FINNISH METEOROLOGICAL INSTITUTE

Sea Ice Thickness from Altimetry

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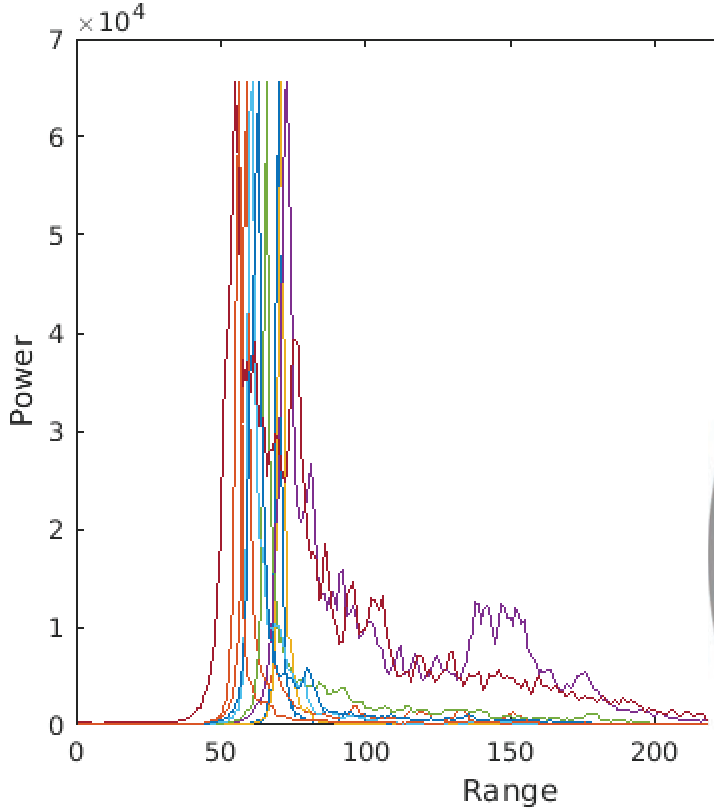
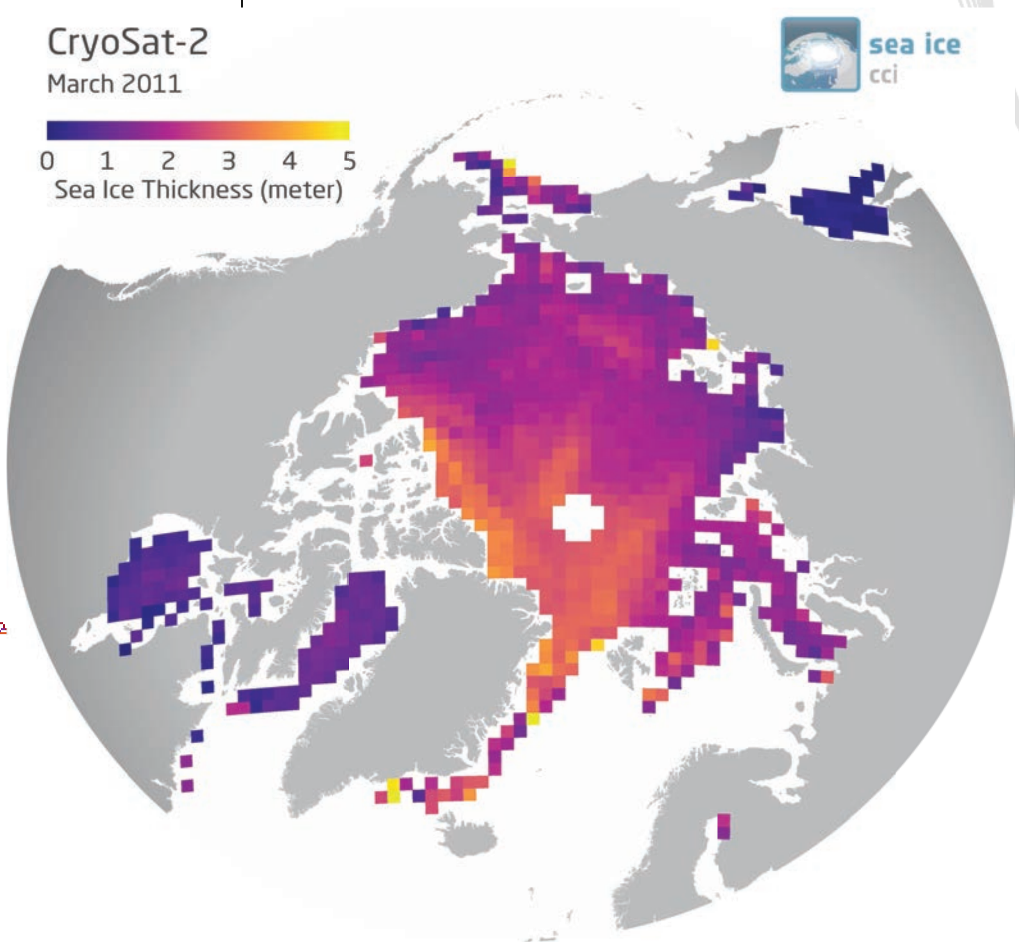
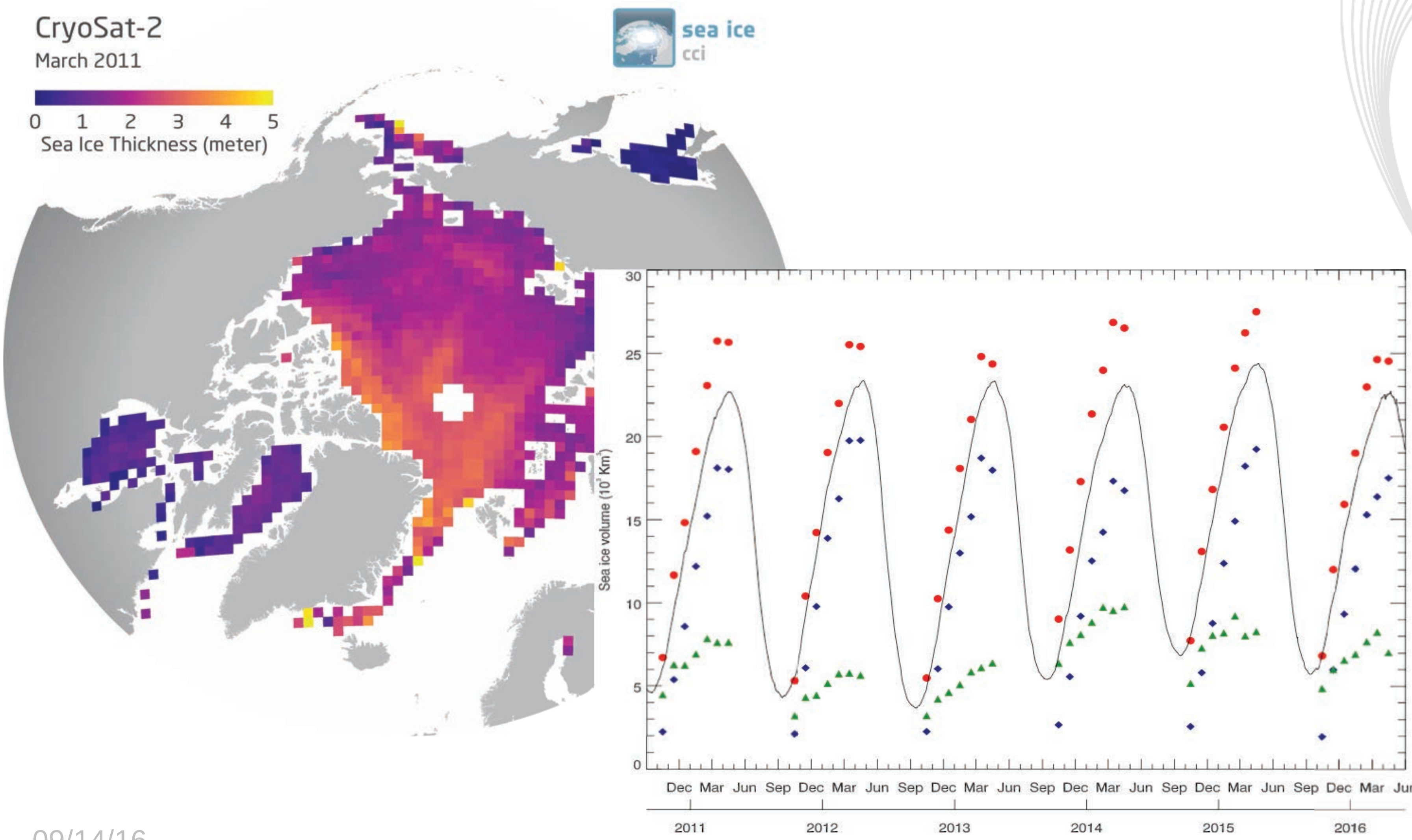
From waveforms to SIT maps

