Leveraging recent and upcoming NASA-ESA Cal/Val efforts to improve and reconcile the sea ice thickness record

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Reliably profiling sea ice thickness from space is a key objective of the sea ice research community as this provides invaluable information regarding the state of polar sea ice missing from the more routine measurements of sea ice coverage. Active altimetry missions have been launched by both NASA and ESA in the last two decades, e.g. NASA's ICESat (2003-2008), ESA's CryoSat-2 (2010 onwards) and NASA's ICESat-2 (2018 onwards), which have driven much of these recent efforts to-date. However, such efforts are hindered by the challenge of obtaining accurate altimetry measurements of ice freeboard (its extension above sea level), along with the ancillary data needed (e.g. snow depth, ice/snow density) to accurately infer ice thickness.

To help calibrate and validate these satellite altimetry thickness estimates, several different airborne and in-situ campaigns have been launched by both agencies. NASA's Operation IceBridge has provided annual multi-sensor airborne profiling of western Arctic and Southern Ocean sea ice since 2009, while ESA's CryoVEx has provided airborne and ground-based data collection across various years since 2002, including several coordinated campaigns with Operation IceBridge. These activities have provided invaluable data for cross-calibration and validation, with future campaigns expected to continue to provide the necessary data needed to improve our understanding of CryoSat-2 returns and calibrate/validate the new ICESat-2 mission. Several other ground-based sea ice campaigns have been undertaken and are yet to be fully exploited. Here we present a summary of these joint NASA-ESA efforts, provide examples of recent attempts to improve and reconcile the sea ice thickness record from these various altimetry missions, and look ahead to upcoming cal/val opportunities.

Satellite altimetry of sea ice

We now have at our disposal data from nearly 20 years of active altimetry missions that provide data over the polar oceans, with their utility (spatial/temporal coverage, orbit, resolution, sensors) consistently improving, especially in more recent years, together with new possibilities for multi-satellite analyses.

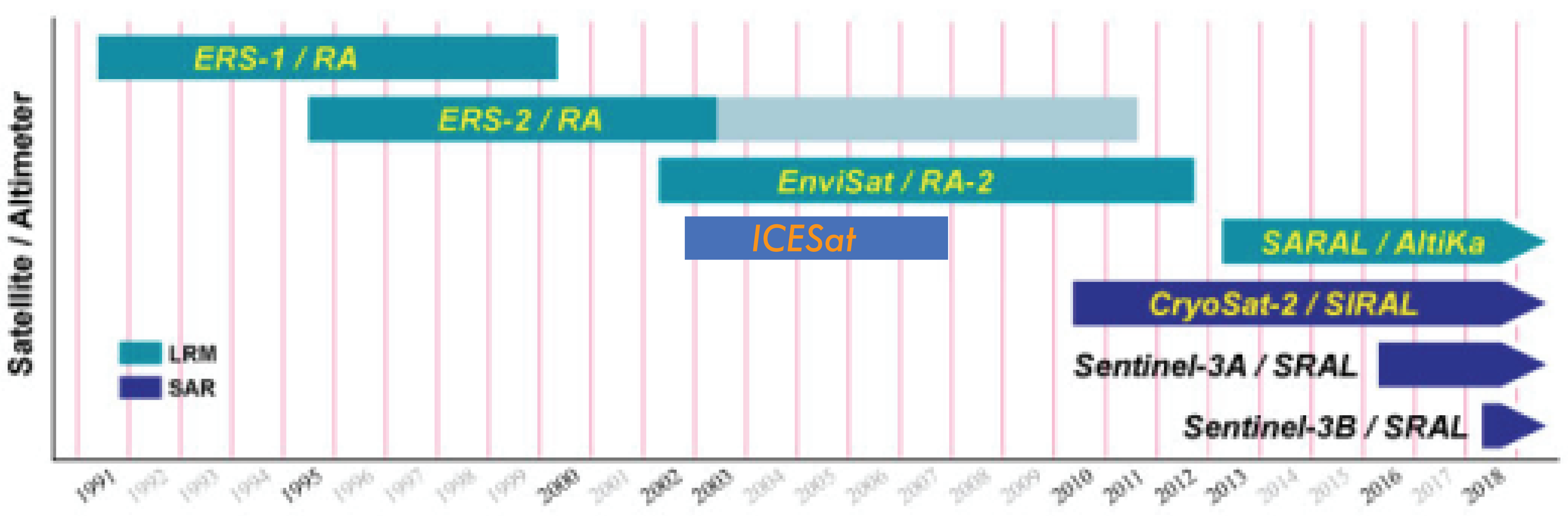


Figure 1: Time series of satellite altimetry missions with polar orbits, suitable for altimetry of sea ice (from Quartly et al., 2019)

2019: A golden year of sea ice remote sensing?

