Verisk | Atmospheric and Environmental Research

Climatology and interannual variability of Arctic winter sea ice leads in the ICESat-2 era

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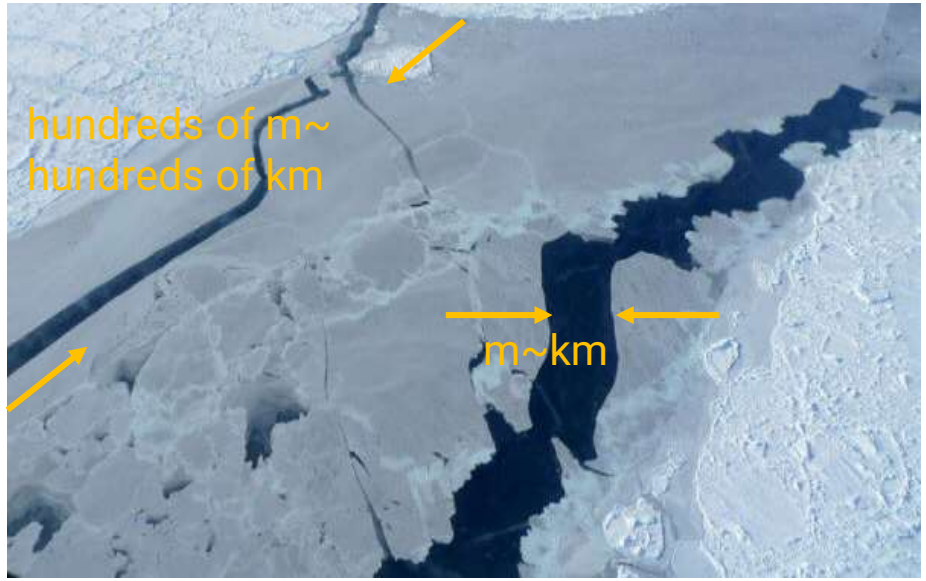
Motivation: influence on polar climate

Sea ice leads play an important role in climate:

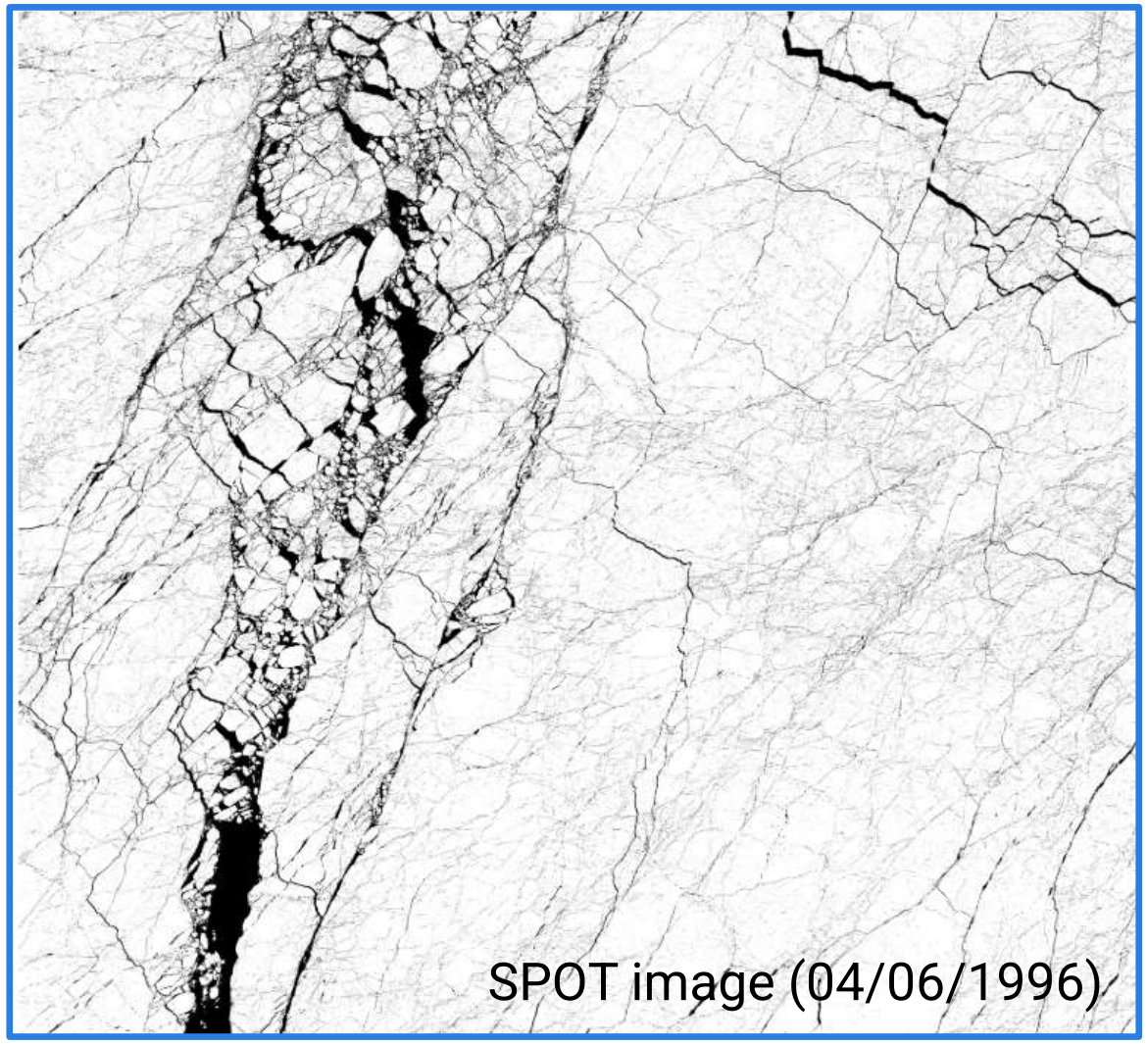
- Atmosphere: vents of ocean heat and moisture
- Ecosystem: phytoplankton blooms
- **Ocean: sites of active mixing (freezing season) and heat absorption (melting season)**
  - **Memory/feedbacks?**

