# Overview and Status of CRISTAL:
# Copernicus Polar Ice and Snow Topography Altimeter

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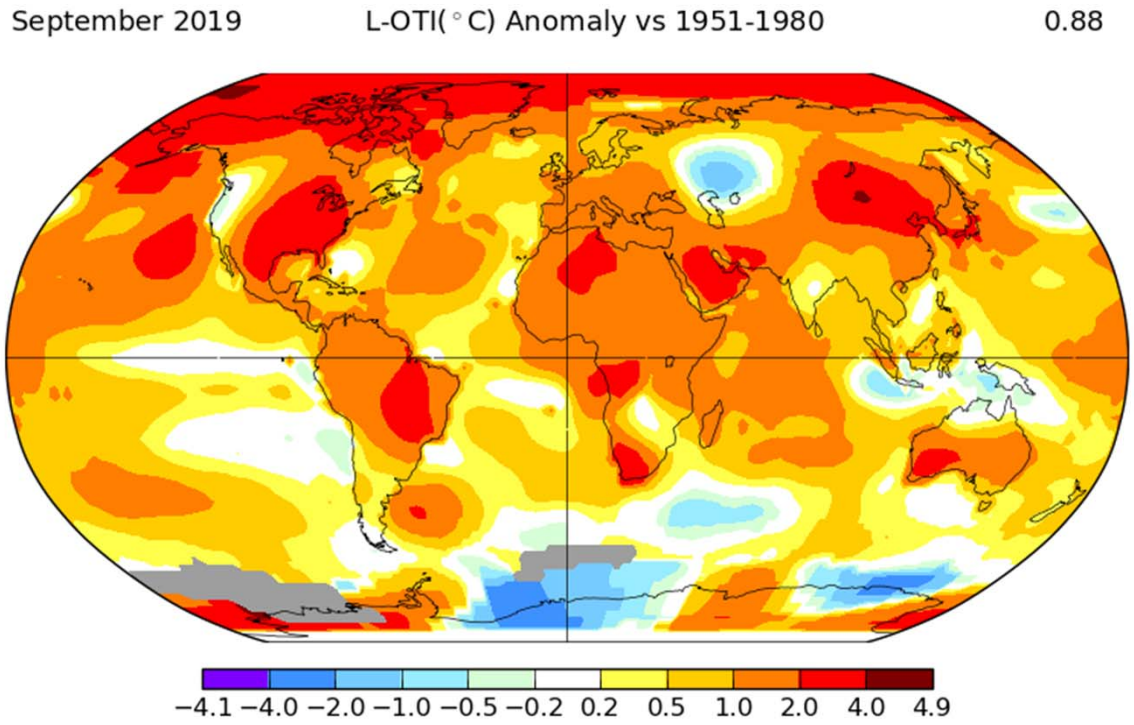
# Global temperature anomaly

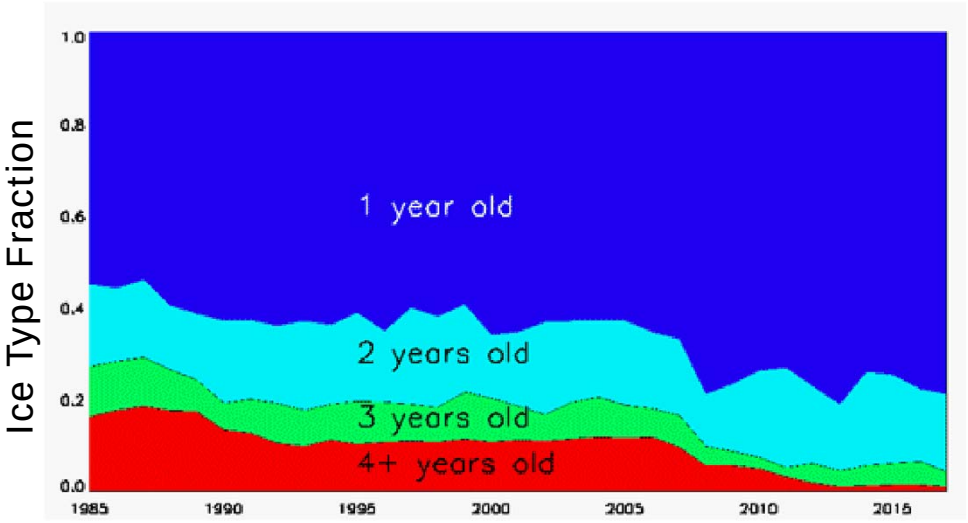



Due to Arctic amplification, the Arctic was ~ 2°C warmer

*Source: NASA GISS*

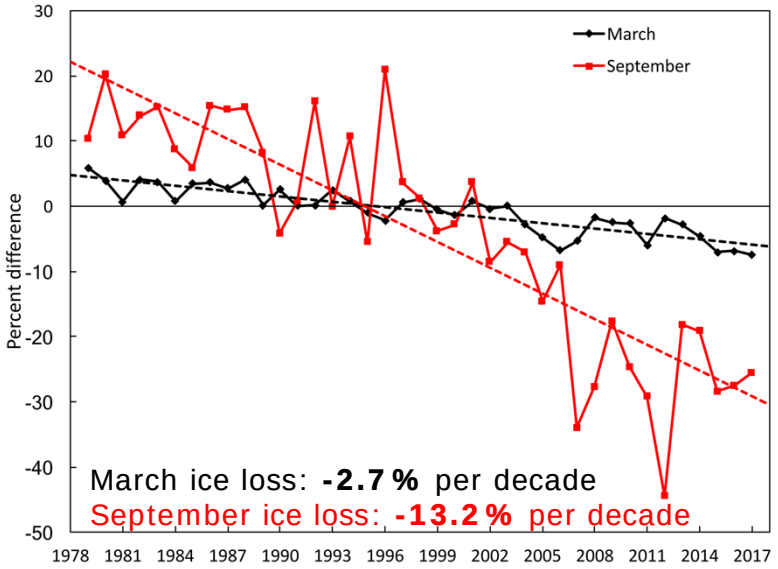
# Declining Arctic Sea Ice Cover

Fraction of Ice Types, 1985 - 2017




Seasonal, first-year sea ice in the Arctic currently ~79%, compared to ~50% in 1980s

