ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

IceBird 2019 Winter

ICESat-2 Validation Data Acquisition Report

Issued by

Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research

Stefan Hendricks

Robert Ricker

Arttu Jutila

Date

2019/08/25

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

1 Table of Contents

2 Purpose of this document

This technical report provides information on validation activities of ICESat-2 sea ice products in April 2019 by airborne observations within the IceBird aircraft campaign series of the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research. The airborne data acquisition includes direct observations of snow freeboard, snow depth on sea ice and sea-ice thickness by a set of sensors. The following sections specify the extent of airborne data collocated with an ICESat-2 orbit, the specification of the sensors and the file format of the validation data.

3 Document Version

Rev 1.0	August 25, 2019	Initial Version

4 IceBird 2019 Winter

4.1 Scientific Objective

Aim of the aircraft campaign “IceBird Winter” is to conduct sea ice surveys over different ice regimes when the Arctic sea ice is close to its maximum extent. The surveys contribute to a sea-ice observing system that spans the western part of the Arctic Ocean from the Fram Strait to the Western Beaufort Sea. The set of sensors include a towed EM-System for estimation of ice thickness, an airborne laser scanner for high-resolution surface roughness and a snow radar for snow depth on sea ice. In addition, a set of air-launchable buoys will be to mark flight tracks over the drifting sea ice for revisits by follow-up surveys. Results from airborne surveys serve the main objective of understanding Arctic Change, but the work is attributed to several topics:

- Observation and analysis of the sea ice thickness distribution in several parts of the Arctic Ocean and its thermodynamic and dynamic history
- Estimation of sea-ice thickness variability and trends from a long-term data record of airborne observation during the annual sea-ice maximum
- The regional distribution of snow and its role on the energy and mass balance of Arctic sea ice
- Validation of satellite retrievals from CryoSat-2, ICESat-2, Sentinel-3A/B and AltiKa of Arctic sea ice freeboard

More information on the IceBird program is available on the projects website:

https://www.awi.de/en/science/climate-sciences/sea-ice-physics/projects/ice-bird.html

4.2 Operations

The 2019 implementation excludes surveys from Svalbard and Greenland, which have been part of the IceBird Winter program in the past. Instead, the 2019 winter campaign had its focus on stations in Canada and in Alaska.

Table 1: Stations for the IceBird 2019 Winter field campaign

Station Name	Airport Code	Lon (deg east)	Lat (deg north)	Period
Resolute Bay	YRB	-94.83	74.70	Mar 21 – Mar 25
CFS Alert	YLT	-62.31	82.50	Mar 25 – Mar 30
Eureka Weather Station	YEU	-85.81	79.98	Mar 30 – Apr 6
Inuvik	YEV	-133.48	68.30	Apr 6 – Apr 11
Utqiagvik (Barrow)	PABR	-156.76	71.28	Apr 12 – Apr 16

The reference and download location for all flight tracks for the IceBird 2019 Winter campaigns can be found online:

Hendricks, Stefan; Ricker, Robert; Jutila, Arttu (2019): Master tracks in different resolutions during POLAR 6 campaign ICEBIRD_2019. Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, PANGAEA, https://doi.org/10.1594/PANGAEA.902895

