Sea Surface Height of the Polar Oceans from Satellite Altimetry

Ron Kwok
Polar Science Center
University of Washington
Seattle, WA

Acknowledgment:
Jamie Morison, Suzanne Dickinson (PSC/UW)
Marco Bagnardi, Alex Petty, Nathan Kurtz (GSFC)
Sahra Kacimi (NASA/JPL)

Published in the
Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society

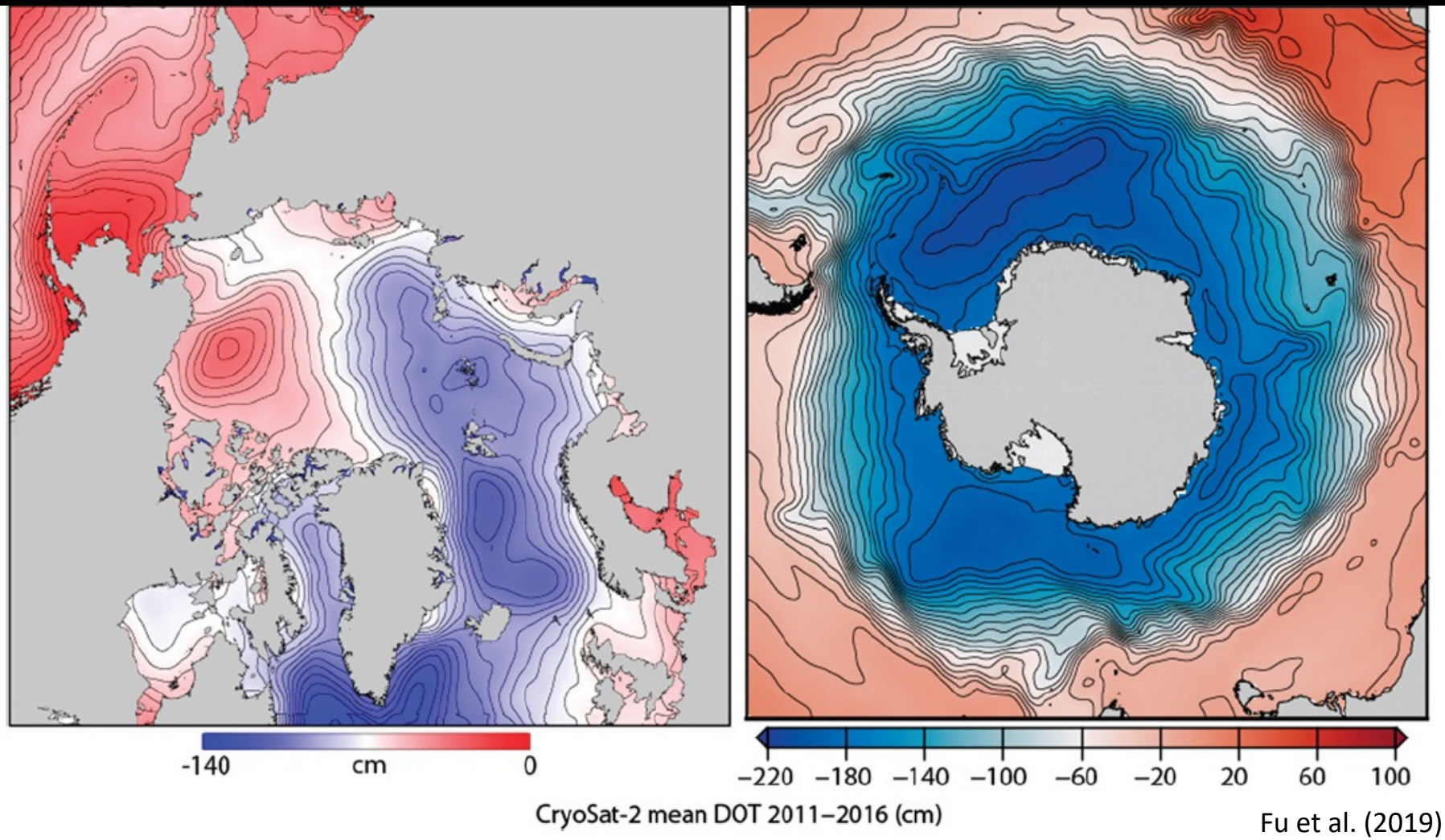
COMMUNITY WHITE PAPER

10.5270/OceanObs09.cwp.50

Combining Satellite Altimetry, Time-Variable Gravity, and Bottom Pressure Observations to Understand the Arctic Ocean: A Transformative Opportunity

R. Kwok[(1)], S. Farrell[(2)], R. Forsberg[(3)], K. Giles[(4)], S. Laxon[(4)], D. McAdoo[(5)], J. Morison[(6)], L. Padman[(7)], C. Peralta-Ferriz[(6)], A. Proshutinsky[(8)], M. Steele[(9)]

Mean Dynamic Ocean Topography of the Polar Oceans From CryoSat-2 (2011-2016)



Fu et al. (2019)

FIG. 5-29. Dynamic ocean topography from *CryoSat-2*. (a) Arctic Ocean [after Kwok and Morison (2015)]; (b) Southern Ocean [after Armitage et al. (2018)]

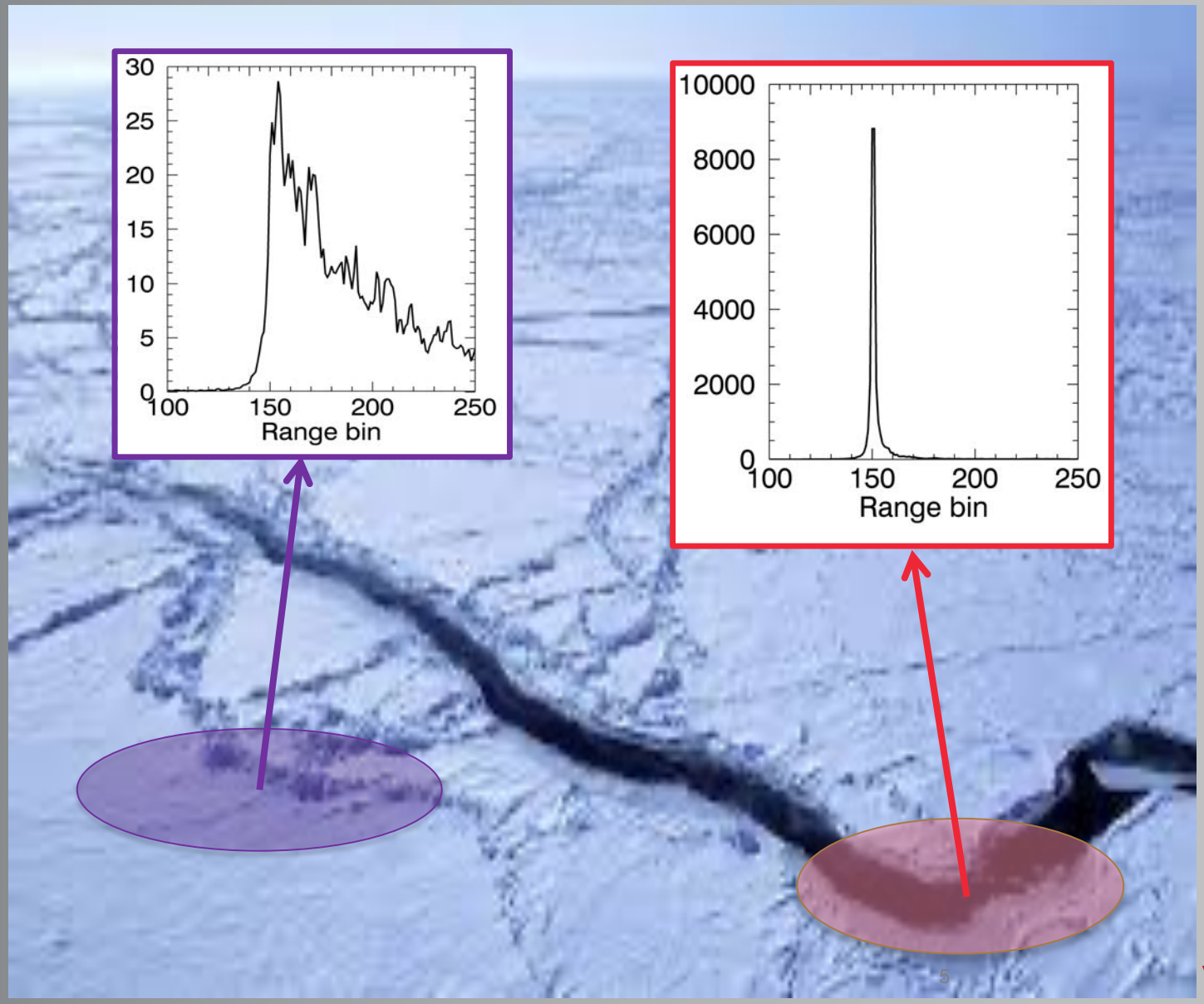
Outline

- Motivation: Overview of available observations
- SSH from two current on-orbit altimetry missions (ICESat-2 and CryoSat-2)
- Comparisons of SSH retrievals
- New wide-swath interferometer (SWOT)
- Summary remarks and outlook

Separation of sea surface returns from ice-covered oceans

Satellite Altimetry

- Conventional open-ocean processing fails in the presence of sea ice
- Identify returns from narrow openings to measure SSH
- Surface scattering is highly inhomogeneous
  - Leads appear very bright (mirror-like)
  - Ridges/deformation features
- SSH retrieval based on received pulse properties



