

High-Resolution Airborne Observations of Sea Ice Pressure Ridge Sail Height

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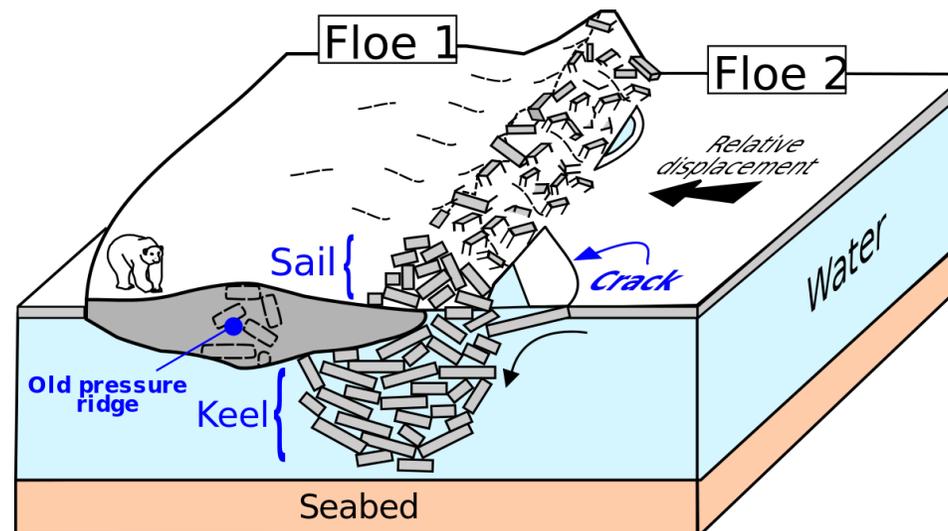
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Motivation

- Climatologically important: mass, energy, and momentum transfer budgets of Arctic Ocean
- Quantifying the fraction of ridged ice in the Arctic will help us better understand the contributions of ridging to total ice thickness, and volume.
- Understanding the inter-annual variability and trends of pressure ridges is important for better understanding sea ice dynamics and improving dynamics in sea ice models.
- Important for maritime operations - ridges pose a serious navigational threat to ships and oil platforms





Data Sets

- We utilize NASA Operation IceBridge (OIB) Digital Mapping System (DMS) visible imagery to measure pressure ridge sail height through analysis of cast shadows.
- DMS images have 10cm spatial resolution and are ~600m x 400m in size when captured at nominal flight altitude of 500m.
- This study seeks to demonstrate the utility of the DMS dataset for measuring sail heights.
- DMS sail heights are compared with coincident OIB Airborne Topographic Mapper (ATM) laser altimeter data to examine accuracy of DMS results.

Methodology

- A more detailed explanation of the methodology is presented in our manuscript (currently in review)
- In short, we exploit the fact that pressure ridges cast shadows on the sea ice surface
- We have developed a methodology to detect the pixels occupied by shadows and with solar information we are able to derive sail heights.

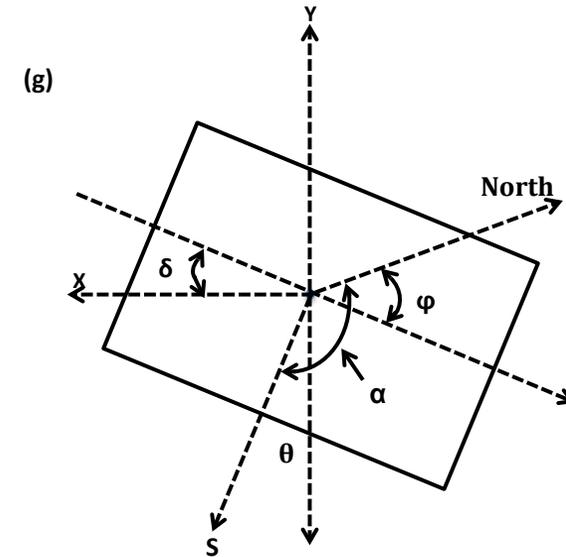
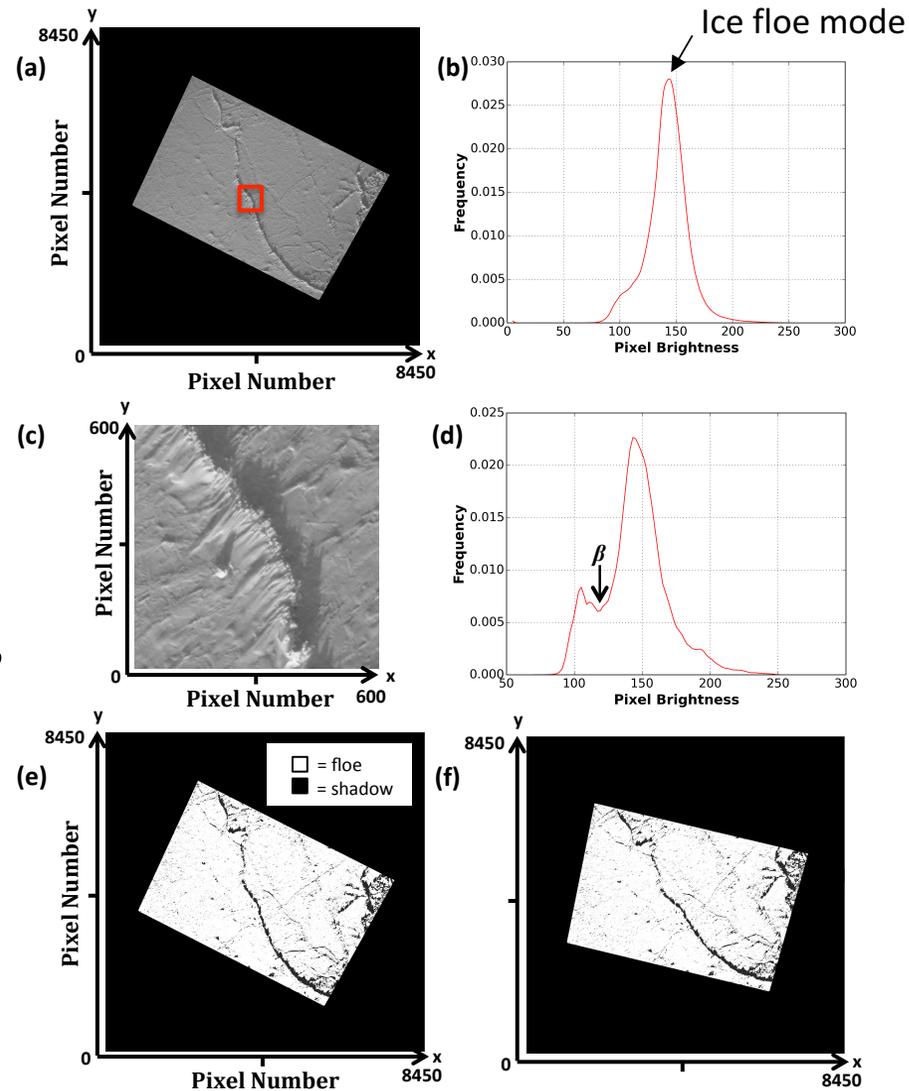
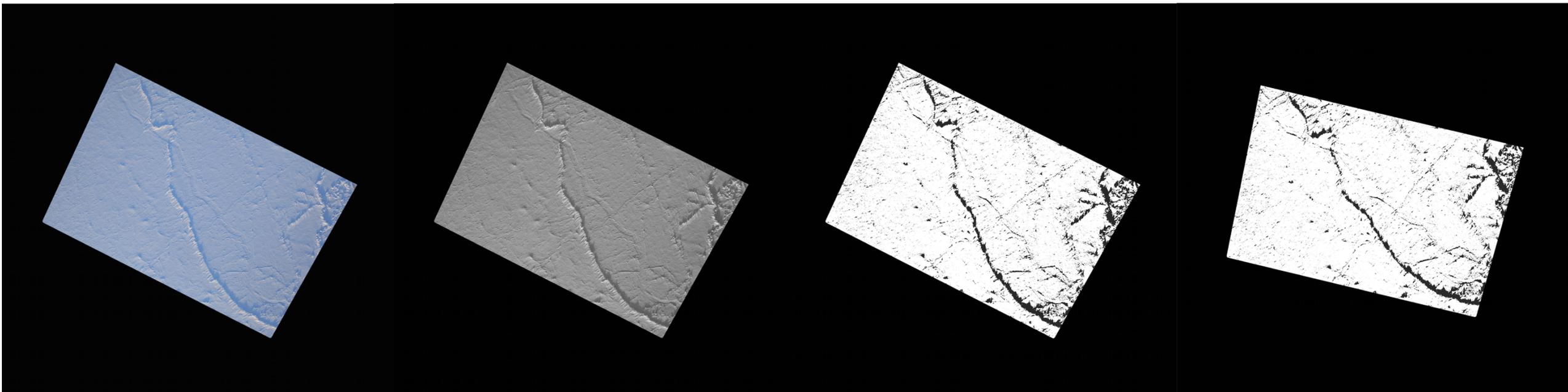