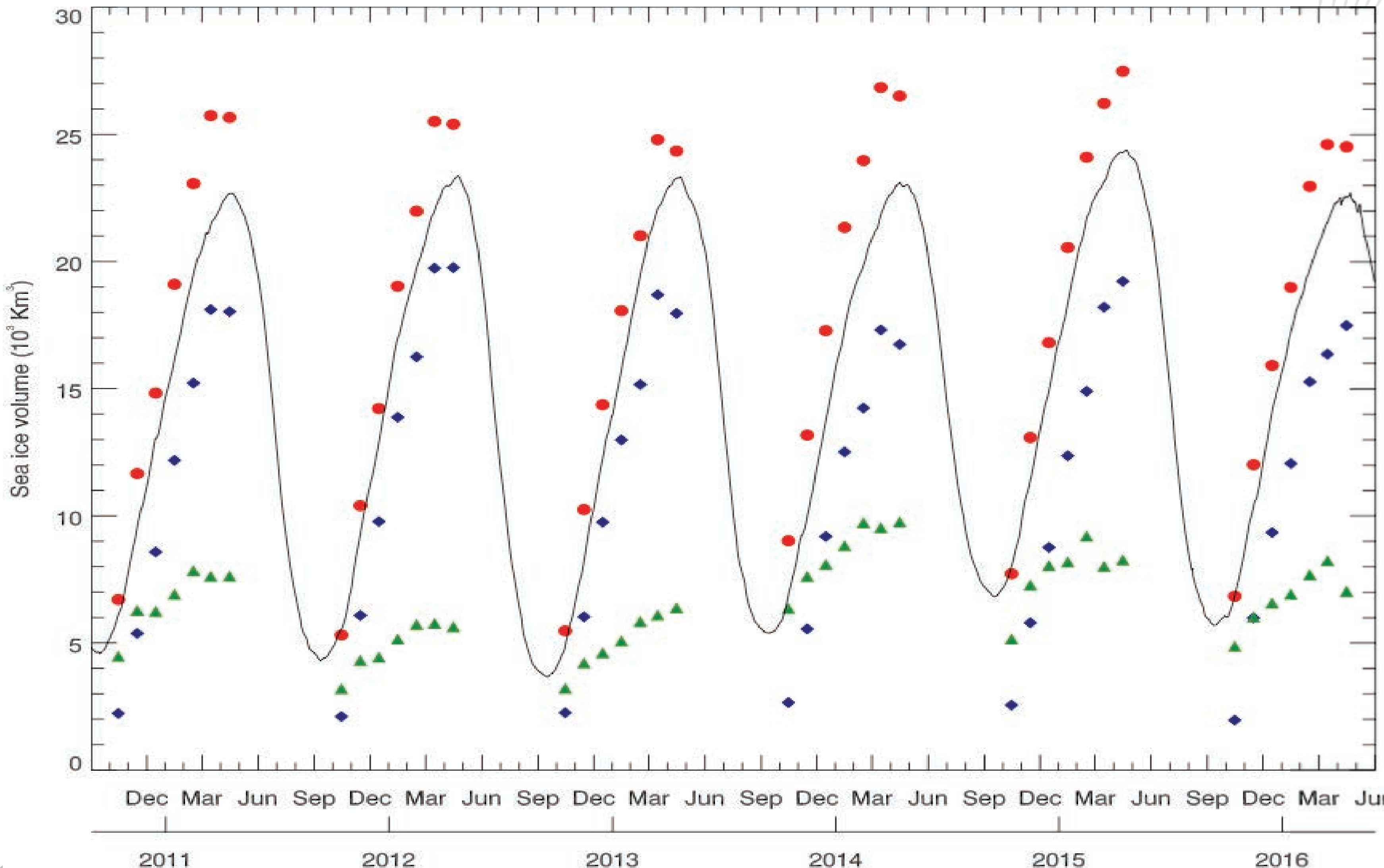




From SIT maps to time series



The interesting stuff!

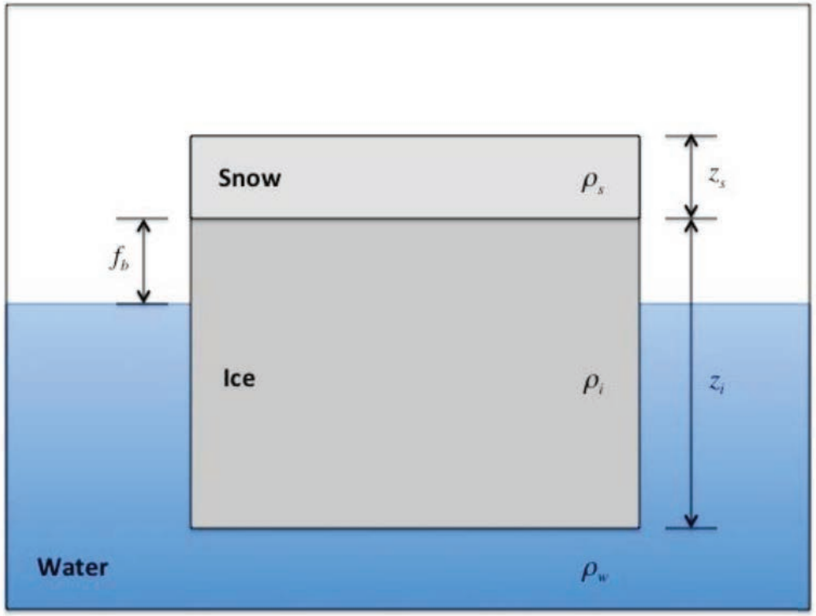


Bit of vocabularity

- Sea ice = Frozen seawater (will taste saline if you lick it)
- Fb = Freeboard = “Height of the tip of an iceberg”
- Floe (also, ice floe) = Piece of sea ice floating in sea
- Lead = An ice free area <u>between floes</u>
- Open water (also, open ocean) = Sea area with no sea ice

Basic idea

- *We measure the elevation difference between the ice and water (freeboard).*
- Detect echoes from ice floes and leads
- Fit a surface to leads to interpolate water level
- Use Archimedes principle



Source: ESA CCI Sea Ice / ATBD

“The flowchart”

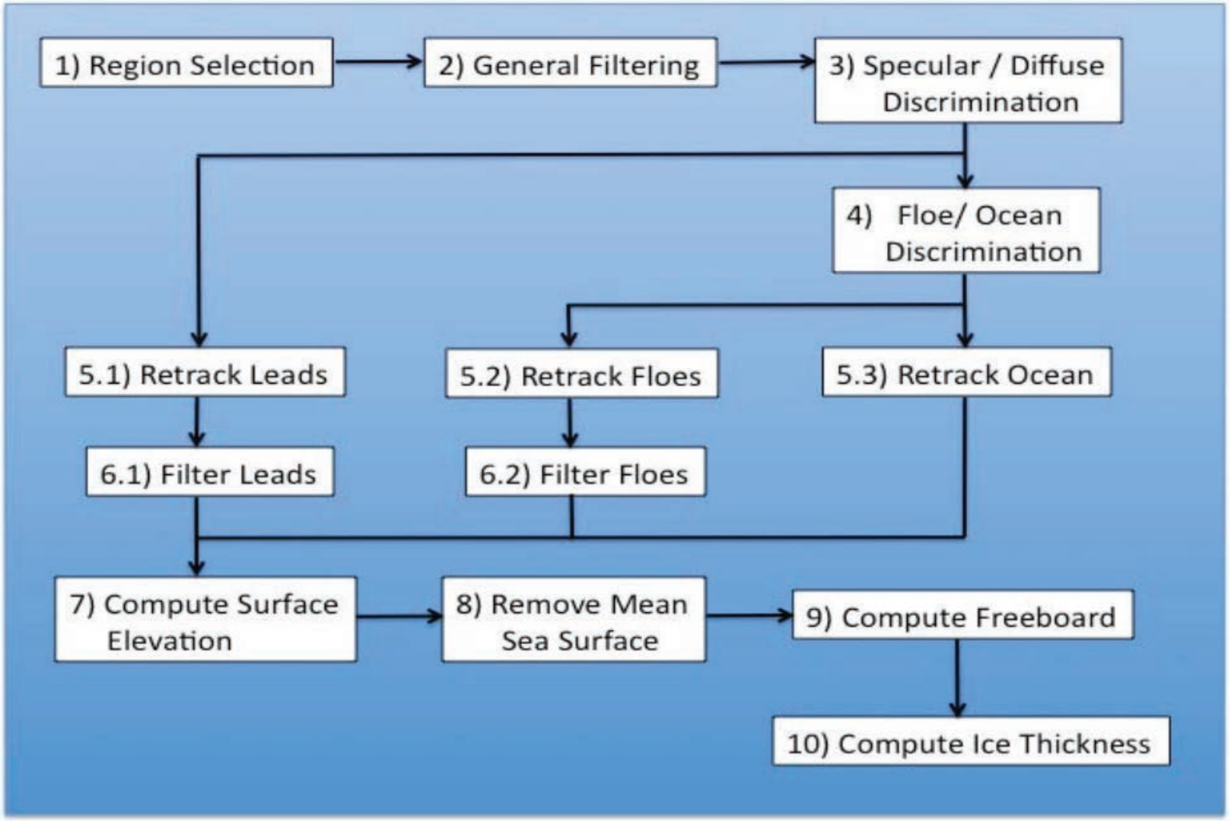


Figure 2-2: Flow chart for the Sea Ice Thickness Processor

Source: ESA CCI Sea Ice / ATBD

“The flowchart”

