Arctic 2012 LVIS-LARC ICEBridge Land Ice Flight Lines

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The following document presents LVIS flight lines to be considered for the Spring 2012 Greenland OIB deployment. The constraints and guidelines used to develop the flight lines are outlined.

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Direct connection to OIB Baseline Science Requirements:
IS1: Measure surface elevation with a vertical accuracy of 0.5m or better.
IS2: Measure annual changes in ice sheet surface elevation sufficiently accurate to detect 0.15m changes in uncrevassed and 1.0m changes in crevassed regions along sampled profiles over distances of 500m. We are repeating existing altimetry lines flown by ATM and LVIS 2009-2011. Where the existing altimetry data were laid down by ATM, the sampled profiles will be at the width of the ATM swath (400m) and where the data were laid down by LVIS will be in excess of 1.2km.
IS7: Collect elevation data so that the combined ICESAT-1-OIB sampling provides an elevation measurement within 10km for 90% of the area within 100km of the edge of the GIS. Each area has a densification of flight lines within 100-km of the edge of the continuous GIS.
IS8: Approximate flow line mapping of selected glaciers is implemented.
IS6: Remeasure surface elevation along established airborne altimeter and ICESat lines that extend from near the glacier margin to near the ice divide. Several candidate ICESat-1 tracks selected based on their temporal and along-track sampling between the glacier margin and divide. In addition, the LVIS swath mapping provides an abundance of ICESat-1 and future mission (ICESat-2) underflight data that samples near the glacier margin to near the ice divide.
IS9: Measure once surface elevation across flow transects at 3km and 8km upstream of the terminus. Flight lines provide the opportunity to acquire the across flow transects.
IS11: Measure elevation over 10 Greenland glaciers that are rapidly changing. Each area has a densification of flight lines to provide the basis of 5-km grid sampling with better than 10-km sampling for the surrounding regions of glacier lower catchments.

The flight lines also provide excellent sampling of GRACE “global-ice” mascons (see Figure 11).

Information used when placing lines:
2. Icesat lines where good temporal and spatial coverage exists (in NW Greenland) or are shared with the P3 plan (in Jakobshavn area)
3. Icesat lines where poor temporal coverage exists (S Greenland)
4. Icesat lines where good spatial and temporal coverage exists and that cross the main mapping lines in NW and SE Greenland (for crossover analyses).
5. Glacier centerline targets (in SW Greenland) – see section below for supporting information
6. Lines extending from the ice sheet terminus to the divide – several ICESat lines (with good temporal and spatial coverage) identified in NW Greenland (to be used for transits or as crossing lines where it makes sense). Line 0166 in S Greenland also a good candidate (overlap with #3 above).
7. Flow lines up to and over divide in S Greenland (to be used for transits where it makes sense). Flow line map provided by Bea Csatho, based on Thomas et al., Science (2000).
8. Actual ICESat footprint data (not reference tracks) used to specify ICESat line locations.
9. Opportunity to overlap P3 2012 lines (engineering data for continued ATM/LVIS intercomparisons) (e.g., Icesat track 0300)

There are 100 science flight hours approved with ~15 possible flight days possible. At the time this was written, the Falcon Jet duration and speed parameters are not finalized, thus making it premature to develop specific flight plans. However, we expect a clearer picture of plane readiness in the next couple of weeks. Flight plans will be developed each to gather scientific data that meet the Level 1 requirements and guided by the priorities defined by the Science Team.

**Line Priorities to be used when planning flights, in order:**
(refer to figures 1-5 for color coding)

1. SW glacier lines (from Kanger base) (green lines, red boxes)
2. Icesat lines in NW, Jakobshavn (P3 lines), and S Greenland (purple)
3. 2010 Repeat Altimetry Lines in the NW (dark brown and red). Start with 10km spacing, densify to 5km with subsequent flights.*
4. New 2012 lines in W and NW (light blue).*
5. 2011 Repeat Altimetry lines in the NW and W (light brown)*
   *Icesat tracks from terminus to divide (black dashed) or other Icesat tracks (purple or dashed purple) used as crossing lines
6. 2010 Repeat Altimetry lines in SE (dark brown and red)**
7. New 2012 lines south of ~62S (blue)**
8. 2011 Repeat Altimetry lines and new 2012 lines in SE (light brown and blue)**
   **Icesat tracks (purple) or flow lines (orange) to be used as crossing lines
9. Canadian icecap lines (Figure 10)

