Radar Altimetry Theory in the Polar Ocean

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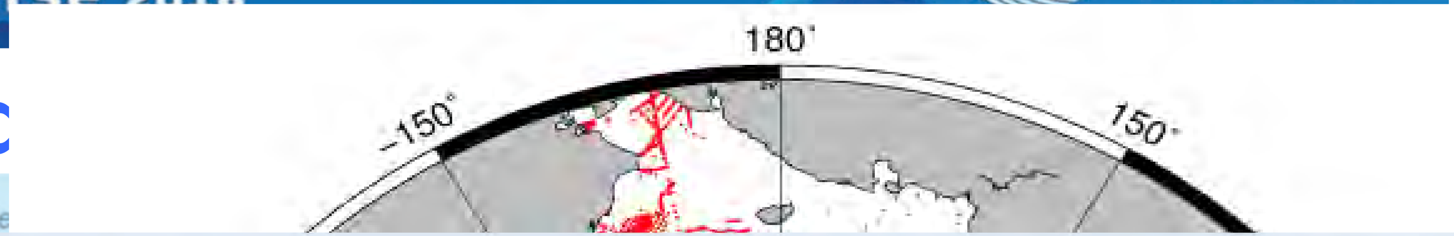
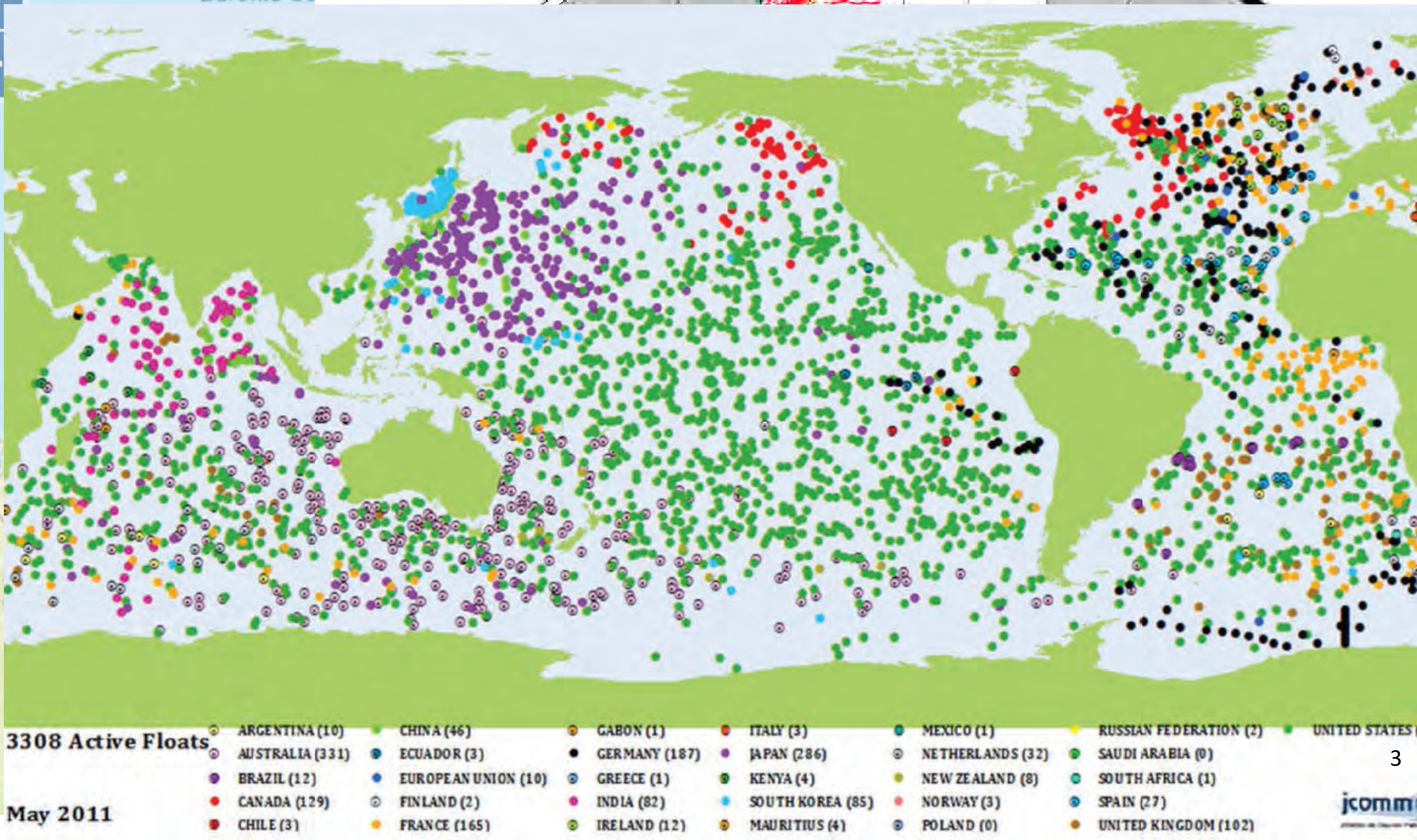
Overview

- Why: the importance for the Arctic
- What is satellite altimetry
- How to derive SSH, SWH and wind speed
- Satellite at worlds end
- Conventional (LRM) vs SAR
- Polar Ocean

Tic

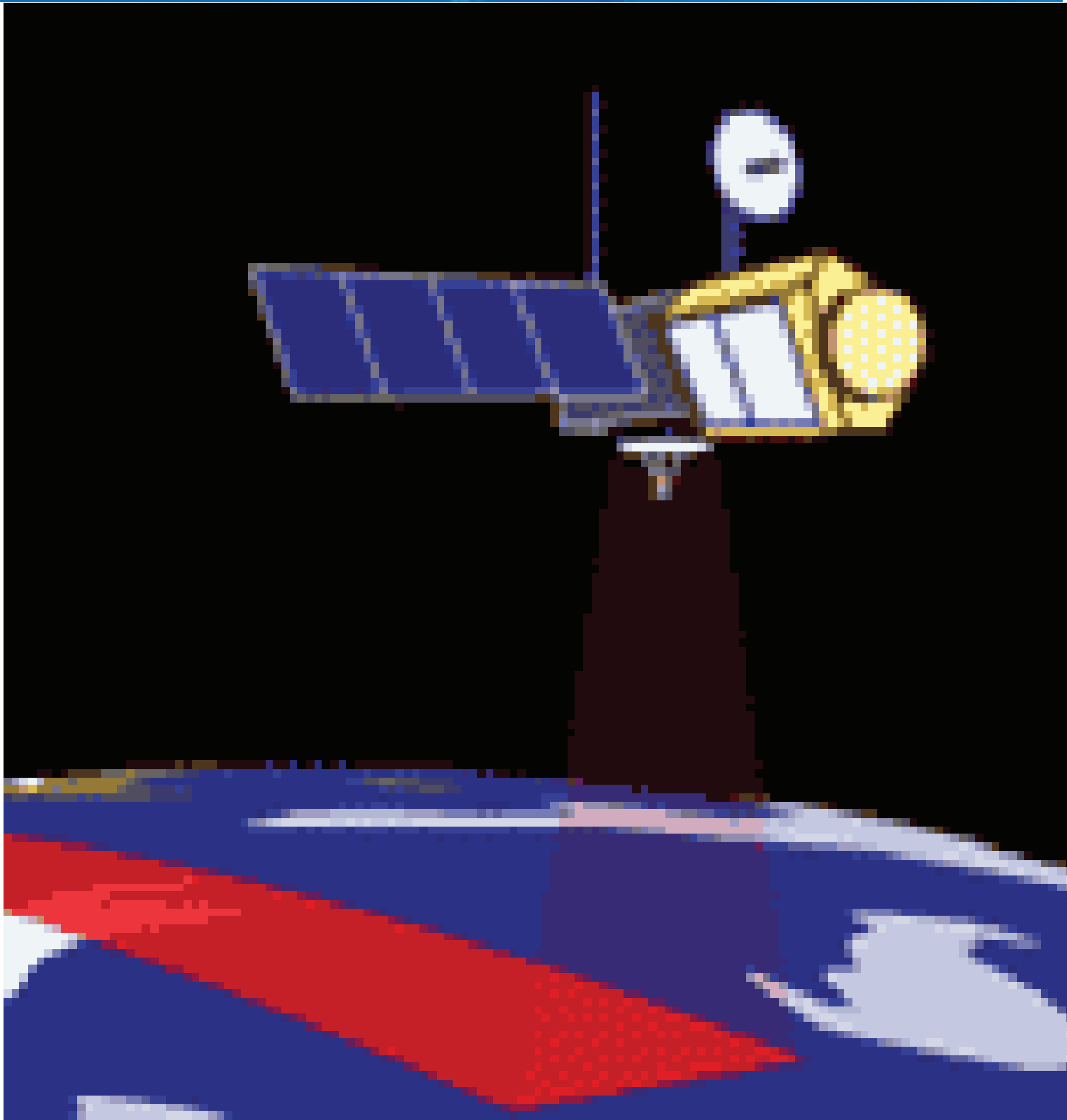

Barents Se


180°
-150°
150°


3308 Active Floats
May 2011
ARGENTINA (10)
AUSTRALIA (331)
BRAZIL (12)
CANADA (129)
CHILE (3)
CHINA (46)
ECUADOR (3)
EUROPEAN UNION (10)
FINLAND (2)
FRANCE (165)
GABON (1)
GERMANY (187)
GREECE (1)
INDIA (82)
IRELAND (12)
ITALY (3)
JAPAN (286)
KENYA (4)
SOUTH KOREA (85)
MAURITIUS (4)
MEXICO (1)
NETHERLANDS (32)
NEW ZEALAND (8)
NORWAY (3)
POLAND (0)
RUSSIAN FEDERATION (2)
SAUDI ARABIA (0)
SOUTH AFRICA (1)
SPAIN (27)
UNITED KINGDOM (102)
UNITED STATES

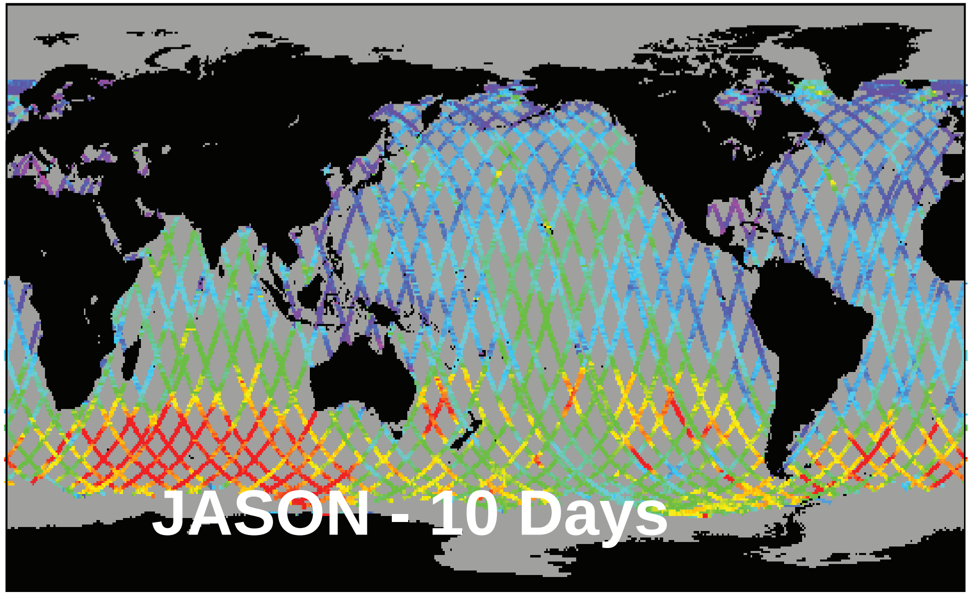
Satellite Altimeters

- Nadir looking
- Only one point
- PRF=2-4000 kHz
- 1 hz = 6 km
- 20Hz =300 m
- <100 m



Orbit parameters

The coverage of the sea surface depends on the orbit parameters (inclination of the orbit plane and repeat period).



	Satellite	Repeat Period	Track spacing	Inclination Coverage
Repeating (ERM)	ERS1/ERS2/ENVISAT	35 days	95 km	98°(+/-82)
	Sentinel 3A+B	27 days	70/35 km	98°(+/-82)
	JASON 1-2-3	9.915days	315 km	66.5°
Geodetic	Cryosat-2	369 days	7 km	88°

What can satellite altimetry provide

- Mapping sea level (and its changes and its rise)
- Sea level extremes & predictions
- Mapping freshwater storage and
- Mapping ocean currents and freshwater-fluxes
- Mapping gravity field and bathymetry
- Mapping sea ice thickness and decline (mass)
- Mapping of ice-sheet and ice-caps
- Mapping of River and lakes.

- SATELLITE ALTIMERY PROVIDE **LONG TERM** MONITORING AND **UNIQUE SPATIAL SAMPLING**.

Principle of satellite altimetry

(1) Radars transmit pulses of electromagnetic radiation at radio frequencies

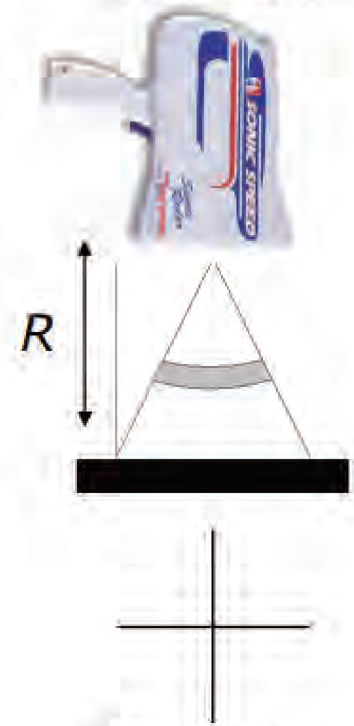
(2) The radar pulse is scattered or reflected by solid surfaces.

(3) The backscattered pulse (echo) is detected by the radar receiver

(4) The pulse travel time is recorded.

(5) The travel time is converted into the distance (range) separating the radar and the surface.

Side view

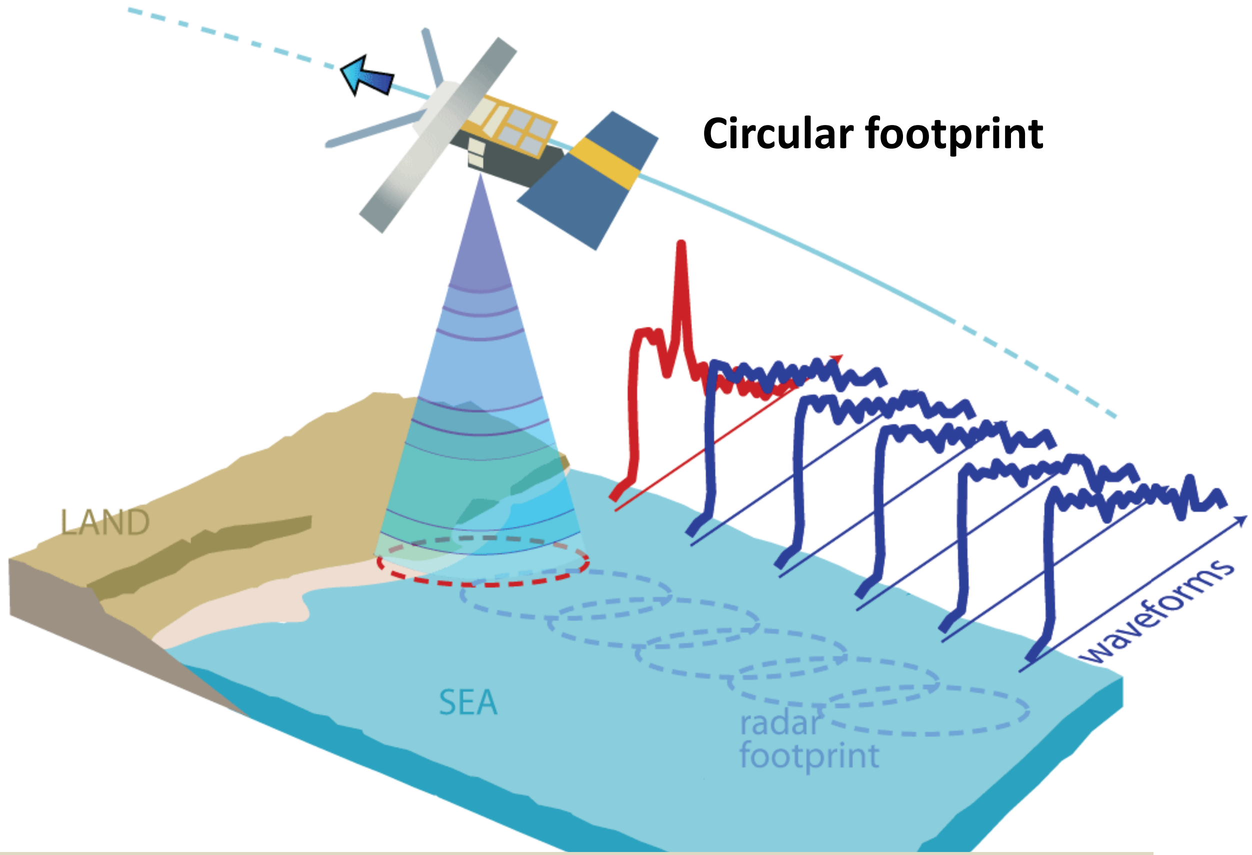


Plan view

How: Conventional LRM (low resolution)

