An analysis and summary of options for collecting ICESat-like data from aircraft through 2014
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January 2009
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EXECUTIVE SUMMARY

The time gap between the end of ICESat-I, which will probably occur this year, and the launch of ICESat-II in the 2014-15 time window creates a data gap in laser observations of the changes in ice sheets, glaciers and sea ice. For the ice sheets and glaciers, the ICESat laser delivers critical ice thickness data on the properties of the rapidly changing ice streams; for the sea ice, the laser measures ice thickness. Given this gap, an inquiry was set up in November-December 2008, to investigate the possibility of using aircraft with a variety of instruments to serve as a gap-filler.

The purpose of this gap filler mission is not to attempt to repeat all of the ICESat tracks over the sea ice and ice sheets, rather it is to carefully employ aircraft resources to follow what is happening in the most sensitive and critical parts of the sea ice, ice sheets and glaciers, such as the coastal glaciers of Greenland and Antarctica. This document describes these critical areas, the current aircraft high-latitude programs, and the potential aircraft and instrument programs that would be involved in such a study. The critical areas are coastal Greenland, coastal Antarctica including the Antarctic Peninsula, interior Antarctica, in particular the sub-glacial lakes and certain fast moving glaciers, the southeast Alaskan glaciers, and the Antarctic and Arctic sea ice thicknesses. The assumption is made here that other satellite instruments such as GRACE, can cover the Greenland interior. Also, if the forthcoming launch of the ESA CryoSat satellite (currently scheduled for late 2009-early 2010) is successful, its radar altimeter may provide data on the sub-glacial lakes.

The current aircraft ice programs have taken place over Greenland using the Airborne Topographic Mapper (ATM) laser on the Wallops NASA P-3, and in October 2008 over the Antarctic Peninsula using the ATM on a Chilean P-3, so that the program described herein largely extends existing observations. For the Greenland and Antarctic ice sheets, another advantage of an aircraft gap filler is that the aircraft can carry the low-frequency ice sounders that are currently being flown in Greenland and Antarctica, where these sounders provide measurements of the bottom topography beneath the ice. Such missions are currently being carried out by the Wallops P-3 and this study recommends extending such a capability to the DC-8 and eventually the Global Hawk. The combination of the laser surface and sounder depth measurements will provide critical data for the development of numerical models of the outflow glaciers of the ice sheets.

For sea ice, using the laser to measure the difference in freeboard between the ice and seawater surface provides an estimate of ice thickness. Particularly for the Arctic sea ice, this is a critical measurement, since
in combination with surface measurements, these measurements show that not only is the sea ice area decreasing, but also the volume is decreasing. Continuity in these measurements is particularly important.

The document also describes the aircraft and instruments available for these measurements. There are nine aircraft considered in the study; they range from the P-3 to the G-V HAIPER (NSF) to the Global Hawk. Because of the extended range of the Global Hawk, it will likely be an excellent high altitude aircraft for studies of Antarctica. Missions that use the Global Hawk initially incur higher costs in upgrading instruments, providing aircraft mounts, building a portable ground station that could be deployed to sites near Antarctica.

From the standpoint of data management, the operation can been viewed as a virtual satellite, in that the laser data from of the various platforms must be placed into a common format and stored at a archive, probably NSIDC, so that it is available for all investigators.

The estimated cost of this study for a characteristic series of flights is as follows:

<table>
<thead>
<tr>
<th>YEAR</th>
<th>($M)</th>
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<tr>
<td>2009</td>
<td>$22</td>
</tr>
<tr>
<td>2010</td>
<td>$26</td>
</tr>
<tr>
<td>2011</td>
<td>$21</td>
</tr>
<tr>
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<td>2014</td>
<td>$15</td>
</tr>
<tr>
<td>TOTAL:</td>
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The reason for the large initial costs is that work must be done up front to rebuild the instruments so that they can serve on a variety of aircraft, and to provide for the Global Hawk operation. This involves procurement of a mobile launch and recovery ground station, so that the Global Hawk can be deployed from airfields in Australia or New Zealand. In the later years, once the infrastructure is built, the costs are reduced. This budget also assumes that a new cohort of laser altimeters currently in development will reach maturity in 2011, and that instrument intercomparison flights will be used to downselect for phase 2 payloads in 2012-2014.
1. Introduction

This report provides options for providing laser altimetry and when possible, radar altimetry measurements from aircraft, over priority regions of the Arctic and Antarctic, in order to provide initial “rough order-of-magnitude” estimates to NASA management on providing ICESat-like data from aircraft until launch of ICESat-2.

This report is intended to be a first step in providing a series of flexible options that take place over 2 phases: Spring 2009 – Fall 2011 (herein referred to as Phase I), and Spring 2012 – Fall 2014 (Phase II) and enable the weighing of the cost, schedule, and science return of different options. Phase 1 is composed primarily of near term, high TRL instruments, that can be easily modified to provide greater coverage, while Phase 2 includes a number of new platforms and instruments that are expected to become available in the near future.

Given the quick turnaround requested for this report, there were a number of general assumptions made that should be stated outright in addition to the assumptions that are listed for each of the mission concepts proposed. The first assumption is that it is not likely to be feasible for aircraft and payloads to cover all of the areas that ICESat covered, especially twice per year. The ICESat science team provided priority areas where time series information was especially important and this information guided planning and estimation. Because of the challenges of covering even these select areas located in very remote regions and across entire continents, we assumed that there would need to be a budget to cover aircraft as well as instrument upgrades and in some cases procurements. These costs are specifically called out and rolled up into each estimate. The last major assumption is that the existing ICESat DAAC maintained at the National Snow and Ice Data Center would be responsible for all data archiving and that participating scientists would agree to an open data policy with a similar timetable to that of the GLAS science products. While this report does not speak to archiving, we do include estimates of science team operations and data processing.

1.1 ICESat description and instrument specifications

The NASA ICESat Geoscience Laser Altimeter System (GLAS), launched in January 2003, was designed to provide precise and accurate altimetry of land and sea ice globally using a series of three diode pumped Q-switched Nd:YAG lasers operating in the near infrared (1064 nanometers). Observations took place from a polar orbit with a 183 day repeat pattern and measured ice elevation to within 10cm vertical accuracy across a 70m beam swath. After early failures of lasers 1 and 2, the remaining laser has been used for 33 days at a time, 2 times each year in March and October (see figure 1 below).
With the follow-on mission, ICESat-II, not scheduled for launch until 2014, this leaves the gap in coverage of this key earth system science parameter, while the rapid rate of change seen recently in Greenland ice sheets, the Arctic sea ice, and the Antarctic shelves are a source of concern both to scientists and policy-makers. The situation requires balancing several options for providing a gap-filler datasets that will enable meaningful continuity and calibration between ICESat-I and ICESat-II and maintain this important time series over areas of scientific interest.

1.2 A summary of science requirements and regions of interest

While the primary goal of this analysis is to provide airborne laser altimetry data to complement ICESat data, the ICESat Science team requested that ice-penetrating radar measurements be considered as secondary payloads to provide soundings of ice depth, and to assist in resolving uncertainties related to surface snow. Minimum repeat time for measurements is the spring and fall 33-day GLAS operations schedule. In addition, the Science team requested seasonal measurements of Arctic and Antarctic sea ice.

The NASA ICESat science team provided information on priorities for extending ICESat-like measurements. The team assumed that not all of the orbits could be covered so they focused on 5 regions that are sensitive to climate change and are showing rapid change. These regions are the Greenland glacial outlets, Arctic and Antarctic Sea Ice, Interior Antarctica, and the Southeast Alaskan glaciers. These regions are described briefly below.

1.2.1 Greenland

The glacial outlets of Greenland are of most interest to the science community. Measurements of the interior, largely used to close ice mass balance estimates, can now be derived from GRACE. The regions of interest for coverage in Greenland are shown as polygons in figure 2 below.
These regions are best served from either Thule or Iceland, and cost estimates were based upon mission experience from both locations. The NASA SMD ESD Cryosphere Science Program is funding P-3 flights of Bill Krabill's Airborne Topographic Mapper in Spring of 2009. A payload of that similar to the Arctic 2007 campaign with ATM, the Land Vegetation Imaging Sensor (LVIS), and the Global Ice Sheet Mapping Observer (KU RADAR sounder) would provide continuity with existing time series in the region, while enabling larger area collects of laser altimetry. Since KU RADAR sounder has already been integrated on the P-3, this would enable rapid response coverage in 2009 and then there could be a more formal selection process for payloads in subsequent seasons.

Figure 2
1.2.2 Arctic and Antarctic Sea Ice

ICESat data over sea ice have successfully been used to retrieve sea ice thickness and to study regional and inter-annual variability. Those results have contributed to a better understanding of the sea ice mass balance and its relation to the changes in the polar climate. It is critical that the laser altimeter time series established by ICESat-1 be interrupted as little as possible.

Four radial spoke-like track-lines, A, B, C and D, are proposed for the Southern Ocean that cover the main Antarctic areas. If sea ice flights are connected with ice sheets flights out of Chile and Australia/New Zealand those lines can be modified. The transects with the highest priority are line A (only the Weddell Sea has large amounts of 2nd-year ice) and line B (the areas east and west of the Antarctic peninsula is currently observing the greatest changes)

Temporal coverage: Seasonally (November/February/May/August)

Figure 3
Spatial coverage requested for Arctic Sea ice. Assumes flights would leave from Thule with a stop-over in Barrow. Flight lines are only conceptual and actual track-lines may differ depending on ice conditions and decisions made to fly, in part, along ICESat or CryoSat ground-tracks.
1.2.3 Coastal Antarctica

Many coastal glacial outlets are changing at dramatic rates. These rates are so high that they could not have persisted for long into the recent past. Either they are episodic, or they are the harbinger of an ice sheet beginning to shed increasing volumes of ice into the ocean, raising sea levels worldwide. These two cases require vastly different societal response. Monitoring the most active areas is the only means to gather the necessary information to predict future behavior of these areas. Seasonal changes do occur, but they are relatively small and annual measurements are minimally sufficient to monitor the ongoing changes. The largest changes occur at the boundary of grounded and floating ice, where fast-moving glaciers and ice streams flow into thick floating ice shelves.