2019 is looking like a golden year for those intereseted in the remote sensing of sea ice. NASA's newly launched ICESat-2 mission is now providing routine high-resolution elevation measurements over sea ice in both hemispheres, with official product releases expected imminently. ESA's CryoSat-2 is still operating well, along with new and complimentary radar altimetery missions such as Sentinal-3 and AltiKa. Both NASA and ESA have also organized significant airborne campaigngs to help better understand these various assets, enabling comprehensive multi-sensor profiling of sea ice at basin-scales.

Calibration/validation efforts

ESA's CryoVex

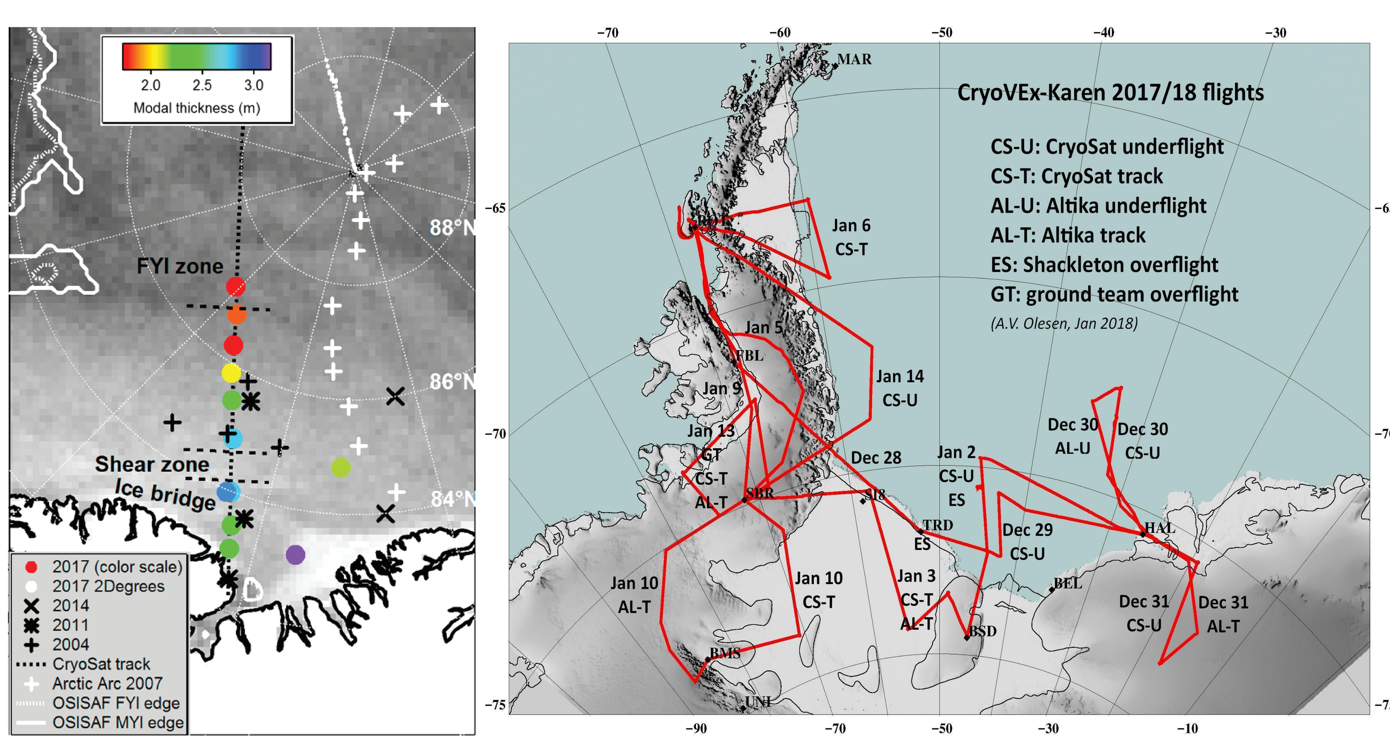


Figure 3: (left) Map of CryoVEx 2017 sampling locations along CryoSat-2 orbit 37159 (black dotted line) and two sites in the northeast, color coded by modal total ice thickness. Small white dots show locations of the 2017 2-Degrees Expedition.

