Arctic 2011 ICEBridge Flight Plans
1 April 2011 Draft

The following document presents LVIS flights to be considered for the spring 2011 Greenland OIB deployment.The following constraints and guidelines were used to develop these flight plans.

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Connection to data acquisition strategy and science requirements:

- Following the data acquisition strategy, *"Towards a Long Term OIB Flight Planning Strategy," Draft Feb. 2, 2011,* we have designed the proposed flights such that they: (1) provide the "LVIS epoch" for the base set of mapping to be later sampled by the low elevation instruments (radar and ATM) at a different epoch and LVIS again at multiple epochs to observe surface elevation change, (2) can be connected to the science requirements, and (3) optimize resources.
- The fundamental structures of the flight plans are contour grids within regions that facilitate the efficient allocation of resources while directly addressing numerous science requirements.

Direct connection to OIB Baseline Science Requirements:

- IS1: Measure surface elevation with a vertical accuracy of 0.5m or better.
- IS2: As noted above, the proposed flight plans provide the "LVIS epoch" for the base setof mapping to be later sampled by the low elevation instruments (radar and ATM) at a different epoch, and to be again sampled by LVIS at multiple epochs. This will facilitate detection of 0.15 m changes in uncrevassed and 1.0 m changes in crevassed regions along sampled profiles over distances much greater than 500m.
- IS10: Each flight plan contour grid provides flight lines that approximately map the 1000, 2000 and 2500 m ice sheet elevation contours.
- IS7: Each flight plan contour grid has a densification of flight lines within 100-km of the edge of the continuous GIS. This data acquisition then forms the baseline sampling to provide elevation measurements within 10-km for 90% of the area.
- IS11: Each flight plan contour grid 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.
- IS8: Approximate flow line mapping of selected glaciers can be implemented for selected glaciers. Some examples have already been included.
- IS9: Each flight plan contour grid provides the opportunity to acquire the across flow transects.
- IS6: As noted in the flight plan details described below, we are flying several ICESat-1 tracks based on their temporal and along-track sampling and their opportunity to be combined with existing contour grid lines and lines that provide a good number of LVIS-LVIS xovers and also sample ICESat-1 crossovers for cal/val. In addition, the LVIS swath mapping provides an abundance of ICESat-1 and future mission (ICESat-2 and DESDynI) underflight data that samples near the glacier margin to near the ice divide (see Figure 3).
- The proposed flight lines provide excellent sampling of GRACE "global-ice" mascons (see Figure 2 in appendix).

Please note, that these flight lines follow a gridded approach based on GRACE mascons and level 1 science requirement spacing. In some cases grid lines end or do not follow the ice edge enough to monitor outlet glacier trunks. We ask the science team to please review the flight lines carefully to make sure we are not missing any import areas for ice dynamics.

The table below gives the estimated flight time to complete the boxes including transit, ascending and descending and turn time. This does not take into account the glacier flights at the end of the document.

Box Number	Estimate Flight Time	Priority
Box 2	25 hours/ 3 days	High
Box 5+glaciers	35 hours/ 7 days	High
Box 3	25 hours/ 5 days	Medium
Box 1+glaciers	8 hours/ 1 days	Medium
Box 4+glaciers	25 hours/ 5 days	Medium
Interiors of Box6 and Summit/EGIG	10 hours/ 2 days	Low

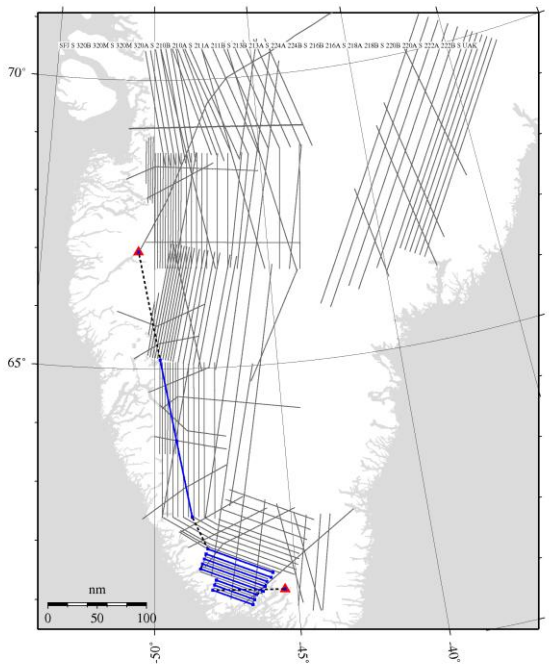
There are ~130 hours of flight plans which is 50% more than the 80hours and 16 possible flight days scheduled. The plans provide geographic distribution so hopefully it is always possible to find one area that is clear. The flight plans should stand alone as a flight that will gather scientific data to meet the Level 1 requirements. Additionally as multiple flight plans within a box are flown they will complete a better sampling of the box for the gridded sampling approach.

Box 2 Flight 1 (1 pilot option)

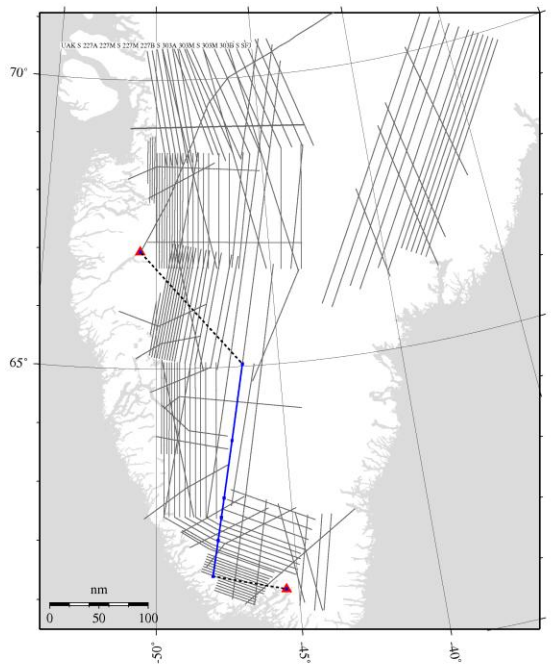
This mission is the first flight to be flown in Box 2 assuming the box is clear. It assumes one pilot, an 8 hour flight day and a refuel in Narsarsuaq. This flight samples every 10 km on the southern end of the box and hits 2 ICESat tracks and the 1500 and 2000 m contours. Track 1297 is near the 1500 m contour in Box 3.

Box Priority: High (P1) **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track: 1297,1290 **Flight Time:** 5 hours, 2.5 hours

box2_5 option



box2_52 option

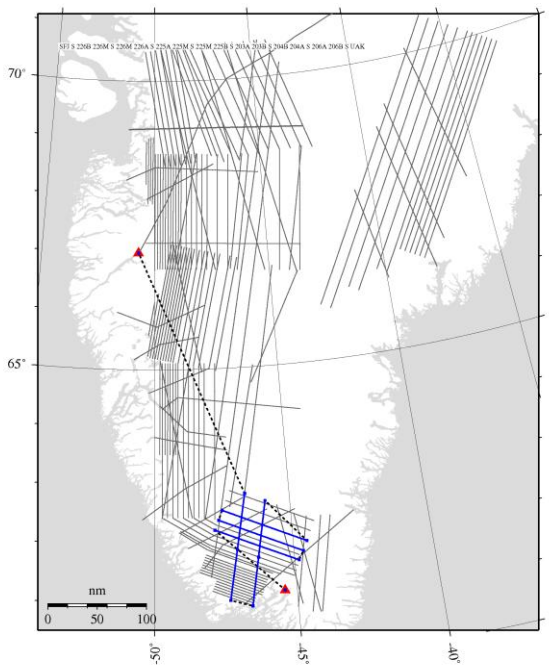


Box 2 Flight 2 (1 pilot option)

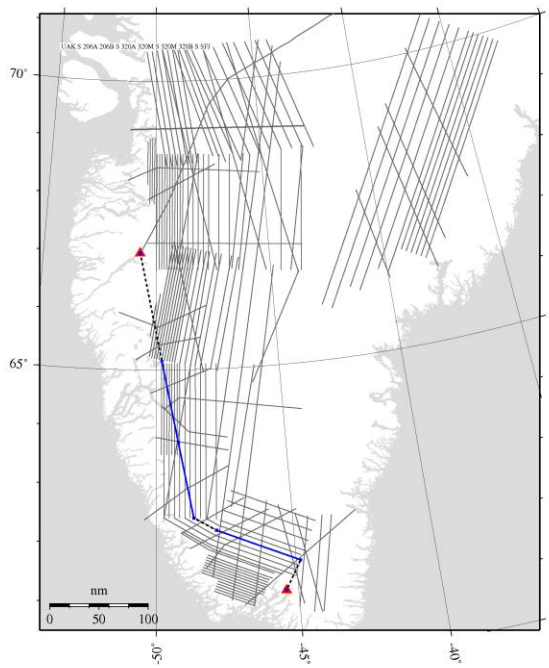
This mission is the second flight to be flown in Box 2 assuming the box is clear. It assumes one pilot, an 8 hour flight day and a refuel in Narsarsuaq. This flight hits the remaining ICESat tracks in Box 2, continues the grid farther inland hitting part of the 2500 m contour and picks up a costal line in Box 4 on the return. Line spacing is 10 and 20 km.

