Lecture: Polar Oceans and Climate Change from Space

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Dragon 4 Advanced Training Course in Ocean & Coastal Remote Sensing
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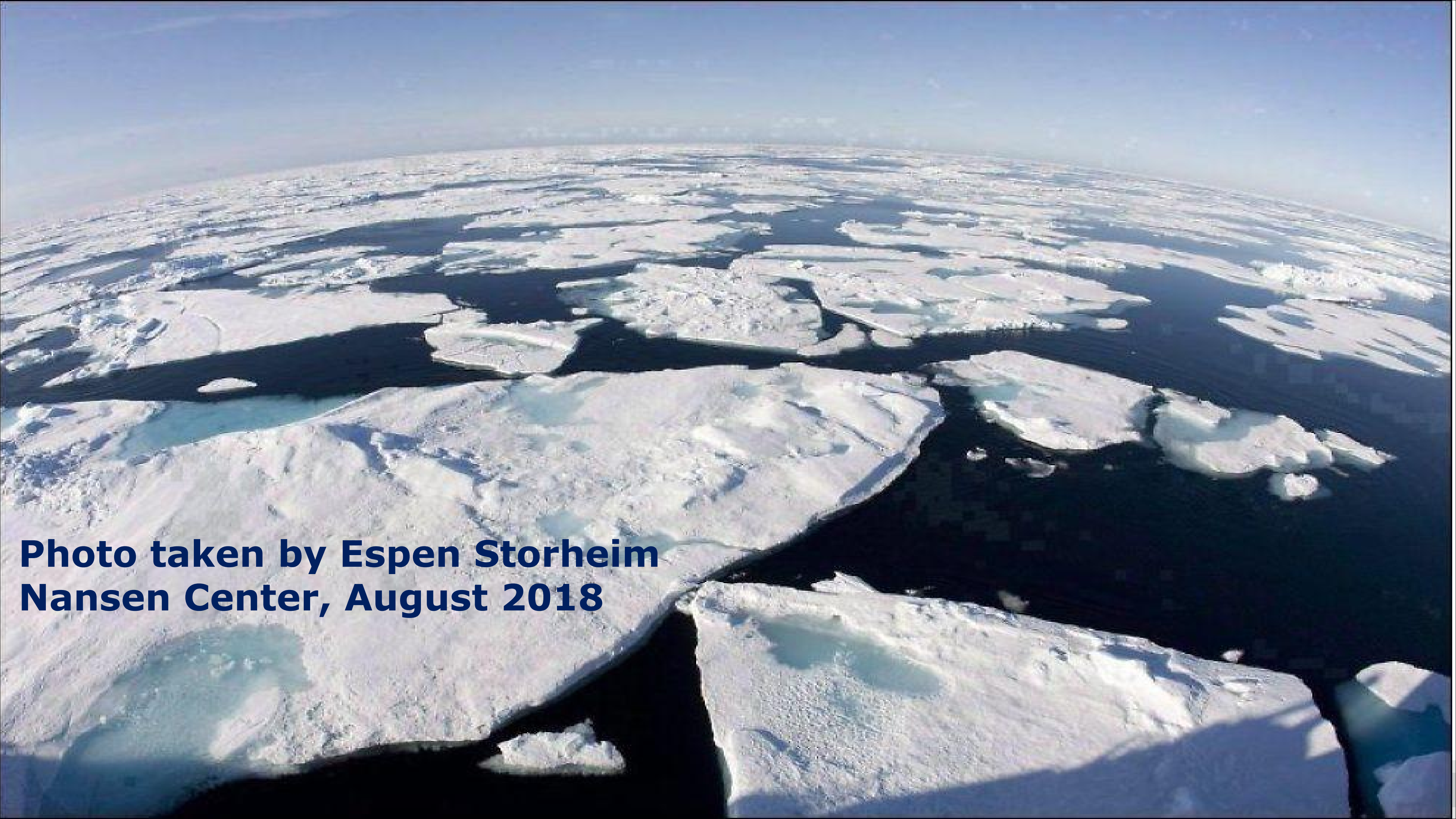
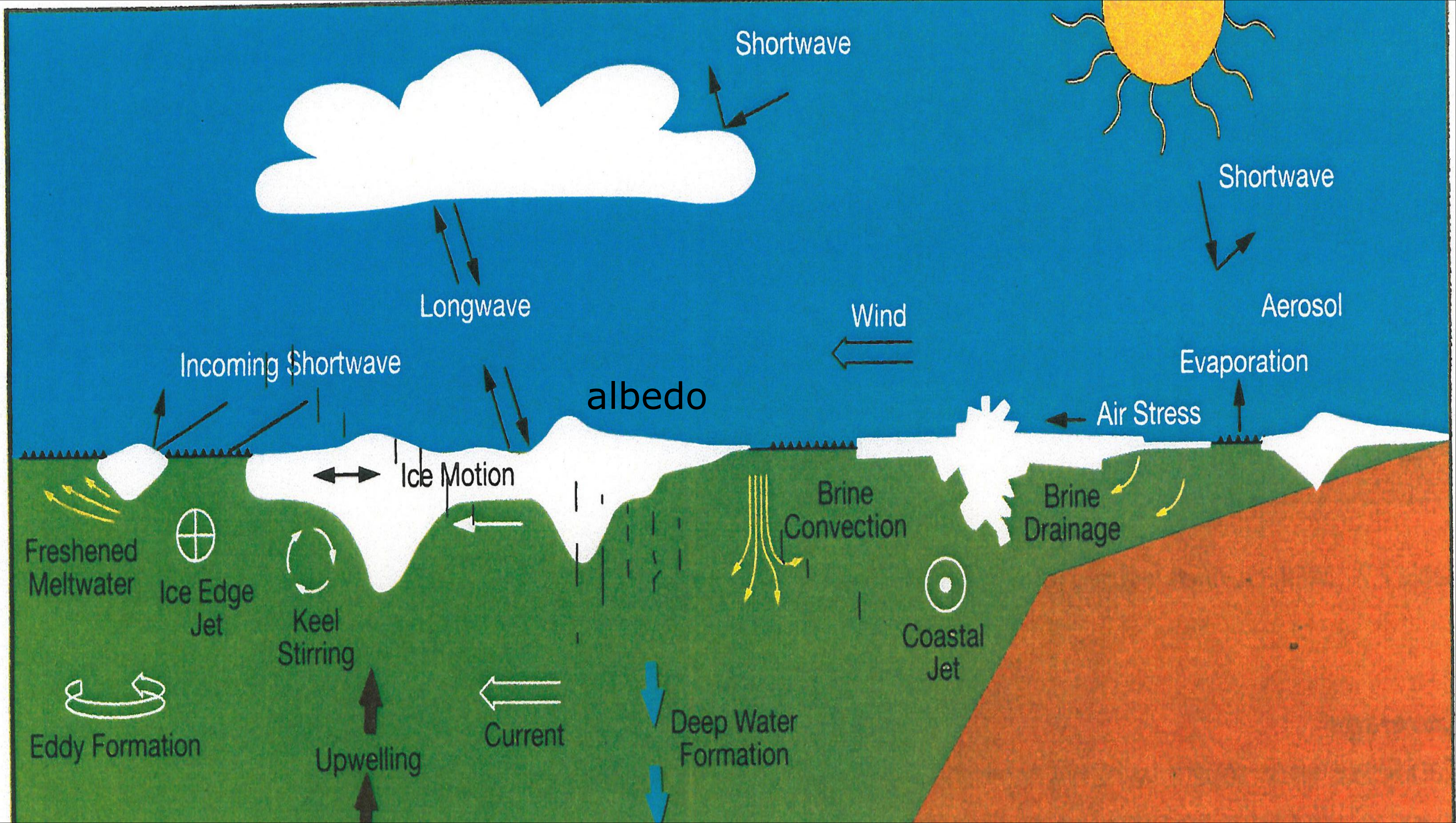


Photo taken by Espen Storheim
Nansen Center, August 2018



Shortwave
Shortwave
Longwave
Wind
Aerosol
Incoming Shortwave
Evaporation
albedo
Air Stress
Ice Motion
Brine Convection
Brine Drainage
Freshened Meltwater
Ice Edge Jet
Keel Stirring
Coastal Jet
Eddy Formation
Current
Deep Water Formation
Upwelling

Earth's Energy Imbalance

Warmer atmosphere

Warmer Earth surface

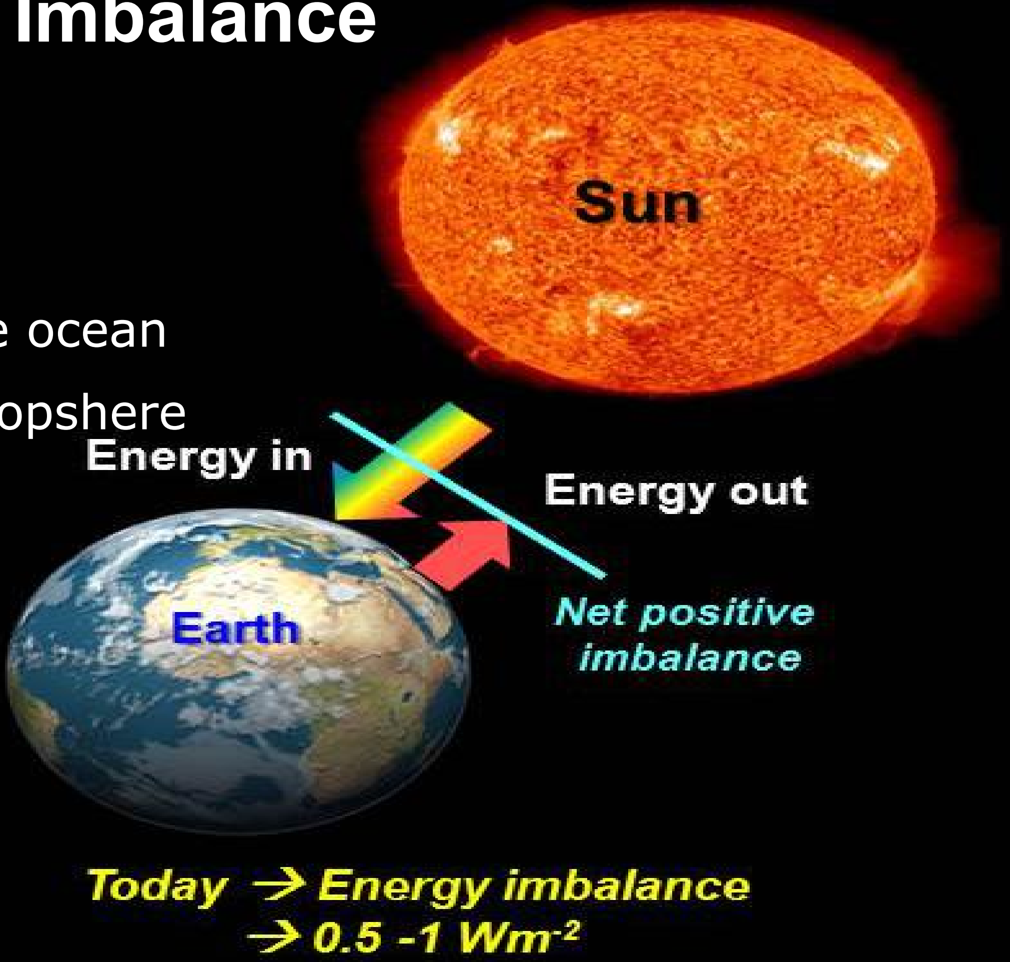
More heat uptake in the ocean

More melting of the cryopshere

Less ice sheet/glaciers

Less sea ice

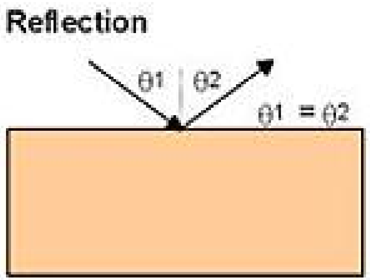
Increased sea level



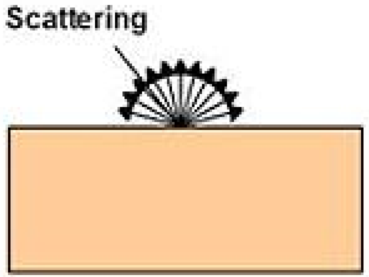
Satellite Observations in the Arctic

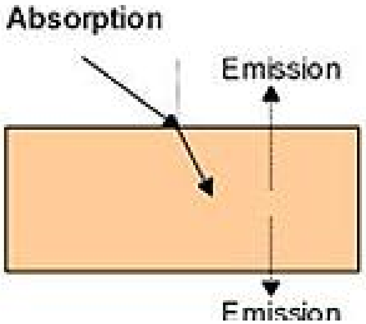
Sea Ice	Concentration, type, area, thickness,age drift, leads, polynias, iceberg, ridges,	Passive microwaves, SAR, Scatterometer, altimeter, optical
Sea level	In open water direct, *in presence of sea ice the freeboard must be removed*	Altimeter
Ice sheet/ glaciers	Elevation change, retreat, surging, mass change	Altimeter, SAR, Interferometry, 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 this ice detection*
Surface Current	Geostrophic current, Ekman current, Stokes drift,	Altimeter, SAR, scatterometer
Snow cover	Extent, *thickness, Snow-water equivalent*	SAR, altimeter, scatterometer

