Monitoring Arctic Sea Ice with CryoSat-2 and ICESat-2

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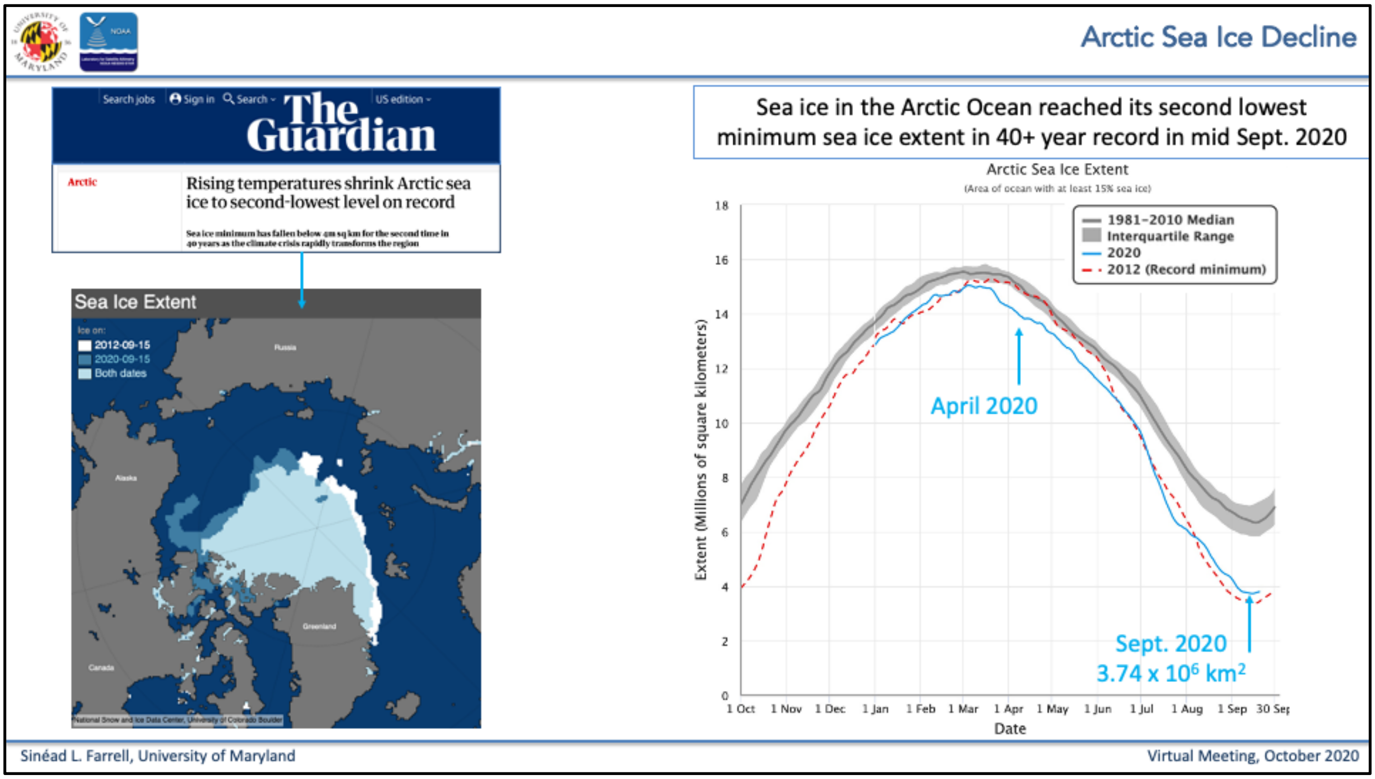
Abstract: There is widespread observational evidence that significant, and rapid, changes are occurring in the Arctic climate system. Air temperatures in the Arctic are warming at twice the global rate causing sea surface and permafrost temperatures to increase. Perhaps one of the largest changes has occurred in the sea ice covering the Arctic Ocean, which has declined in both extent and thickness over the last four decades. The ongoing loss of ice has not only serious implications for Earth's climate, but also wide-ranging ecological and socio-economic impacts. The Advanced Topographic Laser Altimeter System (ATLAS) on ICESat-2 offers a new remote sensing capability to measure the complex sea ice surface at high resolution. Here we provide a review of the recent changes underway in the Arctic. We also explore the first two years of sea ice retrievals from ICESat-2, demonstrating its capability to track the evolution of the ice cover in all seasons. We compare ICESat-2 sea ice freeboard and thickness results with independent, but complementary results from ESA's CryoSat-2 radar altimeter.

