→ 10th COASTAL ALTIMETRY WORKSHOP

SAR Altimetry Training Course

SAR Altimetry Processing for Sea Level in Polar Ocean

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21–24 February 2017 | Florence, Italy

The Arctic Ocean

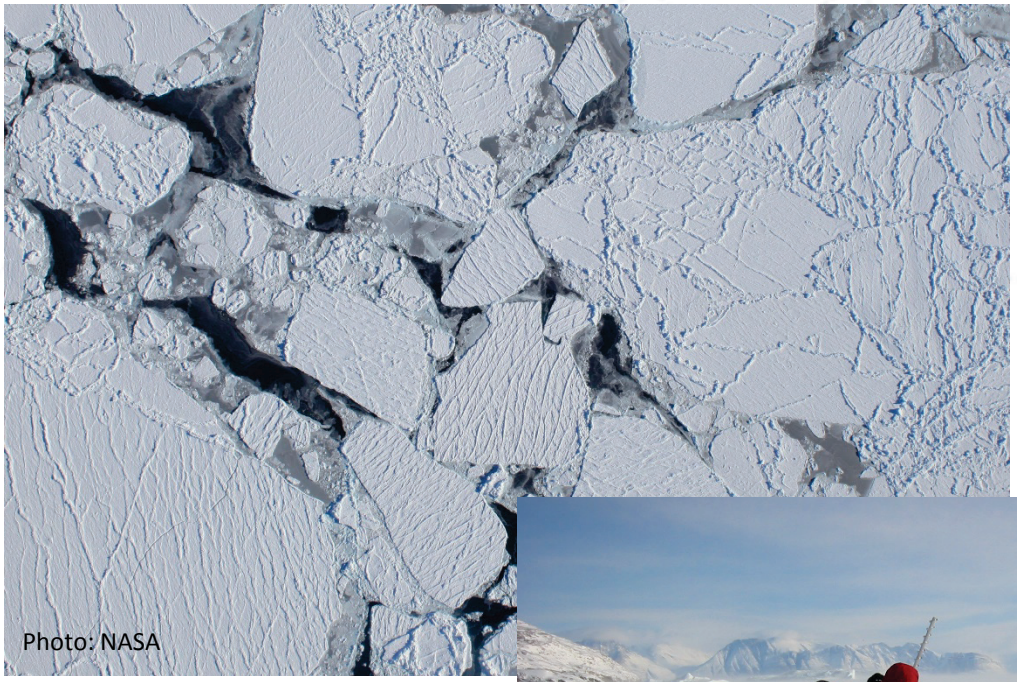


Photo: NASA

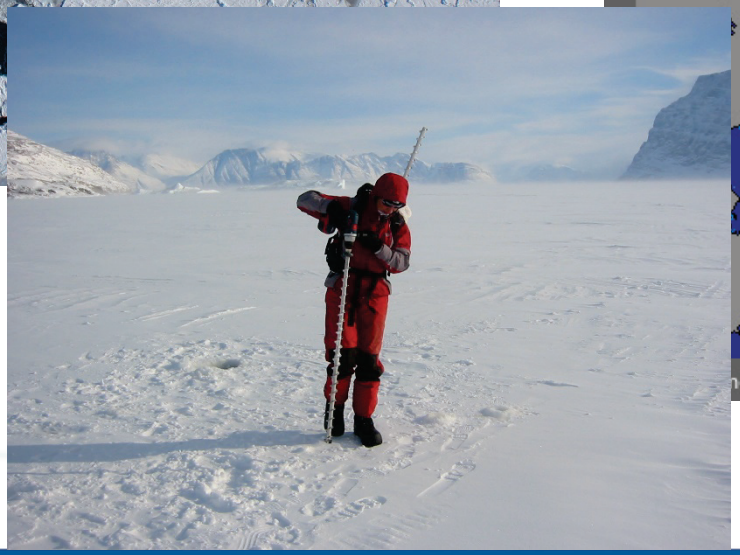
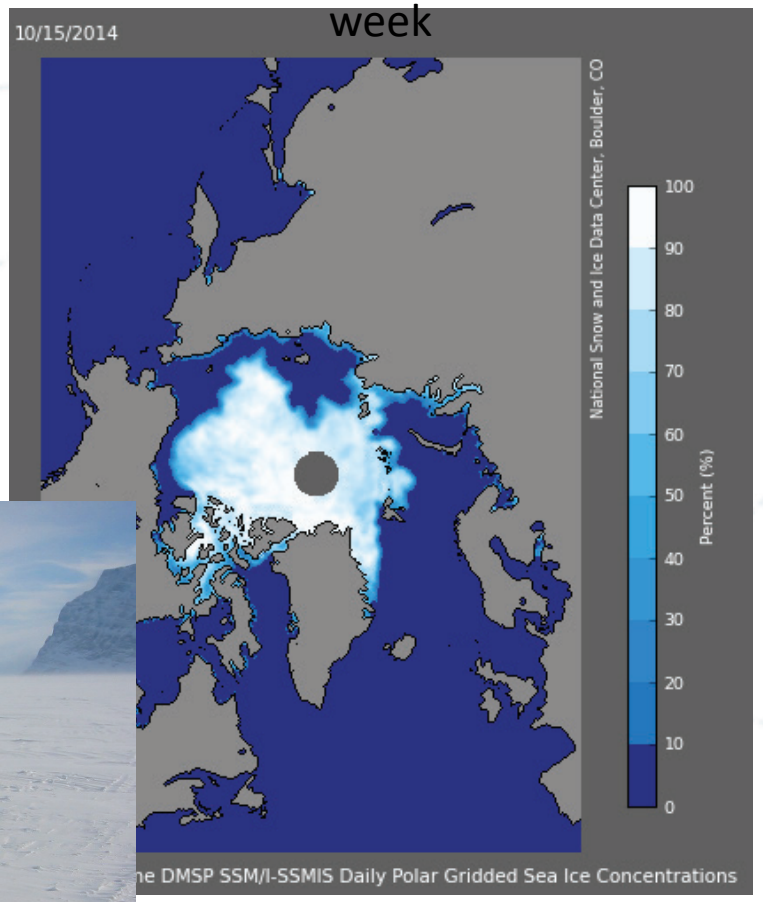


Photo: DTU Space

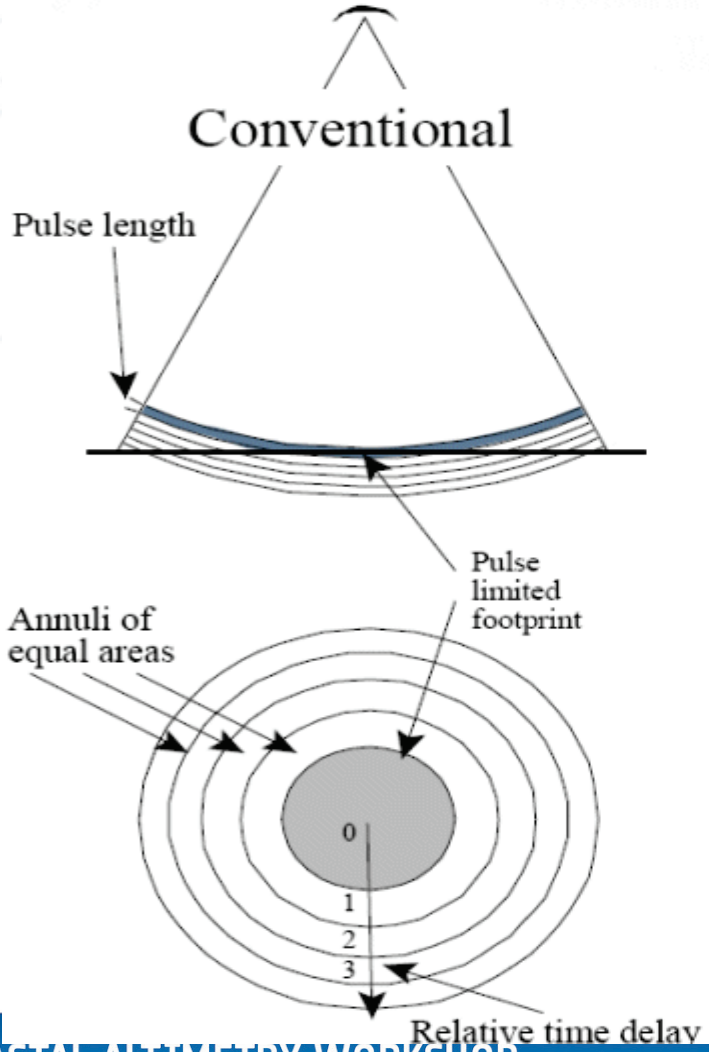
Sea ice concentration sept 2015

week

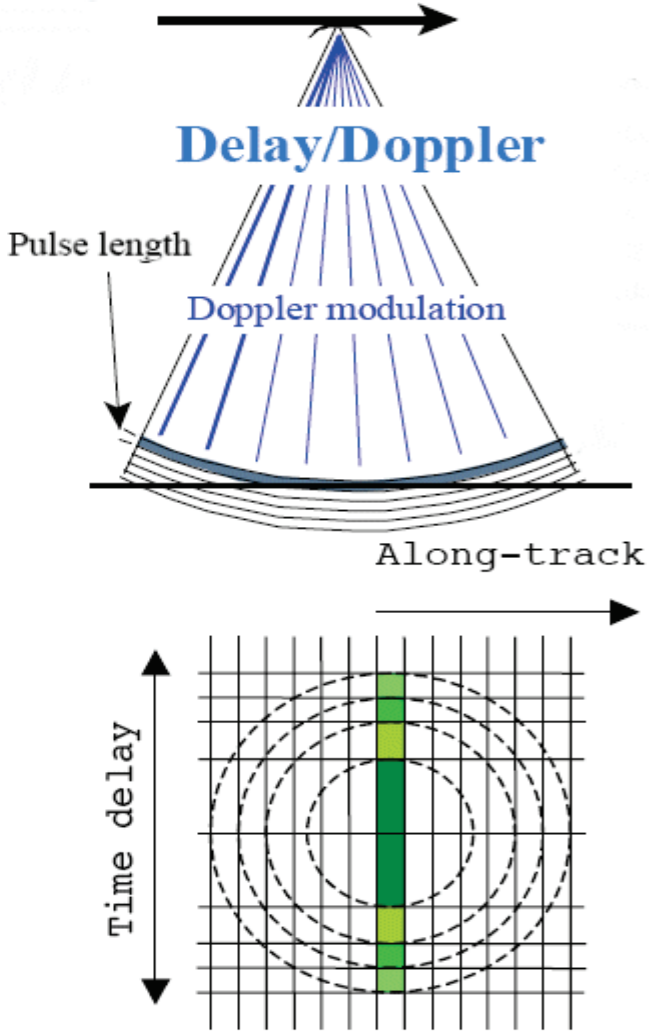


National Snow and Ice Data Center
Maslanik and Stroeve 1999

Jason/ENVISAT LRM

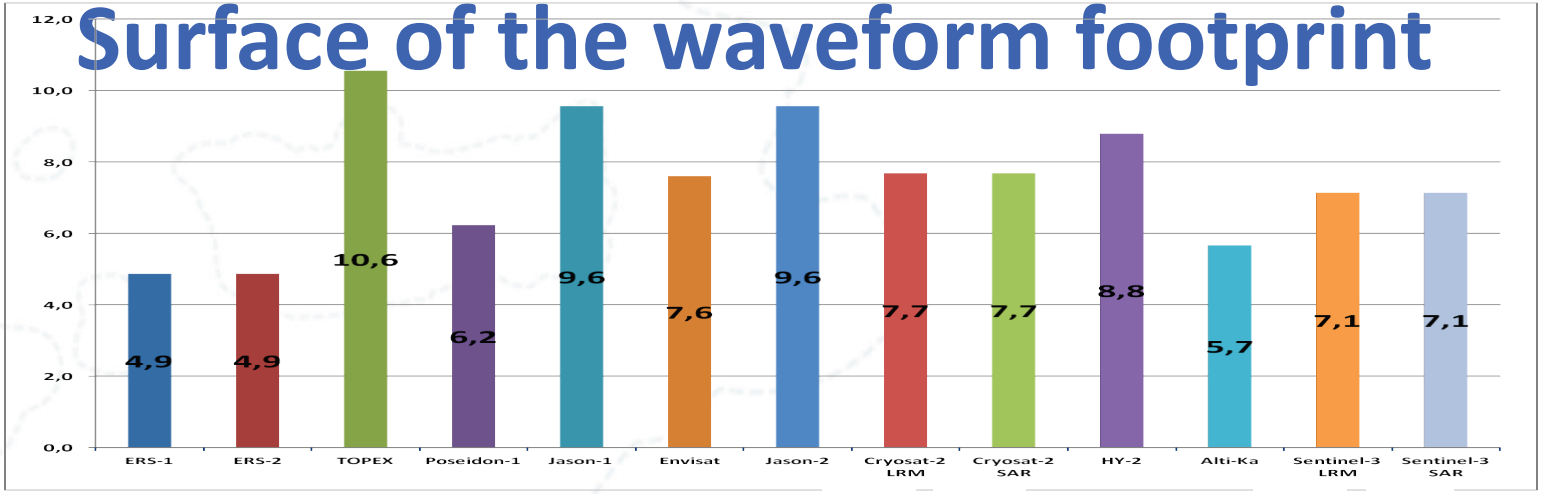


Cryosat-2, Sentinel-3 SAR

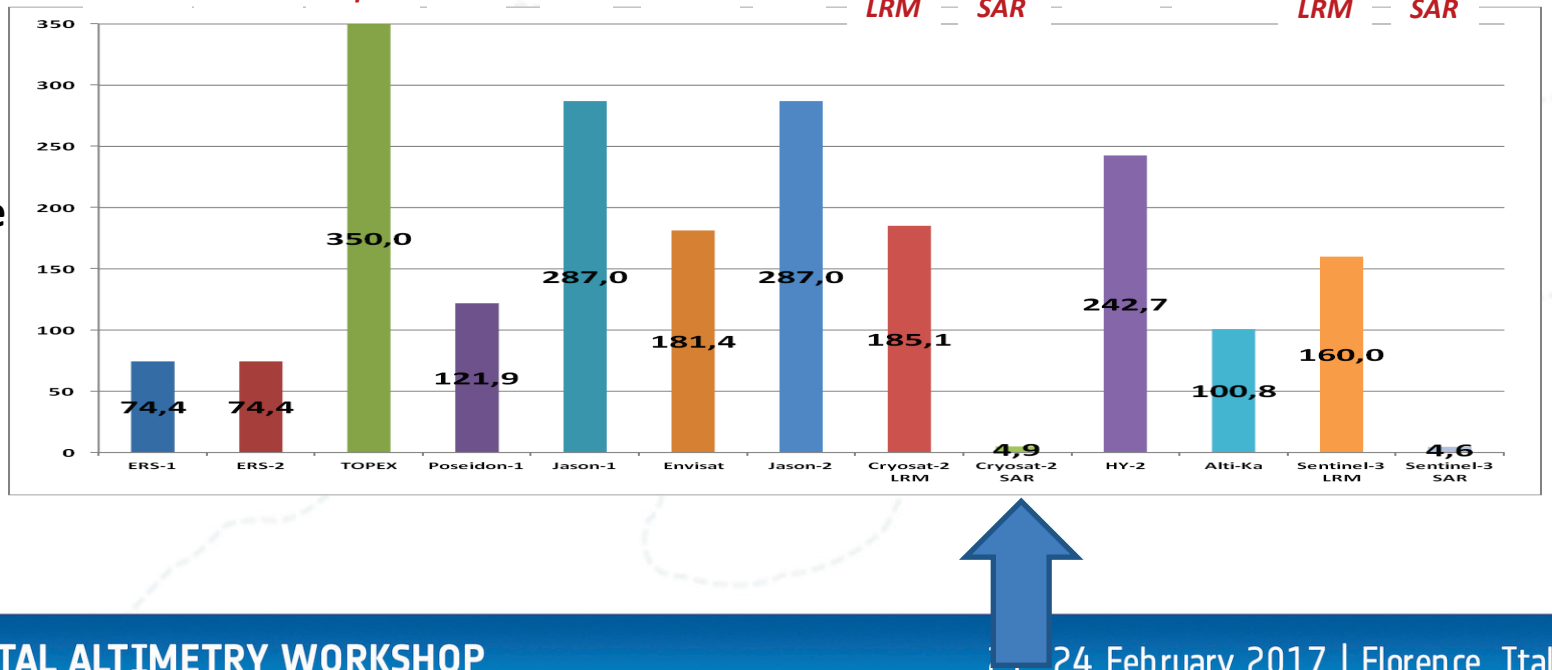


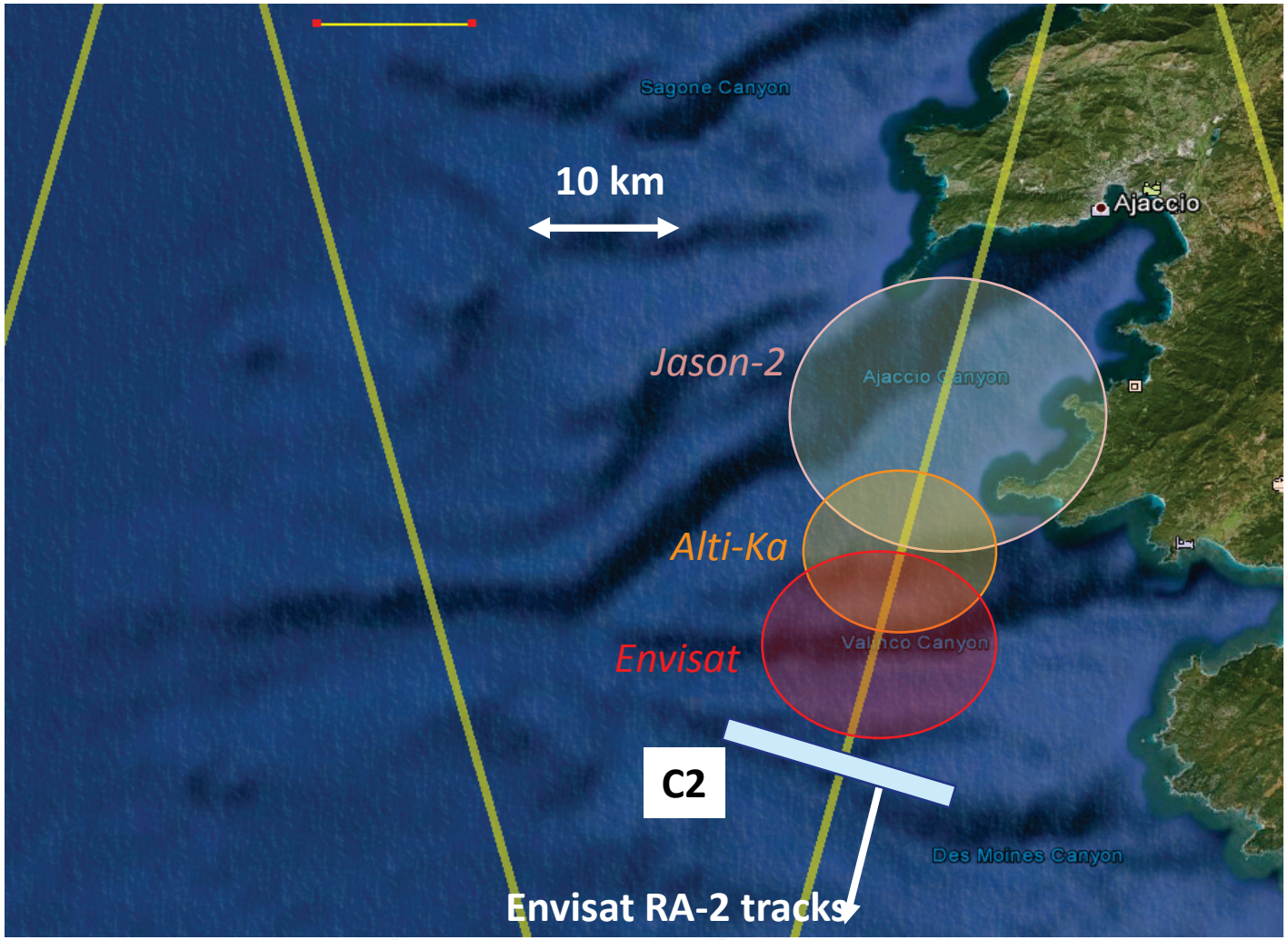
Surface of the waveform footprint

Radius of the waveform footprint (km)