Remote Sensing Principles



Visible imaging & Passive Microwaves



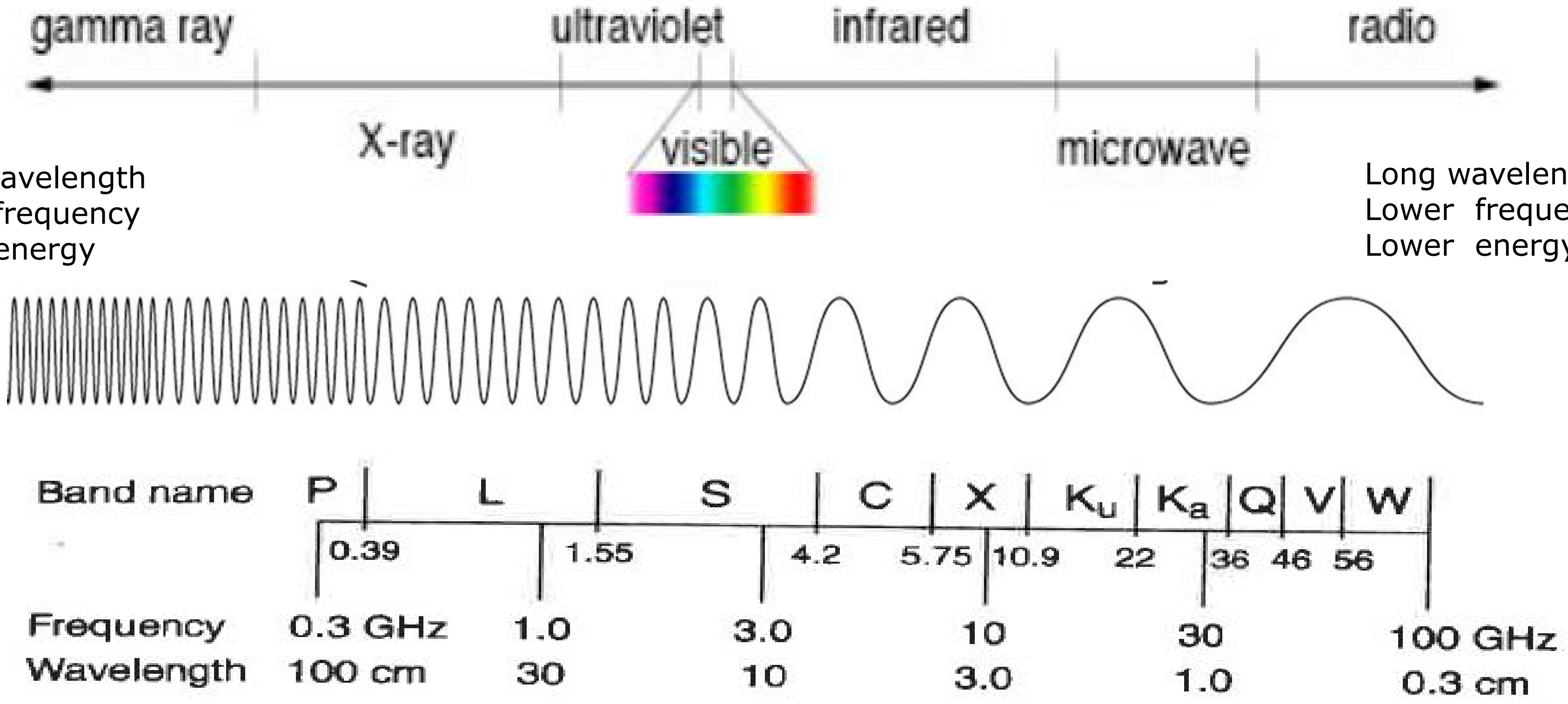


Radar (active mirco-Wave) sensors

Infrared & Passive Microwaves

Frequencies in the Microwave domain

Short wavelength
Higher frequency
Higher energy



Long wavelength
Lower frequency
Lower energy

Antenna size, wavelength, beam width and coverage

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

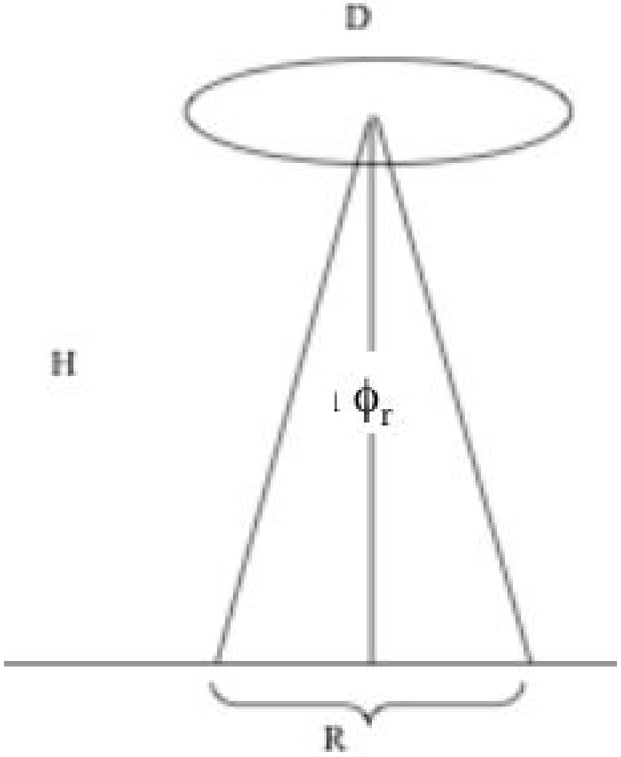
$R = 2 H \lambda / D$

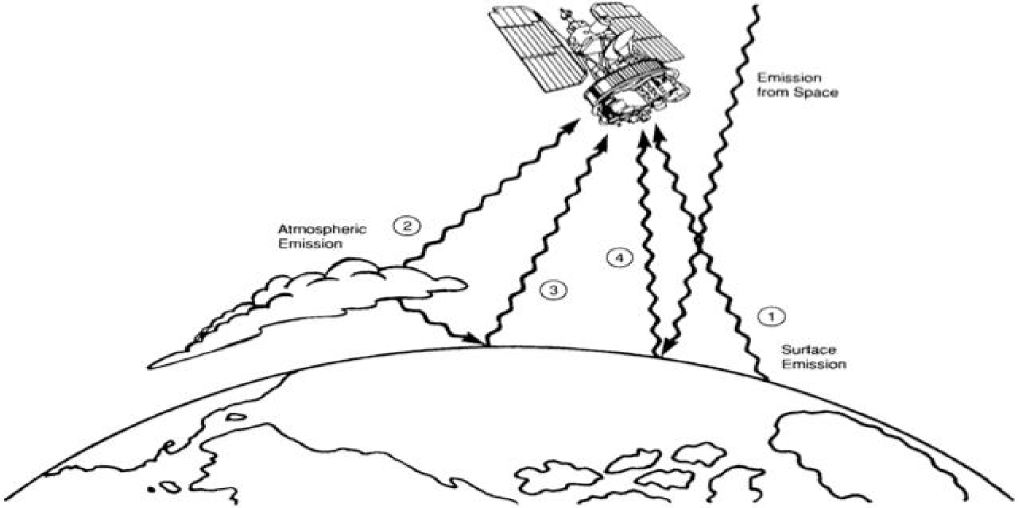
$H = 800$ km

$\lambda = 1$cm

$D = 1$m

$\Longrightarrow R = 16$ km





When ε ≈ 1 as for sea ice the reflectivity is minor. For sea water ε < 0.4.

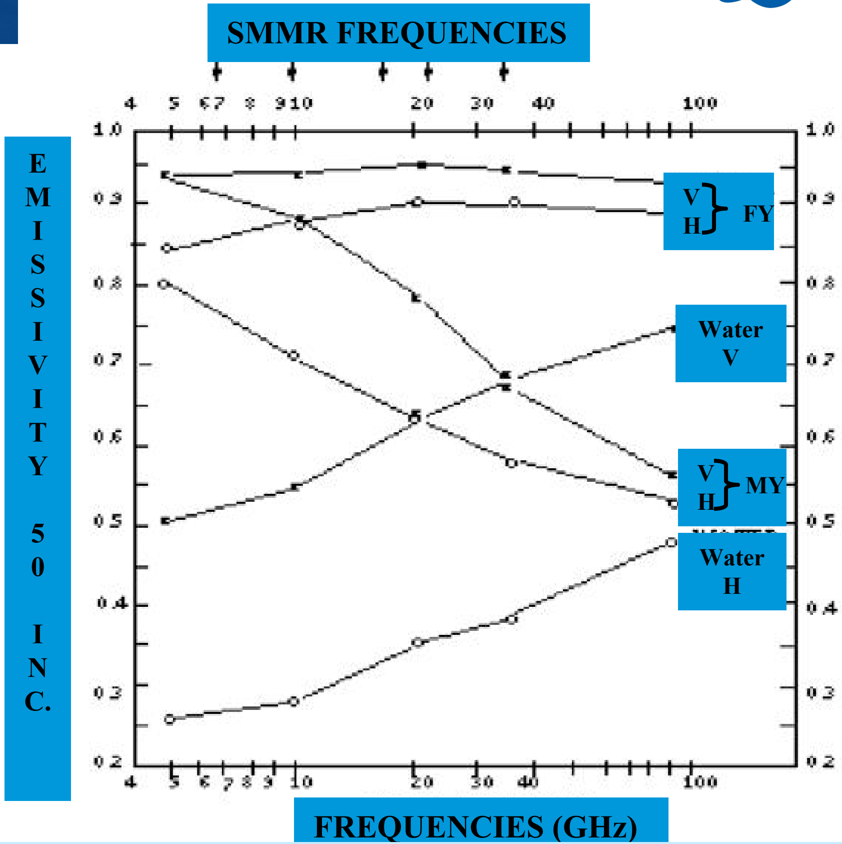
τ is the transmittance. τ ≈ 1 or 0 implies no or strong absorption. Clouds both absorb and re-emit.

For λ < 1 mm the absorption is large. In from H_2O og O_2. For λ < 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)

Multi-channel use of sea ice - water classiciation



FY = First Year Ice

MY = Multi Year Ice

Principles: Sea Ice Concentration

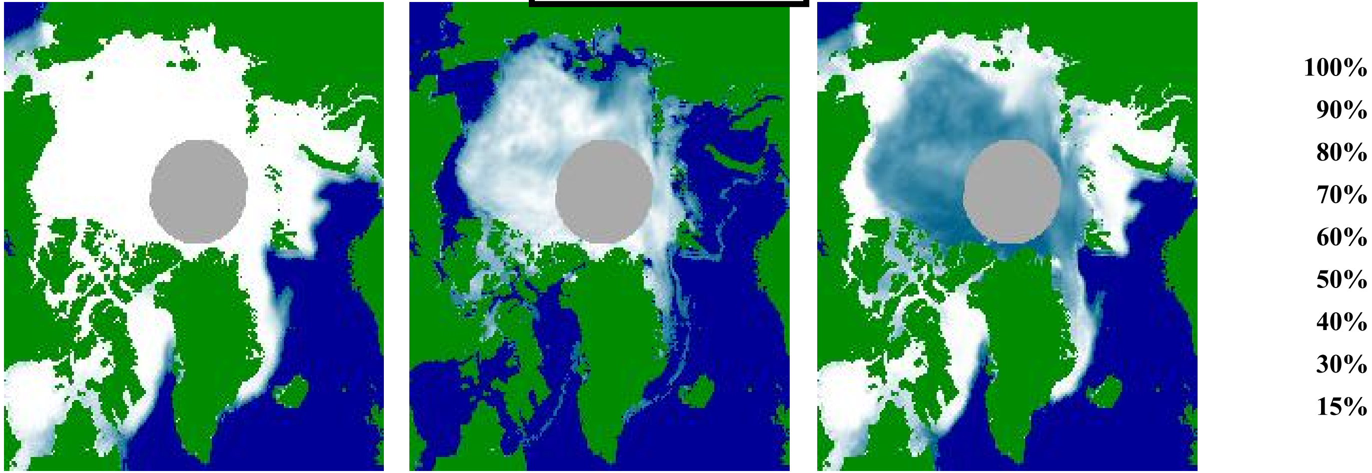
$$TB = (1 - C)\,TB_W + C\,TB_{ice}$$

C=0% | C=100% | $0\% < C < 100\%$

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

Passive Microwave-derived ice type concentration

December 1980

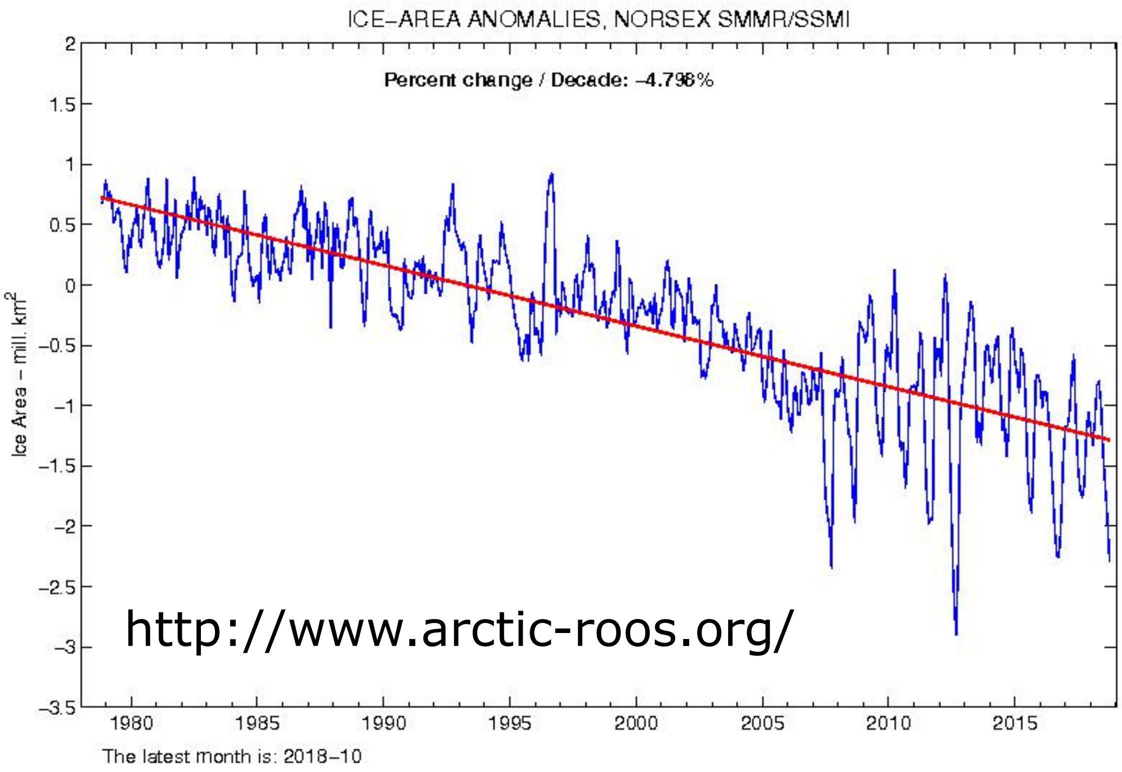


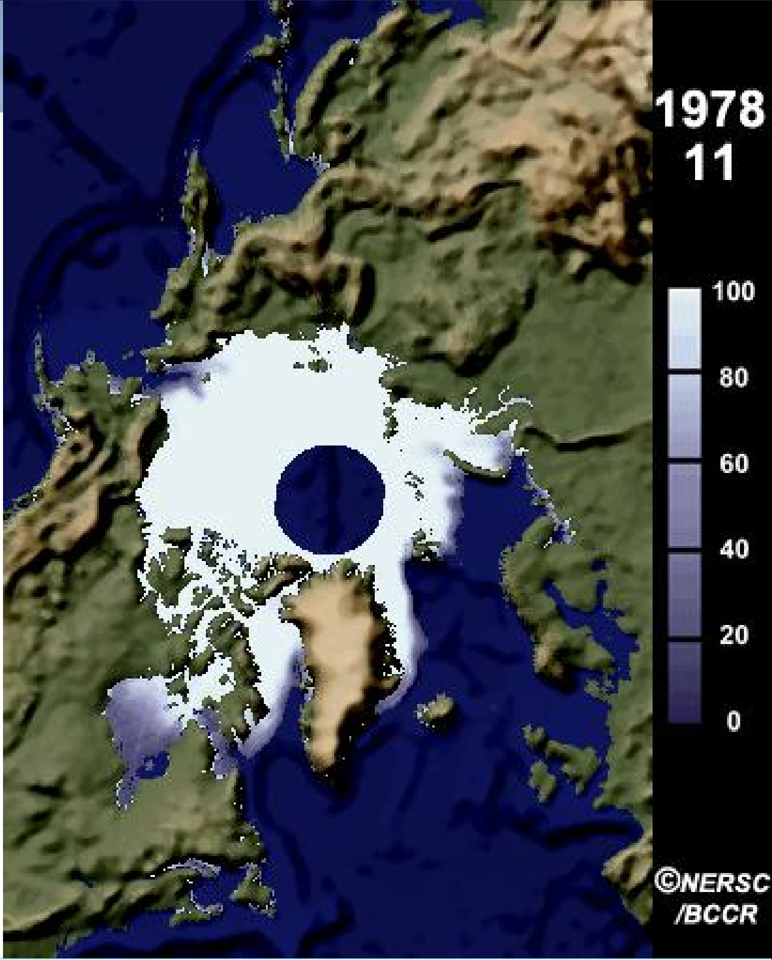
TOTAL ICE COVER = MULTI-YEAR ICE + FIRST-YEAR ICE

MULTI-YEAR ICE: ice that has survived one summer

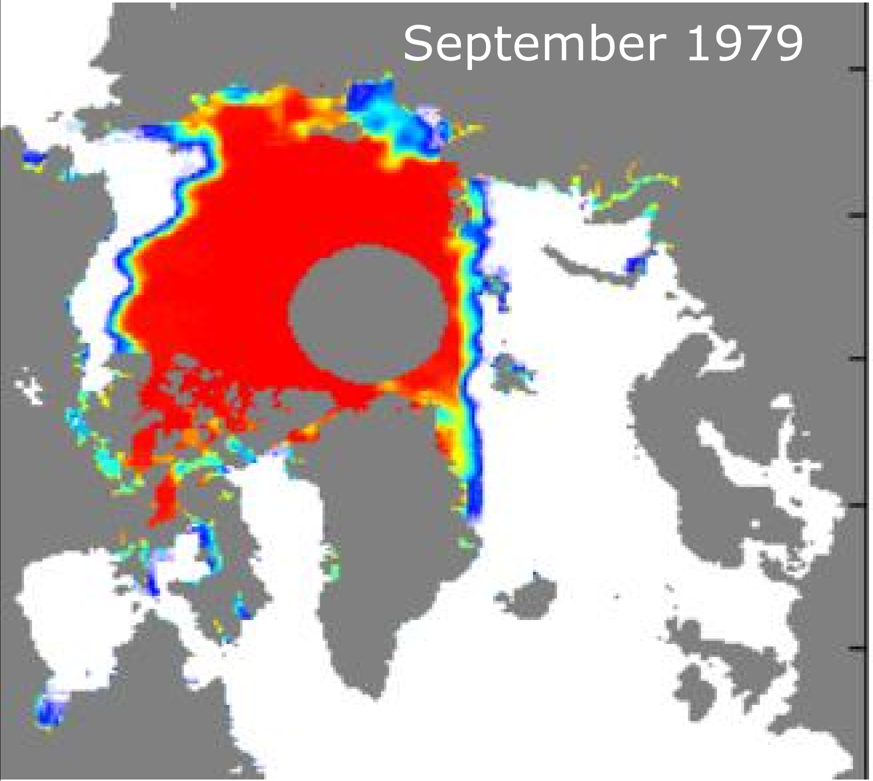
FIRST-YEAR ICE: ice that has formed during last winter

