esa

→ EARTH OBSERVATION SUMMER SCHOOL

Earth System Monitoring & Modelling

30 July–10 August 2018 | ESA–ESRIN | Frascati (Rome) Italy

Remote Sensing of Sea Ice – Sea ice concentration

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Technical University of Denmark DTU

European Space Agency

Acknowledgements

Thomas Lavergne[1], Atle Macdonald Sørensen[1], Stefan Kern[2], Rasmus Tonboe[3], Dirk Notz[4], Signe Aaboe[1], Louisa Bell[4], Gorm Dybkjær[3], Steinar Eastwood[1], Carolina Gabarro[5], Georg Heygster[6], Mari Anne Killie[1], Matilde Brandt Kreiner[3], John Lavelle[3], Roberto Saldo[7], Stein Sandven[8], Leif Toudal Pedersen[7]

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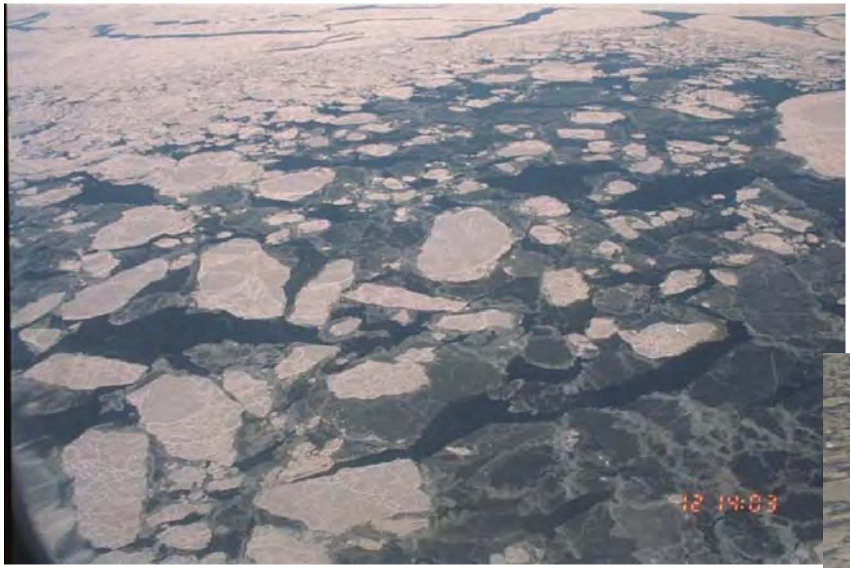
[7]Danish Technical University-Space, Copenhagen, Denmark
[8]Nansen Environmental and Remote Sensing Center, Bergen, Norway

And others ☺ + a number of figures from Ulaby et al, 1986

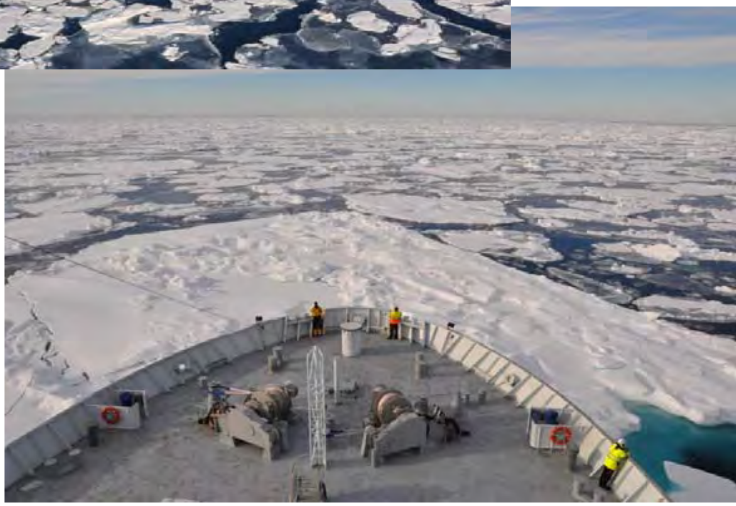
The EUMETSAT Network of Satellite Application Facilities | OSI SAF Ocean and Sea Ice | Copernicus Europe's eyes on Earth | Danmarks Meteorologiske Institut | cci | Technical University of Denmark DTU

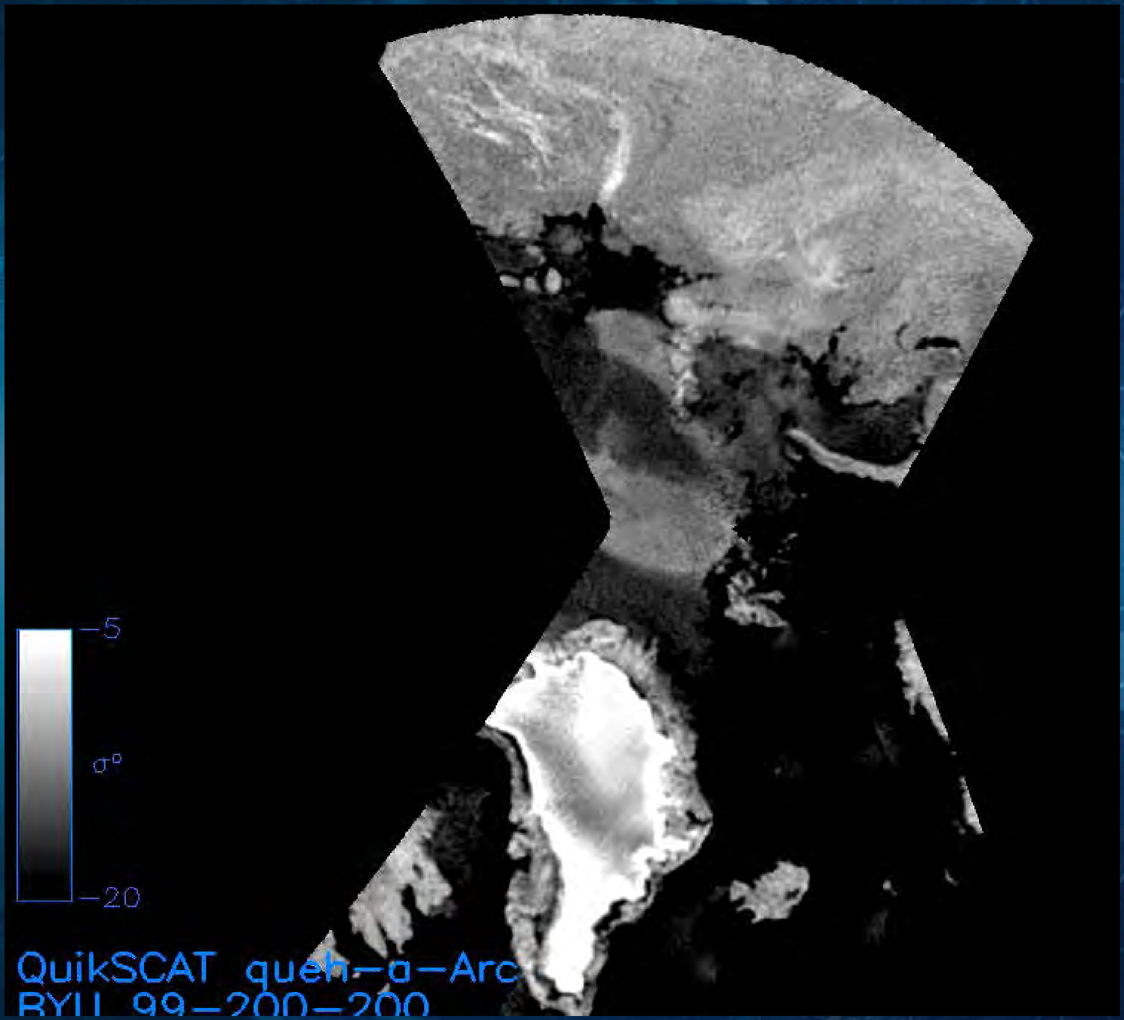
In situ observations – Oden/LOMROG 2009

Airborne observations – new ice & icebergs



Navigation in ice





Arctic Sea ice 1999-2007

QuikSCAT

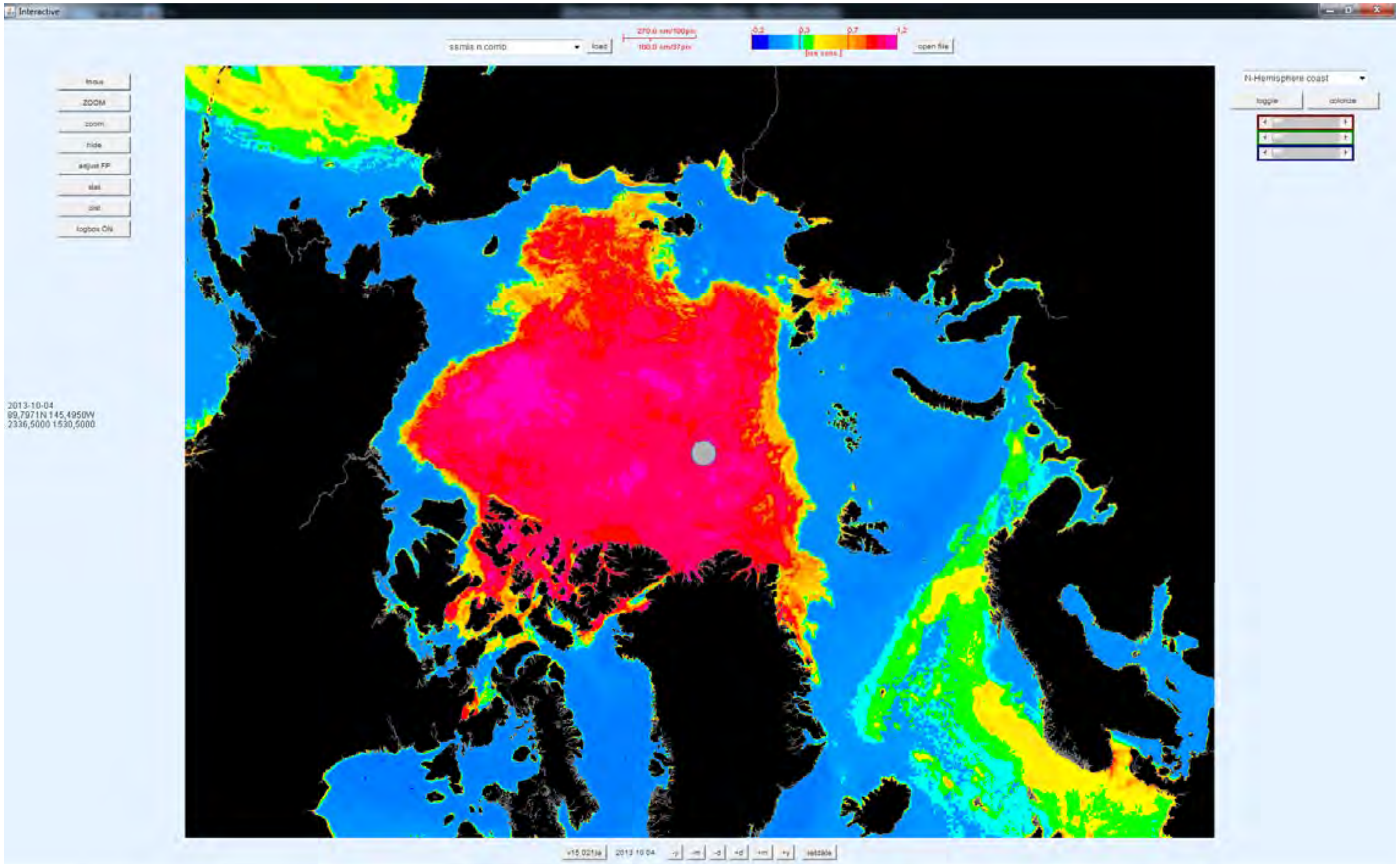
From Brigham Young University, US

MODIS Visible light imagery of the Arctic

Aug 24, 2013

Oct 4, 2013

Microwave imagery during the Polar Night (October 4, 2013)