Box Priority: High **Flight Priority:** Medium **Instrument Priority:** LVIS
ICESat Track: 55, 174 **Flight Time:** 4.8 hours, ~2.4 hours

box2_52525 option



box2_5252 option

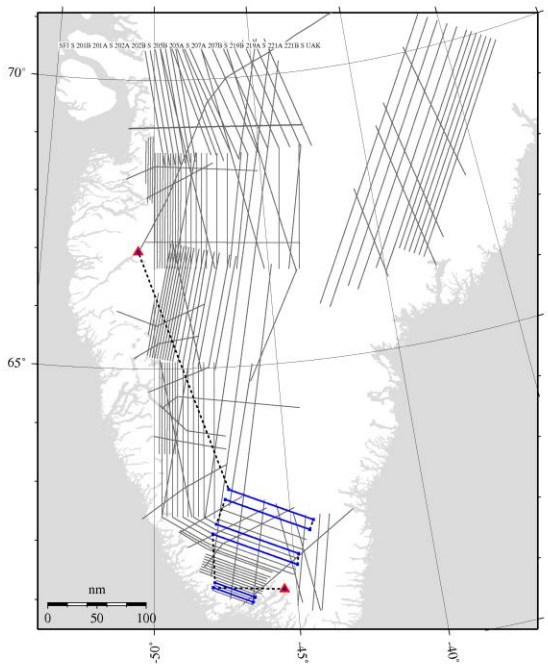


Box 2 Flight 3 (1 pilot option)

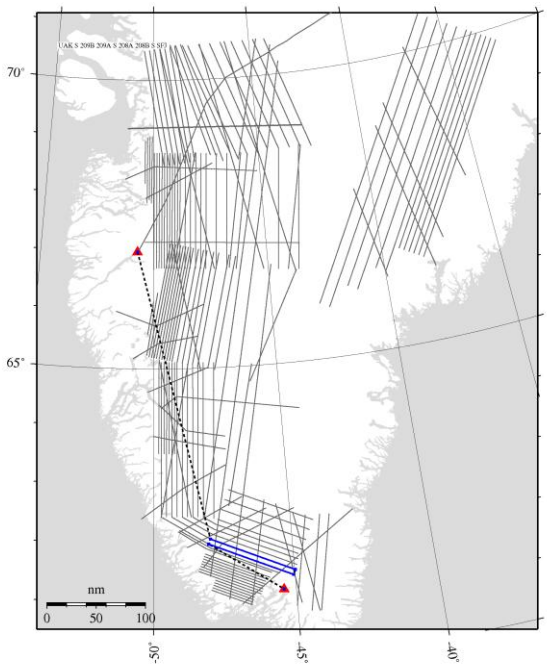
This mission is the third flight to be flown in Box 2 assuming the box is clear. It assumes one pilot, an 8 hour flight day and a refuel in Narsarsuaq. This flight samples many of the remaining lines in Box 2 to complete the coverage of the box with the first 2 flights. It also completes the 2500 m contour. Line spacing is every 10 to 20 km and fills in to 5 km near the coast.

Box Priority: High **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time:** 5 hours, 2.85 hours

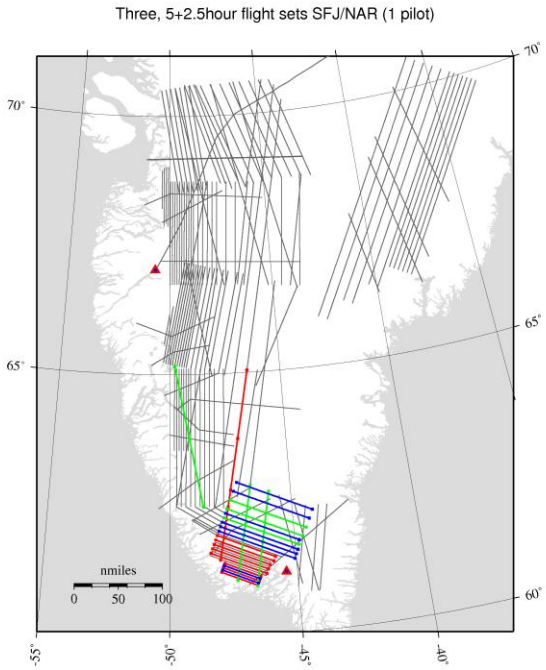
box2_525255 option



box2_525252 option



Coverage if all 3 days of flying are completed for Box 2 assuming a single pilot and an 8 hour day.

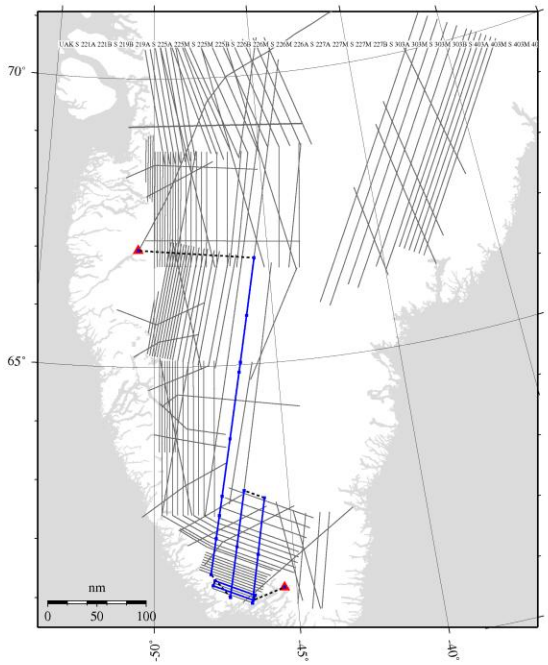


Box 2 Flight 1 (2 pilot option)

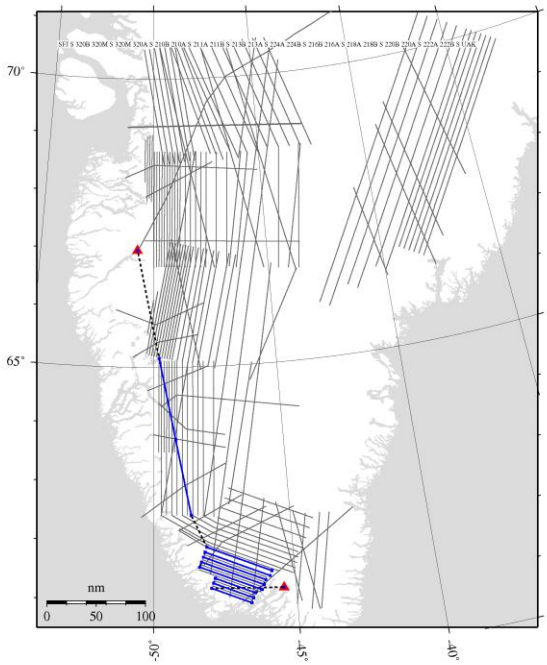
This mission is the first flight to be flown in Box 2 assuming the box is clear. It assumes two pilots, a 10 hour flight day and a refuel in Narsarsuaq. This flight samples every 10 km on the southern end of the box and hits all ICESat tracks in box 2. This mission will sample the 1500 and 2000 m contours in Box 2. Track 1297 is near the 1500 m contour in Box 3. Line spacing is every 10 km and fills in to 5 km near the coast. The ICESat track will be flown first.

Box Priority: High **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track: 1297,1290, 55, 174 **Flight Time:** ~5 hours 5 hours

box2_55 option



box2_5 option

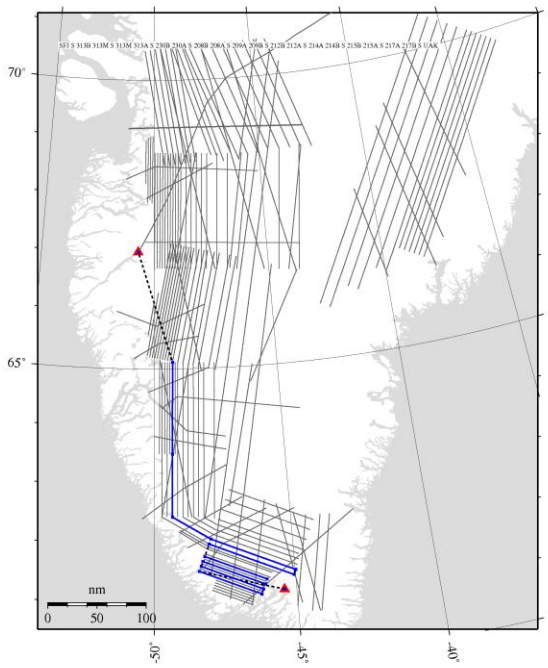


Box 2 Flight 2 (2 pilot option)

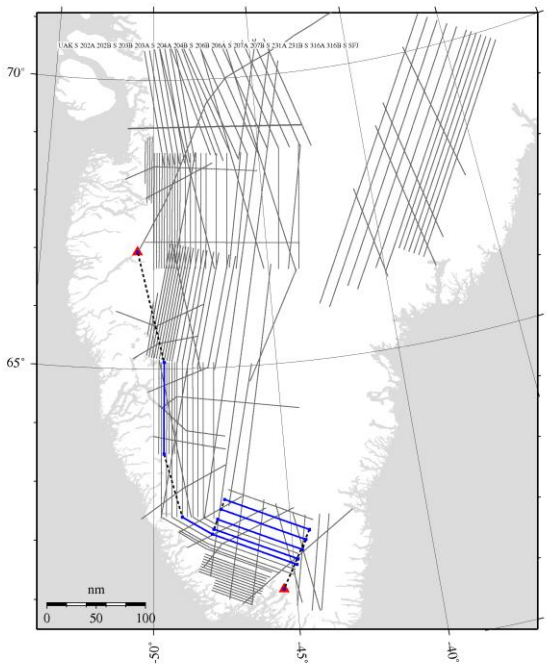
This mission is the second flight to be flown in Box 2 assuming the box is clear. It assumes two pilots, a 10 hour flight day and a refuel in Narsarsuaq. This flight fills in the Box 2 grid near the 1500 and 2000 m contour and hits part of the 2500 m contour. Line spacing is every 10 to 20 km and fills in to 5 km near the coast.