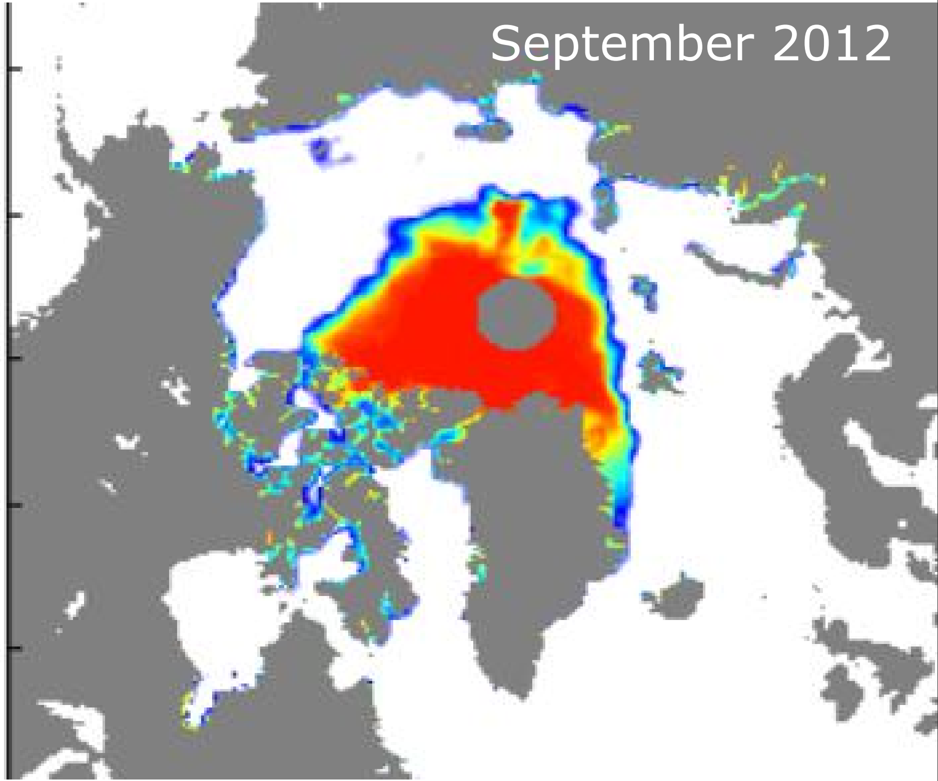
Sea Ice Area


ICE–AREA ANOMALIES, NORSEX SMMR/SSMI
Percent change / Decade: –4.798%
Ice Area – mill. km²
2
1.5
1
0.5
0
–0.5
–1
–1.5
–2
–2.5
–3
–3.5
1980
1985
1990
1995
2000
2005
2010
2015
The latest month is: 2018–10
http://www.arctic-roos.org/

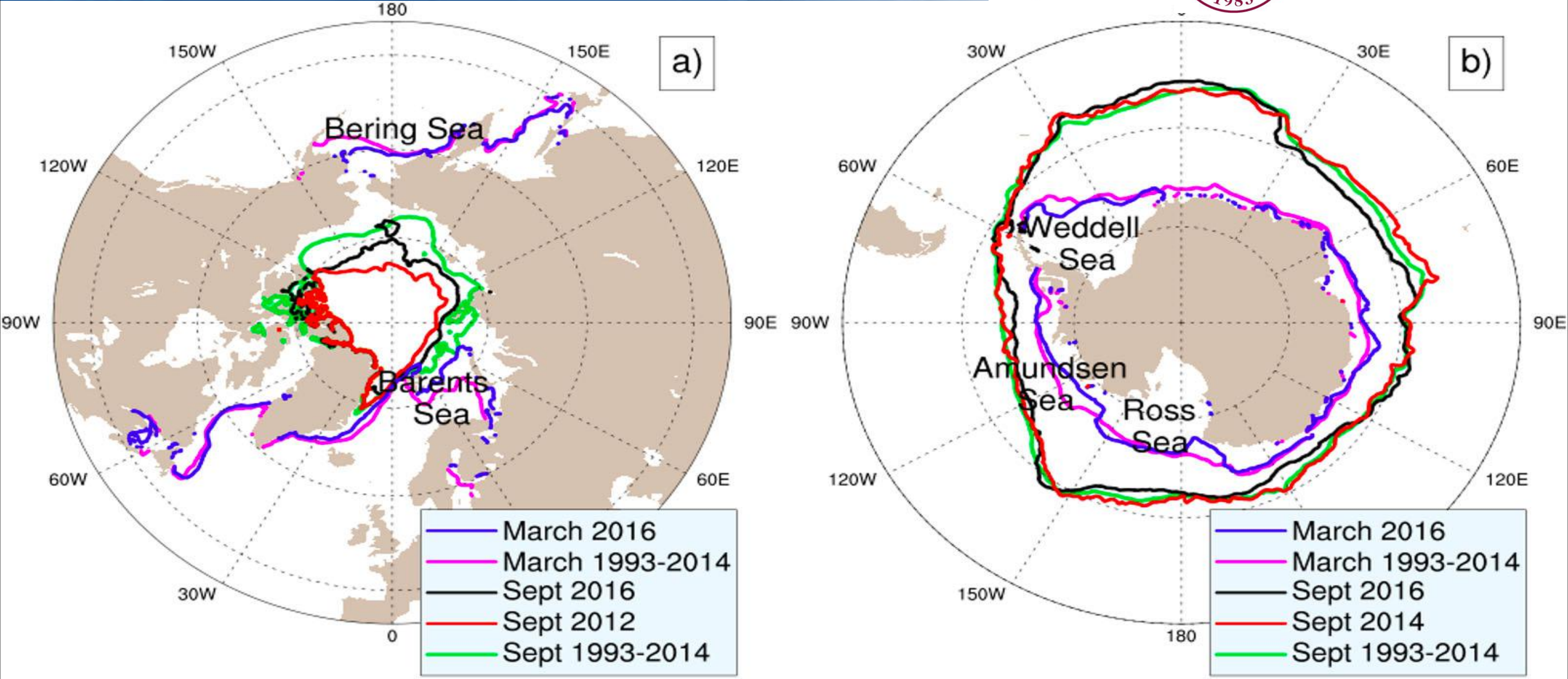

1978
11
100
80
60
40
20
0
©NERSC
/BCCR

Sea Ice Area September Minimum

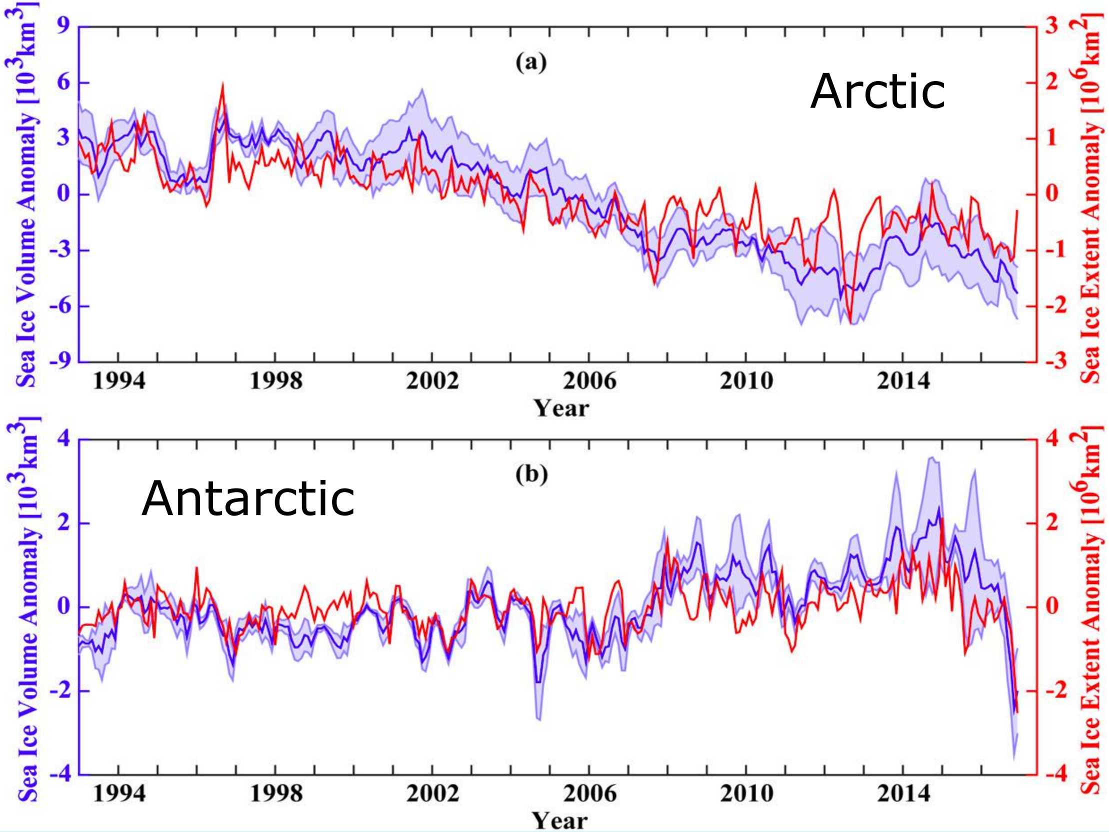




Sea Ice Climatology, Maximum and Minimum



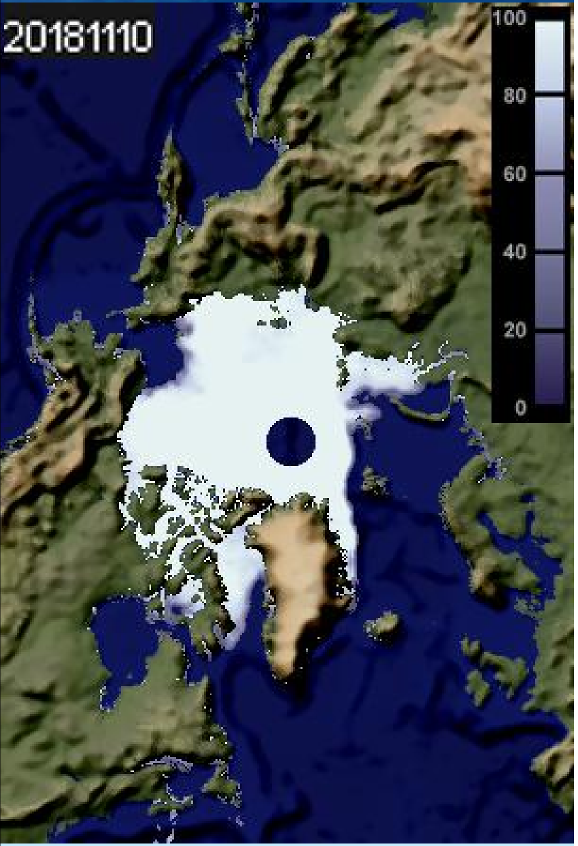
Monthly Anomalies in Sea Ice Extent & Volume



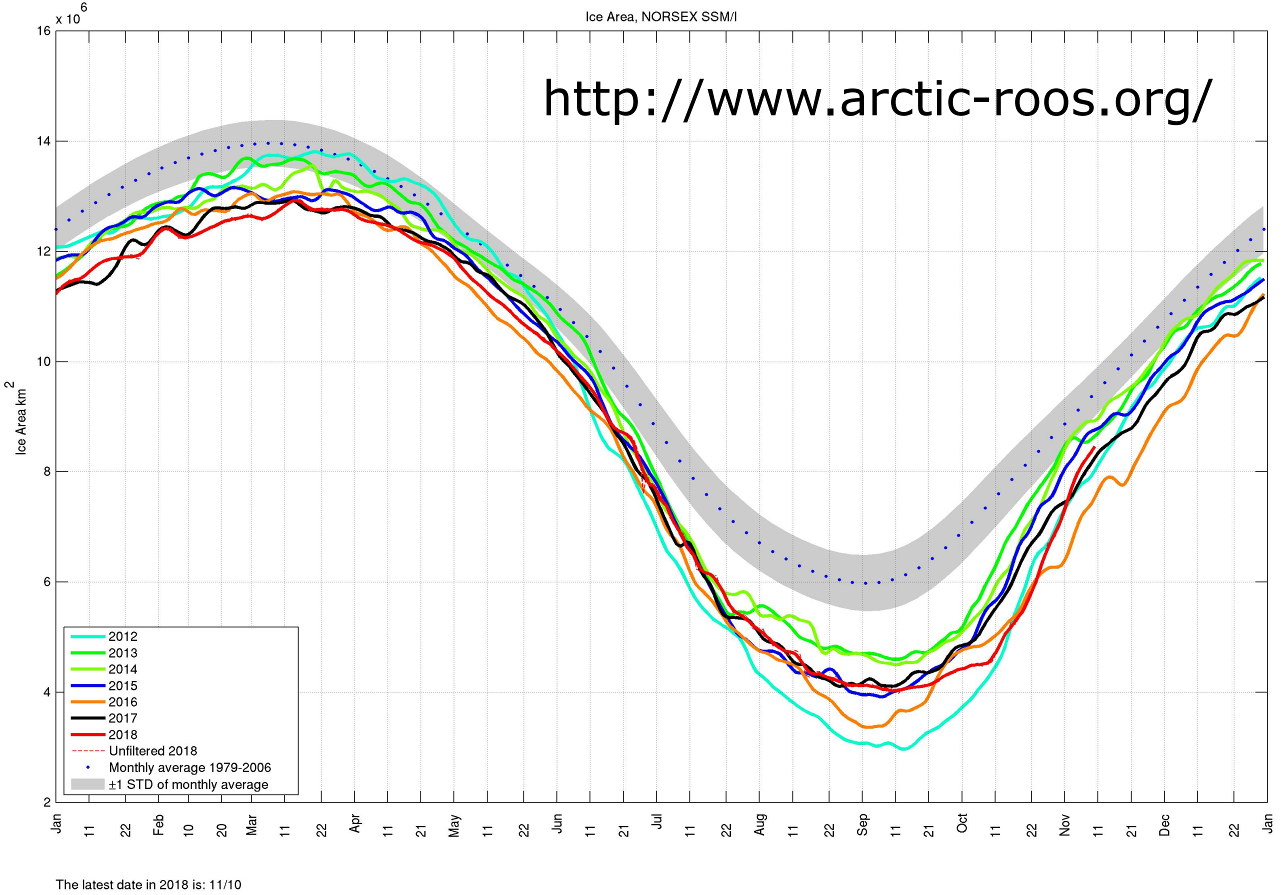
The Arctic has lost sea ice volume at a rate of 15.4% per decade since 1993. Accordingly, the Arctic Ocean freshwater content has increased and show a record high in 2016.