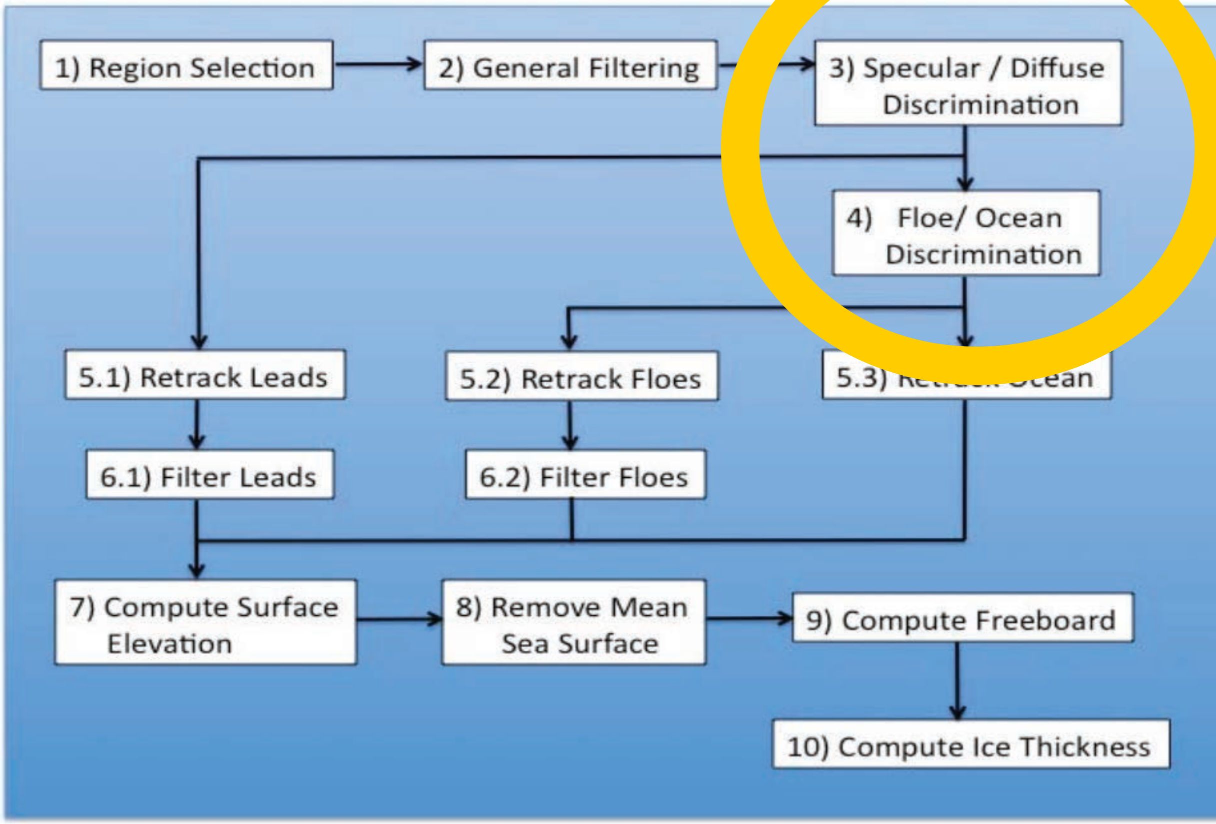


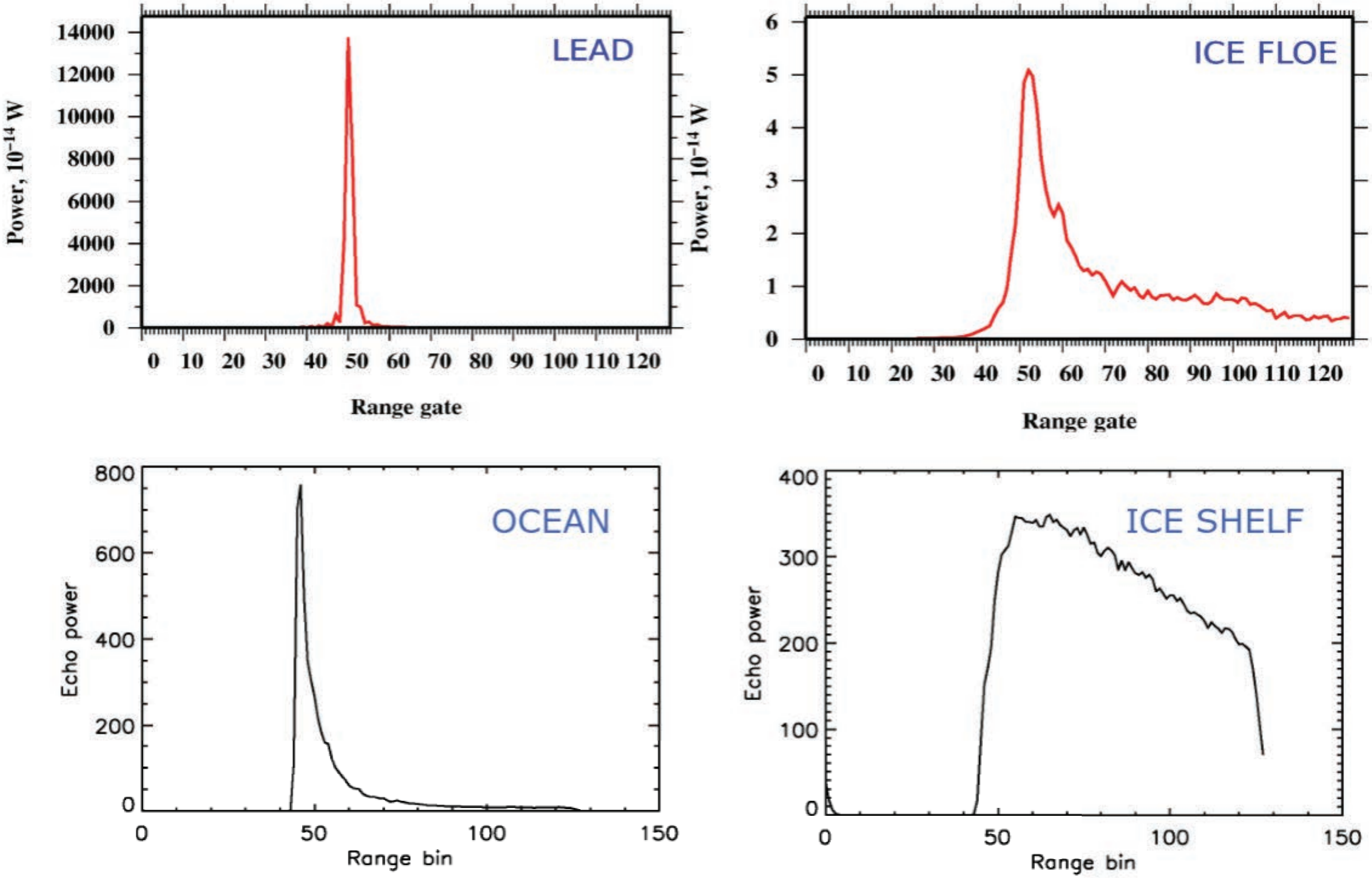
Figure 2-2: Flow chart for the Sea Ice Thickness Processor

Source: ESA CCI Sea Ice / ATBD

What Louise said about waveforms!

- Waveform is the received power as a function of time (and time equals range)
- Different surfaces result into different waveforms.
- Lead → narrow and high
- Floe → diffuse

Radar waveforms from different surfaces



Different lead detection schemes

- Pulse limited (ERS RA, Envisat RA-2):
  - Pulse Peakiness alone (Laxon 2003, “The SICCI way”)
- Delay-Doppler (CryoSat-2, Sentinel 3):
  - Pulse Peakiness and Stack Standard Deviation (Laxon 2013 “The UCL way”)
  - PP + SSD + Left & Right Pulse Peakiness (Ricker 2013, “The AWI way”)

“The flowchart”

