Early Assessment of Sentinel-3A Measurements over Arctic Sea Ice

Laurence Connor[1], Eric Leuliette[1], Sinéad L. Farrell[1,2], Kyle Duncan[1,2]
David C. McAdoo[1,2], John Lillibridge[1]

[1] NOAA Laboratory for Satellite Altimetry, NCWCP, College Park, MD
[2] Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, MD

Introduction

- Launched February 16, 2016, Sentinel-3A will provide critical measurements of sea ice freeboard and sea surface height in the Arctic Ocean (to 81.5 °N).
- Since 2002, the NOAA Laboratory for Satellite Altimetry has cooperated with ESA, EUMETSAT, and NASA to conduct airborne validation experiments over the Arctic Ocean to assess how well sea ice freeboard (and hence ice thickness) can be measured from space using satellite altimetry.
- On 21 April 2016, a NASA Operation IceBridge (OIB) airborne survey was conducted over Arctic sea ice and was timed to coincide with an overpass of the Sentinel-3A satellite (Figure 1). This was the first coordinated airborne survey over sea ice while Sentinel-3A was operating in SAR mode.
- Here we present an early evaluation of Sentinel-3A measurements over Arctic sea ice collected on Cycle 3, Orbit #186, on 21 April 2016, via comparison with coincident OIB measurements and MODIS imagery.
- Lead locations and sea ice pressure ridge conditions along the Sentinel-3A (S3A) orbit are derived from the OIB visible Digital Mapping System (DMS) imagery and compared with the S3A sigma-0 and waveform data.

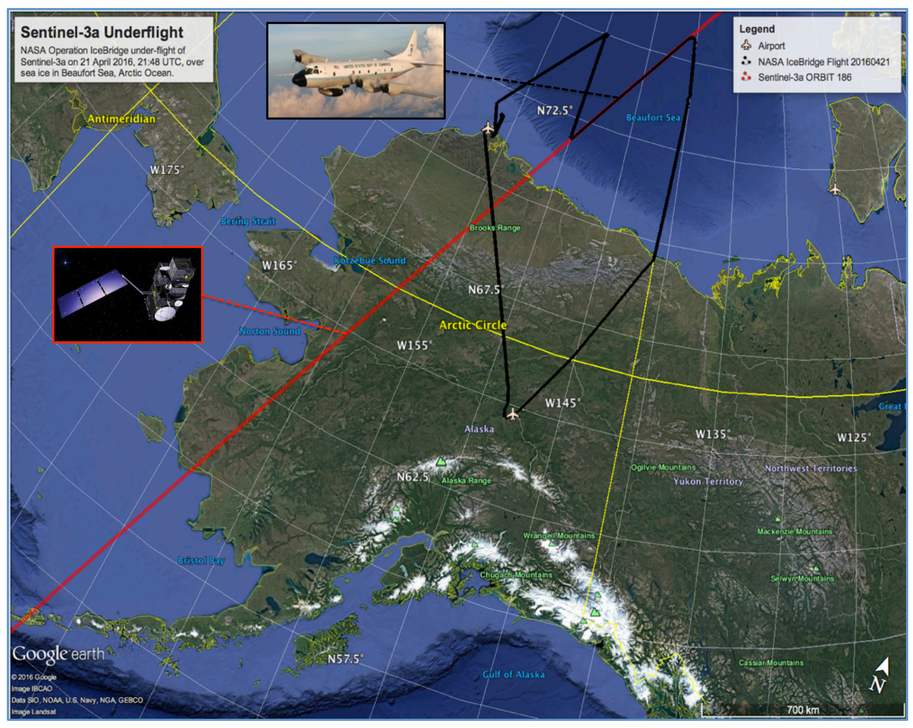

Figure 1: Spatially and temporally coincident data were collected by both OIB and Sentinel-3A in the eastern Beaufort Sea, north of Alaska, on 21 April 2016.

