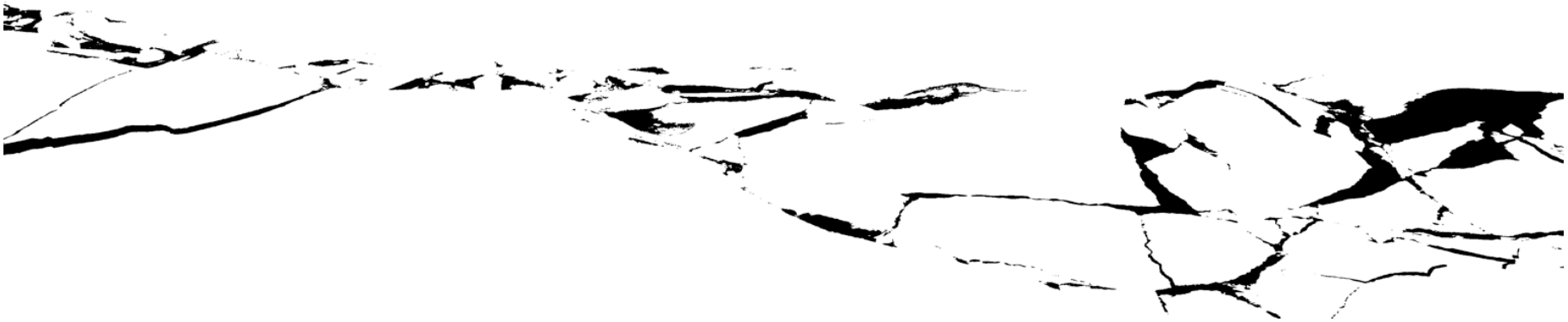
Atmospheric form drag over Arctic sea ice using remotely sensed ice topography data



Alek Petty, Michel Tsamados, Nathan Kurtz

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End of AGU 2015 talk: Characterizing Arctic sea ice topography using high-resolution IceBridge data

"Exciting future work…

…Form drag can be calculated from these data using existing drag parameterizations."

Atmospheric (wind) drag over sea ice

Wind drag = drag coefficient * winds

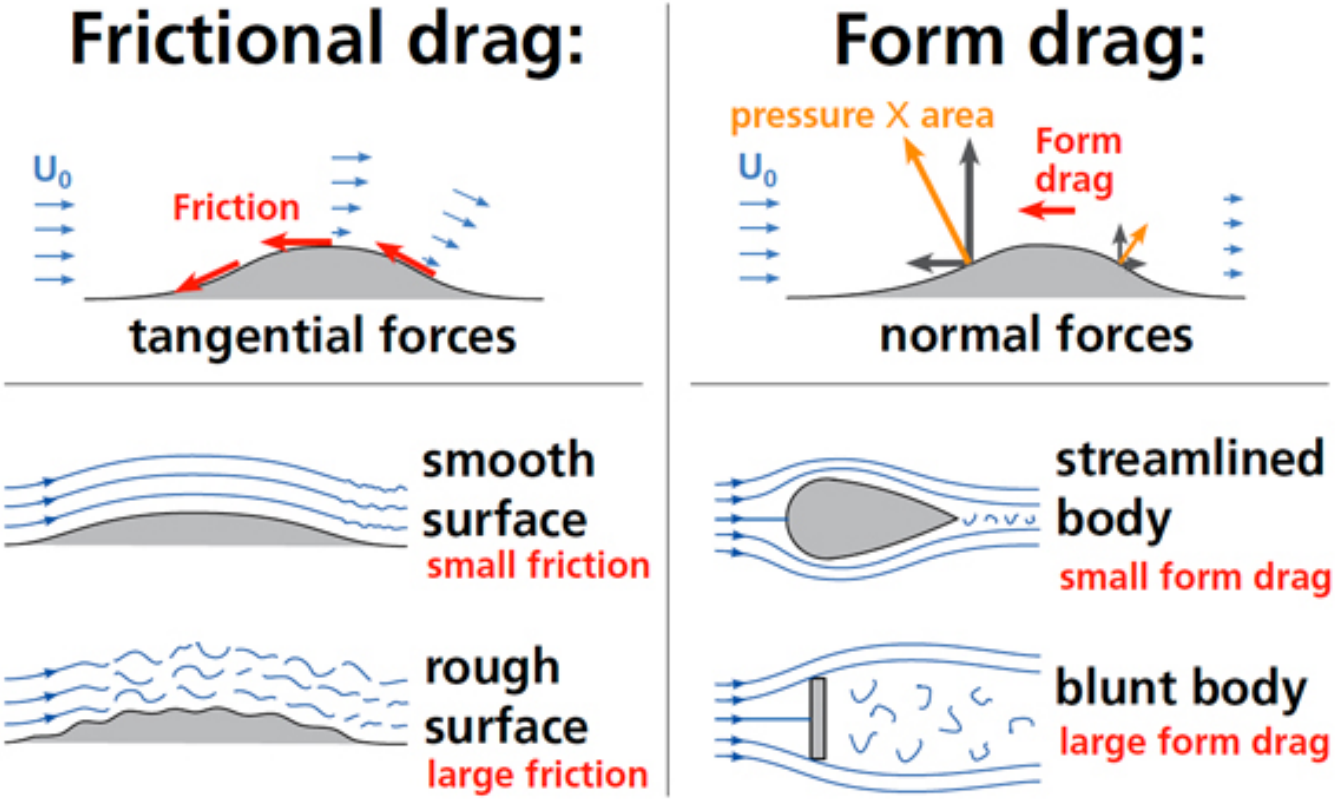
$$\tau_{\mathbf{a}} = \rho_a C_{da} |\mathbf{U}_{\mathbf{a}}| \mathbf{U}_{\mathbf{a}}$$

**assumes ice drift << wind speed*

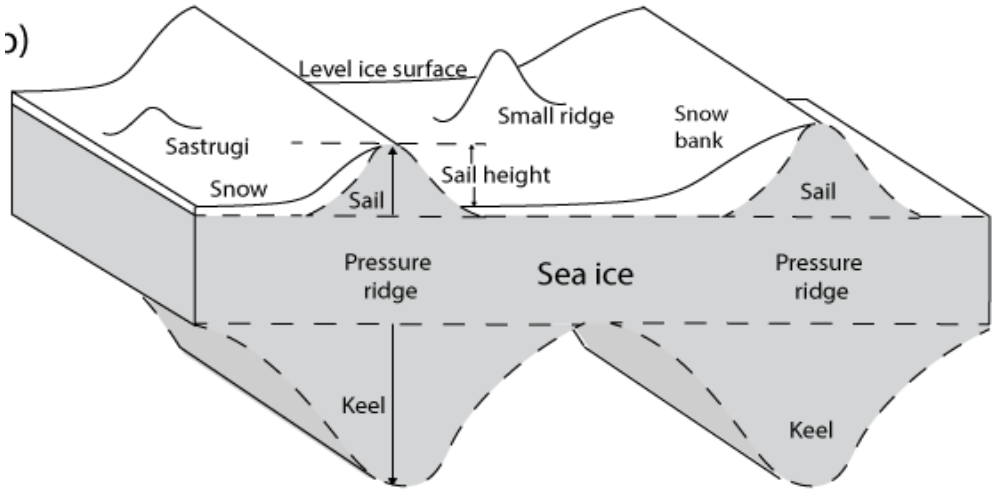
We actually calculate the *neutral* drag coefficient C_{da}^{n}
(which can be modified by boundary layer stability effects)

Atmospheric drag (skin and form)