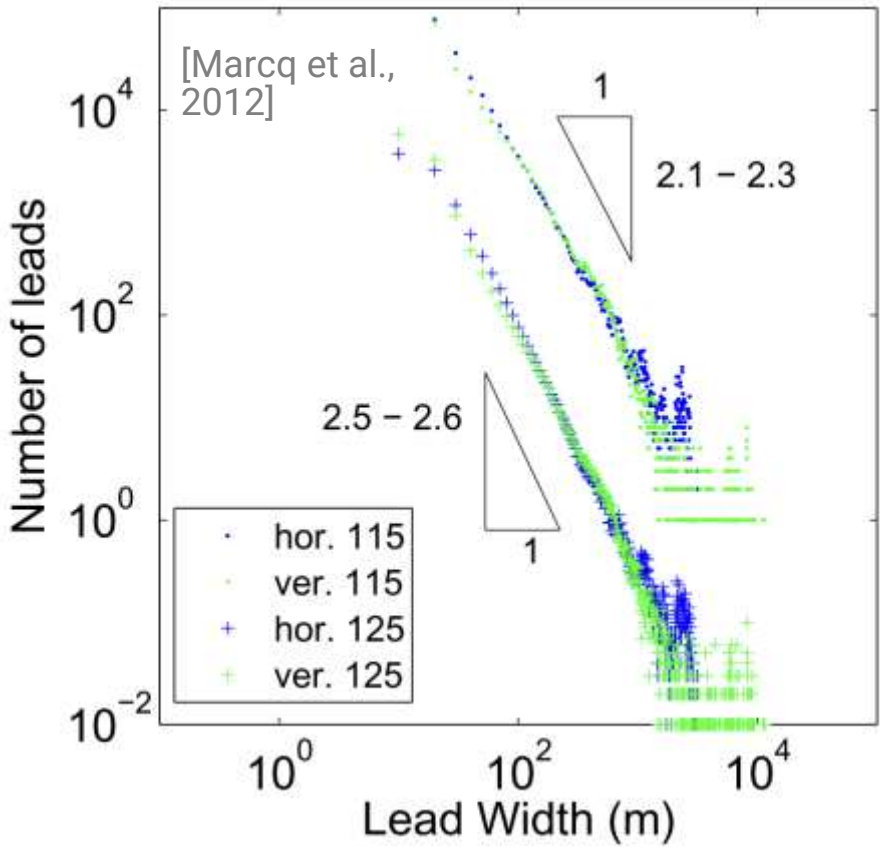
Climate models can not resolve leads:

- Essential to accurately represent polar energy fluxes, ocean mixing, sea ice concentration, etc.
- Need to understand lead characteristics and their **bulk effect** to improve model parameterizations



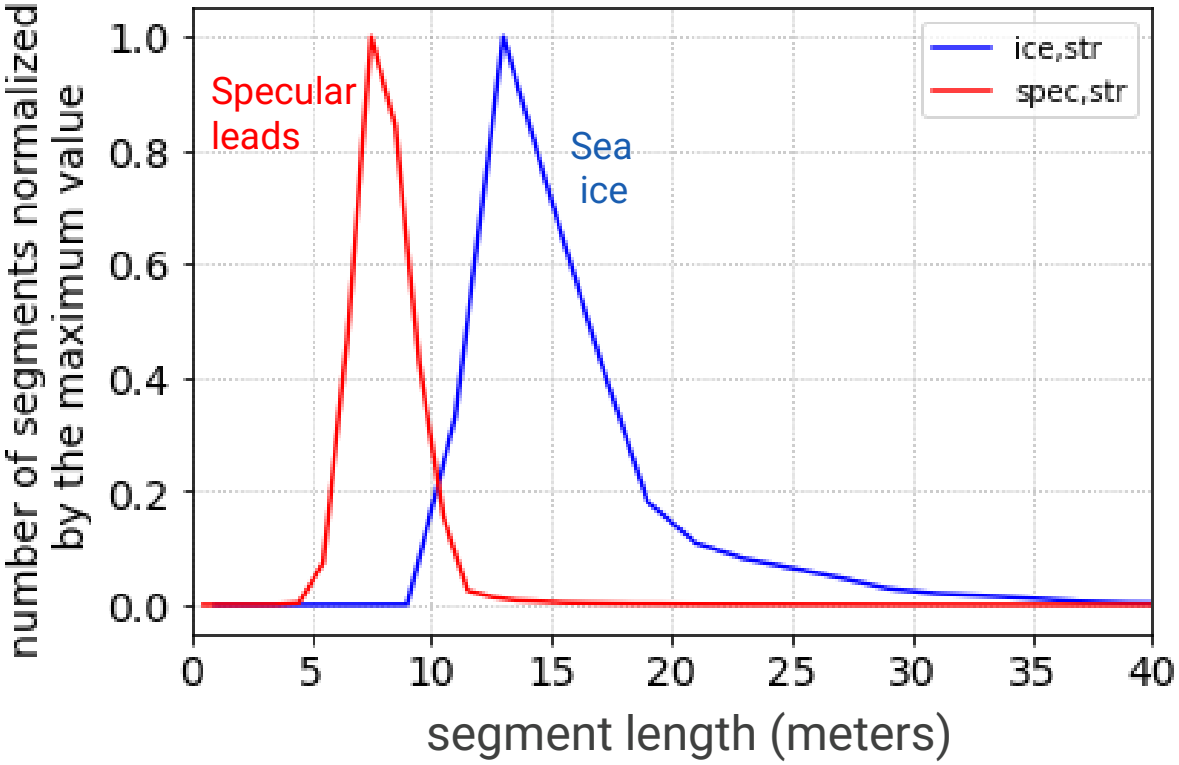
Motivation: need for high-resolution Pan-Arctic measurements





