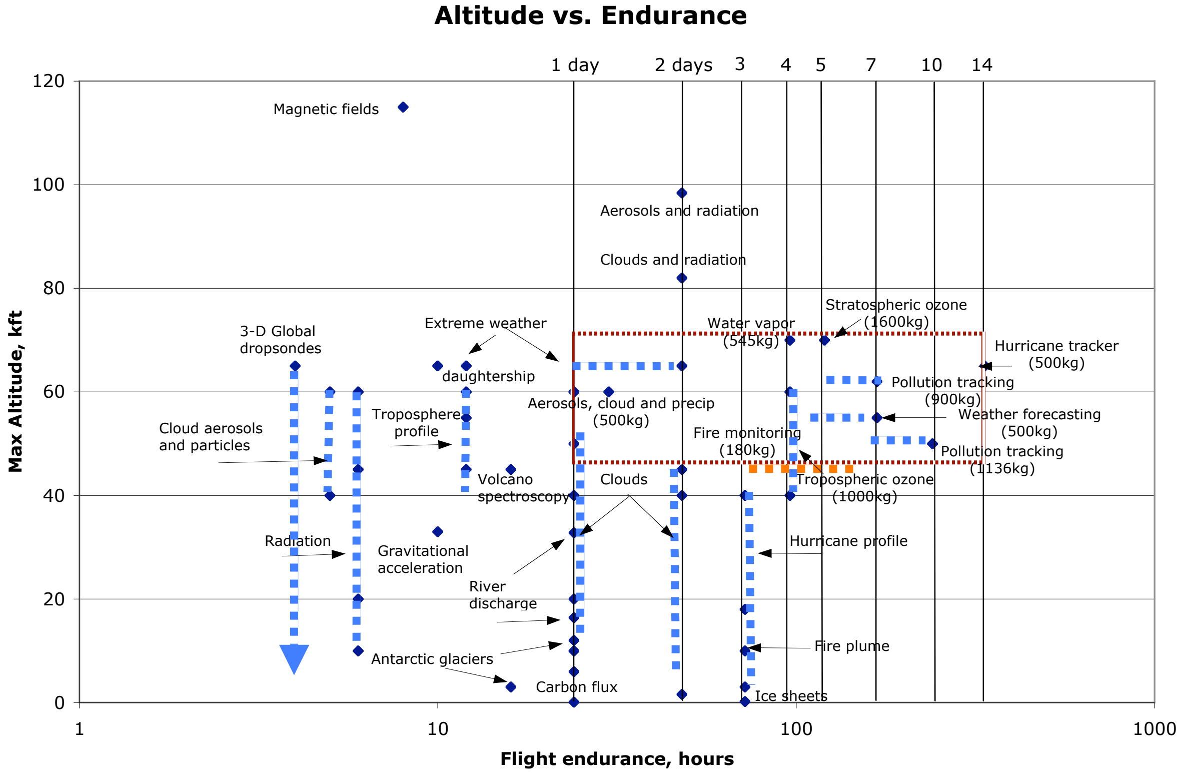

Figure 3a: Altitude vs. Endurance for mission concepts

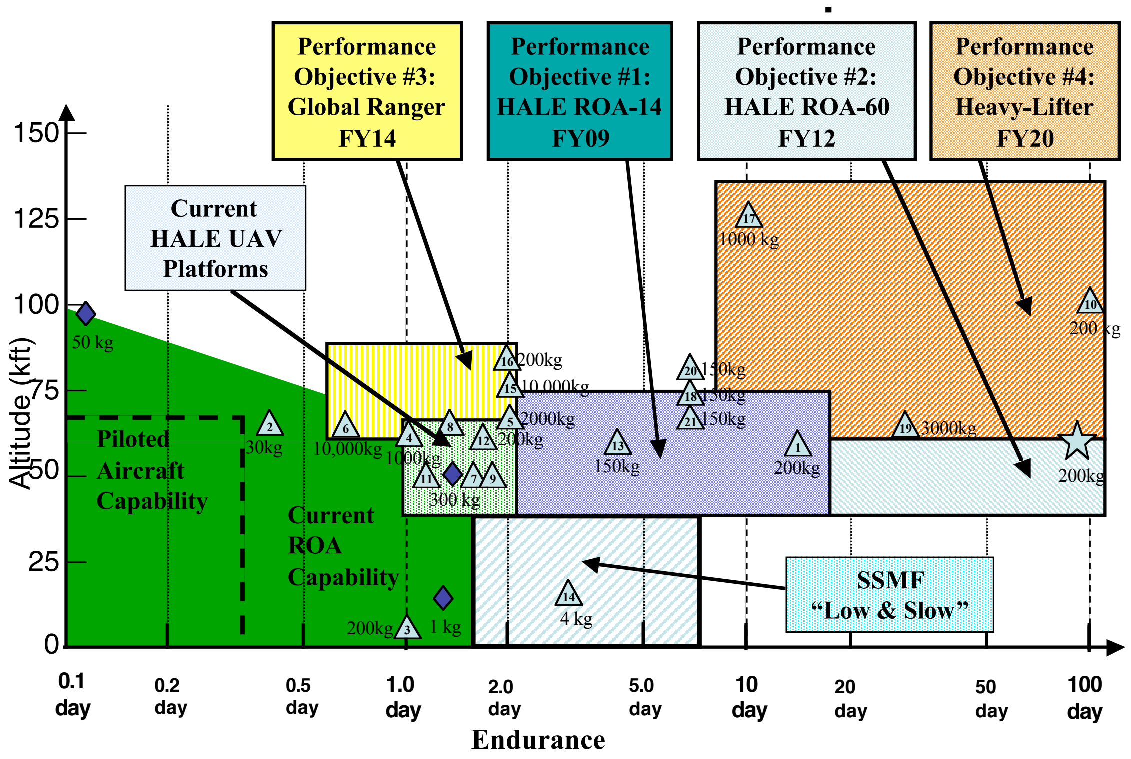

Figure 3b. Altitude vs. Endurance showing flight regimes for platforms under consideration in the Vehicle Systems Program (from John Sharkey)