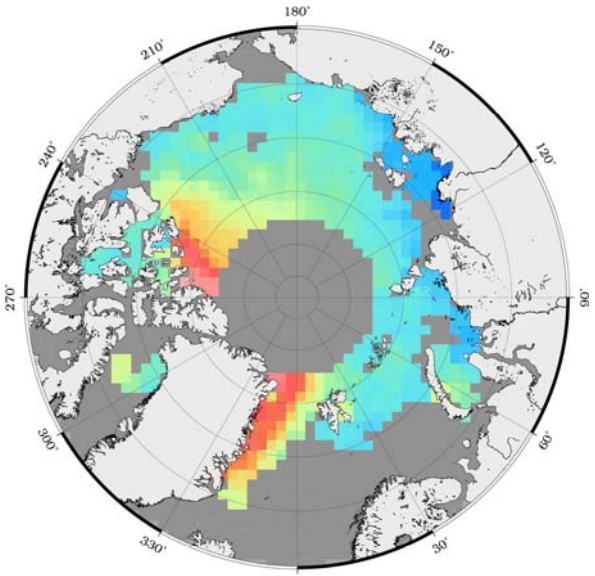
Anomalies (%) in Sea Ice Extent, relative to 1981-2010



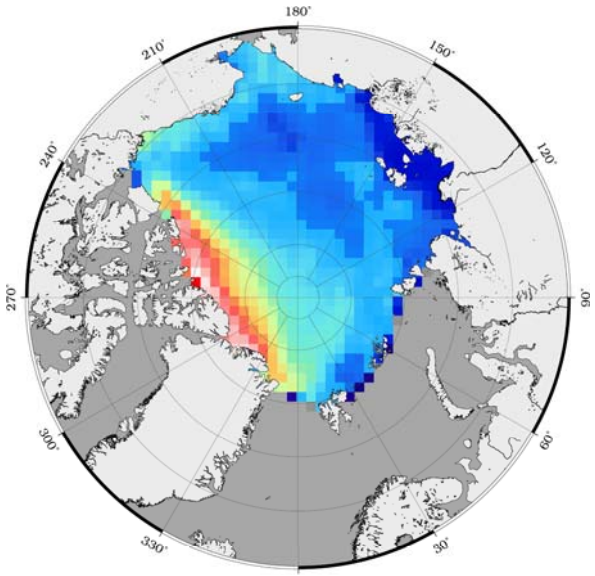

*Source: Perovich et al., Arctic Report Card, 2017*

# Declining Arctic Sea Ice Thickness

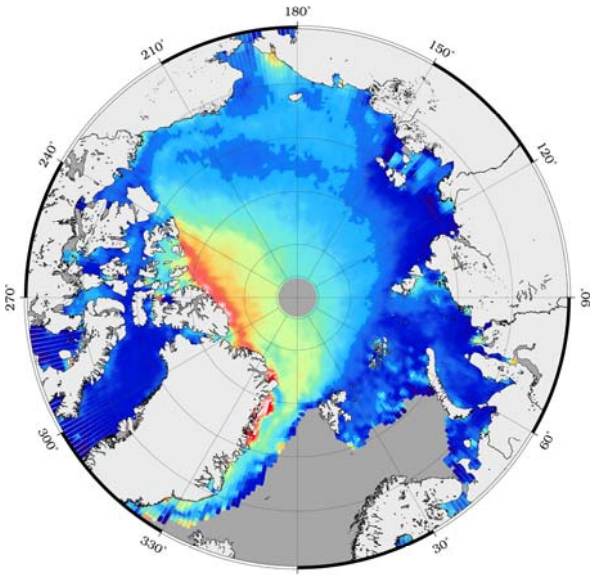
ERS1/2: 1993 - 2001




ICESat: 2004 - 2009




CryoSat-2: 2011 - 2016



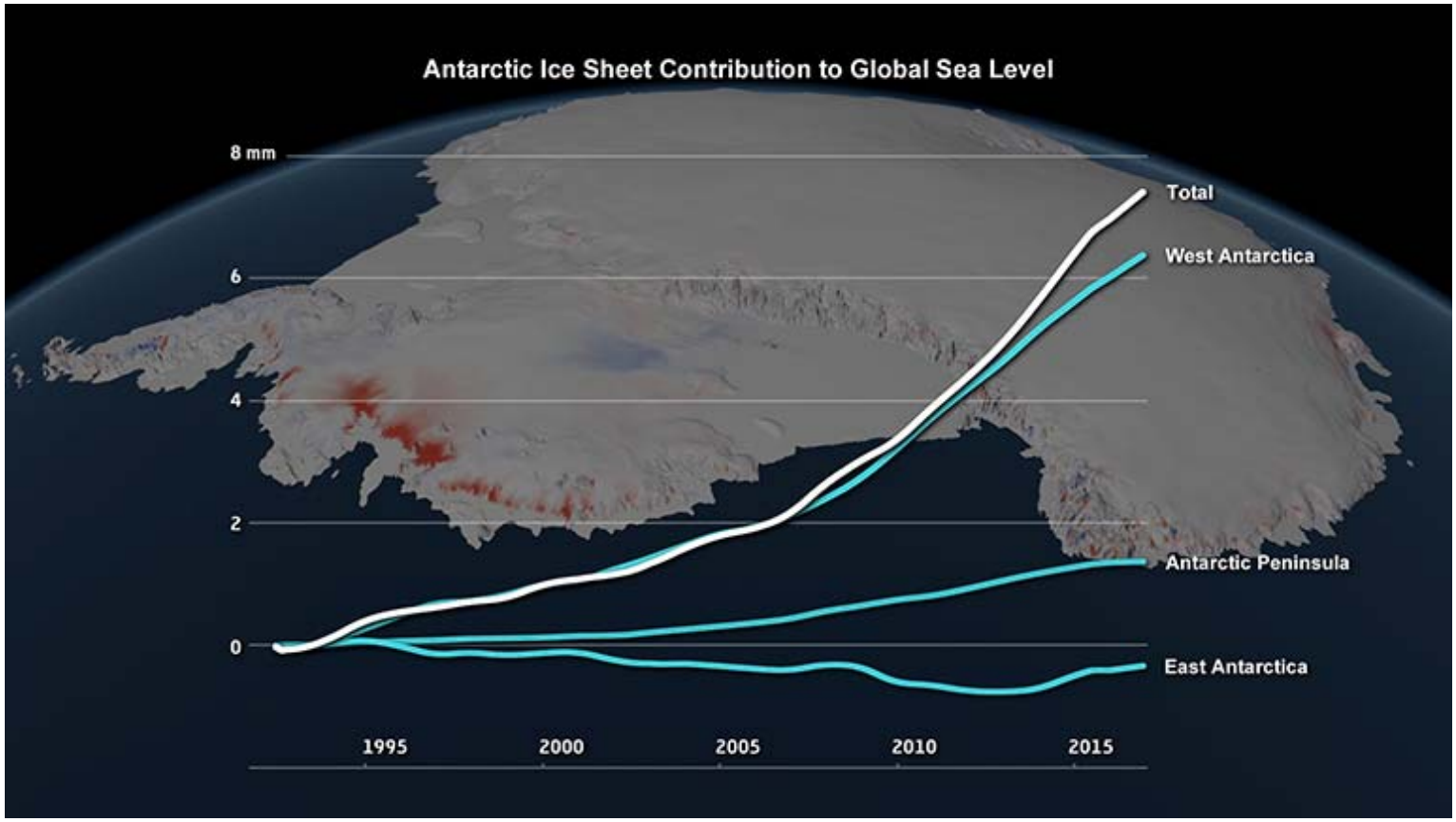

**Drop in average winter ice thickness by ~0.6 m over 24 year period**

Mean Winter Ice Thickness


*Sources: Laxon et al., 2003; Yi and Zwally, 2009; Hendricks et al., 2016*