ICESat-2 can resolve leads with scales of a few meters

- ATL07: along-track sea surface and ice height and type
- Each segment aggregates 150 photons, length varies
- Each segment is assigned a type:
  - Specular leads, dark leads, ice
- We use strong beams only; focus on specular leads [potential dark lead misclassification]



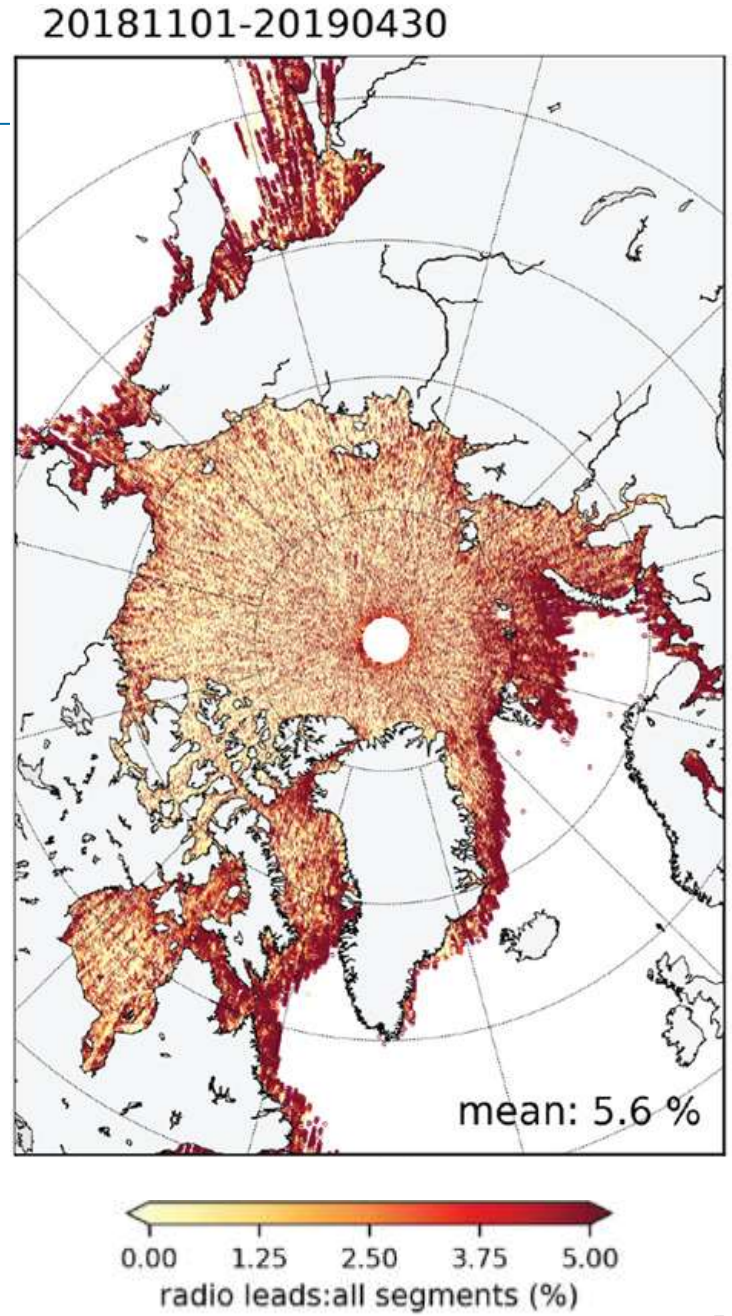
ICESat-2 to characterize leads

Pioneering work by Petty et al. (2021):

- Validate ATL07 lead detection
- Pan-Arctic lead fraction in the winter of 2018-2019
- Along-track

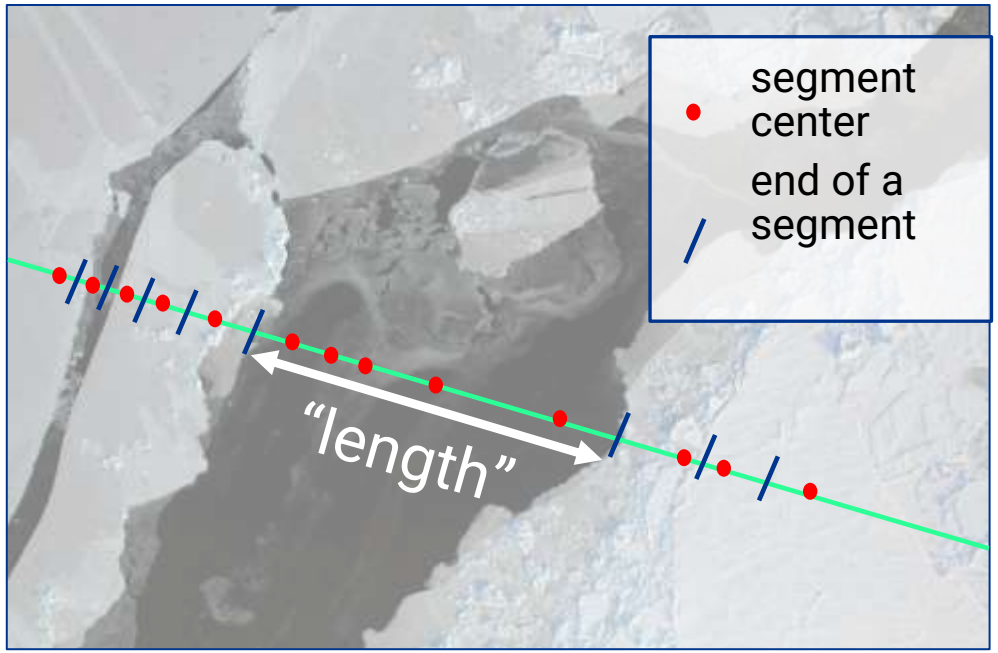
Our goal: characterize spatiotemporal variations of lead fraction and size in winter months (Nov-Apr)

