



**SEA ICE IN THE EARTH SYSTEM:
A MULTIDISCIPLINARY PERSPECTIVE**

June 4-6 2019, Brest, France

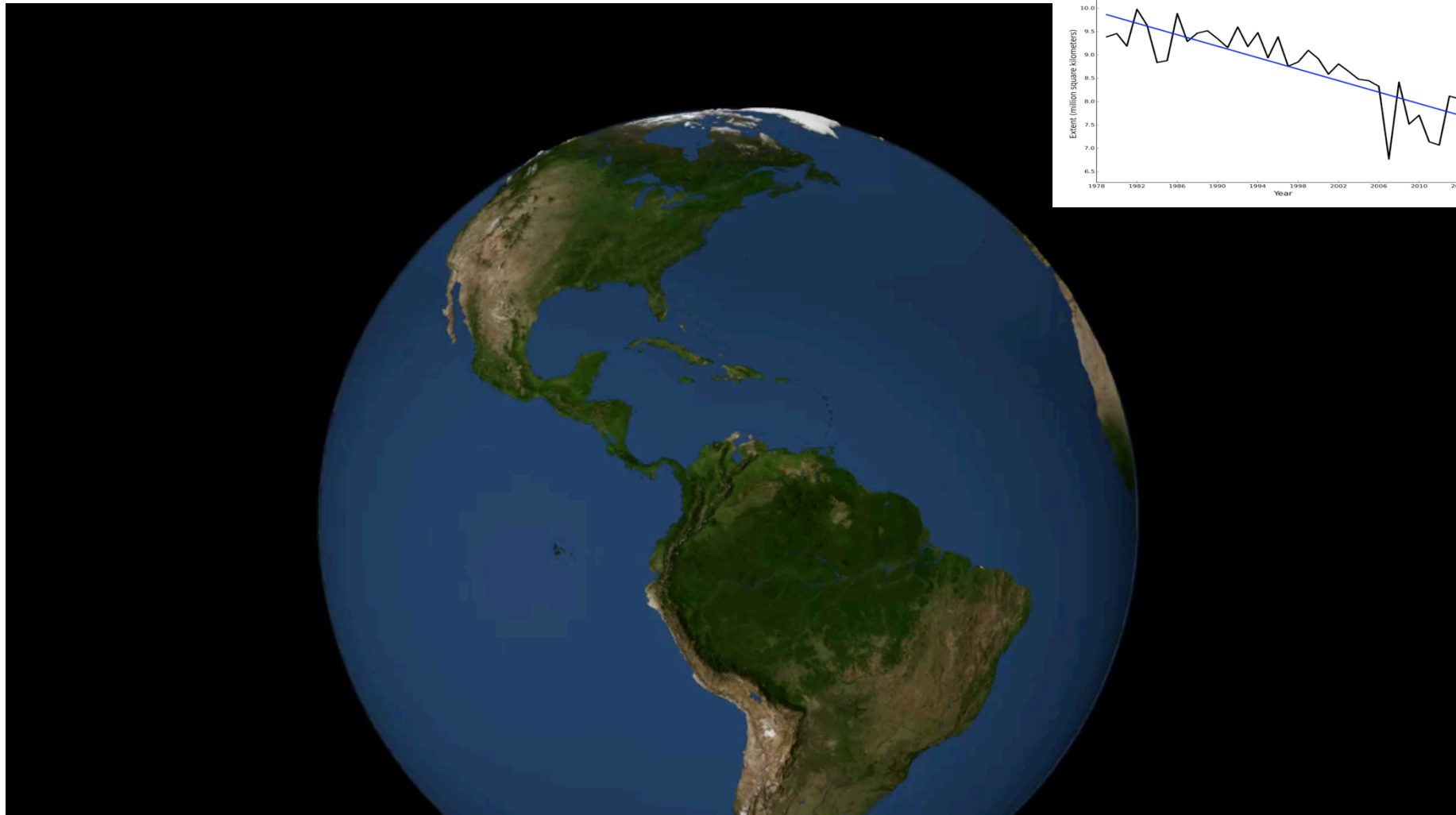
Snow Depth and Sea Ice Thickness using Satellite Altimeters

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What Needs for Sea Ice Thickness ?

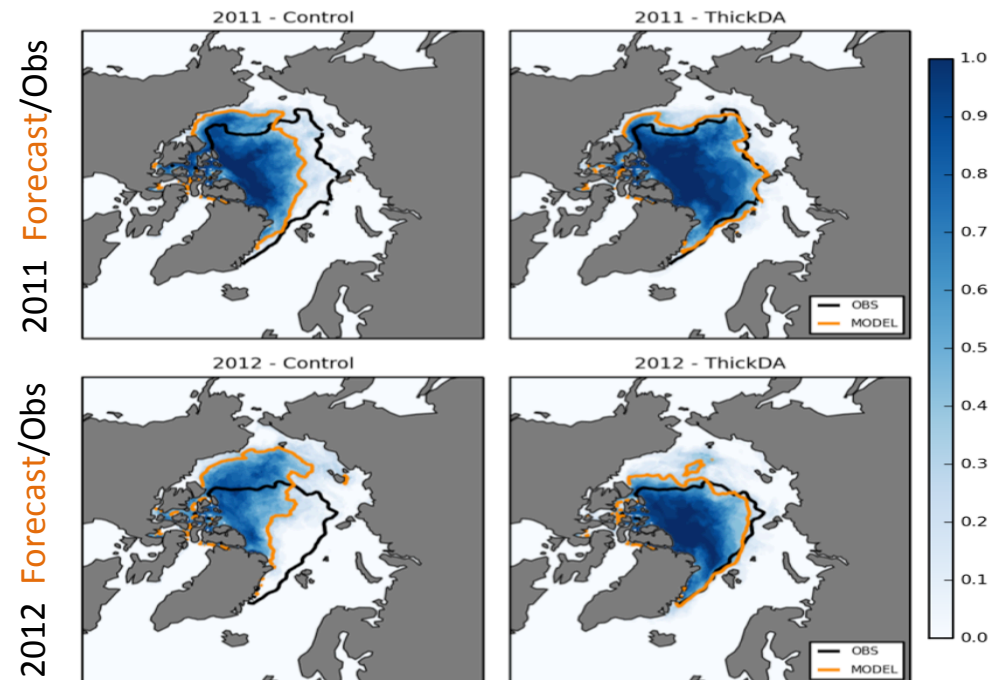


What Needs for Sea Ice Thickness ?



