Detecting and Characterizing Sea Ice Pressure Ridges with ICESat-2

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Abstract

Since its launch, in September 2018, ICESat-2's Advanced Topographic Laser Altimeter System (ATLAS) has collected high-resolution measurements of Arctic sea ice by sampling the surface every 70 cm along-track. We utilize the high-resolution capabilities of ATLAS with a novel algorithm called the University of Maryland-Ridge Detection Algorithm (UMD-RDA) to investigate sea ice topography across a range of scales. Applying the UMD-RDA to the ATL03 Global Geolocated Photon product we measure surface roughness and derive the frequency, height, width, and angle of individual pressure ridge sails. Aggregating data from multiple orbit crossings per day we investigate ridge characteristics at length-scales varying from 1 km (individual floes) to the pan-Arctic scale (central Arctic Ocean). Here, we present an evaluation of pressure ridge characteristics during the winter seasons of 2018/19, 2019/20, and 2020/21, comparing results from distinct regions with varying ice conditions. Near-coincident, independent observations of pressure ridges with Operation IceBridge (OIB) Airborne Topographic Mapper (ATM) lidar data, OIB near-coincident Continuous Airborne Mapping By Optical Translator (CAMBOT) high-resolution (~15 cm) optical imagery, and WorldView high-resolution (~30 cm) panchromatic satellite imagery are used to evaluate the accuracy of our ICESat-2 ridge detection scheme. There are many potential use-cases for a high-resolution sea ice topography data product within the community, ranging from navigational hazard mitigation to ecological studies of marine mammal habitats. We discuss plans for releasing these data products and discuss the improvements such data would make within high-resolution sea ice models.

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INTRODUCTION

ICESat-2 is the successor mission to the Ice, Cloud and Land Elevation Satellite (ICESat) that was launched on 15 January 2003 and carried a single-beam, 532-nm photon-counting laser altimeter operated at 40 Hz. The laser footprint diameter was 70 m and the along-track spacing was 172 m.

Sea ice freeboard measurements from ICESat have been used to estimate sea ice volume and thickness. This is accomplished through comparisons of the ICESat sea height with University of Bremen Ridge Detection Algorithm (UBRDA) sea ice height data, which are used to define the local sea surface height. Previous studies report that ICESat's laser footprint, which spans 70 m, and its large vertical footprint, which ranges between tens and hundreds of meters, depending on surface roughness, cloud cover, and atmospheric conditions, can lead to a high bias in the ice freeboard estimate. This bias is caused by the presence of leads within the laser footprint, which can lead to an underestimate of the local sea surface height, and therefore an overestimate of sea ice freeboard. Although the ICESat-2 laser footprint is still 10 times larger than the along-track spacing, the footprint is now much closer to the scale of the ice features of interest, and the improved vertical resolution of the ATLAS instrument should allow for better discrimination between leads and ridges.

DATA & METHODOLOGY

ATL03

The ICESat-2 ATLAS Global Geolocated Photon Height product contains photon heights above the WGS-84 ellipsoid (ITRF2014), latitude, longitude, and time for all photons that are processed onboard the ATLAS instrument. Ancillary and auxiliary information would be appended to ATL03 in Phase 3 of the mission (Neumann et al., 2016).

Product landing page: https://nsidc.org/data/atl03/overview#2

ATL07

The ICESat-2 ATLAS Sea Ice Height product is derived from the ATL03 product. ATL07 contains along-track heights for sea ice surfaces and the leads (sea surface height) in the ice pack, along with various other parameters (e.g. height, width, other statistics) for geophysical and land corrections, and uncertainties for each segment (Kwok et al., 2016).

Product landing page: https://nsidc.org/data/atl07/overview#2

ATM

The Airborne Topography Mapper (ATM) is a scanning scanning laser and lidar system used by the NASA Operation IceBridge mission to measure elevation, surface roughness, and sea ice freeboard. ATM data are regularly collected over the Arctic for comparison of ICESat data.

Product landing page: http://nsidc.org/data/icebr/atm/overview.html

UBRDA Ridge Sea Ice Product

The University of Bremen Ridge Sea Ice Product (UBRDA) is a sea ice height product that includes the attributes of ridges and of leads (Ridge Sea Ice Product and Lead Sea Ice Product). The UBRDA ridge product is derived from ATL07 sea ice height data and is provided by the Alfred Wegener Institute (AWI).