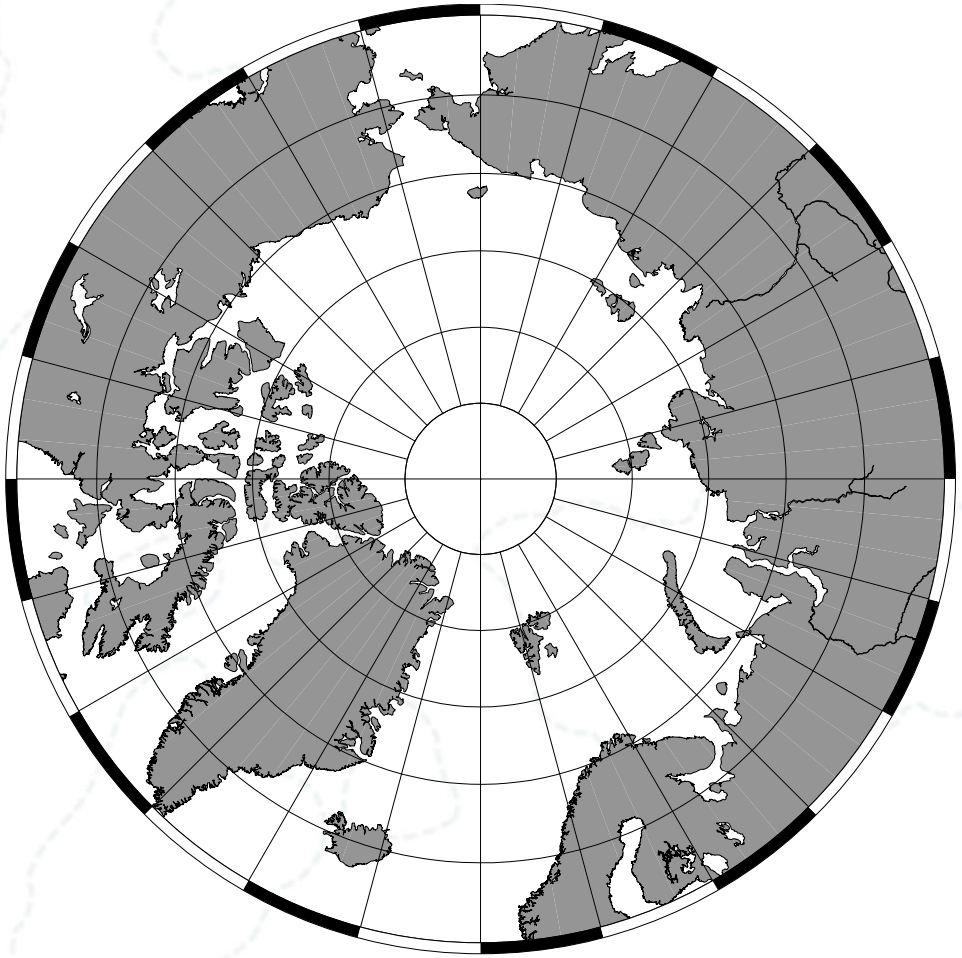


Surface of the waveform footprint (km^2)



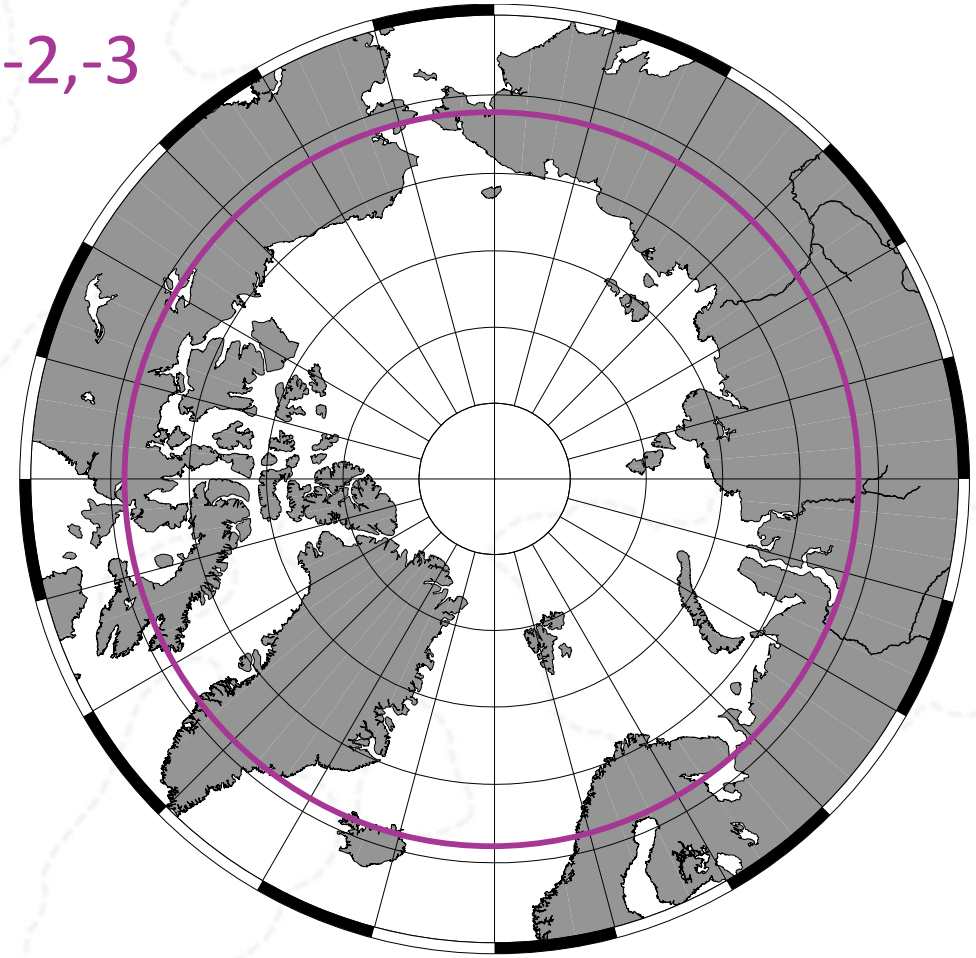

Sagone Canyon
10 km
Ajaccio
Jason-2
Ajaccio Canyon
Alti-Ka
Envisat
Valinco Canyon
C2
Des Moines Canyon
Envisat RA-2 tracks

Altimetry at worlds end



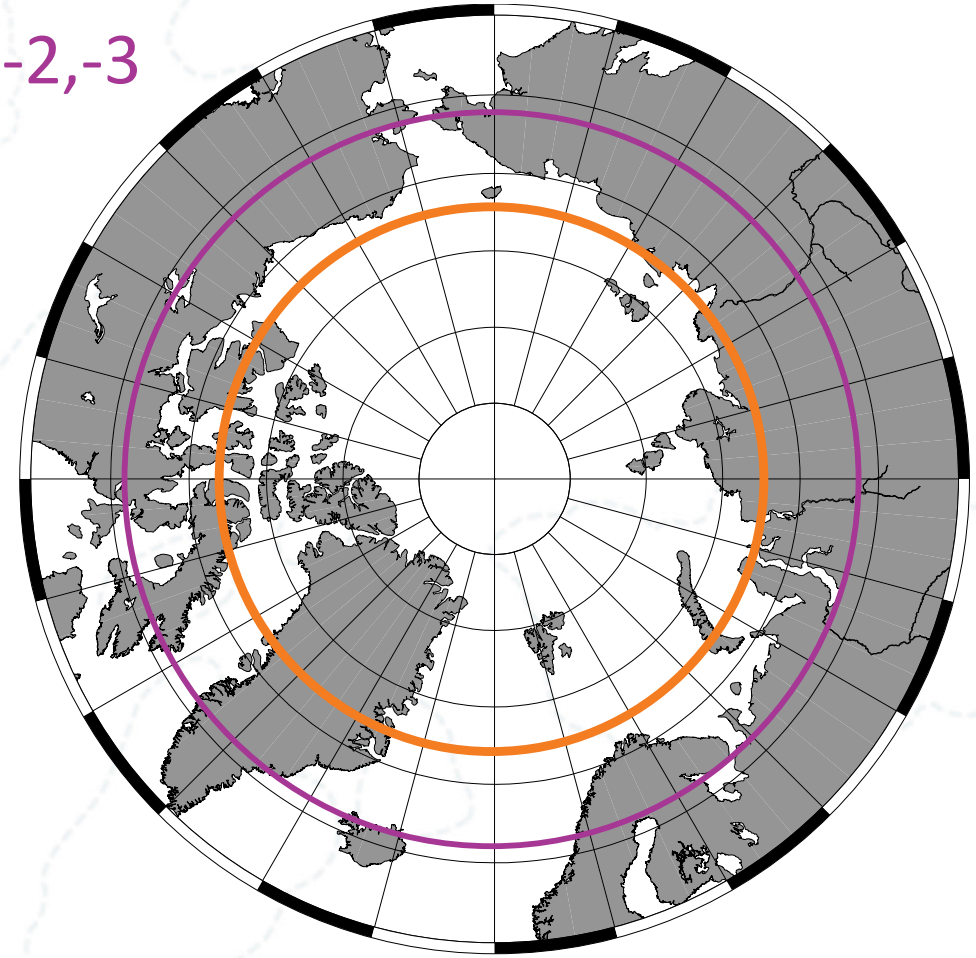
Altimetry at worlds end

- TOPEX/Poseidon, Jason-1,-2,-3



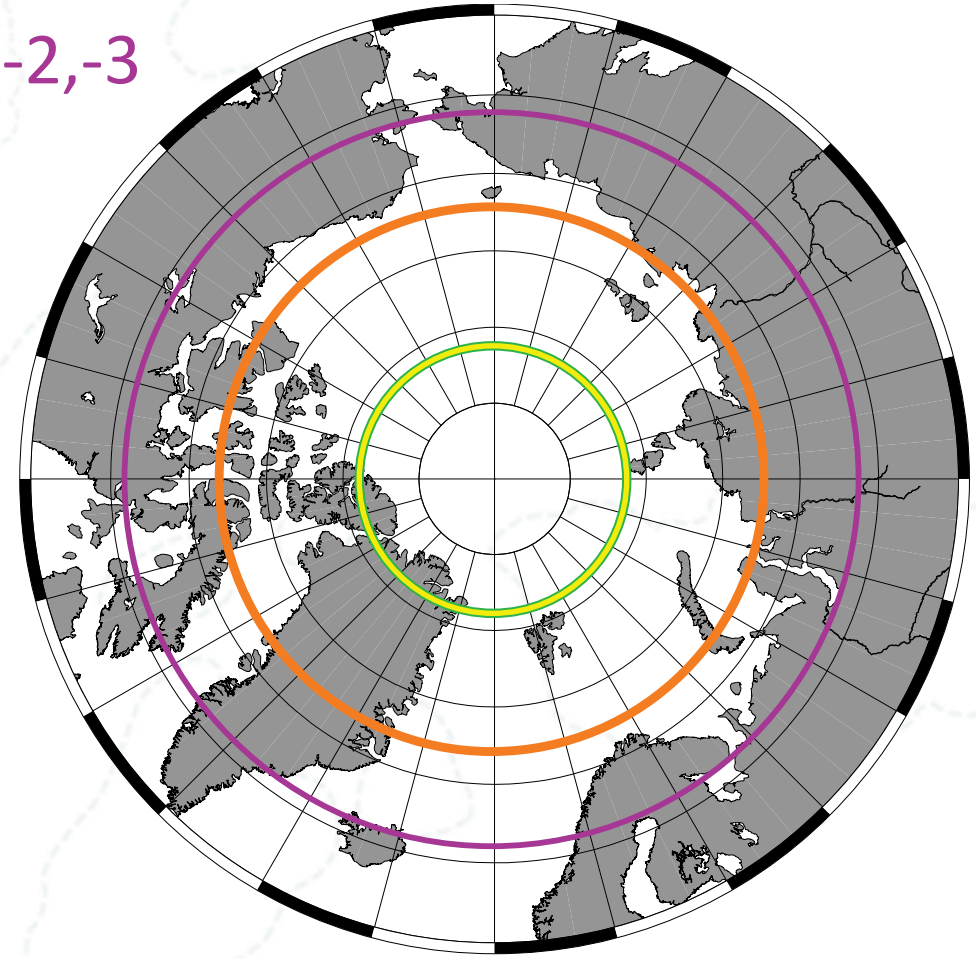
Altimetry at worlds end

- TOPEX/Poseidon, Jason-1,-2,-3
- Geosat, GFO



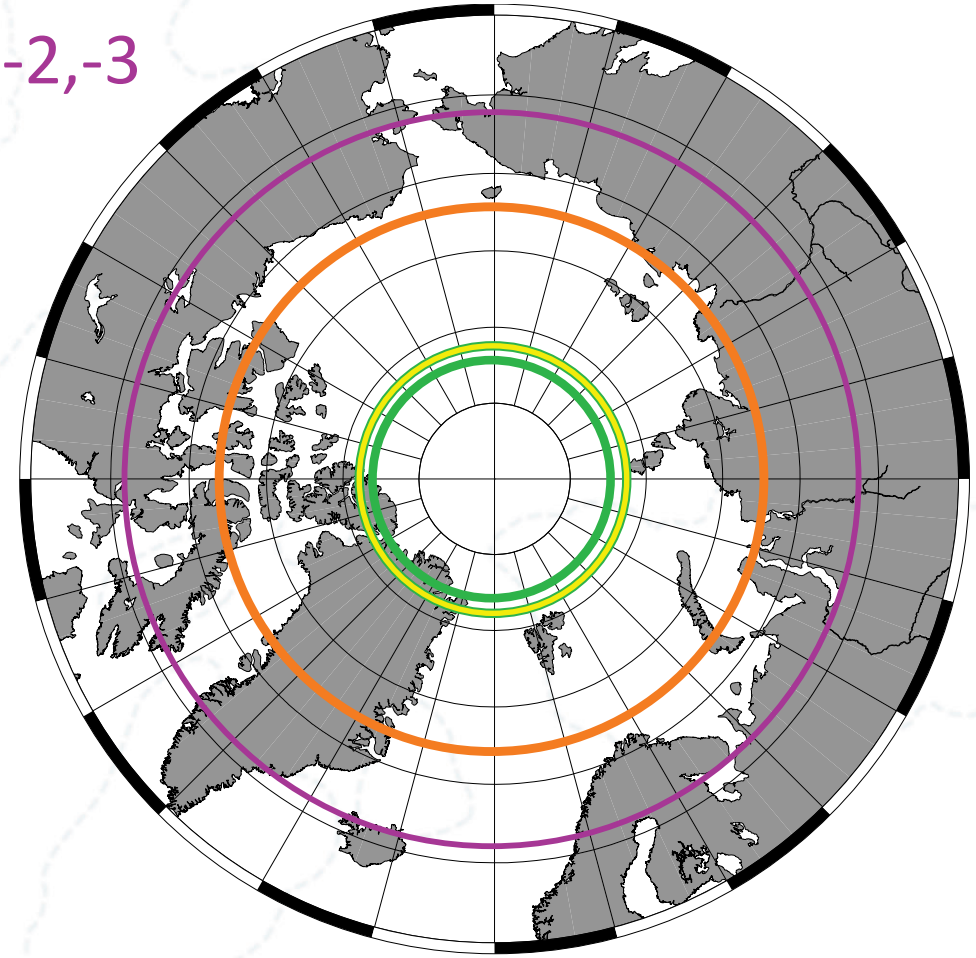
Altimetry at worlds end

- TOPEX/Poseidon, Jason-1,-2,-3
- Geosat, GFO
- S3A S3B



Altimetry at worlds end

- TOPEX/Poseidon, Jason-1,-2,-3
- Geosat, GFO
- S3A S3B
- ERS-1, -2, N1, HY2,SARAL