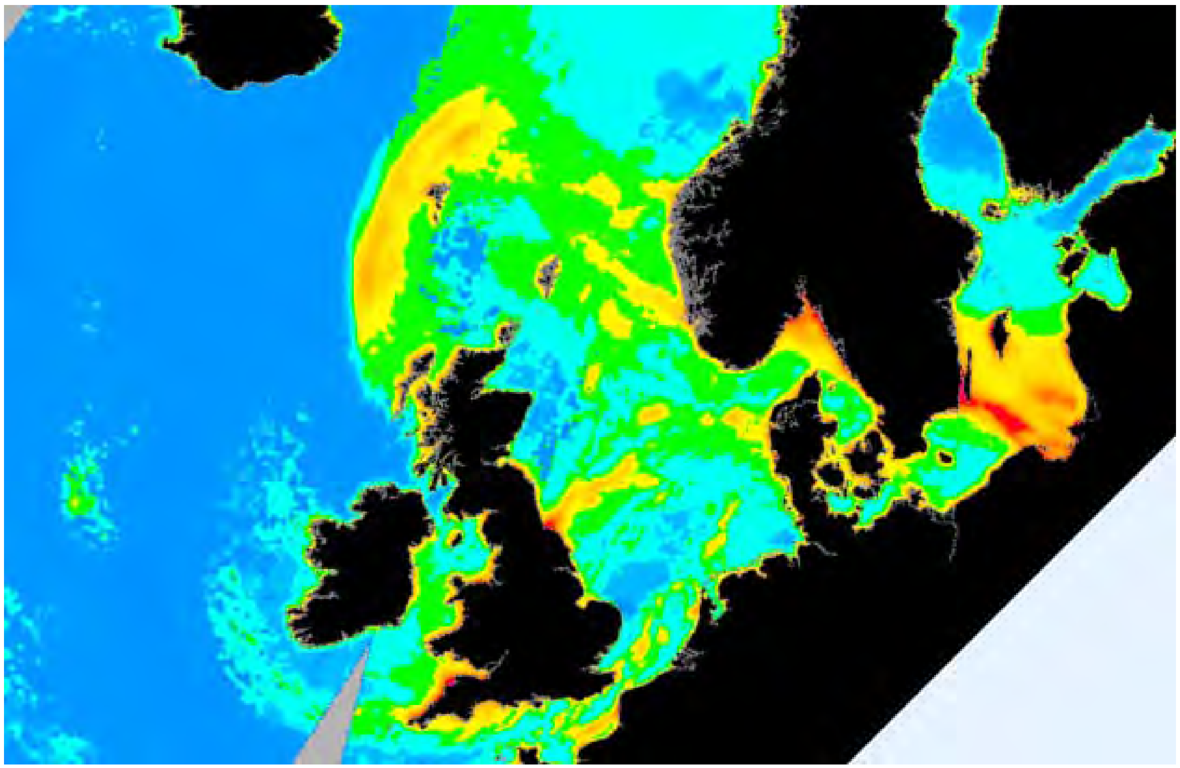


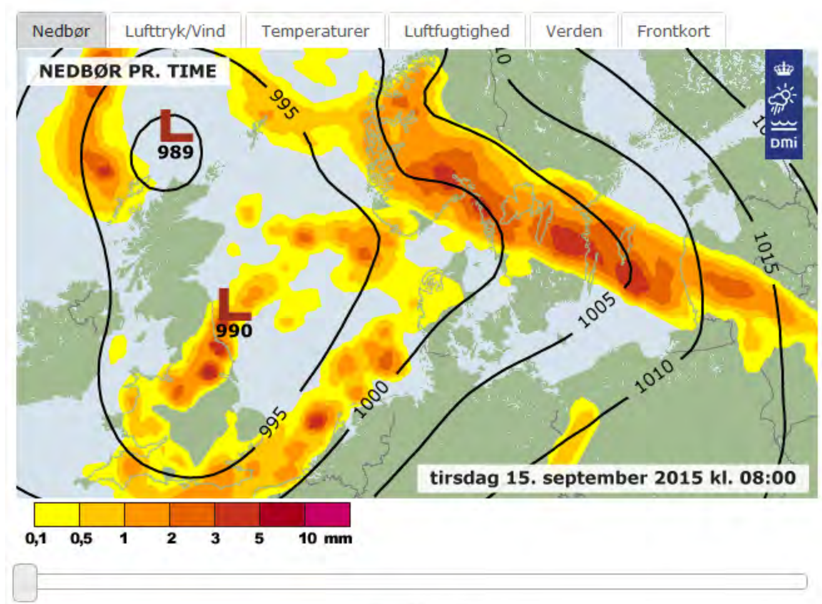
Microwave radiometry

All weather
Day and night

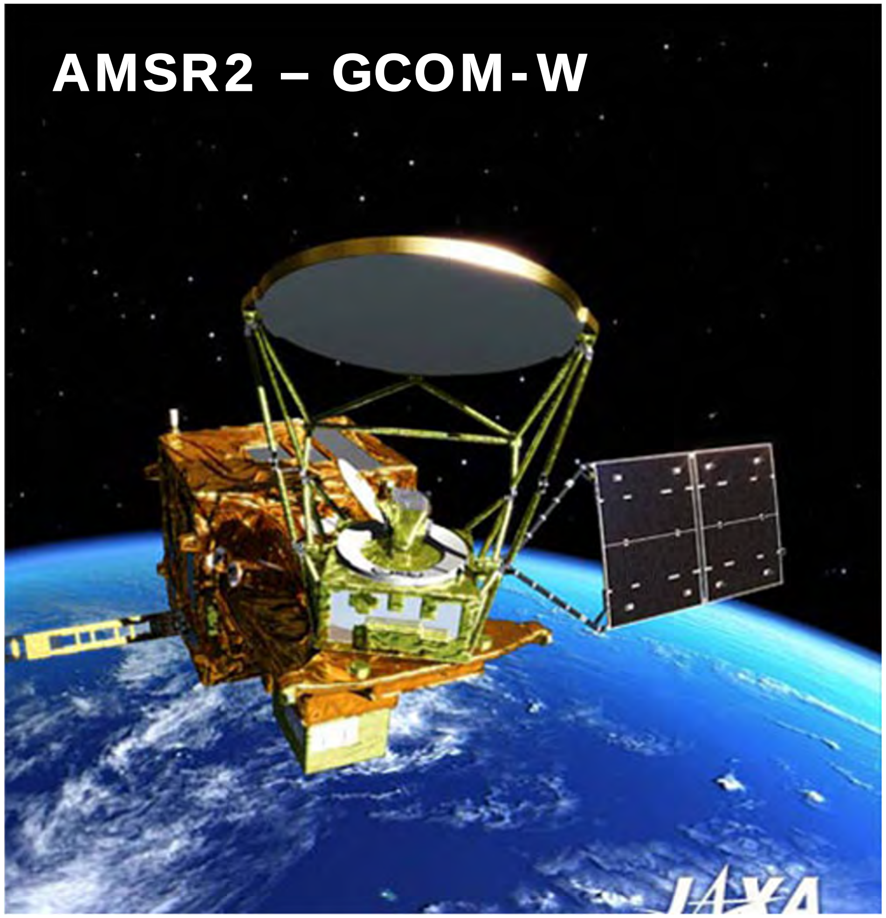
However, at higher frequencies not independent of weather influence

September 15, 2015, morning AMSR2, atmospheric influence

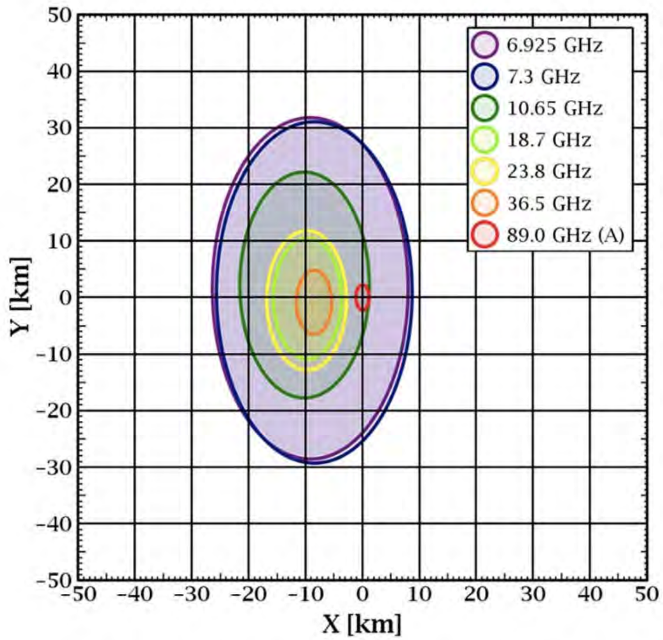




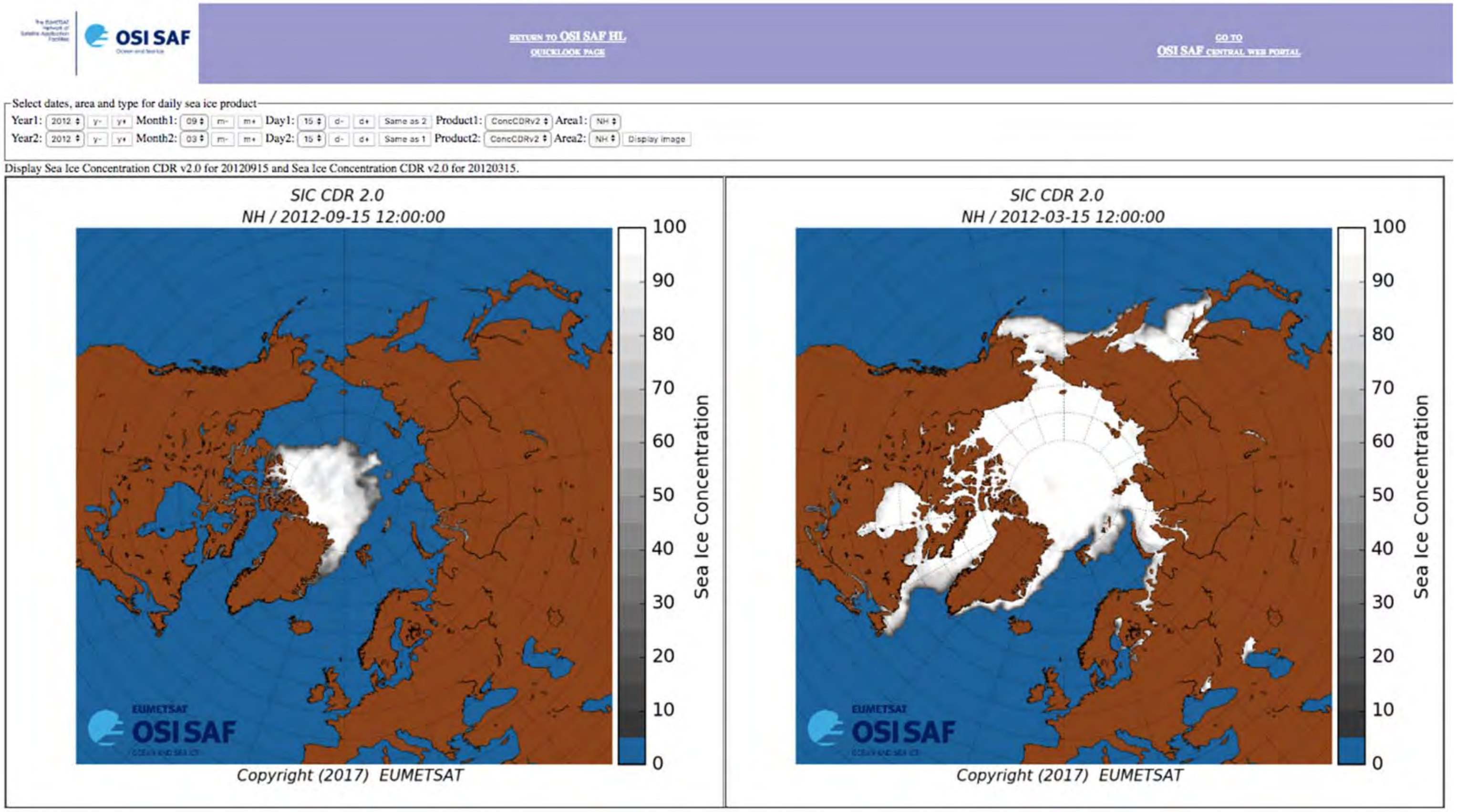
Resolution – why do we want high frequencies?