Chevallier et al. 2018, Allard et al. 2018, Xie et al. 2018, Schroder et al. 2018, Blockley et al. 2018, ...

4 months sea ice edge forecast for Sept using
1) sea ice concentration 2) sea ice thickness



04/06/19

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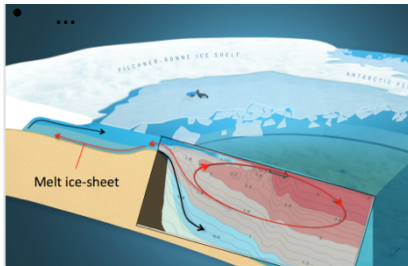
[Met Office, Blockley and Peterson, in TC 2018]

What Needs for Sea Ice Thickness ?



Access to sea ice volumes:

- variation of salinity
- stratification
- thermohaline circulation
- freshwater mass balances, ...



Chevallier et al. 2018, Allard et al. 2018,
Xie et al. 2018, Schroder et al. 2018,
Blockley et al. 2018, ...

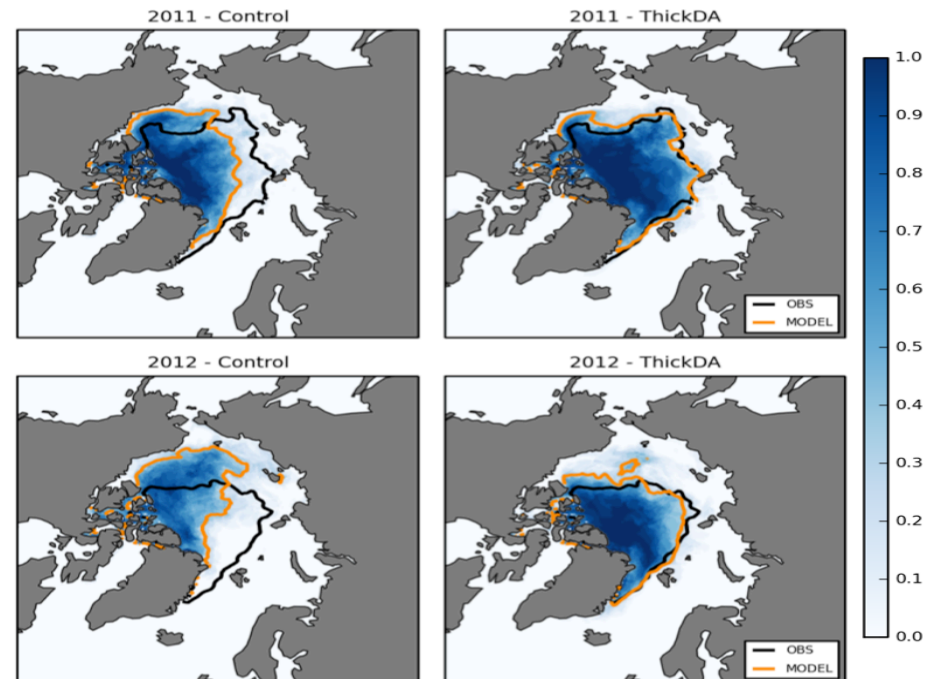
4 months sea ice edge forecast for Sept using

1) sea ice concentration

2) sea ice thickness

2011 Forecast/Obs

2012 Forecast/Obs

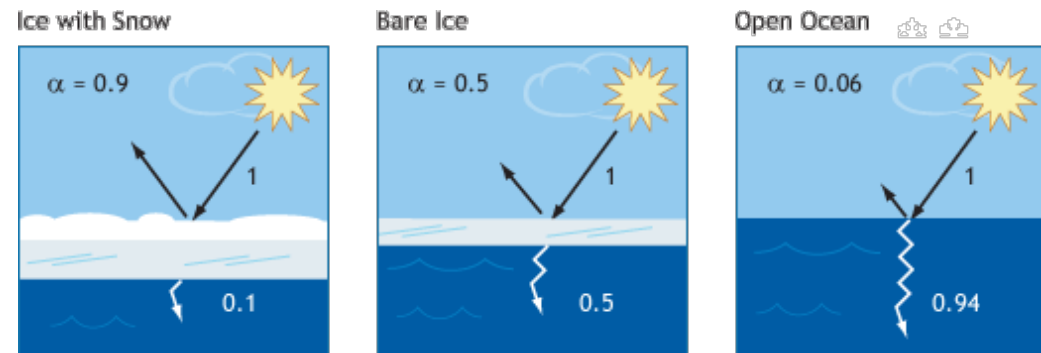


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[Met Office, Blockley and Peterson, in TC 2018]

And the Snow ?