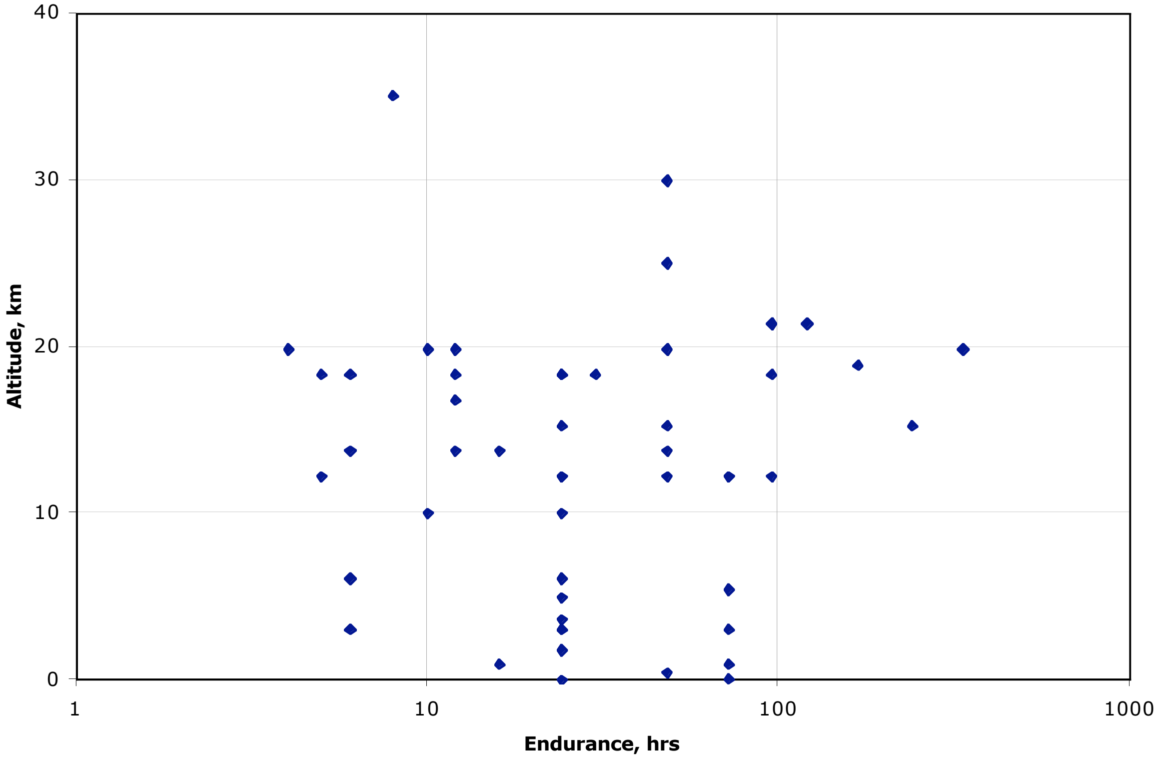

Figure 3c. Altitude vs. Endurance – Raw data

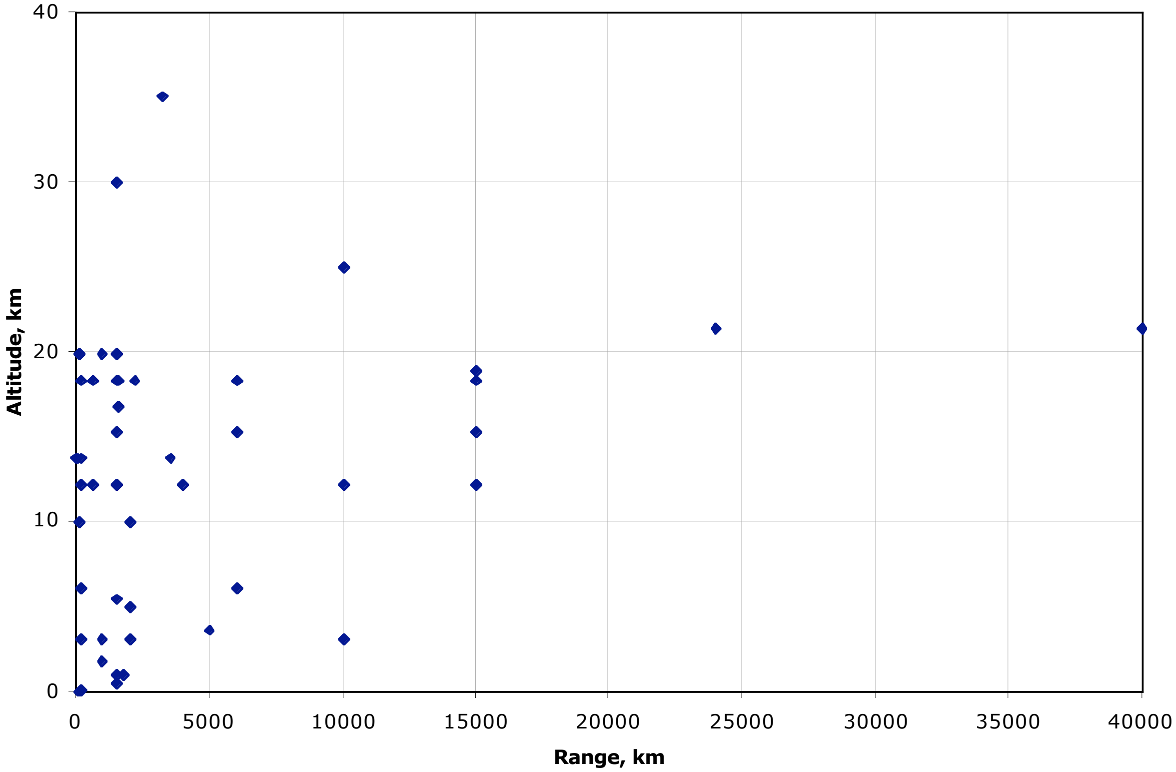

Figure 4: Altitude vs. Range – Raw data

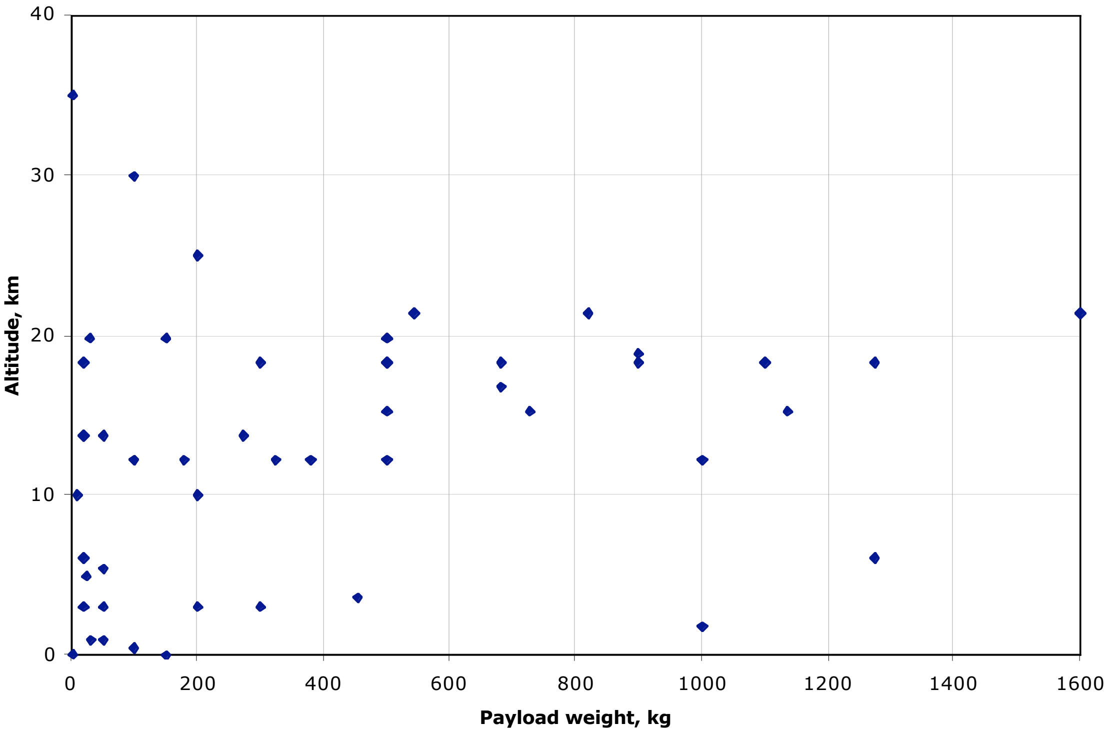

Figure 5a: Payload weight vs. Altitude – Raw data

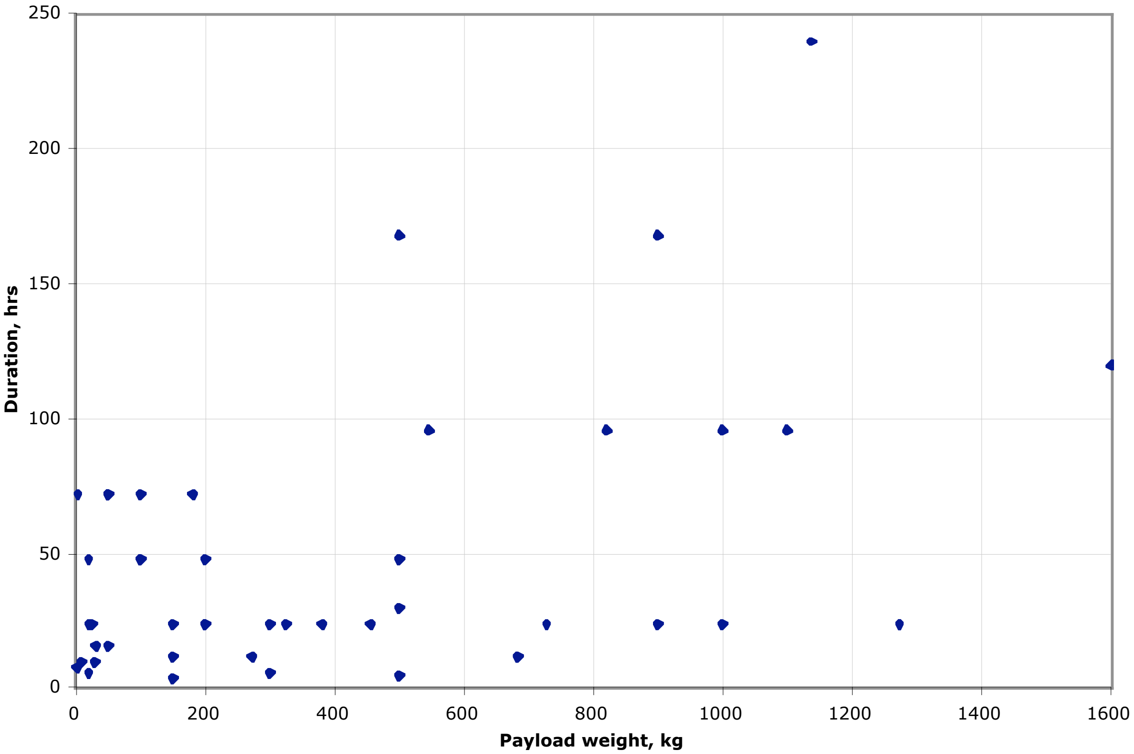

Figure 5b. Payload weight vs. Endurance – Raw data

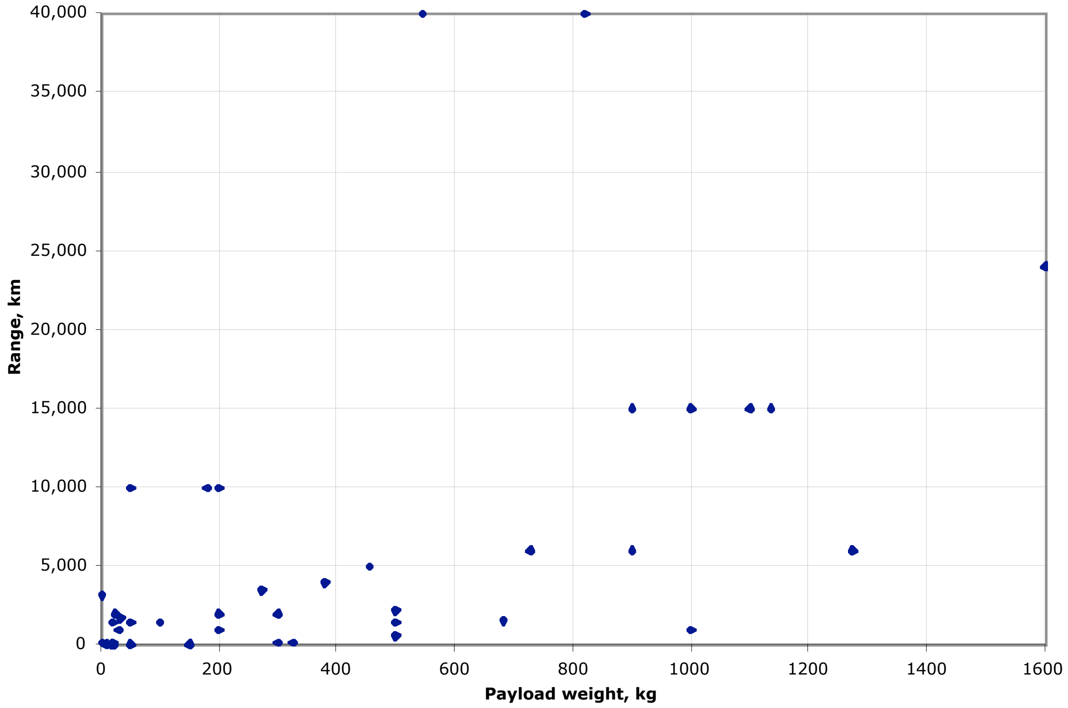

Figure 5c. Payload weight vs. Range – Raw data

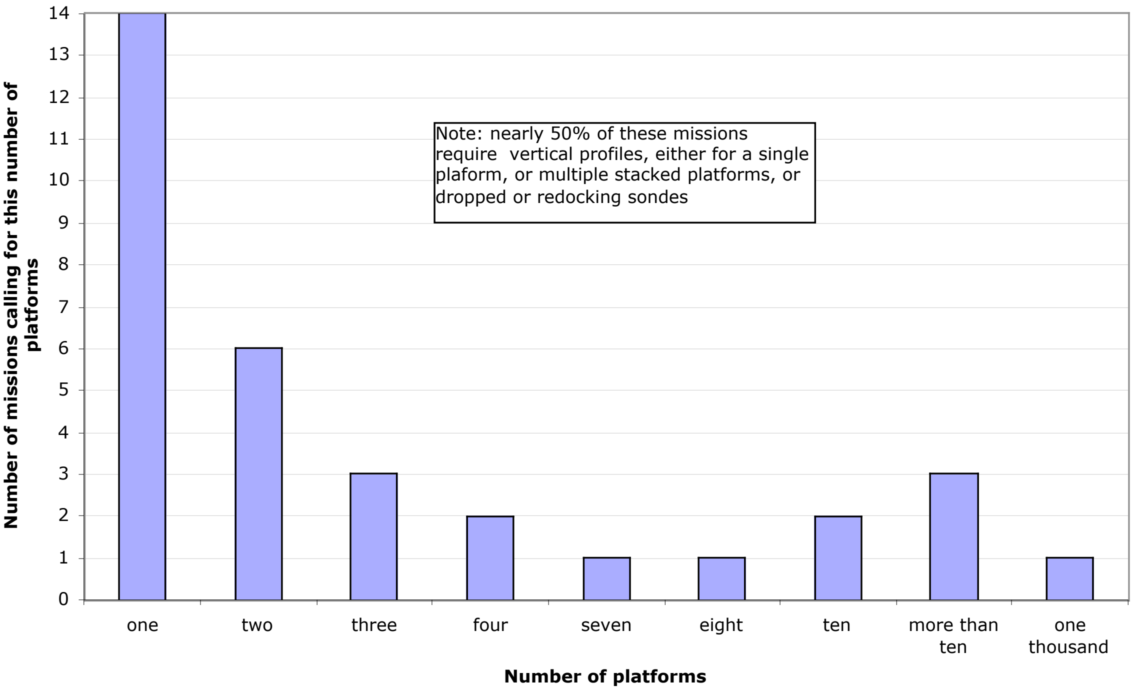

Figure 6: Number of platforms per mission. (The last category includes the use of dispensible assets.)

Mission Descriptions

Participants were asked to describe the mission in a narrative and also using any flight profiles or maps they could provide. Figures 