Coastal Antarctica contains three active areas: the Antarctic Peninsula where progressive disintegration of ice shelves southward along both the east and west coasts has led to rapid thinning and acceleration of feeding glaciers; the Amundsen Sea where the basins drained by a series of glaciers, most notably the Pine Island and Thwaites Glaciers are rapidly thinning and accelerating; and a variety of locations along the coast.

Figure 4
Spatial coverage requested for Antarctic Sea ice. Solid lines denote ideal flight lines, while dashed indicate flight lines that could be modified in conjunction with coastal and interior flights.
Satellite altimetry has provided fundamental observations that have quantified the ice volume changes, and thus the consequent sea-level impacts, associated with the ice dynamics of each of these areas. In the case of the Antarctic Peninsula ice shelves, the sudden removal of an ice shelf rapidly causes changes at the fronts of the feeding glaciers causing a wave of thinning to propagate upstream. Elevations before, during and after the ice shelf disintegration are critical to understand this major adjustment of forces. How fast, how large and how far upstream this adjustment extends must be measured to enable models to better simulate such dramatic ice sheet behavior.

The critical coastal regions and their priorities are listed below.

Figure 5
Antarctic glacier priority coverage regions.
1.2.4 Antarctic Sub-Glacial Lakes and Interior Features

The under-ice lakes are important because they lubricate the glacier flow. They also express their change in volume by changes in surface elevation (~10-m). These should be surveyed at intervals of twice/year: in spring and in fall, at intervals of approximately 6 months. For comparison with ICESat observations, these profiles should be run along ICESat lines. The exact location of these lines will have to be worked out with the investigators. The priority regions are found in figure 6 below.

Another priority 2 region in the vicinity of the Whillans lakes are the Whillans and Kamb Ice Streams. These represent the class of “mega-glaciers” are much larger than the more numerous mountain, tidewater, or outlet glaciers elsewhere in the polar regions. These two ice streams feed much of the ice comprising the vast Ross Ice Shelf, the largest ice shelf in existence and roughly the size of Texas. They also drain another large sector of the West Antarctic ice sheet, also across a bed well below sea level. This marine-bed situation is considered unstable for the ice sheet and these two ice streams continue to experience extraordinary dynamic changes revealed by a combination of altimetric and kinematic (GPS) observations. The Kamb Ice Stream suddenly ceased its rapid motion approximately 150 years ago over most of its 300-kilometer length. Since that time, a large bulge of ice has been growing upstream at a rate of nearly 0.5 m/a as ice slowing collects immediately upstream of now-stagnant trunk.

Figure 6
Priority areas in Antarctica associated with sub-glacial lakes.
This ice bulge is increasing the stresses on the ice, on the subglacial bed and modifying the flow of subglacial water. Experts do not know how this situation will evolve, possibly to a reactivation of the ice stream, possibly to some other result, but the longer it develops, the more dramatic will be the dynamic change. Equally dramatic is the evolution of the adjacent Whillans Ice Stream. This ice stream is declining in activity, decelerating 1-2% per year over much of its 400-kilometer length. It is here that laser altimetry revealed an active subglacial water system, with large volumes of water moving between subglacial lakes on a sub-annual time scale. This water movement may prove critical in understanding the deceleration, a process that is contributing to a decrease in sea-level. Observations of the Whillans Ice Stream may well be the only opportunity to witness the stagnation of an ice stream. Continued altimetric observations of both the movement of subglacial water and the evolving thickening of this ice stream as it slows cannot be accomplished anywhere else. Continuity of these elevation data sets will prove instrumental in improving numerical simulation of ice sheet behavior.

The temporal coverage for both the lakes and the ice streams is twice per year.

Figure 7
*Glacial outlets in southeast Alaska.*
1.2.5 Southeast Alaska glaciers

Priority 1: Yakutat Icefield is the most rapidly thinning icefield in Alaska (see figure 7). Bering/Bagley and Malaspina/Seward glaciers are the largest glaciers in Alaska with considerable area at low elevations and a large sensitivity to changing climate. Hubbard Glacier is an advancing tidewater glacier. The glacier periodically advances to form a freshwater lake that threatens to flood the town of Yakutat and its fisheries.

Priority 2: Glacier Bay, Stikine and Juneau Icefields are located in maritime environments with numerous tidewater glacier systems in unstable phases of retreat.

Priority 3: Columbia Glacier is Alaska’s largest rapidly retreating tidewater glacier and is making large contributions to rising sea level. A network of ground measurements are available. These combined with altimetry data provide insight into processes driving dynamic ice losses.

Figure 8
Subset of NASA ATM (Red) first sampled in 2005 along with ICESat lines (Black) and locations of regions included in a NASA Sponsored study (Sauber et al).
Payloads and Platforms

There are a number of existing aircraft and payload systems for providing coverage of ICESat priority regions and systems currently in development will likely play a large role as well. Each system is described briefly below with details on the existing system and a description of any modifications that would be required for integration and operations on available aircraft.

2.1 Instrument descriptions

The following set of instruments were reviewed by the ICESat Science Team and Mission Scientist for consideration in this study. Cost estimates for instrument upgrades in this section are for the instrument only and do not include aircraft engineering costs that are included in the final mission costs estimates.

2.1.1. Airborne Topographic Mapper (ATM)

**Principle Investigator:** Bill Krabill, GSFC

**Instrument description:** The Airborne Topographic Mapper (ATM) is a scanning LIDAR instrument developed at NASA Wallops Flight Facility for the Greenland ice-sheet project. It is primarily used for topographic change detection by repeating measurements over the same area over specific periods.
**Current status:** The instrument is available. As flown on the P-3, the system is mature. It has flown Greenland for more than 15 years and has flown the Antarctic, most recently (October 2008) out of Chile. Is already scheduled for Greenland, May 2009.

**Current performance:** Flies on the P-3 at 1500 ft AGL. Vertical resolution < 10 cm.

**Potential upgrade:** To fly higher, (e.g., on the DC-8), the system needs upgrade to higher power.

- ROM Cost ($k) $255 K
- Schedule: ~1 year

### 2.1.2. Laser Vegetation Imaging Sensor (LVIS)

**Principle Investigator:** Bryan Blair, GSFC

**Instrument description:** LVIS is a scanning laser altimeter, which records the returned signal from the target surface. These data are processed to generate products such as topography and vegetation coverage.

**Current status:** The instrument is available. It has flown in Greenland, most recently in 2007. Vertical resolution <7 cm.

**Current performance:** Flyable on various platforms, including P-3, DC-8

**Potential upgrade:** To fly both Arctic / Greenland and Antarctic in the same season, a duplicate instrument is needed.

- ROM Cost ($k) $500 K
- Schedule: 8-10 months year

Note: A facility-type instrument is planned for development for the Global Hawk to support DESDyni, ICESat-2, and LIST missions

### 2.1.3. Multi-functional Fiber Laser Lidar (MFLL)

**Principle Investigator:** Michael Dobbs, ITT Space Systems

**Co-I Team:** William Krabill, Mike Cisewski, CK Shum
**Instrument description**: MFLL offers cross-track scanning using diffractive optics in lieu of a mechanical scanner and 4 corner calibration pixels, which reduces error from attitude variations and ‘campaign to campaign’ bias. The transmitter is presently implemented using a fiber laser at 1μm, but can be just as easily implemented at wavelengths which have been optimized for vegetation canopy, ice sheet topography, bathymetry, aerosols and clouds, lunar navigation and exploration.

**Current status**: The instrument is available. The Mark I system was successfully demonstrated on the B-90 in 2008. It is suitable for various aircraft, including P-3 and B-200. Currently optimized for operation at 500 to 1500m AGL (1500 to 6000 ft).

**Current performance**: Suitable for various aircraft, including P-3, B-200, DC-8. Vertical resolution <10 cm. System includes Applanix 610 Pos AV INS/GPS.

**Potential upgrade**: To fly at higher altitude (>30,000 ft) with optimum performance, a Mark II version has been designed and is ready for implementation.

- ROM Cost ($k) $100 K
- Schedule: 6-9 months

Note: ASCENDS version of instrument also provides CO2 measurements.

### 2.1.4. Ice Roughness Laser Profilometer

**Principle Investigator**: James Maslanik, University of Colorado

**Instrument description**: The laser profilometer is a small instrument (2-3 lbs) packaged for an Unmanned Aircraft System (UAS). It measures glacial ice surface roughness. It is also suitable for sea ice measurements.

**Current status**: The instrument is available. It has flown on the Aerosonde and Manta UAS and has been packaged for the SIERRA and Scan Eagle UAS. It has flown from Alaska and Greenland.

**Current performance**: Suitable for various aircraft, ideal for UAS. Vertical resolution <10 cm.

**Potential upgrade**: The system is semi-disposable. Suitable for multiple aircraft in a single mission, if duplicated

- ROM cost for duplicate instrument: $8 K
- Schedule: several months
Note: The system is scheduled for IPY flight out of Svalbard in May 2009.

2.1.5. Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL)

**Principle Investigator**: David Harding, GSFC

**Instrument description**: SIMPL is an airborne prototype in development to demonstrate laser altimetry measurement methods and components that enable efficient, high-resolution, swath mapping of topography and surface properties from space. Will be part of an Efficient Swath Mapping Laser Altimetry Demonstration.

**Current status**: Proof-of-concept flight is scheduled for P-3 in late 2008.

**Current performance**: Suitable for flight from 1500 to 25,000 ft. Vertical resolution < 7 cm.

**Potential upgrades**: To fly operationally on P-3
- ROM Cost ($k) $120 K (beyond IIP funding)
- Schedule: 1 year

To fly on the DC-8 or HIAPER
- ROM Cost ($k) $1.2 M
- Schedule: 1-2 years

To fly on S-3 or Global Hawk (requires pressurized package and automation)
- ROM Cost ($k) $2.5 M
- Schedule: 3-5 years

2.1.6. Pulse Compression Lidar

**Principle Investigator**: Prasad Gogineni, University of Kansas

**Instrument description**: The Pulse-compression Lidar is a non-scanning lidar designed for high-resolution snow surface topography.

**Current status**: Prototype is scheduled for test flight at 500 m AGL on the Twin Otter in spring 2009.
**Current performance:** Suitable for flight on P-3. Vertical resolution <50 cm with accuracy <5 cm.

