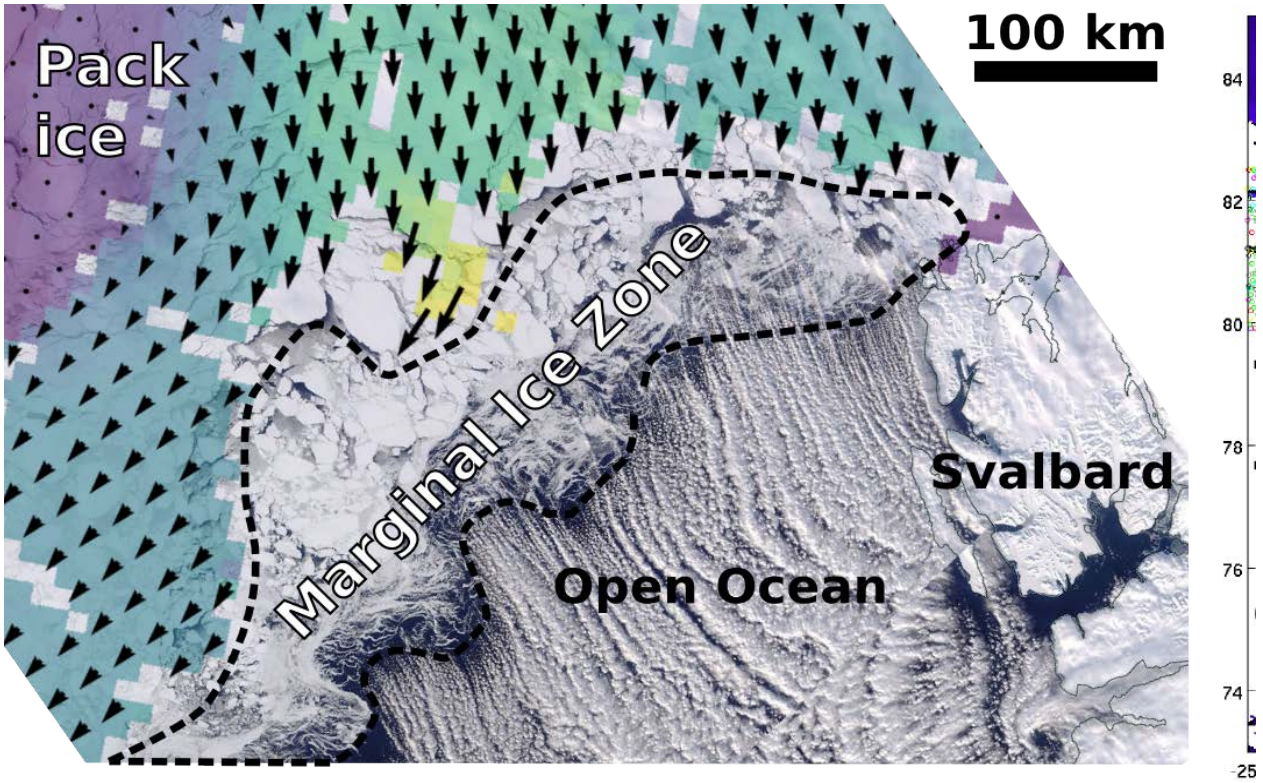
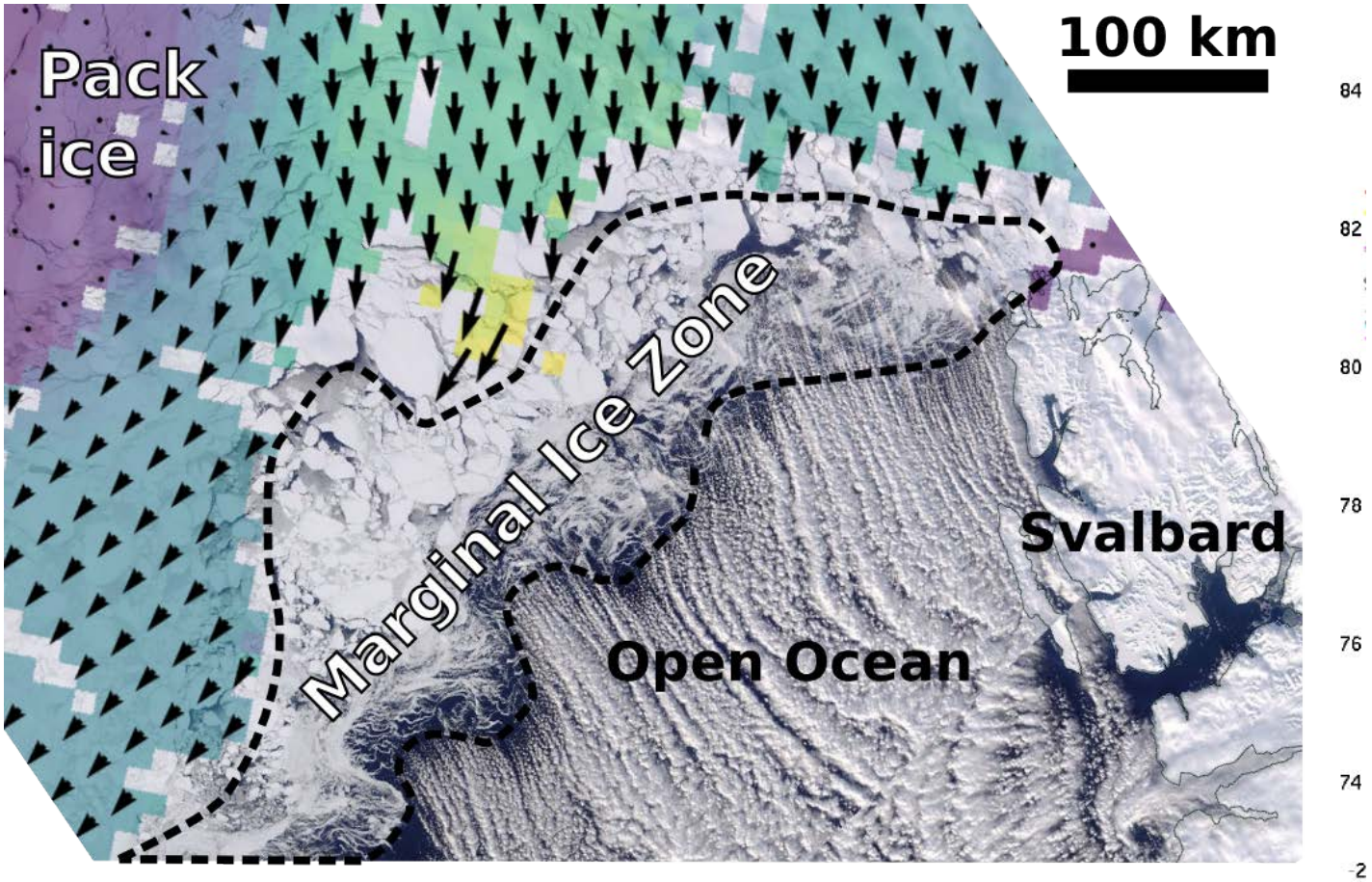
Mesoscale processes and dynamics in the Marginal Ice Zone: Importance of satellite observations



Johnny A. Johannessen

with contribution from Anton Korosov, Einar Olason,

NERSC

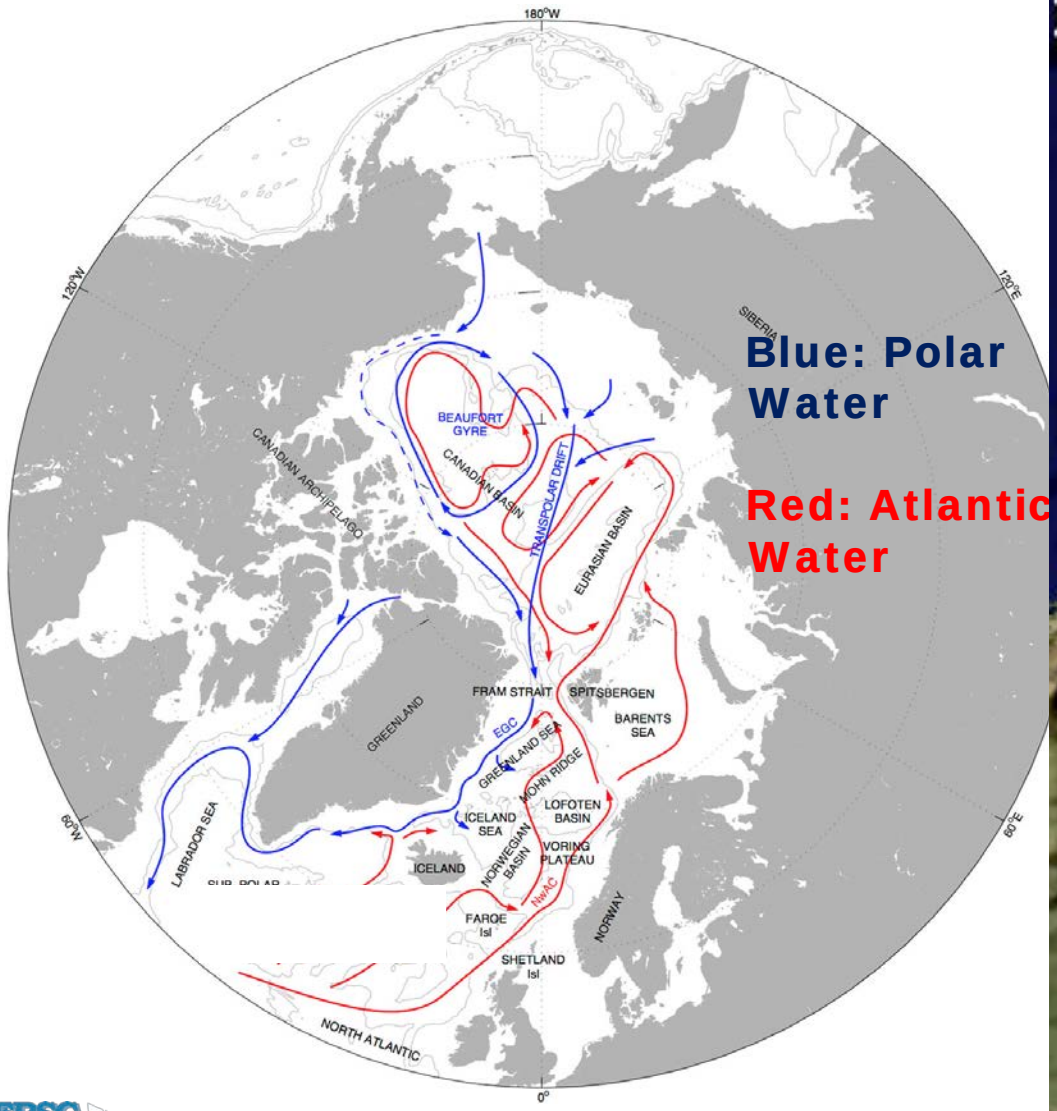


Mesoscale processes and dynamics in the MIZ are entirely resulting from coupled air - sea ice – ocean interactions

CONTENT

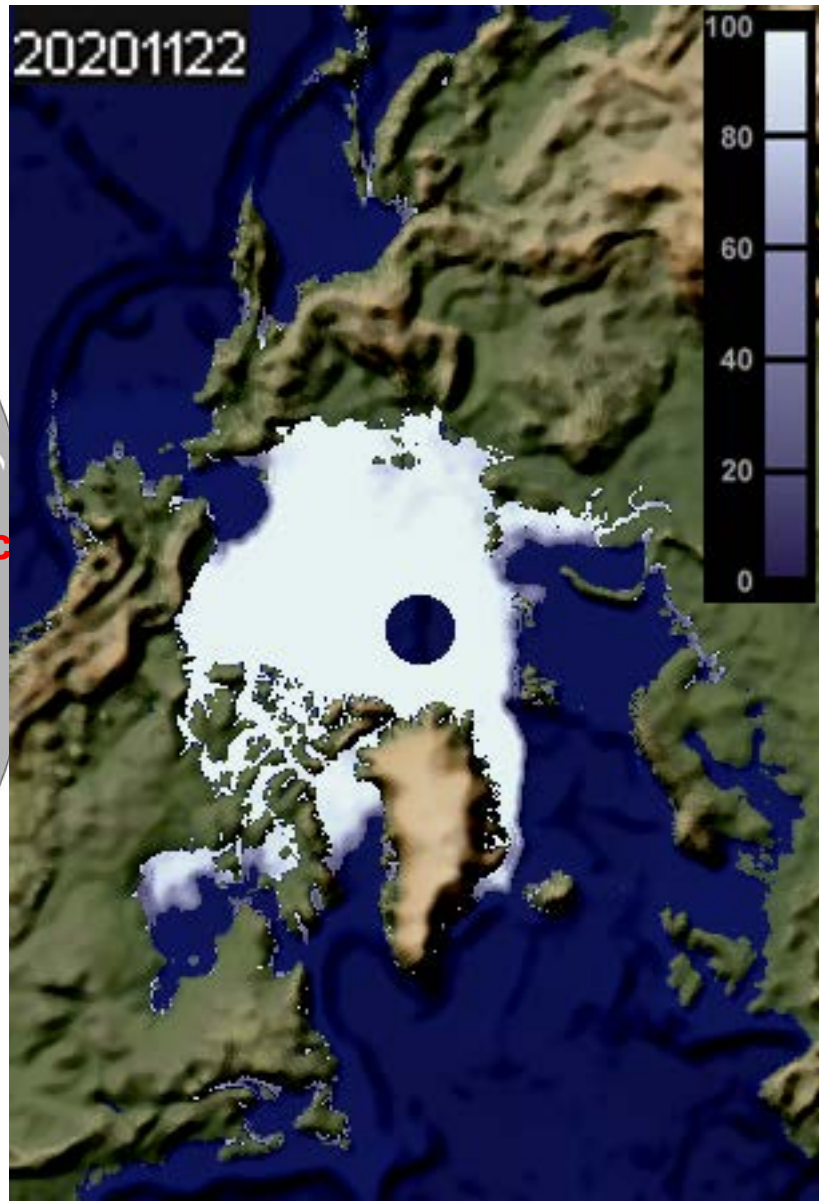
- Background
- Satellite observations
- The Marginal Ice Zone
- Mesoscale processes and variability
- Summary