Image Rotation



Original RGB DMS Image

Red Band Image

Binary Mask Image

Rotated Mask Image

Next step is to use the rotated mask image to calculate sail heights...

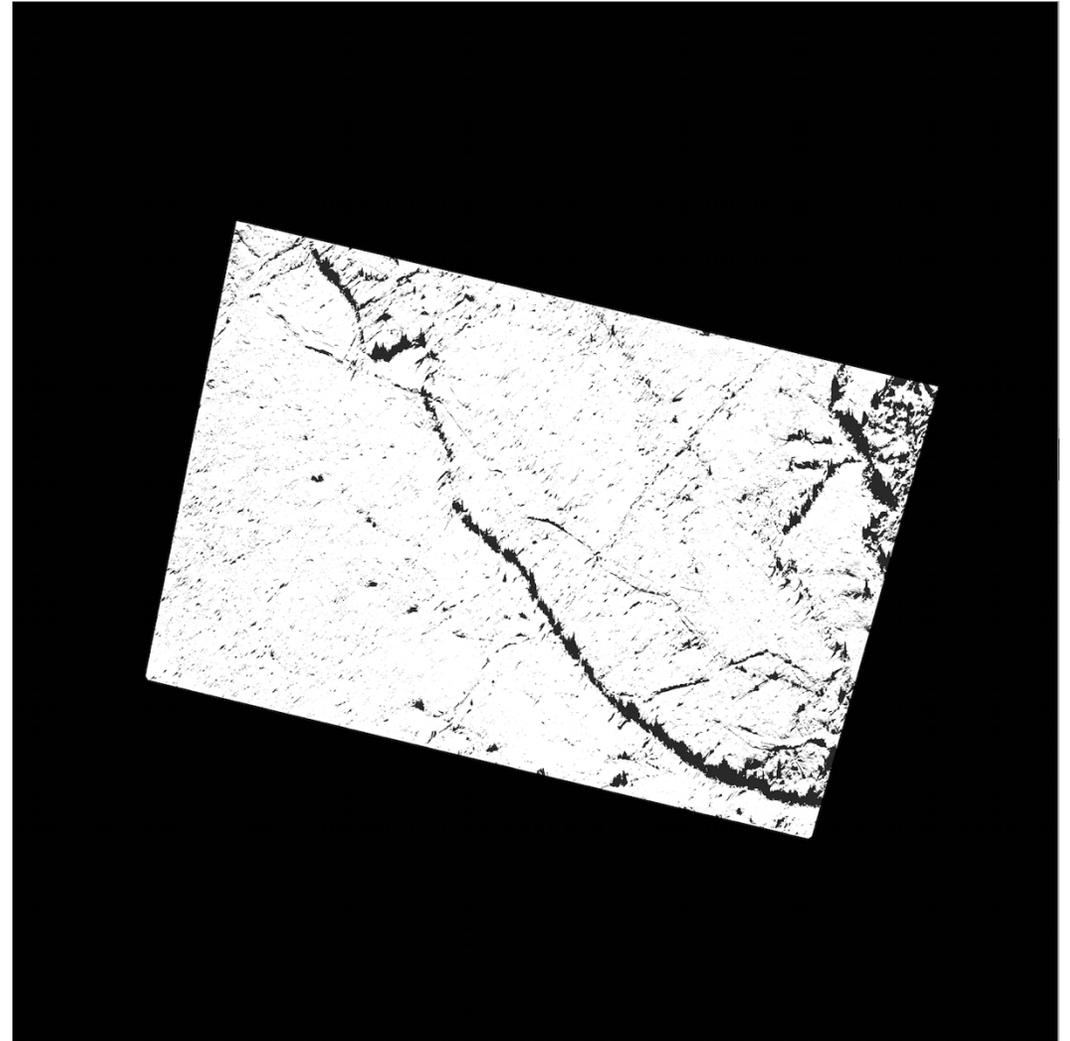
Derivation of Sail Height

- A binary mask of the image is created that distinguishes ice floe pixels (white) and pressure ridge shadows (black).
- The binary mask image is scanned column-wise (top to bottom, left to right) to identify and calculate the length of individual shadow segments.
- The number of pixels in each segment are multiplied by the pixel size of that specific image to obtain shadow length, ℓ , measured in meters.
- Therefore, sail height (H_s) is defined as:

$$H_s = \ell \times \tan a$$

where, a is the solar elevation angle.

- Only sail heights greater than 0.6 m were considered so as not to include sastrugi or other surface features.





Coincident ATM Data

- ATM data provide an independent measure of the height, H , of the surface topography, and are coincident with DMS.
- Here we define a surface elevation anomaly, H_A , for direct comparison with sail height.
- The surface elevation anomaly is defined as:

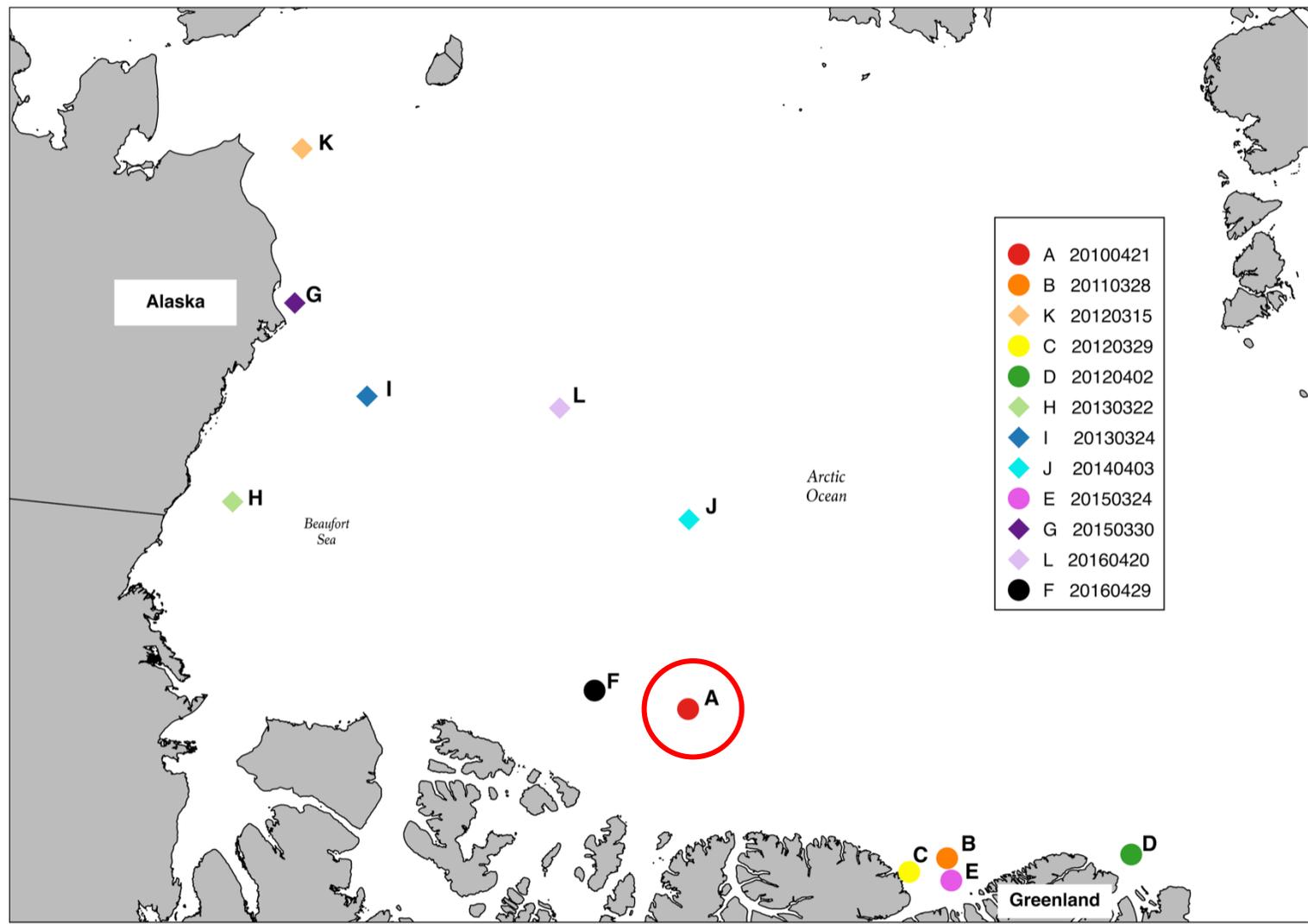
$$H_A = H - H_L$$

where H_L is the height above the local level ice surface

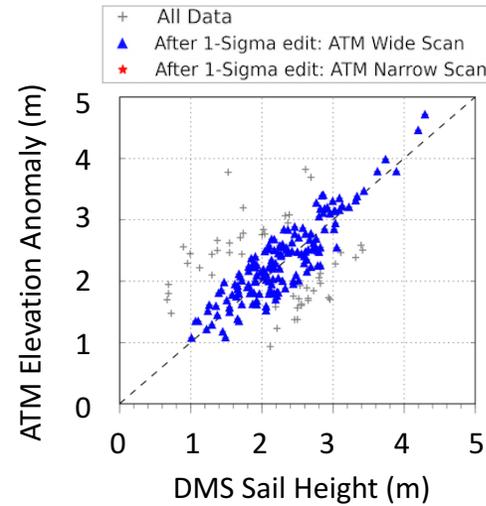
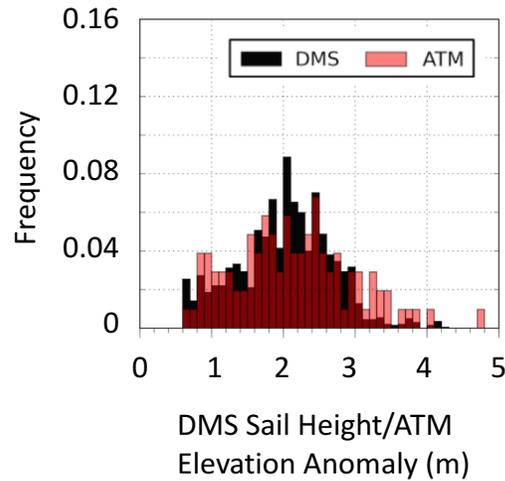
- The local level ice surface is a confined area of smooth ice/snow located within the bounds of the DMS image and in the vicinity of the pressure ridge that is defined by low elevation standard deviation.
- The local level ice surface is computed by averaging no fewer than 300 ATM measurements in the area of smooth ice/snow.
- This average is subtracted from the original ATM elevation values, H , resulting in ATM elevation anomaly which is compared with derived sail heights from DMS.



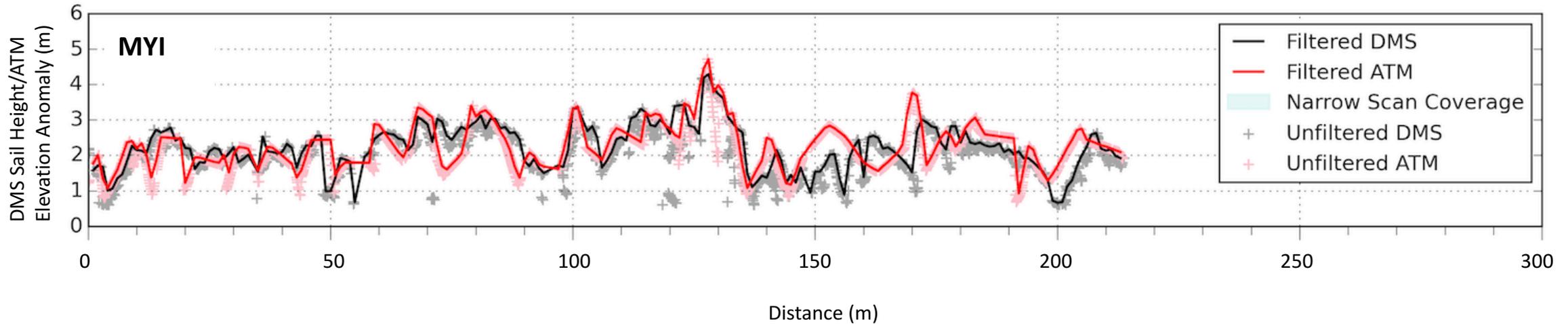
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Example #1: Central Arctic, FY pressure ridge in MYI