(right) Map of the Antarctic CryoVex/Karen campaign. Note the joint CryoSat-2 underflight and Shackleton overflight in the Weddell Sea, of high interest to the sea ice remote sensing community.

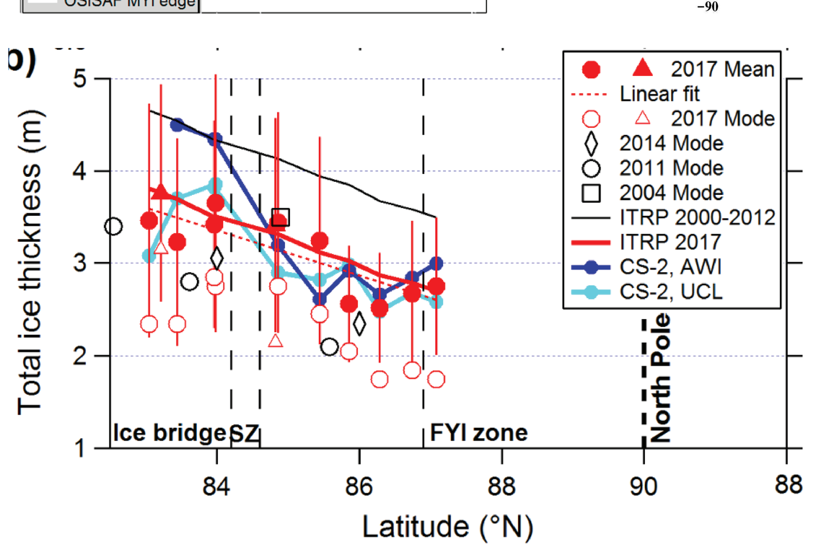


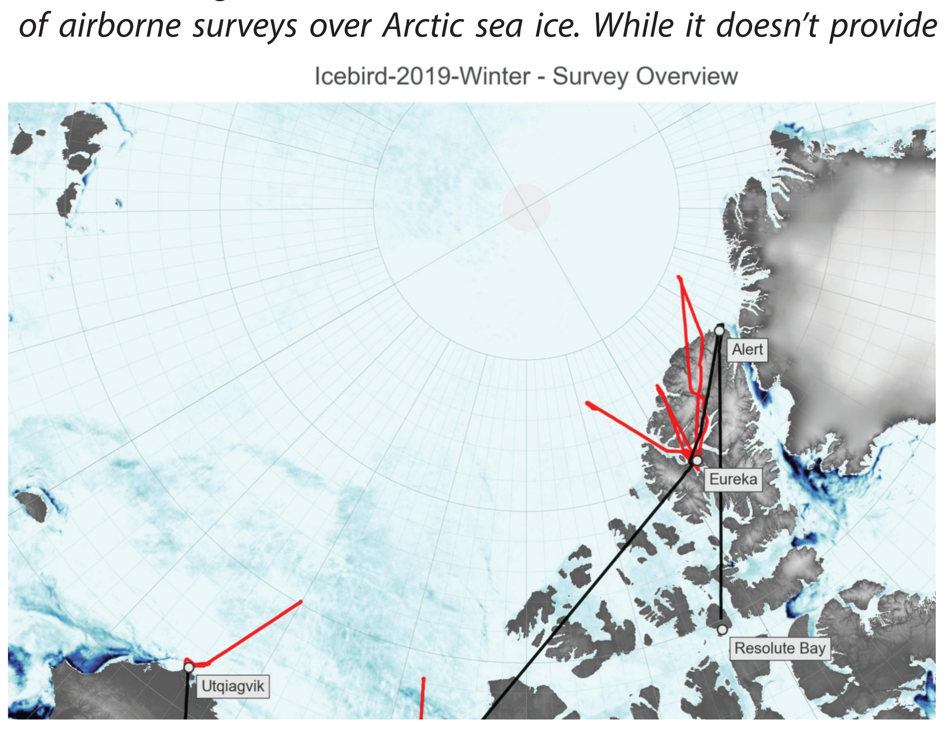
Figure 4 (left) Sea ice thickness measurements collected during the CryoVEx 2017 campaign (red circles) and CryoSat-2 thicknesses based on the Warren climatology based on the CPOM and AWI processing (blue lines), from Haas et al., (2017).