Box Priority: High **Flight Priority:** Medium **Instrument Priority:** LVIS
ICESat Track: None **Flight Time:** ~5 hours, ~5 hours

box2_555 option



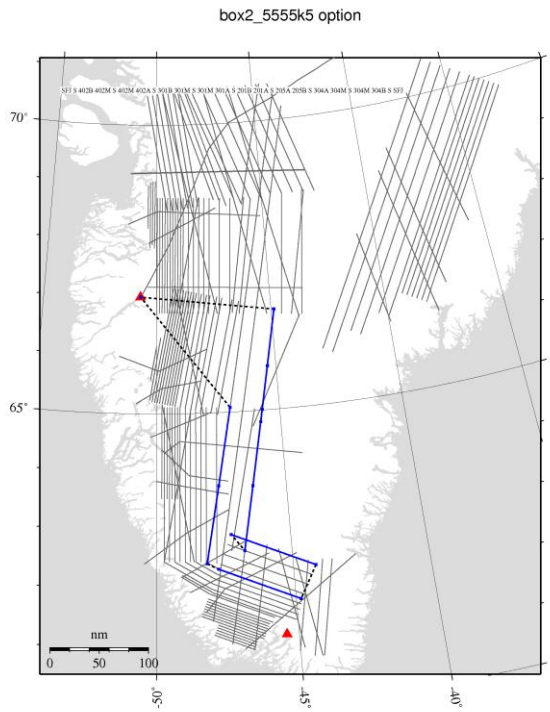
box2_5555 option



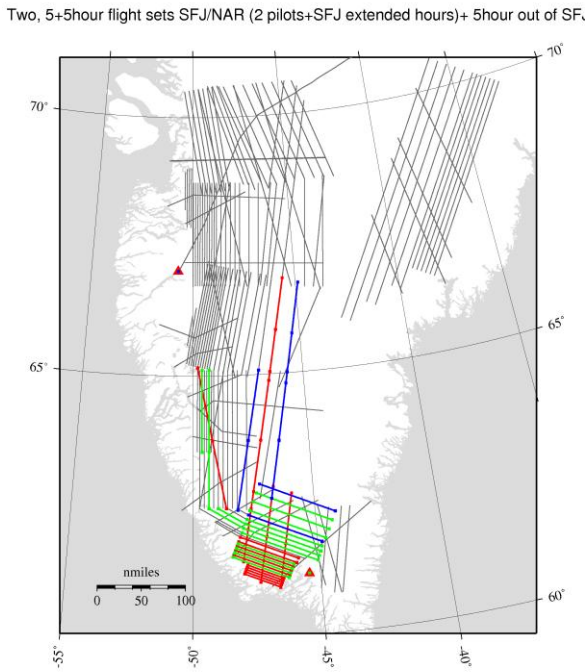
Box 2 Flight 3 (2 pilot option)

This mission is the third flight to be flown in Box 2 assuming the box is clear. It assumes one pilot, a 5 hour flight day from Kangerlussuaq. This flight fills in the northern part of Box 2 and the 2500 m contour. It also traverses on ICESat tracks in Box 3.

Box Priority: High **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: Track 55, 308 **Flight Time:** ~5 hours



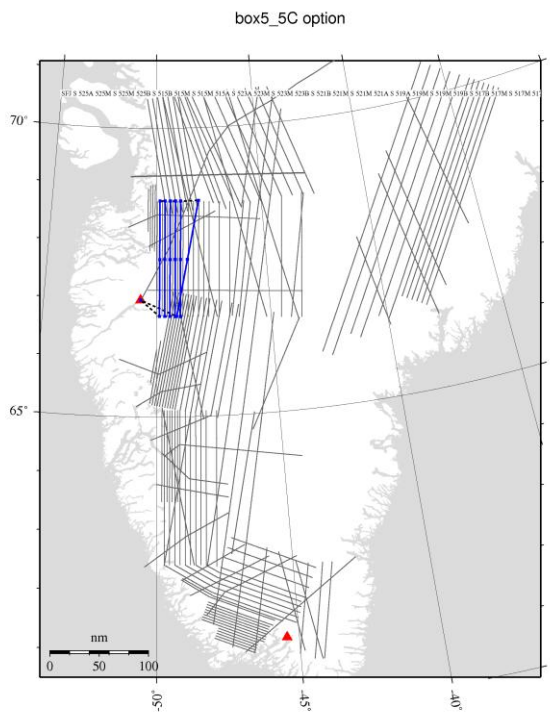
Coverage if all 3 days of flying are completed for Box 2 assuming two pilots and a 10 hour day.



Box 5 Flight 1

This mission is the first flight to be flown in Box 5 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the coastal box at 5 km, an ICESat track and lines near the 1500 m contour. Line spacing is 10 km.

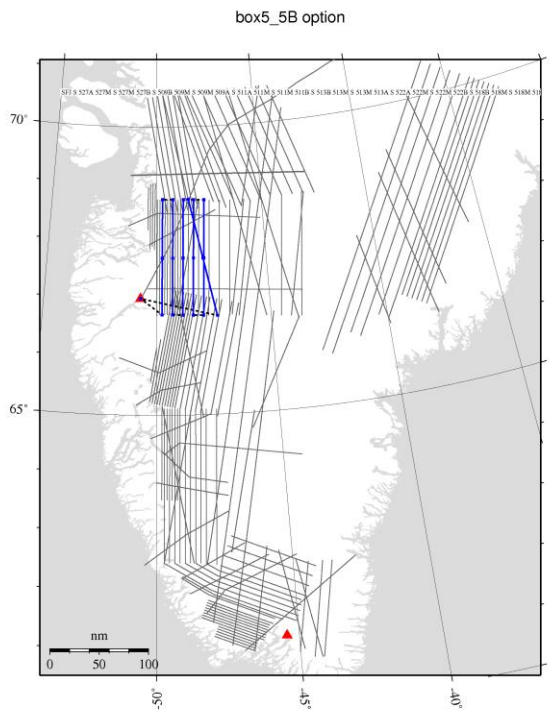
Box Priority: High(P2) **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track: 323 **Flight Time:** ~5 hours



Box 5 Flight 2

This mission is the second flight to be flown in Box 5 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the coastal box at 5 km, an ICESat track and lines near the 1500 m contour. Line spacing is 15 km.

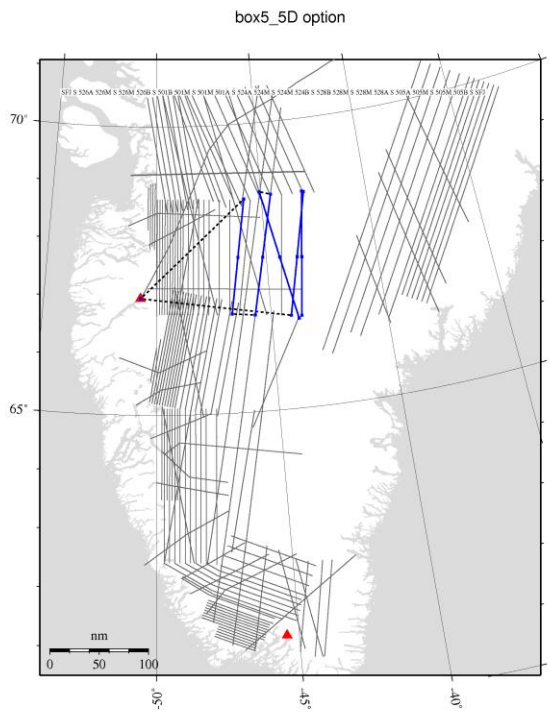
Box Priority: High(P2) **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track: 419 **Flight Time:** ~5 hours



Box 5 Flight 3

This mission is the third flight to be flown in Box 5 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the interior of box 5, 2 ICESat tracks and the 2000 and 2500 m contours

Box Priority: High(P2) **Flight Priority:** Medium **Instrument Priority:** LVIS
ICESat Track: 32, 174, 1290 **Flight Time:** ~5 hours

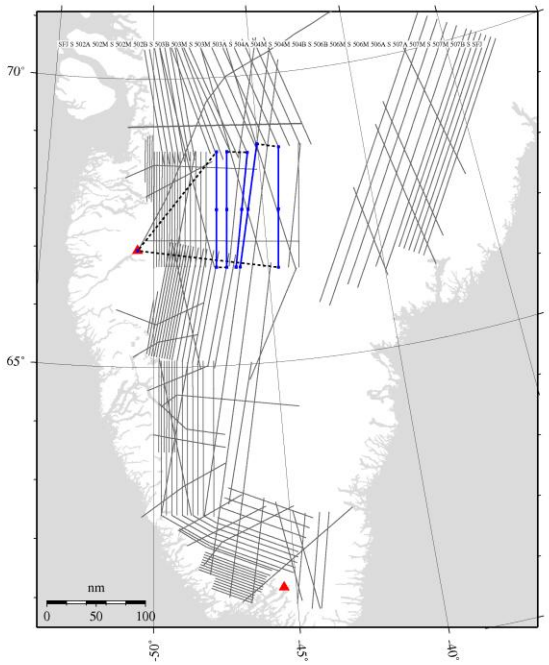


Box 5 Flight 4

This mission is the fourth flight to be flown in Box 5 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the middle of box 5 and 2 ICESat tracks. Line spacing is ~10 km.

Box Priority: High(P2) **Flight Priority:** Medium **Instrument Priority:** LVIS
ICESat Track: 308, 1290 **Flight Time:** ~4.8 hours

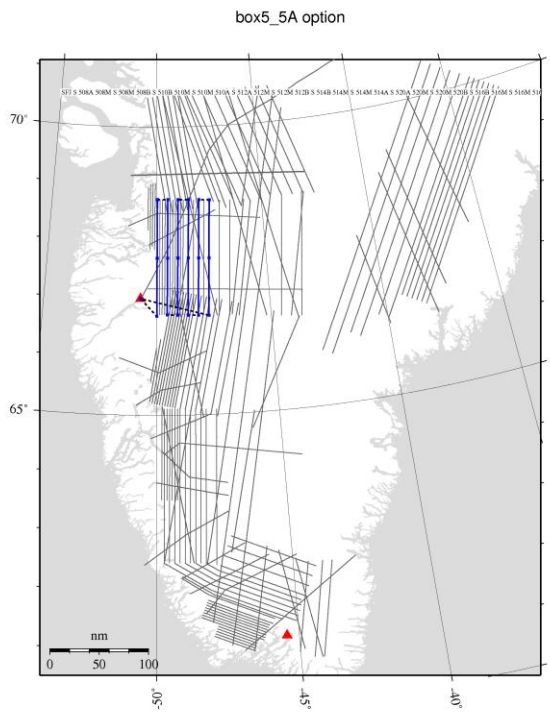
box5_5E option



Box 5 Flight 5

This mission is the fifth flight to be flown in Box 5 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight complete box 5 by sampling the last 6 km spaced lines in the coastal portion of box 5. Line spacing is 15 km but fills in for 5 km spacing near the coast.