Large scale ocean circulation in the high latitude and Arctic Ocean



Blue: Polar Water

Red: Atlantic Water



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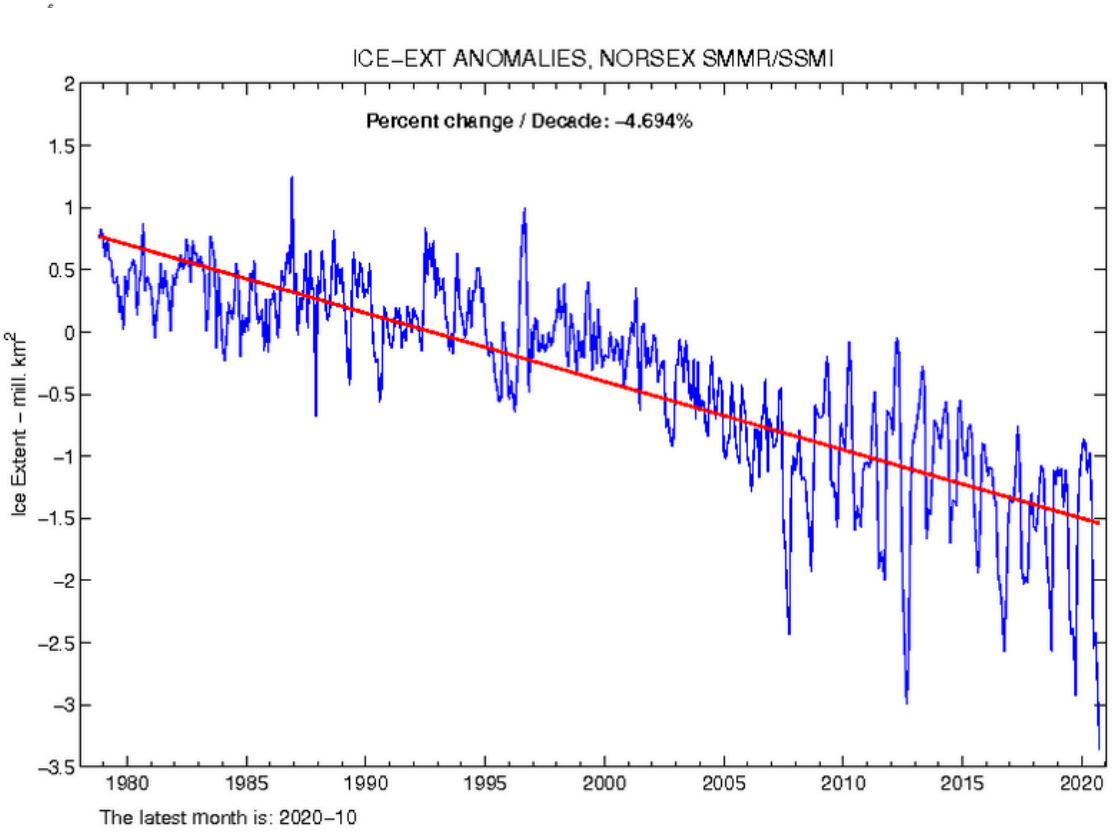
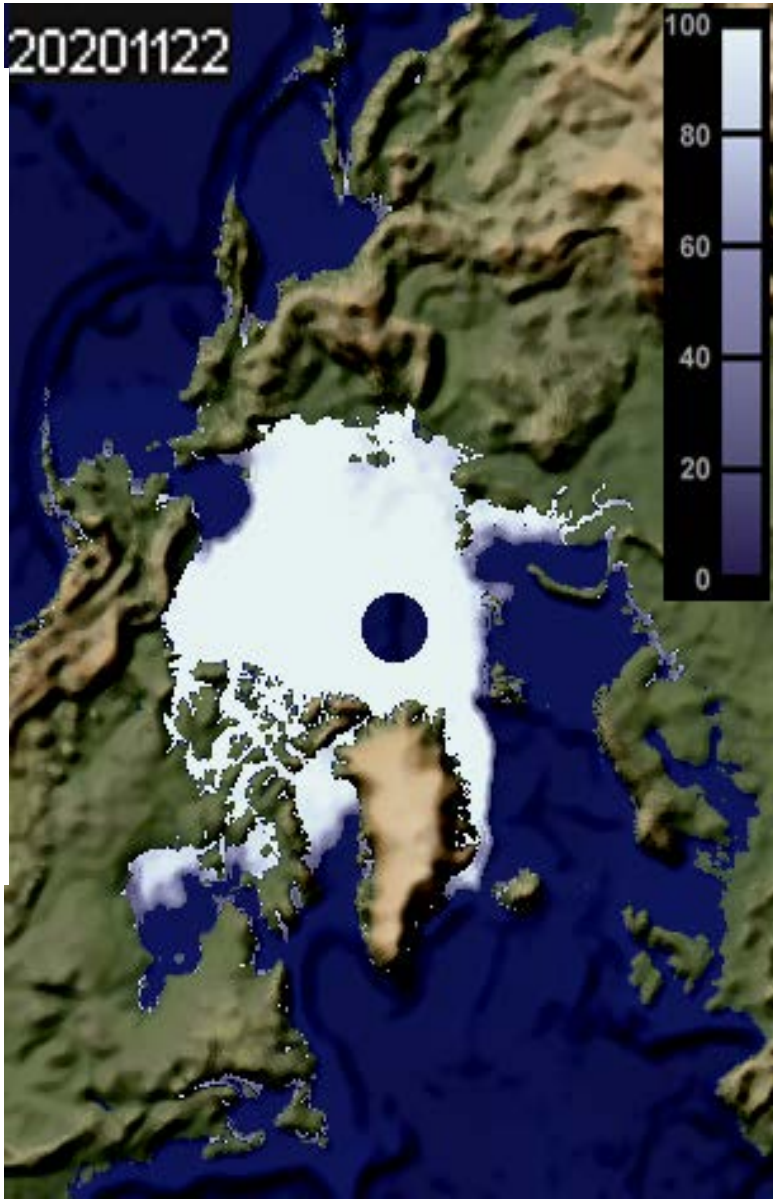
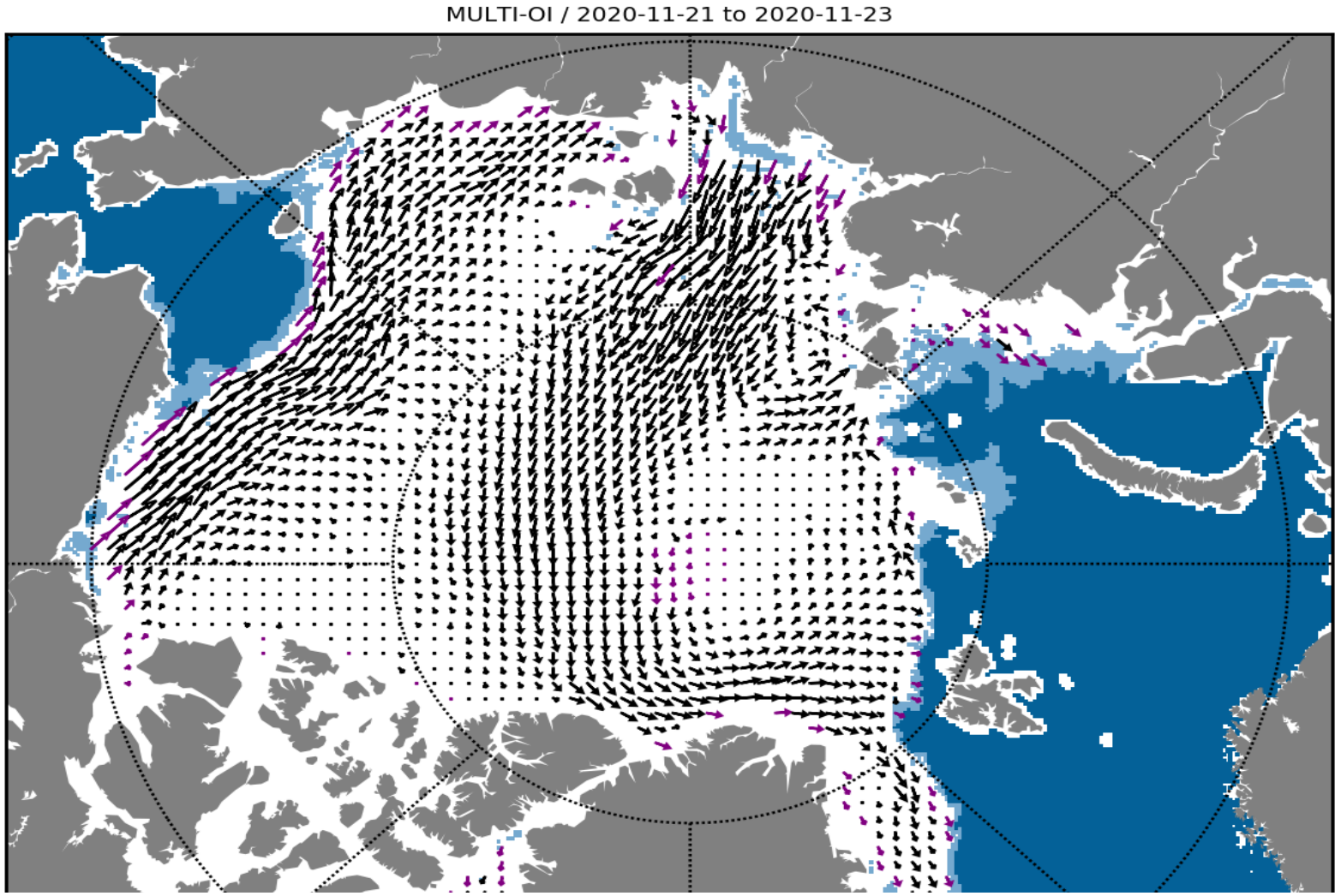
Passive Microwave Observations from SSMI





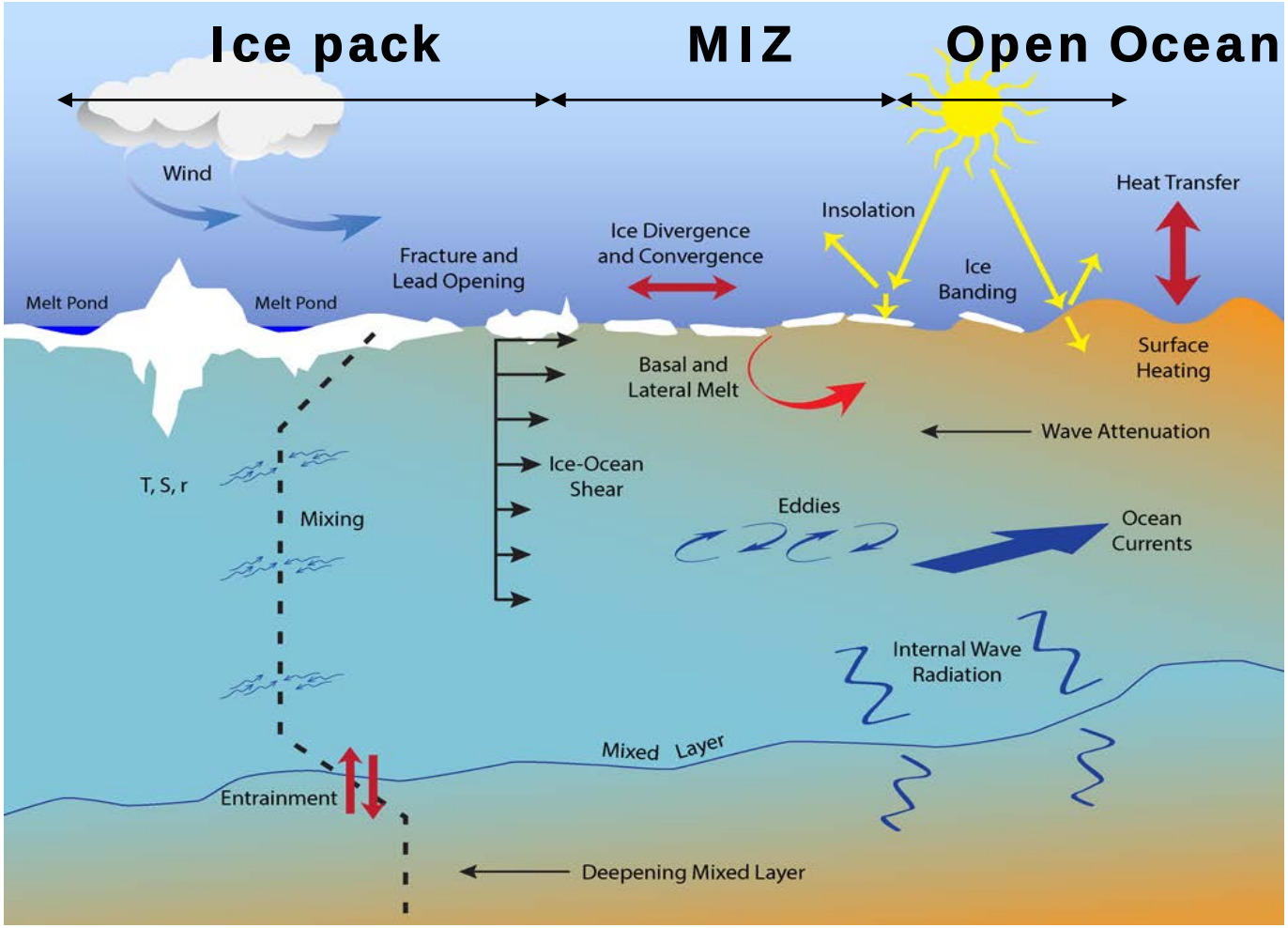
http://www.arctic-roos.org/

Large scale sea ice drift – 21-23 NOV. 2020



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

Atmosphere-ocean-ice interactions in the Marginal Ice Zone



Source: apl.washington.edu

Ice cover heterogeneity plays a role in:

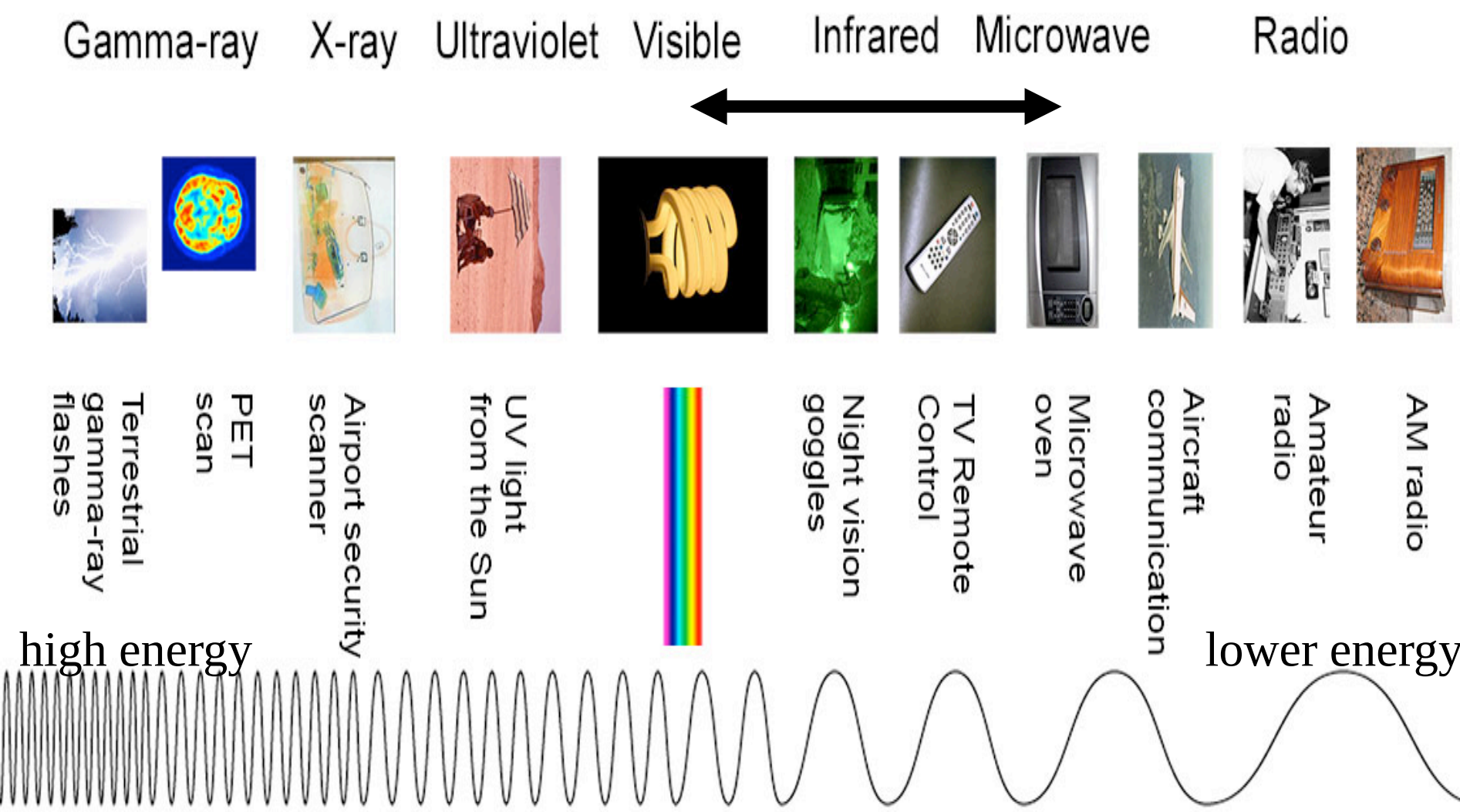
- Melt-pond distribution
- Ridge formation
- Lead formation
- Momentum transfers
- Heat exchange

There are complex feedbacks and processes yet to be understood

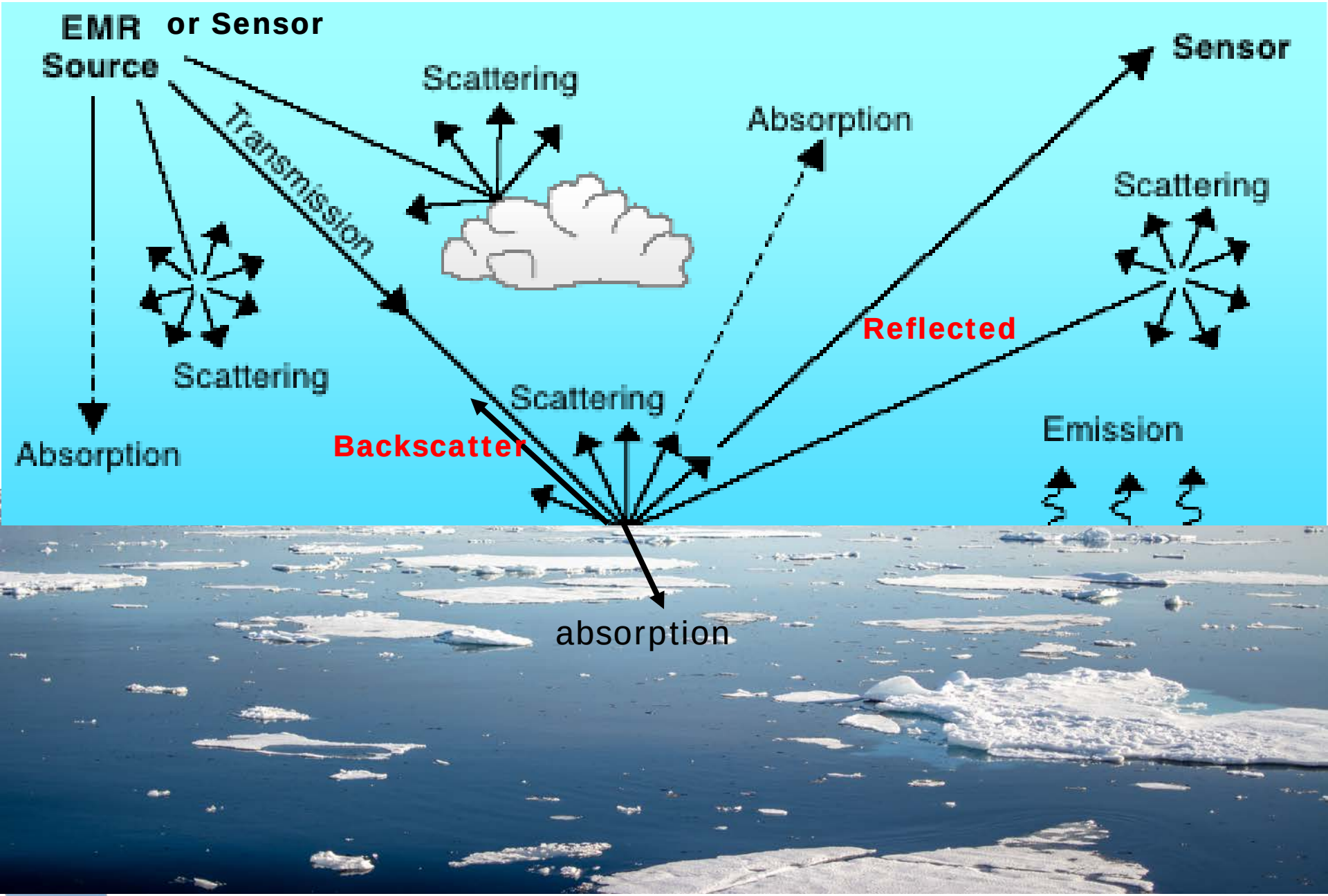
Satellite Observations in the Arctic Marginal Ice Zone