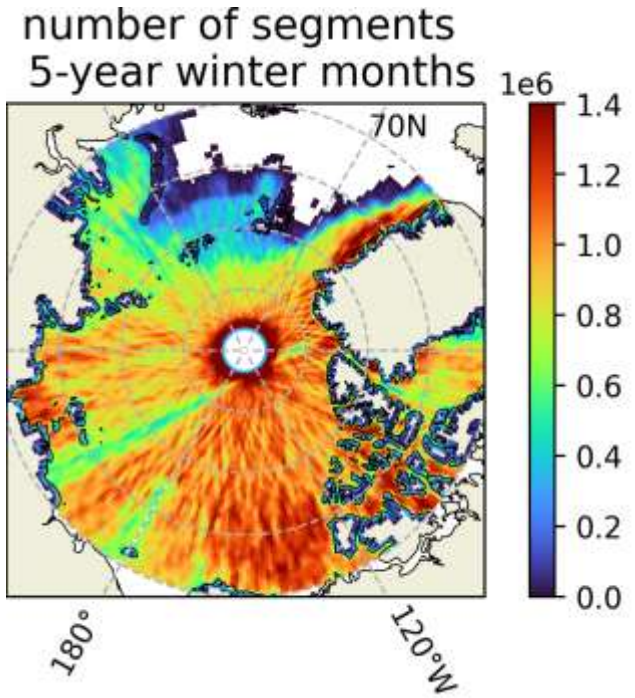
- Most recent ATL07 algorithms
- Gridded (to help with bulk parameterizations)
- Interannual variations (2018-2023 [2024])

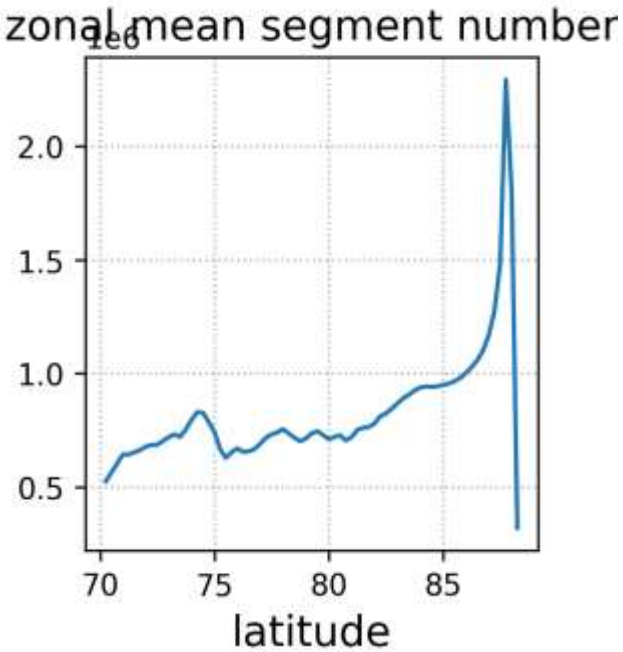


Defining lead fraction

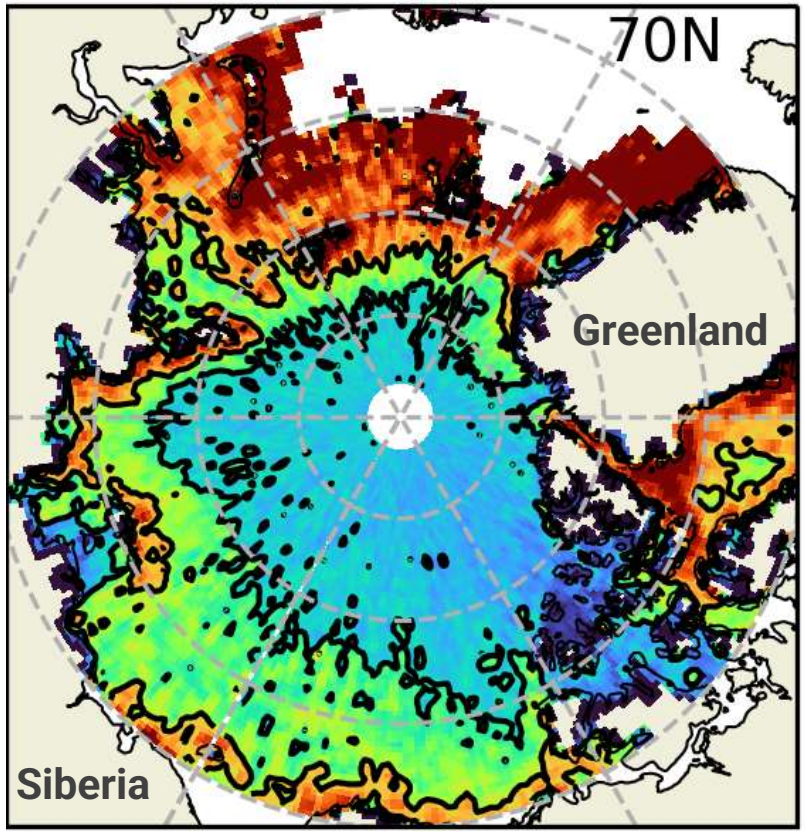
- Single lead/ice floe: consecutive segments with same surface type
- Lead “length”: distance between the first and last segment centers + ½ first and last segment length
- **Lead fraction**: total length of leads / total length of leads + ice
- Bin in 2° ×2° cells