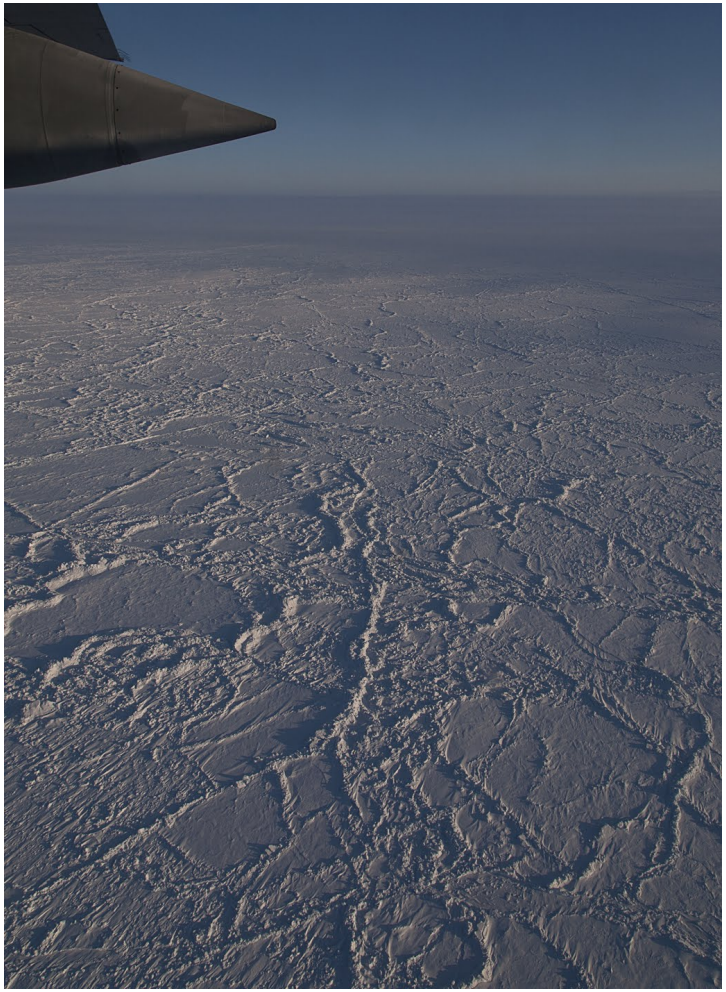
Viscous pressure drag (form drag), and drag due to surface roughness (skin friction drag)



Sea ice morphology



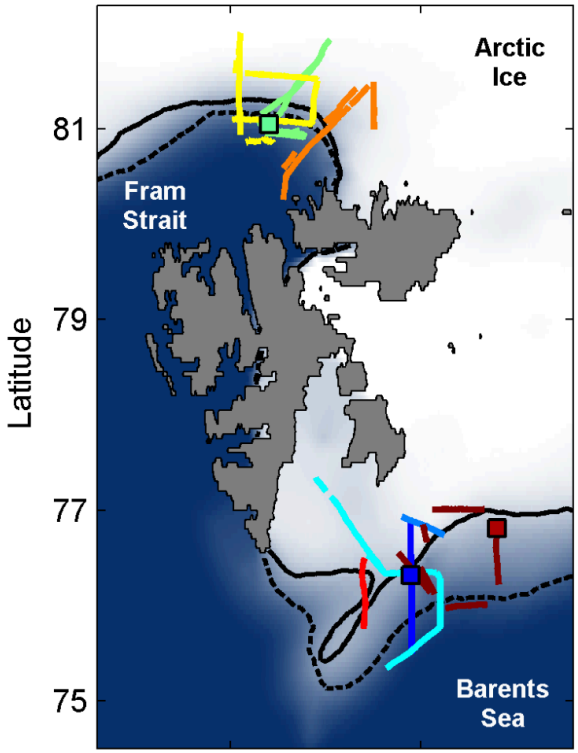
- Sea ice is a heterogeneous medium, which varies regionally and temporally.
- Pressure ridges dominate the ice topography in the central Arctic.
- Sastrugi, dunes, hummocks also likely to feature. Also floe edges in the MIZ!

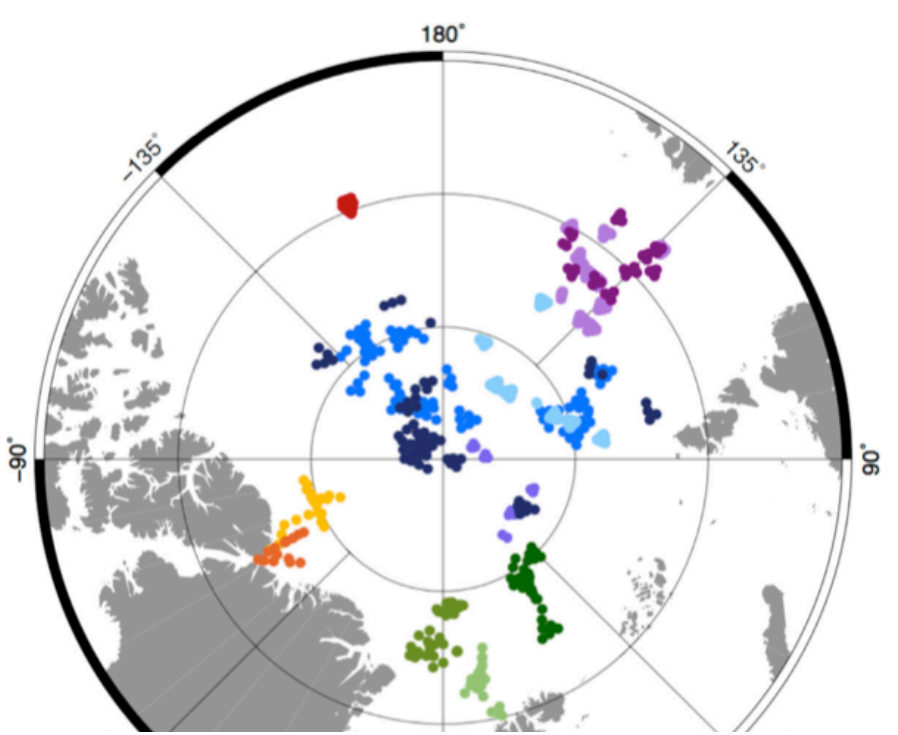


(Photo by Jeremy Harbeck, taken during an IceBridge sea ice flight)

Recent estimates of atmospheric drag

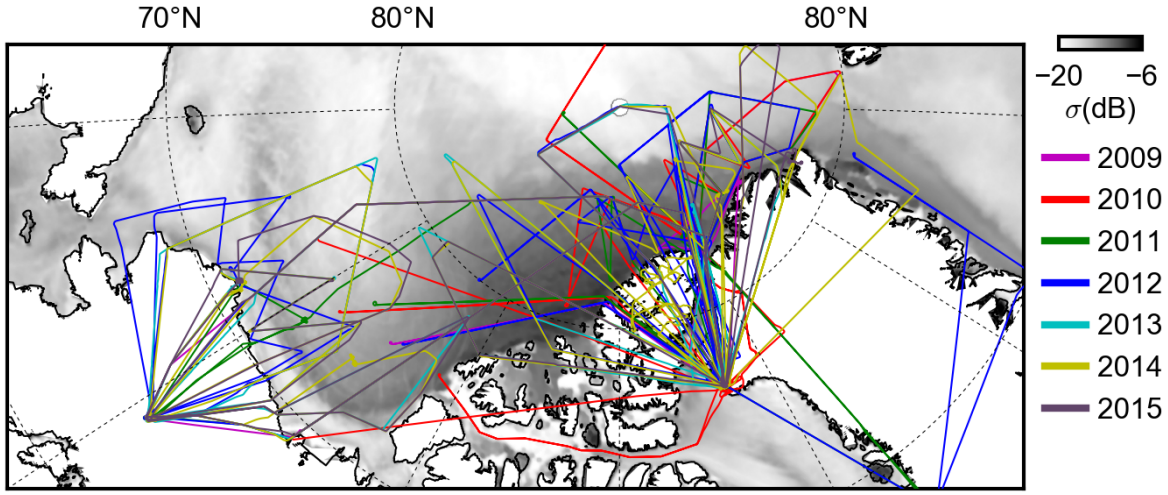
- *Elvidge et al., [2016]*
  Total atmospheric drag coefficient in the MIZ using eddy covariance.