**Potential upgrades:** To fly at 35,000 ft.
- ROM Cost (\$k) $775 K
- Schedule: 2 years

### 2.1.7. Mapping Laser Altimeter

**Principle Investigator:** Anthony Yu, GSFC

**Instrument description:** The mapping laser altimeter is a new IIP project. It is a swath-mapping laser altimeter designed to meet the goals of the proposed Lidar Surface Topography (LIST) Decadal Survey mission. It produces both altimetry and depolarization ratio data. Will be part of an Efficient Swath Mapping Laser Altimetry Demonstration.

**Current status:** The instrument is in development. A prototype is being readied for test flight on the Lear 25 in the summers of 2009 and 2010.

**Current performance:** Suitable for various aircraft, up to at least 30,000 ft. Vertical resolution TBD.

**Potential upgrade:** Unknown, prototype in development

### 2.18. Ku-band Ice Sounder

**Principle Investigator:** Prasad Gogineni, University of Kansas; Ken Jezek, Ohio State University

**Instrument description:** The Ku-band sounder is a NASA ESTO-funded instrument designed by a team of investigators from The Ohio State University, The University of Kansas, JPL and Vexcel Corporation. It has the ability to make 3-dimensional measurements of the thickness and base (basal) topography beneath an ice sheet up to 5 km deep.

**Current status:** The instrument is available. Has demonstrated more than 40 hours of successful operation on the P-3. Has flown over Greenland. Has flown with ATM.

**Current performance:** Potentially suitable for various aircraft.
Potential upgrades:

- Six months of effort would be required to increase the number of data channels and to redesign the antenna array for optimum implementation on the NASA-P3. Estimated cost is $600k for implementation of optimized configuration.

A system redesign is required for operation at higher altitude and speed (e.g., DC-8).

- ROM Cost ($k) $3M
- Schedule: >1 year

2.1.9. Pathfinder Advanced Radar Ice Sounder (PARIS)

Principle Investigator: Keith Raney, Johns Hopkins Applied Physics Lab

Instrument description: PARIS is a NASA Instrument Incubator Project with the goal to demonstrate ice thickness sounding from a high-altitude airborne radar.

Current status: The instrument is available as a demonstrator. It will be available operationally after May 2009.

Current performance: Currently configured to fly on P-3 only. Demonstration flights on P-3 with ATM took place in 2007. Flew in Chile in 2008.

Potential upgrades: Preparation for operational flight on P-3.

- ROM Cost ($k) $72K
- Schedule: 3-6 months

Ground-up development for DC-8 capability:

- ROM Cost: $2M
- Schedule: >1 year.

2.1.10. Ka-band SAR on G-III (UAVSAR)

Principle Investigator: Delwyn Moller, JPL
**Instrument description:** JPL is currently demonstrating a reconfigurable, polarimetric L-band synthetic aperture radar (SAR), specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. The single-pass Ka-band version is required for snow and ice penetration measurements. The Ka instrument has satellite demonstrator heritage.

**Current status:** The instrument will be demonstrated on the G-III in Greenland in May 2009.

**Current performance:** Suitable for various aircraft, including concept for Global Hawk. Vertical resolution < 10 cm.

**Potential upgrade:** Independent pod.

- ROM Cost ($k) several hundred K$
- Schedule: 3-6 months

**Global Hawk, non-pod version**

- ROM Cost ($k) several million $
- Schedule: 2 years

Note: The system recently won an SBIR award for further development

### 2.1.14 Commercial Options for ICESat Data Continuity

One option for ICESat continuity data might evolve from integrating COTS measurement capabilities on NASA aircraft. Commercially available LIDARs appear to be able to meet the 10 cm vertical accuracy

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<th>LIDAR hardware Providers</th>
<th>Capability</th>
<th>Hardware costs</th>
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<td>Optech <a href="http://www.optech.ca/">http://www.optech.ca/</a></td>
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<tr>
<td></td>
<td>ALTM 3100EA</td>
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All include DashMap, ALTM-Nav, installation and full training in both software processing and hardware operations.

**Table 2**

*LIDAR hardware providers with potential science quality mapping systems.*
requirements. This approach would need to be led by a science team that would develop a measurement plan to assure the science quality of the data, and a mission plan to address payload integration, deployment management, data archiving.

Three hardware providers were selected from the web search, and were reviewed looking for off the shelf mapping instruments that appear to meet the core requirement of 10 cm vertical accuracy (See table 2).

2.2 Platforms available and in development

NASA operates a small fleet of highly modified aircraft to serve as platforms for instrument development, satellite cal/val, and to support process studies and model development. The aircraft considered in this

<table>
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<th>Platform</th>
<th>Cruise Altitude (ft)</th>
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<td>450</td>
<td>10</td>
<td>5400</td>
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<tr>
<td>L1011 (Orbital)</td>
<td>35,000</td>
<td>1,000-42,000</td>
<td>430</td>
<td>10.5</td>
<td>5,000</td>
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<tr>
<td>S-3</td>
<td>35,000</td>
<td>1,000-40,000</td>
<td>450</td>
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<tr>
<td>P-3</td>
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<td>200-35,000</td>
<td>330</td>
<td>12</td>
<td>3,800</td>
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<tr>
<td>Twin Otter</td>
<td>20,000</td>
<td>500-25,000</td>
<td>150</td>
<td>7</td>
<td>500</td>
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<tr>
<td>SUAS*</td>
<td>3,000</td>
<td>100-12,000</td>
<td>60</td>
<td>11</td>
<td>600-1,200</td>
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</table>

*Small UAS include SIERRA, Aerosonde, Manta, and Scan Eagle

Table 3
Aircraft considered for this analysis and a short summary of their specifications.

<table>
<thead>
<tr>
<th>Greenland</th>
<th>P-3</th>
<th>DC-8</th>
<th>Global Hawk</th>
<th>G-III</th>
<th>S-3</th>
<th>SUAS*</th>
<th>Haiper (G-V)</th>
<th>L-1011</th>
<th>Twin Otter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic Sea Ice</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
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<tr>
<td>Antarctic, coastal</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

*Small UAS include SIERRA, Aerosonde, Manta, and Scan Eagle

Table 4
Assumed aircraft coverage for each ICESat science priority regions.

NOTE: All assets are controlled by NASA except for the HAIPER (NSF), Twin Otter (Twin Otter Intl.), and the L-1011 (Orbital).
report (see table 3) were chosen because they have the range and payload capabilities to support the instruments listed above.

Because these aircraft support a variety of science disciplines it should be assumed that this effort would have a potentially significant impact without serious consideration of interagency partnerships, commercial leasing as well as aircraft procurement.

3 Airborne Mission concepts for ICESat data continuity

The following mission concepts enable coverage of the priority areas defined by the NASA ICESat science team for both poles. This list of options is not exhaustive but is intended to provide enough information to weigh the cost benefit of different strategies. The following section provides details on one implantation using recommended options from this section in order to provide total cost estimates by year and site. The summary in section 4 provides an example of one implementation based upon this set of options.

3.1 Greenland

3.1.1 Greenland Spring 2009

Option 1a: - P-3 flights of ATM, LVIS and KU RADAR sounder (Code 1L)

*Description:* The ATM and P-3 teams are funded to fly in Spring 2009. This option would extend the mission to include higher altitude (~25 kft) flights of LVIS and/or MFFL and other commercial sensors for large area coverage, and to assess the relative performance of candidate systems. To fly at higher altitudes ATM will require modifications that could not be achieved by March 2009. Low altitude flights provide high precision and accuracy for local areas and maintain the Krabill time series. A further extension of this option will be addressed in the Arctic sea ice mission concepts.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k) 100hrs/ 350
Estimated Aircraft Operations costs ($k): 140
Integration Costs ($k): 600
Science Team Costs ($k): 375
Total Cost ($k): 1,465

Option 1b: G-III flights of Ka-Band UAVSAR (Code 3H)

*Description:* The Ka-Band UAVSAR and G-III teams are already planning to test the system in Greenland in
Spring 2009 in conjunction with Option 1a above. This option would extend operations to enable coincident coverage with the P-3.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 10/0
Estimated Aircraft Operations Costs ($k): 0
Integration Costs ($k): 0
Science Team Costs ($k): 0
Total Cost ($k): 0 (already funded by NASA SMD ESD Cryosphere Program)

Option 2: Medium altitude P-3 flights of LVIS and KU RADAR sounder/PARIS (Code 1M)

Description: This mission would be a follow-on and extension of flights that accompanied ATM during Arctic 2007. This option would enable measurements over the entire continent, including the science priority areas.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/350
Estimated Aircraft Operations costs ($k): 290
Integration Costs ($k): 0
Science Team Costs ($k): 425
Total Cost ($k): 1515

3.1.2 Greenland Fall 2009

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)

Description: This option assumes upgrades to the ATM to enable flights at 20-25 k ft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/350
Estimated Aircraft Operations costs ($k): 140
Integration Costs ($k): 0
Science Team Costs ($k): 1,125
Total Cost ($k): 1,615

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (Code 2M)
**Description**: This option would enable coverage of the entire continent. Requires new integrations of LVIS and radar installation for KU RADAR sounder/PARIS. This option assumes that P-3 ATM flight continue high resolution time series. This option would enable coverage of the entire continent.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 130  
Estimated Aircraft Operations costs ($k): 1,671  
Integration Costs ($k): 3414 (LVIS & KU RADAR sounder); 2000 (PARIS)  
Science Team Costs ($k):  
Total Cost ($k): 6870 (assuming KU RADAR sounder)

### 3.1.2 Greenland Spring 2010

**Option 1**: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)

**Description**: This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 100  
Estimated Aircraft Operations costs ($k): 144  
Integration Costs ($k): 0 (Assuming integration costs covered in 09)  
Science Team Costs ($k): 1,158  
Total Cost ($k): 1663

**Option 2**: Medium altitude DC-8 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 2L)

**Description**: This option would enable coverage of the entire continent. Requires new integrations of LVIS and radar installation for KU RADAR sounder/PARIS. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 130/780  
Estimated Aircraft Operations costs ($k): 1721  
Integration Costs ($k): 255 (ATM)  
Science Team Costs ($k): 1091  
Total Cost ($k): 3871
3.1.3 Greenland Fall 2010

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

**Description:** This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/350
Estimated Aircraft Operations Costs ($k): 144
Integration Costs ($k): 0
Science Team Costs ($k): 1091
Total Cost ($k): 1596