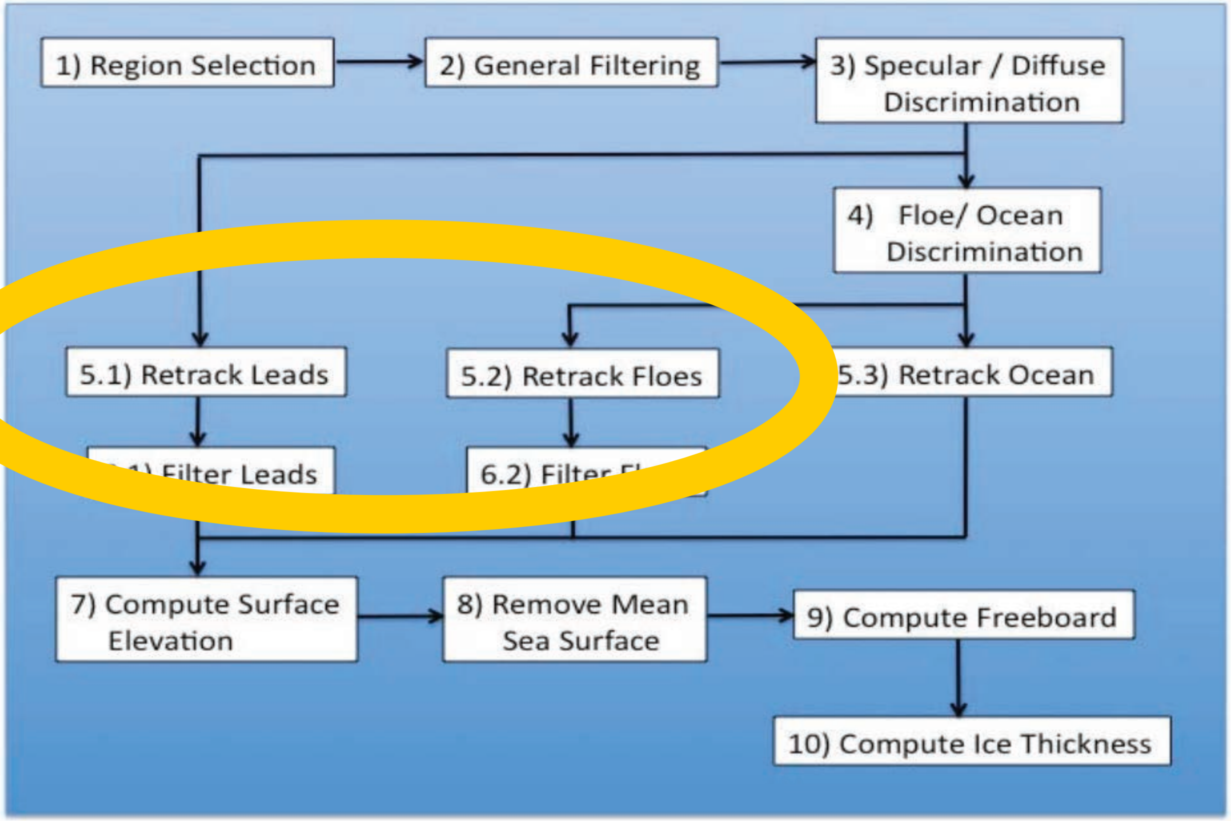


Figure 2-2: Flow chart for the Sea Ice Thickness Processor

Source: ESA CCI Sea Ice / ATBD

Different retracking schemes

R(waveform) → number

- Unsurprisingly, there are several:
  - UCL, AWI, SICCI, Kurtz...
- No one best way to do this!
  - Very hard to validate
  - Accuracy, robustness, simplicity.
- Pick your poison, or make your own!

"The flowchart"