The recent study by Haas et al., (2019) (Figure 3a & 4) demonstrated an increasingly needed effort for the sea ice observation community - assessing multiple satellite retrivals with in-situ data collected over a large region (capturing both multi-year and first-year ice). The data shows surprising agreement with thickness data generated using the now outdated Warren snow depth climatology, however more analyses like these are needed across different regions and seasons of the Arctic (and Southern Ocean) system.

ESA's IceBird mission

The Alfred Wegener Institute for Polar and Marine Research (AWI) operates an airborne mission - IceBird - which is a series of airborne surveys over Arctic sea ice. While it doesn't provide the same spatial coverage of Operation IceBridge, the multi-sensor approach is similar, and the use of an EM-bird provides information of ice draft not provided by Operation IceBridge (above right). The IceBird campaigns also take place twice a year: In summer (August) and winter (March/April) and operate out of multiple Arctic bases as shown on Figure 5.

IceBird data provides a useful compliment to Operation IceBridge due to the differing instrament suite and the contrast in regions/time period of the relevant campaigns. The data needs to be better exploited by the community, especially those interested in validating data collected by both NASA's ICESat-2 and ESA's CryoSat-2. The mission is also likely to gain importance as Operation IceBridge comes to an end and IceBird can continue providing consisent airborne profiling of Arctic sea ice.



AWI IceBird campaign; Four week campaign based out of 5 different Arctic bases, taken from Twitter (@sthendricHendricks)

NASA's ICESat-2 and ESA's CryoSat-2

NASA's ICESat-2 mission was launched in September 2018 with the primary goal of monitoring our fast-changing polar regions. The sole instrument onboard, the Advanced Topographic Laser Altimeter System (ATLAS), is now providing us with routine, very high-resolution, surface elevation data over the Earth's surface, including the Arctic and Southern Oceans. At the NASA Goddard ICESat-2 project science office, we have developed a new processing chain to convert the official along-track ICESat-2 freeboard product (ATL10) into sea ice thickness, focusing for now on the Arctic sea ice cover. We primarily make use of snow depth and density data produced from the NASA Eulerian Snow on Sea Ice Model (NESOSIM) and are comparing this with thicknesses estimates derived from modified versions of the Warren snow climatology. The data and souce code will all be made publically available shortly after the release of the official (ATL10) freeboard product (expected release: summer 2019).