Spatial resolution
Antenna beamwidth
$\theta_{3dB} \sim 1.2\lambda/D$

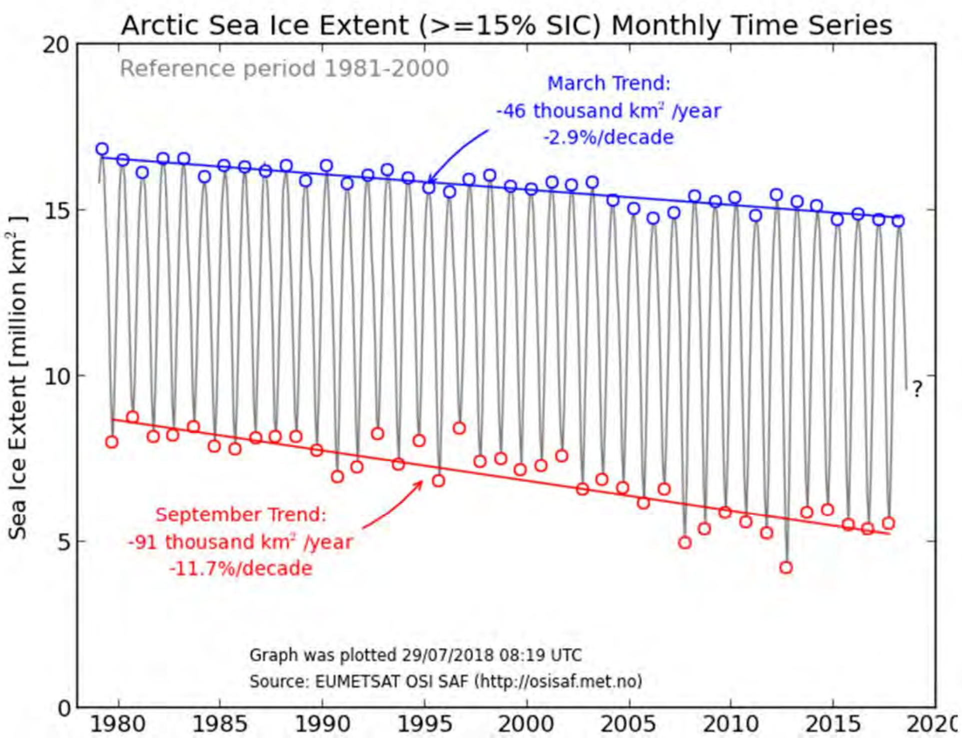


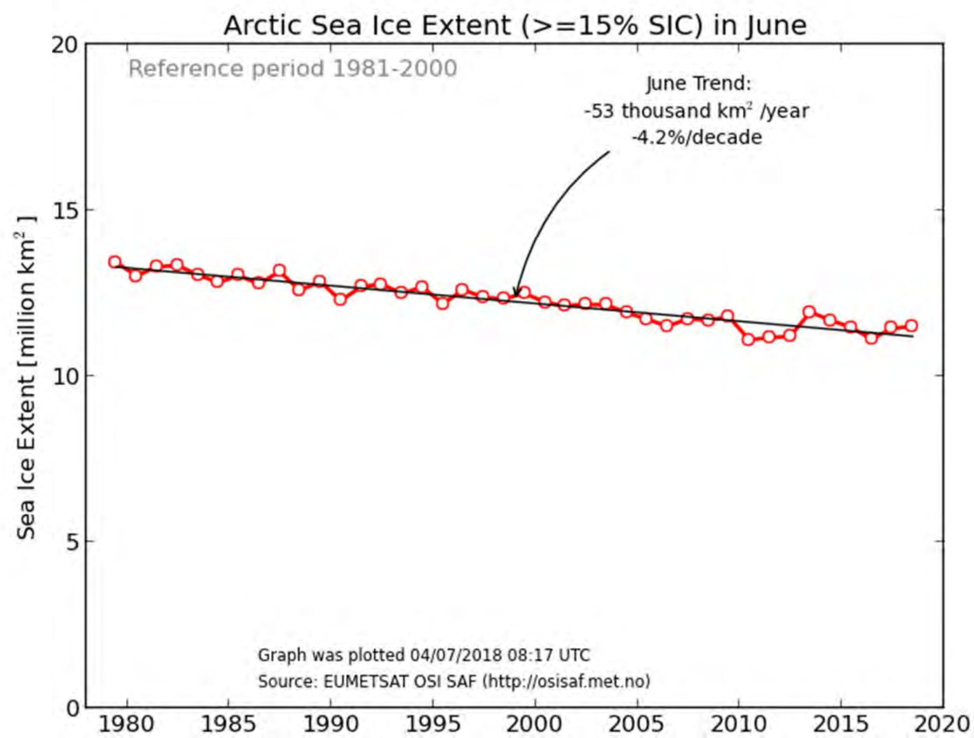
OSISAF/SICCI Sea Ice CDR
http://osisaf.met.no/p/ice_reproc_daily_twoimg.php



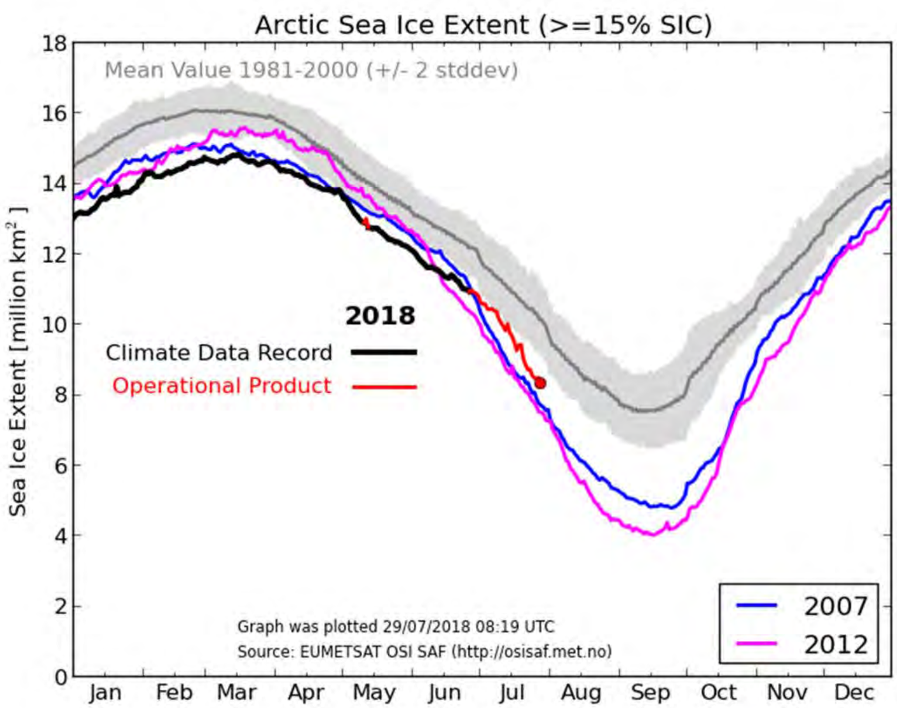
Atmospheric correction and proper algorithm selection allows daily near weather independent sea ice concentrations since late 1978