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, CFOSAT, 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, (CFOSAT)
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, CFOSAT
Wind	Wind speed, streaks, vector wind	SAR, scatterometer, altimeter, CFOSAT
Color	Chlorophyll, phytoplankton	Spectrometers
Sun glitter	Sunlight reflected from the surface	Spectrometers

The Electromagnetic spectrum



Typical Interaction for Electromagnetic Radiation in the MIZ

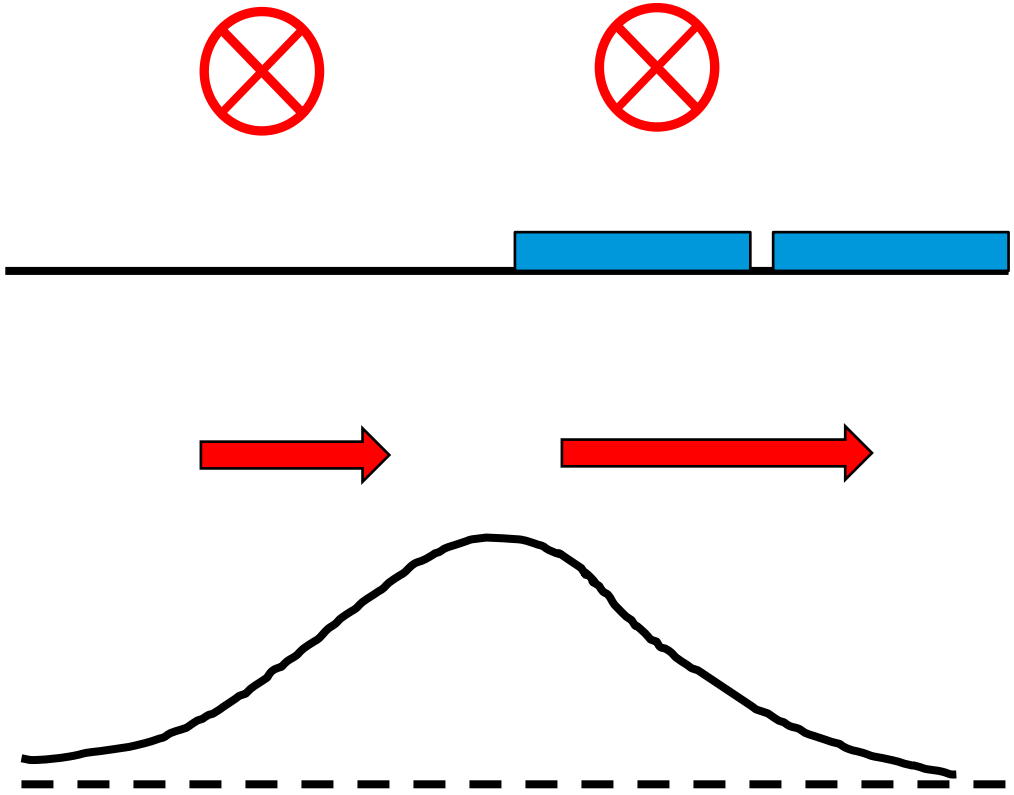


MIZ processes

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



Wind Stress atmosphere to water:

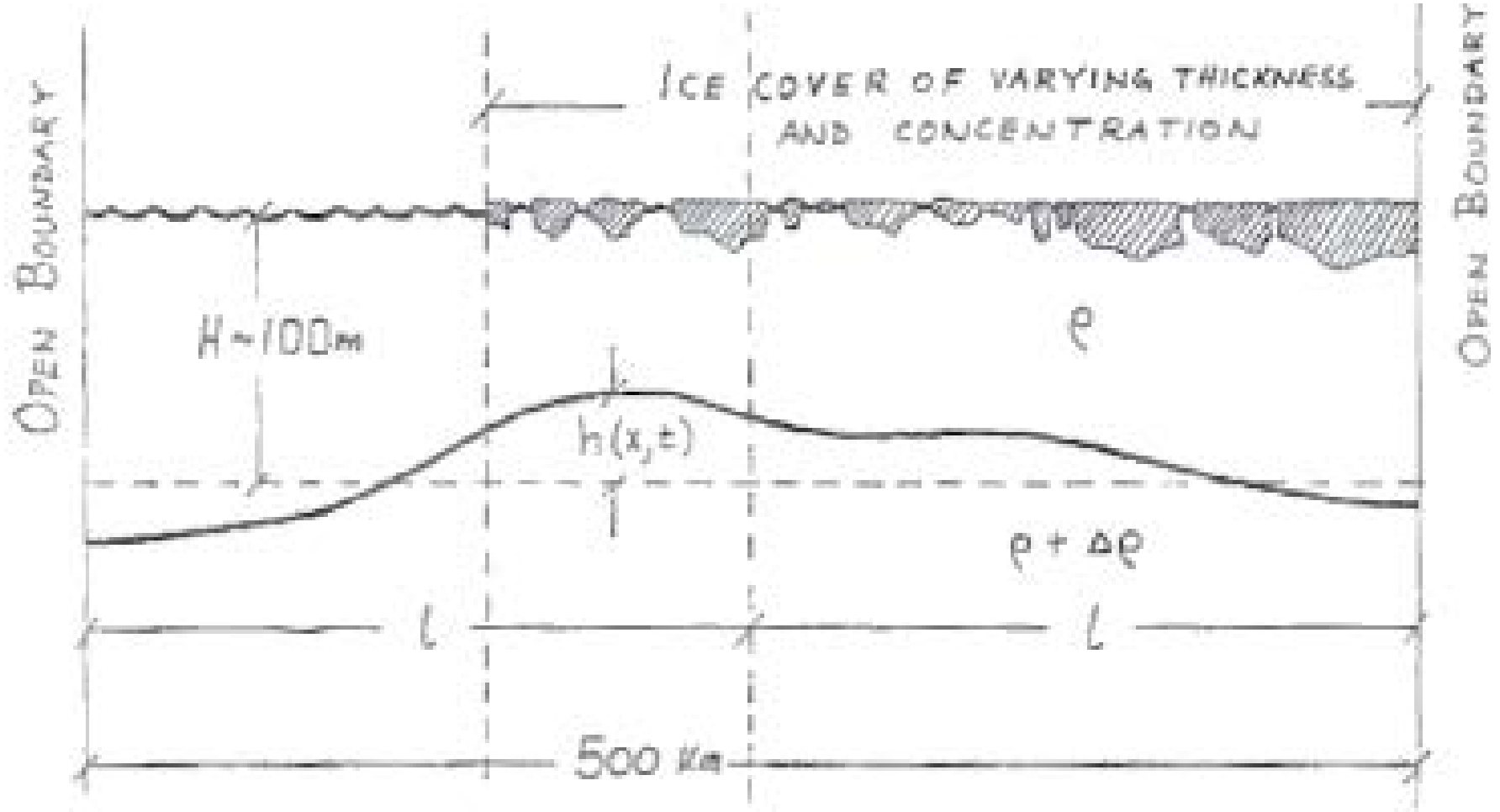
$$\tau_w = \rho_a C_w U^2$$

Wind Stress atmosphere to sea ice:

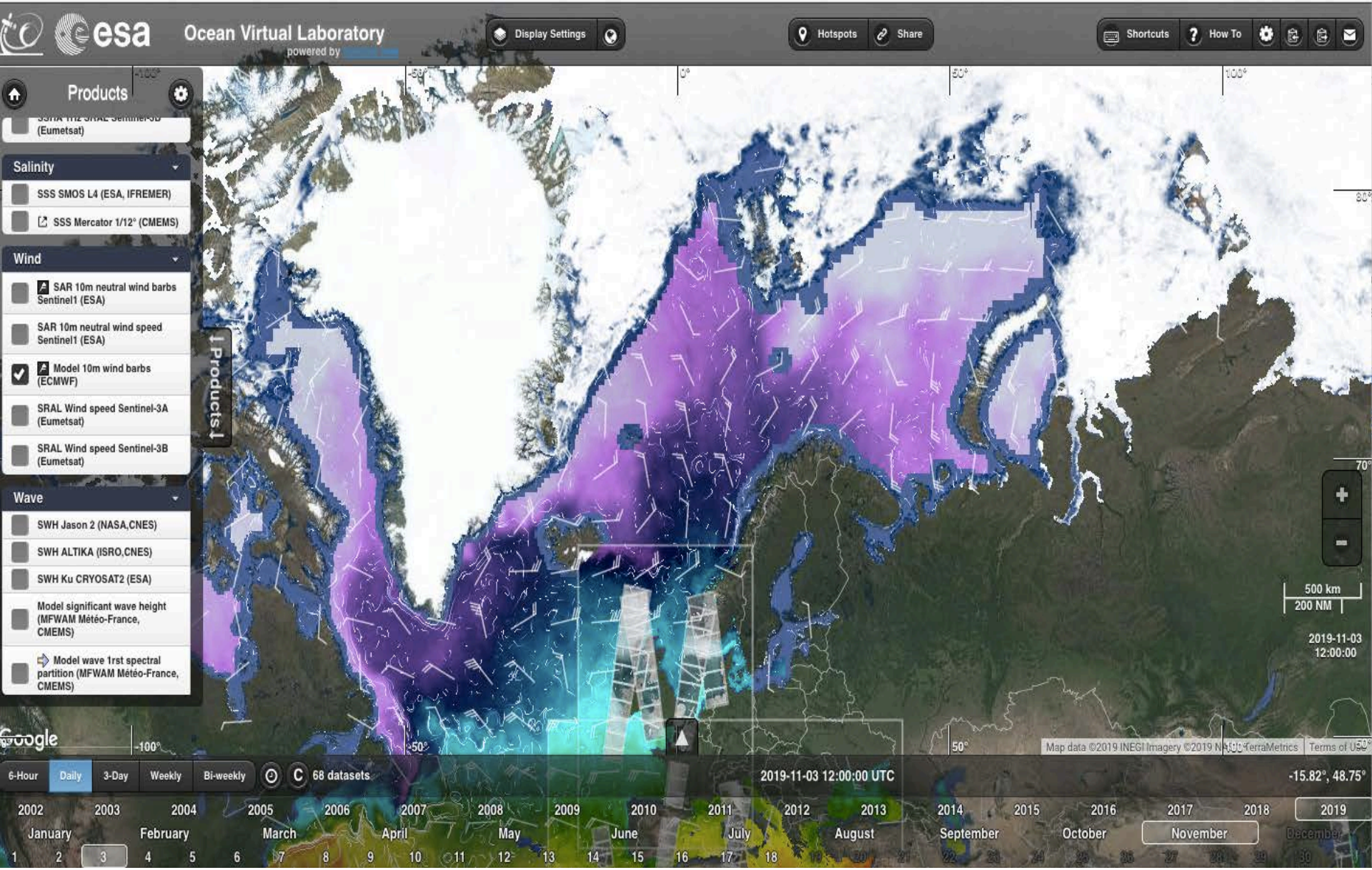
$$\tau_{si} = \rho_a C_{si} U^2$$

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

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



COURTECY RØED and O´BRIEN, 1983


esa
Ocean Virtual Laboratory
powered by
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
Google
Map data ©2019 INEGI Imagery ©2019
Terms of Use
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
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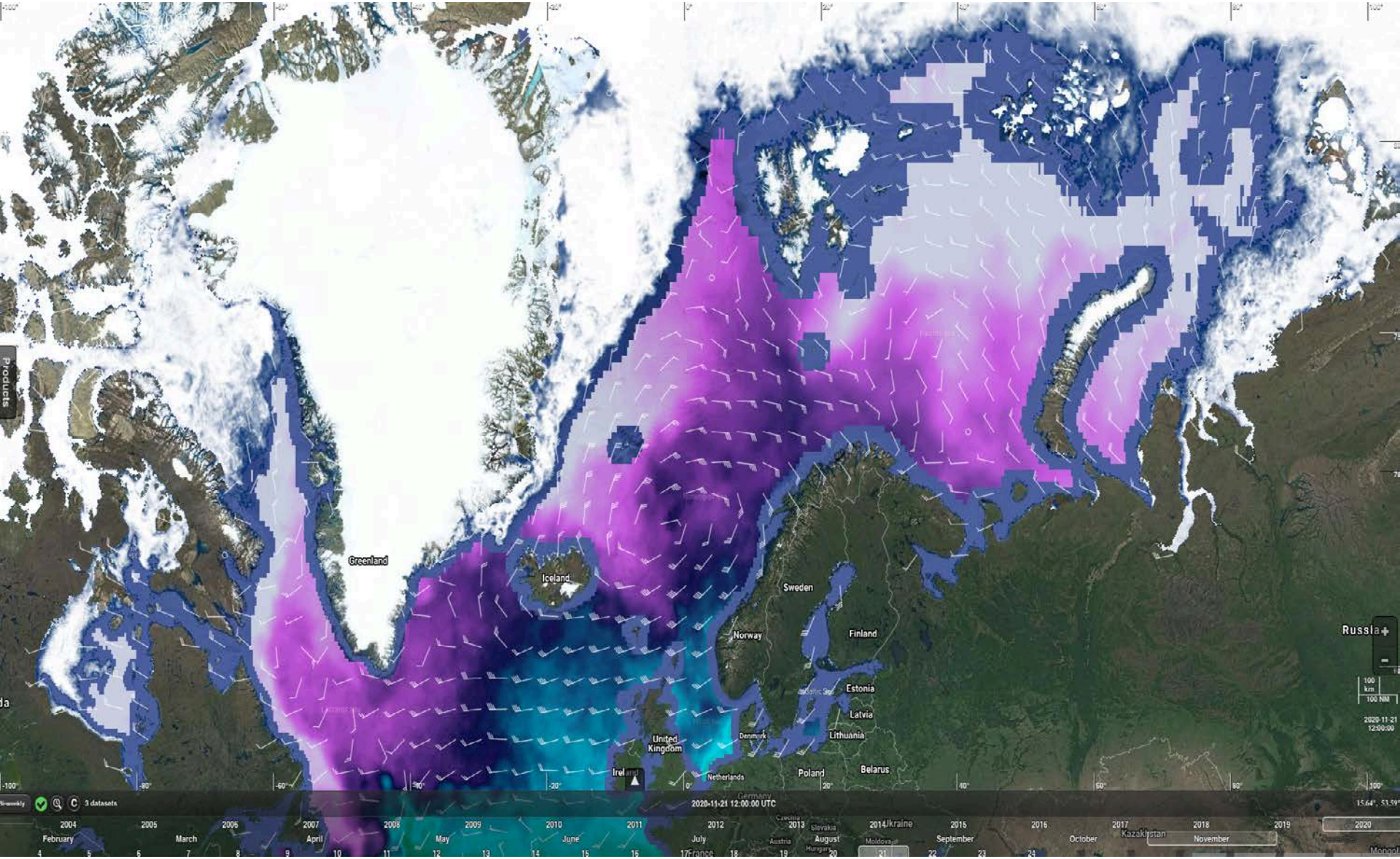
December



https://ovl.oceandatalab.com

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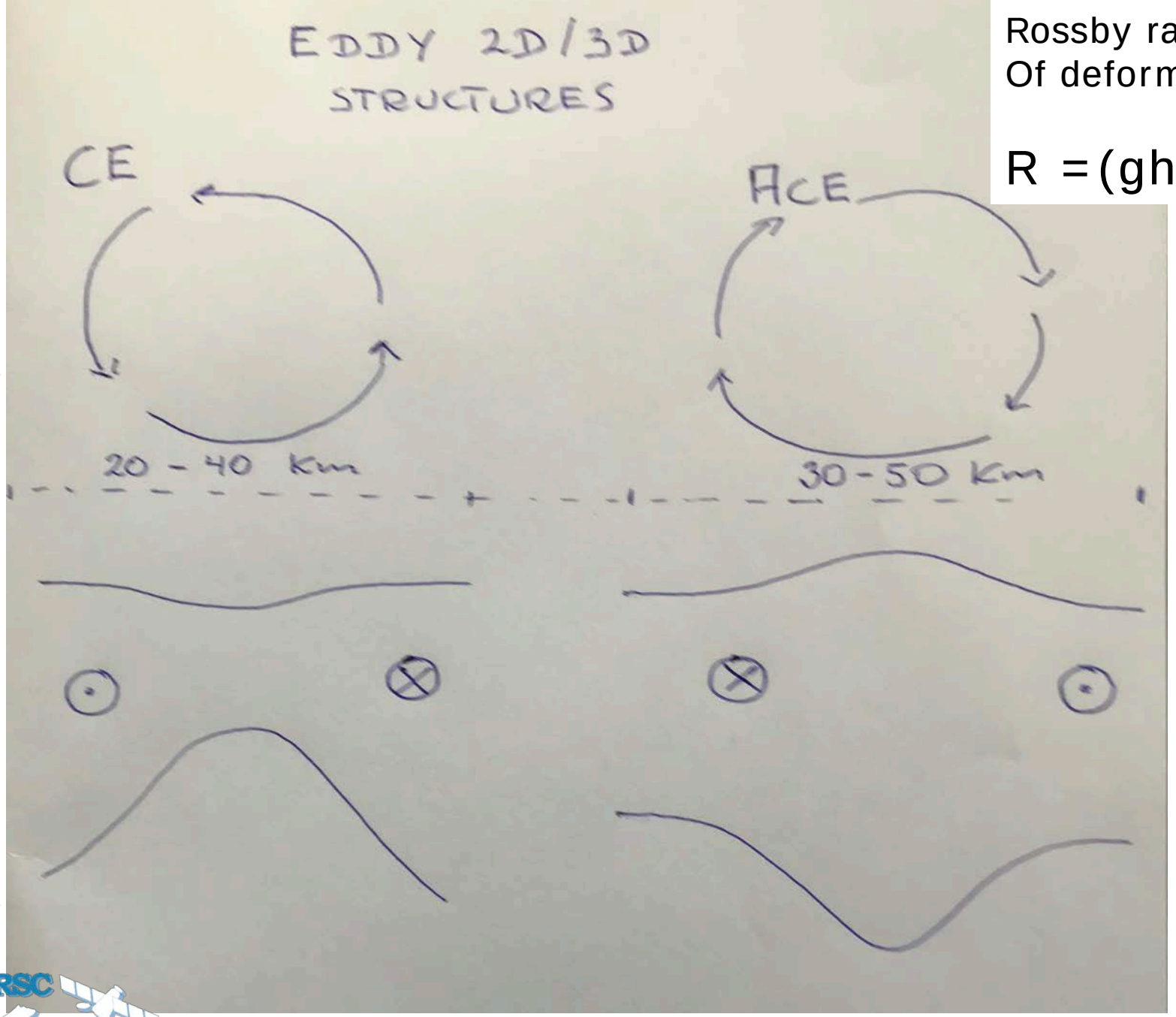
SOLab, RSHU, St. Petersburg, 24-26 November, 2020