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

Sea Ice Area



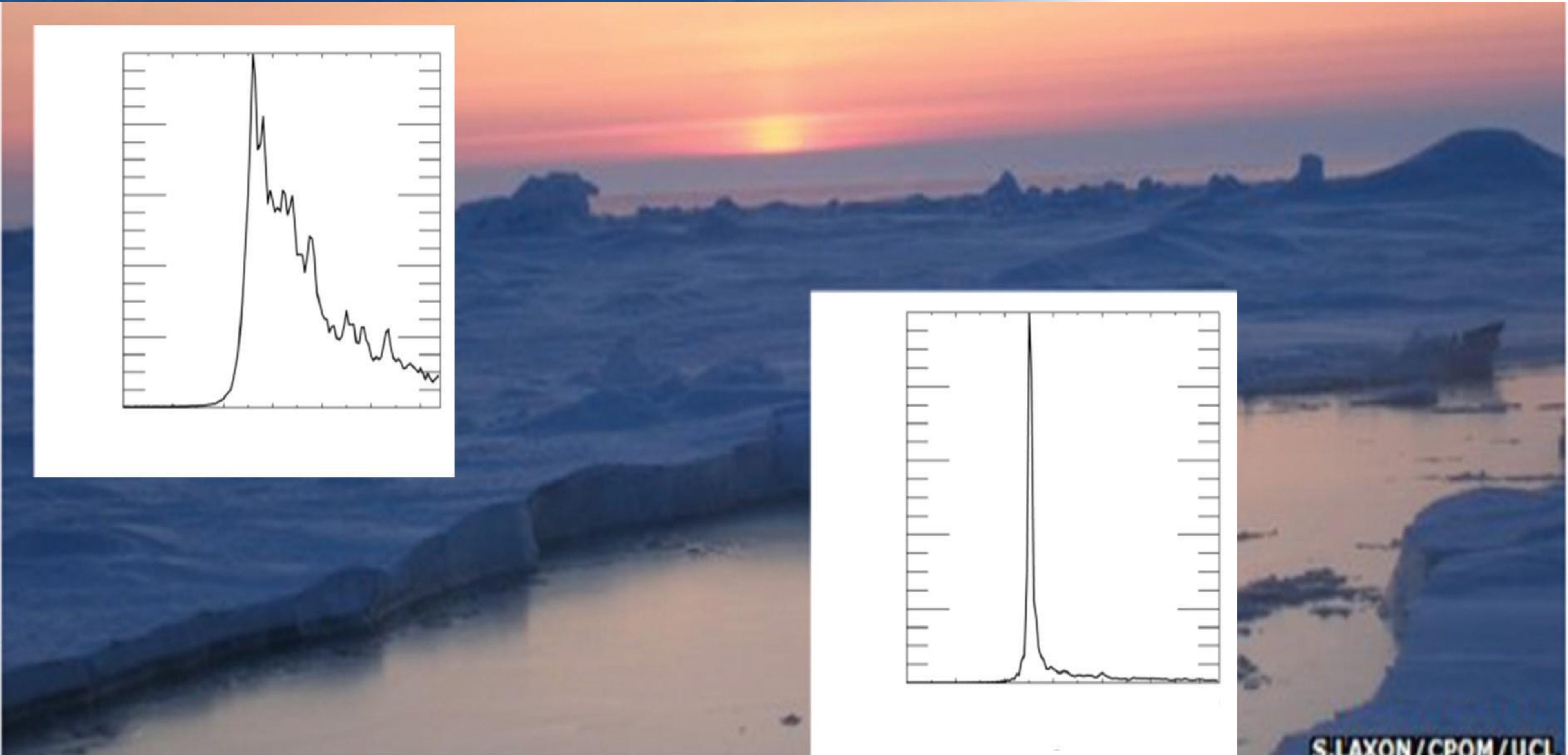
20181110
100
80
60
40
20
0



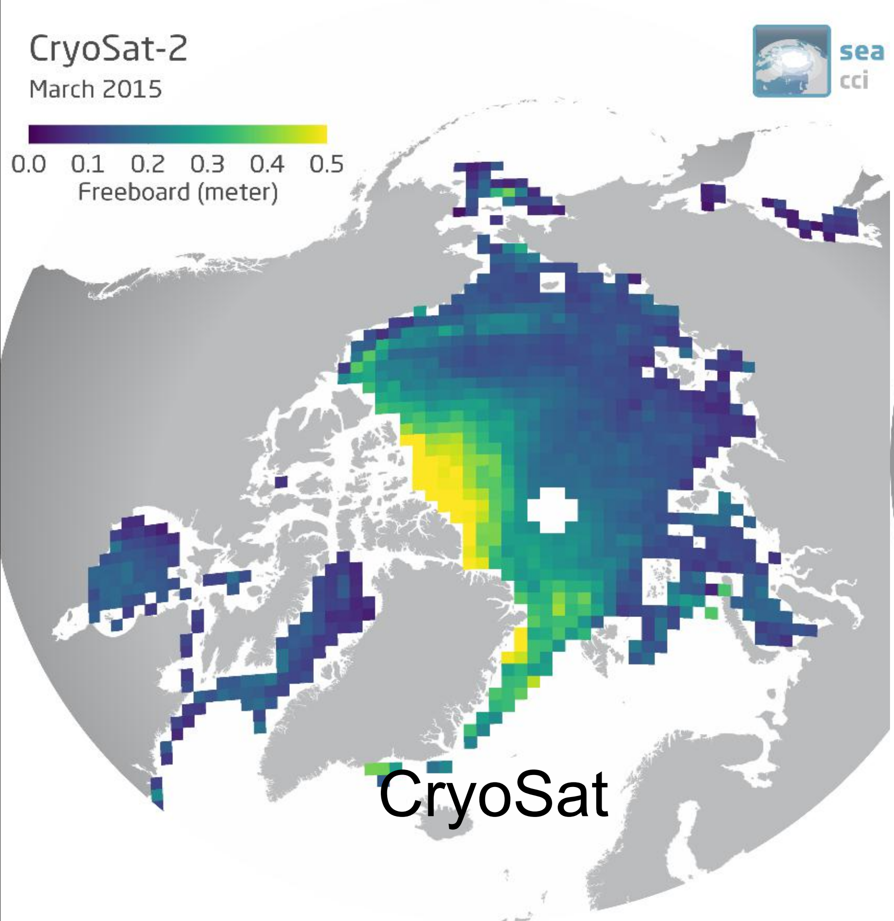
Ice Area, NORSEX SSM/I
http://www.arctic-roos.org/
x 10^6
Ice Area km^2
2012
2013
2014
2015
2016
2017
2018
Unfiltered 2018
Monthly average 1979-2006
±1 STD of monthly average
Jan 11 22 Feb 10 20 Mar 11 22 Apr 11 21 May 11 22 Jun 11 21 Jul 11 22 Aug 11 22 Sep 11 21 Oct 11 22 Nov 11 21 Dec 11 22 Jan
The latest date in 2018 is: 11/10