Box Priority: High(P2) **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time:** ~5 hours

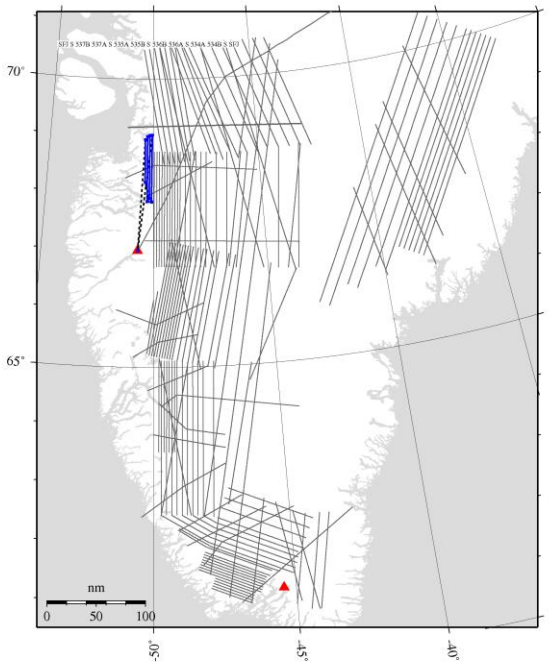


Box 5 Flight 6

This mission is the sixth flight to be flown in Box 5 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight adds grid lines towards the coast that are added to sample glaciers.

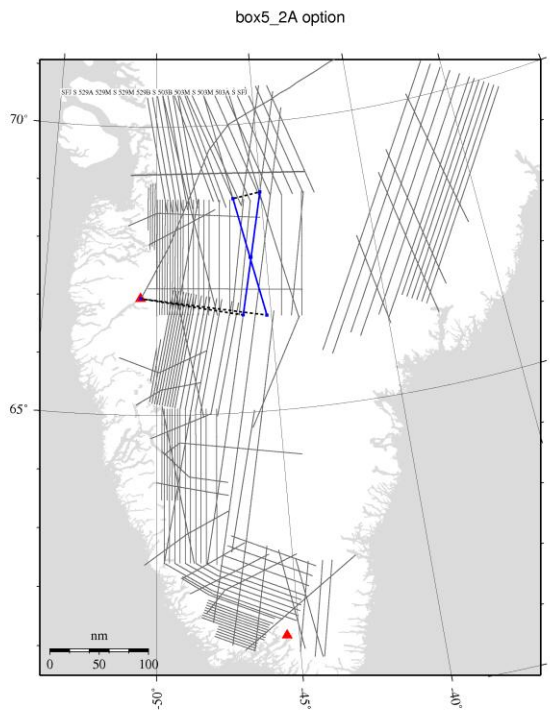
Box Priority: High(P2) **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time:** 3 hours

box5_BeaNew option



Box 5 Flight 1.5

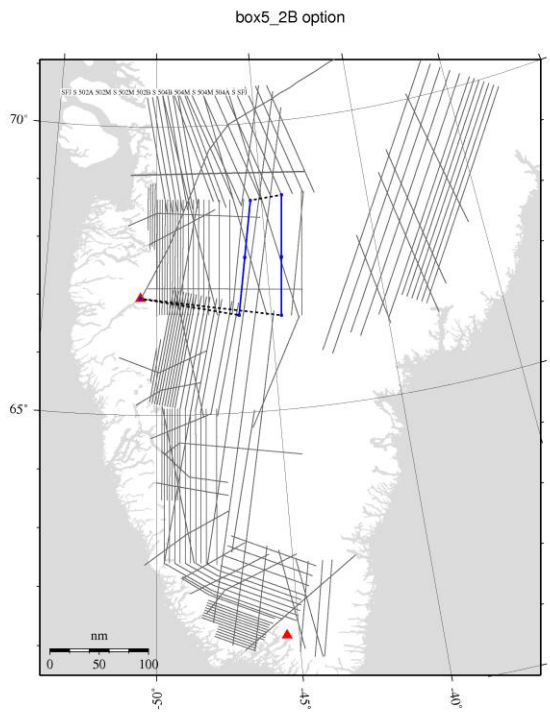
This mission is the first flight to be flown in Box 5 assuming the box is clear and we can get **two** flights in during day. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples 2 ICESat tracks. Flight Box 5 Flight 4 will be adjusted if this flight is flown before it by one line.
Box Priority: High(P2) **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track: 308, 285 **Flight Time**: ~2.6 hours



Box 5 Flight 2.5

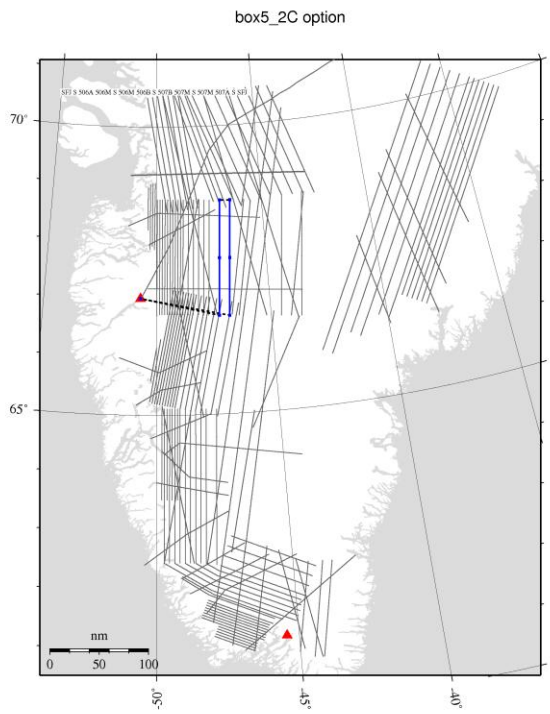
This mission is the second flight to be flown in Box 5 assuming the box is clear and we can get **two** flights in during a day. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples 2 ICESat tracks. Flight Box 5 Flight 4 will be adjusted or eliminated if this flight is flown.

Box Priority: High(P2) **Flight Priority:** Medium **Instrument Priority:** LVIS
ICESat Track: none **Flight Time**: ~2.6 hours

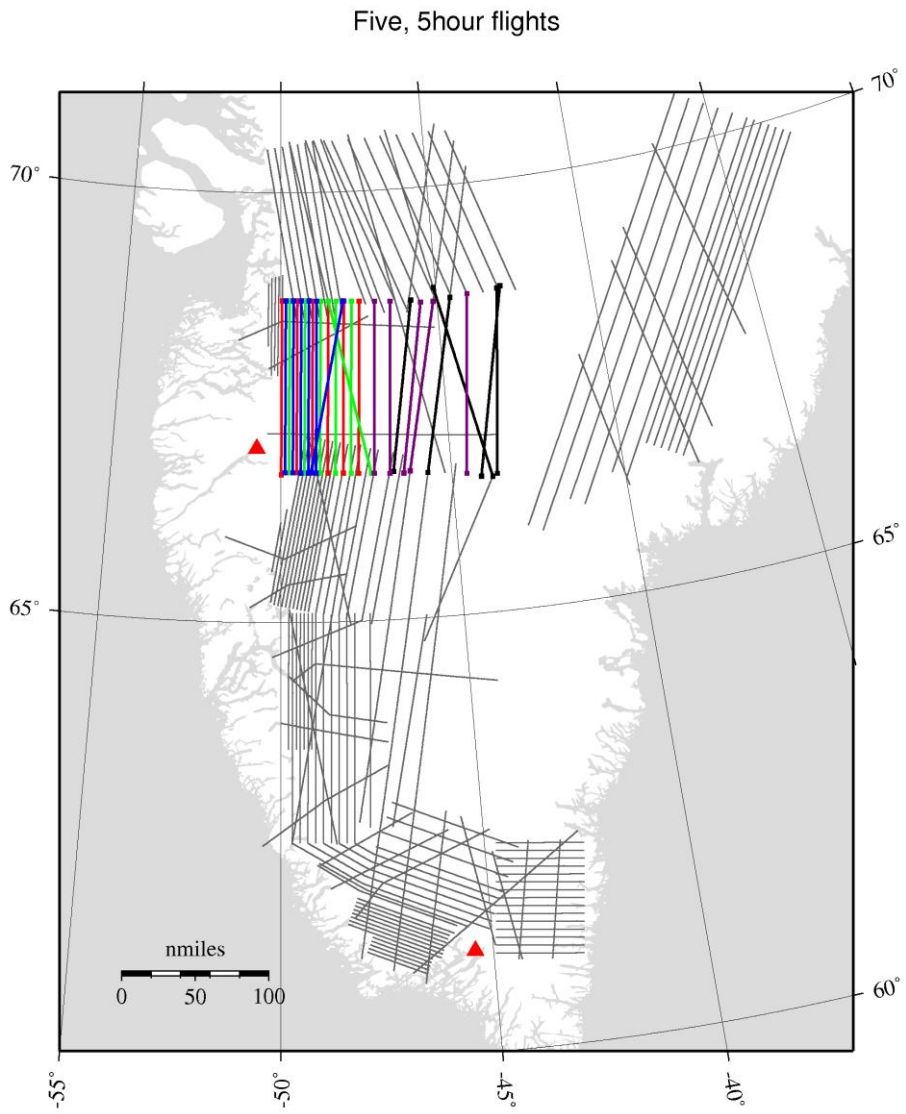


Box 5 Flight 3.5

This mission is the third flight to be flown in Box 5 assuming the box is clear and we can get **two** flights in during a day. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples 2 ICESat tracks. Flight Box 5 Flight 4 will eliminate if this flight is flown.
Box Priority: High(P2) **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time**: ~2.6 hours



Coverage if all 5 or 6 days of flying are completed for Box 5.