- Albedo and climate
- Sea ice dynamics

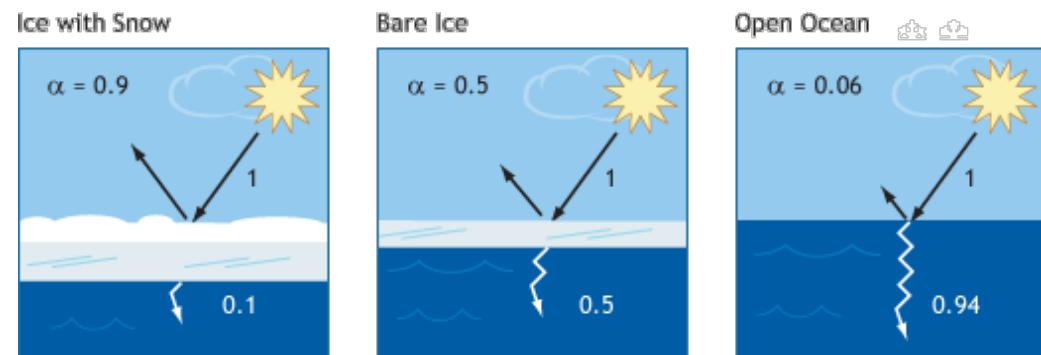


- thermal insulation of the snow that limits the growth of the ice
- melting ponds in summer that accelerate ice melting
- UV filter for ice algae and plankton
- Impacts sea ice thickness measurements by altimetry



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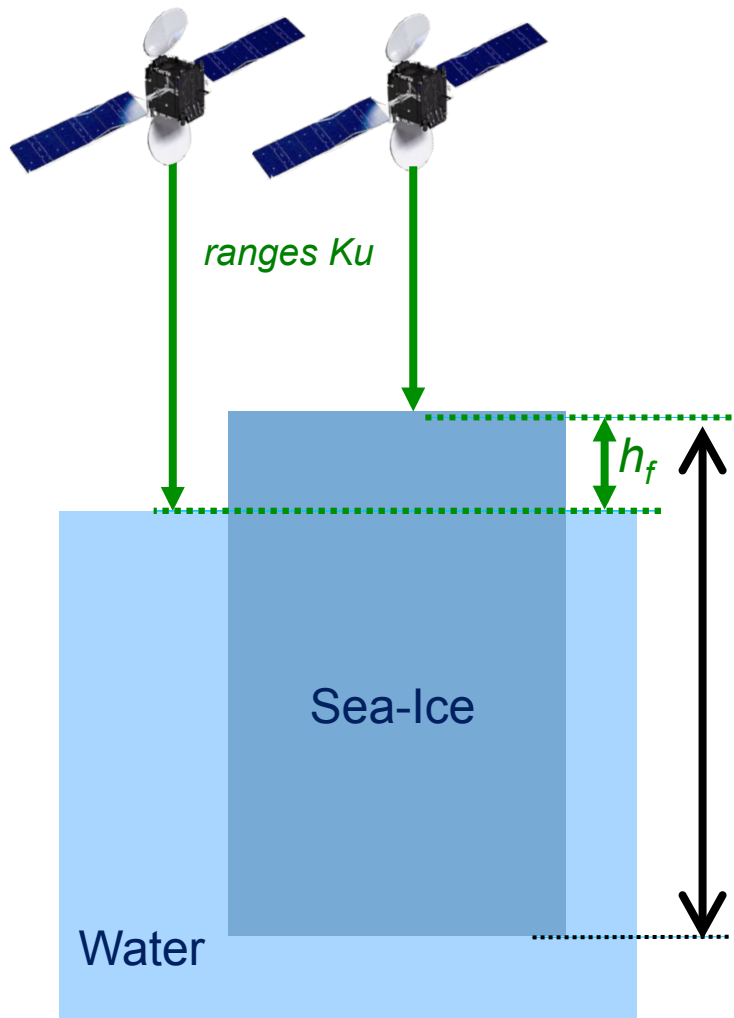


- **Impacts sea ice thickness measurements by altimetry**

Sea Ice Thickness by Altimetry

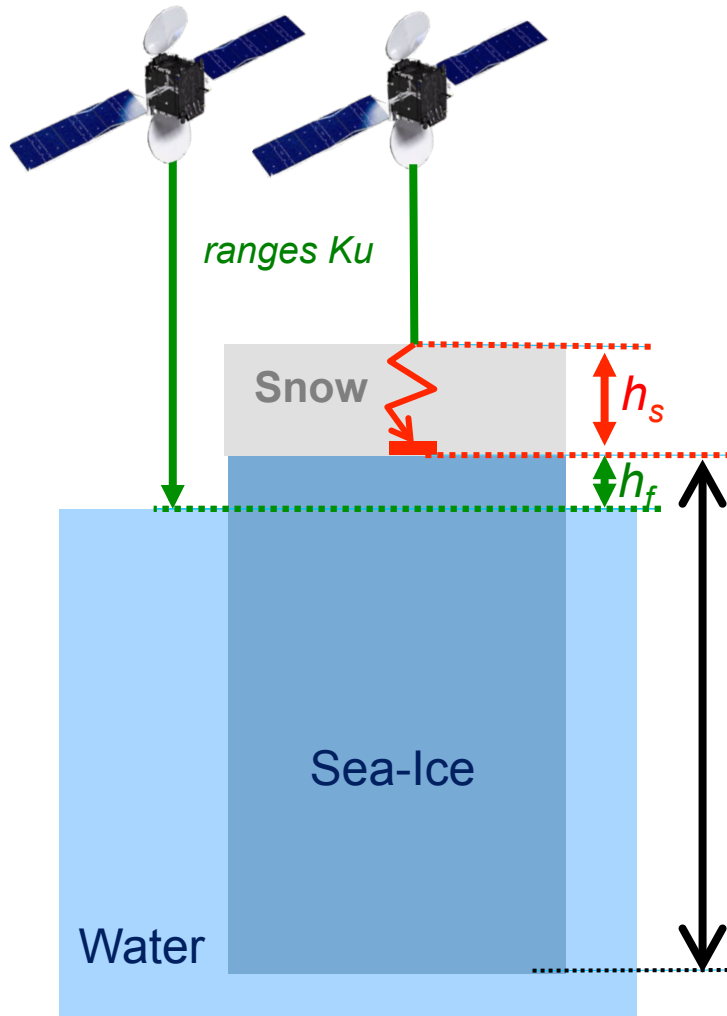


The “freeboard methodology”



$$SIT = \frac{\rho_w h_f}{\rho_w - \rho_i}$$

Sea Ice Thickness by Altimetry



The “freeboard methodology”