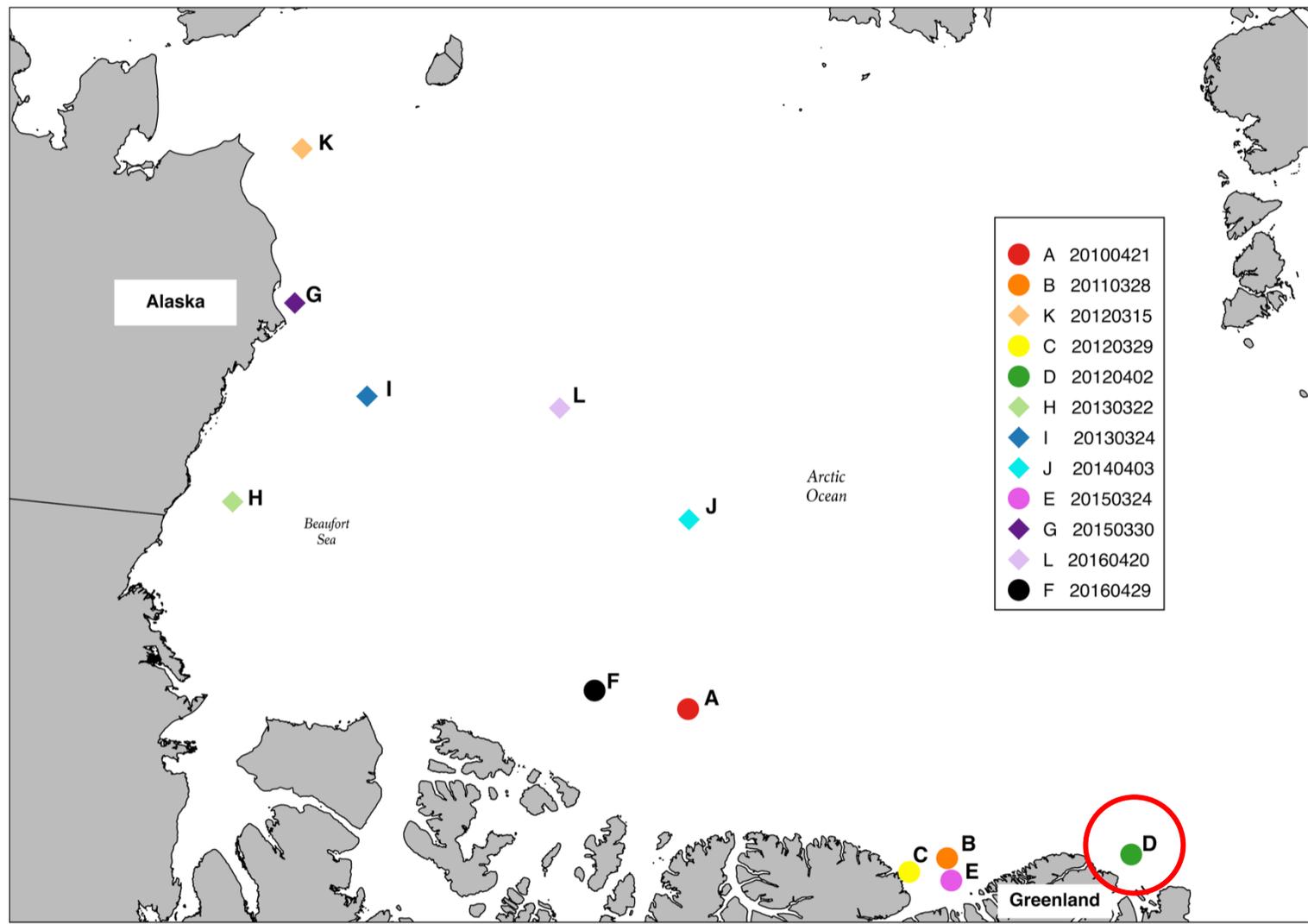


	DMS	ATM
# meas.	1974	101
mean	2.02	2.13
max.	4.2	4.7
r	0.89	
RM	-0.08	

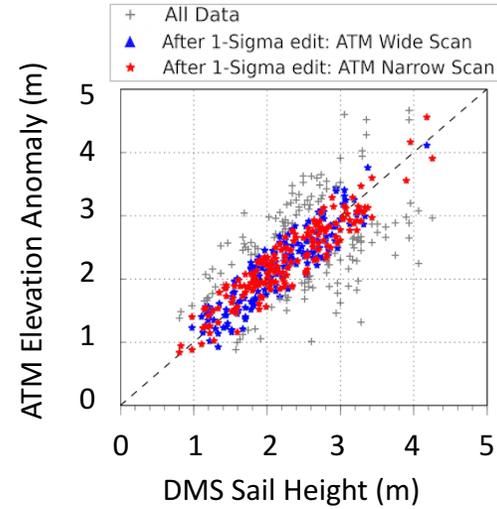
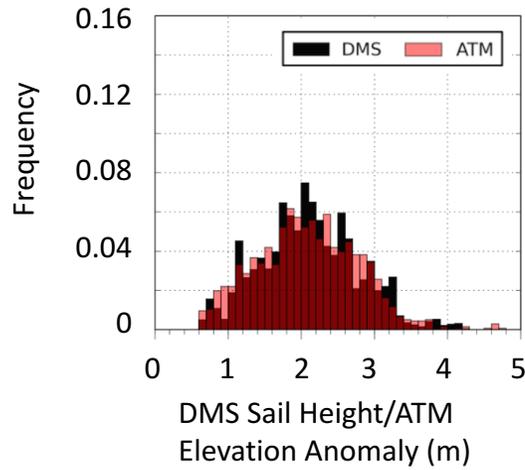
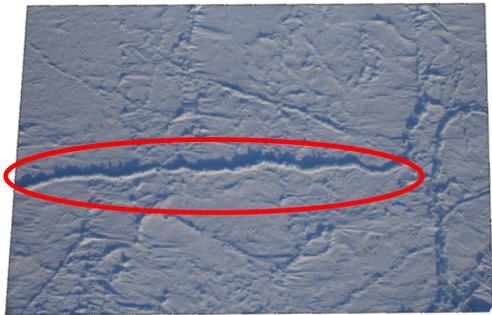




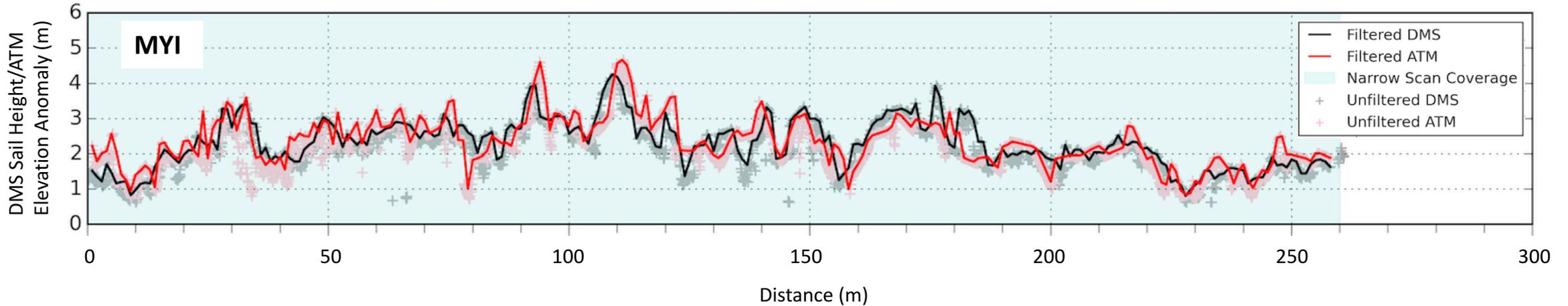
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Example #2: North Greenland, FY pressure ridge in MYI