Current dedicated ice missions

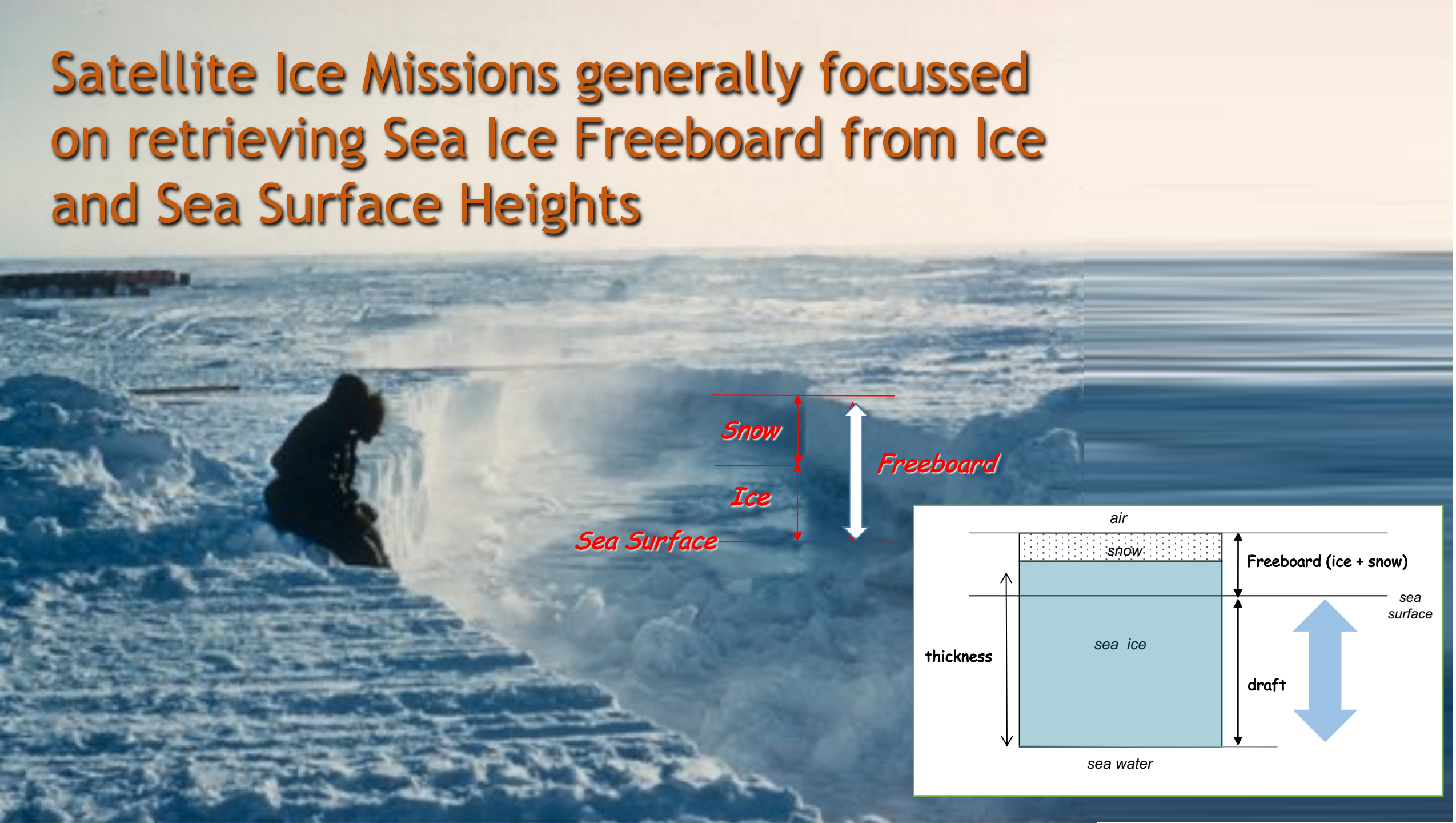
CryoSat-2

- Launched Apr 2010
- Profiling radar altimeter (single beam)
- Coverage to 88°

ICESat-2

- Launched Oct 2018
- Multiple beam lidar
- Coverage to 88°

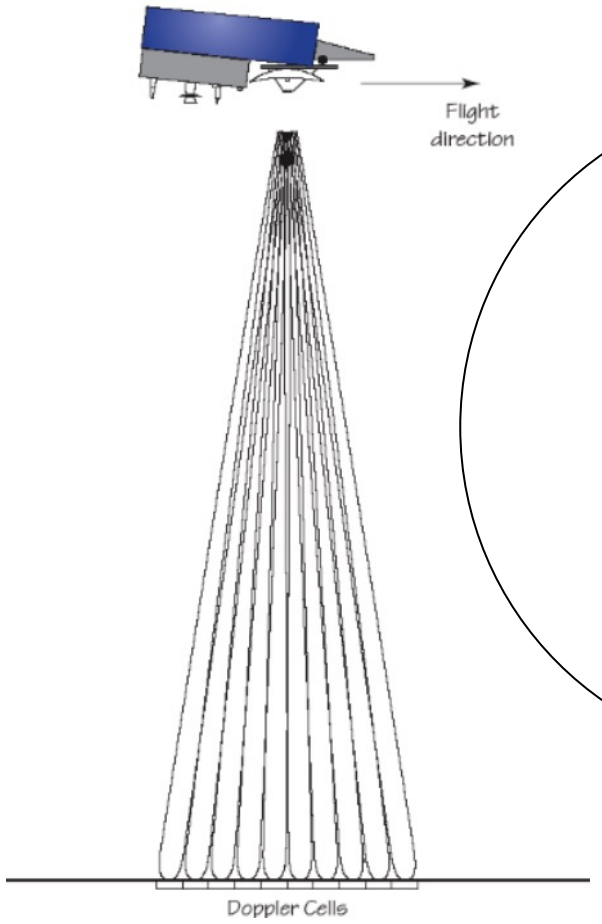
Satellite Ice Missions generally focussed on retrieving Sea Ice Freeboard from Ice and Sea Surface Heights

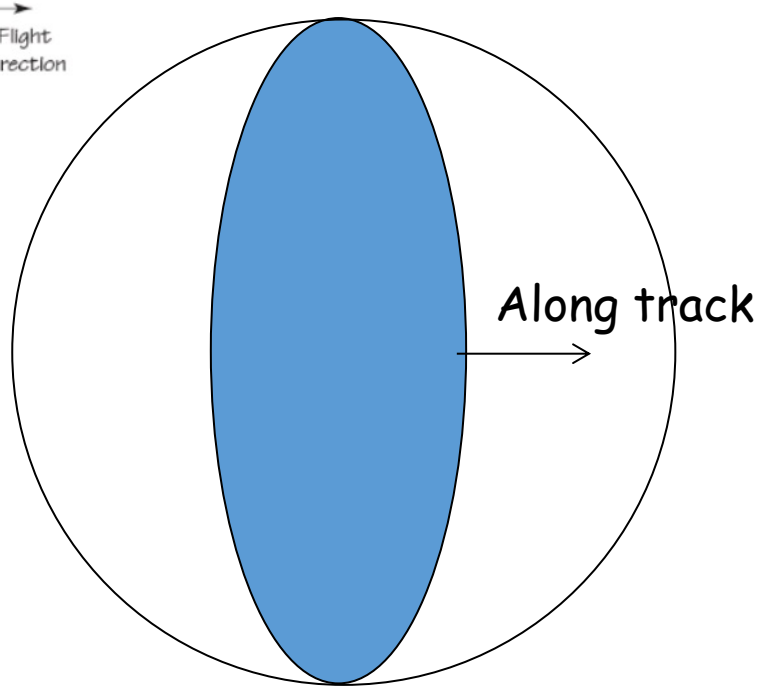


CryoSat-2 (Delayed-Doppler Processing)

- Radar: 13.575 GHz
- Pulse repetition frequency: 18.181 kHz in SAR and SIN mode
- Pulse Bandwidth: 320 MHz (Range resolution: 46.8 cm)
- Range sampling (in SAR): 0.2342 m
- (beam width: 70-110 urad)
- Pulse limited footprint: 313 by 1670 m

- Satellite
  - Inclination: 92 deg
  - Altitude: 717 km
  - Launched: Apr 2010

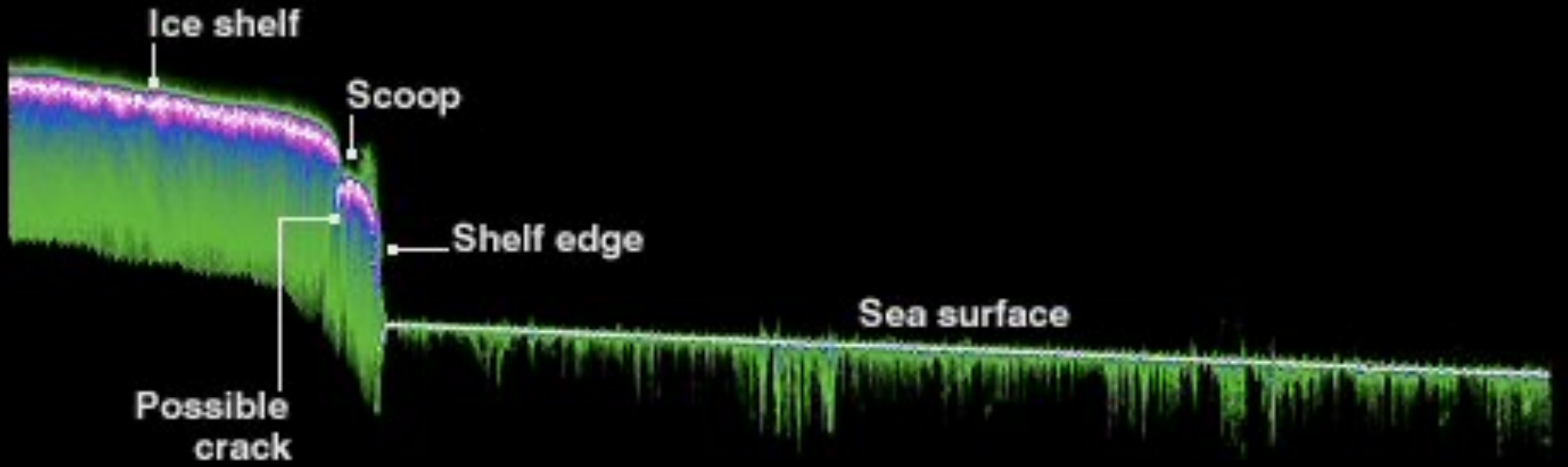




Nominal radar footprint:

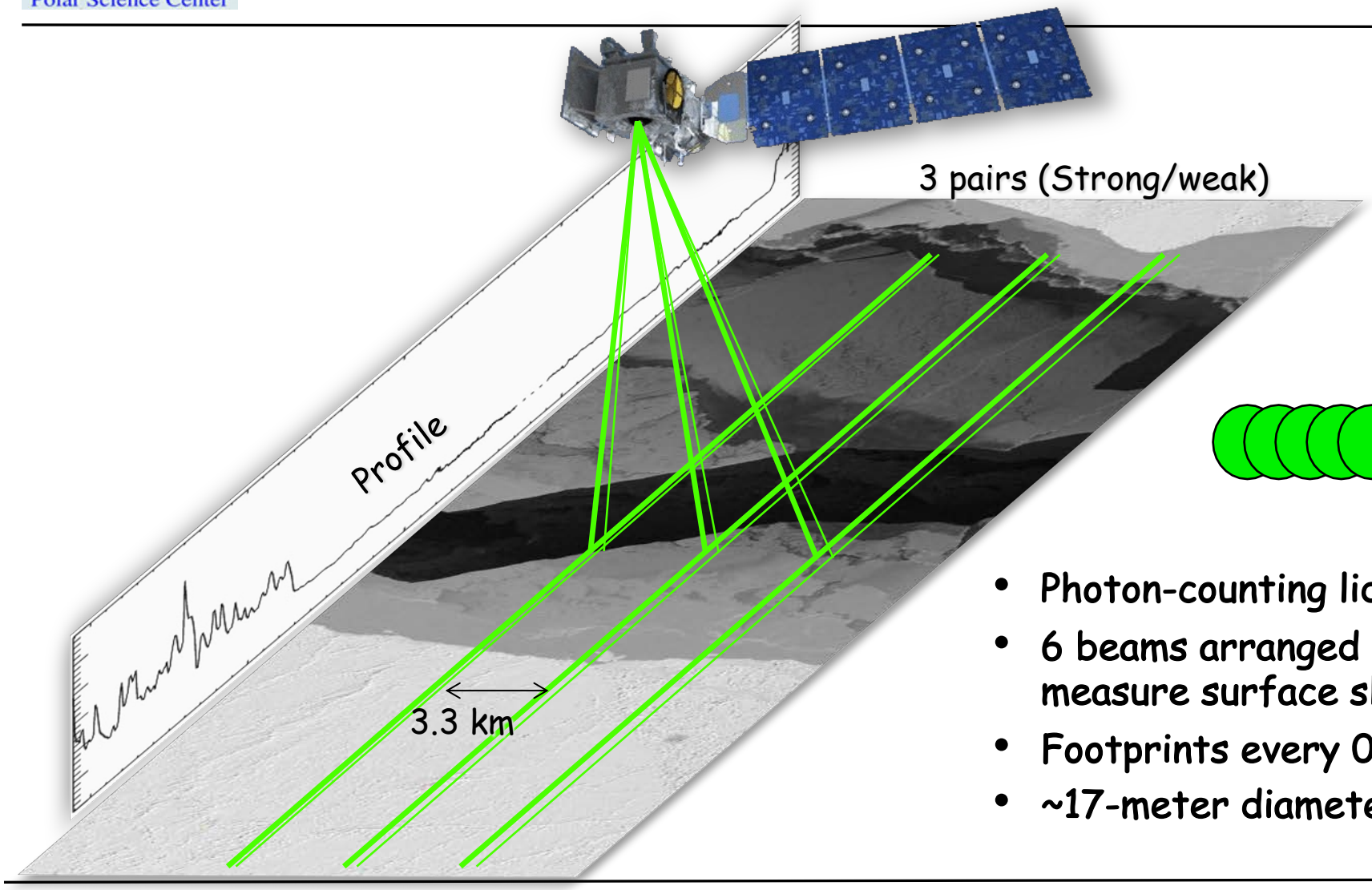
~0.3 km by 1.6 km

CRYOSAT-2: Data from the Ross Ice Shelf, Antarctic



Source: ESA/UCL

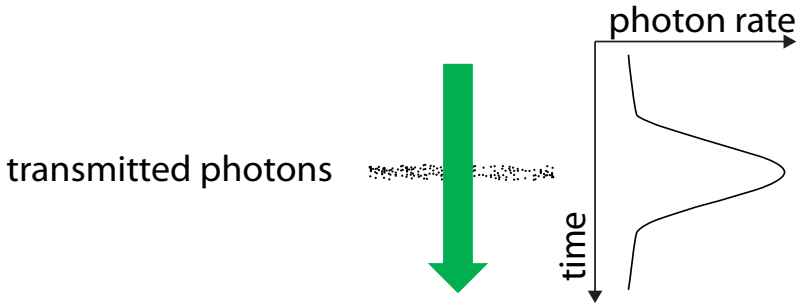
Multibeam Photon Counting Altimetry

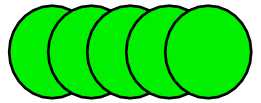


Overlapping 11 m diameter footprint:
0.7 m pulse repetition

- Photon-counting lidar
- 6 beams arranged in 3 (Strong/weak) pairs to measure surface slope directly
- Footprints every 0.7 m (ICESat-1 167 m)
- ~17-meter diameter (ICESat-1 50-70 m)

Multibeam Photon Counting Altimetry

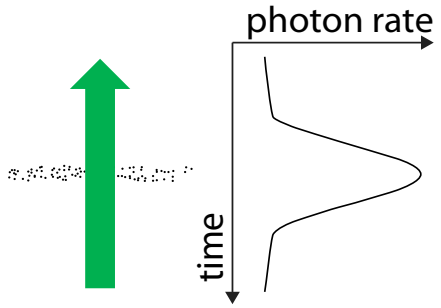


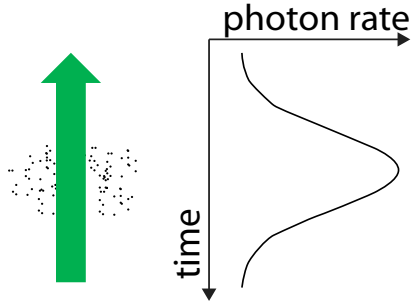


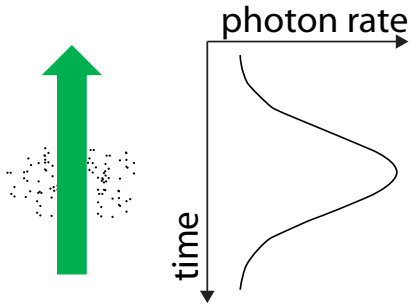
11 m diameter footprint

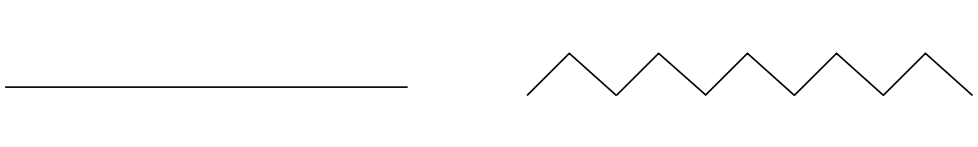
0.7 m pulse repetition

Height estimate for every detected photon event !