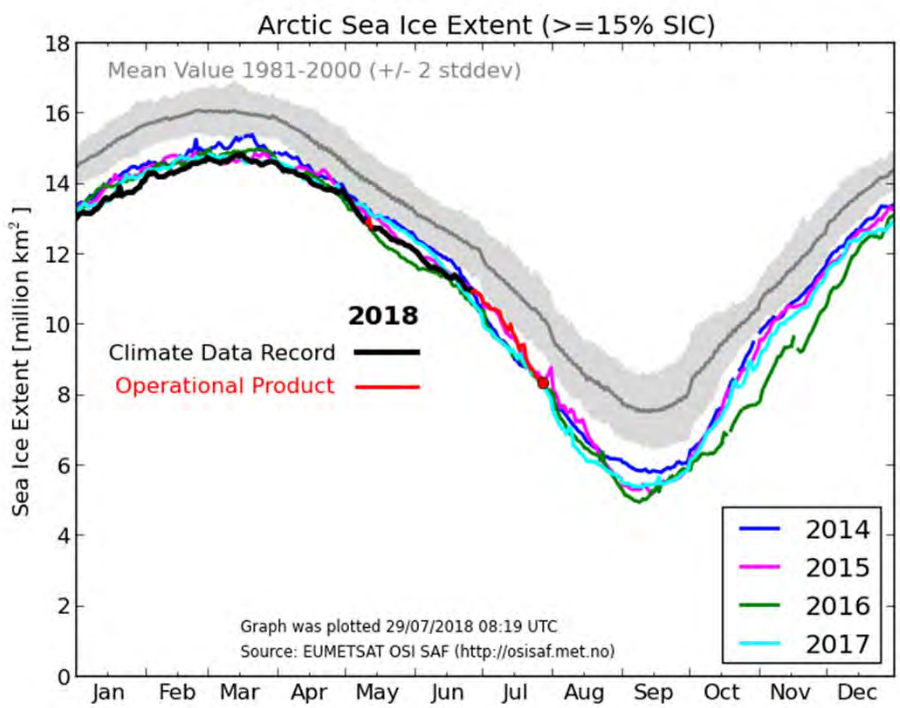
OSISAF Arctic Sea Ice extent CDR



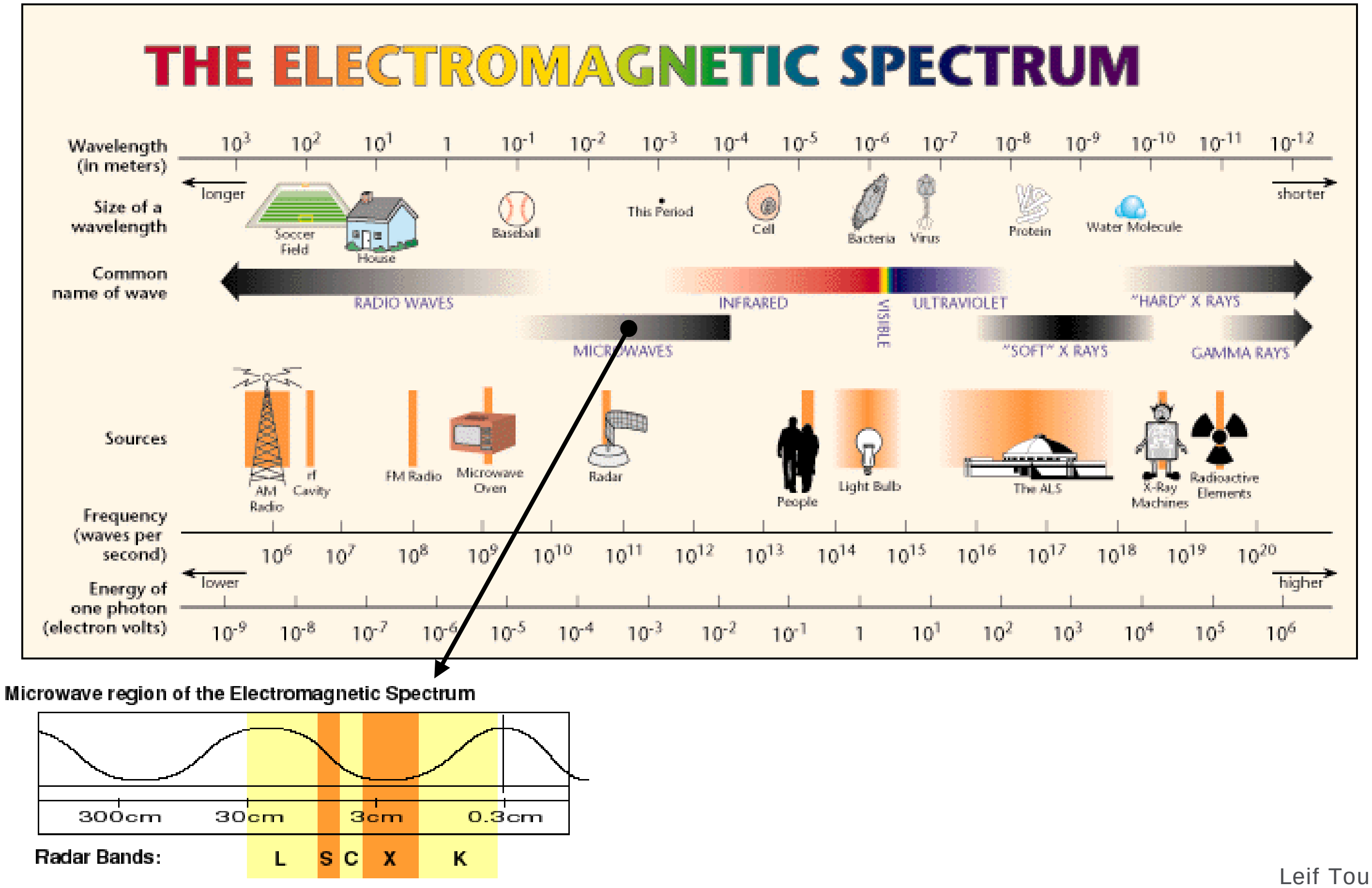


OSISAF Arctic Sea Ice extent CDR



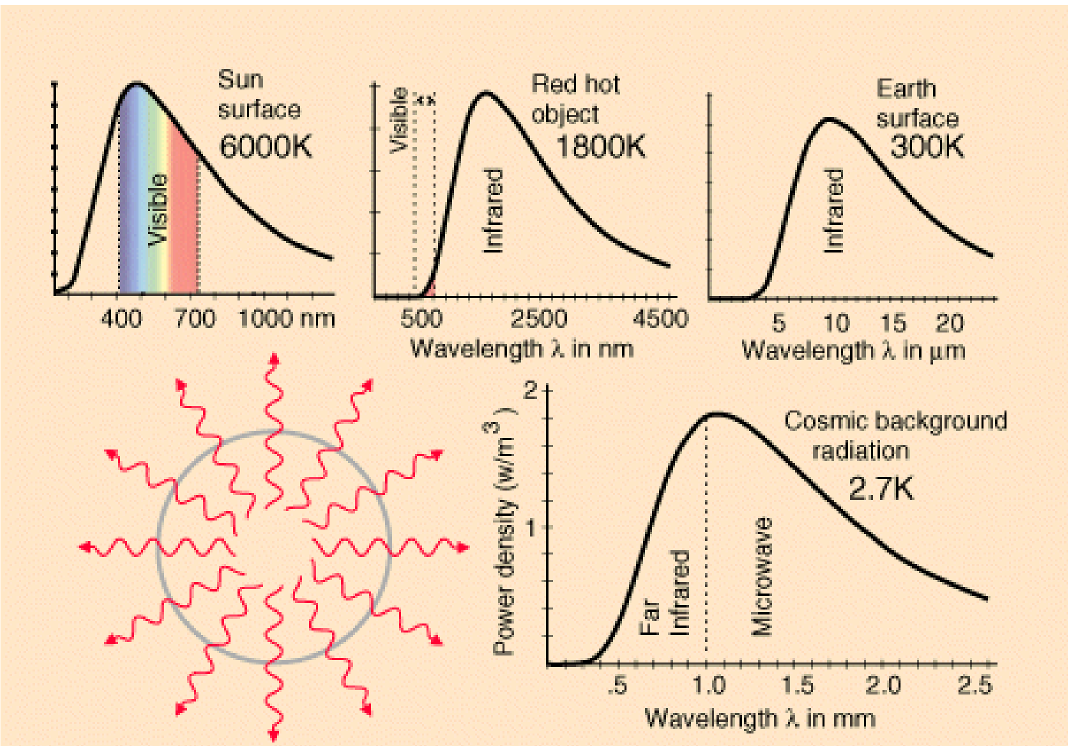


Microwaves?



THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
Size of a wavelength
Common name of wave
Sources
Frequency (waves per second)
Energy of one photon (electron volts)
longer
shorter
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
lower
higher
Microwave region of the Electromagnetic Spectrum
300cm
30cm
3cm
0.3cm
Radar Bands:
L
S
C
X
K

Planck's law of thermal radiation

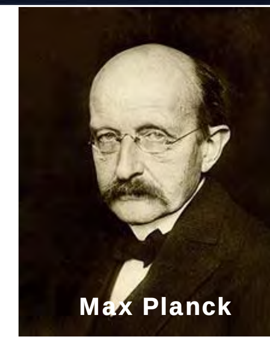


$$E(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$h = 6.625 \times 10^{-27}$ erg- sec (Planck Constant)

$k = 1.38 \times 10^{-16}$ erg/ K (Boltzmann Constant)

$c = 3 \times 10^{10}$ cm/sec (Speed of Light)



Steffan - Boltzmann Law: $\boxed{E = \sigma T^4}$

$\sigma = 5.6705 \times 10^{-5}$ erg - cm^2 - K^{-4}- sec^{-1}

(Steffan - Boltzmann Constant)

Wien Displacement Law: $\boxed{\lambda_{Max} = \frac{3 \times 10^7}{T}}$

(λ in Angstroms T in Kelvin)

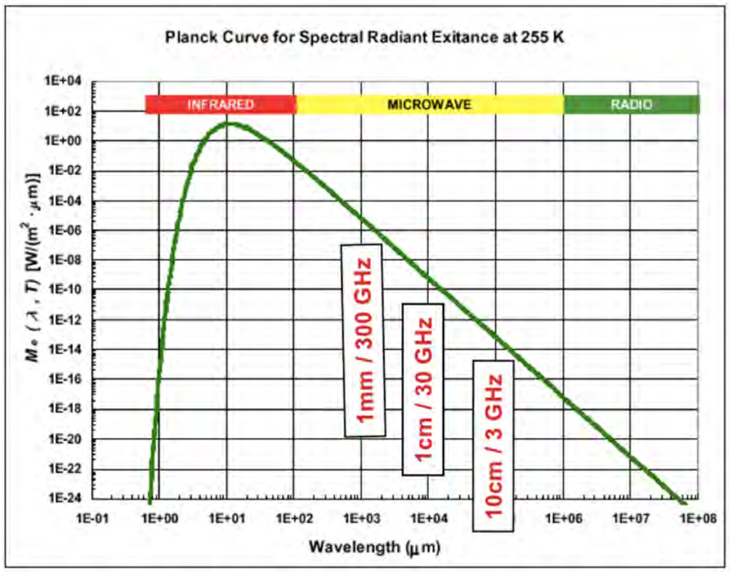
Emissivity and brightness temperature

$T_B = \varepsilon T$ (grey body)

$\varepsilon = T_B \; / \; T$

ε is emissivity

T_B is brightness temperature



In 1900 Max Planck empirically derived an expression for Blackbody Radiation expressed in terms of wavelength $\lambda = c/v$:

$$B_\lambda(T) = \frac{2c^2}{\lambda^5}\frac{h}{e^{\frac{hc}{\lambda kT}} - 1}$$

Wikipedia, 2017

where h is Planck's constant. The Planck law does not suffer from an ultraviolet catastrophe, and agrees well with the experimental data, but its full significance (which ultimately led to quantum theory) was only appreciated several years later. In the limit of very high temperatures or long wavelengths, the term in the exponential becomes small, and so the denominator becomes approximately $hc/\lambda kT$ by power series expansion. Specifically,

$$\frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \approx \frac{1}{\frac{hc}{\lambda kT}} = \frac{\lambda kT}{hc}$$

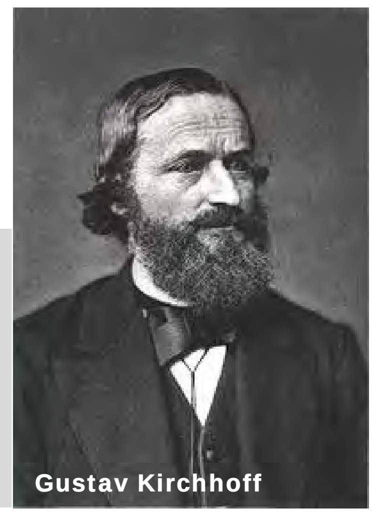
which results in the full Planck Function reducing to