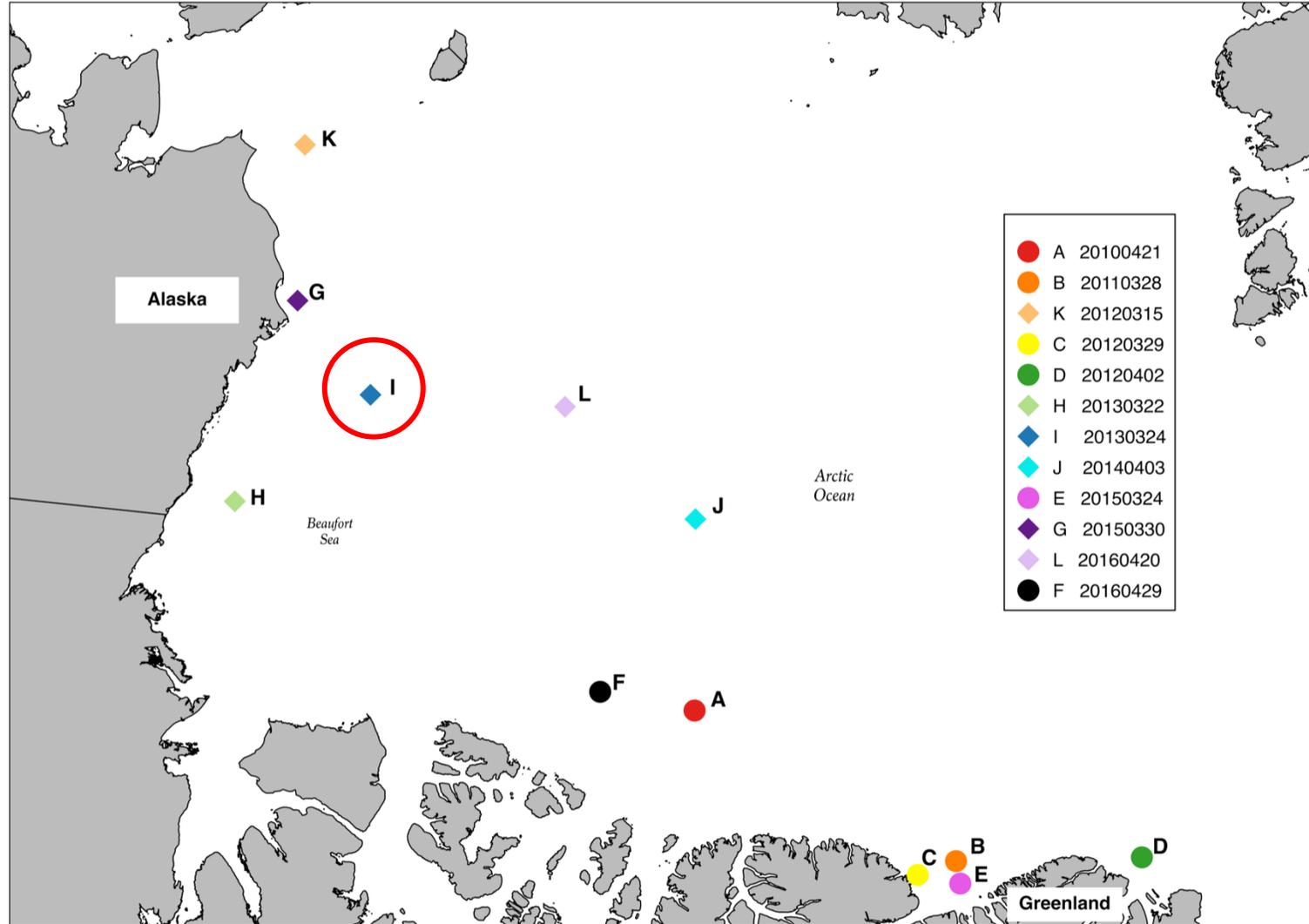


	DMS	ATM
# meas.	2823	625
mean	2.11	2.09
max.	4.2	4.7
r	0.91	
RM	-0.01	

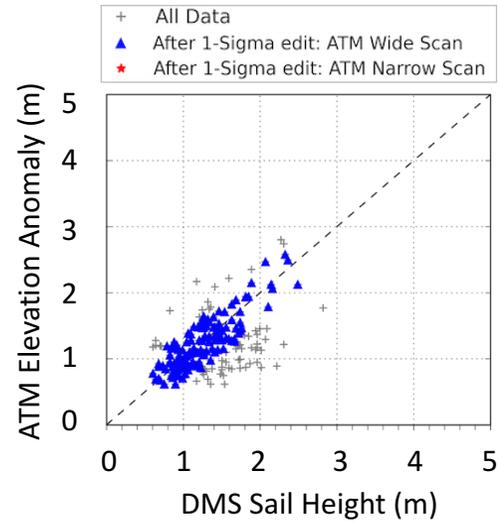
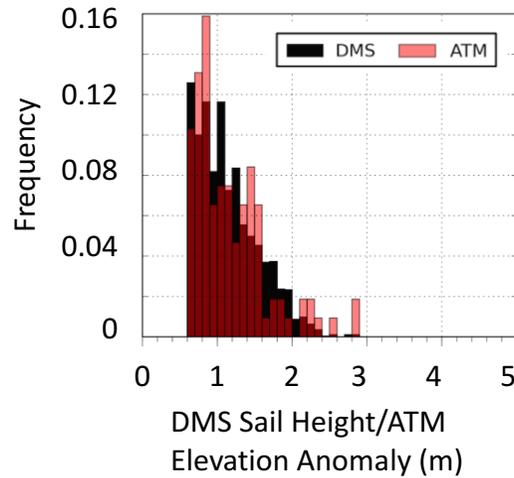
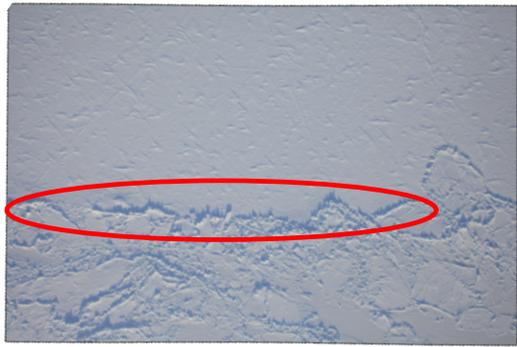




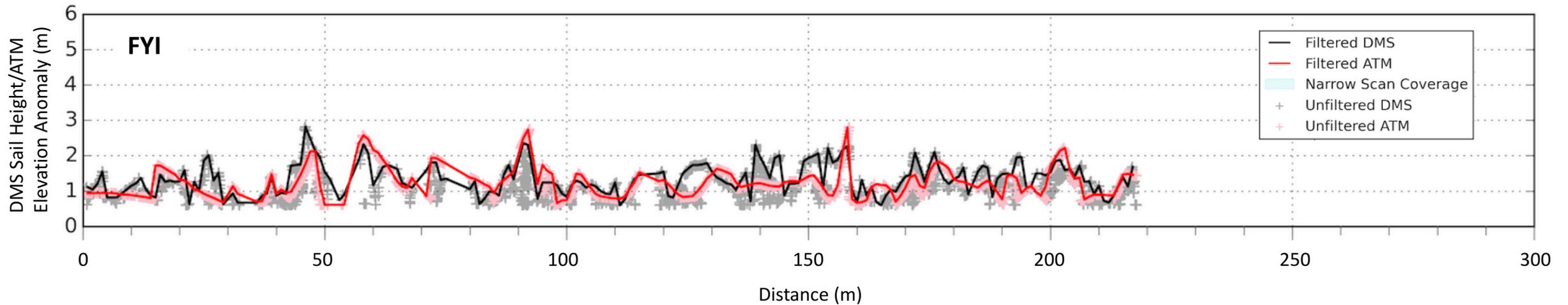
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Example #3: Beaufort Sea, FY pressure ridge in FYI