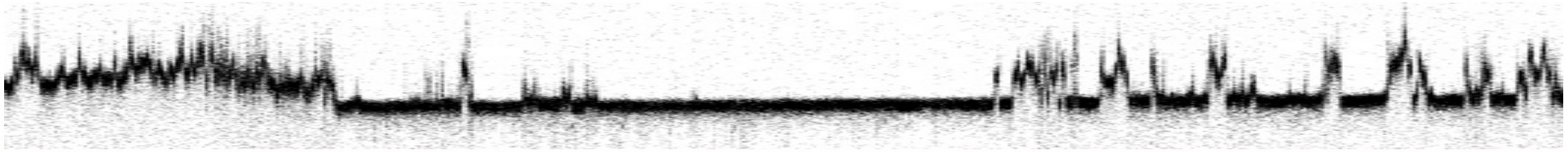


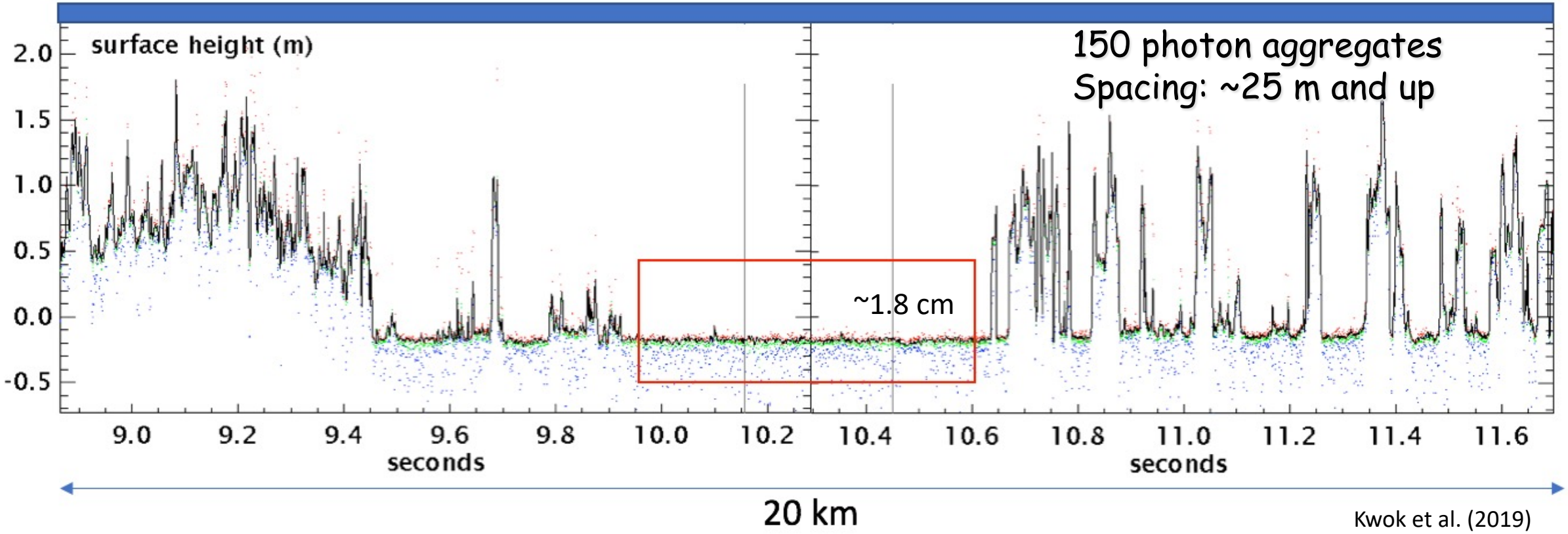
flat surface

rough surface

sloped surface

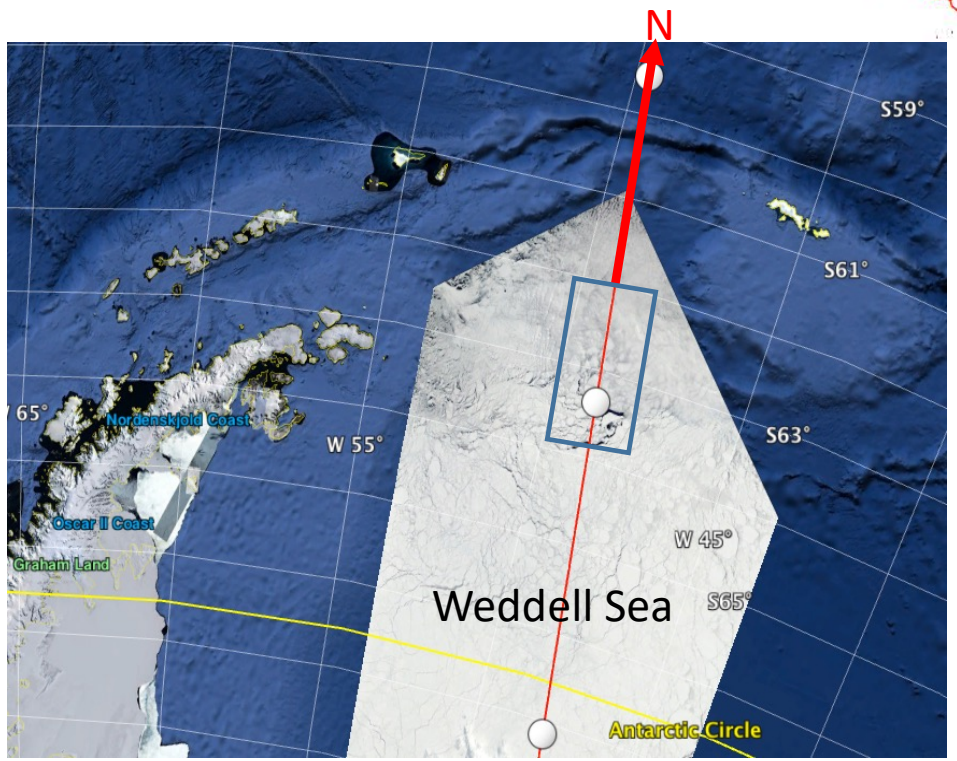
Height Precision



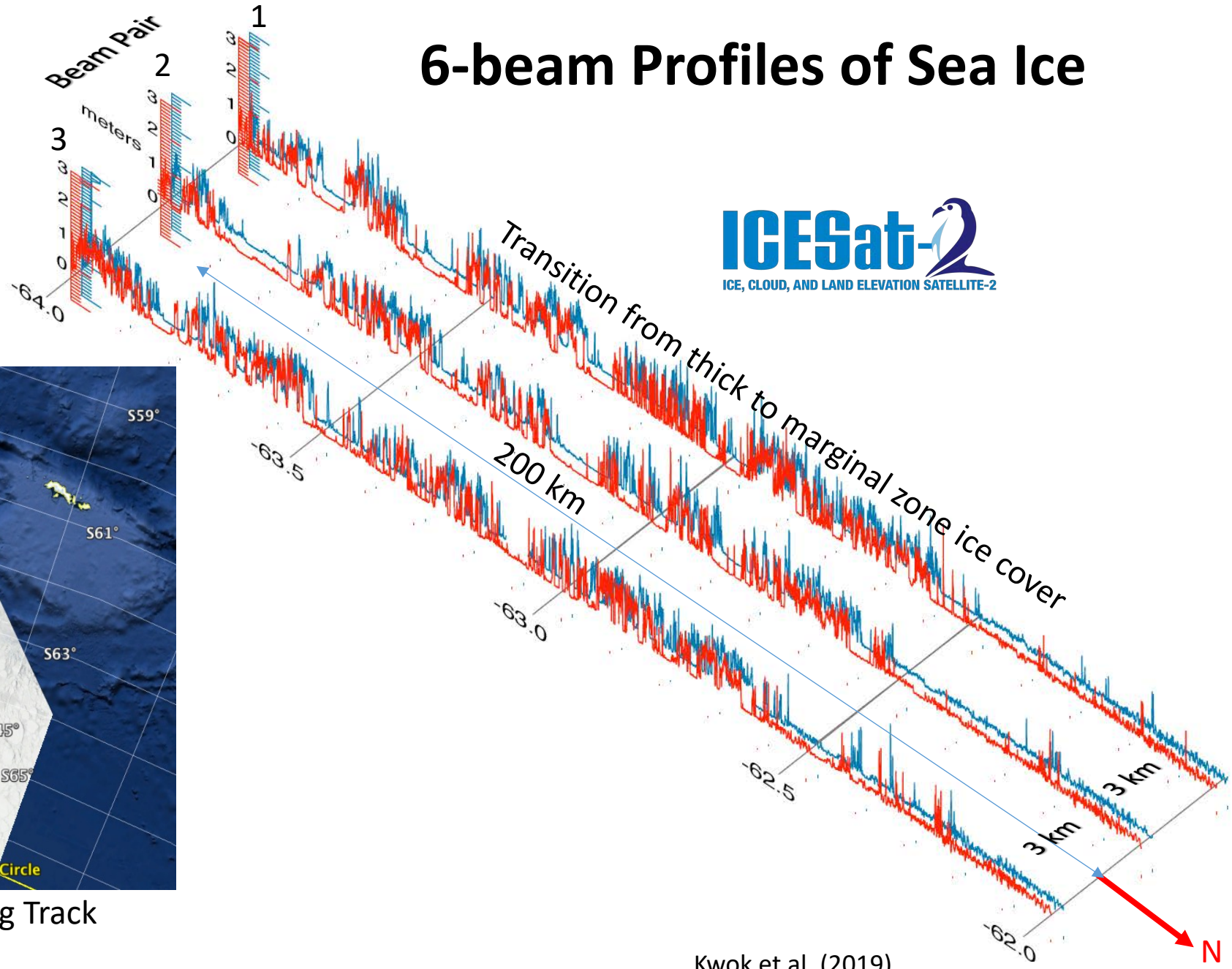


Kwok et al. (2019)

6-beam Profiles of Sea Ice



October 17, 2018 – Ascending Track



Kwok et al. (2019)

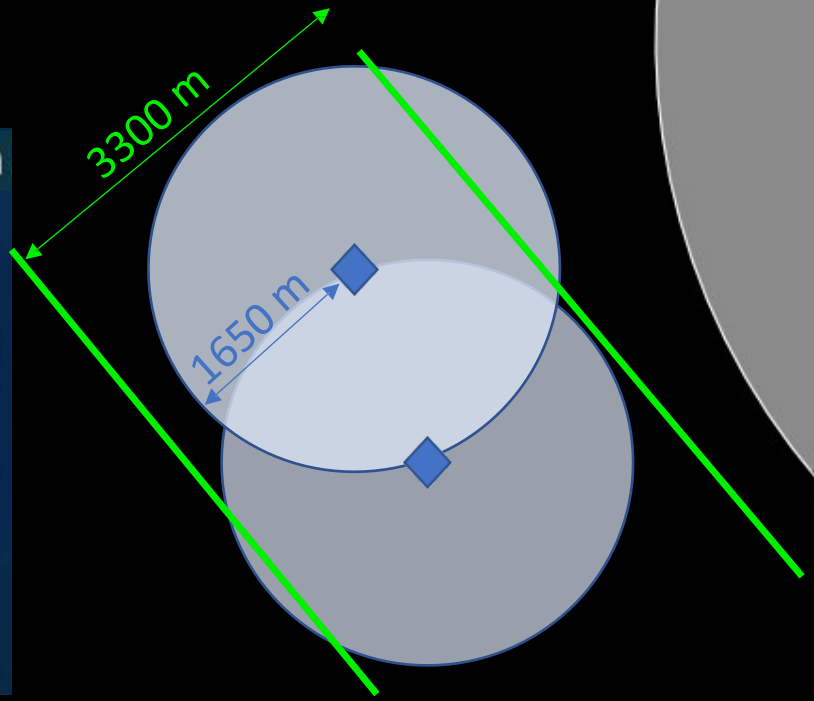
CRYO2ICE Operations

August 04, 2020 February 10, 2022)

CryoSat-2/ICESat-2 Resonance Orbits:

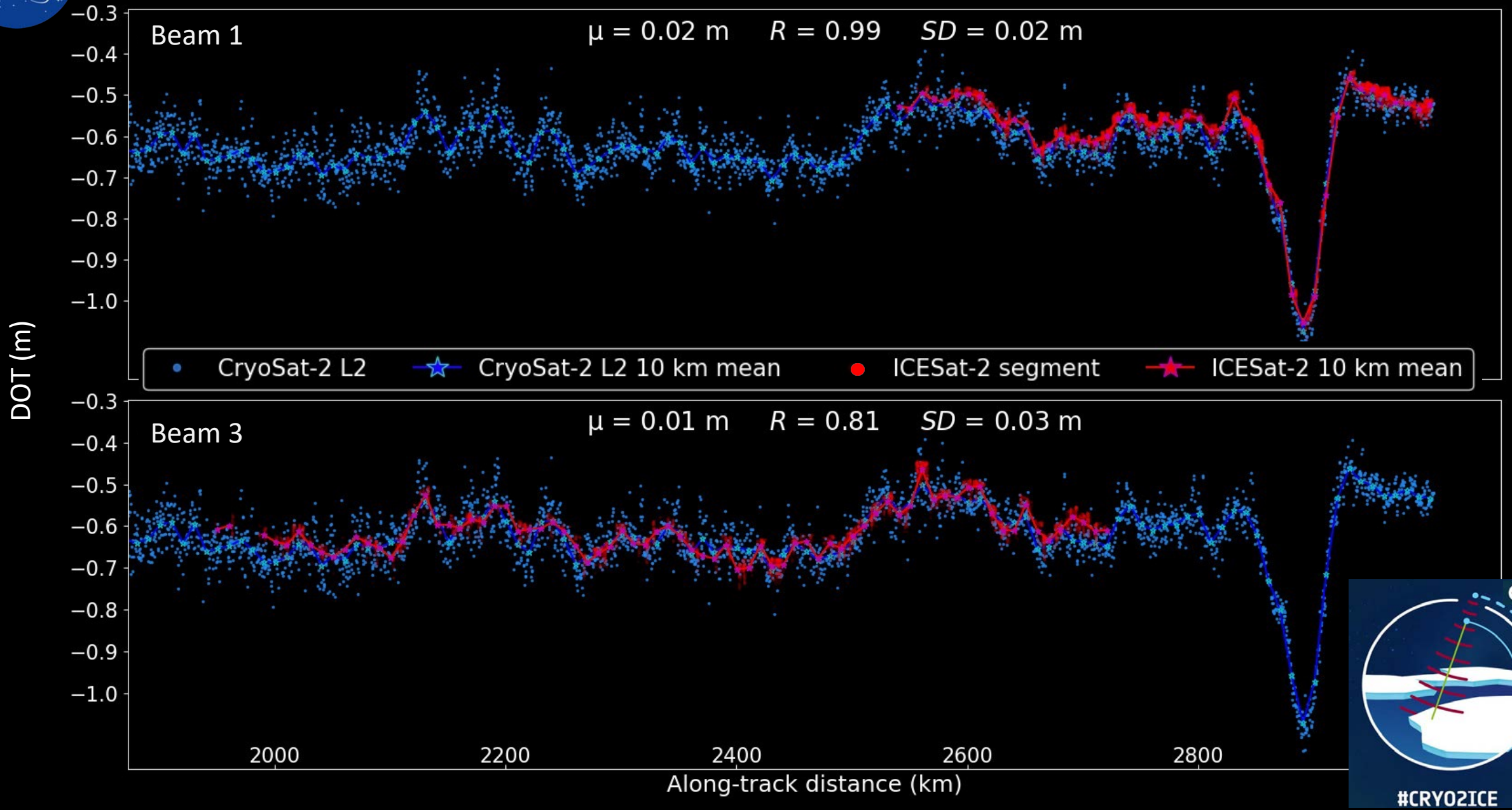
CryoSat-2 and ICESat-2 passed over coincident polar areas at approximately the same time every 19 orbits, roughly every 31 hours.

30 semi-synchronous orbits over Arctic Ocean



CRYO2ICE: the great ones

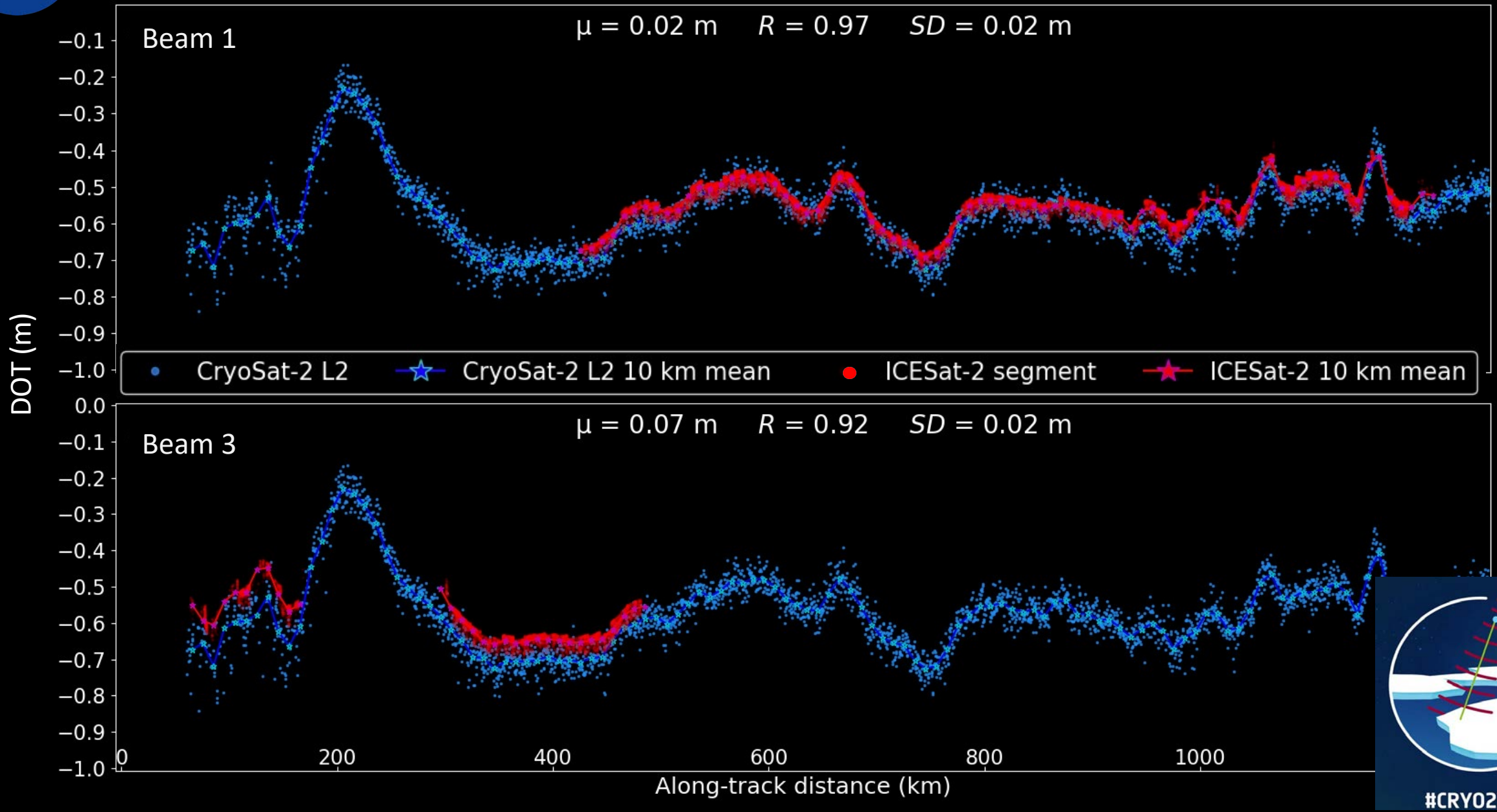
Bagnardi et al. (LPS, 2022)