Sentinel-3A Product Variables: Arctic Ocean

S3A Parameter	Mode	Frequency	Variable Name
Waveforms	SAR/Ku-band	20 Hz	waveform_20_ku
Backscatter - Ocean	SAR/Ku-band	20 Hz	sig0_ocean_20_ku
Backscatter - Sea Ice	SAR/Ku-band	20 Hz	sig0_sea_ice_sheet_20_ku
Surface Type	SAR/Ku-band	20 Hz	surf_type_20_ku
Corrected OCOG altimeter range	SAR/Ku-band	20 Hz	range_ocog_20_ku
Corrected Range - Ocean	SAR/Ku-band	20 Hz	range_ocean_20_ku
Corrected Range - Sea Ice	SAR/Ku-band	20 Hz	range_sea_ice_20_ku
Freeboard	SAR/Ku-band	20 Hz	freeboard_20_ku
SSHA	SAR/Ku-band	20 Hz	ssha_20_ku
SSH - sea ice	SAR/Ku-band	20 Hz	sea_ice_sea_surf_20_ku
SSHA - sea ice	SAR/Ku-band	20 Hz	sea_ice_ssha_20_ku
Interpol. Sea Ice SSHA	SAR/Ku-band	20 Hz	int_sea_ice_ssha_20_ku
Snow Depth	n/a	20 Hz	snow_depth_20_ku
Snow Density	n/a	20 Hz	snow_density_20_ku

LSA Validation Data Products: Arctic Ocean

Mission/Platform	Surface Parameter	Instrument
NASA IceBridge	Sea ice/ocean elevation	Airborne Topographic Mapper (ATM)
NASA IceBridge	Surface roughness	Airborne Topographic Mapper (ATM)
NASA IceBridge	Sea ice freeboard	Airborne Topographic Mapper (ATM)
NASA IceBridge	Surface type (lead/floe)	Digital Mapping System (DMS)
NASA IceBridge	Pressure Ridge Height	Digital Mapping System (DMS)
NASA IceBridge	Snow depth on sea ice	Snow Radar
NASA Aqua/Terra	Surface type (lead/floe)	MODIS
Metop-A	Backscatter (NRCS)	Advanced Scatterometer (ASCAT)
Metop-A	Multi-year Ice Flag	Advanced Scatterometer (ASCAT)

Table 1: Primary Sentinel-3A product variables to be evaluated over Arctic sea ice (top) and the sea ice validation data set available at the NOAA Laboratory for Satellite Altimetry (LSA), comprising airborne and satellite remote sensing data products.

Sentinel – 3A Preliminary Analysis

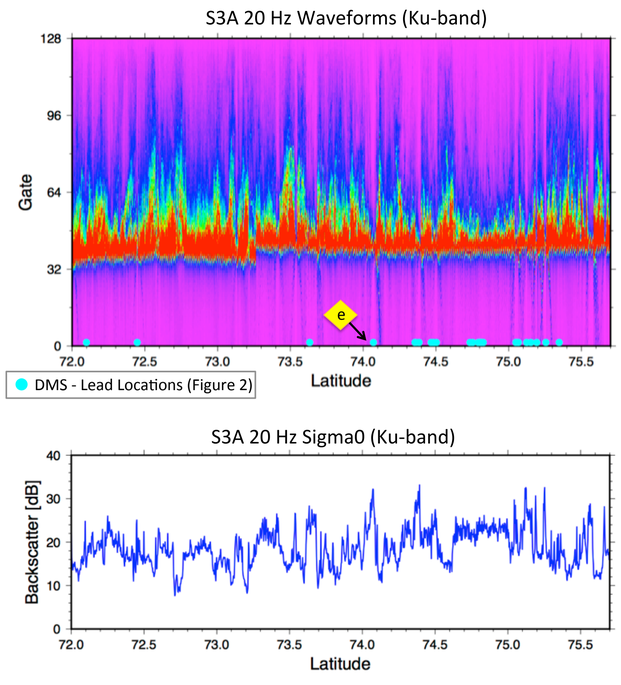

Figure 3: **TOP:** Lead locations (cyan dots) agree with specular returns evident in the S3A waveform stack. **MIDDLE**: S3A backscatter profile over sea ice. **BOTTOM**: Backscatter coefficients overlaid on MODIS imagery.