Altimetry at worlds end

- TOPEX/Poseidon, Jason-1,-2,-3
- Geosat, GFO
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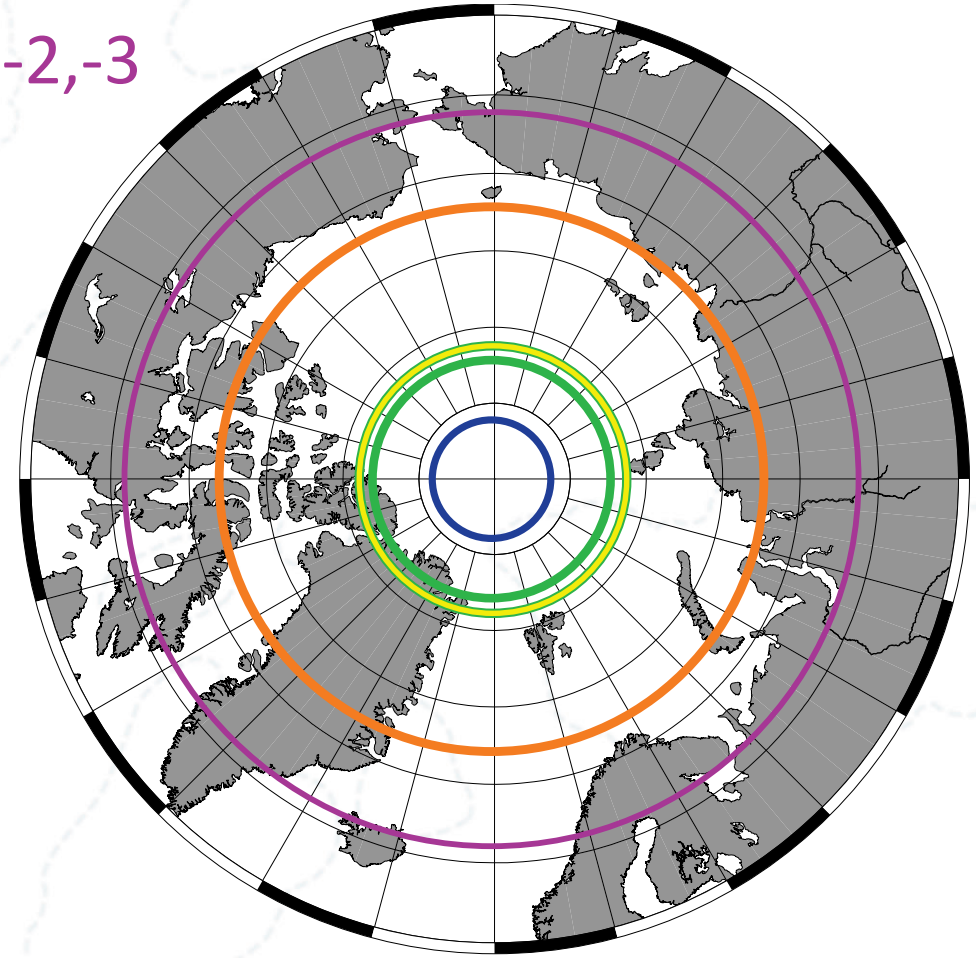
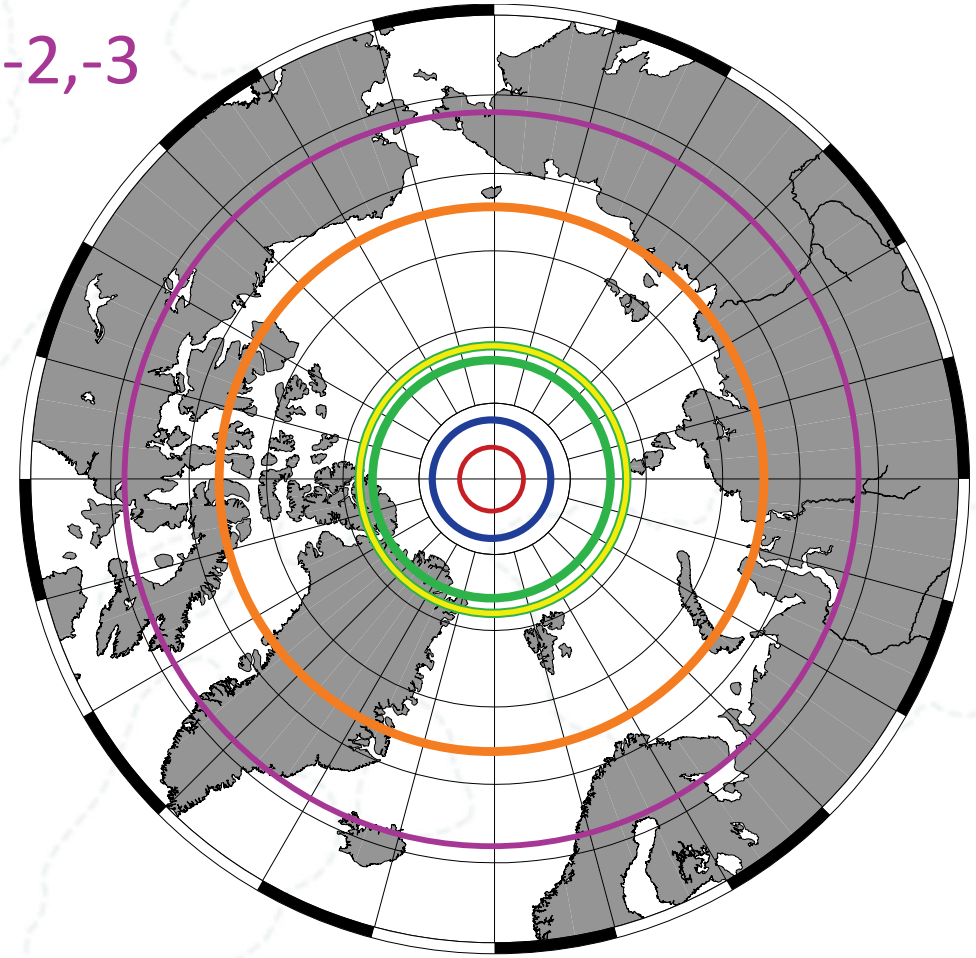
- IceSat

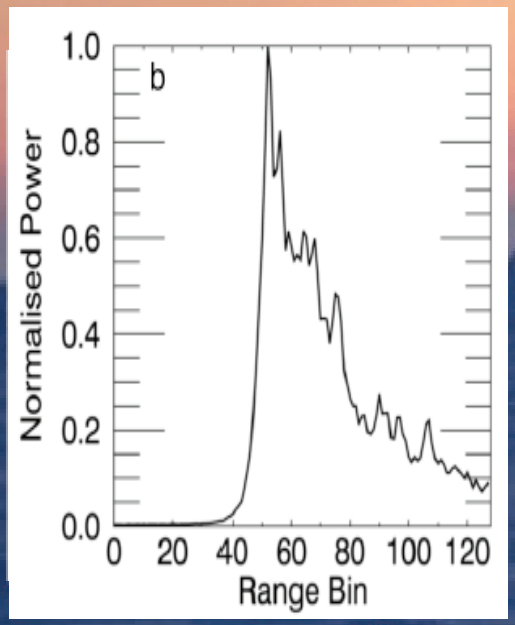


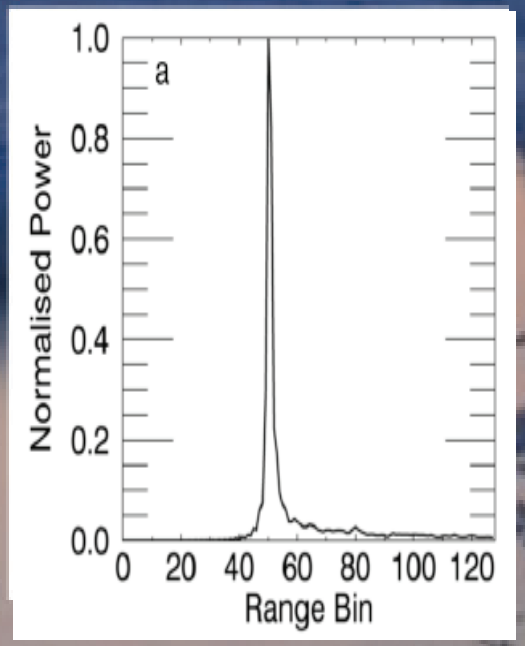
Altimetry at worlds end

- TOPEX/Poseidon, Jason-1,-2,-3
- Geosat, GFO
- S3A S3B
- ERS-1, -2, N1, HY2,SARAL
- IceSat
- CryoSat-2



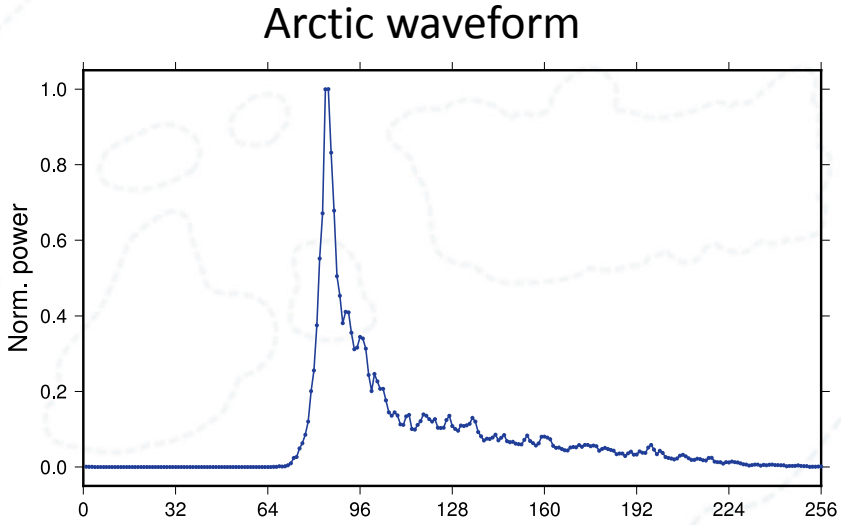
Waveforms in the Arctic





S.LAXON/CPOM/UCL

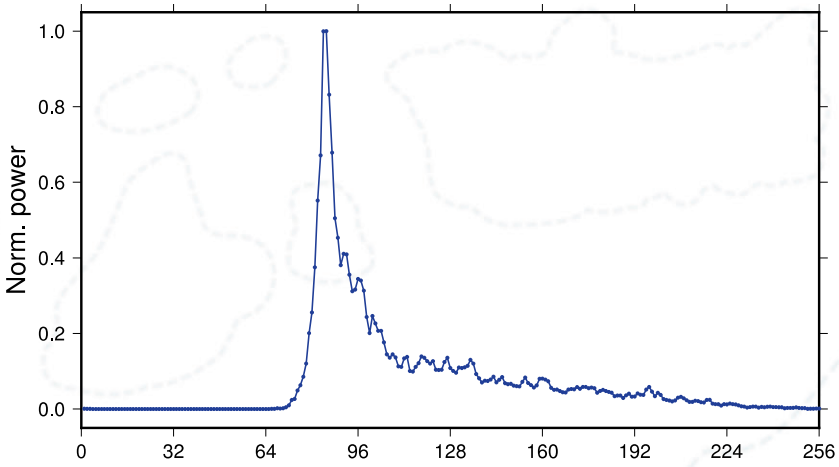
Waveforms in the Arctic



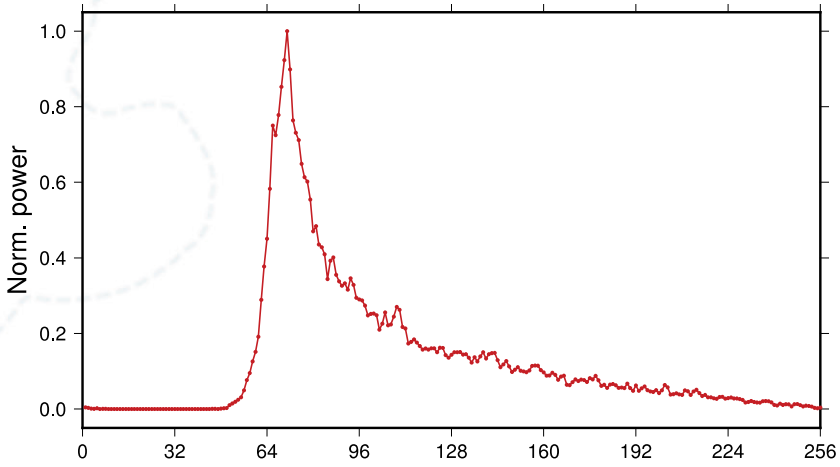
Data provided by CLS/CNES

Waveforms in the Arctic

Arctic waveform



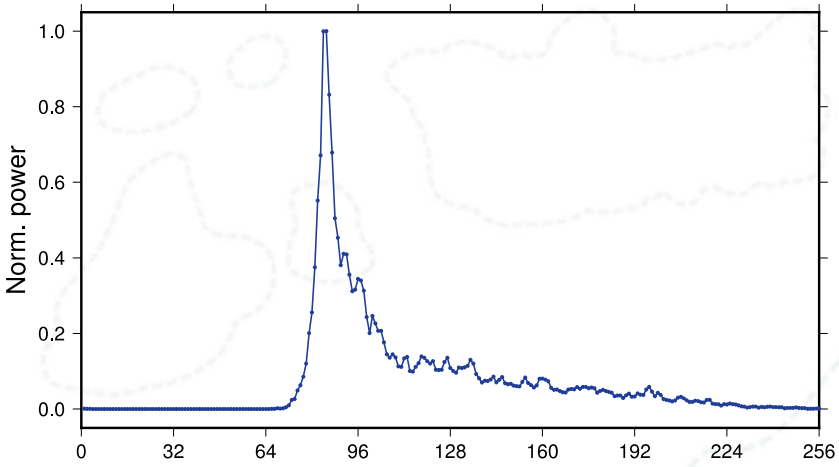
Ocean waveform



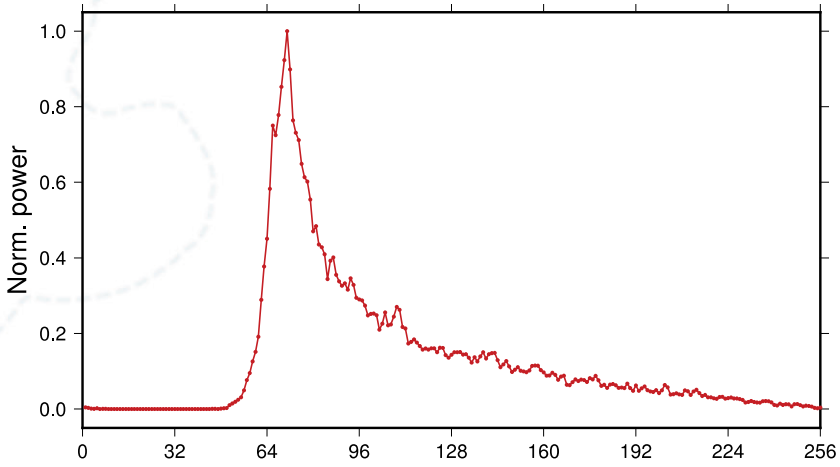
Data provided by CLS/CNES

Waveforms in the Arctic

Arctic waveform



Ocean waveform

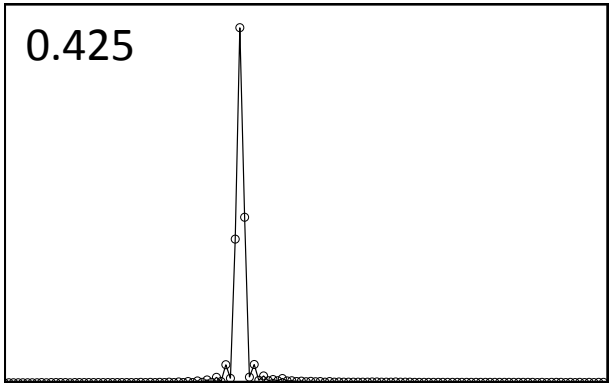


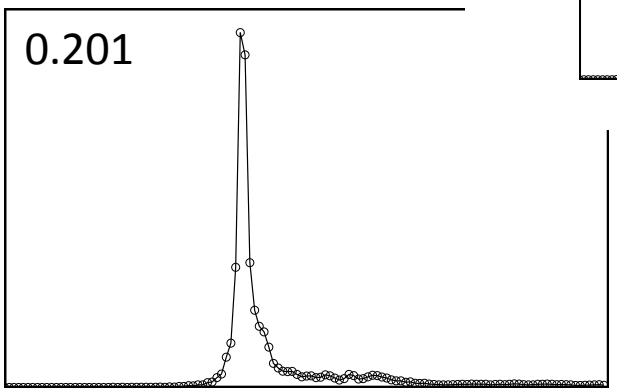
Data provided by CLS/CNES

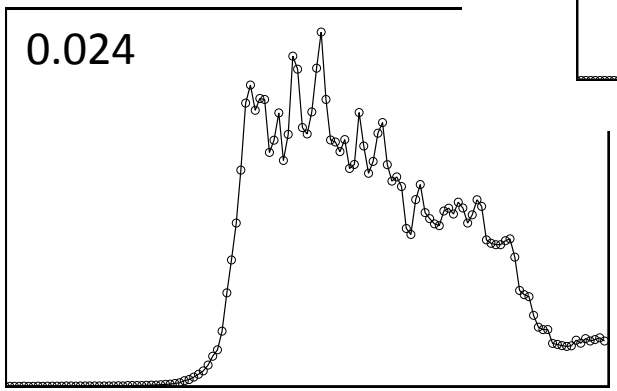
Classification

Pulse Peakiness (PP)

$$PP = \frac{65535}{\sum_{i=0}^{127} p_i}$$



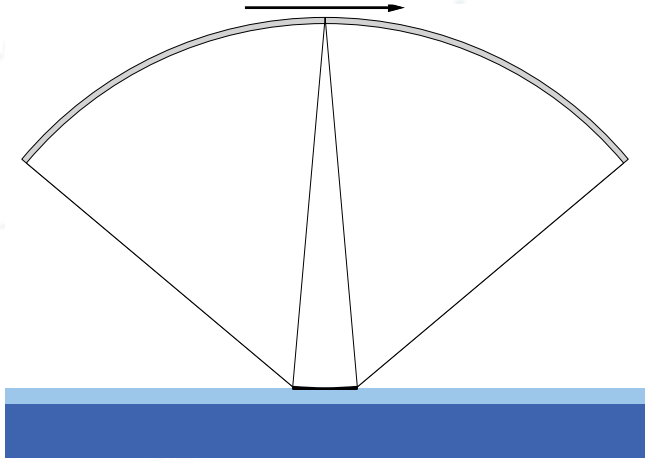




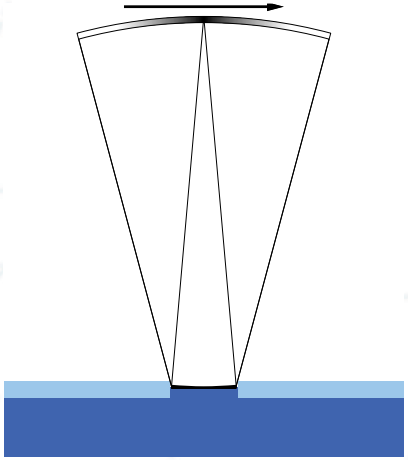
Francis (1991), Laxon (1994), and Stenseng (2014a)

Classification

Sea ice



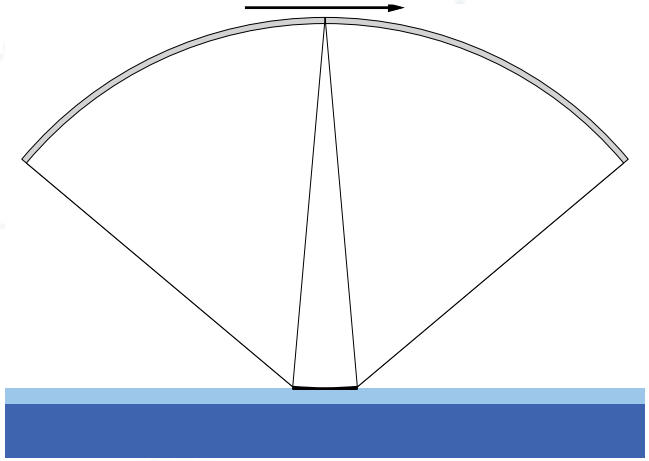
Lead in sea ice



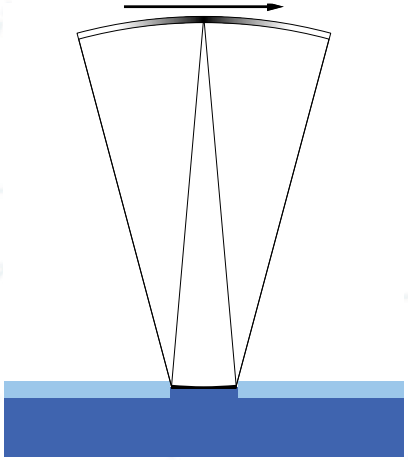
Stenseng (2014a)

Classification

Sea ice

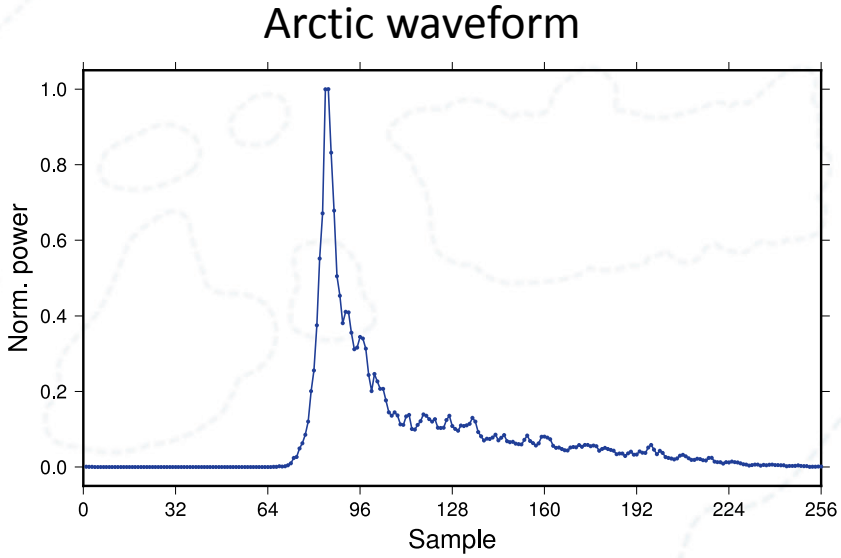


Lead in sea ice



Stenseng (2014a)