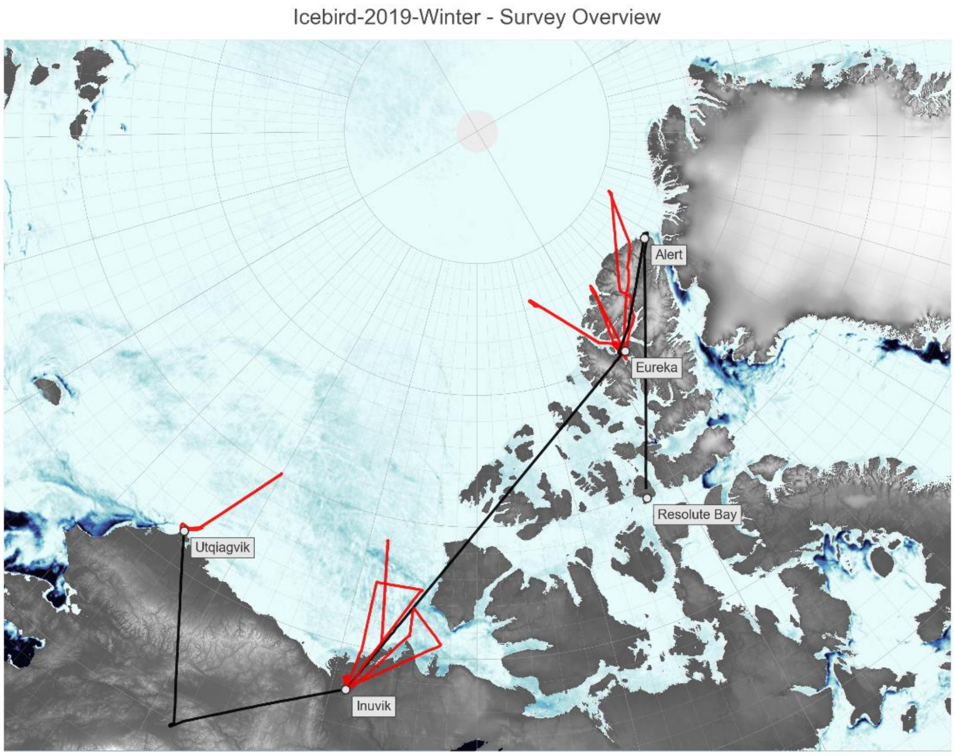

Figure 1: Sea ice surveys (red tracks) of the IceBird 2019 Winter aircraft campaign

4.3 Survey Layout

The general survey layout is based on two legs over the same track over sea ice at two different altitudes.

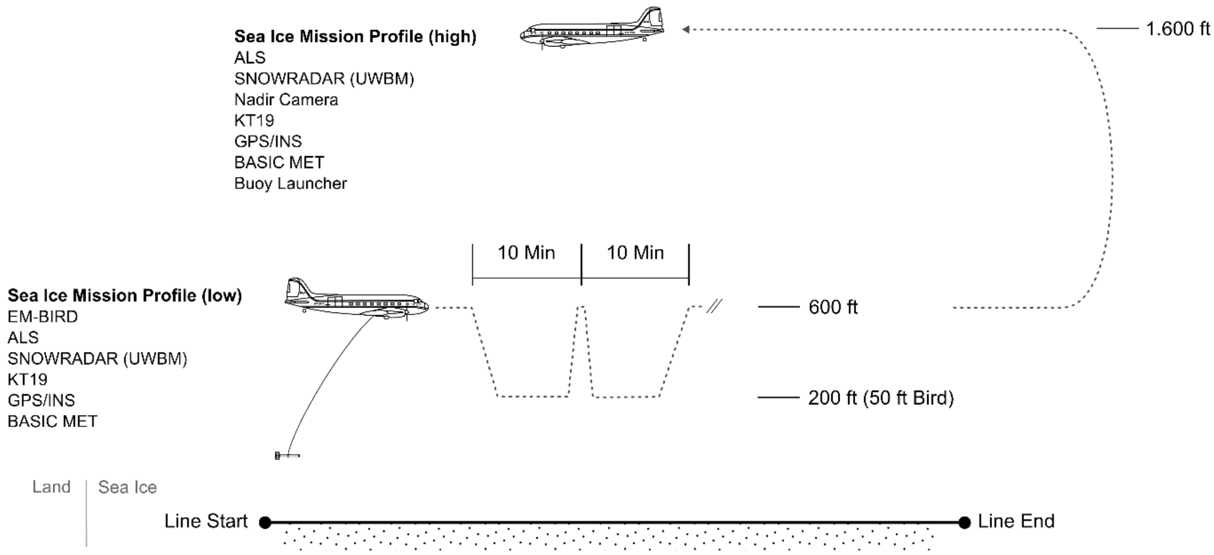

Figure 2: Survey layout for sea ice flight, consisting of a low outbound leg with EM-Bird and a return leg at higher altitude.

The outward leg contains the EM-Bird sea-ice thickness measurements at low flight level. Correspondingly, the airborne laser scanner and the snow radar are operated in low-level mode. The return leg at higher altitude (1600 ft, the maximum range for the snow radar) provides laser freeboard data with a wider swath. The return leg is flown at higher speeds to maximize the operational range for the observing sea-ice thickness gradients at the outbound leg.

5 IceBird Instrumentation

The primary sea ice sensors of the IceBird Winter campaigns consists of

1. EM-Bird : sea + snow thickness
2. Airborne Laserscanner: snow freeboard
3. Snow Radar : snow depth on sea ice

Sensor specifications and their configuration settings during IceBird 2019 Winter are described below.