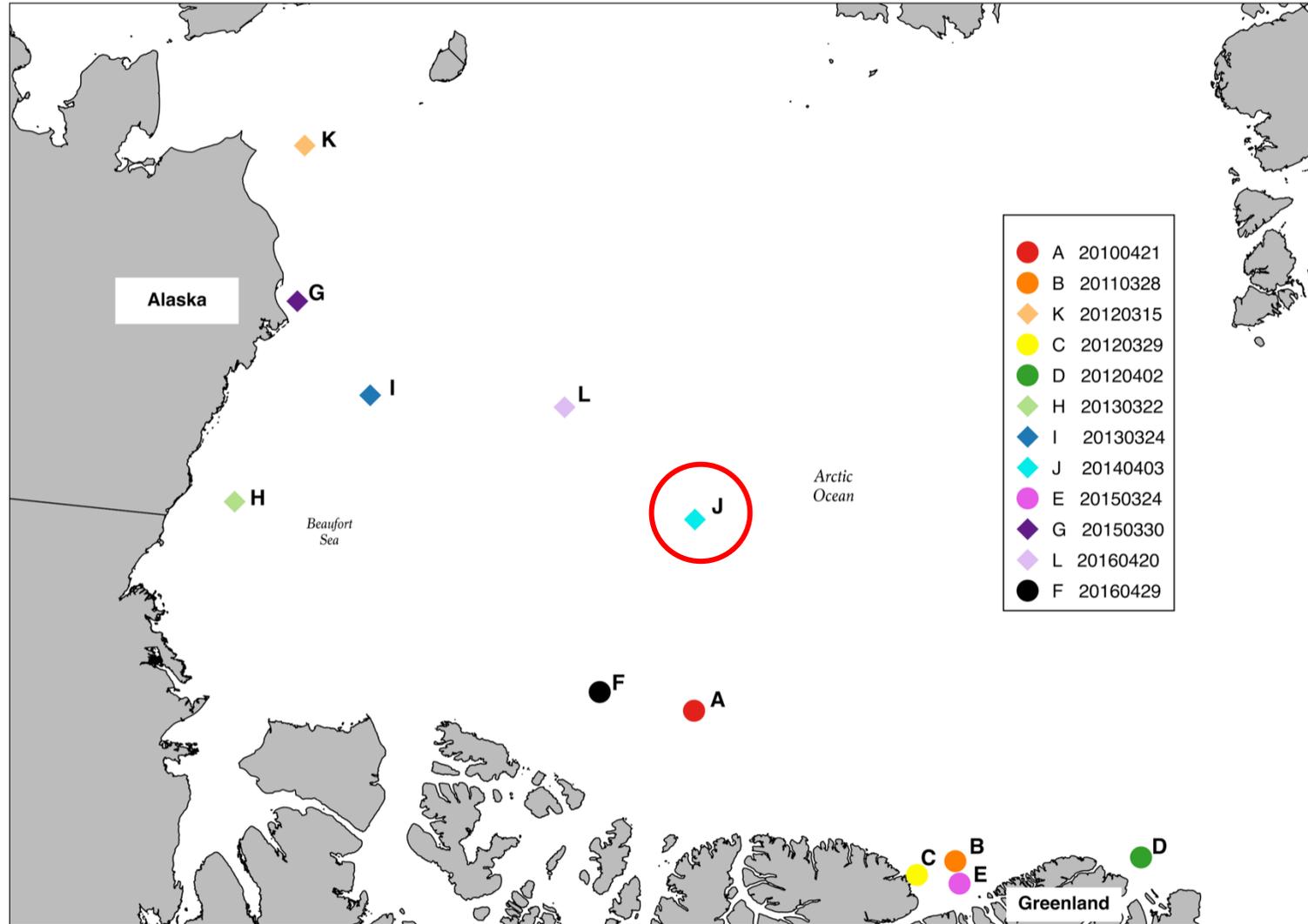


	DMS	ATM
# meas.	2420	107
mean	1.15	1.18
max.	2.8	2.8
r	0.85	
RM	0.11	

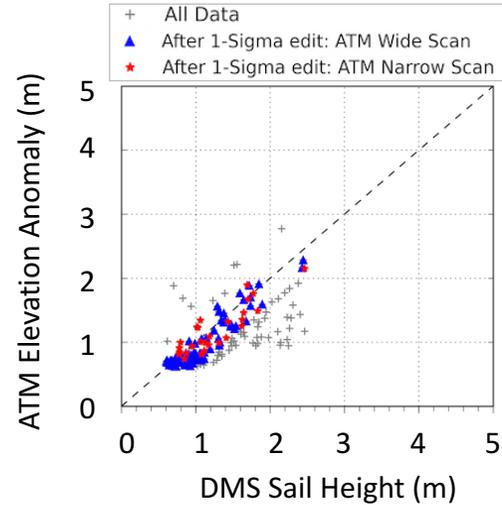
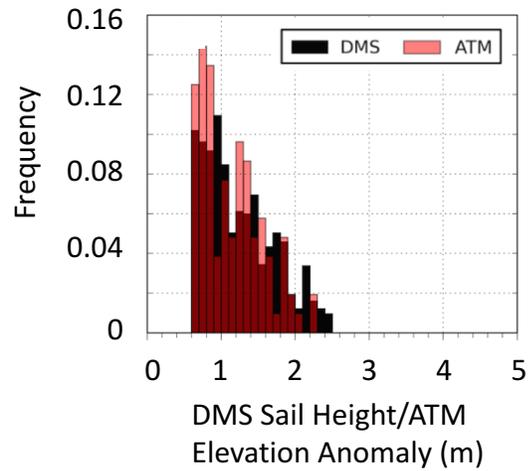
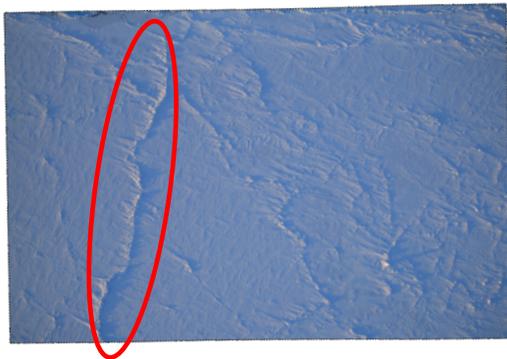