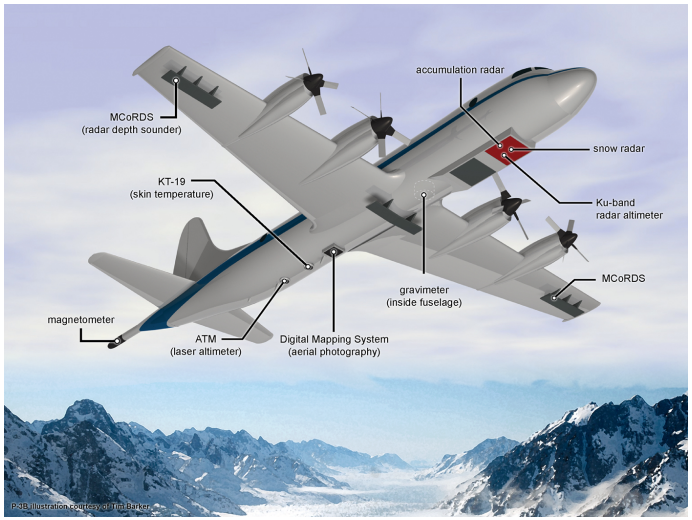
- *Castellani et al., [2014]*
  Atmospheric form drag estimated using ice topography profiles across the Arctic.
  Most of the data taken within the pack ice.

NASA's Operation IceBridge – Arctic sea ice



- High data coverage in the Central Arctic
- Good (and improving) coverage in the Beaufort Sea, a region of rapid ice decline.

OIB Town Hall on Wednesday (12.30), West 2020

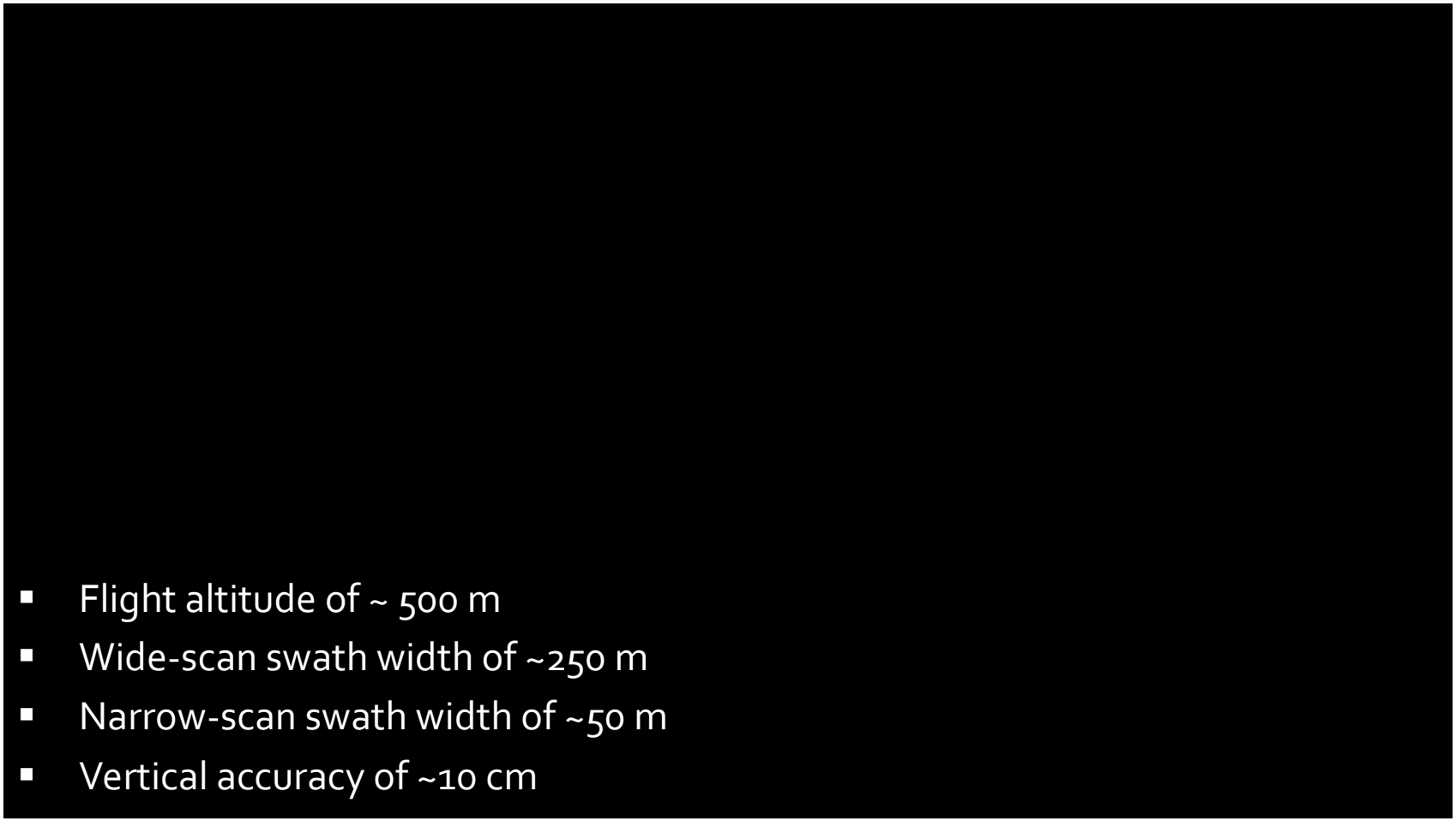


IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness

This data set contains derived geophysical data products including sea ice freeboard, snow depth, an
IceBridge Snow Radar, Digital Mapping System (DMS), Continuous Airborne Mapping By Optical Trar
data were collected as part of Operation IceBridge funded campaigns.

http://nsidc.org/data/docs/daac/icebridge/idcsi4/

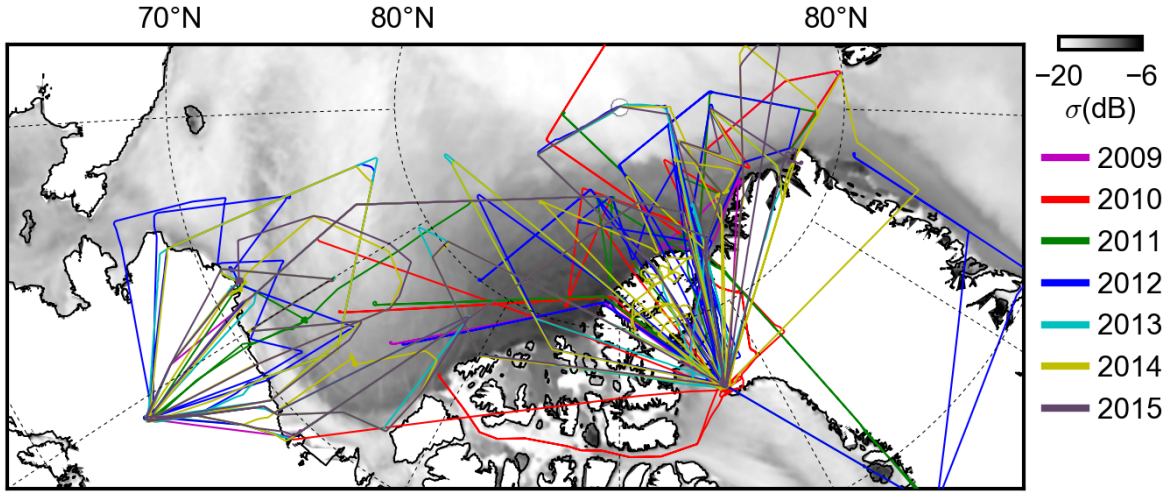
The Airborne Topographic Mapper (ATM)