Ice sinking under the weight of snow

Speed propagation reduction (~20%)

$$SIT = \frac{\rho_w h_f + \rho_s h_s (1 + \alpha)}{\rho_w - \rho_i}$$

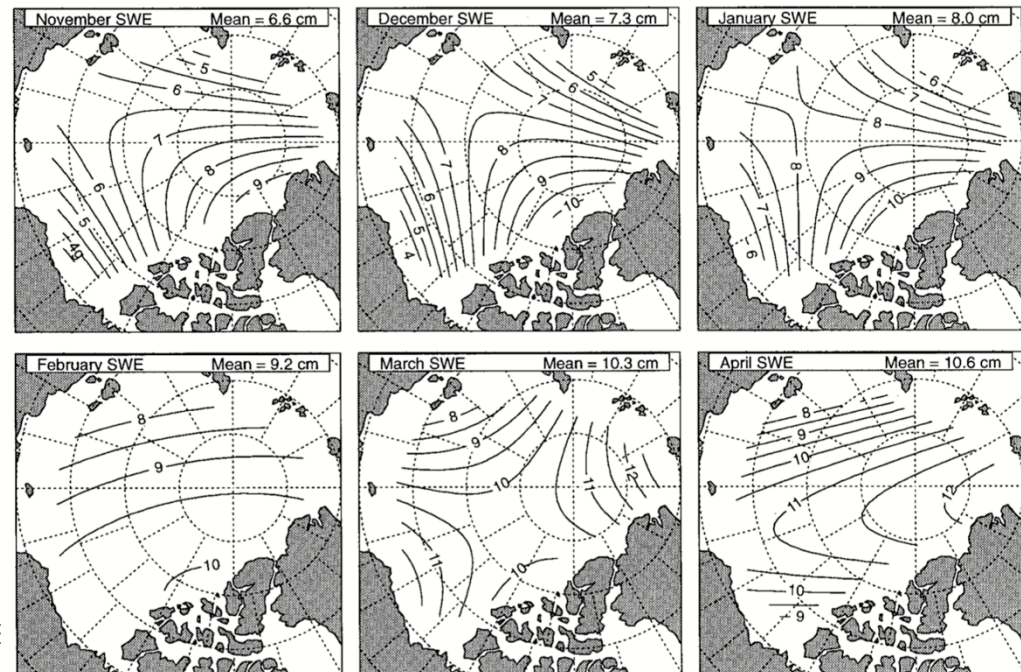
lack of knowledge of snow

=> 30 to 100% of error on the Sea Ice Thickness



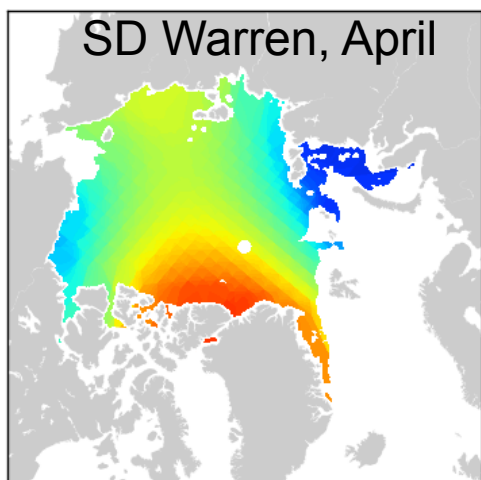
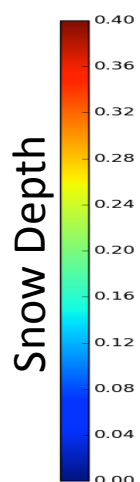
Sea Ice Snow Depth ?

- All Sea Ice Thickness product computed from altimetry use the **Warren climatology**
- Climatology published in 1999 from **in-situ measurements made between 1954 et 1991**, *i.e.* before the sensible effects of the global warming.
- Available only in Arctic

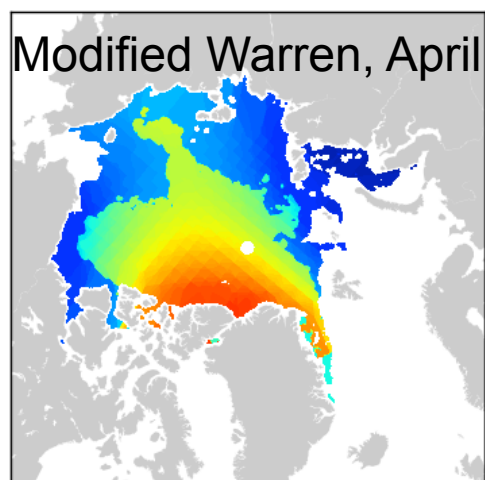
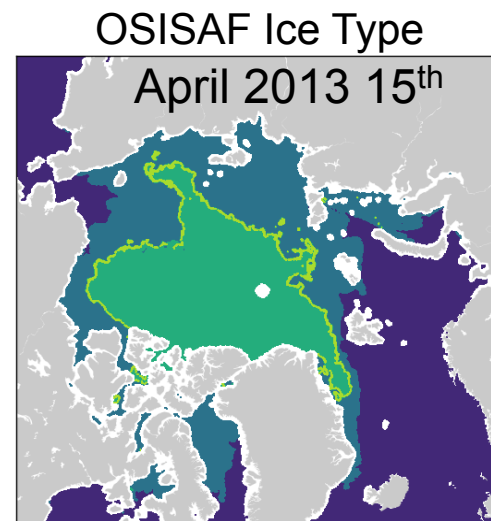


Sea Ice Snow Depth ?