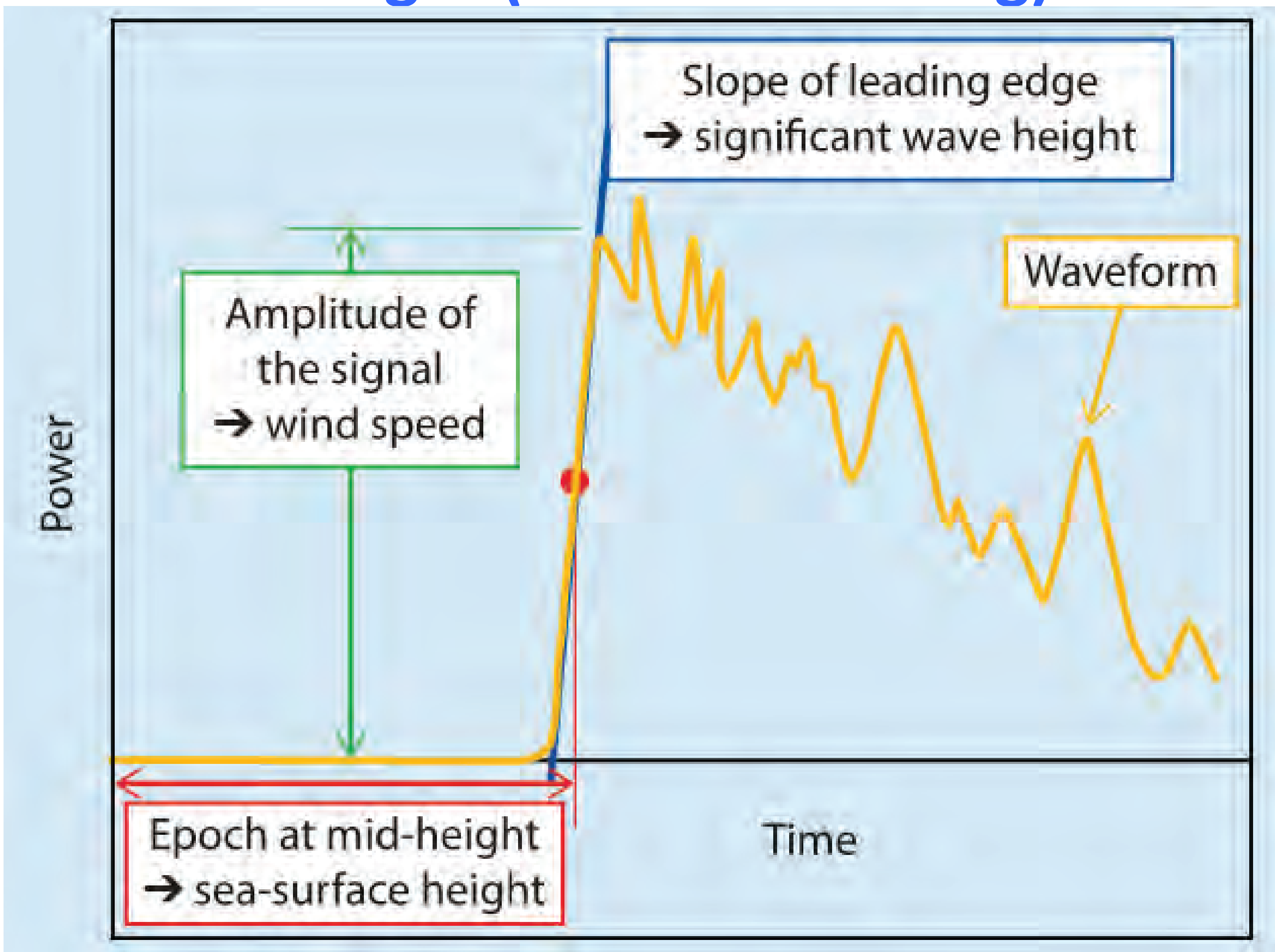
WF = FSSR * PTR * PDF

WF : Waveform
FSSR : Flat Sea Surface Response
PTR : Point Target Response
PDF : Probability Density Function of wave heights within footprint



IMPORTANT……….
Typical foot-print is 100-300 km2
ALL REFLECTORS (ocean, sea ice, land) within footprint contribute to waveform.
Water is better reflector than i.e. land – so will dominate…

From Power(t) to Epoch or sea surface height (waveform fitting)



Altimetric Observations

Trick:

You turn accurate time (epoch) into Range(Distance x2) and hence SSH

Based on Equation: Range = time * c / 2

c is speed of light (nearly constant)

SSH = Height_{sat} – Range

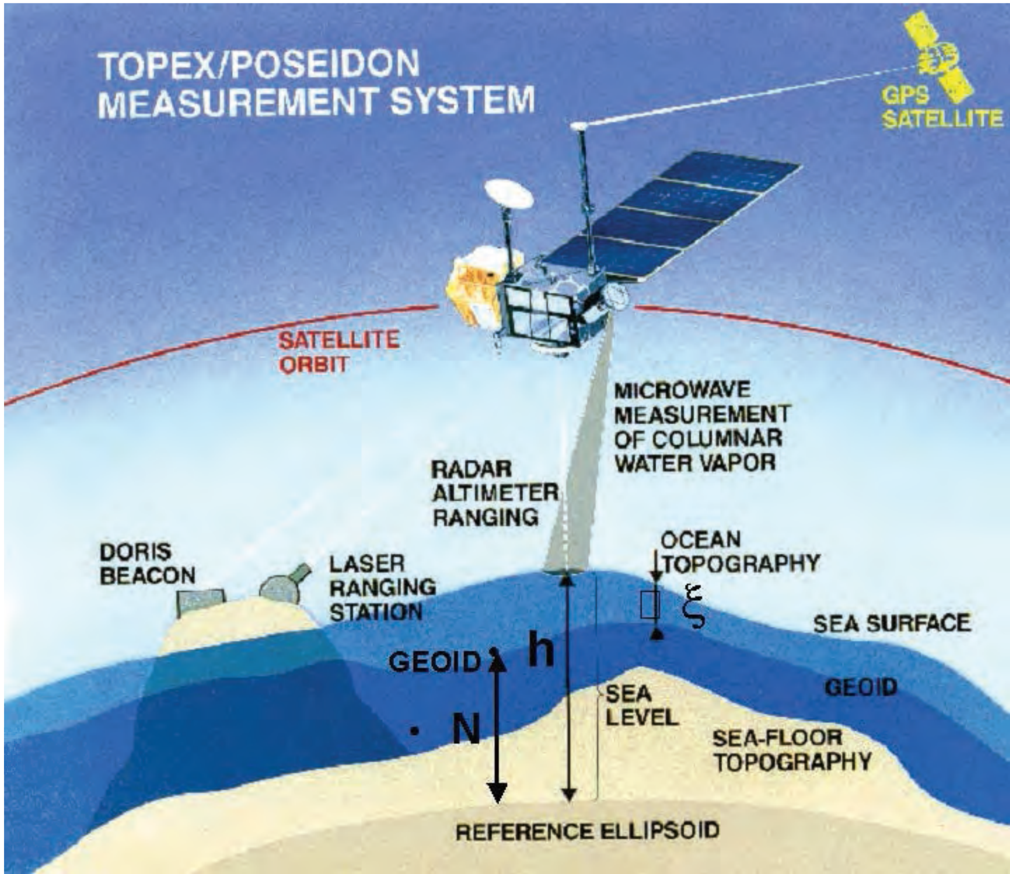
Height_{sat} is determined using

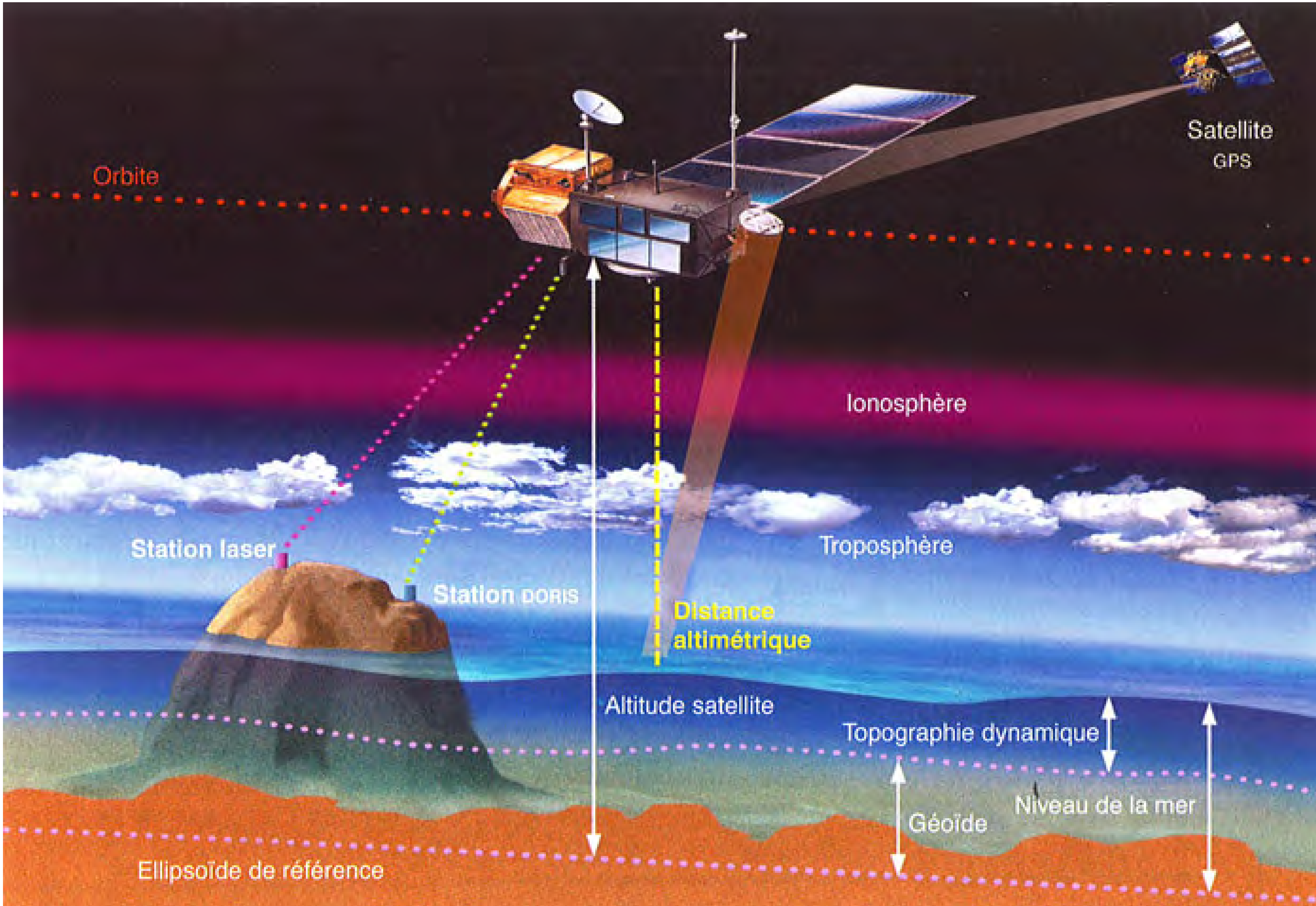
GPS or DORIS/Laser ranging

Relative to the reference ellipsoid

Ellipsoid is "best" mathematical

model of the Earth Shape (WGS84)




Orbite
Satellite
GPS
Ionosphère
Troposphère
Station laser
Station DORIS
Distance
altimétrique
Altitude satellite
Topographie dynamique
Niveau de la mer
Géoïde
Ellipsoïde de référence

Correcting the Range.

Correcting the Range.

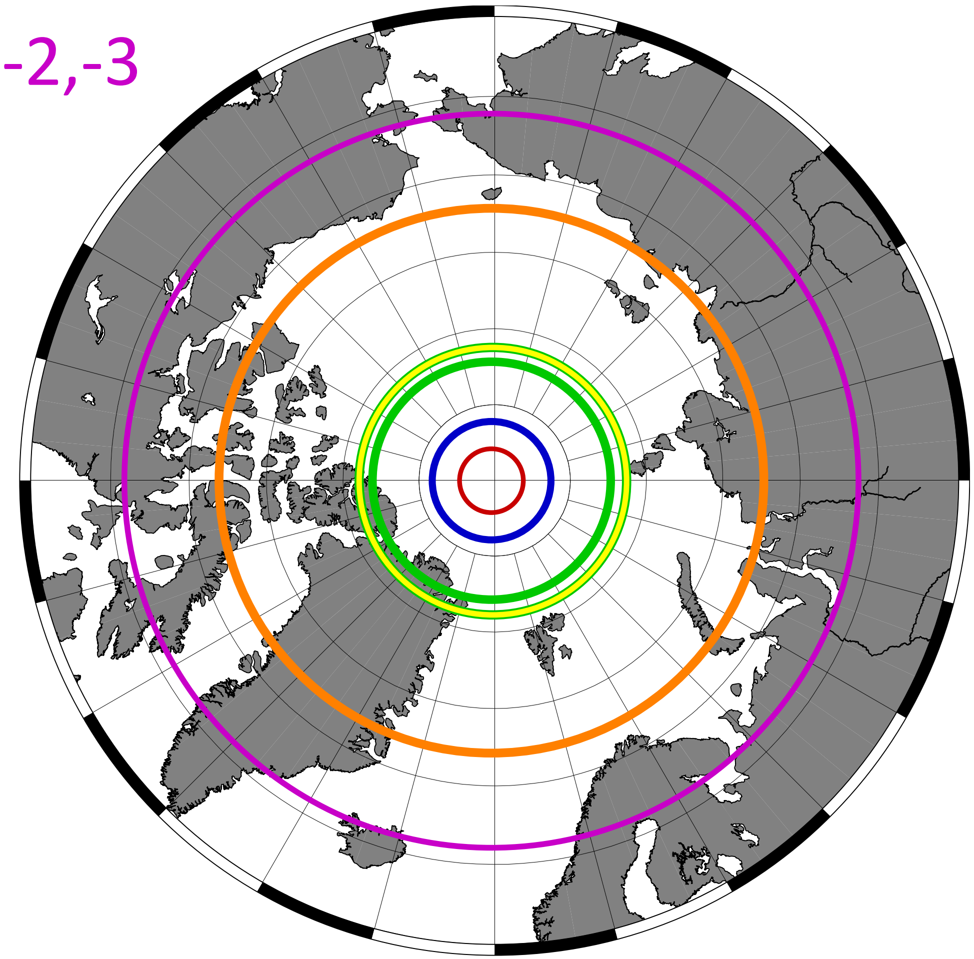
$$SSH = H - R_{ange} - \Delta h_{dry} - \Delta h_{wet} - \Delta h_{iono} - \Delta h_{ssb} - h_{tides} - h_{ib} - h_{geoid/MSS}$$

Range correction Surface+ Geophysical Corrections

Range is derived from the time R_{ange} = time*c/2

Altimetry at worlds end

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



Global sea level estimates leave out the Arctic Ocean (Jason based)

The Arctic Ocean

Sea ice concentration sept 2015 week


Photo: NASA

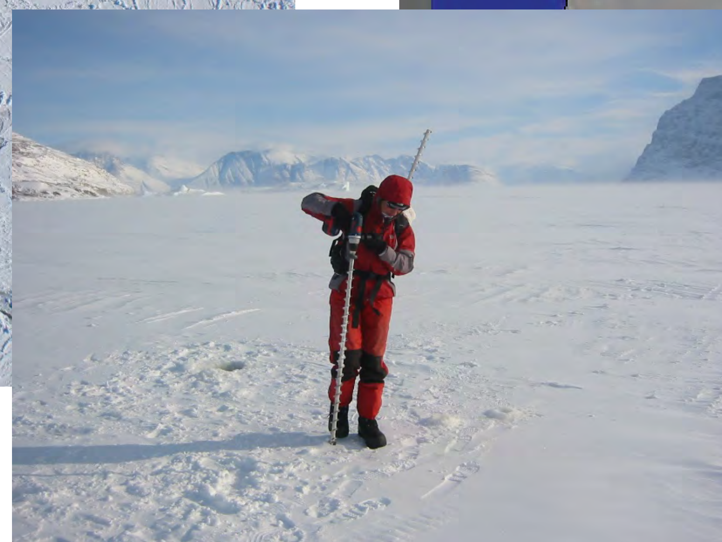
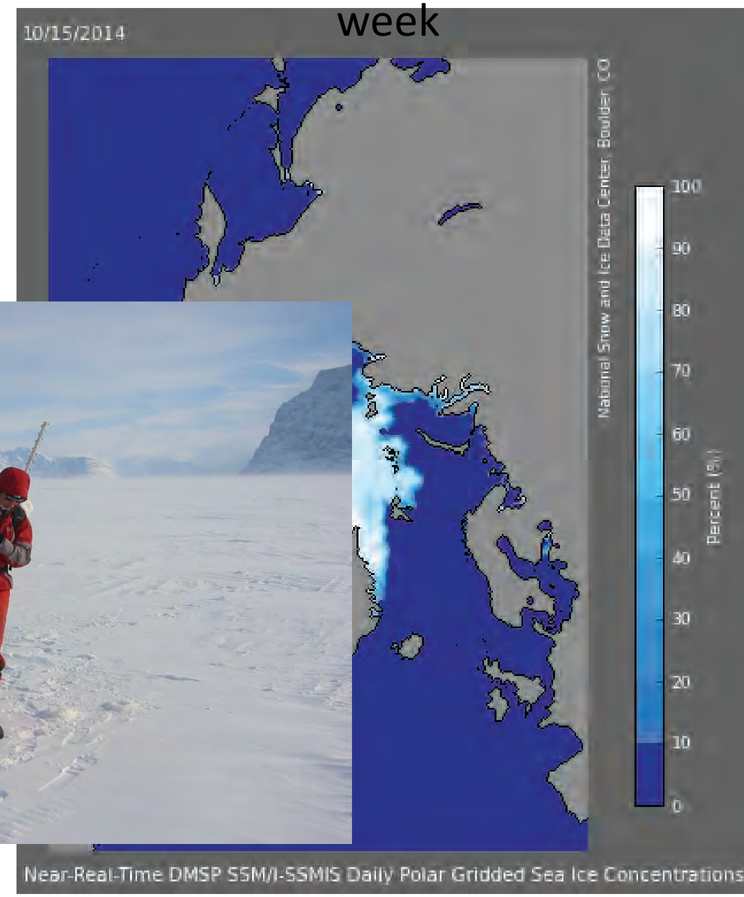


Photo: DTU Space



National Snow and Ice Data Center
Maslanik and Stroeve 1999

Conventional altimetry is frequently contaminated in the presence of sea ice due to the large footprint

Conventional:

Jasons, SA, ERS+ENV + HY

SAR altmeters

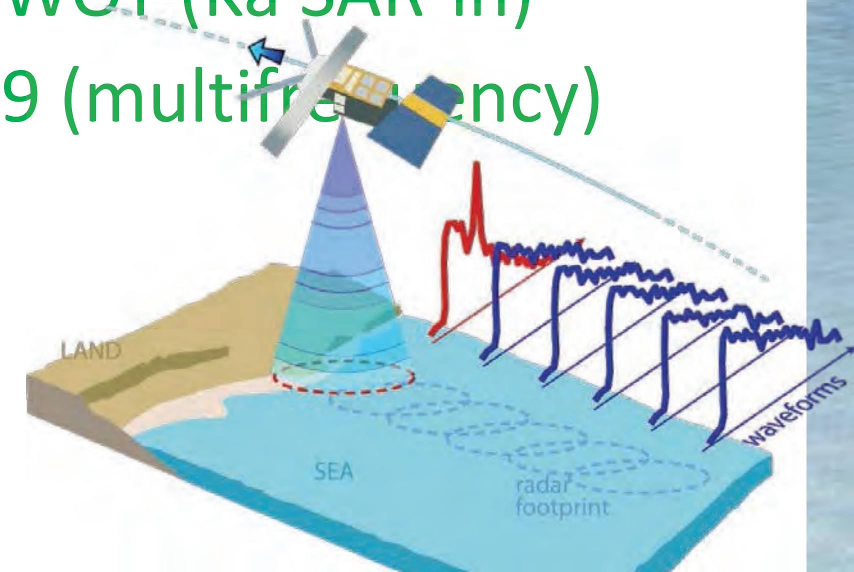
Cryosat-2, S3A+3B

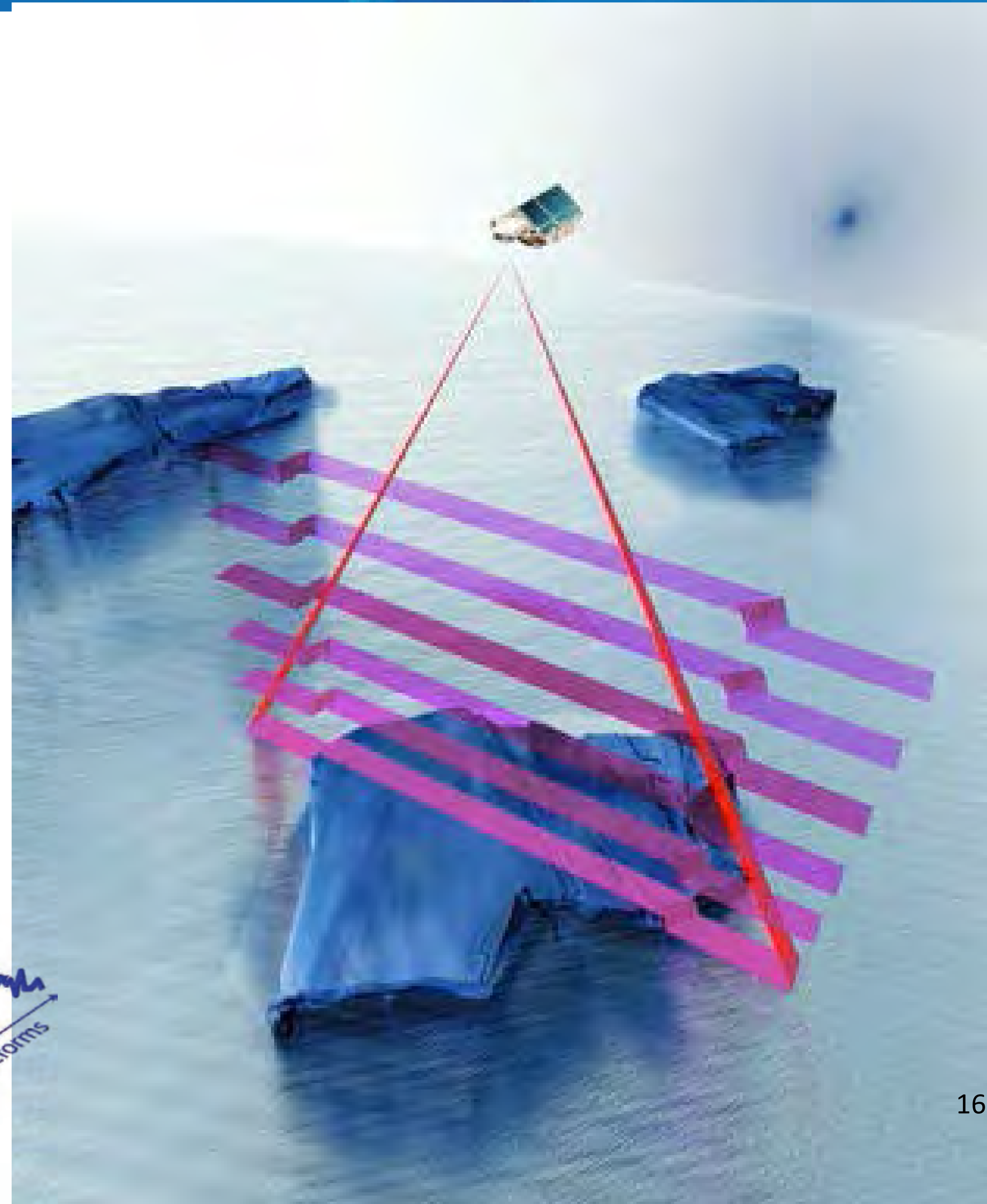
Next generation

S6 (2020) Both

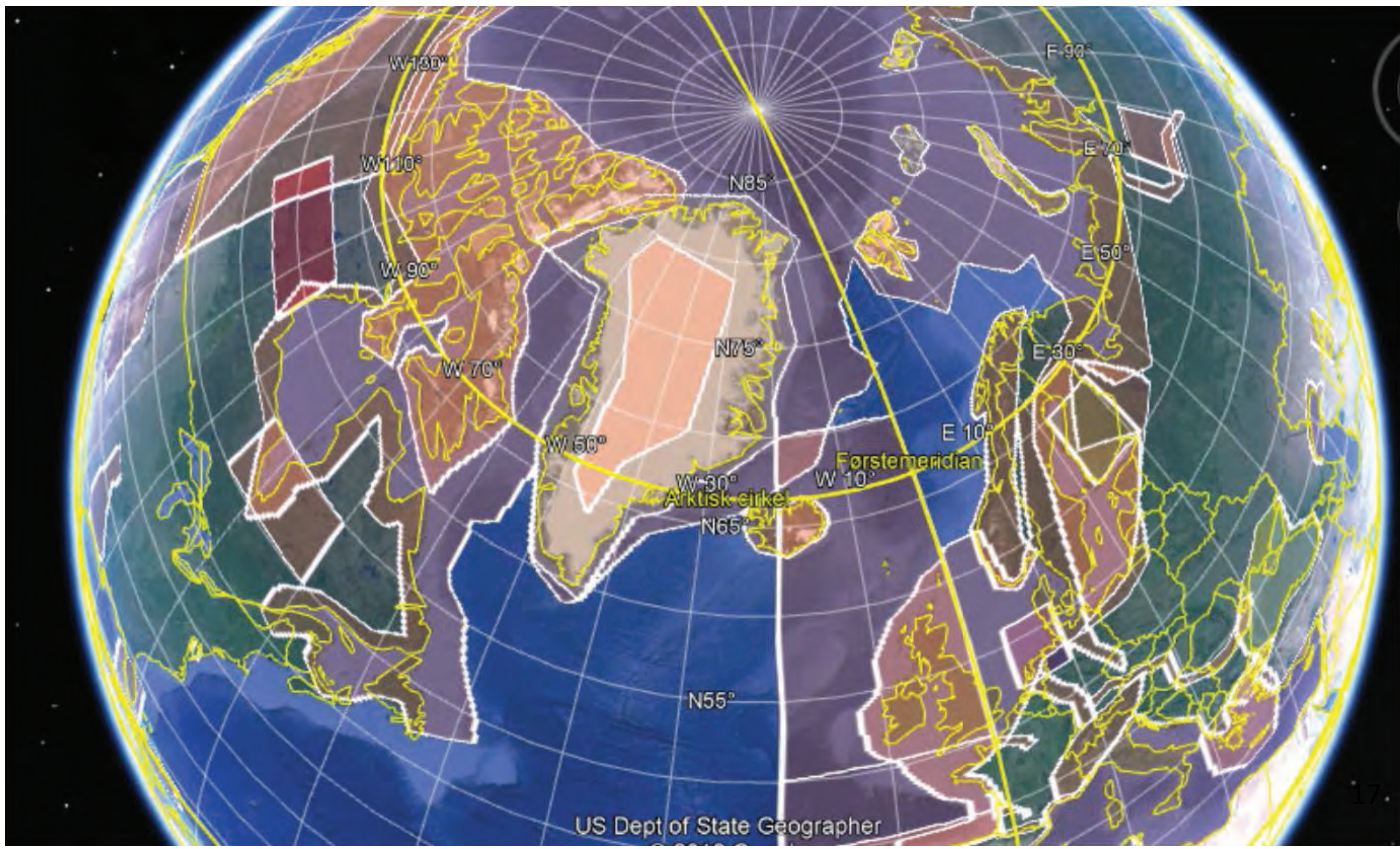
SWOT (Ka SAR-in)

S9 (multifrequency)



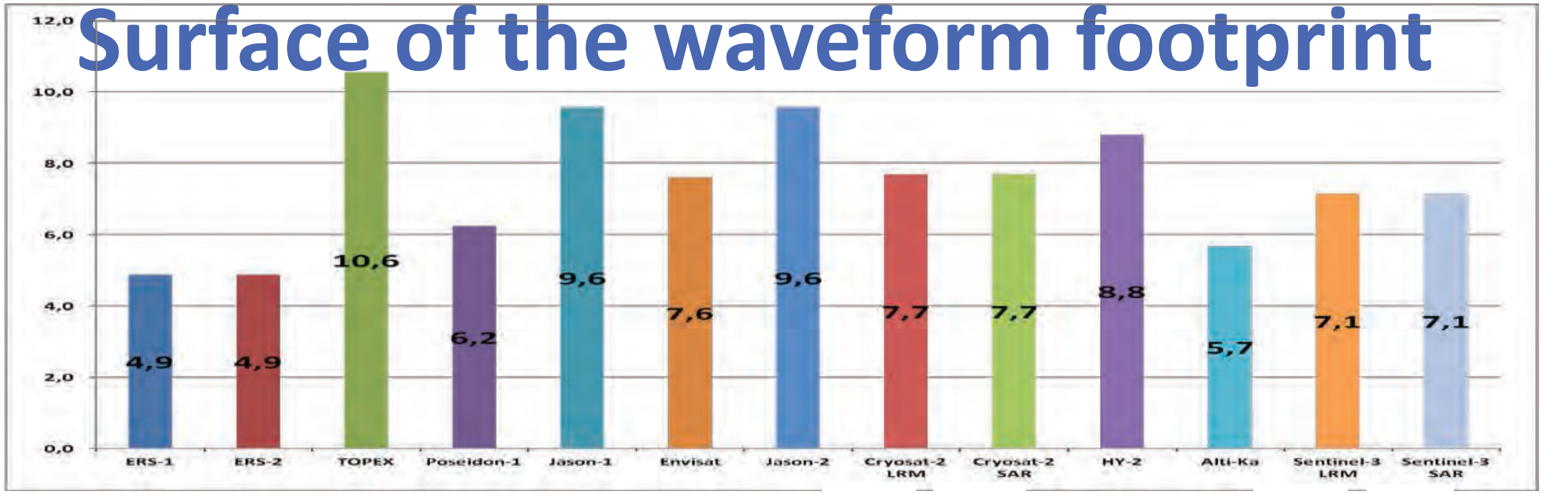


Cryosat-2 not SAR everywhere
Modemask controlled by 80% Arctic
Sentinel 3A+3B only SAR



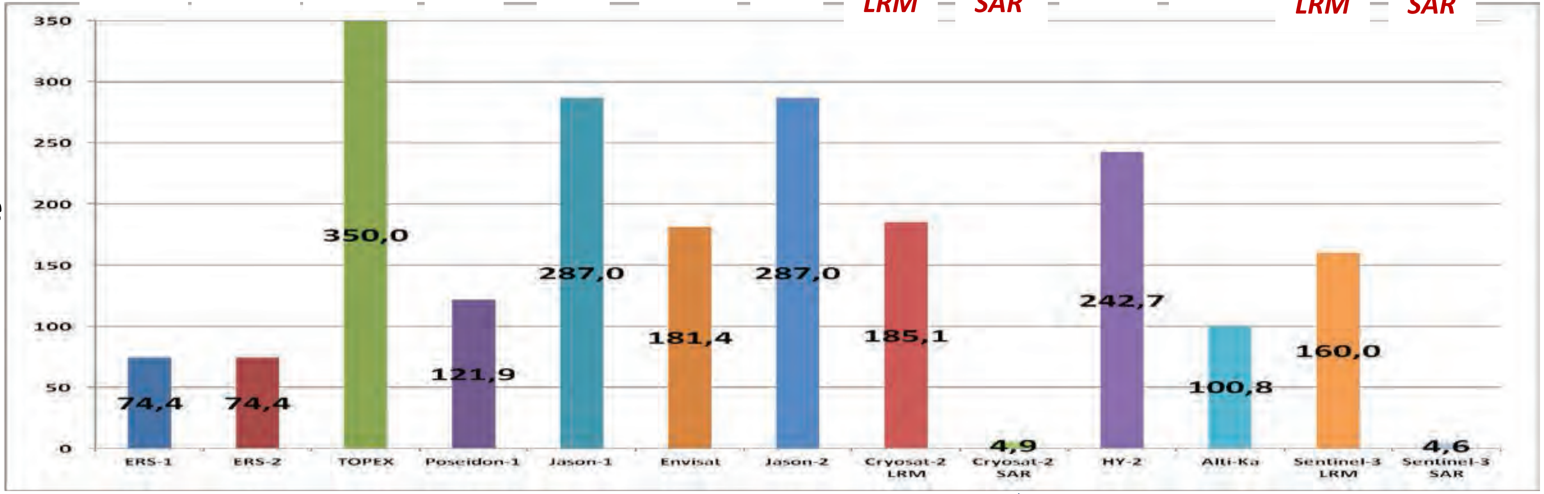
Surface of the waveform footprint

Radius of the waveform footprint (km)

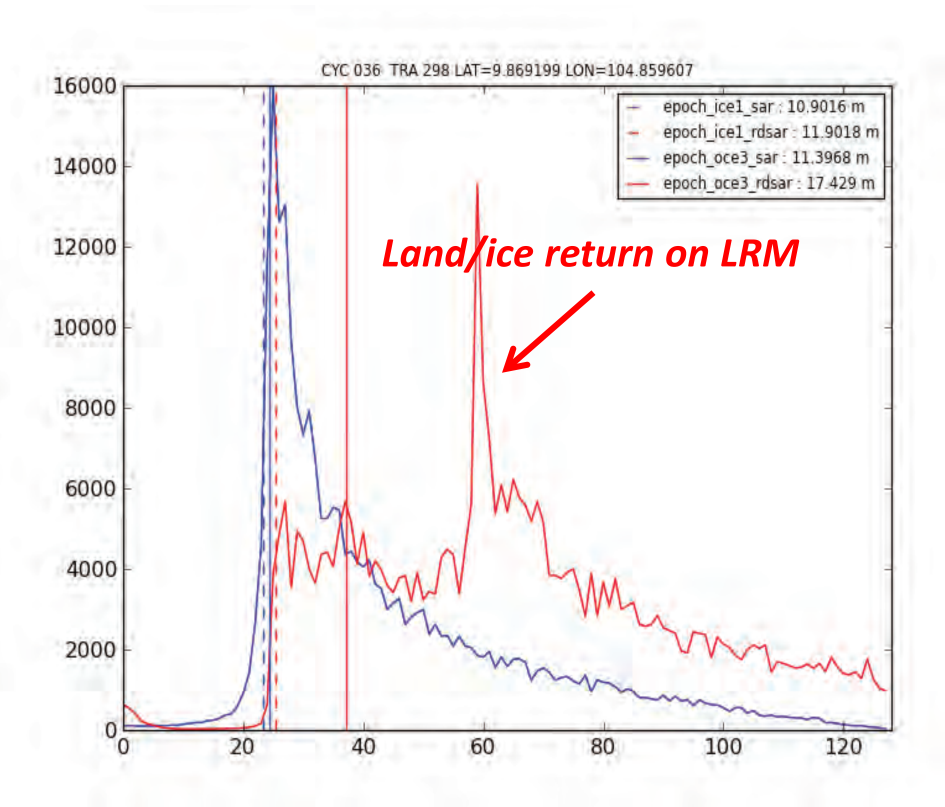


ERS-1 ERS-2 Topex P-1 J-1 RA-2 J-2 CS-2 LRM CS-2 SAR HY-2 AltiKa S3 LRM S3 SAR

Surface of the waveform footprint (km^2)