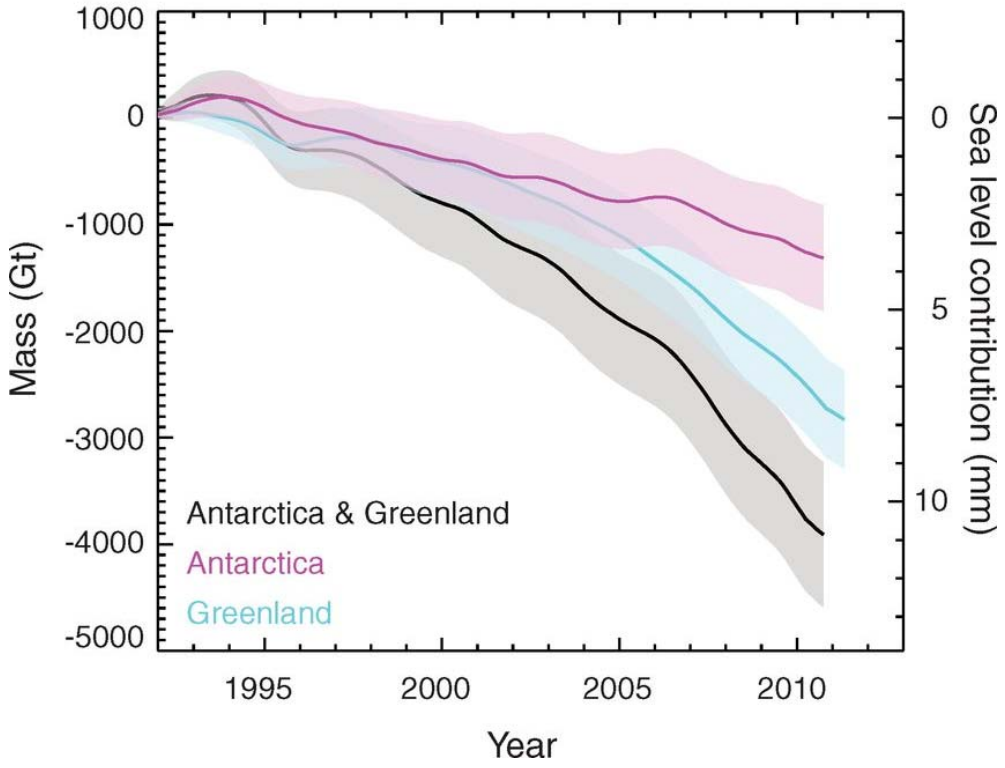
**The thinner the ice gets, the more it is thermodynamically fragile:** the ice melts more easily
**… the more it is mechanically fragile:** the ice fractures and gets exported by wind and currents

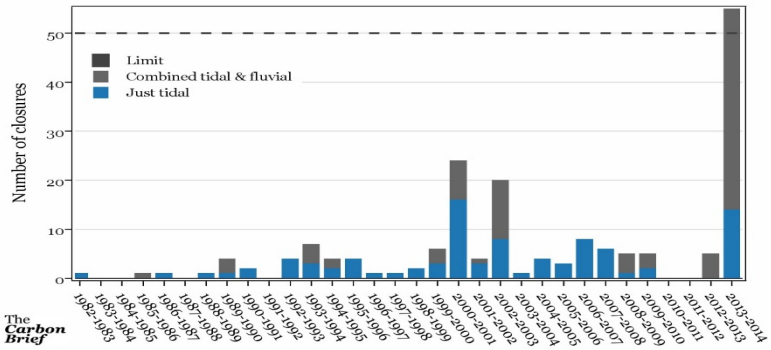
# Antarctic Mass Loss & Global Sea Level 1992-2017




*Source: IMBIE Team, Nature, 2018 / Planetary Visions*

# Contributions of Global Mass Loss to Sea Level




Mass loss from **Antarctic and Greenland ice sheets** is responsible for ~50% of current sea level change