$$B_\lambda(T) = \frac{2ckT}{\lambda^4}$$

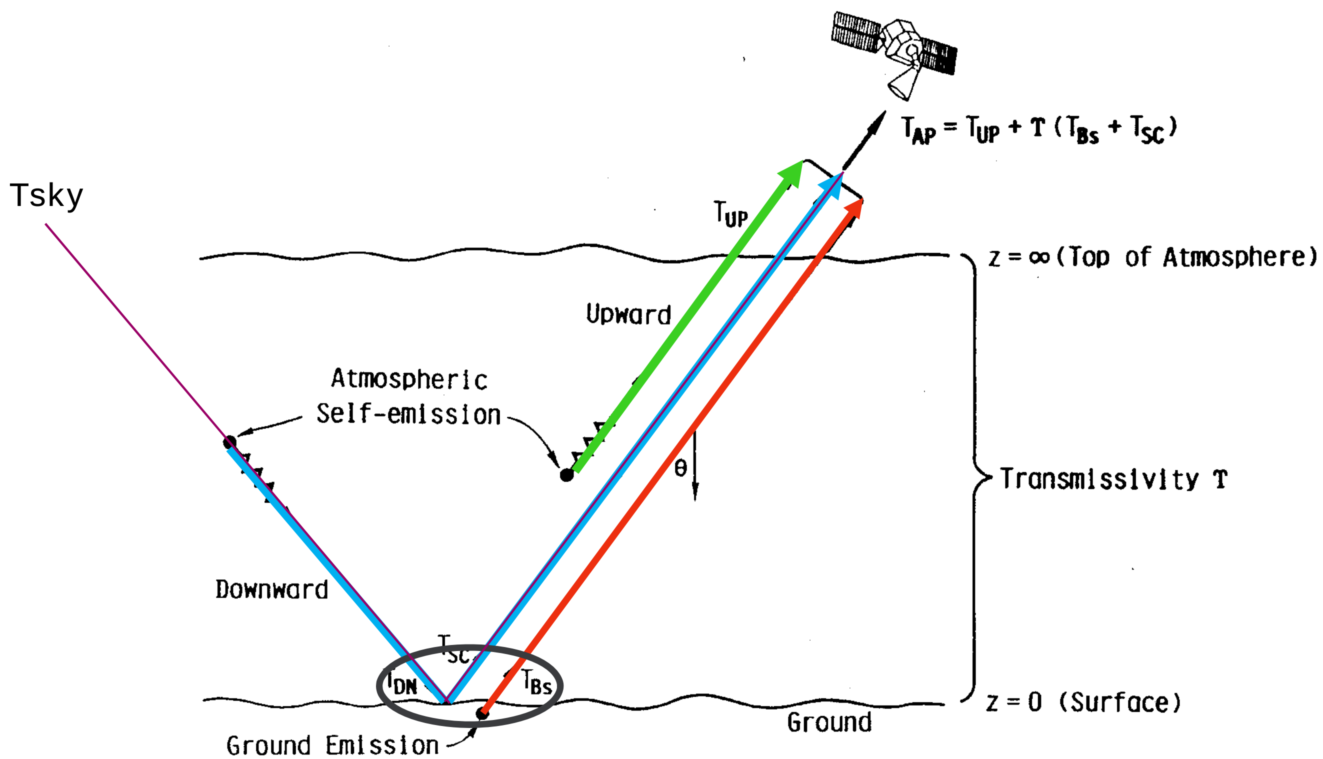
which is identical to the classically derived Rayleigh–Jeans expression.

$\varepsilon = \langle$

In thermodynamic equilibrium emissivity (ε) = absorptivity (α)



The Atmosphere- Radiative transfer



$$T_{ap} = T_{UP} + \varepsilon T_S (e^{-\tau}) + T_{DN}(1-\varepsilon)(e^{-\tau}) + T_{SP}(1-\varepsilon)(e^{-2\tau})$$

$$T_{UP} = \frac{1}{\cos(\theta_0)} \int_0^H T_a(z)\alpha(z) e^{-\tau(z,H)/\cos(\theta_0)} dz$$

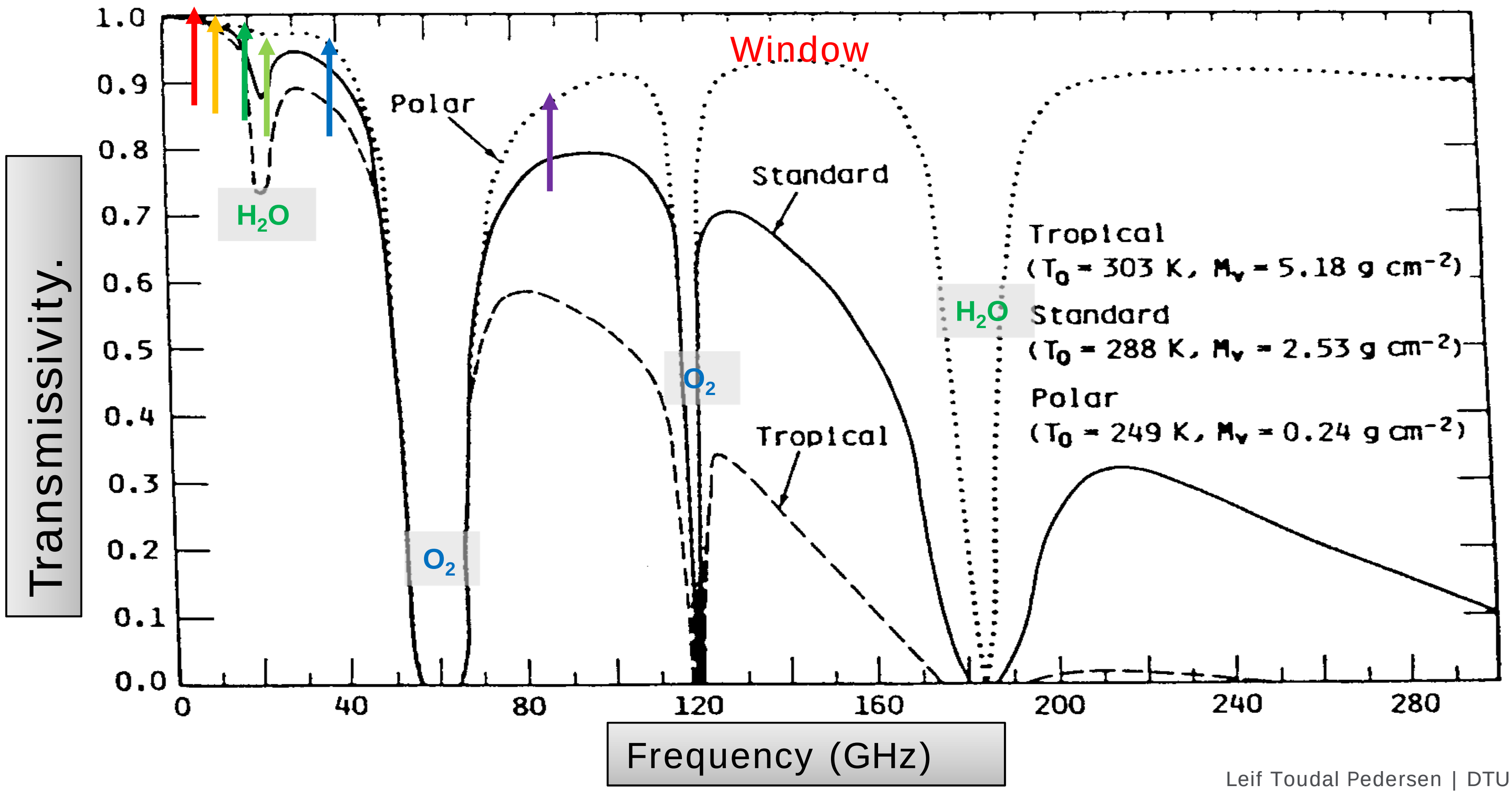
Upwelling

$$\tau(z,H) = \int_z^H \alpha(z) dz$$

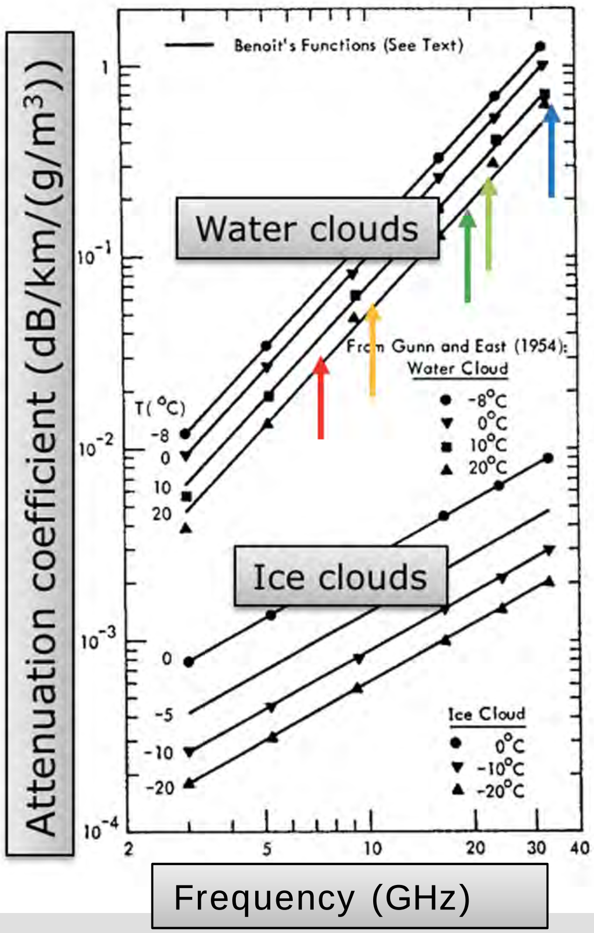
$$T_{DN} = \frac{1}{\cos(\theta_0)} \int_0^H T_a(z)\alpha(z) e^{-\tau(0,Z)/\cos(\theta_0)} dz$$

Downwelling

The Atmosphere - Transmissivity



Cloud attenuation and Downwelling temperature (T_{DN})



Typical T_{DN} values at higher latitudes

Frequency [GHz]	T_{DN} [K]	|exp(-τ)|
6.9	3-5	0.982
10.7	4-6	0.979
18.7	7-17	0.955
23.8	10-35	0.918
36.5	20-40	0.886
50.5	120-140	0.487
52.8	210-230	0.139
89	30-110	0.749