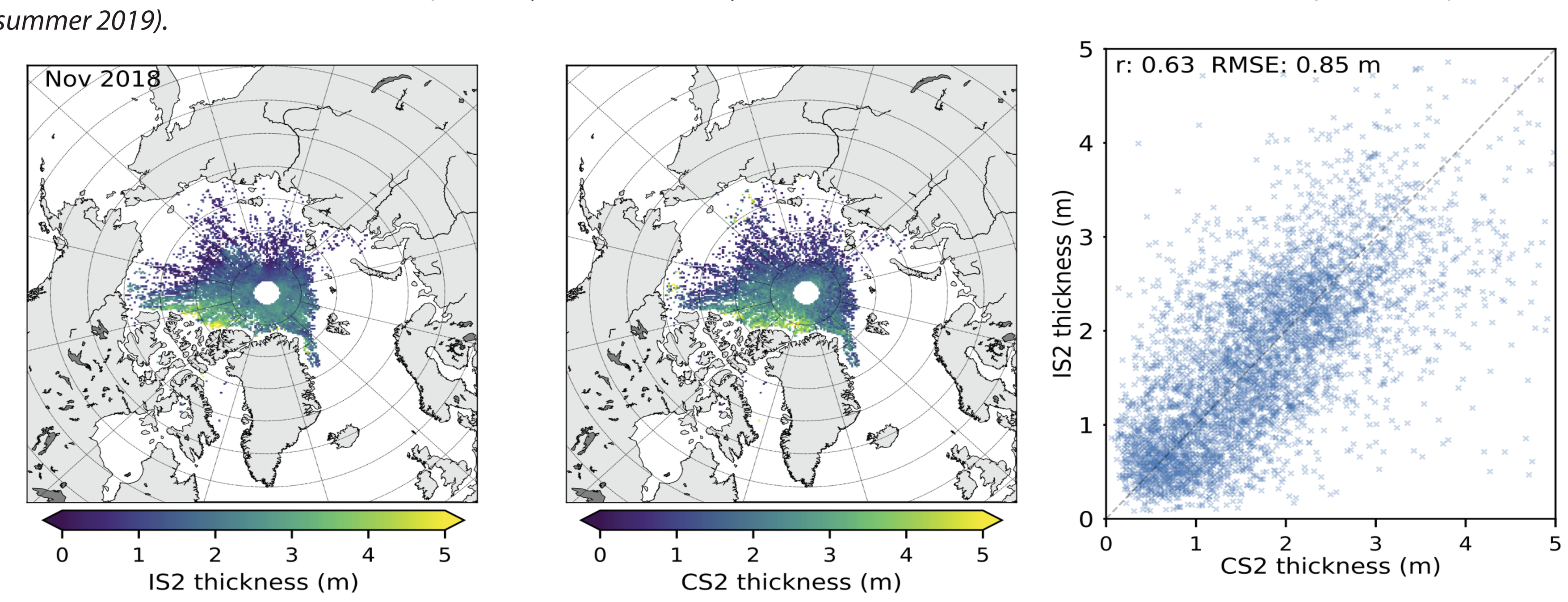


Figure 2: Preliminary comparison of sea ice thickness derived from ICESat-2 (ATL10) and CryoSat-2 freeboards using NESOSIM snow depth and density) for data collected in November 2018. More work needs to be done to explore these comparisons across the available CryoSat-2 products and using different input assumptions.

ESA's CryoSat-2 mission was launched in 2010 and continues to provide routine monitoring of the polar regions. Multiple international groups are now using these data to produce estimates of sea ice freeboard and thickness. Comparisons of ICESat-2 and CryoSat-2 thickness data are currently underway, with considerations of differences in both the radar retracking (CryoSat-2) and input data assumptions needed to better understand potential biases/differences. Our hope is that ICESat-2 data (and data collected by NASA's airborne mission Operation IceBridge) can be used to improve CryoSat-2 sea ice estimates and we are actively working with the community to explore these ideas.