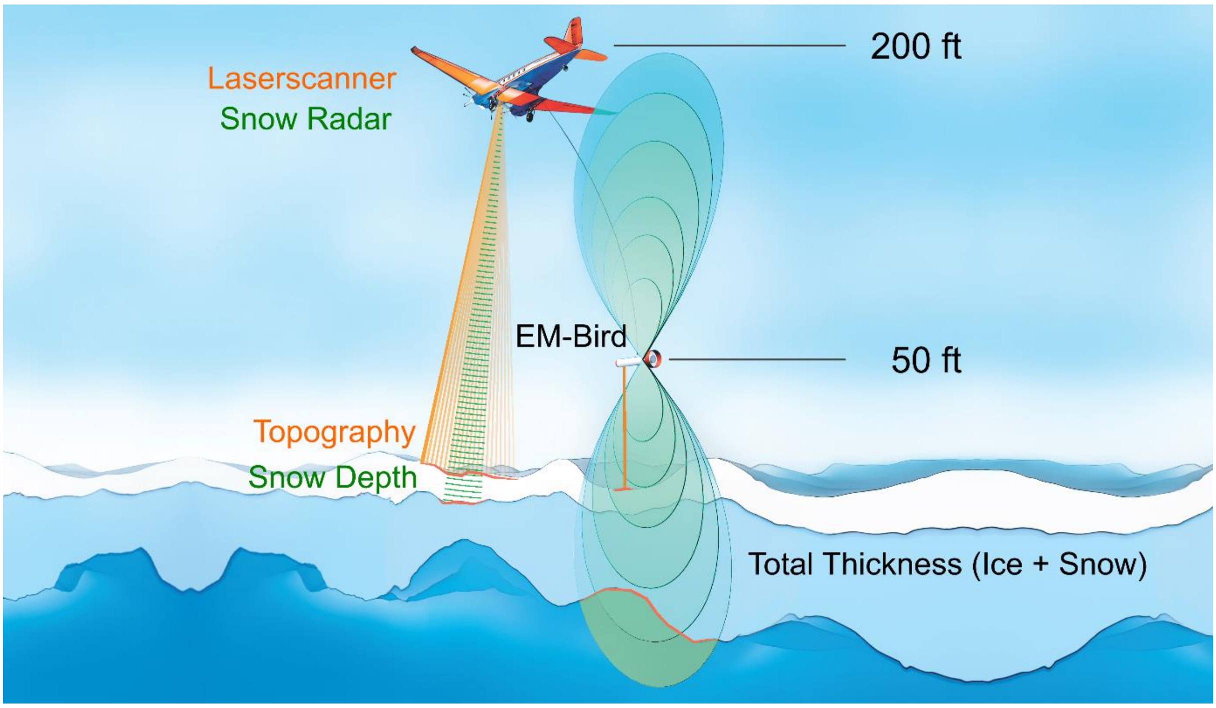

Figure 3: Primary sea ice sensors on IceBird Winter aircraft campaigns, here in “sea ice mission profile low”

5.1 EM-Bird

The EM-Bird is a towed system that requires operation close to the sea ice surface with an operational altitude of 40 to 70 feet AGL.

Parameter	Value
Method	Frequency-domain electromagnetic induction (FDEM)
EM Frequency	4060 Hz
Sampling Rate	10 Hz (4-5 meter point spacing at 120 kts)
EM Footprint	40 – 50 m
Uncertainty	10 cm (level sea ice)
Laser Altimeter	Jenoptik LDM 301

5.2 Airborne Laserscanner (ALS)

The laser scanner model installed in Polar-6 is a Riegl VQ-580. The scanning mechanism is realised with a rotating mirror resulting in linear and parallel scan lines. Its specifications are given in the table below (from Riegls Q580 data sheet):

Table 2: Airborne Laserscanner (Riegl VQ580) technical specifications

Parameter	Value
Field of View	+/- 30 deg
Angle Measurement Resolution	0.001°
Scan Speed (selectable)	10 – 150 lines per second
Laser Pulse Repetition Rate (selectable)	50 – 380 kHz
Minimum Range	10 m
Accuracy	25 mm
Precision	25 mm
Wavelength	near infrared (1064 nm)
Laser Class	3B

The scanner needs to be configured for the specific flight profile and two configurations are required for the sea ice low (EM-Bird) and sea ice high (return leg) flight altitudes. Its nominal settings are described in the table below.