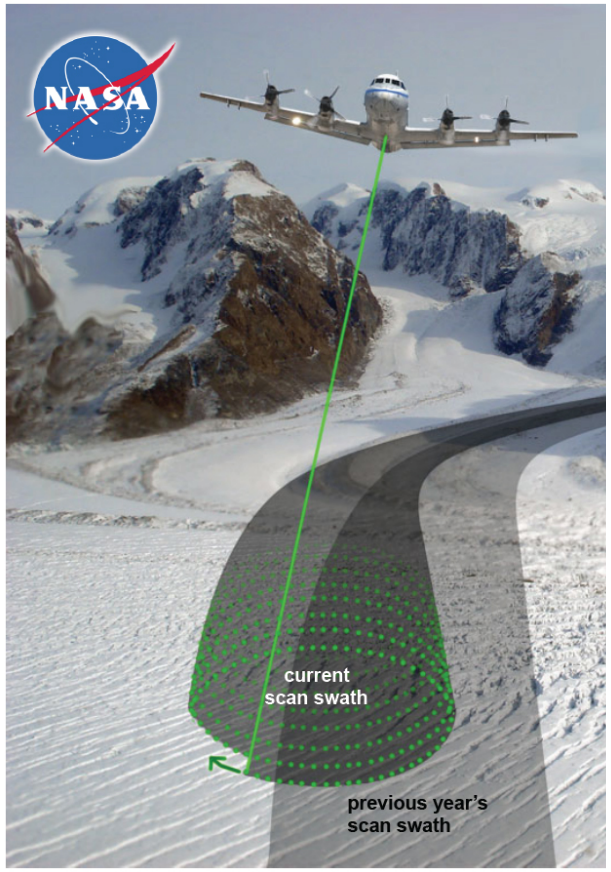
- Flight altitude of ~ 500 m
- Wide-scan swath width of ~250 m
- Narrow-scan swath width of ~50 m
- Vertical accuracy of ~10 cm

Video courtesy of NASA's GSFC Science Visualization Studio (preliminary media)

The Airborne Topographic Mapper (ATM)

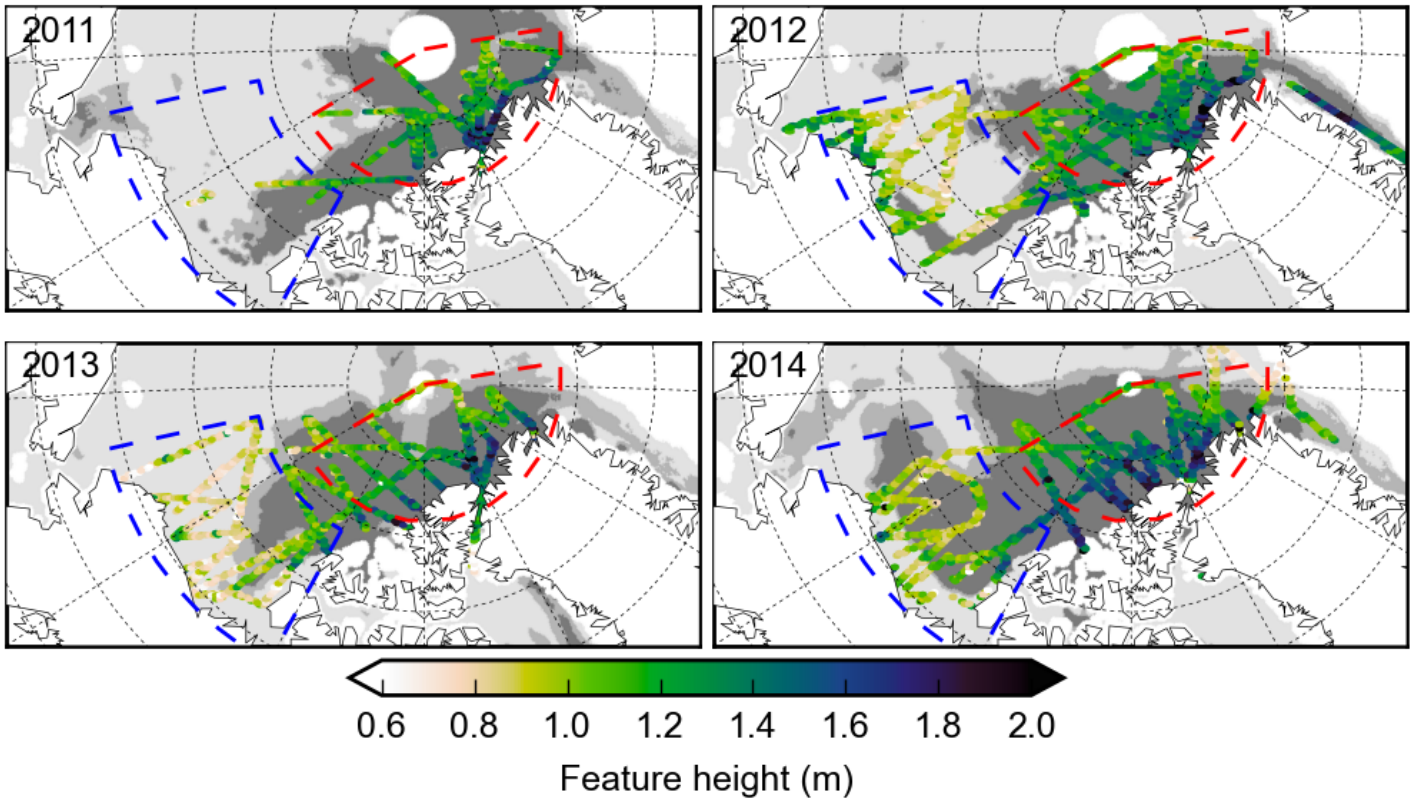


Year	2009	2010	2011	2012	2013	2014	2015
Along-track coverage (km)	8,762	14,505	10,080	24,625	18,092	21,028	??
ATM swath area (km²)	2,216	5,043	2,432	6,284	4,614	5,232	??



- ATM vertical accuracy over sea ice of around 10 cm.
- Efforts underway to improve this (down to a few centimeters) with laser upgrades.

Arctic ice topography variability



Dark grey =MYI, light grey=FYI, from OSI-SAF ice type product

Characterizing Arctic sea ice topography using high-resolution IceBridge data

Alek A. Petty[1,2], Michel C. Tsamados[3], Nathan T. Kurtz[2], Sinead L. Farrell[1,2,4], Thomas Newman[1,4], Jeremy P. Harbeck[2], Daniel L. Feltham[5], and Jackie A. Richter-Menge[6]

Petty et al., 2016, The Cryosphere

Estimating atmospheric form drag from ice topography data

Total *neutral* drag coefficient = skin drag + form drag

Surface feature height - from *Petty et al., [2016]*

Form drag

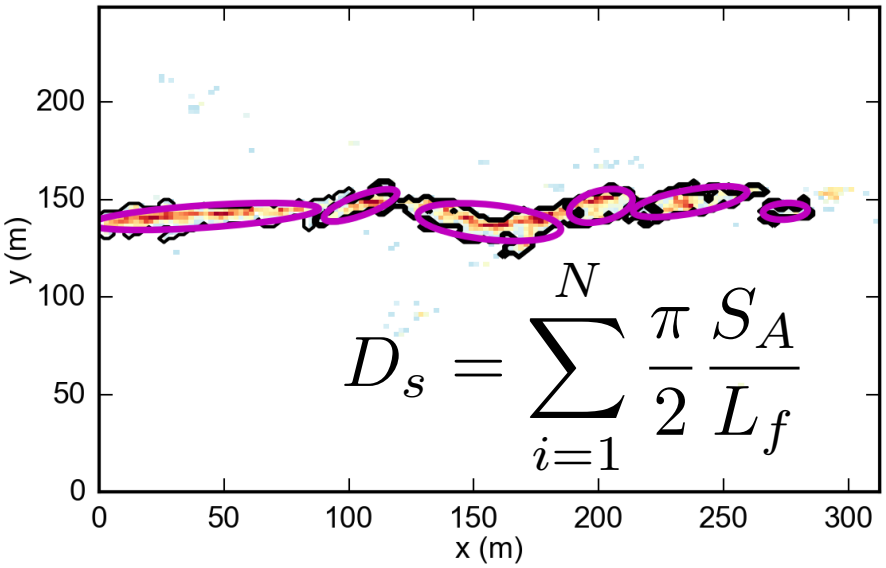
$$= \frac{c_w}{\pi} \frac{h_f}{D_s} \frac{[\ln(h_f/z_0) - 1]^2 + 1}{\ln(10/z_0)}$$