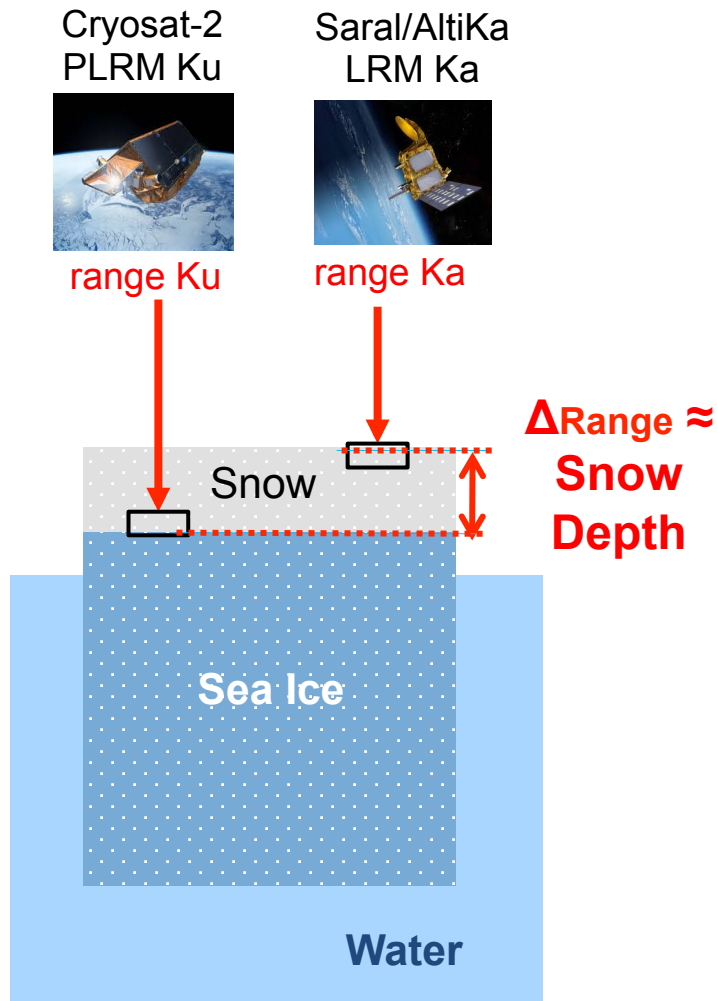
- Or the Modified Warren Climatology :



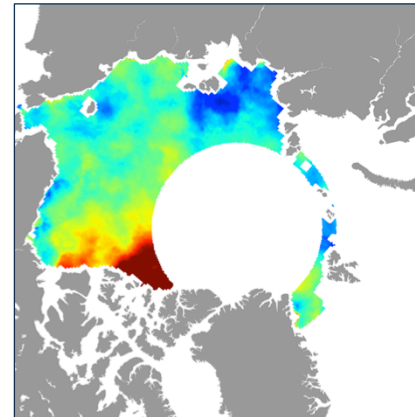
Multi Year Ice : **SD x 1**
First Year Ice : **SD x 0.5**



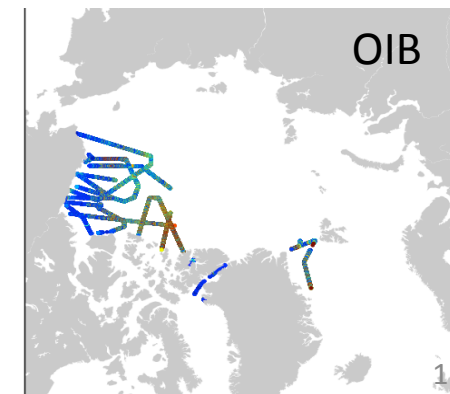
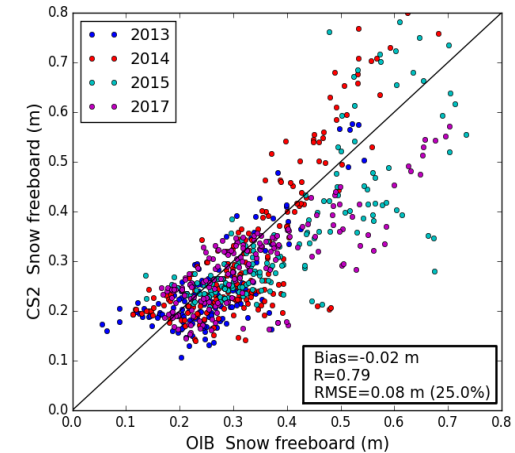
Snow Depth with Bi-Frequency Altimetry