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (Code 2M)

**Description:** This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/780
Estimated Aircraft Operations Costs ($k): 1,721
Integration Costs ($k): 0 (assuming flights in 2009)
Science Team Costs ($k): 1035
Total Cost ($k): 3559

3.1.4 Greenland Spring 2011

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)

**Description:** This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/371
Estimated Aircraft Operations costs ($k): 148
Integration Costs ($k): 0
Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (Code 2M)

Description: This option would enable coverage of the entire landmass of Greenland. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/828
Estimated Aircraft Operations costs ($k): 1772
Integration Costs ($k): 0
Science Team Costs ($k): 1193
Total Cost ($k): 3793

Option 3: Medium altitude S-3 flights of SIMPL/MFLL/SMLA (Code 4N)

*Description*: This option would make use of this newly modified platform and provide an opportunity to test-bed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/280
Estimated Aircraft Operations costs ($k): 475
Integration Costs ($k): 2500
Science Team Costs ($k): 80
Total Cost ($k): 3334

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (Code 5N)

*Description*: This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/403
Estimated Aircraft Operations Costs ($k): 691 + 6000 one-time investment for mobile Ground Control Station
Integration Costs ($k): 2000
Science Team Costs ($k): 1066
Total Cost ($k): 4160 or 10160 w/ GCS
3.1.5 Greenland Fall 2011

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

Description: This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/371
Estimated Aircraft Operations Costs ($k): 148
Integration Costs ($k): 0
Science Team Costs ($k): 1193
Total Cost ($k): 1713

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

Description: This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/828
Estimated Aircraft Operations costs ($k): 1772
Integration Costs ($k): 0
Science Team Costs ($k): 1193
Total Cost ($k): 3793

Option 3: Medium altitude S-3 flights of ATM/LVIS & SIMPL/MFLL/SMLA (Code 4N)

Description: This option would make use of this newly modified platform and provide an opportunity to test-bed operational data production from instruments that are currently in development, alongside well-characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/280
Estimated Aircraft Operations costs ($k): 475
Integration Costs ($k): 0 (assumes NRE from Spring 2011)
Science Team Costs ($k): 79
Total Cost ($k): 834

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

*Description*: This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/403
Estimated Aircraft Operations costs ($k): 691
Integration Costs ($k): 0
Science Team Costs ($k): 1066
Total Cost ($k): 2160

### 3.1.6 Greenland Spring 2012

**Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)**

*Description*: This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/382
Estimated Aircraft Operations costs ($k): 153
Integration Costs ($k): 0
Science Team Costs ($k): 1,229
Total Cost ($k): 1,765

**Option 2: Medium altitude DC-8 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 2M)**

*Description*: This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/852
Estimated Aircraft Operations Costs ($k): 1,826
Option 3: Medium altitude S-3 flights of ATM/LVIS & SIMPL/MFLL/SMLA (Code 4N)

**Description:** This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/288
Estimated Aircraft Operations Costs ($k): 490
Integration Costs ($k): 0
Science Team Costs ($k): 81
Total Cost ($k): 859

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (Code 5M)

**Description:** This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/415
Estimated Aircraft Operations Costs ($k): 712
Integration Costs ($k): 1193
Science Team Costs ($k): 1193
Total Cost ($k): 2320

### 3.1.7 Greenland Fall 2012

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)

**Description:** This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/382
Estimated Aircraft Operations Costs ($k): 152
Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

**Description:** This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/852
Estimated Aircraft Operations Costs ($k): 1825
Integration Costs ($k): 0
Science Team Costs ($k): 1229
Total Cost ($k): 3907

Option 3: Medium altitude S-3 flights of SIMPL/MFLL/SMLA (4N)

**Description:** This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/288
Estimated Aircraft Operations Costs ($k): 489
Integration Costs ($k): 0
Science Team Costs ($k): 81
Total Cost ($k): 859

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (Code 5M)

**Description:** This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/415
Estimated Aircraft Operations Costs ($k): 712
Integration Costs ($k): 0
Science Team Costs ($k): 1098
Total Cost ($k): 2225

3.1.8 Greenland Spring 2013

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

*Description:* This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/394
Estimated Aircraft Operations Costs ($k): 157
Integration Costs ($k): 0
Science Team Costs ($k): 1266
Total Cost ($k): 1817

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

*Description:* This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/878
Estimated Aircraft Operations Costs ($k): 1881
Integration Costs ($k): 0
Science Team Costs ($k): 1266
Total Cost ($k): 4024

Option 3: Medium altitude S-3 flights of SIMPL/MFLL/SMLA (4N)

*Description:* This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/297
Estimated Aircraft Operations Costs ($k): 503  
Integration Costs ($k): 0  
Science Team Costs ($k): 83  
Total Cost ($k): 885

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

**Description:** This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 115/428  
Estimated Aircraft Operations Costs ($k): 733.08  
Integration Costs ($k): 0  
Science Team Costs ($k): 1131  
Total Cost ($k): 2291

### 3.1.9 Greenland Fall 2013

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

**Description:** This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 100/394  
Estimated Aircraft Operations Costs ($k): 158  
Integration Costs ($k): 0  
Science Team Costs ($k): 1266  
Total Cost ($k): 1817

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

**Description:** This option would enable coverage of the entire Arctic basin. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 130/878
Option 3: Medium altitude S-3 flights of ATM/LVIS & SIMPL/MFLL/SMLA

*Description:* This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/297
Estimated Aircraft Operations Costs ($k): 504
Integration Costs ($k): 0
Science Team Costs ($k): 83
Total Cost ($k): 885

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

*Description:* This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/428
Estimated Aircraft Operations Costs ($k): 733
Integration Costs ($k): 0
Science Team Costs ($k): 1131
Total Cost ($k): 2291

3.1.10 Greenland Spring 2014

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

*Description:* This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/406
Estimated Aircraft Operations Costs ($k): 162
Integration Costs ($k): 0
Science Team Costs ($k): 1304
Total Cost ($k): 1872

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

Description: This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/904
Estimated Aircraft Operations Costs ($k): 1937
Integration Costs ($k): 0
Science Team Costs ($k): 1304
Total Cost ($k): 4145

Option 3: Medium altitude S-3 flights of SIMPL/MFLL/SMLA (Code 4N)

Description: This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/306
Estimated Aircraft Operations Costs ($k): 519
Integration Costs ($k): 0
Science Team Costs ($k): 86
Total Cost ($k): 911

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

Description: This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/440
Estimated Aircraft Operations Costs ($k): 755
Integration Costs ($k): 0
Science Team Costs ($k): 1165
Total Cost ($k): 2360

3.1.11 Greenland Fall 2014

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

Description: This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 100/406
Estimated Aircraft Operations Costs ($k): 162
Integration Costs ($k): 0
Science Team Costs ($k): 1304
Total Cost ($k): 1872

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

Description: This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series. Depending on the flexibility of science requirements regarding timing of acquisitions, this option may prevent DC-8 observations in Antarctica.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/904
Estimated Aircraft Operations Costs ($k): 1937
Integration Costs ($k): 0
Science Team Costs ($k): 1304
Total Cost ($k): 4145

Option 3: Medium altitude S-3 flights of SIMPL/MFLL/SMLA (Code 4N)

Description: This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development alongside well characterized instruments.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 80/306
**Estimated Aircraft Operations Costs ($k):** 519  
**Integration Costs ($k):** 0  
**Science Team Costs ($k):** 86  
**Total Cost ($k):** 911

Option 4: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (Code 5M)

**Description:** This option would demonstrate the utility of a UAS for providing extended range observations over all of Greenland.

**Base of Operations:** Thule  
**Estimated Flight Hours/Cost ($k):** 115/440  
**Estimated Aircraft Operations Costs ($k):** 755  
**Integration Costs ($k):** 0  
**Science Team Costs ($k):** 1165  
**Total Cost ($k):** 2360

### Arctic Sea Ice

#### Arctic Sea Ice Spring 2009

Option 1: Low altitude P-3 flights of ATM, LVIS, & KU RADAR sounder/PARIS (1L)

**Description:** This would be an extension of an already funded deployment described in section 3.1.1 above, so the estimates include only additional expenses, and not the entire cost of the mission. The KU RADAR sounder and PARIS are included only because they will be used in Greenland.

**Base of Operations:** Thule/Fairbanks  
**Estimated Flight Hours/Cost ($k):** 39/141  
**Estimated Aircraft Operations Costs ($k):** 52  
**Integration Costs ($k):** 0 (assumes integration funded for Greenland flights)  
**Science Team Costs ($k):** 98  
**Total Cost ($k):** 291

Option 2: Low altitude SUAS flights of a laser profilometer (Code 8D)

**Description:** This is an funded deployment that would provide limited coverage of arctic sea ice, but will demonstrate a new capability for providing high resolution measurements in remote regions.
Base of Operations: Svalbard, Norway
Estimated Flight Hours/Cost ($k): 100/120
Estimated Aircraft Operations Costs ($k): 0
Integration Costs ($k): 0
Science Team Costs ($k): 0
Total Cost ($k): 0 (already funded by UAV IPY)

Option 3: Medium altitude G-III flights of Ka-Band UAVSAR (3H)

*Description*: This mission would take advantage of a UAV IPY project to investigate the use of a Ka-Band radar for sea ice mapping. This would be an extension of a planned mission to Greenland and so costs do not include integration.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 88/220
Estimated Aircraft Operations Costs ($k): 592
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 912

### 3.2.2 Arctic Sea Ice Fall 2009

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

*Description*: This would be an extension of an already funded deployment described in section 3.1.1 above so the estimates include only additional expenses, not the entire cost of the mission. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/140
Estimated Aircraft Operations Costs ($k): 52
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 290

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)
Description: This would be an extension of an already funded deployment described in section 3.1.2 above so the estimates include only additional expenses, not the entire cost of the mission. This option assumes that P-3 ATM flight continue high resolution time series. This option may prevent coverage of Antarctica because the HAIPER is unavailable and the L-1011 may not be ready.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130
Estimated Aircraft Operations Costs ($k): 1671
Integration Costs ($k): 0
Science Team Costs ($k): 1175
Total Cost ($k): 2548