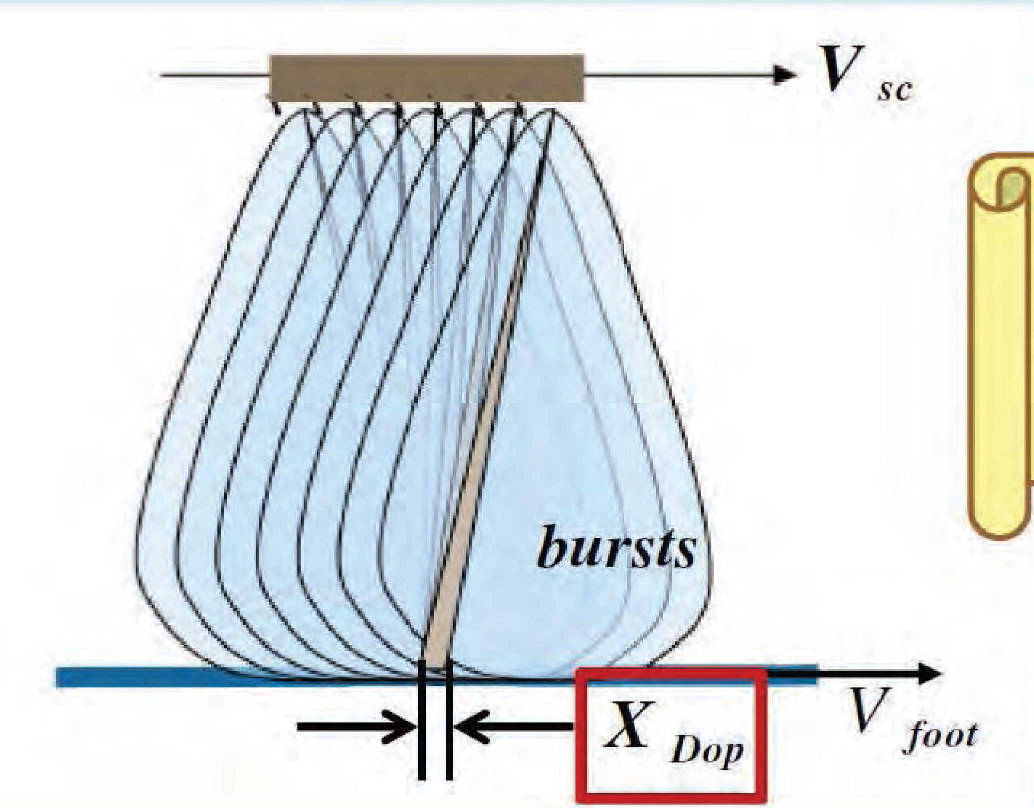


Far smaller change that SAR altimetry is contaminated due to smaller footprint



Notice: All reflectors within footprint contribute to waveform

Maximum precision (*minimum SSH std*) => maximum number of uncorrelated looks

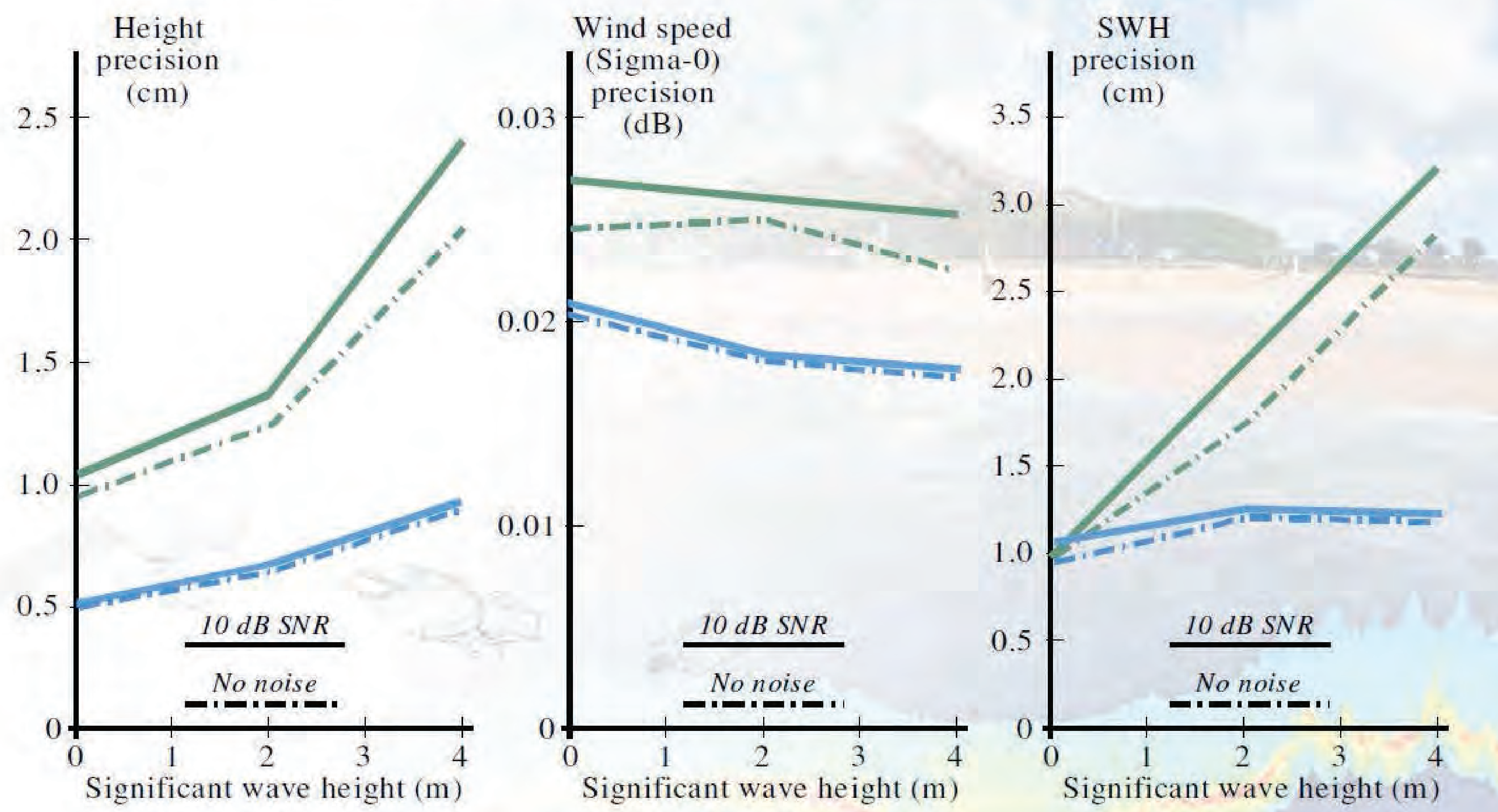


Smaller X_{Dop} implies larger number of looks per second N_{sec}

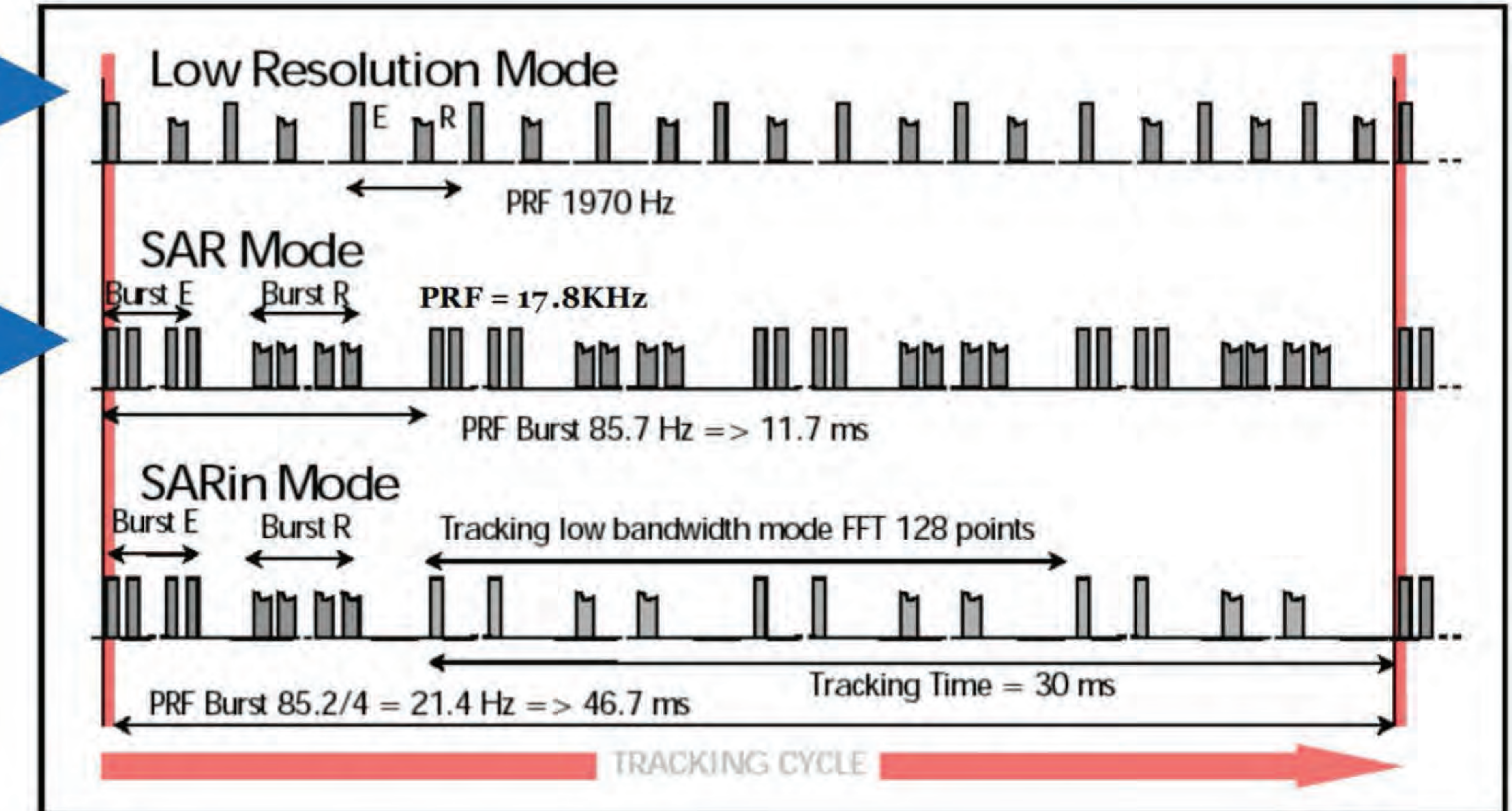
…but of course there are other considerations and trades

SAR Improved range "precision"

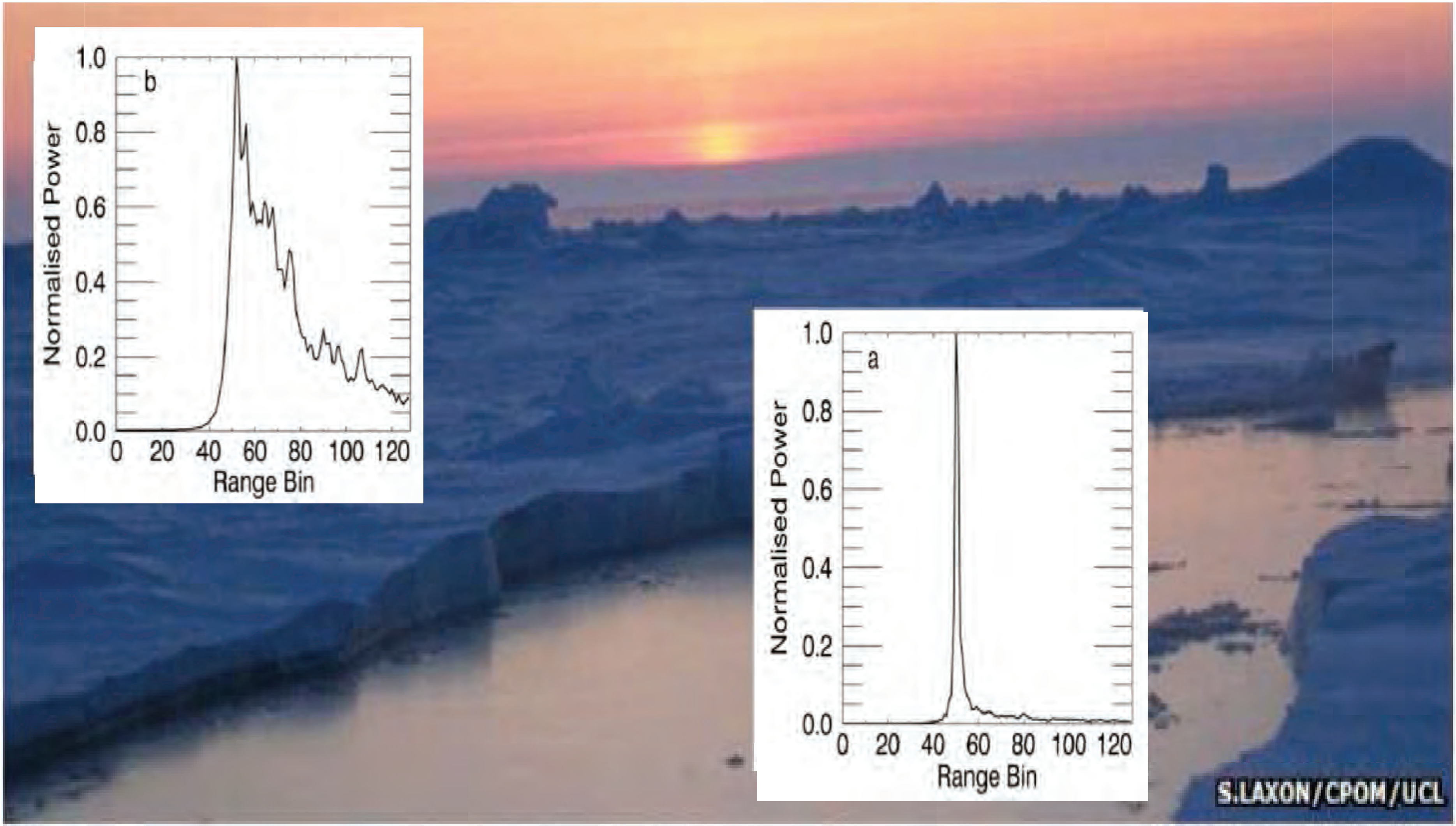
Delay/Doppler ~ *x2* ***better*** *than* *conventional*



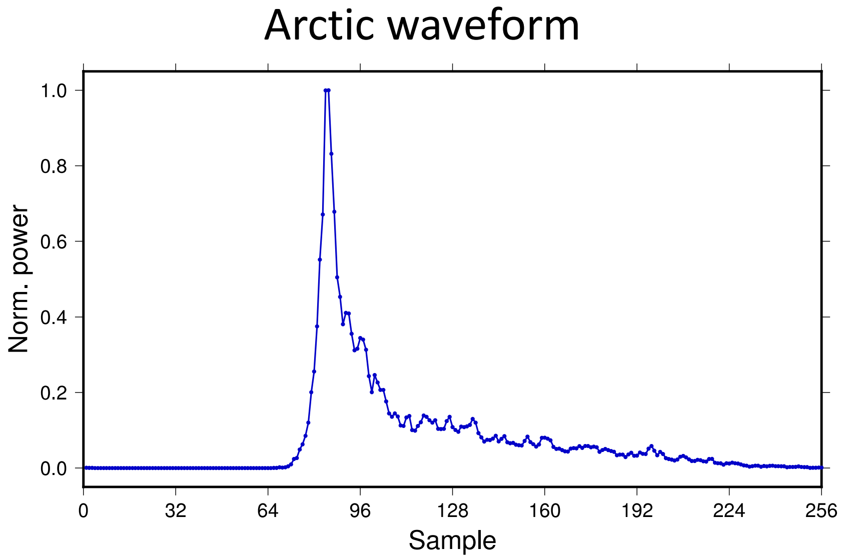
Unfortunately………………

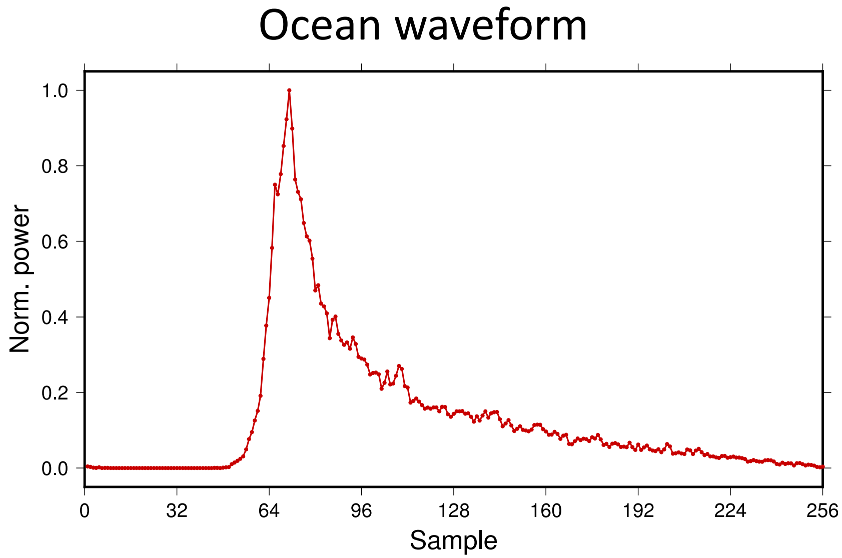


Polar Ocean – Arctic Waveforms



Waveforms in the Arctic

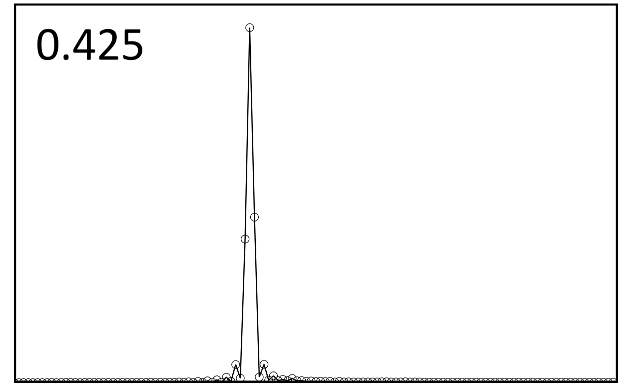


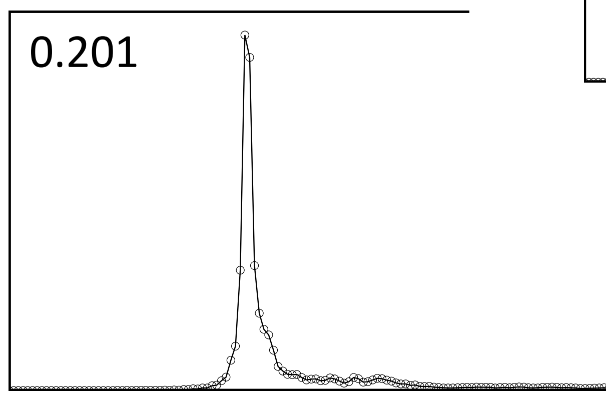


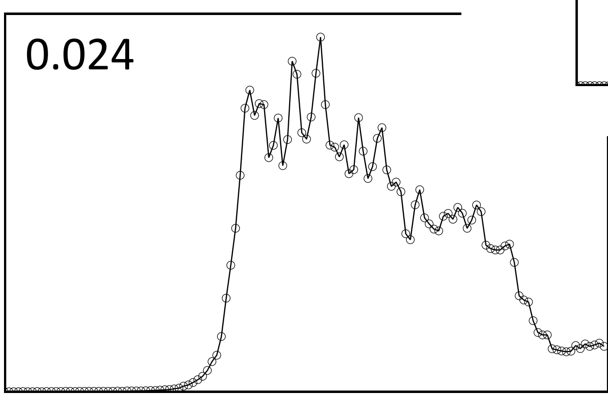
Classification

Pulse Peakiness (PP)

