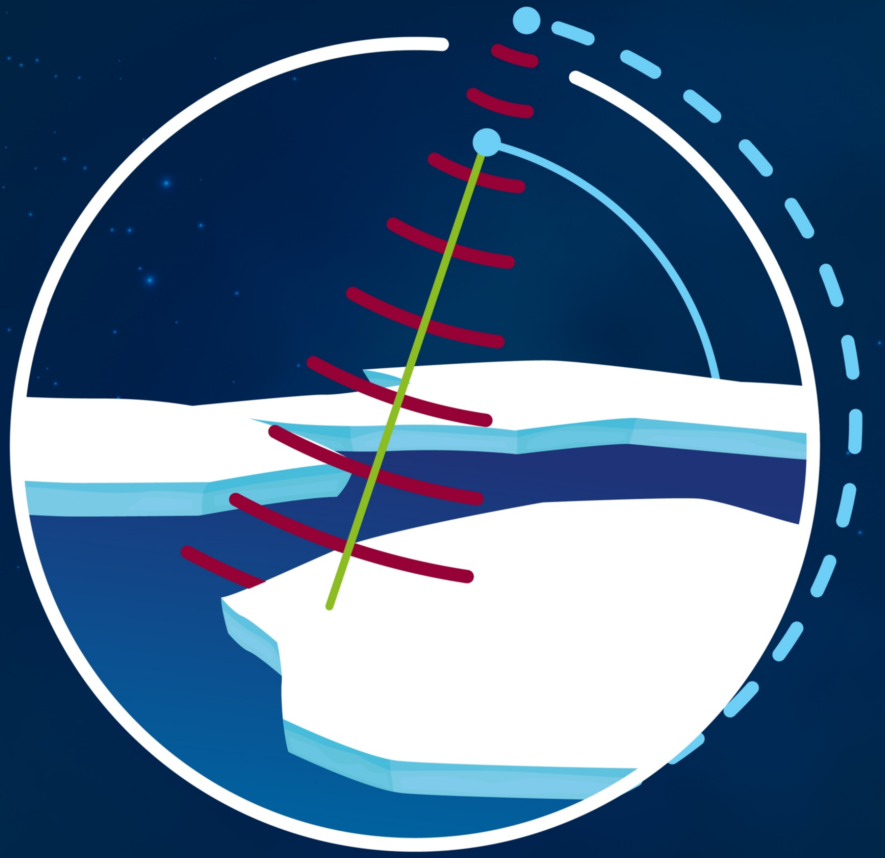
Introduction to CryoSat-2 ICESat-2 Resonant Orbits



#CRYO2ICE

Motivation

Programmatic

- CryoSat Extension
- Preparation of HPCM CIMR and CRISTAL
- Support to International Climate Programs and initiative (UNFCC, CCI, IMBIE)
- Support to Copernicus Services
- Inspire future missions
- D/EOP Objectives
- ESA Space 4.0

Innovation

- Innovative orbit resonance concept
- Unique opportunity for laser & radar altimetry
- Better understanding of multi-sensor scattering horizon and seasonal dependency
- Improved knowledge of the SAR/SARin Ku radar altimeter footprint
- New products employing AI image processing

International Cooperation

"An amazing example of International Collaboration" [cit. Prof. Helen Fricker]

- Strength collaboration with NASA
- Inspire joint missions with other space agency
- Energize new projects (i.e. EU) and collaborations
- Motivate different scientific communities to work together

Scientific

- Improve geophysical retrievals and important **climate indicators** like sea ice thickness and land ice elevation and mass balance
- Derive pan-artic and Antarctic **snow map** bending laser and radar altimetry
- Improve understanding of **horizon scattering** at different seasonal conditions
- Better characterize polar ocean circulation, fresh water budget and heat flux models in polar regions
- Improve resolution of **marine gravity**
- Improve cloud climatology in polar regions
- Improve information of ice state for **operation** applications

Historical Timeline

Sep 2014
Mission Extension approved by **PB-EO**. Primary mission objectives achieved

Jul 2016
Proposal to FD to explore resonance **orbits** with ICESat-2. Confirmation of 92◦ inclination

Mar 2017
Banff Conference. First presentation of orbit change to users

Feb 2018
Meeting Nasa @GSFC. Presentation to ICESat-2 scientific community

Sep 2018
ICESat-2 launch

Jan 2019
3rd Mission Extension by **PBEO.** Orbit change in new mission objectives

May 2019
Presentation of orbit change to worldwide community **@LPS19** and to Michael Freilisch

Jul 2019
JPPG Meeting: presentation to NASA representative Jack Kaye

April 2020
Operational timeline consolidated and **GO** for operations

7 Jul 2020
Steering Group Meeting. Review readiness and endorsement by ESA Management

16 Jul 2020
Campaign Starts
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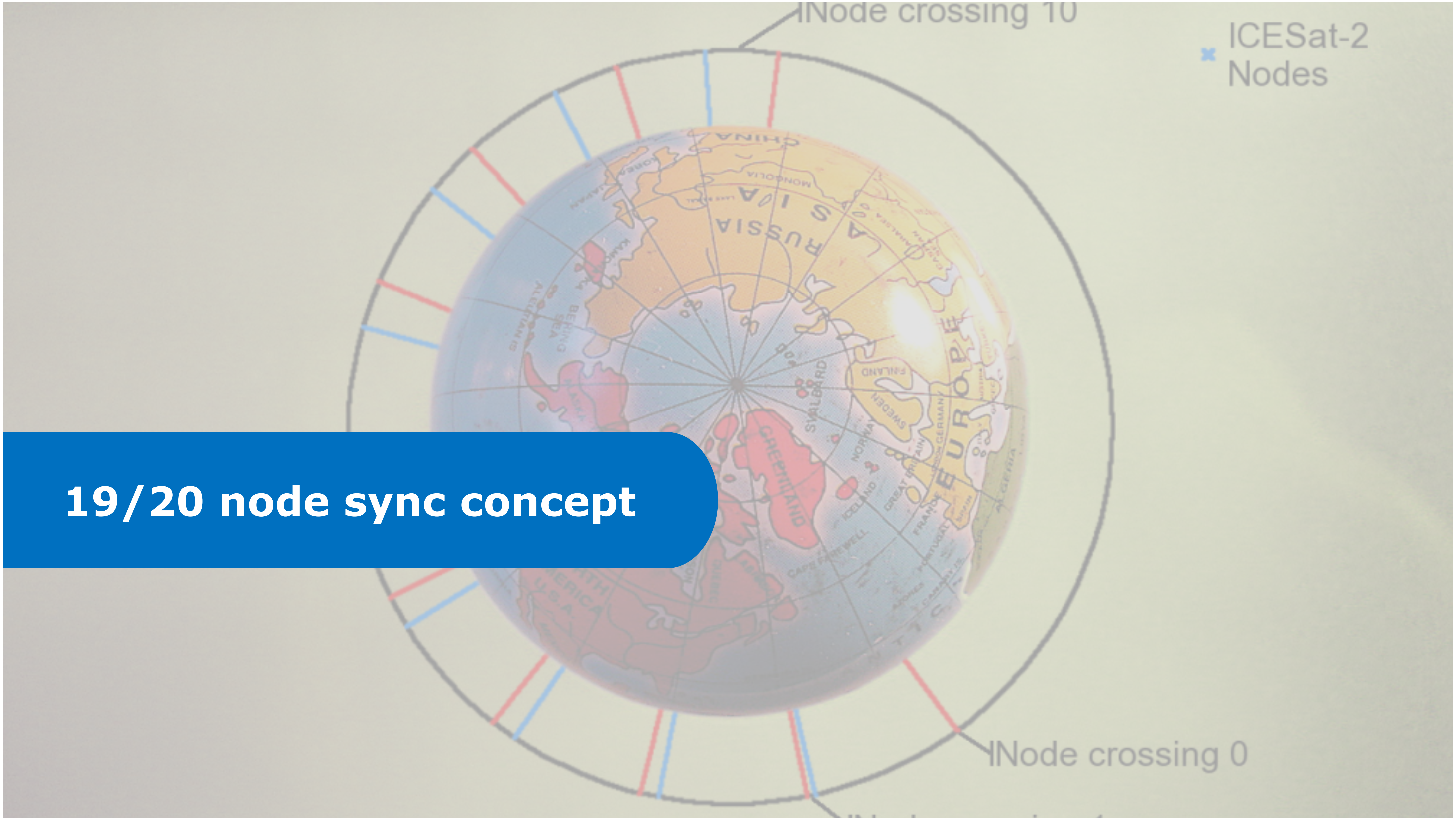


19/20 node sync concept

CryoSat-2

ESA's Earth Explorer Ice Mission

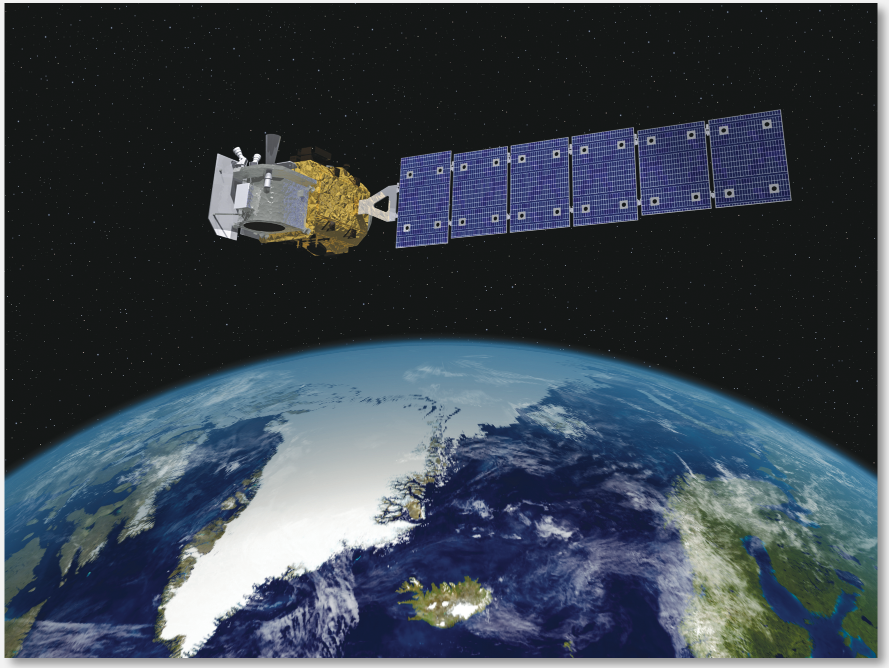
- **Launched**: 8 April 2010
- **Launcher:** DNEPR from Baikonur Cosmodrome
- **Orbit**: Altitude of 720km, near-circular not sun-synchronous, inclination 92°, repeating ground track every 369 days
- **Main Payload**: SAR Interferometric Radar Altimeter (SIRAL) operating at 13.6 GHz (Ku band)
- **Mission Objectives:** precise measurement of arctic sea-ice thickness and polar land ice elevation changes
- **Mission Management and Operations:** ESRIN, ESOC
- **Mission Lifetime**: 3.5 years (still in operations, consumables for another 5+, 2025+)
- **Other:** CryoSat-2 follows CryoSat-1 launched in 2005