*Source: Shepherd et al., 2012*

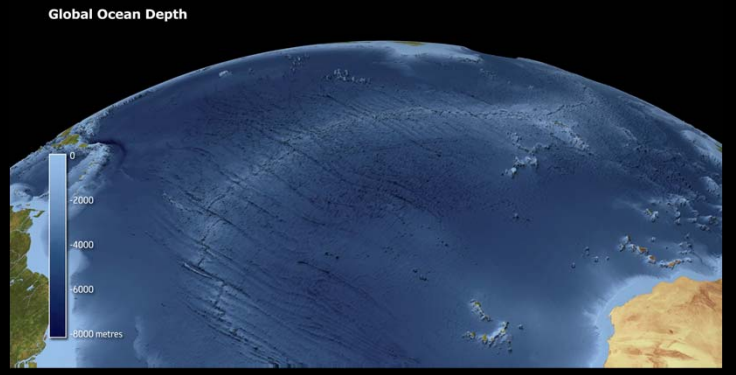
# CRISTAL Mission Objectives

## Primary Objectives

- To measure and monitor variability of Arctic and Southern Ocean **sea-ice thickness** and its **snow depth**.
- To measure and monitor the **surface elevation and changes** therein of **glaciers, ice caps and the Antarctic and Greenland ice sheets**.


## Secondary Objectives

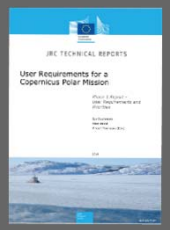
- To contribute to the observation of **global ocean** topography **as a continuum up to the polar seas.**
- To support applications related to **coastal and inland waters**.
- To support applications related to **snow cover and permafrost**.




Animations by Planetary Visions Limited
Data from ESA/CPOM/UCL/D Sandwell/AVISO+/EU Copernicus Marine Service

# Copernicus Services and Parameters of Interest

*CRISTAL addresses a wide range of parameters and applications required by end users*


*Copernicus Polar Expert Group (PEG) Reports, 2017*

*ESA CRISTAL Mission Requirements Document*

| Copernicus Service | Relevant Parameters of Interest | Applications |
|---|---|---|
| Marine (CMEMS) | • Sea ice thickness<br>• Sea level anomaly and ocean currents in polar oceans<br>• Significant wave height in polar oceans | • Marine monitoring<br>• Marine forecast<br>• Global ocean topography up to the North Pole |
| Climate (C3S) | • Ice sheet topography<br>• Sea ice thickness and volumes<br>• Global sea level<br>• Snow depth | • Sea ice volume projections<br>• Ice sheet melting<br>• Sea level rise<br>• Warming of ocean temperatures<br>• Precipitation, including Arctic |
| Land (CLMS) | • Ice sheet and glaciers topography<br>• Snow depth<br>• Sea ice volume variations | • Terrestrial cryosphere<br>• Water cycle<br>• Energy budget |
| Atmosphere (CAMS) | • Snow depth | • Meteorology and climatology |
| Emergency (EMS) | • Global sea level<br>• Snow depth<br>• Lakes and rivers level/state | • Inundations<br>• Impacts of permafrost degradation |

# CRISTAL Payload

The mission draws from the heritage experience of several in-orbit missions and from the on-going development of the Sentinel-6 and MetOp-SG programmes


CryoSat-2


SARAL


MetOp-SG

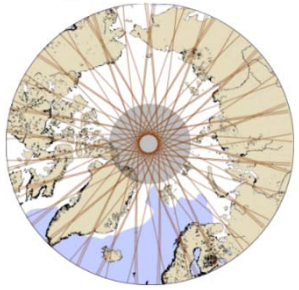

Sentinel-6

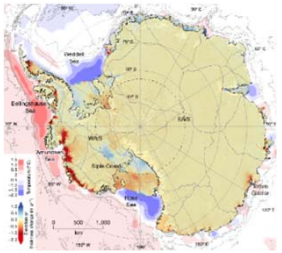

Sentinel-3

- A high spatial resolution dual Ku/Ka-band SAR altimeter to make observations of sea ice and land ice elevations
- A Passive microwave radiometer with capability to provide global ocean retrieval of Total Column Water Vapour up to typically 10-20 km from the coast
- GNSS receiver compatible with Galileo and GPS constellations
- Laser Retro-reflector Array for satellite laser ranging for validation of the orbit

# Key Mission & Performance Requirements

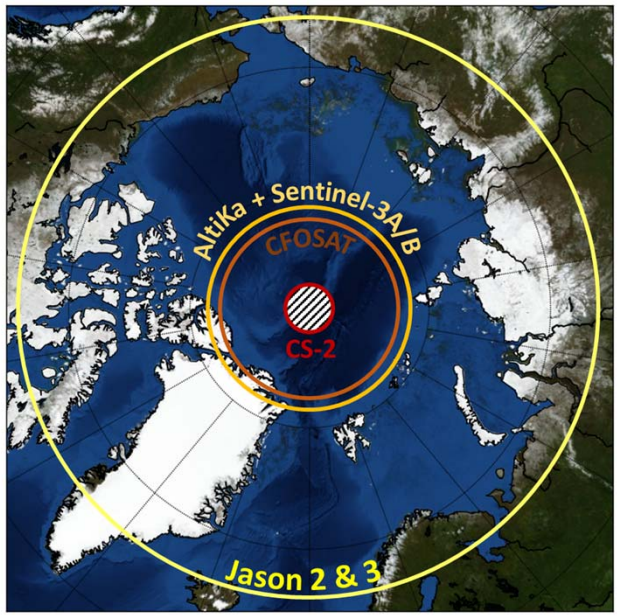
- **SAR Interferometric Altimeter** for global elevation & topographic retrievals over land and marine ice, ocean and terrestrial surfaces.
- Additional **Ka-band channel** for snow depth measurement to distinguish between snow and ice layer.
- **Vertical resolution of ~31cm** with enhanced freeboard measurement accuracy compared to today.
- **Horizontal resolution of < 10m** to resolve ice floes.
- Improved interferometric measurements (angle of arrival) **20 arcsec**
- **Microwave Radiometer (MWR) for** wet trop delay corrections.
- **High data volume** due to SAR mode to be downlinked.
- **Sea ice thickness and Freeboard**: Horizontal resolution of sea ice thickness products <=80 m; Vertical uncertainty of sea ice thickness of 0.1 m; Temporal sampling of 10 days or less.
- **Ice Sheets, Glaciers and Ice Caps**: Ice surface elevation with uncertainty of 2 m; Temporal sampling of 30 days or less.