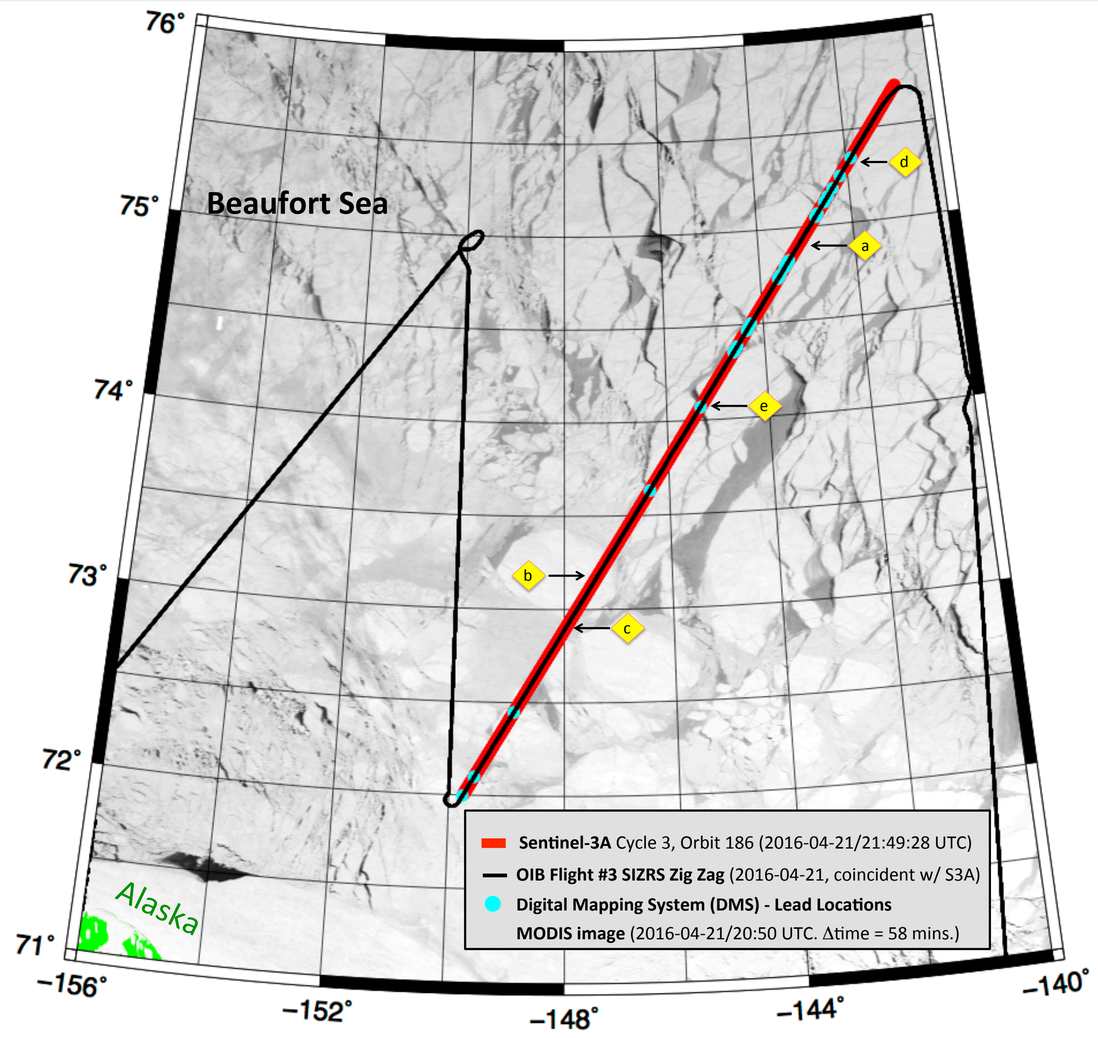

Figure 2: Study-area comprised large, multi-year and first-year sea ice floes, interspersed with numerous open and refrozen leads, as demonstrated in coincident MODIS visible image captured 58 minutes earlier.

IceBridge - Digital Mapping System (DMS)