Table 3: Riegl VQ580 settings for low and high alt mission profile

Parameter	Sea Ice Low Mission Profile *	Sea Ice High Mission Profile
Altitude AGL	600 ft	1600 ft
Ground Speed	120 kn	160 kn
Scan Mode	Line	Line
Measurement Program	300 kHz	200 kHz
Monitor Step Multiplier	36	24
MTA Zone	Mission Parameter	Mission Parameter
Line Start/Stop	60deg	60deg
Line Speed/Increment	150 lps	117.25 lps
Line Distance	0.4112 m	0.7020 m
Point Distance	0.2297 m	0.7018 m
Swath Width	211.17 m	563.12 m
Point Density	10.59 pts/m^3	2.03 pts/m^3
Max Range	211.173 m	563.124 m

* 600ft is maximum altitude during EM-Bird calibration procedure, nominal survey altitude is 200 ft AGL with smaller swath width and higher across track point density.

5.3 Snow Radar

The snow radar or ultra wideband microwave radar (UWB/M) is for mapping near surface internal layers with very fine resolution and measuring the thickness of snow over sea ice. The system is designed to operate in Frequency-Modulated and Continuous Wave (FMCW) mode for low-altitude measurements (500-1000 m) and stretch mode for high-altitude measurements 2500 m and above.

During IceBird the radar will only be operated in low altitude mode in both sea ice low and sea ice high mission profles. However, 10dB dampeners are inserted at the transmitter to avoid saturation at the low mission profile.

Table 4: Snow Radar (UWB/M) specifications

Parameter	**Value**
Operating Frequency	2-18 GHz
Num of Transmit Channels	2 (H-pol. and V-pol.)
Transmit Power	100 mW @ 200 ft; 1000 mW @ 1600 ft
Num of Receive Channels	2 (H-pol. and V-pol.)
Receiver Sampling Rate	125 MHz
Digitizer	14-bit A/Ds
Antenna	Dual-pol. Horn or Vivaldi array
Across-track footprint (pulse-limited)	2.1 m @ 200 ft; 6.0 m @ 1600 ft
Along-track footprint (unfocussed SAR)	2.0 m @ 200 ft; 10.8 m @ 1600 ft
Range resolution (snow density 300 kg/m^3)	0.94 – 1.14 cm

6 ICESat-2 Cal/Val

6.1 Reference Ground Tracks

The reference ground tracks are available as kml files at the NASA ICESat-2 website:

https://icesat-2.gsfc.nasa.gov/science/specs

For the IceBird 2019 Winter surveys, the reference ground track for the strong center beam was provided by John Sonntag, NASA to the IceBird science team.

6.2 Beam Targets

ICESat-2 has 3 beam pairs, consisting of a strong and weak beam spaced 90 meter apart.

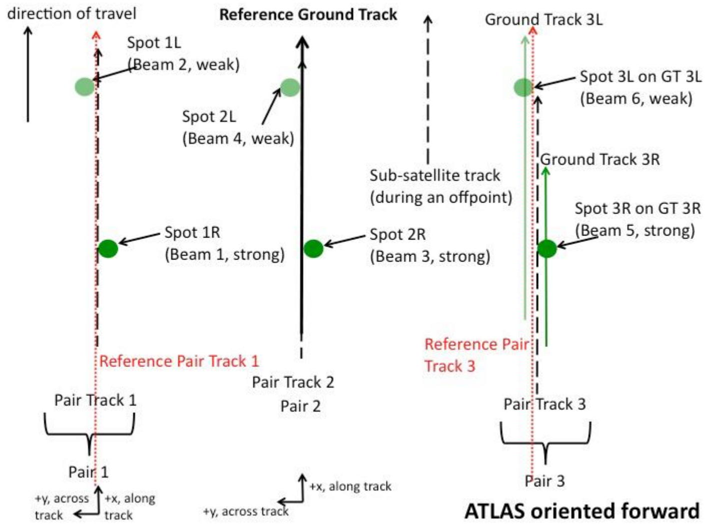

Table 5: ICESat-2 beam parameters with spacecraft moving forward (from ATL03 ATBD)

Parameter	**Value**
Footprint size	17 m
Field of view	45 m
Pulse repetition frequency	10kHz (~0.7m on the ground)
Laser wavelength	532 nm

The center beam pair nominally is located at the reference ground track. The center of the two outer beam pairs are spaced by 3.3 km. Thus, the locations of the beams can be computed by offsetting the location of the RGT in the perpendicular direction to the RGT. Here we use the convention that a positive offset is an offset to the right in the direction of travel.