#CRYO2ICE

CRYO2ICE: the good ones

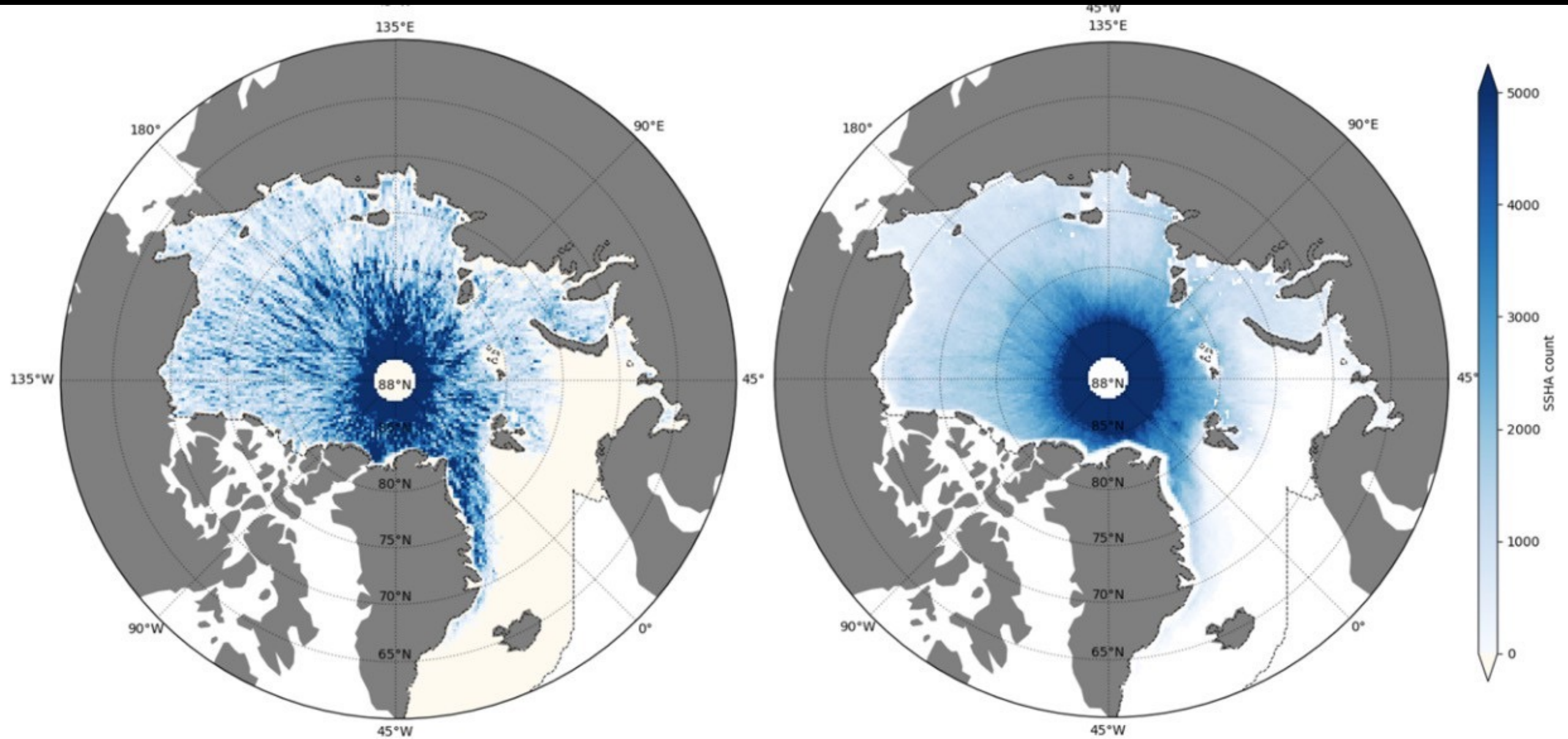
Bagnardi et al. (LPS, 2022)



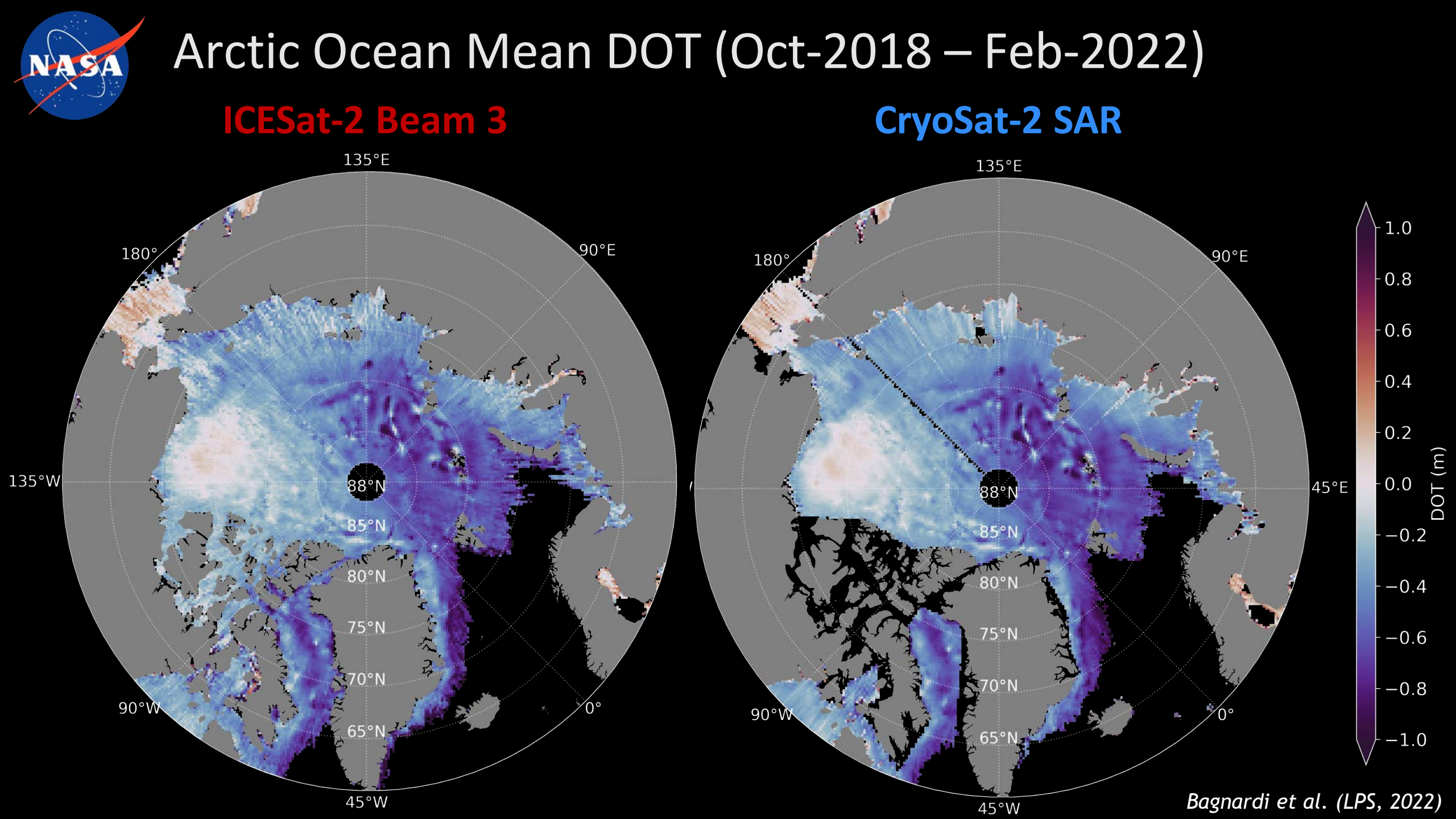
#CRYO2ICE

SSHA count

From *Bagnardi et al.*, GRL, 2021



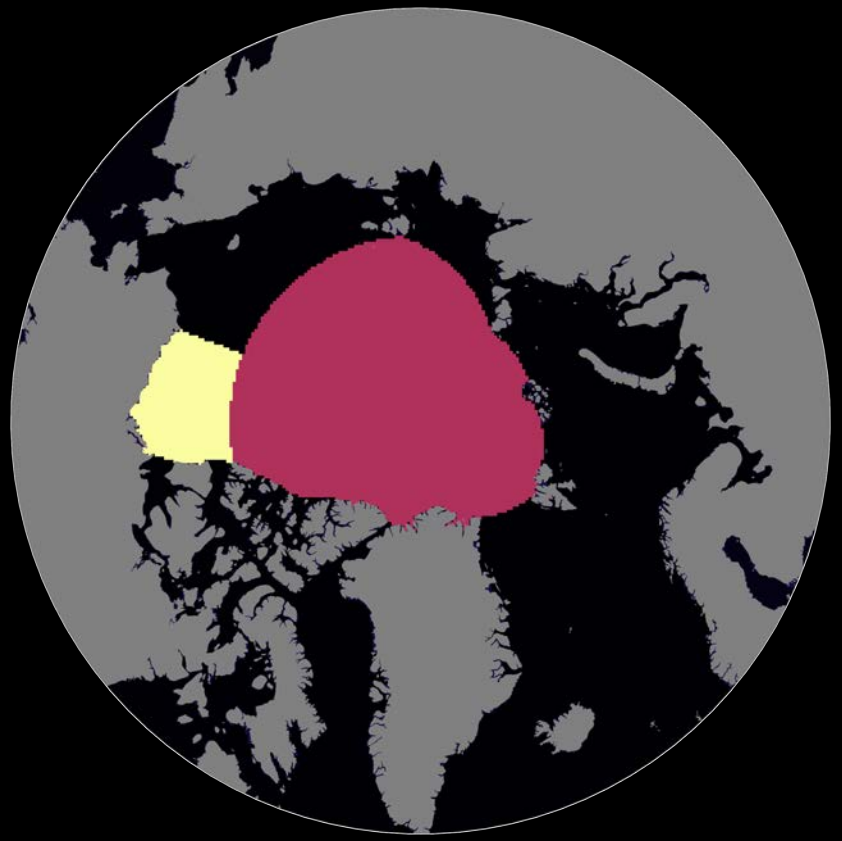
Arctic Ocean Mean DOT (Oct-2018 – Feb-2022)