Alti Snow Depth:
PLRM Ku – LRM Ka



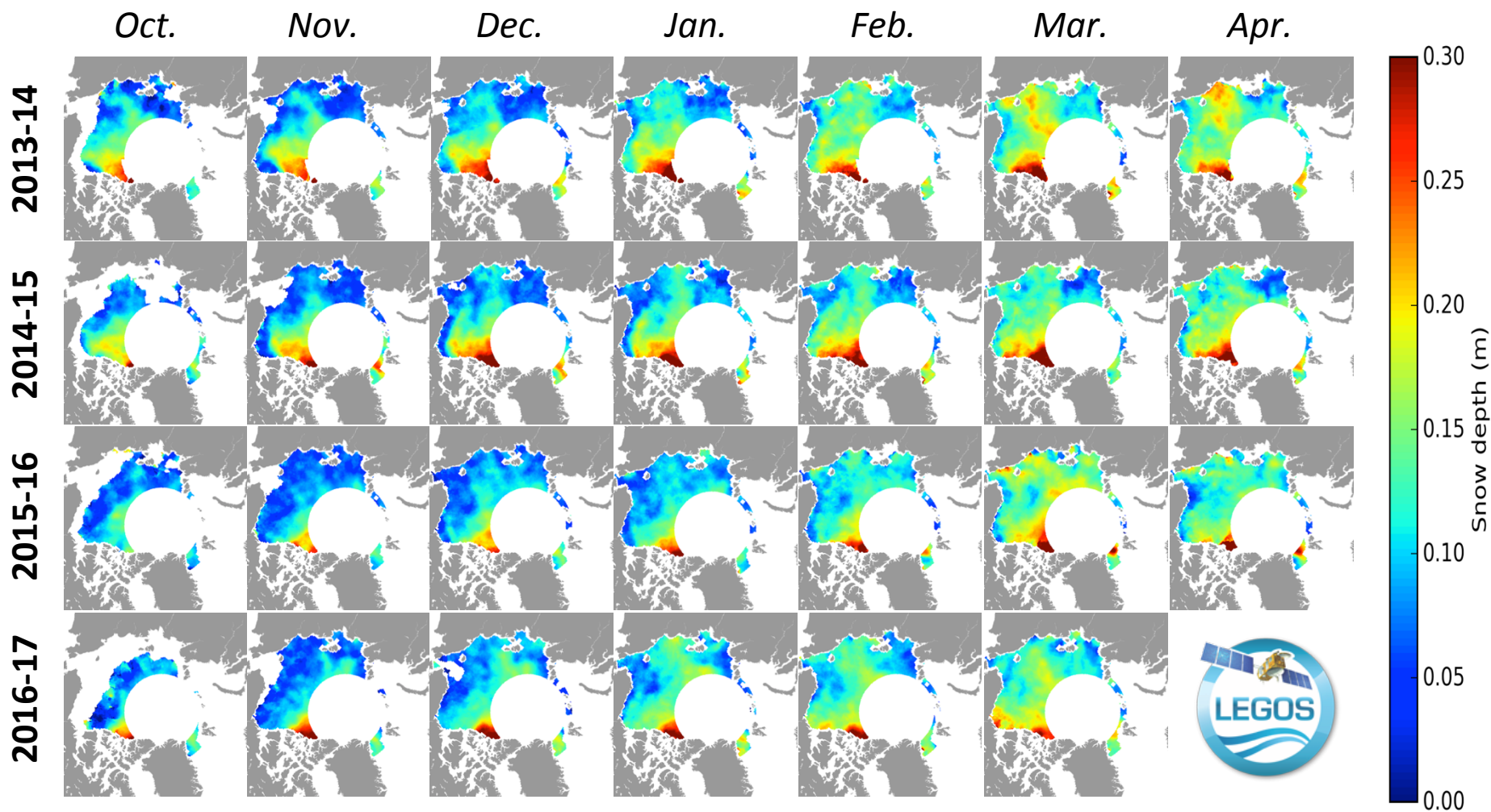
Validation with OIB
airborne snow radar



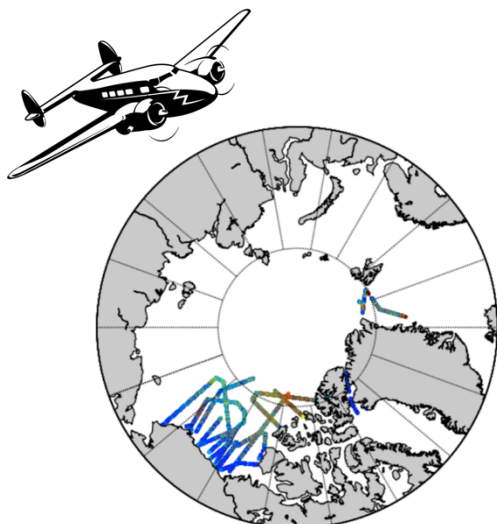
[Guerreiro et al, Potential for estimation of snow depth on Arctic sea ice from CryoSat-2 and SARAL/AltiKa missions. RSE 2016]

ce, Brest

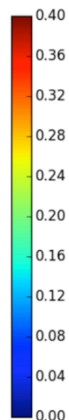
Winters Arctic Snow Depth 2013-17



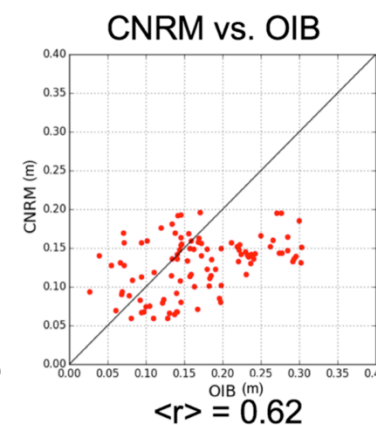
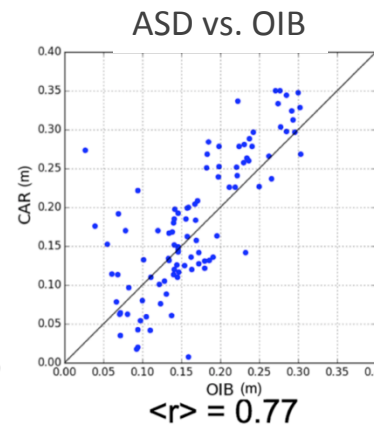
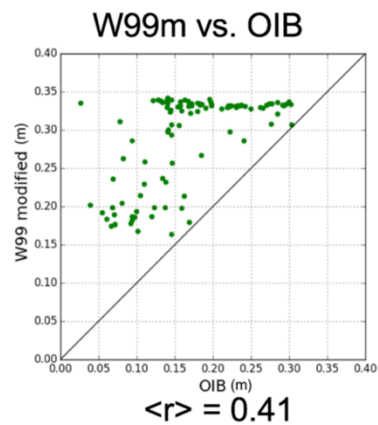
SD comparisons