7 and 8 show mission concept graphics for several missions that were developed in conjunction with the workshop. Figure 7 illustrates the area needing to be mapped for earthquake faults. Figure 8 illustrates a flight profile desired for tropospheric sampling.

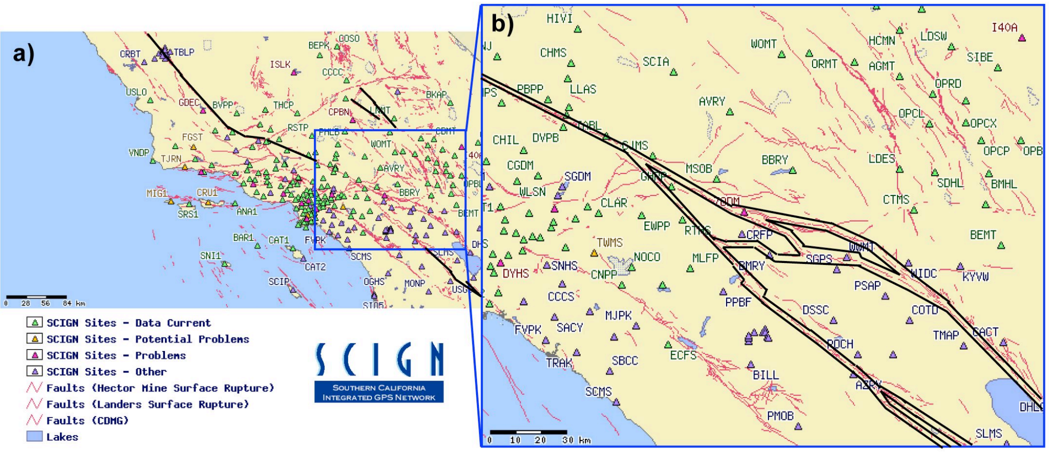

Figure 7. Mapping Fault Zones

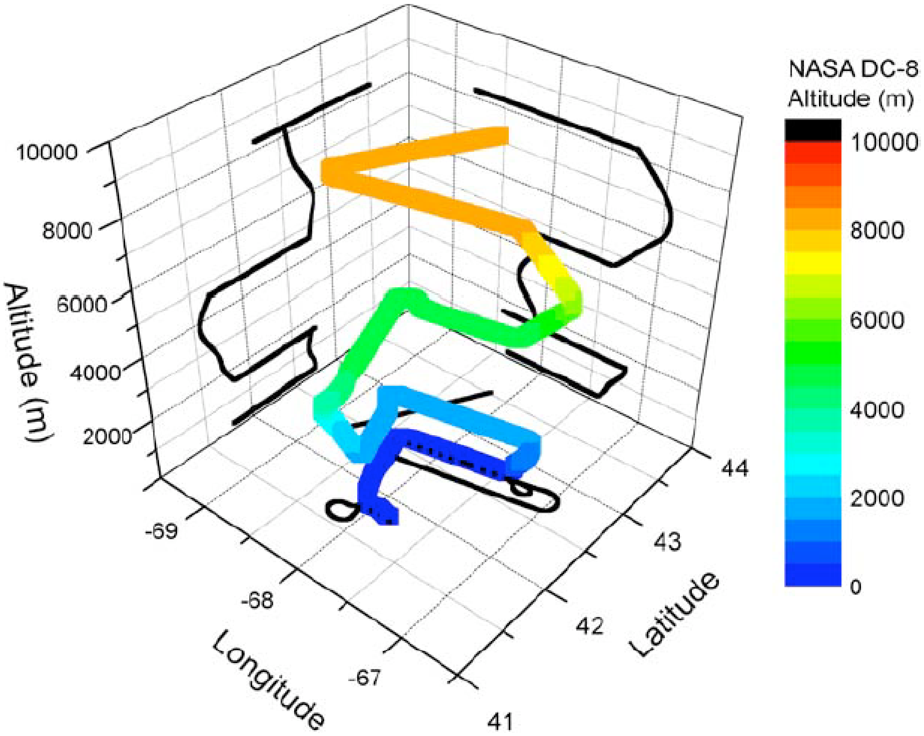

Figure 8. Example of vertical profiling based on INTEX mission

Directed Studies

In parallel with the workshop, two directed study efforts were undertaken to develop mission concepts in greater detail. As mentioned earlier, these were Antarctic an mission entitled ***"Mission Concepts for Uninhabited Aerial Vehicles in Cryospheric Science Applications"*** and a carbon flux mission in the Southern Ocean, entitled ***"A Suborbital Mission Concept for Eddy Covariance Measurements in the Southern Ocean Marine Boundary Layer Using Long-Duration, Low-Altitude Unmanned Aircraft."*** The final reports on these studies are available on the project website, or by contacting the Suborbital Science Office.

Cryospheric Missions

The specific requirements for a set of three cryospheric missions are summarized in Table 2. The missions are described by three flight regimes, from short flights based in Greenland to very long flights from a base in the Southern Hemisphere. Each would require detailed measurement profiles. A nominal flight path for the Antarctic sea ice mission is shown in Figure 9.