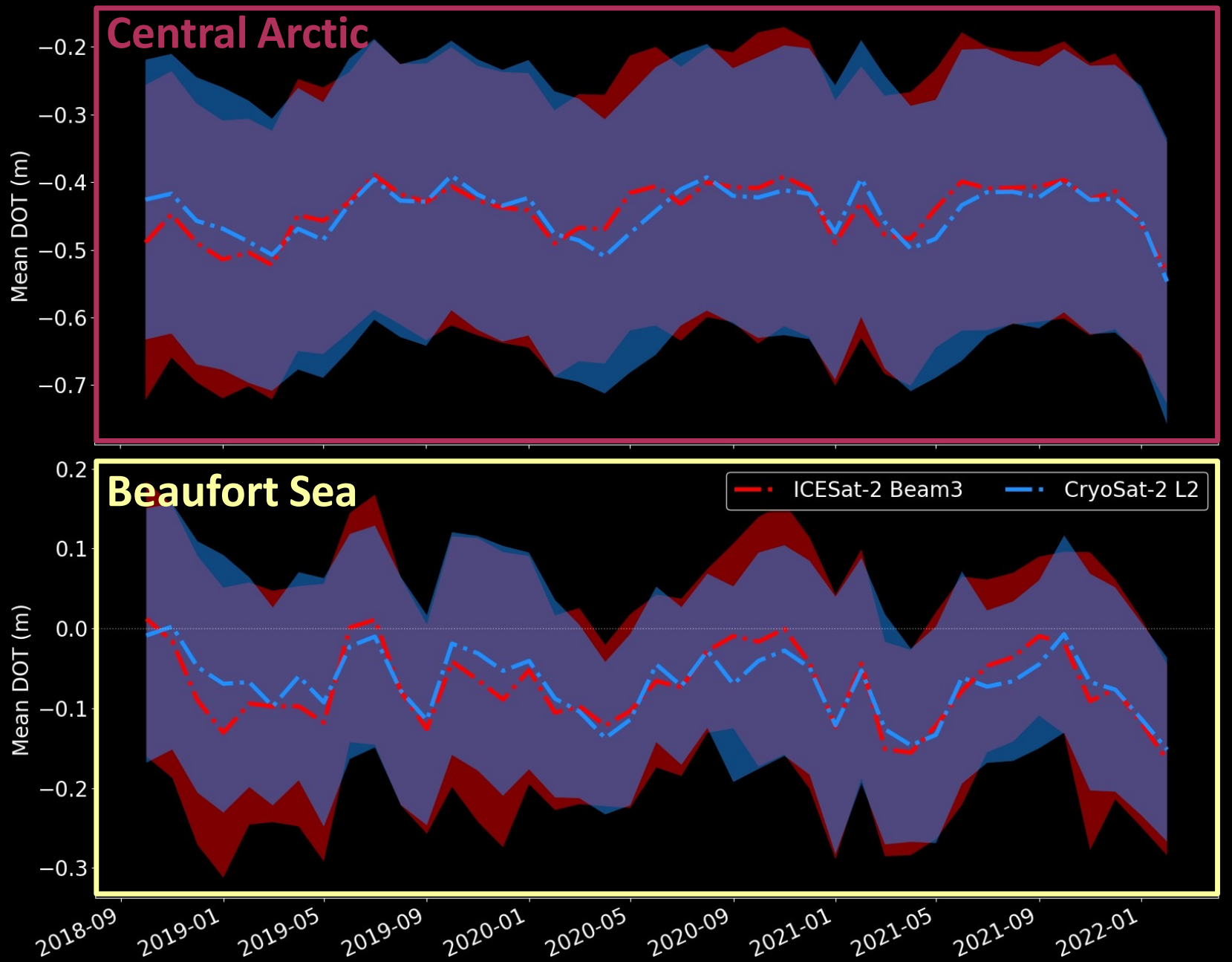


Bagnardi et al. (LPS, 2022)

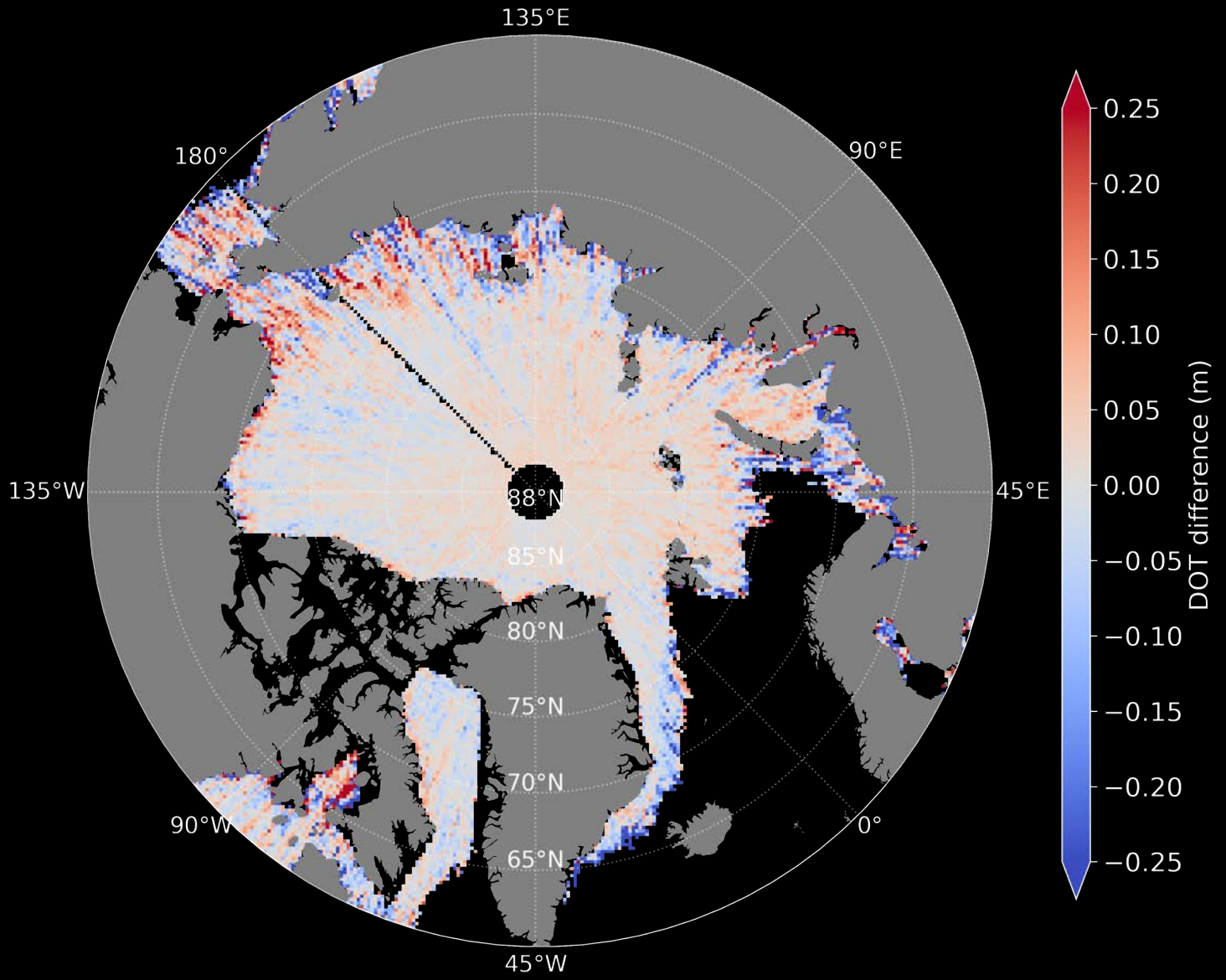
Monthly Mean DOT time series

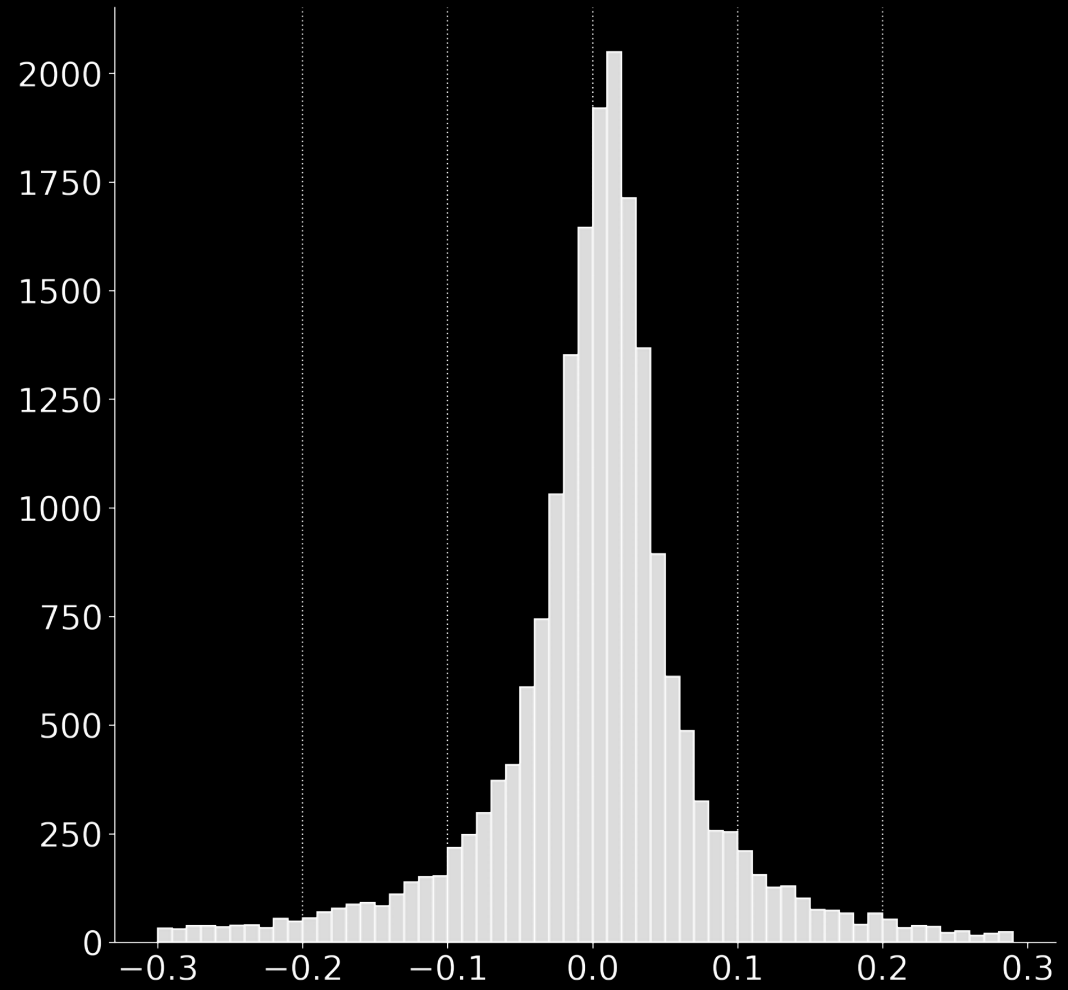
Bagnardi et al. (LPS, 2022)





Arctic Ocean Mean DOT (Oct-2018 – Feb-2022)