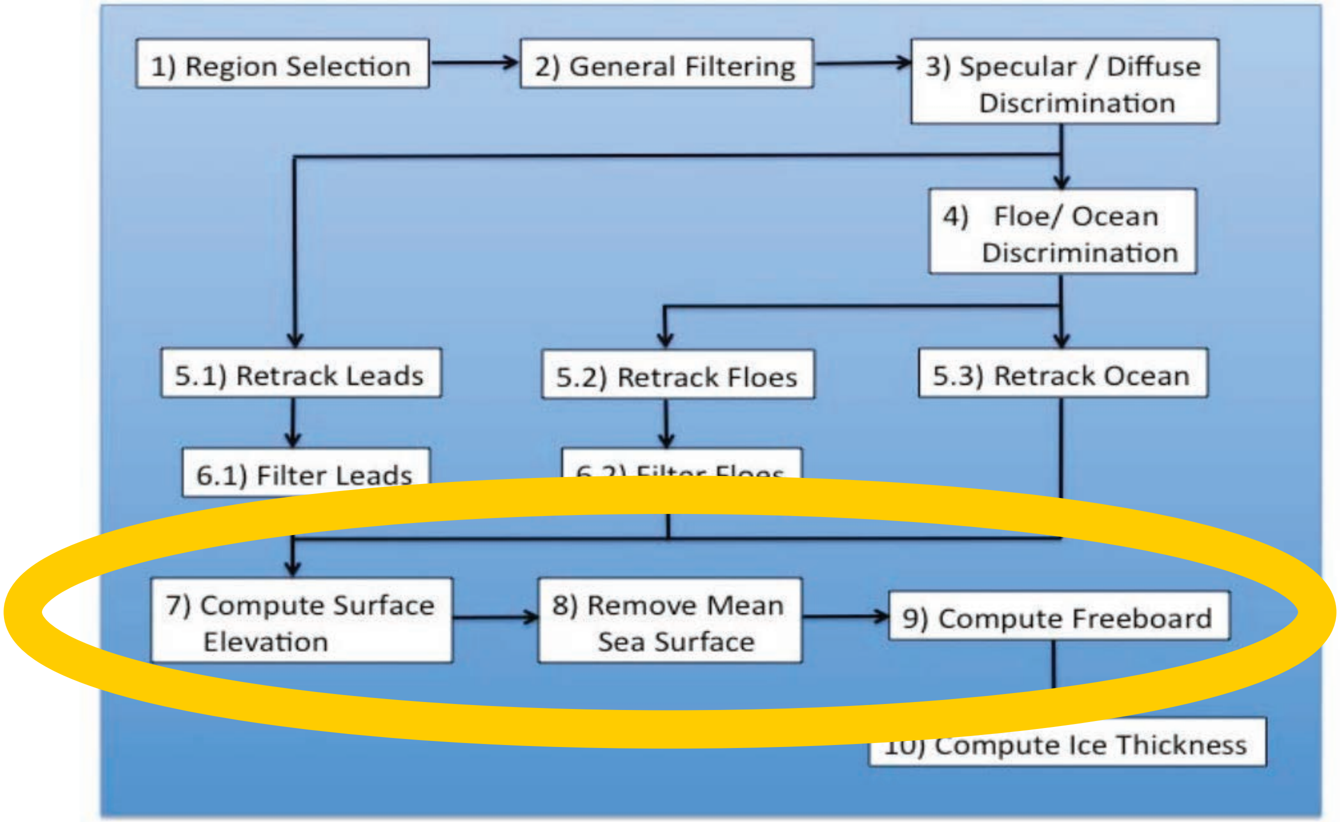


Figure 2-2: Flow chart for the Sea Ice Thickness Processor

Source: ESA CCI Sea Ice / ATBD

From elevation to freeboard

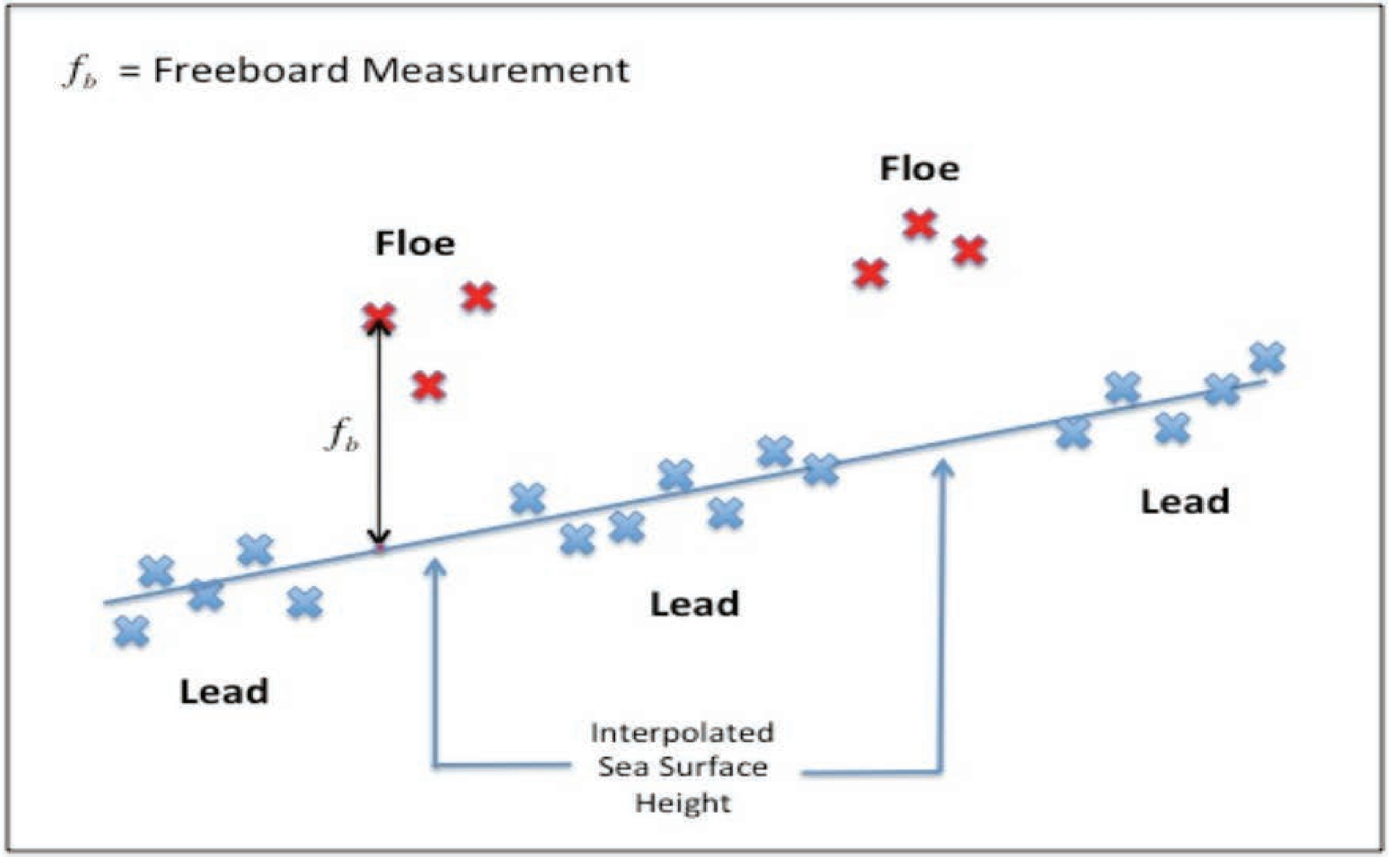
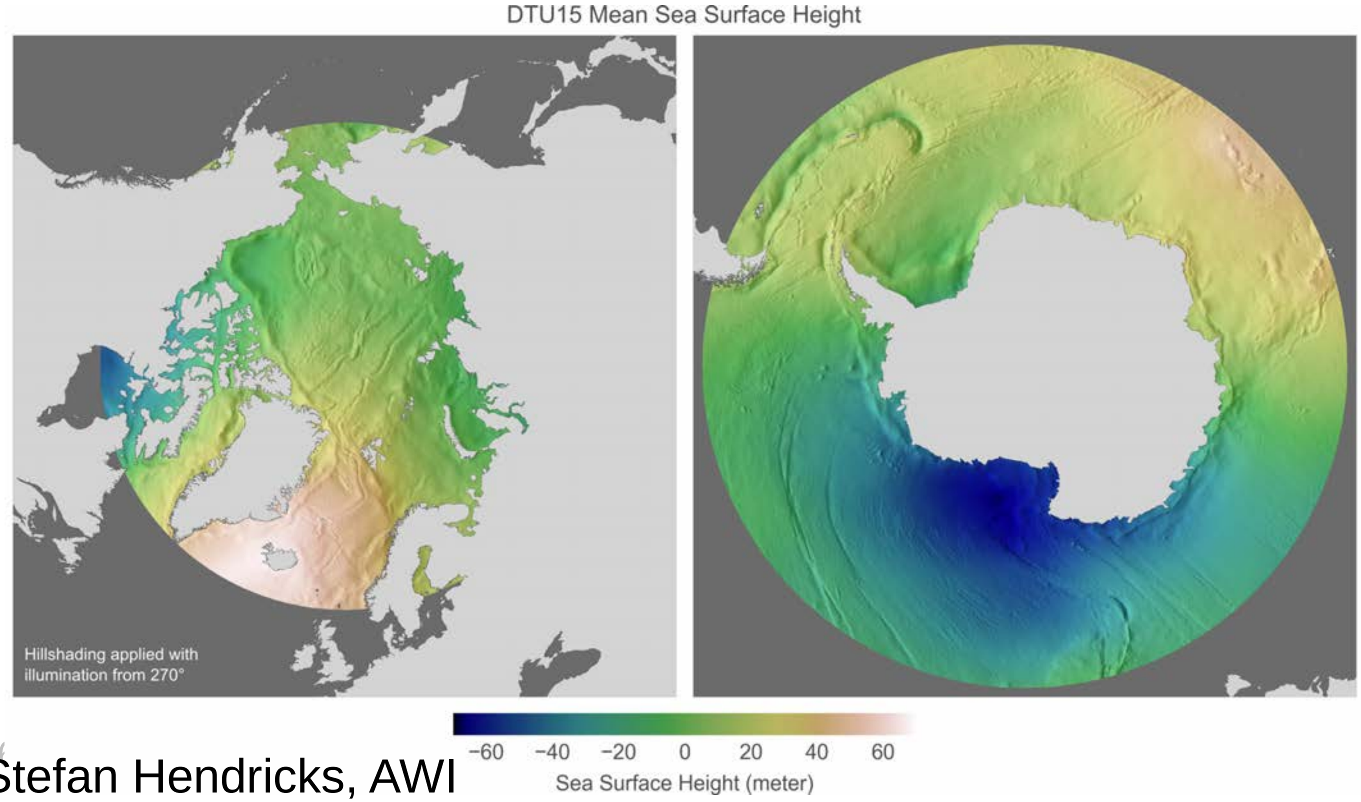


Figure 2-6: Computation of Ice Freeboard

Mean Sea Surface Height

- The geoid used by altimeters is not the MSSH.
- The curvature of local sea level will interfere with lead elevation interpolation and thus must be removed!



Credits: Stefan Hendricks, AWI

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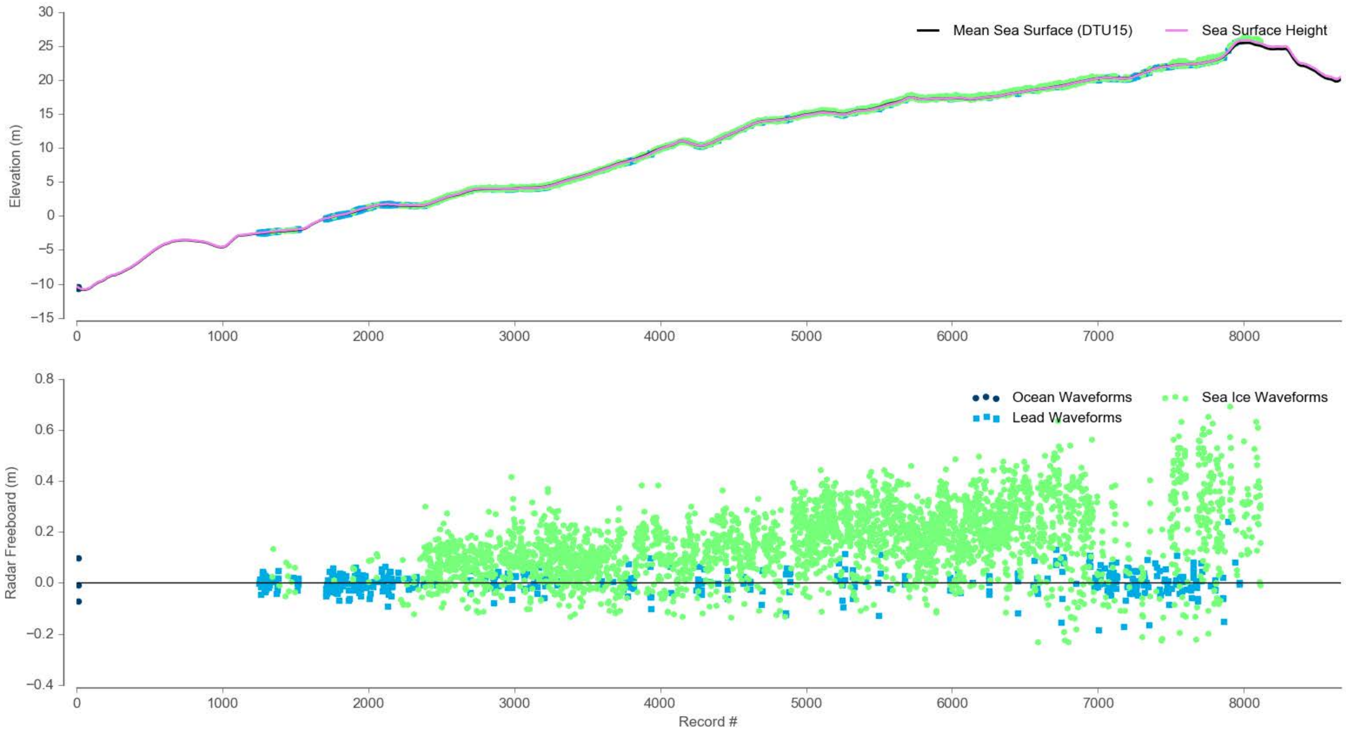