The pointing bias of the beams has been improved during the IceBird campaign and was found to "well within the +-45 m mission requirement for pointing" (pers. comm. N. Kurtz) at the time the ICESat-2 underflight was implemented.

Table 6: ATLAS beams and their location with respect to the reference ground track when spacecraft is oriented forward

ATLAS beam #	**ATLAS spot #**	**Strength**	**Location**
1	1R	strong	RGT – 3300m + 45m
2	1L	weak	RGT – 3300m - 45m
3	2R	strong	RGT + 45m
4	2L	weak	RGT - 45m
5	3R	strong	RGT + 3300m + 45m
6	3L	weak	RGT + 3300m - 45m

7 ICESat-2 calibration/validation data

7.1 Validation Orbit

The IceBird 2019 Winter campaign included one collocated survey with an ICESat-2 orbit. Other underflights were attempted, but had to be canceled due to insufficient weather conditions.

The successful ICESat-2 survey is located in the Eastern Beaufort Sea (ICESat-2 RGT cycle 3 RGT 189) on the morning of April 10, 2019. The aircraft survey started approximately 1 hour after the satellite overpass and covered a range of ice types from young first-year sea ice close to the coast, to older first-year ice as well as a thicker multi-year ice broken with first-year ice at different stages of development. A Sentinel-1 scene is available and was acquired shortly after the aircraft was on the survey line over sea ice.

The survey targeted the strong center beam without any inflight correction for ice drift. The outbound leg of the survey was flown at 200 ft survey altitude and the return leg at 1600 ft survey altitude.