Table 2. Mission Requirements for Cryospheric Missions

	REQUIREMENT	VALUE	COMMENTS
Tier A: Short-range missions			
PLATFORM	location	Arctic (Greenland), possible Antarctic	
	season	warm season	May in Arctic, November in Antarctic
	frequency	3+ flights over several weeks	
	altitude	2000 ft AGL	
	range	300 nm + 200 nm from base	
	endurance	3+ hours	
	speed	100 knots	
	environment or special conditions	snow/ice runway, winds	terrain following
PAYLOAD	**instrument 1**	scanning laser altimeter	
	weight	20 lb	
	volume	3 ft3	
	power	100 W	
	environmental conditions		
	access	downward looking	
	data characteristics	data stored on board	
	instrument 2	radar depth sounder	
	weight	100 kg	

	volume	.5m x .5m x .5 m	
	power	200 - 300 W	
	environmental conditions		
	access	downward looking	
	data characteristics	data stored on board	
COMMUNICATIONS	platform command and control	line-of-sight?	
	payload command & control	required to turn on/off ?	
	data downlink	for instrument health & status	
	data rate	data stored on board	
AUTONOMY AND INTELLIGENCE	platform autonomy	flies pre-programmed way points	terrain following with stable attitude
	payload autonomy / intelligence	TBD	

Cryospheric Missions	REQUIREMENT	VALUE	COMMENTS
Tier B: Medium to long-range missions			
PLATFORM	location	based in Antarctica, flies entire continent	3 bases needed to reach entire continent
	season	polar summer	
	frequency	100 missions per season	
	altitude	2000 ft AGL	for survey
	range	4000 km	
	endurance	14.5 hrs	
	speed	150 knots	
	environment or special conditions	high winds and cold temperatures	terrain following
PAYLOAD	**instrument 1**	scanning laser altimeter	(same as A)
	weight	20 lb	
	volume	3 ft3	also cameras,
	power	100 W	magnetometers,
	environmental conditions	cold temperatures	and gravimeters
	access	downward looking	
	data characteristics	stored on board and downlinked	
	instrument 2	radar depth sounder	(same as A)
	weight	100 kg	could be minimized
	volume	.5m x .5m x .5 m	could be minimized
	power	200 - 300 W	
	environmental conditions	cold temperatures	

	access	downward looking	
	data characteristics	stored on board and downlinked	
COMMUNICATIONS	platform command and control	OTH via satellite or relay	
	payload command & control	required to turn on/off ?	
	data downlink	for instrument health & status, also real-time data delivery	
	data rate	broadband, rate TBD	
AUTONOMY AND INTELLIGENCE	platform autonomy	flies pre-programmed way points	terrain following with stable attitude
	payload autonomy / intelligence	TBD	

Cryospheric Missions	REQUIREMENT	VALUE	COMMENTS
Tier C: Long-range, over-water missions			
PLATFORM	location	Antarctica	from New Zealand, Chile or Tasmania
	season	all, especially winter	
	frequency	3+ flights over several weeks	
	altitude	2000 ft AGL	for survey only, optimum for transit
	range	3650 nm total	1500 nm each way from base
	endurance	4.5 hours on station	> 24 hours total
	speed	200 knots on station	max in transit
	environment or special conditions	wind, dark	terrain following
PAYLOAD	**instrument 1**	scanning laser altimeter	(same as A)
	weight	20 lb	
	volume	3 ft3	also cameras,
	power	100 W	magnetometers,
	environmental conditions		and gravimeters
	access	downward looking	
	data characteristics	stored on board and downlinked	
	instrument 2	radar depth sounder	(same as A)
	weight	100 kg	could be minimized
	volume	.5m x .5m x .5 m	could be minimized
	power	200 - 300 W	
	environmental conditions		
	access	downward looking	

	data characteristics	stored on board and downlinked	
COMMUNICATIONS	platform command & control	OTH via satellite	
	payload command & control	required to turn on/off ?	
	data downlink	for instrument health & status and real-time data delivery	
	data rate	broadband (rate TBD)	
AUTONOMY AND INTELLIGENCE	platform autonomy	flies pre-programmed way points	
	payload autonomy / intelligence	TBD	

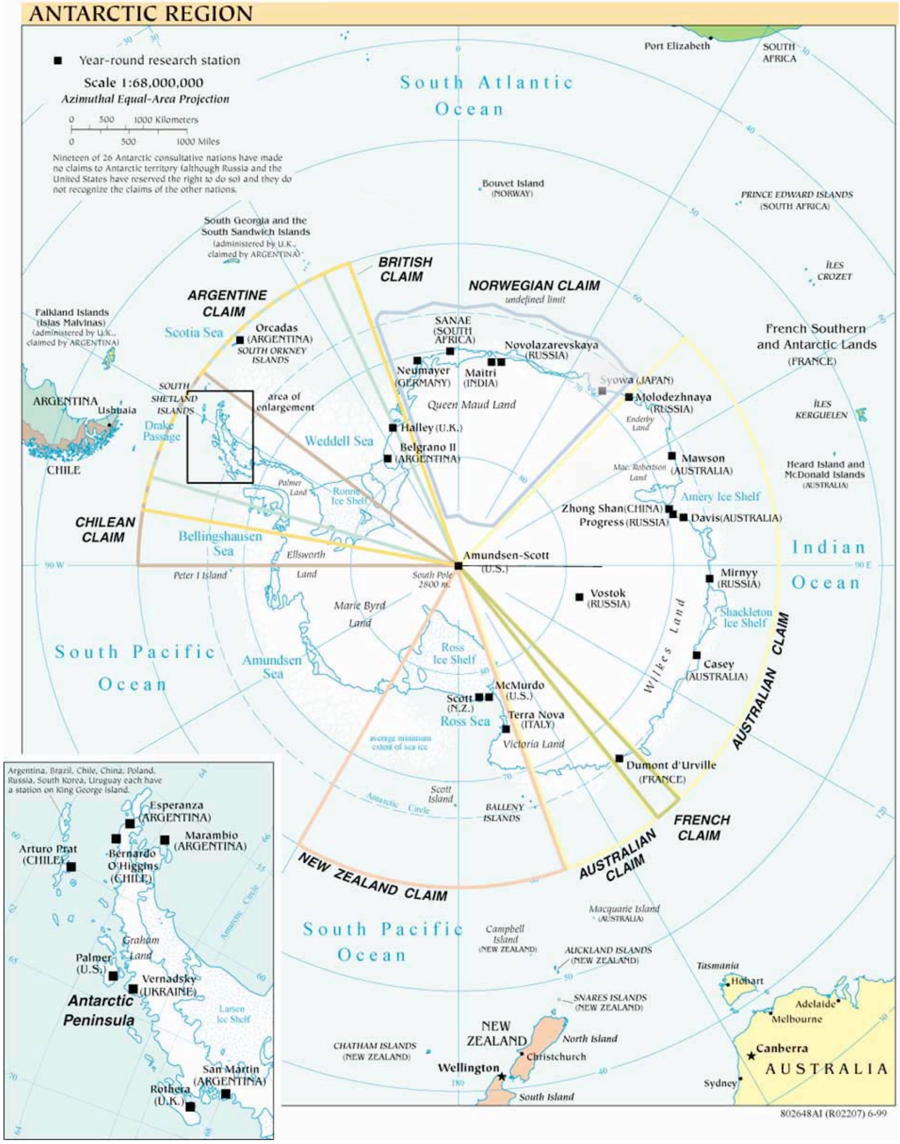

Figure 9. Antarctic Sea Ice Mission

Southern Ocean Flux Mission

The southern ocean flux measurements would require very low altitude flight over the ocean for a precisely patterned flight. The requirements are summarized in Table 3. The flight profile is shown in Figure 10.