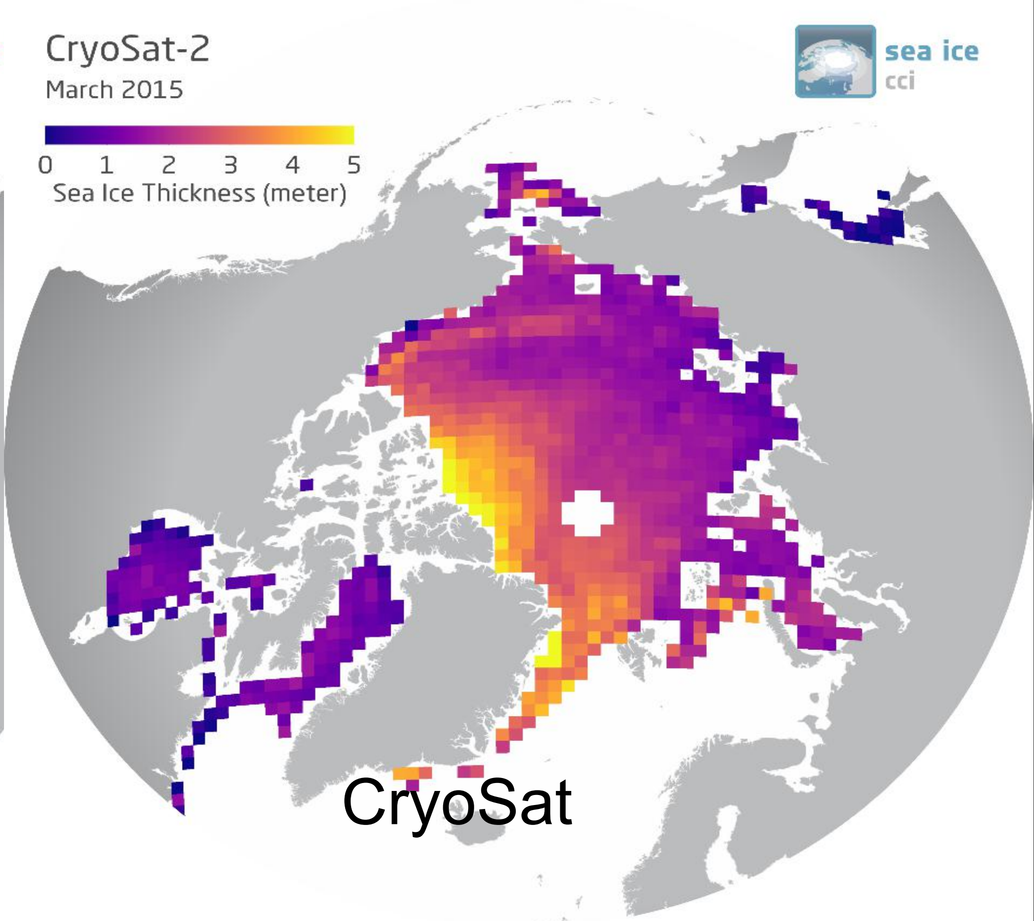
FREEBOARD HEIGHT & THICKNESS

Freeboard height estimation from Altimetry

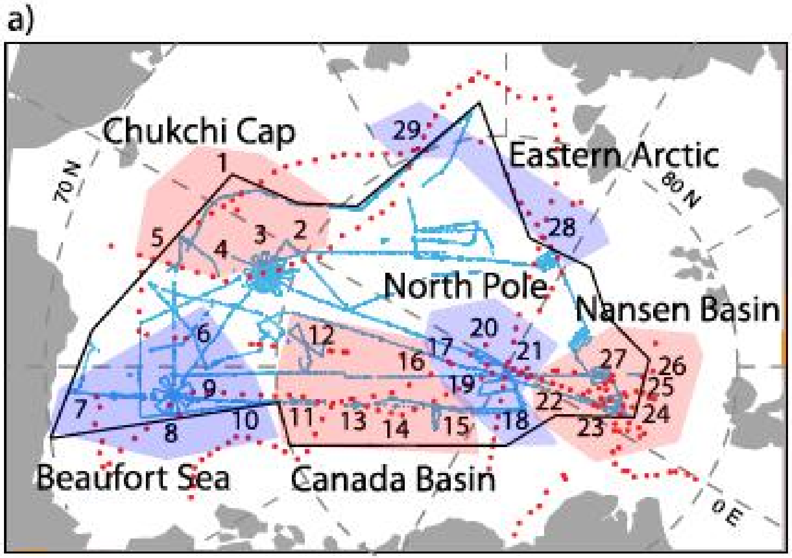


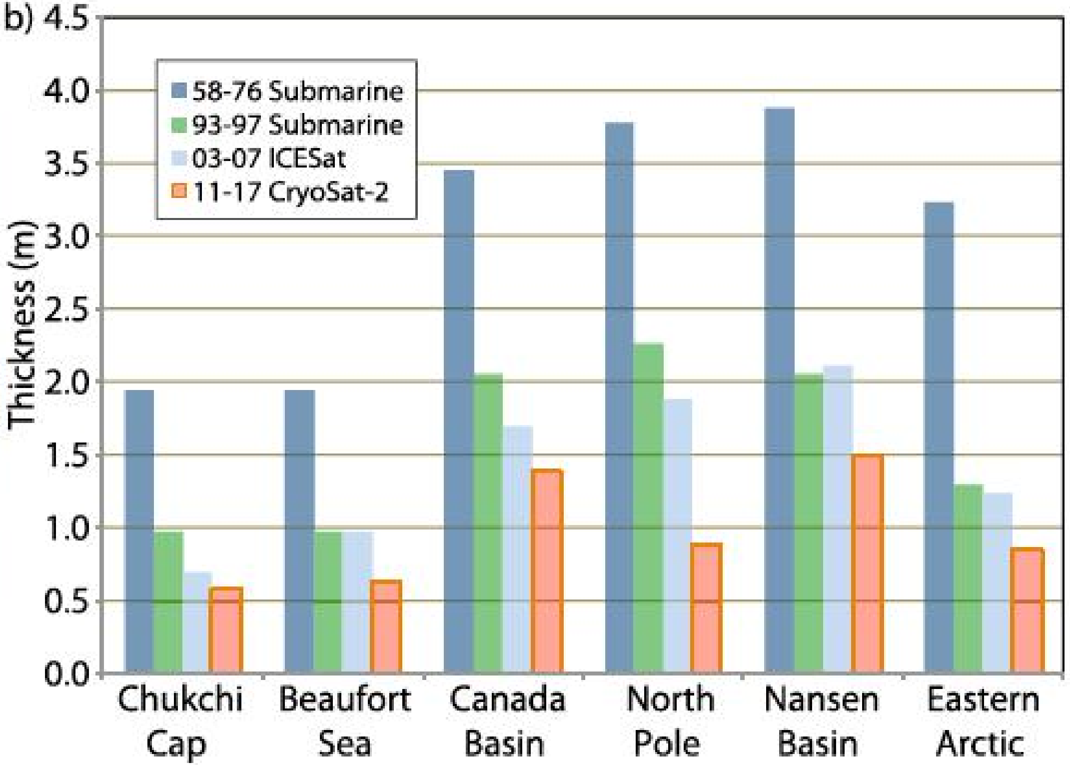
From freeboard to thickness



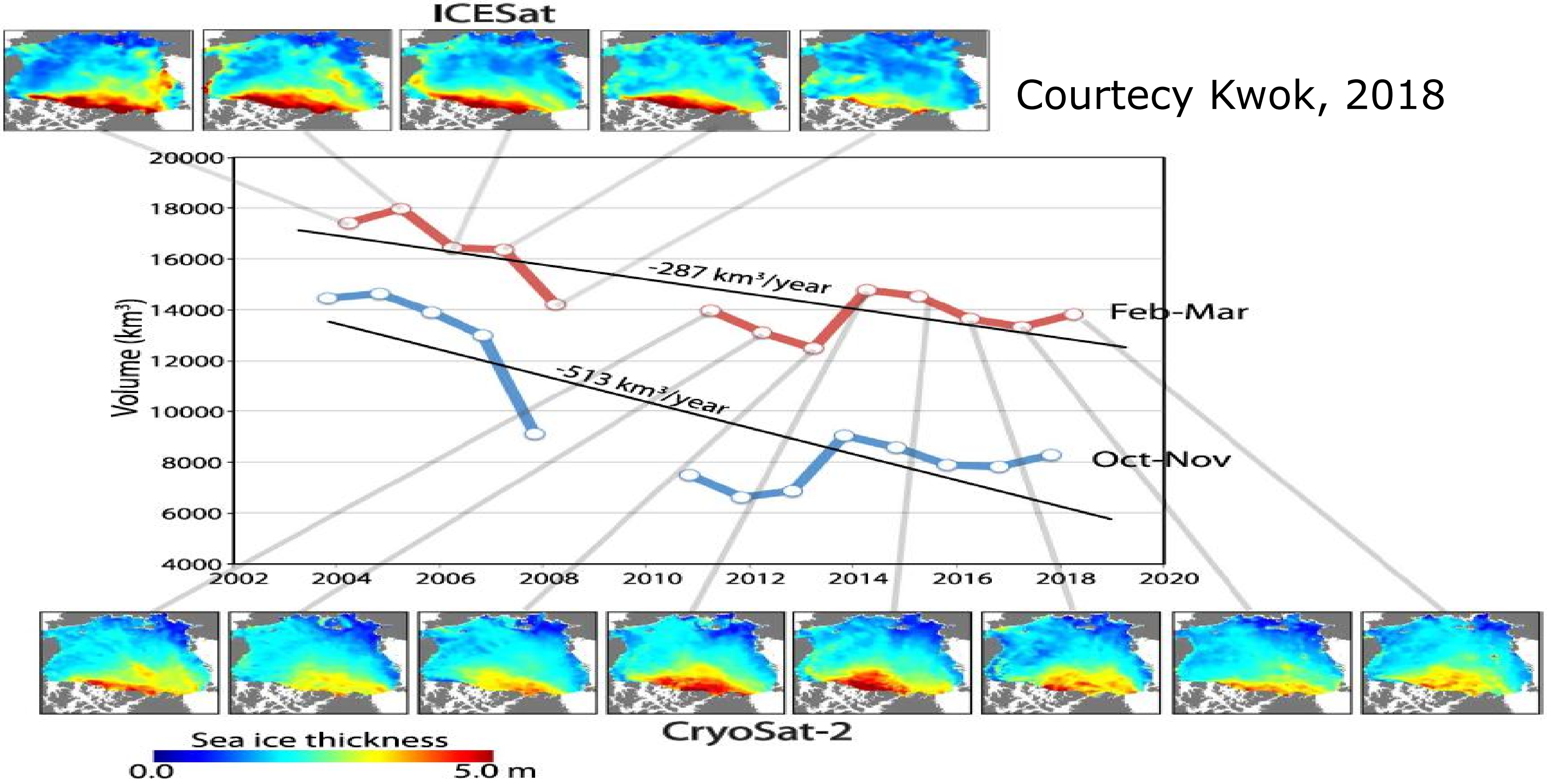


Sea Ice Thickness



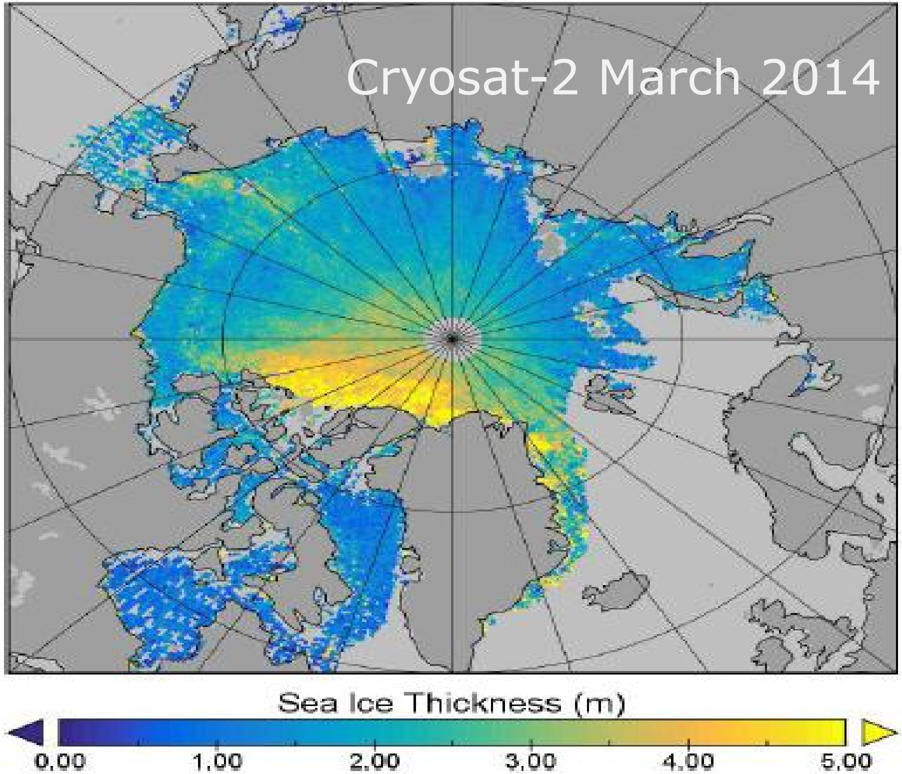


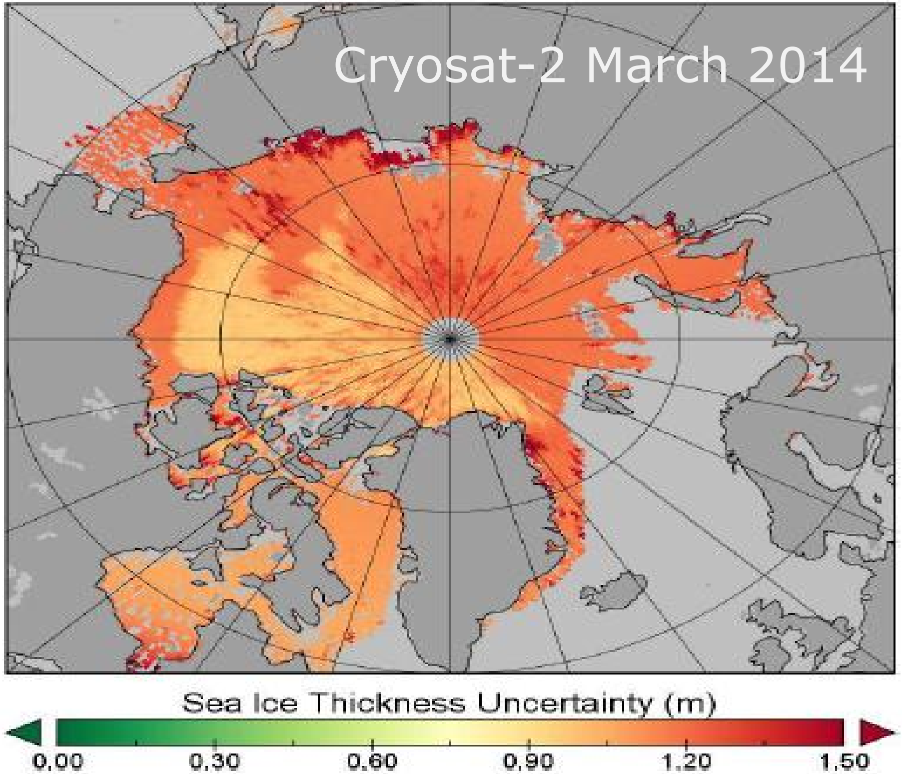
Courtecy Kwok, 2018



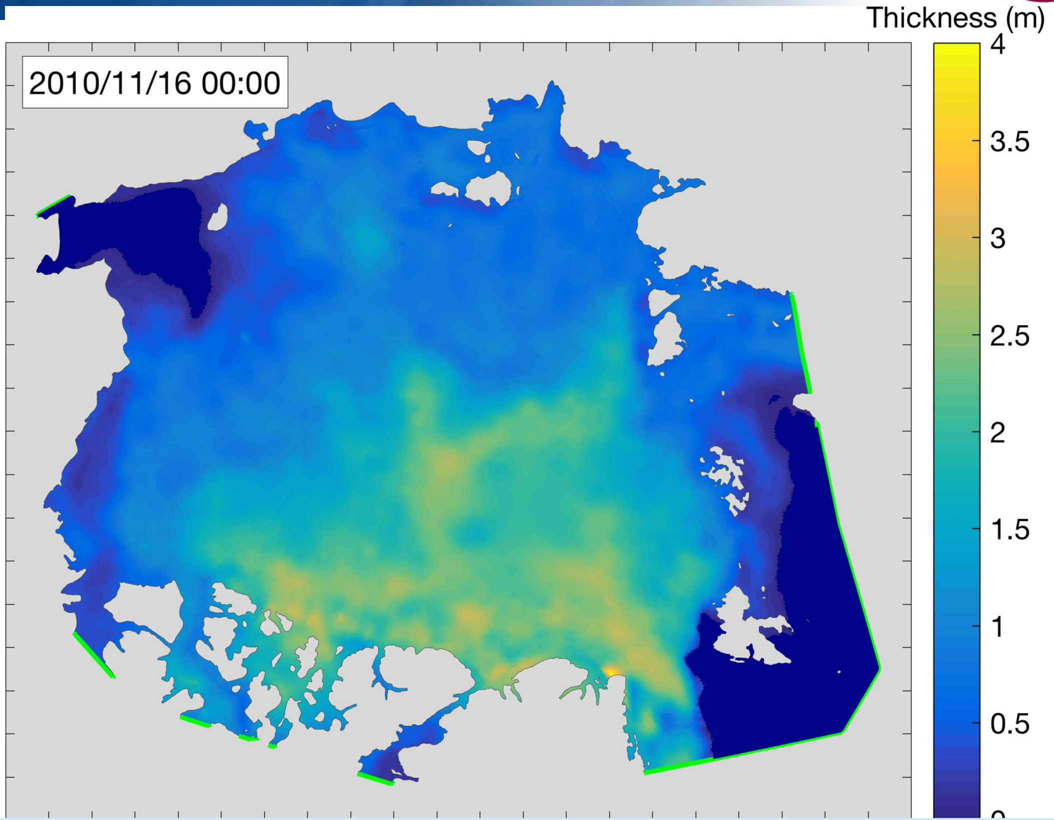
Courtecy Kwok, 2018

Sea ice thickness with uncertainty



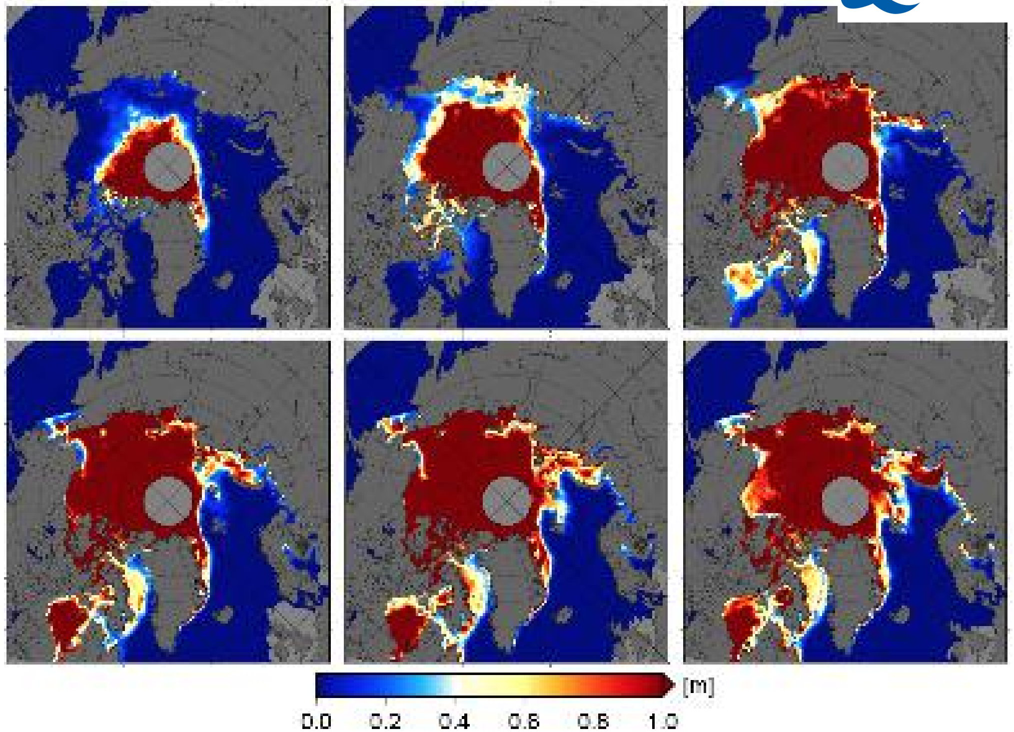


neXtSIM for sea ice thickness studies

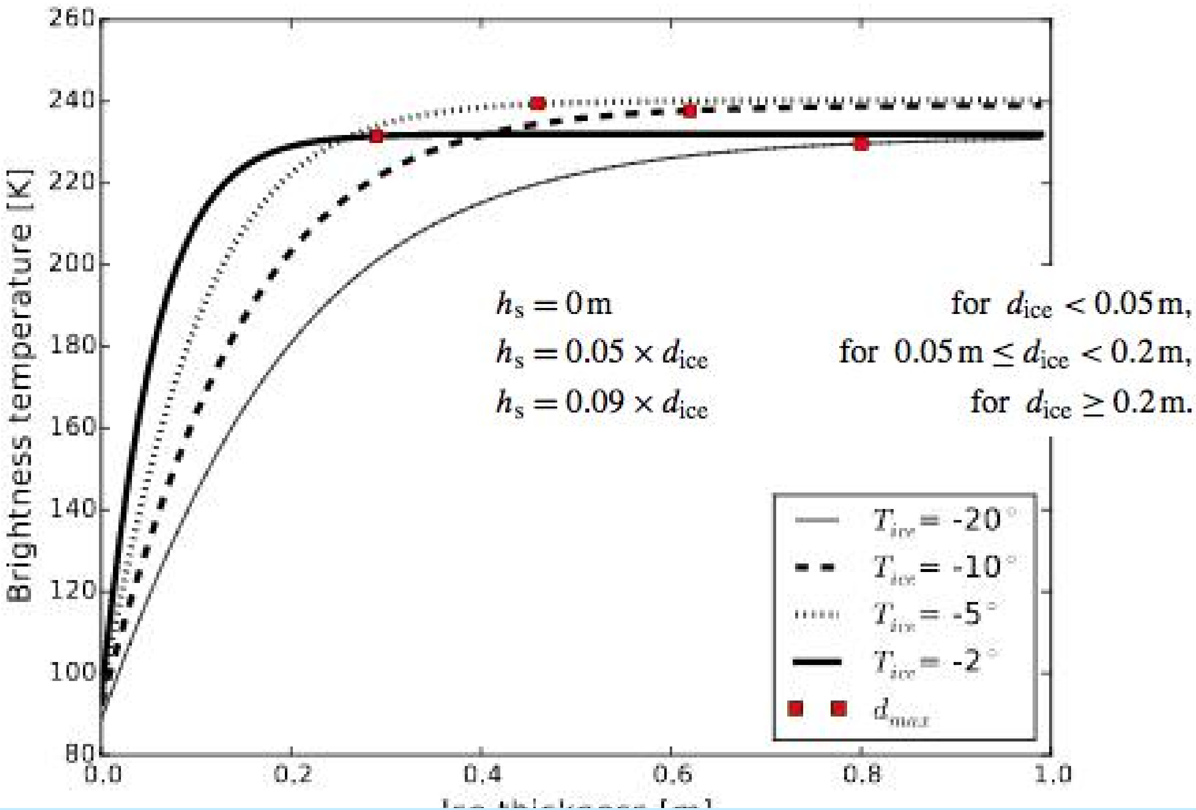


Olason, Rampal, Bouillon, in prep.