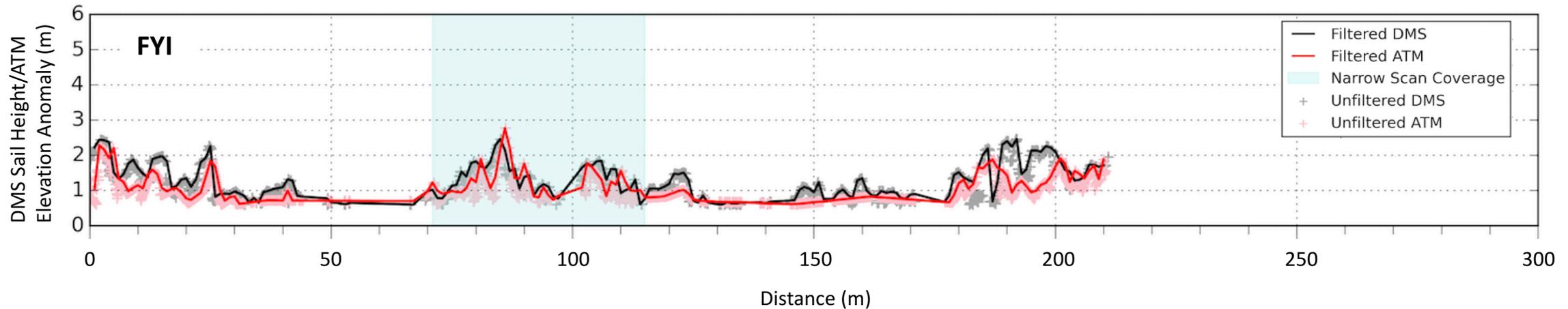
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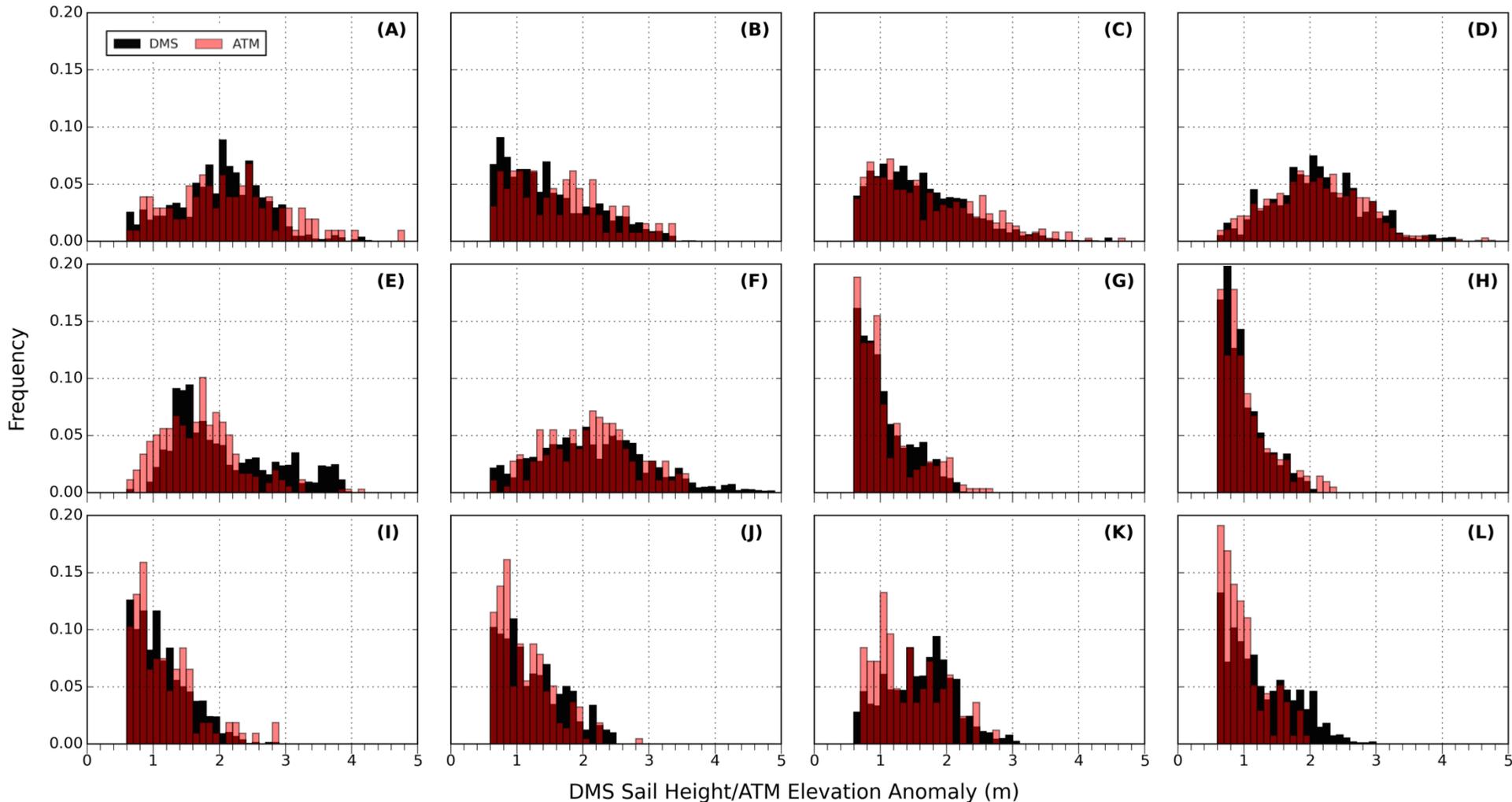
Example #4: Central Arctic, FYI pressure ridge in FYI



	DMS	ATM
# meas.	1572	216
mean	1.24	1.14
max.	2.4	2.2
r	0.90	
RM	0.17	



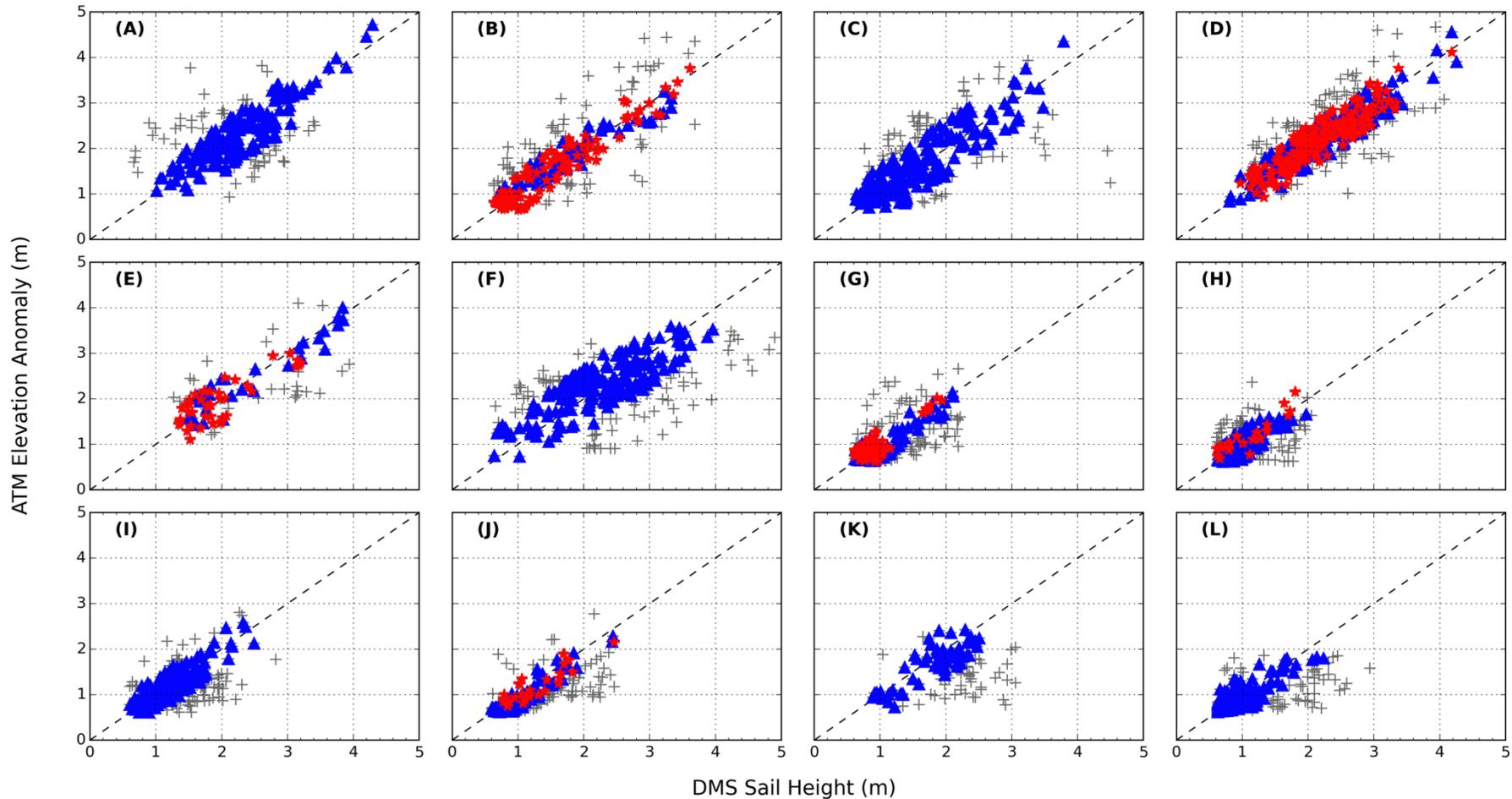
Sail Height/Elevation Anomaly Distributions