3.2.3 Arctic Sea Ice Spring 2010

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS

Description: This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/144
Estimated Aircraft Operations Costs ($k): 53
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 299

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

Description: This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series. This option may prevent coverage of Antarctica because the HAIPER is unavailable.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/803
Estimated Aircraft Operations Costs ($k): 1721
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 3735
3.2.4  Arctic Sea Ice, Fall 2010

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

*Description:* This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/145
Estimated Aircraft Operations Costs ($k): 53
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 298

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

*Description:* This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/803
Estimated Aircraft Operations Costs ($k): 1773
Integration Costs ($k): 0
Science Team Costs ($k): 100  (Assumes extension of Greenland mission)
Total Cost ($k): 2625

3.2.5  Arctic Sea Ice Spring 2011

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

*Description:* This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/145
Estimated Aircraft Operations Costs ($k): 53
Integration Costs ($k): 0
Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

**Description:** This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 130/828  
Estimated Aircraft Operations Costs ($k): 1772  
Integration Costs ($k): 0  
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)  
Total Cost ($k): 2704

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

**Description:** This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 115/403  
Estimated Aircraft Operations Costs ($k): 691  
Integration Costs ($k): 3700 (one-time integration)  
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)  
Total Cost ($k): 6041

### 3.2.6 Arctic Sea Ice, Fall 2011

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)

**Description:** This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule  
Estimated Flight Hours/Cost ($k): 39  
Estimated Aircraft Operations Costs ($k): 53  
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 302

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

**Description**: This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/828
Estimated Aircraft Operations Costs ($k): 1772
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 2704

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

**Description**: This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/403
Estimated Aircraft Operations Costs ($k): 691
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 1187

### 3.2.7 Arctic Sea Ice, Spring 2012

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

**Description**: This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/149
Estimated Aircraft Operations Costs ($k): 55
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 310

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (Code 2M)

**Description:** This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/852
Estimated Aircraft Operations Costs ($k): 1826
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 2785

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5N)

**Description:** This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/415
Estimated Aircraft Operations Costs ($k): 712
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 1223

3.2.8 Arctic Sea Ice, Fall 2012

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

**Description:** This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/146
Estimated Aircraft Operations Costs ($k): 55
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 311

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2N)

*Description*: This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/852
Estimated Aircraft Operations Costs ($k): 1826
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 2785

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5N)

*Description*: This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/427
Estimated Aircraft Operations Costs ($k): 712
Integration Costs ($k): 0
Science Team Costs ($k): 100 (Assumes extension of Greenland mission)
Total Cost ($k): 1223

3.2.9 Arctic Sea Ice, Spring 2013

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

*Description*: This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/154
Estimated Aircraft Operations Costs ($k): 56
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 320

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (Code 2N)

*Description*: This option would enable coverage of the entire continent. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/878
Estimated Aircraft Operations Costs ($k): 1881
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 2785

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (Code 5M)

*Description*: This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/428
Estimated Aircraft Operations Costs ($k): 712
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 1223

### 3.2.10 Arctic Sea Ice Fall 2013

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 1L)

*Description*: This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/154
Estimated Aircraft Operations Costs ($k): 56
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 320

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

Description: This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/878
Estimated Aircraft Operations Costs ($k): 1881
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 2869

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5N)

Description: This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/428
Estimated Aircraft Operations Costs ($k): 733
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 1260

3.2.11 Arctic Sea Ice Spring 2014

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

Description: This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39/158
Estimated Aircraft Operations Costs ($k): 58
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 326

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (2M)

*Description*: This option would enable coverage of the entire Arctic Basin. Requires new integrations of LVIS and radar installation for KU RADAR sounder/PARIS. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/904
Estimated Aircraft Operations Costs ($k): 755
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 2955

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (5M)

*Description*: This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/440
Estimated Aircraft Operations Costs ($k): 755
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 1298

3.2.12 Arctic Sea Ice Fall 2014

Option 1: Medium altitude P-3 flights of ATM, LVIS, KU RADAR sounder/PARIS (1L)

Description: This would be an extension of an already funded deployment. This option assumes upgrades to the ATM to enable flights at 20-25 kft for greater coverage. Higher altitudes introduce some risk of schedule delays incurred by low lying clouds but margins have been included in the schedule.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 39
Estimated Aircraft Operations Costs ($k): 58
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 330

Option 2: Medium altitude DC-8 flights of LVIS & KU RADAR sounder/PARIS (Code 2M)

*Description:* This option would enable coverage of the entire Arctic Basin. This option assumes that P-3 ATM flight continue high resolution time series.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 130/904
Estimated Aircraft Operations Costs ($k): 1937
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 2955

Option 3: Medium altitude Global Hawk flights of LVIS and KU RADAR sounder/PARIS (Code 5M)

Description: This option would demonstrate the utility of a UAS for providing extended range observations over the entire Arctic Basin and would be an extension of the mission described in 3.1.4.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 115/440
Estimated Aircraft Operations Costs ($k): 755
Integration Costs ($k): 0
Science Team Costs ($k): 100
Total Cost ($k): 1309

### 3.3 Antarctic sea ice and coastal glaciers

#### 3.3.1 Antarctic sea ice and coastal glaciers Spring 2009

Option 1: Low altitude P-3 (Chilean) flights of ATM, LVIS and PARIS

*Description:* This option would follow on the success of the recently completed missions in Fall 2008 and repeat coverage of the Antarctic peninsula only.
Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): TBD
Estimated Aircraft Operations Costs ($k): TBD
Integration Costs ($k): TBD
Science Team Costs ($k): TBD
Total Cost ($k): TBD

3.3.2 Antarctic sea ice and coastal glaciers, Fall 2009

Option 1: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)

Description: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/870
Estimated Aircraft Operations Costs ($k): 1801
Integration Costs ($k): 2775
Science Team Costs ($k): 1175
Total Cost ($k): 6549

Option 2: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

Description: This option includes that a safe and airworthy pod can be designed for the belly to attach where Pegasus are interfaced and launched. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1000
Estimated Aircraft Operations Costs ($k): 1200
Integration Costs ($k): 3669
Science Team Costs ($k): 1175
Total Cost ($k): 7044

3.3.3 Antarctic sea ice and coastal glaciers, Spring 2010

Option 1: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)
Description: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Thule
Estimated Flight Hours/Cost ($k): 145/896
Estimated Aircraft Operations Costs ($k): 1855
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3961

Option 2: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1030
Estimated Aircraft Operations Costs ($k): 1236
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3476

3.3.4 Antarctic sea ice and coastal glaciers Fall 2010

Option 1: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)

Description: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/896
Estimated Aircraft Operations Costs ($k): 1855
Integration Costs ($k):
Science Team Costs ($k): 1210
Total Cost ($k): 3961

Option 2: Medium altitude HAIPER flights of ATM, LVIS/MFLL (6AB)
**Description**: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 96  
Estimated Aircraft Operations Costs ($k): 898  
Integration Costs ($k): 1614  
Science Team Costs ($k): 709  
Total Cost ($k): 3544

**Option 3**: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

**Description**: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 200/1030  
Estimated Aircraft Operations Costs ($k): 1236  
Integration Costs ($k): 0  
Science Team Costs ($k): 1210  
Total Cost ($k): 3476

### 3.3.5 Antarctic sea ice and coastal glaciers Spring 2011

**Option 1**: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)

**Description**: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 145/922  
Estimated Aircraft Operations Costs ($k): 1910  
Integration Costs ($k): 0  
Science Team Costs ($k): 1246  
Total Cost ($k): 4080
Option 2: Medium altitude HAIPER flights of ATM, LVIS (6AB)

**Description:** Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 96/323  
Estimated Aircraft Operations Costs ($k): 898  
Integration Costs ($k): 0  
Science Team Costs ($k): 709  
Total Cost ($k): 1930

Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 5L)

**Description:** We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 140/490  
Estimated Aircraft Operations Costs ($k): 821  
Integration Costs ($k): 2000  
Science Team Costs ($k): 1246  
Total Cost ($k): 4557

Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 200/1060  
Estimated Aircraft Operations Costs ($k): 1273  
Integration Costs ($k): 0  
Science Team Costs ($k): 1210  
Total Cost ($k): 3476
3.3.6 Antarctic sea ice and coastal glaciers, Fall 2011

Option 1: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)

Description: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/922
Estimated Aircraft Operations Costs ($k): 1910
Integration Costs ($k): 0
Science Team Costs ($k): 1246
Total Cost ($k): 4080

Option 2: Medium altitude HAIPER flights of ATM, LVIS/MFLL (6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 709
Total Cost ($k): 1930

Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 5L)

Description: The Global Hawk project has identified an already existing Northrup Grumman radome that may facilitate LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/490
Estimated Aircraft Operations Costs ($k): 821
Integration Costs ($k): 2000
Science Team Costs ($k): 1246
Total Cost ($k): 4557

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1061
Estimated Aircraft Operations Costs ($k): 1236
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3476

3.3.7 Antarctic sea ice and coastal glaciers, Spring 2012

Option 1: Medium altitude DC-8 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 2L)

**Description:** This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/951
Estimated Aircraft Operations Costs ($k): 1968
Integration Costs ($k): 0
Science Team Costs ($k): 1284
Total Cost ($k): 4202

Option 2: Medium altitude HAIPER flights of ATM, LVIS/MFLL (6AB)

**Description:** Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.
Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 730
Total Cost ($k): 1951

Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 5L)

*Description:* We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/505
Estimated Aircraft Operations Costs ($k): 846
Integration Costs ($k): 0
Science Team Costs ($k): 1283
Total Cost ($k): 2634

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (9L)

*Description:* This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1093
Estimated Aircraft Operations Costs ($k): 1311
Integration Costs ($k): 0
Science Team Costs ($k): 1284
Total Cost ($k): 3687

**3.3.8 Antarctic sea ice and coastal glaciers, Fall 2012**

Option 1: Medium altitude DC-8 flights of ATM, LVIS & KU RADAR sounder/PARIS (2L)

*Description:* This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.
Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/951
Estimated Aircraft Operations Costs ($k): 1968
Integration Costs ($k): 0
Science Team Costs ($k): 1284
Total Cost ($k): 4202

Option 2: Medium altitude HAIPER flights of ATM, LVIS (6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 730
Total Cost ($k): 1951

Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (5L)