Thin Sea Ice Retrievals

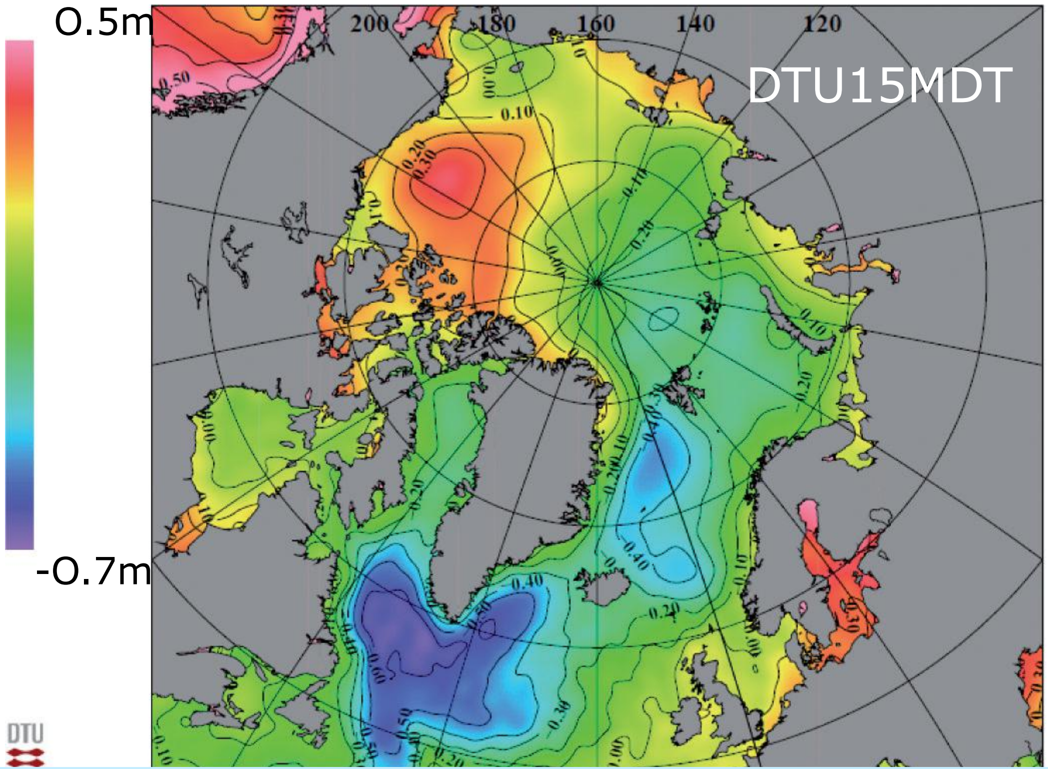


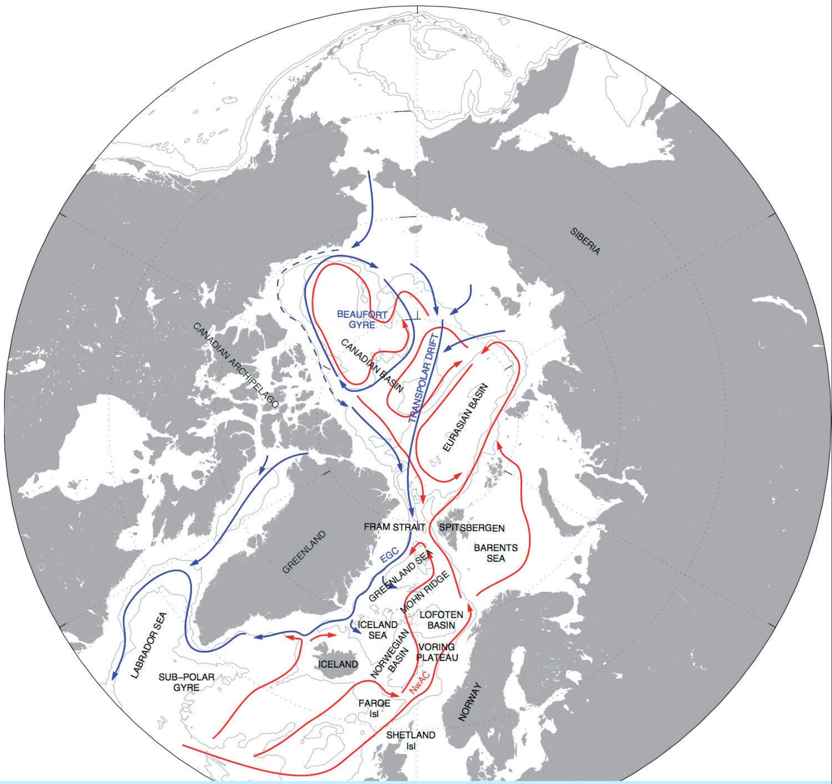
Monthly SMOS sea ice thickness derived´during freeze-up period October 2012-March 2013



Brightness temperature [K]
260
240
220
200
180
160
140
120
100
80
0.0
0.2
0.4
0.6
0.8
1.0
$h_s = 0\,m$ for $d_{ice} < 0.05\,m$,
$h_s = 0.05 \times d_{ice}$ for $0.05\,m \leq d_{ice} < 0.2\,m$,
$h_s = 0.09 \times d_{ice}$ for $d_{ice} \geq 0.2\,m$.
T_{ice} = -20°
T_{ice} = -10°
T_{ice} = -5°
T_{ice} = -2°
d_{max}

Mean dynamic topography (MDT) for the Arctic





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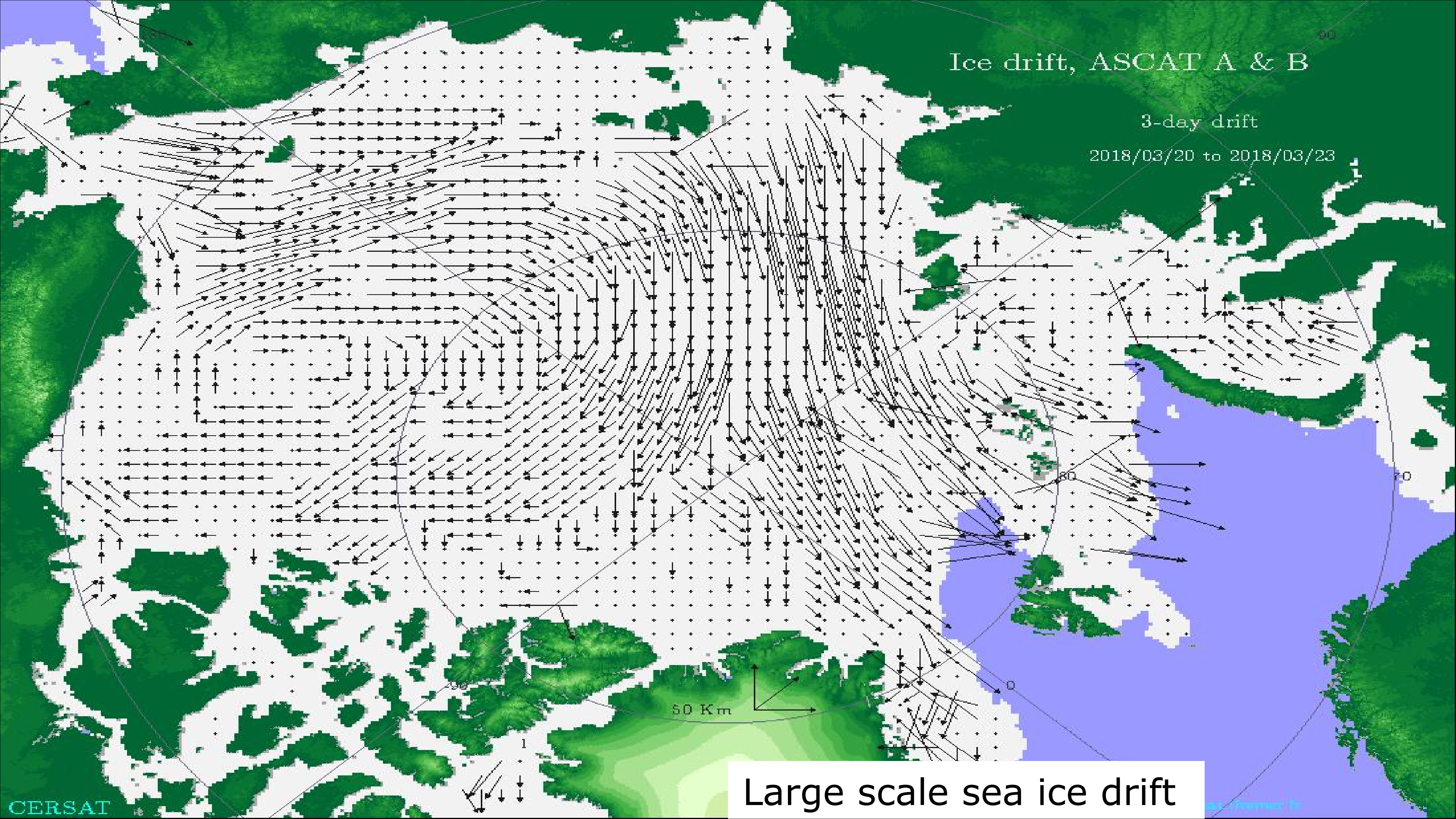
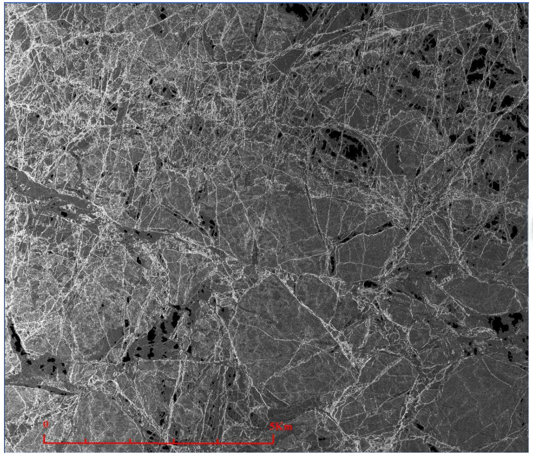


Large scale sea ice drift

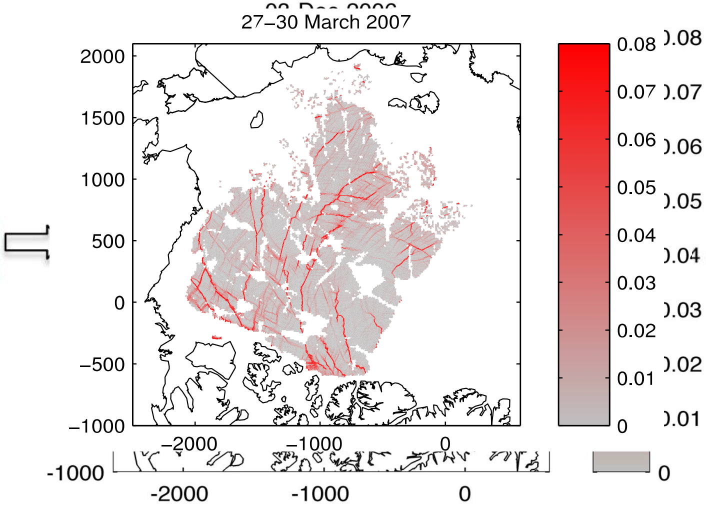
LEAD FRACTION AND SHEAR/DIV ZONES

SAR image(s)

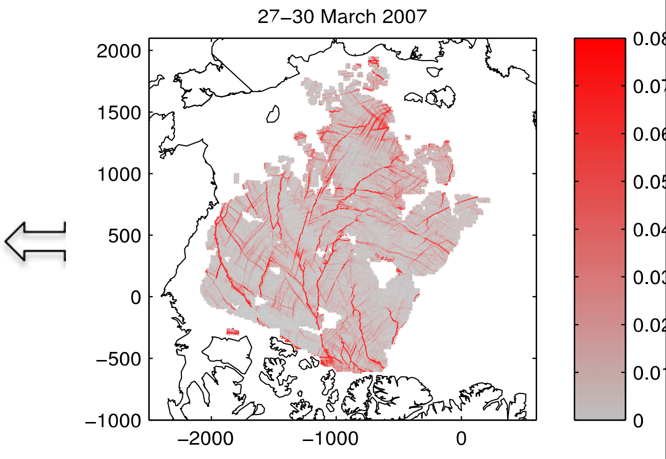


10 KM

From SAR image(s)



Elasto-Brittle model

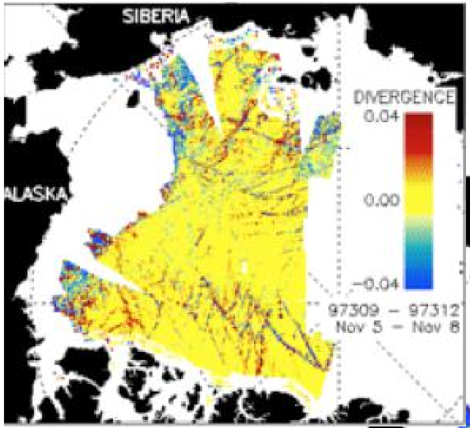


Courtecy Pierre Rampal, NERSC

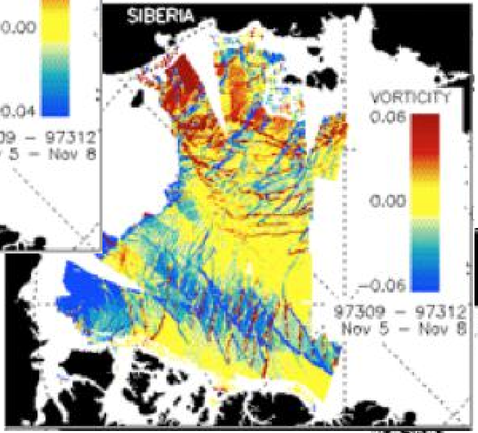
Sea Ice Deformation

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

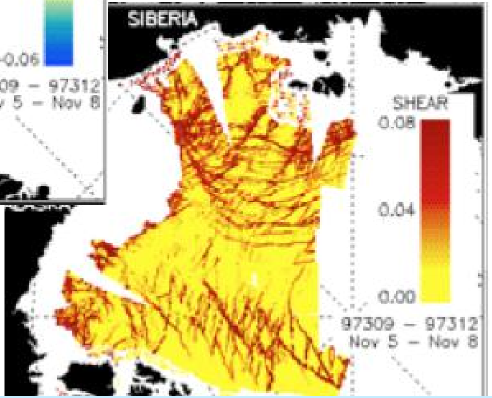
The record of area change reflects the opening of the lead running through the cell.