Table 3. Mission Requirements for Southern Ocean Flux Mission

	REQUIREMENT	VALUE
PLATFORM	>24 hour duration on station	Provide data of sufficient temporal and spatal resolution to understand diurnal effects on air-sea carbon fluxes
	1000+ km range	Enables basin wide scaling of ship and aircraft flux data to satellite derived estimates of air sea flux
	stable flight at ~50 knots	Slower speeds allow for higher spatial resolution sampling as well as facilitating Langrangian, or air mass following flights.
	all season capability	Allows for measurements in winter and summer to constrain seasonal and yearly flux estimates
	ship deployment and/or retrieval capability	Deployment and/or retrieval from ship provides measurements over the open ocean and other remote areas
	stable flight at 10-100m altitude over long distances	Enables the measurement of flux within the Marine Boundary Layer where there is currently very little data to constrain global models
PAYLOAD	Nose mounted turbulence probe	Provides directional wind velocity measurements used to derive ambient wind field characteristics
	Fast response CO^2 sensor	Enables high spatial and temporal resolution CO^2 flux data
	Javad GPS antennae or Inertial Navigation Unit	Provides aircraft attititude for further derivation of wind vectors
	laser altimeter/radar	Ensures that the aircraft maintains a stable altitude during sampling as well as providing information on ocean surface dynamics
COMMUNICATIONS	Over the horizon (eg. Ku-band)	Allows for command/control and data telemetry anywhere on earth
	Line of site communications (e. C-band)	Provides a means of communicating and coordinating with other assets in the observation domain without using OTH bandwidth
AUTONOMY and INTELLIGENCE	multi-aircraft collaboration	Enables multiple aircraft to obtain vertical profiles and constrain flight path to optimize science return
	payload driven avionics	Ensures that the aircraft maintains a stable altitude during sampling; allows for autonomous controls

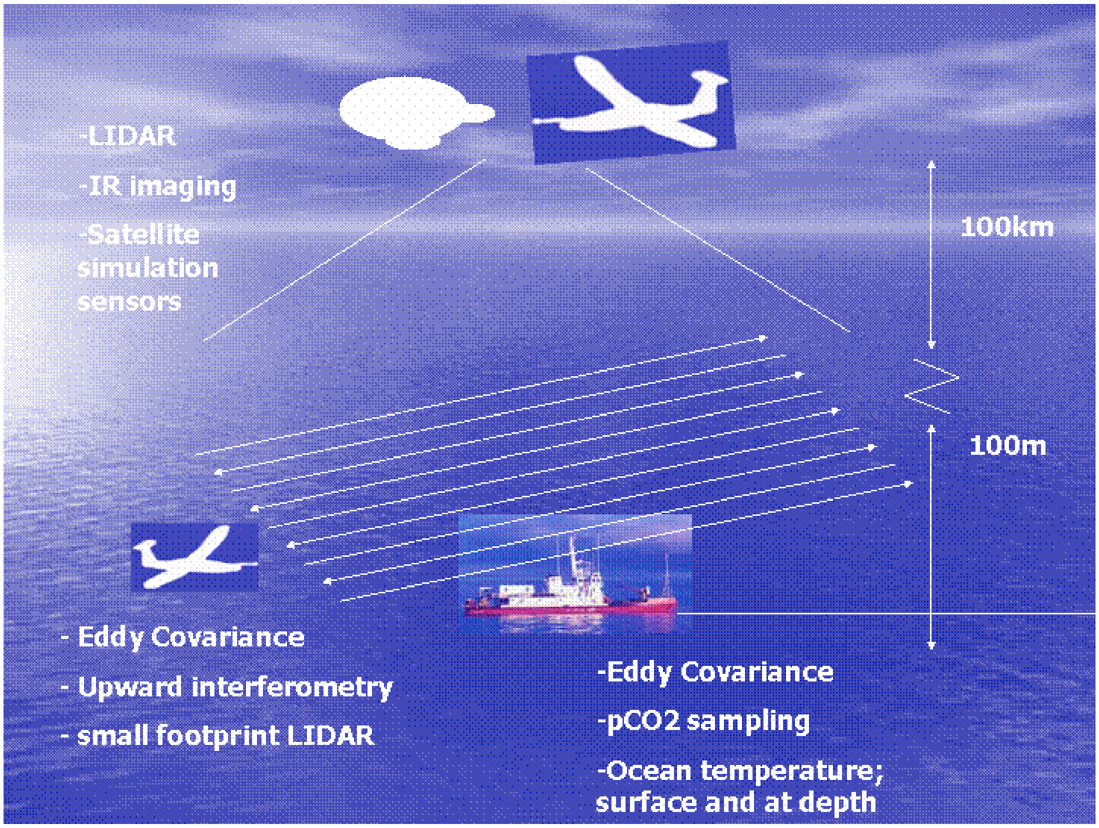

Figure 10: A diagram of an eddy covariance calibration maneuver over an instrumented research vessel. Stage one measurements will begin with sub 100m altitude flights, while later stages will fly higher payload aircraft with complementary instruments for providing larger scale estimates.

Comments on Communications and Autonomy

Scientists were also asked about their needs for communications with the platform and payload during flight and about their desires for autonomy capabilities within the system. Some comments are listed in Table 4 below. In general, most of the missions indicate a need for over-the-horizon communication with the platform, primarily to monitor location and status while the platform is flying out of the line-of-sight of the ground station. In many cases, the aircraft will be preprogrammed to fly to specific way points or follow specific tracks. However, it will still be necessary to know where it is at all times, to be responsive to FAA or international flight requirements. Also, real-time communication with the sensor payload is desired by scientists so that they can monitor both the functionality of instruments and the science data during flight. In some instances, scientists would provide feedback to the flight plan based on the data monitored.

In more sophisticated missions, instrument data could be automatically used by the platform control to direct or redirect the flight. An example might be to follow a plume or a surface feature. A number of missions call for stacked platforms flying simultaneously through a vertical column. Automated tracking between platforms would be required for such flights.

Table 4. Communications and Autonomy Requirements

Mission Type	**Real-time data communications**	**Autonomy needs**
Clouds and Aerosols	OTH for distance missions	Inter-aircraft communication for stacked platforms
Tropospheric and Stratospheric Composition	OTH for distance missions	Payload-directed flight to follow composition or condition surfaces; Lagrangian measurements
Weather / storm surveillance	OTH for distance missions and real-time monitoring	Long endurance surveillance requires autonomous health and loiter control
Fire or natural event monitoring	OTH for distance and high band-width event tracking; imaging	Flight path optimization based on external input from sensor web
Low altitude terrain or ocean surface following, track or formation flying	OTH for distance missions, situation awareness	Precision flying in horizontal and vertical coordinates; multiple platforms
Earth surface and water	Limited to platform control	Feature extraction, sensor-driven flight pattern
Climate change / vertical profiles	Real-time OTH data from sondes or other vertical platforms	Autonomous management of location

Analysis and Conclusions

Although the requirements are all over the map, literally, but there are some interesting trends. These are listed below and in Table 5.
- There are multiple requirements for cloud data, and corresponding all-weather platforms.
- There are almost universal OTH requirements, especially since many flights are long and beyond line-of-sight.
- Real-time data to the scientist on the ground is desired, as a minimum to check instrument functionality.
- There are many missions requiring multiple, coordinated platforms.
- Interesting combinations of mother/daughter platforms or sondes are proposed.
- Intelligent, autonomous tracking of events or phenomena is desirable.
- Synergy with satellite activities would enhance many of missions and many missions would complement satellite activities.