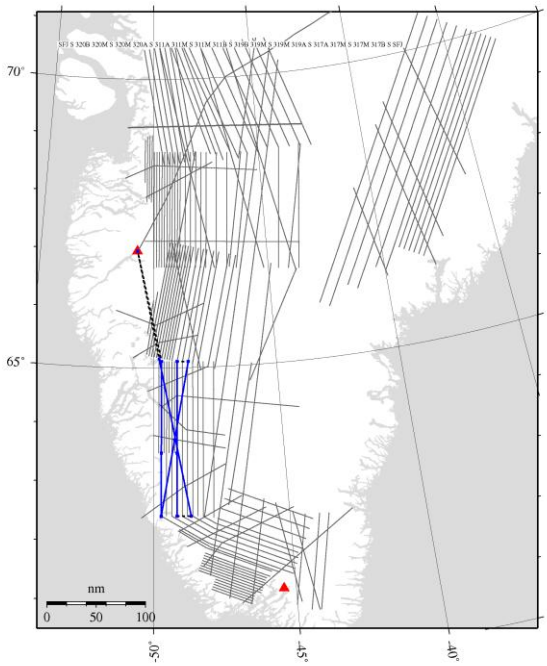


Box 3 Flight 1

This mission is the first flight to be flown in Box 3 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples 2 ICESat tracks and coastal lines. This plan will be modified if Box 2 flight 1 has already been flown. If this is the case, ICESat 1297 will removed and a line from Box 3 Flight 5 will be flown.

Box Priority: Medium(P3) **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track:1297,70 **Flight Time**: ~4.5 hours

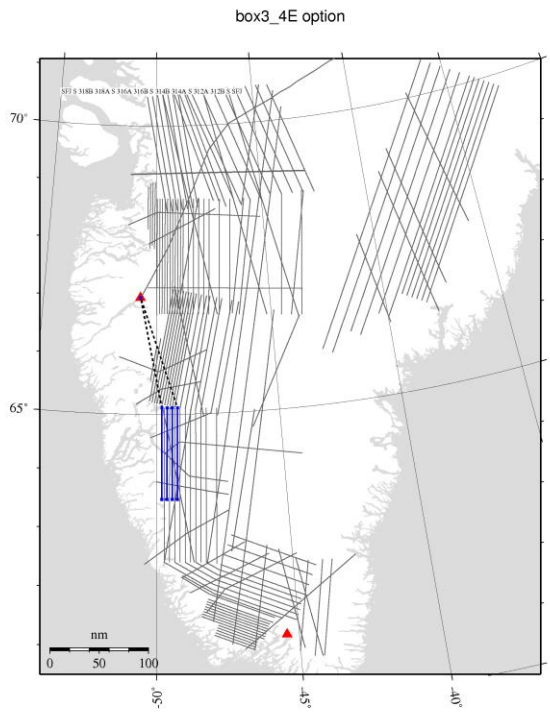
box3_5C option



Box 3 Flight 2

This mission is the second flight to be flown in Box 3 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 10 km grid lines near the 1500 m contour and the coastal region of the box.

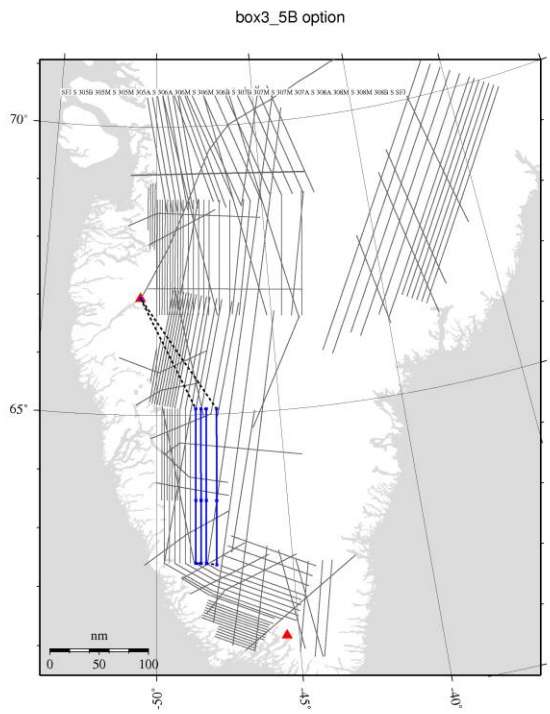
Box Priority: Medium(P3) **Flight Priority:** High **Instrument Priority:** LVIS
ICESat Track: none **Flight Time**: 3.5 hours



Box 3 Flight 3

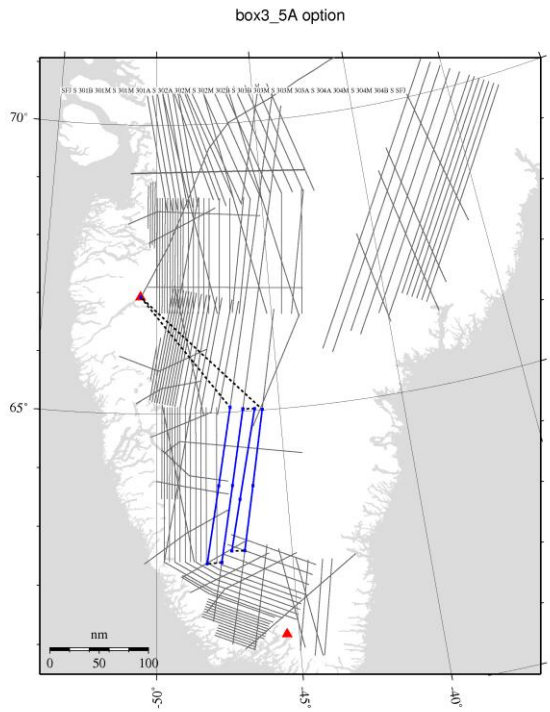
This mission is the third flight to be flown in Box 3 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 10 km grid lines near the 2000 m contour.

Box Priority: Medium(P3) **Flight Priority:** medium **Instrument Priority:** LVIS
ICESat Track:none **Flight Time**: ~4.5 hours



Box 3 Flight 4

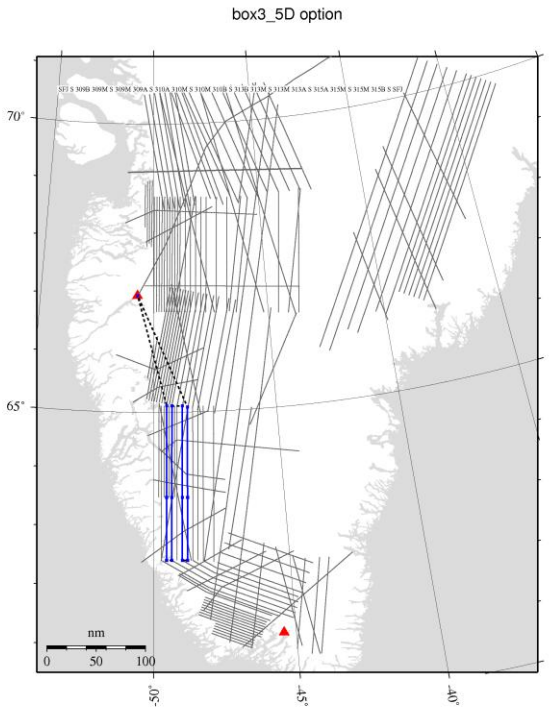
This mission is the forth flight to be flown in Box 3 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the ~20 km grid lines near the 2500 m contour and 2 ICESat tracks. This line will be adjusted Box 2 flight one was previously flown. The ICESat tracks will be replaced with grid lines from Box3 Flight 5.
Box Priority: Medium(P3) **Flight Priority:** Meduim **Instrument Priority:** LVIS
ICESat Track:1290, 308 **Flight Time**: ~4.5 hours



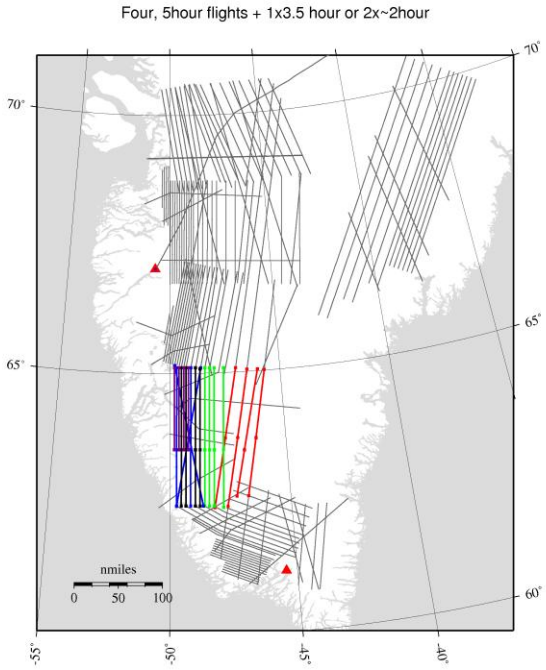
Box 3 Flight 5

This mission is the fifth flight to be flown in Box 3 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 10 km grid lines and completes Box 3.

Box Priority: Medium(P3) **Flight Priority:** low **Instrument Priority:** LVIS
ICESat Track:none **Flight Time**: ~4.5 hours



Coverage if all 4 days of flying are completed for Box 3 assuming a single pilot and an 8 hour day.

