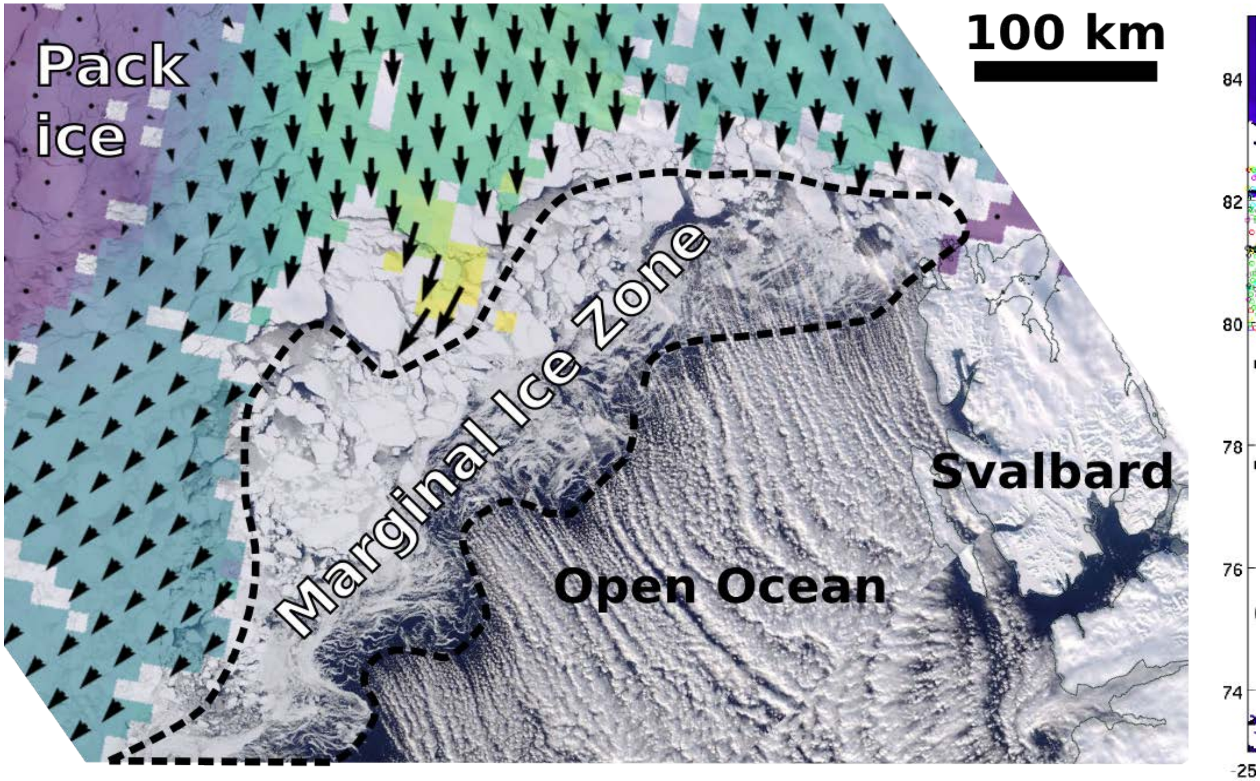
Mesoscale processes and dynamics in the Marginal Ice Zone: Importance of satellite observations

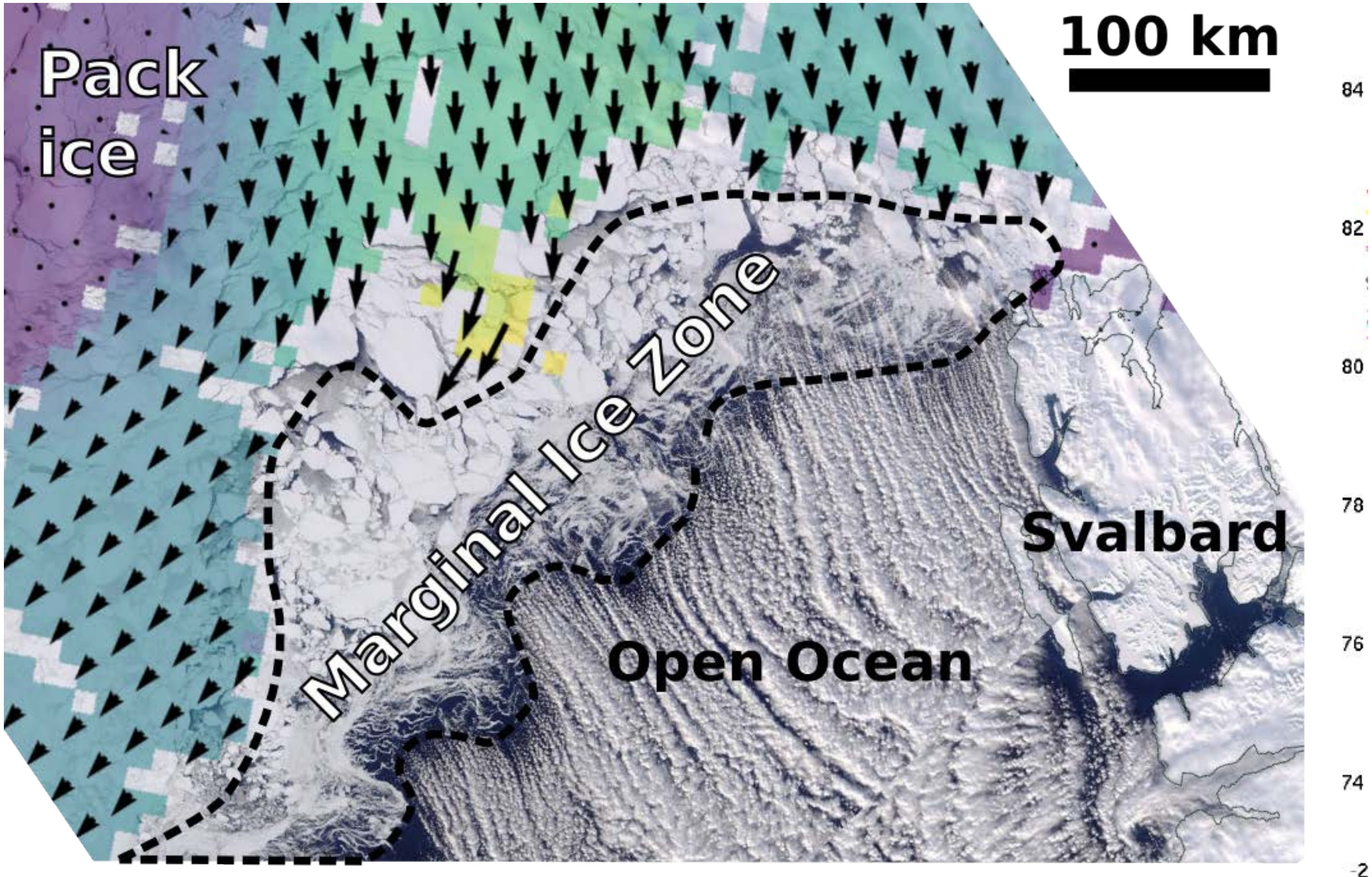


Johnny A. Johannessen

with contribution from Anton Korosov, Pierre Rampal, Jeong-Won Park, Mohamed Babiker

Young Scientist school on “Atmosphere-Ocean-Ice System in the Arctic and its Investigation Using Satellite Data”.

SOLab, RSHU, St. Petersburg, 19-21 November, 2019



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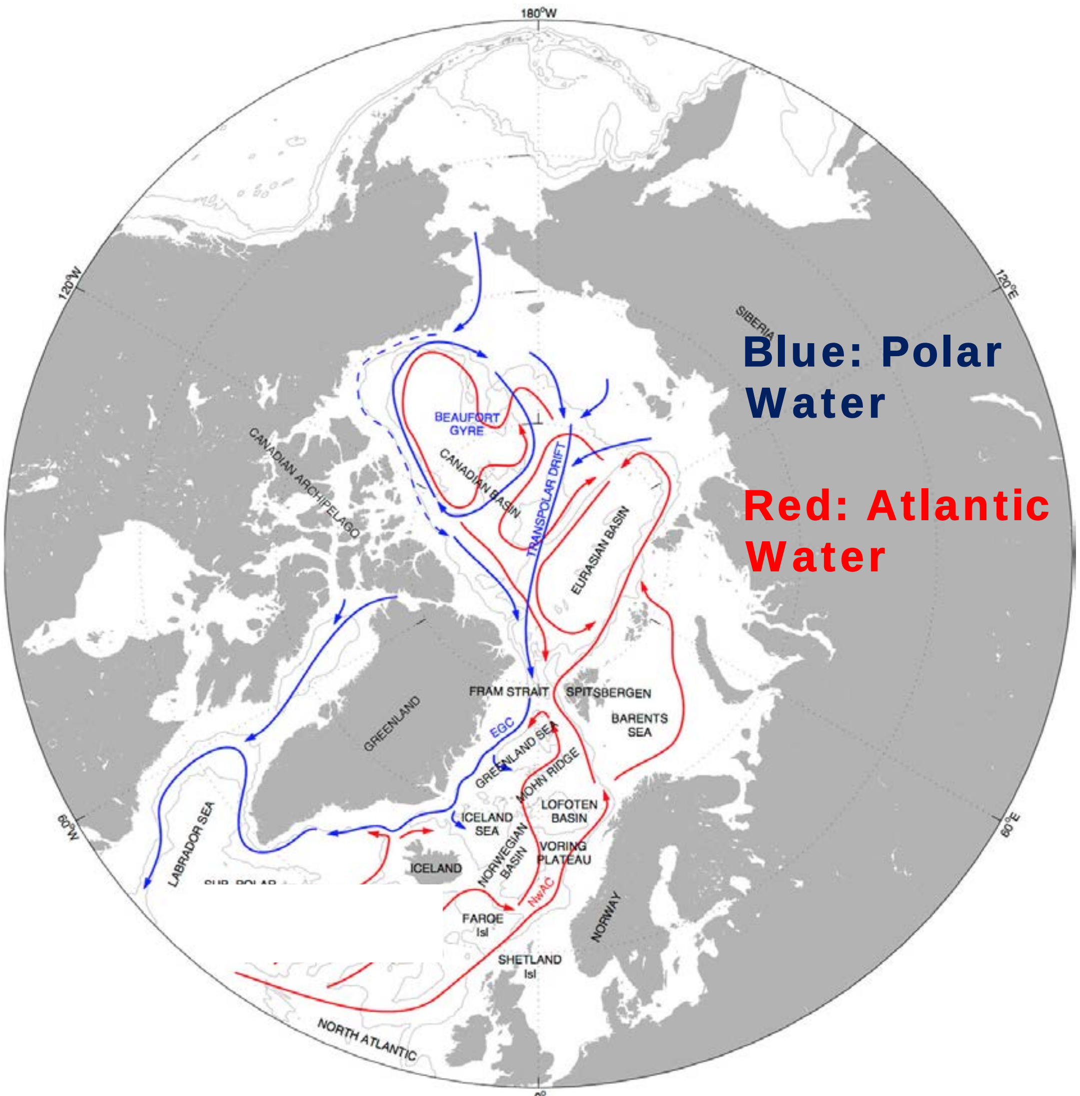
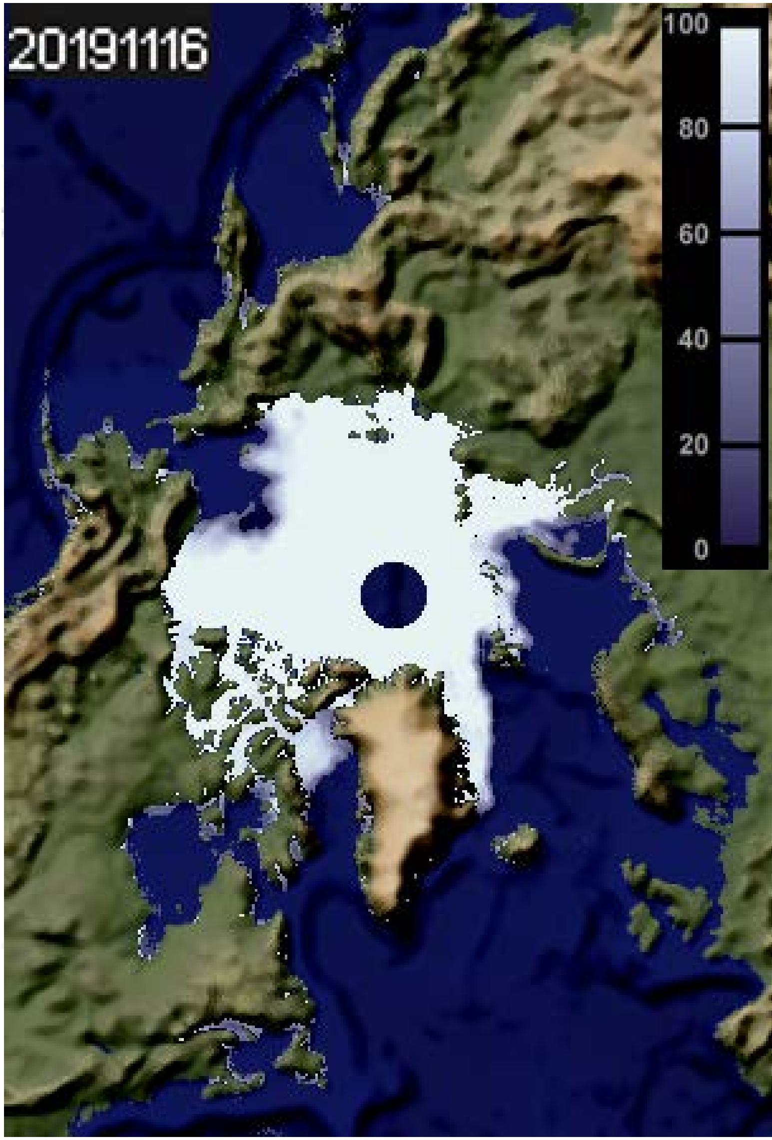
- Background
- Satellite observations
- The Marginal Ice Zone
- Mesoscale processes and variability
- Summary

Large scale ocean circulation in the high latitude and Arctic Ocean



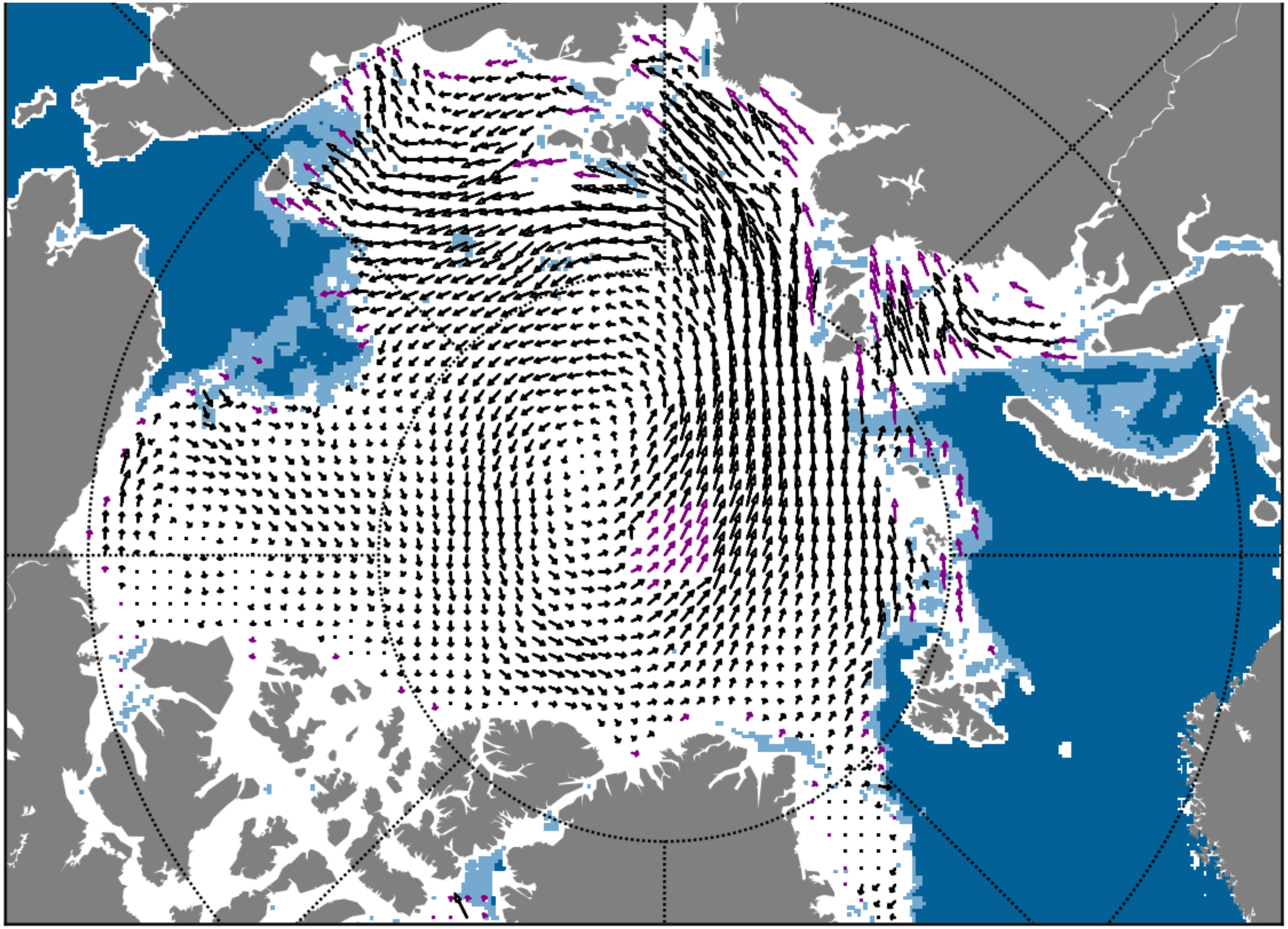
Blue: Polar Water

Red: Atlantic Water



SOLab, RSHU, St. Petersburg, 19-21 November, 2019

Large scale sea ice drift – 16-18 NOV. 2019



Zone: Arctic Ocean / Image: Copyright (2019) EUMETSAT

http://osisaf.met.no/p/osisaf_hlprod_qlook.php?prod=LR-Drift&area=NH

Earth's Energy Imbalance – Global Warming

Warmer atmosphere

Warmer Earth surface

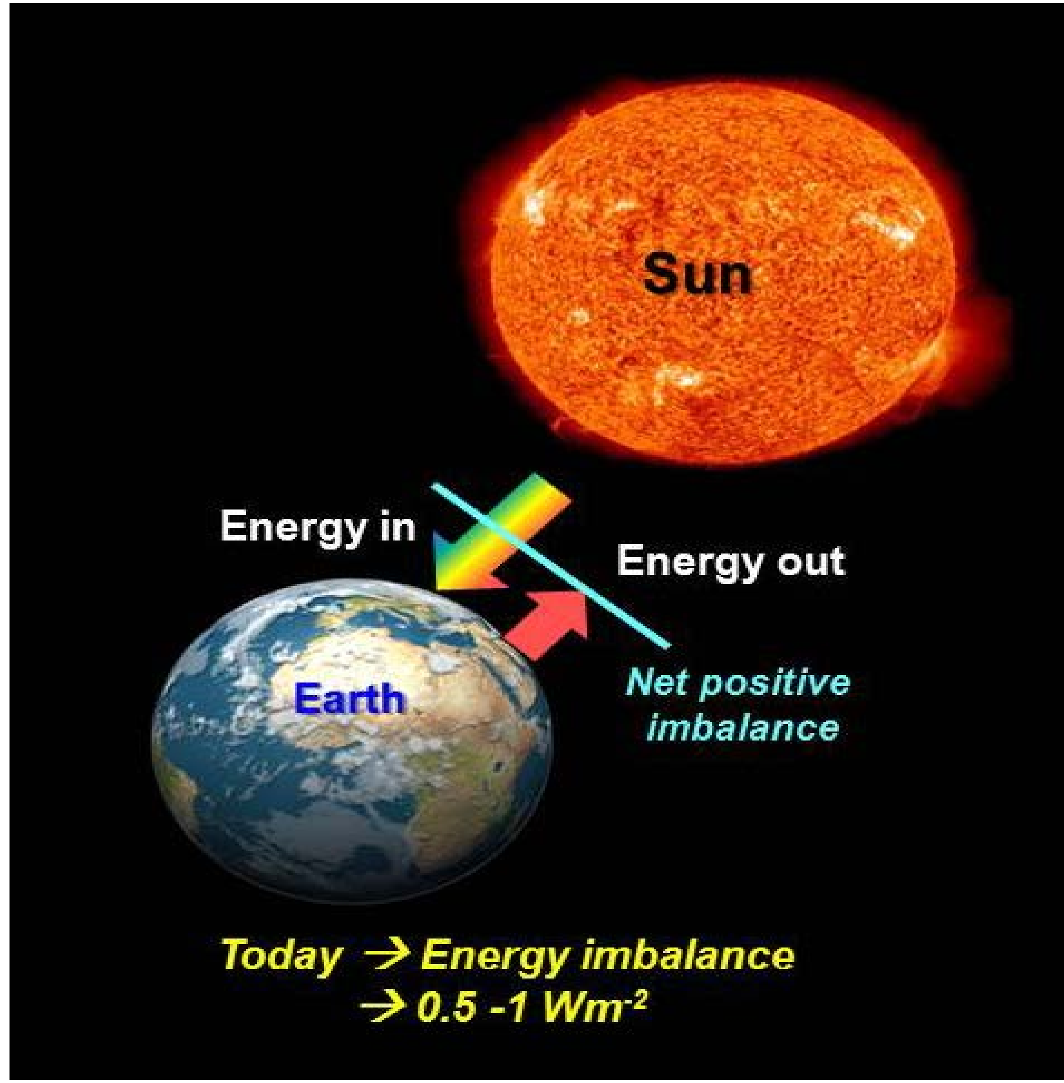
More heat uptake in the ocean

More melting of the cryopshere

Less ice sheet/glaciers/sea ice

Reduction in the albedo

Increased sea level



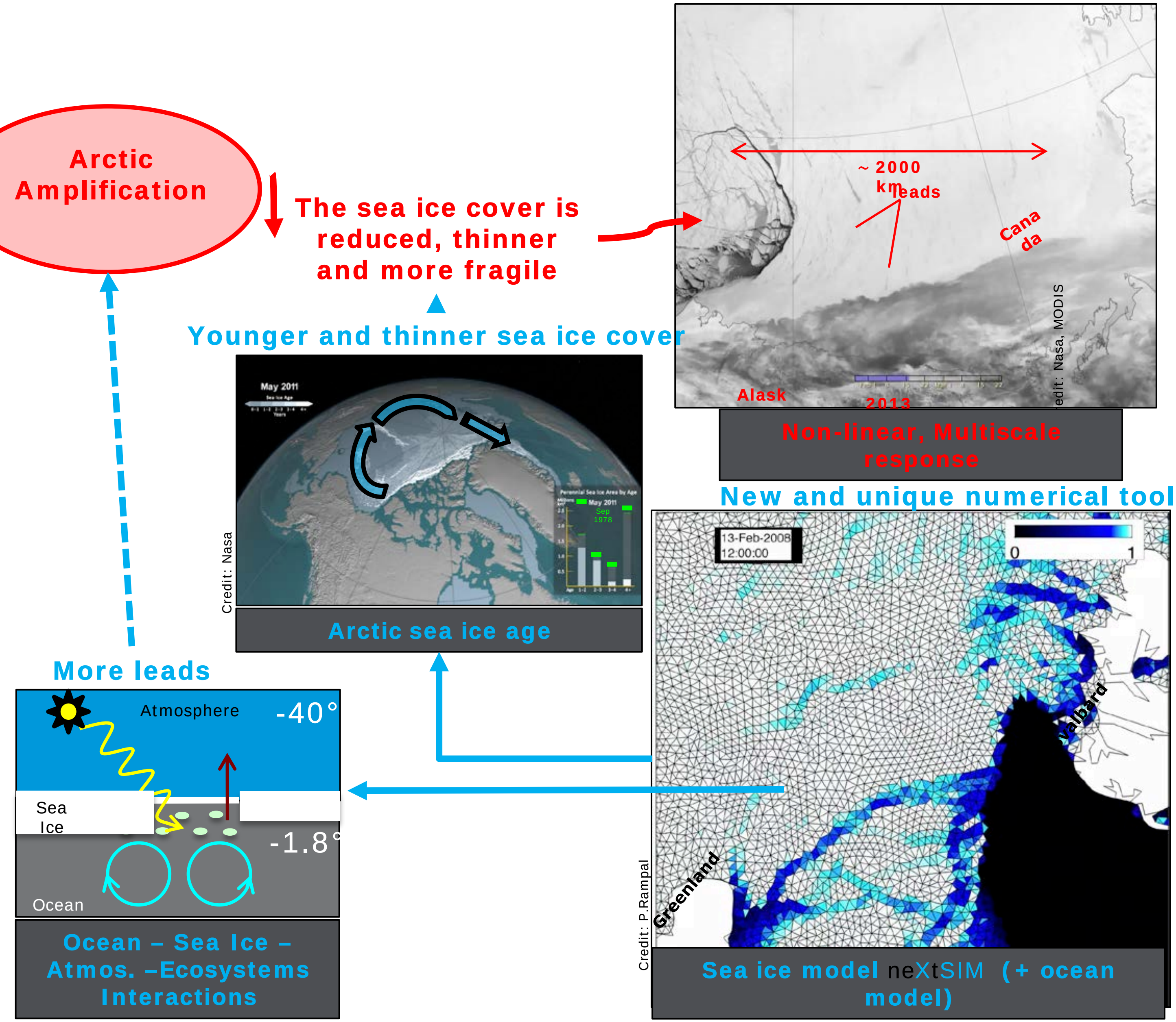
Sea ice – albedo feedback – Arctic Amplification

Ratio of the intensty of light reflected from the surface to the total incoming light from the sun.

Albedo for sea ice ≈ 0.5-0.7

Albedo for water ≈ 0.06

Summer enhanced sea ice loss is dominated by the albedo feedback. Snow-covered sea ice reflects most of the incident solar radiation. As the snow and ice melts the open ocean absorbs more solar radiation. In turn, this heat melts more ice, which then promotes more solar heating of the ocean, thus creating a positive melting feedback (Perovich et al. 2011).

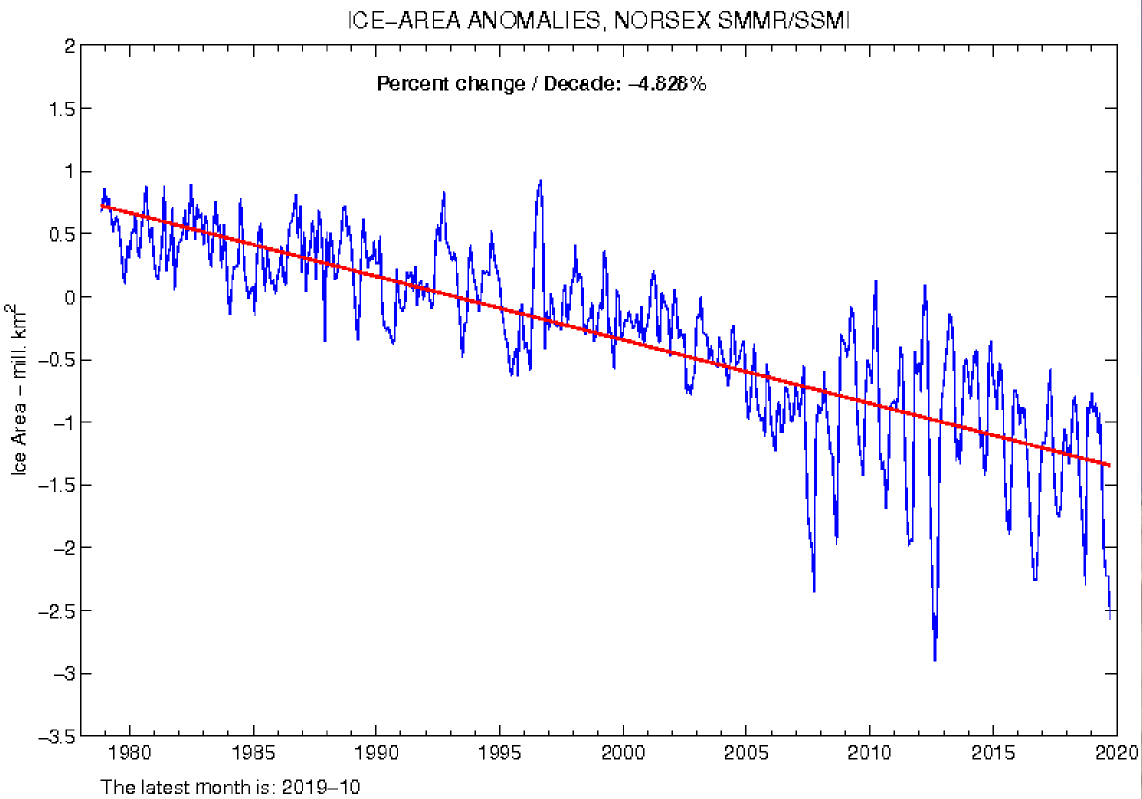


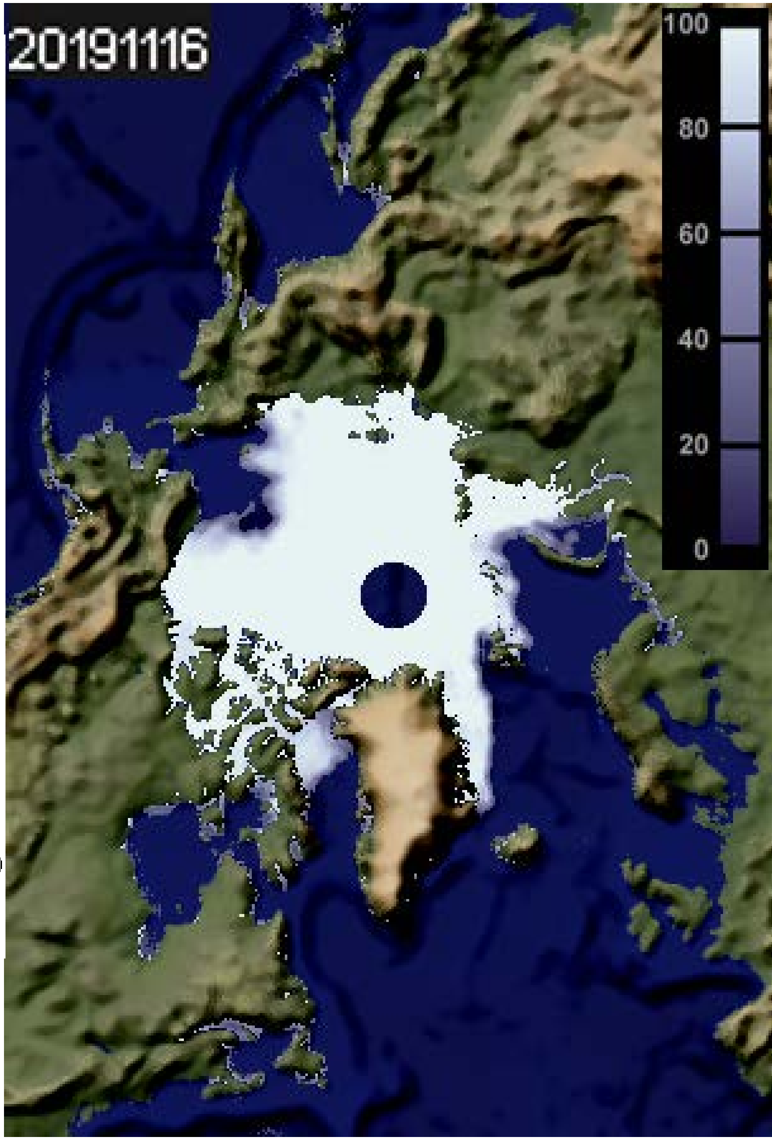
A multi-modal approach, courtecy P. Rampal

Arctic Amplification is associated with the ice–albedo feedback:

- sea ice cover retreats more in summer;
- more release of heat to the atmosphere from the ocean during autumn freeze-up;
- thinner sea ice cover through the winter season;
- spring warm-up in the atmosphere near the sea ice surface;
- limit radiative cooling of the sea ice cover;
- increased humidity and cloud cover and hence warming of the lower atmosphere.