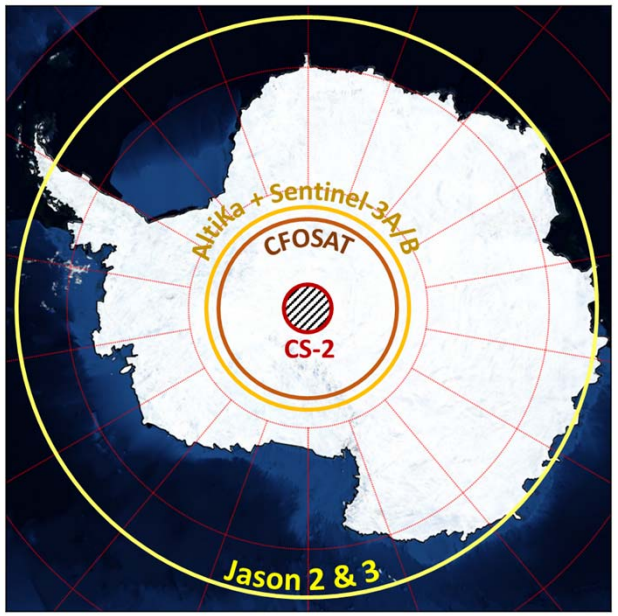


✓ CRISTAL directly addresses EU Arctic Policy & Primary User Requirements (PEG reports)

# Coverage of the Current Polar Altimeters

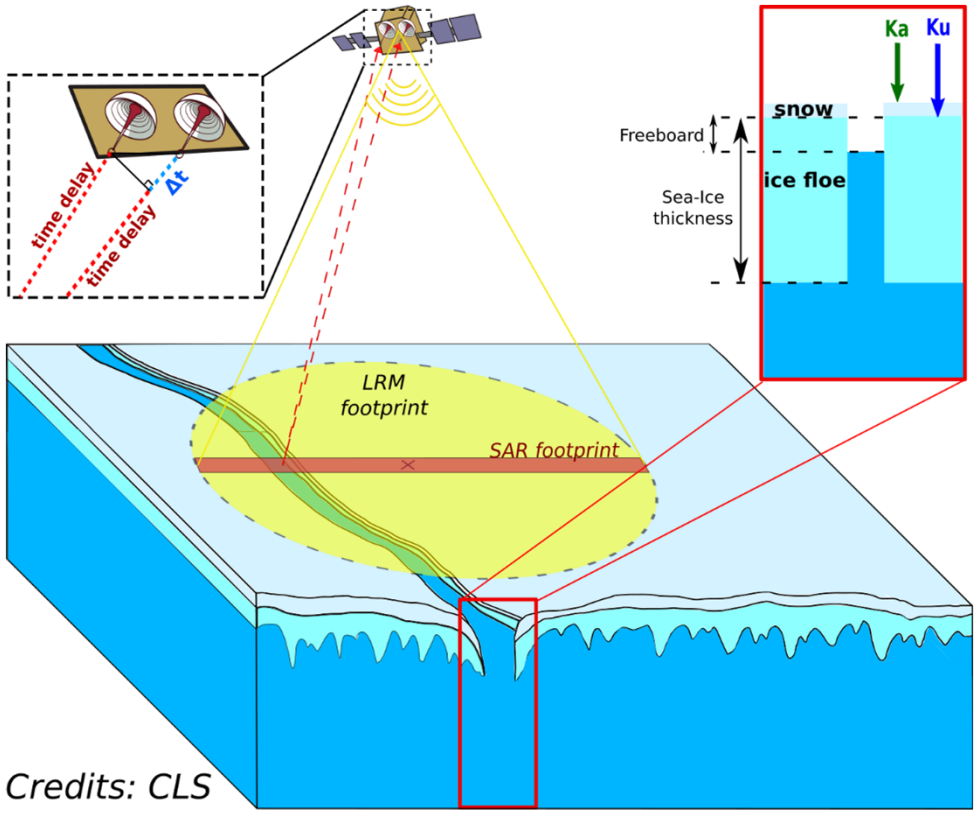


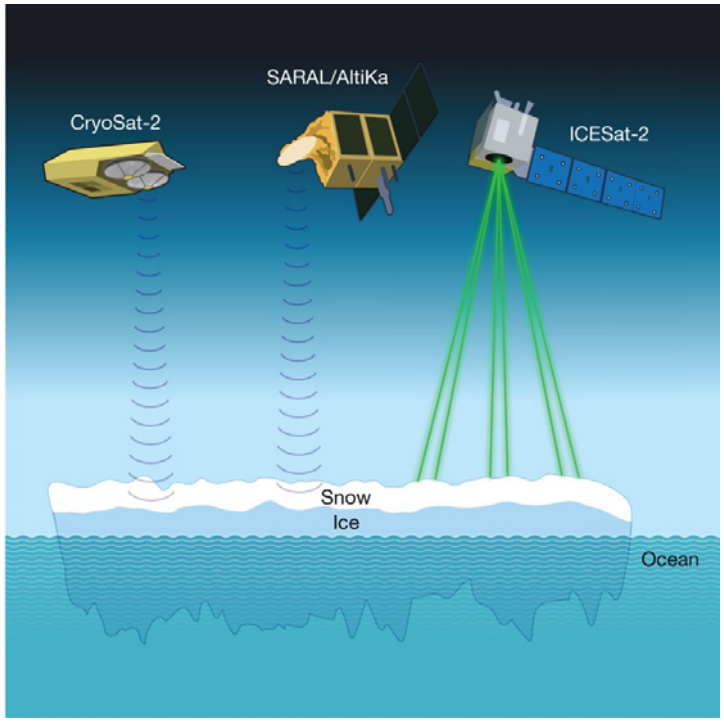

- ✓ CRISTAL responds to need for continual altimetric monitoring of Arctic Ocean north of 81.5°N
- ✓ CRISTAL builds on heritage experience of several in-orbit missions