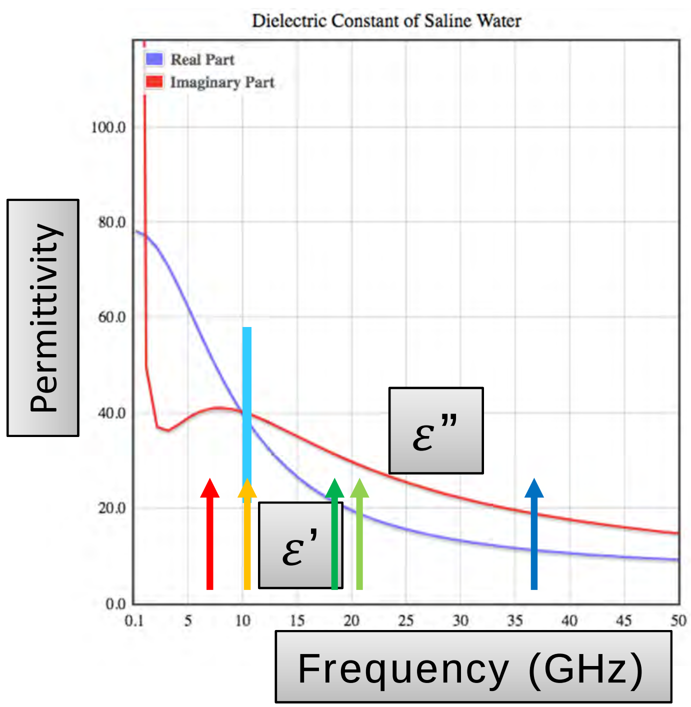
Incl.
O_2
H_20
Cloud
T_{air}

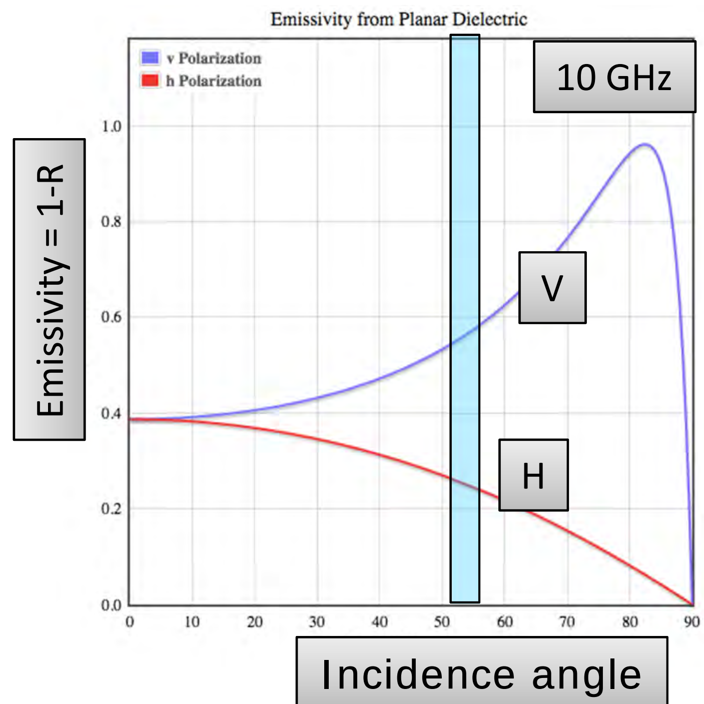
Excl.
T_{SC}

Water – Ocean surface reflection
Fresnell reflection coefficients

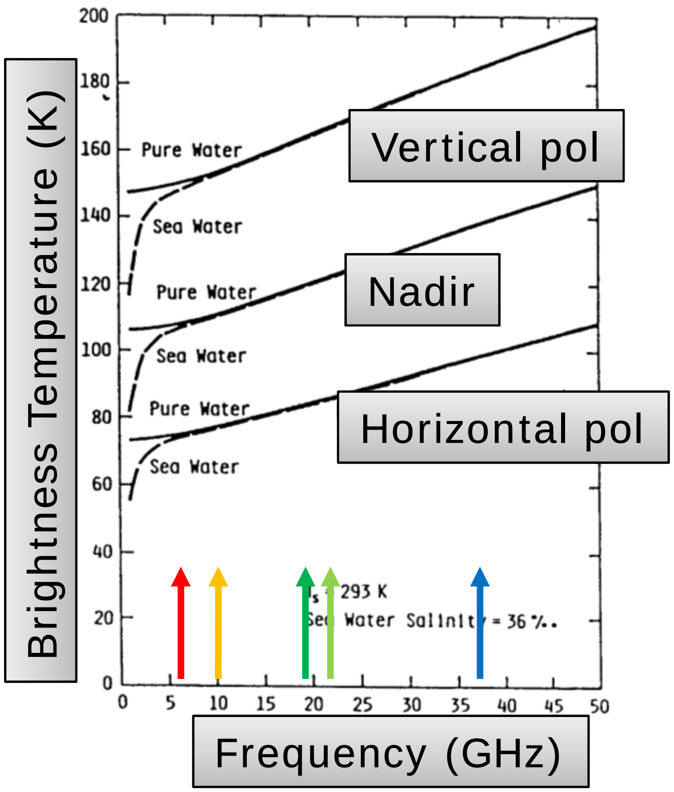
$$R_v = \left| \frac{\varepsilon\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2 \qquad R_h = \left| \frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2$$

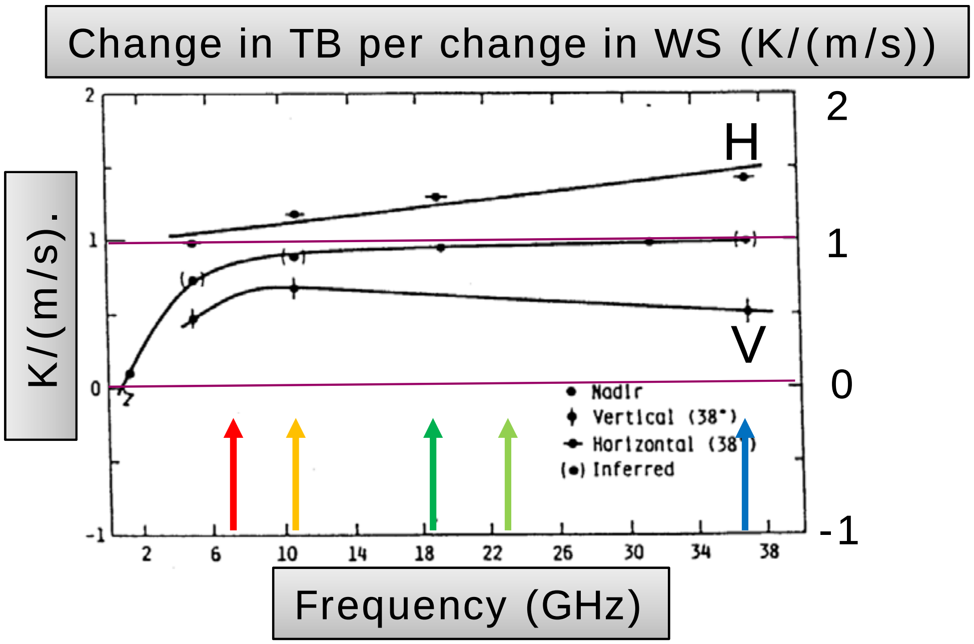
ε is relative permittivity
θ is incidence angle



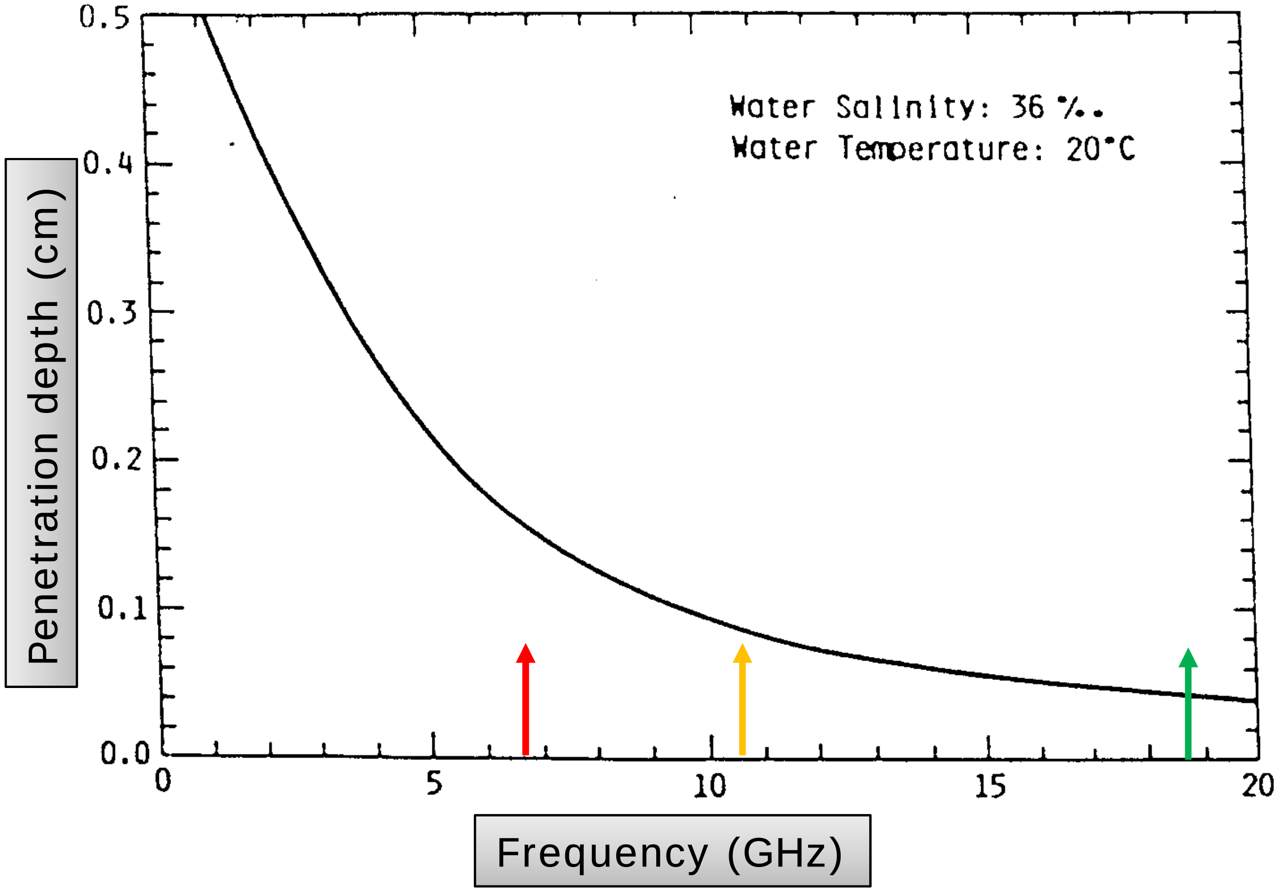


Water - Brightness temperature
The effect of wind





Water - Microwave penetration depth

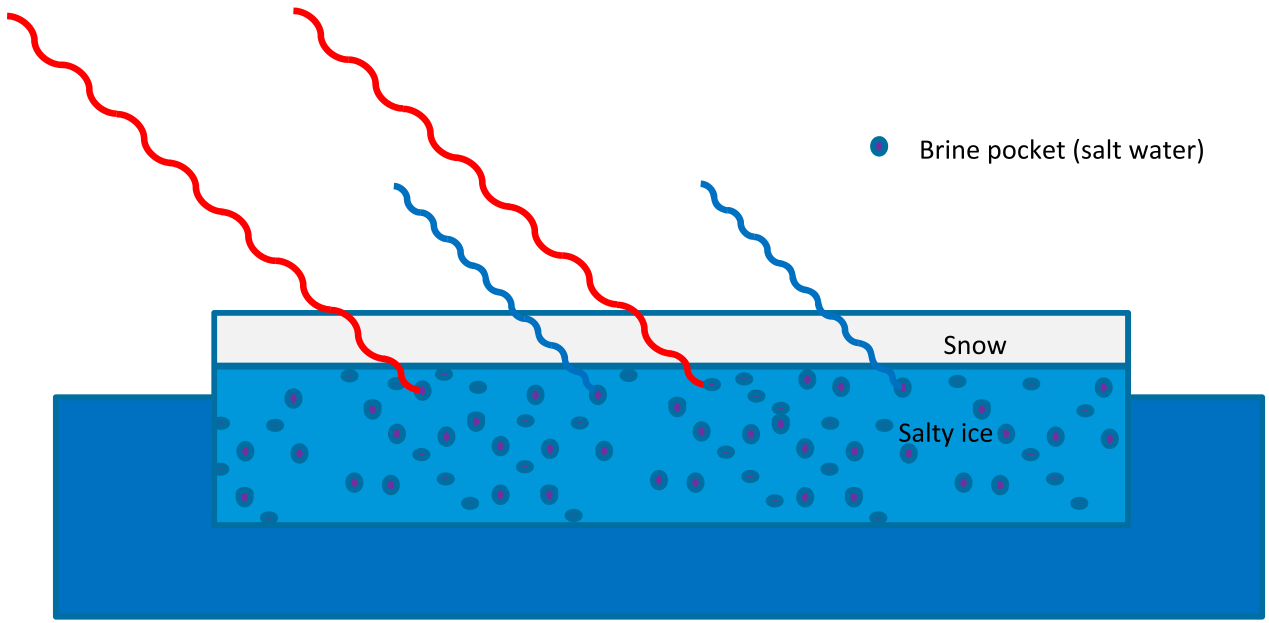


0.5 to 1 mm water on top of ice will have the same T_B as the ocean and cannot be distinguished from open water

Above 5 GHz the curve looks almost the same also for lower salinity and temperatures