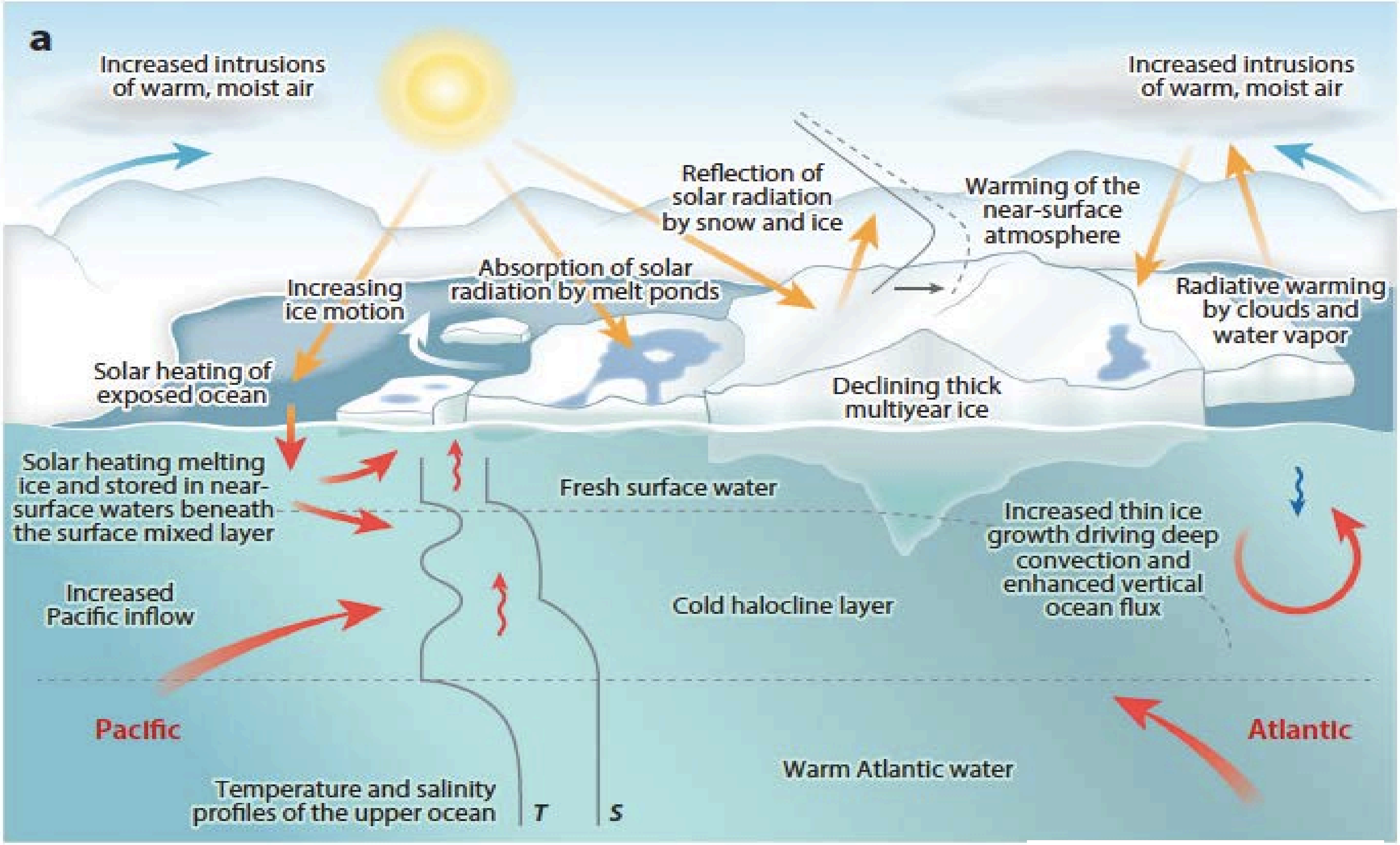
Passive Microwave Observations from SSMI





http://www.arctic-roos.org/

Conceptual illustration of Air-Sea ice – Ocean interaction in the Arctic Ocean

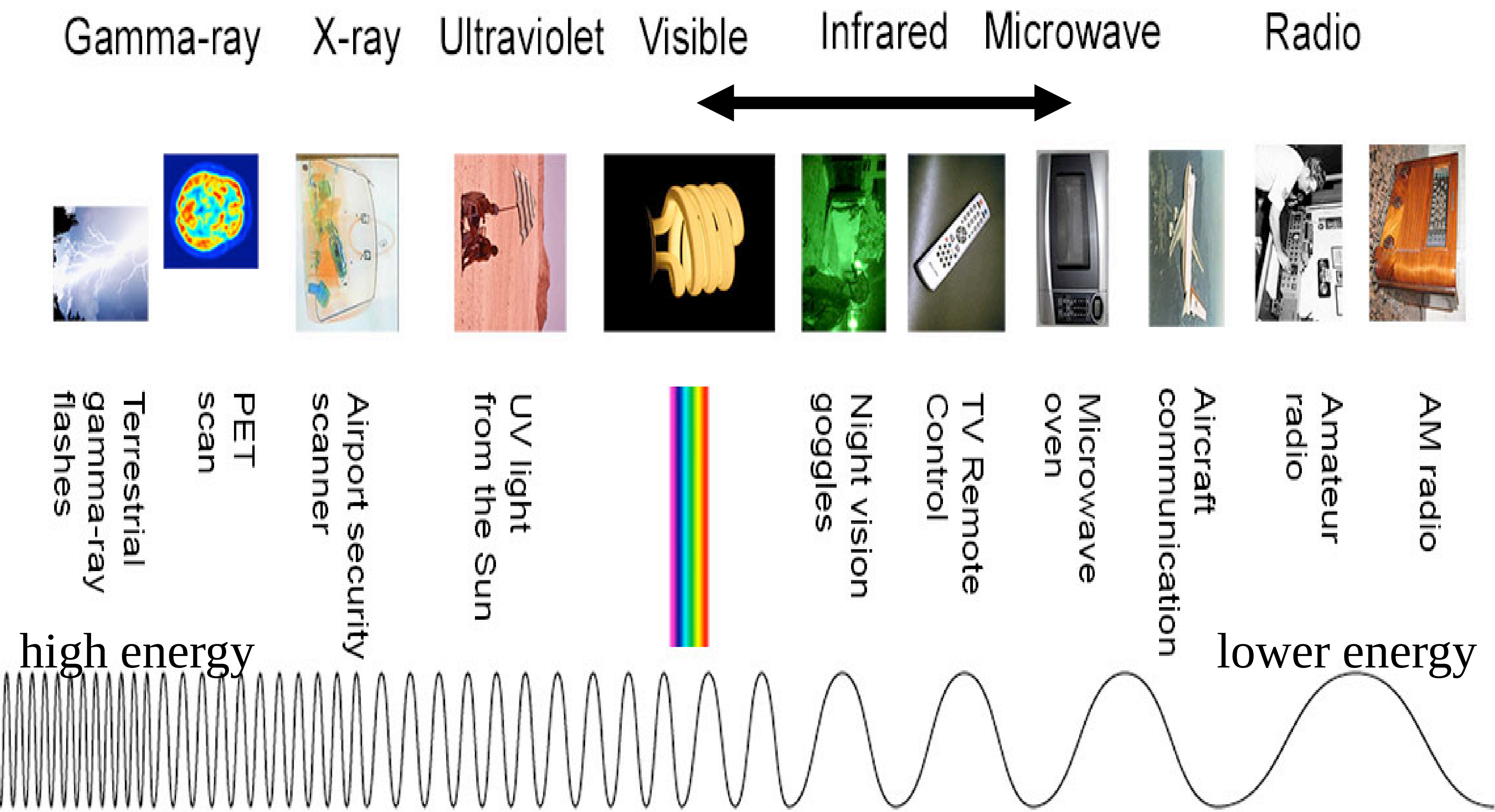


From Maksym, 2019

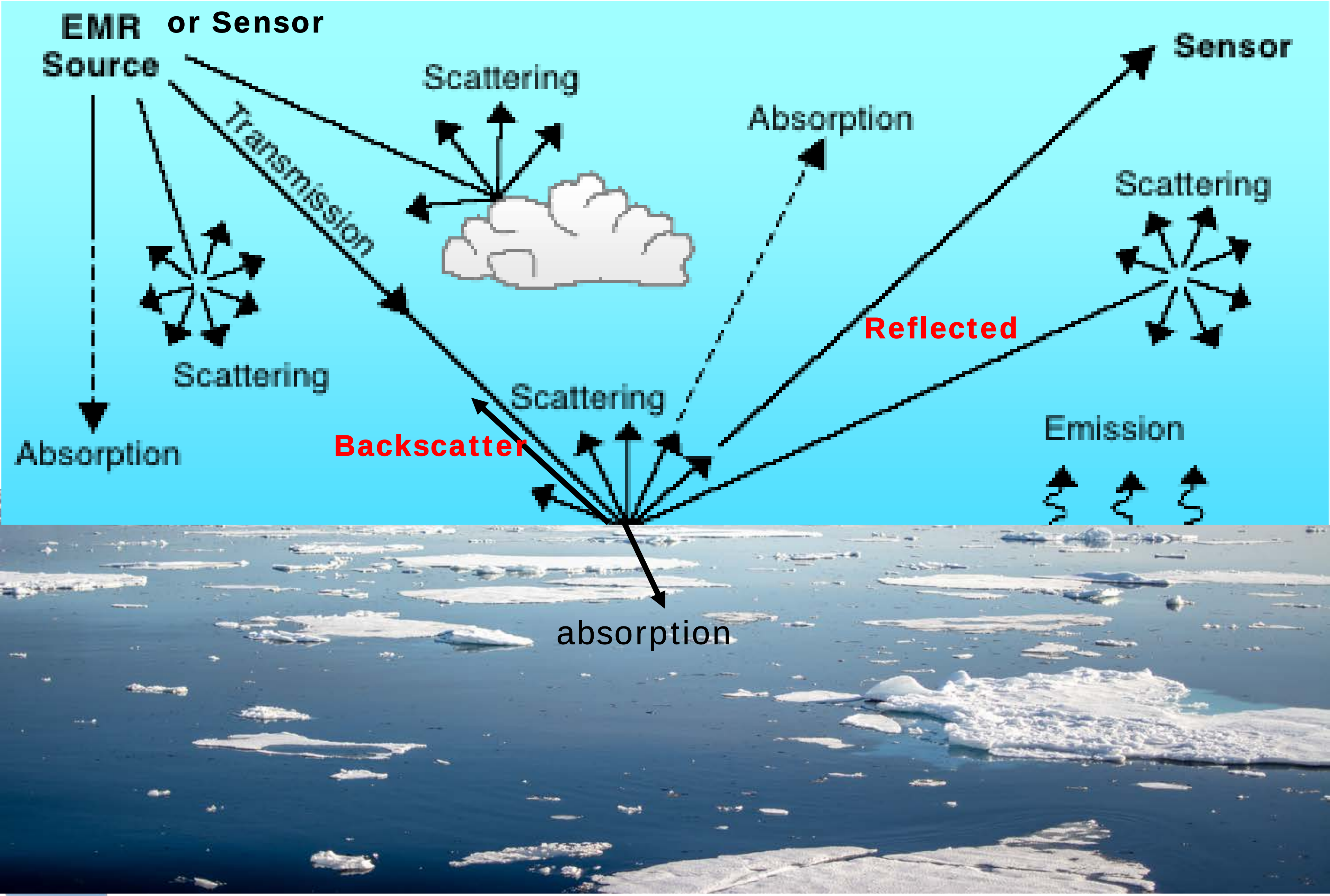
Satellite Observations in the Arctic Marginal Ice Zone

Quantity	Type of observation and variable	Key satellite sensors
Sea Ice	Concentration, type, area, thickness, age, drift, leads, polynias, iceberg, ridges,	Passive microwaves, SAR, Scatterometer, altimeter, optical
SST	Skin temperature *(upper micrometer and upper cm)*	Infrared radiometer, Passive microwave radiometer
SSS	Skin salinity *(upper 20 cm)*	Passive microwave radiometer *valueable for thin ice detection*
Surface Current	Geostrophic current, Ekman current, Stokes drift, range Doppler-based total surface current	Altimeter, SAR, scatterometer
Snow cover	Extent, *thickness, Snow-water equivalent*	SAR, altimeter, scatterometer
Sea level	In open water direct, *in presence of sea ice the freeboard must be removed*	Altimeter
Surface waves	Wavelength, wave spectra, SWH	SAR, optical, altimeter
Wind	Wind speed, streaks, vector wind	SAR, scatterometer, altimeter
Color	Chlorophyll, phytoplankton	Spectrometers
Sun glitter	Sunlight reflected from the surface	Spectrometers

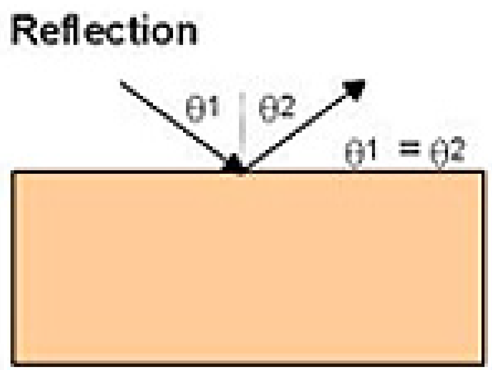
The Electromagnetic spectrum



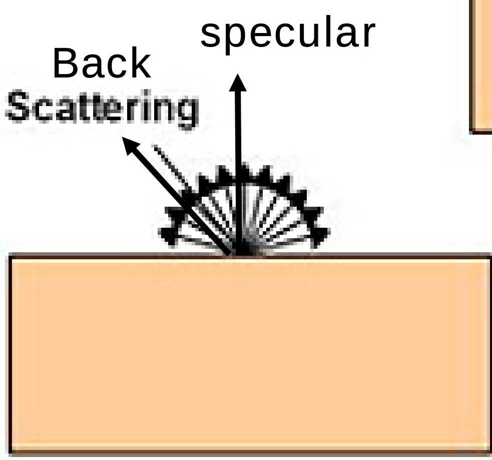
Typical Interaction for Electromagnetic Radiation in the MIZ



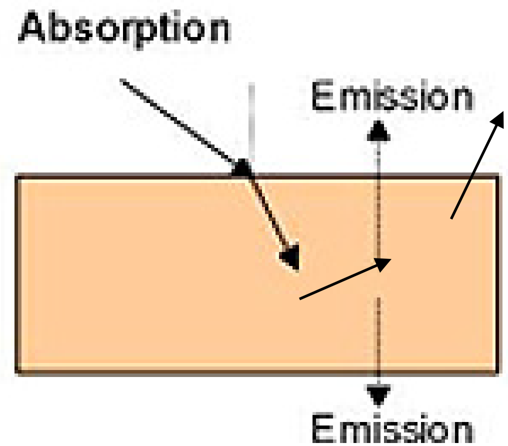
Interaction of the electromagnetic signals with the surface



Visible imaging & Passive Microwaves



Radar (active micro-wave) sensors



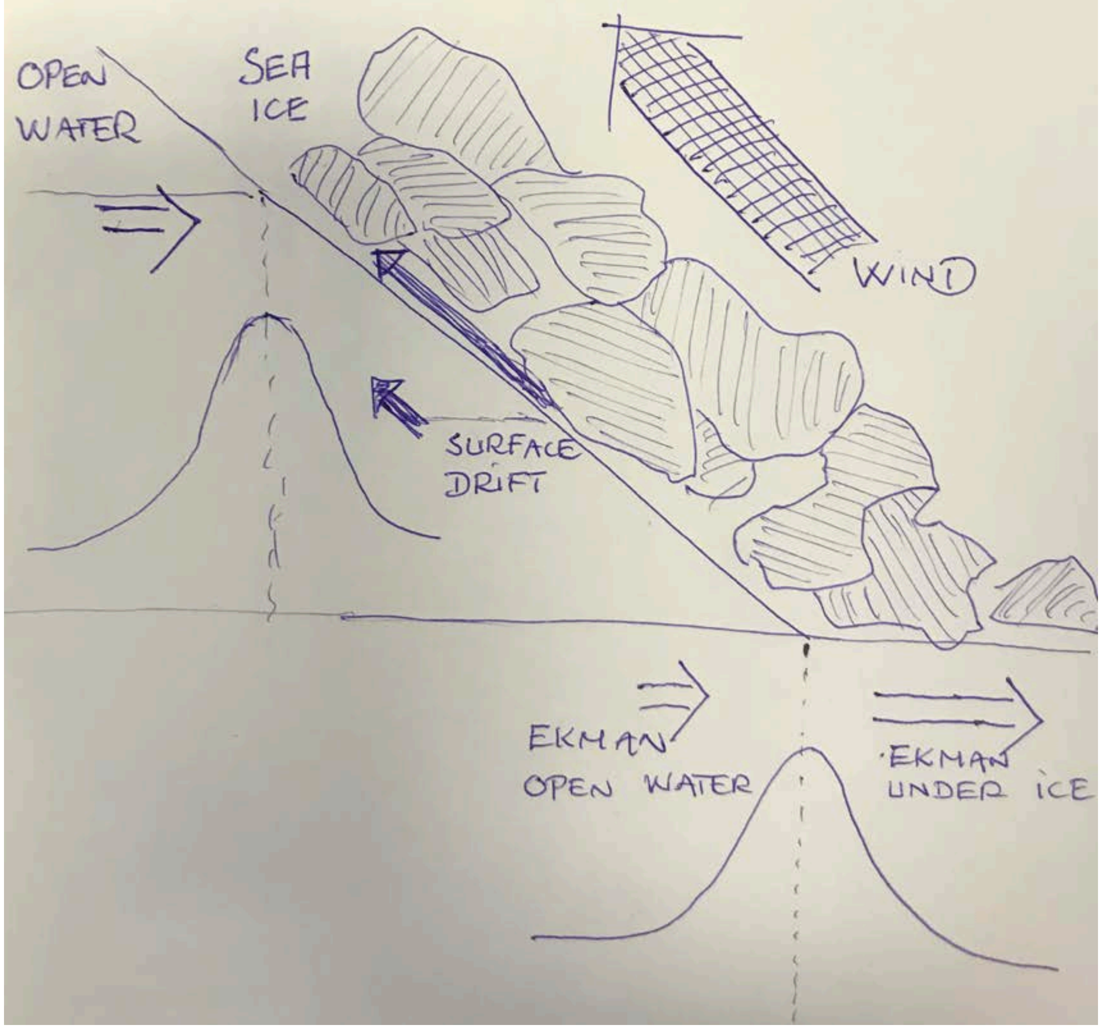
Infrared, visible & Passive Microwaves

MIZ processes

The marginal ice zone is known to undergo complex Ocean - Sea Ice - Atmosphere interactions that are manifested both in the structure of the ice edge, in the sea ice motion and in the open water. Among these are:

Type of process	Dominant forcing	Satellite sensing
Upwelling	Wind driven shear in the Ekman current	SAR, optical, PMW, Scatt
Mesoscale eddies	Current shear & frontal instabilities in the upper ocean	SAR, optical
Wind streaks	Unstable atmospheric boundary layer	SAR, optical
Wave break-up	Wave propagation in ice	SAR, optical
Internal waves (IW)	Tides, current fronts	SAR, optical
Ice jets, bands, filaments	Upper ocean	SAR, optical

UPWELLING IN THE MIZ



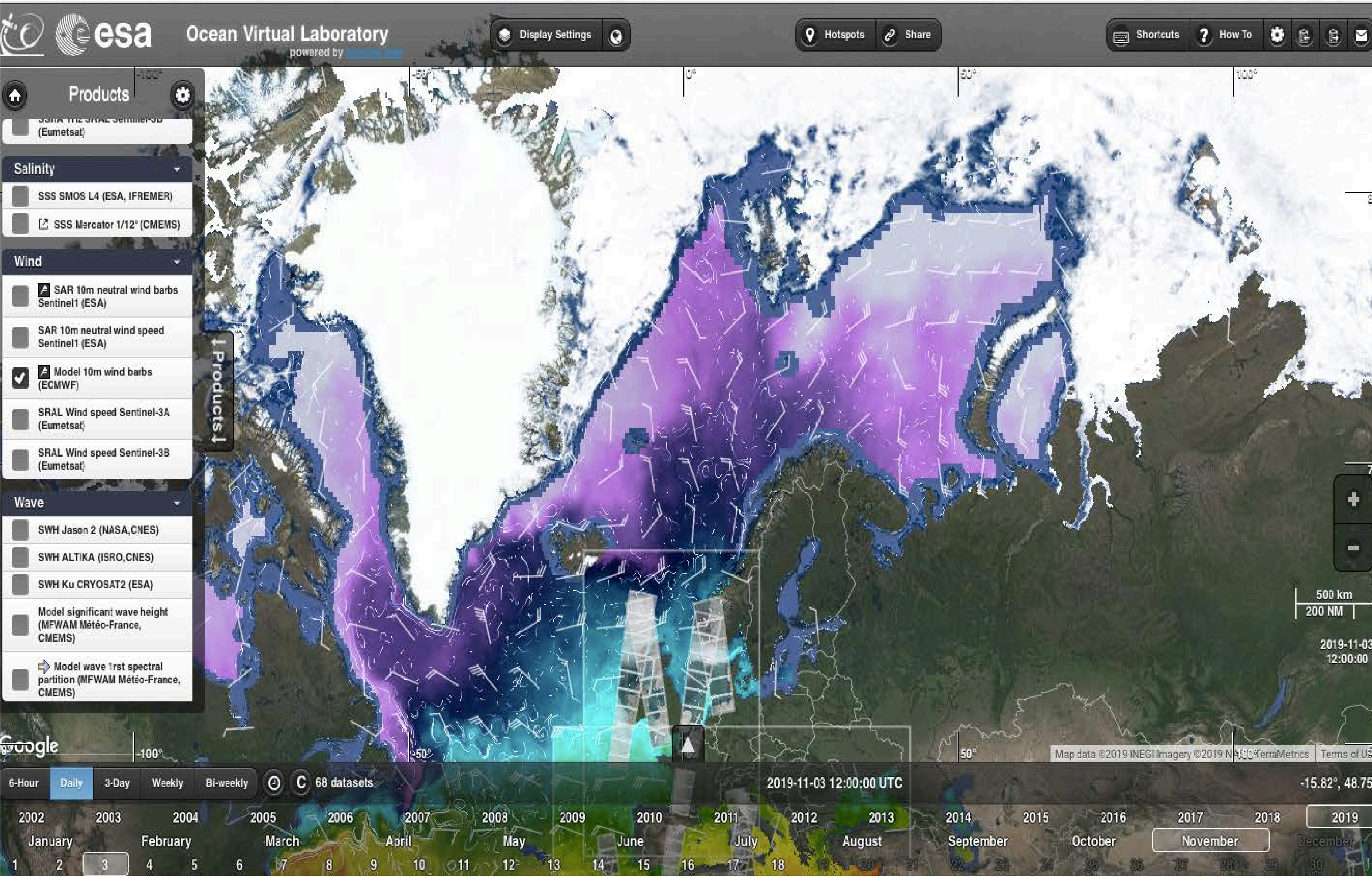
Stress atmosphere to water:

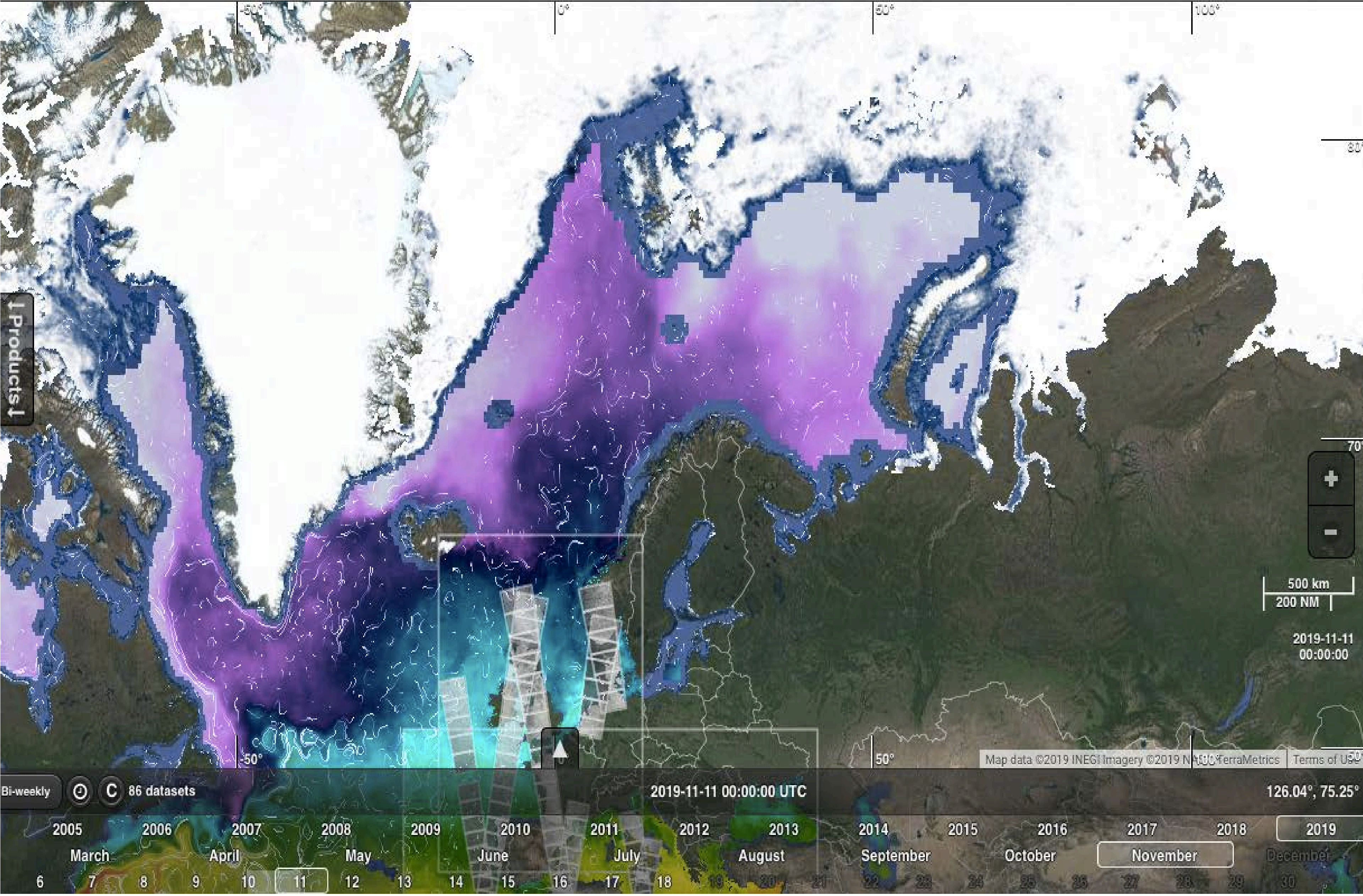
$$\tau_w = \rho_a C_w U^2$$

Stress atmosphere to sea ice:

$$\tau_{si} = \rho_a C_{si} U^2$$

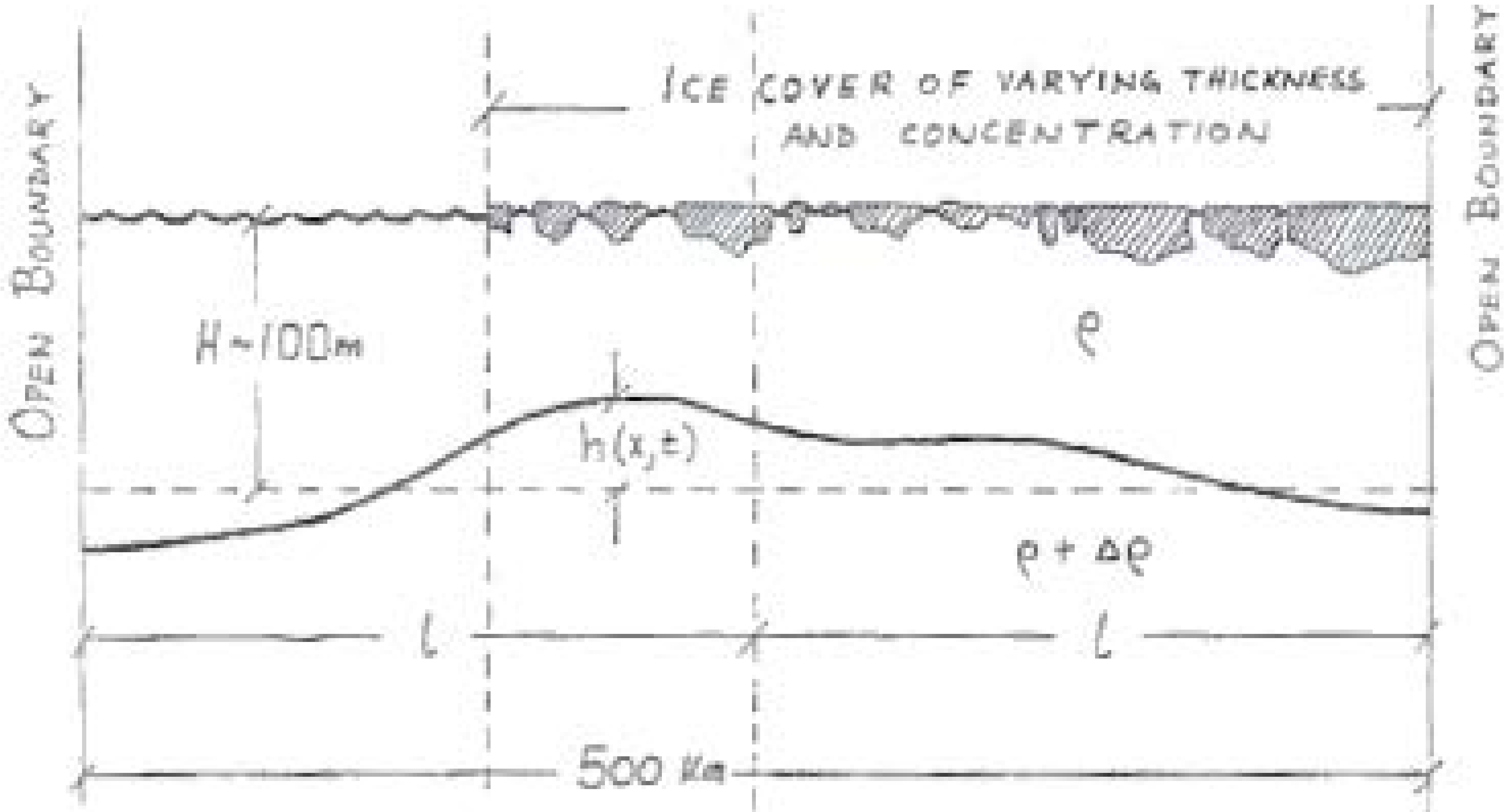
$$\tau_{si}\ \mathrm{H}\ 2\ \tau_w$$


esa
Ocean Virtual Laboratory
Display Settings
Hotspots
Share
Shortcuts
How To
Products
(Eumetsat)
Salinity
SSS SMOS L4 (ESA, IFREMER)
SSS Mercator 1/12° (CMEMS)
Wind
SAR 10m neutral wind barbs Sentinel1 (ESA)
SAR 10m neutral wind speed Sentinel1 (ESA)
Model 10m wind barbs (ECMWF)
SRAL Wind speed Sentinel-3A (Eumetsat)
SRAL Wind speed Sentinel-3B (Eumetsat)
Wave
SWH Jason 2 (NASA,CNES)
SWH ALTIKA (ISRO,CNES)
SWH Ku CRYOSAT2 (ESA)
Model significant wave height (MFWAM Météo-France, CMEMS)
Model wave 1rst spectral partition (MFWAM Météo-France, CMEMS)
Products
500 km
200 NM
2019-11-03 12:00:00
6-Hour
Daily
3-Day
Weekly
Bi-weekly
68 datasets
2019-11-03 12:00:00 UTC
-15.82°, 48.75°
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
January February March April May June July August September October November December



Products
-50°
0°
50°
100°
80°
70°
500 km
200 NM
2019-11-11
00:00:00
Map data ©2019 INEGI Imagery ©2019 NASA, TerraMetrics
Terms of Use
Bi-weekly
86 datasets
2019-11-11 00:00:00 UTC
126.04°, 75.25°
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
March
April
May
June
July
August
September
October
November
December

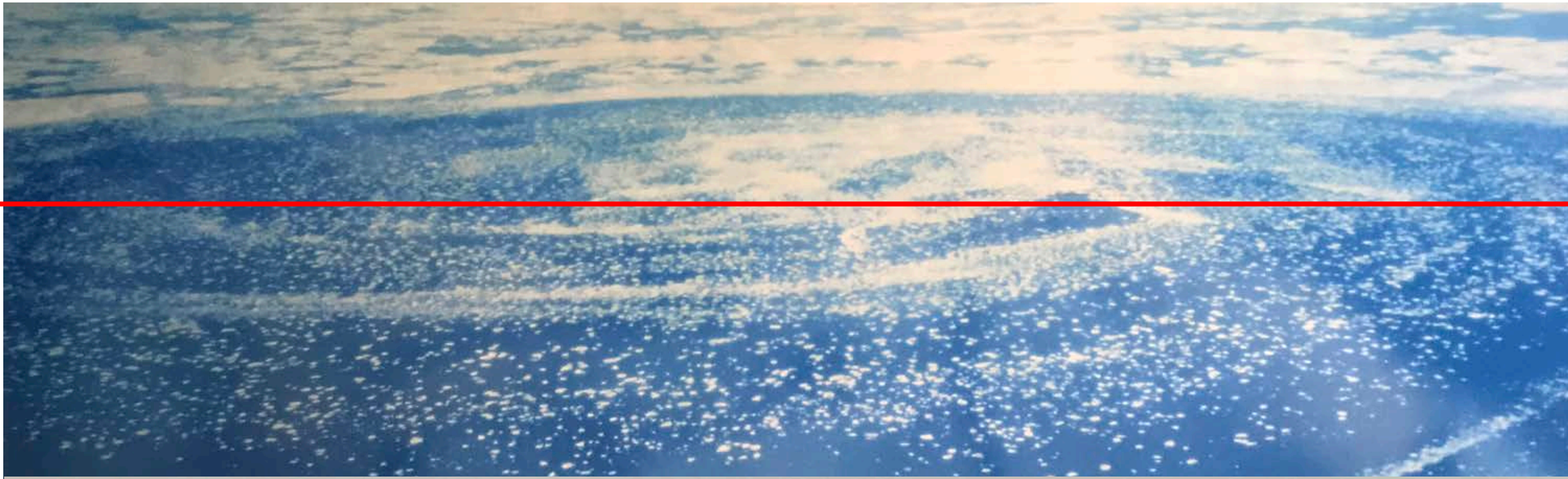
SIMULATED ICE EDGE UPWELLING USING A SEA ICE MODEL
COUPLED WITH A 2-LAYER OCEAN MODEL