https://earth.esa.int/eogateway/missions/cryosat

ICESat-2

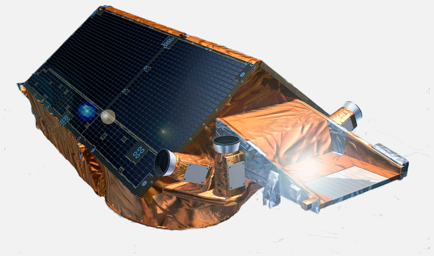
NASA's ICE, CLOUD and ELEVATION Satellite

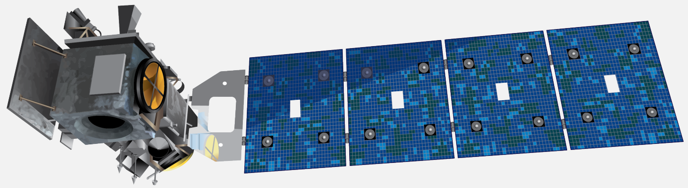
- **Launched**: 15 September 2018
- **Launcher:** Delta II from Vandenberg Air Force Base
- **Orbit**: Altitude of 496km, near-circular not sun-synchronous, inclination 92°, repeating ground track every 91 days
- **Main Payload**: Advanced Topographic Laser altimeter (ATLAS) operating at 532 nm (light green)
- **Mission Objectives:** precise measurement of heights of the Earth's ice, vegetation, land surface, water and clouds
- **Mission Management and Operations:** NASA's GSFC
- **Mission Lifetime**: 3 years (consumables for 7 years)
- **Other:** ICESat-2 follows ICESat-1 launched in 2003



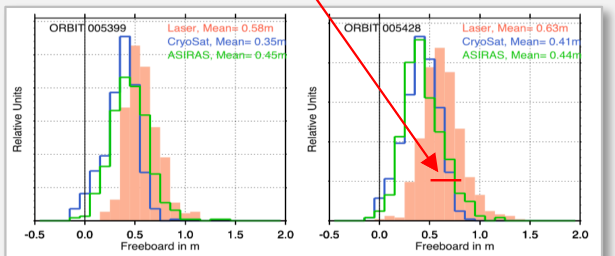
https://icesat-2.gsfc.nasa.gov

Measurements Concepts

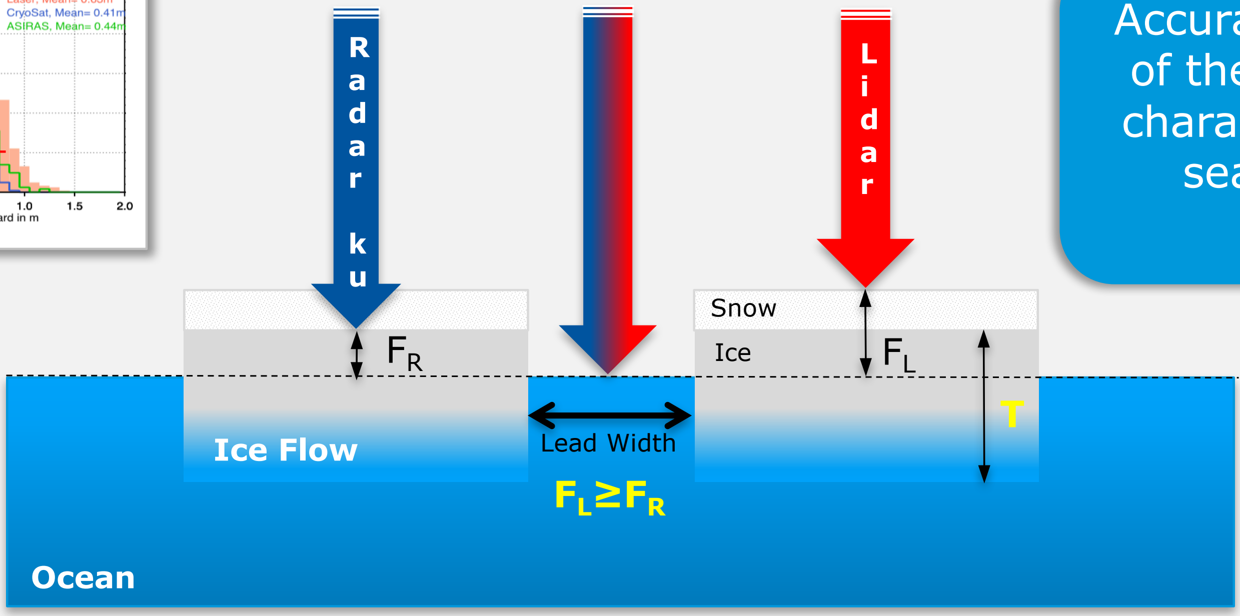




Difference in mean horizon scattering



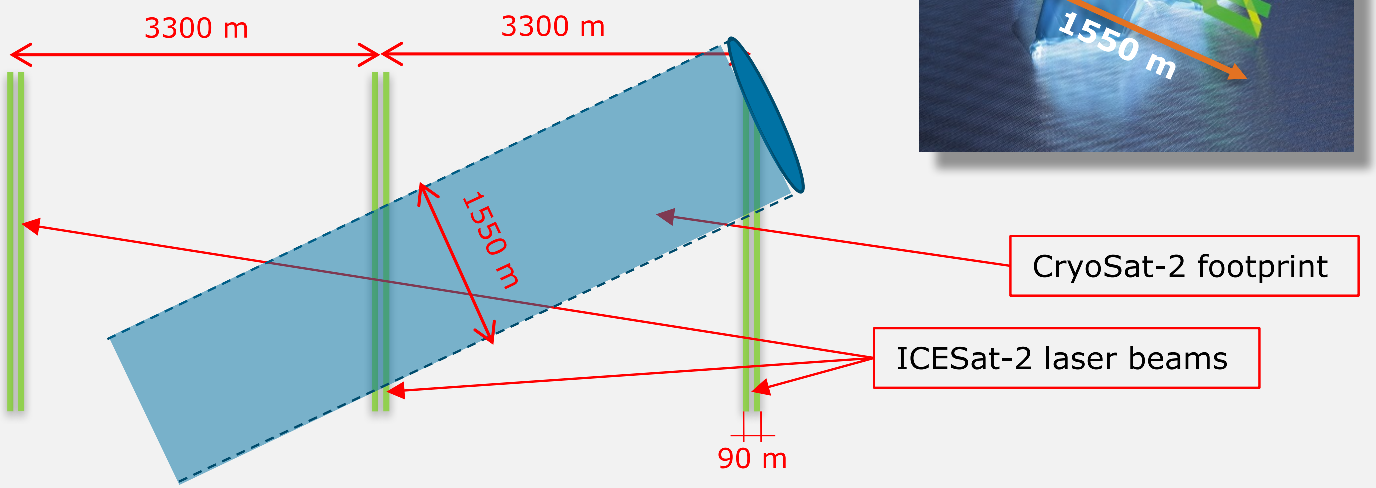
Courtesy: S. Hendrix AWI

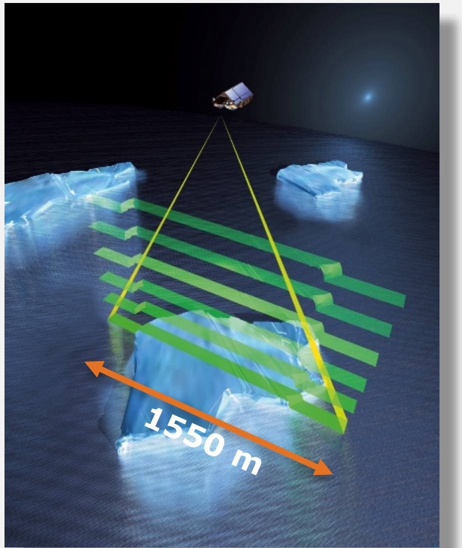


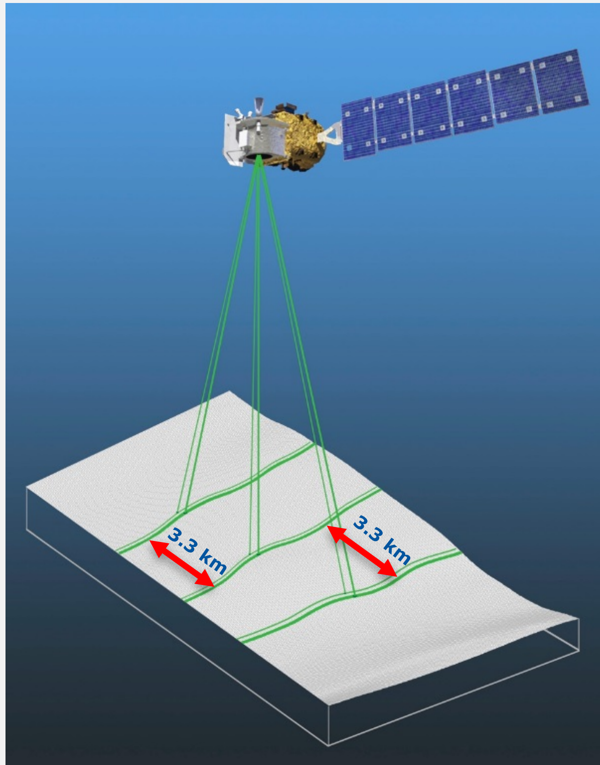
Accurate measurement of the snow layer and characterization of the seasonal horizon scattering