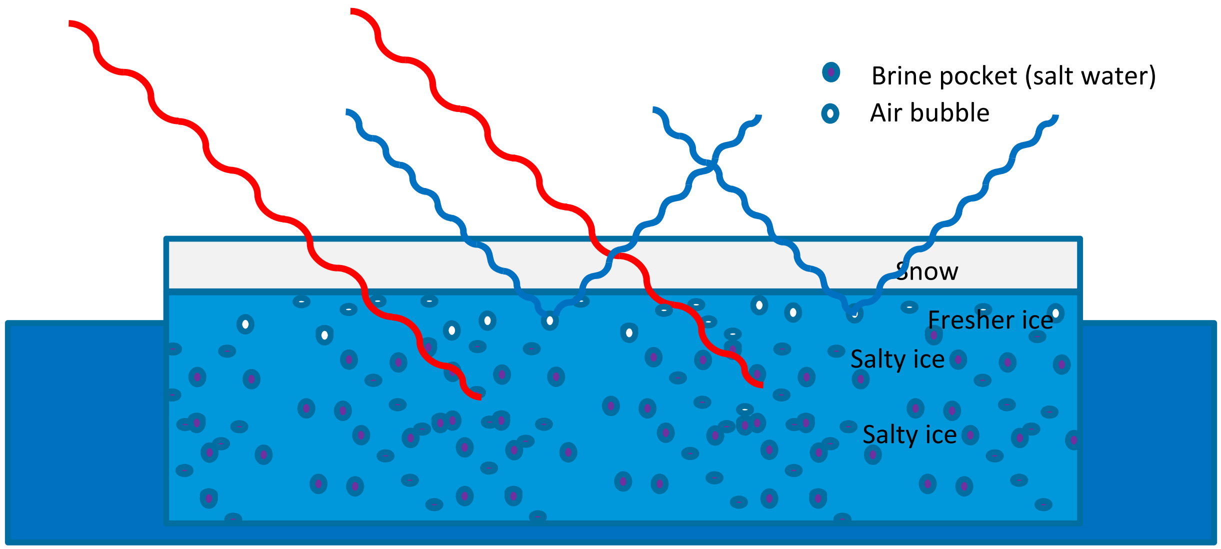
Ice - First-year ice signatures - Winter

Absorbs almost almost all incoming radiation –
nearly a black body at microwave wavelengths (emissivity ~0.9)



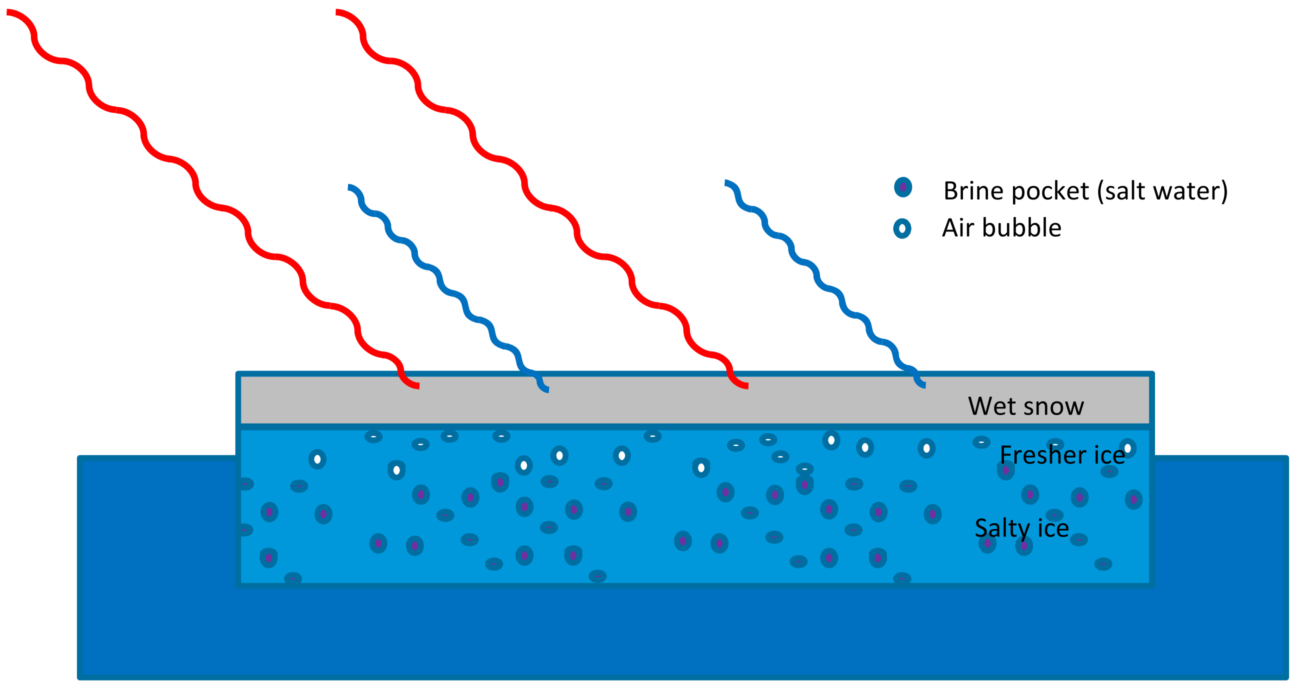
Ice - Multi-year ice signatures - Winter

Absorbs almost all incoming radiation at longer wavelengths – nearly a black body (emissivity ~0.9)
Scatters radiation at shorter wavelengths (<2 cm) –> lower emissivity

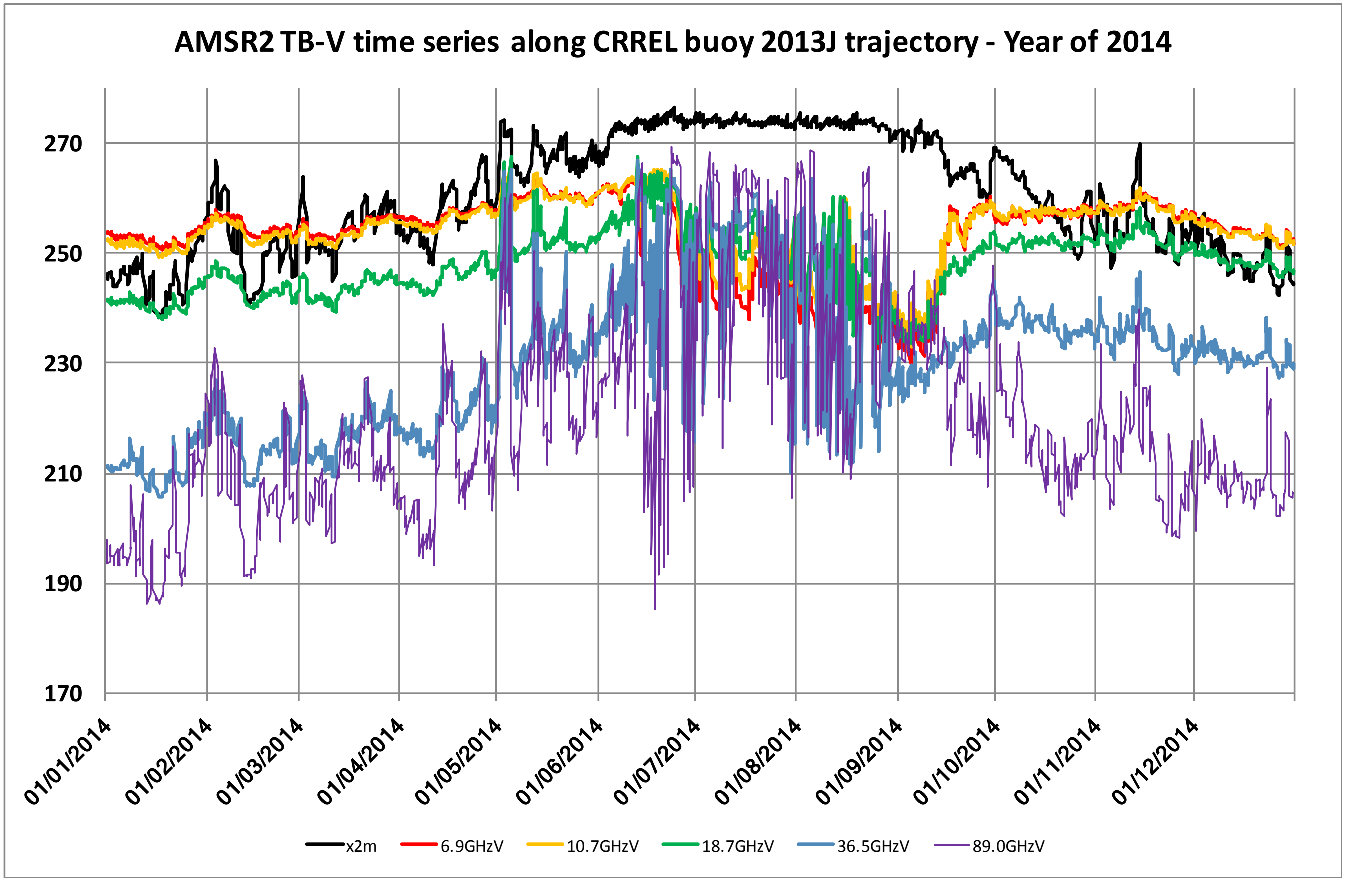


Ice - Signatures- Summer

Wet snow absorbs almost all incoming radiation -> nearly a black body (emissivity ~0.9)