Product landing page: http://www.meereisportal.de/en/ICESat-2/UBRDA/

UBRDA DEM

The UBRDA DEM is a surface elevation dataset for sea ice surface height. The UBRDA DEM is supplied by the AWI and provided as a gridded product. Each grid cell contains the median, mean, standard deviation, and other statistical information for the sea ice surface height within the grid cell. The UBRDA DEM is derived from ATL07 sea ice height data. The segments in ATL07 are aligned across the beam pairs, so the UBRDA DEM can be generated from a single beam. The UBRDA DEM is provided in a polar stereographic projection with a grid cell size of 25 m. The UBRDA DEM is also available in a 1-km grid cell size, which is the minimum along-track resolution of ATL07 for a single beam. The UBRDA DEM is also available in a 25-km grid cell size, which is the minimum along-track resolution of ATL07 for a single beam. The UBRDA DEM is also available in a 25-km grid cell size, which is the minimum along-track resolution of ATL07 for a single beam. The UBRDA DEM is also available in a 25-km grid cell size, which is the minimum along-track resolution of ATL07 for a single beam.

VALIDATION

UPS-Ridge and ATLAS* Validation with DIA-UPW

We select ATM data for comparison with the UBRDA Ridge Sea Ice Product because it provides the most comprehensive and consistent ICESat-2 data. On April 25, 2017 ATM gridded data for coastal along-track lines of ICESat-2 tracks (ATL03 and ATL07) are available for the Beaufort Sea, Chukchi Sea, and Lincoln Sea.

First, the ATM data are filtered and binned to a 25-m grid. Then, the ATM data are compared with the UBRDA Ridge Sea Ice Product and the ATL07 sea ice height product. The ATM data is then processed using the UPW-Lead Sea Ice Product (UPS-Lead) and the UPS-Ridge Sea Ice Product (UPS-Ridge). The UPS-Ridge Sea Ice Product is a modified version of the UBRDA Ridge Sea Ice Product, which includes modifications, such as the calculation of the local sea surface height using the UPS-Lead Sea Ice Product. The UPS-Lead Sea Ice Product is a modified version of the UBRDA Lead Sea Ice Product, and ATL07 profiles. The profiles are then re-sampled to 25-m grid, and filtered using a maximum filter to reduce the impact of small-scale variability in the local sea surface height.

Correlation between ATM and UBRDA Ridge is 0.0 for 1-km, which increases to 0.4 for 25-km and 0.5 for 1-km. The UBRDA DEM's slopes are 1 and 0.9 for 1-km and 25-km respectively. ATLAS* shows agreement to the Beaufort Sea

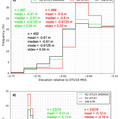

Figure 1: (a) Map of ATM Lead Fraction for April 25, 2017. Green lines show the coincident ICESat-2 ATL03 and ATL07 ground tracks. Lower right: Histogram of Lead Fraction. Lead Fraction is defined as the number of lead points divided by the total number of points in the 25-m grid cell.

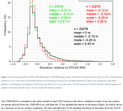

Figure 2: (a) Comparison of the Arctic-wide ATM data to ICESat-2 ATL07 sea ice height data. The ATM data are binned to a 25-m grid, and the ATL07 data are re-sampled to a 25-m grid. The ATM data are filtered using a maximum filter to reduce the impact of small-scale variability in the local sea surface height. (b) Comparison of the Arctic-wide ATM data to ICESat-2 ATL07 sea ice height data. The ATM data are binned to a 25-m grid, and the ATL07 data are re-sampled to a 25-m grid. The ATM data are filtered using a maximum filter to reduce the impact of small-scale variability in the local sea surface height. (c) Comparison of the Arctic-wide ATM data to ICESat-2 ATL07 sea ice height data. The ATM data are binned to a 25-m grid, and the ATL07 data are re-sampled to a 25-m grid. The ATM data are filtered using a maximum filter to reduce the impact of small-scale variability in the local sea surface height. (d) Comparison of the Arctic-wide ATM data to ICESat-2 ATL07 sea ice height data. The ATM data are binned to a 25-m grid, and the ATL07 data are re-sampled to a 25-m grid. The ATM data are filtered using a maximum filter to reduce the impact of small-scale variability in the local sea surface height.

Further examination of the Arctic-wide data (see Figure 2) finds that each of the three profiles also provides a local correlation (Figure 3a-c). Comparisons of the two datasets at each profile show agreement. The correlation of the data is 0.5 for the Beaufort Sea, 0.6 for the Chukchi Sea, and 0.7 for the Lincoln Sea. The UBRDA DEM's slopes are 1 and 0.9 for 1-km and 25-km respectively. The UBRDA DEM's slopes are 1 and 0.9 for 1-km and 25-km respectively. The UBRDA DEM's slopes are 1 and 0.9 for 1-km and 25-km respectively. The UBRDA DEM's slopes are 1 and 0.9 for 1-km and 25-km respectively. The difference in the median and mean values of the UBRDA DEM and ATM data are 0.0 and 0.1 for the Beaufort Sea, 0.0 and 0.1 for the Chukchi Sea, and 0.0 and 0.1 for the Lincoln Sea