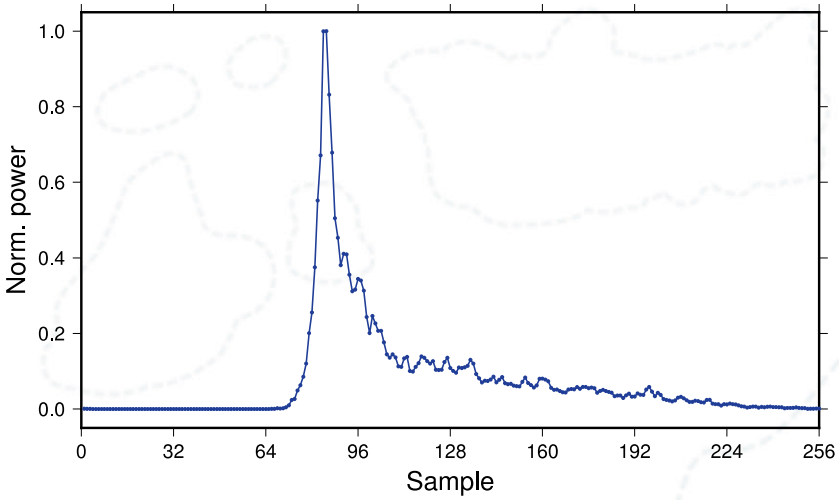
Waveforms in the Arctic



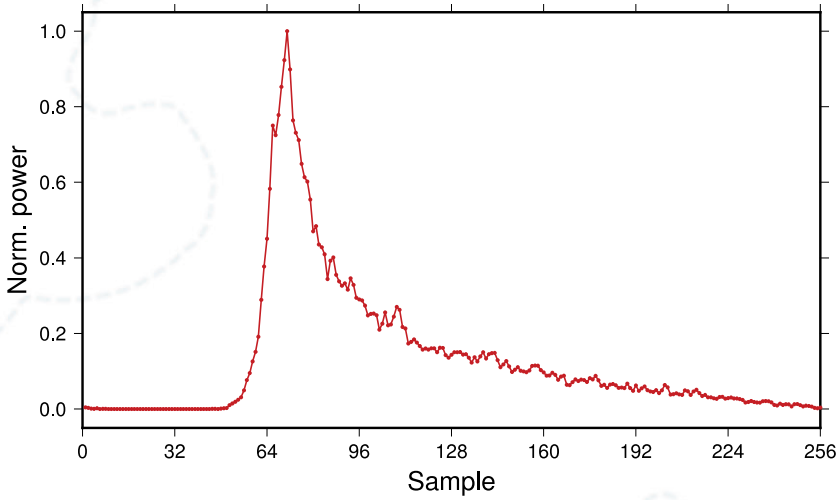
Data provided by CLS/CNES

Waveforms in the Arctic

Arctic waveform



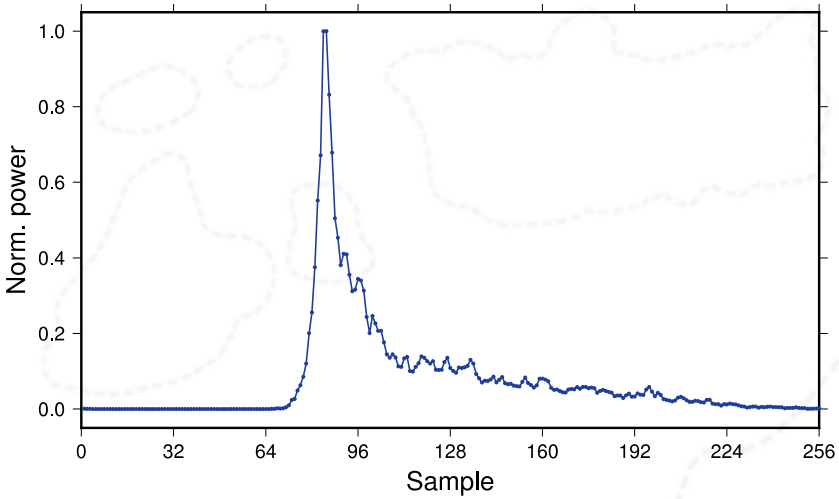
Ocean waveform

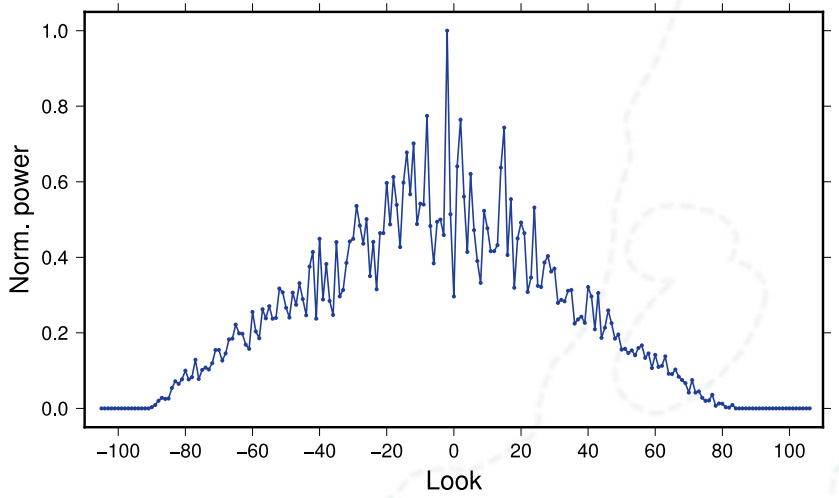


Data provided by CLS/CNES

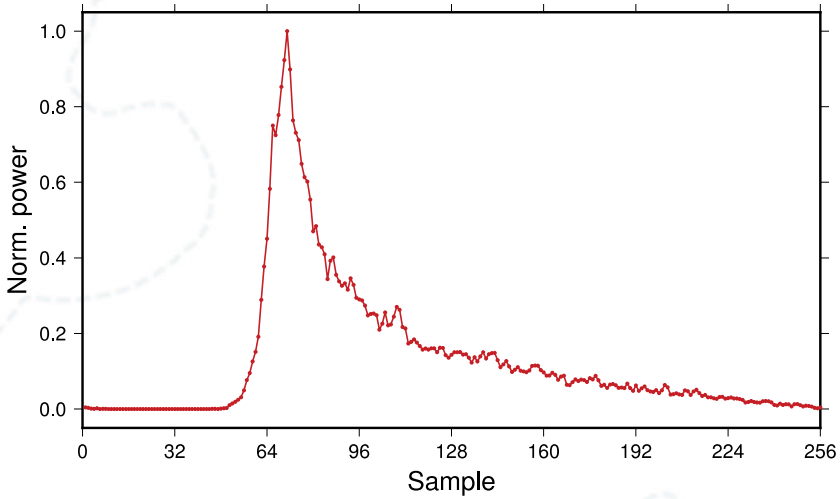
Waveforms in the Arctic

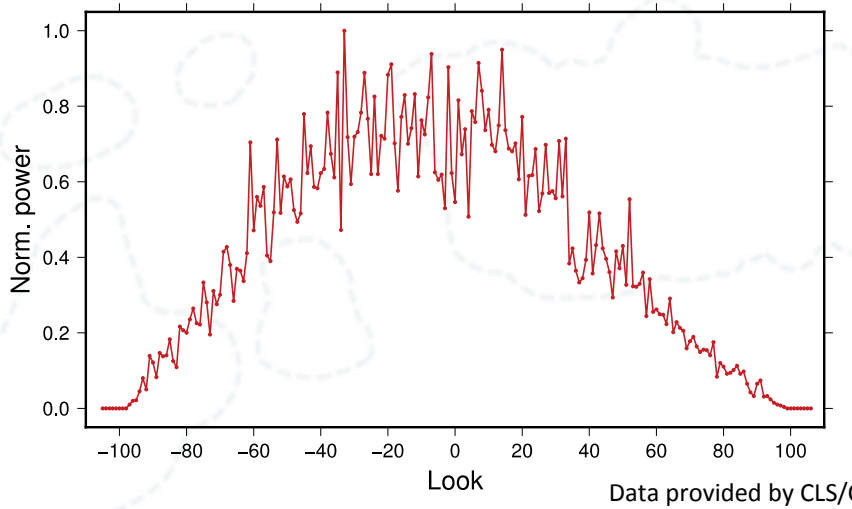
Arctic waveform





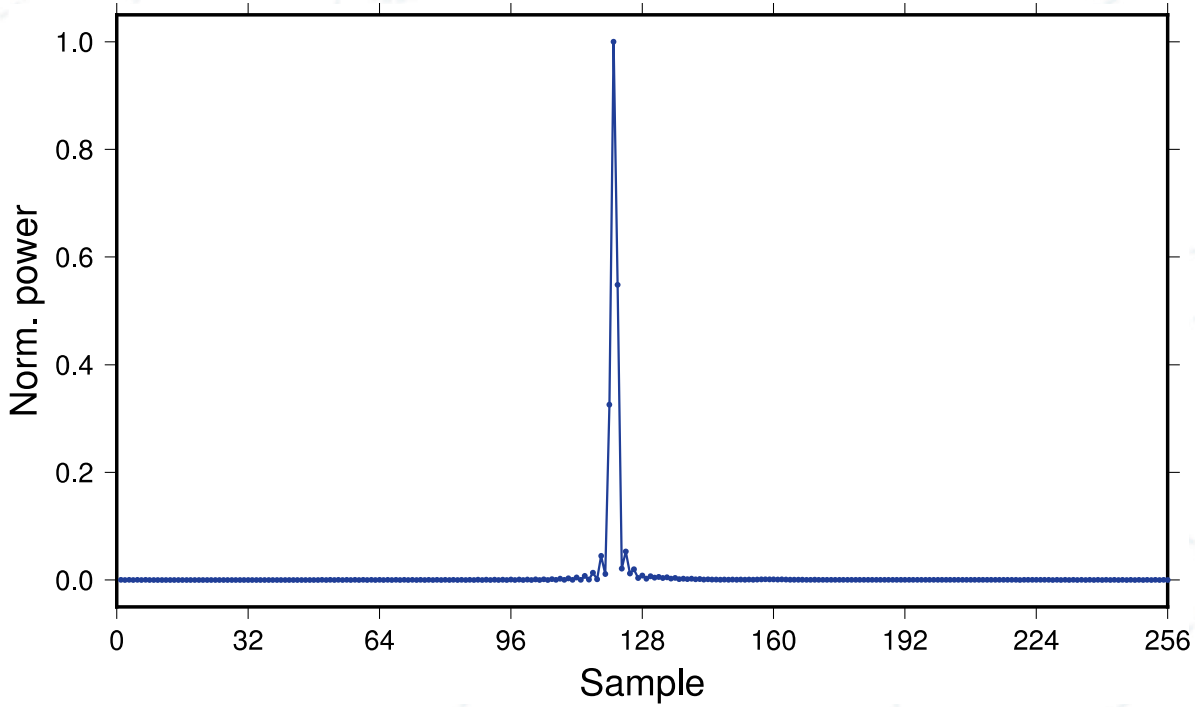
Ocean waveform





Data provided by CLS/CNES

Waveforms in the Arctic



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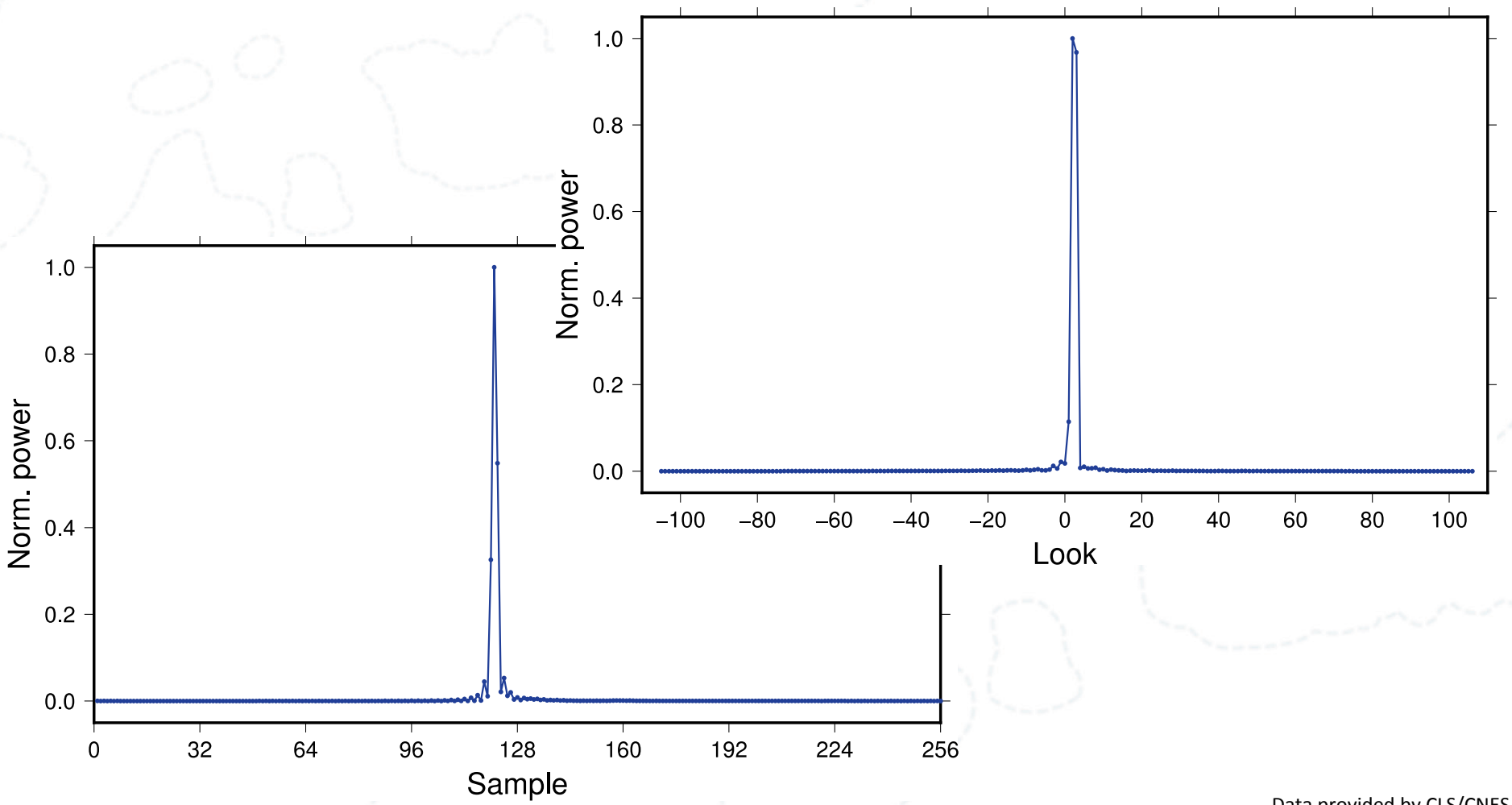
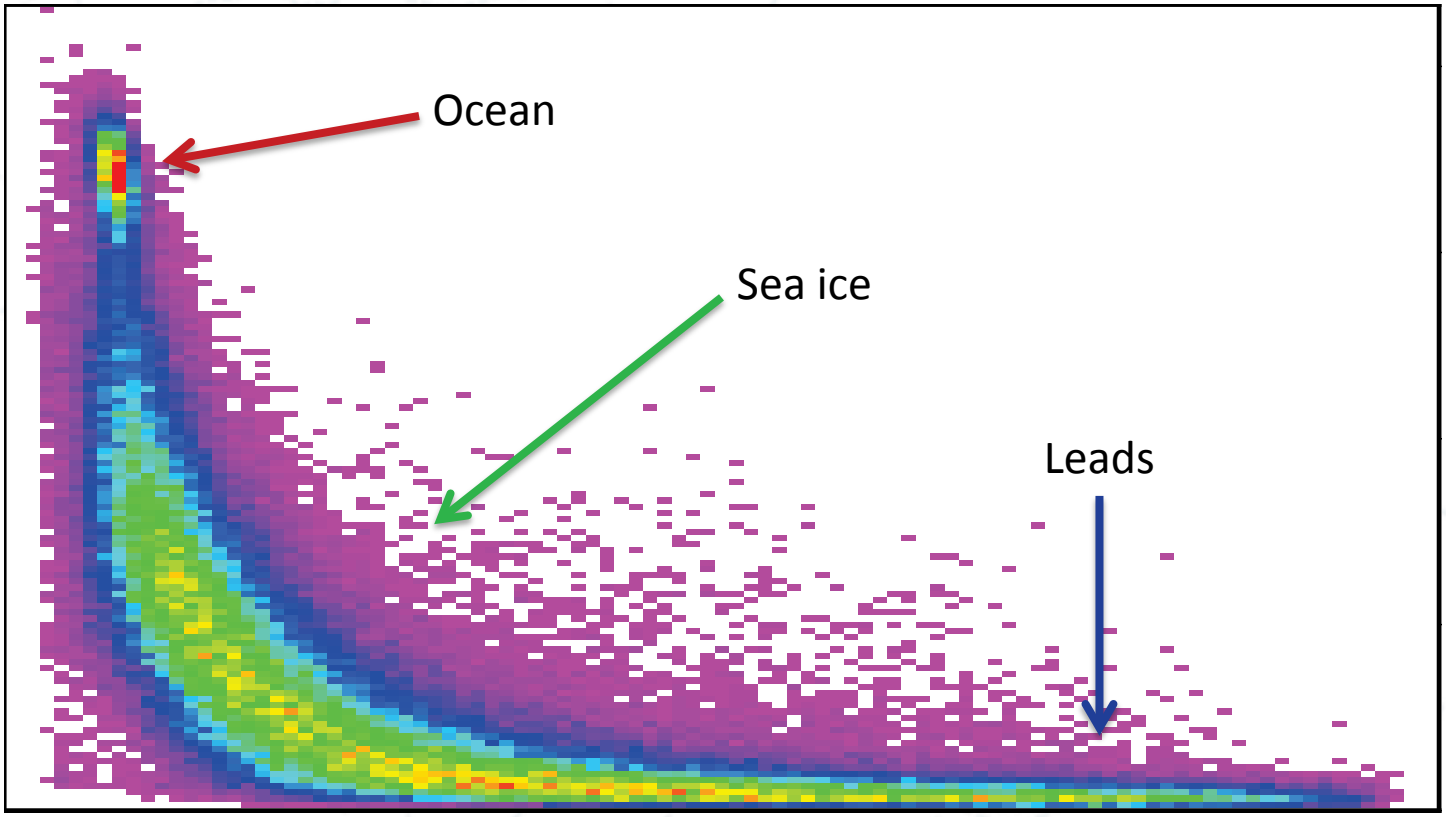
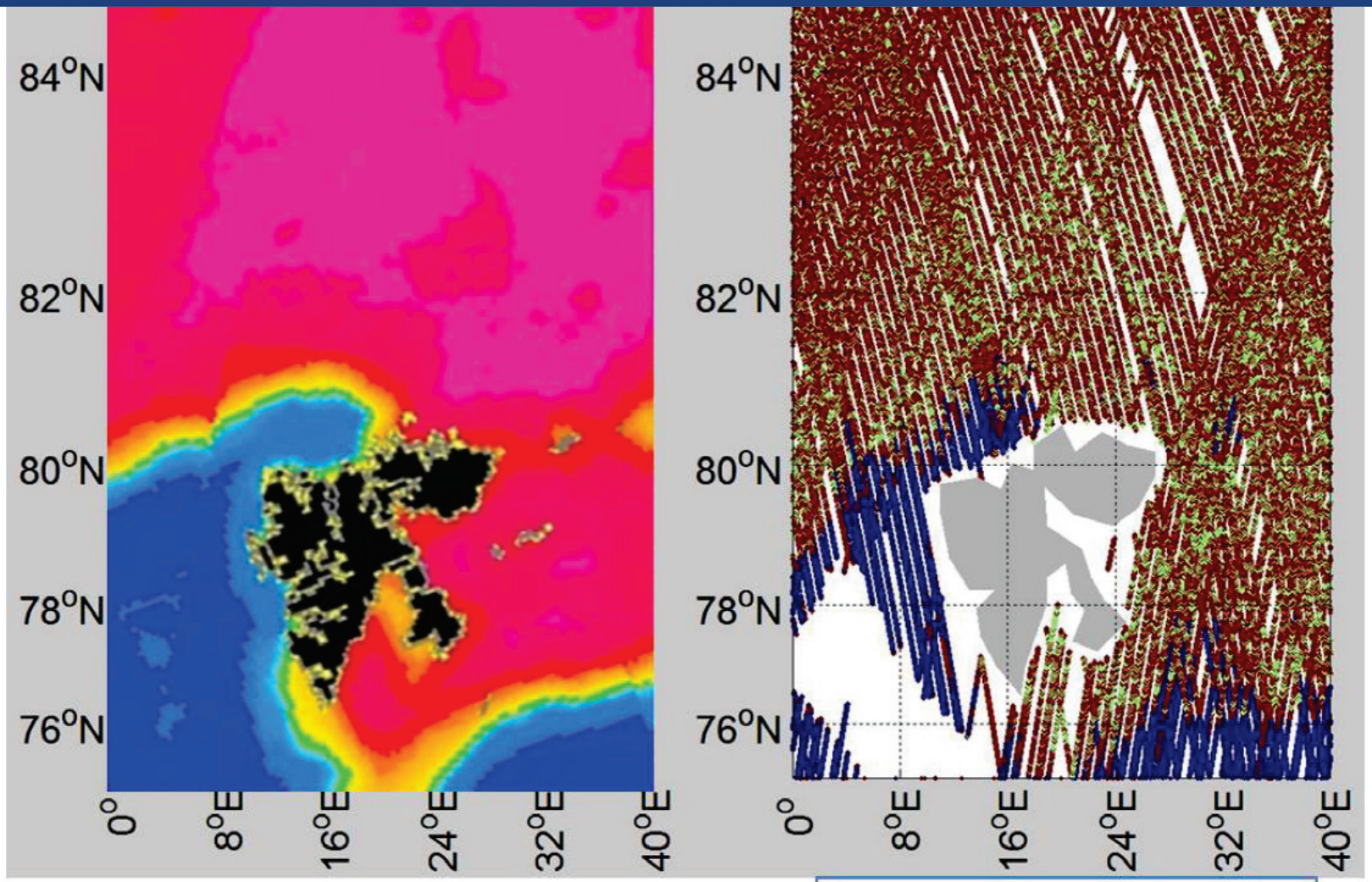
Waveforms in the Arctic