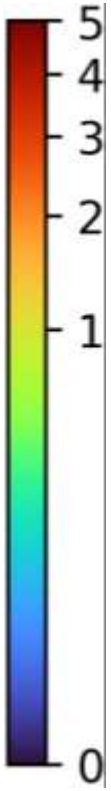




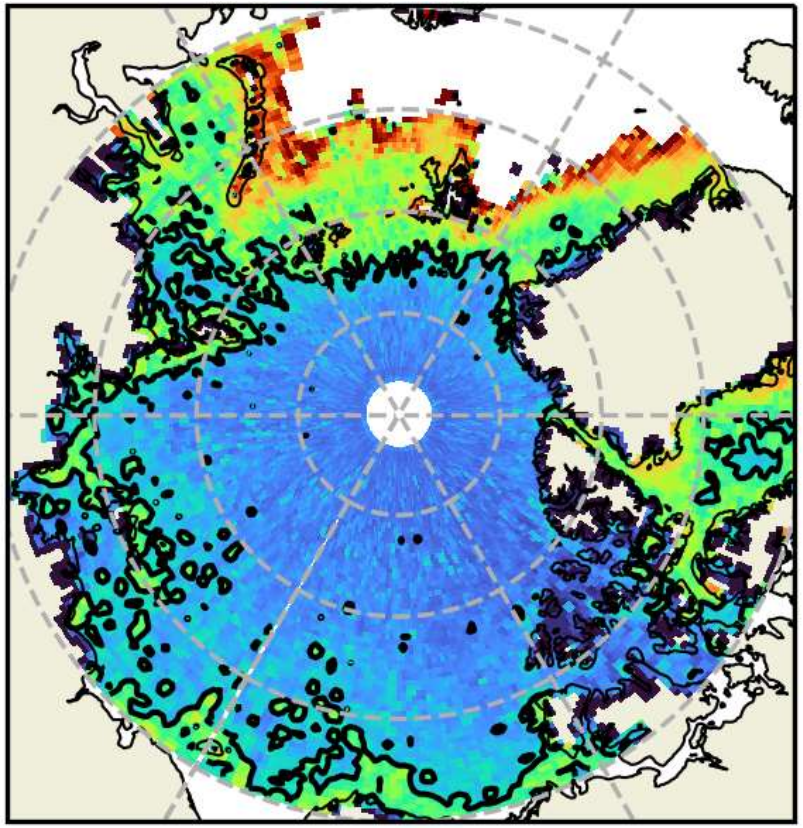
Lead fraction – 2° ×2° 5-year winter climatology



Cell-mean lead fraction (%)



Contours:
0.2%/1%



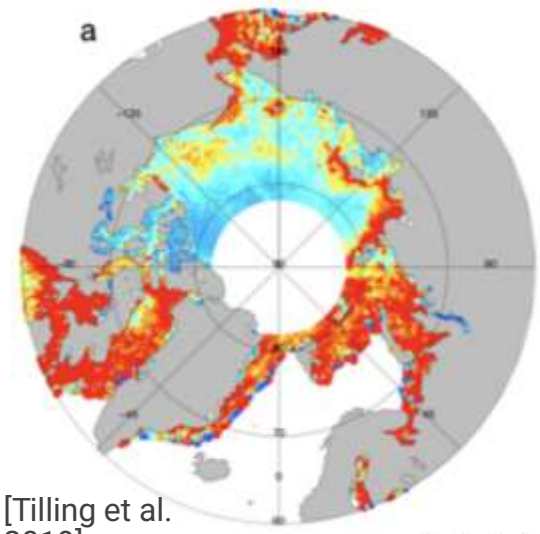
Std Err across beams in cell

- Pan-Arctic specular lead fraction = 0.59%
- Lead fraction <5%: largest in marginal ice zones; smallest in Canadian Archipelagos

- SE generally ~10-20%
- Differences in lead fraction are significant between “regimes”

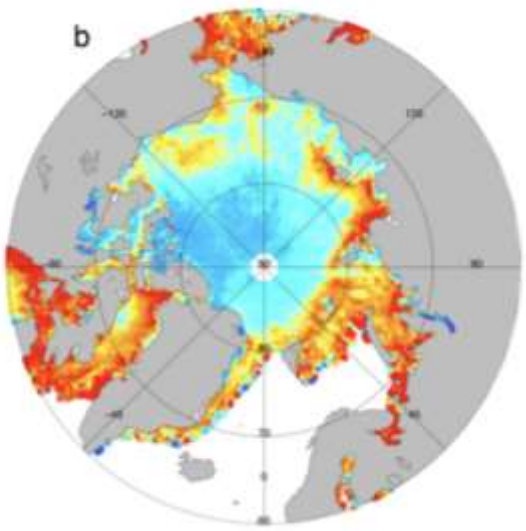
Lead fraction: comparison with previous work