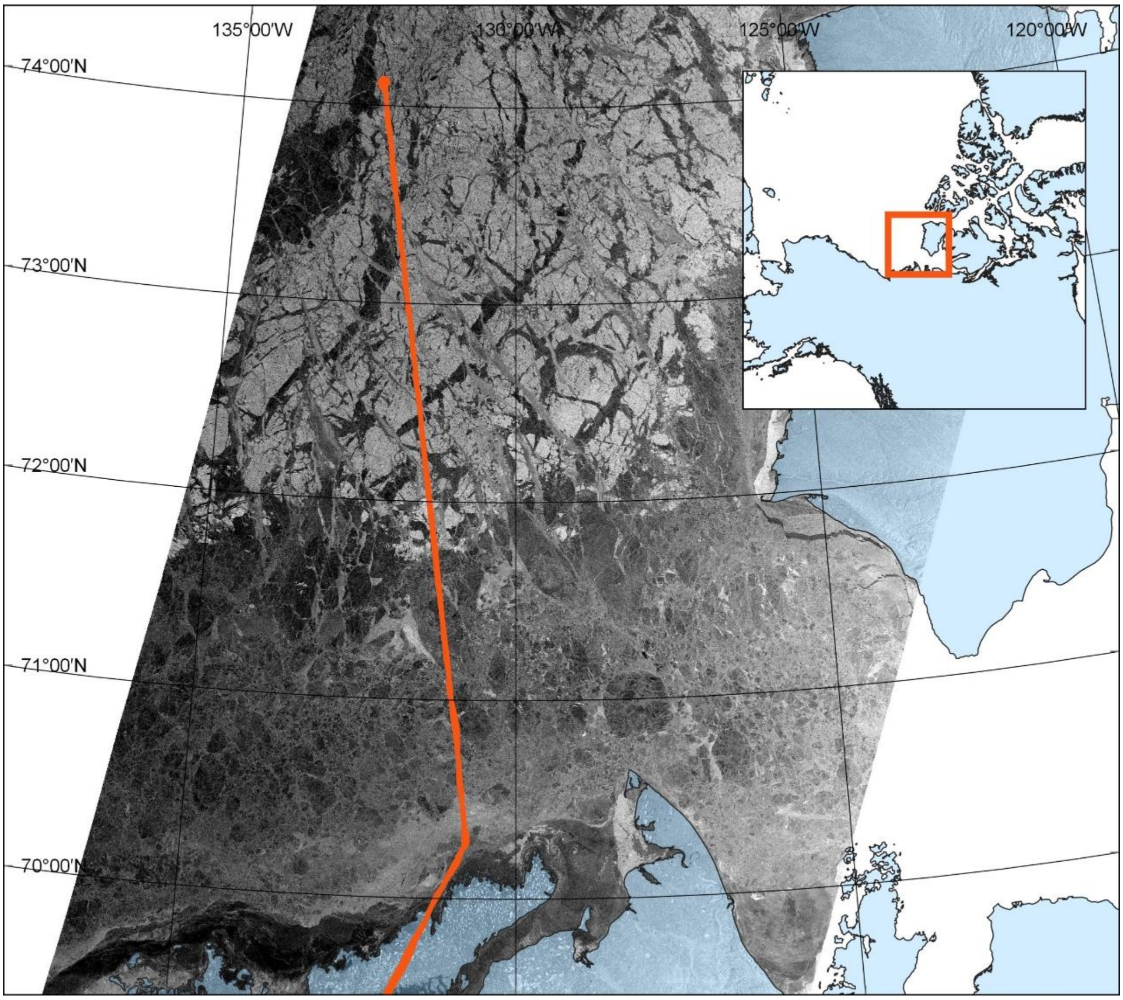

Figure 4: Location of the ICESat-2 validation survey of the IceBird 2019 Winter aircraft campaign on April 10, 2019. The survey lines contain an outbound and return leg at different altitudes.

7.2 Preliminary Results

All aircraft sensors have recorded nominally during the outbound and return legs.

7.2.1 Sea Ice Thickness

The EM-Bird is shown in the figure below. Gaps in the data arise due to high altitude calibrations of the sensor. All collected data for the ICESat-2 flight on April 10, 2019 has been processed.

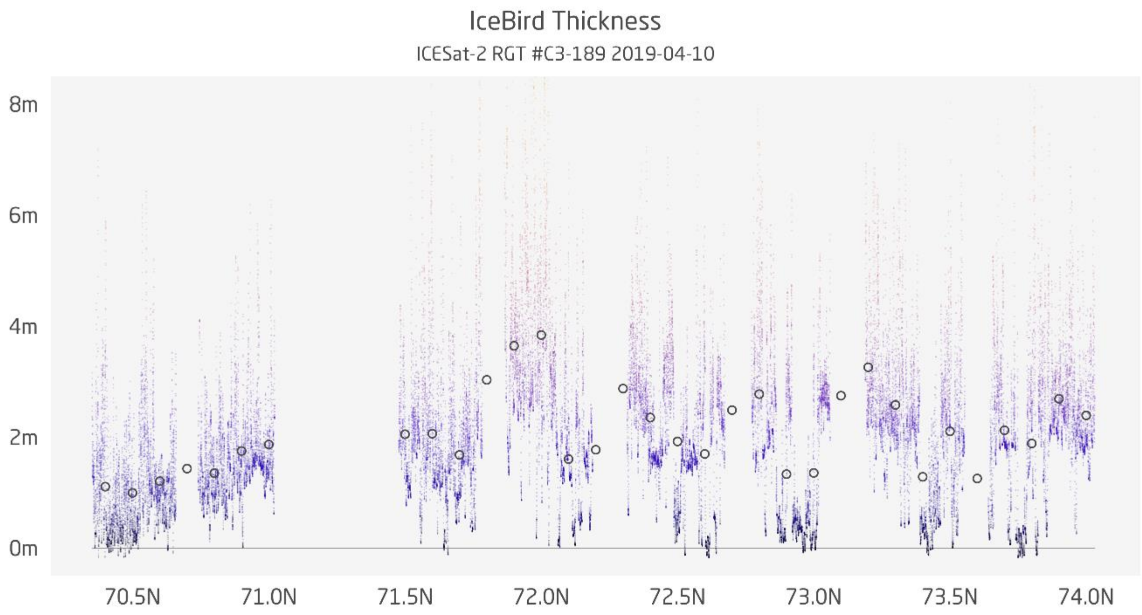

Figure 5: Sea ice + snow thickness profile based on EM-Bird observations on the ICESat-2 underflight on April 10, 2019. Circles indicate mean thickness in 1/10 degrees of latitude bins.

NOTE: The EM-Bird was only operated at the low-level outbound survey leg.

7.2.2 Airborne Laserscanner

The workflow for processing laser scanner point cloud data is as follows:

1. Outlier filtering based on aircraft altitude and initial ranges
2. Computing WGS84 surface elevations using aircraft INS and post-processed aircraft GPS
3. Manual detections of leads and along-track interpolation aided by a mean sea surface
4. Create 1 minute subsets of the scanner data
5. Projecting point cloud data to polar stereographic projection
6. Gridding of freeboard point cloud data with a grid resolution of 25 cm for low altitude and 50 cm for high altitude survey modes.
7. Interpolation of small gaps (1 grid cell)

All collected data for the ICESat-2 flight on April 10, 2019 has been processed. ALS data is available from both outbound and return survey legs.