Divergence



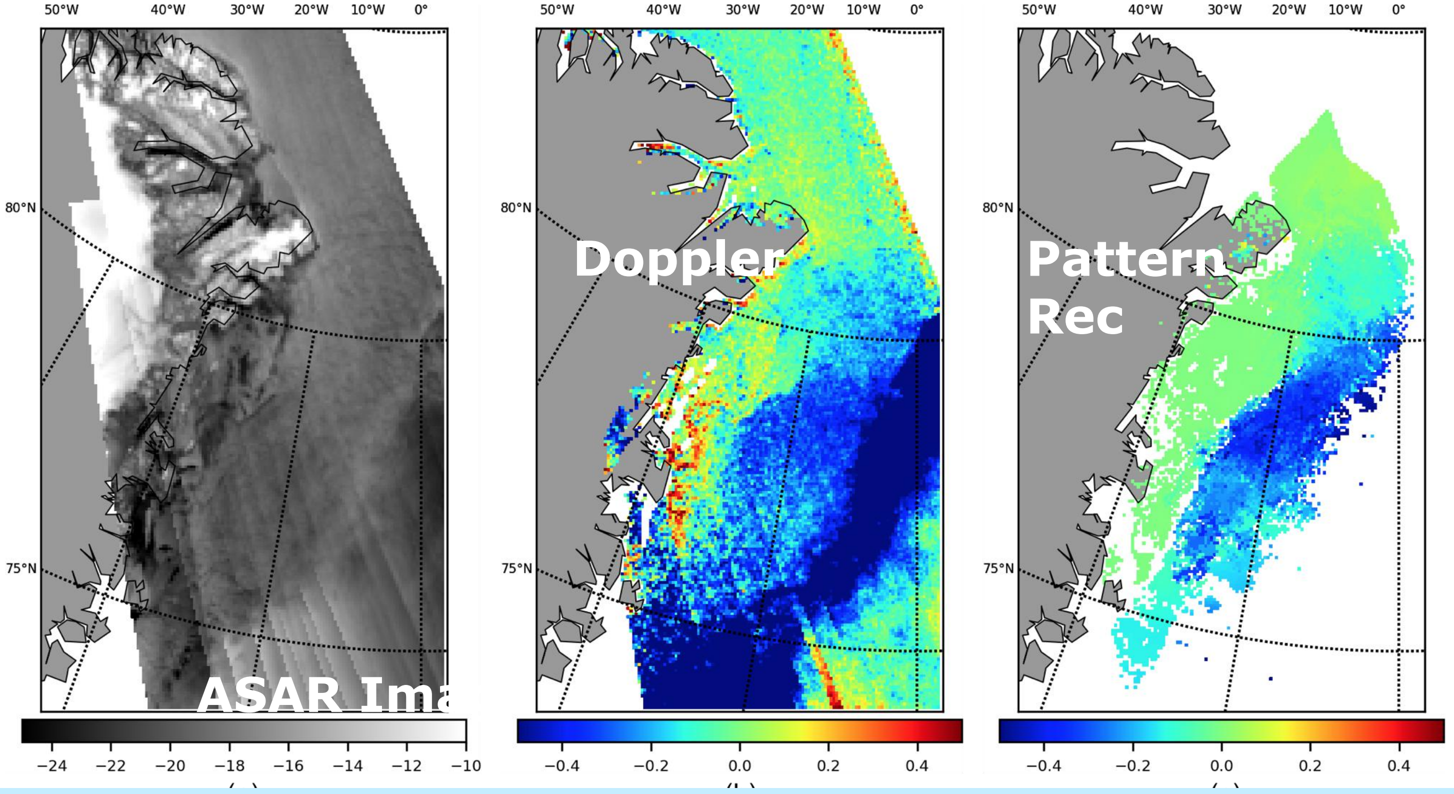
Vorticity



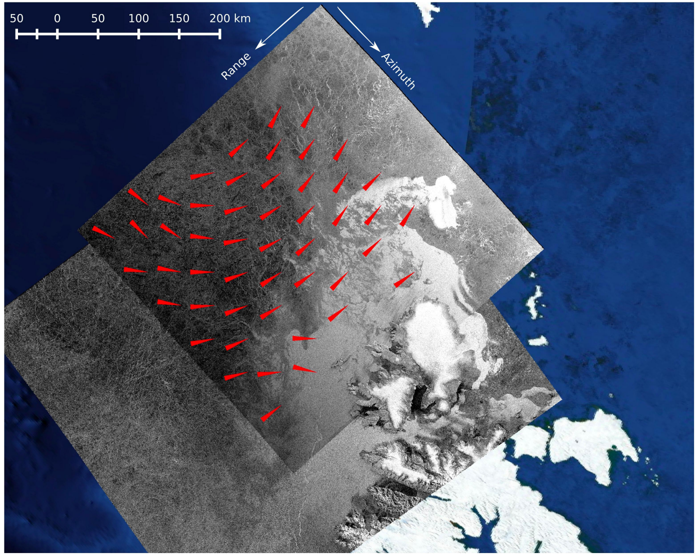
Shear

Courtesy Ron Kwok

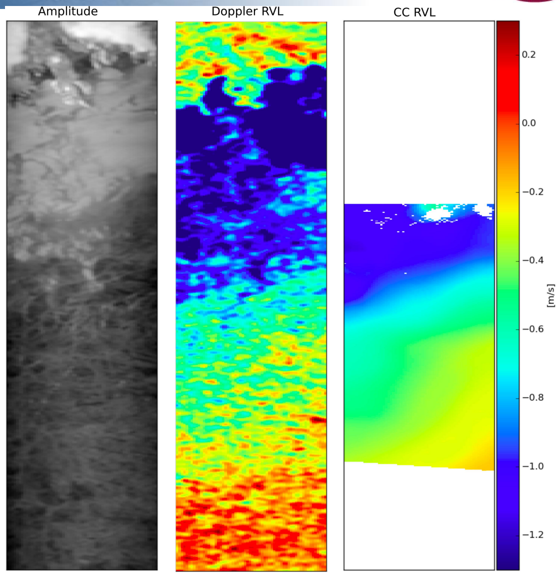
Doppler velocities and Pattern recognition



Sentinel-1 TOPS Doppler & Sea Ice Drift



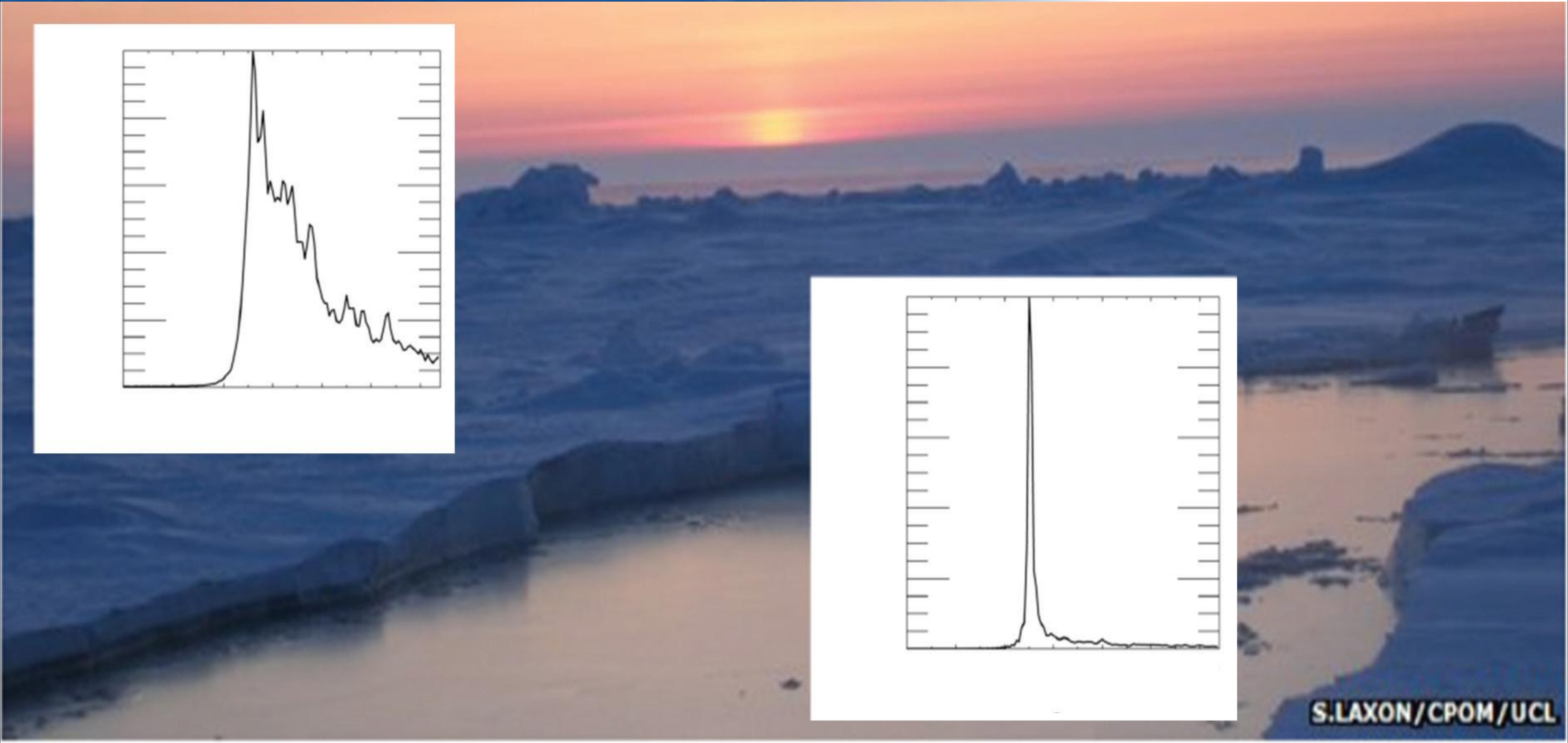
Collocated (25 min time separation) RSAT-2 and S1a EW with estimated sea ice drift vectors overlaid. Area: North West of Svalbard



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

Sea Level estimation



Global mean sea level change =

ean thermal expansion + Ocean mass varia

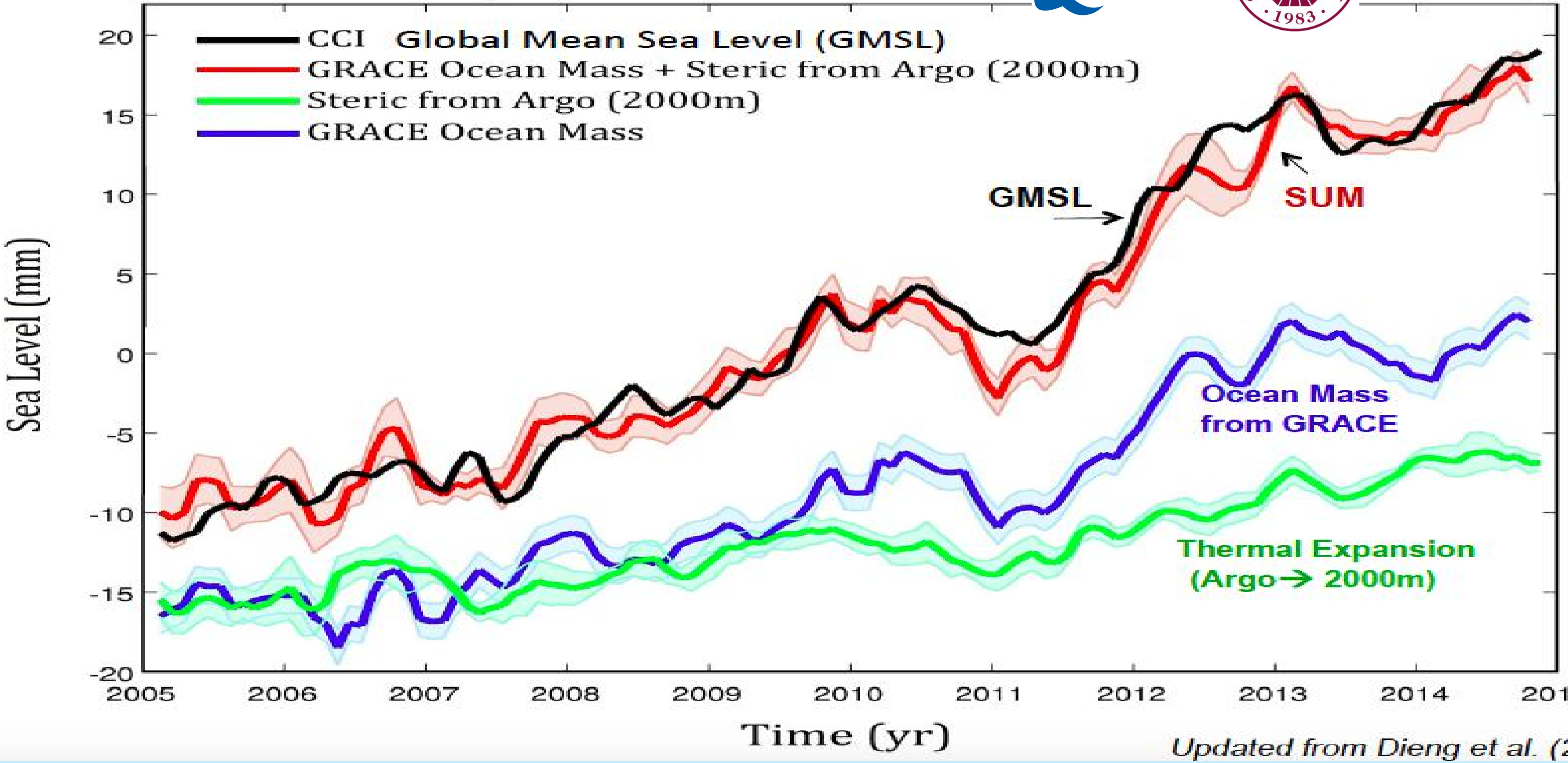
XBT & ARGO

$$\Delta M_{ocean} = -\Delta M_{LI} - \Delta M_{LW} - \Delta M_{WV}{}_{Snow}\ \Delta M$$

ΔM = Mass changes; LI = Land ice (glaciers + ice sheets); LW = Land waters

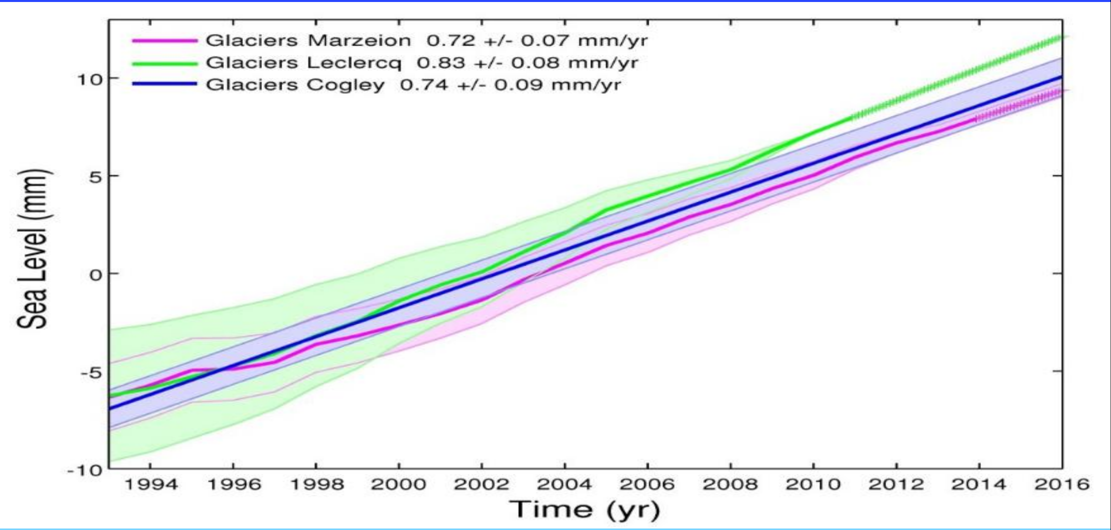
WV = Atmospheric water vapor; Snow = snow water equivalent

Thermal expansion + Ocean mass change



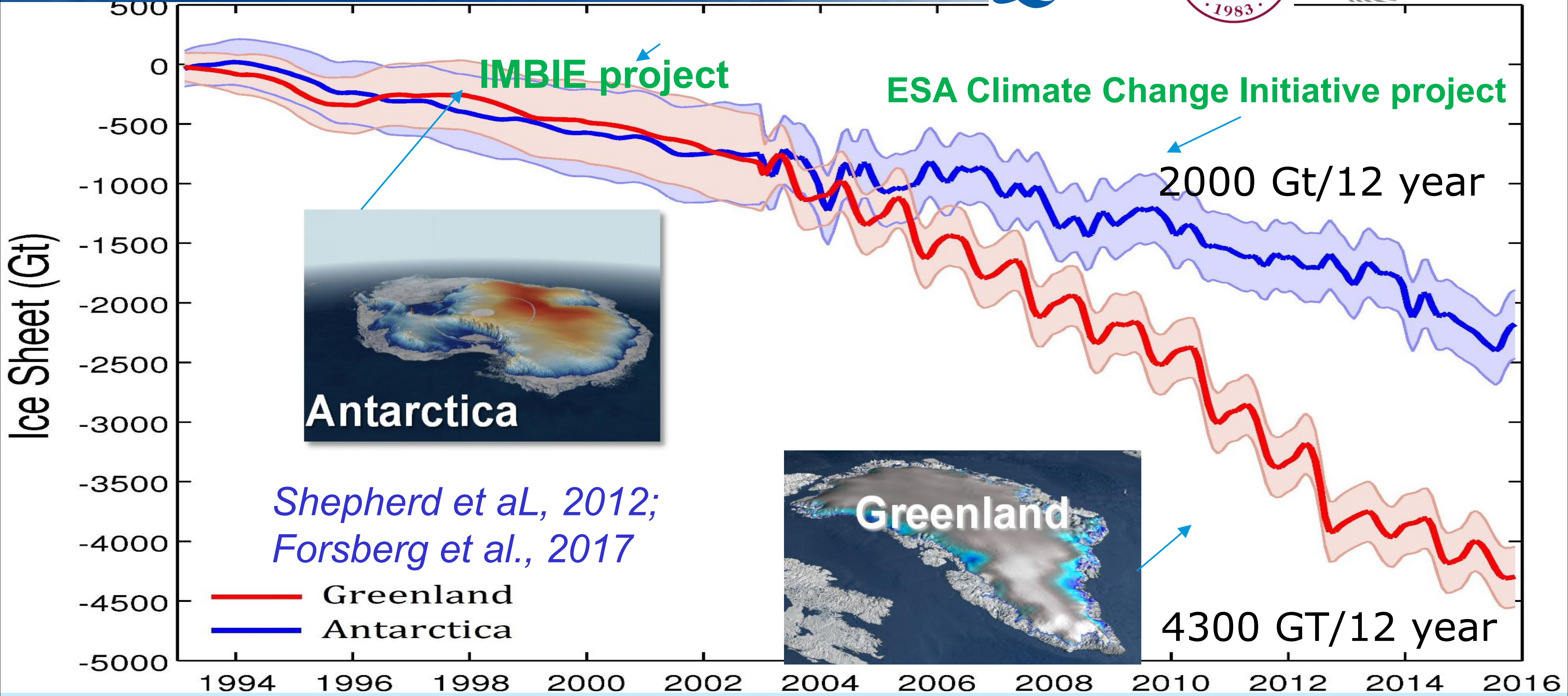
Updated from Dieng et al. (2015)