Rossby radius
Of deformation

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

Ice edge eddy with diameter of 30-40 km

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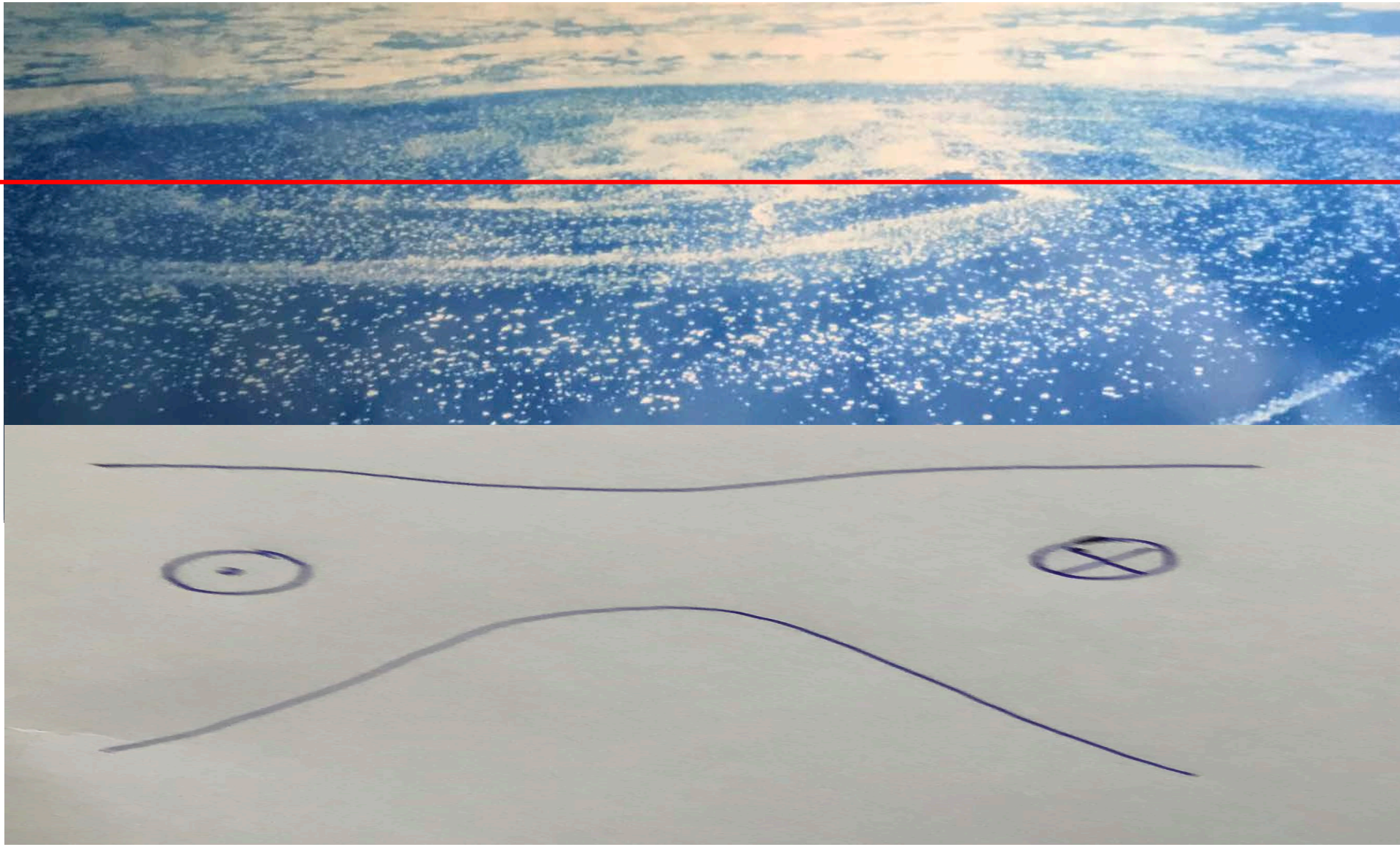
Ice edge eddy with diameter of 30-40 km



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Ice edge eddy with diameter of 30-40 km

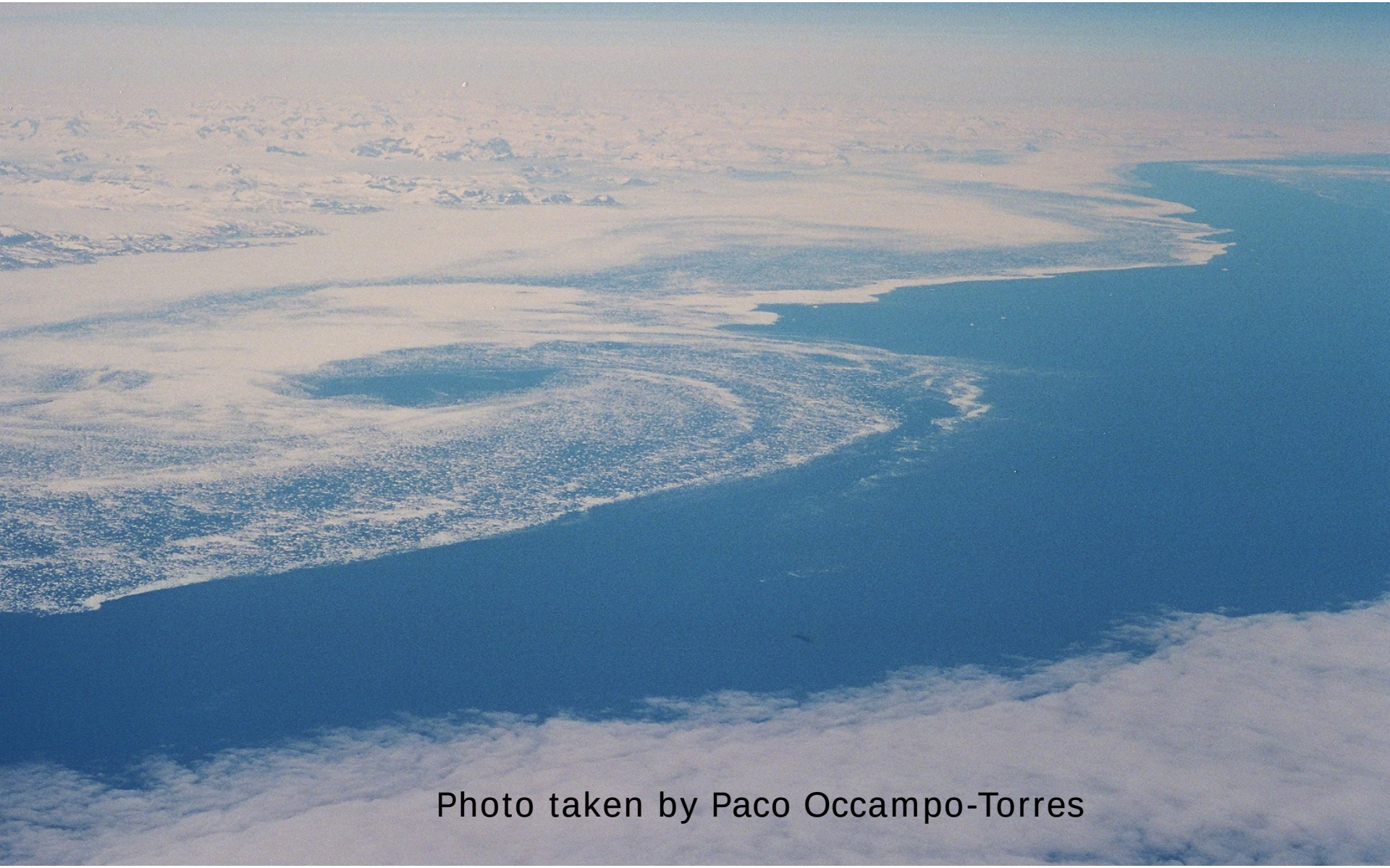

Photo taken by Paco Occampo-Torres

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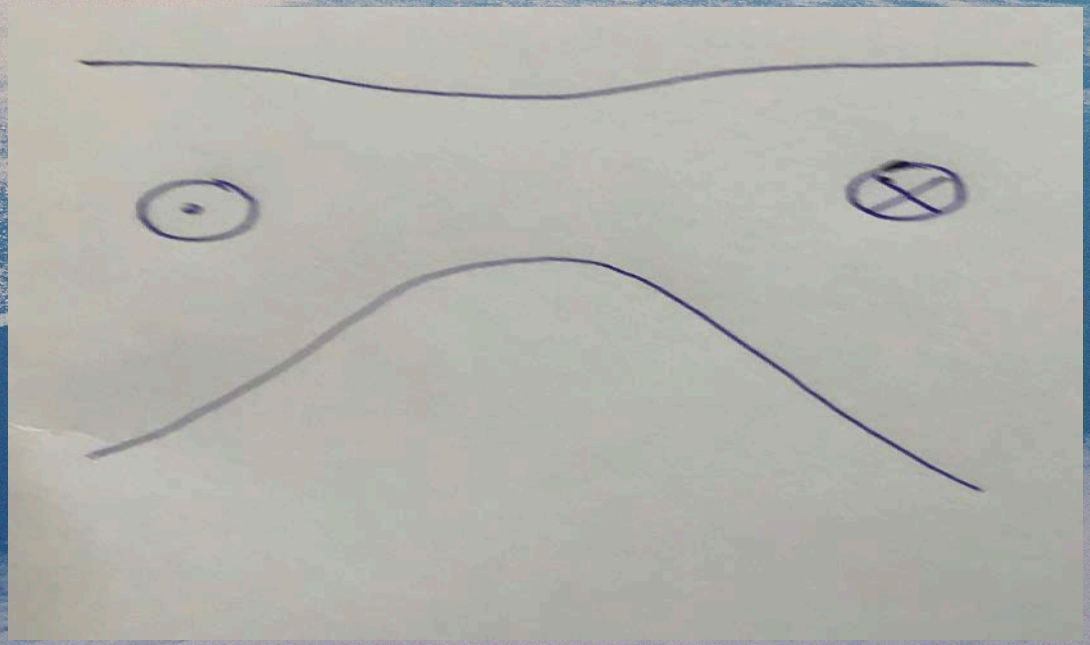
Ice edge eddy with diameter of 30-40 km