Description: We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/520
Estimated Aircraft Operations Costs ($k): 846
Integration Costs ($k): 0
Science Team Costs ($k): 1283
Total Cost ($k): 2634

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.
3.3.9 Antarctic sea ice and coastal glaciers, Spring 2013

Option 1: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)

Description: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/979
Estimated Aircraft Operations Costs ($k): 2027
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 4329

Option 2: Medium altitude HAIPER flights of ATM, LVIS (Code 6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 
Science Team Costs ($k): 752
Total Cost ($k): 1973

Option 3: Medium altitude Global Hawk flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 5L)

Description: We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.
Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 9L)

*Description*: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Option 1: Medium altitude DC-8 flights of ATM, LVIS/MFLL, 7 KU RADAR sounder/PARIS (Code 2L)

*Description*: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Option 2: Medium altitude HAIPER flights of ATM, LVIS/MFLL (6AB)

*Description*: Would require upgrades to ATM and new integrations for all instruments.
This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k):
Science Team Costs ($k): 752
Total Cost ($k): 1973

Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 5L)

Description: We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/520
Estimated Aircraft Operations Costs ($k): 871
Integration Costs ($k):
Science Team Costs ($k): 1322
Total Cost ($k): 2713

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 9L)

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1126
Estimated Aircraft Operations Costs ($k): 1350
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 3798

3.3.11 Antarctic sea ice and coastal glaciers, Spring 2014

Option 1: Medium altitude DC-8 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 2L)
Description: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/1009
Estimated Aircraft Operations Costs ($k): 2088
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 4459

Option 2: Medium altitude HAIPER flights of ATM, LVIS (6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 775
Total Cost ($k): 1996

Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (5L)

Description: We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLL. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/535
Estimated Aircraft Operations Costs ($k): 897
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 2795

Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 9L)

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This
would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1159
Estimated Aircraft Operations Costs ($k): 1391
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 3913

3.3.12 Antarctic sea ice and coastal glaciers, Fall 2014

Option 1: Medium altitude DC-8 flights of ATM, LVIS, & KU RADAR sounder/PARIS (2L)

*Description*: This option assumes upgrades to the DC-8 to provide antennae, upgrades to ATM, and a new LVIS integration. Sea ice tracks C & D are not accessible via this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/1009
Estimated Aircraft Operations Costs ($k): 2088
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 4459

Option 2: Medium altitude HAIPER flights of ATM, LVIS/MFLL (6AB)

*Description*: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 775
Total Cost ($k): 1996
Option 2: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (5L)

*Description*: We have identified an already existing radome that may enable LVIS integration but this option would require upgrades to ATM and MFLF. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 140/535  
Estimated Aircraft Operations Costs ($k): 897  
Integration Costs ($k): 0  
Science Team Costs ($k): 1362  
Total Cost ($k): 2795

Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

*Description*: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 200/535  
Estimated Aircraft Operations Costs ($k): 1391  
Integration Costs ($k): 0  
Science Team Costs ($k): 1362  
Total Cost ($k): 3913

### 3.4 Antarctic sub-glacial lakes

#### 3.4.1 Antarctic sub-glacial lakes, Spring 2009

No current options exist for this time period given the need to integrate new instruments on either the DC-8, L-1011, or HAIPE and no project in place.

The cost estimates below represent the deployment costs of all Antarctic missions, including coverage of sea ice, coastal glacial outlets, and sub-glacial lakes within a 30 day period. If the sub-glacial lake missions are chosen separately the cost will be roughly half of the cost of the estimates below.
3.4.2 Antarctic sub-glacial lakes, Fall 2009

Option 1: Medium altitude DC-8 flights of ATM, LVIS, KU RADAR sounder/PARIS (2L)

**Description:** Assumes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 145/870
Estimated Aircraft Operations Costs ($k): 1801
Integration Costs ($k): 0 (Integration costs book kept in Antarctic coastal)
Science Team Costs ($k): 1175
Total Cost ($k): 3846

Option 2: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1000
Estimated Aircraft Operations Costs ($k): 1200
Integration Costs ($k): 0
Science Team Costs ($k): 1175
Total Cost ($k): 3375

3.4.3 Antarctic sub-glacial lakes, Spring 2010

Option 1: Medium altitude DC-8 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 2L)

**Description:** Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/896
Estimated Aircraft Operations Costs ($k): 1855
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3961

Option 2: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1030
Estimated Aircraft Operations Costs ($k): 1236
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3476

### 3.4.4 Antarctic sub-glacial lakes, Fall 2010

Option 1: Medium altitude DC-8 flights of ATM, LVIS/MFLL, KU RADAR sounder/PARIS (2L)

**Description:** Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/896
Estimated Aircraft Operations Costs ($k): 1855
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3961

Option 2: Medium altitude HAIPER flights of ATM & LVIS (6AB)

**Description:** Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.
Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 730
Total Cost ($k): 1951

Option 2: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1030
Estimated Aircraft Operations Costs ($k): 1236
Integration Costs ($k): 0
Science Team Costs ($k): 1210
Total Cost ($k): 3476

3.4.5 Antarctic sub-glacial lakes, Spring 2011

Option 1: Medium altitude DC-8 flights of ATM, LVIS, KU RADAR sounder/PARIS (2L)

Description: Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/923
Estimated Aircraft Operations Costs ($k): 1911
Integration Costs ($k): 0
Science Team Costs ($k): 1246
Total Cost ($k): 4080

Option 2: Medium altitude HAIPER flights of ATM & LVIS (6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.
This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 96/323  
Estimated Aircraft Operations Costs ($k): 898  
Integration Costs ($k): 0  
Science Team Costs ($k): 752  
Total Cost ($k): 1973

Option 3: Medium altitude Global Hawk flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (5L)

**Description:** This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 140/490  
Estimated Aircraft Operations Costs ($k): 821  
Integration Costs ($k): 0  
Science Team Costs ($k): 1246  
Total Cost ($k): 2557

Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch  
Estimated Flight Hours/Cost ($k): 200/1061  
Estimated Aircraft Operations Costs ($k): 1273  
Integration Costs ($k): 0  
Science Team Costs ($k): 1246  
Total Cost ($k): 3581
### 3.4.6 Antarctic sub-glacial lakes, Fall 2011

**Option 1:** Medium altitude DC-8 flights of ATM, LVIS/MFLL, KU RADAR sounder/PARIS (Code 2L)

**Description:** Includes costs associated with new upgrades to ATM, MFLL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

- **Base of Operations:** Puenta Arenas
- **Estimated Flight Hours/Cost ($k):** 145/923
- **Estimated Aircraft Operations Costs ($k):** 1911
- **Integration Costs ($k):**
- **Science Team Costs ($k):** 1246
- **Total Cost ($k):** 4080

**Option 2:** Medium altitude HAIPER flights of ATM & LVIS (Code 6AB)

**Description:** Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

- **Base of Operations:** Puenta Arenas/Christchurch
- **Estimated Flight Hours/Cost ($k):** 96/323
- **Estimated Aircraft Operations Costs ($k):** 898
- **Integration Costs ($k):** 0
- **Science Team Costs ($k):** 752
- **Total Cost ($k):** 1973

**Option 3:** Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 5L)

**Description:** This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

- **Base of Operations:** Puenta Arenas/Christchurch
- **Estimated Flight Hours/Cost ($k):** 140/490
- **Estimated Aircraft Operations Costs ($k):** 821
- **Integration Costs ($k):** 0
Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (9L)

*Description*: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

*Base of Operations*: Puenta Arenas/Christchurch  
*Estimated Flight Hours/Cost ($k)*: 200/1061  
*Estimated Aircraft Operations Costs ($k)*: 1273  
*Integration Costs ($k)*: 0  
*Science Team Costs ($k)*: 1246  
*Total Cost ($k)*: 3581

### 3.4.7 Antarctic sub-glacial lakes, Spring 2012

Option 1: Medium altitude DC-8 flights of ATM, LVIS, KU RADAR sounder/PARIS (2L)

*Description*: Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

*Base of Operations*: Puenta Arenas  
*Estimated Flight Hours/Cost ($k)*: 145/951  
*Estimated Aircraft Operations Costs ($k)*: 1968  
*Integration Costs ($k)*: 0  
*Science Team Costs ($k)*: 1283  
*Total Cost ($k)*: 4202

Option 2: Medium altitude HAIPER flights of ATM & LVIS (6AB)

*Description*: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.
Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (5L)

**Description:** This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/534
Estimated Aircraft Operations Costs ($k): 846
Integration Costs ($k): 0
Science Team Costs ($k): 1251
Total Cost ($k): 2630

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1093
Estimated Aircraft Operations Costs ($k): 1311
Integration Costs ($k): 0
Science Team Costs ($k): 1284
Total Cost ($k): 3688

### 3.4.8 Antarctic sub-glacial lakes, Fall 2012

Option 1: Medium altitude DC-8 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 2L)
Description: Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/951
Estimated Aircraft Operations Costs ($k): 1968
Integration Costs ($k): 0
Science Team Costs ($k): 1283
Total Cost ($k): 4202

Option 2: Medium altitude HAIPER flights of ATM, LVIS (Code 6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/322
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 775
Total Cost ($k): 1996

Option 3: Medium altitude Global Hawk flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 5L)

Description: This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/505
Estimated Aircraft Operations Costs ($k): 846
Integration Costs ($k): 0
Science Team Costs ($k): 1251
Total Cost ($k): 2630
Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (9L)

*Description:* This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1093
Estimated Aircraft Operations Costs ($k): 1311
Integration Costs ($k): 0
Science Team Costs ($k): 1284
Total Cost ($k): 3688

3.4.9 Antarctic sub-glacial lakes Spring 2013

Option 1: Medium altitude DC-8 flights of ATM, LVIS/MFLL, KU RADAR sounder/PARIS (Code 2L)

*Description:* Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/980
Estimated Aircraft Operations Costs ($k): 2027
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 4329

Option 2: Medium altitude HAIPER flights of ATM & LVIS (Code 6AB)

*Description:* Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Option 2: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 5L)

Description: This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/520
Estimated Aircraft Operations Costs ($k): 846
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 2688

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 9L)

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1126
Estimated Aircraft Operations Costs ($k): 1350
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 3798

3.4.10 Antarctic sub-glacial lakes Fall 2013

Option 1: Medium altitude DC-8 flights of ATM, LVIS, KU RADAR sounder/PARIS (Code 2L)