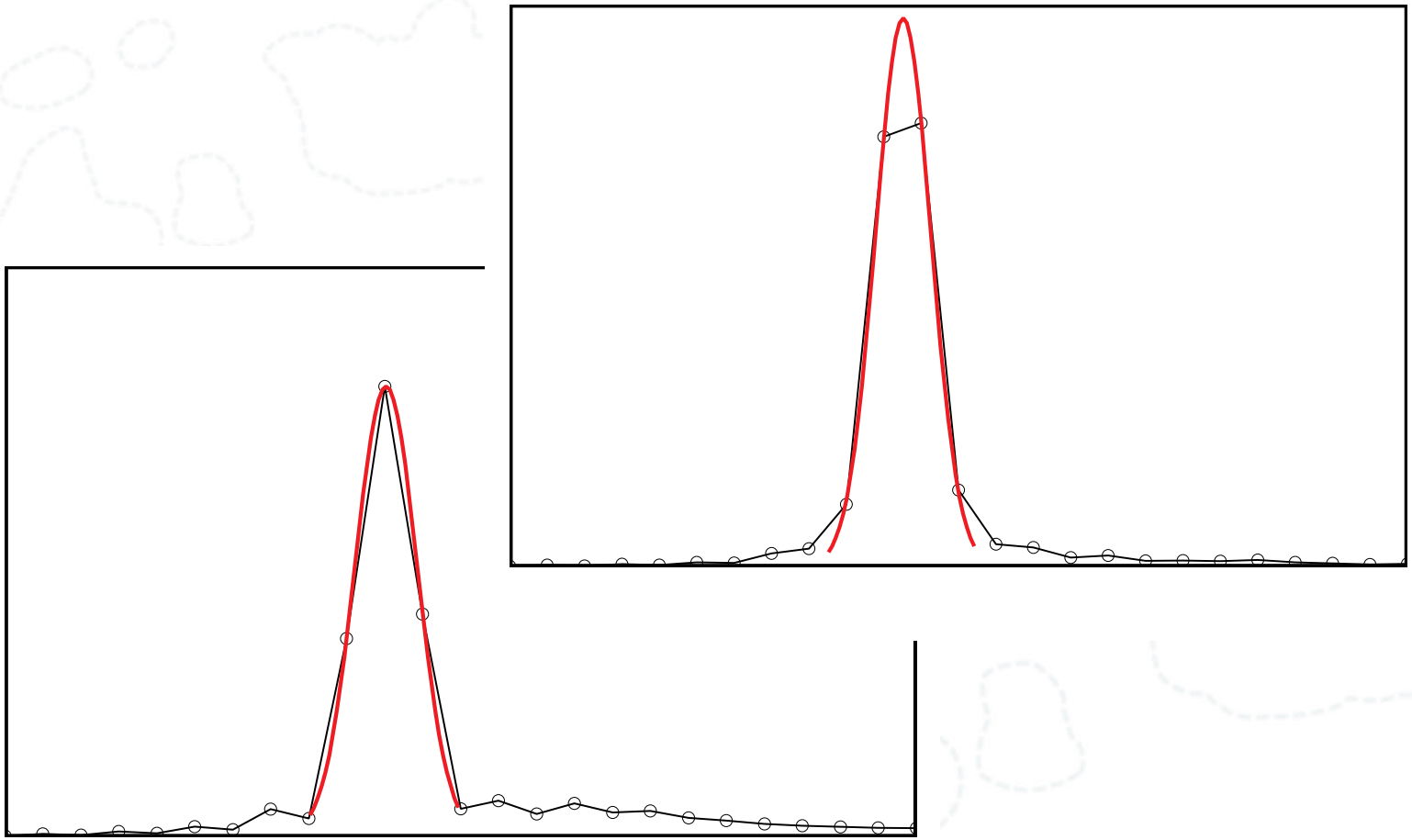
Data provided by CLS/CNES

Classification




84°N
82°N
80°N
78°N
76°N
0°
8°E
16°E
24°E
32°E
40°E
0
1
Blue : Ocean Type
Green : Lead Type
Brown : Irregular Type

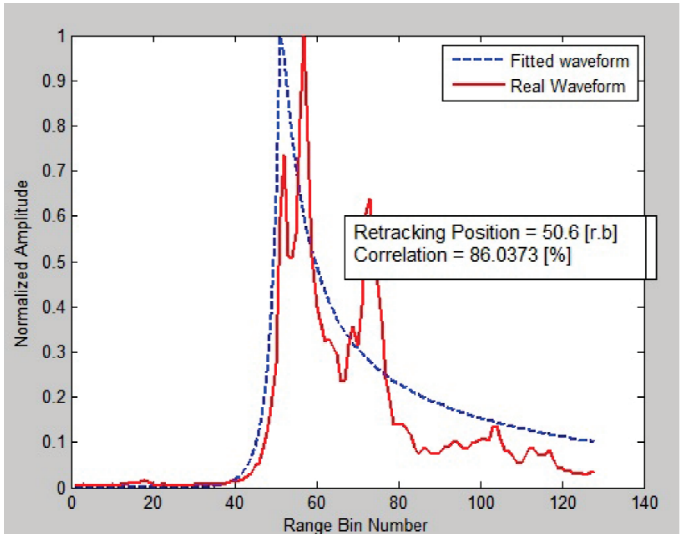
Sampling and peak power



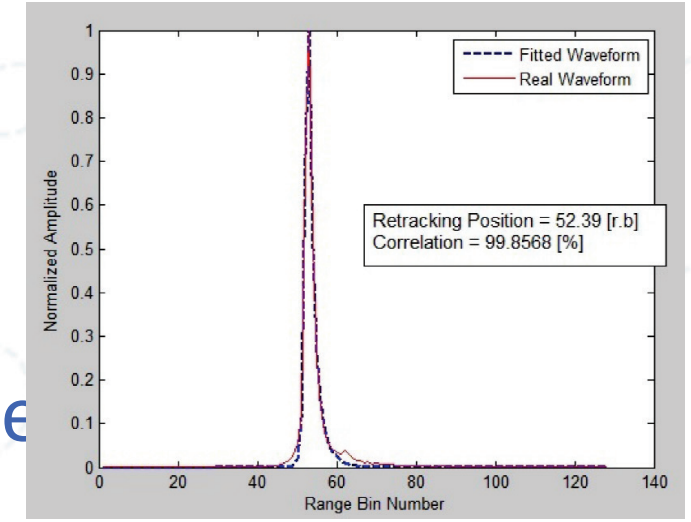
Stenseng (2014a)

Retracking

- SAMOSA3 Physical retracking.
- SAMOSA3L adapted for Leads
- Yields 3 parameters(h,swh,s0)



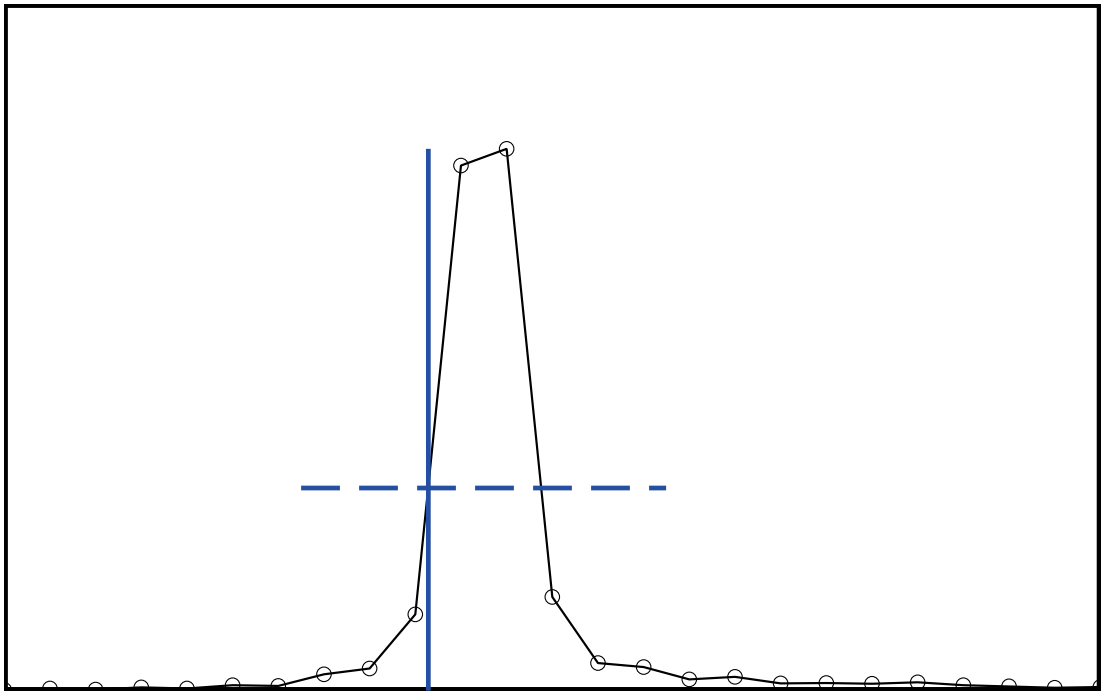
- If only height is required
- Simple EMPERICAL retrackers
- Results in more data and is
- Preferred due to processing time



Threshold Retracking

$$P_b = \frac{1}{5} \sum_{i=m-2}^{m+2} p_i$$

$$E = \frac{F_T \cdot P_b - p_{j-1}}{p_j - p_{j-1}} + j - 1$$



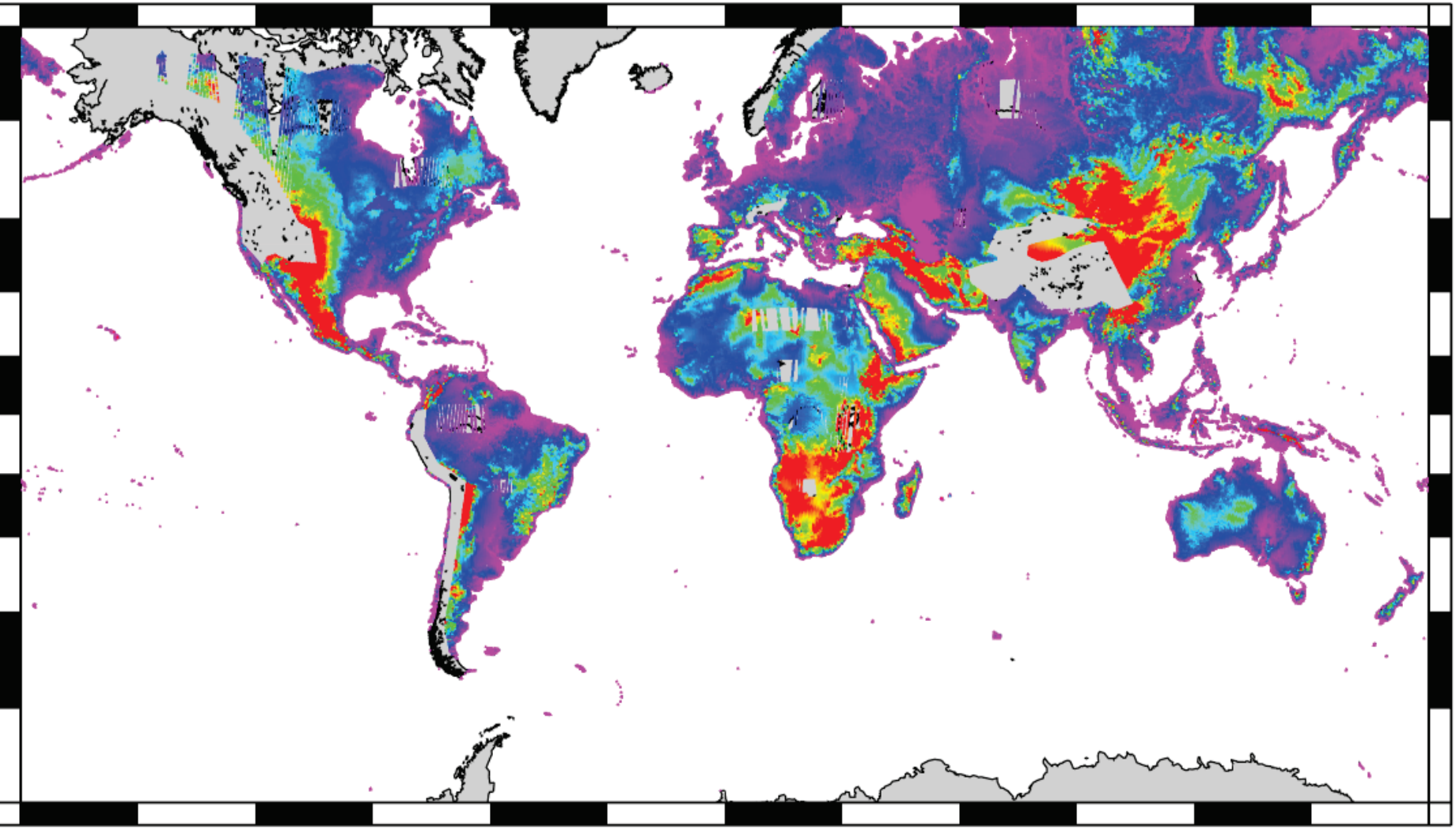
Davis (1997) and Stenseng (2011/2014a)

DTU LARS retracking System

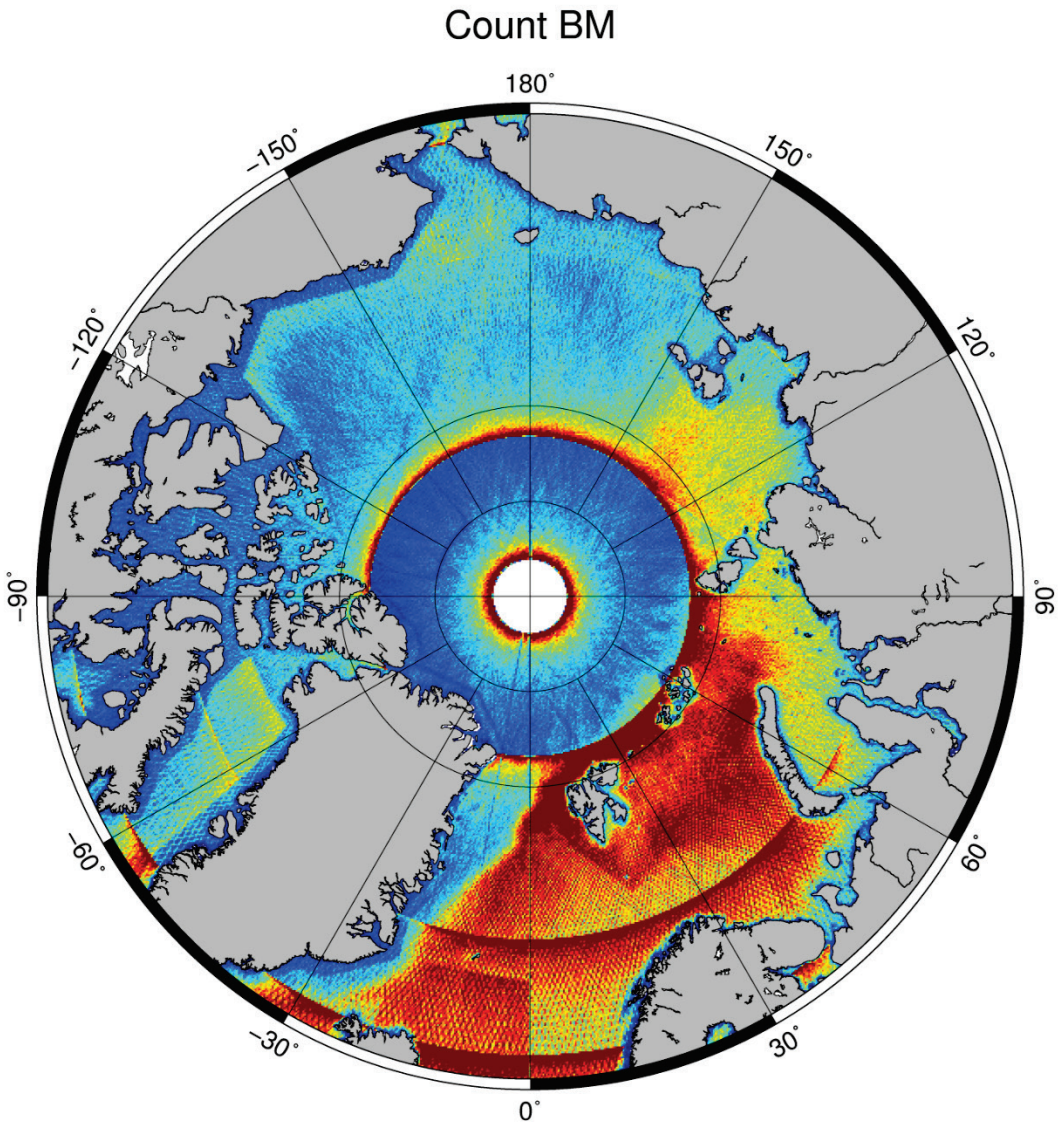
Retracker	Type	Reference
OCOG	Empirical	Wingham et al. (1986)
Treshold	Empirical	Davis (1997)
Improved treshold	Empirical	Hwang et al. (2006), Lee et al. (2008)
Beta 5 parameter	Empirical	Martin et al. (1984)
Beta 9 parameter	Empirical	Martin et al. (1984)
Modified Beta 5	Empirical	Zwally et al. (1990), Deng and Featherstone (2006)
Brown-Hayne's	Physical	Brown (1977), Hayne (1980)
Cryosat retracker	Empirical	Wingham et al. (2006)
Simplified Cryosat retracker	Empirical	Giles et al. (2007)
SAMOSA	Physical	Gommenginger et al. (2011), Martin-Puig et al. (2010)
Gaussian peak	Empirical	Armitage and Davidson (2013)
Modified Gaussian	Empirical	Unpublished