COURTECY RØED and O´BRIEN, 1983

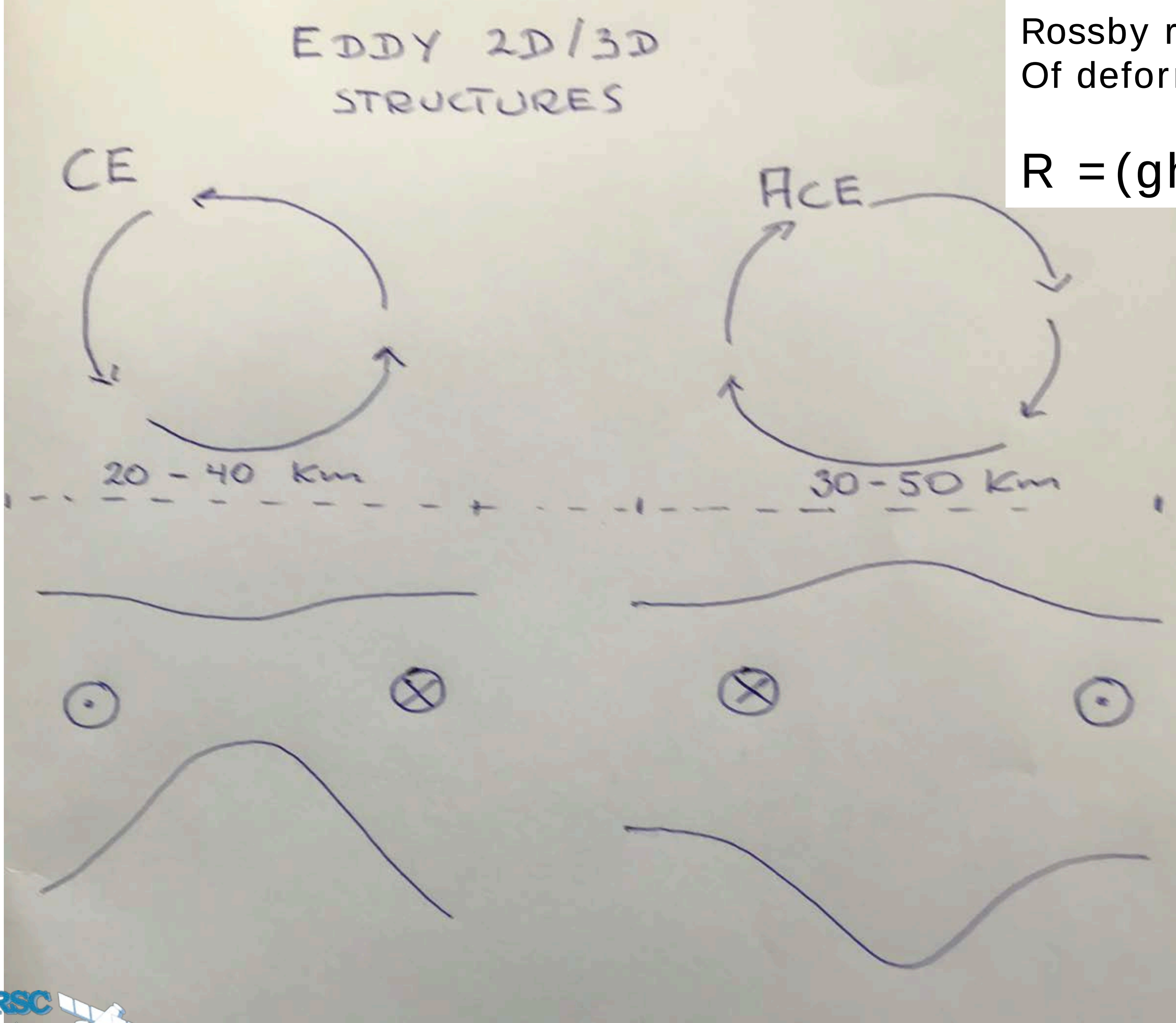
Ice edge eddy with diameter of 30-40 km

Ice edge eddy with diameter of 30-40 km



TOP VIEW

SIDE VIEW



Rossby radius
Of deformation

$$R = (gh\delta\rho/f\rho)^{1/2}$$

Ice edge eddy with diameter of 30-40 km

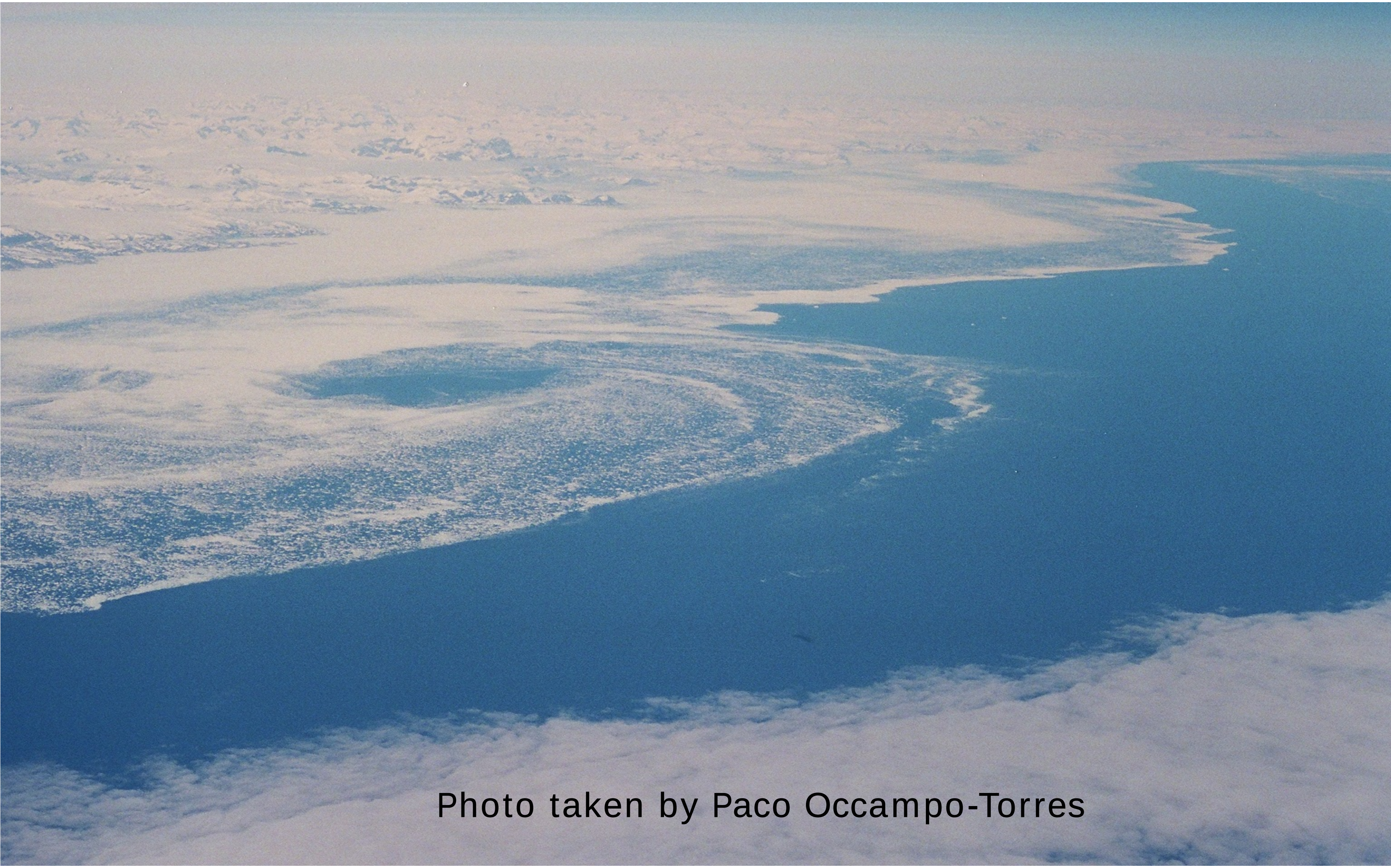
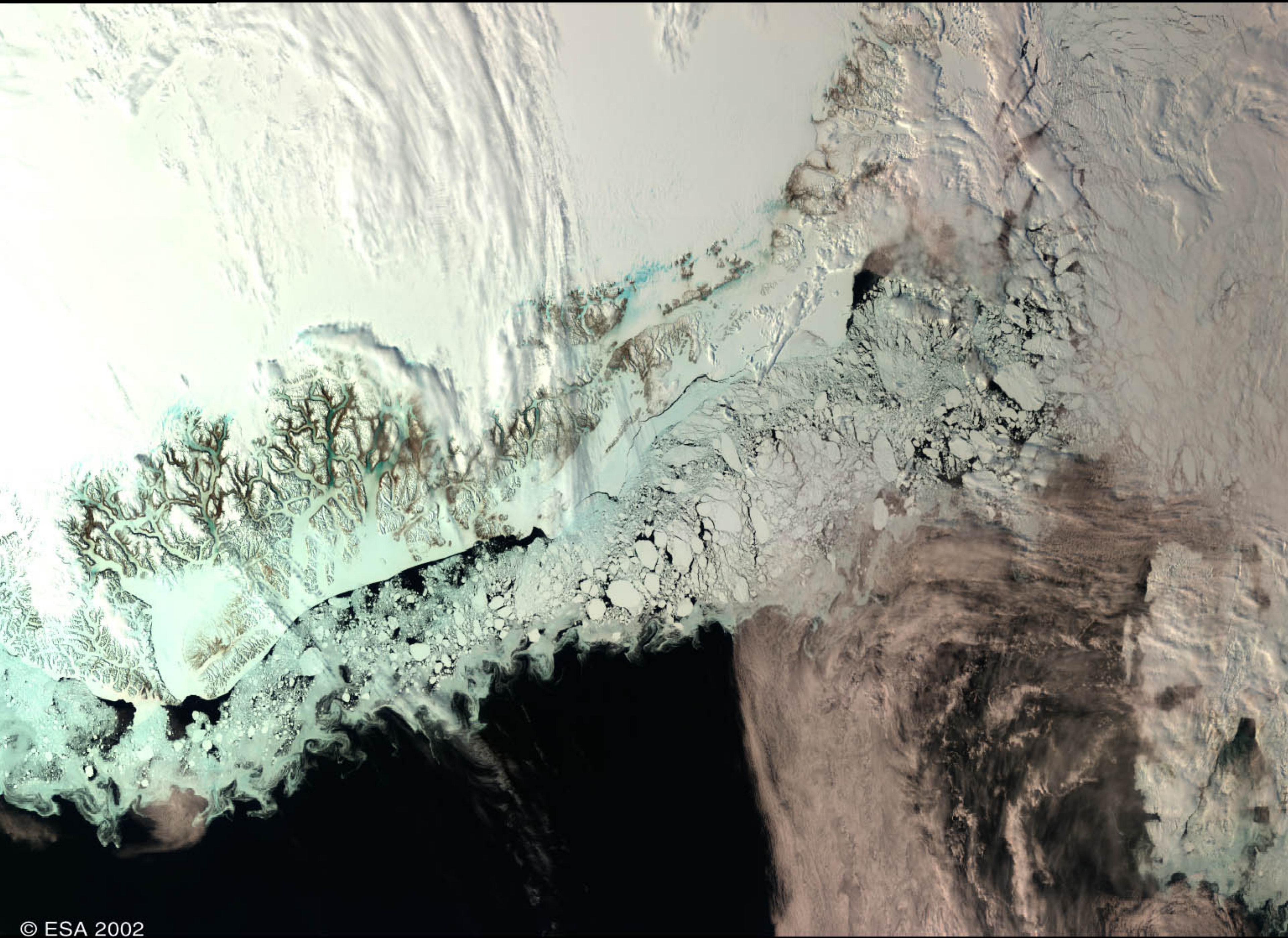
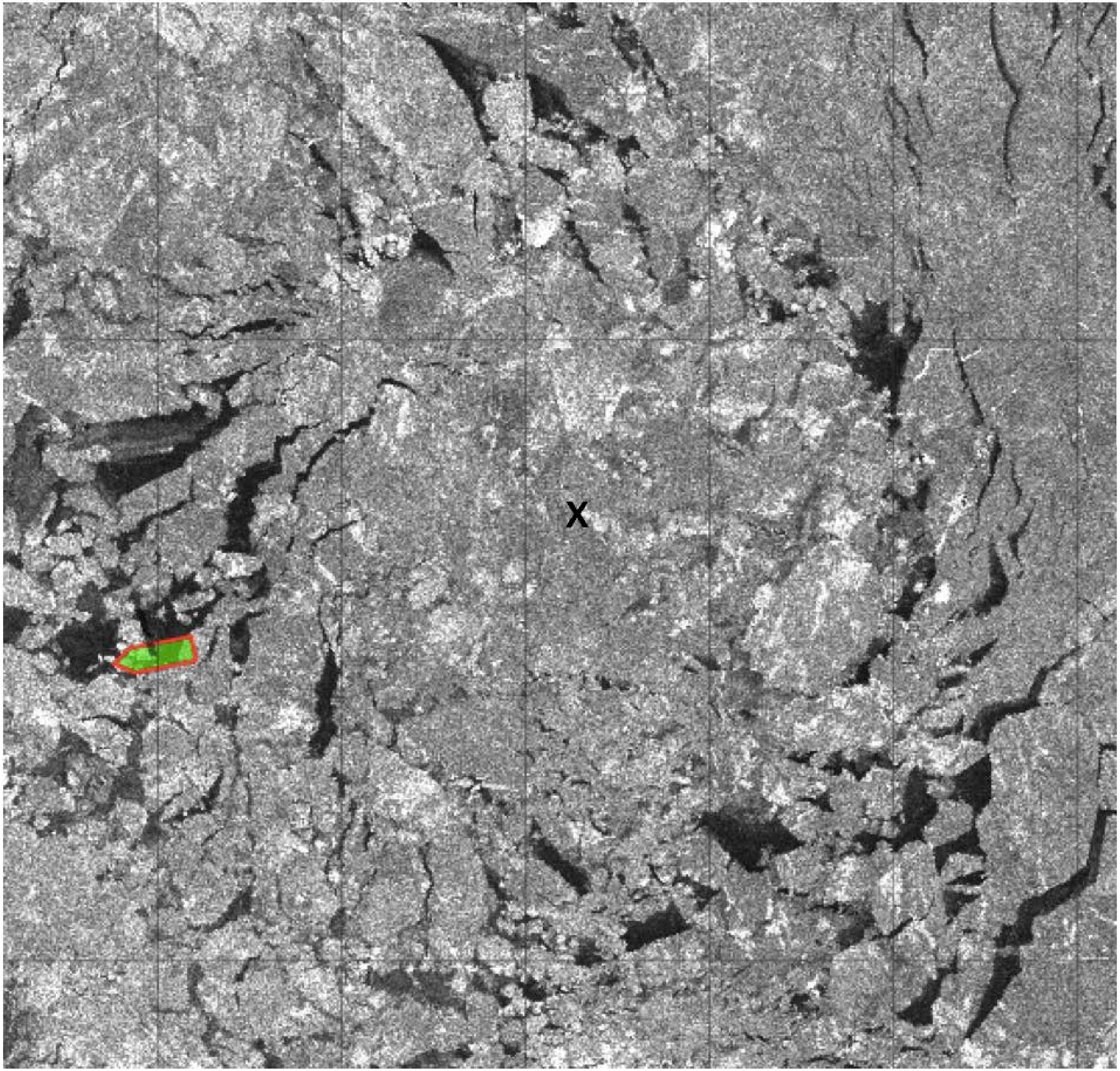


Photo taken by Paco Occampo-Torres


© ESA 2002


© ESA 2002



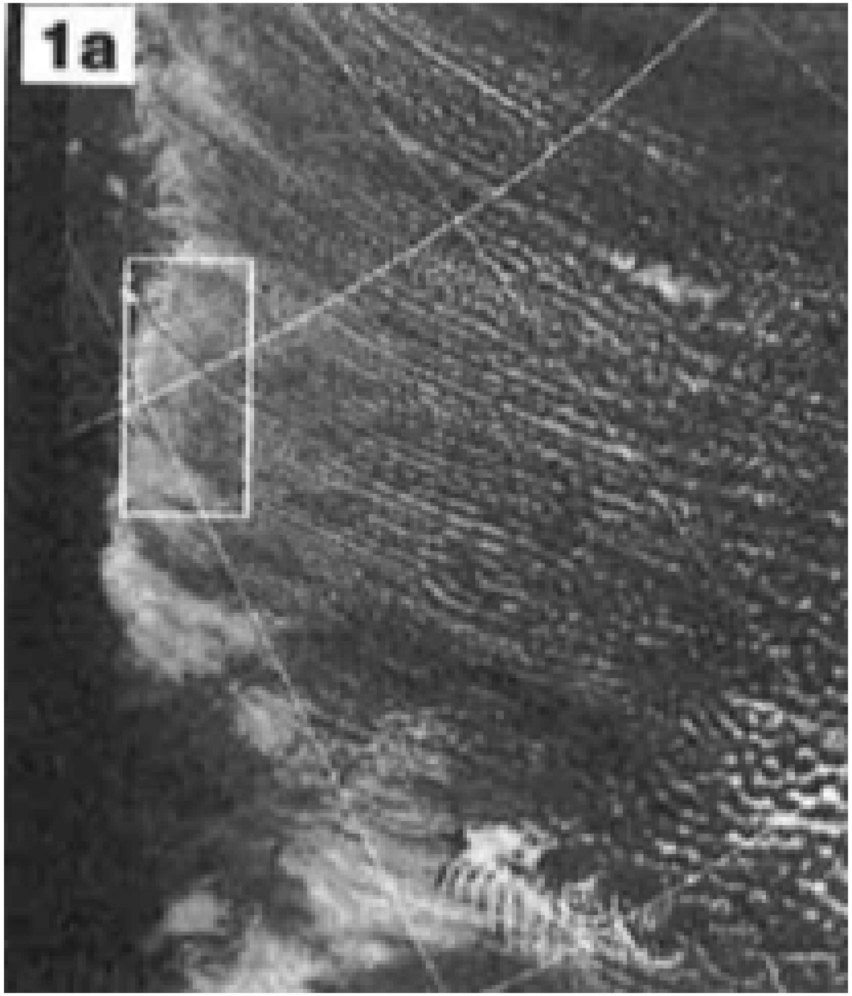
Radarsat-2 SAR image from 30 October 2015

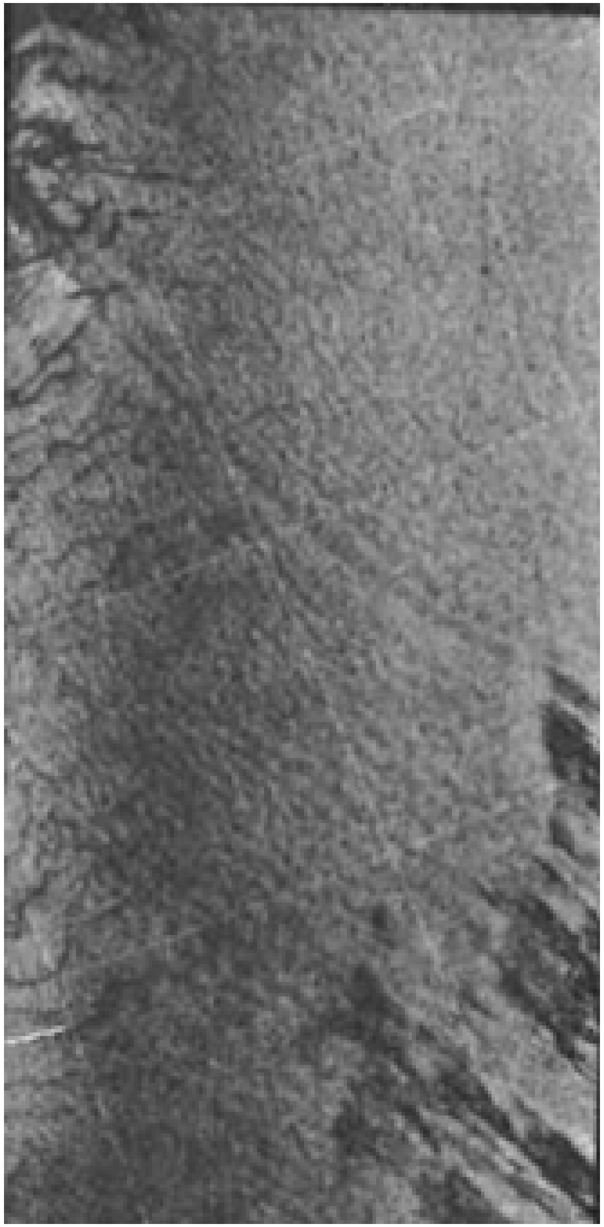
X - marks center of eddy

Courtecy Ben Holt JPL/NASA

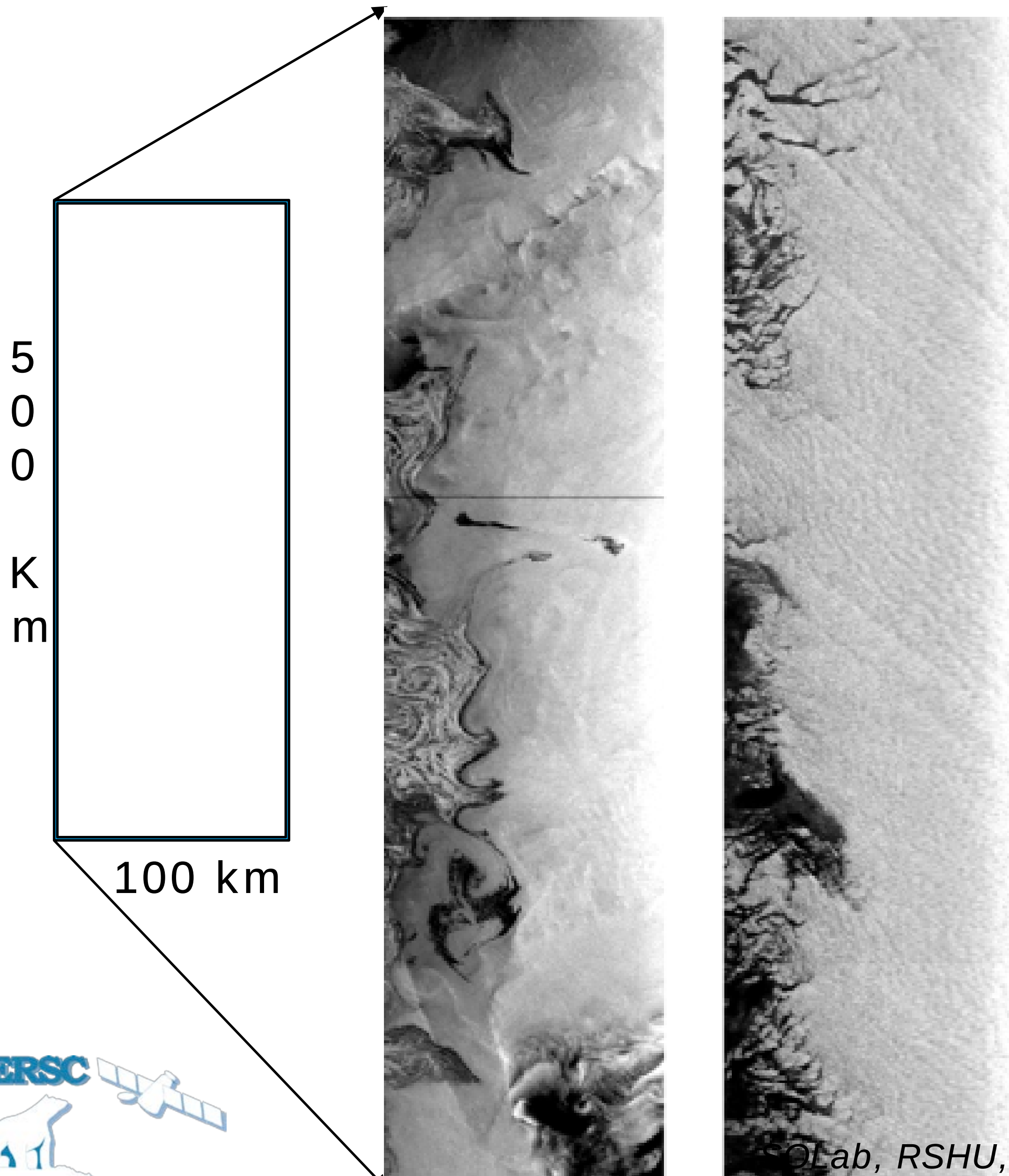
Ice edge bands

Wind streaks in cloud structures and SAR roughness



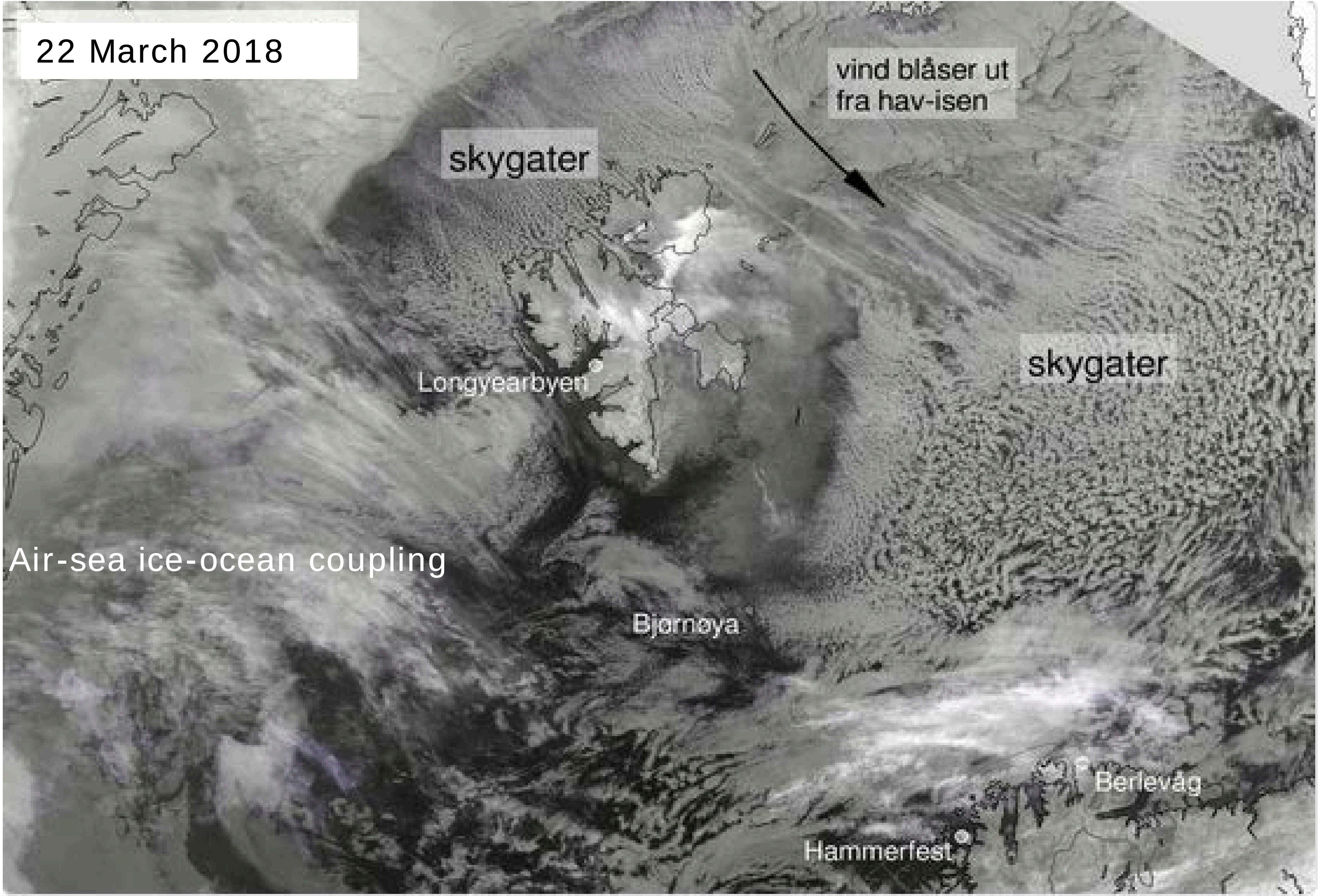


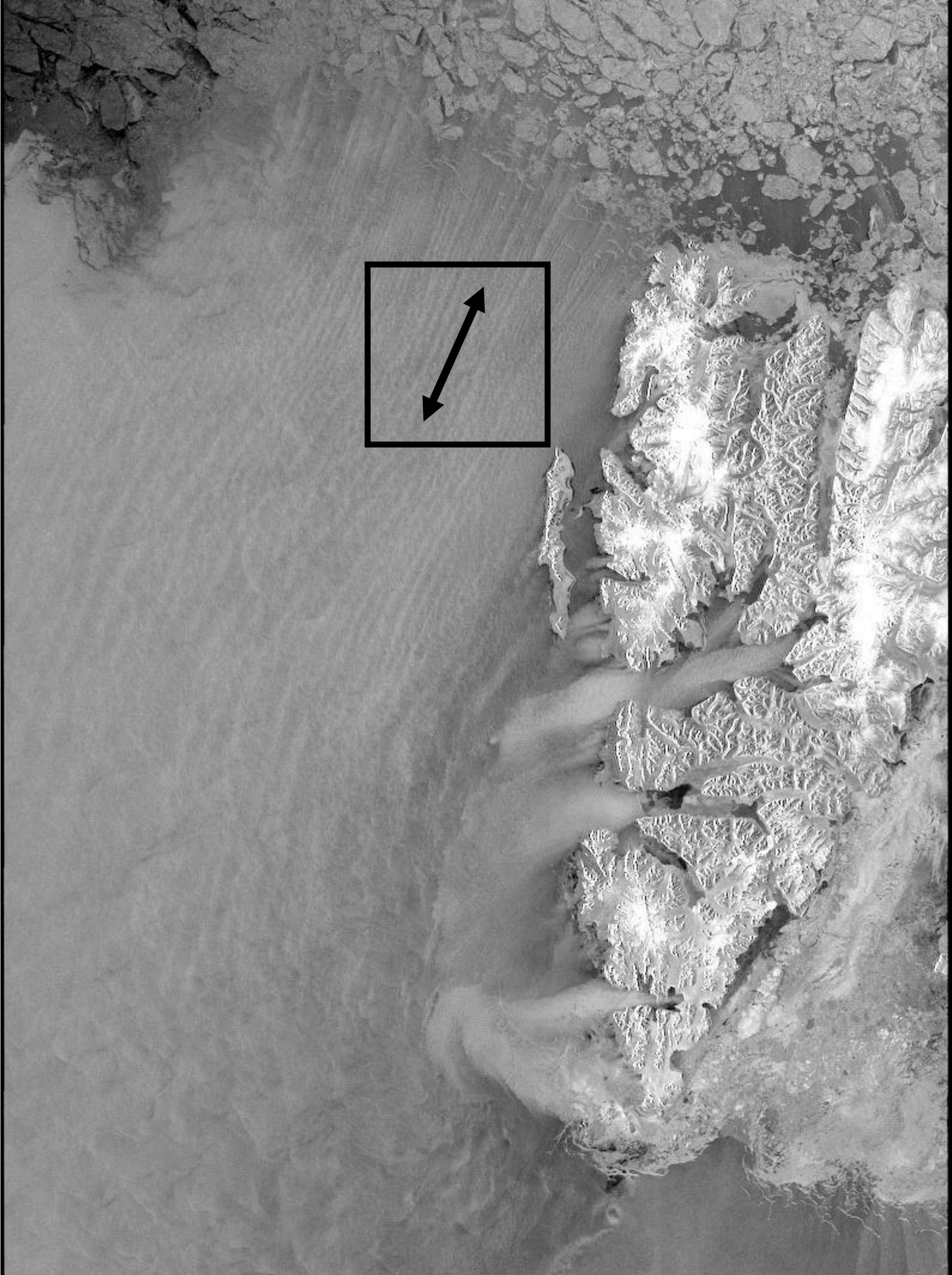
Structural changes in the MIZ – 3 days interval

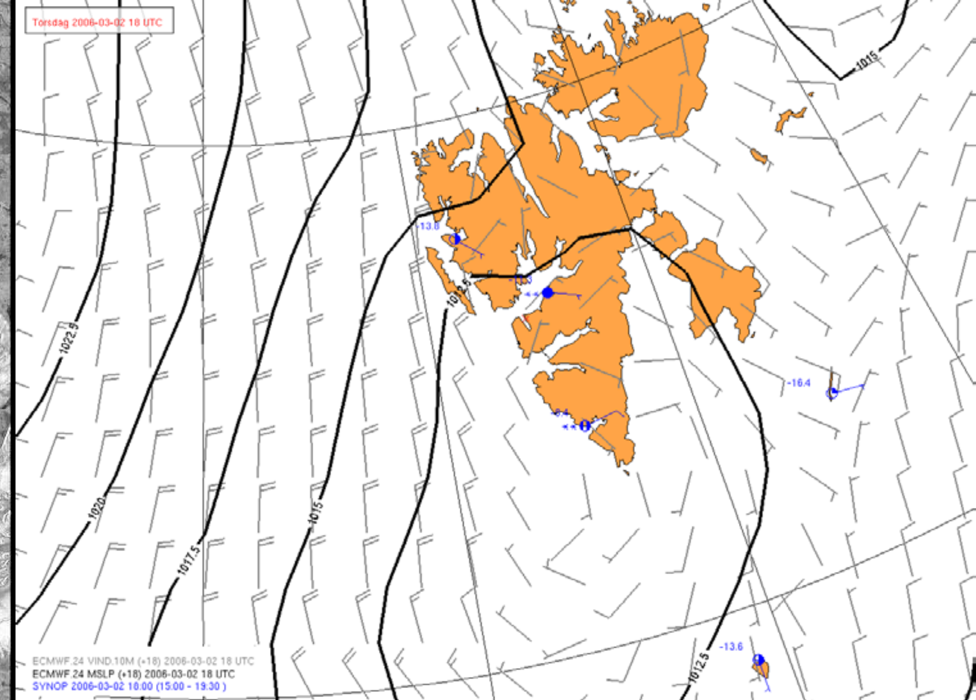


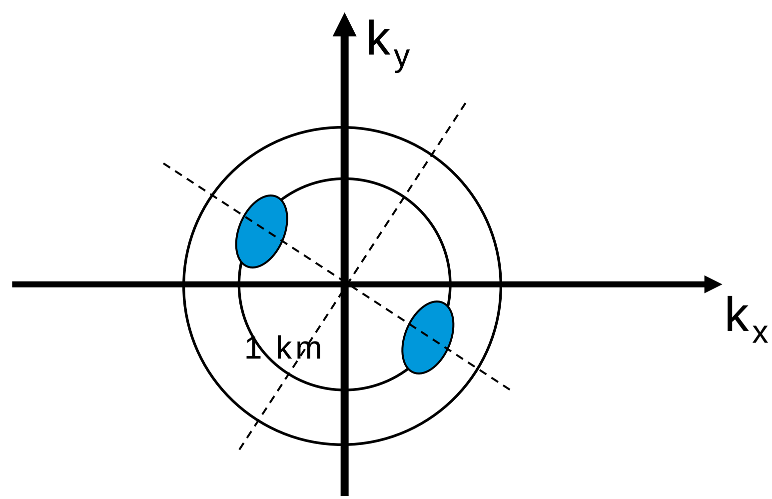
ERS-1 SAR image of a 500 km area along the MIZ in the Greenland Sea from 13 January 1992.

Same area imaged by ERS-1 on 16 January 1992.


22 March 2018
vind blåser ut
fra hav-isen
skygater
skygater
Longyearbyen
Air-sea ice-ocean coupling
Bjørnøya
Berlevåg
Hammerfest

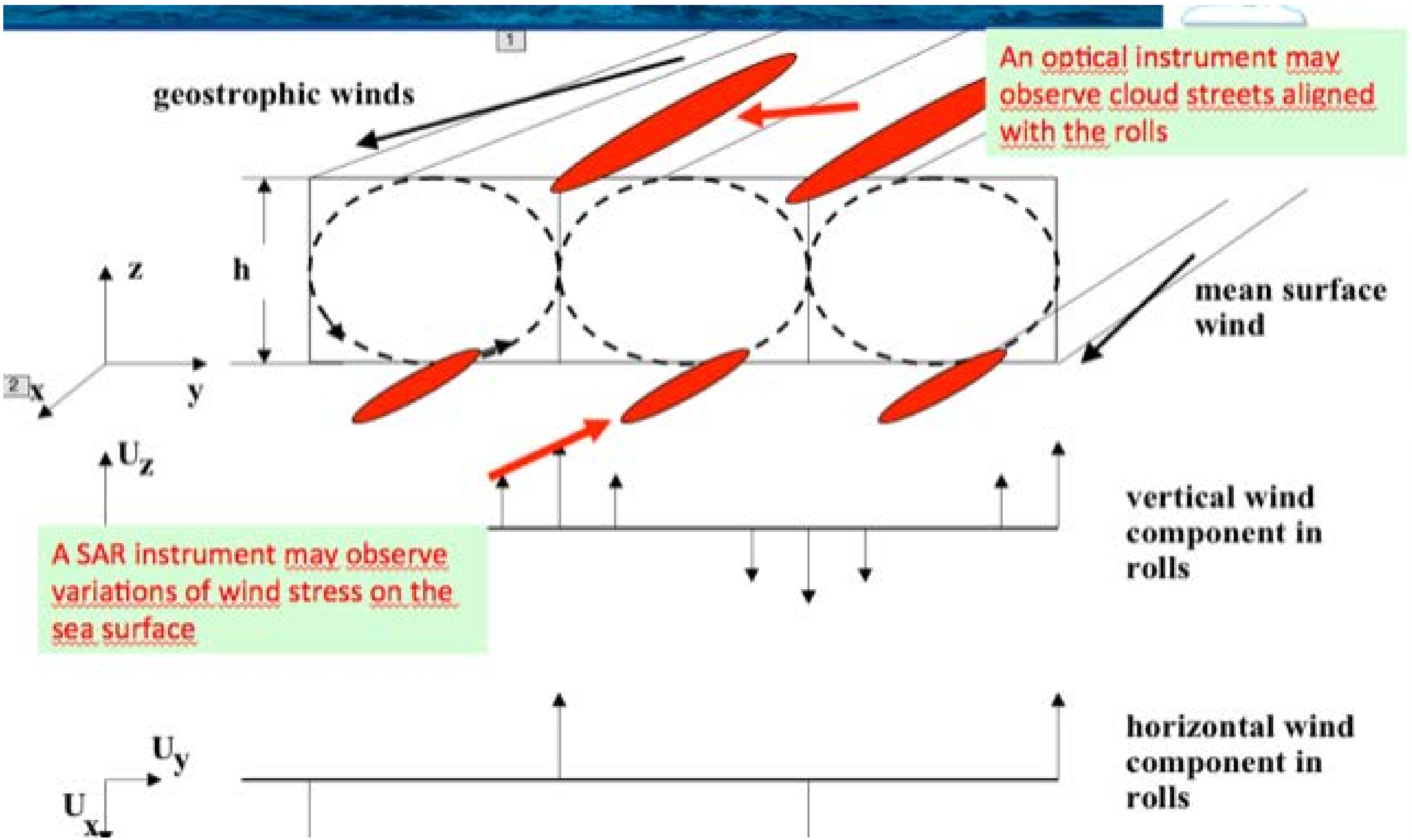






3 March 2006 - ASAR

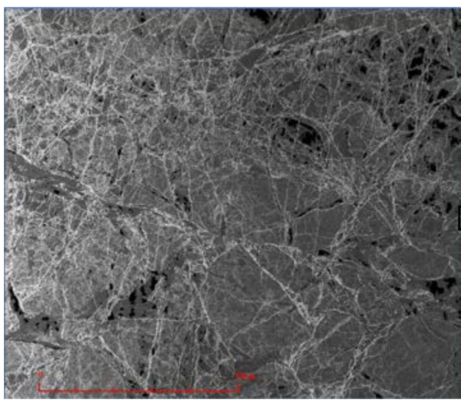
Wind streaks and cloud structures



LEAD FRACTION AND SHEAR/DIV ZONES

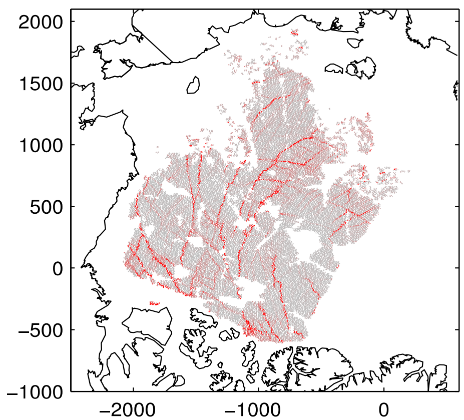
Processes at the mesoscale to sub-mesoscale

SAR image(s)

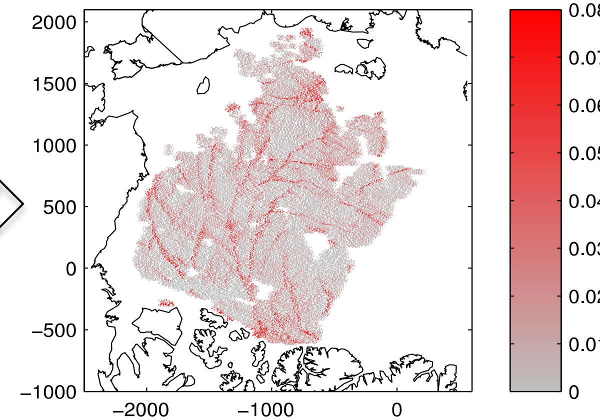


10 KM

From SAR image(s)