Instrument footprints

- CryoSat-2’s SIRAL footprint can be approximated by pulse over an area 1550 meters wide.
- The ICESat-2 instrument footprint consists of 6 laser beams, which are operated in 3 pairs
- **Physical overlaps** between laser and radar footprints are considered in searching for the the new orbit



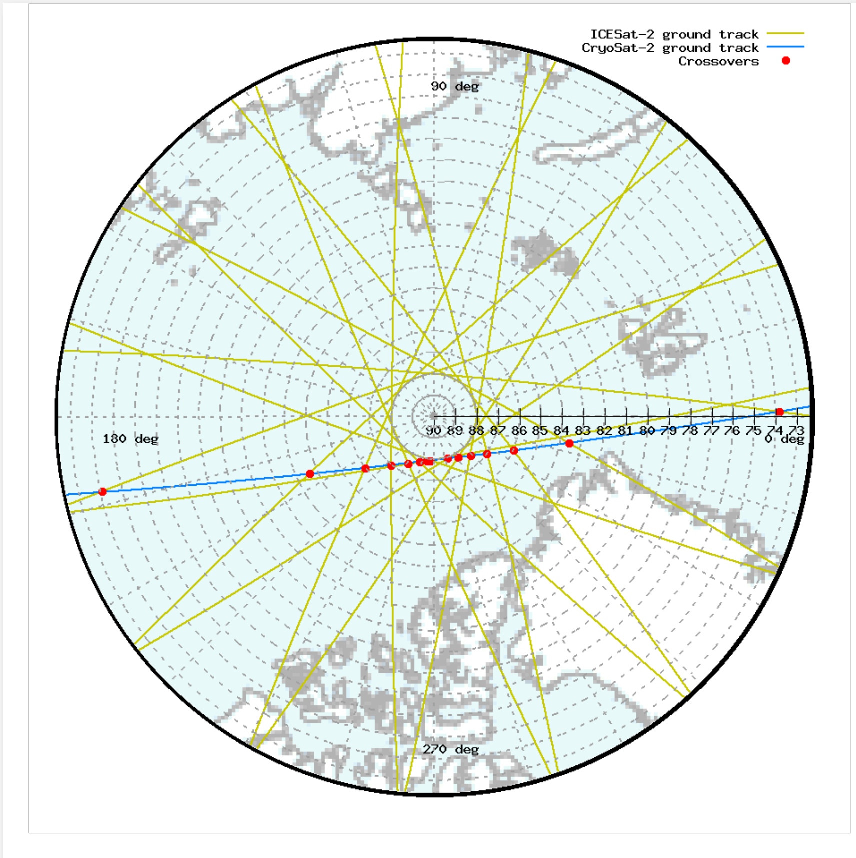




Credit: NASA's Goddard Space Flight Center

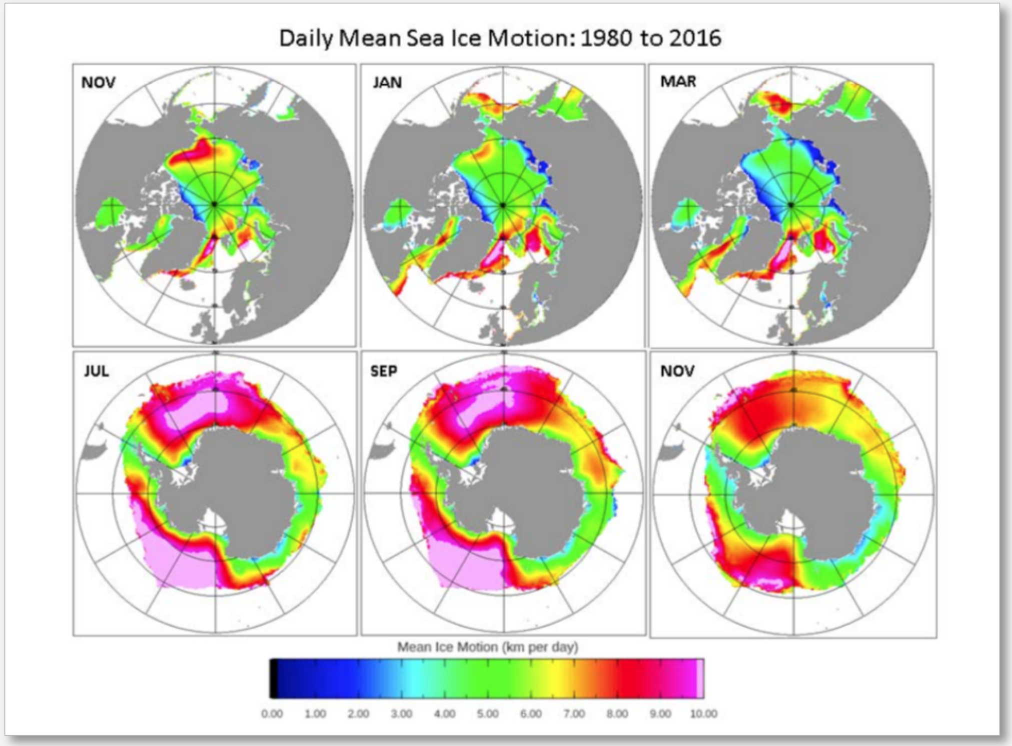
Current situation

- The geometry of both orbits leads to repeated ground track intersections over the polar areas with different time differences
- In a time span of 24 hours, one single CryoSat-2 orbit will intersect ICESat-2 orbit around 13-14 times over the areas above 60° of latitude.
- As expected, crossovers accumulate in the areas close to the maximum latitude
- In one year, there are around 140,000 of crossovers (North and South Pole 60-90°), most of them of very short duration (<1 sec)



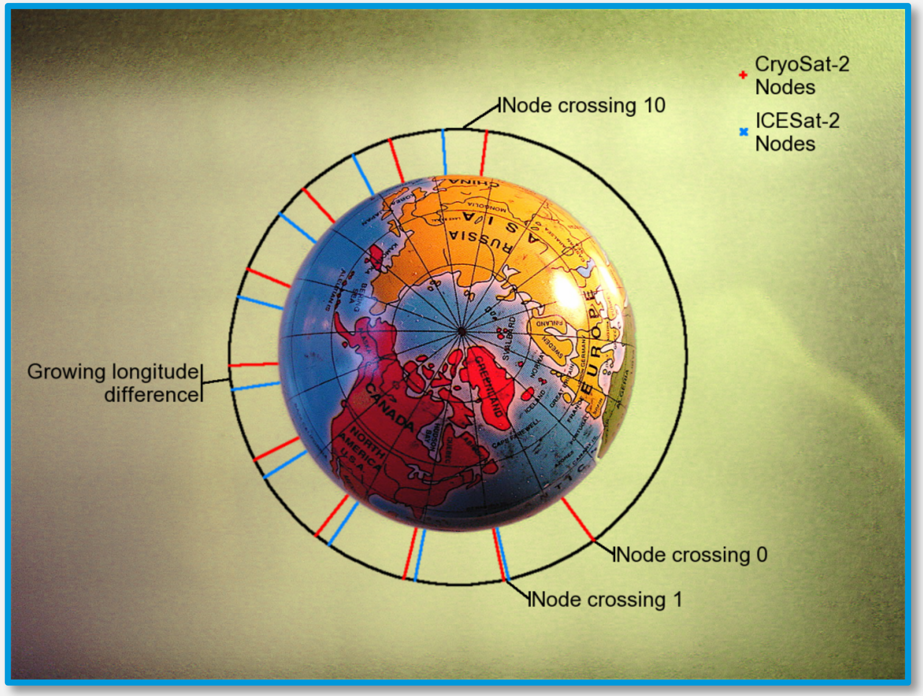
Challenges for new orbit

- **Increase** the duration of overlaps over the poles over sea and land ice
- **Reduce** the difference between observations of longer overlaps, particular important for sea ice which require time difference between observations around of 3-5 hours due to daily mean motion
- **Minimise** the impact on the current ground track distribution, on current temporal and spatial sampling for sea and land ice measurements to preserve climate records
- **Reverting** to the current orbit is always possible