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



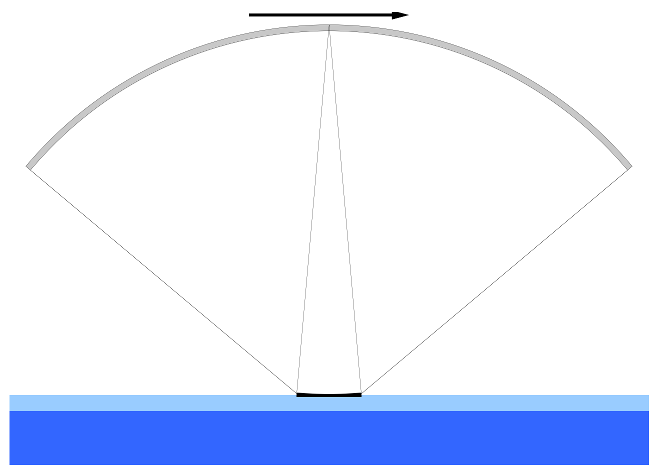




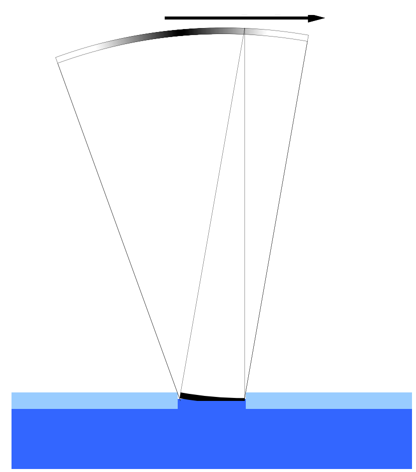
Francis (1991), Laxon (1994), and Stenseng (2014a)

C2+S3 Additional Classification using multi-look “stack” (SAR)

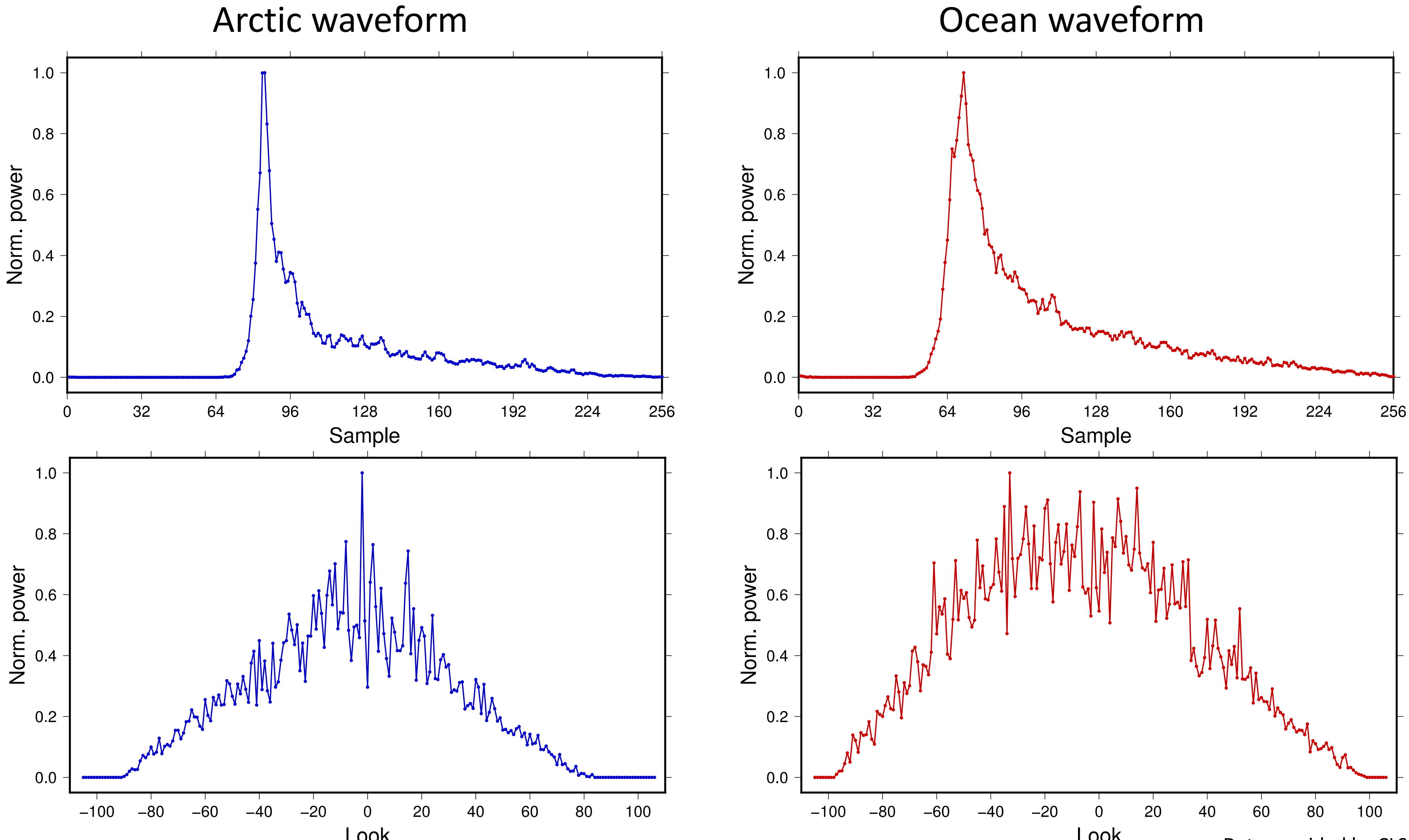
Sea ice



Lead in sea ice



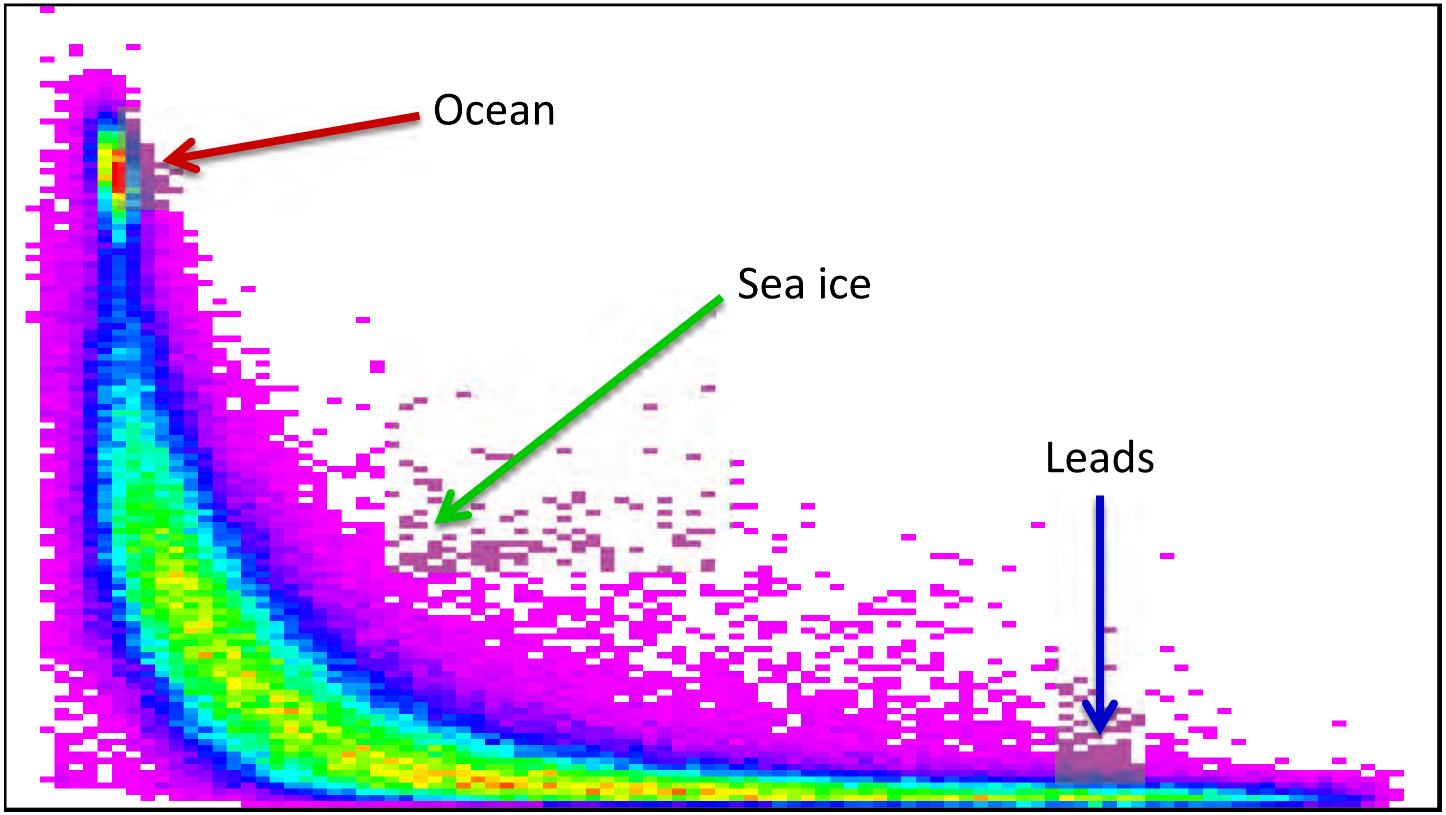
Waveforms in the Arctic

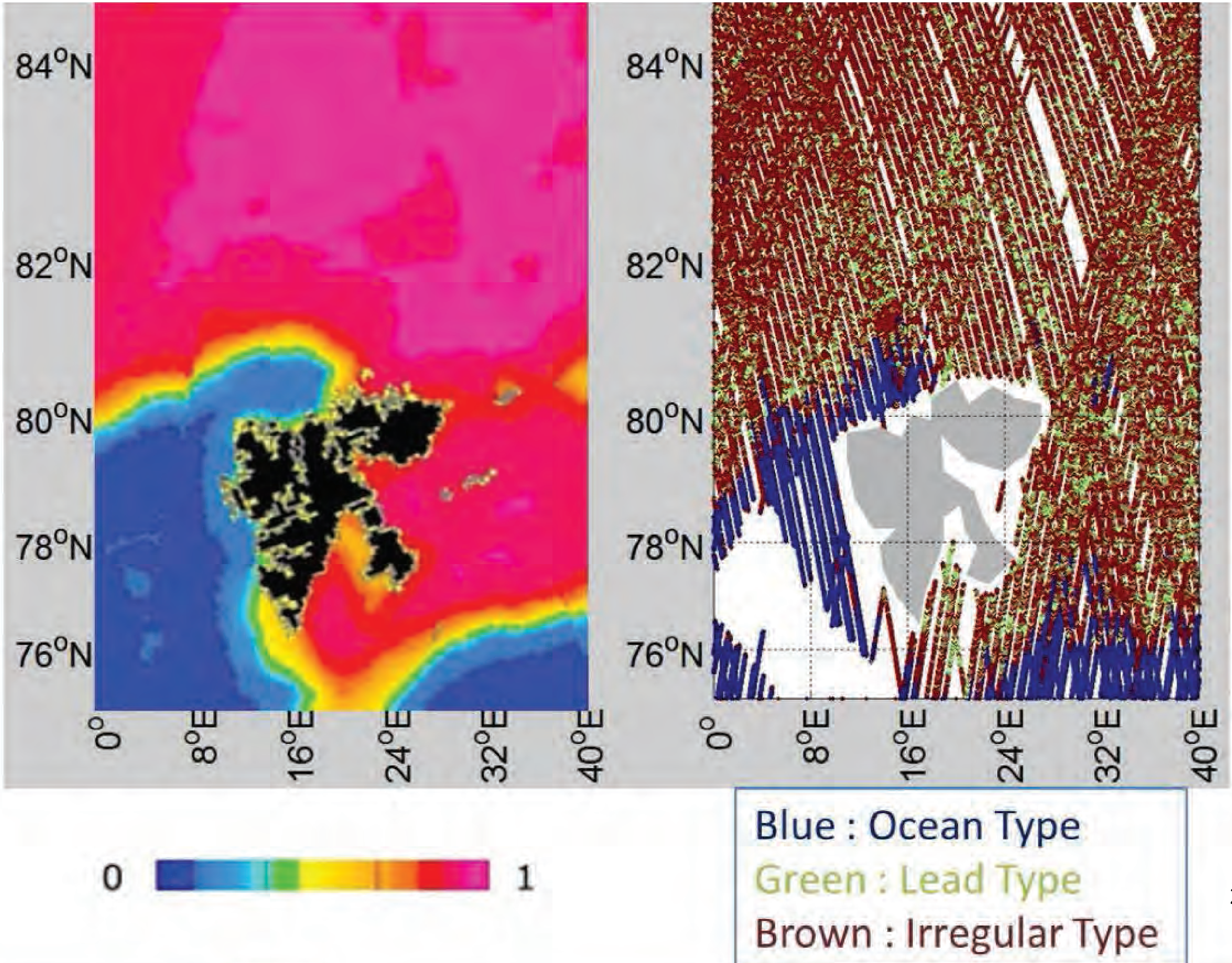


Data provided by CLS/CNES

Computing the Std of the looks (Stack Std Dev)

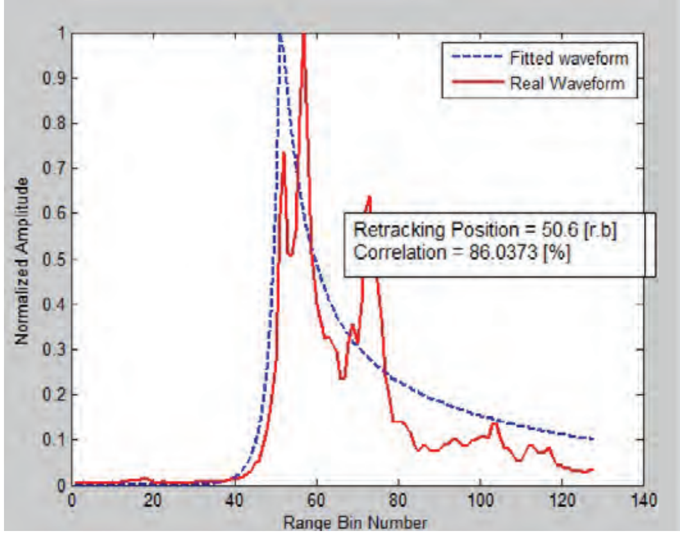
Classification



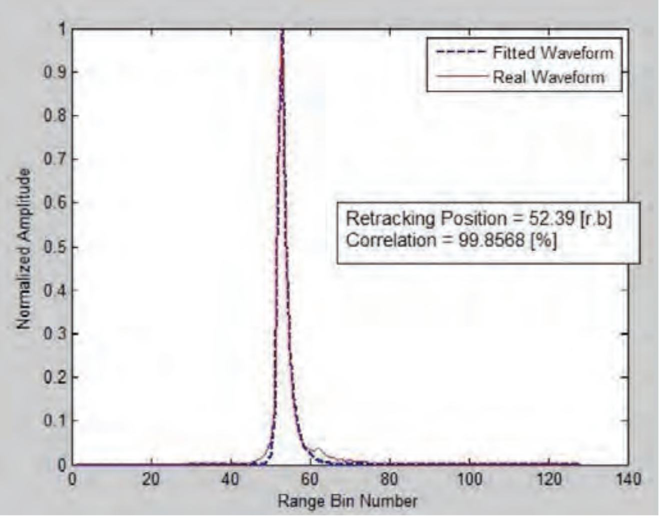

84°N
82°N
80°N
78°N
76°N
0°
8°E
16°E
24°E
32°E
40°E
0
1
Blue : Ocean Type
Green : Lead Type
Brown : Irregular Type

Retracking

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

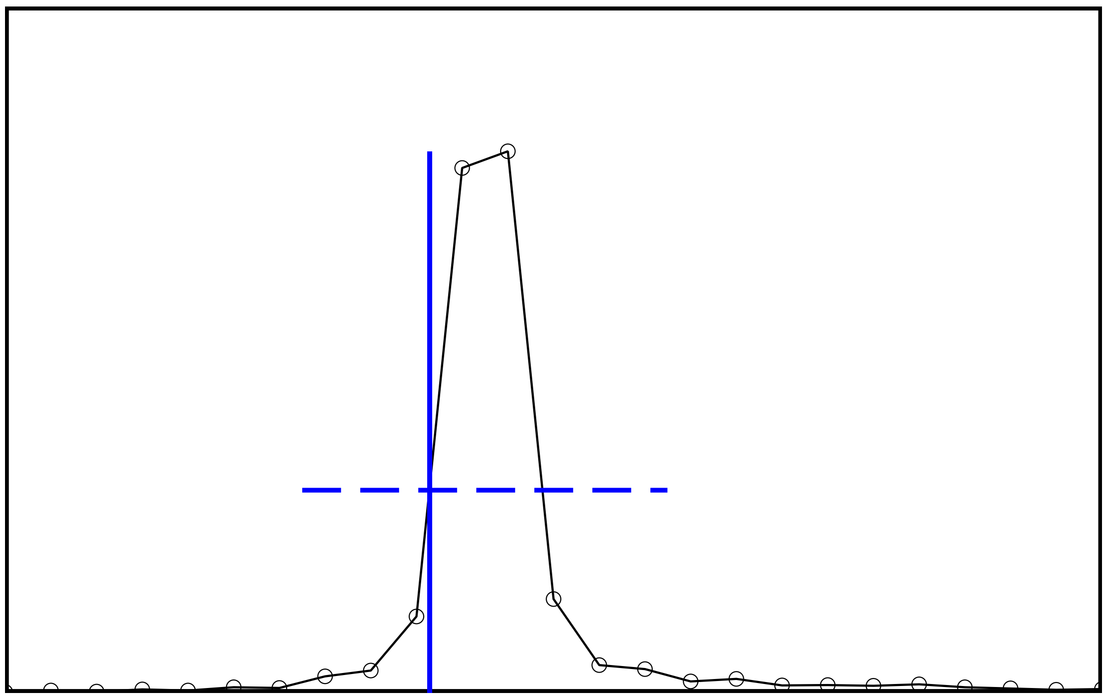


- If only height is required
- Simple EMPERICAL retrackers
- Results in more data and is
- Preferred due to processing time