**Information still needed:**
1. Sea ice flight lines (3 primary, 2-3 in reserve)
2. OK to priorities
3. SW Glacier lines: prioritize glaciers for complete vs centerline mapping. Lines still need adjusting once plane capabilities established.
Figure 1: Greenland 2012 LVIS-LARC OIB lines colored by type.
Figure 2: Close up of Greenland 2012 LVIS/OIB lines in vicinity of Thule.
Figure 3: Close up of Greenland 2012 LVIS/OIB lines in vicinity of Kangerlussuaq.
Figure 4: Close up of Greenland 2012 LVIS/OIB lines south of Kangerlussuaq.
Figure 5 Close up of Greenland 2012 LVIS/OIB lines east of Kangerlussuaq.
SW Glacier lines:

<table>
<thead>
<tr>
<th>ID</th>
<th>Glacier name</th>
<th>Long</th>
<th>Lat</th>
<th>RP</th>
<th>FP</th>
<th>50s</th>
<th>80s</th>
<th>2000s</th>
<th>Behavior</th>
<th>Note</th>
<th>Box flight</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nordenskjold</td>
<td>-50.62</td>
<td>68.39</td>
<td>M</td>
<td>H</td>
<td>R</td>
<td>A</td>
<td>Fast and slow thinning alternating</td>
<td>Xover 5011037; complex spatial and temporal behavior</td>
<td>B5F6</td>
<td>Weidick 1991</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Unnamed</td>
<td>-48.86</td>
<td>62.24</td>
<td>M</td>
<td>L</td>
<td>R</td>
<td>R</td>
<td>recent strong thinning</td>
<td>B5F6, Weidick 1991</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Isunnguate Sermia</td>
<td>-50.1</td>
<td>67.2</td>
<td>L</td>
<td>L</td>
<td>R</td>
<td>A</td>
<td>recent strong thinning</td>
<td>B5F6, Weidick 1991</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ice sheet near Sukkertoppen</td>
<td>-49.93</td>
<td>65.73</td>
<td>L</td>
<td>L</td>
<td>A</td>
<td>A</td>
<td>complex behavior</td>
<td>B34F6, Weidick 1991</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Saaqap Sermia</td>
<td>-50.38</td>
<td>65.3</td>
<td>H</td>
<td>A</td>
<td>A</td>
<td></td>
<td>stable first, followed by thinning, 2001034</td>
<td>B34F6, Weidick 1991</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Narsoq Sermia</td>
<td>-49.58</td>
<td>64.7</td>
<td>H</td>
<td>H</td>
<td>R</td>
<td>A</td>
<td>increasing thinning, especially since '08;</td>
<td>The only region always thinning and retreating since 1950s - velocity increased in the 2000s</td>
<td>B34F6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Kangia Nunata Sermia, N</td>
<td>-49.5</td>
<td>64.2</td>
<td>H</td>
<td>L</td>
<td>R</td>
<td>R</td>
<td>thinning, -2 m/yr at 1000 m</td>
<td>The only region always thinning and retreating since 1950s - velocity increased in the 2000s</td>
<td>B34F6 also B2F4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Kangia Nunata Sermia, S</td>
<td>-49.5</td>
<td>64.2</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>R</td>
<td>thinning, -2 m/yr at 1000 m, dynamic thinning from ATM</td>
<td>The only region always thinning and retreating since 1950s - velocity increased in the 2000s</td>
<td>B34F6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Isortuarsuup Tasia</td>
<td>-49.8</td>
<td>63.82</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>A</td>
<td></td>
<td>B34F6, Weidick 1991</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Frederikshab Isblink</td>
<td>-49.8</td>
<td>62.6</td>
<td>H</td>
<td>H</td>
<td>R</td>
<td>R</td>
<td>1.7 m thickening (P)</td>
<td>Landterminating, controversial behavior</td>
<td>B34F6</td>
<td>Weidick 1991</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Qajuuttap Sermia</td>
<td>-45.44</td>
<td>61.5</td>
<td>H</td>
<td>A</td>
<td>A</td>
<td></td>
<td>Thinning followed by recent thinning,</td>
<td>very well documented, best in Greenland</td>
<td>??</td>
<td>Weidick 2009</td>
<td></td>
</tr>
</tbody>
</table>