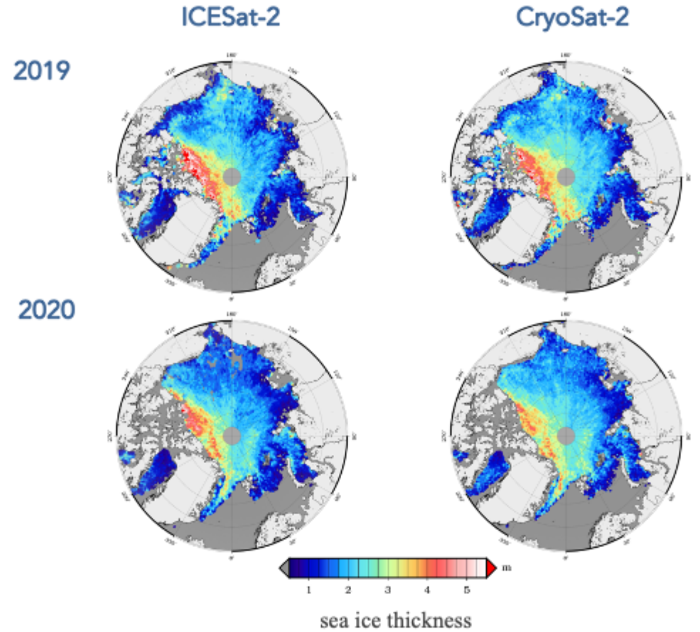


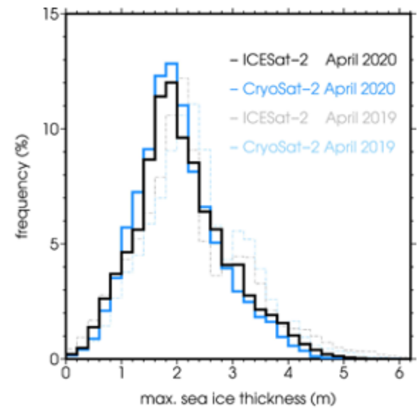
Sea ice in the Arctic Ocean reached its second lowest minimum extent in 42 year record on September 15, 2020. The ice cover was 3.74 million square kilometers, 2.5 million square kilometers below the climatological average (computed over the period 1981-2010).

The record minimum ice extent occurred in 2012 when ice extent was 3.4 million square kilometers.

The ice cover of the Arctic Ocean reached its winter maximum in April 2020. However, at that time it was the 3rd - 4th lowest maximum sea ice extent on record.

Drop in Arctic Sea Ice Thickness





	Sea Ice Thickness (m)			
	2020		2019	
	ICESat-2	CryoSat-2	ICESat-2	CryoSat-2
mean	2.10	2.01	2.25	2.35
median	1.99	1.93	2.10	2.19
mode	1.90	1.90	2.10	2.30

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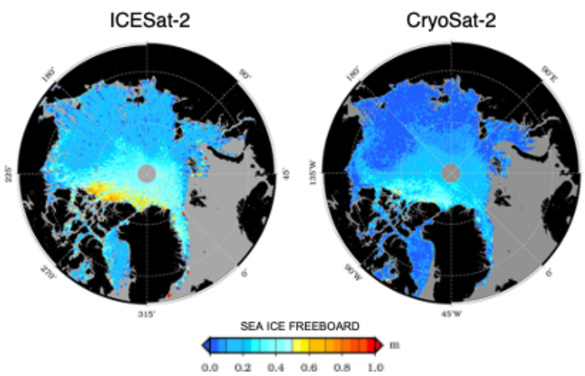
Arctic sea ice reaches its maximum thickness in April every year.
Here we determine changes in Arctic sea ice **thickness** comparing results derived from ICESat-2's laser altimeter measurements and CryoSat-2's radar altimeter measurements.
We find that ice thickness in 2020 was on average 0.15-0.34 m thinner than in 2019, and modal ice thickness was 0.2 – 0.4 m thinner. In April 2020, ice was thinner in the central Arctic and Canada Basin compared to the same regions in winter 2019.

Cryo2Ice: Aligning CryoSat-2 with ICESat-2

Cryo2Ice: a spacecraft maneuver was successfully conducted in July 2020 to raise the semi-major axis of the CryoSat-2 orbit by ~900 m

- Longitude of CryoSat-2 and ICESat-2 satellites become periodically synchronized every 19th CS2 revolution and every 20th IS2 revolution