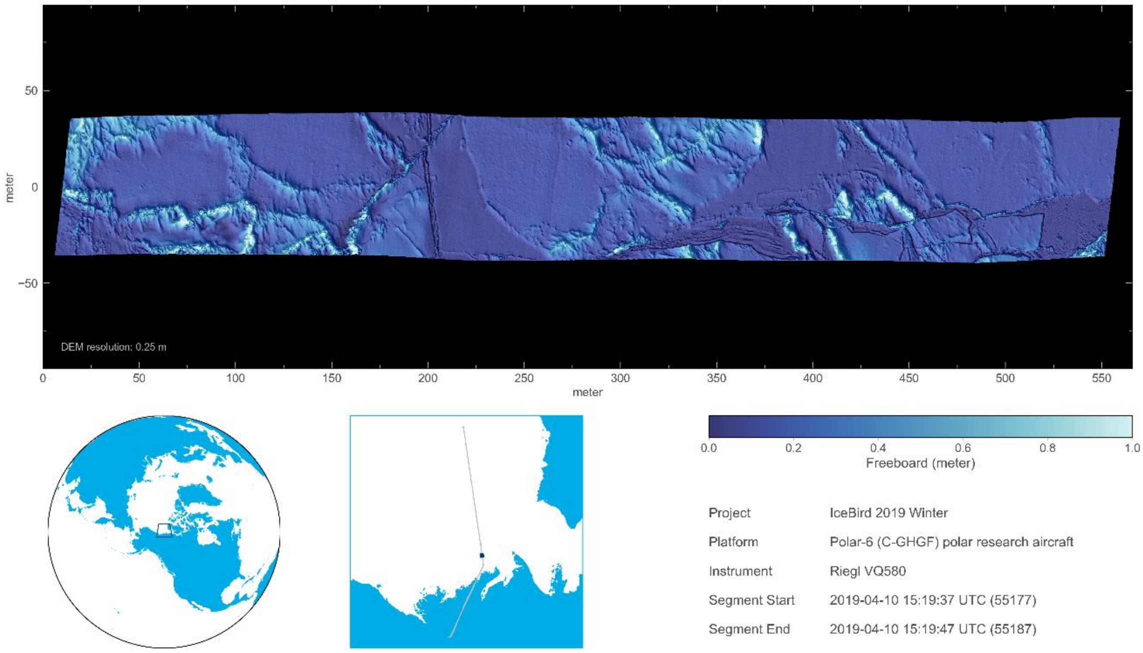

Figure 6: Example of gridded freeboard data (10 seconds segment) at a resolution of 25 cm

7.2.3 Snow Radar

The workflow for the processing of the snow radar data contains the following steps:

1. Initial processing of the raw data using the CRESIS Matlab Toolbox
2. Coherent noise removal
3. Deconvolution of echograms
4. Interface (air-snow, snow-ice) detection based on a modified wavelet algorithm from Newman et al. 2014 and implemented in the python toolbox pySnowRadar by J. King (Environment and Climate Change Canada)

At this version of the data acquisition report the processing and quality control of the snow radar is still ongoing and the data from the April 10, 2019 flight is not considered science ready yet.

The analysis of the quick view version and initial validation however does not indicate major issues with the data and a release version of the snow radar data can safely be expected.

8 Data Release

8.1 Download location

ICESat-2 sea ice validation data from the IceBird 2019 Winter campaign can be downloaded at the AWI ftp:

ftp://ftp.awi.de/sea_ice/aircraft/icebird2019winter/2019-04-10/

8.2 EM-Bird

The EM-Bird total (sea ice + snow) thickness is located in the aem subfolder. The single ASCII file contains all observations from the outbound leg.

Filenaming:

```
awi-icebird-l2-sithick-embird-<yyyy><mm><dd>.dat
```

The file content is as follows:

Table 7: EM-Bird file content specification

Column	Parameter
1	Year (integer)
2	Month (integer)
3	UTC second of the day (float)
4	Fiducial number (integer)
5	Latitude in degrees north (float)
6	Longitude in degrees east (float)
7	Along-track distance in meter (float)
8	Thickness of the sea ice and snow layers in meter (float)
9	Laser range in meter (float)

8.3 Laserscanner Data

The ALS snow freeboard data is released 1 minute segments with processing level 4 (interpolated data on a space-time grid). The ftp subfolder location is als/l4-freeboard.