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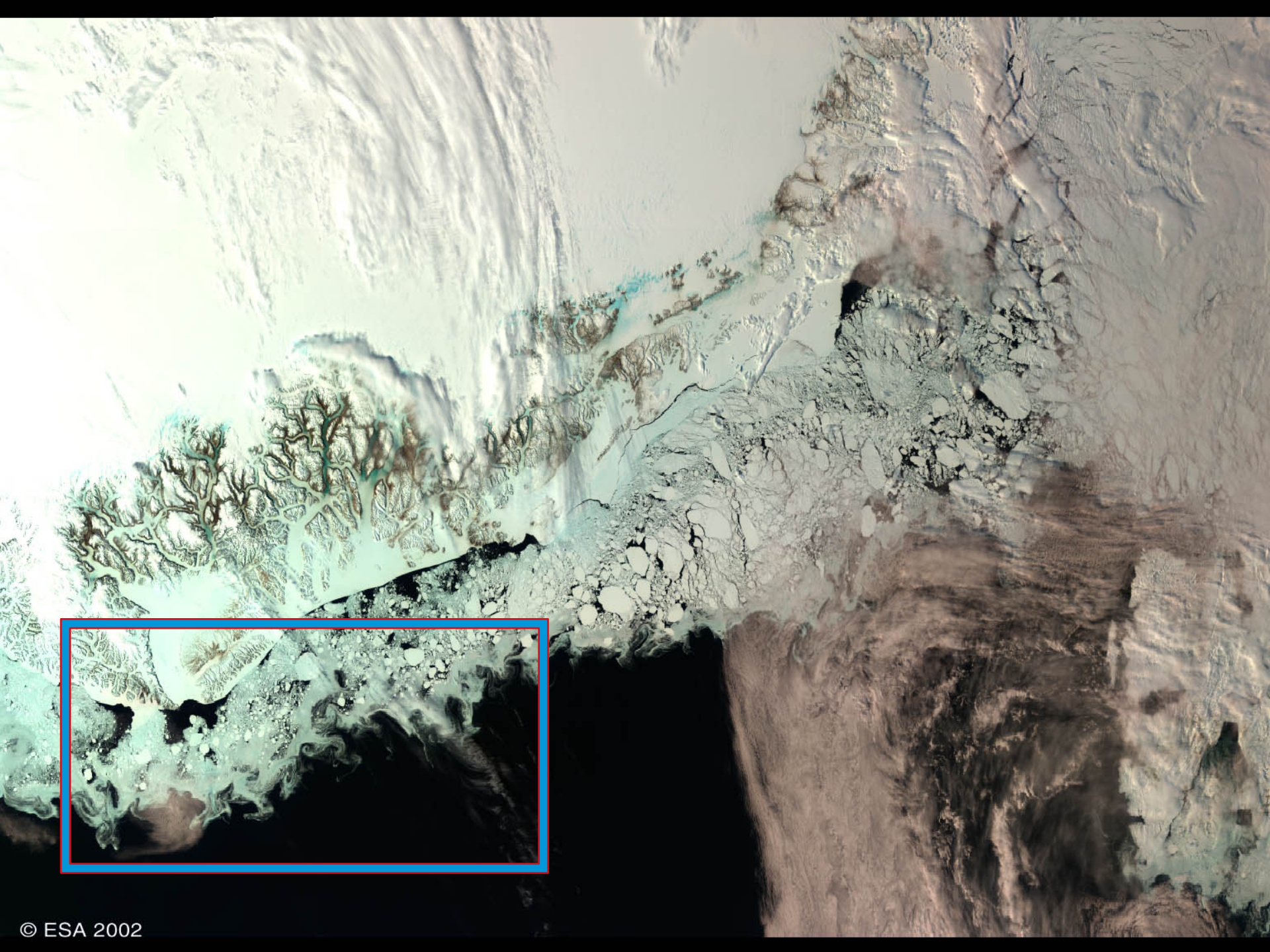
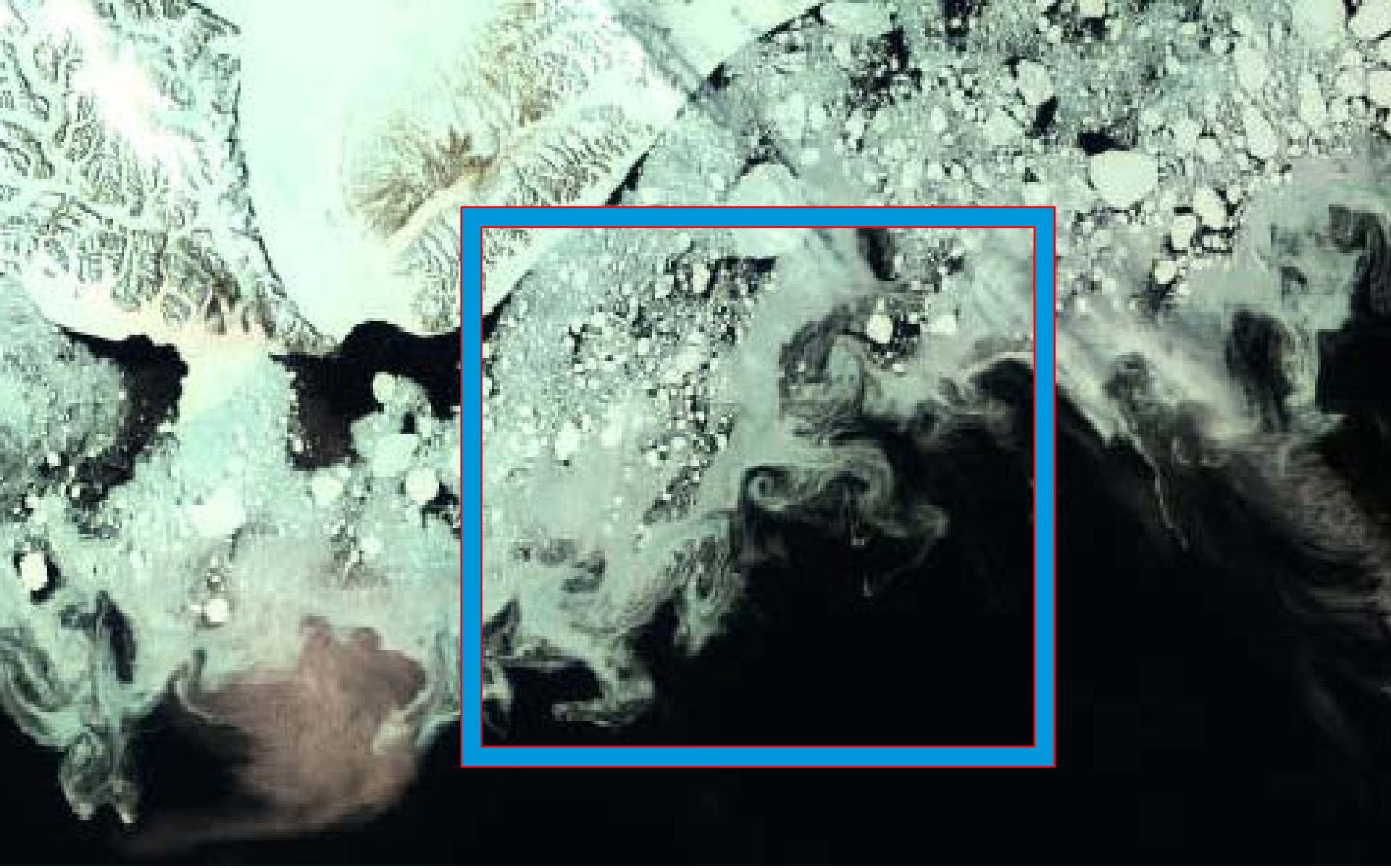
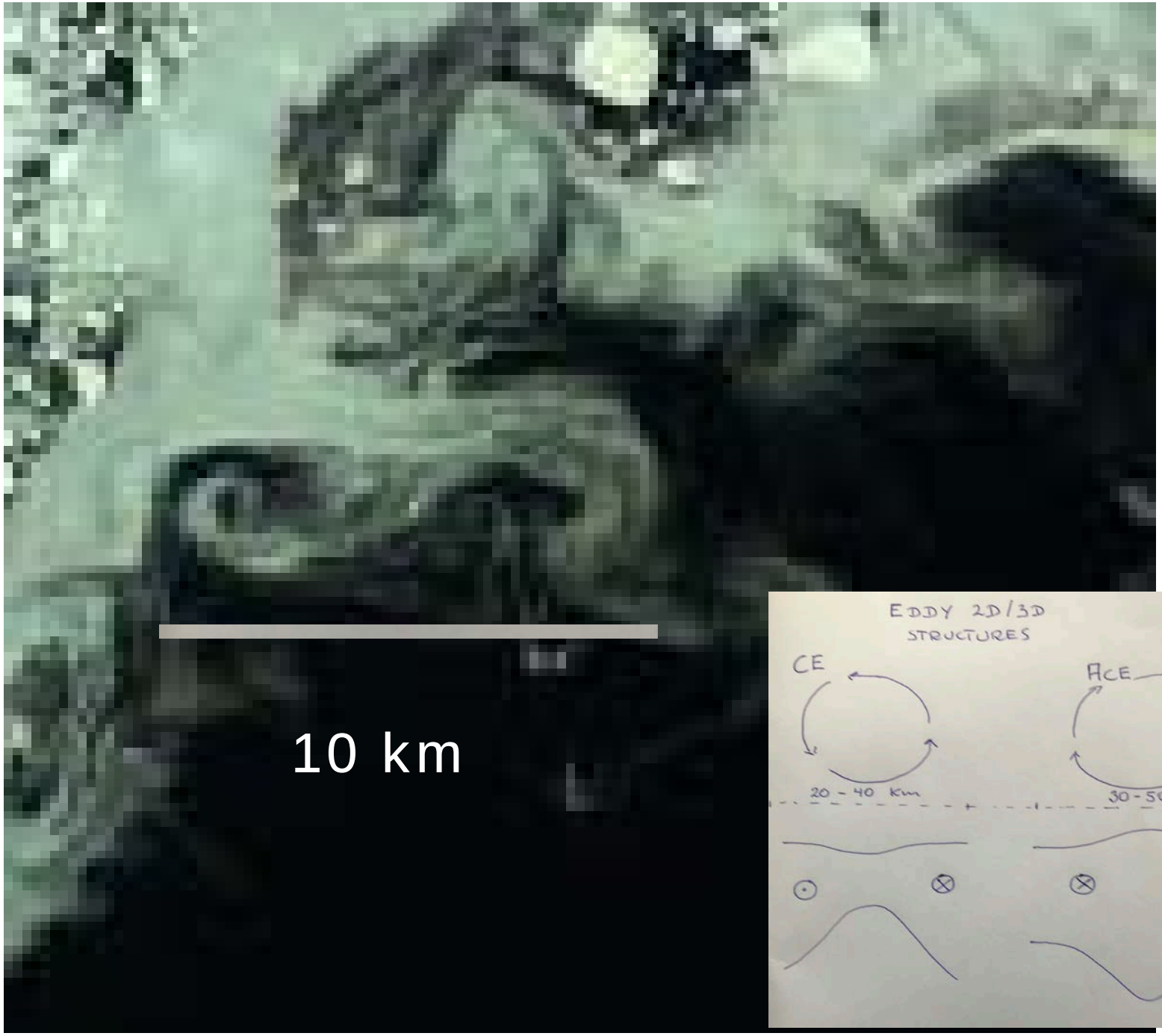
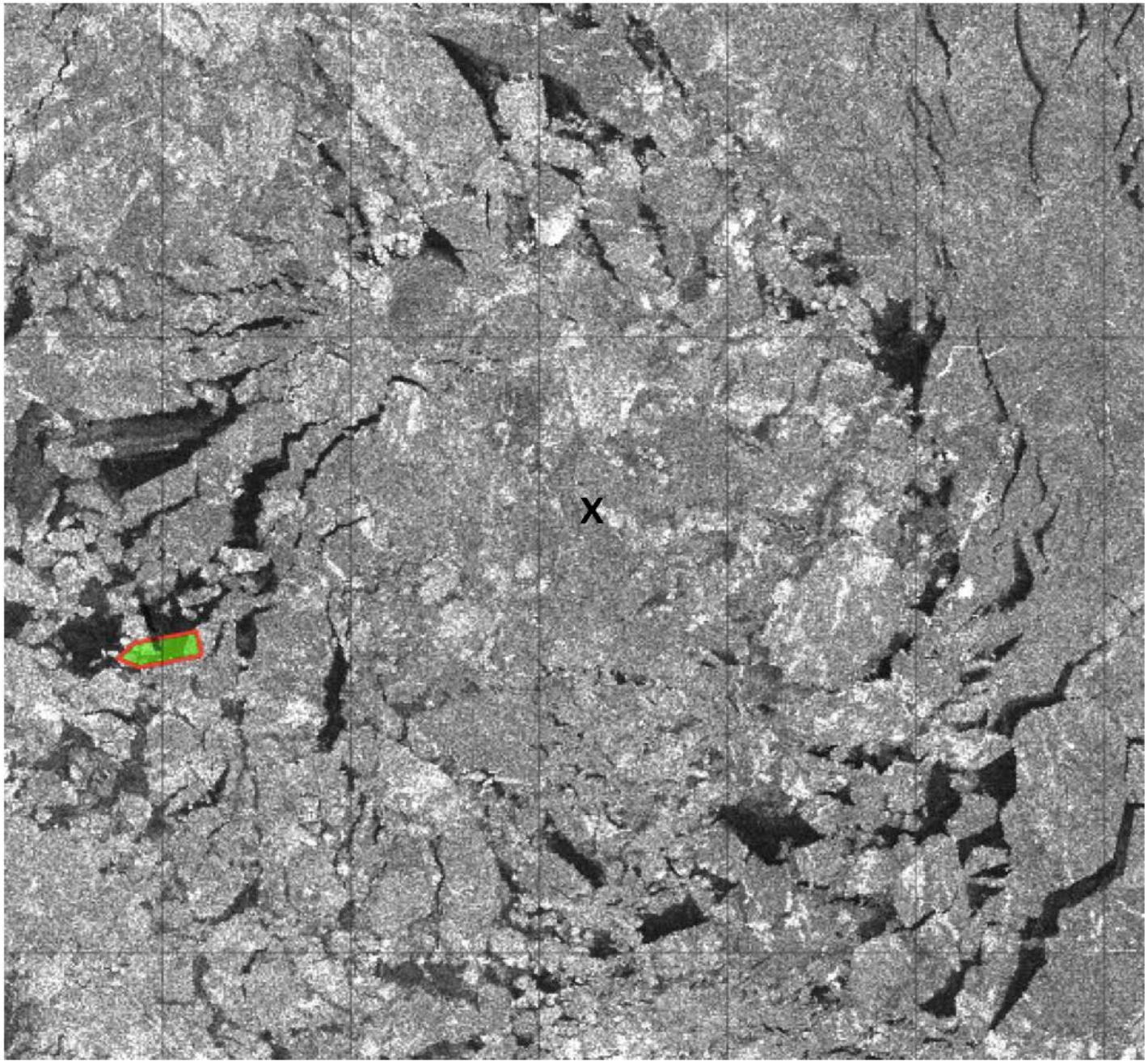





10 km
EDDY 2D/3D
STRUCTURES
CE
ACE
20 - 40 km
30 - 50 km

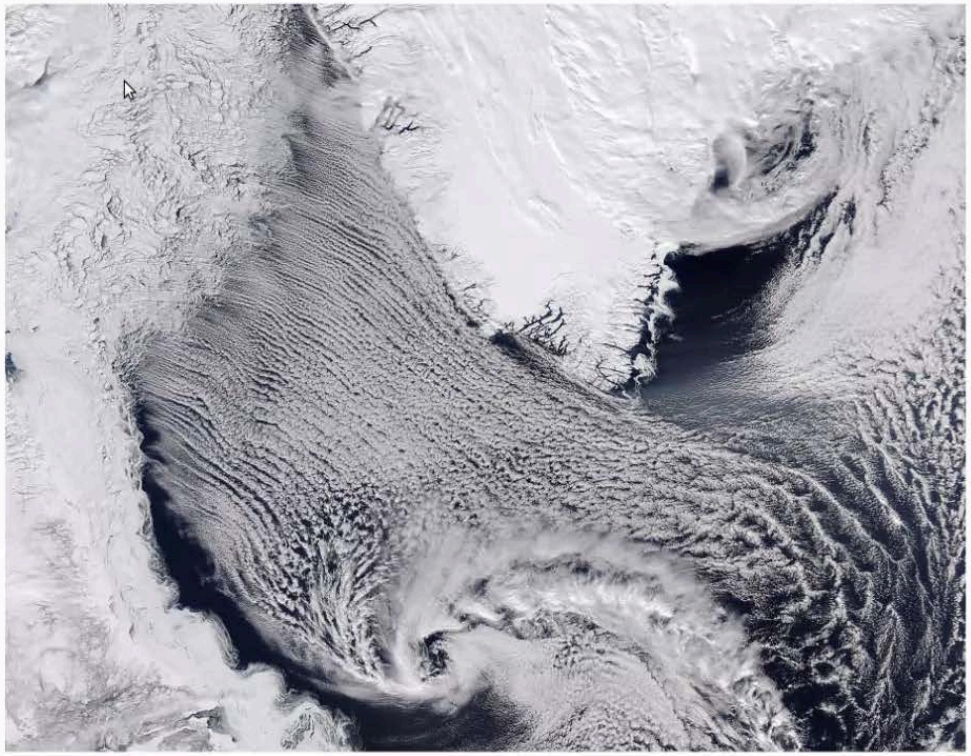


Radarsat-2 SAR image from 30 October 2015

X - marks center of eddy

Courtecy Ben Holt JPL/NASA

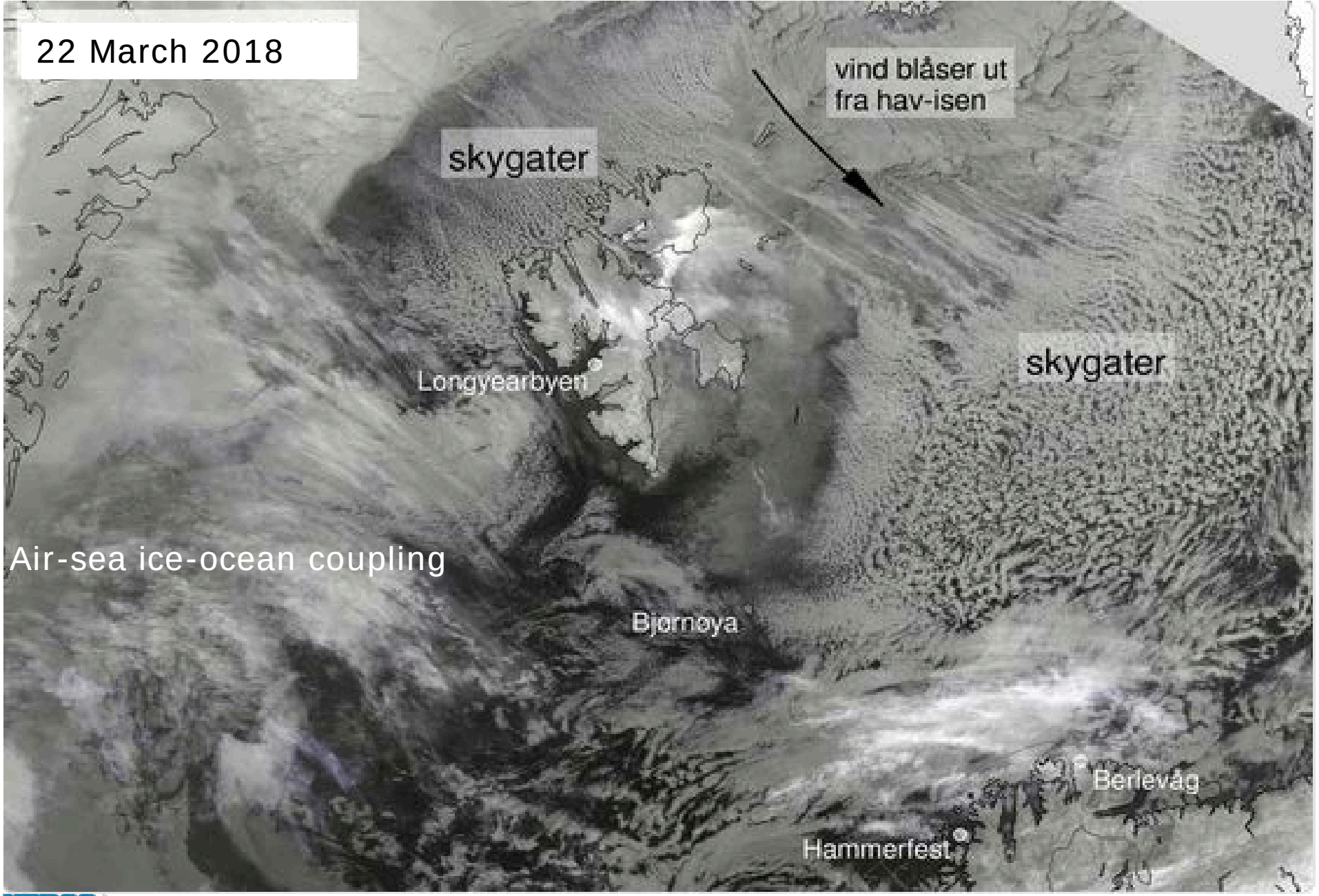
Cold Air Outbreak and Air-sea ice-ocean coupling



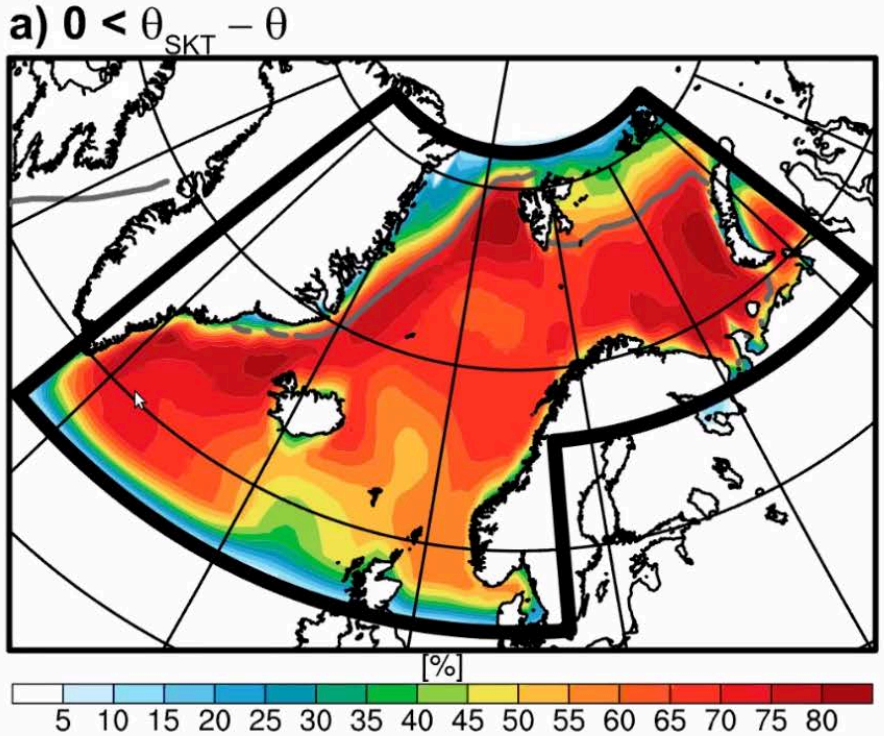
NASA,
https://modis.gsfc.nasa.gov/gallery/individual.php?db_date=2014-04-06