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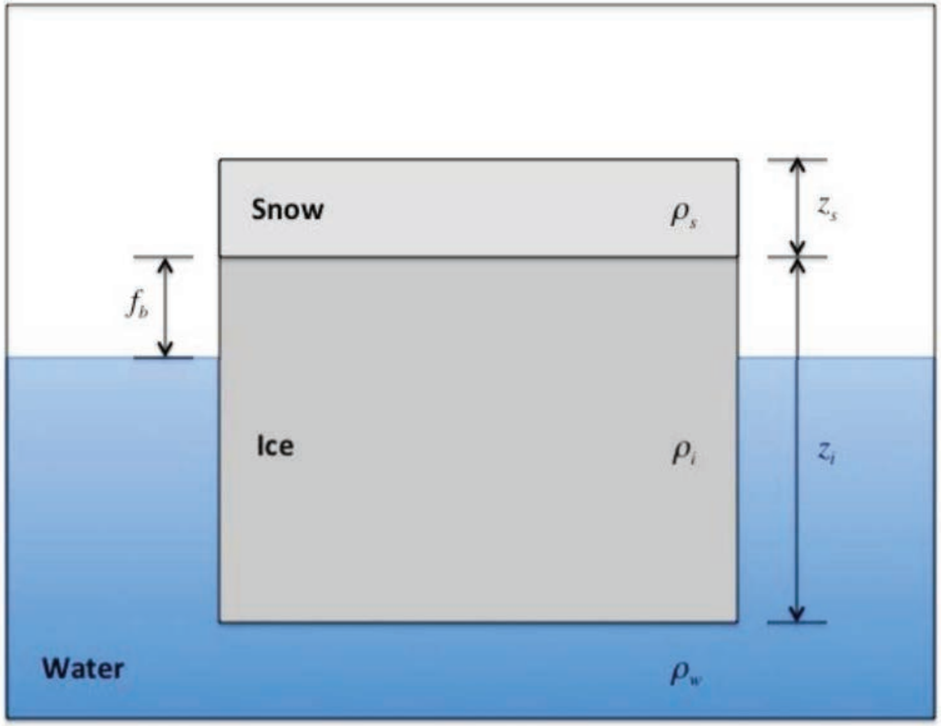
From freeboard to sea ice thickness



$$z_i = \frac{z_s \rho_s + f_b \rho_w}{\rho_w - \rho_i}$$

Where:

z_i = Ice thickness. z_s = Snow depth. f_b = Freeboard.

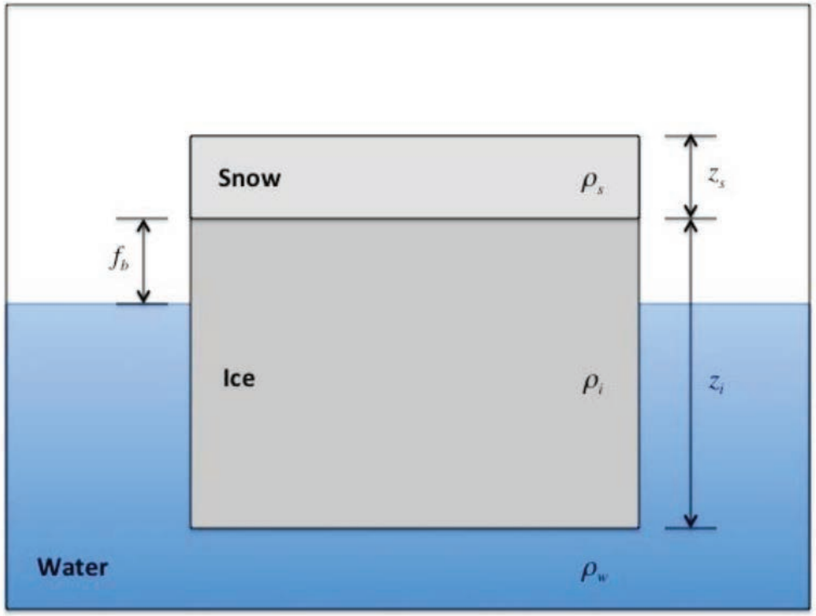
ρ_s = Snow density. ρ_w = Density of sea water. ρ_i = Density of sea ice.

Post-processing steps

- The signal is noisy → average!
- Grid into a convenient grid
  - There are thicknesses and thicknesses. Beware!
- Write into a convenient file format

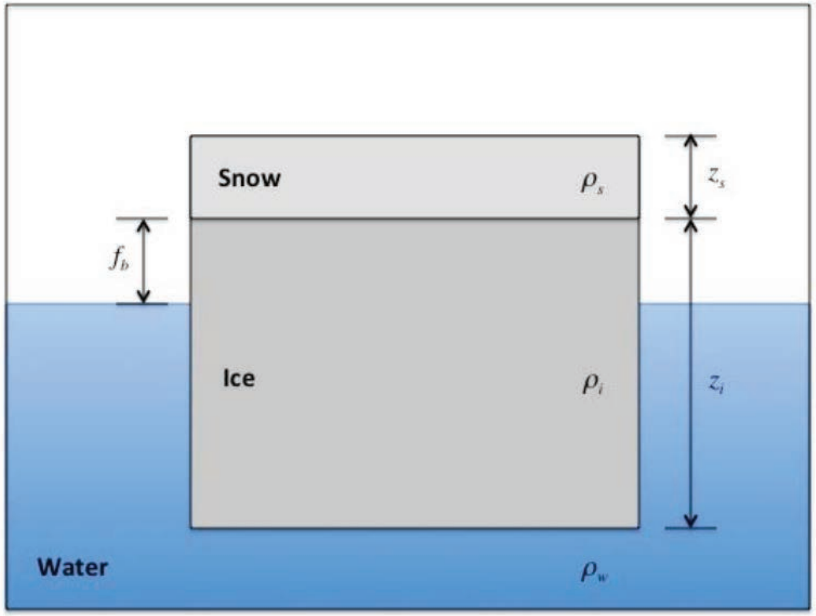
Sources of uncertainty

- Noise
- Preferential sampling
- Radar penetration
- Ice density
- Snow



Why does it only work in the winter?

- Melt ponds will interfere with lead / floe detection
- Radar penetration is ambiguos during melting.



Validation

LAXON ET AL.: CRYOSAT-2 SEA ICE THICKNESS AND VOLUME

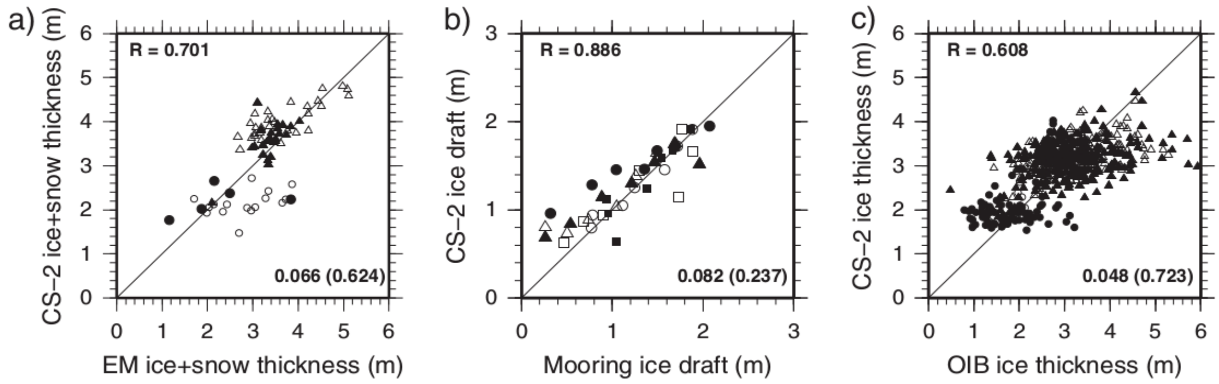
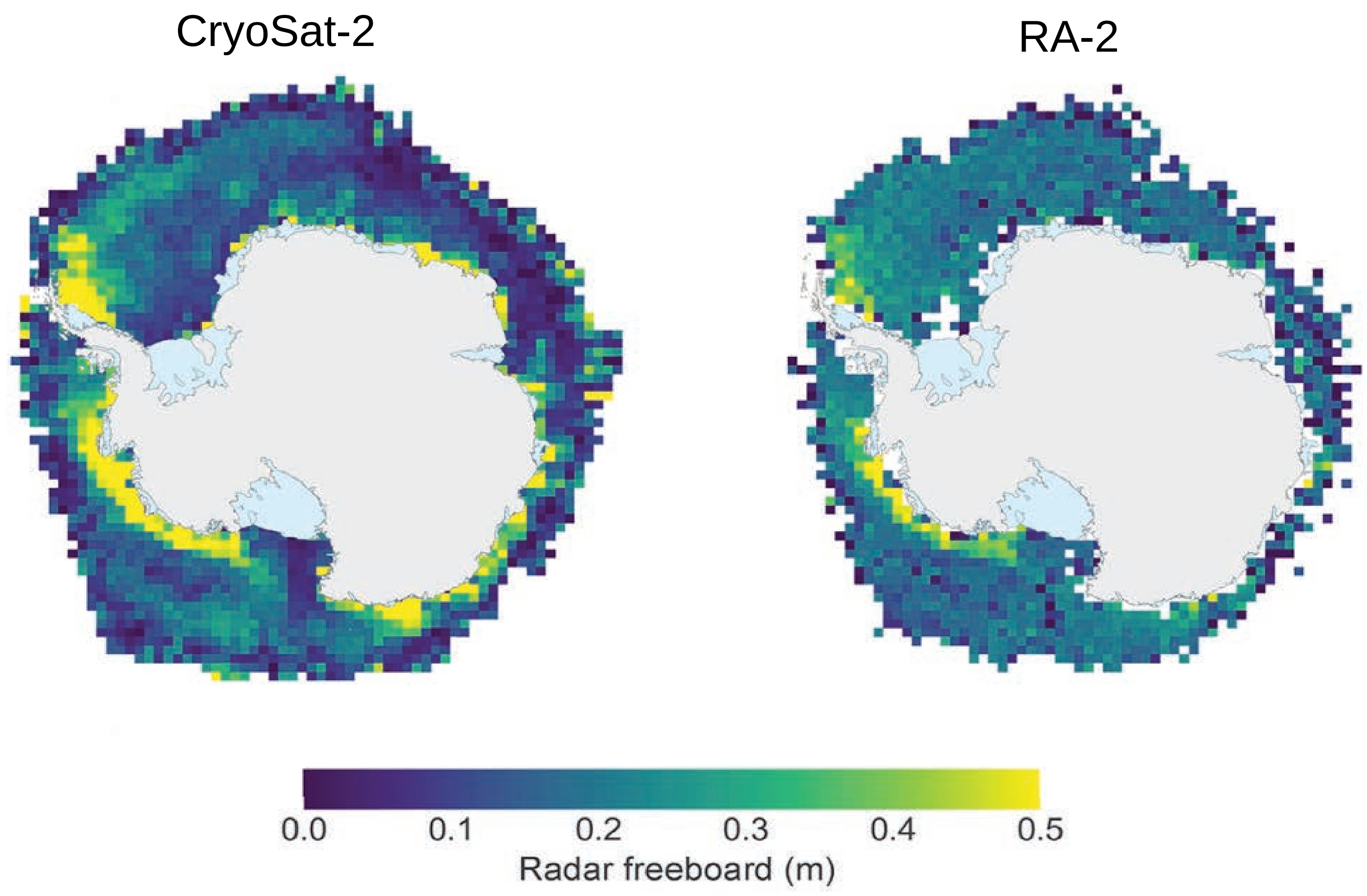