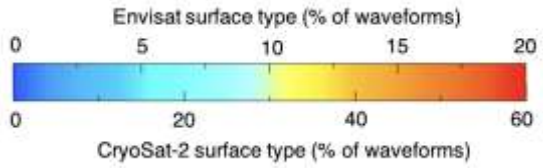
Envisat



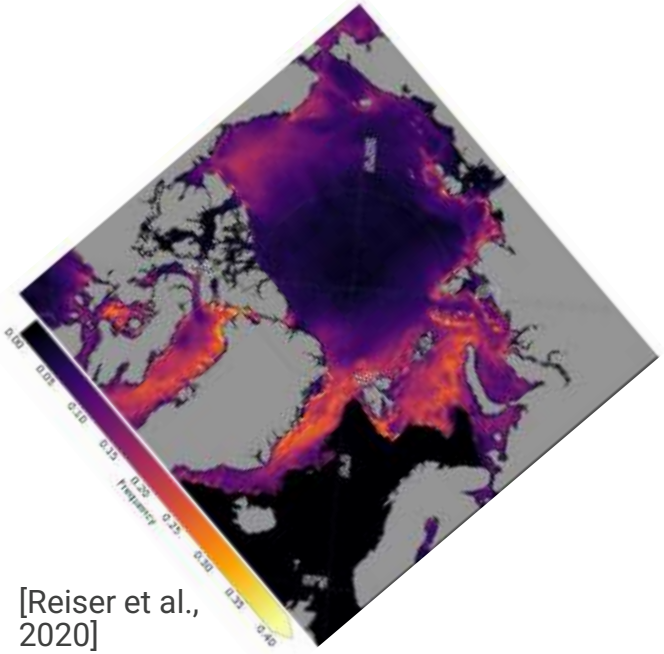
[Tilling et al. 2019]

CryoSat-2



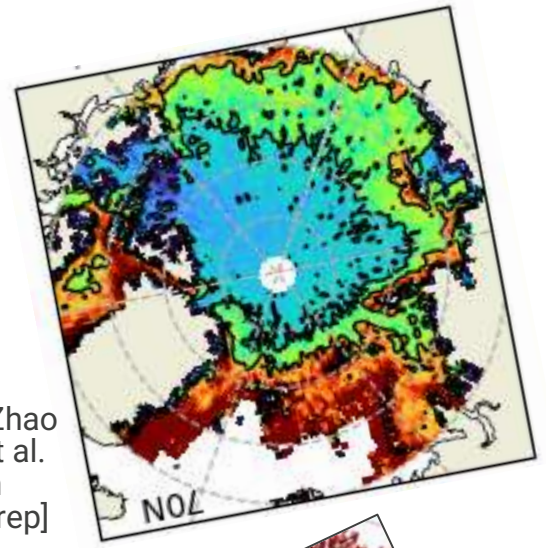


MODIS

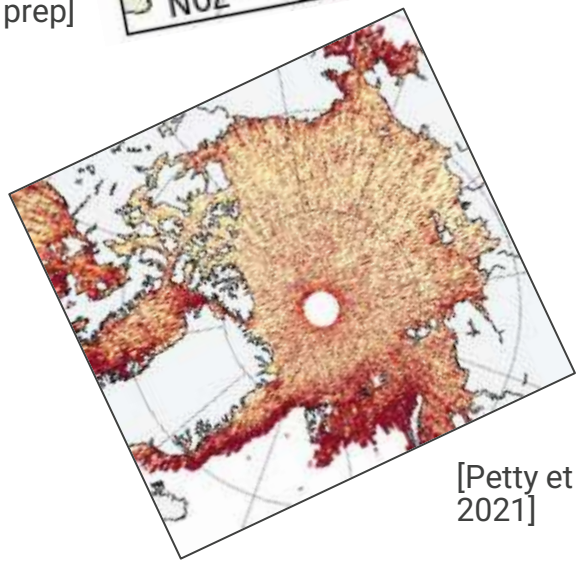


[Reiser et al., 2020]

ICESat-2 ATL07



[Zhao et al. in prep]

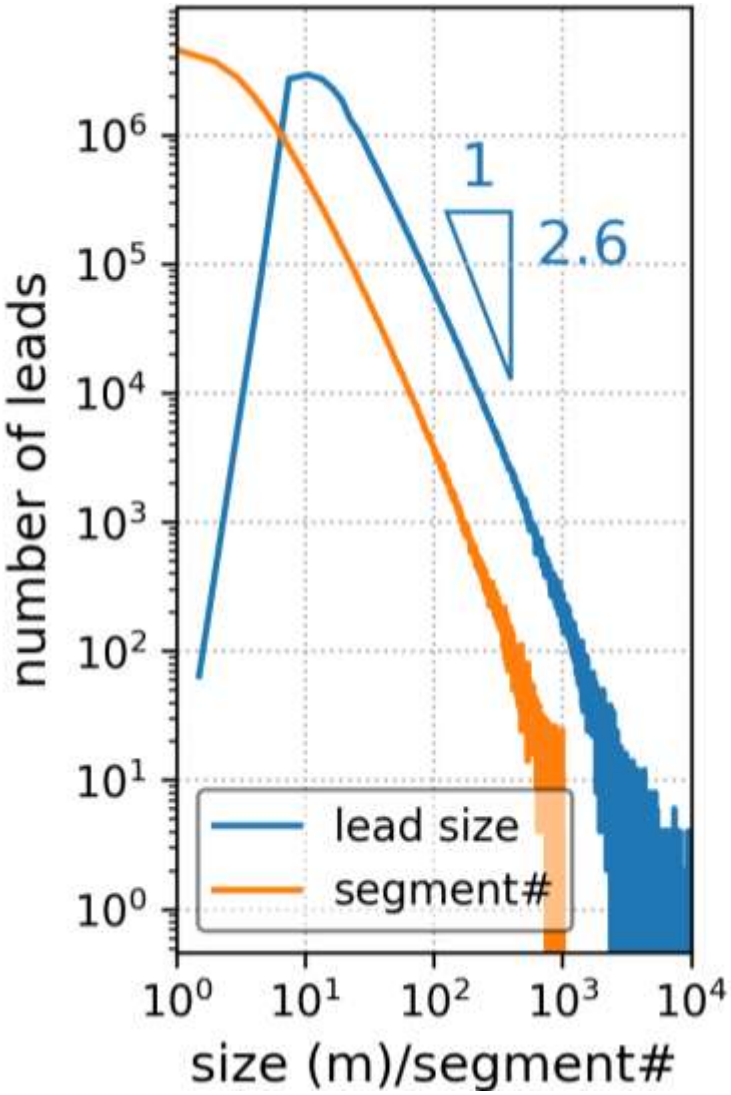


[Petty et al. 2021]