Range + Geophys corr (wet, dry, iono, Load, solid, pole tide, geoid)

DTU LARS retracking System

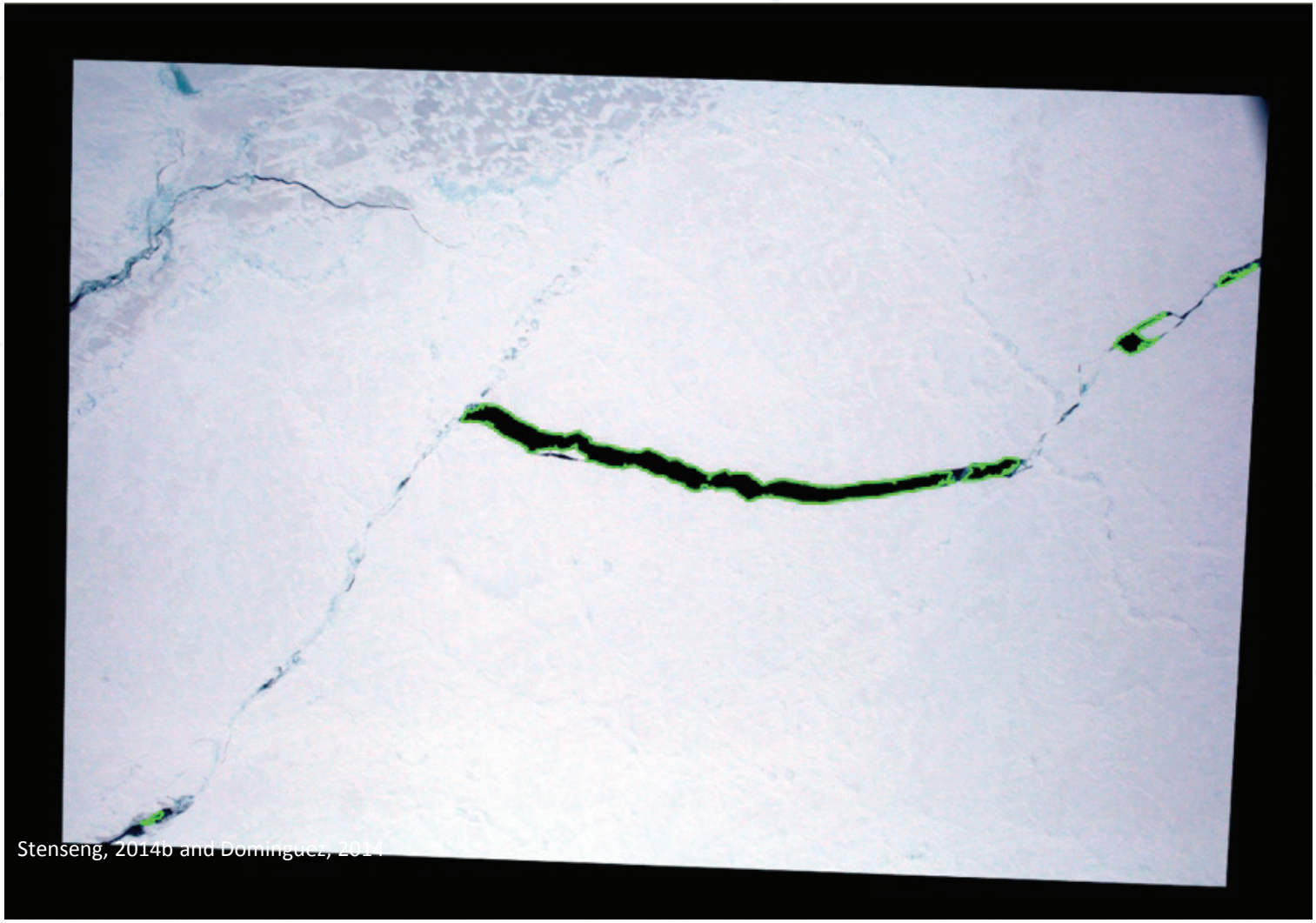


Range + Geophys corr (wet, dry, iono, Load, solid, pole tide, geoid)



Counts per 10x 10 km

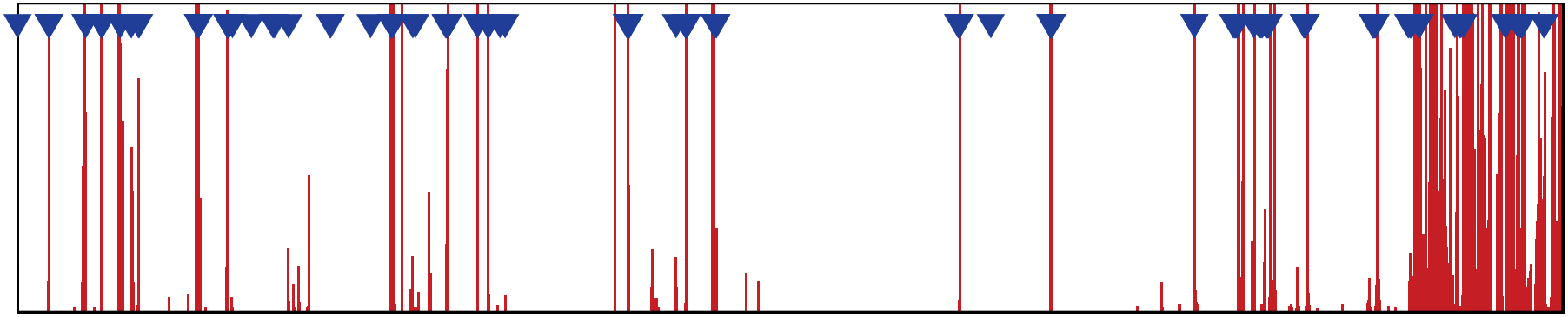
Validation: IceBridge



Stenseng, 2014b and Dominguez, 2014

Validation: IceBridge

Leads in aerial photos and CryoSat-2 data

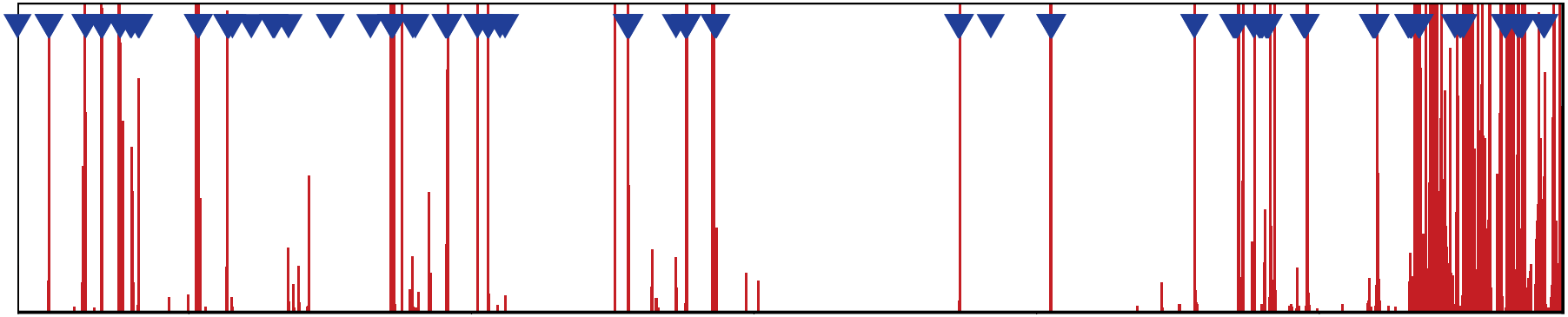


- Detected ~80% of leads >500 m^2
- LiDAR observations ~4 cm std. dev.

Stenseng (2014b)

Validation: IceBridge

Leads in aerial photos and CryoSat-2 data

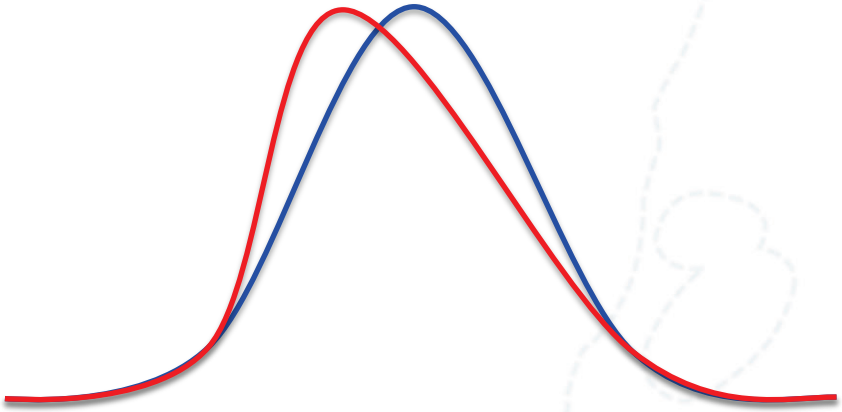


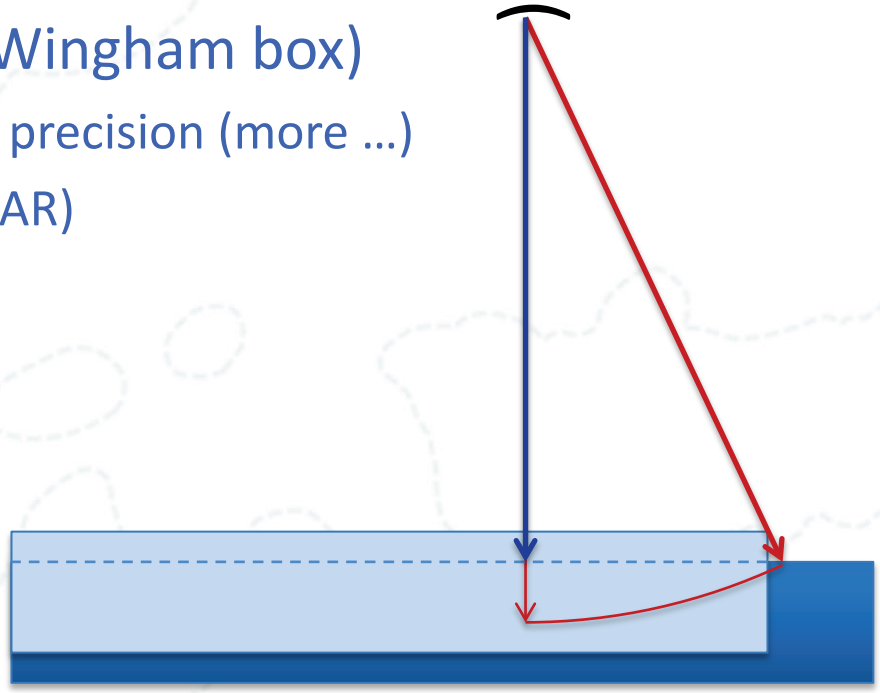
- Detected ~80% of leads >500 m^2
- LiDAR observations ~4 cm std. dev.
- Mean difference 0 cm Only 34 collocated observations

Stenseng (2014b)

"Snagging"

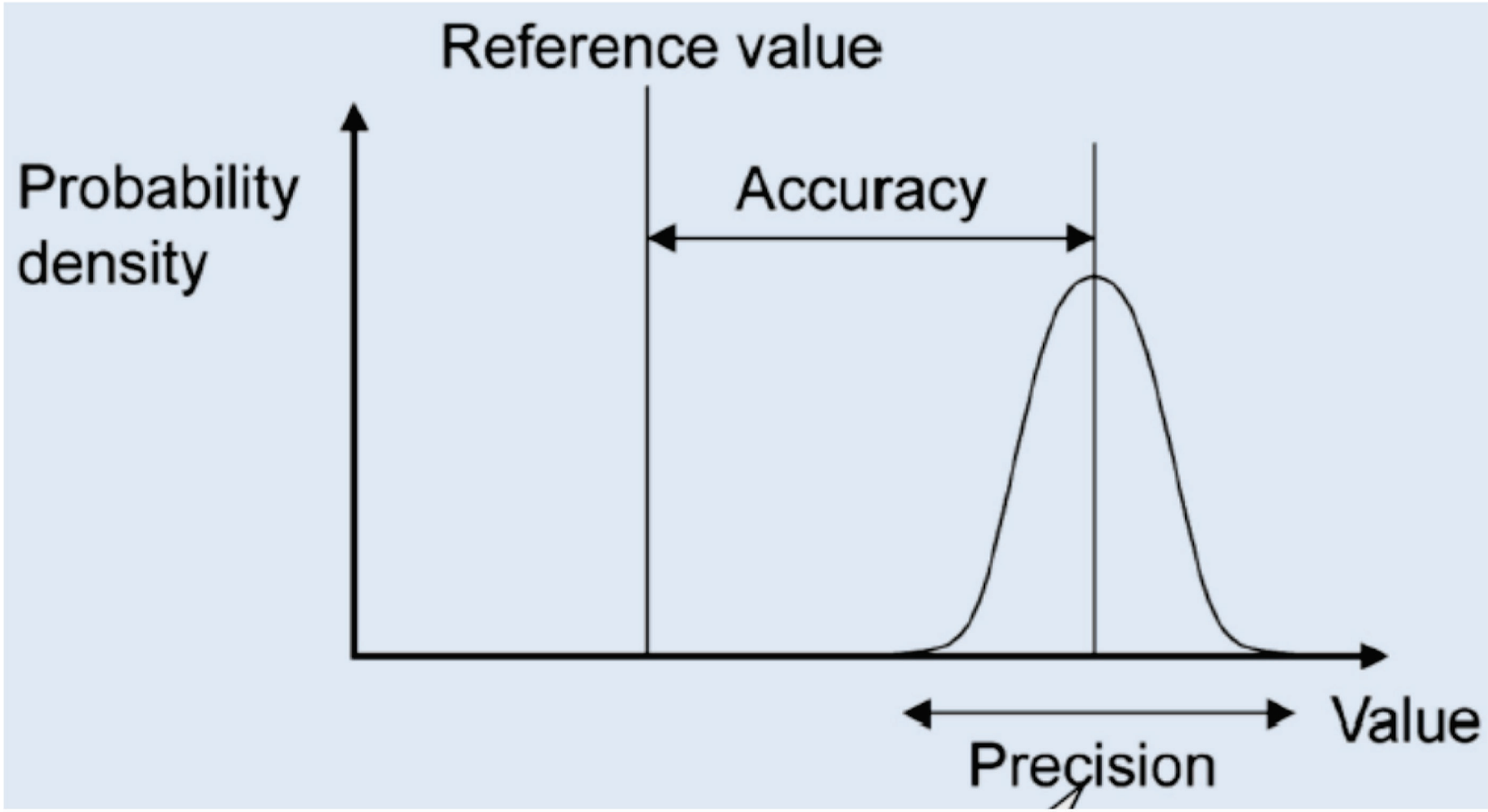
- Bright off nadir targets dominates
- Range to target longer ➔surface lower
- Cross-track angle from SARin (the Wingham box)
  - CryoSat-2 SARin mode: accuracy over precision (more …)
  - Only 1 burst per radar cycle (vs. 4 in SAR)





Stenseng (2014b), Armitage and Davidson (2014)

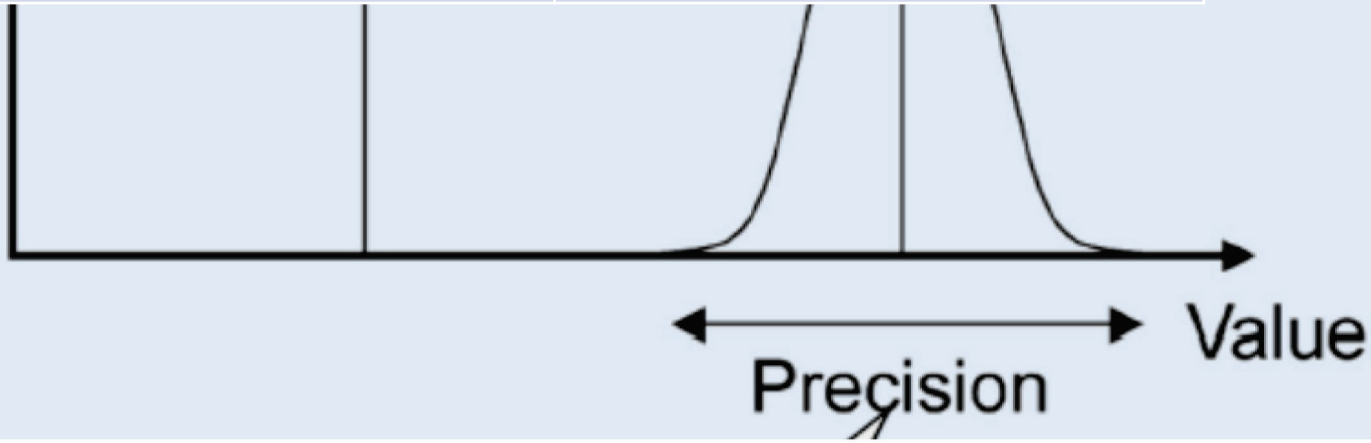
Application: Precision vs Accuracy



K. Raney

Application: Precision vs Accuracy

Oceanography (surge+tides)	Accuracy
Ice-sheet topography + dynamics	Accuracy and Precision
Gravity & Bathymetry	Precision
Mean Sea Surface Seaice-Freeboard	Precision and Accuracy
Mean Dynamic Topography	Precision and Accuracy + Geoid