Table 5. Summary Conclusions

Observation	Location	Altitude	Duration/Range	Payload	Comm.	Autonomy	Other
Varied, but many groups interested in cloud physics	Worldwide; varied; including both poles, oceans and land	Surface to 80k ft.	5 hrs. to 2 weeks some loiter capability transoceanic distances	20 to 3,500 lb. Active and passive Dispensible In-situ and remote Smart and recoverable expendables	Nearly all OTH Some inter-platform	Necessary, especially for tracking phenomena Very applicable to planetary exploration	Many missions with multiple, coordinated platforms Frequent deployment / short turn-around

3.3 Summaries – Key Capabilities Requirements

Following is a list of some of the key requirements noted by participants. The responses are grouped by platform / flight requirements, operational requirements, sensor development needs and systems integration

<u>Platform / Flight regime / flight control requirements</u>

- Cutting-edge remote sensors/platforms
- Increased range, duration, payload capacity, geophysical performance
- Low-and-slow as well as high-and-slow platforms
- Diurnal cycle observations
- Sea-land, sea-air, land-air
- High precision GPS and pointing
- All different classes of platforms
- Many 1000's of hours of annual flight time over many years,
- Experimental regimes -- long duration, 3-d sampling, large volumes, many repetitions. e.g., month-long campaigns in each of several years.
- Low cost per flight hour, fewer required personnel, reliability and maintainability.
- Environmentally friendly and tolerant, and system friendly platforms (engine, vehicle, airspace, etc).
- Pointability, formation flying, etc.,

<u>Operational requirements: Communications, Intelligent Mission Management and Data</u>

- Real-time data downlink

- Adaptive, event-driven observations (hurricanes, winter storms, flooding); regional events
- Improved data user interface and rapid delivery (near real-time)
- Large, reliable, long term, easily accessible archival system

<u>Sensor development</u>

- Cutting-edge remote sensors/platforms
- Continuous flask sampling from UAV's
- Contemporaneous phasing of instruments and platforms and science (co-evolution)
- Onboard calibration and monitoring

<u>System integration / sensor web</u>

- Integrated orbital, suborbital, ground-based, and subsurface system-of-systems
- Adaptable and readily deployable systems for observation of abrupt or unpredictable phenomena.
- Access to international airspace
- Coordination with overflying satellites for validation of retrieval algorithms;

3.4 Miracles

In a final session of the workshop, facilitators led a brainstorming exercise to address the statement:

"It would be a miracle if we had the technology that would enable …."

This led to a lively discussion of out-of-the-box ideas. The primary use of this information will be by those developing technology roadmaps. They can get a sense of the direction the community would like to go.

- Sub-millimeter positioning accuracy
- Broad band data links- Multi-Mb/s-over the horizon
- Light weight high bandwidth large volume (TB) storage
- Small volume high accuracy (microgal) gravity gradiometer
- Accurate low cost gyros and accelerometers
- Sub arcsecond attitude measurement
- Autonomous precise (sub meter) formation flying
- Lightweight antennas
- Rapid transit to sites (400 knot) with slow speed acquisition (100 knots)
- Spatial separated mount points with significant mass and volume capacity

- Sensor Web: If suborbital could be leaders in developing a sensor web so scientists, students, the public – everyone – can get the data from satellites, suborbital and ground-based sources; everyone can get to it quickly and easily; they can grab what they want and tailor it to their use
- Reduced flight cost: fly for 10,000 hours; get cost/flight hour down
- Traditional way of looking at flight cost should not apply to these mission concepts
- “Indy 500” type system for UAV’s: They come into the “pit”, we slap everything new on, pull one payload off, put new one on, and put it right back in the air
- Standardized interfaces for data systems and sensors… interchangeable, flexible (goes with “Indy 500”)
- Measure bathimetry – geometry of channels in/and rivers
- Fly through severe weather
- Meter-scale tropo water vapor measurements – remotely
- Penetrate the oceans at 10,000 ft. – remote sensing (same for land)
- Operation by extremely small crew numbers (ideally crew of 1 or 0); Controlled from joystick or mouse – complete automation
- Effectively permanent flight (3 months) – a “roving satellite”
- Daughter ship concept – deploy, descend, and re-dock from mother ship
- Near-expendables – small aircraft, if they’re lost it doesn’t matter; they may be recovered but they are not critical; Many for multi-point measurements
- Illustrated roadmap: how we’re going to get where we’re going from where we are… what it’s going to cost… when we’re going to get there
- Significantly miniaturized instruments
- Very tight formation flying
- Very high precision pointing accuracy for optical communication and energy transmission
- Ability to beam energy to different platforms using microwave (remotely powering platform)
- Pointing accuracy for high-altitude Lidar
- Navigation in hurricanes and severe convection, electrical, icing, wildfires, updrafts, etc. – extreme conditions
- Unrestricted operations in national (international?) airspace
- Very small sense-and-avoid systems
- Small size memory for data storage
- Unrestricted spectrum (frequency)
- Very high bandwidth in polar regions (long range)
- “Returnable bottles”: Sensors so small and so cheap you can go out in the field with a dozen in your back pack… if you bring them back fine; if not, you can get new ones
- Standardized data archive system

- My own platform
- Sensor packages embedded into existing world transportation system
- Autonomy to the level of doing group strategic goals: a number of airplanes flying together to accomplish a mission, with the smarts on board to follow what they want
- System-level integration (satellite, suborbital and ground-based)

4. Recommendations for Technology Development

On the basis of this workshop, and other input from the science community, the Earth Science Capability Demonstration Project at NASA Dryden Flight Research Center has developed a technology development plan. It is part of an overall exercise called the Civil UAV Assessment that has identified needs and gaps relative to the utility of UAVs for Earth and Planetary science. The plan can be obtained from the Aeronautics office at Dryden. Relevant to this workshop effort are the following recommendations:

- Carry out sensor development and miniaturization in parallel with platform development
- Assure access to the national and international airspace for science missions
- Continue efforts on autonomous avionics and Intelligent Mission management
- Develop mother-ship / daughter-ship concepts that allow simultaneous measurements in vertical space.

One planned development is that of a very long endurance platform. The flight envelope and mission opportunities are indicated in Figure 11.