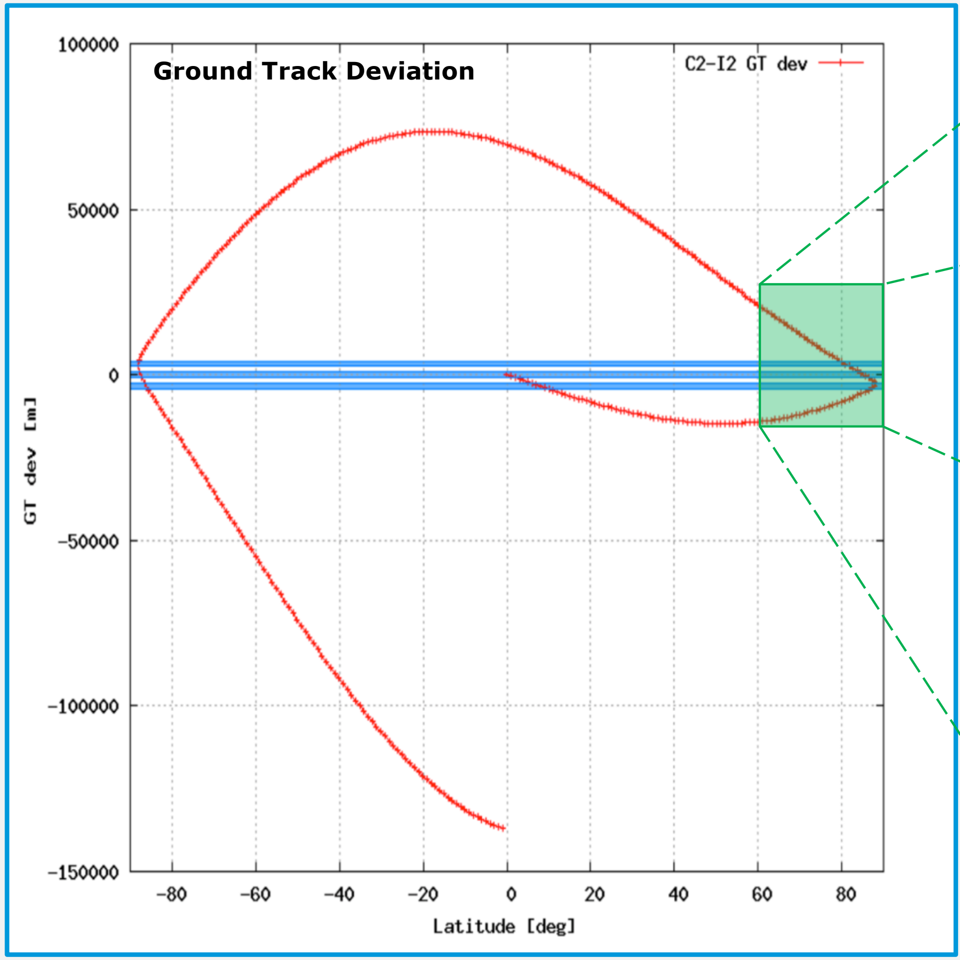


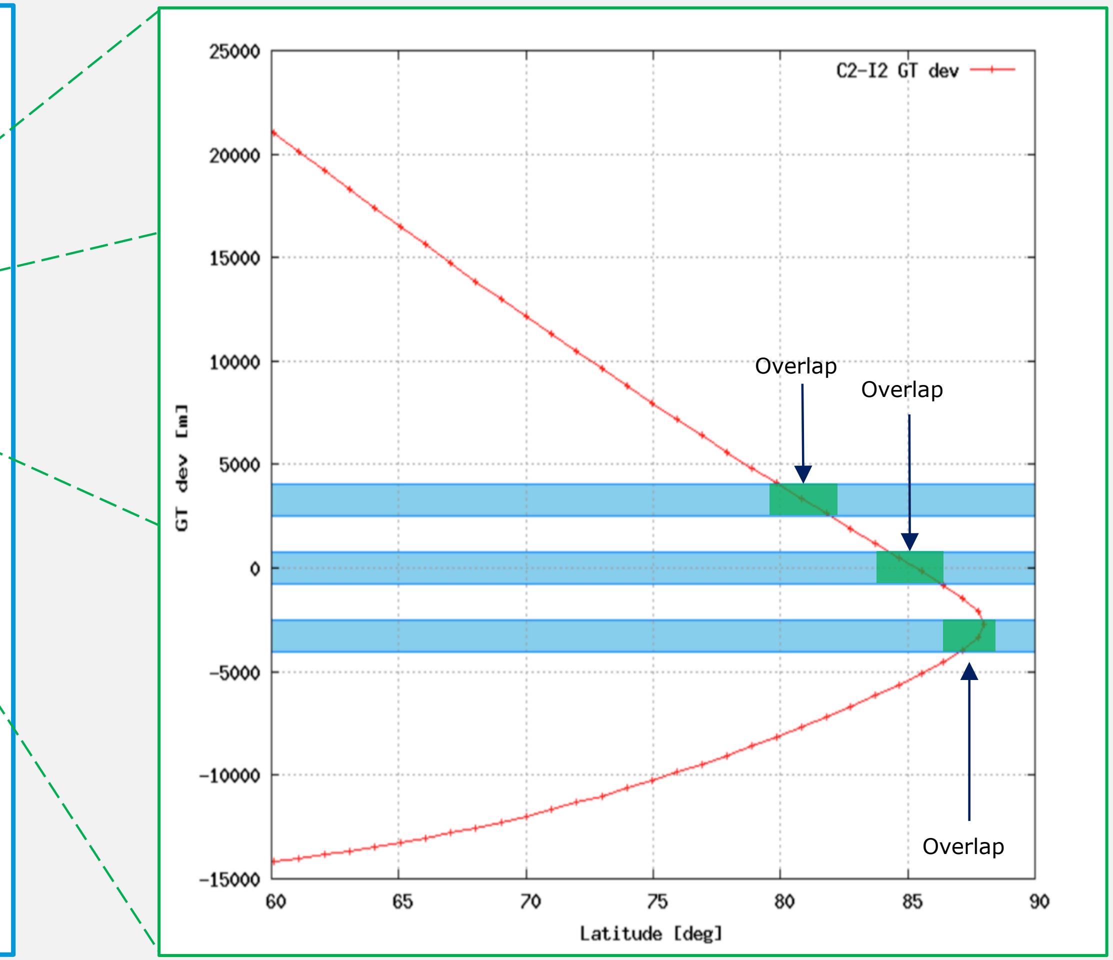
The “19/20 nodal sync” resonance concept

- The orbital period of CryoSat-2 can be adjusted (semi-major axis will be raised by approx. 900m) such that after an integer number of revolutions, both spacecraft share a common equatorial node.
- The longitude of both satellite is in sync every 19th CryoSat-2 revolution and every 20th ICESat-2 revolution
- Longer duration of overlaps over areas of interest can be configurable maximising either the North or South Pole regions (seasonal phasing)
- No change in inclination
- Estimated fuel consumption of 0.5kg



Footprints in 19/20 orbits





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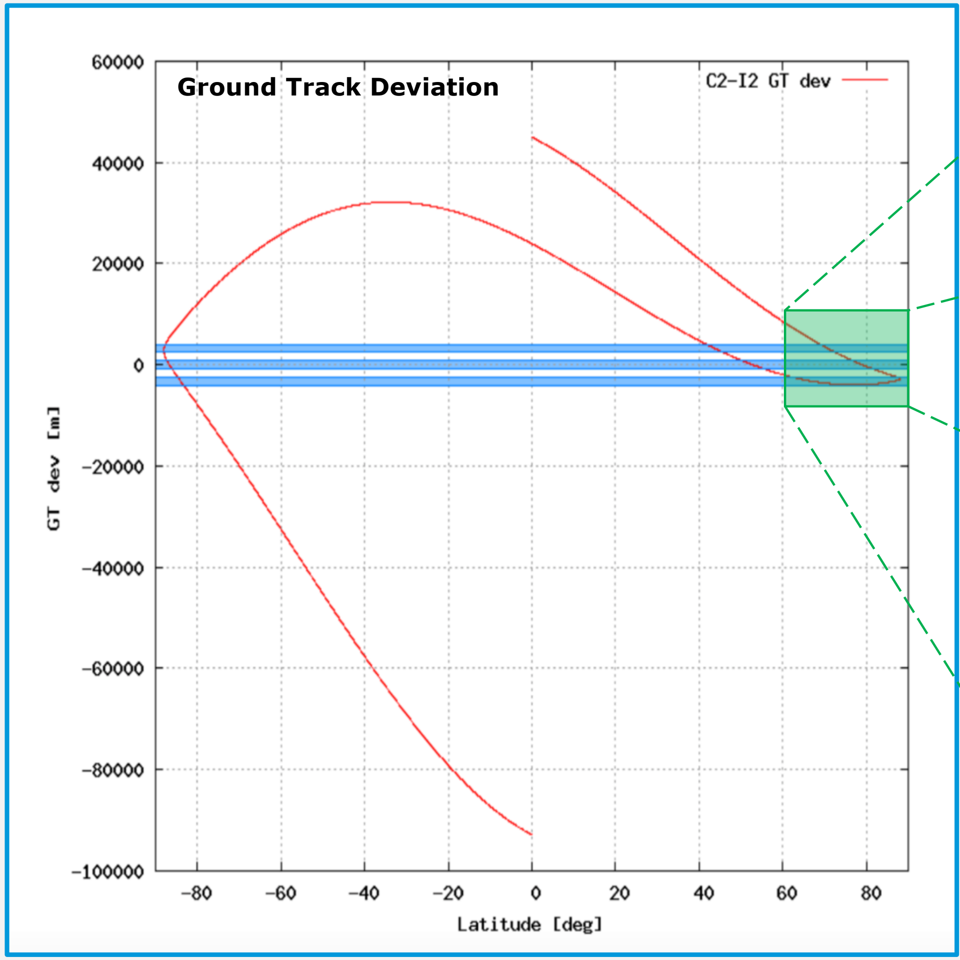
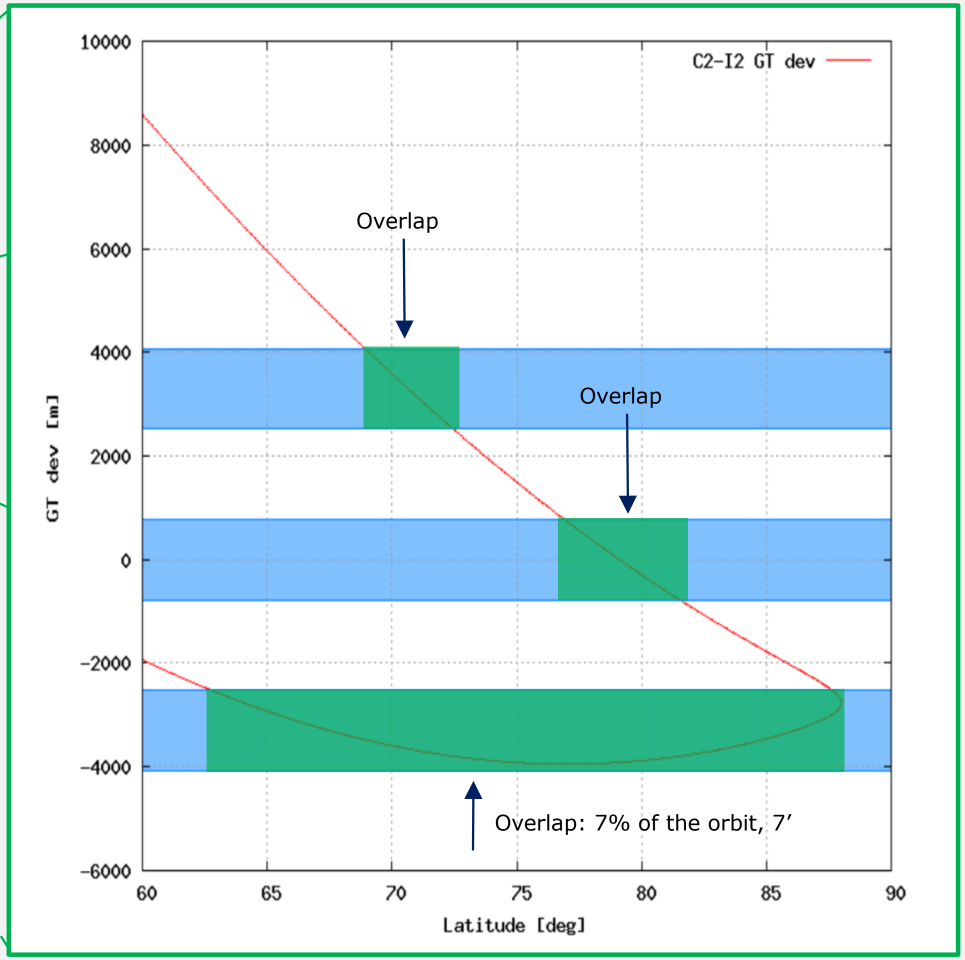
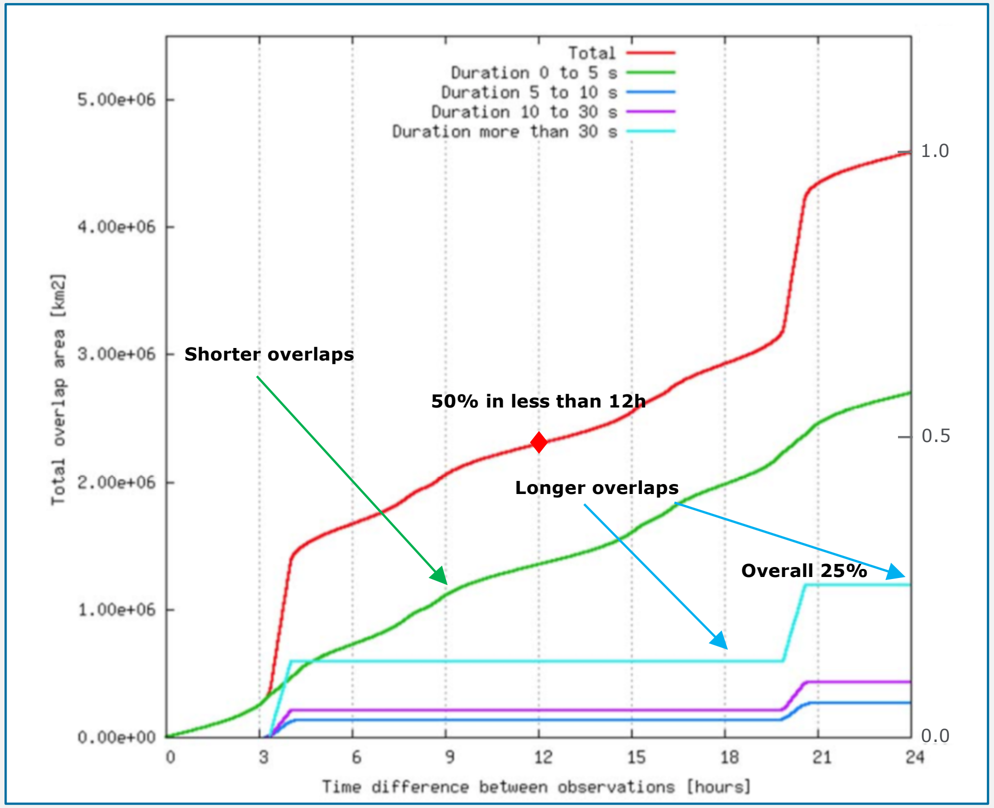