- Quantitative comparisons ongoing, but are often ambiguous
  - Temporal coverage, indirect v. direct detection, inclusion of dark leads, evolving algorithms
- However, spatial pattern in lead fraction is roughly consistent across products

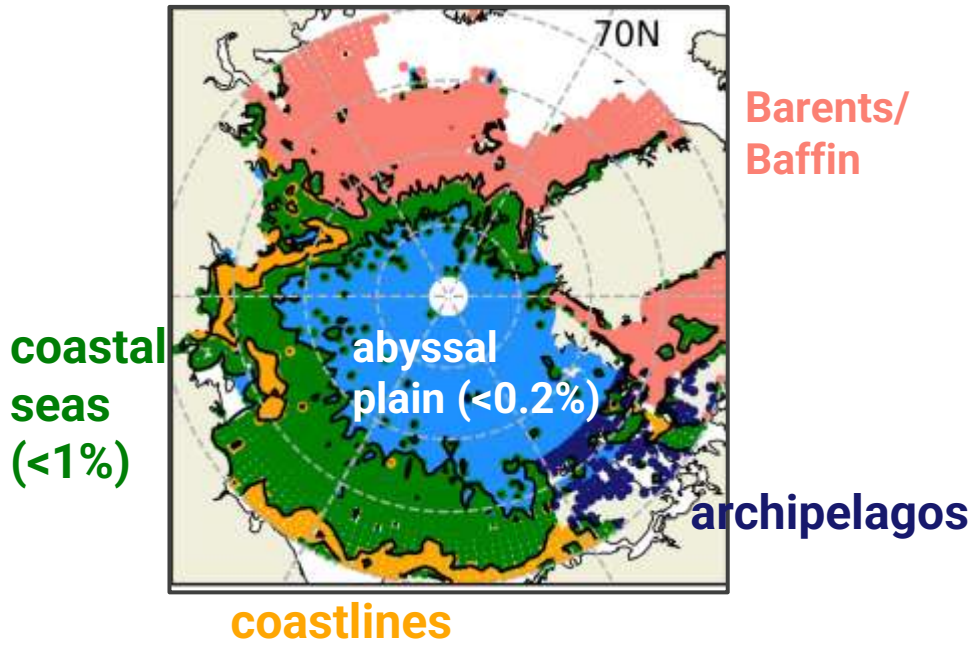
Lead size – pan-Arctic 5-year climatology

- With a large enough sample size, right tail follows a log-log distribution
  - We use the slope over 200 m to 1000 m
  - Higher slope = for any lead fraction, more small leads
- Truncated at ~7.5 m (~ segment length of a specular lead): we're still missing leads!
- Do not consider orientation (hence "size")



Aggregating over regions to assess interannual variability

- Aggregate over regions of similar climatological lead fraction (and size distribution)
- Each beam gives a longer, more representative, sample across regions of similar statistics
- Semi-objective approach (0.2%/1% LF)



Region	5-year climatology lead fraction	5-year climatology size slope
Barents/Baffin	3.3% (±0.04%)	2.1 (±0.01)
coastlines	1.6% (±0.04%)	2.0 (±0.01)
coastal seas	0.5 % (±0.01%)	2.2 (±0.01)
abyssal plain	0.1% (±0.002%)	2.6 (±0.01)
archipelagos	0.02% (±0.003%)	2.4 (±0.06)

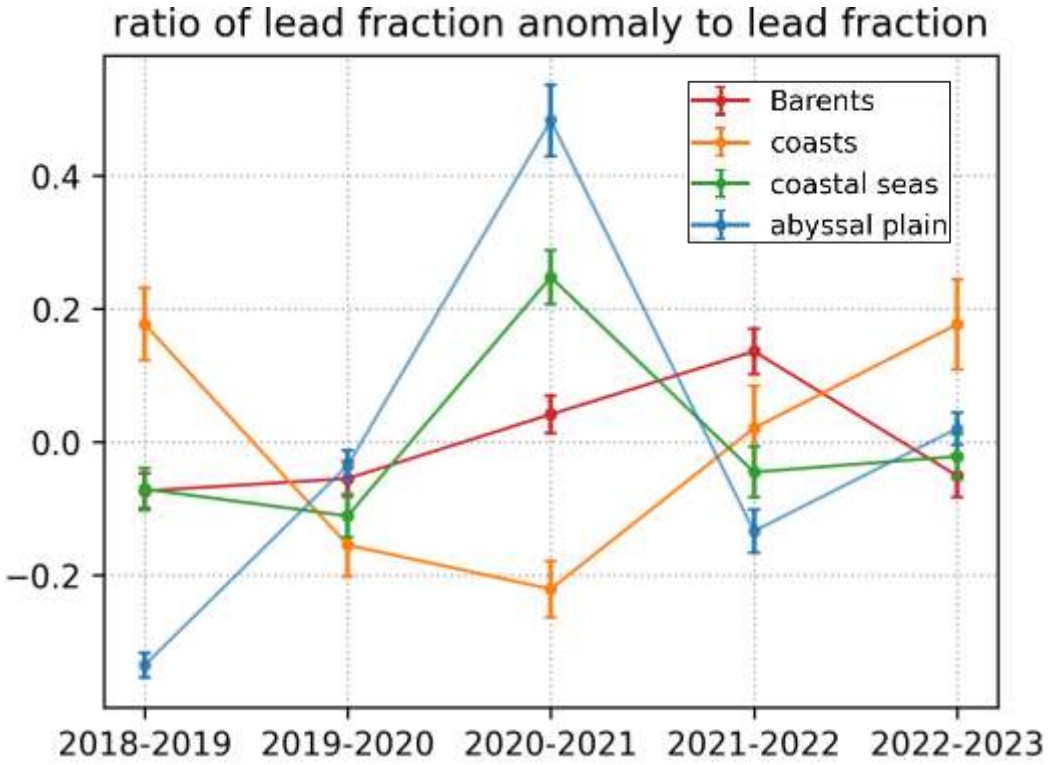
Lead Fraction – interannual

- Significant interannual variations except for archipelago region

- Largest changes relative to climatology in abyssal plain (82%±7%), followed by coastlines (40±5%)