# CRISTAL Observation Concept

## SAR Radar Altimeter with capability of interferometry



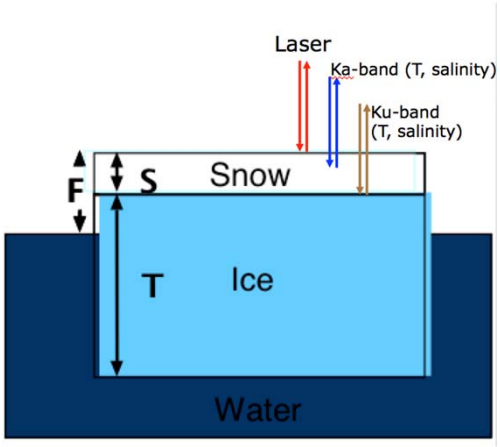
# CRISTAL employs a dual-band altimeter




Impact of Ku, Ka and Laser retrieval
*Source: Shepherd, Fricker and Farrell, Nature 2018*

Over sea and land ice:

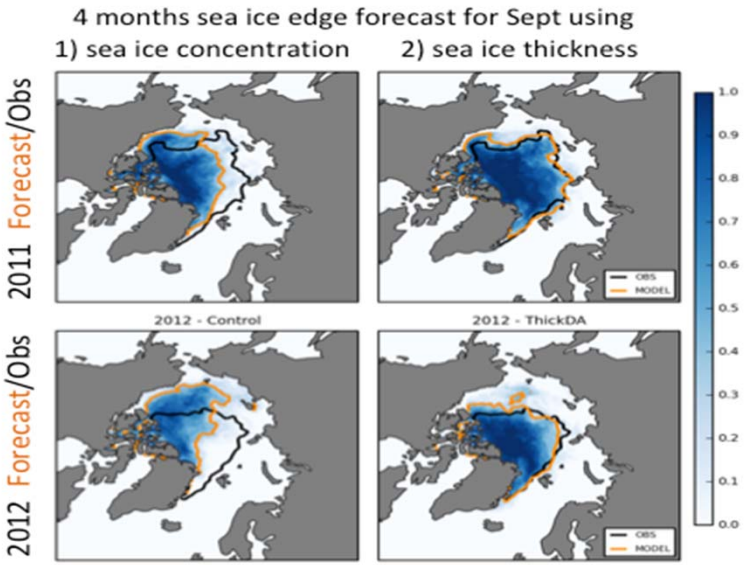
- Laser scatters from air-snow interface
- Radar (Ku-band) scatters closer to snow-ice interface (dependent on salinity, temperature, grain size, etc.) for sea ice
- Radar (Ka-band) scatters closer to air-snow interface (dependent on salinity, temperature, grain size, etc.) for sea ice.
- Hence measured freeboard (and thickness) difference between Ku and Ka.

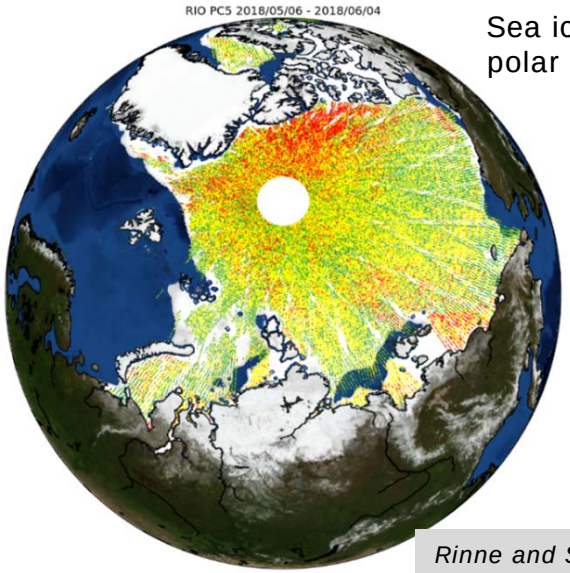



✓ CRISTAL addresses snow on ice surfaces, which is a limiting factor in determining the source and amount of glaciological change.