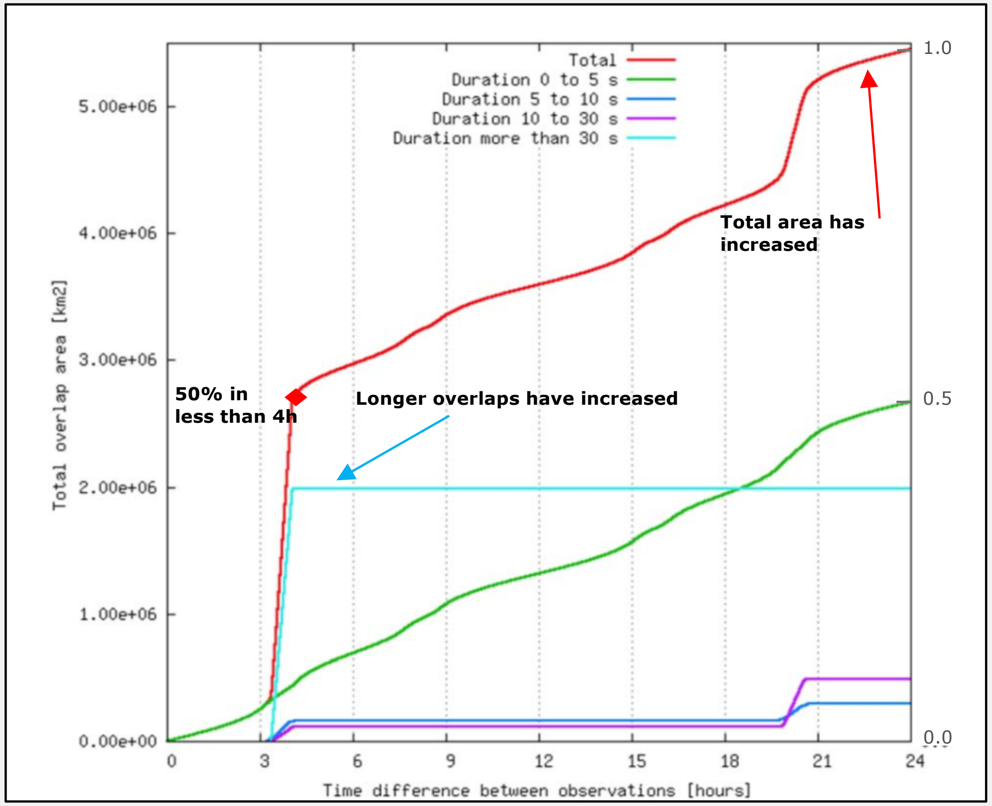


Spatial and time overlaps

Now

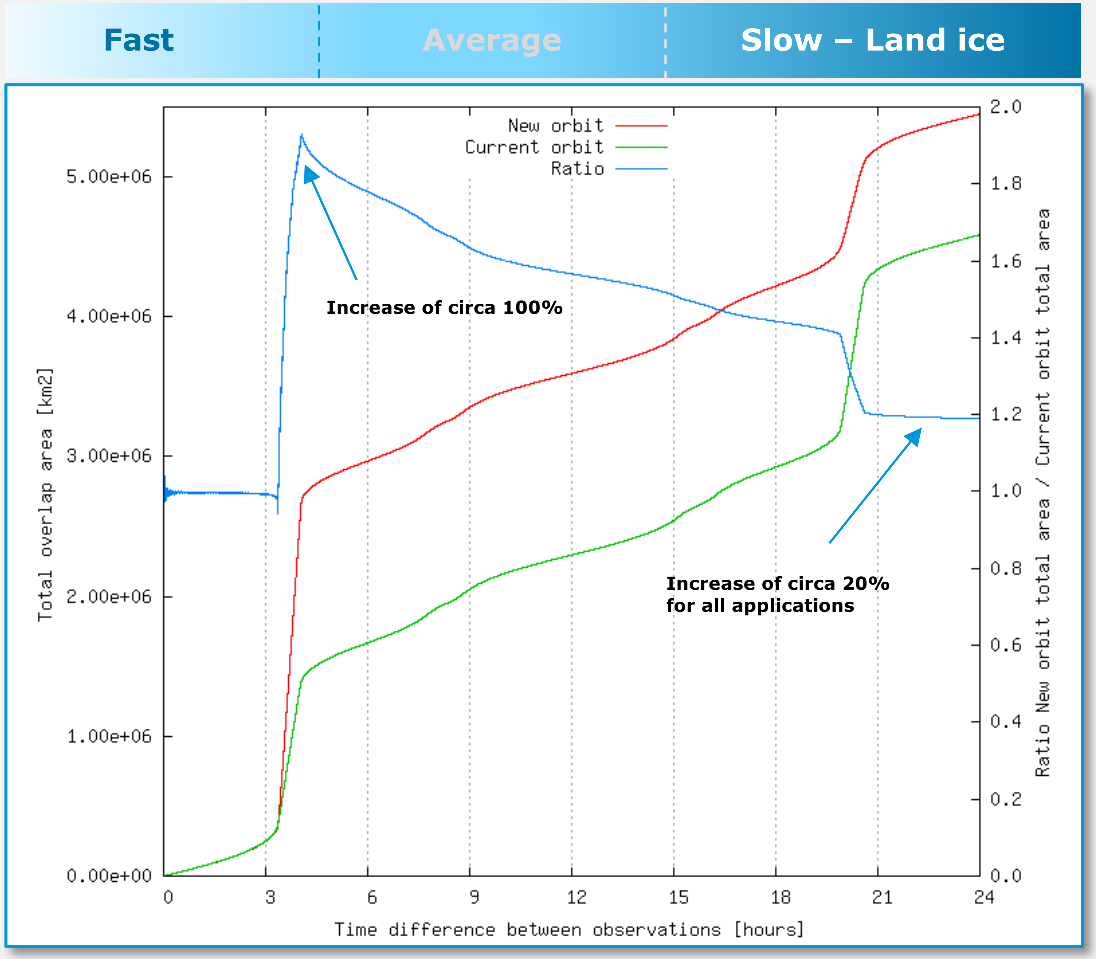


19/20 orbits



Spatial and time overlaps

- The total area of combined observations for events with a time difference of **4 hours or less** is increased by approx. **100%**.
- The total overlap has increased by 20%
- If we compare the different classes of overlaps, the largest one increases by **230%**
- Applications with different time-difference between observations benefit from the new orbit.