Description: Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.
Base of Operations: Puenta Arenas
Estimated Flight Hours/Cost ($k): 145/980
Estimated Aircraft Operations Costs ($k): 2027
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 4329

Option 2: Medium altitude HAIPER flights of ATM, LVIS (Code 6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 798
Total Cost ($k): 2019

Option 3: Medium altitude Global Hawk flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 5L)

Description: This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/520
Estimated Aircraft Operations Costs ($k): 846
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 2688

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 9L)

Description: This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame.
No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1126
Estimated Aircraft Operations Costs ($k): 1350
Integration Costs ($k): 0
Science Team Costs ($k): 1322
Total Cost ($k): 3798

3.4.11 Antarctic sub-glacial lakes Spring 2014

Option 1: Medium altitude DC-8 flights of ATM, LVIS/MFLL, KU RADAR sounder/PARIS (Code 2L)

Description: Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 145/1009
Estimated Aircraft Operations Costs ($k): 2088
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 4459

Option 2: Medium altitude HAIPER flights of ATM & LVIS (Code 6AB)

Description: Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 822
Total Cost ($k): 2043
Option 3: Medium altitude Global Hawk flights of ATM, LVIS & KU RADAR sounder/PARIS (5L)

**Description:** This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/535
Estimated Aircraft Operations Costs ($k): 871
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 2769

Option 4: Medium altitude L-1011 flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1159
Estimated Aircraft Operations Costs ($k): 1391
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 3912

3.4.12 Antarctic sub-glacial lakes Fall 2014

Option 1: Medium altitude DC-8 flights of ATM, LVIS/MFLL, KU RADAR sounder/PARIS (Code 2L)

**Description:** Includes costs associated with new upgrades to ATM, MFFL, and the radars. This option would also require installation of new antennae system as described in section 3.3.x. All sub-glacial lakes but “Totten” are covered with this option.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 145/1009
Estimated Aircraft Operations Costs ($k): 2088
Integration Costs ($k): 0
Option 2: Medium altitude HAIPER flights of ATM, LVIS/MFLL (Code 6AB)

**Description:** Would require upgrades to ATM and new integrations for all instruments.

This option would require interagency cooperation with NSF and NCAR, the operating organization. All regions of interest can be covered but this option would not provide radar sounding.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 96/323
Estimated Aircraft Operations Costs ($k): 898
Integration Costs ($k): 0
Science Team Costs ($k): 822
Total Cost ($k): 2043

Option 3: Medium altitude Global Hawk flights of ATM, LVIS/MFLL & KU RADAR sounder/PARIS (Code 5L)

**Description:** This mission would require upgrades to the platform and instruments. The Global Hawk team has identified an already existing Northrup Grumman radome that may enable LVIS class integration. This option would enable coverage of all regions of interest.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 140/535
Estimated Aircraft Operations Costs ($k): 871
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 2769

Option 4: Medium altitude L-1011 flights of ATM, LVIS & KU RADAR sounder/PARIS (Code 9L)

**Description:** This option assumes that the upfront cost for the pod have been paid for in year 2009. This would require upgrades to instruments and new integrations in the pod. NASA has an existing Blanket Purchase Agreement with Orbital but contracting and safety reviews may be a challenge in this time frame. No data on coverage.

Base of Operations: Puenta Arenas/Christchurch
Estimated Flight Hours/Cost ($k): 200/1159
Estimated Aircraft Operations Costs ($k): 1391
Integration Costs ($k): 0
Science Team Costs ($k): 1362
Total Cost ($k): 3912

3.5 Southeast Alaskan glaciers

3.5.1 Southeast Alaskan glaciers Spring 2009

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)

*Description:* These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/117
Estimated Aircraft Operations Costs ($k): 100
Integration Costs ($k): 0
Science Team Costs ($k): 170
Total Cost ($k): 387

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

*Description:* This option would require extended operations prior to or following the planned Greenland deployment in Spring 2009. This prototype instrument will require significant modifications to become operational beyond Spring 2009. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/205
Estimated Aircraft Operations Costs ($k): 341
Integration Costs ($k): 0
Science Team Costs ($k): 170
Total Cost ($k): 646

3.5.2 Southeast Alaskan glaciers Fall 2009

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)
Description: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/117
Estimated Aircraft Operations Costs ($k): 100
Integration Costs ($k):
Science Team Costs ($k): 170
Total Cost ($k): 387

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

Description: This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/205
Estimated Aircraft Operations Costs ($k): 341
Integration Costs ($k): 0
Science Team Costs ($k): 170
Total Cost ($k): 646

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial sensor (10N)

Description: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/183
Estimated Aircraft Operations Costs ($k): 332
Integration Costs ($k): 0
Science Team Costs ($k): 79
Total Cost ($k): 593

3.5.3 Southeast Alaskan glaciers Spring 2010

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)
**Description**: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD  
Estimated Flight Hours/Cost ($k): 120/124  
Estimated Aircraft Operations Costs ($k): 103  
Integration Costs ($k): 0  
Science Team Costs ($k): 175  
Total Cost ($k): 398

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (3K)

**Description**: This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC  
Estimated Flight Hours/Cost ($k): 82/217  
Estimated Aircraft Operations Costs ($k): 351  
Integration Costs ($k): 0  
Science Team Costs ($k): 103  
Total Cost ($k): 665

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

**Description**: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau  
Estimated Flight Hours/Cost ($k): 73/183  
Estimated Aircraft Operations Costs ($k): 332  
Integration Costs ($k): 0  
Science Team Costs ($k): 79  
Total Cost ($k): 593

### 3.5.4 Southeast Alaskan glaciers Fall 2010

Option 1: Low altitude Twin Otter flights of ATM (7A)
**Description**: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/120
Estimated Aircraft Operations Costs ($k): 103
Integration Costs ($k): 0
Science Team Costs ($k): 175
Total Cost ($k): 398

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (3K)

**Description**: This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/211
Estimated Aircraft Operations Costs ($k): 351
Integration Costs ($k): 0
Science Team Costs ($k): 103
Total Cost ($k): 665

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

**Description**: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/183
Estimated Aircraft Operations Costs ($k): 332
Integration Costs ($k): 0
Science Team Costs ($k): 79
Total Cost ($k): 594

### 3.5.5 Southeast Alaskan glaciers Spring 2011

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)
**Description:** These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD  
Estimated Flight Hours/Cost ($k): 120/124  
Estimated Aircraft Operations Costs ($k): 109  
Integration Costs ($k):  
Science Team Costs ($k): 180  
Total Cost ($k): 410

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

**Description:** This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC  
Estimated Flight Hours/Cost ($k): 82/217  
Estimated Aircraft Operations Costs ($k): 362  
Integration Costs ($k): 0  
Science Team Costs ($k): 107  
Total Cost ($k): 685

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

**Description:** SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau  
Estimated Flight Hours/Cost ($k): 73/188  
Estimated Aircraft Operations Costs ($k): 342  
Integration Costs ($k): 0  
Science Team Costs ($k): 79  
Total Cost ($k): 608

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (4N)

**Description:** This option would make use of this newly modified platform and provide an opportunity to testbed operational data production from these instruments that are currently in development.
3.5.6 Southeast Alaskan glaciers, Fall 2011

Option 1: Low altitude Twin Otter flights of ATM (7A)

*Description:* These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/124
Estimated Aircraft Operations Costs ($k): 107
Integration Costs ($k): 0
Science Team Costs ($k): 180
Total Cost ($k): 410

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (3K)

*Description:* This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/217
Estimated Aircraft Operations Costs ($k): 362
Integration Costs ($k): 0
Science Team Costs ($k): 107
Total Cost ($k): 685

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (10N)

*Description:* SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.
Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/188
Estimated Aircraft Operations Costs ($k): 342
Integration Costs ($k): 0
Science Team Costs ($k): 79
Total Cost ($k): 608

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (4N)

Description: This mission would take advantage of payloads already integrated and flown over Greenland

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/245
Estimated Aircraft Operations Costs ($k): 398
Integration Costs ($k): 0
Science Team Costs ($k): 79
Total Cost ($k): 722

3.5.7 Southeast Alaskan glaciers, Spring 2012

Option 1: Low/Medium altitude Twin Otter flights of ATM (Code 7A)

Description: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/127
Estimated Aircraft Operations Costs ($k): 109
Integration Costs ($k): 0
Science Team Costs ($k): 186
Total Cost ($k): 422

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

Description: This option includes costs associated with building an operational capability. All regions can be covered.
Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

*Description:* SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/194
Estimated Aircraft Operations Costs ($k): 352
Integration Costs ($k): 0
Science Team Costs ($k): 81
Total Cost ($k): 627

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (4N)

*Description:* This mission would take advantage of payloads already integrated and flown over Greenland.

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/252
Estimated Aircraft Operations Costs ($k): 409
Integration Costs ($k): 0
Science Team Costs ($k): 81
Total Cost ($k): 743

### 3.5.8 Southeast Alaskan glaciers, Fall 2012

Option 1: Low altitude Twin Otter flights of ATM (7A)

*Description:* These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.
Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/127
Estimated Aircraft Operations Costs ($k): 109
Integration Costs ($k): 0
Science Team Costs ($k): 186
Total Cost ($k): 422

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (3K)

*Description:* This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/224
Estimated Aircraft Operations Costs ($k): 373
Integration Costs ($k): 0
Science Team Costs ($k): 109
Total Cost ($k): 706

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

*Description:* SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/194
Estimated Aircraft Operations Costs ($k): 352
Integration Costs ($k): 0
Science Team Costs ($k): 81
Total Cost ($k): 627

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (4N)

*Description:* This mission would take advantage of payloads already integrated and flown over Greenland.

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/252
Estimated Aircraft Operations Costs ($k): 409
Integration Costs ($k): 0
3.5.9 Southeast Alaskan glaciers, Spring 2013

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)

*Description*: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

- Base of Operations: TBD
- Estimated Flight Hours/Cost ($k): 120/131
- Estimated Aircraft Operations Costs ($k): 113
- Integration Costs ($k): 0
- Science Team Costs ($k): 191
- Total Cost ($k): 435

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

*Description*: This option includes costs associated with building an operational capability. All regions can be covered.