- Intermittent cold surges
- Occur when cold polar air is discharged over comparatively warm water
- Associated with large turbulent heat fluxes
- Strength defined by sea–air temperature difference

Papritz and Spengler (2017)


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

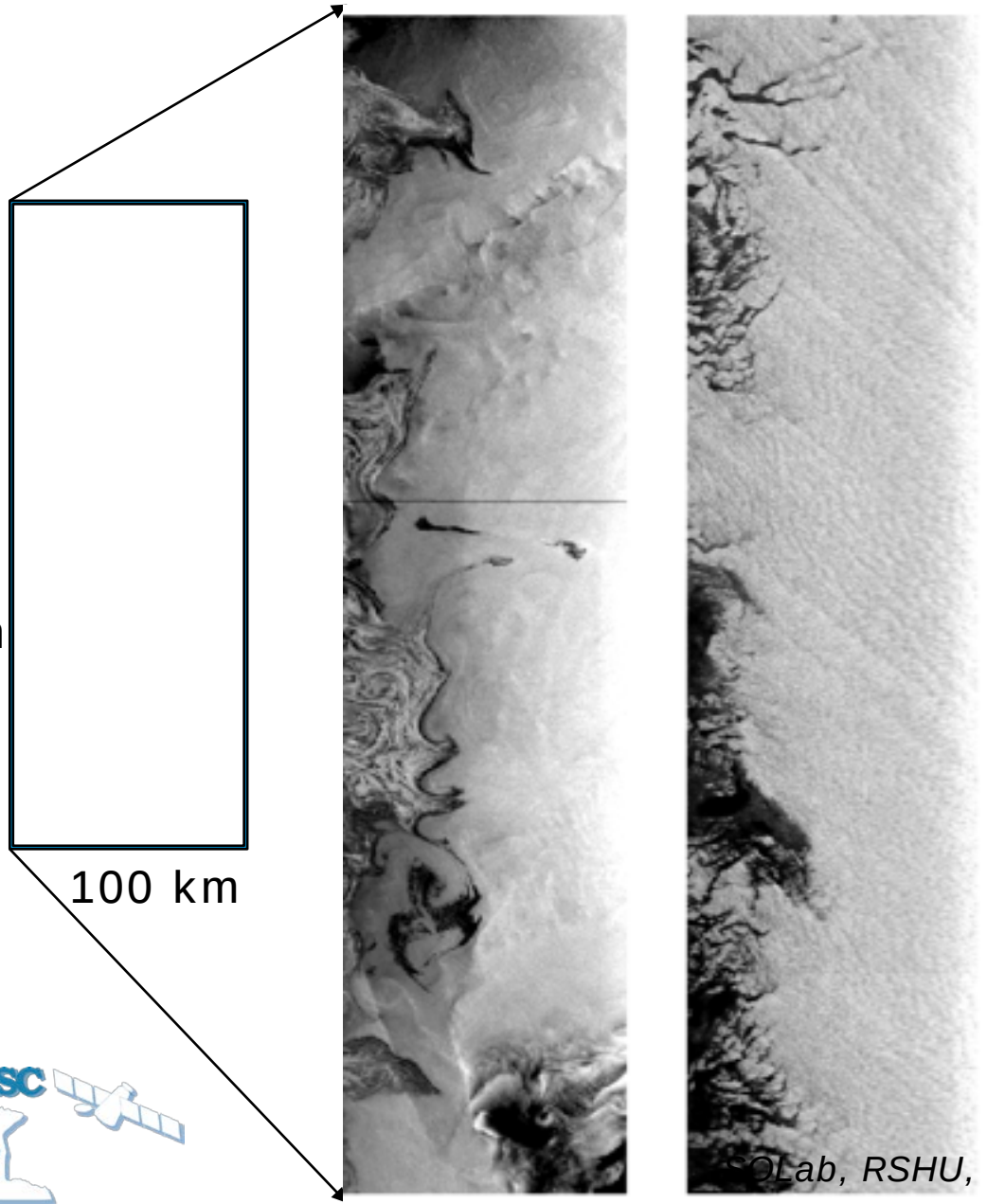
Cold Air Outbreak and Turbulent heat flux



Papritz and Spengler (2017)

- Strongest CAOs found near the ice edge
- CAOs near the ice edge account for up to 80% of the wintertime oceanic heat loss
  $\rightarrow$ CAOs play a key role in the formation of dense waters

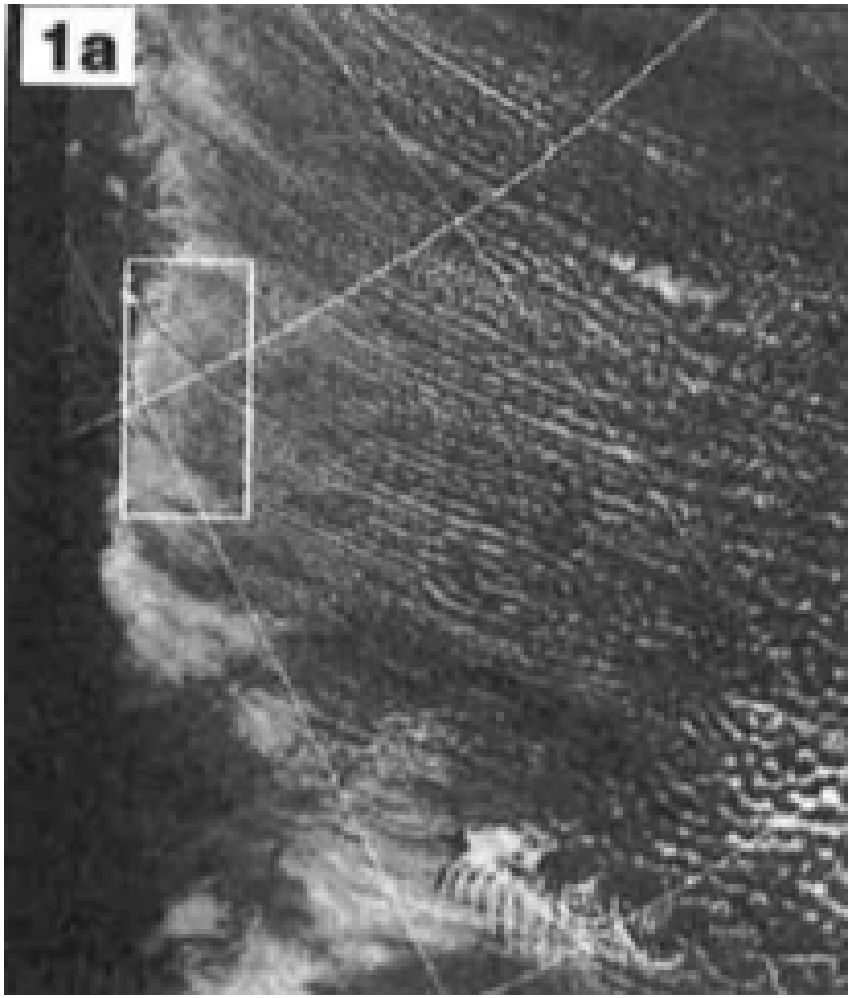
Structural changes in the MIZ – 3 days interval

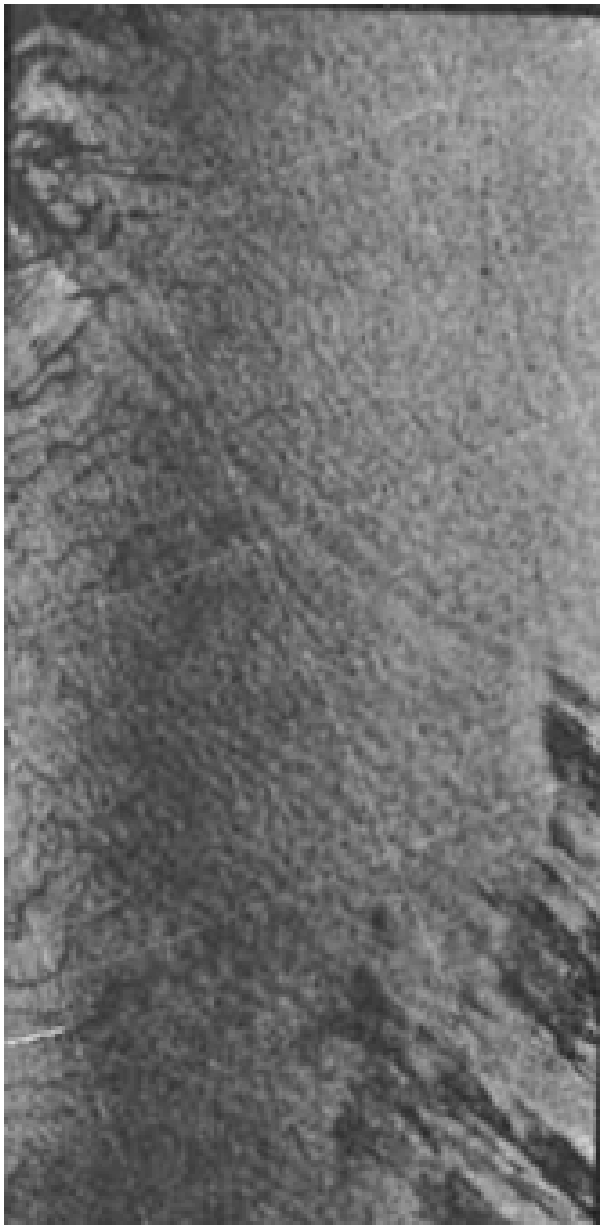


ERS-1 SAR image of a 500 km area along the MIZ in the Greenland Sea from 13 January 1992.

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

Wind streaks in cloud structures and SAR roughness





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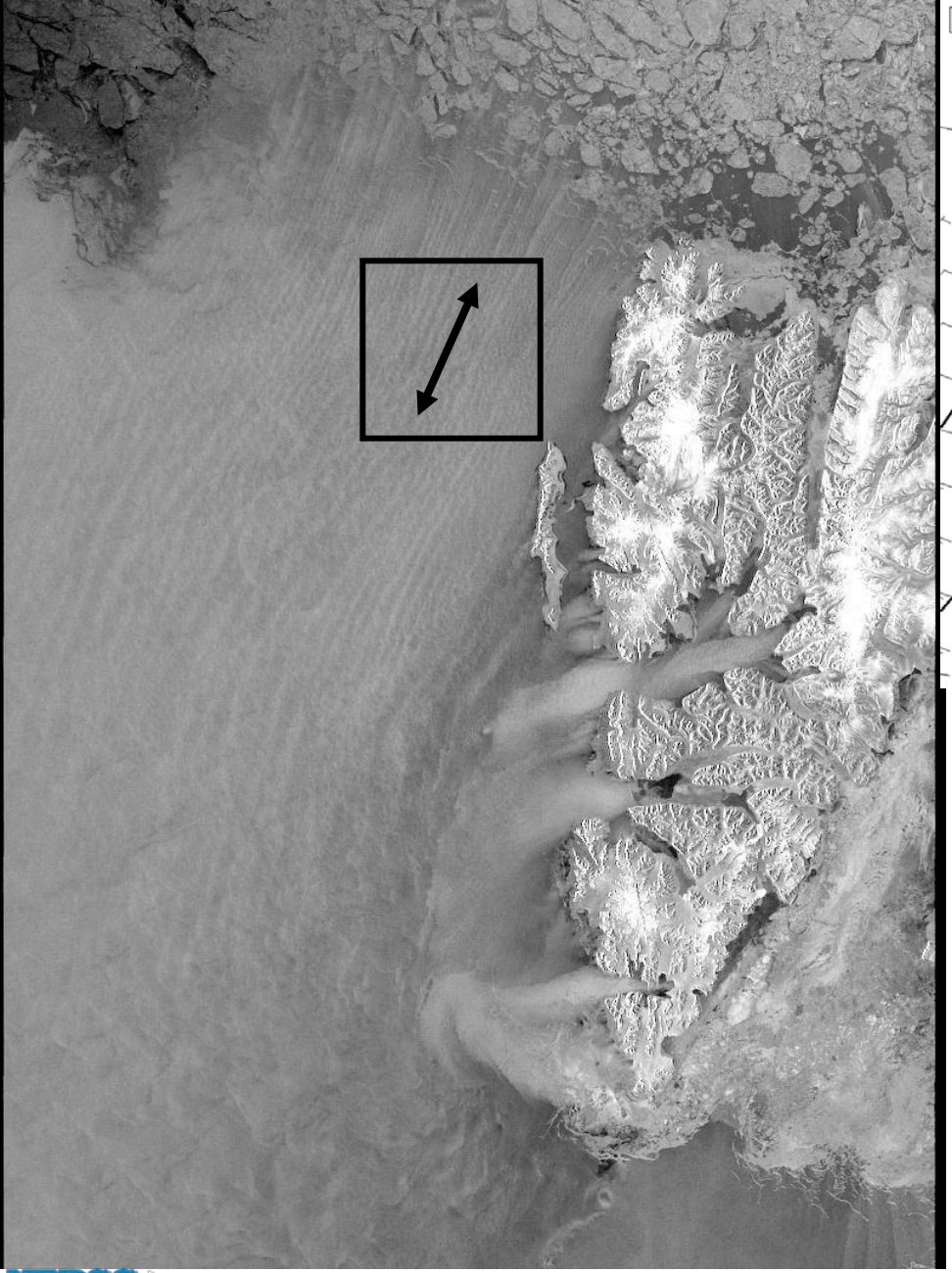