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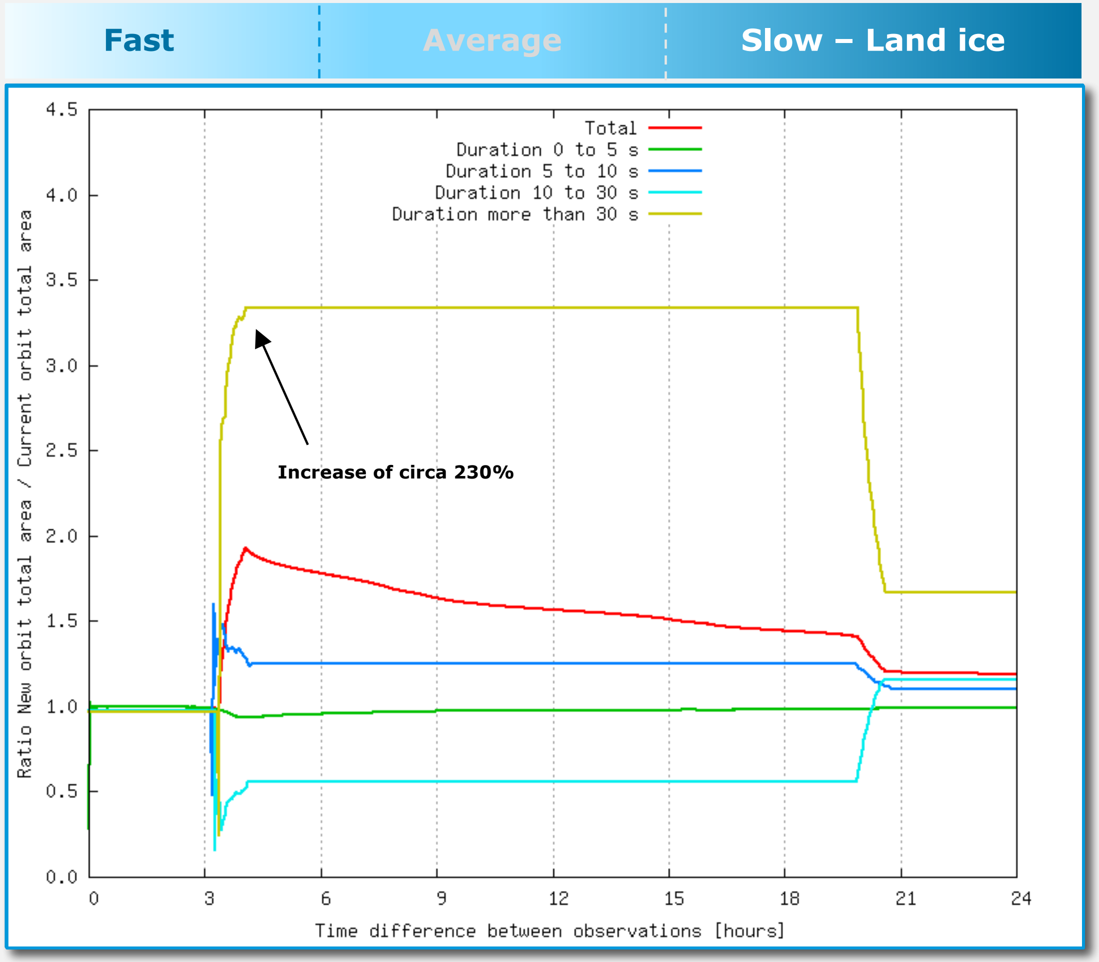
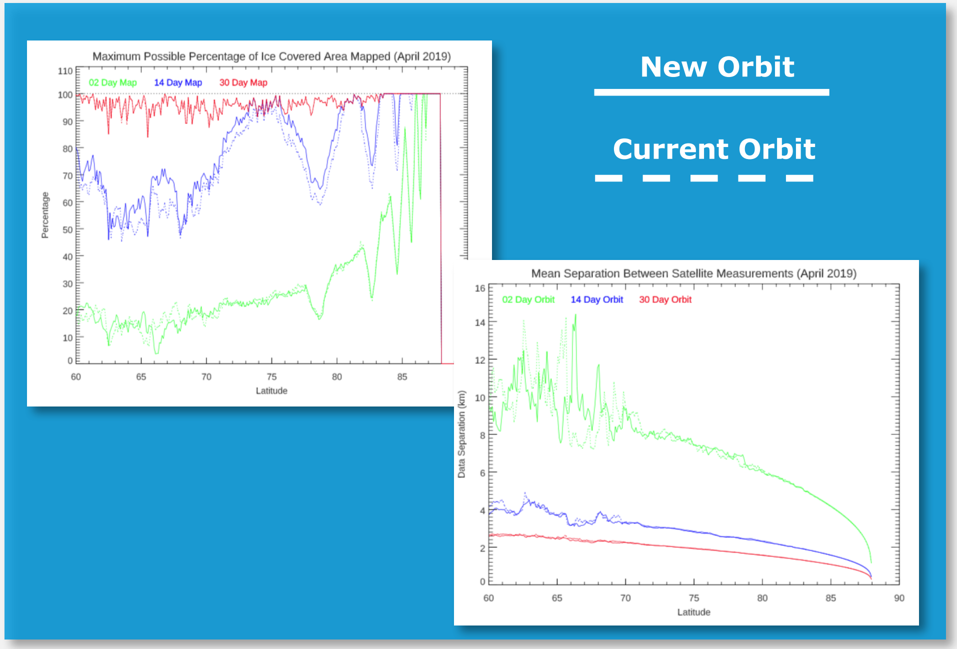
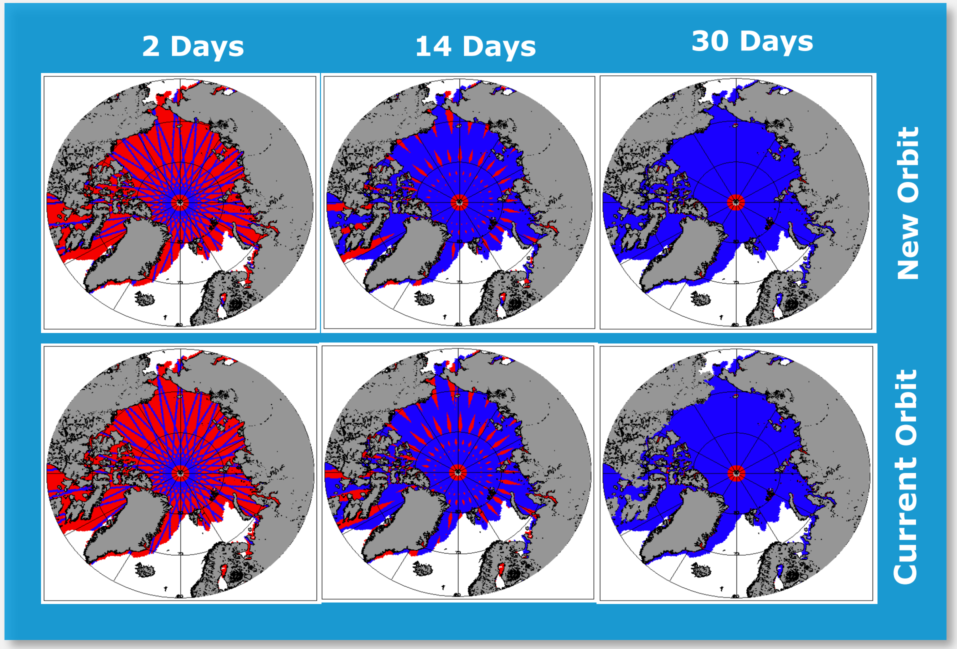