K. Raney

Application: Precision vs Accuracy

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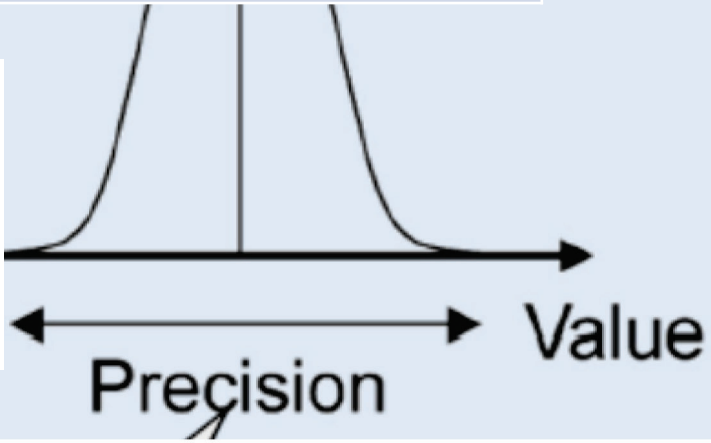
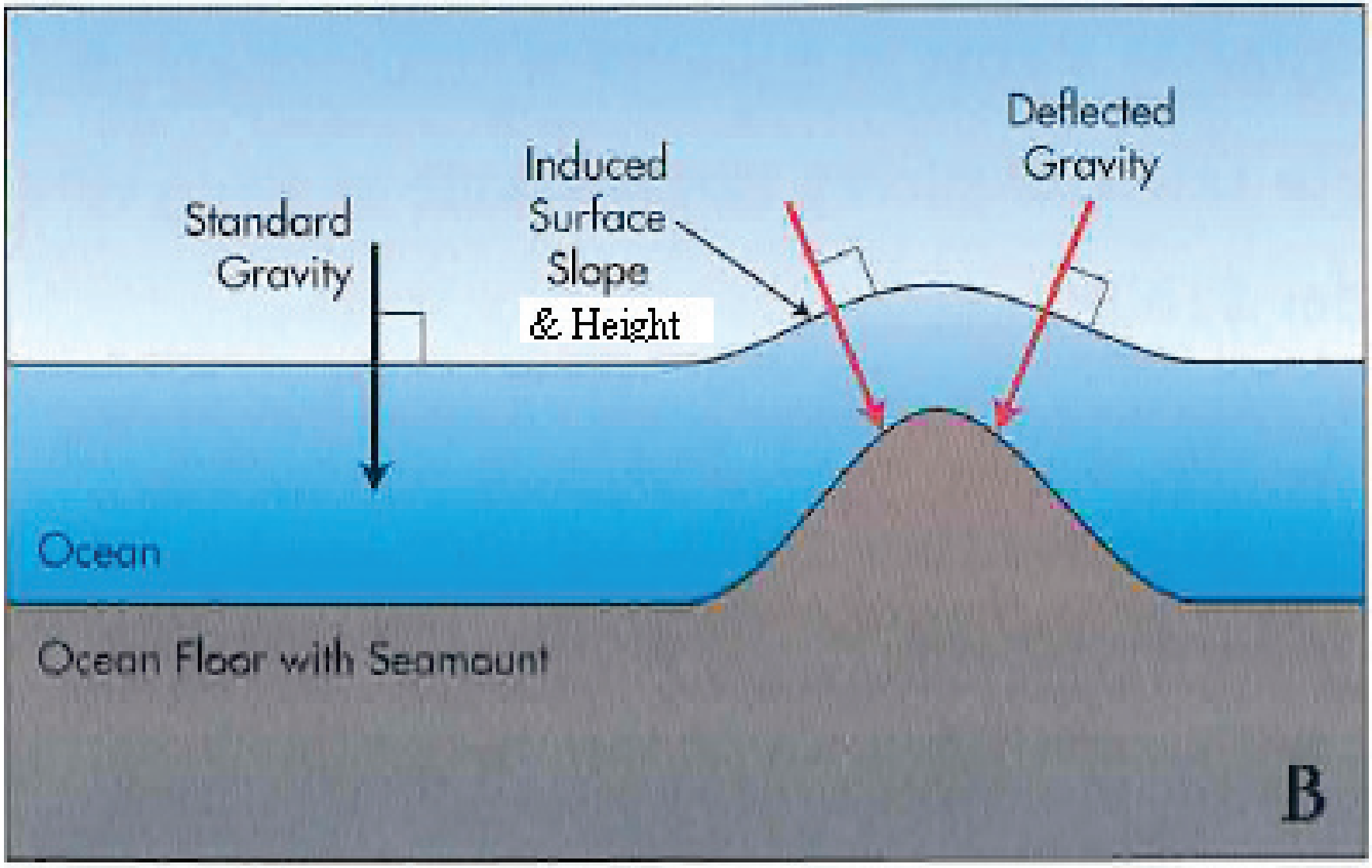
Need highest precision for many purposes
Precision is determined by radar design.
Higher precision than today requires higher PRF and or Open burst or alternative processing (Smith) ?

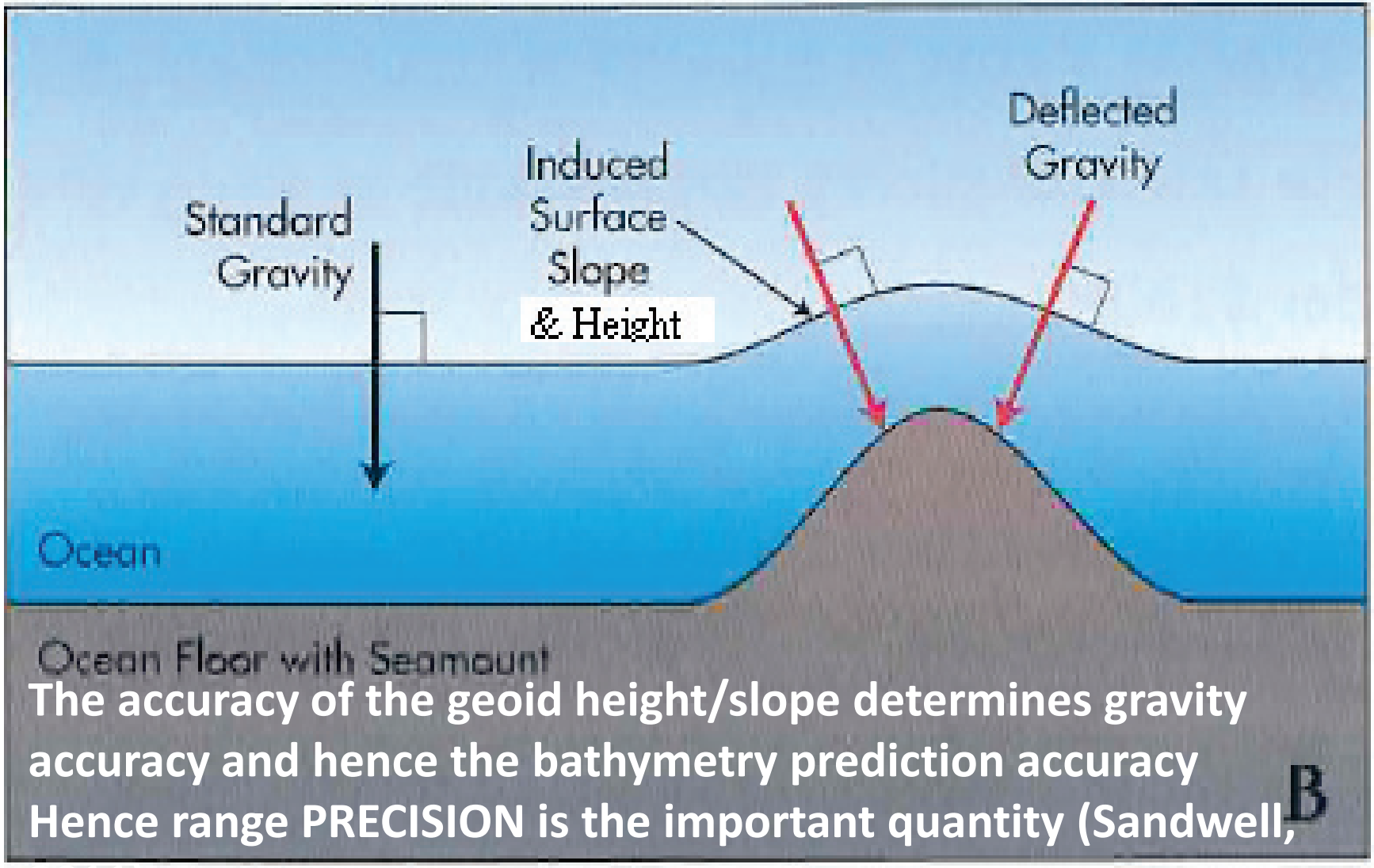


K. Raney

Sea surface height->Gravity->Bathymetry



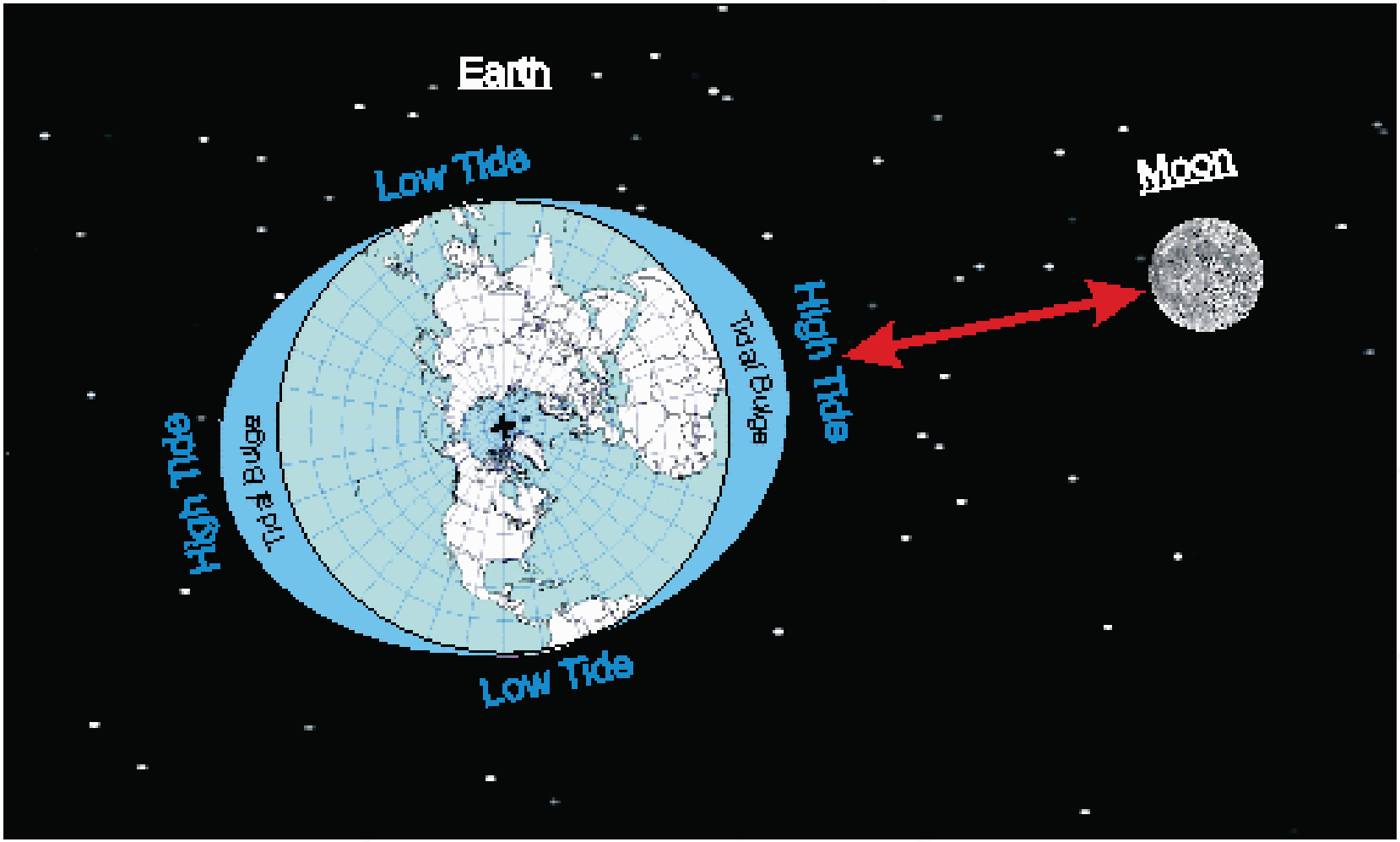
Sea surface height->Gravity->Bathymetry



The accuracy of the geoid height/slope determines gravity accuracy and hence the bathymetry prediction accuracy

Hence range PRECISION is the important quantity (Sandwell, 2011)

Ocean Tides


Earth
Low Tide
Moon
High Tide
Tidal Bulge
Tidal Bulge
High Tide
Low Tide

Sampling and Accuracy

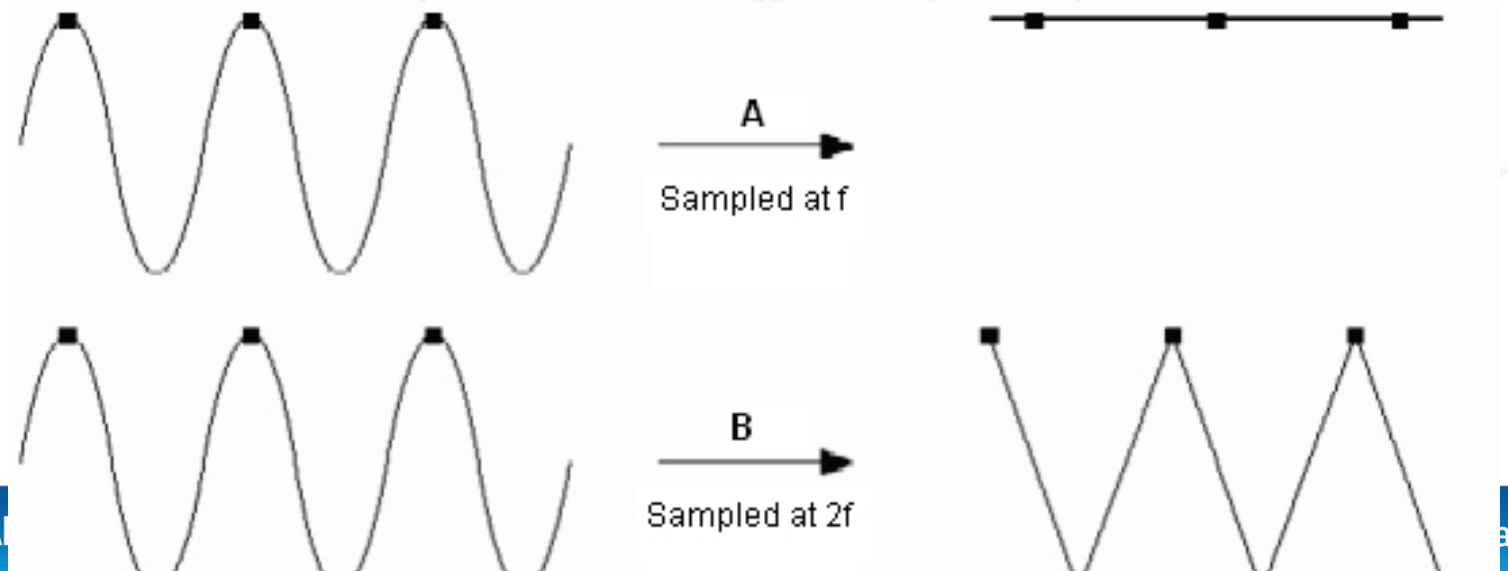
Tide Gauge:
High temporal sampling

Satellite altimetry:
low temporal sampling
=>Aliasing

”Critical Sampling”
(cryosat-2 vs annual signal
ers/envisat/saral/hy-2 vs S2)”

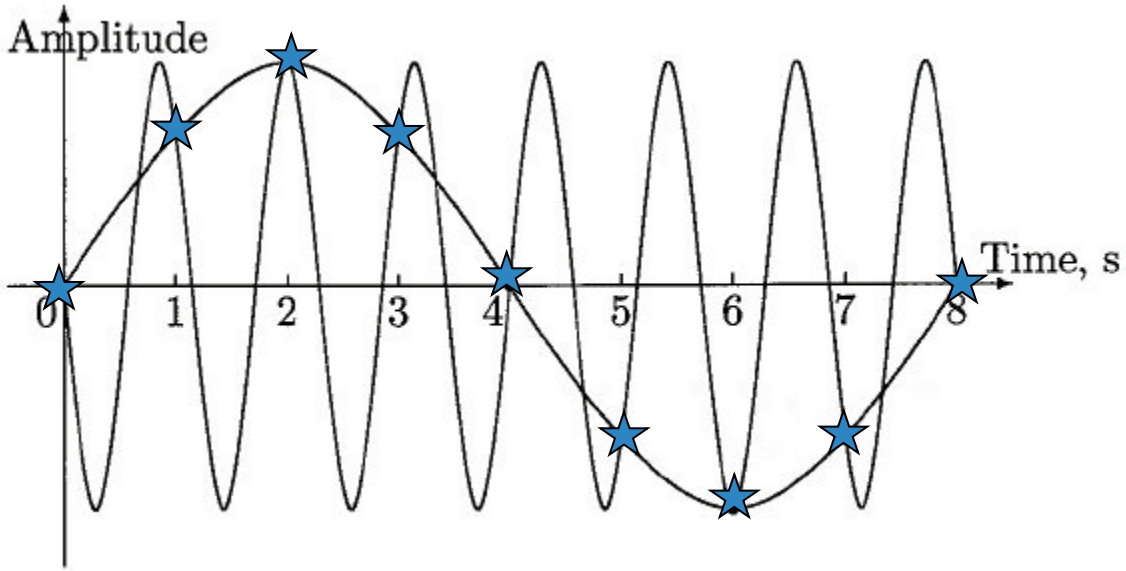
Adequately Sampled Signal

Aliased Signal Due to Undersampling



Sampling:

The FUNDAMENTAL Arctic Problem is Alias Periods



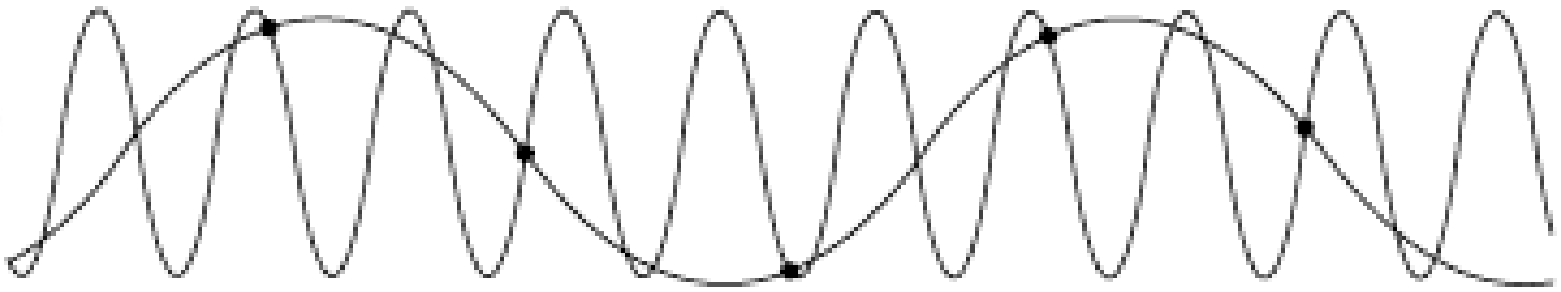
Tides	Tidal Period, hours	Aliased Period, days: ERS/ENVISAT SARAL (35 day)	Aliased Period, days: TOPEX/POSEIDON 10-Day Repeat Orbit
M_2	12.42	−95	62
S_2	12.00	∞	−59
N_2	12.67	97	−50
K_2	11.97	183	−87
O_1	25.82	−75	46
P_1	24.07	−365	−89
K_1	23.93	365	−173
Q_1	26.87	133	−69
M_m	661.30	130	28
M_f	327.84	−80	−36
S_{sa}	4383.00	183	183

Cryosat-2 (369 day)

20.1 years

Actually
All > likely lifetime
Of Cryosat-2.