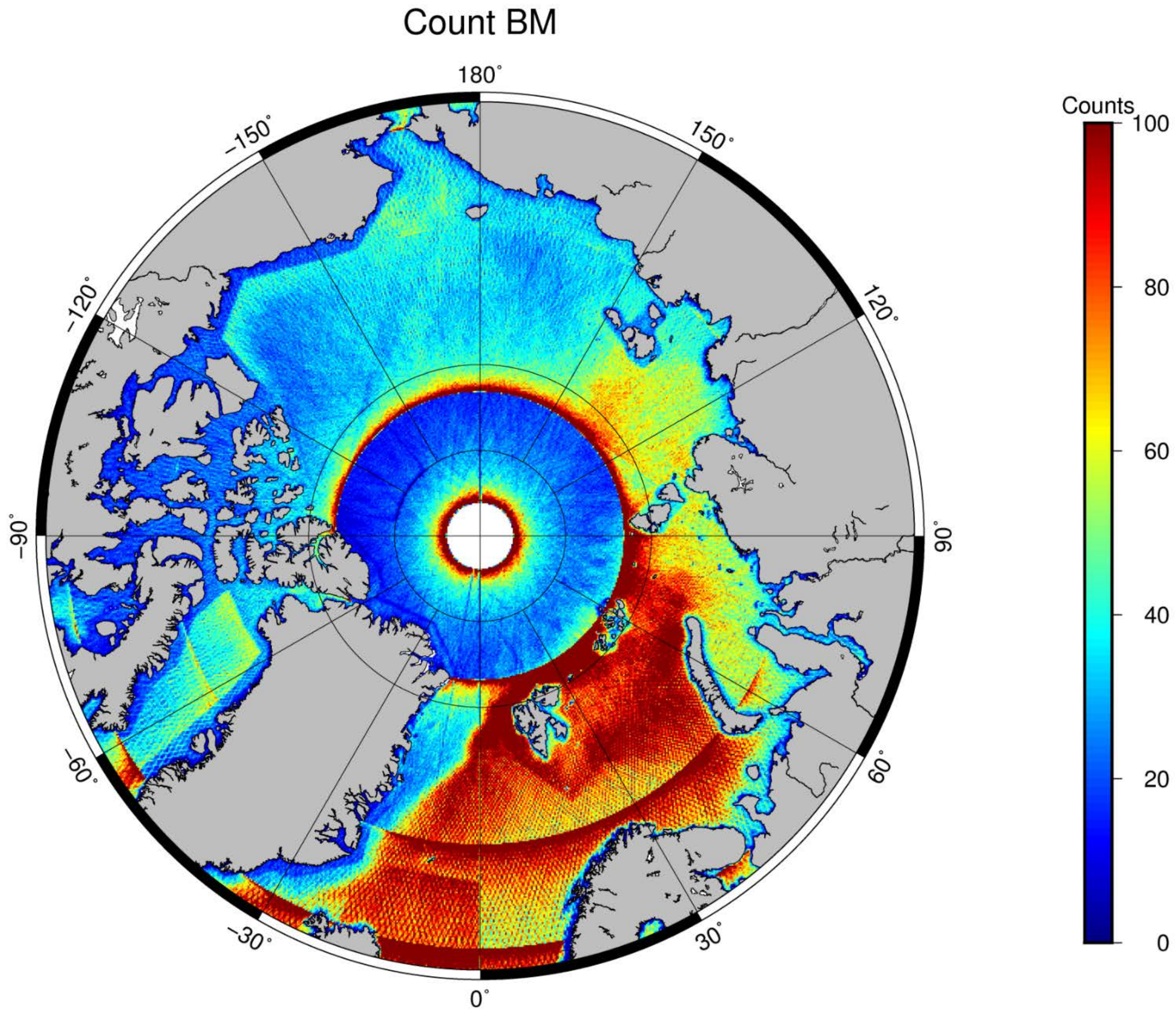
Example: Empirical Threshold Retracking

$$P_b = \frac{1}{5}\sum_{i=m-2}^{m+2} p_i \qquad E = \frac{F_T \cdot P_b - p_{j-1}}{p_j - p_{j-1}} + j - 1$$



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

27 years of sea level observations in the Arctic Ocean (1991-2018).



Counts per 10x 10 km

Application: Precision and Accuracy

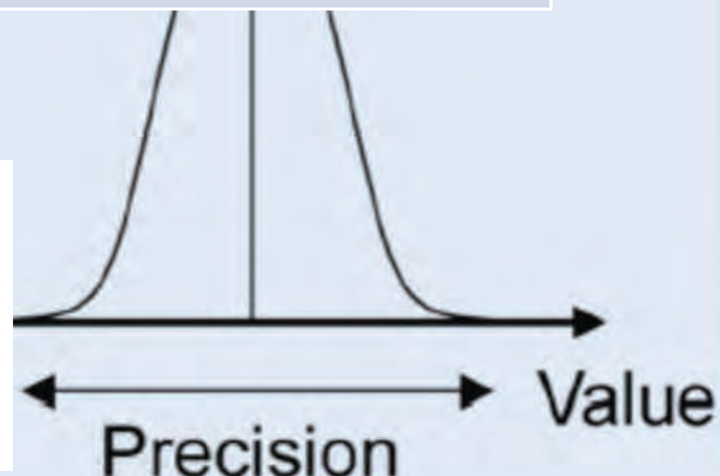
Precision by radar design (basically the std of ssh).

Accuracy is dependent on range corrections (ability to re-measure ssh).

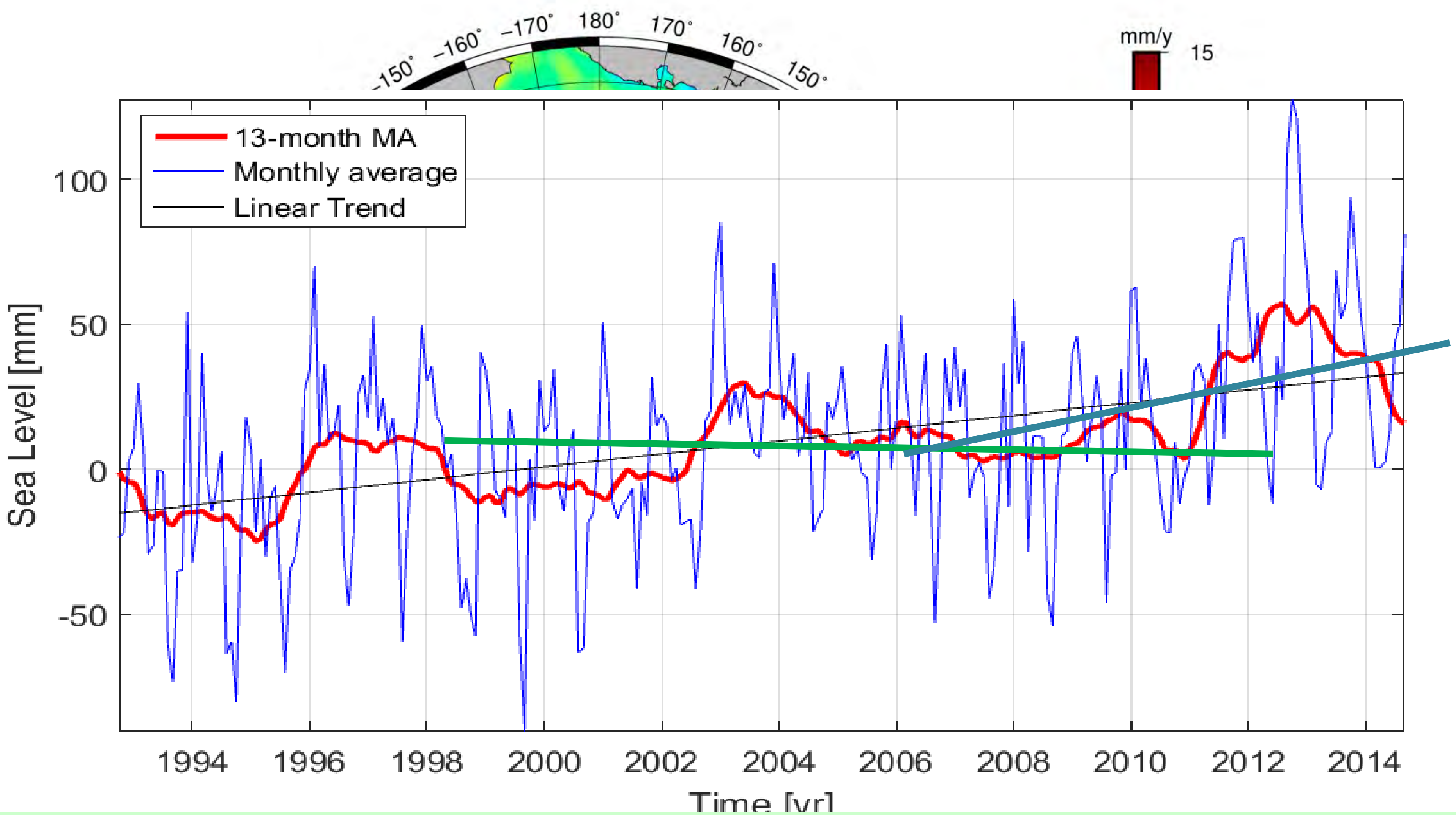
Oceanography + Climate	Accuracy
Ice-sheet topography + dynamics	Accuracy and Precision
Gravity & Bathymetry	Precision
Mean Sea Surface Seaice-Freeboard	Precision and Accuracy
Mean Dynamic Topography	Precision and Accuracy + Geoid

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

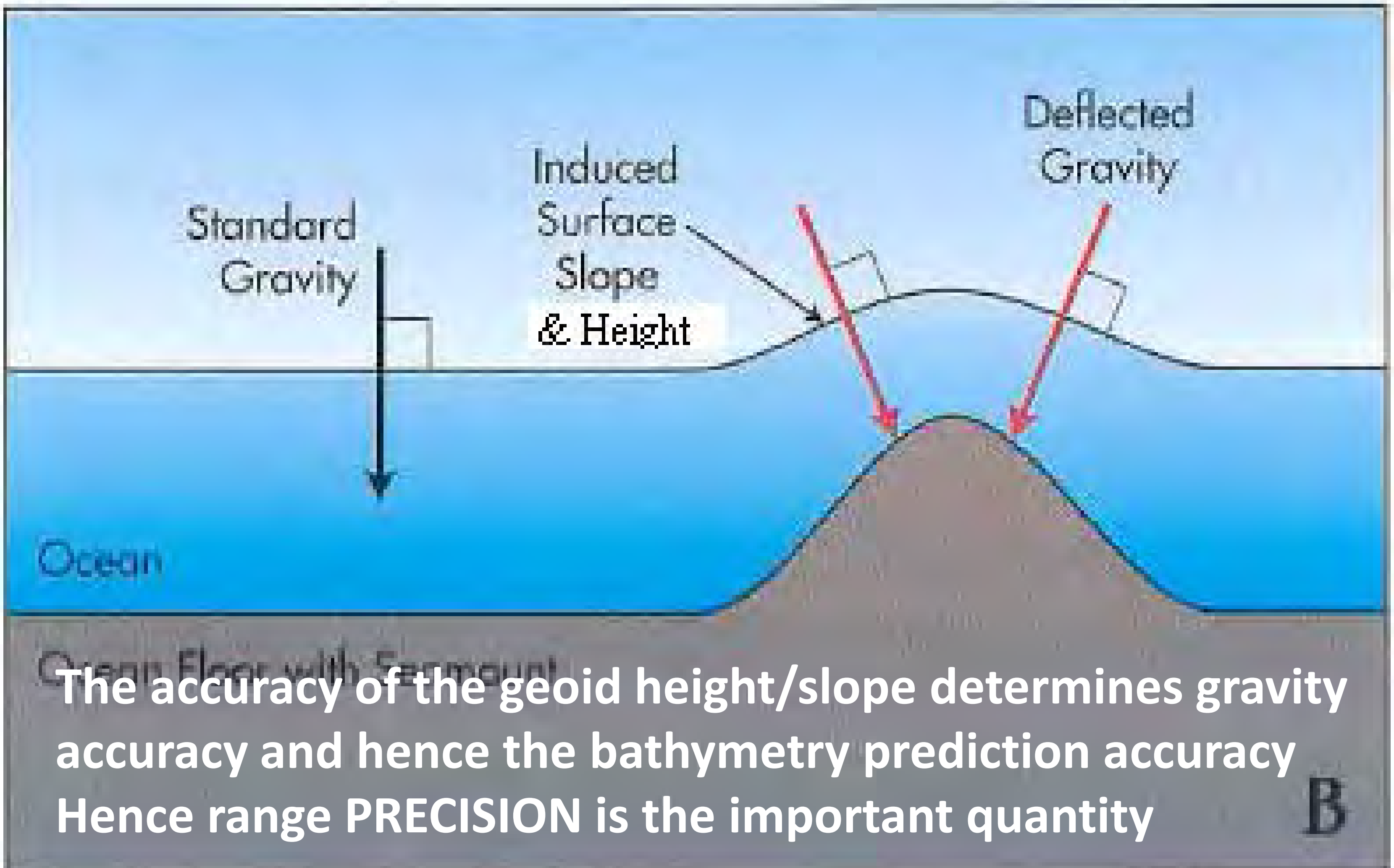


Range accuracy
Arctic Sea Level trend (68°N – 82°N)



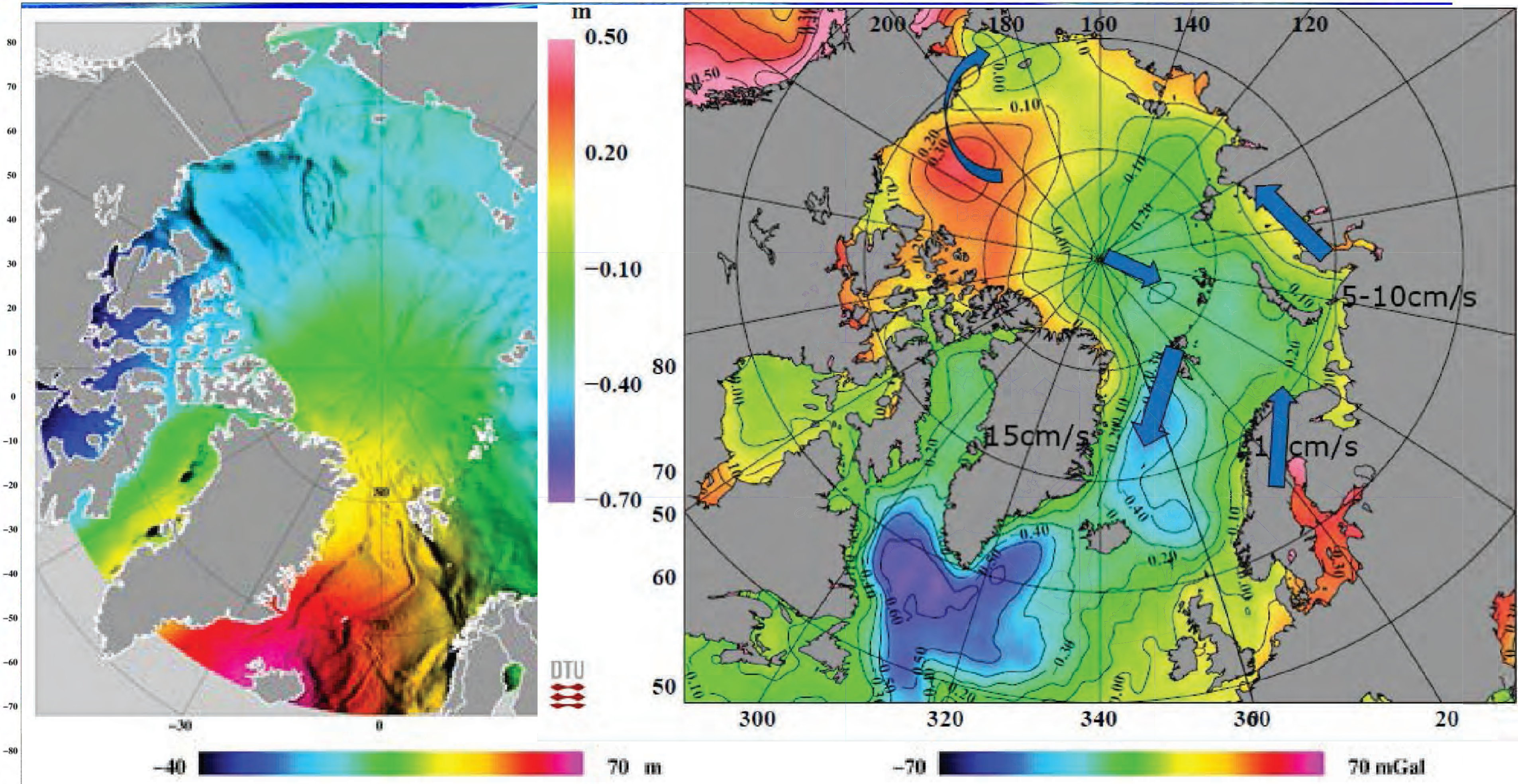
Average linear trend 2.2 mm/year. Large inter-annual variations (AO driven)

Range precision:
Mean Sea Surface->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