Surface feature spacing - a new variable

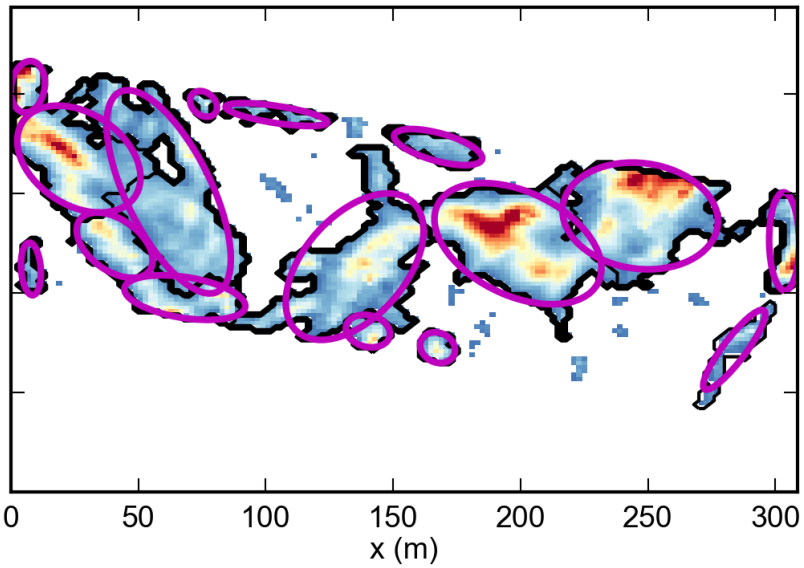
*NB formulation from *Garbrecht et al., [2002]* and *Castellani et al., [2014]*.

Surface feature spacing

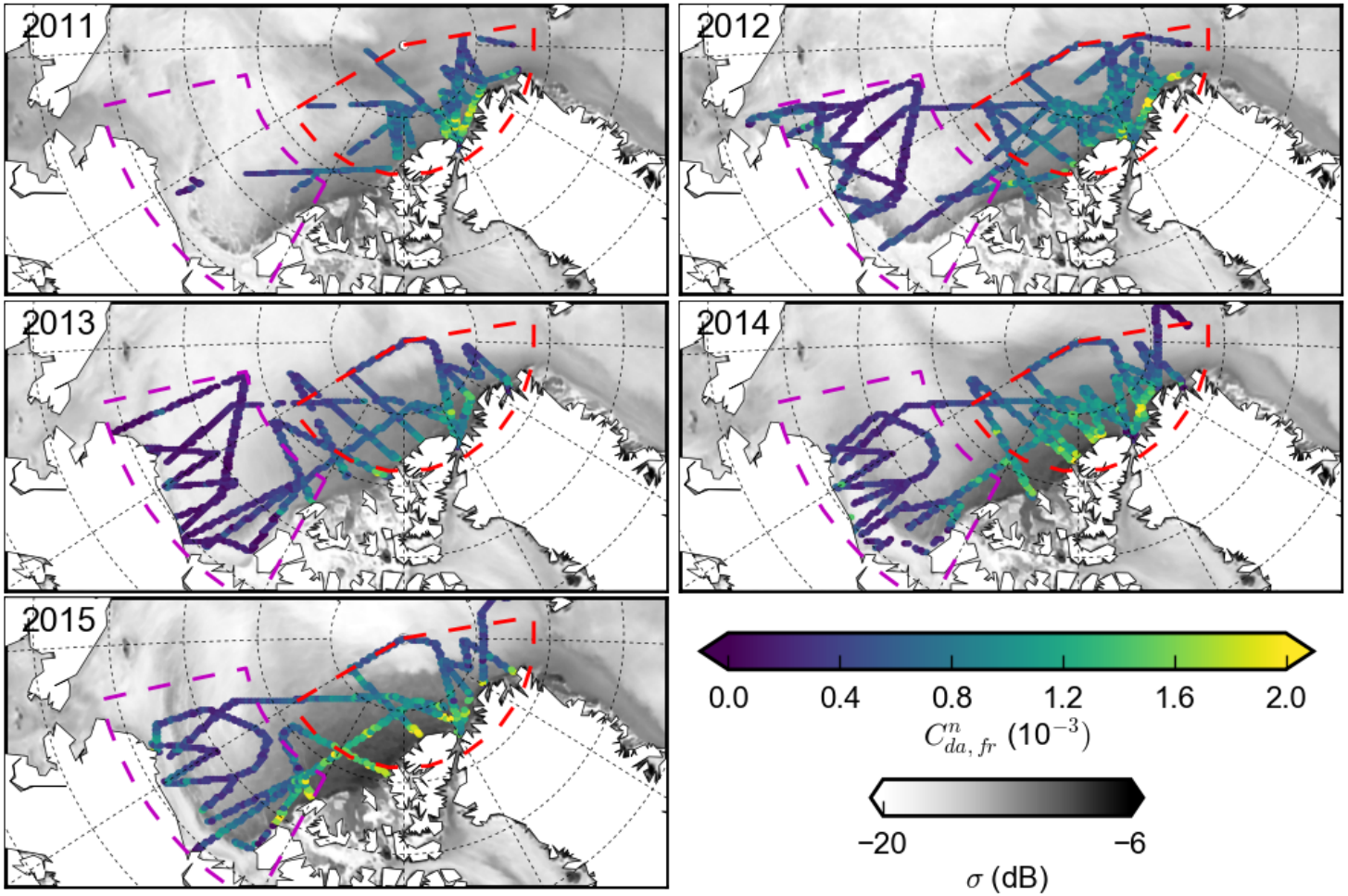
- 2D (linear) profiling - this is simply the spacing between peaks (found using the Rayleigh Criterion).
- 3D (full scan) data - use a feature covariance matrix and assume an elliptical shape. New approach!



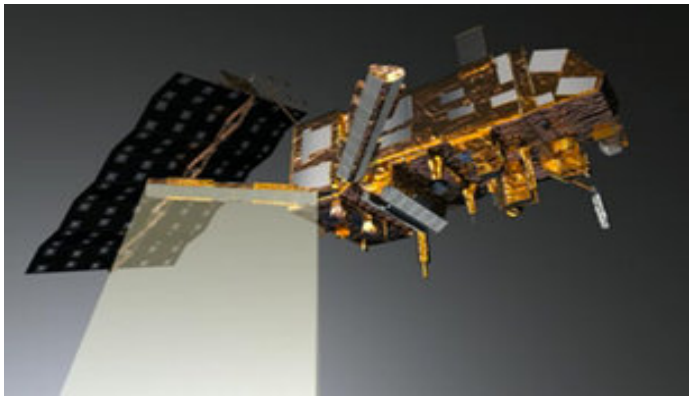
$$D_s = \sum_{i=1}^{N} \frac{\pi}{2} \frac{S_A}{L_f}$$