Figure 2. Validation of CryoSat sea ice thickness. (a) Comparison of Polar-5 aircraft EM and Cryosat-2 snow plus ice thickness over first year (**circle**) and multiyear (triangle) ice during April 2011 (open symbols) and 2012 (solid symbols). (b) Comparison of monthly average ice draft from CryoSat-2 within 200 km of the Beaufort Gyre Experiment Program Upward Looking Sonar Moorings (Mooring A: triangle, Mooring B: circle, Mooring D: square) for the period October 2010 to April 2011 and October 2011 to April 2012 (solid symbols). (c) Comparison of Operation IceBridge (OIB) aircraft laser and Cryosat-2 ice thicknesses over first year (**circle**) and multiyear (triangle) ice between 10 March 2011/12 and 9 April 2011/12 (solid symbols are data from 2012). Both aircraft comparisons were conducted by gridding CryoSat and the aircraft data onto a common (0.4 latitude by 4 longitude) grid and comparing those grid cells in which both data sets contained data. The locations of the in situ data sets are shown in Figure 1.

What about the South?



Schwegmann et al, TC2016, doi:10.5194/tc-10-1415-2016

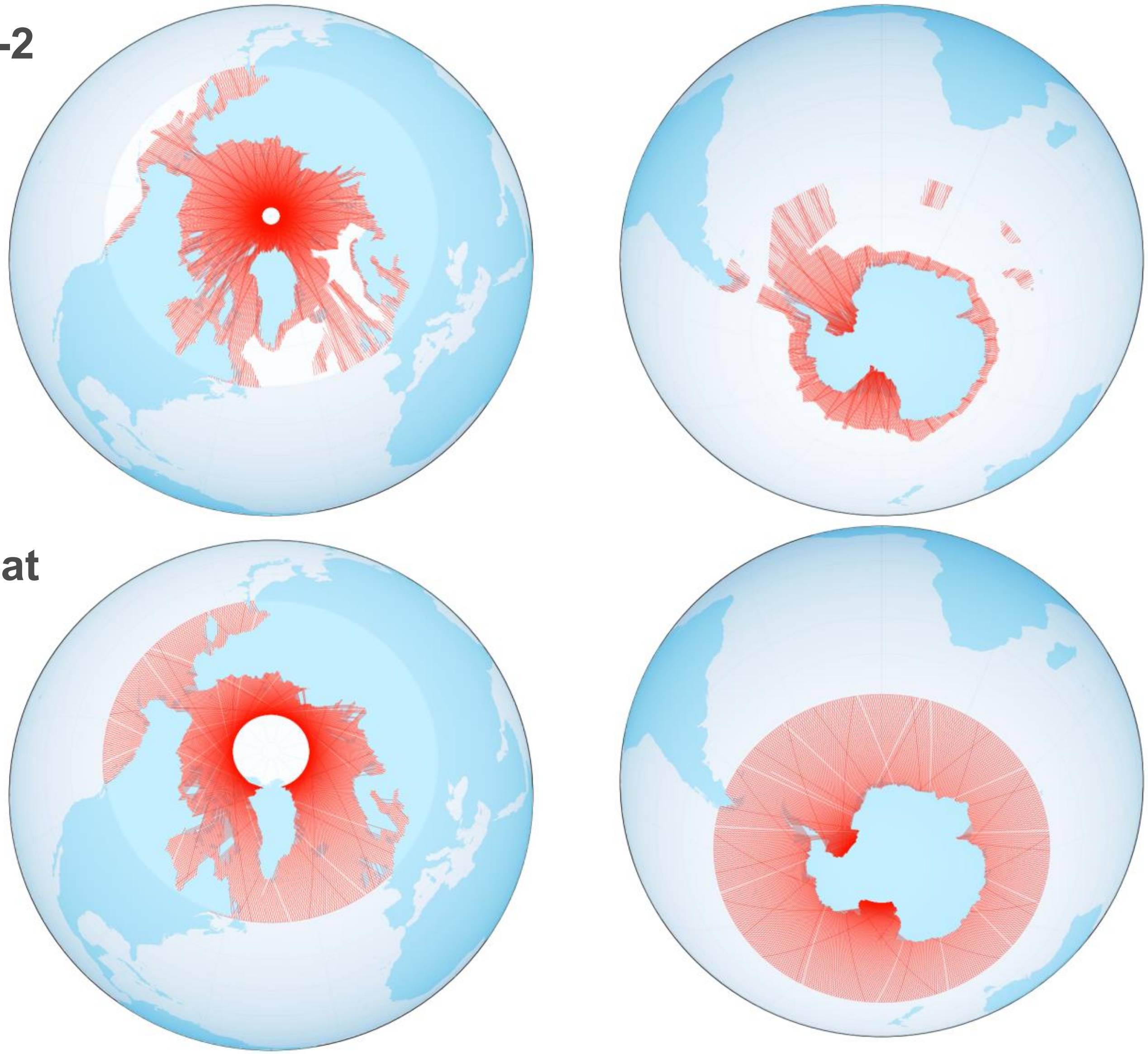
Pysiral

- A python package for altimeter sea ice thickness processing.
- Result of the ESA CCI Sea Ice project
- Open source!
- Ask me or Stefan Hendricks (AWI)