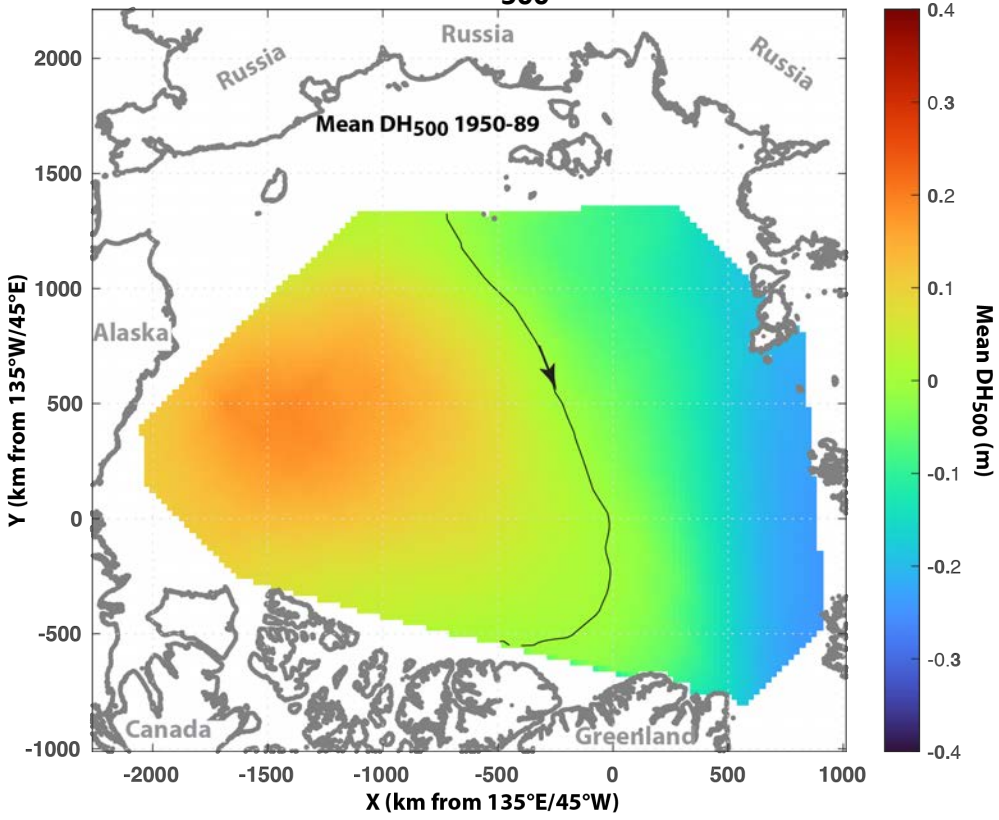




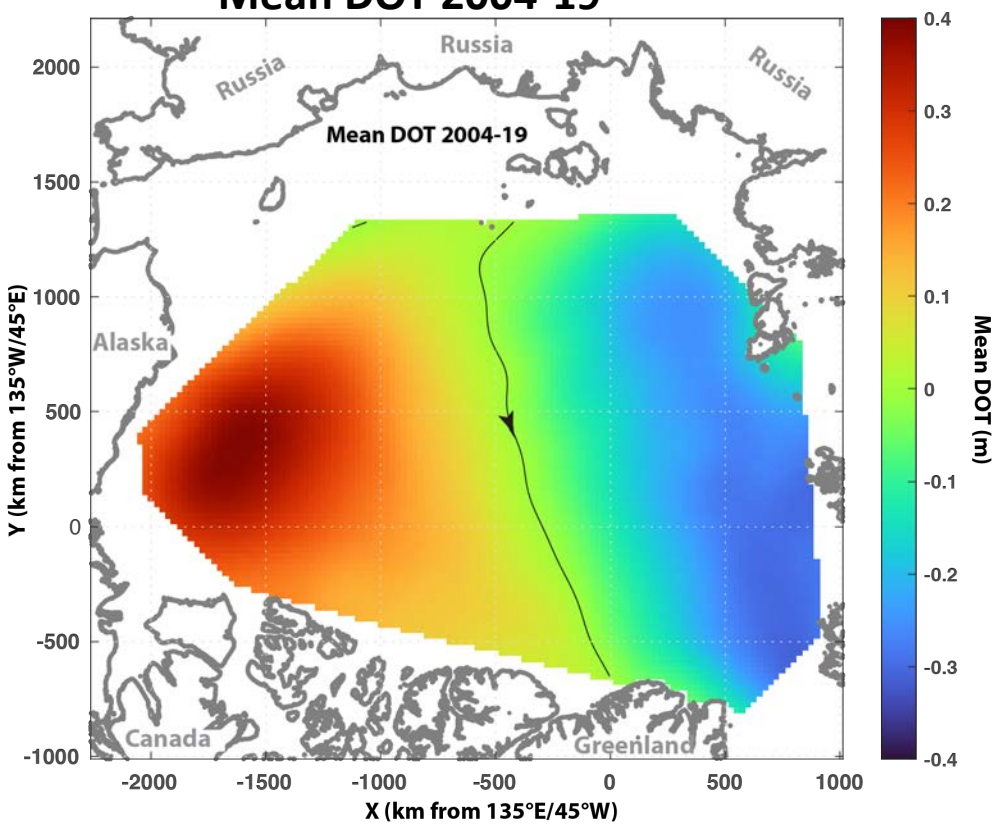
Bagnardi et al. (LPS, 2022)

Dynamic Heights (1950-89) and ICESat/CryoSat-2 DOT (2004-19) Anomalies Relative to Time-averaged Patterns shown here

Mean DH_{500} 1950-89



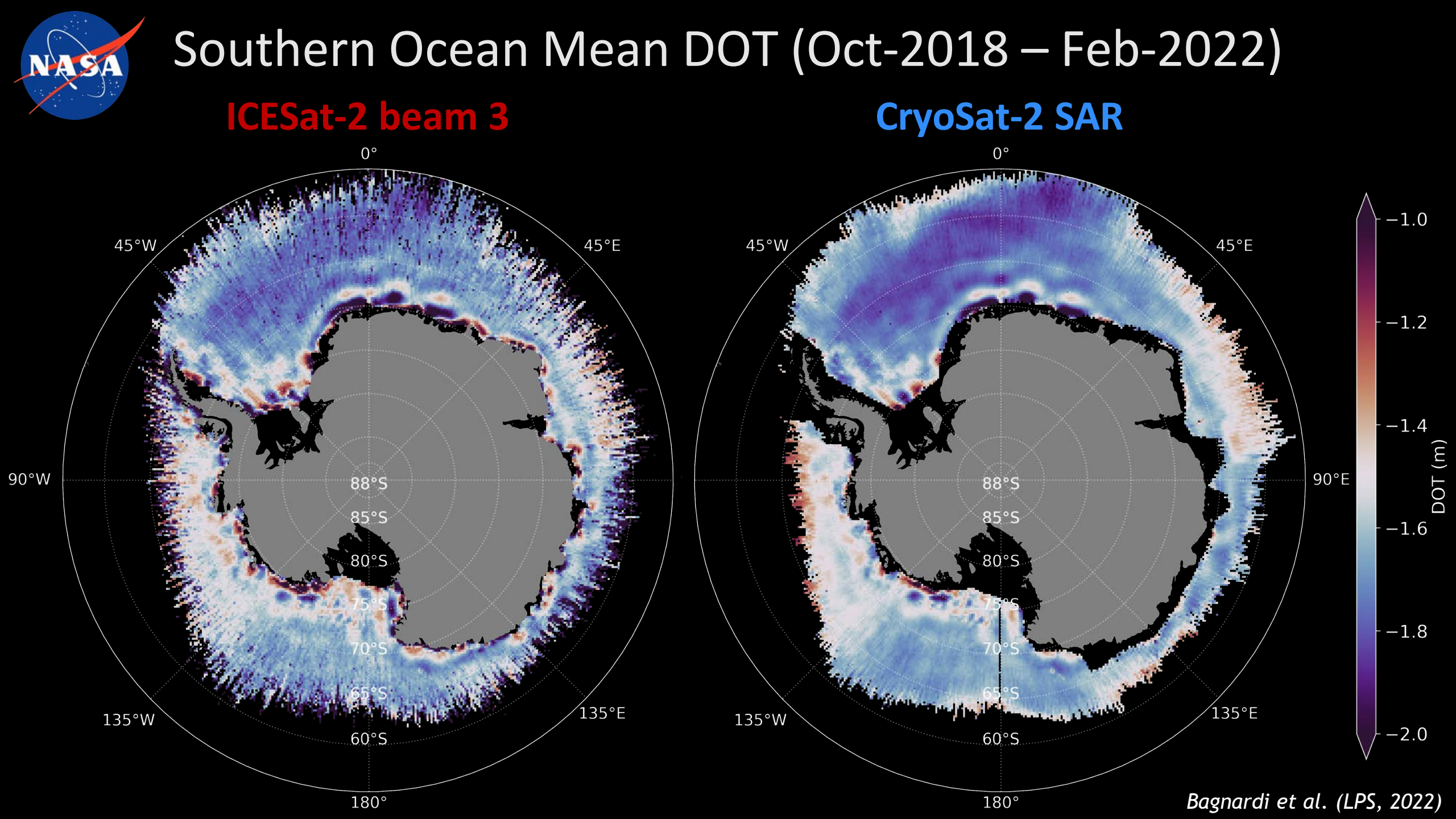
Mean DOT 2004-19



The mean of 2004-19 annual Feb-April DOT (right) is similar to the 1950-89 mean winter DH (left) but the Beaufort Gyre is smaller and more intense, and the Eurasian Basin low is distinct, larger and deeper.

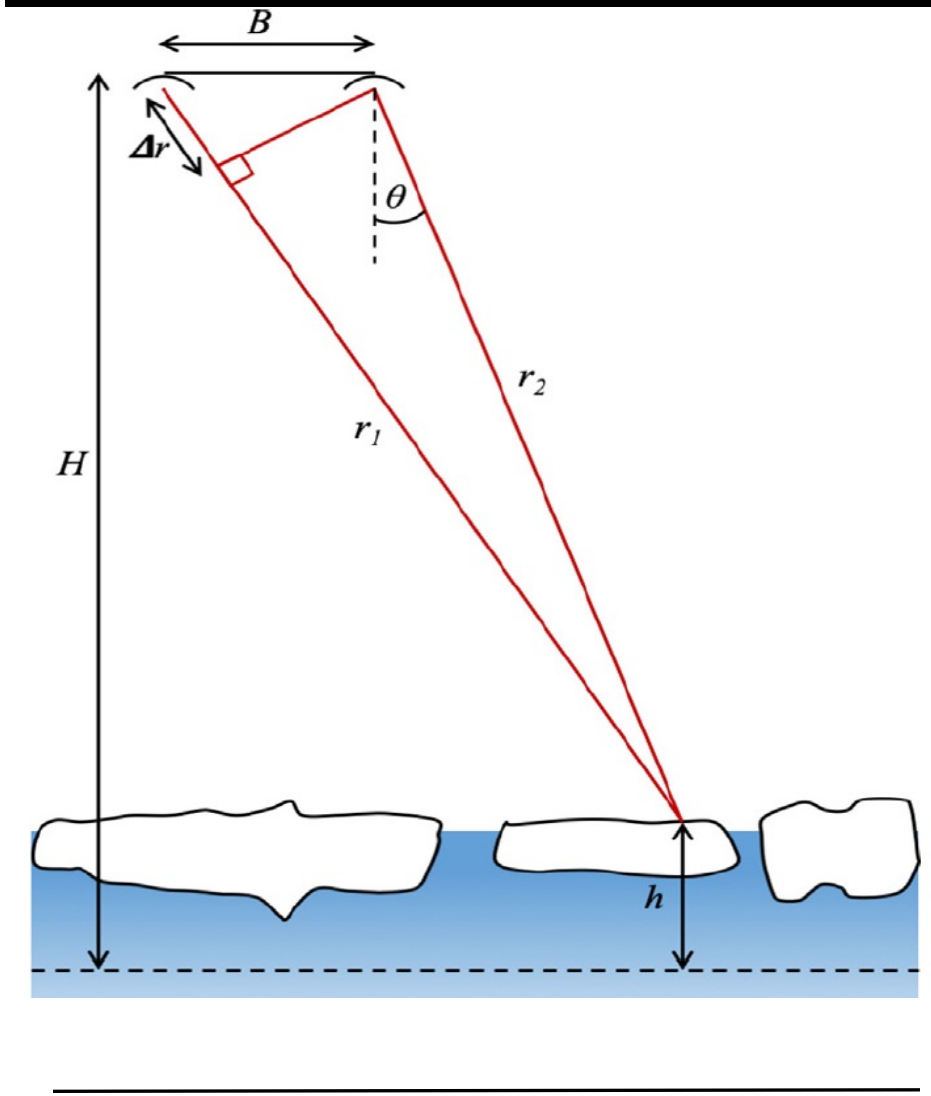
Source: Incidence of the Cyclonic Mode of Arctic Ocean Surface Circulation (Morison, 2022)