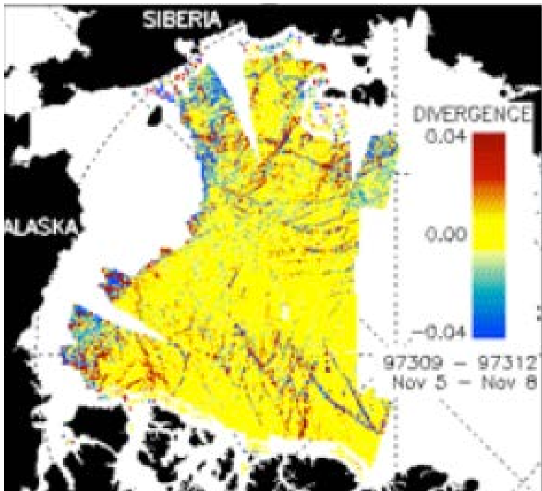


Elasto-Brittle model

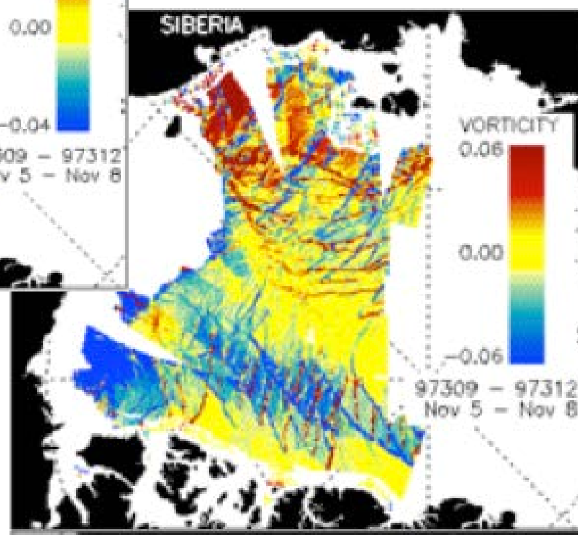


Sea Ice Deformation

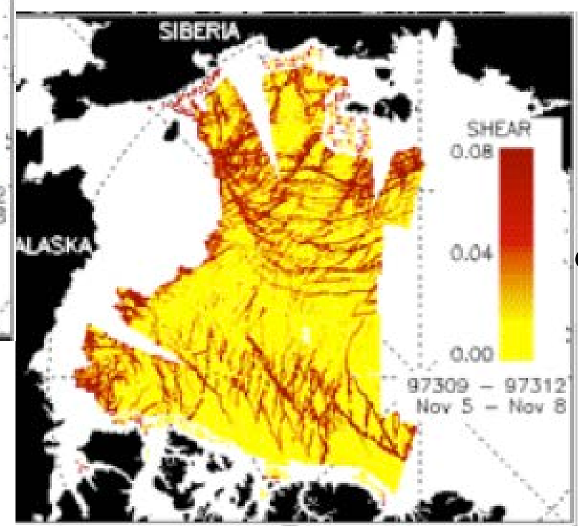
The deformation of a 10 km by 10 km cell over a 41-day period is shown from RADARSAT.
Courtesy Ron Kwok



Divergence
$\delta u/\delta x + \delta v/\delta y$

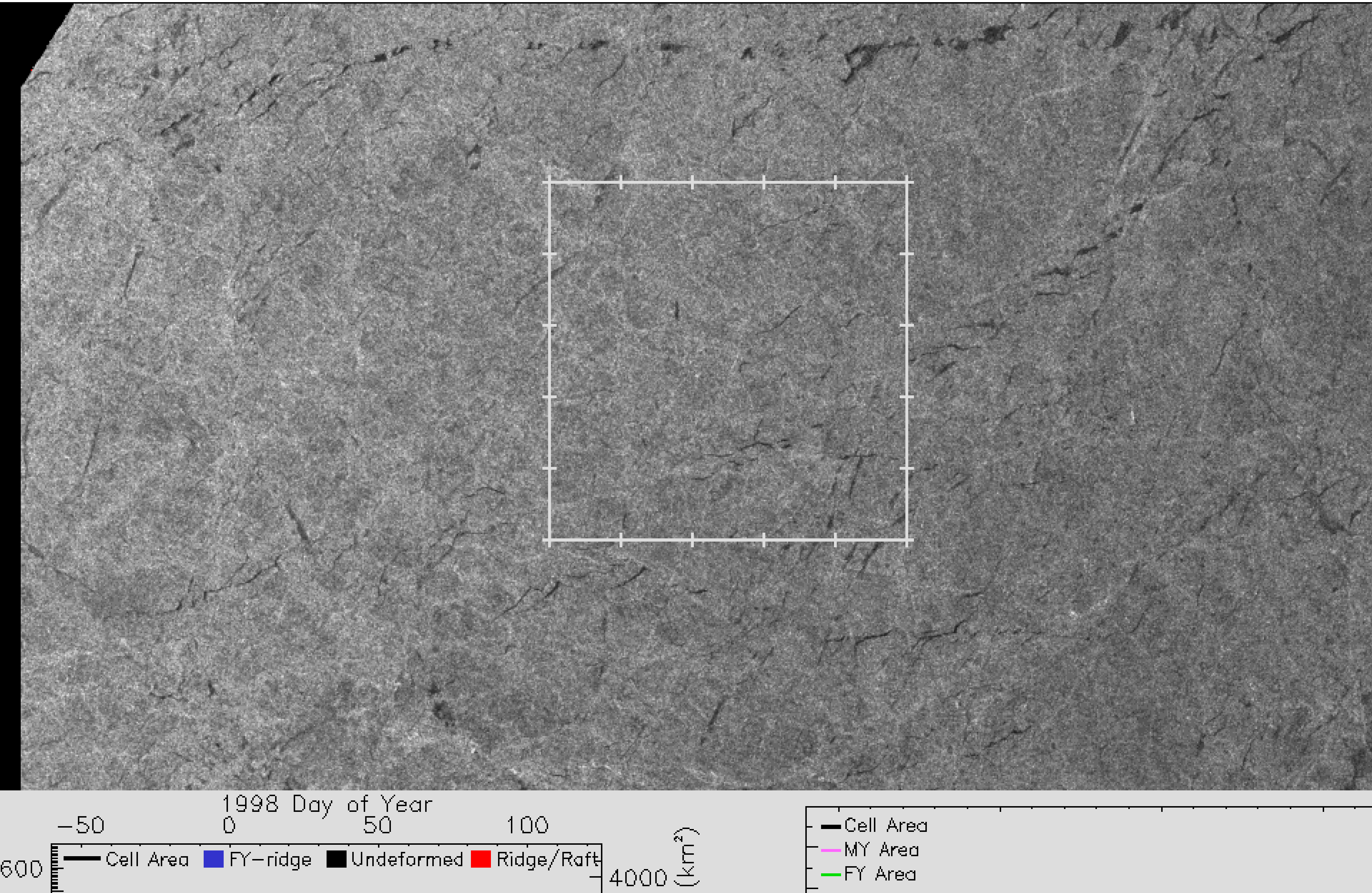


Vorticity
$\delta v/\delta x - \delta u/\delta y$

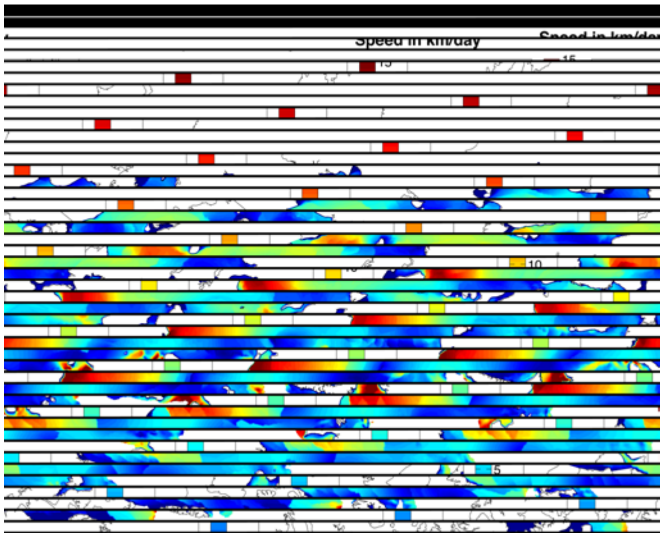


Shear
$\delta u/\delta y + \delta v/\delta x$

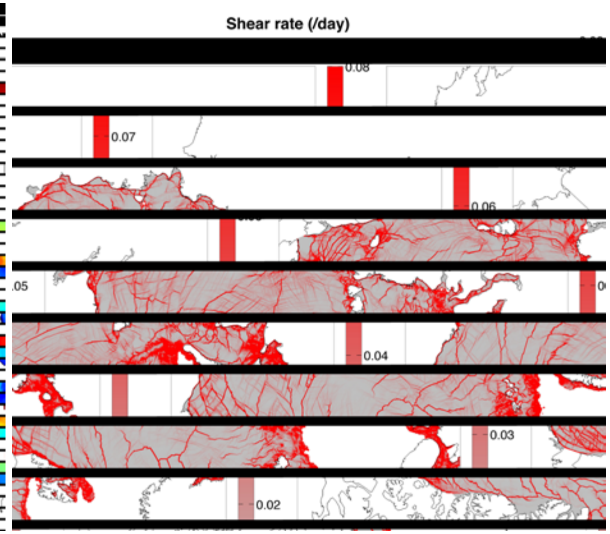
Courtecy Ron Kwok



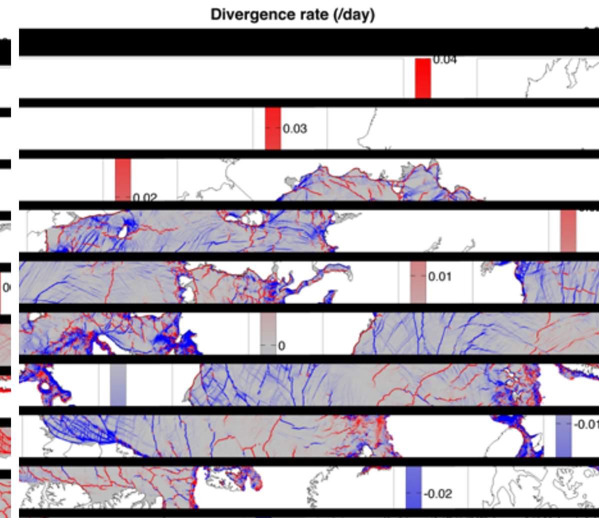
Speed, shear and divergence



Ice speed



Ice shearing rate

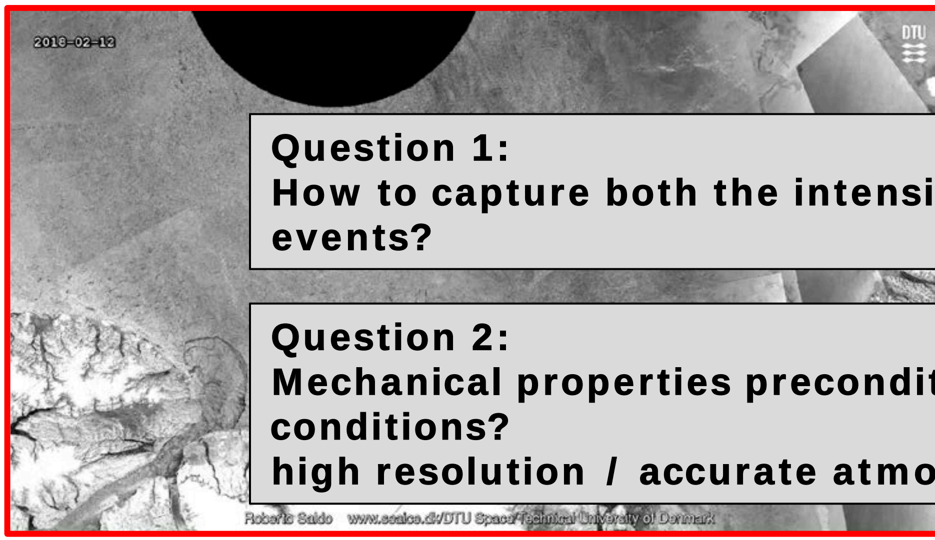


Ice divergence rate

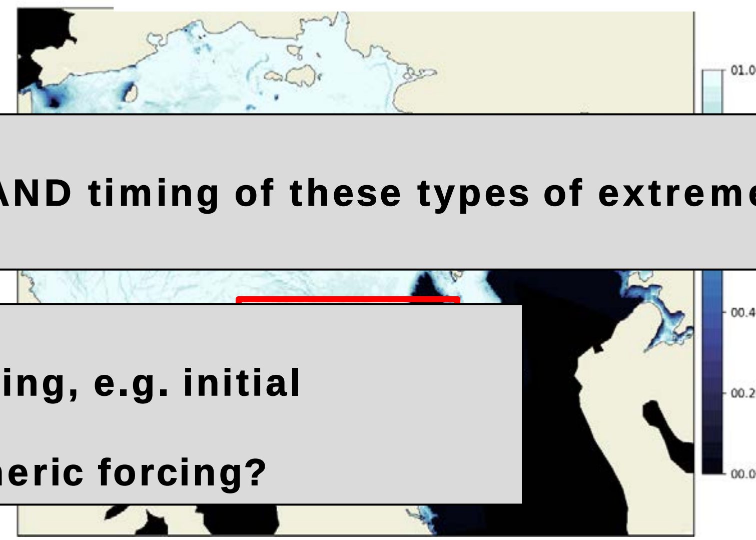
Courtecy P. Rampal

On predicting sea ice breakup events and opening of coastal polynyas

February 2018 polynya opening north of Greenland / warm atmospheric event



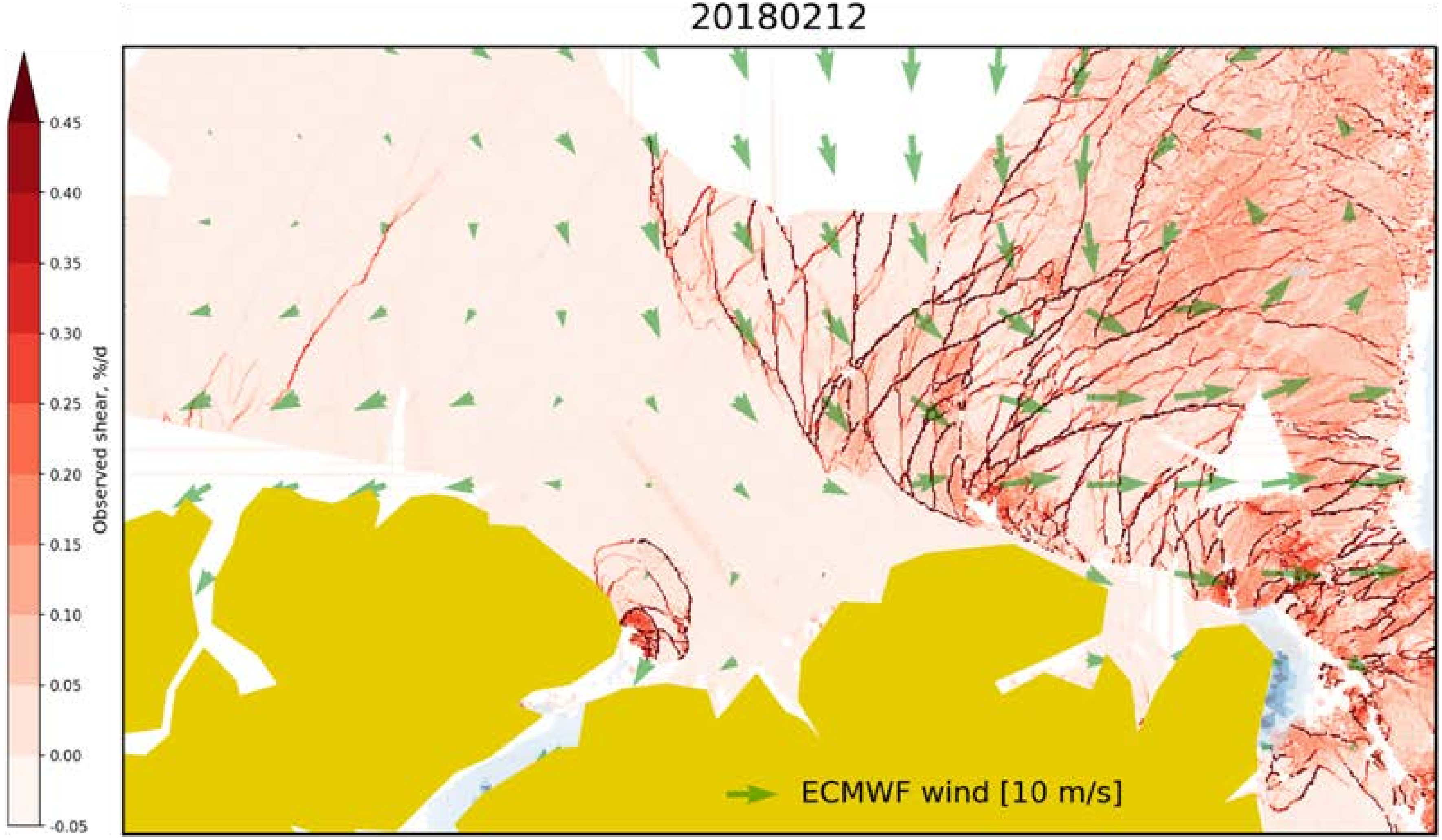
neXtSIM-F forecast for the 26 Feb. 2018



Question 1:
How to capture both the intensity AND timing of these types of extreme events?

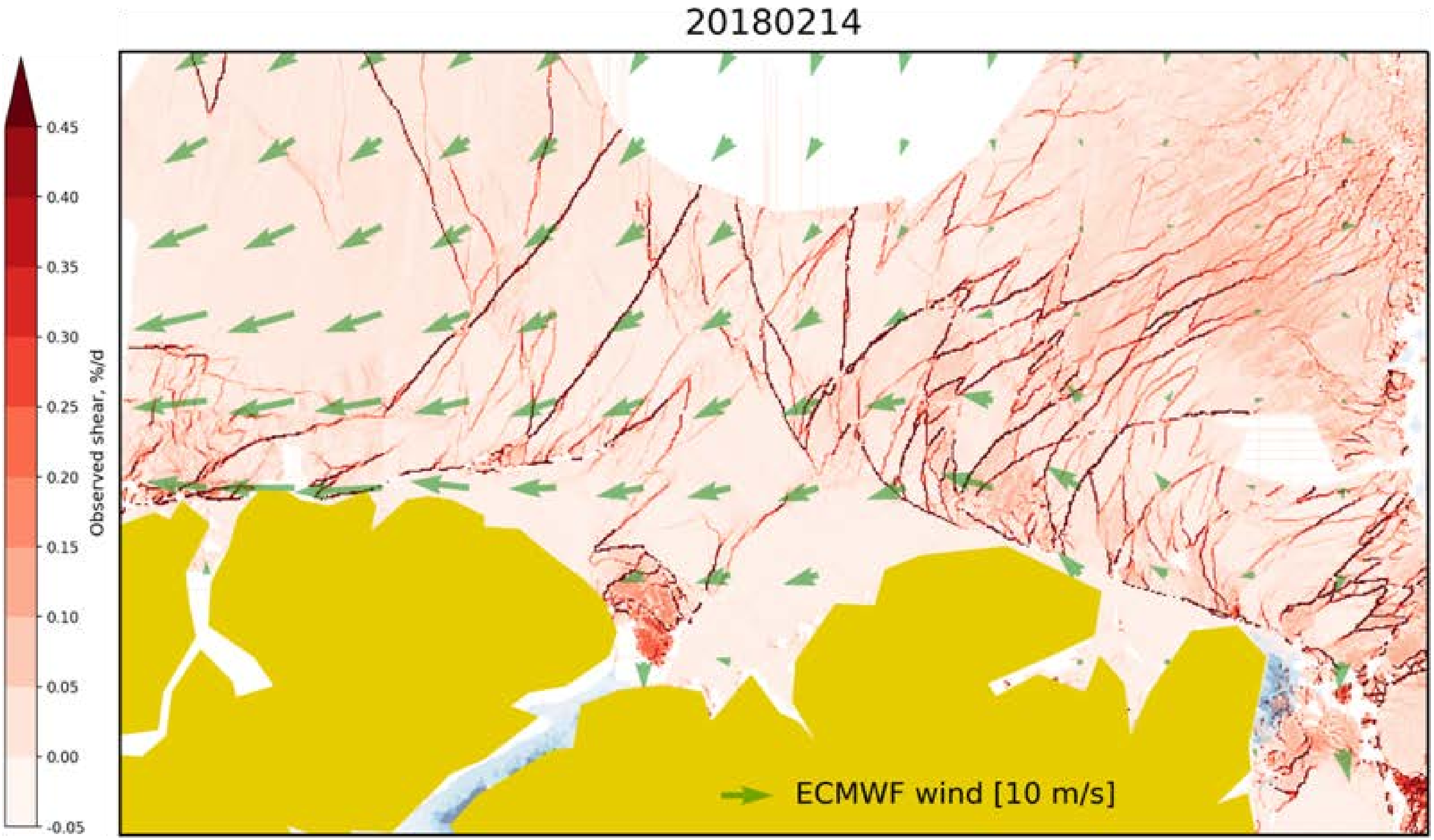
Question 2:
Mechanical properties preconditioning, e.g. initial conditions?
high resolution / accurate atmospheric forcing?

Sea ice deformation from Sentinel-1 (SAR)



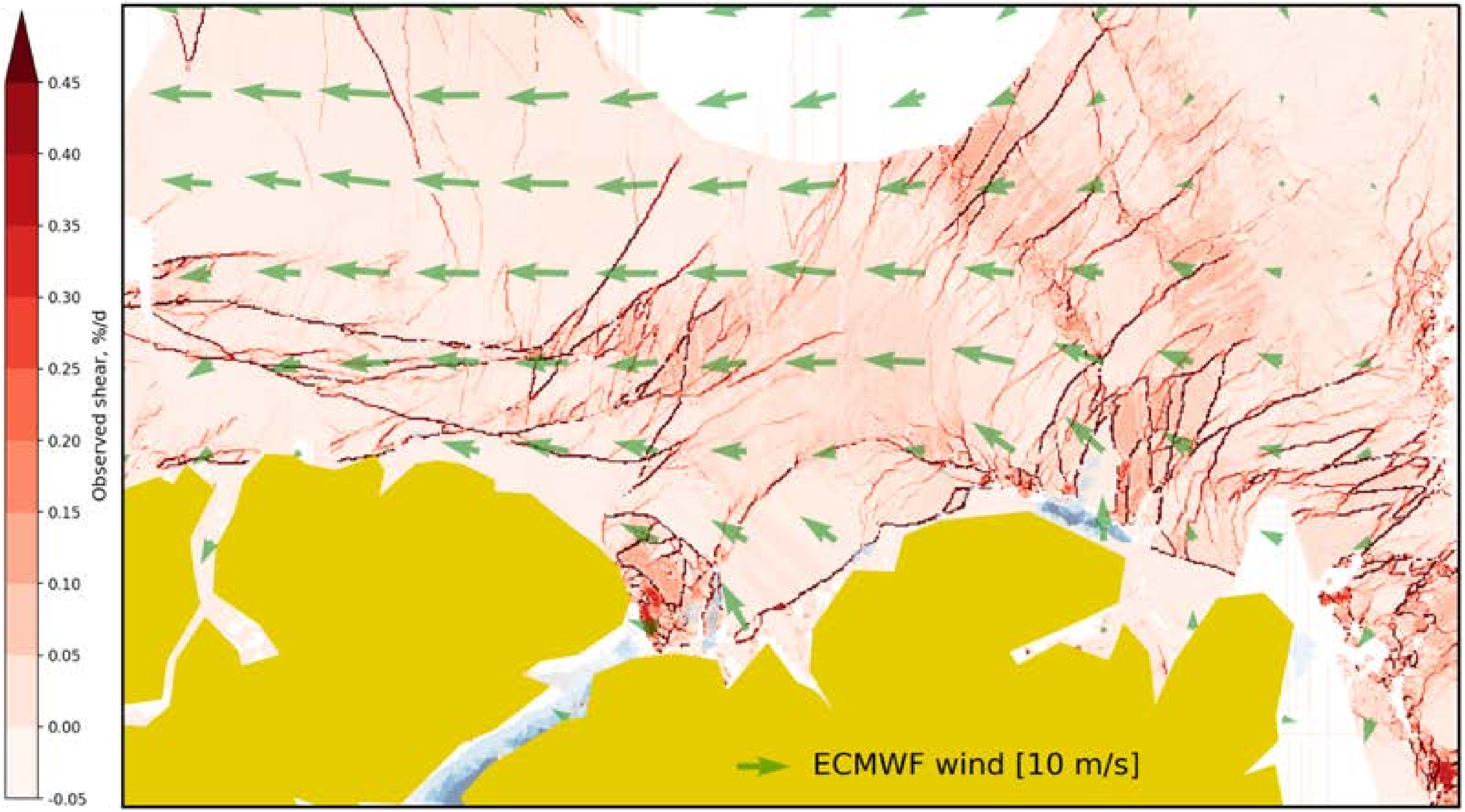
NERSC

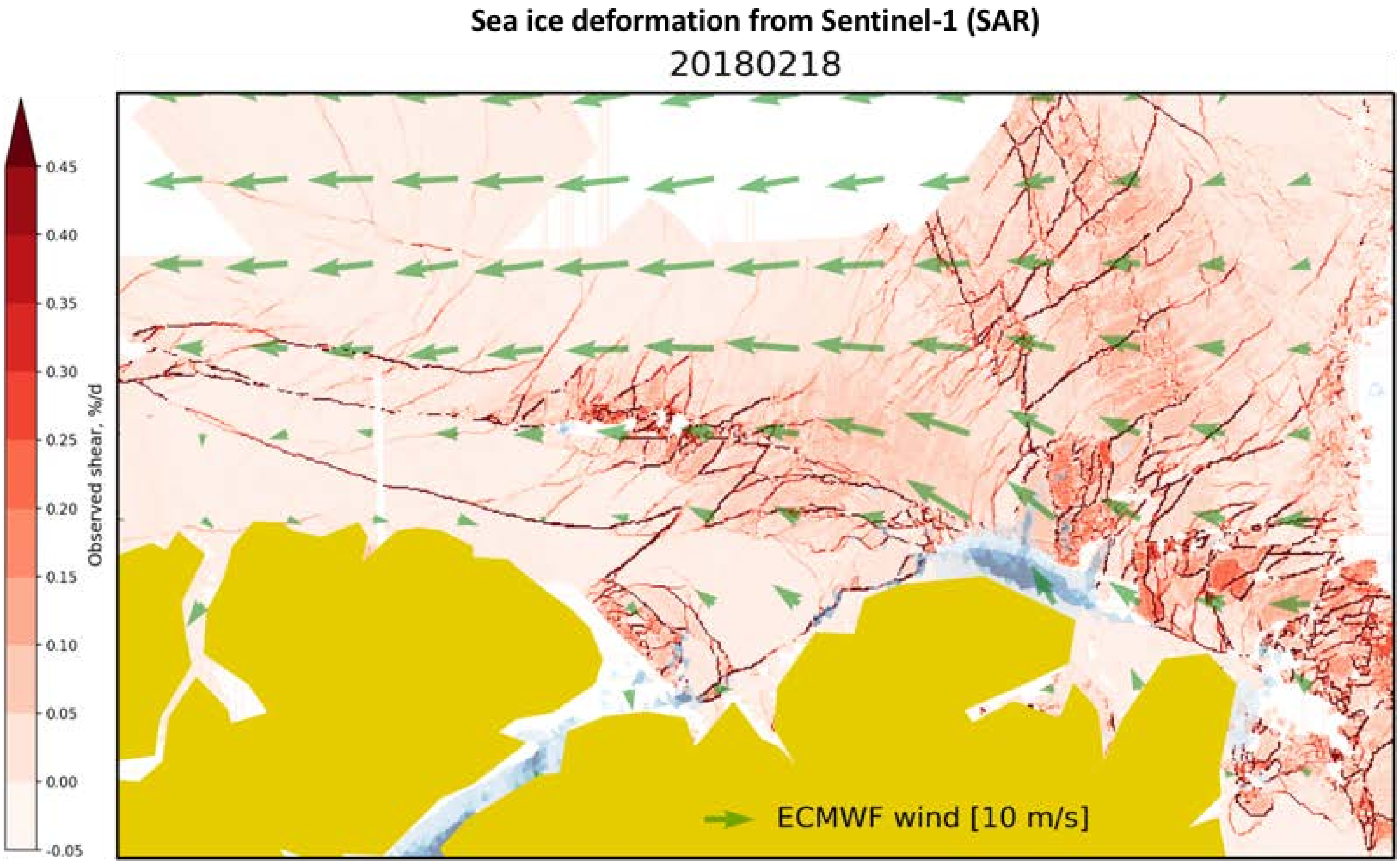
Sea ice deformation from Sentinel-1 (SAR)



Sea ice deformation from Sentinel-1 (SAR)

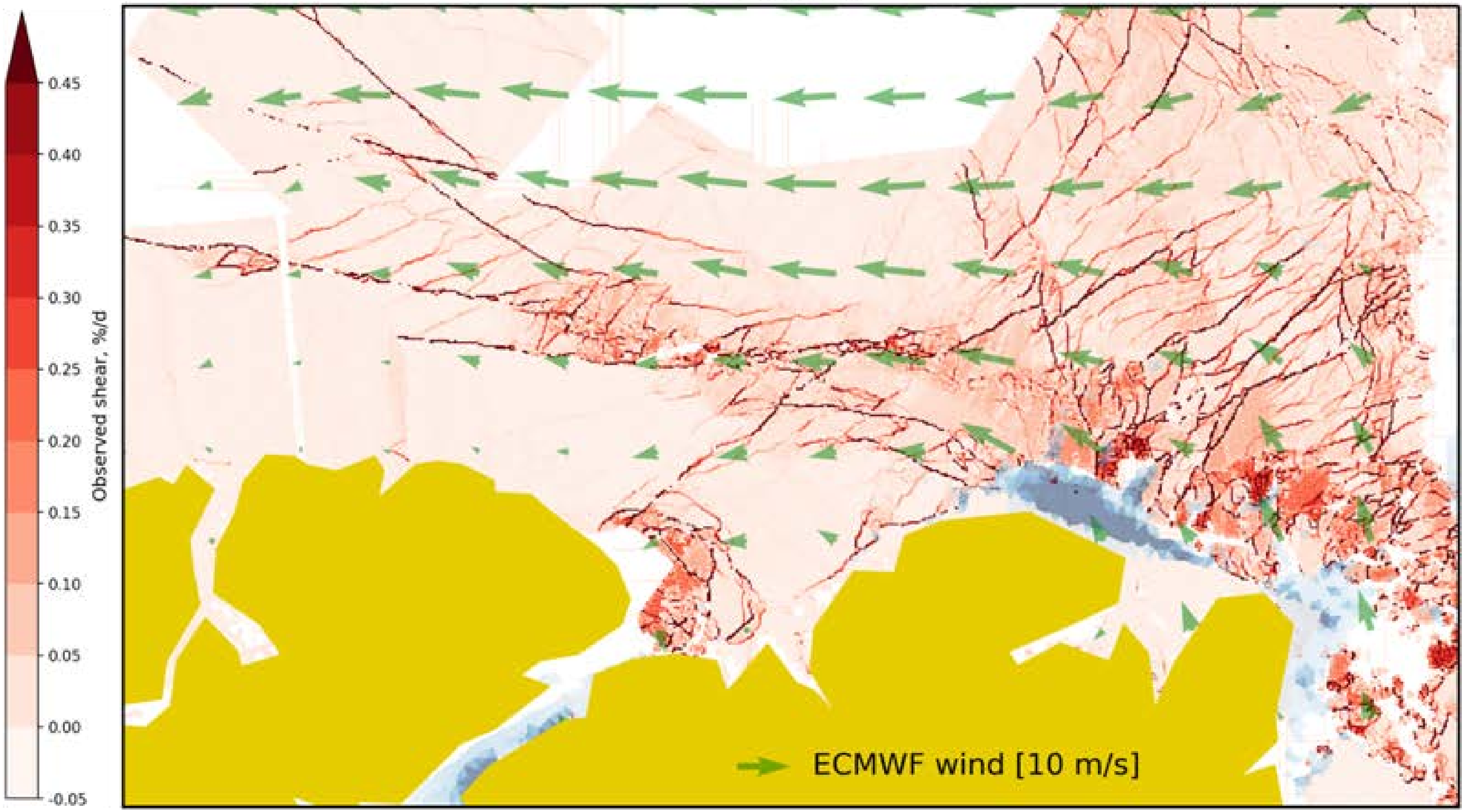
20180216



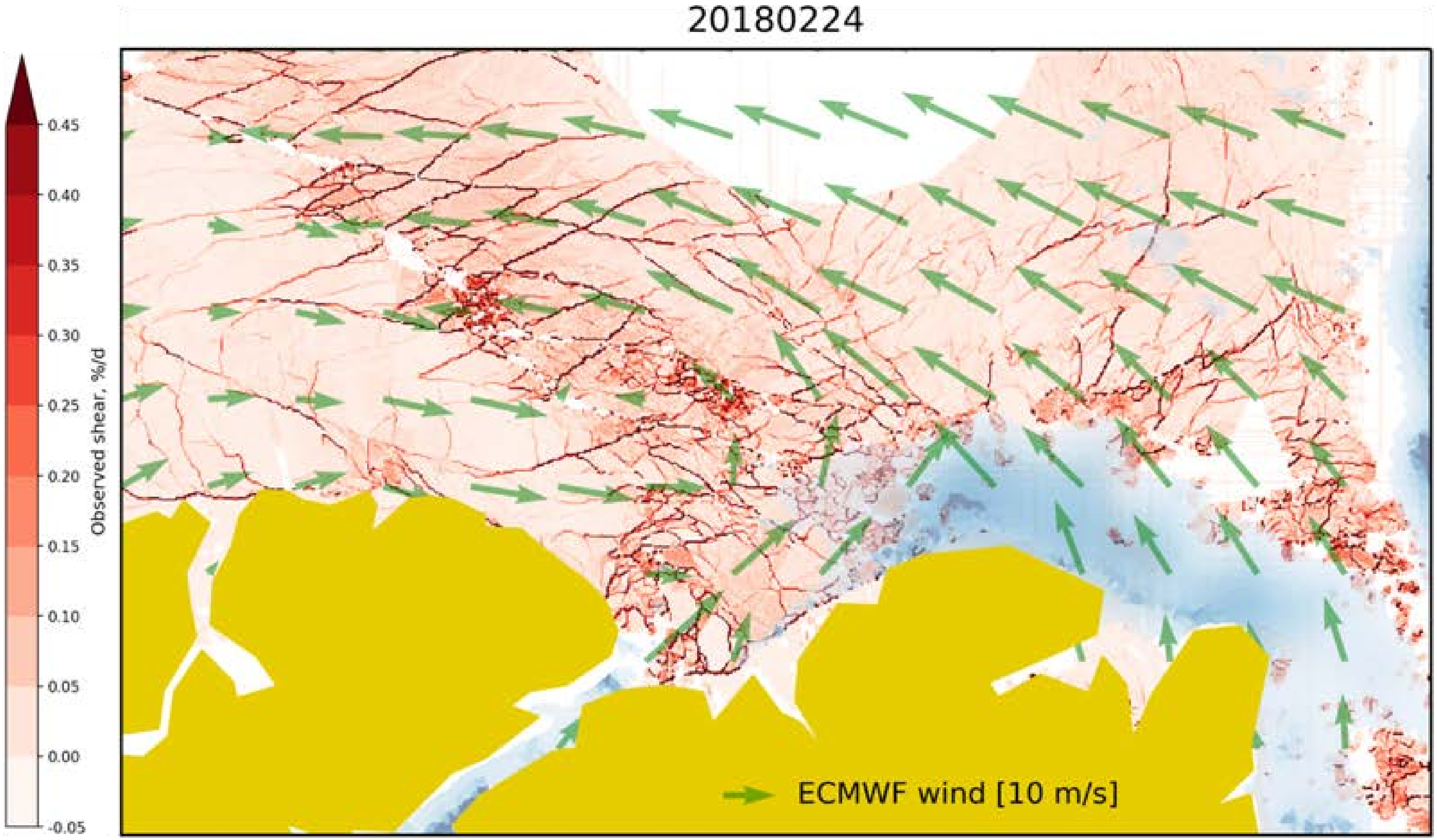

Sea ice deformation from Sentinel-1 (SAR)
20180218
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
Observed shear, %/d
ECMWF wind [10 m/s]