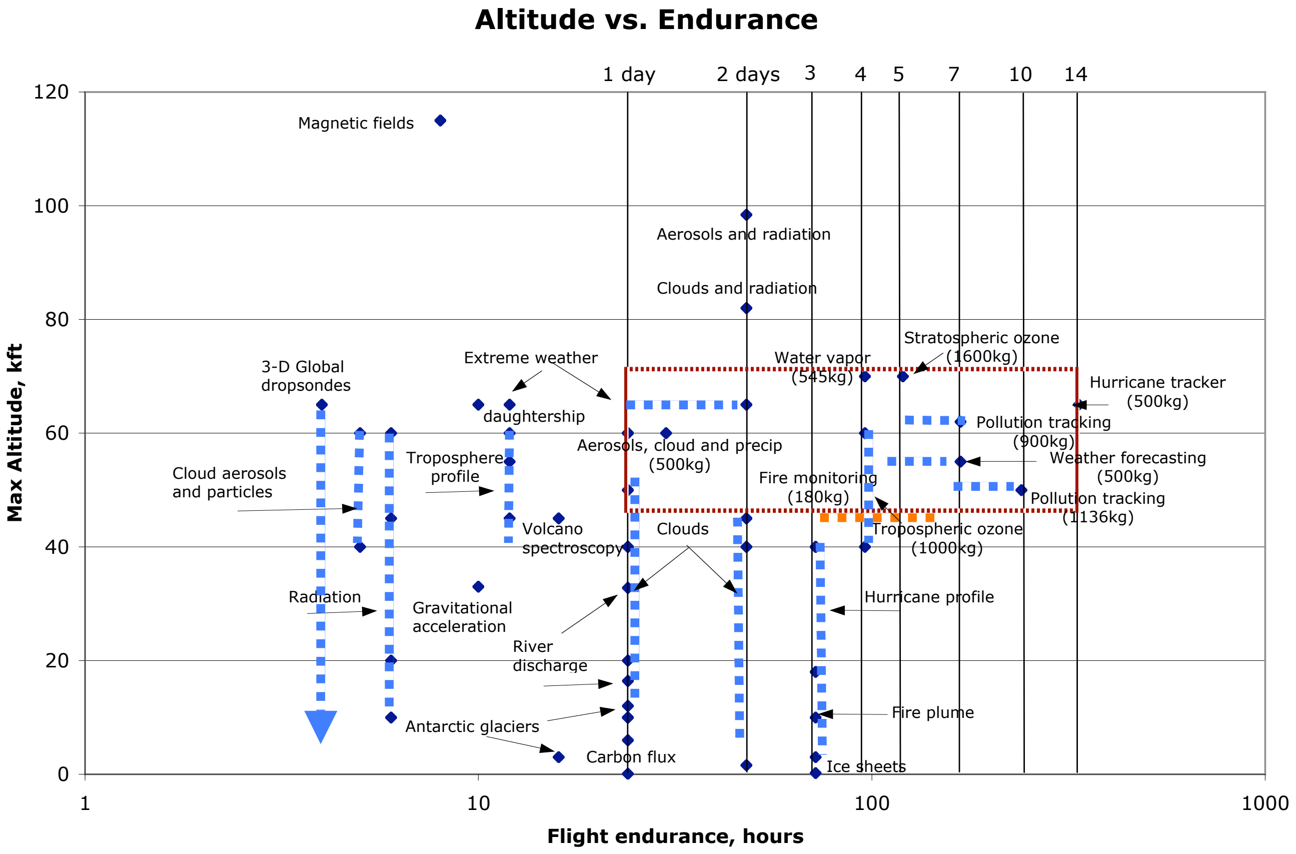

Figure 11. Planned performance of long endurance platform and possible Earth Science missions.

5. Closing

The workshop activity has produced this summary of science mission requirements. Feedback from the science community is sought to validate these requirements, and the resultant technology development plans. A review of these missions from the perspective of the science theme area roadmaps is also sought.

With regard to the two directed studies, it is clear that low altitude, low velocity capability is a requirement. However, it is not currently being pursued within NASA. Both directed study teams are currently seeking capable platforms and opportunities to proceed with these missions.

Appendices

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APPENDIX B: Workshop Schedule And Templates

SUBORBITAL SCIENCE MISSIONS OF THE FUTURE

July 13-15, 2004
Location: Key Bridge Marriott Hotel, Rosslyn, Virginia
Sponsored by: Suborbital Science Program

Purpose and Outcome

Develop innovative mission concepts and system requirements for each of six Earth Science focus areas to guide new investments in suborbital systems development

Meeting Design

Tuesday, July 13 – 8:00am – 5:00pm

8:00am – continental breakfast
8:30am

Opening: Cheryl Yuhas kicks off the meeting with a review of purpose and outcomes. Cindy Zook and John Riordan review the meeting design and groundrules. Participants introduce themselves in their respective groups.

Context: Key leads provide a brief overview of the suborbital science environment:

- **Earth Science –** Dr. Ghassem Asrar, Chief Scientist for Exploration
- **Aeronautics** – John Sharkey, DRFC
- **Directed Studies** – Steve Wegener, ARC
- **Progress reports by 3 directed study teams**

Key Science Questions: Working in focus area workgroups, participants review current roadmaps and define the critical science questions most appropriate for the suborbital platform realm in their assigned Earth Science focus area..

- *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*
- *Are there other things that should be in the Roadmap now that we see what is possible?*
- *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

Networking Lunch

System Requirements and Mission Concepts: Randy Albertson and Steve Wegener review the template and analysis process. Working in focus area workgroups, participants define observation / measurement requirements and mission concepts for one of the priority science questions and prepare to report out results to the larger group the following morning.

Observation / Measurement Definition:

- *For each of the critical observations, what specifically do we want to observe or measure? How would we describe the phenomena we want to measure?*
- *How does this observation or measurement support this Earth Science focus area?*
- *What is the advantage of using a suborbital platform for this observation or measurement?*
- *What other cross-cutting areas are impacted by this observation?*

Observation / Measurement System Requirements:

- *How specifically do we want to observe or measure it?*
- *What are the instrument / payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)?*
- *What are the flight characteristics (location, altitude, endurance, season, frequency)?*
- *What are the communications needs (such as real-time data or instrument control)?*

Mission Concept:

- *What are the key elements of the mission concept? Describe a measurement approach. Provide a narrative describing a "day-in-the-life" of this mission. Provide a diagram showing flight profile in time, space and/or geographic coordinates. Identify any special or unique platform or mission issues.*

5:30pm – 6:30pm – Reception

<u>Wednesday, July 14 – 8:00am – 5:00pm</u>

8:00am – continental breakfast
8:30am
Report Outs: Focus area workgroups report out the results of their work from the previous day for one of the observations. Participants discuss insights from the process and confirm that all groups are headed in the right direction.

System Requirements and Mission Concepts: Participants continue fleshing out system requirements and mission concepts for the other critical observations in their focus area.

Working Lunch

Continue with system requirements

<u>Thursday, July 15 – 8:00am – 12:0pm</u>

8:00am – continental breakfast

8:30am

System Requirements and Mission Concepts: Participants finish fleshing out system requirements and mission concepts for their final observation.

Highlights: Participants discuss in their focus area groups and then report highlights from the planning process to the entire group.

- *What are the highlights that emerged the past two days from our work?*

Next Steps & Follow Up: Cheryl Yuhas reviews the next steps in the planning process and participants provide input.

- *How do we stay involved in and support the planning process?*
- *As a result of this workshop, what are the key messages we want to deliver to the rest of our science community? To other key stakeholders?*

Wrap-up: Participants critique the meeting and close out with one another.

System Requirements Template

Earth Science Focus Area:____

Critical Observation:

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

Explicitly state how this observation and measurement supports this Earth Science focus area.

Explicitly state the advantage of using a suborbital platform for this measurement.

Identify other cross-cutting areas impacted by this observation.

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

- Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Communication needs such as real-time data or instrument control

Mission Concept: Describe in as much detail as possible the measurement approach:

- Provide a narrative describing a “day-in-the-life” of the mission.

- Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Identify any special or unique platform or mission issues

- Summarize the key elements of the mission concept for this measurement.