Snow Radar from
Operation Ice Bridge (OIB)

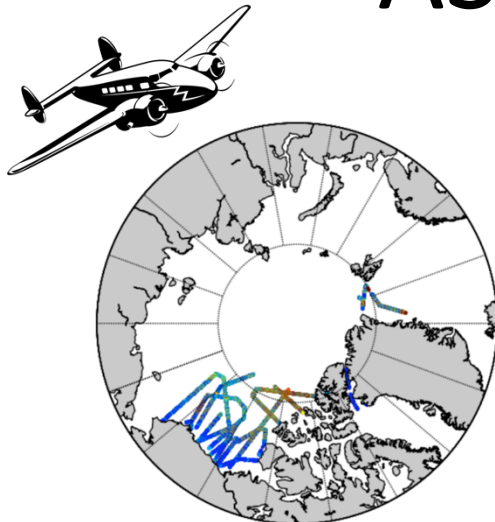


Snow Depth versus OIB

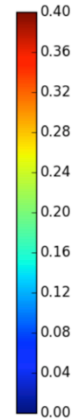




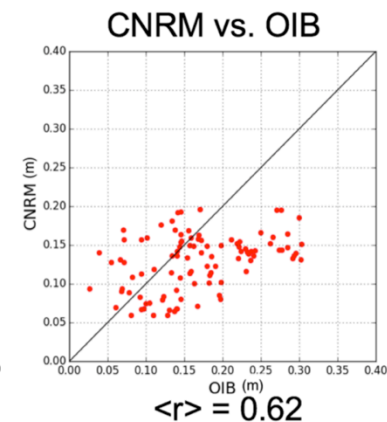
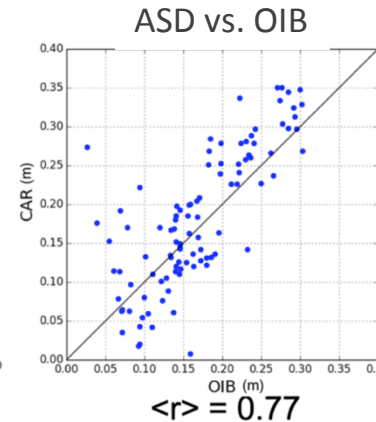
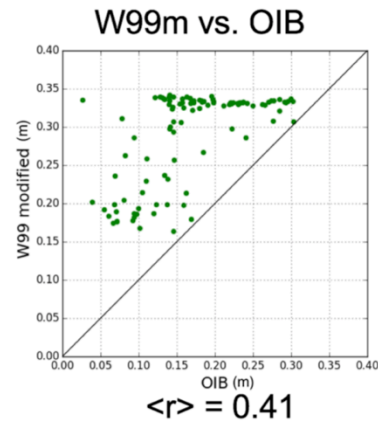
ASD: Validation with OIB



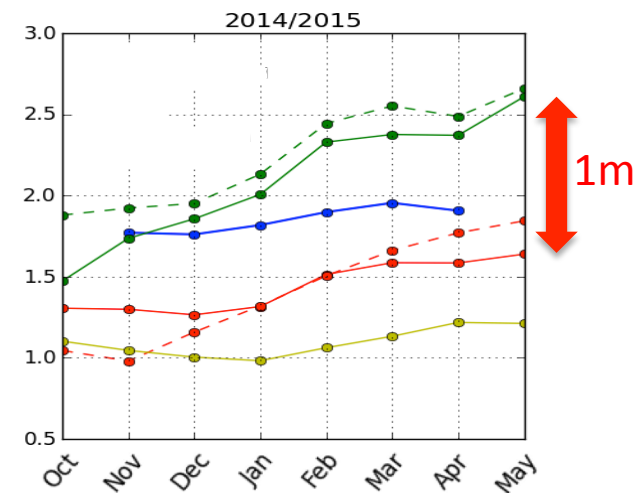
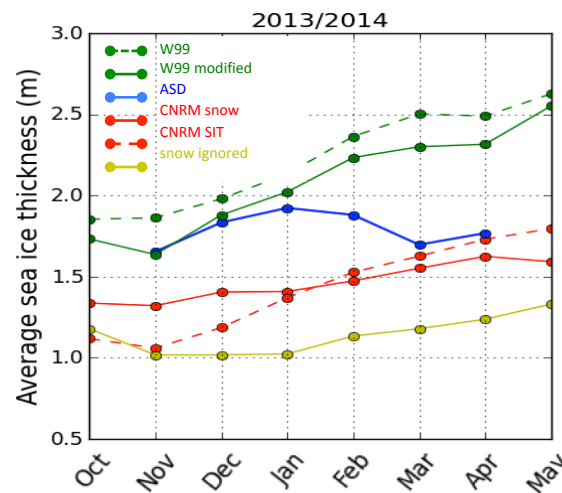
Snow Radar from Operation Ice Bridge (OIB)



Snow Depth versus OIB



Sea Ice Thickness



Toward Ice and Snow Topography



CRISTAL

Copernicus Radar for Ice and Snow Topography **AL**timeter

- Alias: CryoSat FO, S9-Topo, PICE, PIST, PolarIce, ...
- Bi-frequency Ka/Ku SAR/SARin Polar Altimeter
- One of the 6 High Priority Copernicus Missions (HPCM)
 - Anthropogenic CO₂ Monitoring
 - Copernicus Radar Ice and Snow Topography Altimeter (CRISTAL)
 - Copernicus Imaging Microwave Radiometer (CIMR)
 - L-Band Synthetic Aperture Radar Imaging
 - Land Surface Temperature Monitoring (LSTM)
 - Copernicus Hyperspectral Imaging Mission for the Environment (CHIME)
- All the 6 HPCMs have been selected for the Phase B2