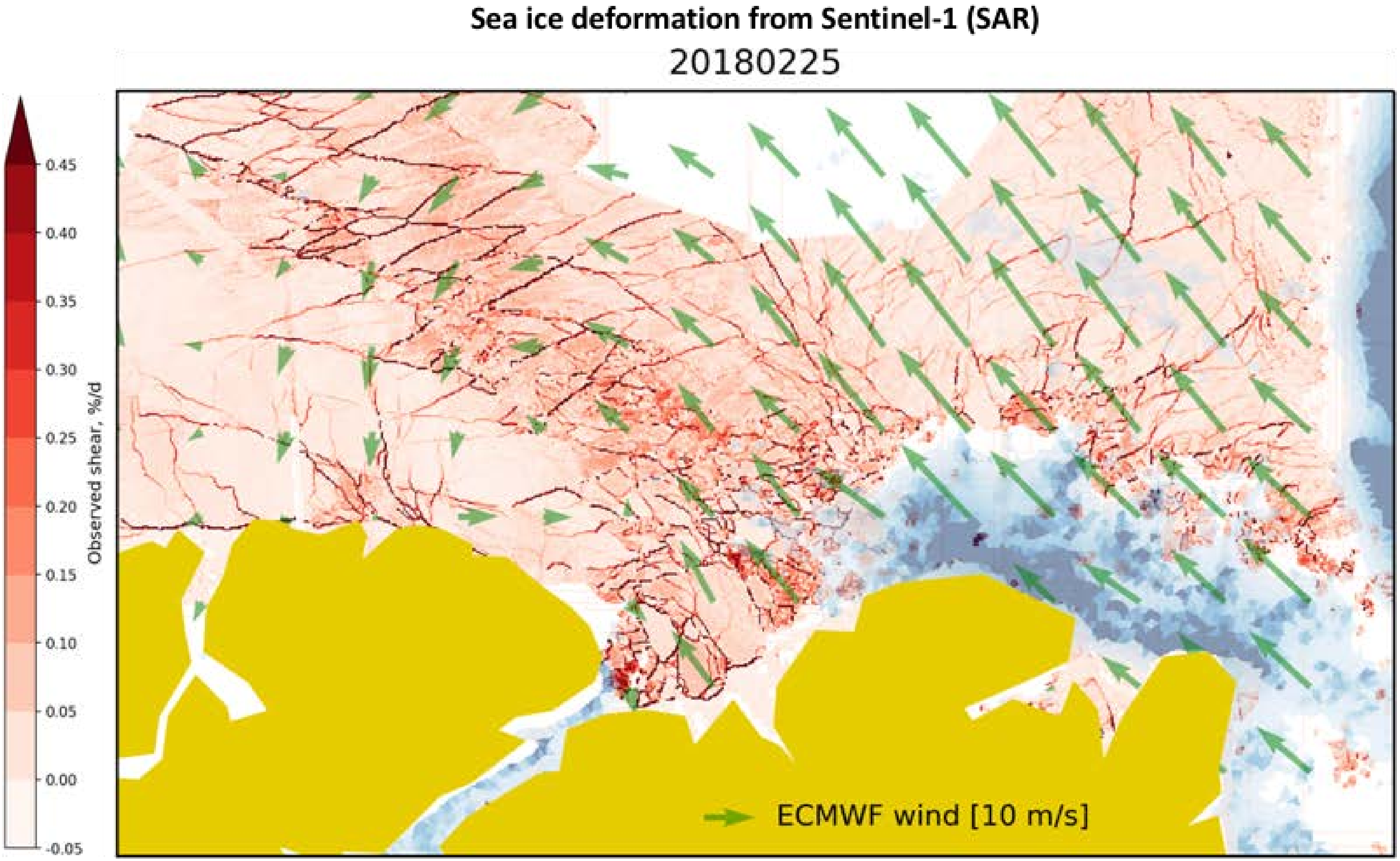
Sea ice deformation from Sentinel-1 (SAR)

20180220

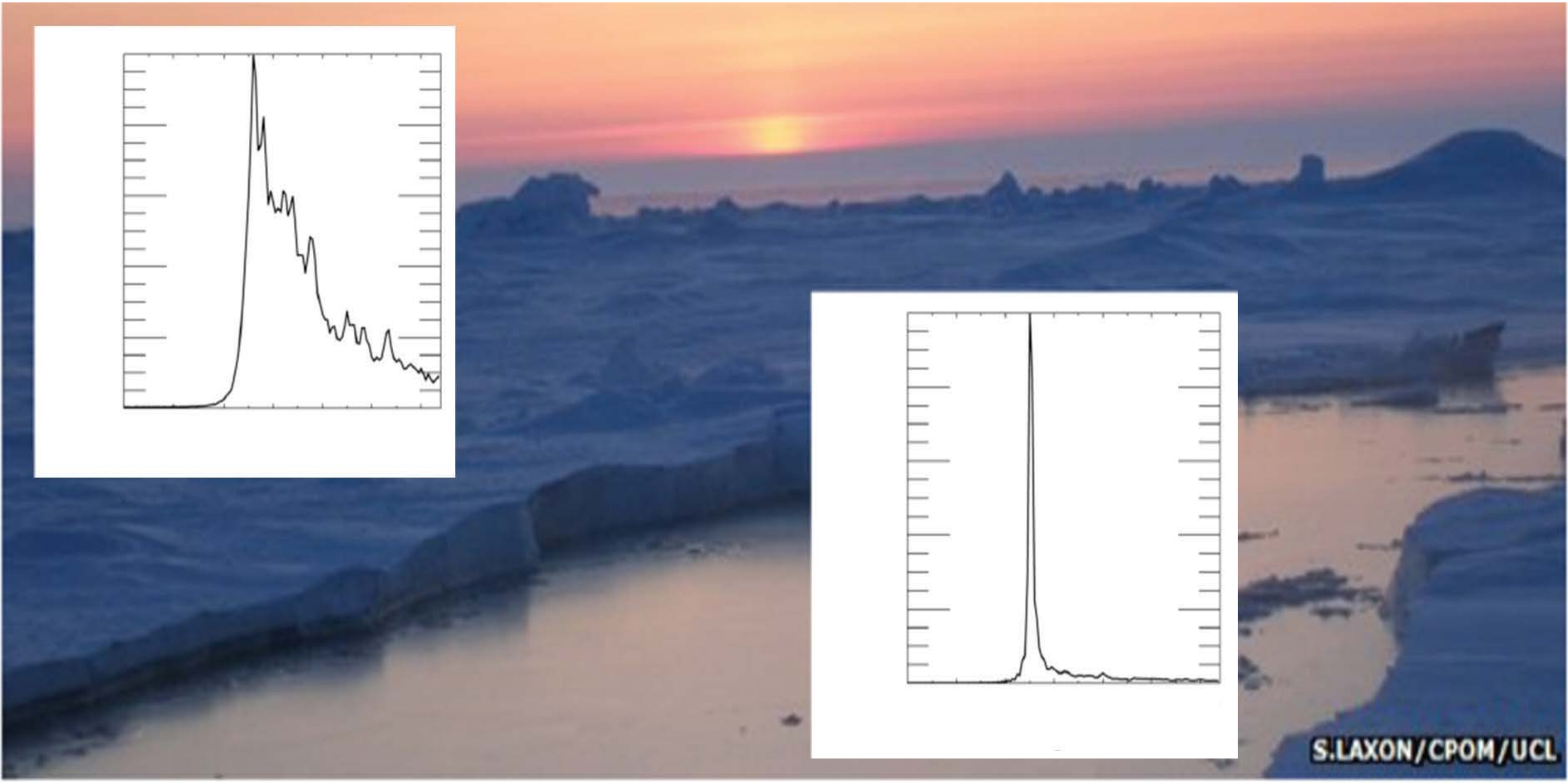


Sea ice deformation from Sentinel-1 (SAR)



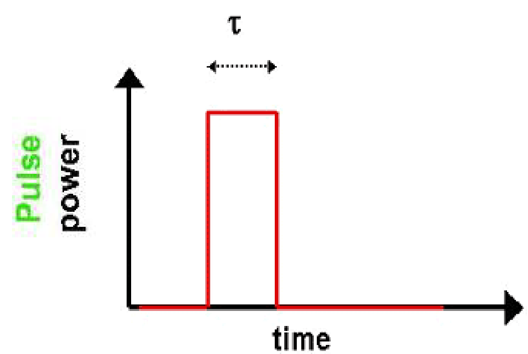

Sea ice deformation from Sentinel-1 (SAR)
20180225
Observed shear, %/d
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
ECMWF wind [10 m/s]

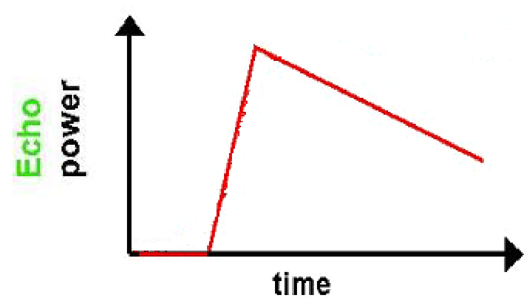
Freeboard height estimation from Altimetry

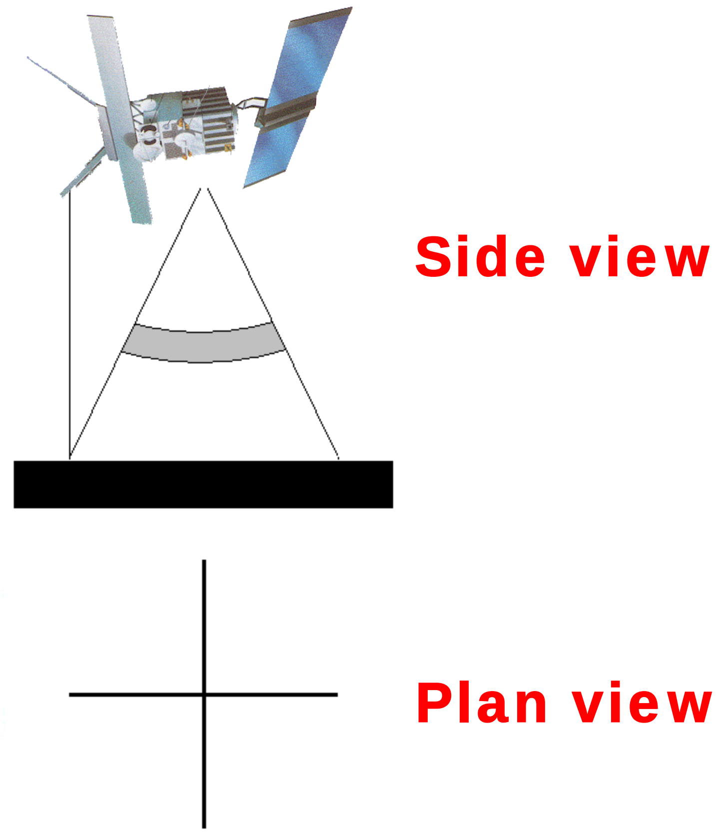


Satellite radar altimetry

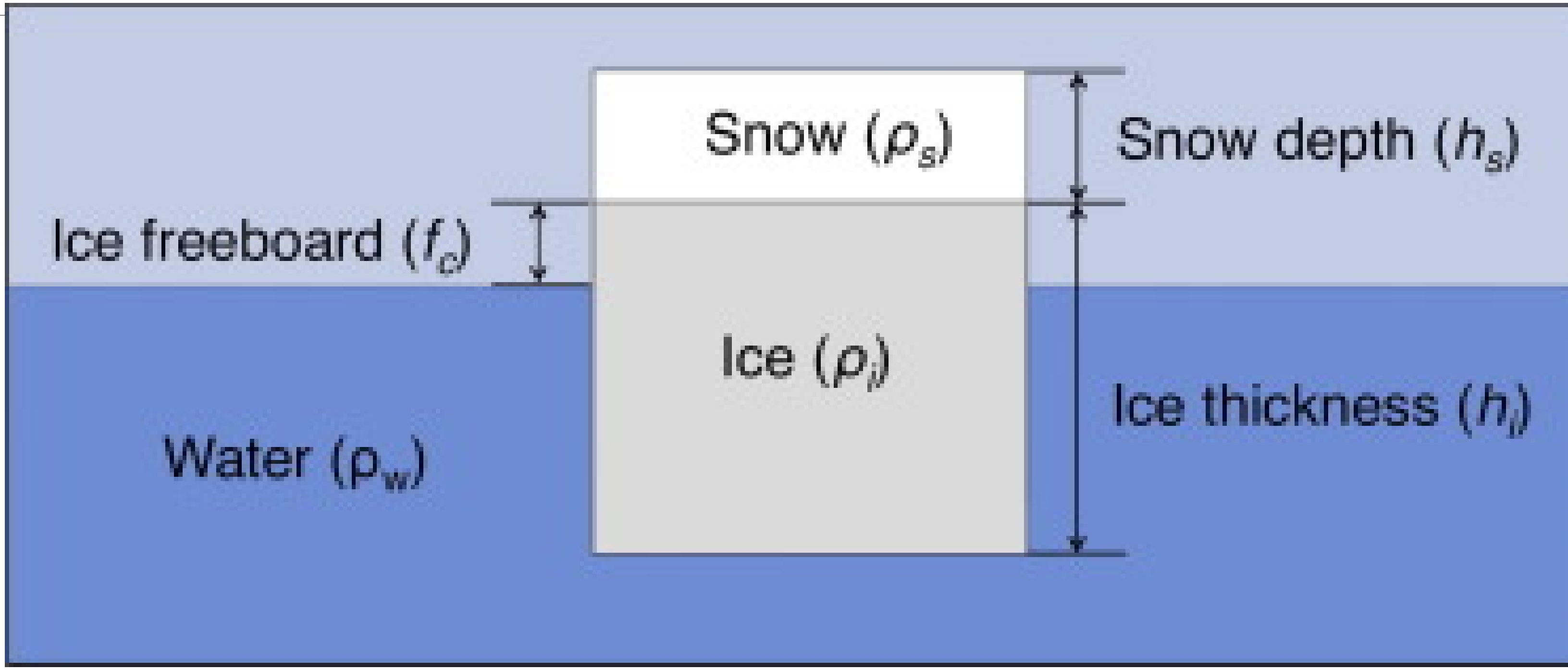
- Radar transmits known pulse
- Echo is distorted as spherical wave-front intercepts surface
- Travel time is calculated by comparing common points on pulse & echo







Range = ½ c * 2-way Travel time



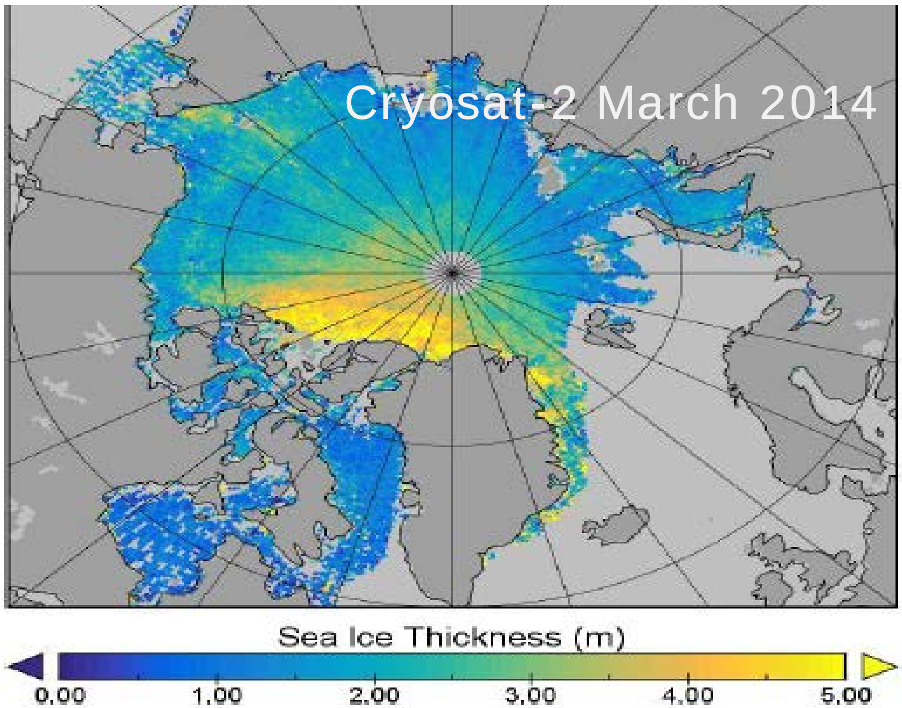
$$f_c = f_i + h_s\left(\frac{c_v}{c_s} - 1\right)$$

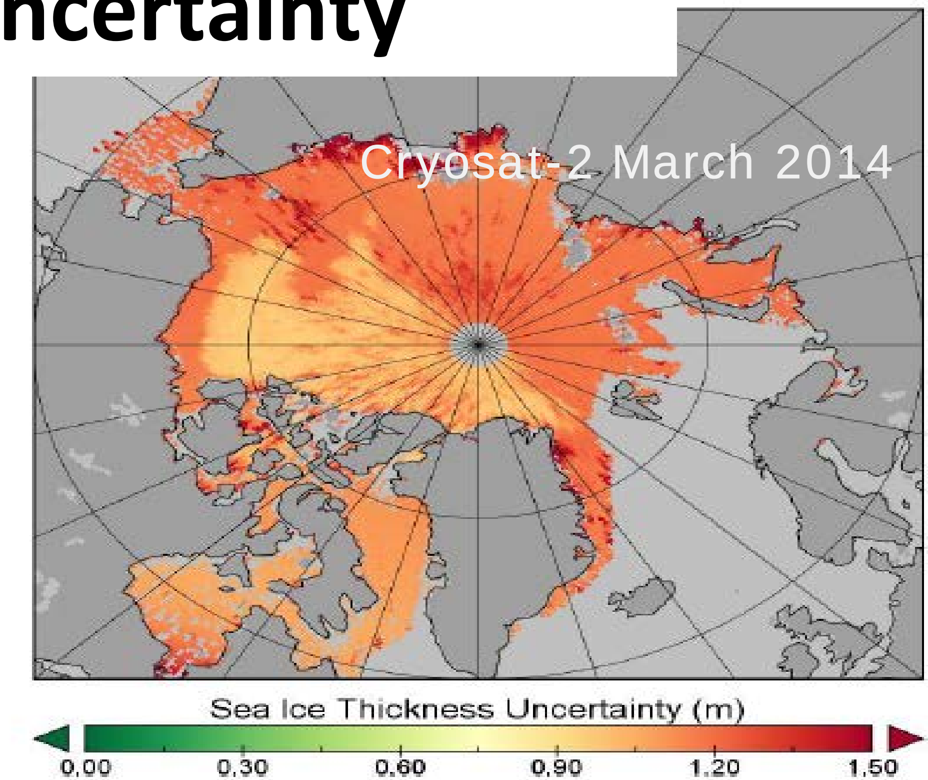
$$h_i = \frac{f_c\rho_w + h_s\rho_s}{\rho_w - \rho_i}$$

f_c and f_i is freeboard height, total and sea ice only; $\rho_{s,w,i}$ is density for snow, water, ice;
h_i is sea ice thickness;
h_s is snow depth; $C_{v,s}$ is speed of light in vacuum and in snow

Parameter Example

Sea ice thickness with uncertainty





CryoSat-2 March 2014

Relevant Websites

1. https://en.wikipedia.org/wiki/Arctic_sea_ice_decline
2. https://sites.uci.edu/zlabe/arctic-sea-ice-figures/
3. https://satellittdata.no/en/mosaic
4. https://www.mosaic-expedition.org/
5. http://arctic-roos.org Arctic Regional Ocean Observing System
6. http://nsidc.org National Snow and Ice Data Center (NSIDC)
7. http://osisaf.met.no, Ocean and Sea Ice Satellite Application Facility (OSISAF – Eumetsat and MET.no))

Summary and Outlook

- ✓ EO in the Arctic is extremely important and valuable in the presence of global warming and climate change.
- ✓ Satellite sensor synergy is well practized.
- ✓ Mesoscale structures in the MIZ is manifested by a mixture of processes and dynamics.
- ✓ Sea ice thickness are obtained from combined use of altimetry and passive microwaves at L-band (e.g. SMOS).
- ✓ Sea ice drift at various spatial scales are obtained from range of satellite sensing methods.
- ✓ Sea ice deformation feasible from SAR at 2-4 days interval
- ✓ Snow on sea ice still challenging - ESA plans CRISTAL

Summary and Outlook

Sea Ice Deformation

- ✓ Sea ice thickness
- ✓ Sea ice rheology (ice mehanical behviour)
- ✓ Sea ice drift
- ✓ Sea ice flow size
- ✓ Sea ice ridging
- ✓ Lead opening-closing
- ✓ Wave induced sea ice break-up present, but not fully detected
- ✓ Influence of tidal current still to clarify

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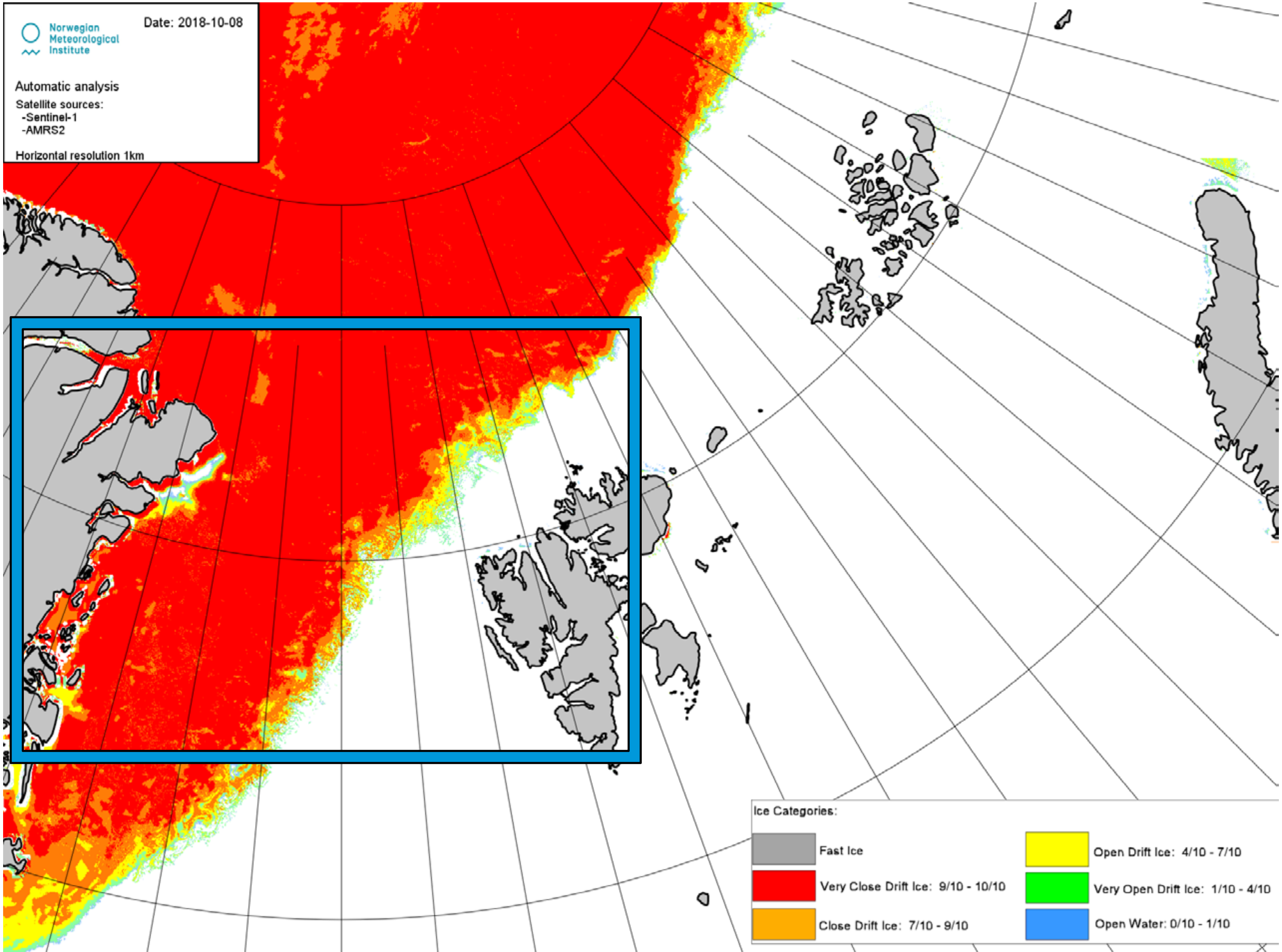
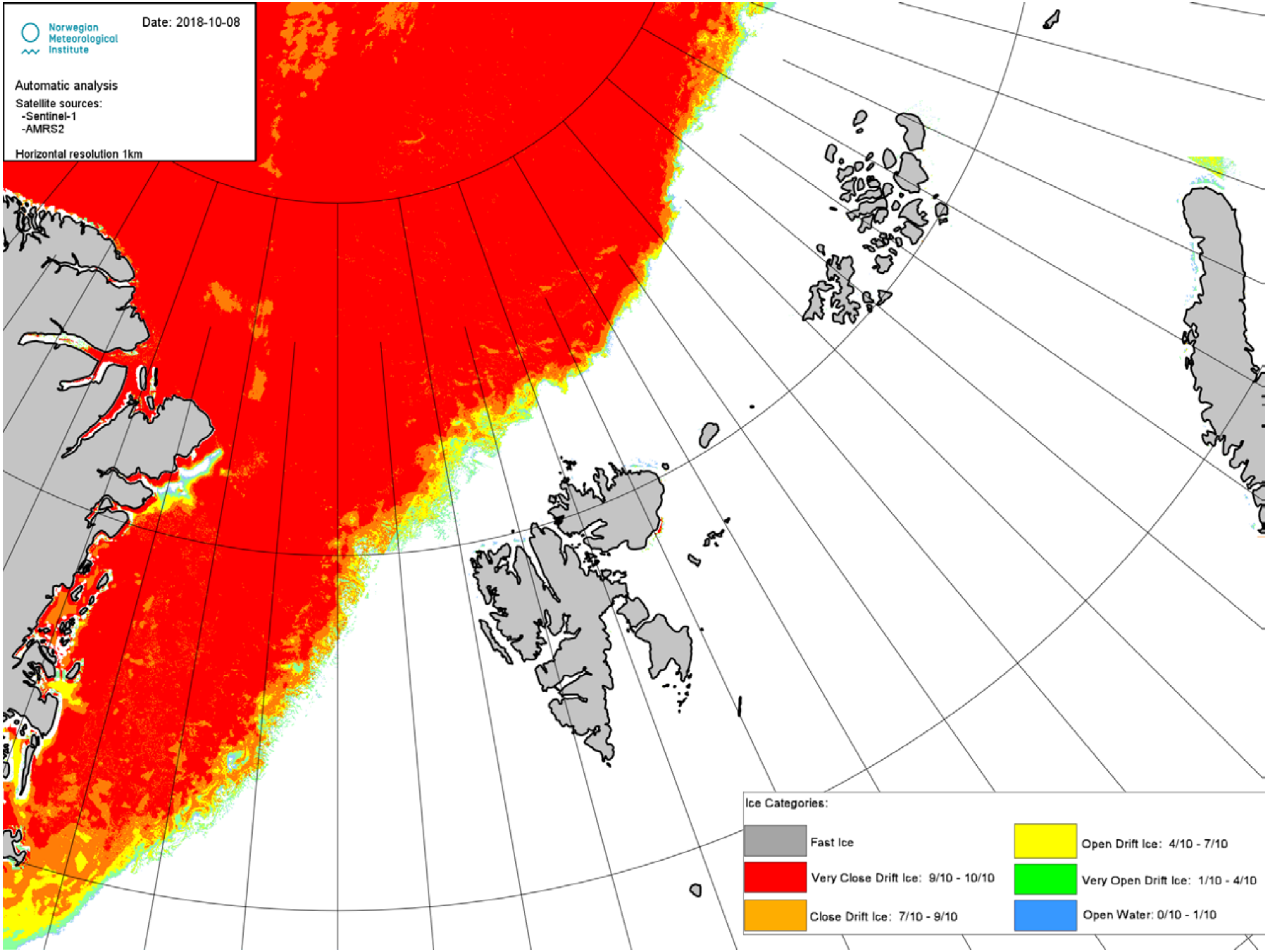
In the interior of the Arctic Ocean


Date: 2018-10-08
Norwegian Meteorological Institute
Automatic analysis
Satellite sources:
-Sentinel-1
-AMRS2
Horizontal resolution 1km
Ice Categories:
Fast Ice
Very Close Drift Ice: 9/10 - 10/10
Close Drift Ice: 7/10 - 9/10
Open Drift Ice: 4/10 - 7/10
Very Open Drift Ice: 1/10 - 4/10
Open Water: 0/10 - 1/10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Very Open Drift Ice: 1/10 - 4/10
Open Water: 0/10 - 1/10

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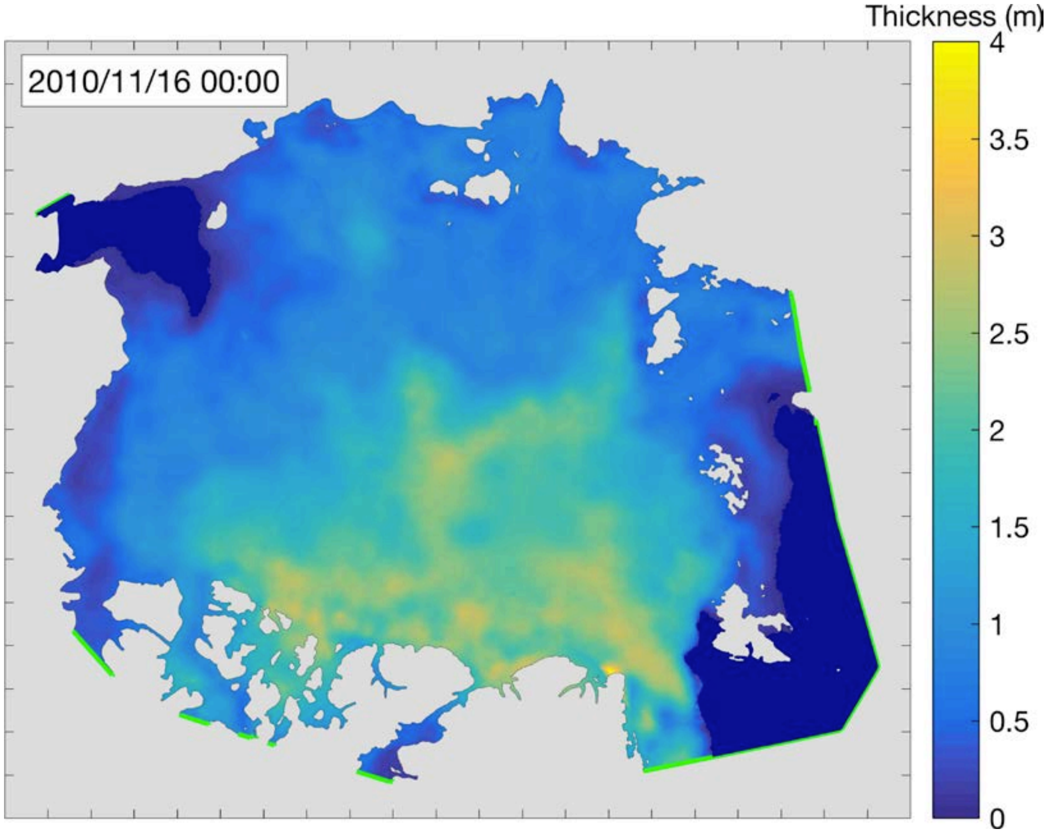
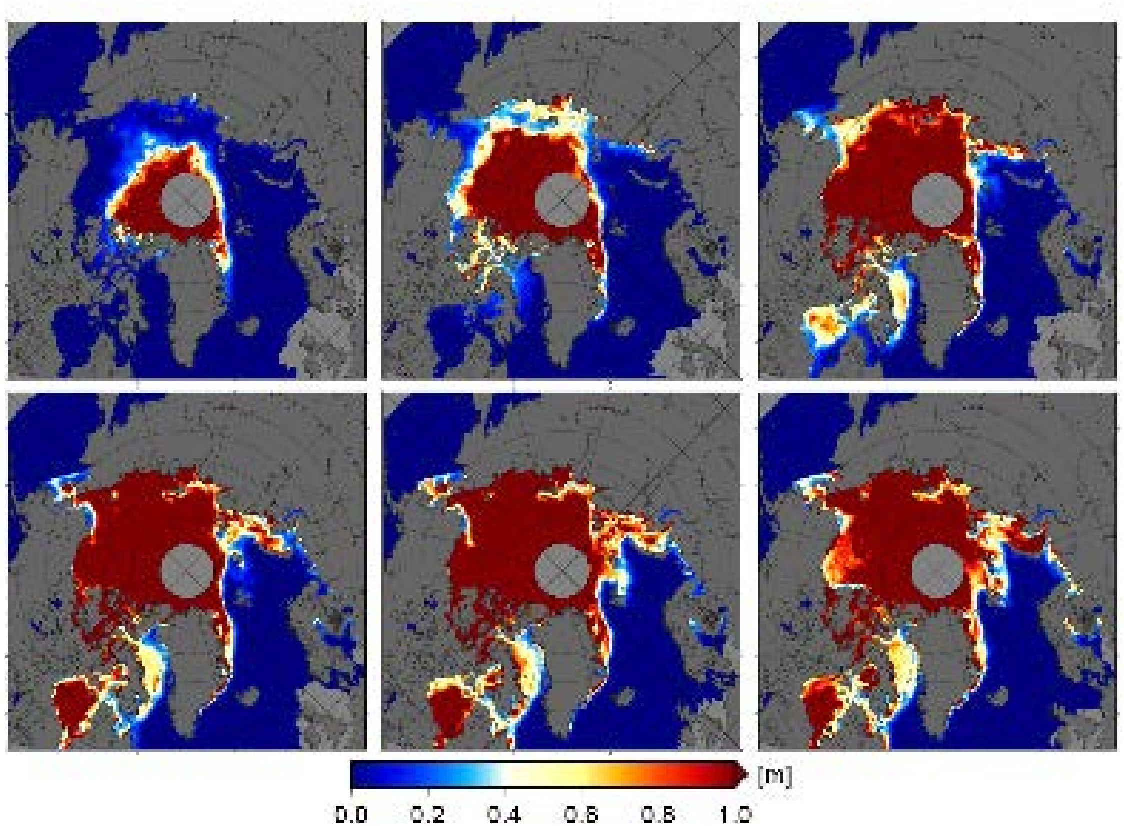
neXt**SIM** for sea ice thickness studies



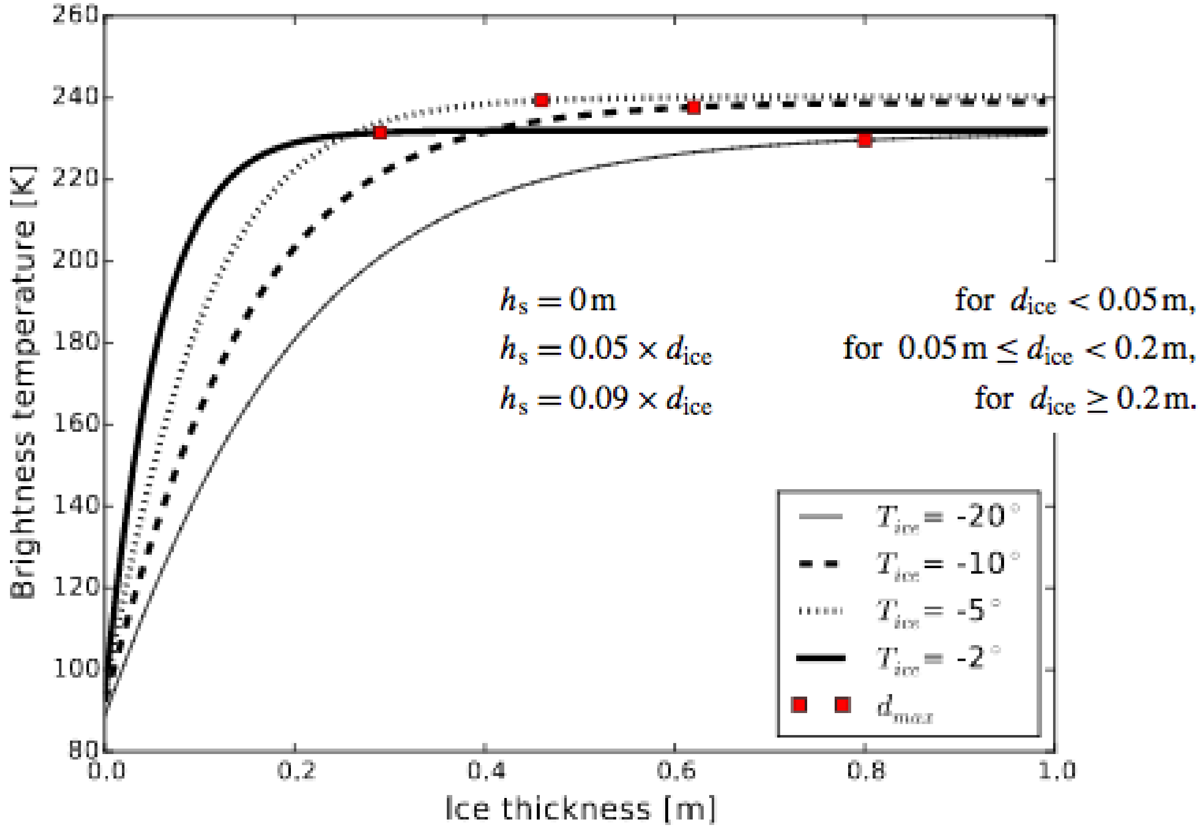
Olason, Rampal, Bouillon, in prep.