Filenaming:

```
awi-icebird-l4-freeboard-vq580-stere_<res>-<start>-<end>-fv1p0.nc
```

with

<start>; <end> time coverage in yyyyMMddThhmmss

<res> resolutions string (e.g 0p25m for a resolution of 25 cm)

The ALS freeboard data is distributed as netCDF v4 files.

Global attributes

```
// global attributes:
:title = "Snow freeboard from airborne laserscanning data";
:Conventions = "ACDD-1.3";
:naming_authority = "de.awi";
:source = "Surface elevations from airborne laserscanner data converted into
           freeboard by manual identication of lead elevations";
:processing_level = "Level-4 (l4)";
:license = "Free and unrestricted access";
:standard_name_vocabulary = "CF Standard Name Table v27";
:creator_name = "Stefan Hendricks, Robert Ricker, Veit Helm";
:creator_url = "www.awi.de";
:creator_email = "stefan.hendricks@awi.de, robert.ricker@awi.de, veit.helm@awi.de";
:institution = "Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research";
:project = "IceBird 2019 Winter";
:geospatial_bounds_crs = "EPSG:54026";
:geospatial_lat_min = 70.21856416397064; // double
:geospatial_lon_min = 70.21856416397064; // double
:geospatial_vertical_min = -0.10247538095824357; // double
:geospatial_vertical_max = 2.305471486285113; // double
:time_coverage_start = "2019-04-10T15:06:55.005010";
:time_coverage_end = "2019-04-10T15:07:54.995316";
:creator_type = "group";
:program = "IceBird airborne sea ice surveys";
:geospatial_lat_units = "m";
:geospatial_lat_resolution = 0.25; // double
:geospatial_lon_units = "m";
:geospatial_lon_resolution = 0.25; // double
:product_version = 1.0; // double
:platform = "Polar-6 (C-GHGF) polar research aircraft";
:instrument = "Riegl VQ580";
```

List of variables

```
variables:
  float freeboard(yc=3729, xc=13065);
    :_FillValue = NaNf; // float
    :coordinates = "time yc xc";
    :long_name = "elevation of the sea ice surface above local sea ice level
                  (sea_ice_freeboard plus surface_snow_thickness)";
    :units = "m";
    :_ChunkSizes = 533U, 1867U; // uint

  short n_points(yc=3729, xc=13065);
    :coordinates = "time yc xc";
    :long_name = "number of level-2 points per grid cell";
    :comment = "n_points = 0 in the presence of a geophysical parameter means that
                the parameter is based on interpolation";
    :units = "m";
    :_ChunkSizes = 746U, 2613U; // uint
```

List of Dimensions and Grid Metadata

```
  float lon(yc=3729, xc=13065);
    :_FillValue = NaNf; // float
    :long_name = "longitude coordinate";
    :standard_name = "longitude";
    :units = "degrees_east";
    :_ChunkSizes = 533U, 1867U; // uint

  float lat(yc=3729, xc=13065);
    :long_name = "latitude coordinate";
    :units = "degrees_north";
    :_FillValue = NaNf; // float
    :standard_name = "latitude";
    :_ChunkSizes = 533U, 1867U; // uint
```

```
    long Polar_Stereographic_Grid(grid_mapping=1);
      :grid_mapping_name = "polar_stereographic";
      :false_easting = 0.0; // double
      :false_northing = 0.0; // double
      :semi_major_axis = 6378137.0; // double
      :semi_minor_axis = 6356752.3142; // double
      :straight_vertical_longitude_from_pole = -45.0; // double
      :latitude_of_projection_origin = 90.0; // double
      :standard_parallel = 70.0; // double
      :proj4_string = "+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +ellps=WGS84 +datum=WGS84";
      :_ChunkSizes = 1U; // uint

    double time(time=1);
      :_FillValue = NaN; // double
      :standard_name = "time";
      :units = "seconds since 1970-01-01";
      :long_name = "reference time of the product";
      :calendar = "standard";
      :bounds = "time_bnds";

    double time_bnds(time_bnds=2);
      :_FillValue = NaN; // double
      :long_name = "time range of the product";
      :calendar = "standard";
      :units = "seconds since 1970-01-01";

    float xc(xc=13065);
      :_FillValue = NaNf; // float
      :standard_name = "projection_x_coordinate";
      :long_name = "x coordinate of projection";
      :units = "m";

    float yc(yc=3729);
      :_FillValue = NaNf; // float
      :standard_name = "projection_y_coordinate";
      :long_name = "y coordinate of projection";
      :units = "m";
```