NASA's Operation IceBridge

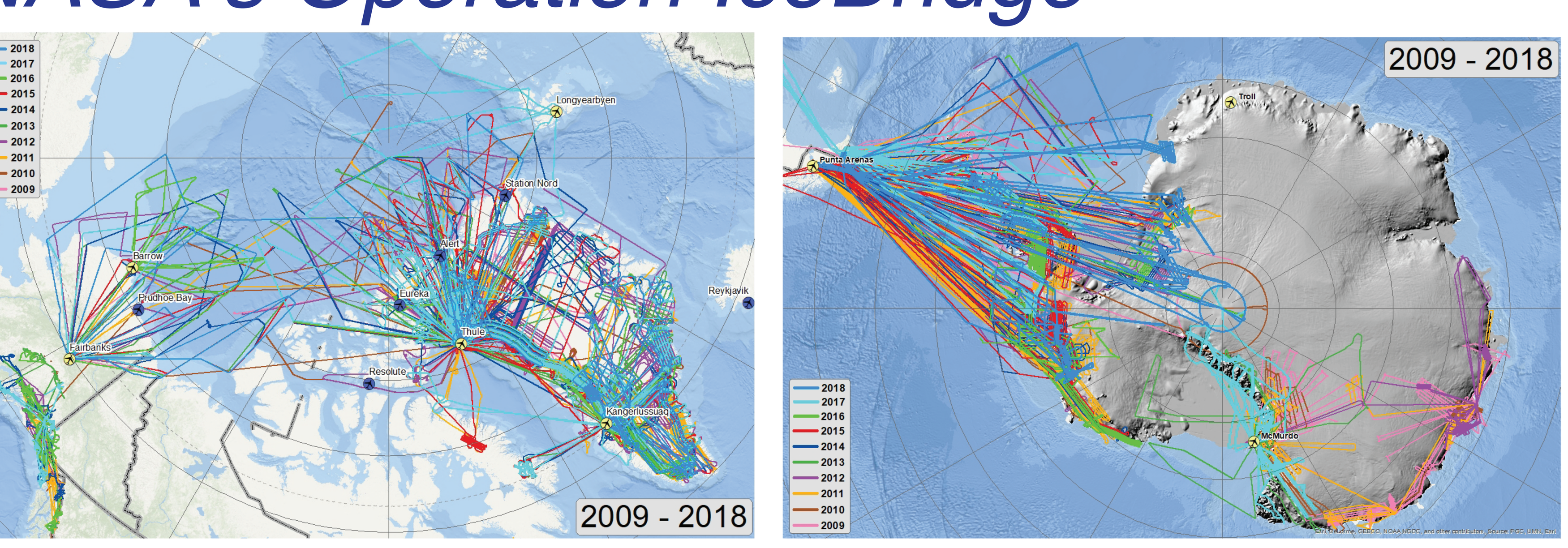


Figure: 2009-2018 Operation IceBridge flight lines.
Recent OIB time-coincident underflights of ESA/DLR satellites over sea ice in the Arctic Ocean during spring P-3 campaigns: 2018: Three underflights, including two beneath Sentinel-3A (639 km) and one beneath CryoSat-2 (432 km), 2019: Two underflights, including one beneath Sentinel-3B (372 km) and one beneath CryoSat-2 (859 km). Potential underflights during last two OIB campaigns: 2019 Arctic summer and 2019 Antarctic onboard NASA G-V

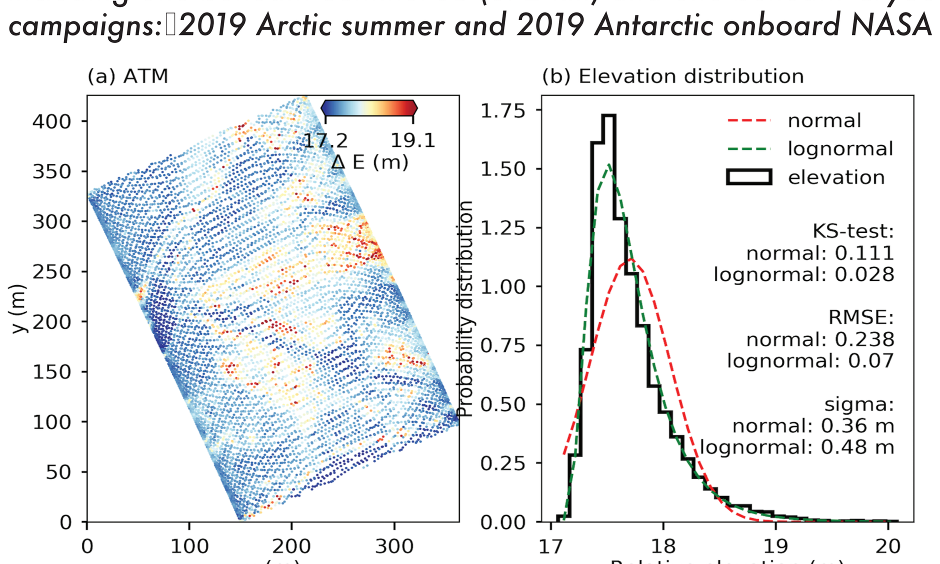


Figure: Elevation distribution from the Airborne Topographic Mapper, operated as part of NASA's Operation IceBridge.

Operation IceBridge is an airborne campaign that started in 2009 to bridge the gap between the end of ICESat (2008) and the launch of NASA's ICESat-2 (which launched successfully in September 2018). Recent campaigns have thus focussed increasingly on validating initial data returns from ICESat-2 over the polar regions (land ice and sea ice). It is expected that IceBridge will end in 2020 as it acheives its principle mission objective (bridging the gap).

The Figure on the left highlights a recent and novel utility of IceBridge data - understand the ice topography distribution for a typical CryoSat-2 sized swath, to better understand the impact of surface roughness on CryoSat-2 radar returns.

Other international efforts?

The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) is an upcoming year-round expedition into the central Arctic (onboard the Polarstern) which will provide an unprecedented opportunity for calibration/validation activities. NASA are closely involved in the MOSAiC mission, through the direct partipation of Dr. Melinda Webster and Dr. Nathan Kurtz (ICESat-2 deputy project scientist). There are talks underway to discuss possible flybys of the MOSAiC camp by Operation IceBridge next spring, although this will depend strongly on the ship's drift through winter.

Future needs

While lots of activities are planned for 2019, future cal/val opportunities are less certain. NASA's Operation IceBridge comes to an end in 2020 and MOSAiC should be completed by early 2020 (if not before). More in-situ campaigns are cleraly needed, preferably with more obvious tie-ins with existing missions/campaigns. The community desperately needs more data to assess seasonal sea ice conditions to help us better understand how various sensors interact with different ice/snow surface conditions. We also encrouage more rapid data release to better enable cal/val analysis, especially as the satellite products move towards more operational data release. Antarctic sea ice is still a largely undersampled medium, so leveraging data already collected and planning appropriate future campaigns is strongly recommened.