Thin Sea Ice Retrievals from SMOS

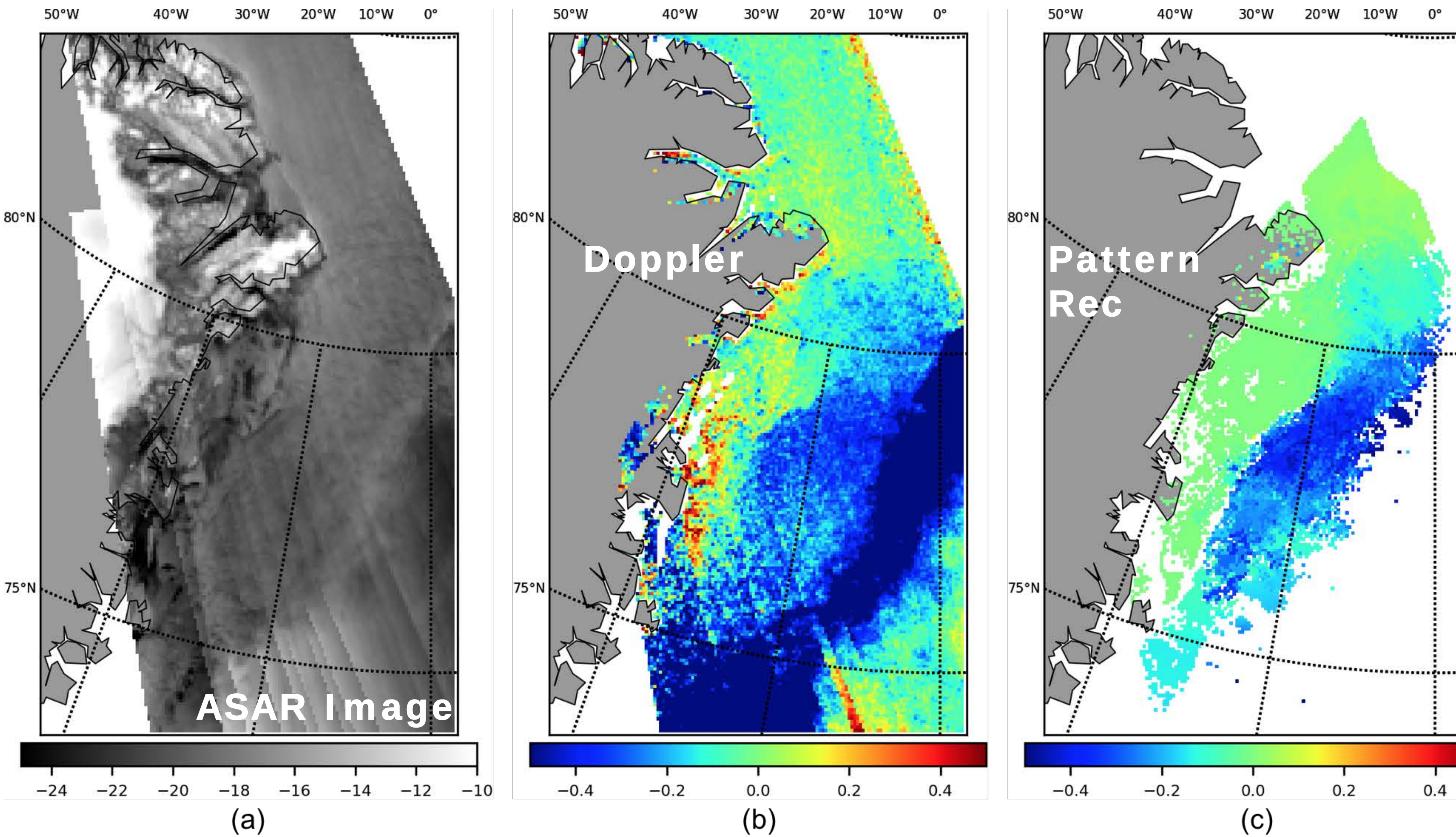


Monthly SMOS sea ice thickness derived´during
freeze-up period October 2012-March 2013

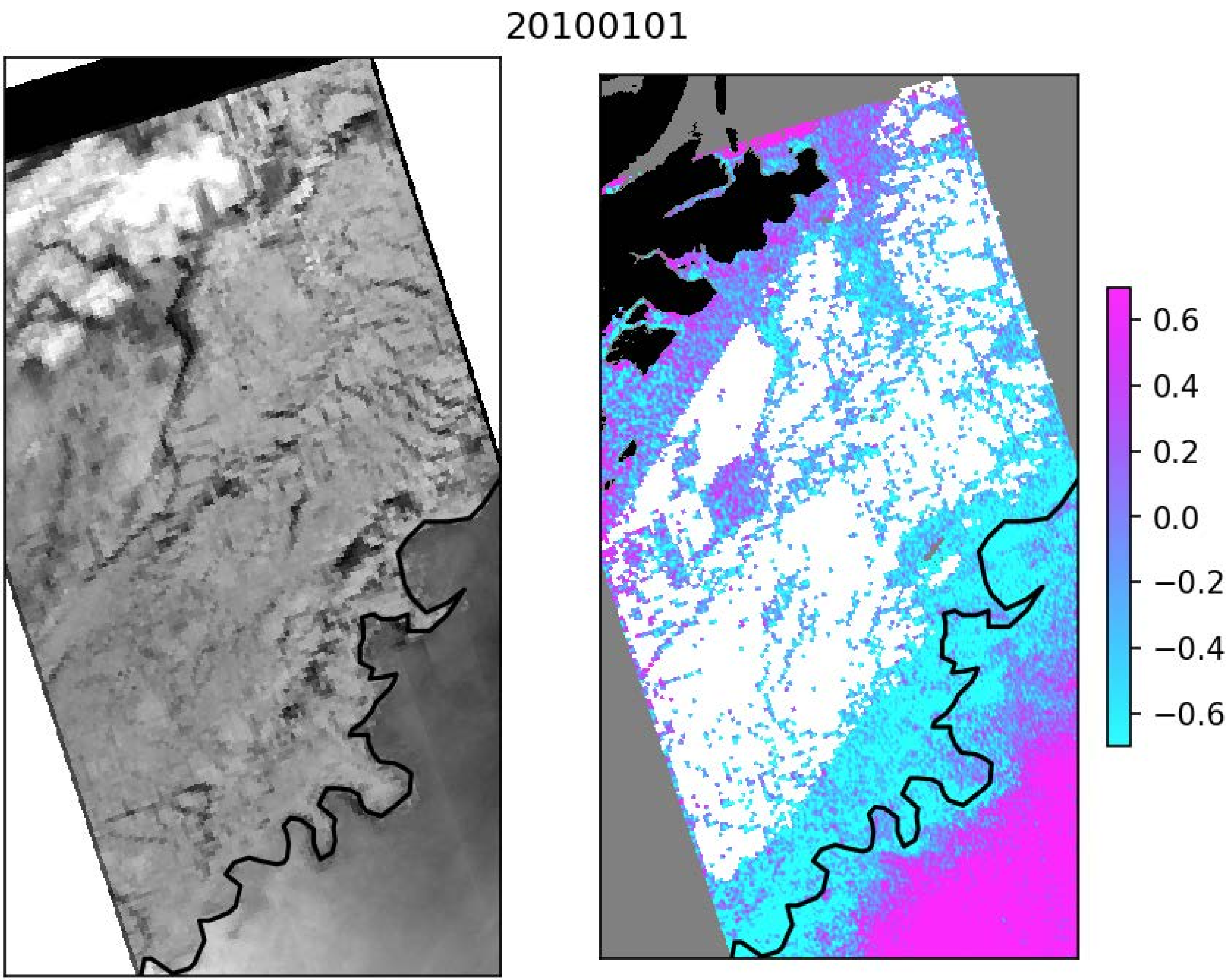
Thin Sea Ice Retrievals



Doppler based velocities and Pattern recognition

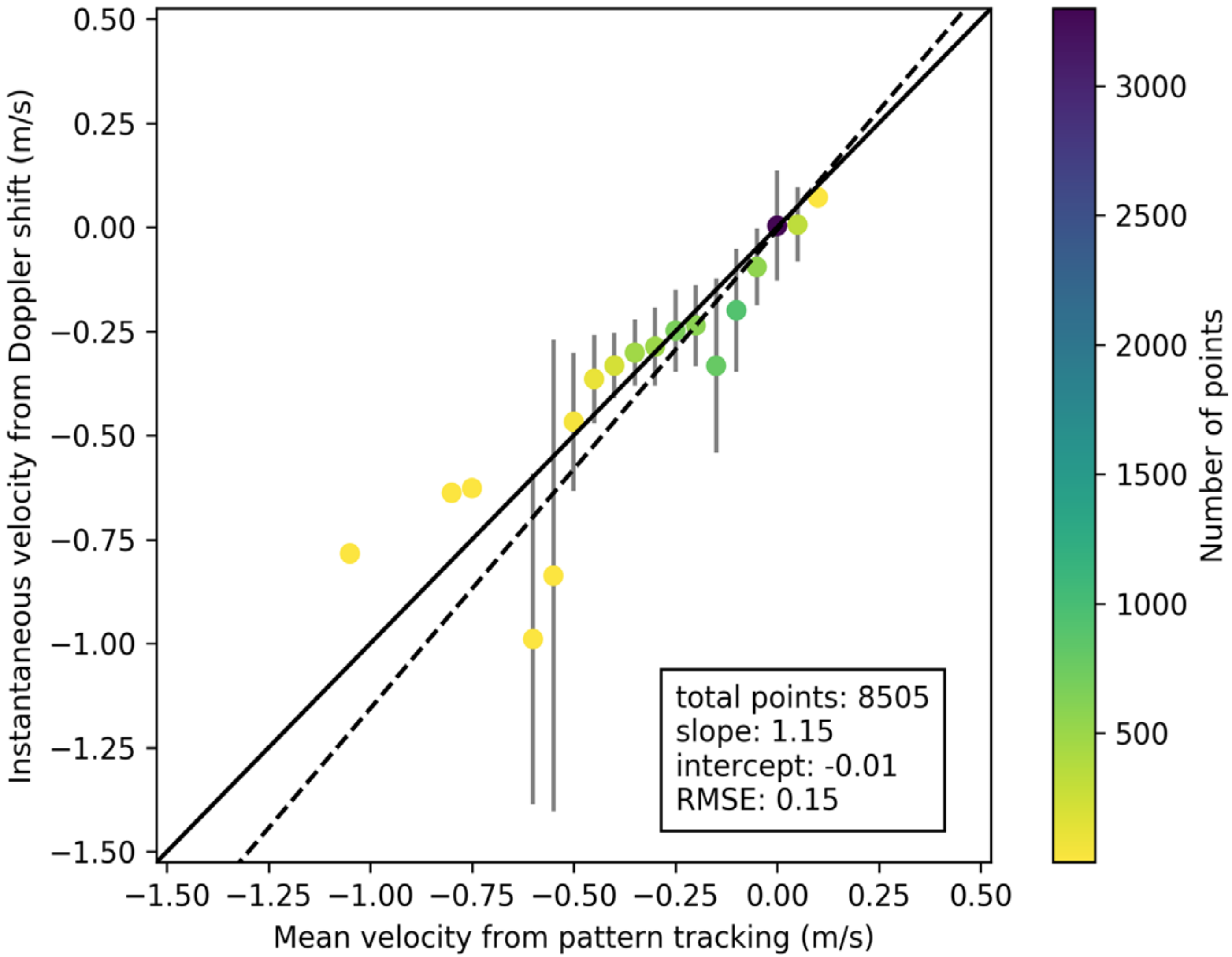


Assessment of sea ice drift from Doppler



Normalized radar backscatter (grayscale image), sea ice edge (black line) and Doppler derived instantaneous velocity (colored image, m/s).

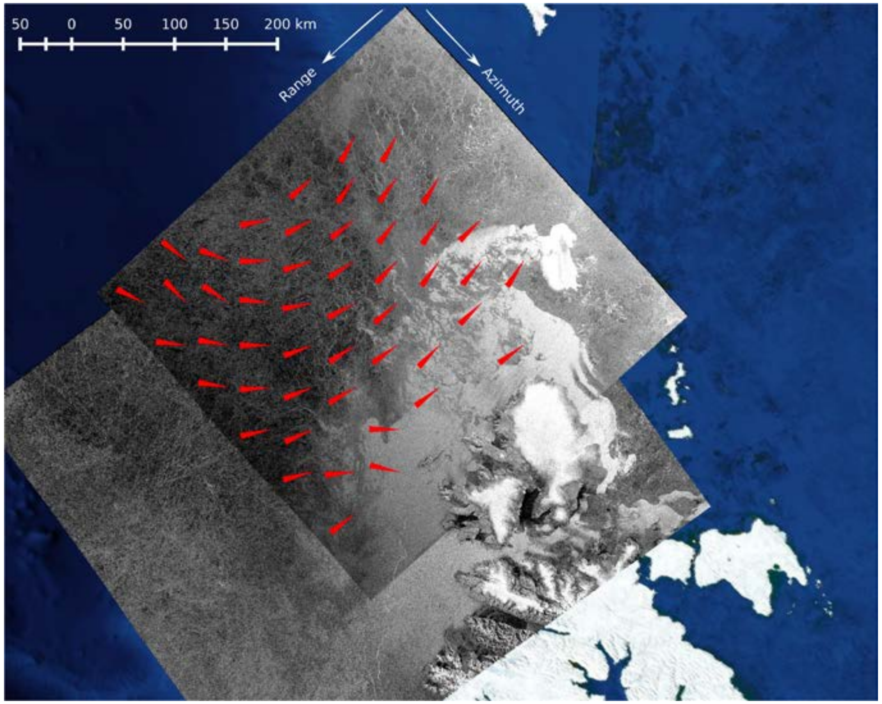
The white area indicate good agreement between the pattern recogn. & SAR Doppler.



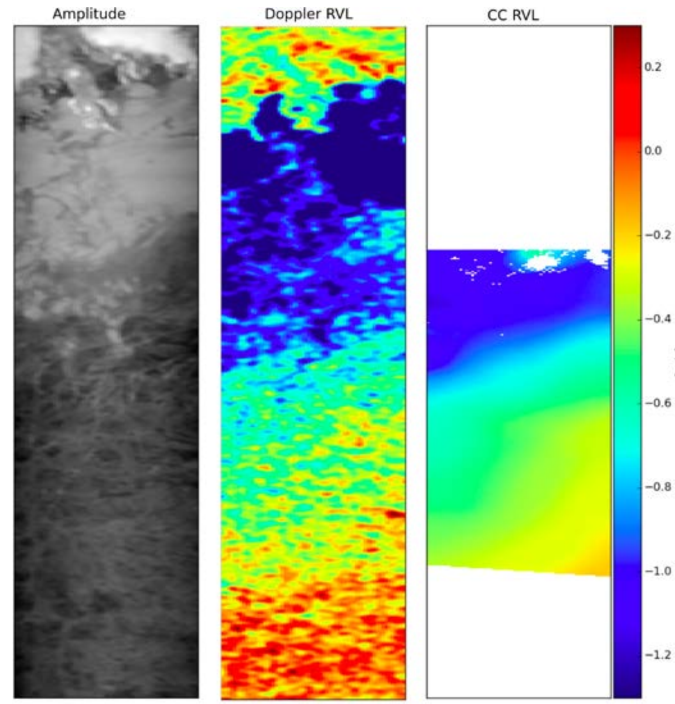
ASSESSMENT

Time averaged velocity fields from Doppler derived instantaneous velocity and pattern matching based mean velocity.

Sentinel-1 TOPS Doppler & Sea Ice Drift



Collocated (25 min time separation) RSAT-2 and S1a EW with estimated sea ice drift vectors overlaid. Area: North West of Svalbard



S-1 intensity image (left), Doppler radial velocity (mid) and cross-correlation (CC) radial velocity (right).

T. Kræmer, H. Johnsen, C. Brekke, Engen G., "Comparing SAR-Based Short Time-Lag Cross Correlation and Doppler-Derived Sea Drift Velocities" IEEE Trans. Geoscience and Remote Sensing, Volume: 56 Issue: 3, ISSN: 1558-0644, DOI: 10.1109/TGRS.2017.2769222, 2017

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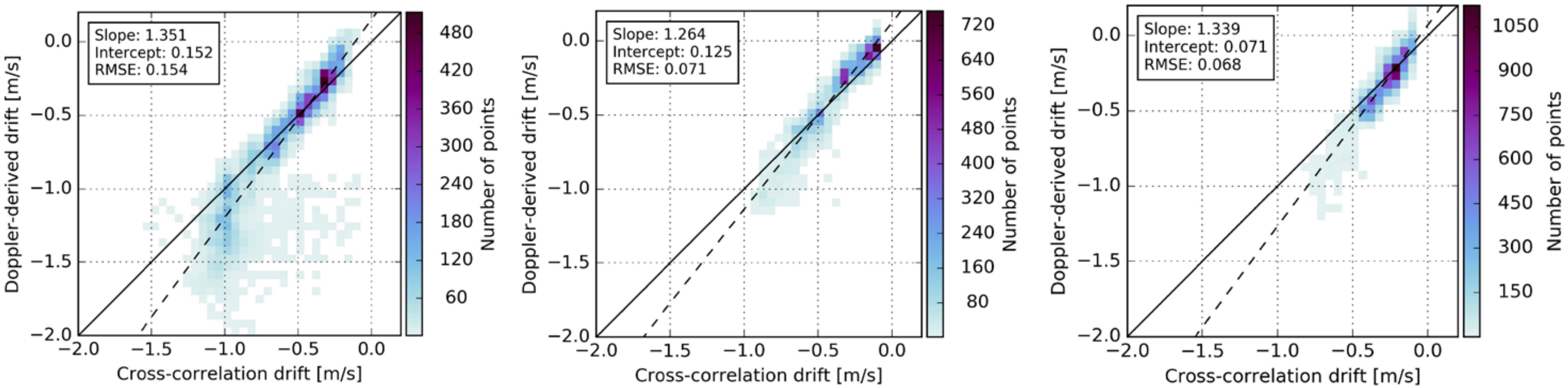
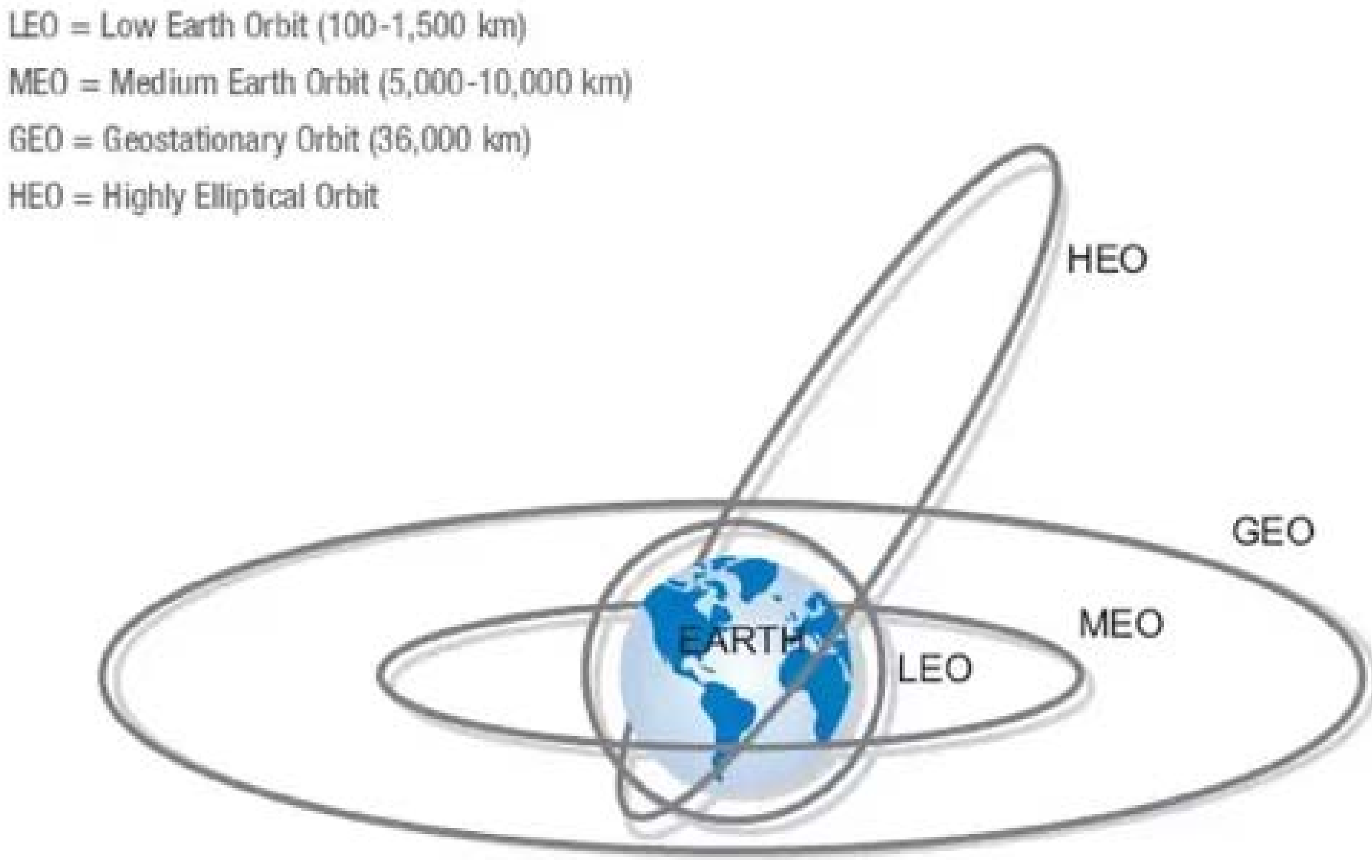
Assessment of Doppler shift retrievals

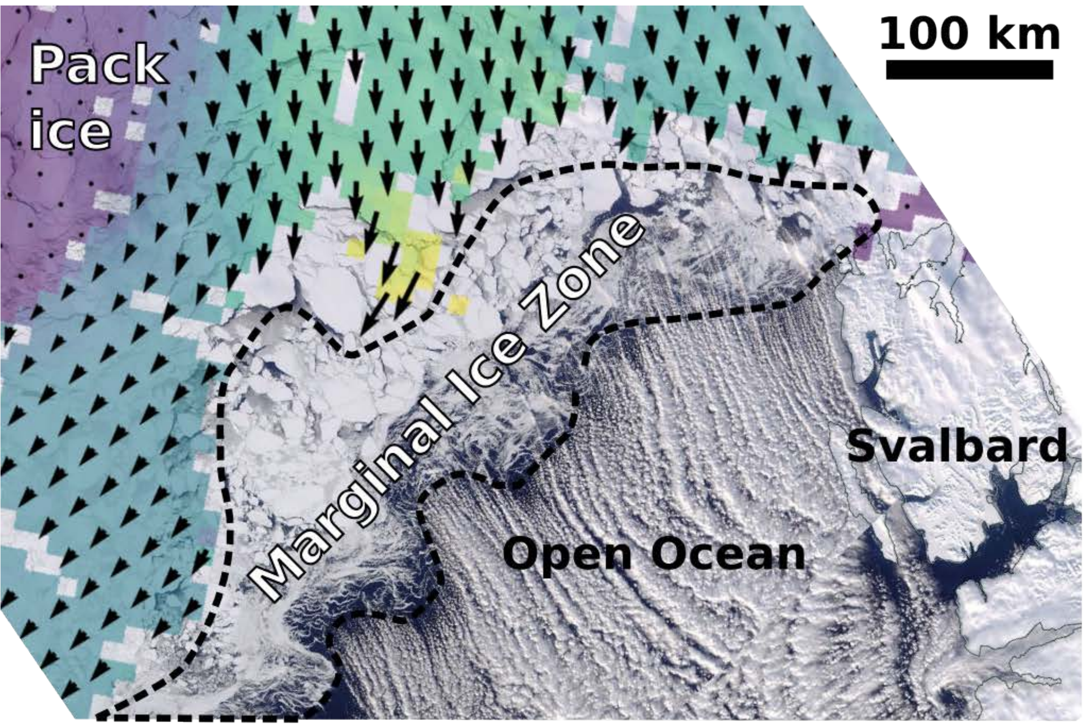


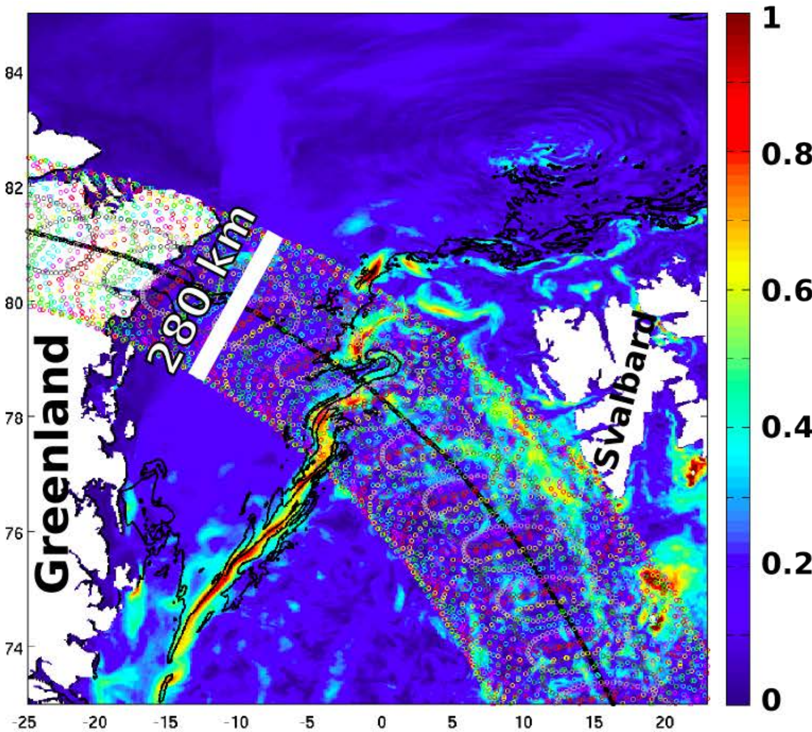
Scatterplot of cross-correlation (RSAT-2 and S1a) radial velocity versus S1a Doppler radial velocity. Left: EW3, Mid: EW4, Right: EW5. All estimates are averaged to around 10km x 10km.

The main source of the bias comes from imperfect compensation for antenna DC bias over swaths.

Orbital opportunities for satellite EO monitoring of the Arctic







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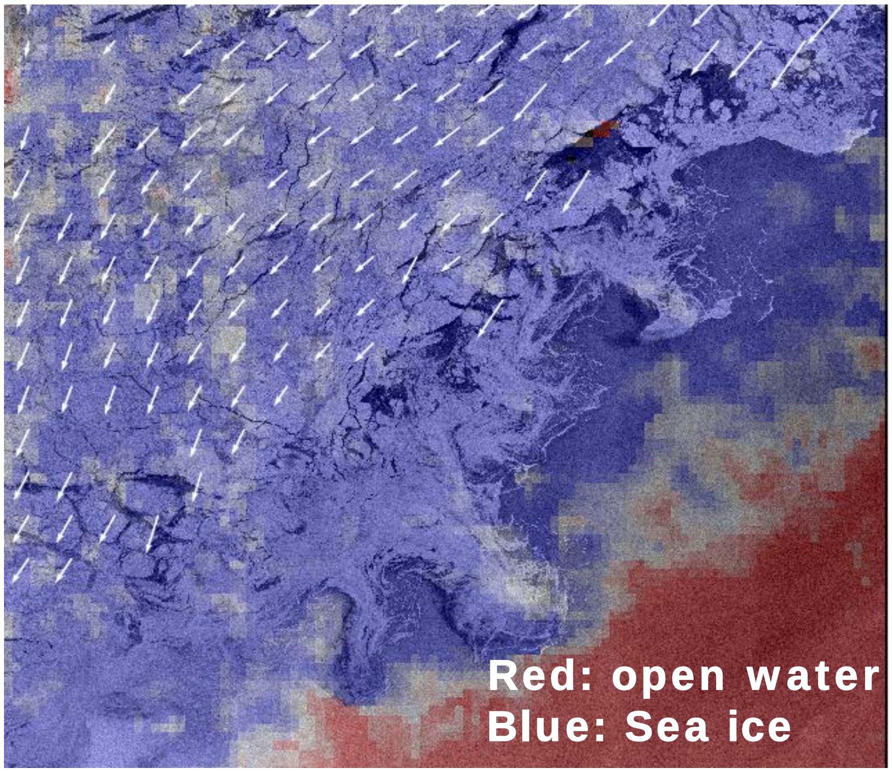
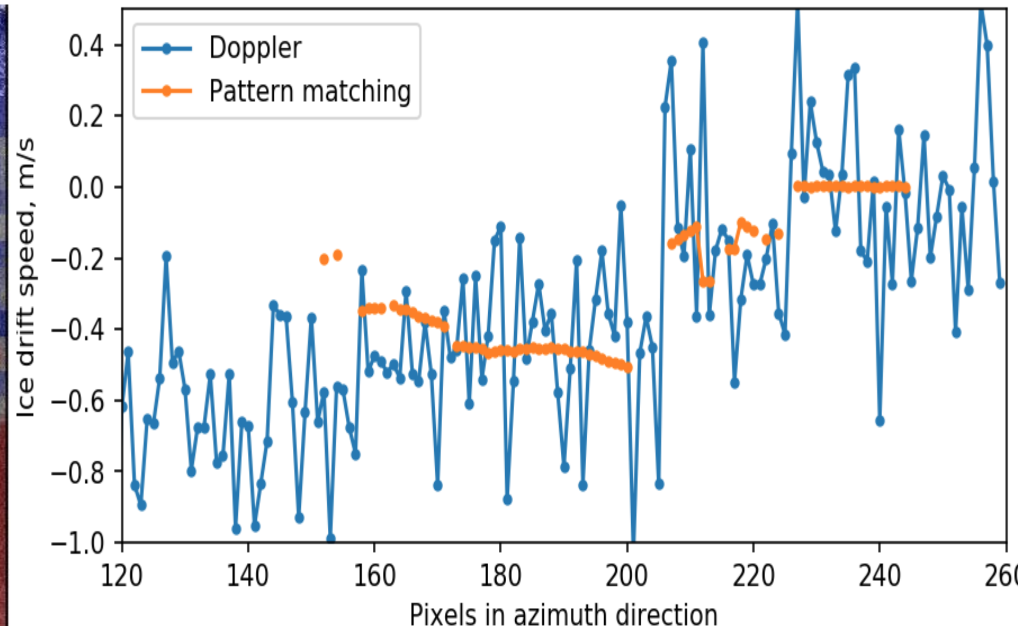
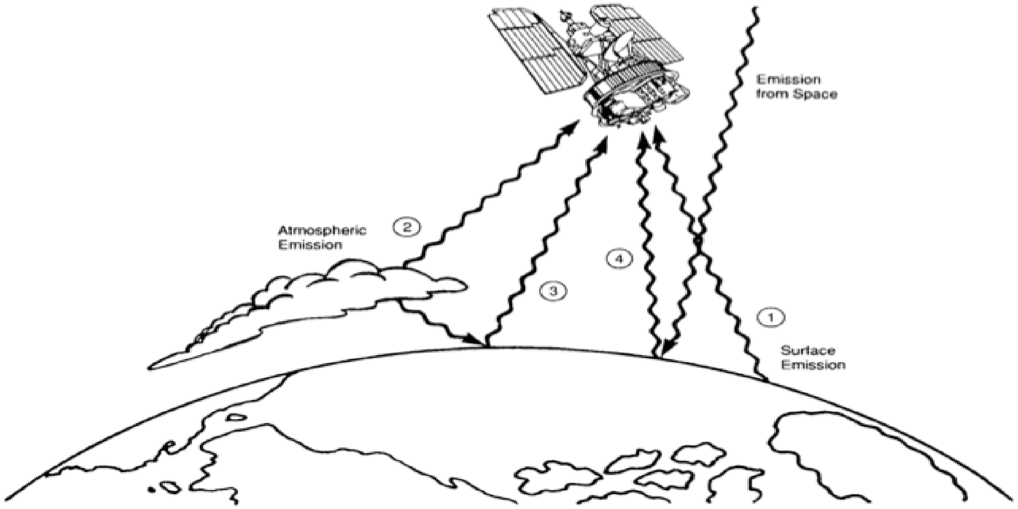
Envisat SAR image from the Fram Strait from 1 January 2010.



Sea ice drift vectors derived from combined pattern recognition and Doppler shift estimation.



Values of sea ice drift speed from pattern matching (orange line) and Doppler shift.

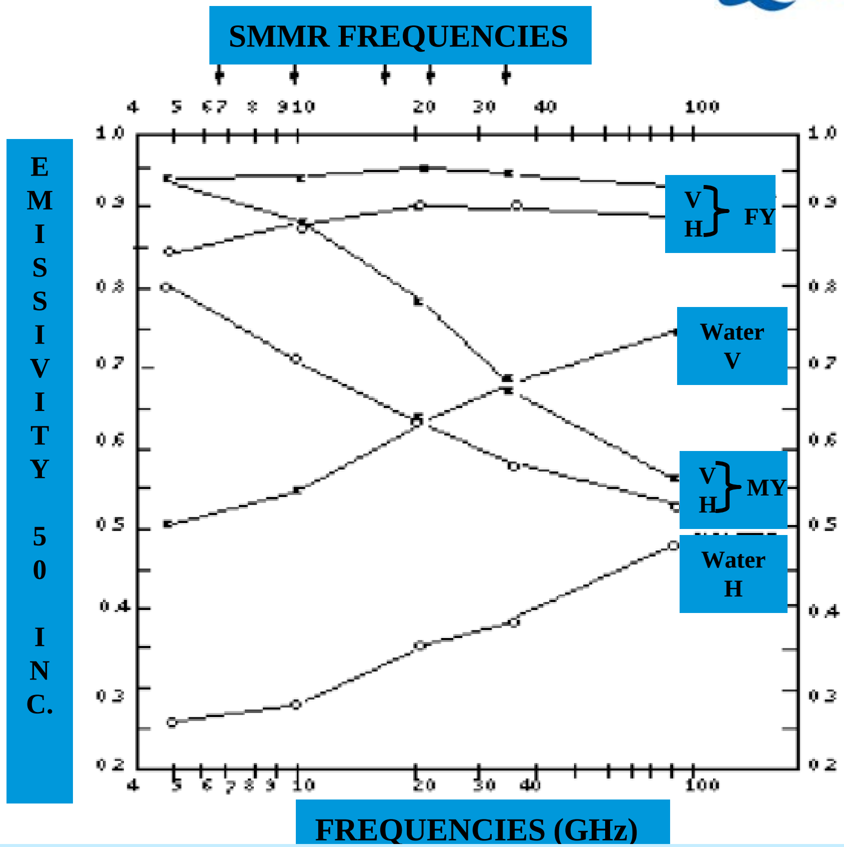


When $\varepsilon \approx 1$ as for sea ice the reflectivity is minor. For sea water $\varepsilon < 0.4$.