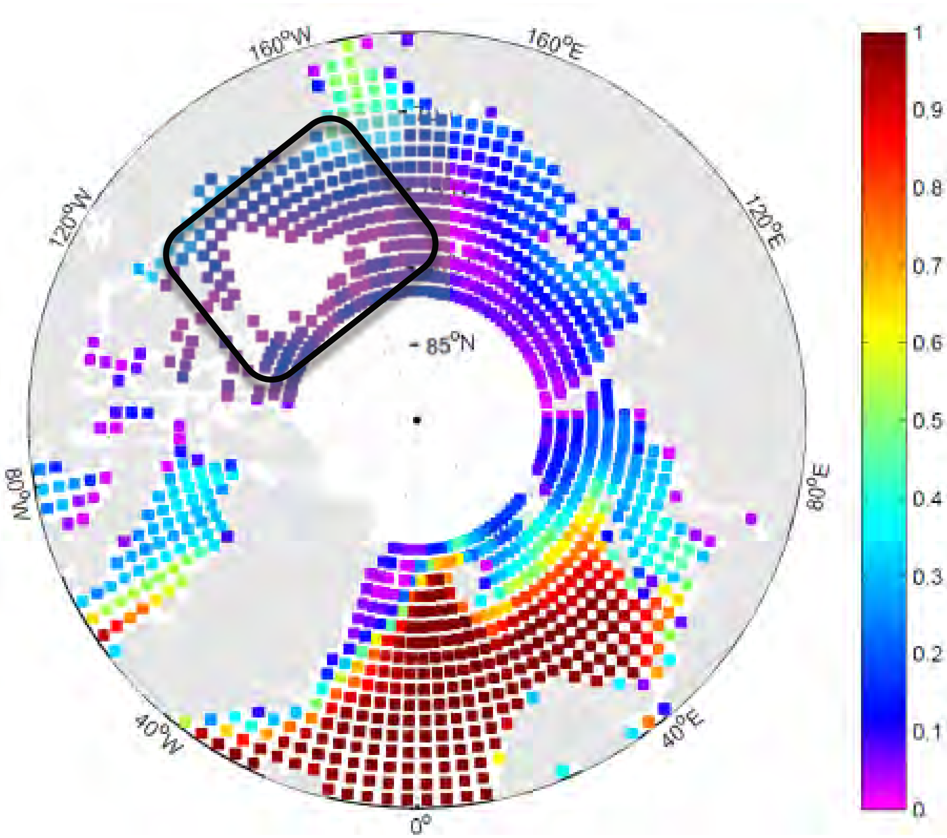
DTU15 MSS and Free Air Gravity

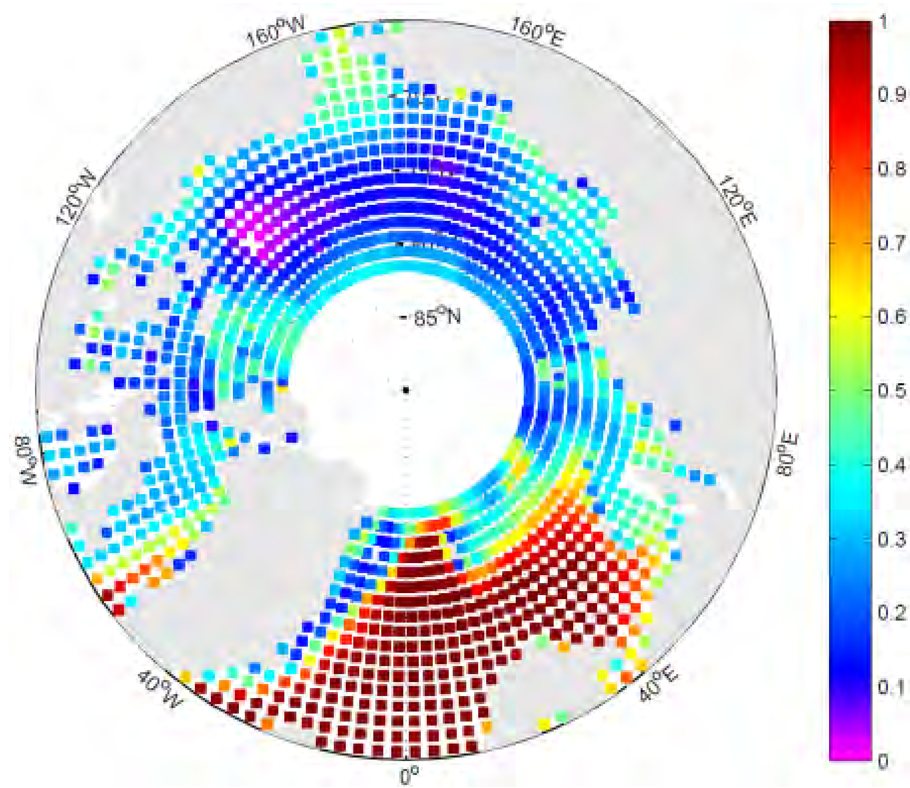


Open issues – Future research

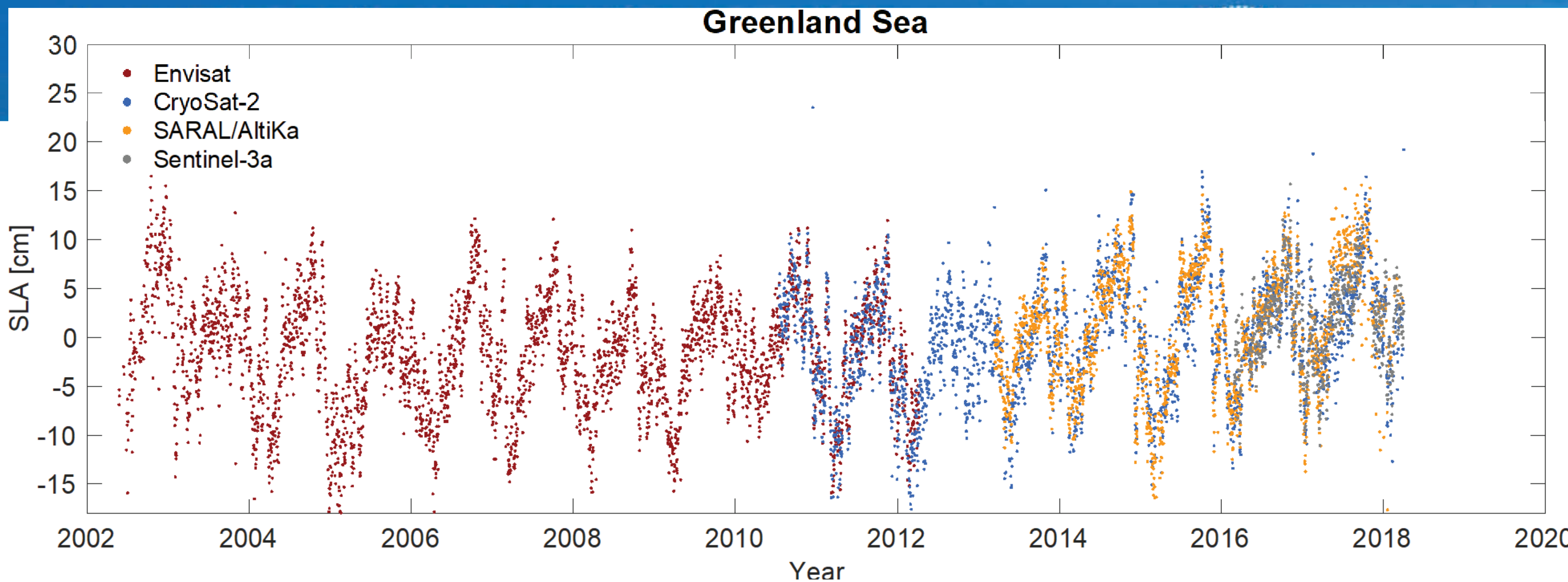
- Sampling (lack of data - Seasonality)
- Snagging + Swath processing
- Snow on Sea ice (next presentation).
- Ocean tides

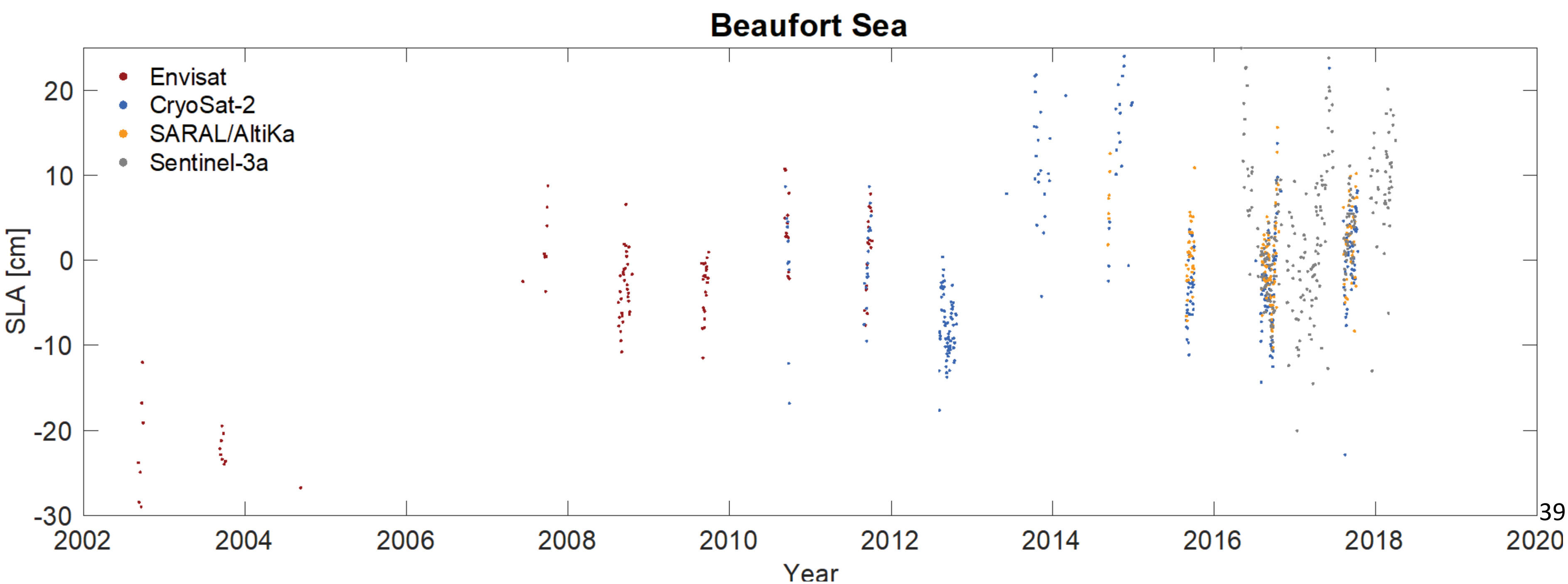
Seasonality



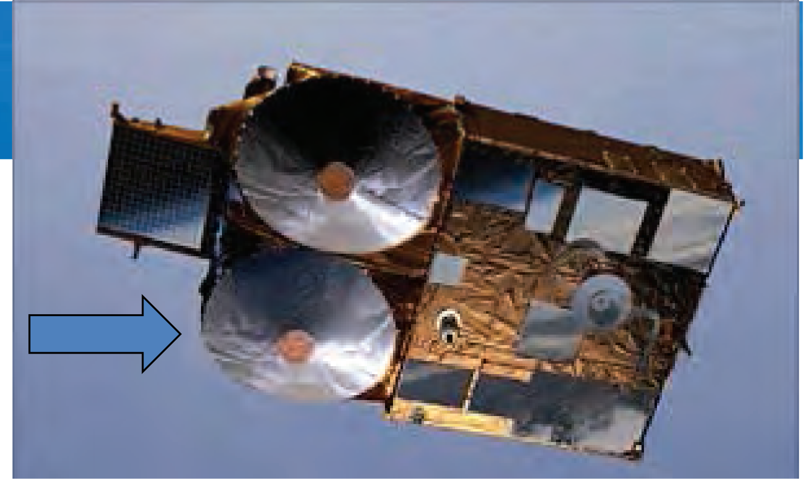


Western Arctic: Through retracking (ALES+ or more tolerant editing) the number of available data increases a lot

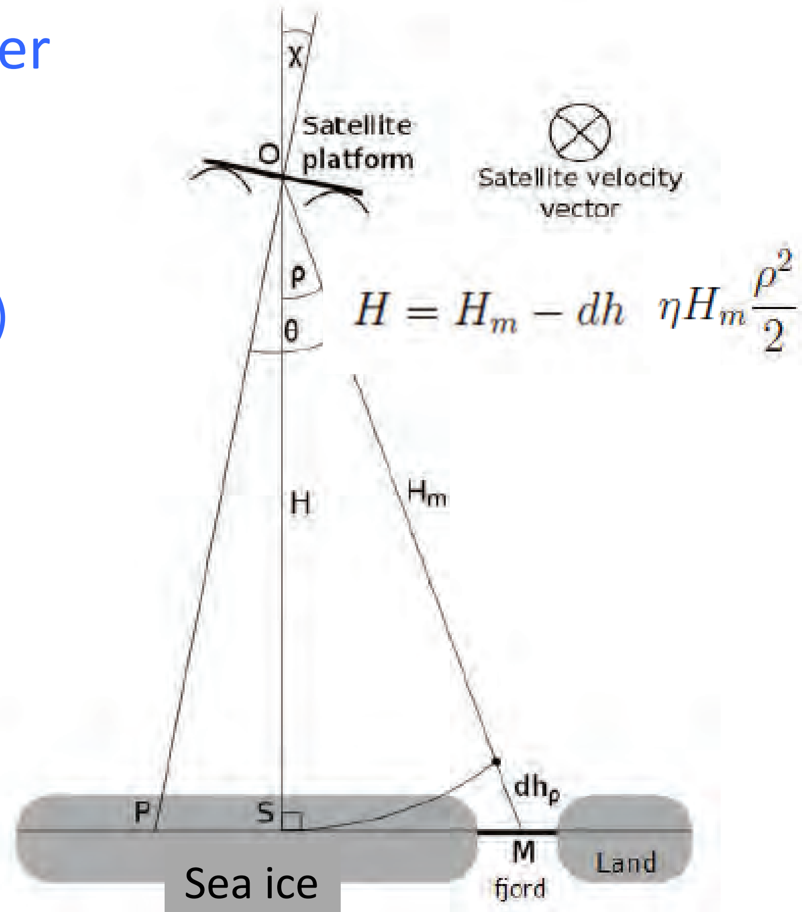

Greenland Sea
Envisat
CryoSat-2
SARAL/AltiKa
Sentinel-3a
SLA [cm]
Year


Beaufort Sea
Envisat
CryoSat-2
SARAL/AltiKa
Sentinel-3a
SLA [cm]
Year

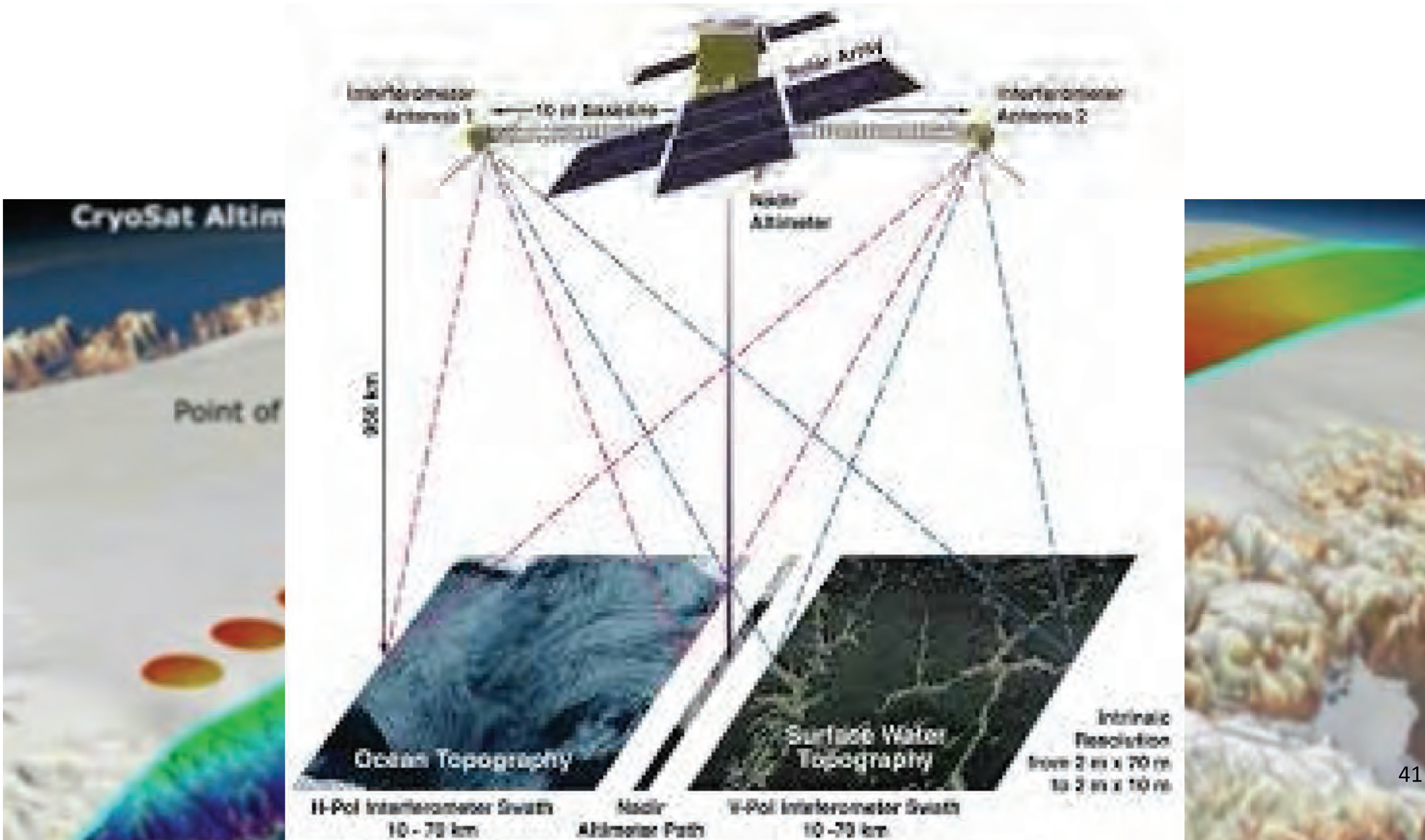
Snagging and (SARin)