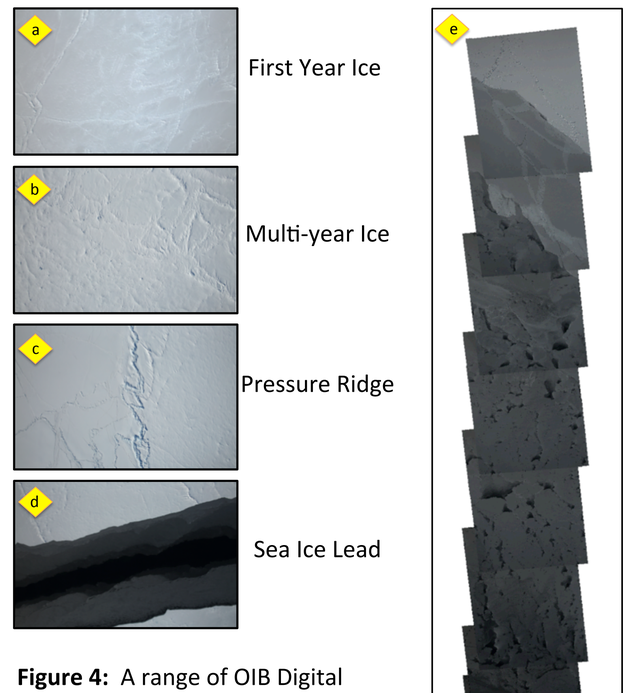

Figure 4: A range of OIB Digital Mapping System (DMS) imagery captured along the Sentinel-3 under-flight showing (a) first-year sea ice floe, (b) multi-year sea ice flow, (c) sea ice pressure ridge, (d) sea ice lead and (e) an extensive lead with new ice growth of varying thickness. The location of these images are shown on Figure 2. Using the OIB DMS dataset we delineate sea ice leads along the Sentinel-3A orbit (cyan dots), as shown on Figure 2.

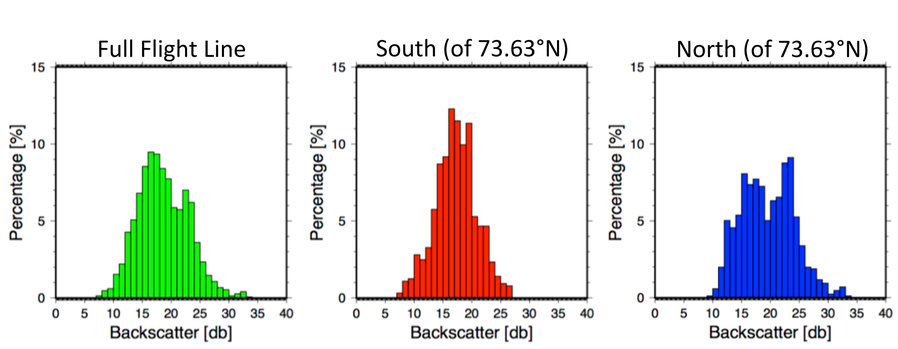

Figure 5: S3A backscatter (20 Hz, Ku-band) distributions along the full flight line (green), the segment south of 73.63°N (red) and the segment north of 73.63°N (blue). A primary mode exists at 15 dB along this S3A orbit segment, however north of 73.63 °N, we find a bi-modal backscatter distribution, with a secondary mode at 23 dB, possibly due to a more diverse mixture of sea ice types.

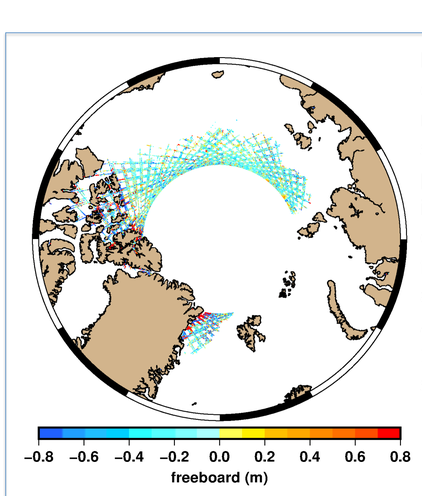

Figure 6: Recently completed reprocessing (V2) shows that the S3A product files now include freeboard estimates. Here freeboard estimates across the Central Arctic basin for 12-25 Oct. 2016 is shown.

Summary

- We assessed a subset of data from Sentinel-3A (S3A) Cycle 3, Orbit #186, collected over Arctic Sea ice in the Beaufort Sea, in April 2016, using a range of validation products including coincident MODIS visible imagery and IceBridge high-resolution DMS imagery, that provide details about sea ice conditions, sea ice types, and lead locations.
- These validation products were used for verification of sea ice lead and floe delineations in the S3A waveforms and backscatter parameters (i.e. to delineate diffuse vs. specular echoes). Our initial assessment of the S3A 20 Hz Ku-band radar waveforms indicates that specular echoes accurately map to locations of sea ice leads identified in the high-resolution IceBridge/DMS imagery. S3A 20 Hz Ku-band backscatter values are also highly consistent with ice conditions along-track, with more diffuse waveforms associated with larger sea ice floes.
- We verified other auxiliary data exists in the S3A data files (e.g. sea ice concentration, snow depth, snow density, surface type, etc.), however the *freeboard_20_ku* parameter does not yet contain data for Cycle 3, Orbit #186 (V1)
- More recent S3A data, for October 2016, that utilizes a new reprocessing scheme (version 2) indicates that freeboard estimates are now available across part of the central Arctic Ocean.

Acknowledgements
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