Scientific Benefits

Impact on Sea Ice Data Acquisition

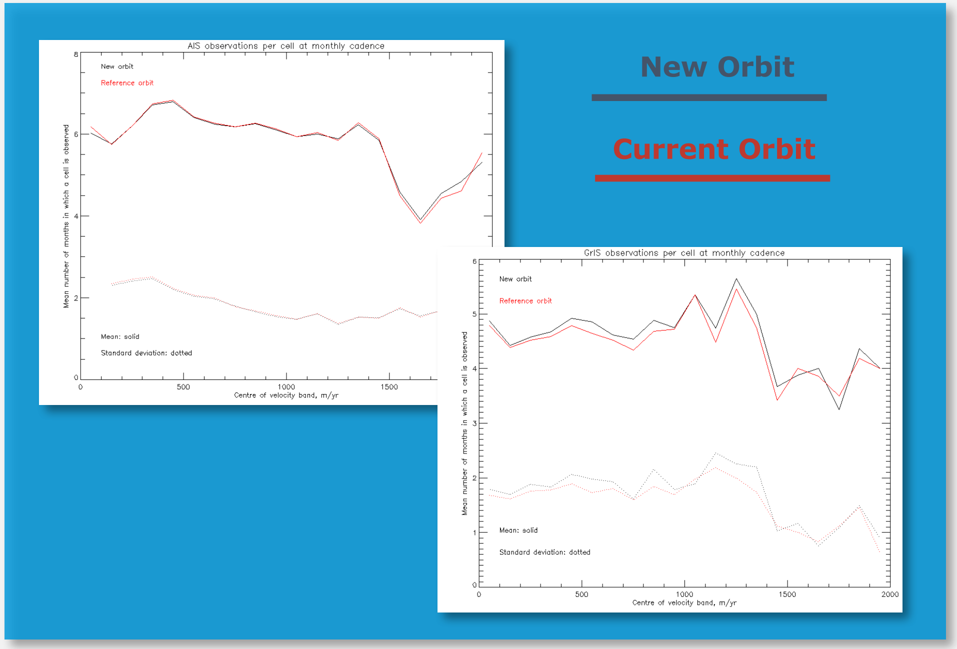


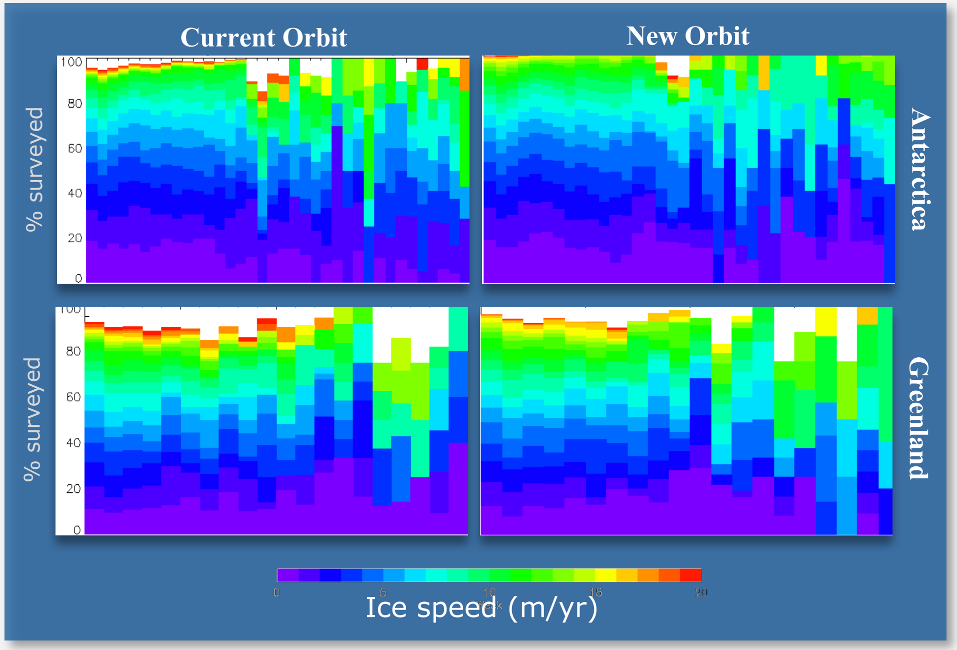


Slightly <u>improved</u> spatial and temporal sampling of sea ice

No significant change in ground track sampling of sea ice

Impact on Land Ice Data Acquisition



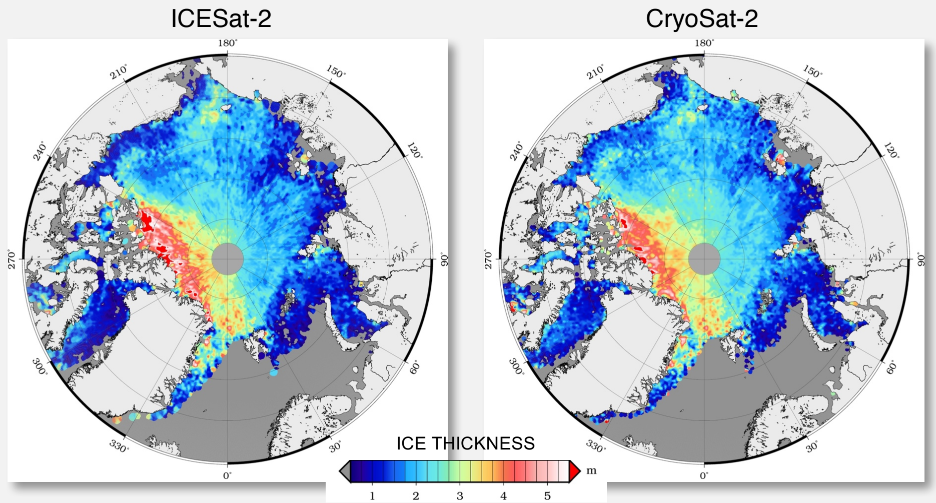


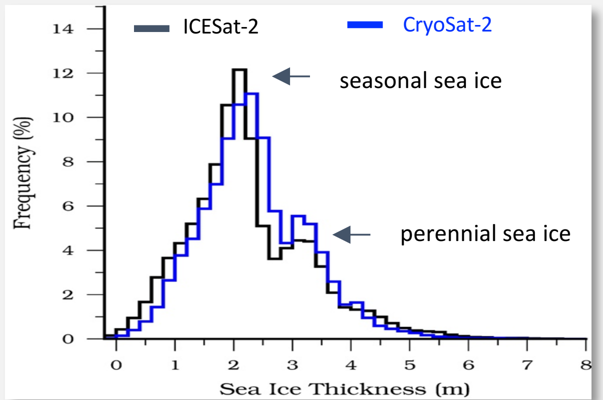
No difference in frequency of sampling over Antarctica and Greenland

Improved spatial sampling of fast flowing ice in Antarctica and Greenland

Scientific Benefits: SEA ICE

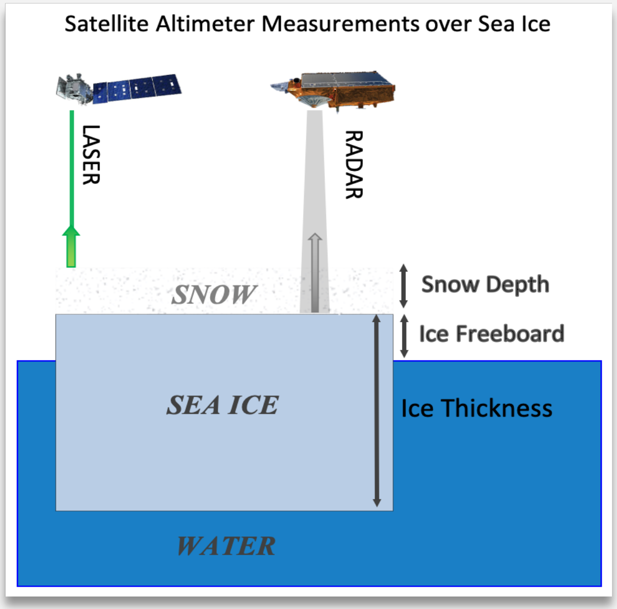
- Allow cross calibration of satellites derived sea ice freeboard
- Evaluate the impact of geometric sampling errors thanks to measurements over different instrument footprints
- Improve of sea-ice thickness estimates, one of the most important **climate** indicators
- Extend CryoSat measurements over melting periods and provide accurate measurement of surface topography and geophysical processes on short-time scales like leads and pressure ridge formation
- Extend sea ice thickness time-series across missions and explore benefits of using multi-sensor altimetry for future missions like **CRISTAL**

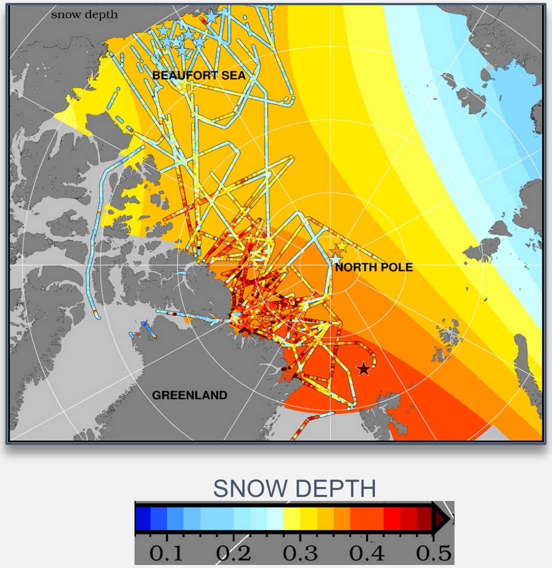




Scientific Benefits: SNOW

- Derive snow depth, the largest source of uncertainty in retrieving sea ice thickness
- Improve pan-arctic and Antarctic sea ice thickness
- Track seasonal evolution of snow depth on sea ice and land ice
- Exploit difference in radar and laser penetration (i.e. scattering horizons) depths into snow pack





- First wide-spread estimates of snow depth and improvement of **snow climatology** maps (e.g. Warren et al., 1999)
- Paves way for multi-frequency missions like CRISTAL

Scientific Benefits: LAND

- Track seasonal evolution of snow depth on polar land ice
- The change in scattering horizons and different penetration (seasonal) will improve our understanding of the interaction between snow/firn/ice with laser and radar signals
- Identify extent of the problem and improve our correction of historical radar altimetry
- Review the ice sheet mass balance records (IMBIE, CCI) and improve **climatology**