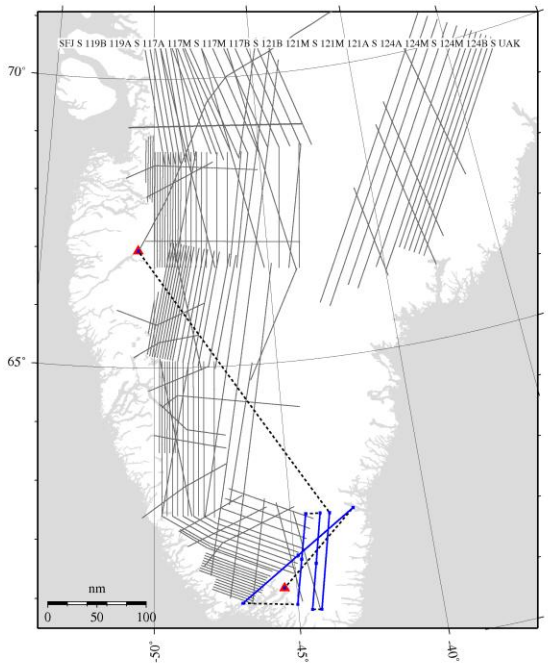


Box 1 Flight 1

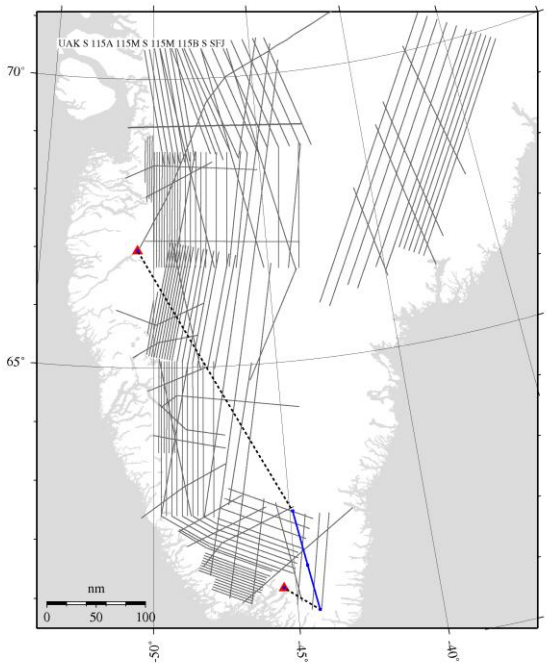
This mission is the first flight to be flown in Box 1 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq with a refuel in Narsarsuaq. This flight samples the grid lines parallel to those flow by the P-3 in the Southeast Fjords 01 flight along ICESat tracks. It also samples a glacier line on Qajuuttap Sermia.

Box Priority: Medium(P4) **Flight Priority:** high **Instrument Priority:** LVIS
ICESat Track: 159 **Flight Time**: 5 hours +2.5 hours

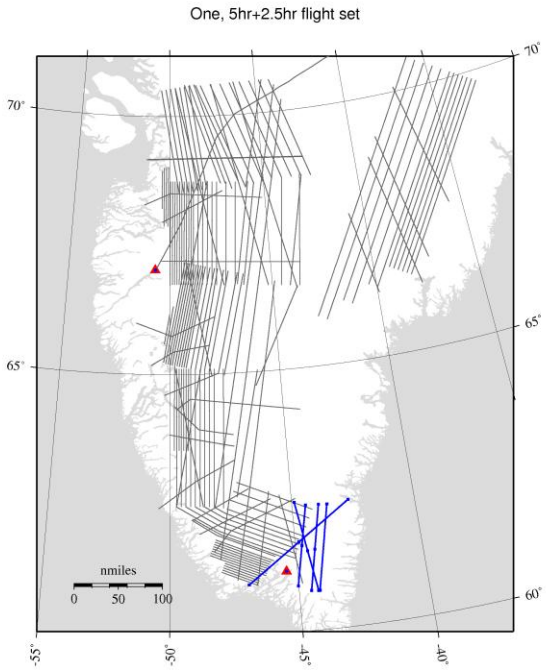
box1_5D option



box1_52D option



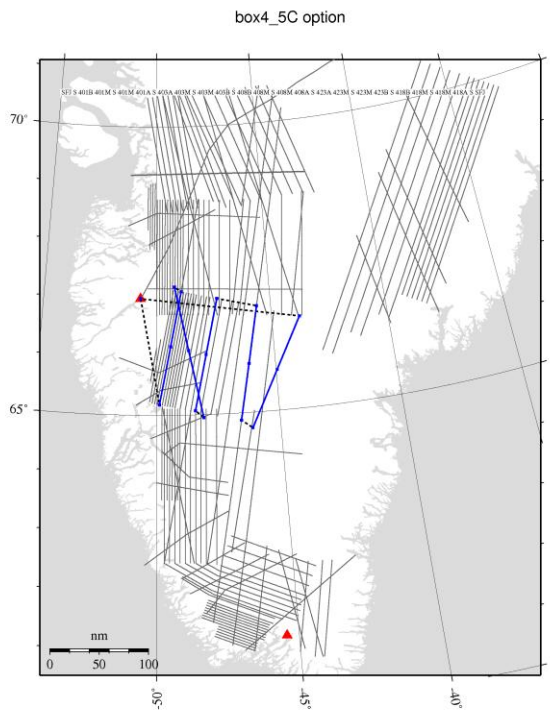
Coverage if all 1 day of flying are completed for Box 1 assuming a single pilot and an 8 hour day.



Box 4 Flight 1

This mission is the first to be flown in Box 4 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples an ICESat track and the 2000m and 2500 m contours.

Box Priority: Medium(P5) **Flight Priority:** high **Instrument Priority:** LVIS
ICESat Track: 181 **Flight Time**: ~5 hours

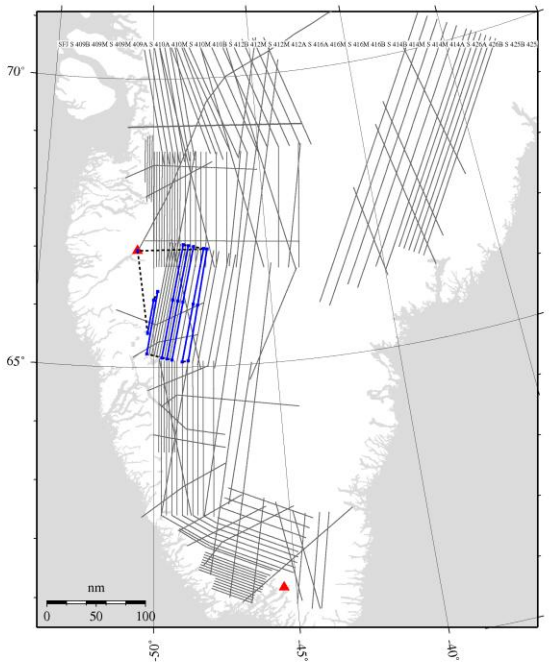


Box 4 Flight 2

This mission is the second to be flown in Box 4 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 10 km grid lines in central section of the box and samples an ICESat track.

Box Priority: Medium(P5) **Flight Priority:** medium **Instrument Priority:** LVIS
ICESat Track: none **Flight Time**: ~5 hours

box4_5B option

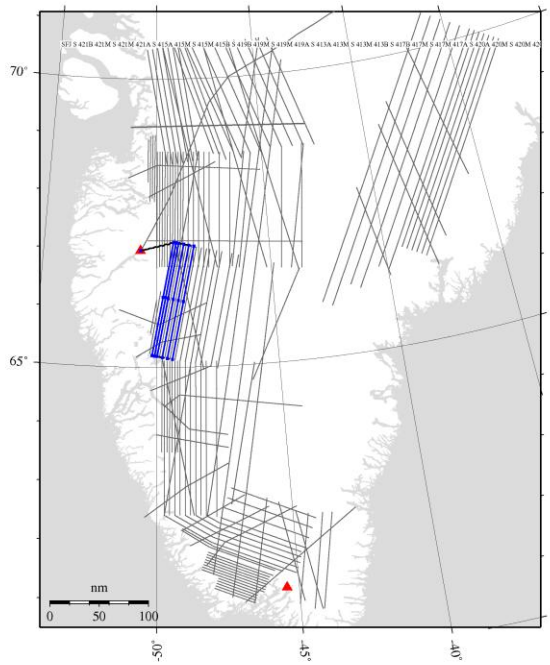


Box 4 Flight 3

This mission is the third to be flown in Box 4 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 10 km grid lines in coastal section of the box, samples an ICESat track and the 1500 m contour.

Box Priority: Medium(P5) **Flight Priority:** high **Instrument Priority:** LVIS
ICESat Track: 323 **Flight Time**: ~5 hours

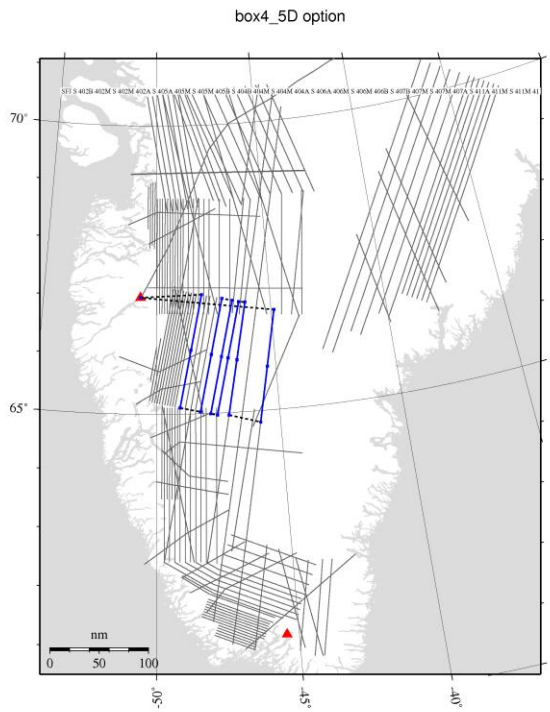
box4_5A option



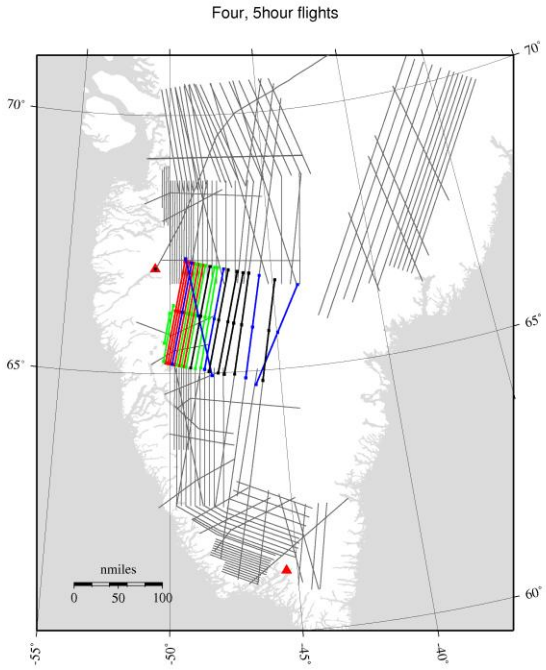
Box 4 Flight 4

This mission is the forth to be flown in Box 4 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 20 km grid lines in the interior section of the box and samples two ICESat track.