RP: Region priority, FP: flight priority, H: High, M: Medium, L: Low, R: retreat, A: advance, N: not known

Table 1: 14 priority glaciers for mapping in the SW, provided by Bea Csatho.

We have included the mapping of several high priority glaciers into the high altitude plans for 2012. After several discussions on how best to map glacier center/flow lines from high altitude, we have worked up two approaches for further discussion by the Science Team:

1. **Centerline** mapping: provides a baseline for a number of different glaciers. It works well for glaciers that are predominantly linear in shape, but requires segmented lines and maybe some misplaced data during the turns if not.

2. **Coverage** mapping: provides a spatially complete baseline map and with LVIS’s ~2 km wide swath a 15km by 100km area can be mapped in a single flight (e.g. Kangiata Nunatak Sermia, Figure 7). With repeat mapping it allows analysis of the effect of different sampling (cf Larsen and Arendt papers from Alaska).

Figures 6 to 8 show Bea’s top choices for both approaches. They’re presented for further discussion by the team as to which approach is the most appropriate for each glacier.
Candidate glaciers for option 1: Centerline mapping

(based on ATM coverage, thinning history, etc.):
1. Nordenskjold, curved glacier, ~6 km wide
5. Saqqap sermia, straight glacier, ~5 km wide
6. Narsap sermia, straight glaciers, ~4.5 km wide
10. Frederickshab Isbrae, curved glacier, ~7 km wide
12. Unnamed glacier near Nunatarsuaq, straight glacier, ~4 km wide
14. Qajuuttap Sermia, this is actually three glaciers + a rapidly thinning ice sheet margin, the glaciers are 2-4 km wide

* Probably sufficient to have one flight along the straight glaciers, depending how well you can aim at the centerline. Ideally the wider and curved glaciers should be covered by parallel lines.
* Consider the curves of the flowline and the straightline fit as end members. The important area is the fast flowing part of the glacier.

Candidate glaciers for option 2: Coverage mapping

8. Kangiata Nunatak Sermia, southern branch, this glacier is the most dynamic in SW Greenland and thinning rapidly. I believe that it has been surveyed by ATM repeatedly, but a complete coverage would be great
5. and 6. Narsap and Saqqap, this is an exciting pair of glaciers, one is land terminating and the other is marine glacier and they must have similar climate forcing.
14. Qajuutap sermia; we don't know much about elevation/thickness changes, but this glacier has the most well documented retreat history.
Figure 6. Nordenskjold Glacier lines, oriented to match the centerline and maximum flow line. Coverage at the join may get misplaced.
Figure 7. Black lines: Centerline approaches for Saqqap and Narsap Sermias, Frederickshab Isbrae and an Unnamed glacier. Red boxes: Complete mapping approach for Saqqap, Narsap and Kangiata Nunatak Sermias. Saqqap and Narsap Sermias can be mapped in a racetrack approach (each box is 9km by 100km). Kangiata Nunatak Sermia and Frederickshab Isbrae show the 100km by 17km boxes each possible in a single flight.
Figure 8. Centerline (black line) and complete mapping approaches (within red box 10x100km) for Qajuutap Sermia.
Figure 9: Backup flight locations: Penny and Barnes icecaps, Baffin Island.
Figure 10. Example flight plan, repeat 2010 ATM lines (10km spacing). Thule base, 5hr duration.
Figure 11. LVIS 2012 OIB Lines on GRACE observed acceleration (provided by Scott Luthcke).