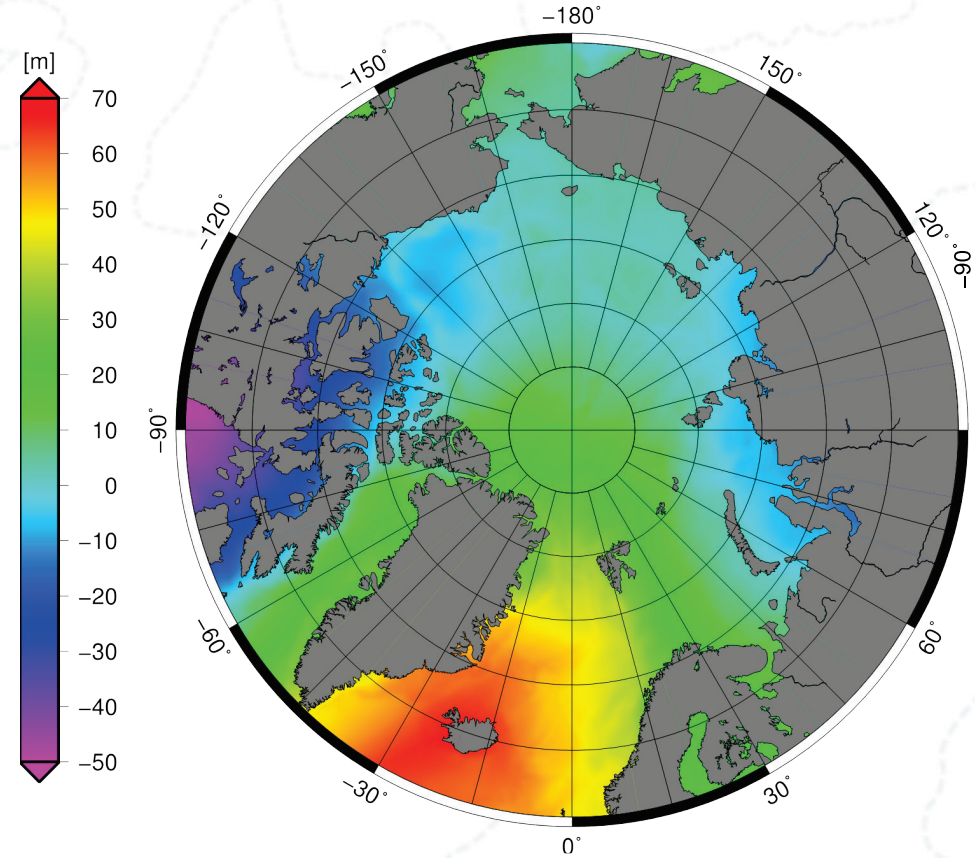
Aliasing

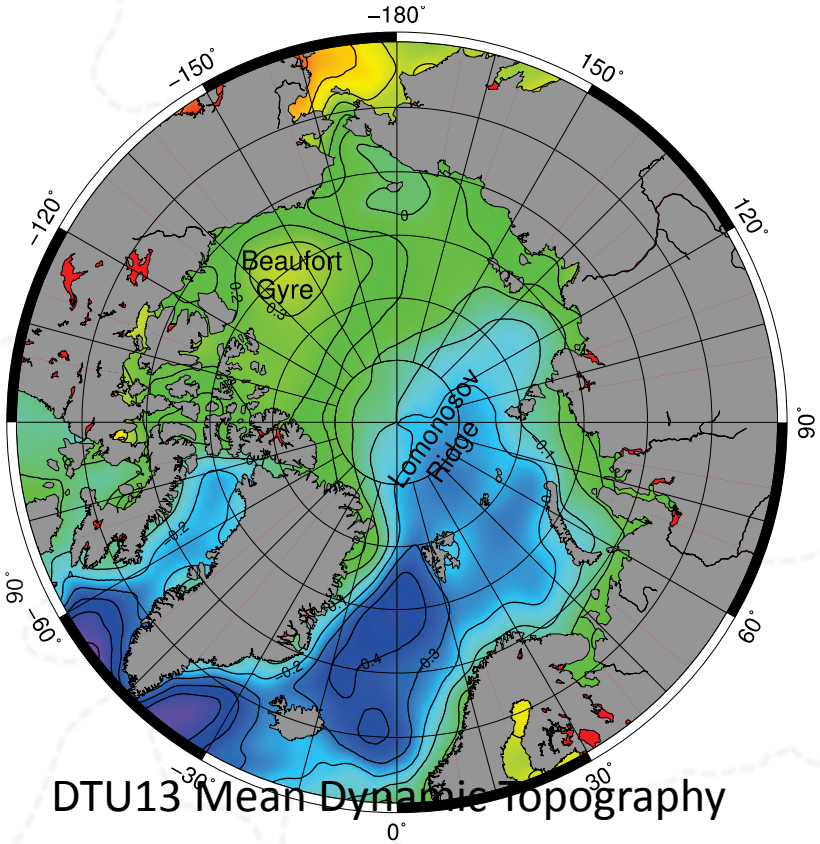


Satellite altimetry samples fN = fs / 2 signals above the Nyquist frequency appears like signals below the Nyquist frequency. If you sample at 2 times the signal frequency you will get no signal.
P(S2) = 0.5 days. Topex/Poseidon samples at PS=9.9156 days
After 9.9156 days Ps-nP(S2) = -0.0844 d (9.9156-20*0.5)
In one day S2 phase change is 2 * 360 ° = 720 °
So 0.0844 days correspond to a phase change of 60.76°
So a full 360 ° signal is obtained after 360/60.76* 9.9156 d = 58.76days

Examples of Putting it all together

DTU13 Mean Sea Surface



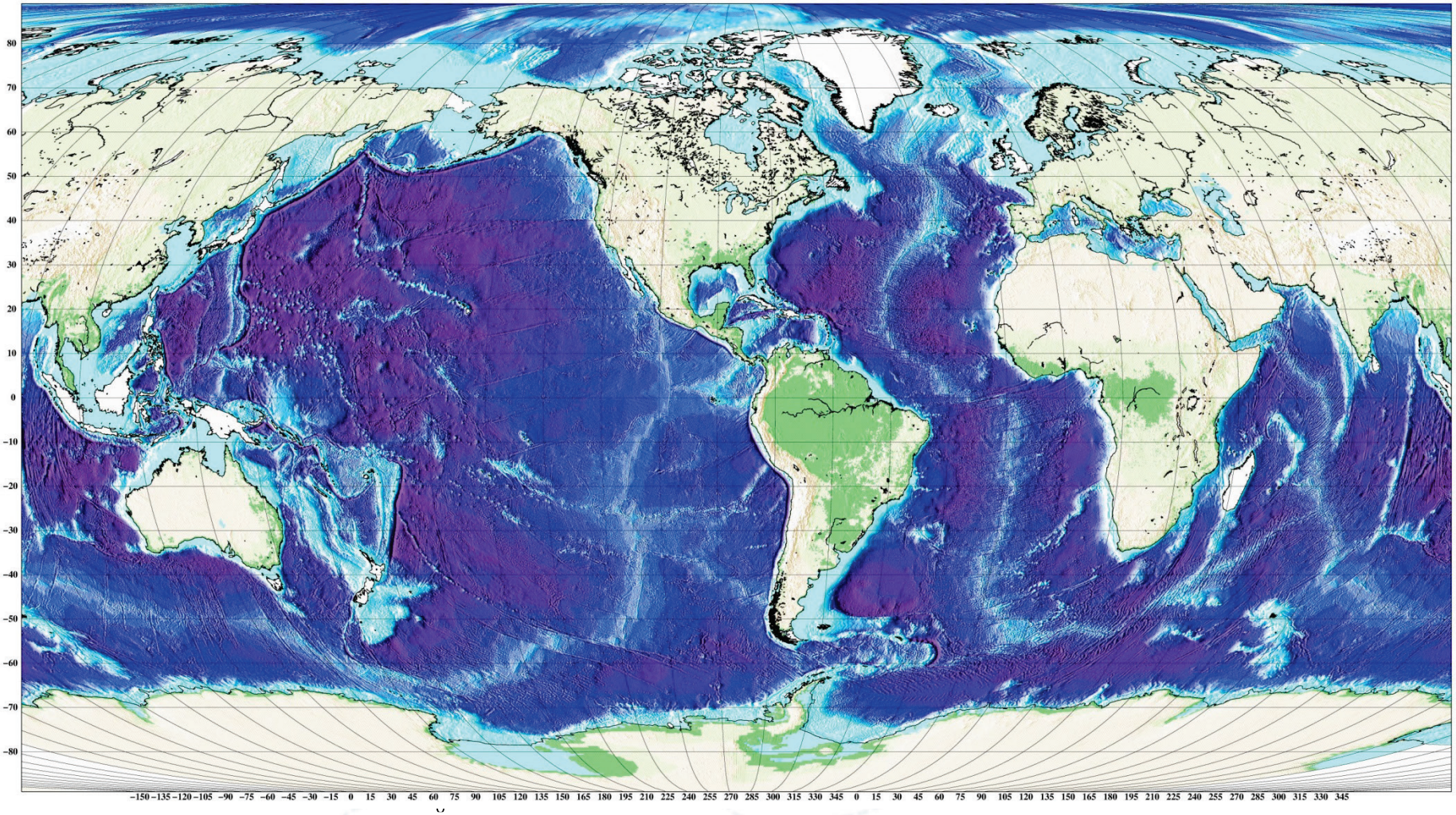


DTU13 Mean Dynamic Topography

ftp://ftp.space.dtu.dk/pub/DTU13

Stenseng et al. (2013/2014)

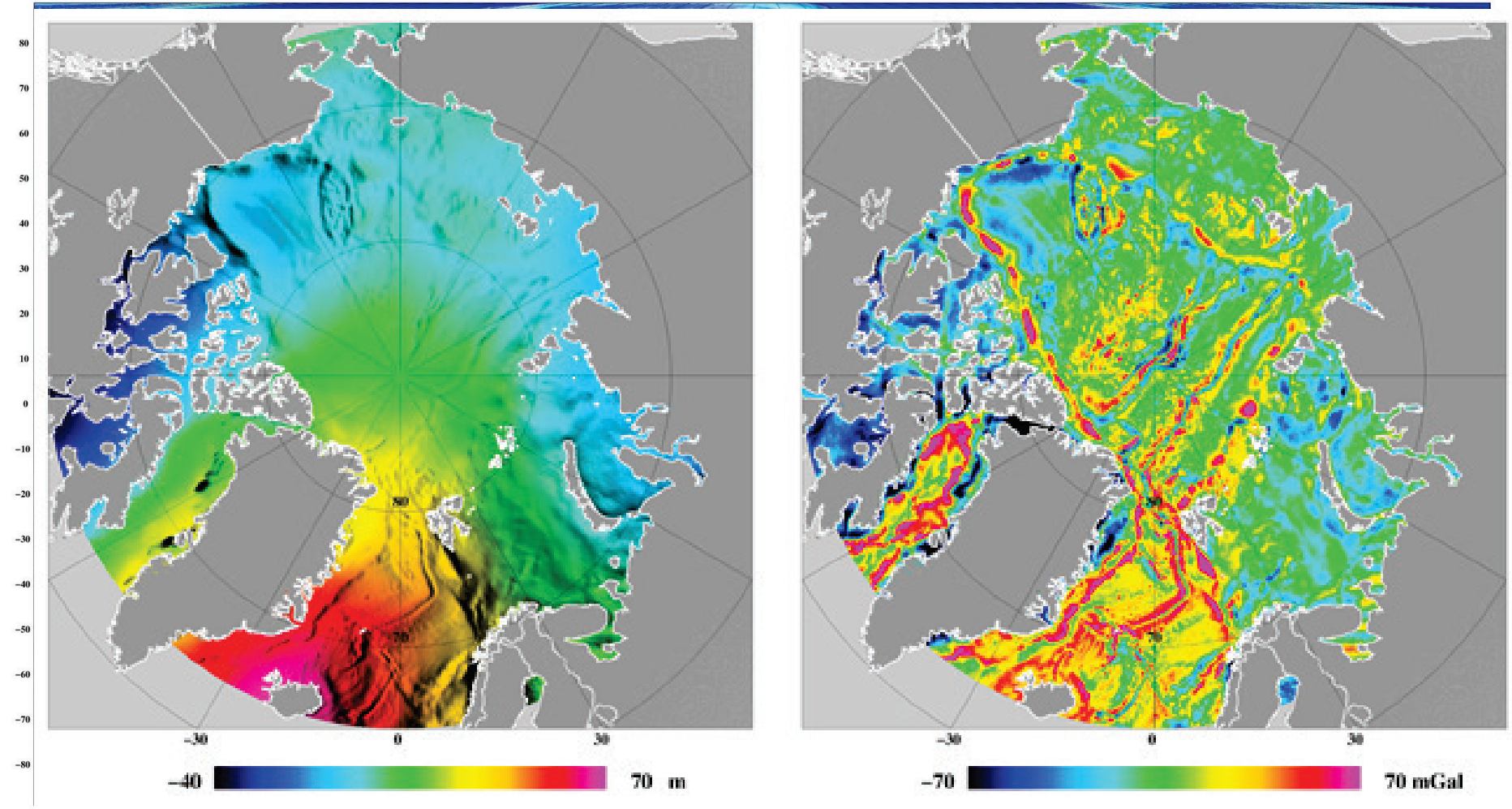
Examples of Putting it all together



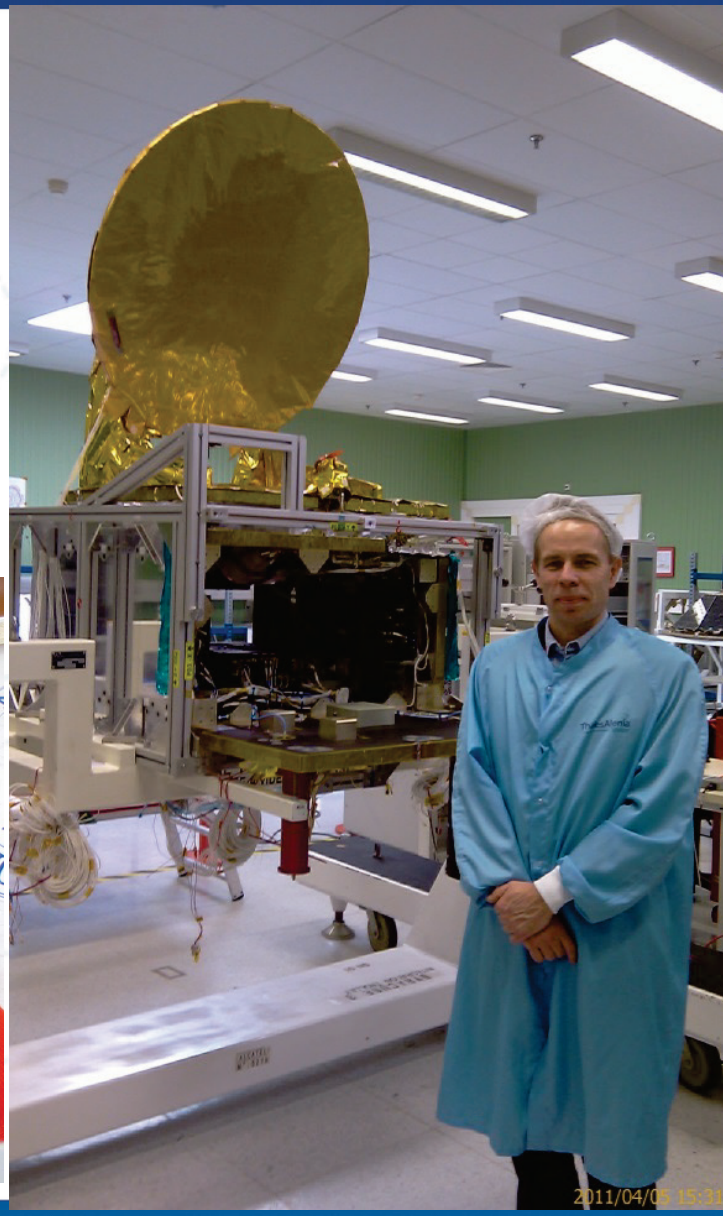
L3

014)

Examples of Putting it all together



Questions?
If you are still awake!



Bibliography

- Andersen, O. B., P. Knudsen and P. Berry (2010) The DNSC08GRA global marine gravity field from double retracked satellite altimetry, Journal of Geodesy, Volume 84, Number 3, DOI: 10.1007/s00190-009-0355-9
- Andersen, O. B., Egbert, G. D, Erofeeva, L., and Ray R. (2006) Mapping nonlinear shallow water tides: a look at the past and Andersen, O. B., and R. Scharroo (2010), Range and geophysical corrections in coastal regions, book chapter in eds. (Vignudelli i et al), Coastal altimetry, ISBN: 978-3-642-12795-3 future, Ocean Dynamics 56, 5-6
- Armitage, T. W. K. and Davidson, M. W. J. (2014). Using the Interferometric Capabilities of the ESA CryoSat-2 Mission to Improve the Accuracy of Sea Ice Freeboard Retrievals. *IEEE Transactions on Geoscience and Remote Sensing*, 52(1):529-536.
- Dominguez, R. (2010, updated 2014). IceBridge DMS L1B geolocated and orthorectified images. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.
- Davis, C. H. (1997). A robust threshold retracking algorithm for measuring ice-sheet surface elevation change from satellite radar altimeters. *IEEE Transactions on Geoscience and Remote Sensing*, 35(4):974–979.
- Krabill, W. B. (2014). IceBridge narrow swath ATM L1B elevation and return strength. version 2. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center.
- Scagliola, M. and Fornari, M. (2013). Known biases in cryosat level1b products. Technical Report C2-TN-ARS-GS-5135, Aresys.
- Stenseng, L. (2014b). Product validation report - Polar Ocean. Technical report, DTU Space, National Space Institute.
- Stenseng, L. (2014a). Algorithm theoretical baseline document - Polar Ocean. Technical report, DTU Space, National Space Institute.
- Stenseng, L., Andersen, O. B., and Knudsen, P. (2014). Enhancing the arctic mean sea surface and mean dynamic topography with cryosat-2 data. In *Geophysical Research Abstracts*, volume 16.
- Stenseng, L. and Andersen, O. B. (2013). Improving the arctic mean sea surface with cryosat-2 data. In *2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec.*, number G41B-0937.
- Stenseng, L. (2011). Polar remote sensing by CryoSat-type radar altimetry. PhD thesis, DTU Space, National Space Institute.

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