- Distribution related to ice type in which ridge forms
- Ridges formed in MYI have broad shaped distribution with large range of sail heights as compared to FYI with narrow shape and smaller range of sail heights
- Max sail height averaged 4.2 m in MYI and 2.6 m in FYI
- Mode averaged 1.5 m in MYI and 0.9 m in FYI

Sail Height/Elevation Anomaly Scatterplots

+ All ATM Data ▲ ATM Wide Scan: After 1σedit ★ ATM Narrow Scan: After 1σedit



- On average DMS and ATM agree to within 0.11m
- Correlation was 0.81 or greater
- For ATM wide scan residual mean and residual standard deviation range from -0.11 to 0.48, and 0.33 m to 0.70 m
- For ATM narrow scan residual mean and residual standard deviation range from -0.16 to 0.11, and 0.35 m to 0.51 m



Summary

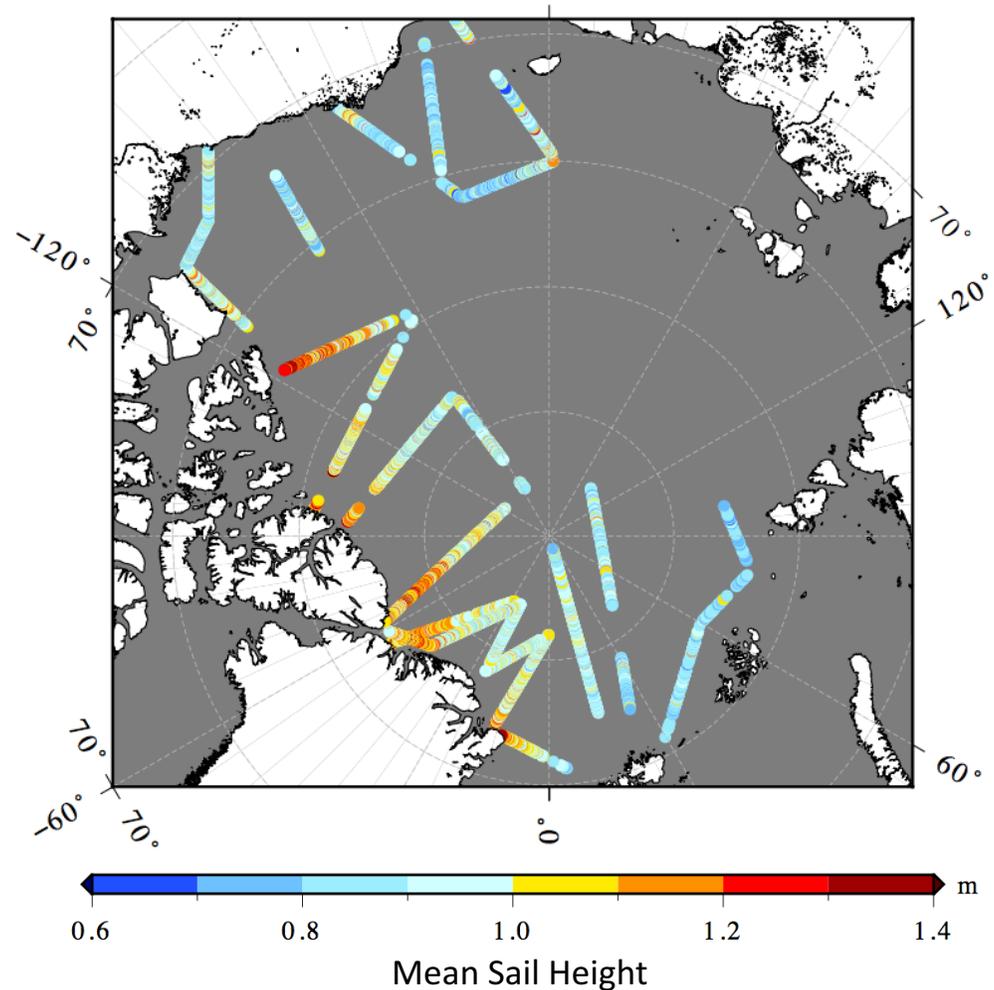
- We have utilized DMS imagery collected by Operation IceBridge to determine pressure ridge sail heights
- We have derived the full sail height distributions for 12 example pressure ridges located across a range of ice types in the Arctic Ocean
- Using independent measurements of surface height (elevation anomaly above local level surface) we assess and validate our results
- The comparisons show that the DMS results are robust and accurate:
 - The correlation coefficient between DMS sail heights and ATM elevation anomalies was 0.81 or greater for all 12 ridges
 - On average DMS and ATM agreed to within 0.11m



Future Work

- Having demonstrated that the method is viable, we are applying it to the full suite of DMS images (2010-2017).
- 50,390 total images with sail height data in 2010-2017 study.
- Examine the differences in the sail height distributions over FYI and MYI in more detail
- Assess the inter-annual variability in sail height and surface roughness during the OIB observation period.
- Set up a data product for sail height

2017 Mean Sail Height





Questions?

Sensor Sampling

- The conical scanning of ATM results in uneven sampling across the sea ice surface with a higher density of ATM footprints at the edges of the swath.
- This can have a big impact on sampling along a ridge depending on where the ridge is located within the swath as well as its orientation.
- Therefore, ATM isn't able to fully capture the details along the entire length of the ridge as well as DMS.
- For both along-track and across-track DMS sampling averaged ~ 8.8 showing that ridge orientation doesn't effect DMS sampling