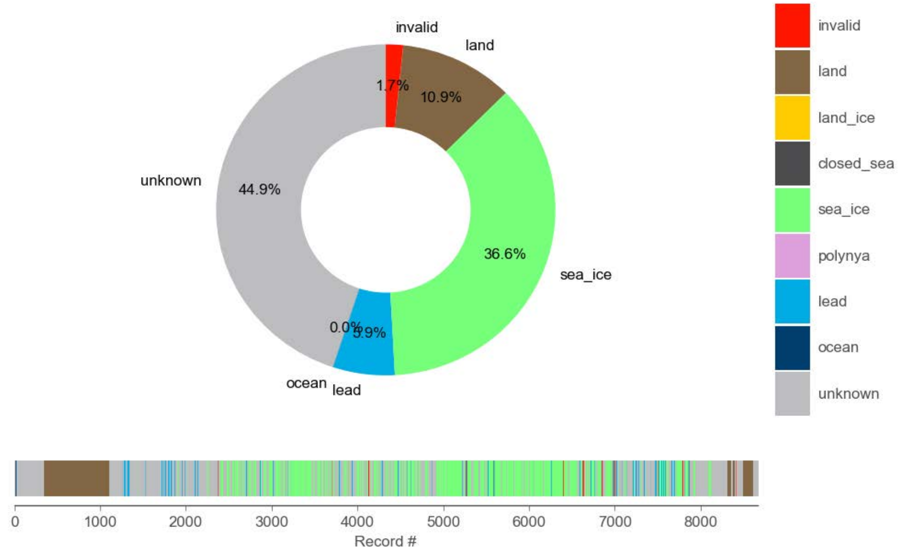
L1B Preprocesing

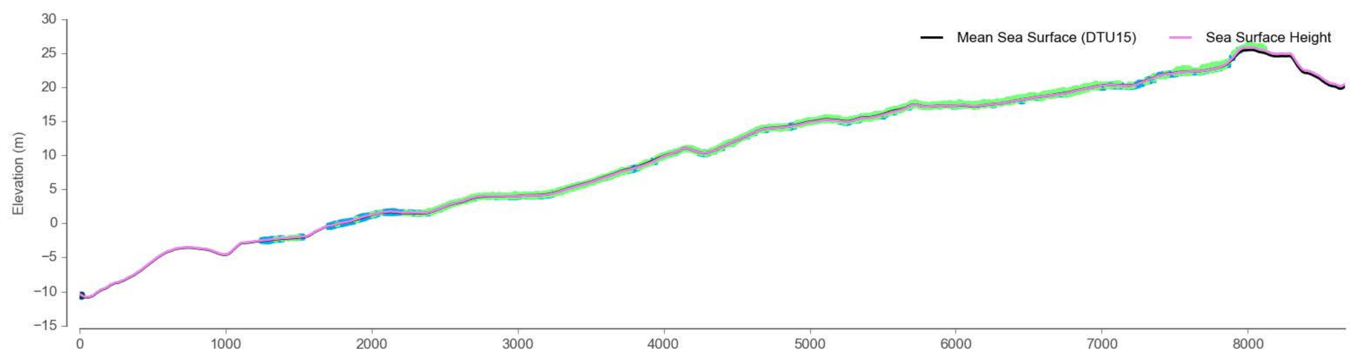
CryoSat-2

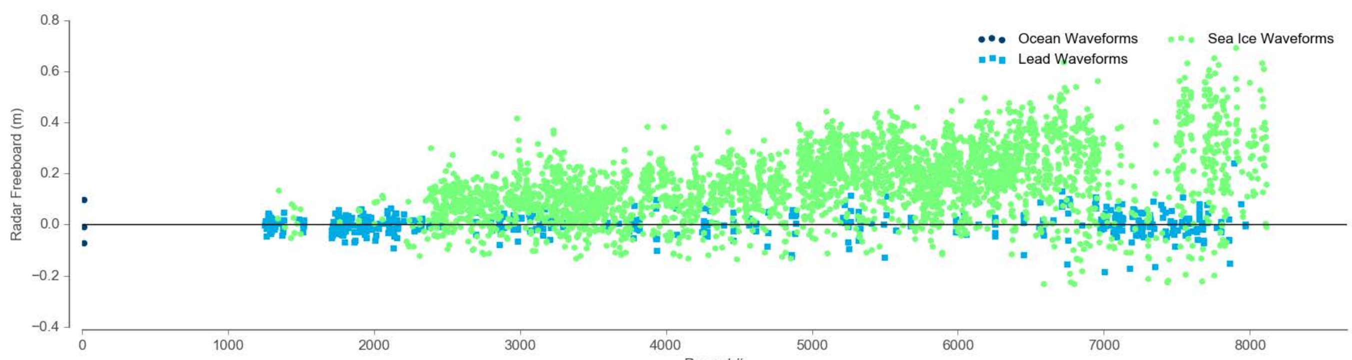
Envisat



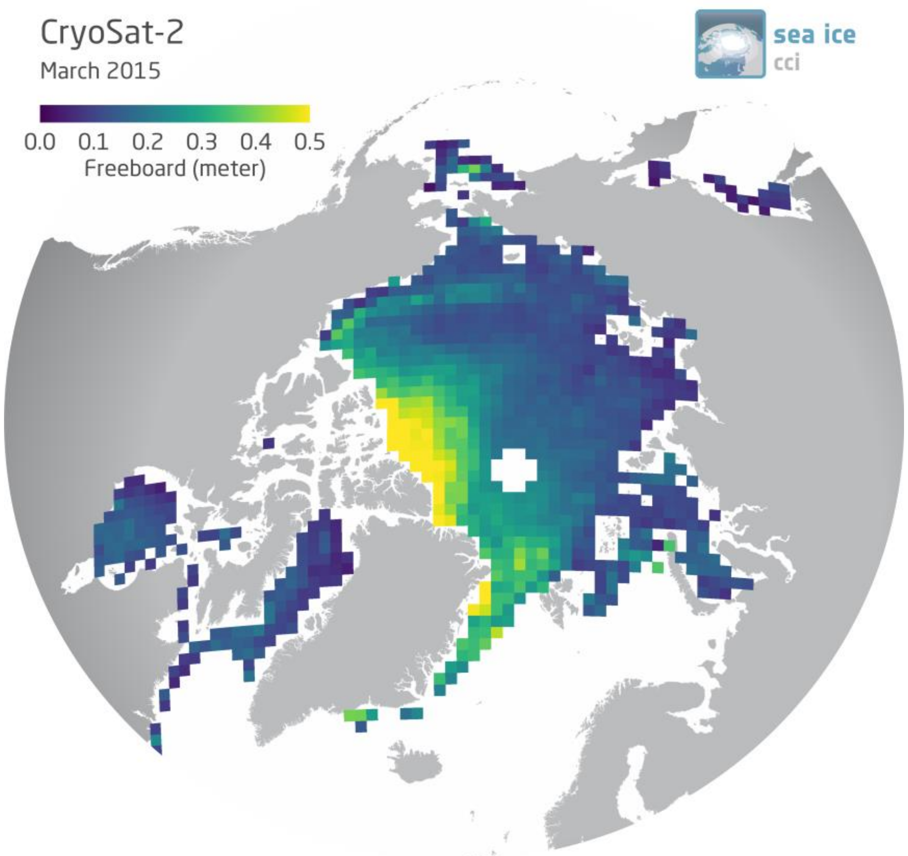
L2 Processing

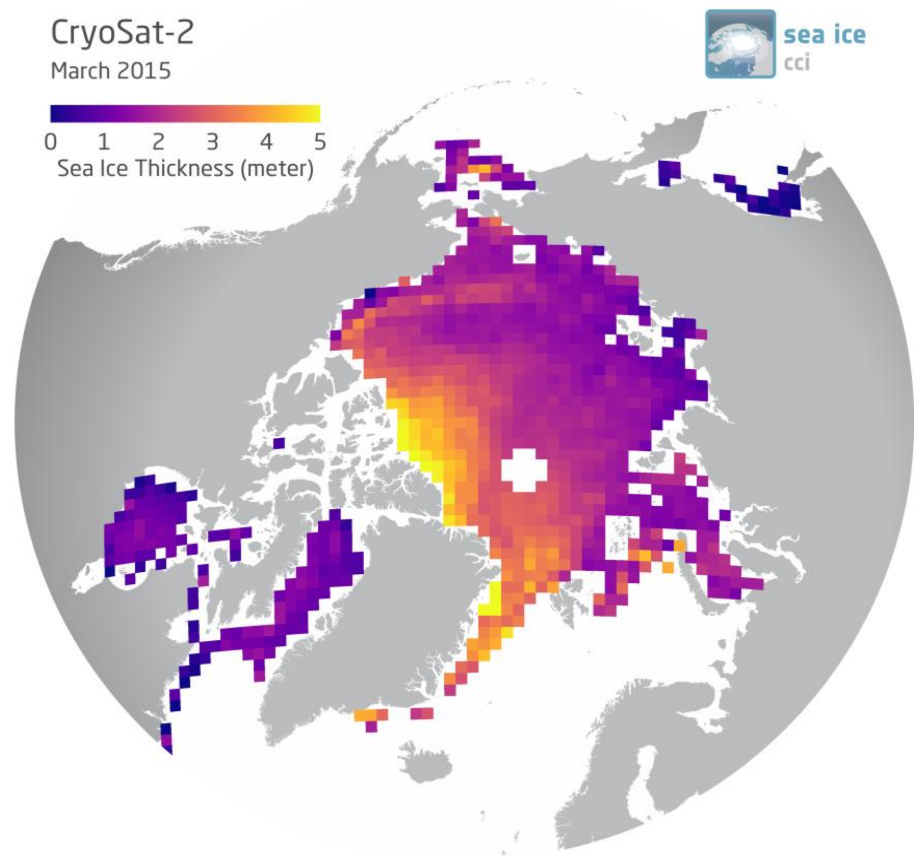






L3 Processing





Further reading (not complete!)

- CCI Sea Ice Algorithm Theoretical Basis Document (ATBD) “A cookbook for an SIT processor”
- Laxon et al.: “High interannual variability of sea ice thickness in the Arctic region”, Nature 2003
- Ricker et al.: Sensitivity of CryoSat-2 Arctic sea-ice freeboard and thickness on radar-waveform interpretation, The Cryosphere 2014.
- Kurtz et al.: An improved CryoSat-2 sea ice freeboard retrieval algorithm through the use of waveform fitting, The Cryosphere 2014.
- Tilling et al.: “Near-real-time Arctic sea ice thickness and volume from CryoSat-2” The Cryosphere, 2016

Practical

- Two independent parts
  - UCL/CPOM processed SIT products
  - L1B → freeboard

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