Box Priority: Medium(P5) **Flight Priority:** low **Instrument Priority:** LVIS
ICESat Track: 55, 308 **Flight Time**: 5.2 hours



Coverage if all 4 days of flying are completed for Box 4 assuming a single pilot and an 8 hour day.

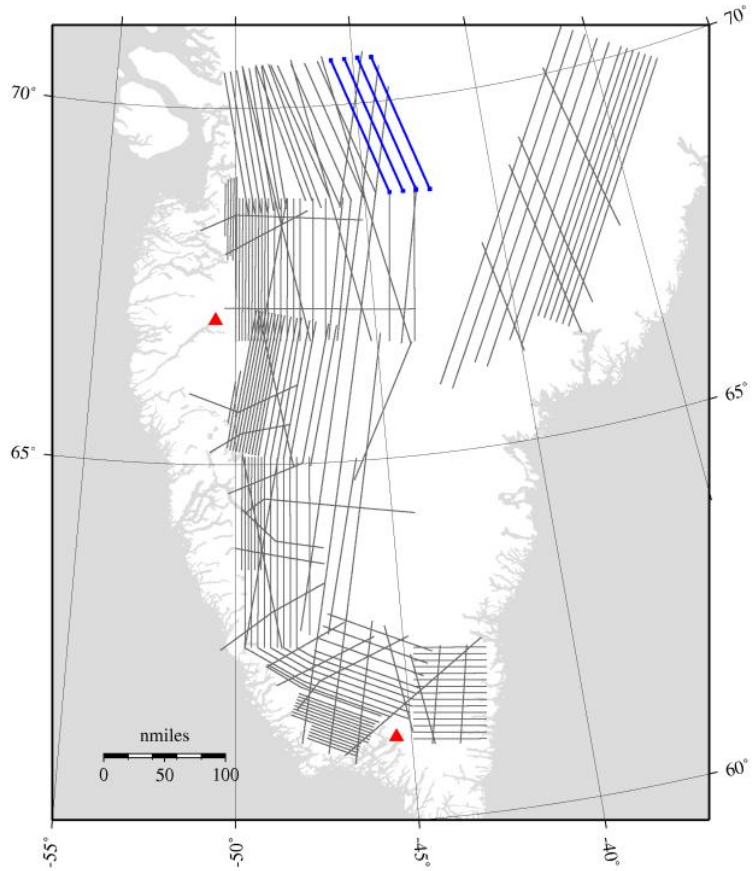


Box 6 Flight 1

This mission is the first to be flown in Box 6 assuming the box is clear. It assumes one pilot and a flight out of Kangerlussuaq. This flight samples the 20 km grid lines in the interior section of the box. The P-3 will be sampling grids in the costal section of the box. If the P-3 does not sample this costal region this flight will shift to the costal ICESat lines and 10 km grid lines.

Box Priority: Low (P6) **Flight Priority:** medium **Instrument Priority:** LVIS
ICESat Track:none **Flight Time**: ~5 hours

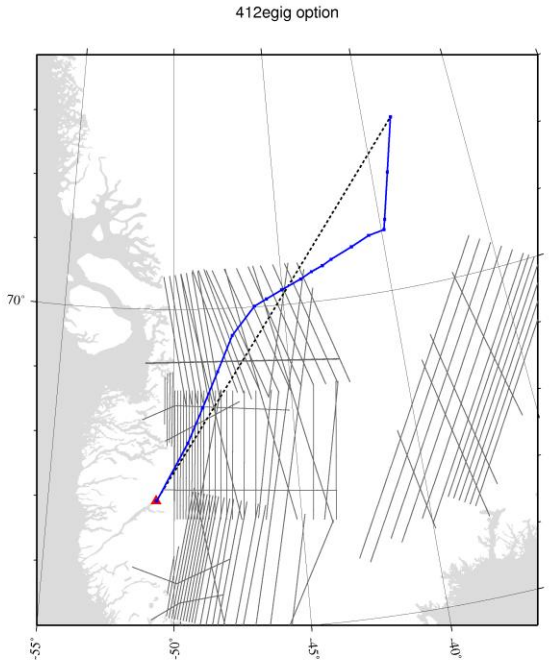
box6_5A option



EGIG/Summit

This mission is the designed as a calibration flight if all coastal areas are cloudy. It assumes one pilot and a flight out of Kangerlussuaq. This flight follow the EGIG line and follow ICESat track 412 over Summit. It is designed to give a flight option if the coastal areas are foggy.

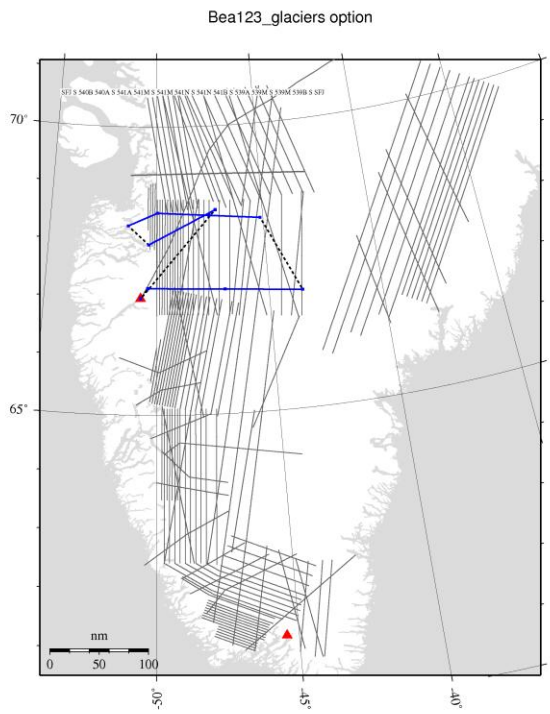
Box Priority: Low (P6) **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track:412 **Flight Time**: ~5 hours



Glacier Flight 1

This mission is the sixth in Box 5 assuming the box is clear. It assumes one pilot, an 8 hour flight day. This flight samples glaciers North to South Nordenskjold, unnamed, and Isunnguate Sermia. Still to be added to this flight will be a flow line along one for the glaciers to test the LVIS instruments accuracies.

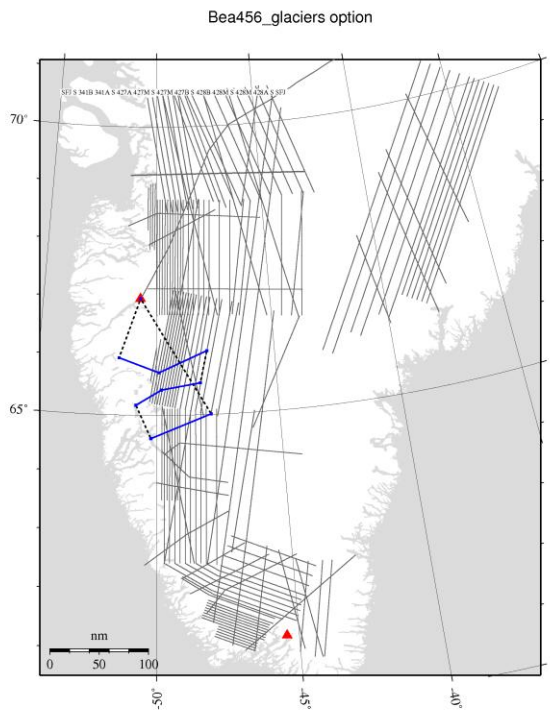
Box Priority: High **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time:** 4 hours



Glacier Flight 2

This mission is the sixth in Box 4 assuming the box is clear. It assumes one pilot, an 8 hour flight day. This flight samples glaciers North to South Sukkertoppen, Saqqap Sermia Narsap Sermia. Still to be added to this flight will be a flow line along one for the glaciers to test the LVIS instruments accuracies.

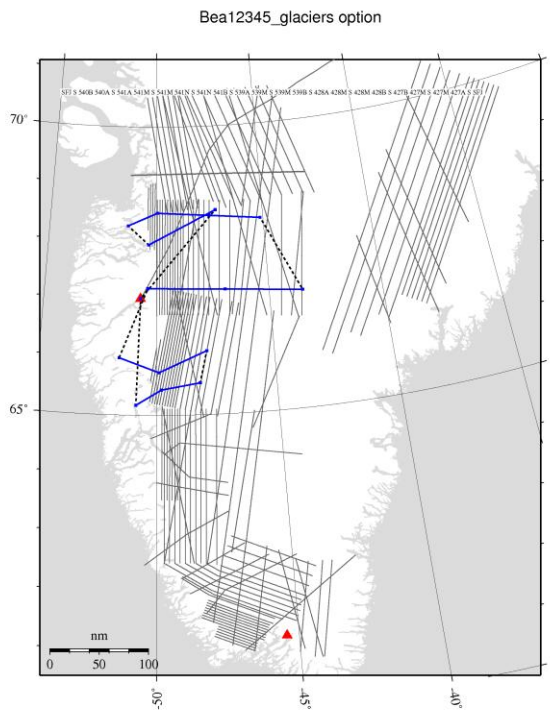
Box Priority: Medium **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time:** 3 hours



Glacier Flight 3 (Logistically Difficult)

This mission is the sixth in Box 4 and 5 assuming the box is clear. It assumes one pilot, an 8 hour flight day. This flight samples glaciers North to South Nordenskjold, unnamed, Isunnguate Servia, Sukkertoppen, and Saqqap Sermia. Still to be added to this flight will be a flow line along one for the glaciers to test the LVIS instruments accuracies.

Box Priority: High **Flight Priority:** Low **Instrument Priority:** LVIS
ICESat Track: none **Flight Time:** 5 hours



Appendix: Overview of Flight Plans for original proposed flight plan document:

- An overview of the flight plans is shown in Figures 1 and 2. Detailed flight plans are provided in the next section. The hours noted below are estimates and will be refined as knowledge of the plane capabilities and final flight line configurations mature. We note again: flight plans presented require significantly more flight hours than allocated in order to provide operational flexibility in the presence of persistent weather issues. A faster and higher flying plane (e.g. G-V) would greatly reduce the required flights hours (faster tracks and more endurance means less wasted time).