- Base of Operations: DFRC
- Estimated Flight Hours/Cost ($k): 82/204
- Estimated Aircraft Operations Costs ($k): 383
- Integration Costs ($k): 0
- Science Team Costs ($k): 112
- Total Cost ($k): 727

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

*Description*: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

- Base of Operations: Juneau
- Estimated Flight Hours/Cost ($k): 73/199
- Estimated Aircraft Operations Costs ($k): 362
- Integration Costs ($k): 0
Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (Code 3N)

**Description:** This mission would take advantage of payloads already integrated and flown over Greenland.

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/260
Estimated Aircraft Operations Costs ($k): 421
Integration Costs ($k): 0
Science Team Costs ($k): 83
Total Cost ($k): 765

### 3.5.10 Southeast Alaskan glaciers, Fall 2013

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)

**Description:** These areas were previously flown by ATM in 2005 and so cost estimates are very reliable and no additional new integration work is required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/131
Estimated Aircraft Operations Costs ($k): 113
Integration Costs ($k): 0
Science Team Costs ($k): 191
Total Cost ($k): 435

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

**Description:** This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/231
Estimated Aircraft Operations Costs ($k): 383
Integration Costs ($k): 0
Science Team Costs ($k): 112
Total Cost ($k): 727
Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

**Description**: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/199
Estimated Aircraft Operations Costs ($k): 362
Integration Costs ($k): 0
Science Team Costs ($k): 83
Total Cost ($k): 646

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (Code 4N)

**Description**: This mission would take advantage of payloads already integrated and flown over Greenland.

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/260
Estimated Aircraft Operations Costs ($k): 421
Integration Costs ($k): 0
Science Team Costs ($k): 83
Total Cost ($k): 765

3.5.11 Southeast Alaskan glaciers, Spring 2014

Option 1: Low altitude Twin Otter flights of ATM (7A)

**Description**: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.

Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/135
Estimated Aircraft Operations Costs ($k): 116
Integration Costs ($k): 0
Science Team Costs ($k): 197
Total Cost ($k): 448

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (3K)
Description: This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/238
Estimated Aircraft Operations Costs ($k): 395
Integration Costs ($k): 0
Science Team Costs ($k): 116
Total Cost ($k): 749

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

Description: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/205
Estimated Aircraft Operations Costs ($k): 374
Integration Costs ($k): 0
Science Team Costs ($k): 86
Total Cost ($k): 665

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (Code 4N)

Description: This mission would take advantage of payloads already integrated and flown over Greenland

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/268
Estimated Aircraft Operations Costs ($k): 434
Integration Costs ($k): 0
Science Team Costs ($k): 86
Total Cost ($k): 788

3.5.12 Southeast Alaskan glaciers, Fall 2014

Option 1: Low altitude Twin Otter flights of ATM (Code 7A)

Description: These areas were previously flown by ATM in 2005 and so cost estimates are reliable and no additional integrations are required. All regions can be covered.
Base of Operations: TBD
Estimated Flight Hours/Cost ($k): 120/135
Estimated Aircraft Operations Costs ($k): 116
Integration Costs ($k): 0
Science Team Costs ($k): 197
Total Cost ($k): 448

Option 2: Medium altitude G-III flights of Ka-Band UAVSAR (Code 3K)

*Description*: This option includes costs associated with building an operational capability. All regions can be covered.

Base of Operations: DFRC
Estimated Flight Hours/Cost ($k): 82/238
Estimated Aircraft Operations Costs ($k): 395
Integration Costs ($k): 0
Science Team Costs ($k): 116
Total Cost ($k): 749

Option 3: Low/Medium altitude Lear 25 flights of SIMPL, MFLL or other commercial (Code 10N)

*Description*: SIMPL has already been integrated, but other instruments would require a new integration and upgrades. All regions covered.

Base of Operations: Juneau
Estimated Flight Hours/Cost ($k): 73/205
Estimated Aircraft Operations Costs ($k): 374
Integration Costs ($k): 0
Science Team Costs ($k): 86
Total Cost ($k): 665

Option 4: Low/Medium altitude S-3B flights of SIMPL, MFLL or other commercial (Code 4N)

*Description*: This mission would take advantage of payloads already integrated and flown over Greenland.

Base of Operations: Anchorage
Estimated Flight Hours/Cost ($k): 70/268
Estimated Aircraft Operations Costs ($k): 434
Integration Costs ($k): 0
Science Team Costs ($k): 86
Total Cost ($k): 788
4.0 Summary

This report provides a set of airborne options for providing ICESat-like data from aircraft in order to provide ice altimetry data, through the launch of ICESat-2 in 2014, over priority regions of the Arctic and Antarctic. The ICESat science team has provided recommendations on areas that should be covered in order to preserve the integrity of the long term data record. Airborne missions could cover an estimated 90% of the total area required by Fall 2009 and 100% of the total areas by Fall 2010. The summary table below provides an example of a mission series that might be implemented from the options above. The yearly mission totals represent Spring and Fall missions in each year, and include 1) aircraft operations, 2) integration costs derived from instrument and platform teams, and 3) science team participation during the mission. Non-recurring engineering is described in Table 6 and these estimates are included in the mission totals.
### Flight Configurations

<table>
<thead>
<tr>
<th>Flight Configurations</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>Totals</th>
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<td>1L, 1M, 3H; 1L</td>
<td>1L; 1L</td>
<td>1L, 4N; 1L, 4N</td>
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<td>1L; 1L</td>
<td>1L; 1L</td>
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<td>1L; 1L</td>
<td>1L; 1L</td>
<td>1L; 1L</td>
<td>1L; 1L</td>
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<td>7A; 7A</td>
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### ROM Mission Costs

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<th>2010 ($k)</th>
<th>2011 ($k)</th>
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<th>2013 ($k)</th>
<th>2014 ($k)</th>
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<td>$3,259</td>
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### Additional Costs

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<td>Duplicate ATM &amp; LVIS</td>
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<td></td>
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<td>$1,961</td>
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<td><strong>Totals by year</strong></td>
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<td><strong>$26,486</strong></td>
<td><strong>$20,937</strong></td>
<td><strong>$14,633</strong></td>
<td><strong>$15,033</strong></td>
<td><strong>$15,394</strong></td>
<td><strong>$114,838</strong></td>
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### Notes:
1) *x* denotes option by season (Spring; Fall)
2) Ka-SAR/G-III flights in Greenland Spring 2009 are in-kind
3) Instrument/Aircraft downselect occurs in 2011
4) Coverage of arctic sea ice is a 1 month extension of yearly P-3 deployments to Greenland
5) The Antarctica estimate encompasses sea ice, coastal, and sub-glacial lakes
6) Assumes routine in-kind airlifts of opportunity from DoD (~$8-10M)

**Table 4**

*Flight configurations and budget details for one example of a reasonable program implementation.*
<table>
<thead>
<tr>
<th>Code</th>
<th>Instrument</th>
<th>Type</th>
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<tr>
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<td>Krabil</td>
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<tr>
<td>B</td>
<td>LVIS</td>
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<td>C</td>
<td>MFFL</td>
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<td>Dobbs/ITT</td>
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<td>D</td>
<td>Ice Roughness profilometer</td>
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<td>E</td>
<td>SIMPL</td>
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<td>F</td>
<td>PCL</td>
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<td>G</td>
<td>Mapping Laser Altimeter</td>
<td>Laser altimeter</td>
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<td>H</td>
<td>Ka-band UAVSAR</td>
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<td>Moller</td>
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<table>
<thead>
<tr>
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<td>Global Hawk</td>
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<td>HAIPER (NSF)</td>
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<td>B/200/Twin Otter</td>
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</table>

**Table 5**
Platform/payload configuration codes for Table 4 above.
<table>
<thead>
<tr>
<th>Instrument</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATM</td>
<td>510</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LVIS</td>
<td>740</td>
<td>325</td>
<td>2500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KuRadar Sounder</td>
<td>600</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PARIS</td>
<td>2600</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SIMPL</td>
<td>4450</td>
<td>325</td>
<td>2500</td>
<td></td>
<td></td>
<td></td>
<td>7275</td>
</tr>
</tbody>
</table>

Notes:
- ATM includes P-3 & DC-8
- LVIS includes DC-8, P-3 & Global Hawk
- SIMPL is a placeholder for GH integration and new instruments

Table 6
Estimated non-recurring engineering for platform/payload combinations described in Table 4 above.

It should be noted that in 2011 there is a significant investment in new integration work on the new Global Hawk and S-3 platforms in anticipation of the maturity of a number of new instruments including SIMPL (Harding), SMLA (Yu), PCL (Gogineni) and MFLL Mark II (Dobbs). This implementation assumes a fly-off in 2011 to determine the best platform payload combinations for any given region.

One of many caveats is that such an aggressive program will likely prevent other science disciplines from having access to these platforms. It is strongly recommended that an additional Global Hawk and P-3 be considered either through procurement or interagency agreements. Significant coordination will be required with the National Science Foundation (NSF) for Antarctic operations and use of the HAIPER for near term coverage of all Antarctic priority regions. A strong relationship with the Department of Defense will also be necessary to enable airlifts of opportunity.

Lastly, it should be noted that because this activity will likely benefit instrument selection and algorithm development for DESDyni, ICESat-2, and LIST, there could be certain portions of the instrument down-select, or entire missions that might be covered under one of these mission lines to offset these estimates. In addition this effort, if implemented would provide a great deal of opportunities for secondary payloads to enable maturation of new instruments and observation opportunities for mature airborne instruments.
Appendix:
A schedule of ICESat gap filler missions in addition to planned missions

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Jill Hat gapfiller</td>
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<tr>
<td>17</td>
<td>ABM (estimation)</td>
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<tr>
<td>20</td>
<td>UAVSAR/RInT (Ka- + L-Band)</td>
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<tr>
<td>21</td>
<td>UAV/IRV + ice roughness</td>
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</tr>
<tr>
<td>22</td>
<td>Jill Hat gapfiller</td>
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<td></td>
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</tr>
<tr>
<td>23</td>
<td>Jill Hat gapfiller</td>
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<tr>
<td>24</td>
<td>ABM - unassigned</td>
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</tr>
<tr>
<td>25</td>
<td>ICESat gapfiller</td>
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</tr>
</tbody>
</table>

Note: The table includes columns for years 2004 to 2015, with a total column at the bottom.