τ is the transmittance. $\tau \approx 1$ or 0 implies no or strong absorption. Clouds both absorb and re-emit.
For $\lambda <$ 1 mm the absorption is large. In from H_2O og O_2. For $\lambda <$ 3 cm the absorption is minor

$$T_b = e\, T_s\, e^{-\tau} + T_{up} + (1\text{-}e) T_{down}\, e^{-\tau} + (1\text{-}e)\, T_{sp}\, e^{-2\tau}$$

(1) (2) (3) (4)

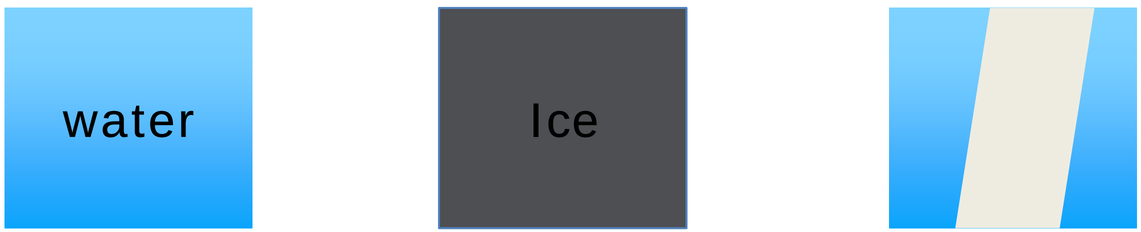


FY = First Year Ice

MY = Multi Year Ice

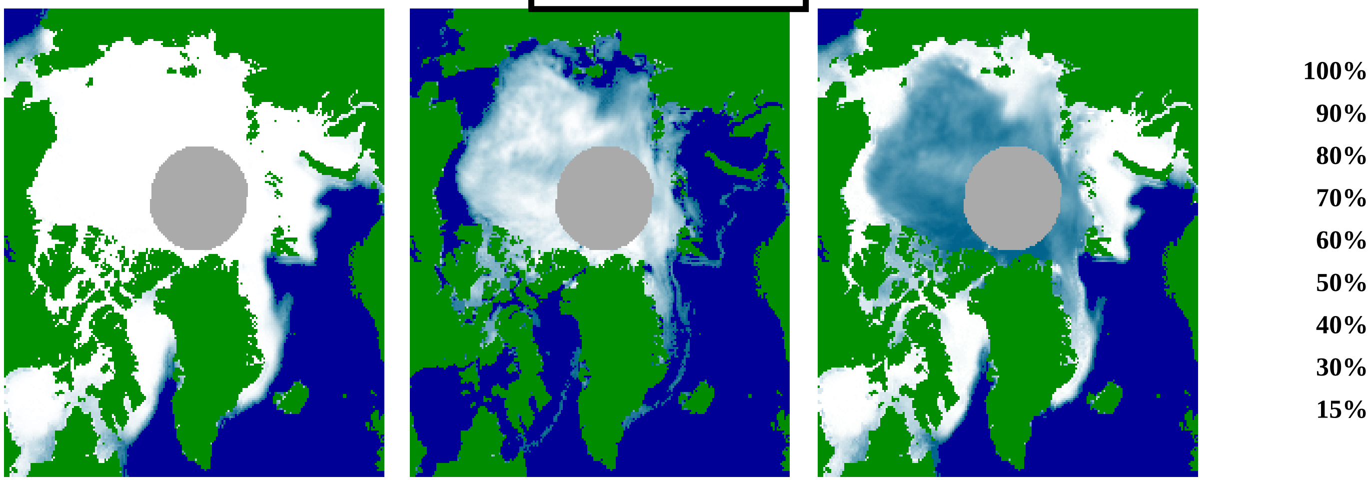
$$TB = (1 - C)\,TB_W + C\,TB_{ice}$$

C=0% | C=100% | 0%<C<100%



Err: weather | emissivity | mixed pixel, resolution (25km -> 12.5km)

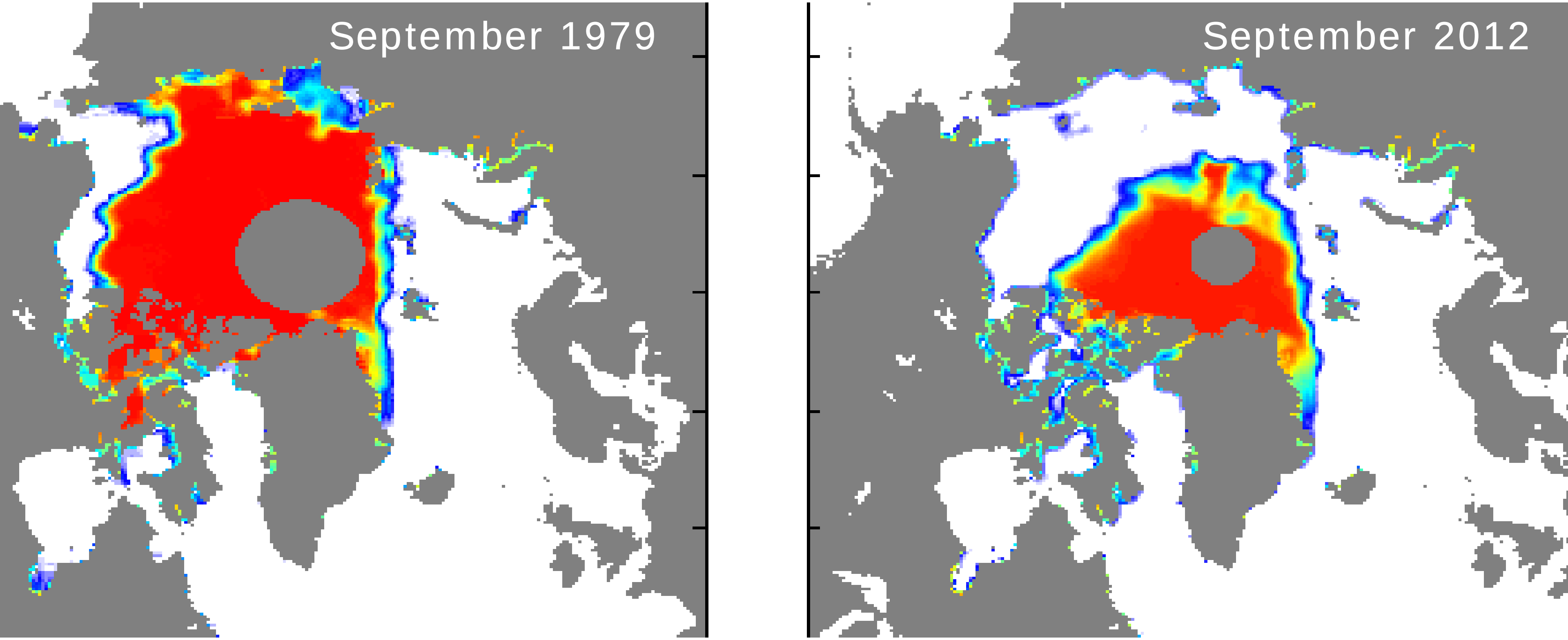
December 1980



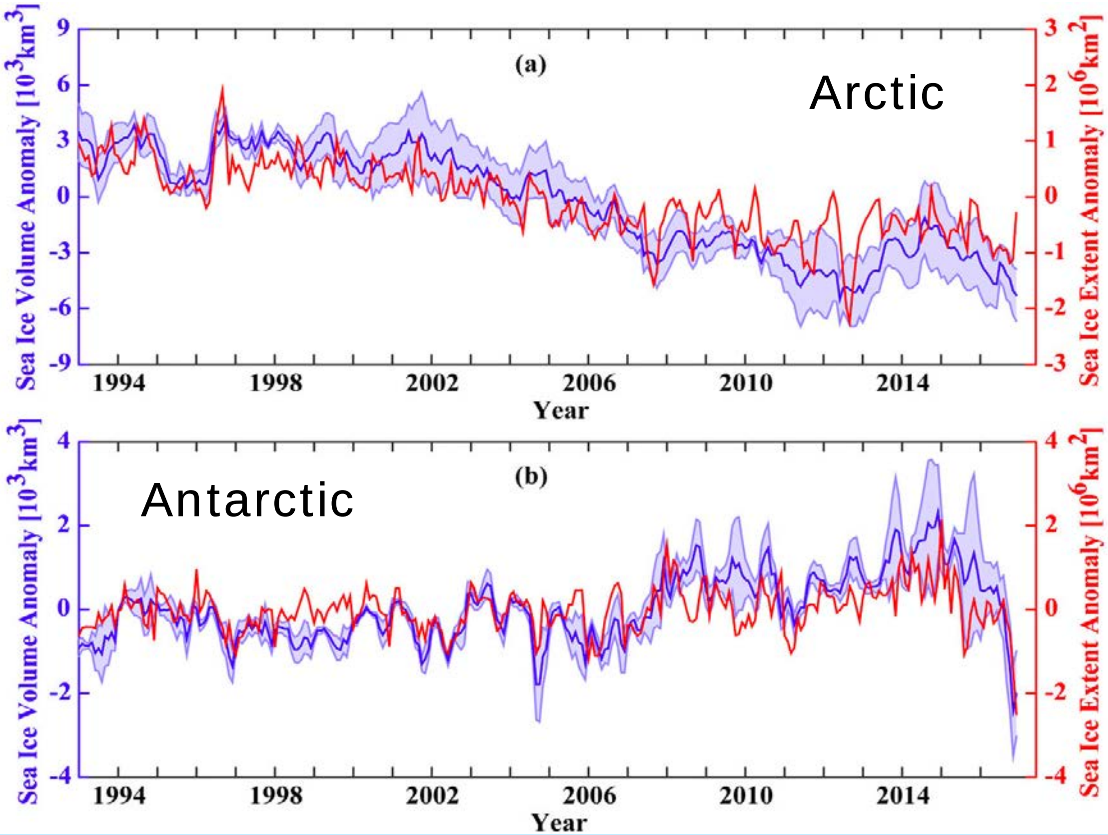
TOTAL ICE COVER = MULTI-YEAR ICE + FIRST-YEAR ICE

MULTI-YEAR ICE: ice that has survived one summer

FIRST-YEAR ICE: ice that has formed during last winter

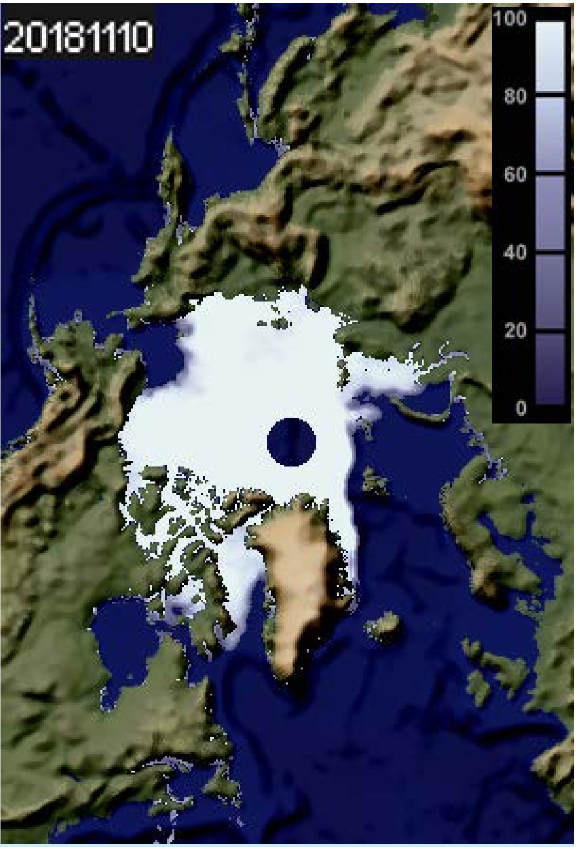


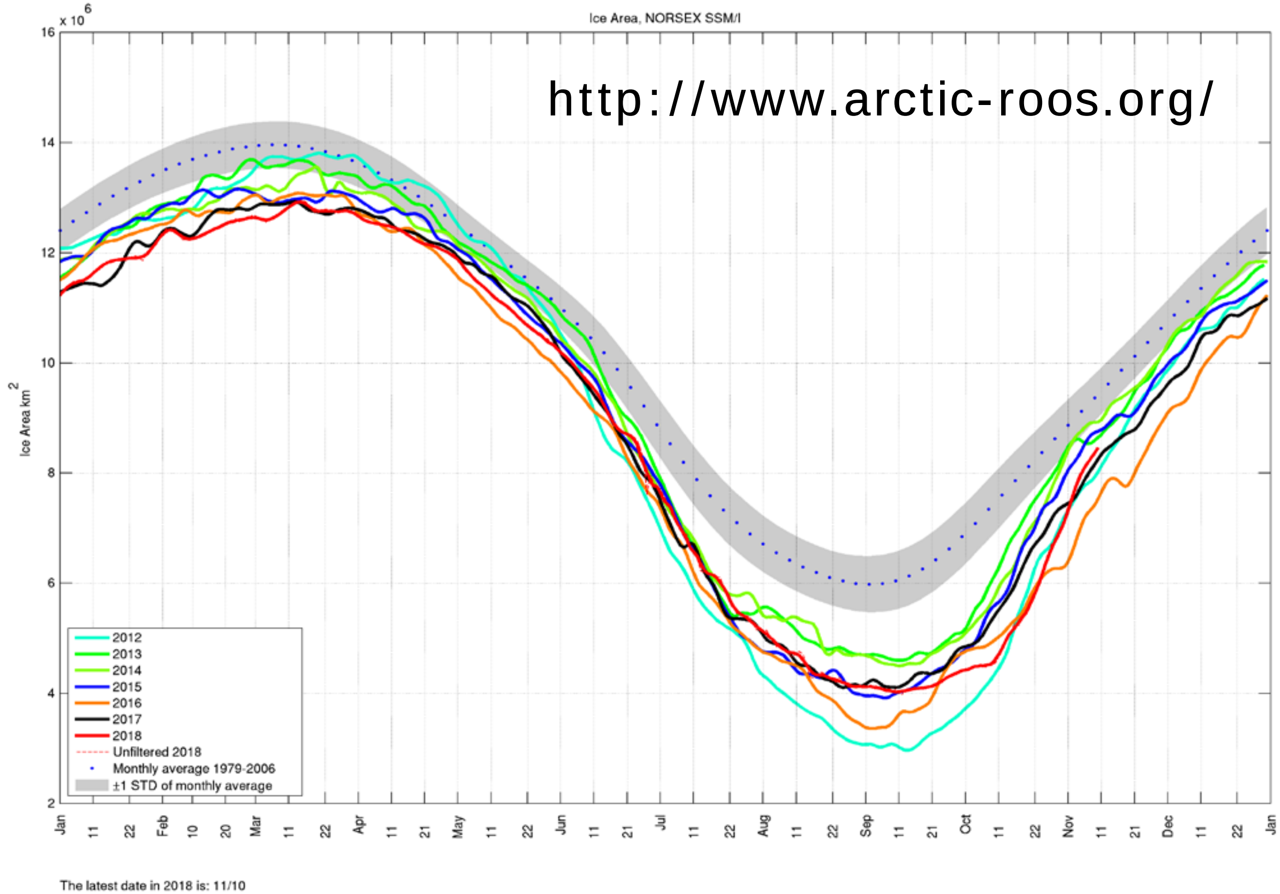
Dragon 4 Advanced Training Course in Ocean & Coastal Remote Sensing
Shenzhen University, P.R. China, 12 - 17 November 2018



The Arctic has lost sea ice volume at a rate of 15.4% per decade since 1993. Accordingly, the Arctic Ocean freshwater content has increased and show a record high in 2016.

Unexpectedly, the sea ice extent in the Antarctic Ocean decreased dramatically during the last months of 2016





Dragon 4 Advanced Training Course in Ocean & Coastal Remote Sensing

Shenzhen University, P.R. China, 12 - 17 November 2018

FREEBOARD HEIGHT & THICKNESS

Earth’s Energy Imbalance

Warmer atmosphere

Warmer Earth surface

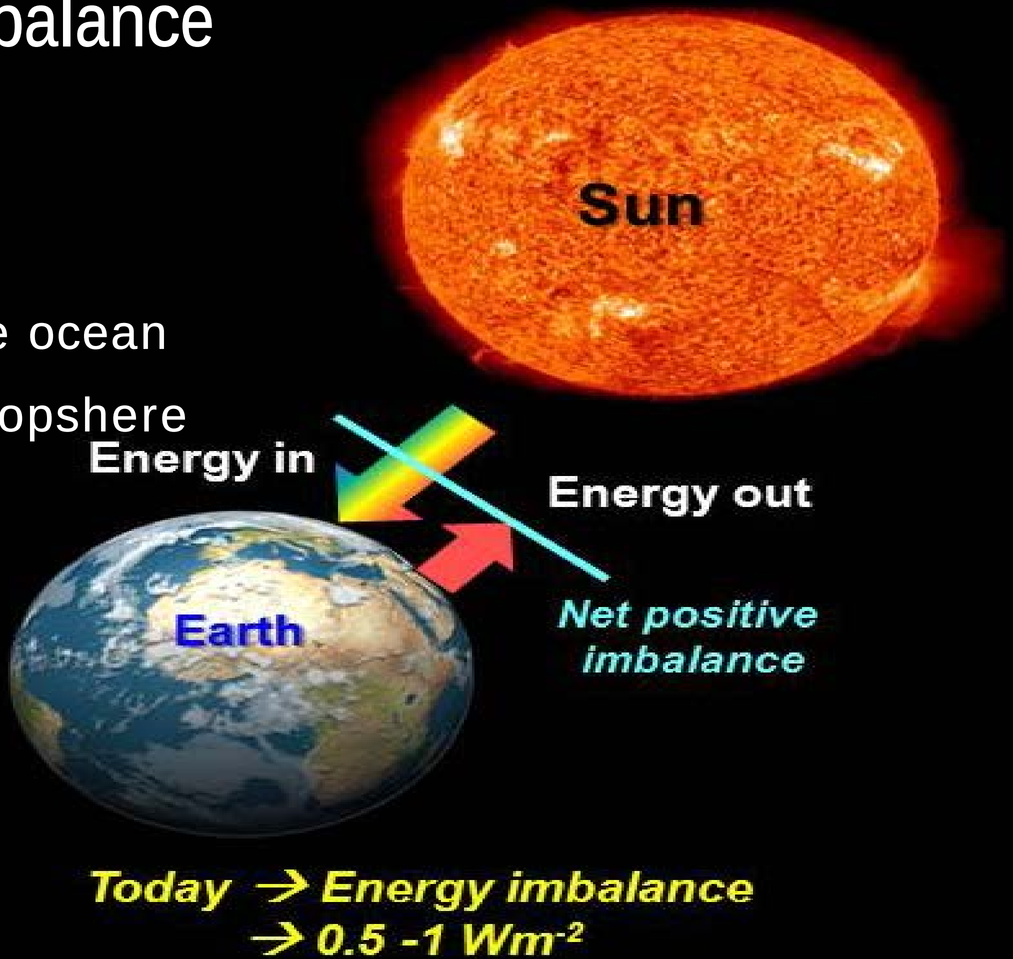
More heat uptake in the ocean

More melting of the cryopshere

Less ice sheet/glaciers

Less sea ice

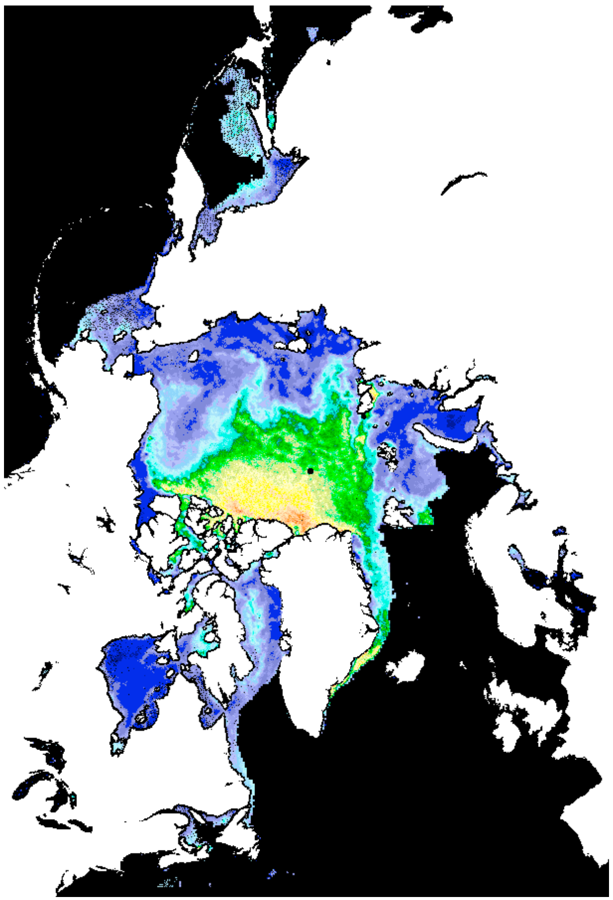
Increased sea level

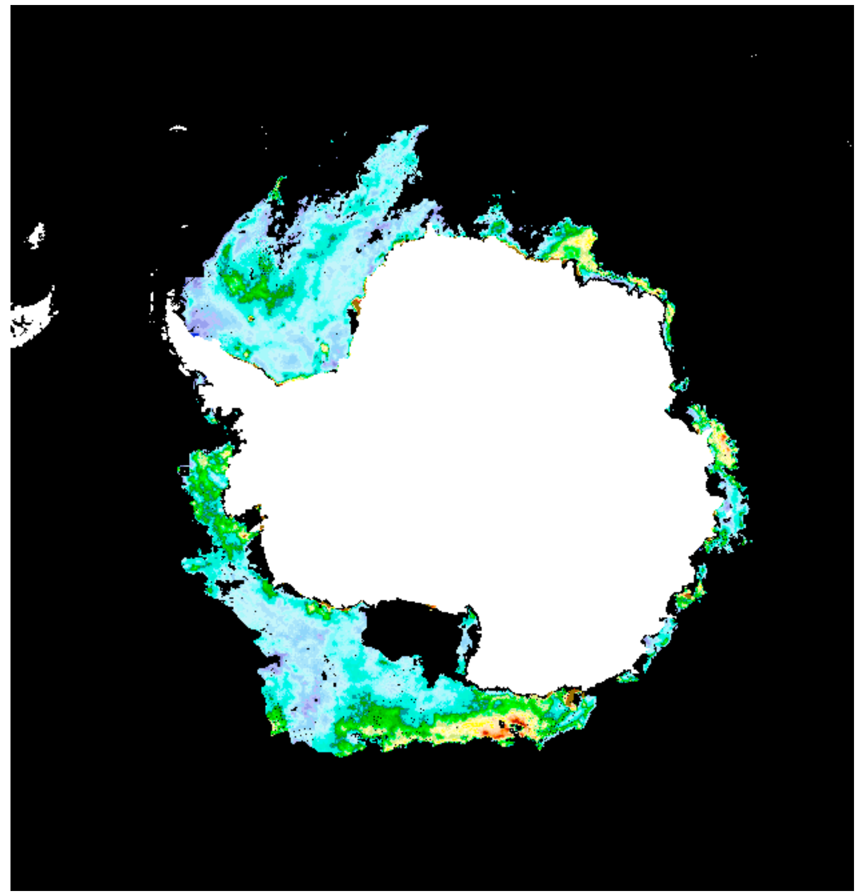


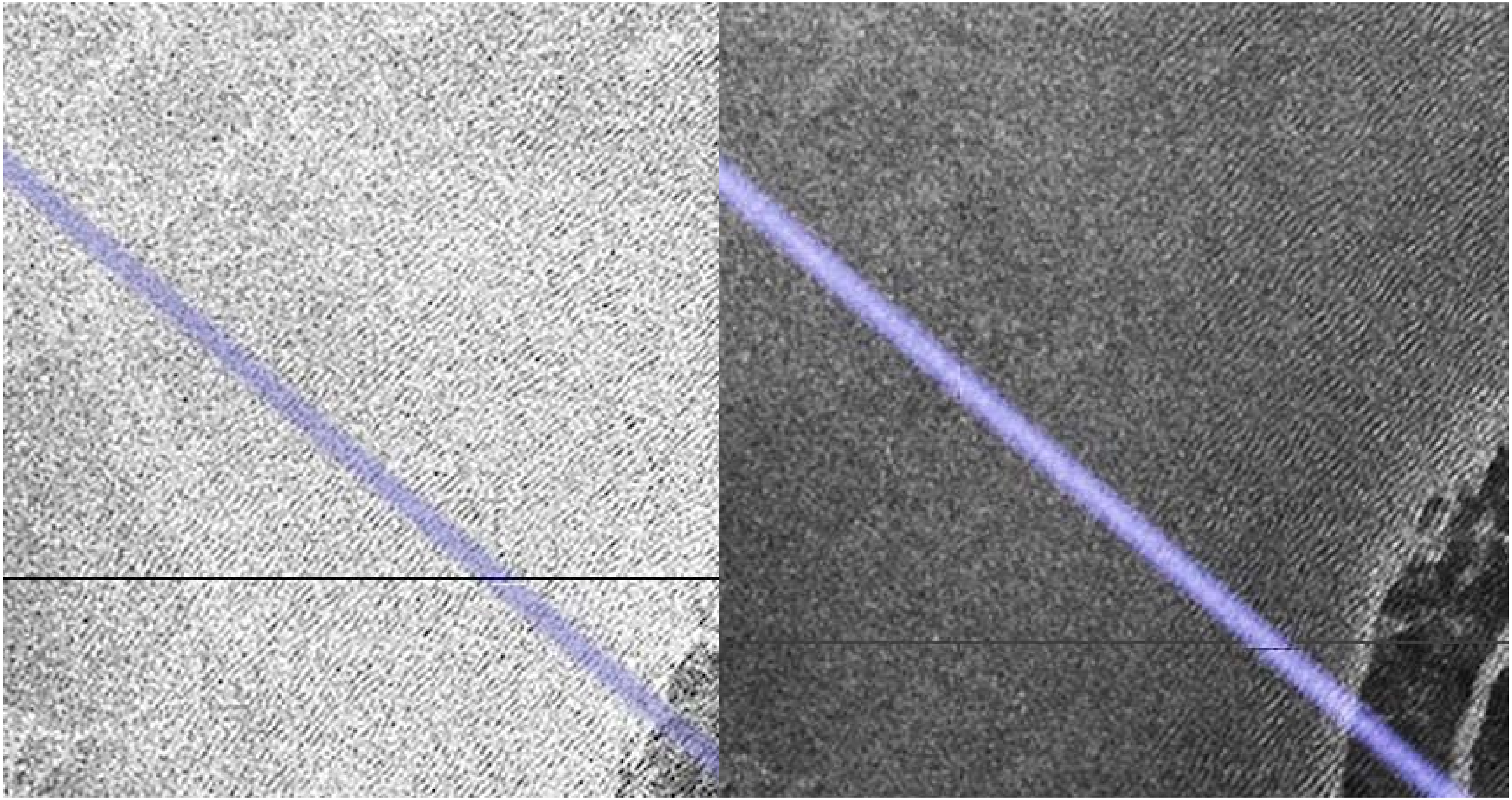
1. Table of Content

Scatterometer over sea ice

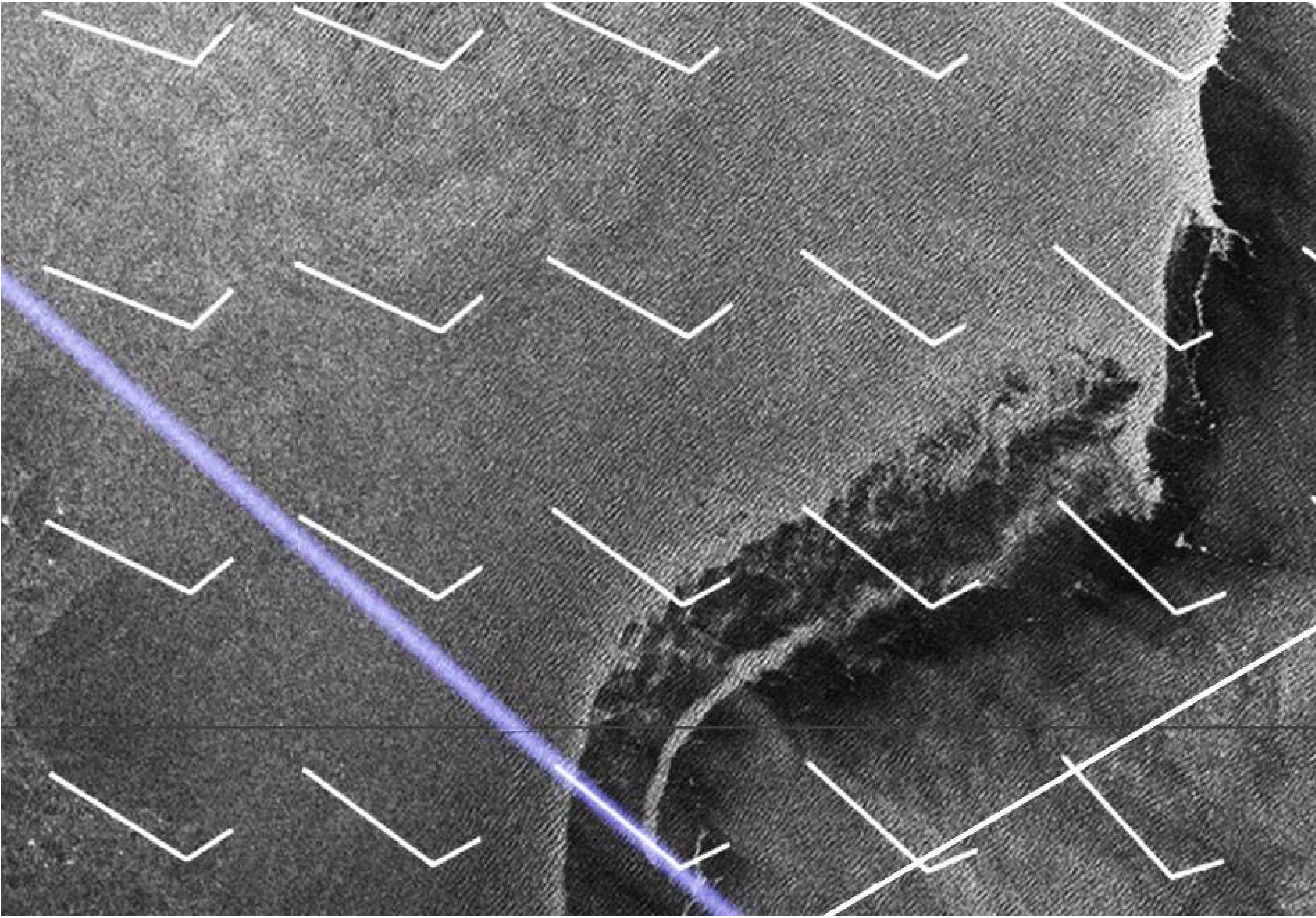
One fourth of the backscatter coefficients obtained from the scatterometers are generated over the polar oceans. In active microwave, sea-ice areas appear as isotropic surfaces. Their signatures are not related to the azimuthal angle dependence but to the incidence angle of the observation and the radar backscattering varies considerably with the incidence angle.