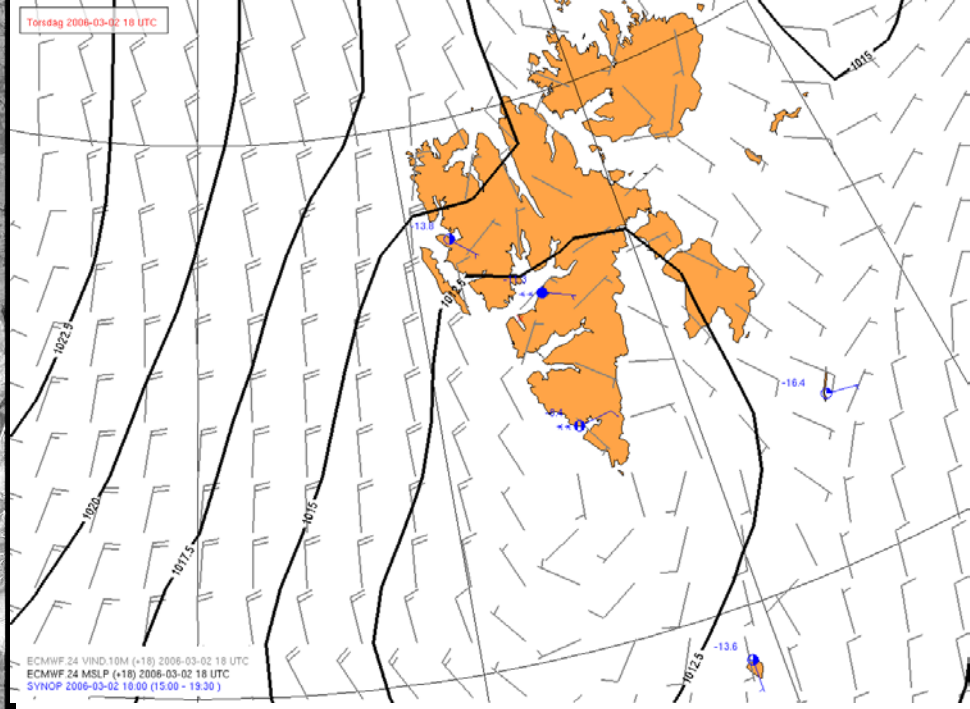

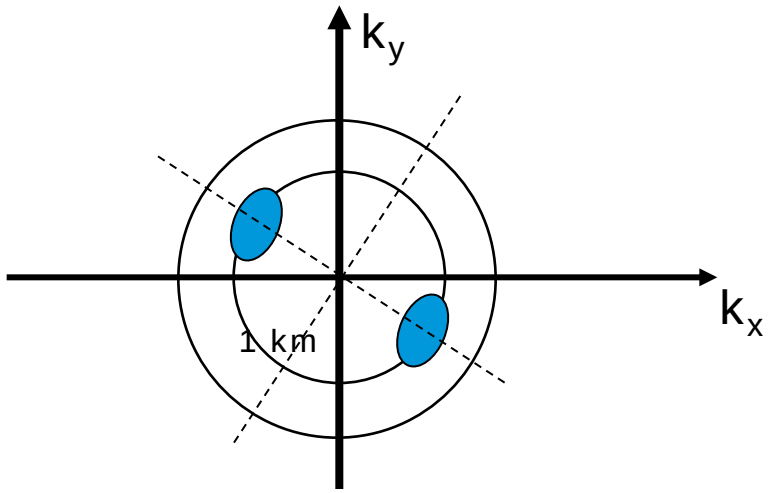

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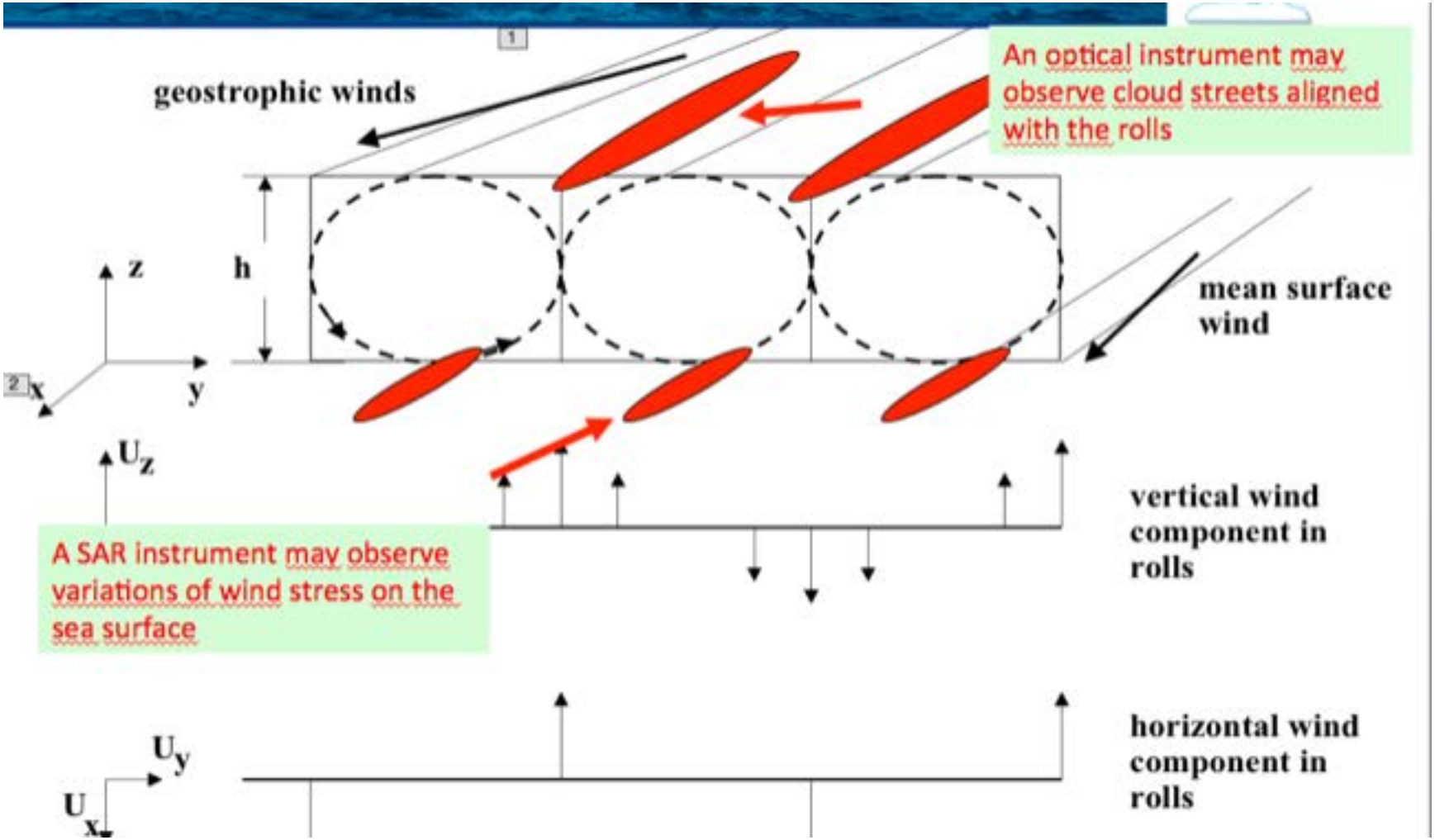
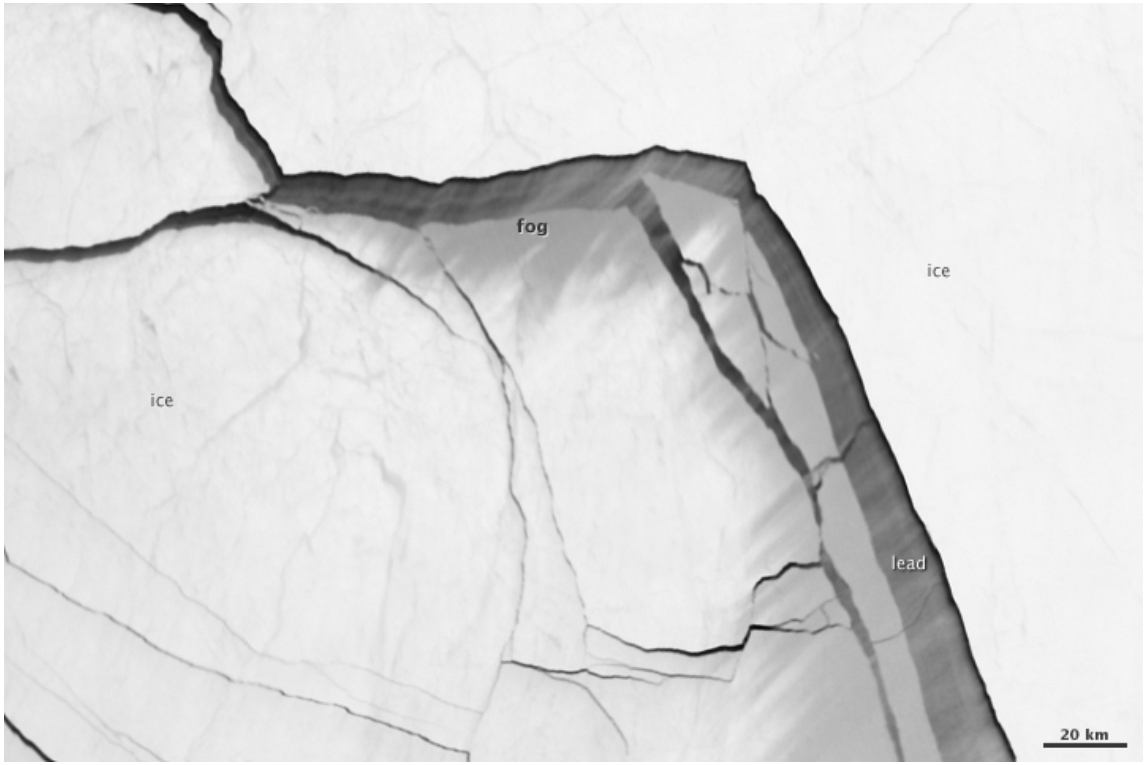
3 March 2006 - ASAR

Wind streaks and cloud structures



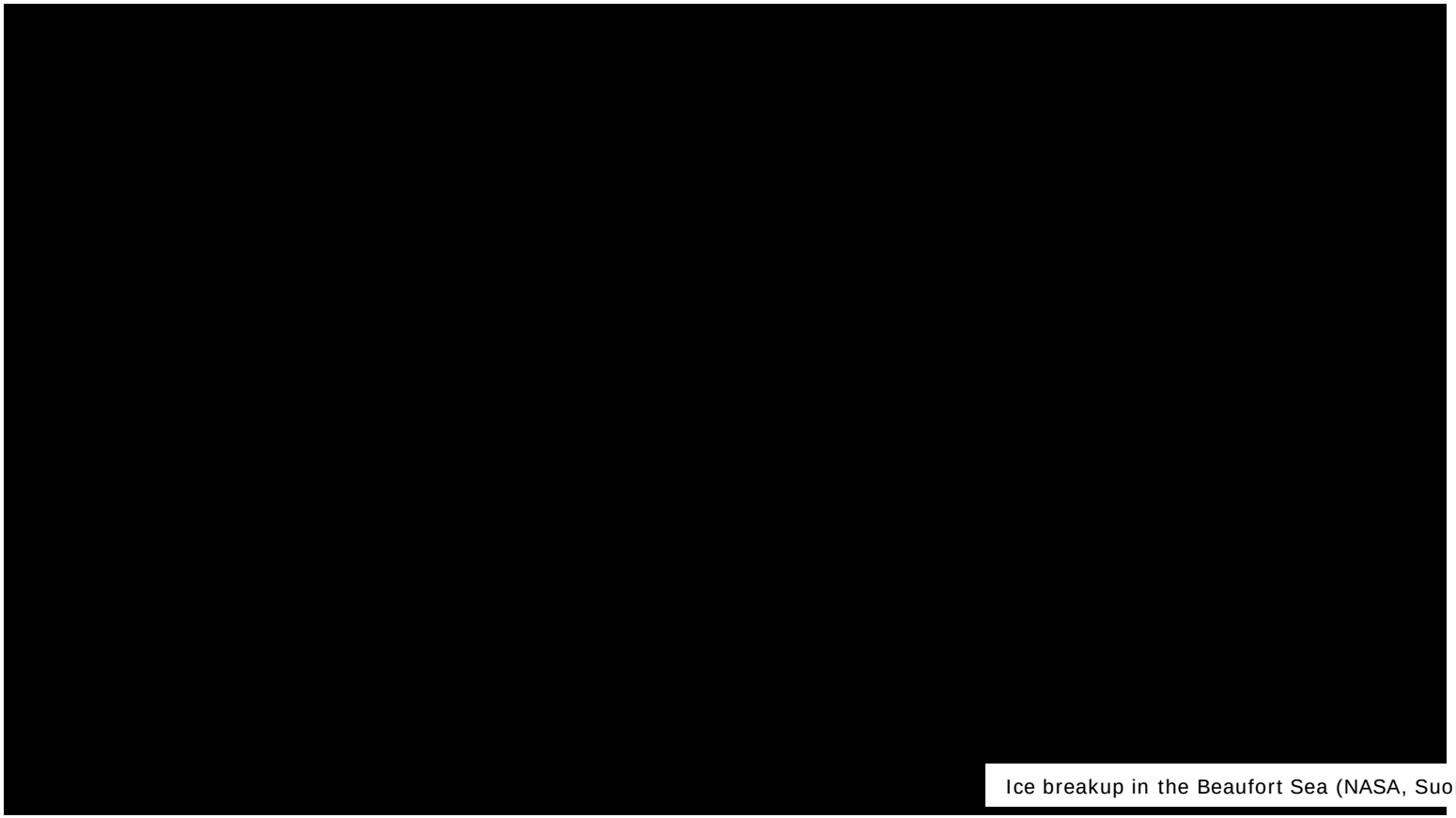
Broken sea ice greatly increases ocean-atmosphere exchanges in the Arctic

1. Broken ice allows increased:
   - Heat fluxes
   - Gas fluxes
   - Momentum transfer
   - Moisture transfer
   - Dense water formation
   - Mixing in the ocean



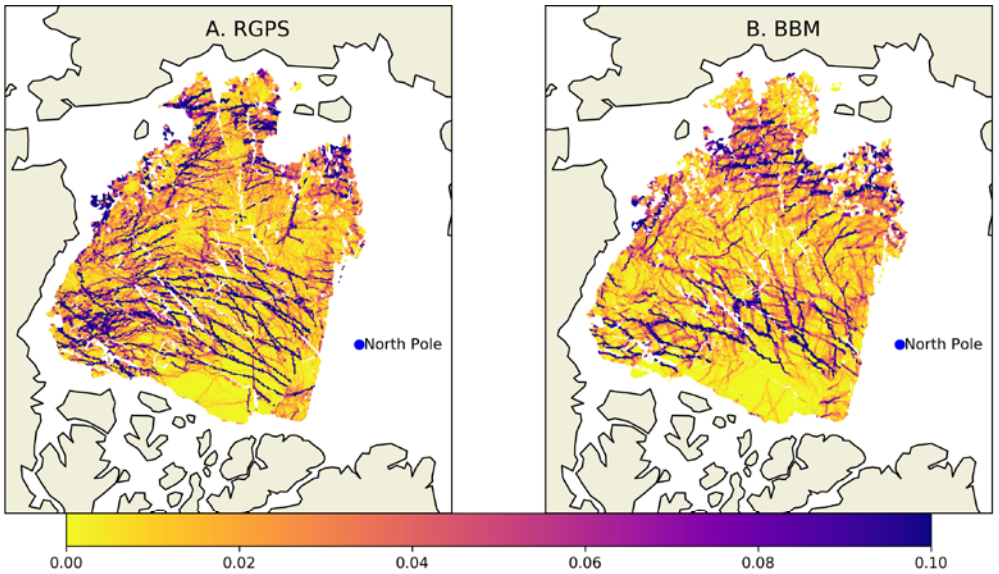
Ice breakup in the Beaufort Sea
(NASA, Suomi NPP, VIIRS)

Ice breakup in February - March 2013 - observed

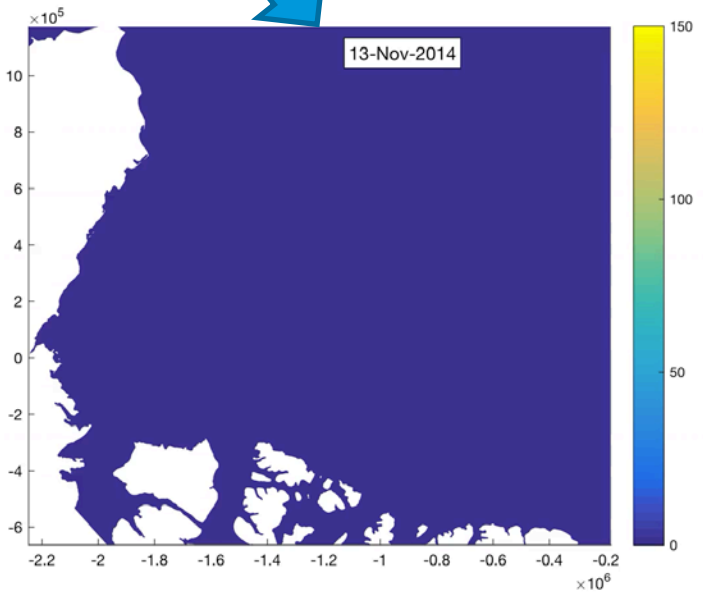


Ice breakup in the Beaufort Sea (NASA, Suomi NPP, VIIRS)

We need advanced ice physics to capture the heterogeneity of the ice cover



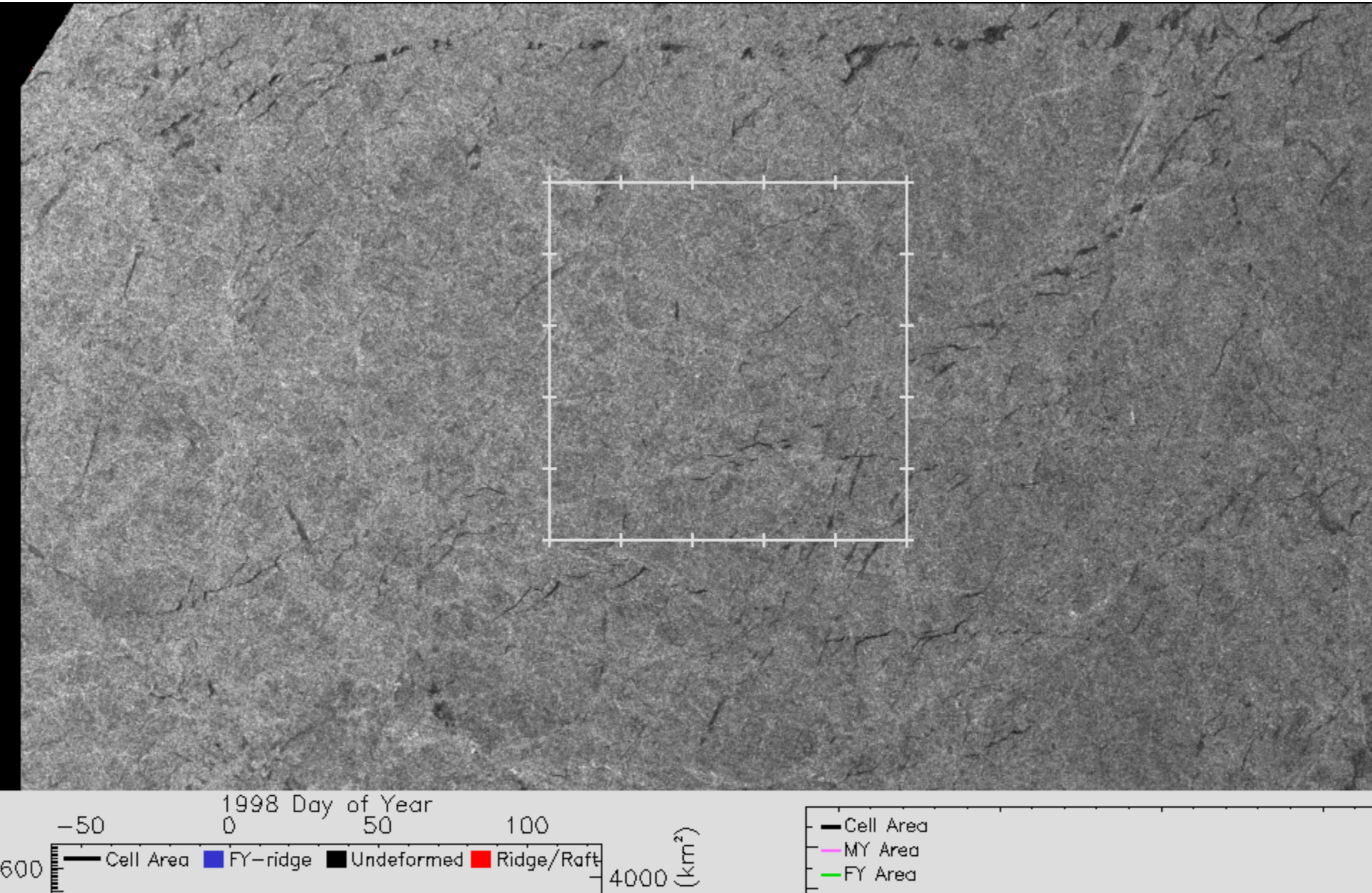
and its impact



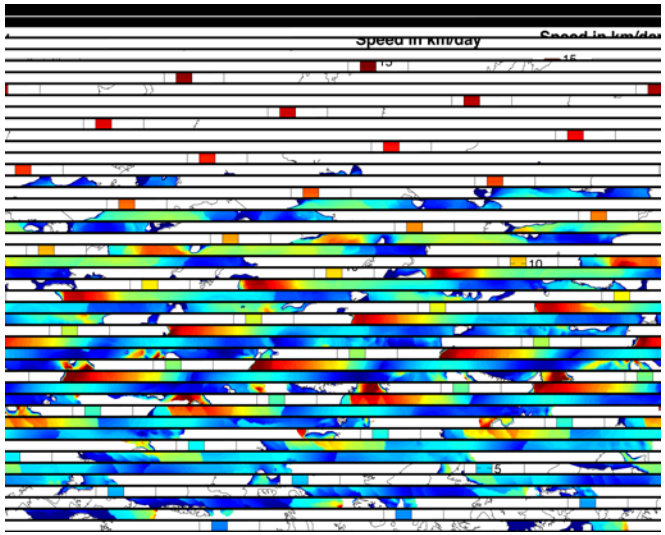
We have developed neXtSIM for this purpose