- Aligning CryoSat-2 with ICESat-2 has many advantages for sea ice research
- **Opportunity** to cross-calibrate SSH and sea ice freeboard at two wavelengths
- Laser and radar altimeters differ in the retrieval sea ice freeboard
- CryoSat-2: unambiguous detection of leads, accurate measurement of SSH
- ICESat-2: smaller altimeter footprint provides details of ice floe topography, accurate measurement of sea ice pressure ridges
- Coincident measurements (after orbit alignment) will:
  - Improve our understanding of penetration of radar energy into the snow pack overlying sea ice
  - Improve accuracy of satellite-derived sea ice freeboard by combining altimeter heights and improving freeboard retrieval algorithms
  - Provide calibration of ICESat-2 SSH measurements
  - Provide an ability to evaluate impact of geometric sampling errors on CryoSat-2 freeboard due to the larger CryoSat-2 footprint



CRISTAL: Copernicus polaR Ice and Snow Topography Altimeter Mission: Planned Launch 2027

	CryoSat-2	ICESat-2	CRISTAL
Mission Management	ESA	NASA	ESA/EU-Copernicus
Launch	April 8, 2010	September 15, 2018	2027 (planned)
Altitude	720 km	496 km	TBD
Orbit	near-circular, non sun-synchronous	near-circular, non sun-synchronous	TBD
Orbital Inclination	92°	92°	92°
Orbital Repeat	369 days (w/ 2 day subcycle)	91 days (w/ 4 day subcycle)	TBD (w/ ~ weekly & ~monthly subcycles)
Primary Payload	SAR Interferometric Radar Altimeter (SIRAL)	Advanced Topographic Laser Altimeter System (ATLAS)	SAR radar altimeter (IRIS)
EM Frequency	13.6 GHz (Ku band)	532 nm (green)	13.5 GHz (Ku band) & 35.75 GHz (Ka band)
Mission Lifetime Goal	3.5 years	3 years	7.5 years
Current Lifetime Expectancy	~2025	2025+	> 2027 - 2034

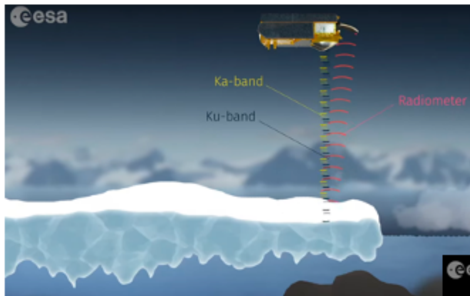


Image Credit: ESA

- Polar altimeter mission
- Extends the CryoSat-2 and ICESat-2 time series
- Dual-frequency radar altimeter (Ku-band and Ka-band)
- Microwave radiometer

Main payload: Interferometric **R**adar Altimeter for **I**ce and **S**now (**IRIS**)
Major Science Goals:
- measure and monitor sea-ice thickness variability
- snow depth
- ice-sheet elevation change

Modified from: Kern et al., 2020. *The Cryosphere*

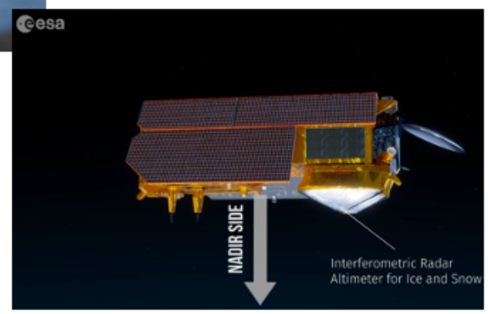


Image Credit: ESA

The **C**opernicus pola**R** **I**ce and **S**now **T**opography **Al**timeter (CRISTAL) mission is currently in Phase B2 of development. The contract for the mission was recently signed (September 2020) and the satellite is planned for launch in 2027.
CRISTAL is an essential part of the topographic ocean and ice measurement family. The mission comprises a single satellite with an orbit optimized for monitoring the polar regions. The payload will include a Ku-band Interferometric Synthetic Aperture Radar Altimeter and a Ka-band channel to measure sea ice freeboard and land ice elevation.
It has a 7.5 years design lifetime and high along-track resolution to distinguish open ocean from sea ice surfaces. The altimeters will be capable of tracking steep terrain with slopes < 1.5°.
Product latency will range from near-real-time (NRT) to 24 hours, depending on the application.

- NOAA PolarWatch (https://polarwatch.noaa.gov) delivers multi-sensor physical and biological **ocean remote sensing data** to diverse end-users within NOAA, and across disciplines, in support of broad applications in the Arctic and Southern Oceans.
- PolarWatch aims to enable **data discovery** and provide easy access to high-latitude satellite data products and relies on the ERDDAP database.
- In addition to traditional level 3 (gridded) satellite data products, higher-level data products, including analyses of inter-annual variability, trends and anomalies will be disseminated to the wider **science and stakeholder communities**.
- The PolarWatch interface allows users to search and filter satellite datasets, providing data previews in polar-stereographic projections.