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- Within each flight contour grid several ICESat-1 tracks were selected for LVIS data collection. LVIS flight lines that follow ICESat tracks are marked in red in Figures 1 and 2. The choice of the ICESat-1 tracks is based on several factors: (1) good temporal sampling (sampling many campaigns), (2) good along-track surface sampling (high number of surface returns), (3) can easily be integrated into LVIS contour grid and provides good sampling of the ice sheet, (4) provides LVIS-LVIS and ICESat-1 crossover data for cal/val. Metrics for temporal and along-track spatial sampling were computed in order to quantify "good" sampling. The ICESat-1 data was sampled in 1000m cells in order to approximate an LVIS swath. The number of campaigns sampled and the total number of points were computed within each cell (see Figure ?? in the Appendix). Summary statistics over all the 1000m cells comprising each ICESat-1 track within each region were computed. Table 1 in the Appendix shows the listing of ICESat-1 tracks per region ("Box") sorted by mean number of campaigns and mean number of observations within a cell. The rows highlighted in orange were selected for LVIS data collection.

- As noted above, flight plans presented require significantly more flight hours than allocated in order to provide operational flexibility in the presence of persistent weather issues. Therefore, we must prioritize the flights first by region and second by flights within each region. Preliminary region priority is as follows: 1) Southwest contour grid 5 (red box), 2) South contour grid 6 (dark blue), 3) Southwest contour grid 4 (yellow box), 4) Southwest contour grid 3 (green), 5) Southwest contour grid 2 (brown), 6) Southwest contour grid 1 (purple), 7) East contour grid 7 (light blue). Within each region flights must be prioritized by science requirements and acquisition efficiency. Without consideration of acquisition efficiency, flights are prioritized as: 1) common ICESat-1 and contour lines, 2) other 1000, 2000 and 2500m contour lines, 3) grid lines within 100km of the edge of the continuous ice sheet, 4) selected glacier lines, 5) other ICESat tracks, 6) all other lines.

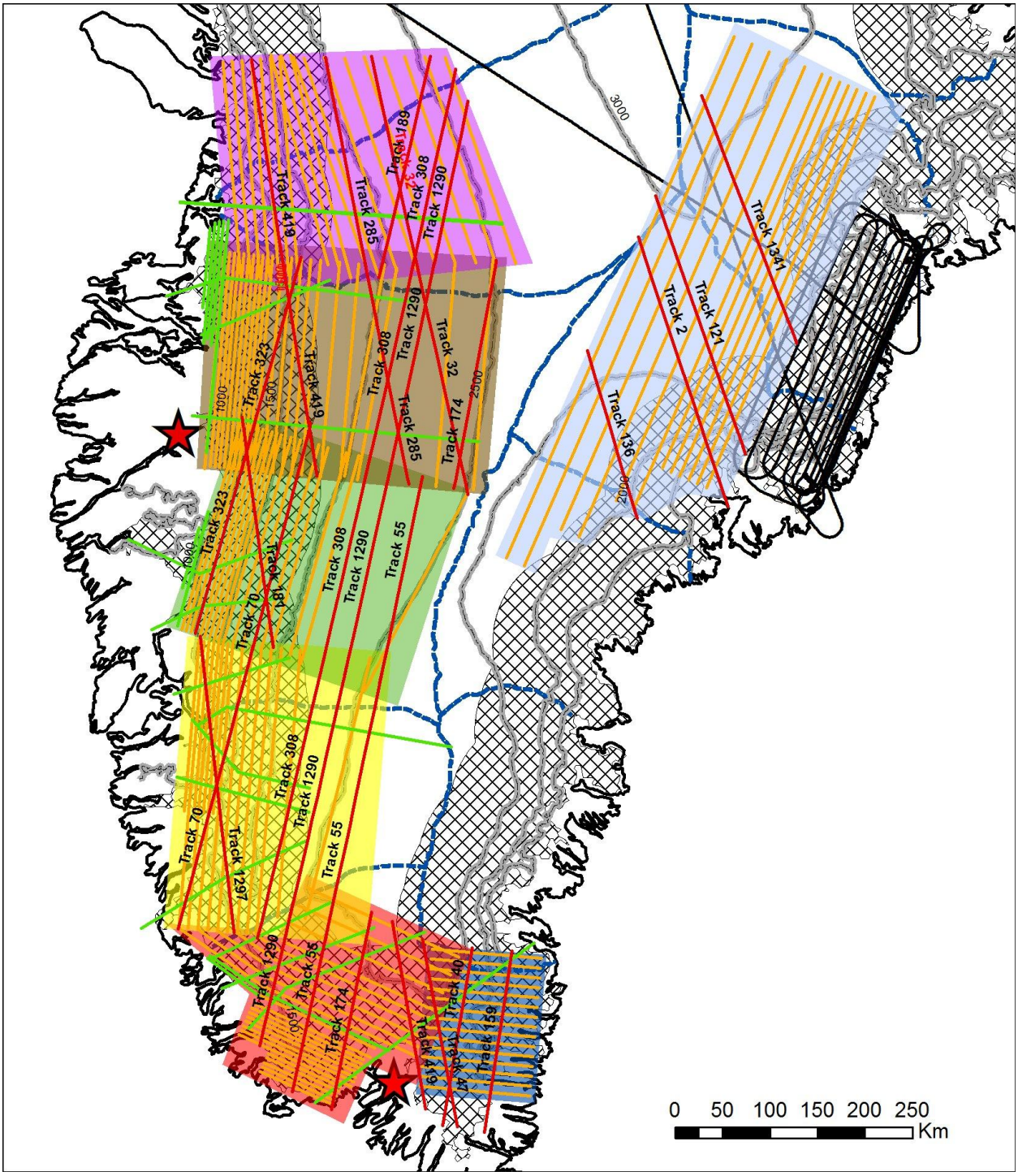

Figure 1. Proposed LVIS flights. Contour grid flight lines in orange; extended glacier lines in red, green and grey; LVIS data already collected in black; area within 100 km of edge of ice sheet is grey-thatched; airports as red stars, drainage basin lines as dashed dark blue.

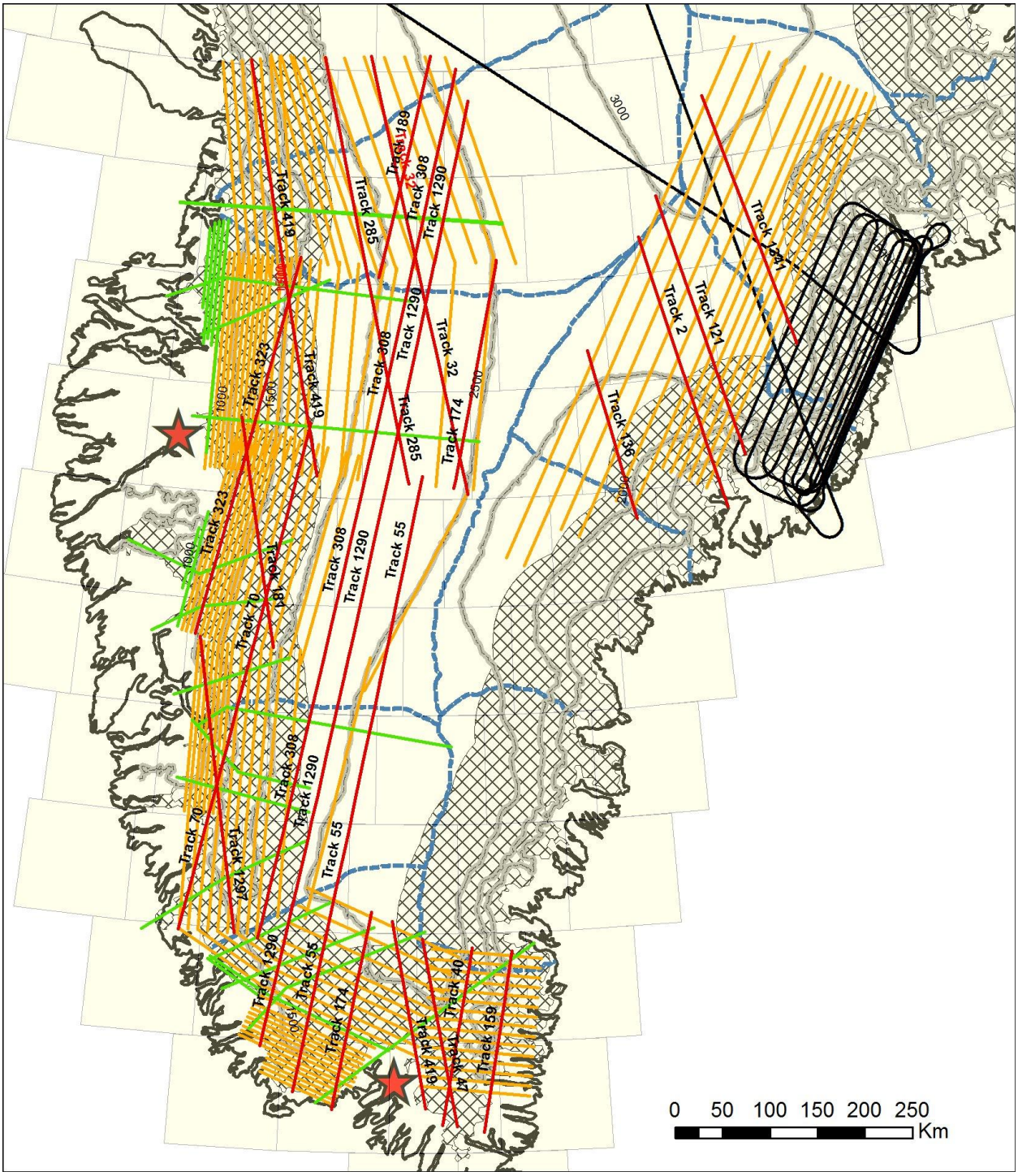

Figure 2. Proposed LVIS flights. Contour grid flight lines in orange; extended glacier lines in red, green and grey; LVIS data already collected in black; area within 100 km of edge of ice sheet is grey-thatched; airports as red stars; GRACE mascons as light yellow boxes outlined in grey, drainage basin lines as dashed dark blue.