Heat fluxes from ocean to atmosphere

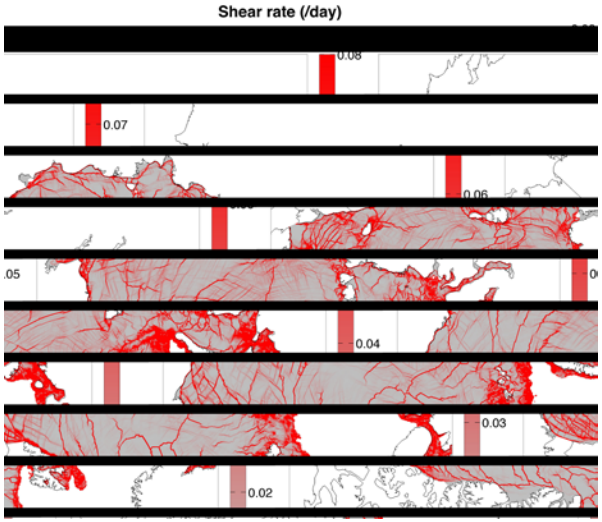
Courtecy Ron Kwok



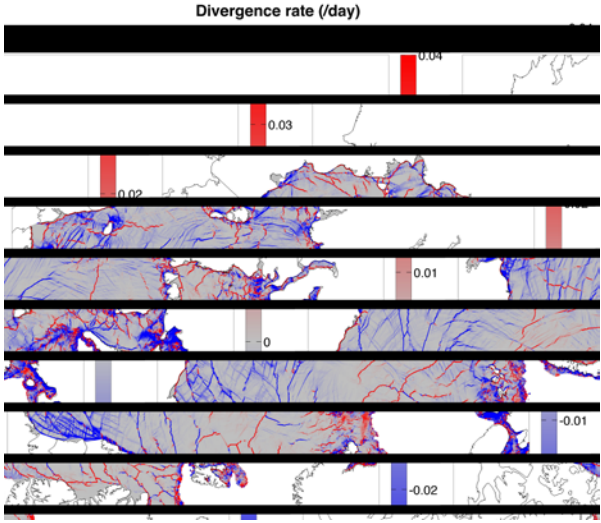
Speed, shear and divergence
&
Sea ice damage



Ice speed



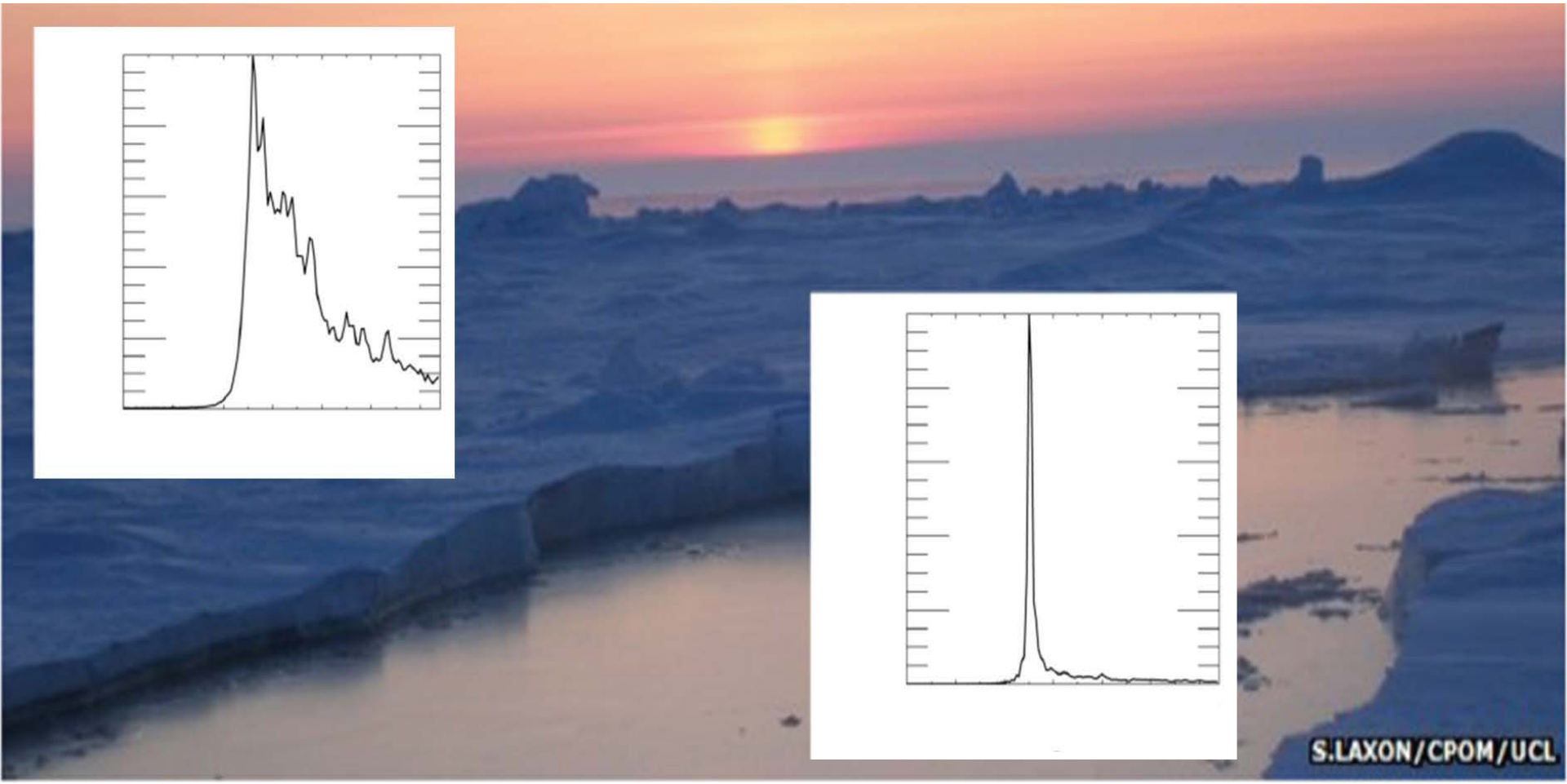
Ice shearing rate



Ice divergence rate

Courtecy P. Rampal

Freeboard height estimation from Altimetry



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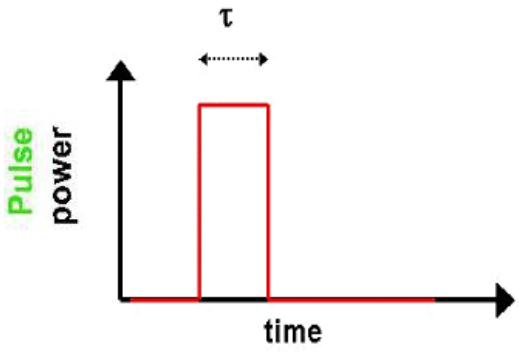
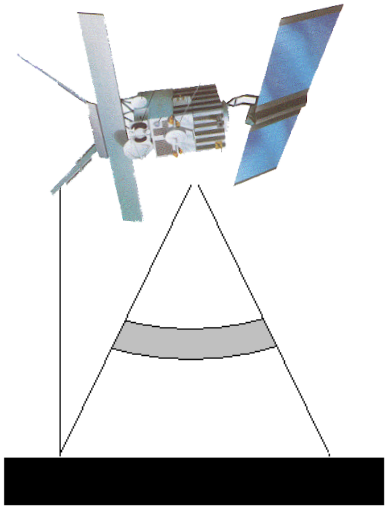
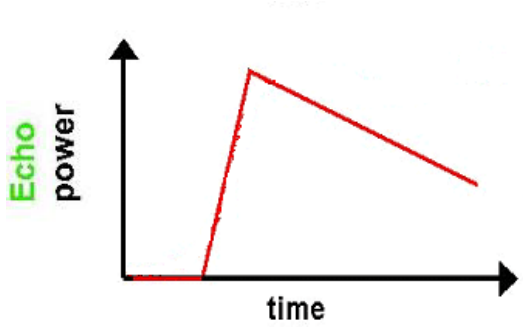
Satellite radar altimetry

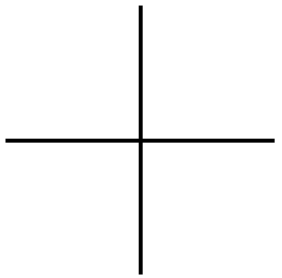
- Radar transmits known pulse
- Echo is distorted as spherical wave-front intercepts surface
- Travel time is calculated by comparing common points on pulse & echo





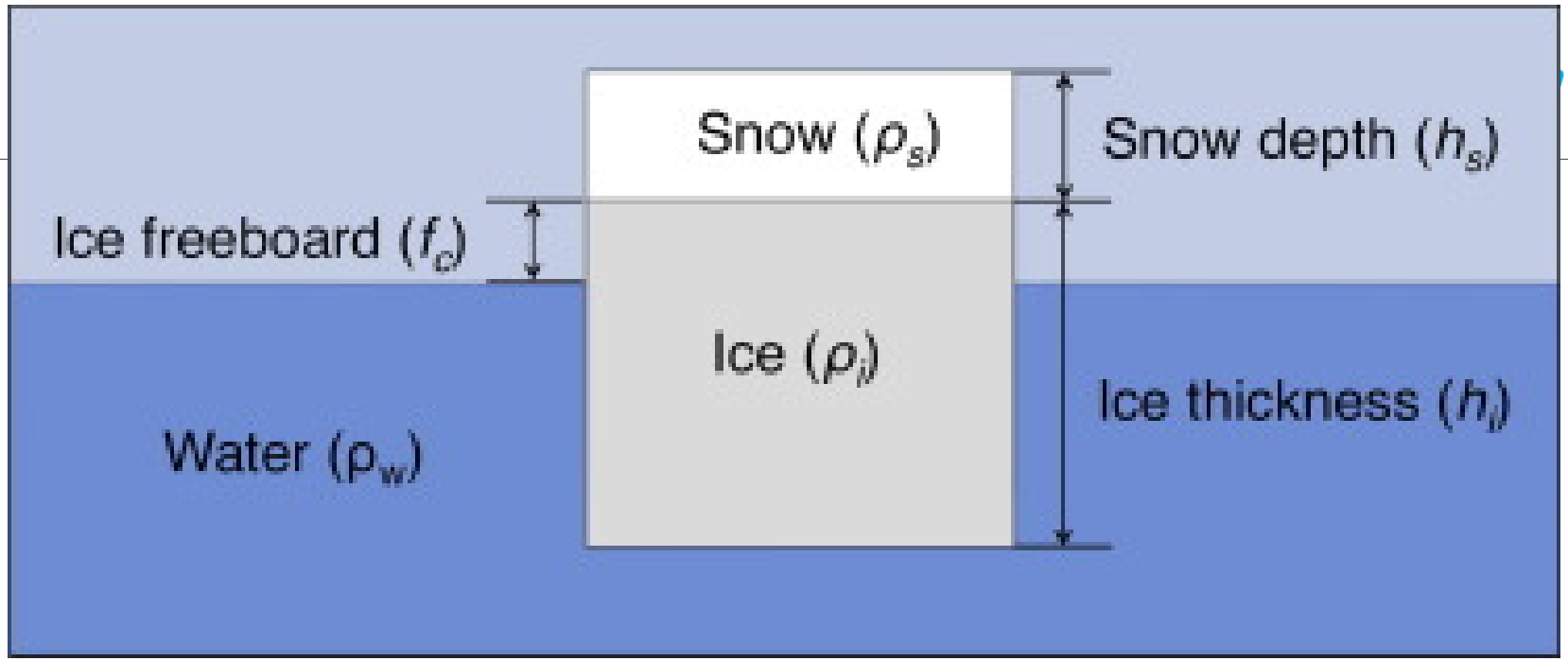
Side view





Plan view

Range = ½ c * 2-way Travel time

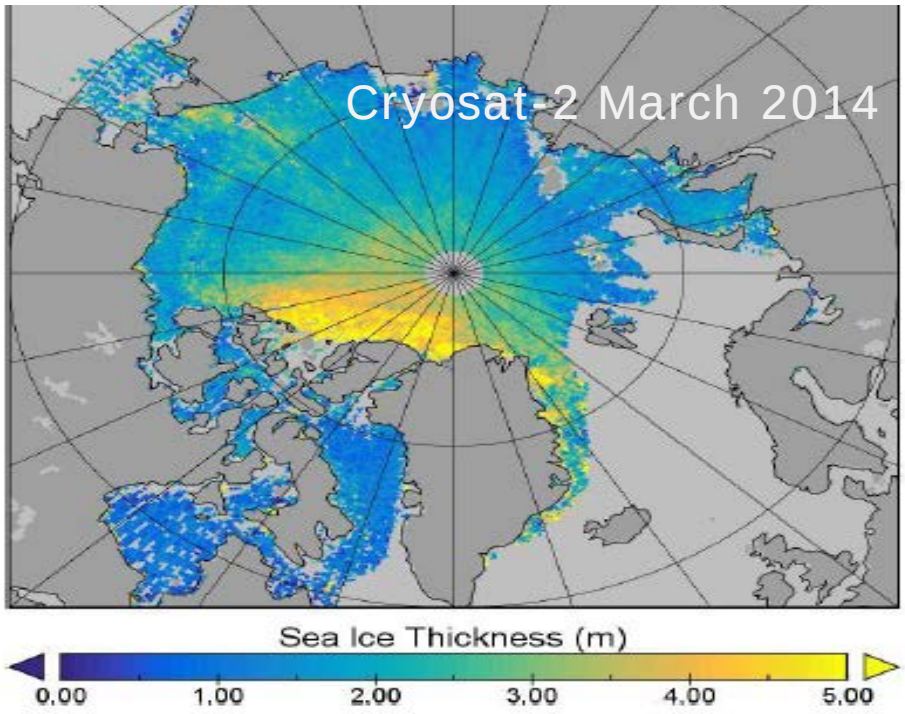


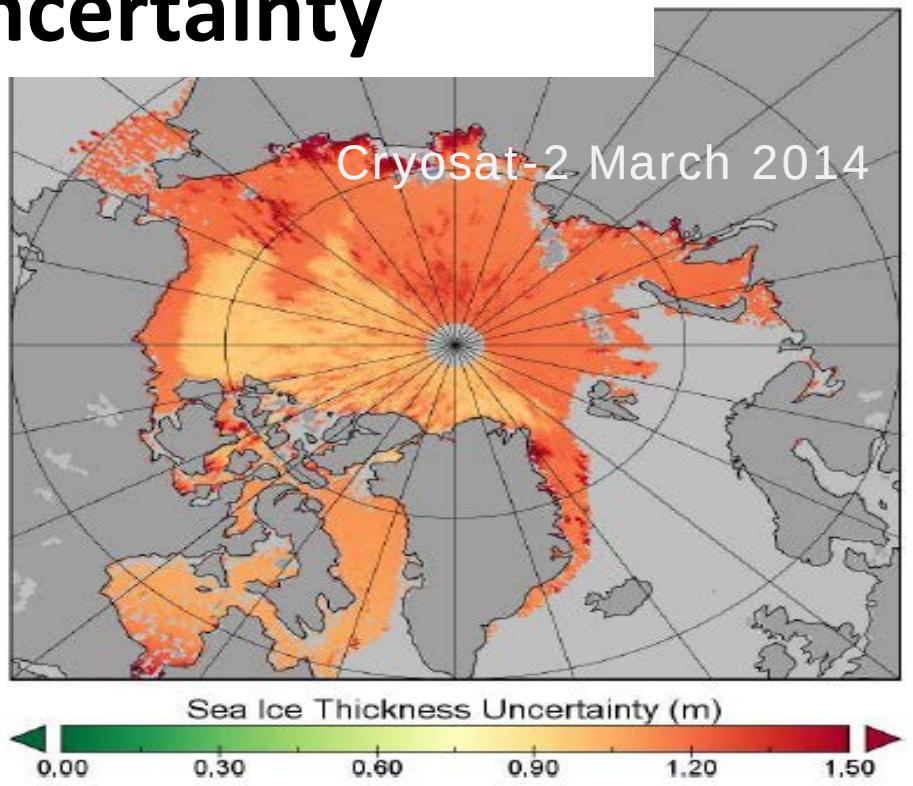
$$f_c = f_i + h_s\left(\frac{c_v}{c_s} - 1\right)$$

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

$f_{c \text{ and }} f_i$ 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

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

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

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

Key present and future (not all approved) satellites fordetection and monitoirng of MIZ processes

Type of process	Dominant forcing	Satellite sensing
Upwelling	Wind driven shear in the Ekman current	Sentinel-1, Radarsat-2, Scatterometer, CFOSAT, + optical HARMONY, CRISTAL, CMIR, SWOT*, SKIM-Light, SWIM NISAR ROSE-L
Mesoscale eddies	Current shear & frontal instabilities in the upper ocean	
Wind streaks	Unstable atmospheric boundary layer	
Wave break-up	Wave propagation in ice	
Internal waves (IW)	Tides, current fronts	
Ice jets, bands, filaments	Upper ocean	