Glaciers contribution

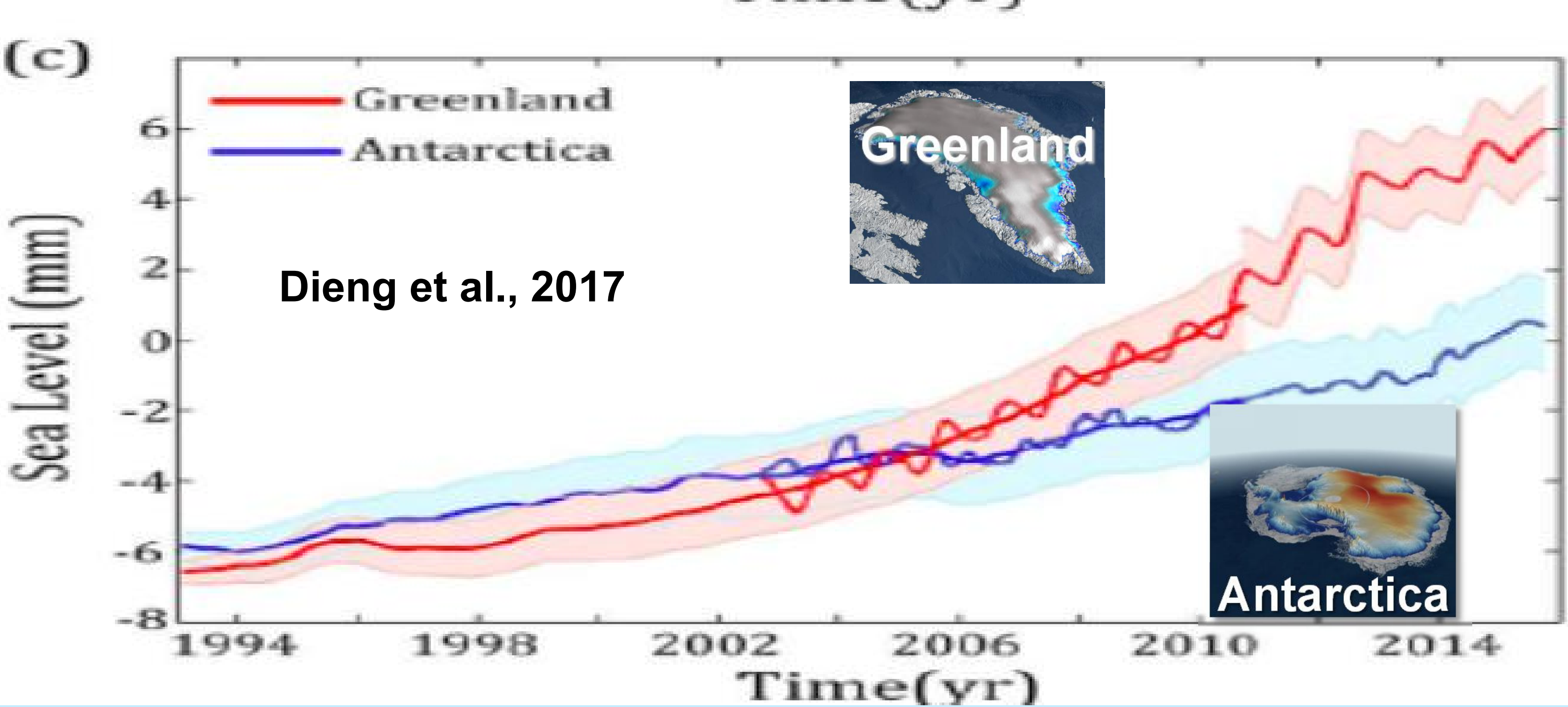


Courtecy Marzeion

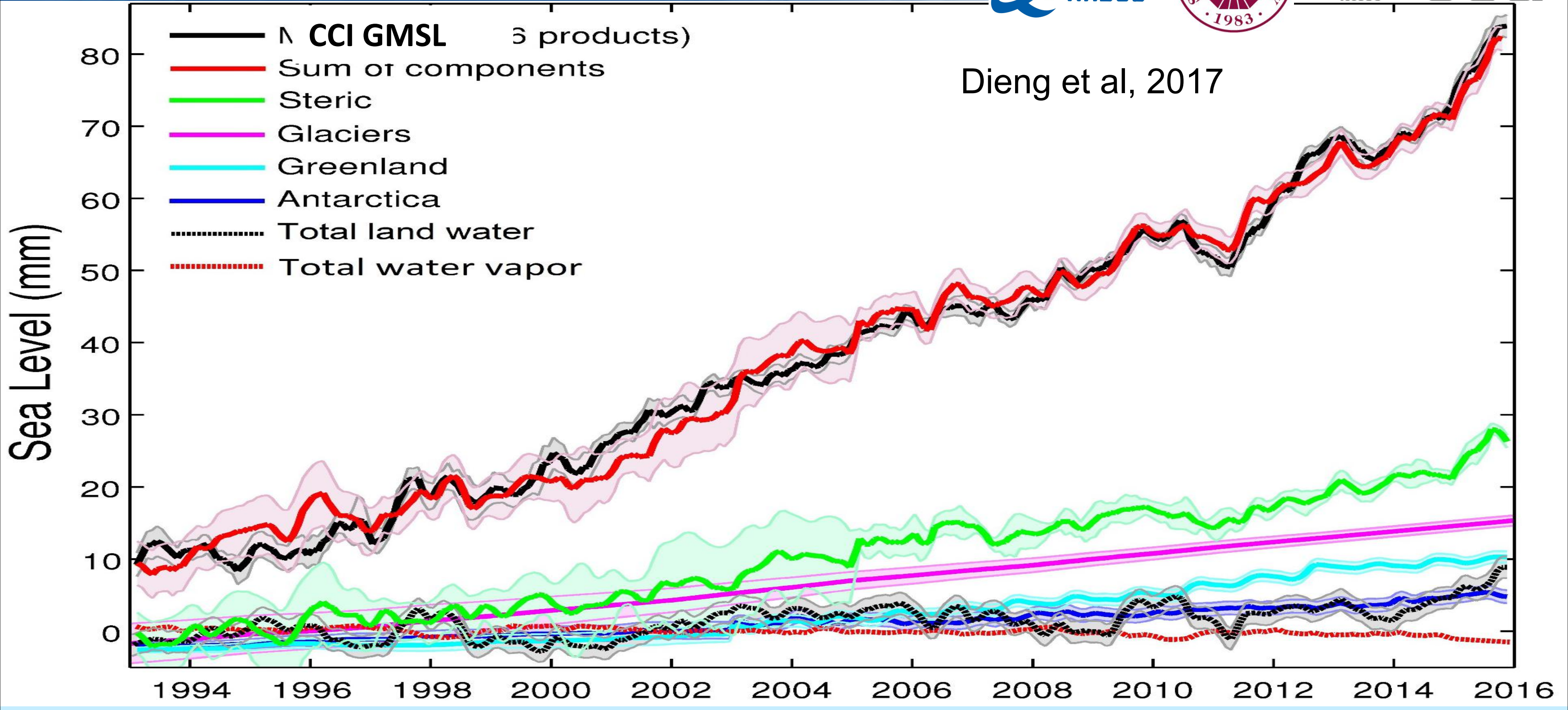
Ice Sheet Mass Loss



Equivalent Ice Sheet Sea Level R

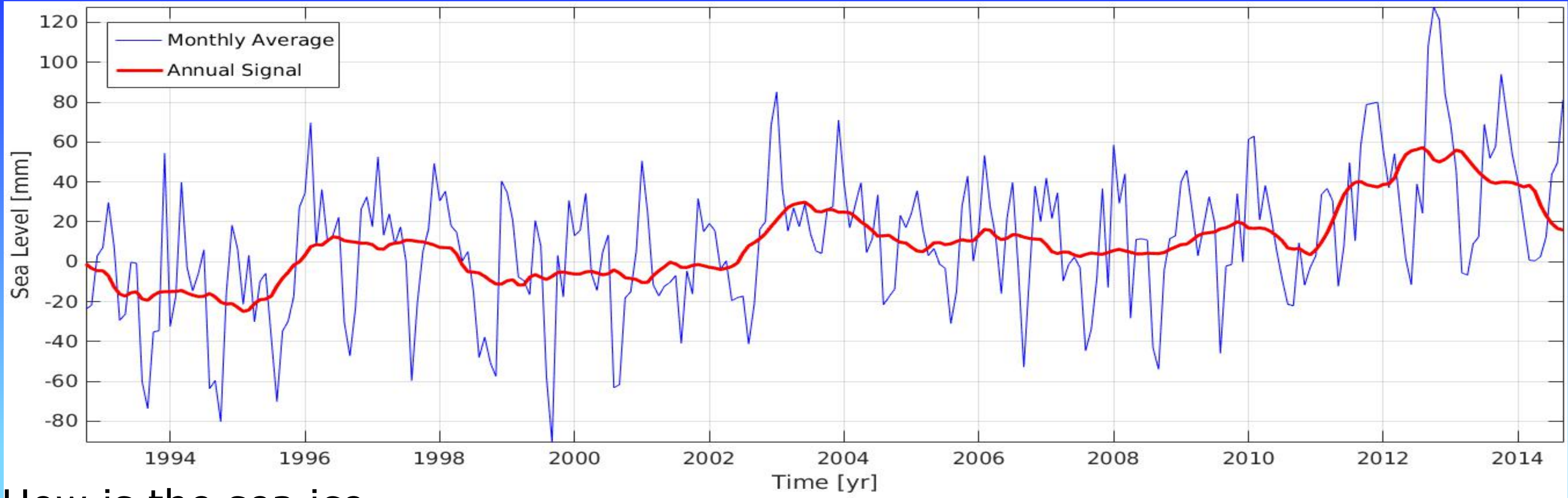


Closing the Sea Level Budget 1993-2016



Arctic mean sea level change

Increase of 2.2 ± 1.1 mm/year

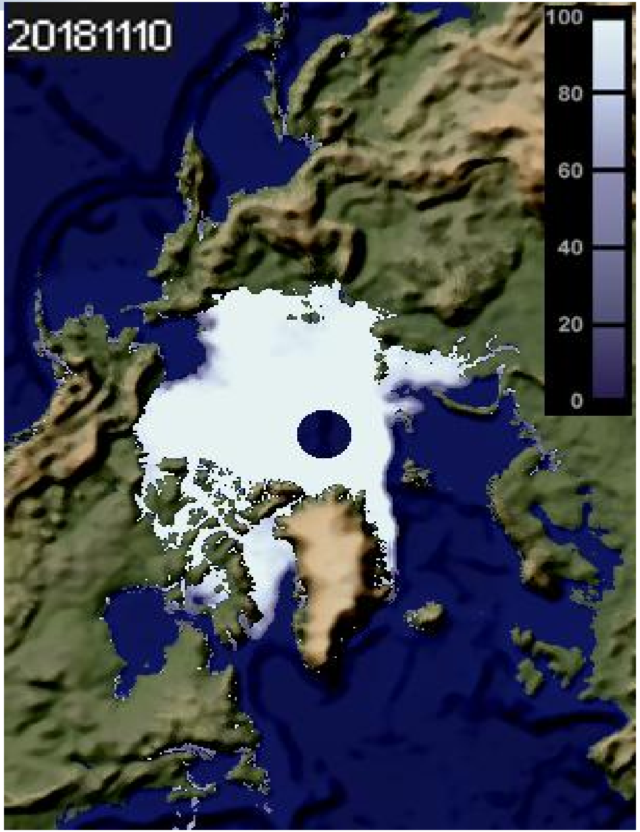


How is the sea ice effect removed from the sea level obs?

Johannessen and Andersen, 2017

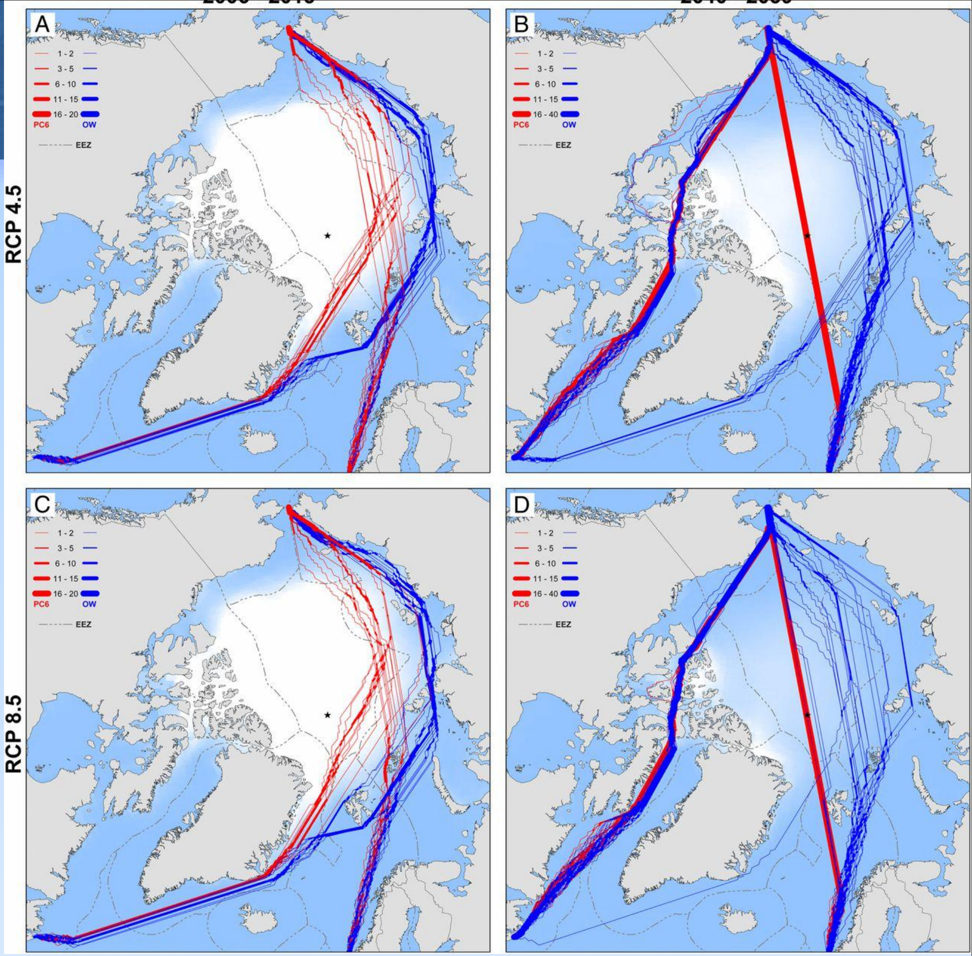
Summary

- ***Sea ice thickness time series from Cryosat-2*** and from ICESat for climate and operational sea ice service;
- Altimetry sampling over the ocean in Polar Regions to constrain ocean models through data assimilation;
- Reliable restitution of sea level in the leads to reach the retrieval accuracy required to monitor Climate Change.
- ***SMOS like observations*** of thin sea ice below 0.5m.
- ***Medium-resolution (5-10 km) passive mircowave*** observations of sea ice concentration, area and extent.
- SAR for sea ice drift, lead fractions and Marginal Ice Zone dynamics



Summary

- **http://cci.esa.int**
- **http://www.arctic-roos.org**
- http://bulletin.mercator-ocean.fr/
- **https://portal.polar-tep.eo.esa.int.**



Ship routing through the Arctic
Today and in the Future