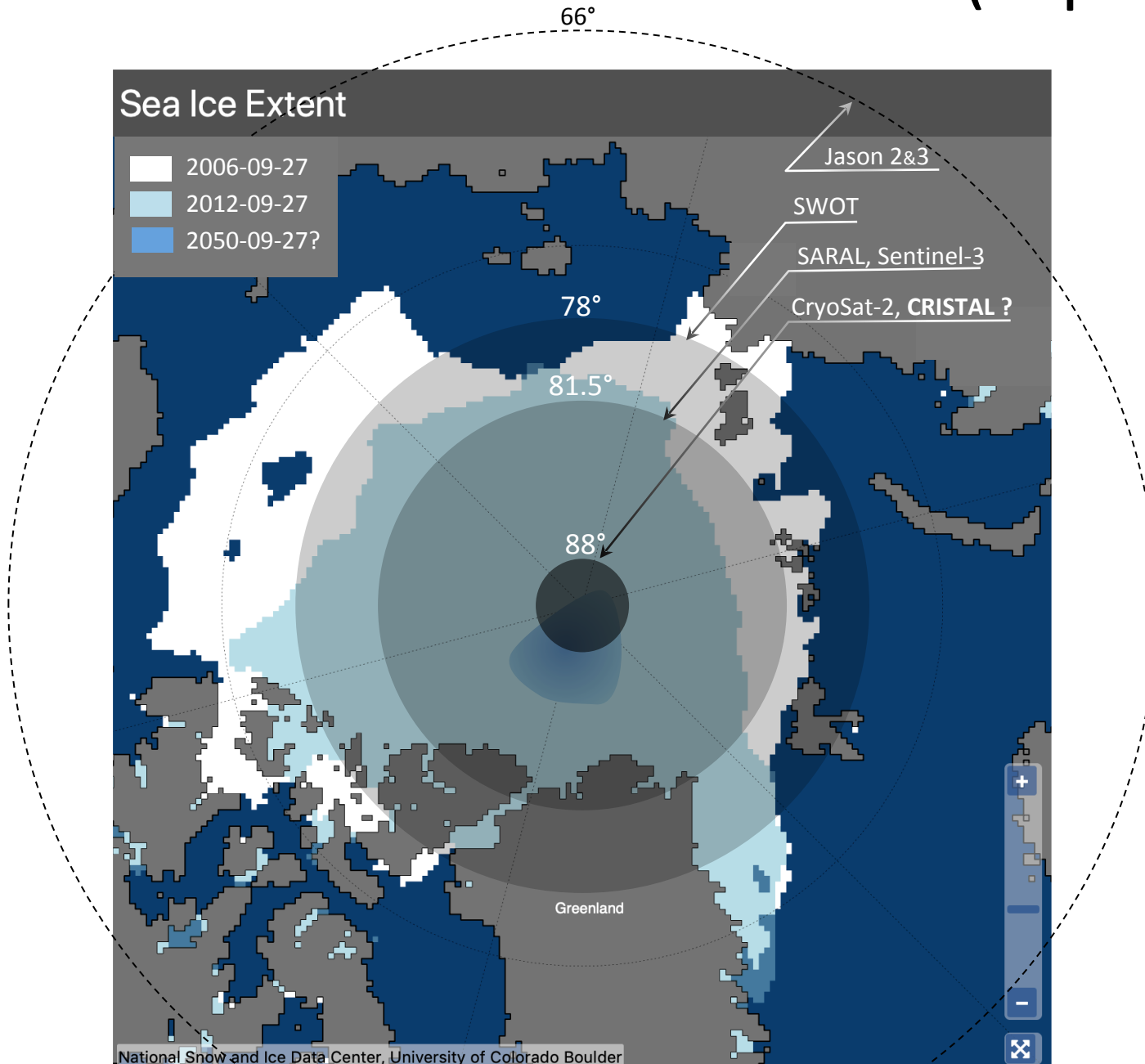


CRISTAL

Copernicus Radar for Ice and Snow Topography **AL**timeter

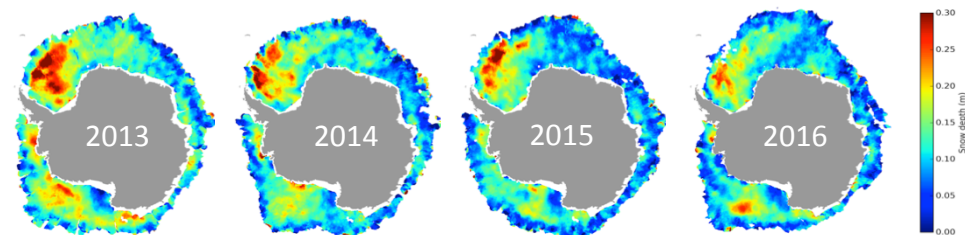
- Primary objectives : Sea Ice, Polar Caps and Glaciers survey
- Secondary objectives :
 - (Polar) Oceans topography
 - Coasts, Rivers and Lakes
 - Permafrost
- Could measure simultaneously SD, FB and SIT
- The only project to ensure the continuity of altimetry measurements over polar regions.
- If selected it can be launched in 2025 (hopefully before the end of CryoSat-2)

Orbits vs. Arctic Sea Ice Extent (Sept.)



To Conclude

- A new method to measure the Snow Depth
- The products over Arctic and Antarctic will be soon available (contact: sara.fleury@legos.obs-mip.fr)



- Studies on going to determine the SD confidence according to the characteristics of the snow (density, salinity, grain sizes, ...)
- Can be used to perform tests of SD assimilation in models ?
- CRISTAL mission:
 - to extend polar topography observations, and
 - to measure simultaneously the SD, the FB and the SIT