# Services supported by CRISTAL:
## monitoring sea ice thickness in NRT

*Blockley et al., 2018*




Sea ice risk product for polar class 5 vessels

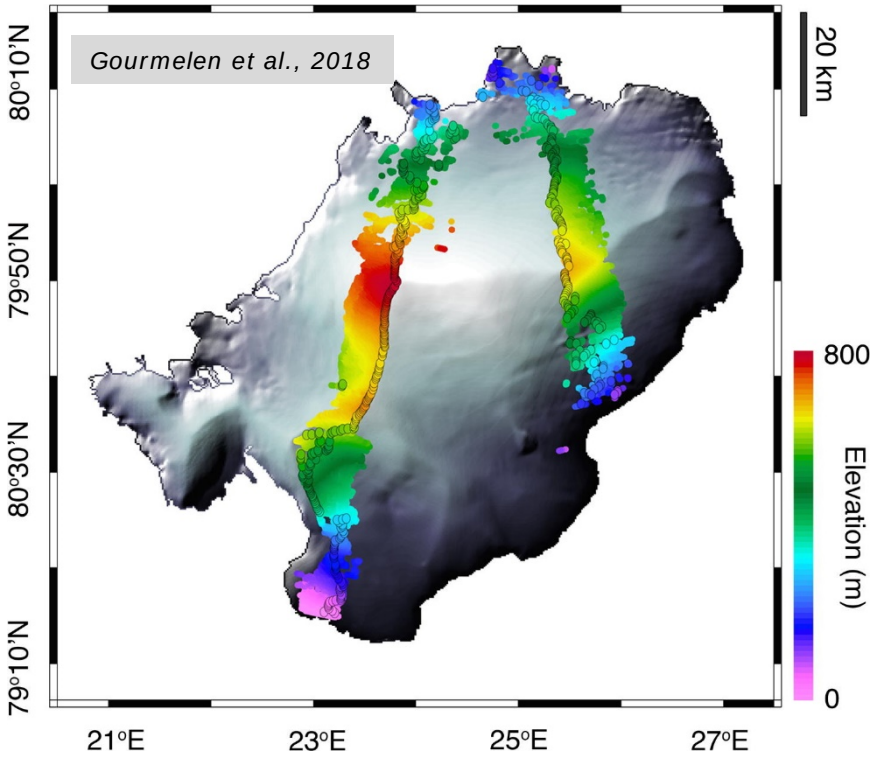
*Rinne and Similä, 2016, FMI 2018*

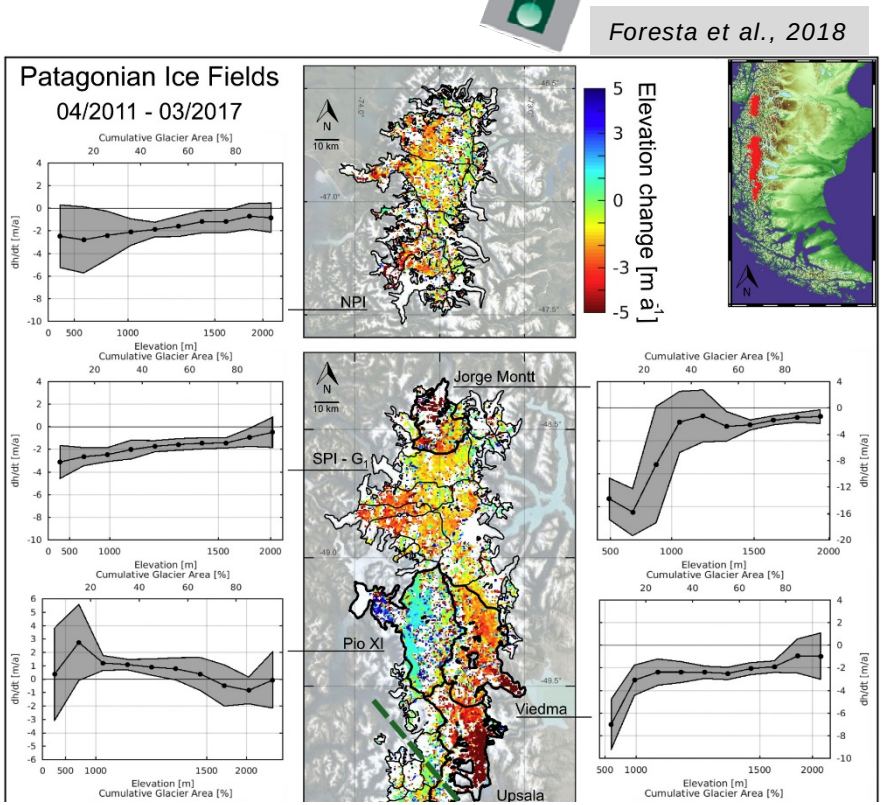
Arctic winter thickness provided by CRISTAL will improve predictive capability for summer ice extent.

Independent measurements of sea-ice thickness distribution provided by CRISTAL will benefit operational ice charting.

# Services supported by CRISTAL:

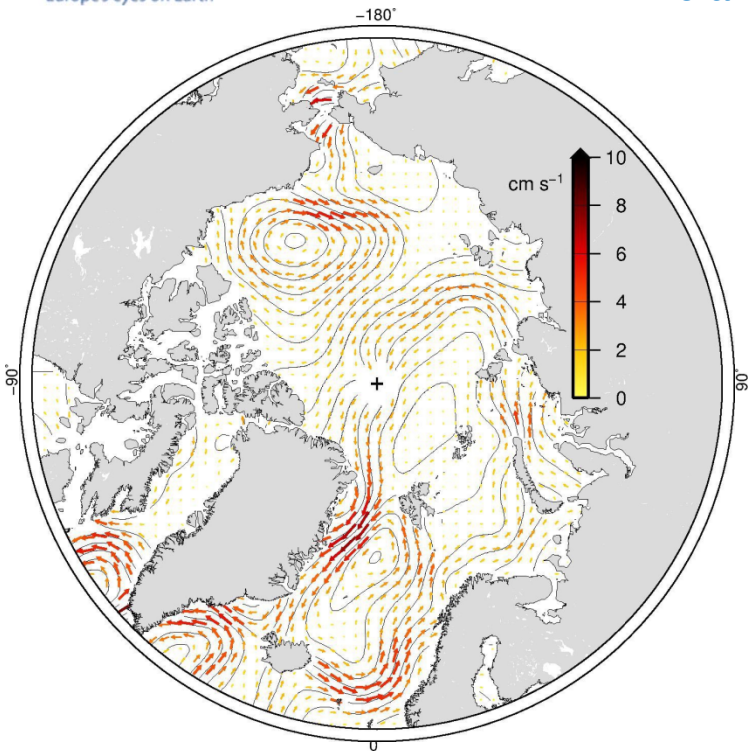
## monitoring ice sheets/glaciers with swath interferometry