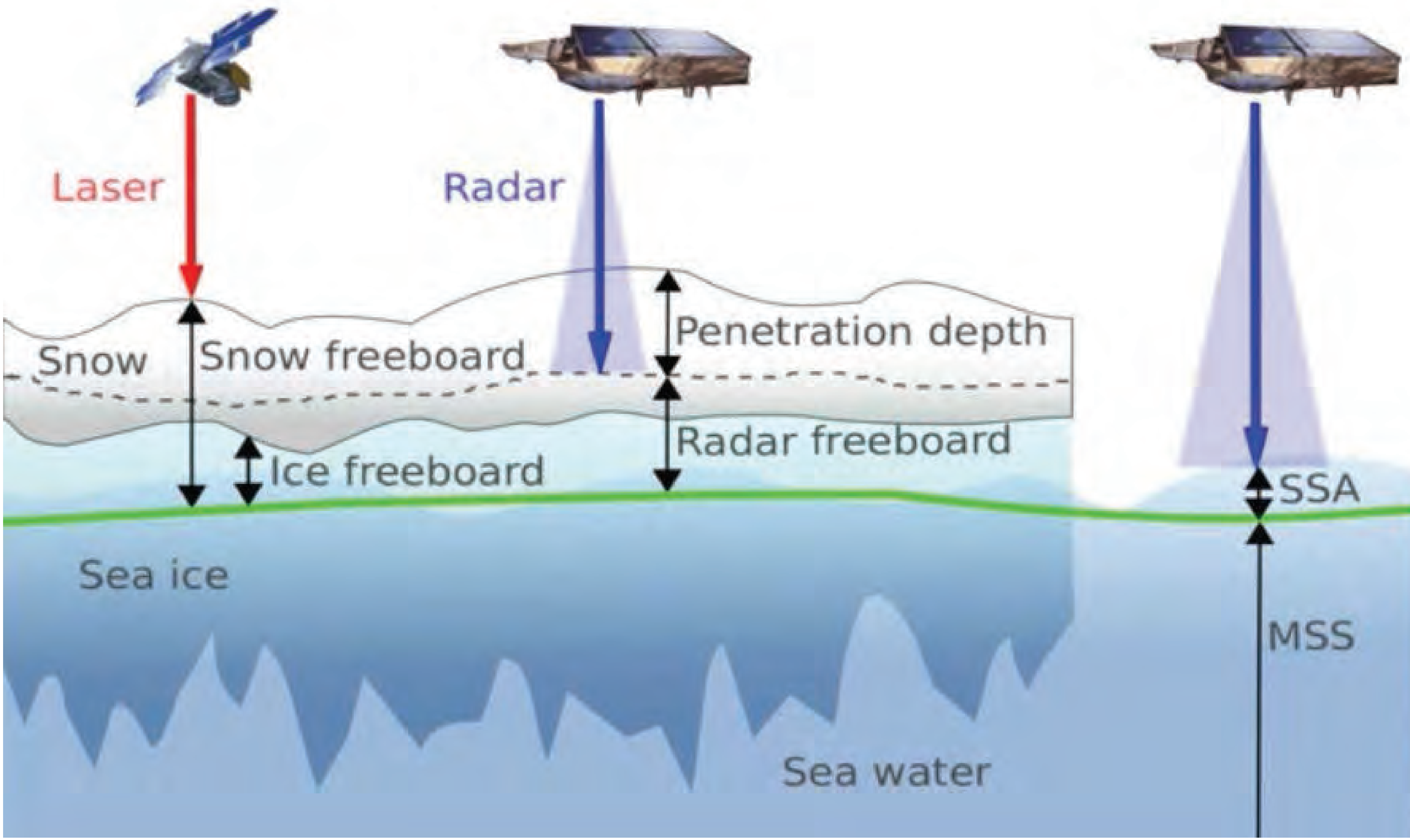
- Bright off nadir like leeds dominates
- Range to target longer ➔surface lower
- Cross-track angle from SARin
- Caviat: Lover precision.
  - Only 1 burst per radar cycle (vs. 4 in SAR)



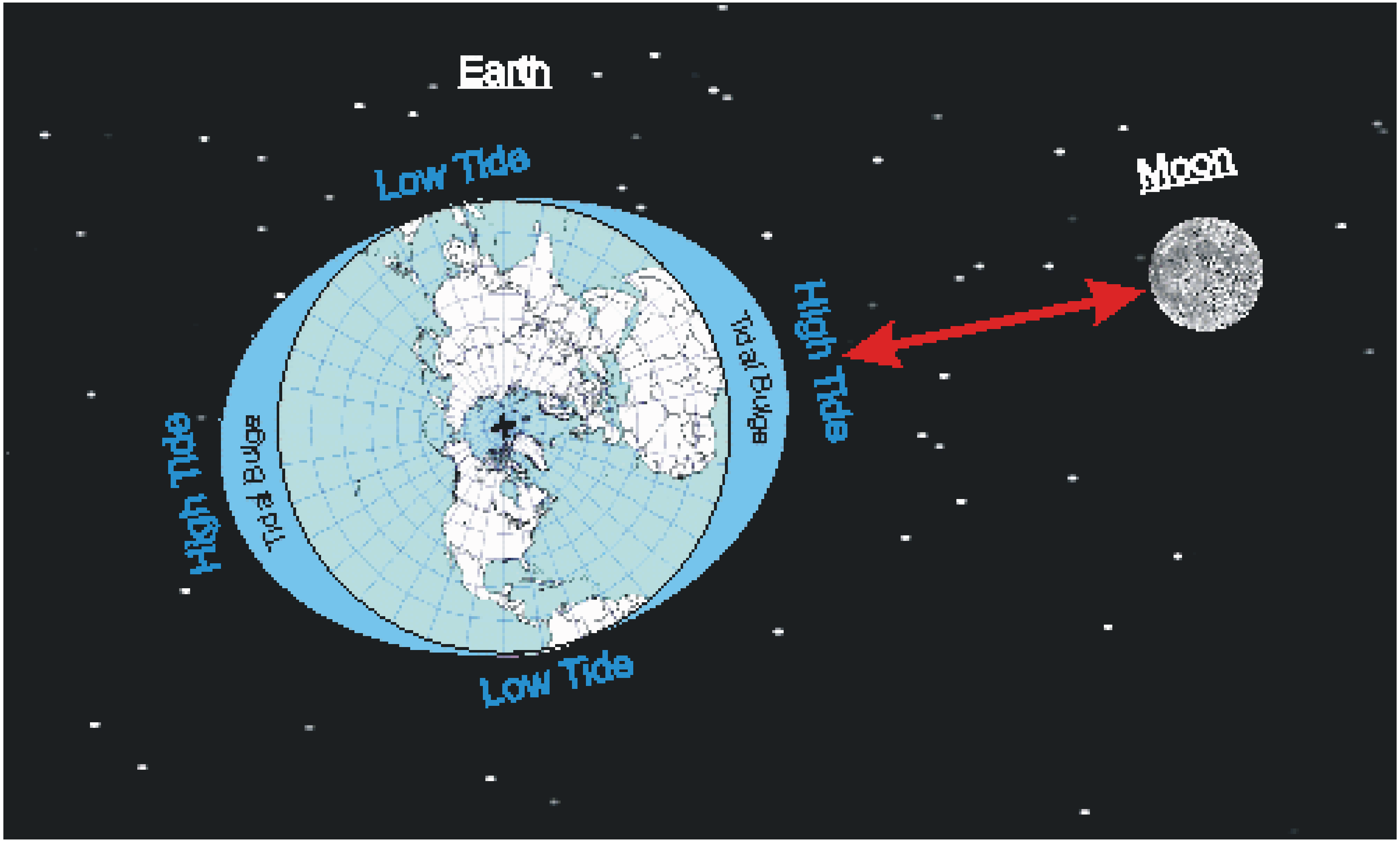
Swath procesing (SARin and SWOT



Freeboard and snow on sea-ice

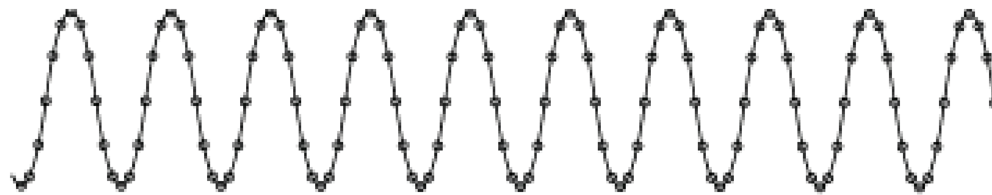


We need better Arctic Ocean Tides



Sampling and Accuracy

Tide Gauge:
High temporal sampling

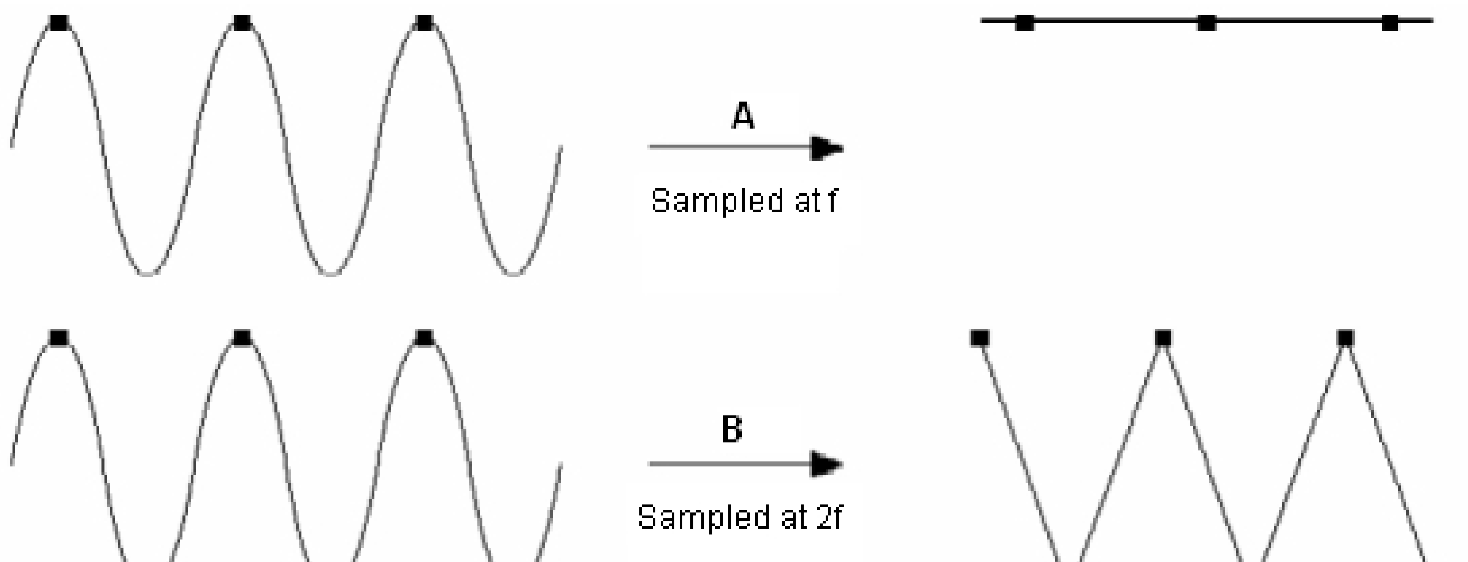


Adequately Sampled Signal

Satellite altimetry:
low temporal sampling
=>Aliasing

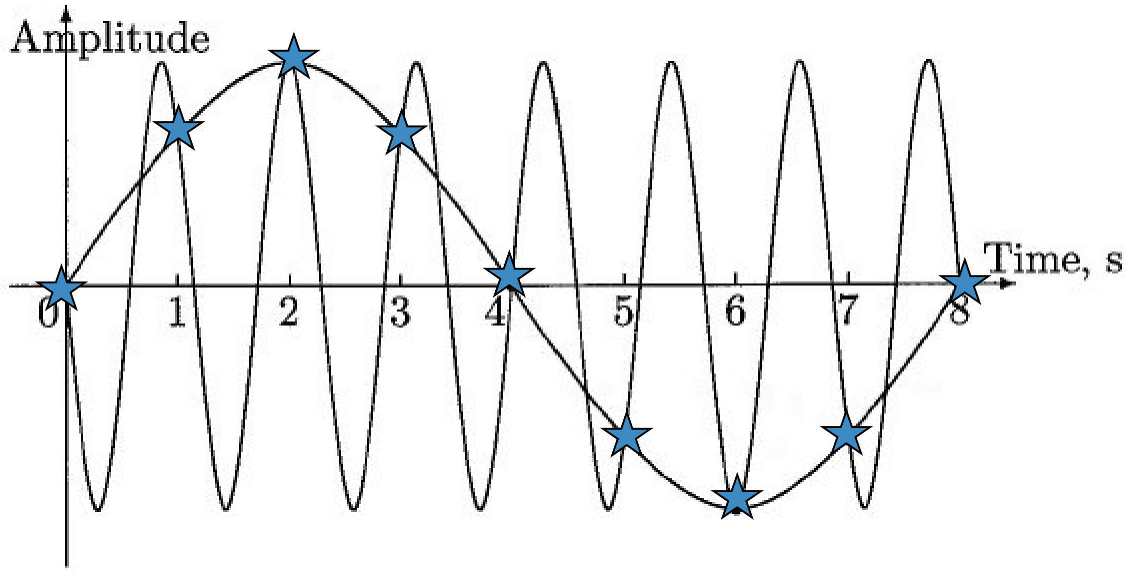
Aliased Signal Due to Undersampling

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



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.

Questions?
If you are still awake!

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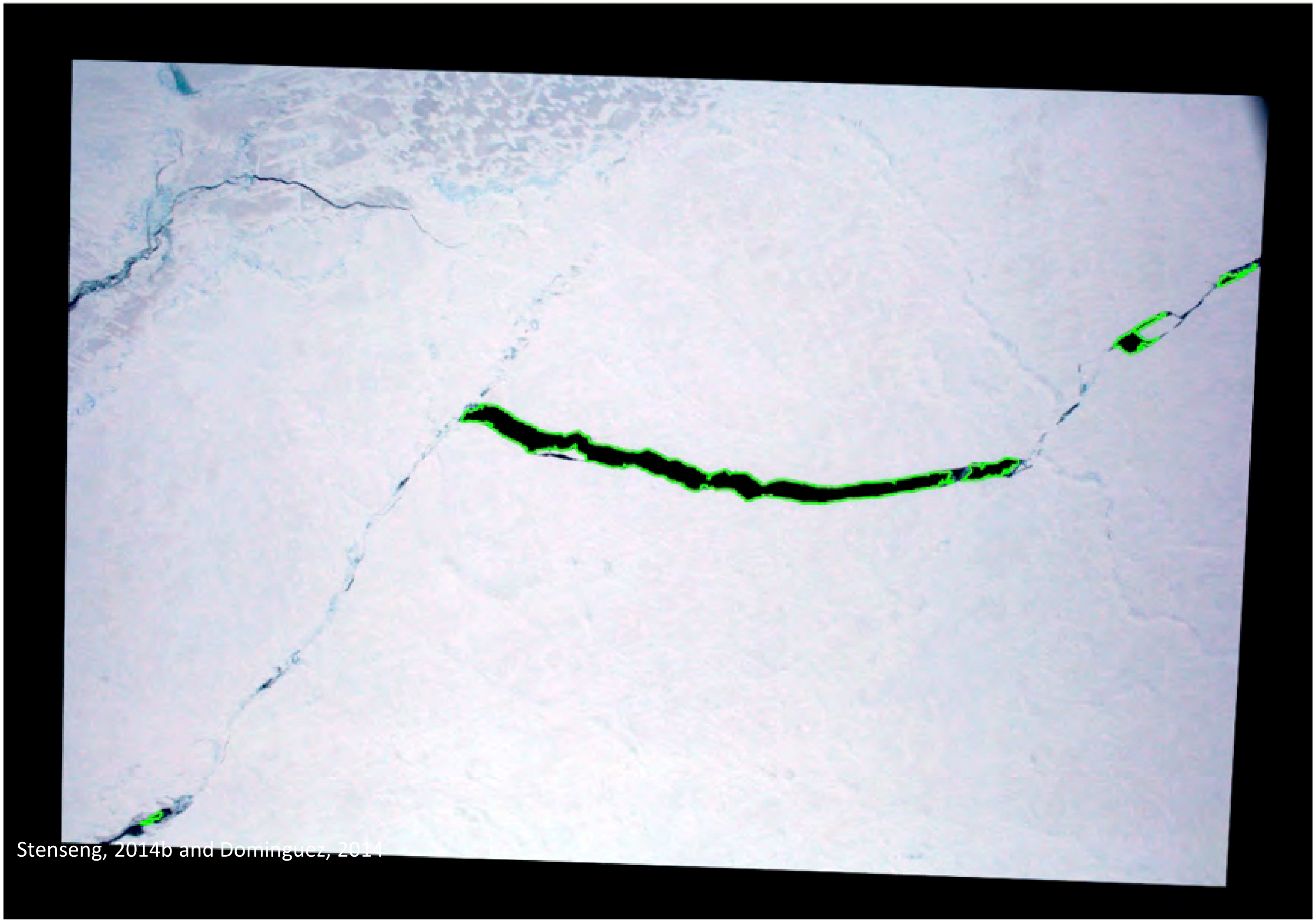
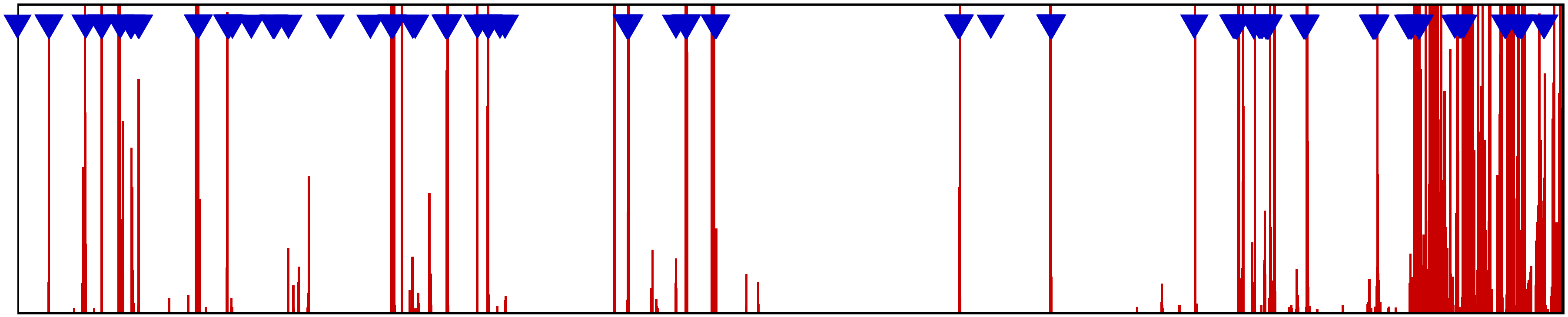
Validation: IceBridge



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)