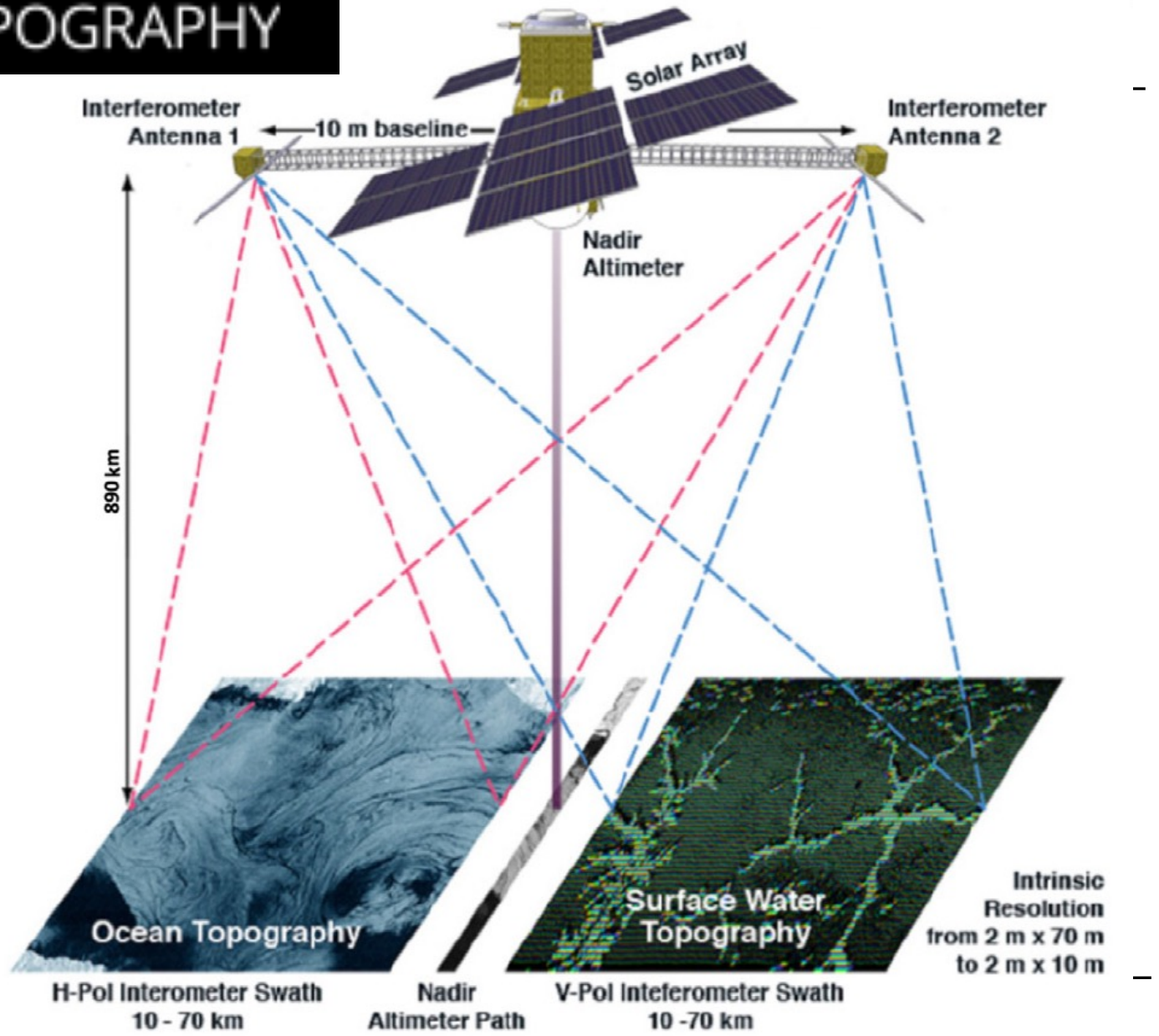
Southern Ocean Mean DOT (Oct-2018 – Feb-2022)

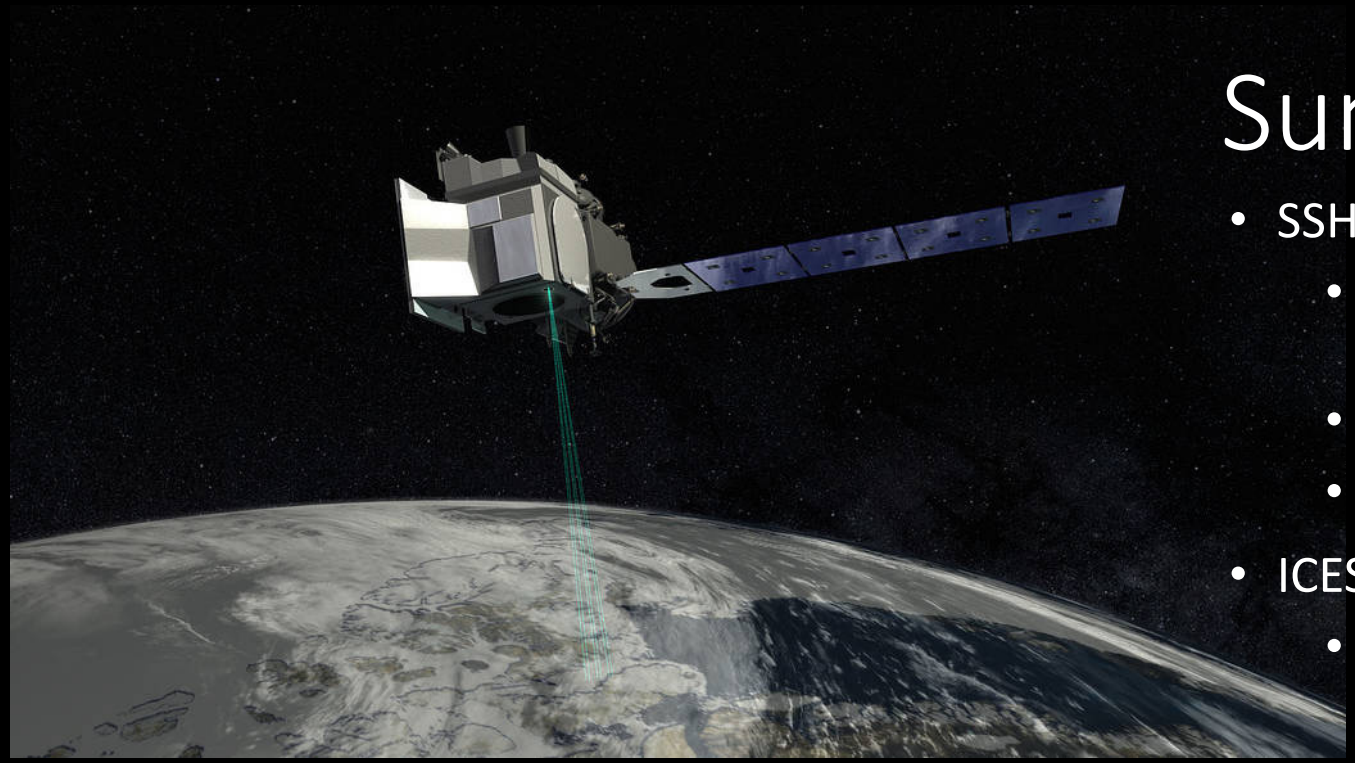


Bagnardi et al. (LPS, 2022)

SWOT SURFACE WATER AND OCEAN TOPOGRAPHY







Summary Remarks

- SSH Retrievals over ice-covered oceans
  - Current dedicated sea ice missions (CryoSat-2, ICESat-2)
  - Also Altika, Sentinel 3
  - Envisat (2002-2012), ICESat (2003-2009)
- ICESat-2 (Oct 2018-present)
  - SSH over open and ice-covered Products (Orbit and Gridded)
  - Available at NSIDC
- Upcoming
  - SWOT (Launch: Nov 2022), Cristal (~2030)
- Current work
  - document variability and accuracy of products.
  - Coastal altimetry (ICESat-2 resolution)
- SSH of ice-covered ocean
  - standard products - Space Agencies

Dynamic height vs Dynamic Ocean Topo

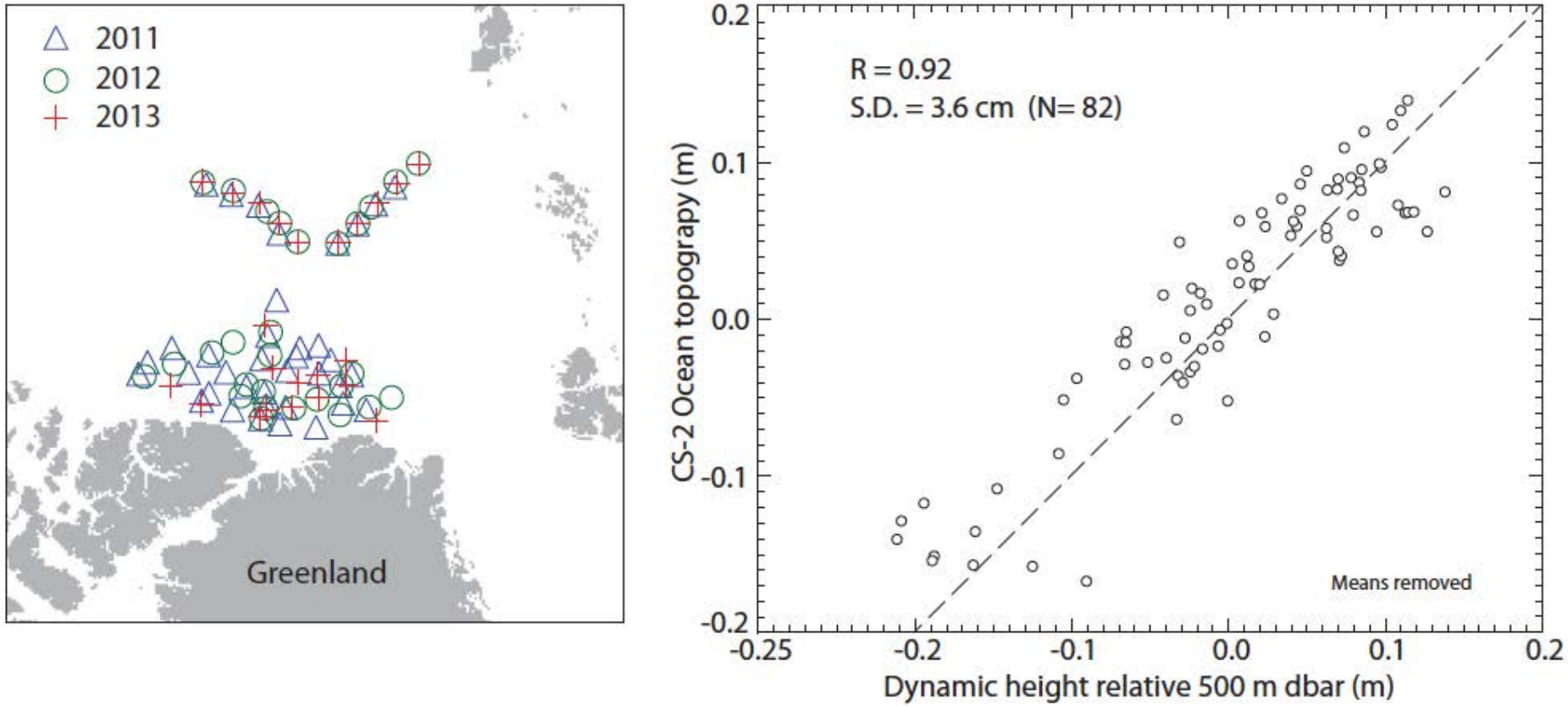


Figure 7. Arctic Ocean dynamic height (DH) versus monthly mean dynamic topography. (a) Locations of hydrography-derived DH estimates (relative to 500 dbar) in 2011, 2012, and 2013. (b) DH from hydrography versus monthly DOT from CS-2 at the 2008 hydrographic stations. Monthly DOTs have been smoothed with a 100 km Gaussian kernel.