Neutral atmospheric form drag coefficient

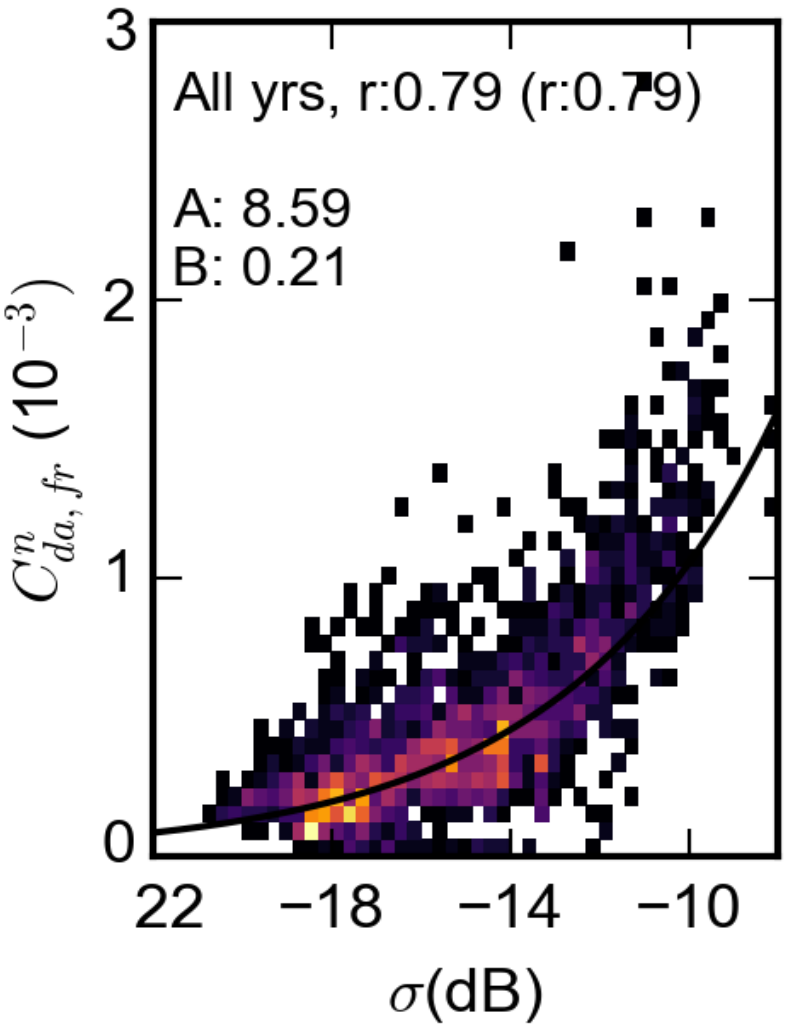


Upscaling with ASCAT backscatter data

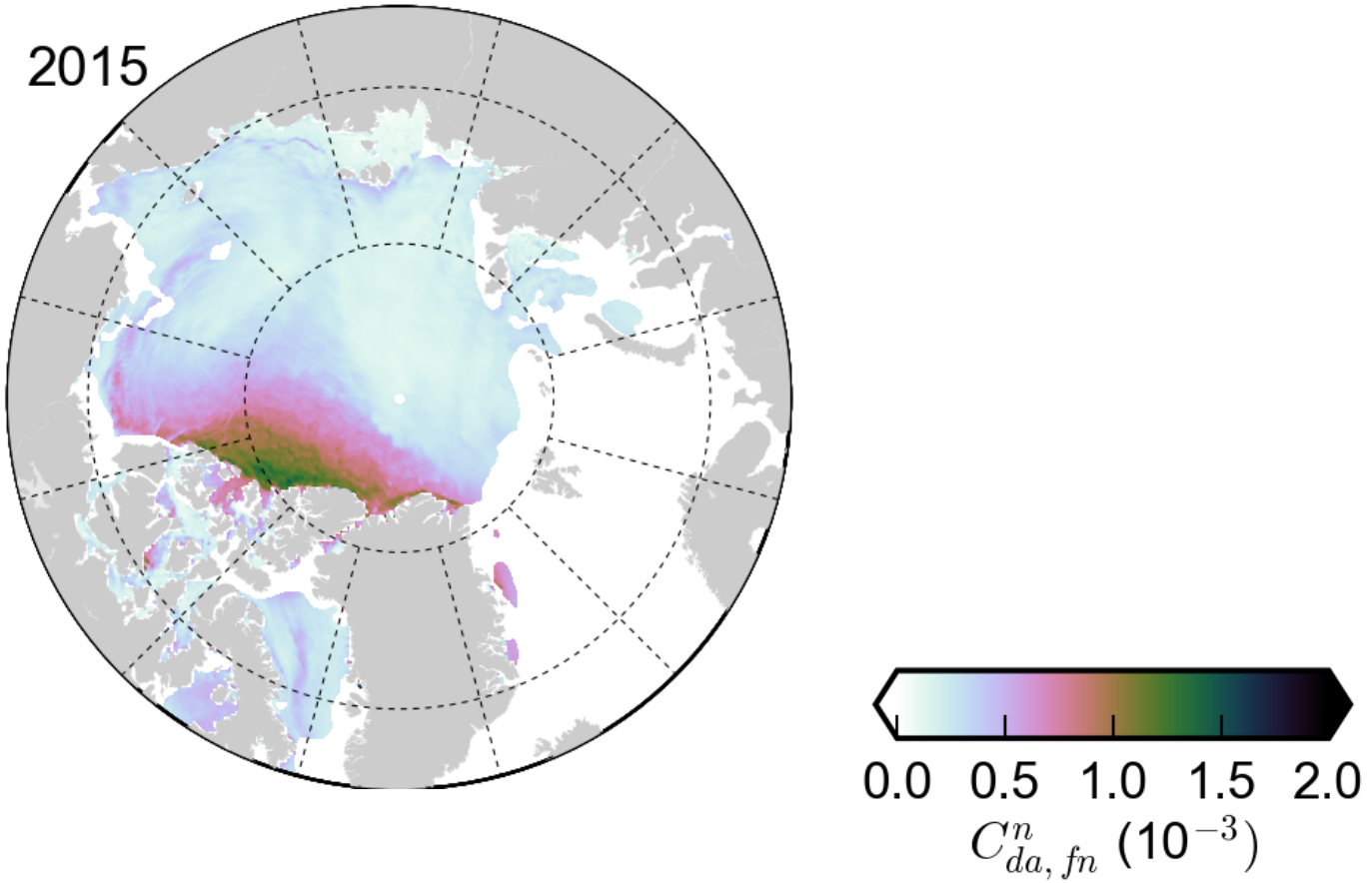


The EUMETSAT ASCAT Satellite

- C-band ASCAT sensitive to surface scattering.
- Strong correlation (r=o.8) between OIB drag and ASCAT backscatter.
- Strong correlation holds across all years.



Atmospheric form drag (from surface features) over the entire Arctic in early spring.



