Sea Surface Height of the Polar Oceans from Satellite Altimetry

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

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

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

- 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)

Overlapping 11 m diameter footprint: 0.7 m pulse repetition
Multibeam Photon Counting Altimetry

Height estimate for every detected photon event!

11 m diameter footprint
0.7 m pulse repetition

transmitted photons

Photon rate

Photon rate

Photon rate

time

time

time

flat surface

rough surface

sloped surface
Height Precision

Kwok et al. (2019)

150 photon aggregates
Spacing: ~25 m and up

~1.8 cm

20 km
6-beam Profiles of Sea Ice

Transition from thick to marginal zone ice cover

200 km

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

Beam 1
\[ \mu = 0.02 \text{ m} \quad R = 0.99 \quad SD = 0.02 \text{ m} \]

Beam 3
\[ \mu = 0.01 \text{ m} \quad R = 0.81 \quad SD = 0.03 \text{ m} \]
CRYO2ICE: the good ones

Beam 1

- \( \mu = 0.02 \text{ m} \)
- \( R = 0.97 \)
- \( SD = 0.02 \text{ m} \)

Beam 3

- \( \mu = 0.07 \text{ m} \)
- \( R = 0.92 \)
- \( SD = 0.02 \text{ m} \)

Bagnardi et al. (LPS, 2022)
SSHA count
From Bagnardi et al., GRL, 2021
Arctic Ocean Mean DOT (Oct-2018 – Feb-2022)

ICESat-2 Beam 3

CryoSat-2 SAR

Bagnardi et al. (LPS, 2022)
Monthly Mean DOT time series

Central Arctic

Beaufort Sea

Bagnardi et al. (LPS, 2022)
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)

ICESat-2 beam 3

CryoSat-2 SAR

Bagnardi et al. (LPS, 2022)
Summary Remarks

- SSH Retrievals over ice-covered oceans
  - Current dedicated sea ice missions (CryoSat-2, ICESat-2)
  - Also Altika, Sentinel 3
  - 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.