Record melt 2012

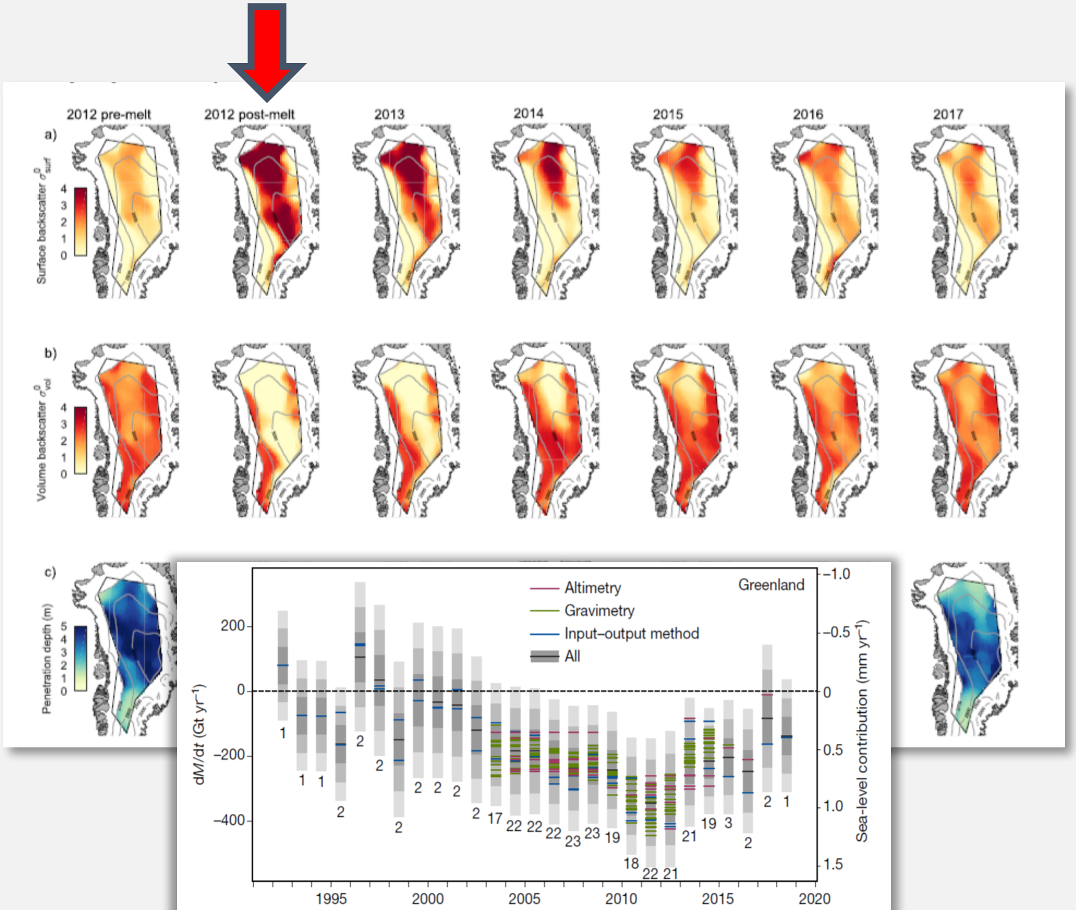
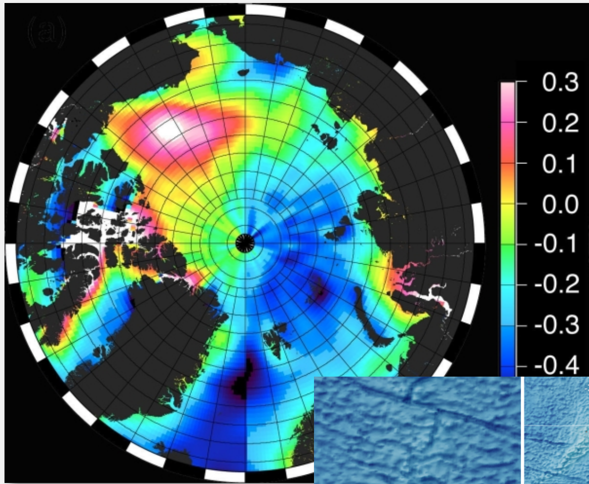
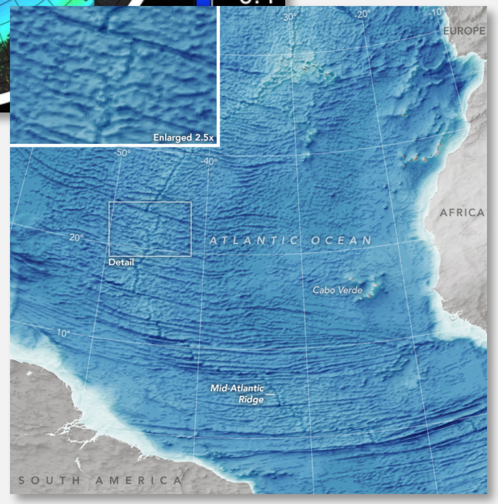


Image courtesy IMBIE

Scientific Benefits: MARINE

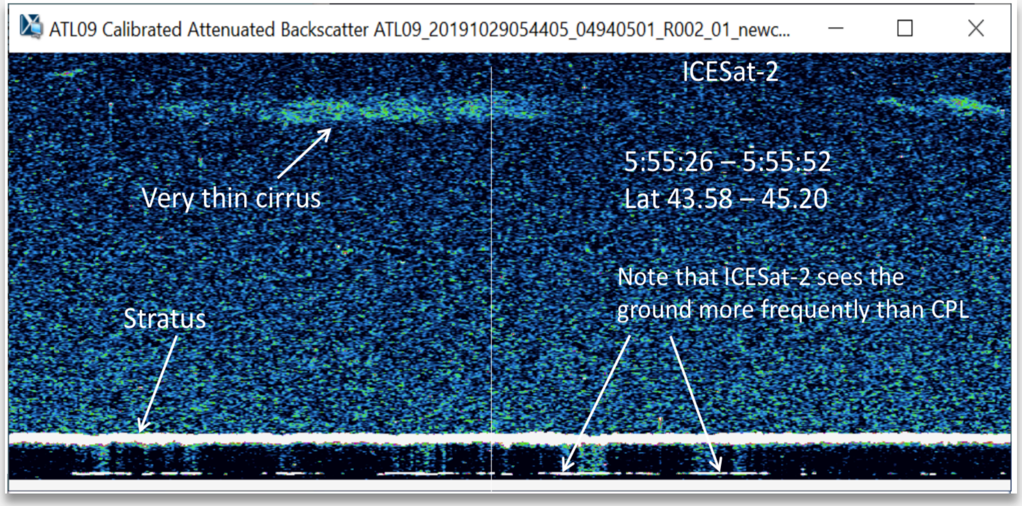
- Better characterization of SSB or DOT and SSH and improved understanding of polar ocean circulation and (sub-)mesoscale dynamics at high latitude
- Improved monitoring of sea ice motion and wave height conditions in the Marginal Ice Zone
- Potential applications for polar stakeholders including national ice centers, maritime safety organizations, to improve safe navigation in ice-infested waters.
- Improved estimates of ocean – ice – atmosphere heat flux models
- Improved resolution and better sampling of **marine gravity** and seafloor bathymetry
- Potential for improving coarser scale radar elevations over near-shore water bodies, rivers and lakes





Scientific Benefits: CLOUD CLIMATOLOGY

- Clouds are expected over sea ice during polar storms. They also occur over leads (cracks) in the sea ice and a widespread across MIZ in the Arctic and Southern Oceans
- While CryoSat-2 sea ice retrievals are not impeded by clouds (radar), ICESat-2 detects cloud height, depth and density
- Coincident measurements will allow us to "fill in" gaps in ICESat-2 where clouds obscure sea ice surface



ICESat-2 Atmospheric Column Profiles Provide Detection of Cloud Layers
Figure Credit: S. Palm, NASA GSFC, ICESat-2 Science Team

- Alignment measurements will allow us to correlate sea ice conditions with overhead cloud formation and understand links between lead in sea and cloud formation
- Improve estimates of ice – snow - ocean – atmosphere heat flux and understand seasonal evolution in clouds over ice-covered oceans

What's next?

Orbit Phasing

Complete orbit raise and LL. Prepare next orbit phasing after consultation with users

Dedicated Calval Campaigns

Plan new calval campaigns in Arctic and Antarctic to maximize scientific return

New ice and snow products

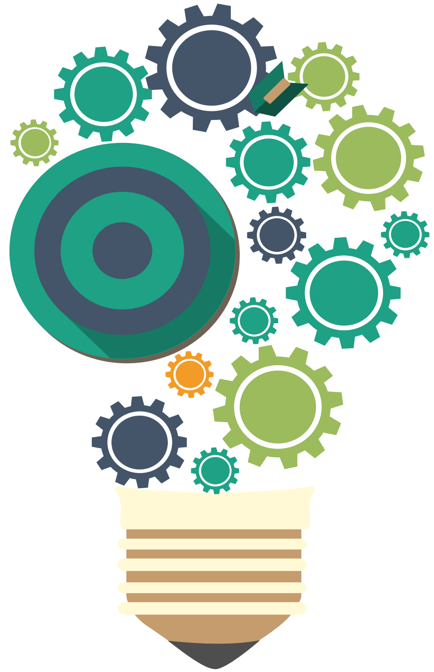
Launch ITT to develop new products and new snow climatology map

Dedicated Workshop 2022

Organize workshop dedicated to the results stemming out from resonance orbit

Outreach +

Implement outreach activities according to communication plan + other ideas



Conclusions

- The orbit change aiming at synchronizing CryoSat-2 to ICESat-2 satellites has been discussed. Once achieved, it will offer a unique (and probably unrepeatable) possibility to have coincident laser and altimeter data over polar areas which are key to understand **climate change**

- This scenario, called "19/20 nodal synch", fulfills all challenges for the new orbit; in particular, increases the duration of the footprint overlaps and reduces the difference of observation time, particularly important for sea-ice **with no** consequences on long-term climate data record

- A complete impact analysis has been carried out to identify possible risks. The analysis surveyed all space and ground subsystems and concluded that there are no major potential risks. The operational plan has been secured including contingency cases. New orbit will be reached in 2 weeks

- The scientific benefits have been briefly presented. The orbit change has been fully endorsed by the scientific CryoSat and ICESat community through their recommendations and letters of support. An extensive communication plan in collaboration with NASA has been set-up

Acknowledgement

For the brainstorming, design, preparation and implementation of #CRYO2ICE
Javier Sanchez, Xavier Marc, Ignacio Clerigo, Stefano Badessi, Jerome Bouffard, Berta Hoyos, Tania Casal, Francesca Andreoli, David Fornarelli, Giuseppe Albini, Alessandro Neto, Serenella di Betta, Vittorio Torroni, Roberta Guerrieri, Marco Meloni, Marco Fornari, Michele Scagliola, Montserrat Pinol Sole, Mark Drinkwater, Elia Maestroni, Andrada Coos, Chiara Stellani, Thomas Neumann (NASA), Nathan Kurtz (NASA), Thorsten Markus (NASA), Lori A. Magruder (NASA), Valerie Casanto (NASA), Kate Ramsayer (NASA), Andrew Shepherd, Sinead Farrell, Louise Sandberg, Ole Baltazar Andersen, Sara Fleury, Christian Haas and Malcolm McMillan

A special acknowledgement goes to the CryoSat Space and Ground Operations Teams and to Industry for their evaluation and proactive recommendations.

A special thanks goes to the entire CryoSat and ICESat scientific community that has endorsed this opportunity with great enthusiasm and encouragement

Special thanks for the contribution to this presentation goes to Javier Sanchez, Sinead Louise Farrell, Jerome Bouffard and Andrew Shepherd