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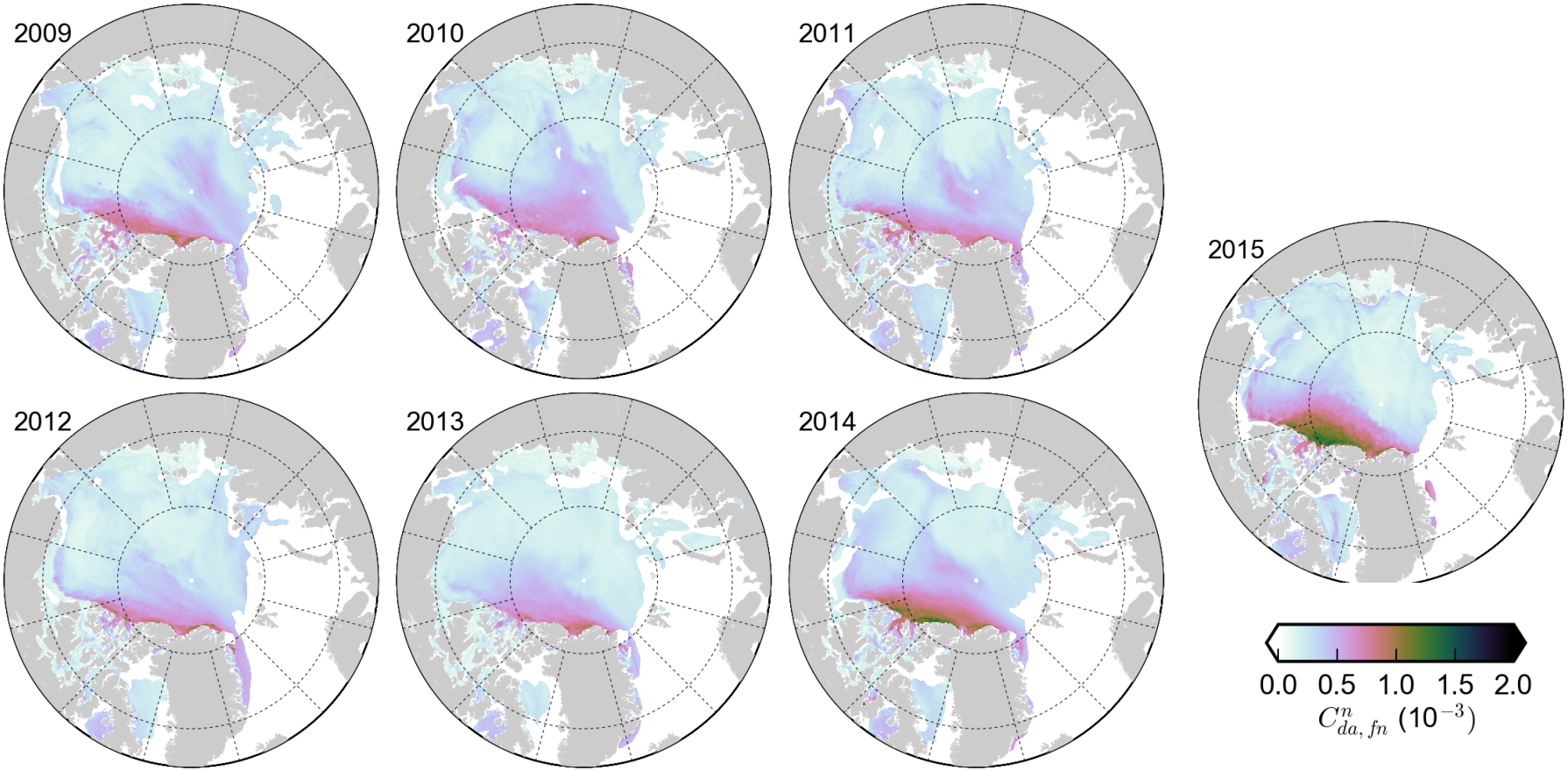
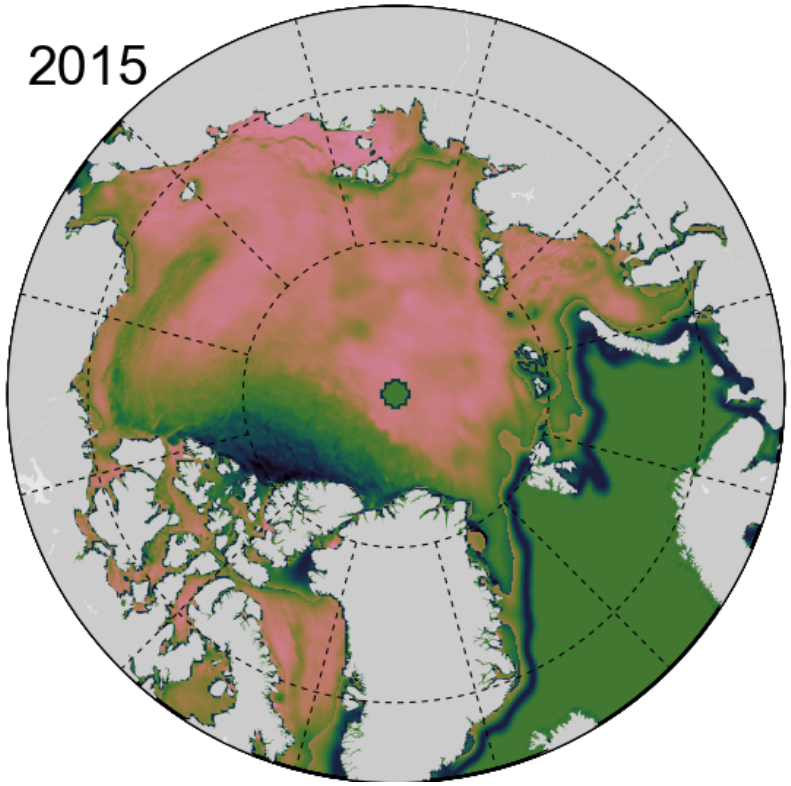
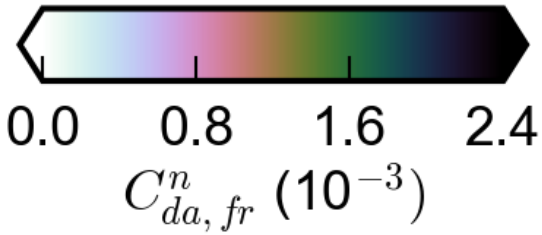


Total neutral atmospheric drag coefficient

Combine with Lupkes 2012 MIZ drag parameterization





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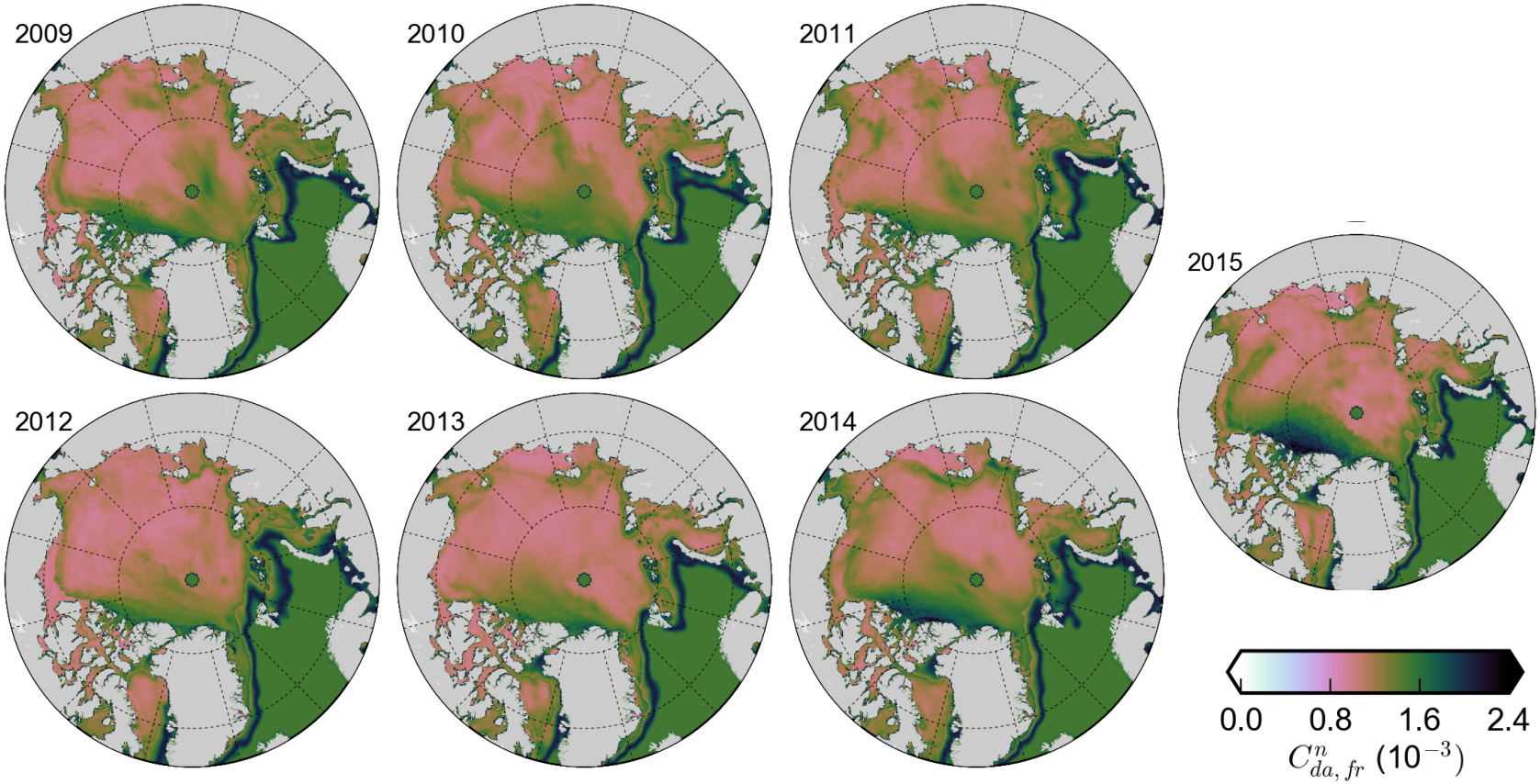