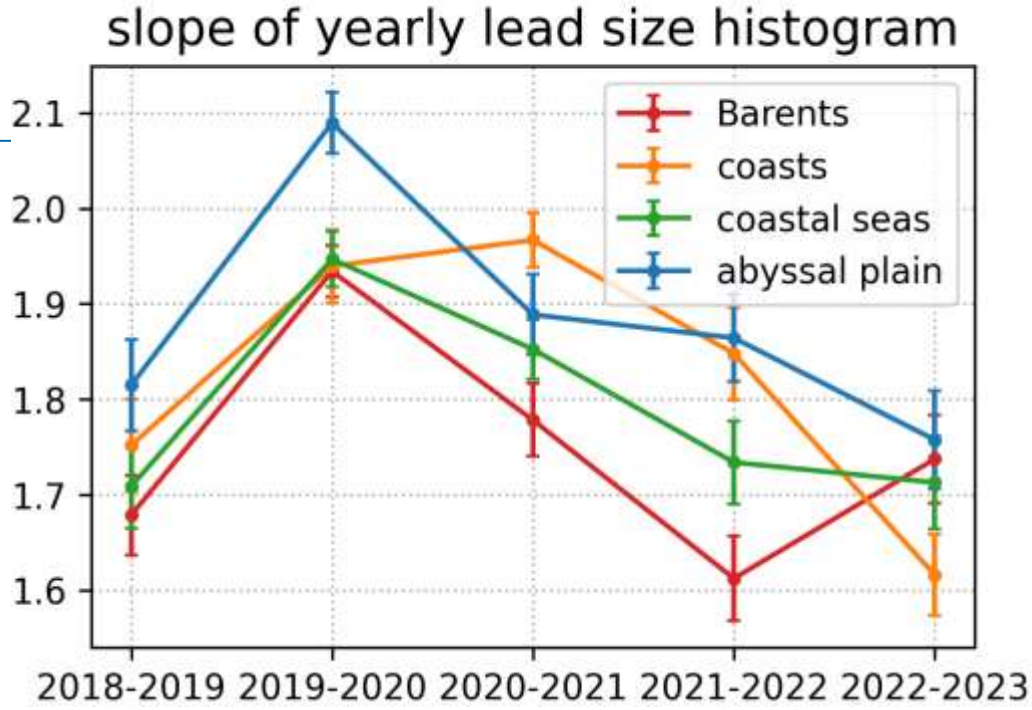
- Year-to-year variations differ across regions

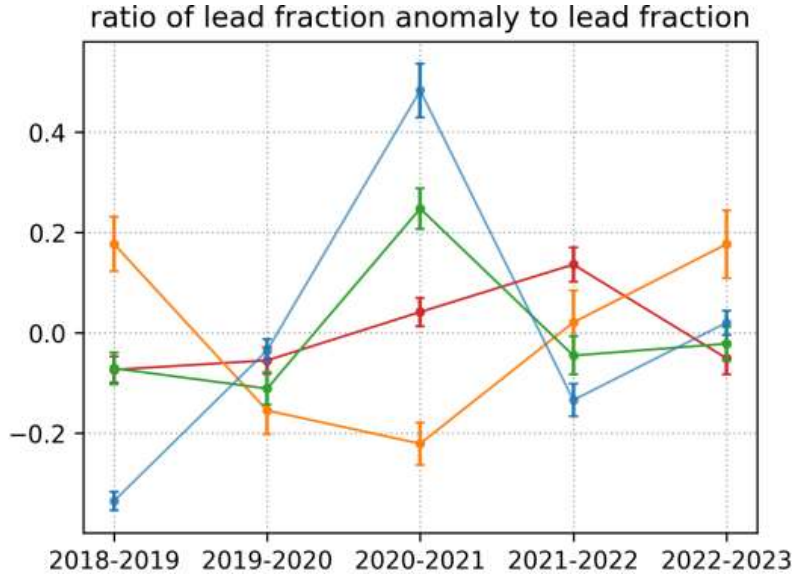
Region	lead fraction SD
Barents/Baffin	0.65% (±0.2%)
coastlines	0.65% (±0.2%)
coastal seas	0.15% (±0.04%)
abyssal plain	0.1% (±0.01%)
archipelagos	0.03% (±0.02%)



Lead size – interannual

- Similar year-to-year variations in different regions, in contrast to lead fraction
- Increase in slope 2018-2019 to 2019-2020; decline in slope afterward
- Developing other characterizations of lead size distribution that might be more appropriate for different climatological “regimes”





Conclusions and next steps

- Climatological patterns of lead fraction calculated from ATL07 products are robust and consistent with previous work
- Lead size exhibits a power-law distribution with a (log/log) slope that varies by region
  - Highest in Canadian Archipelagos and abyssal regions (more small leads)
- Substantial interannual variations in lead fraction and size distribution, significant at regional scales, are evident over the ICESat-2 era
- Next steps
  - Extending analysis through 2023-2024 before publication
  - Physical mechanisms underlying climatology and interannual variability
  - Relate bulk changes in leads to upper ocean salinity profile

Acknowledgments

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  - Rachael Tilling, Alek Petty and Jesse Wimert