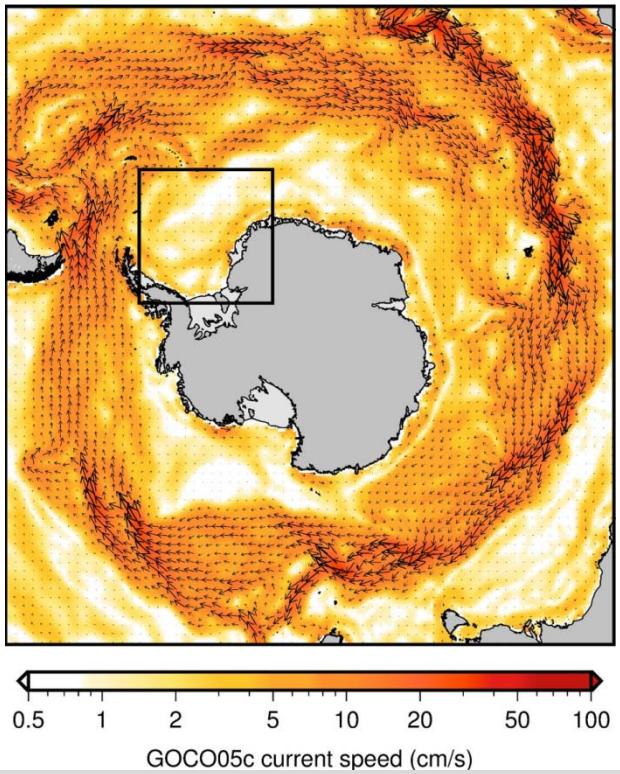



# Services supported by CRISTAL:

## Polar Ocean Circulation




Armitage et al. (2017), TC




Armitage et al (2018), from CryoSat SLA+GOCE geoid data

# CRISTAL Summary

**Characteristics:**

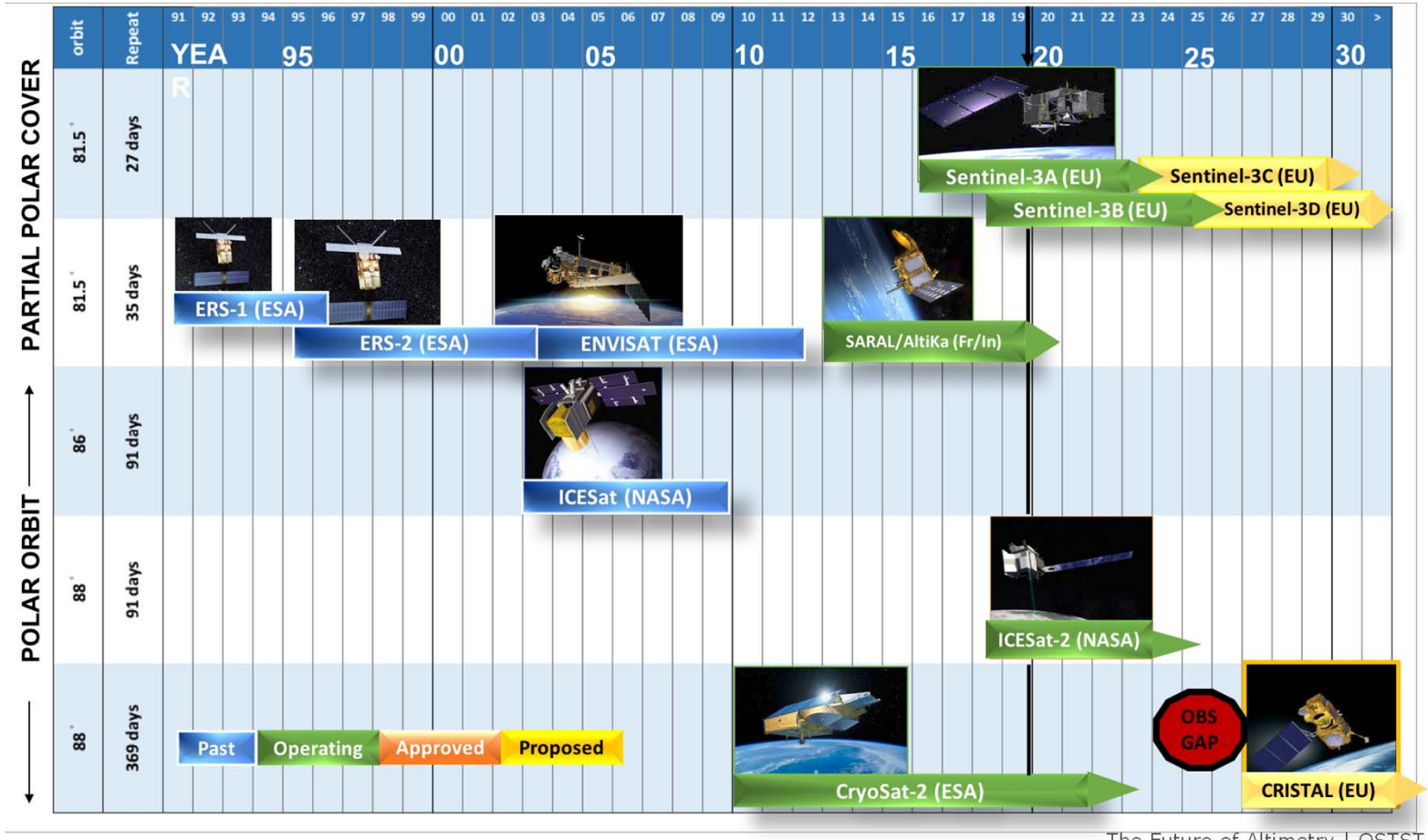
- Essential part of the Topographic Ocean and Ice Measurement Family
- Single satellite covering polar regions embarking: Ku-band Interferometric Synthetic Aperture Radar Altimeter with supporting Ka-band channel measuring sea ice freeboard and land ice elevation
- High and low frequency passive microwave radiometer (wet troposphere correction)
- 7.5 years design lifetime
- Optimized orbit covering polar regions (omission not exceeding 2°; sub-cycle < 10 days)
- High along-track resolution sufficient to distinguish open ocean from sea ice surfaces
- Product latencies from NRT to 24 hrs depending on application
- Capable of tracking steep terrain with slopes < 1.5°

**Status:**

Phase A/B1 parallel studies commenced in April 2018; MRD answers to EC Polar Expert Group (PEG) 1 and 2 reports; System requirements evolving to meet MRD; Preliminary Requirements Review Dec 2018; MRS v.2.0 finalized Feb 2019; **Currently in Phase B1**; concept studied by two industrial consortia; anticipation of a potential Phase B2 start in early 2020. **Launch mid 2020-2030**

**Copernicus Services:** C3S, CMEMS, CLMS, CAMS, CEMS

# Polar Altimeter Time Line

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# Integrated European Policy for the Arctic

It requires specific mitigation and adaptation actions in three priority areas:

1. **Climate Change and Safeguarding the Arctic Environment** (livelihoods of indigenous peoples, Arctic environment).
2. **Sustainable Development in and around the Arctic** (exploitation of natural resources e.g. fish, minerals, oil and gas), “Blue economy”, safe and reliable navigation (e.g. the Arctic Northern Sea Route).
3. **International Cooperation on Arctic Issues** (scientific research, EU and bilateral cooperation projects, fisheries management/ ecosystems protection, commercial fishing).


✓ CRISTAL will monitor the Polar Regions to safeguard both climate and operational service needs.