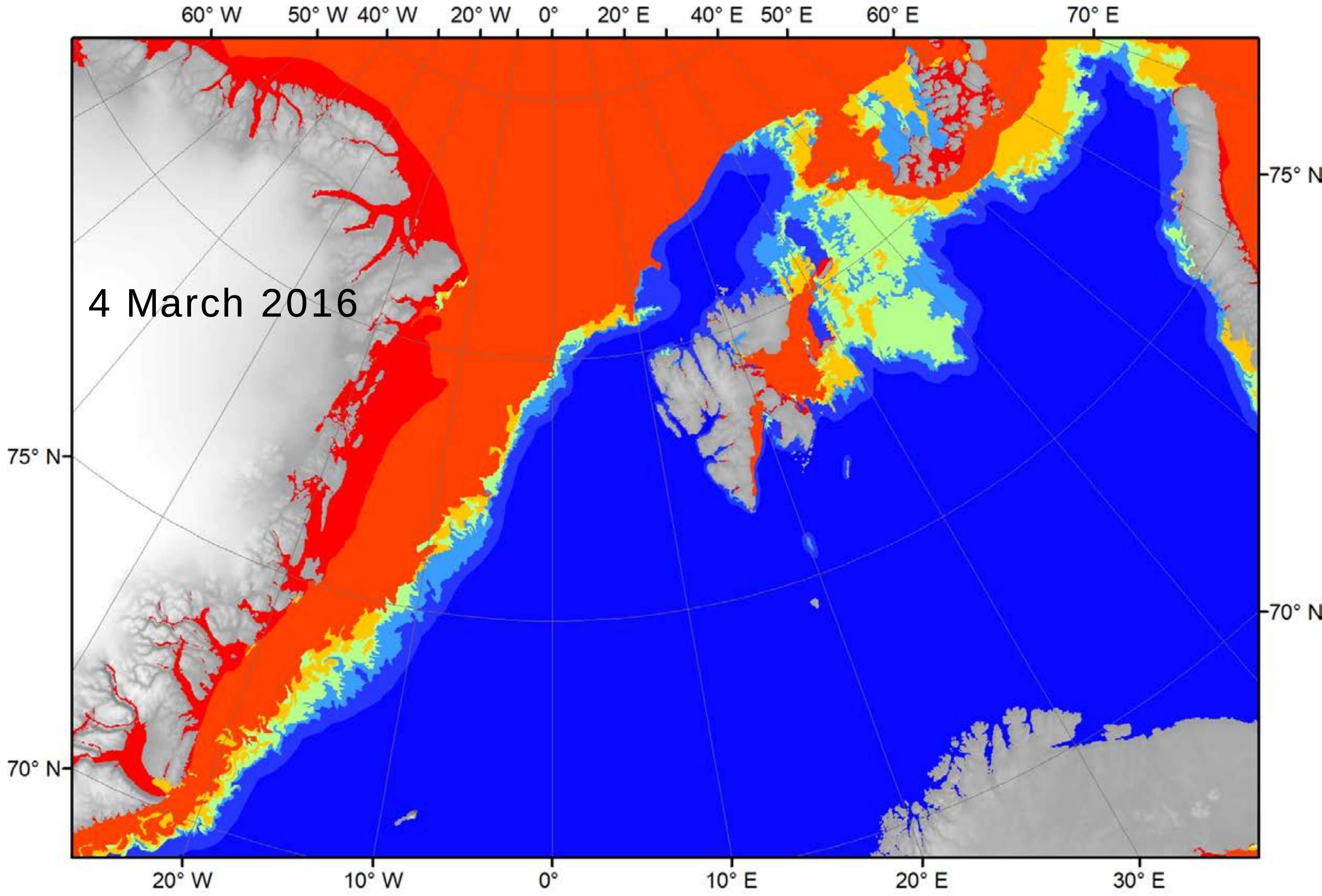


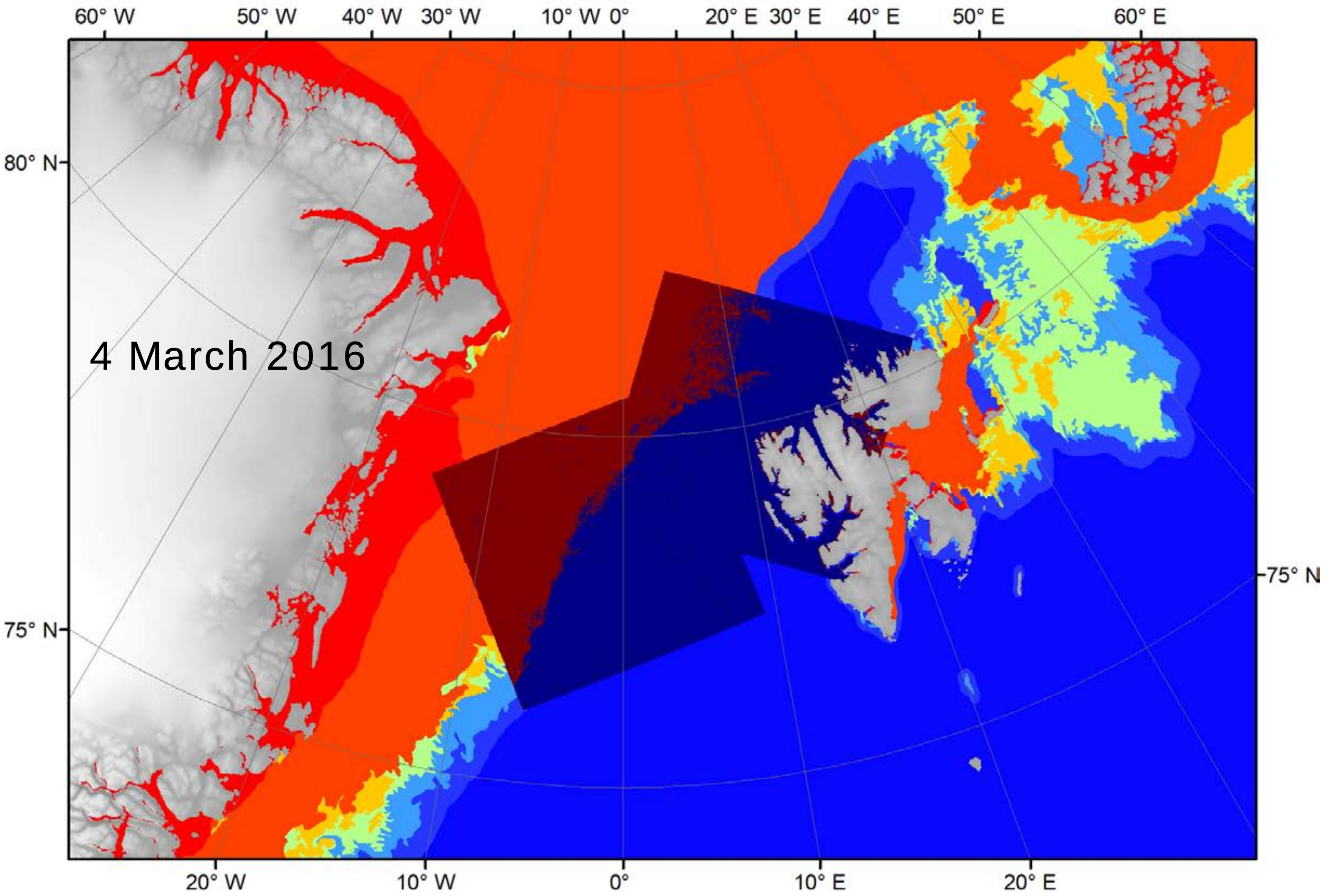


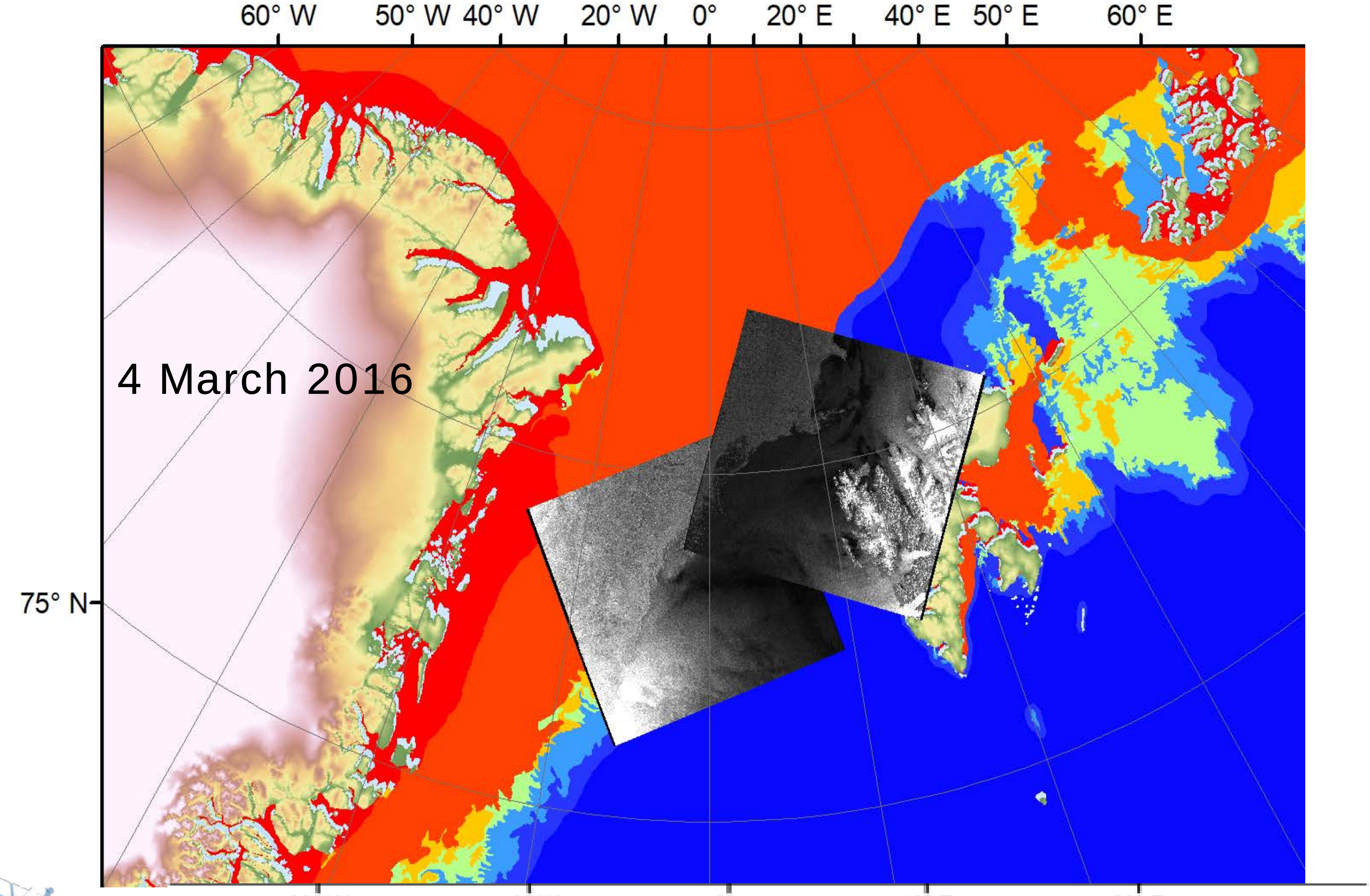
Waves in the ice on 5 October 2014 from S1 (courtesy SWARP Project)



Waves in the ice (courtesy SWARP Project)


4 March 2016
60° W
50° W
40° W
20° W
0°
20° E
40° E
50° E
60° E
70° E
75° N
70° N
75° N
70° N
20° W
10° W
0°
10° E
20° E
30° E

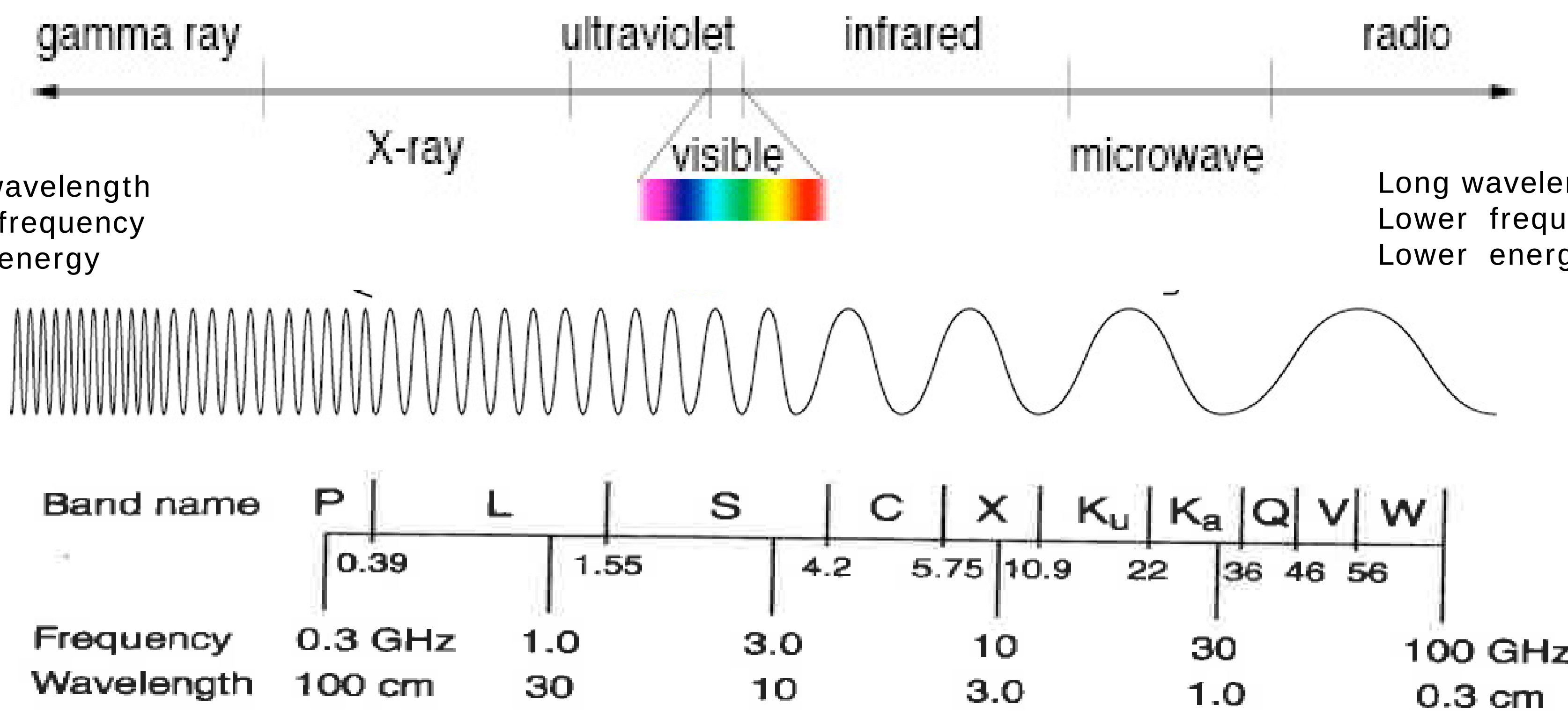

60° W
50° W
40° W
30° W
10° W
0°
20° E
30° E
40° E
50° E
60° E
80° N
75° N
75° N
4 March 2016
20° W
10° W
0°
10° E
20° E


60° W
50° W
40° W
20° W
0°
20° E
40° E
50° E
60° E
4 March 2016
75° N
20° W
10° W
0°
10° E
20° E

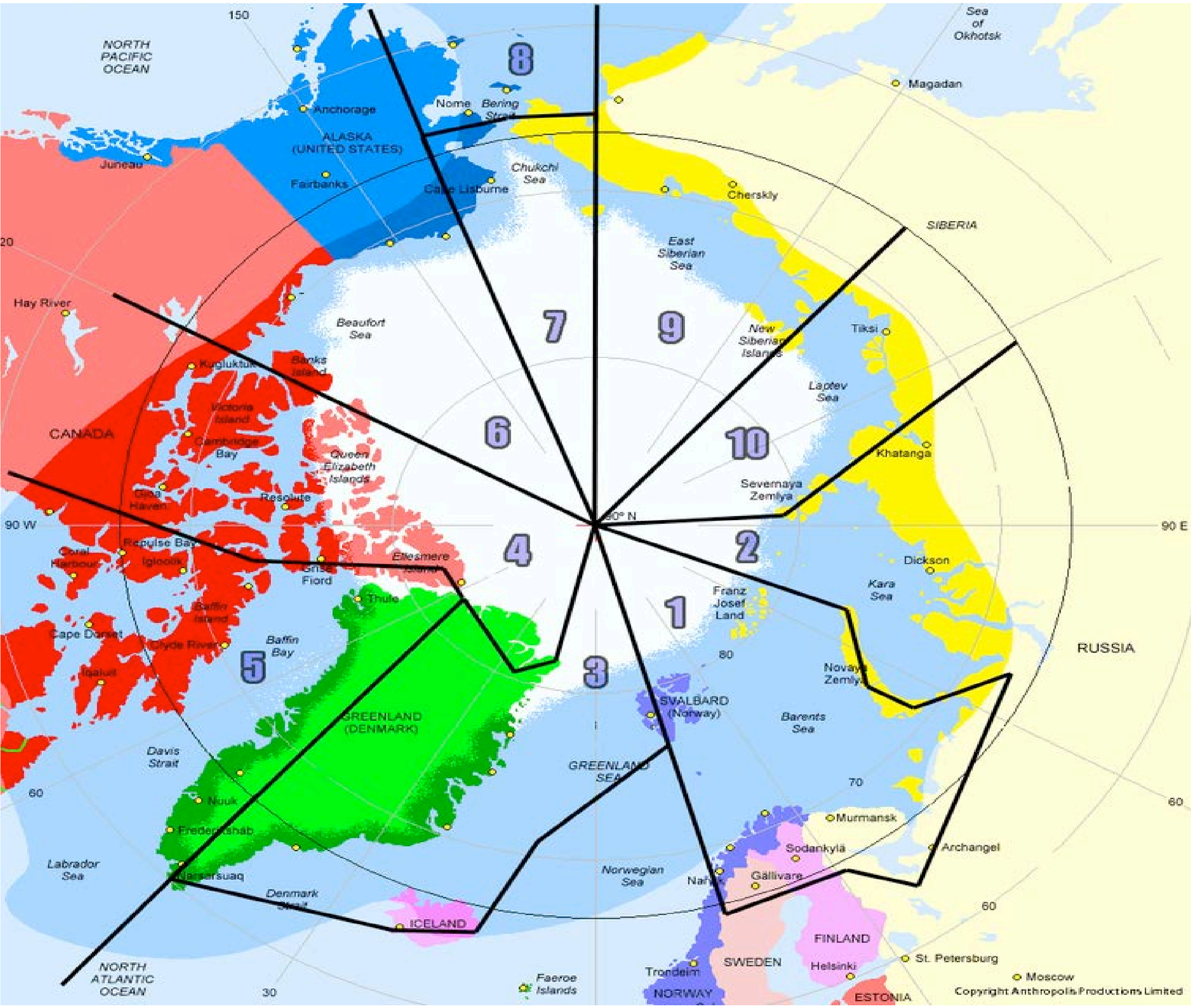
The Electromagnetic Spectrum

Short wavelength
Higher frequency
Higher energy

Long wavelength
Lower frequency
Lower energy



The regions of the Arctic Ocean and surroudning seas



1: Barents Sea Section

2: Kara Sea Section

3: Greenland Sea Section

4: Canadian Arctic Section

5: Baffin Bay Section

6: Beaufort Sea Section

7: Chukchi Sea Section

8: Bering Sea Section

9: East Siberian Sea Section

10: Laptev Sea Sectio

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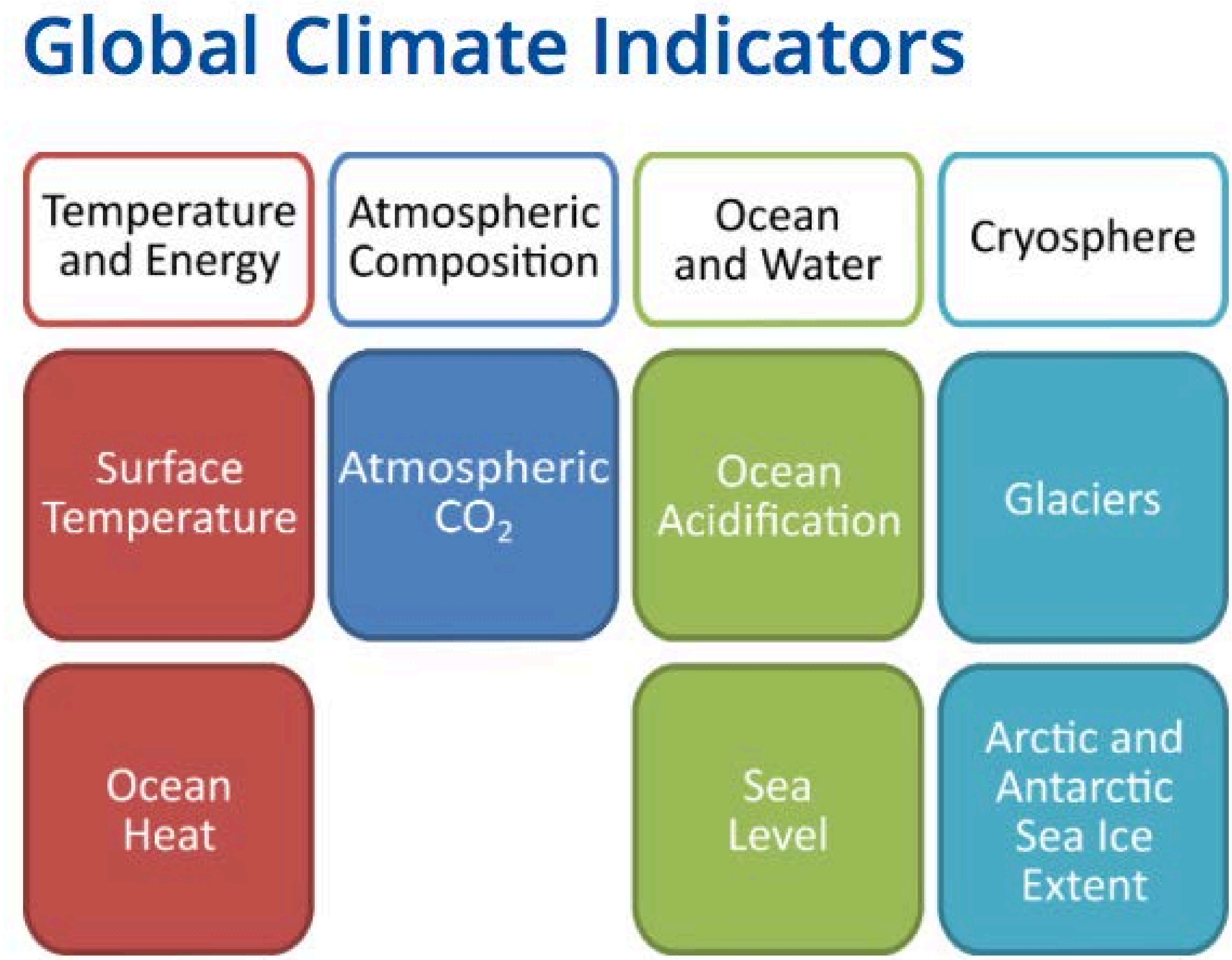
Satellite Observations of the Cryosphere



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Antenna size, wavelength, beam width and coverage

$\sin \phi_r = \lambda / D$ Beam width

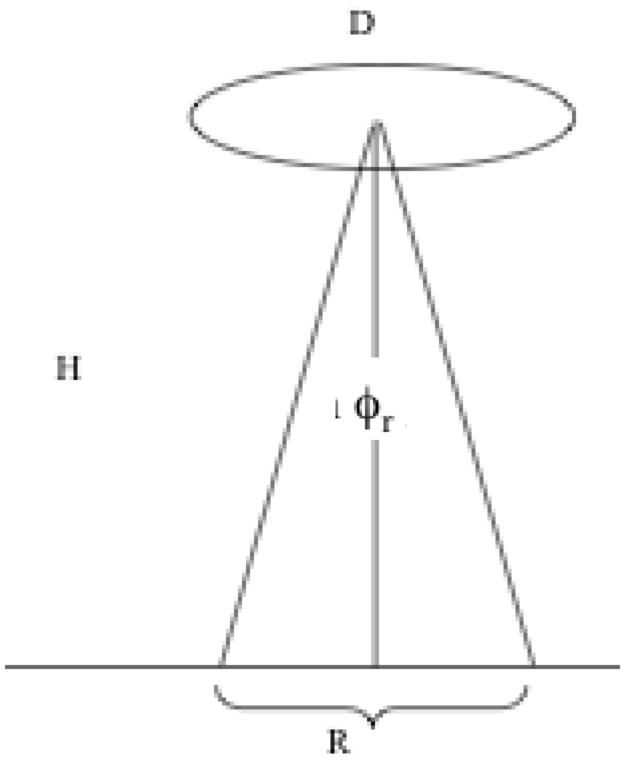
$R = 2 H \lambda / D$

$H = 800$ km

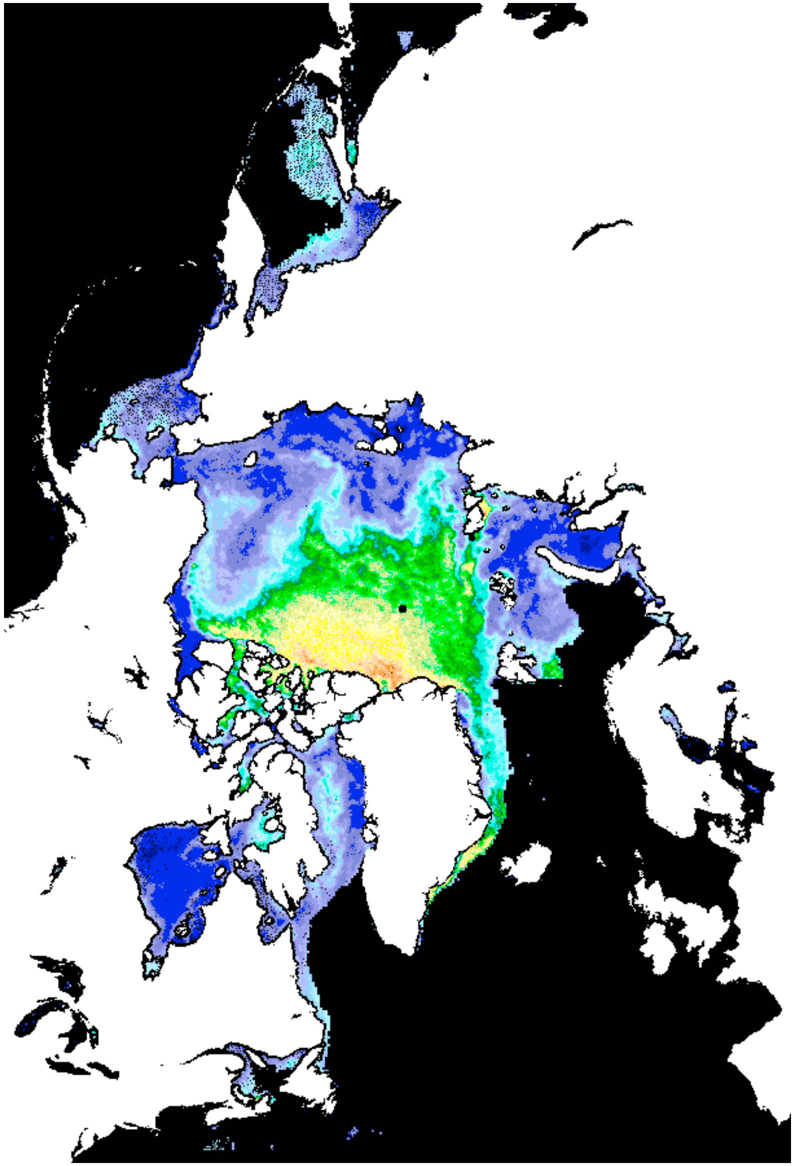
$\lambda = 1$cm

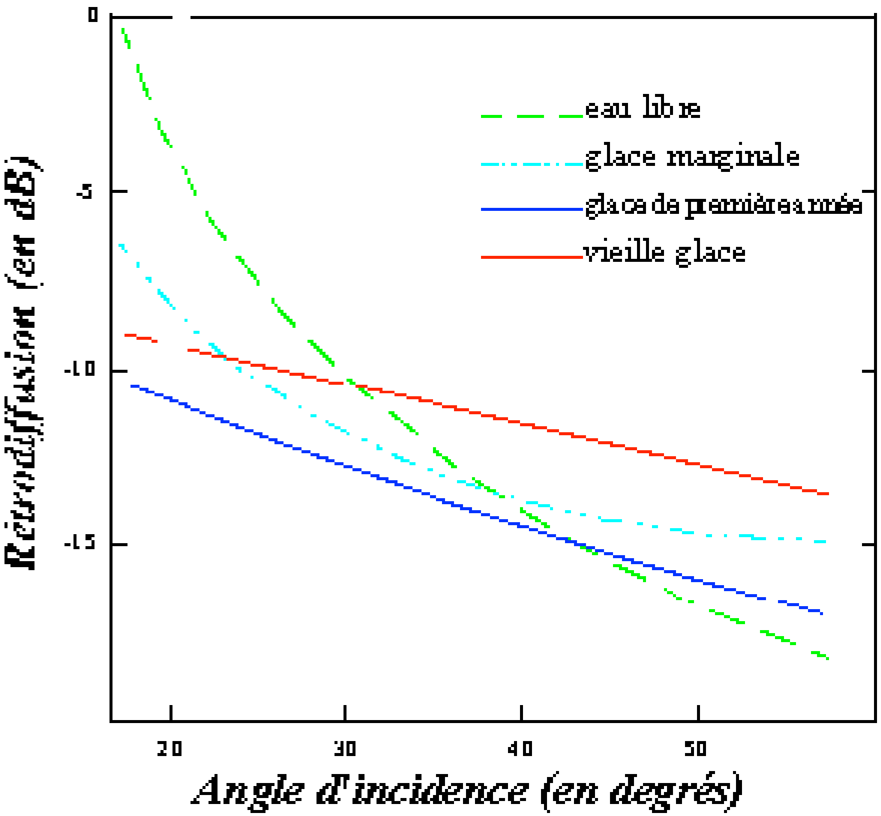
$D = 1$m

$\Longrightarrow R = 16$ km

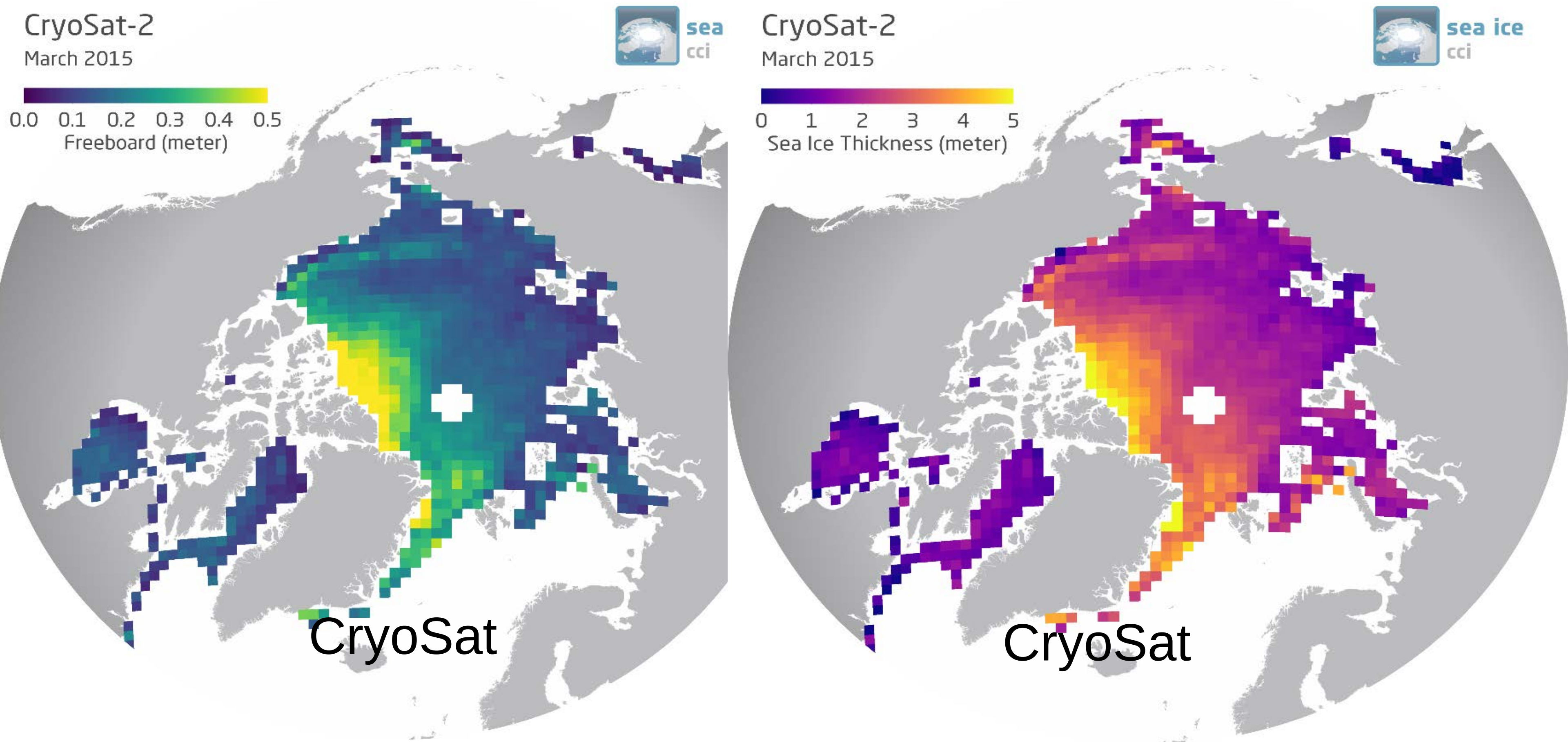


Scatterometer over sea ice

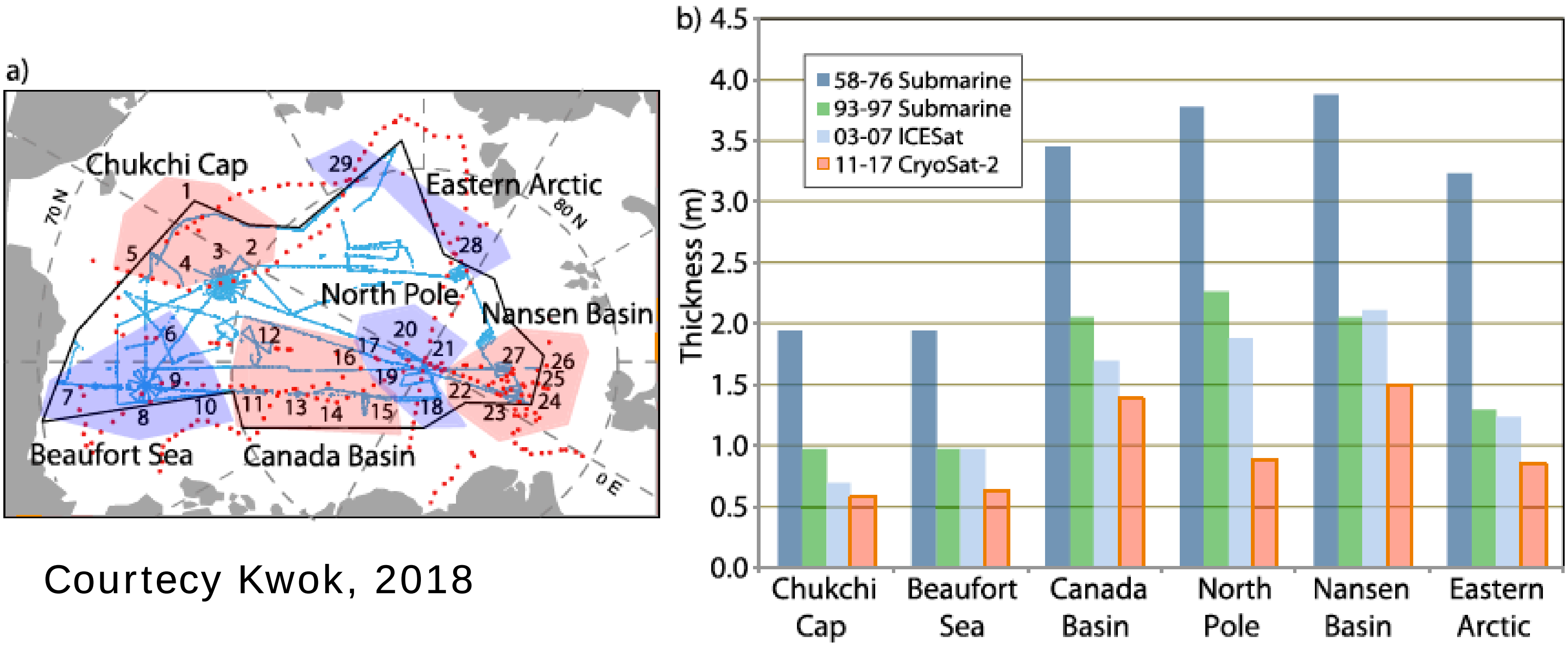




From freeboard to thickness

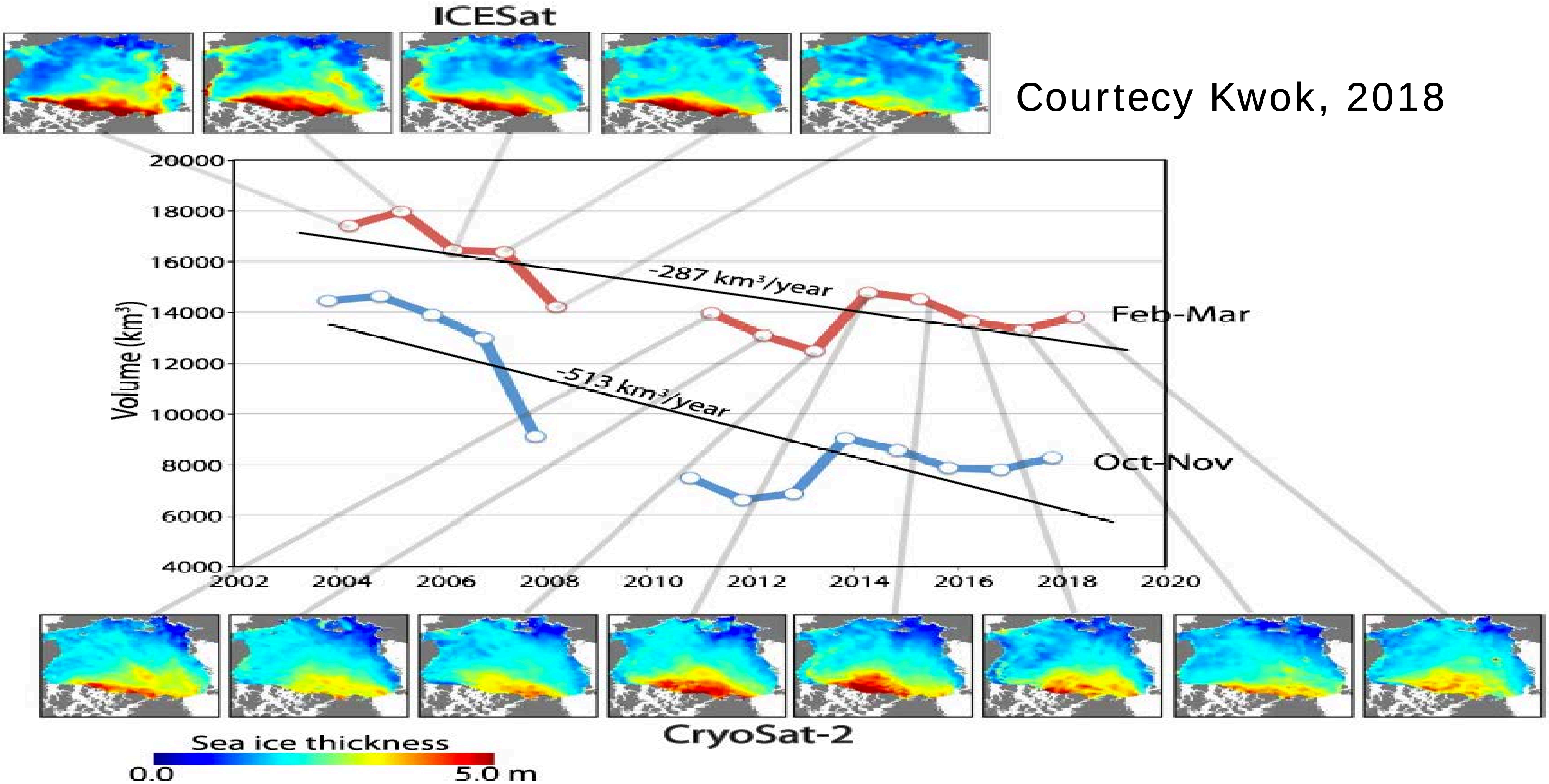


Sea Ice Thickness



Courtecy Kwok, 2018

Sea Ice Thickness



Courtecy Kwok, 2018