Summary

- Arctic ice topography estimates have been used to calculate atmospheric form drag over sea ice.
- Form drag within the pack ice is not constant!
- Need to understand the seasonal variability (some OIB data we can use).
- Extend to Antarctic data.
- Let's start to calibrate/validate the new formulation in CICE.

Questions?

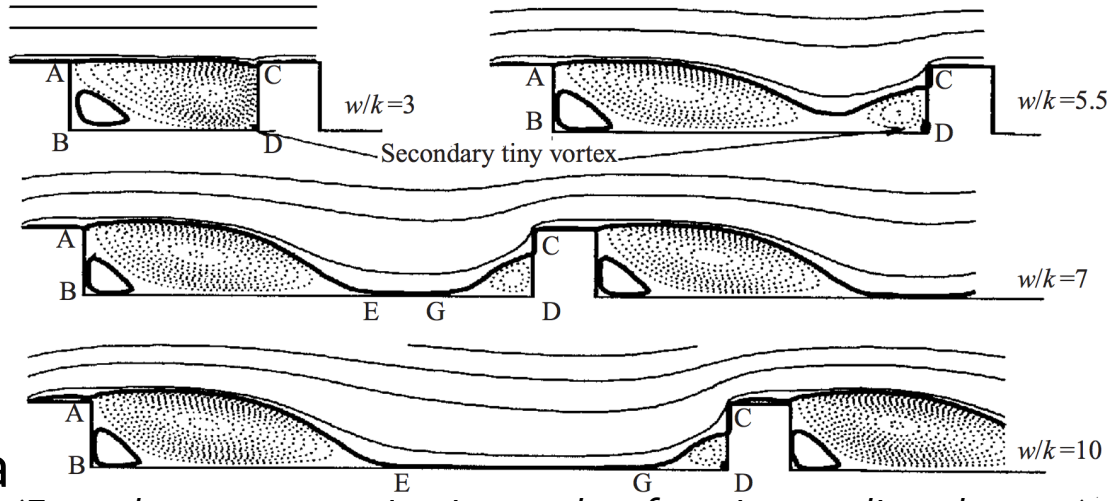
- Discuss Antarctic flights and prelim analysis. Discuss iceberg issues.
- Maybe discuss ideas going forward for model calibration/validation.

To Add

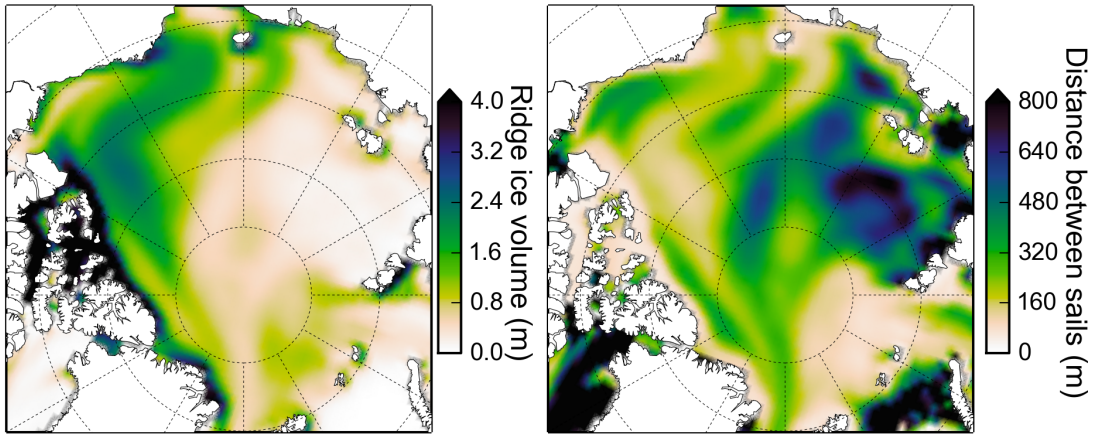
- Show one slide on topography calculation. Highlight the TC paper.
- Add intro to drag following on from the 2015 'exciting future work' slide.
- Show equation and formulation of drag. Discuss how calculated. Assumptions made.
- Show our form drag results. Focus on 2D but say also calculated using 1D to be consistent with older studies.
- Show ASCAT upscaling.
- Show maps of drag. Maybe animate or do slideshow of 2009-2015.
- Discuss Antarctic flights and prelim analysis. Discuss iceberg issues.
- Discuss ideas going forward for model calibration/validation.
-

e.g. Atmospheric form drag over sea ice

- Form drag can be calculated explicitly using existing parameterizations.
- Drag recently incorporated into a sea ice climate model component (CICE).
- Model is still poorly constrained, due to a previous lack of observational data.



(Form drag parameterizations, taken from Leonardi et al., 2013)

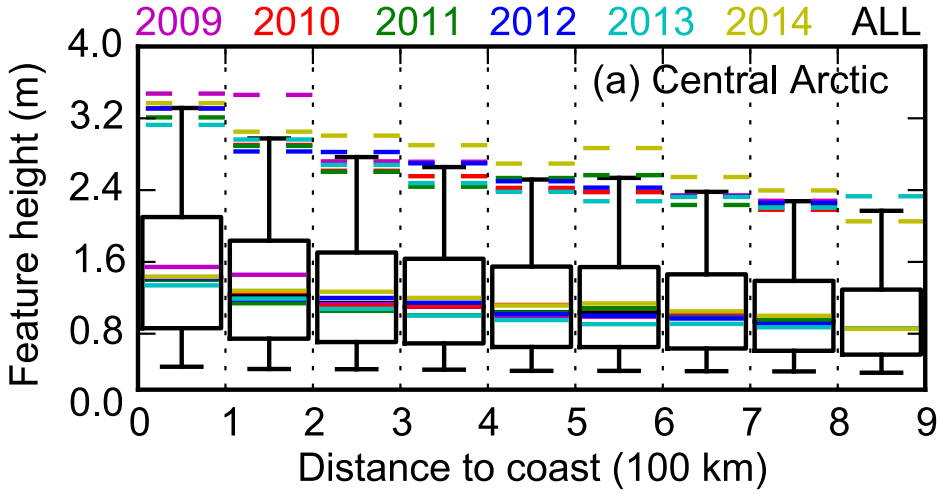


(Example (March 2012) modeled ridging behavior in the new CICE drag parameterization)

Fast ice/melt ponds

Coastal sea ice deformation and fast ice regimes

- 100 km coastal proximity bins
- Individual flight line analysis needed for more detailed insight



Melt ponds and ice topography

- e.g. Flatter ice promotes shallow but extensive melt ponds to form.