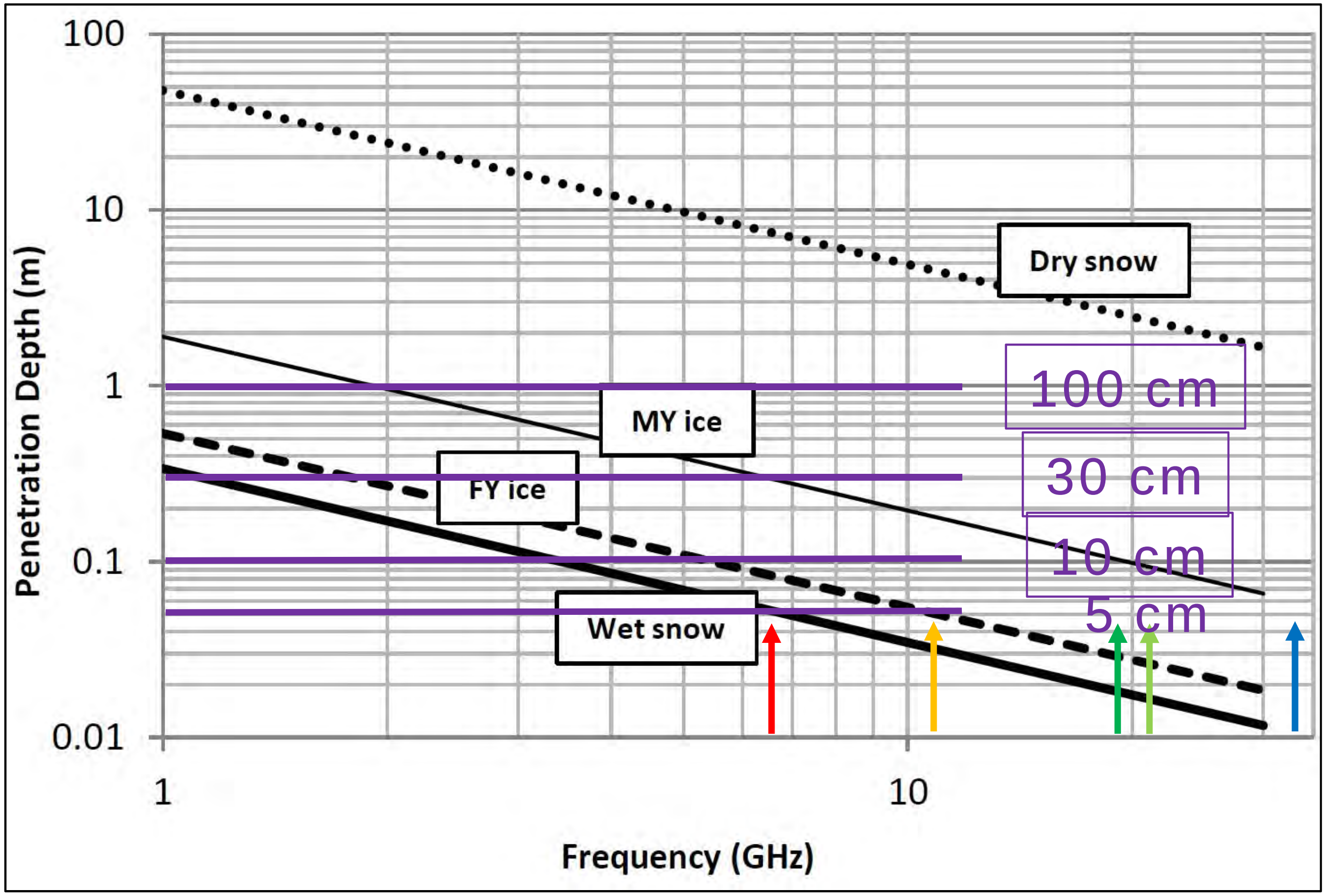
Ice and snow - Seasonal cycle of TBs



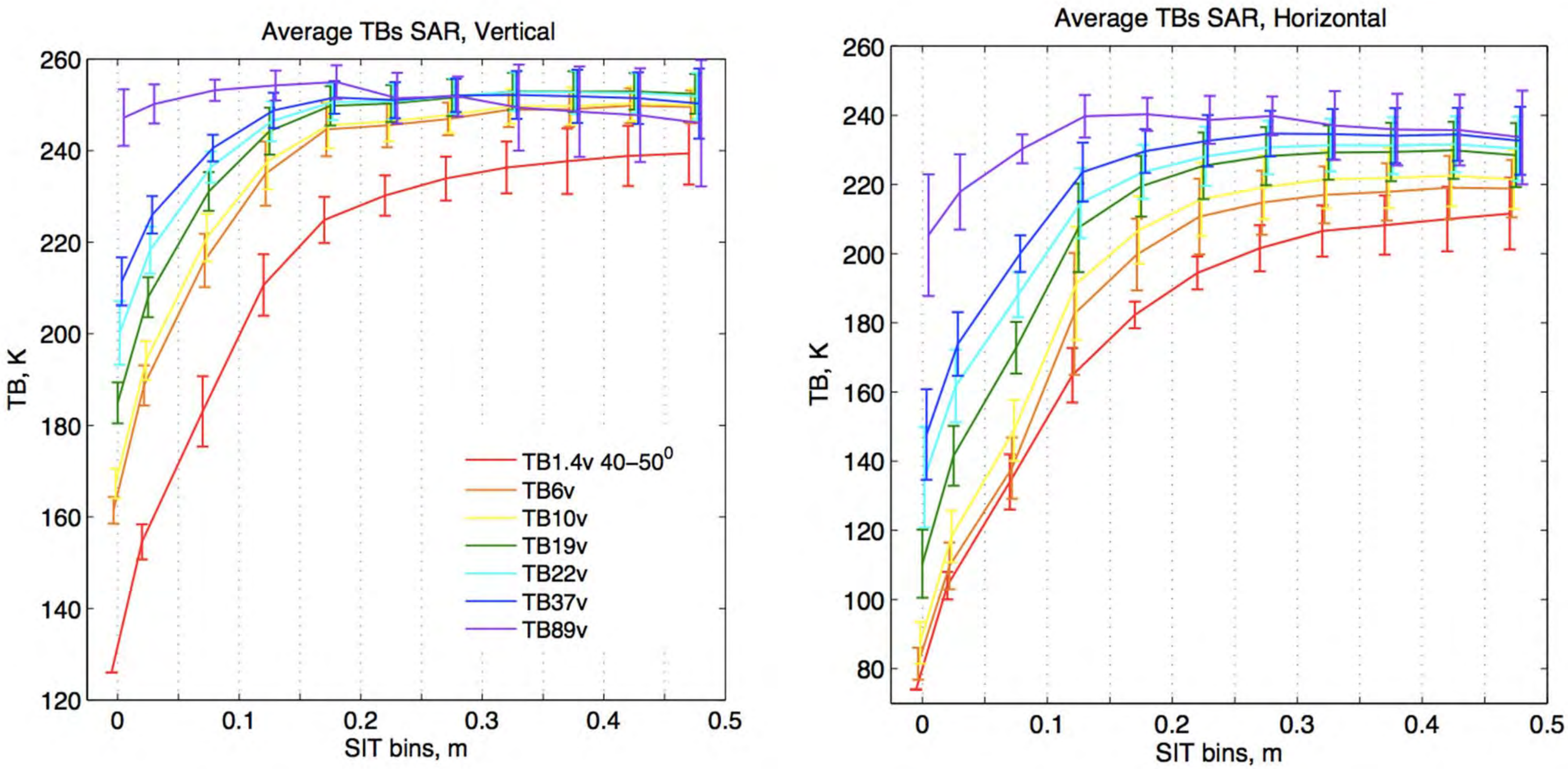
From the ESA CCI Sea ice concentration reference dataset

https://figshare.com/articles/Reference_dataset_for_sea_ice_concentration/6626549

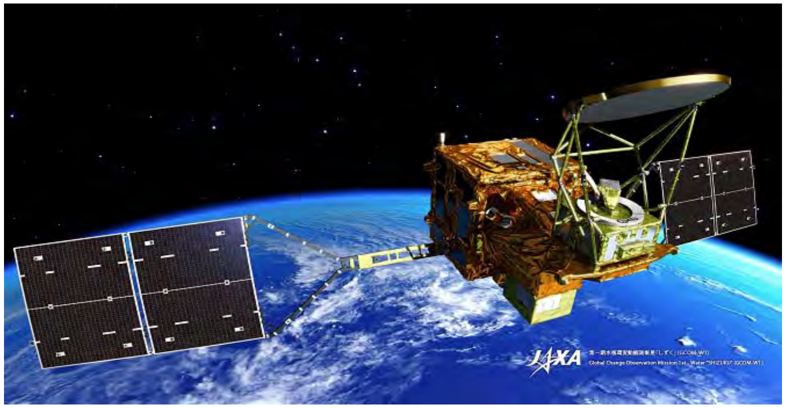
Ice and snow - Penetration depth



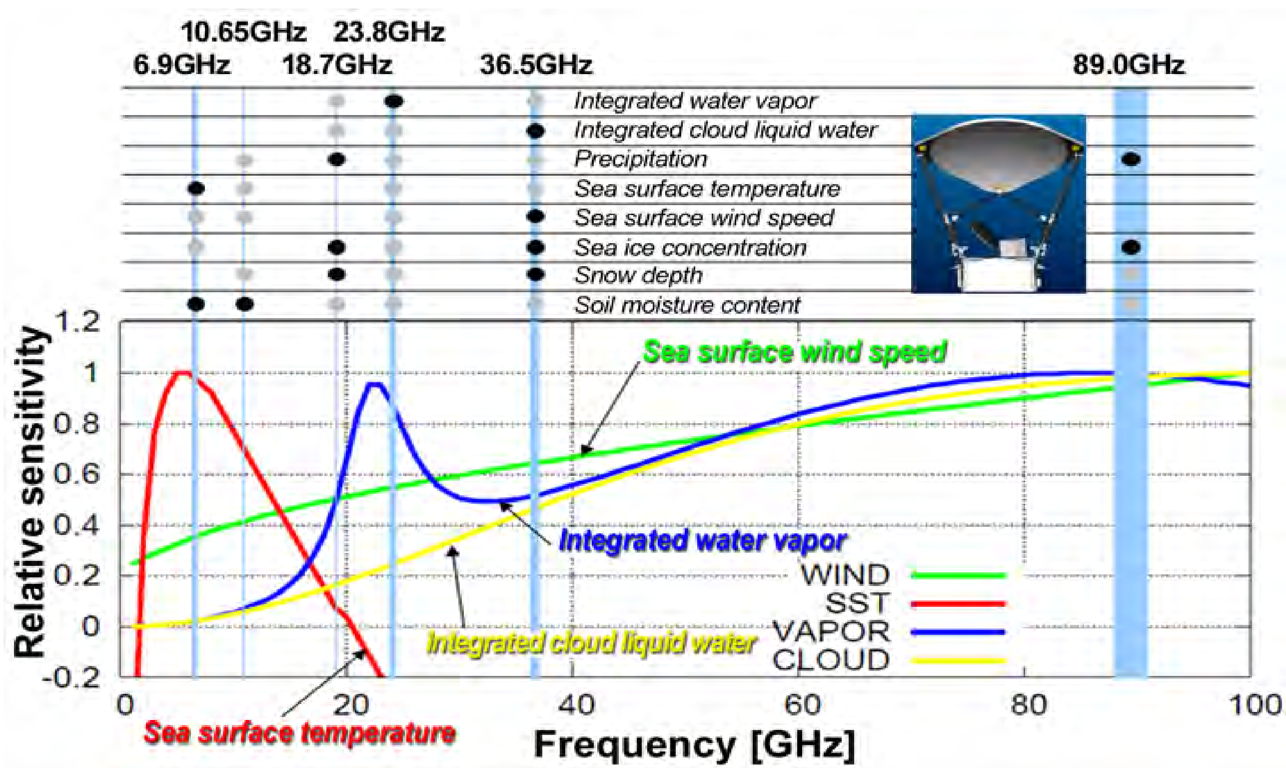
The influence of ice thickness (thin ice)



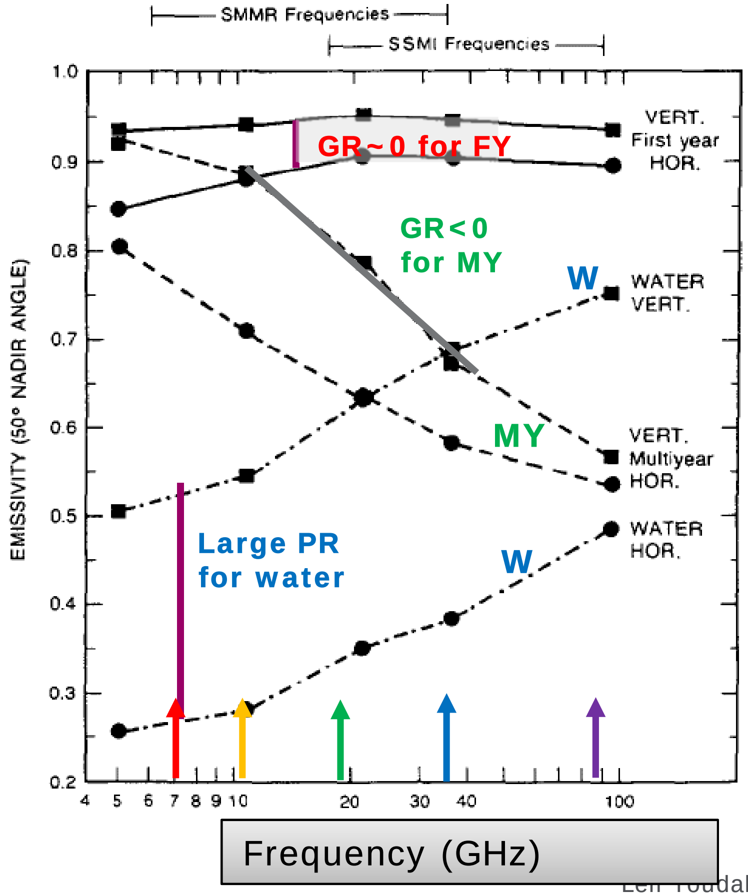
AMSR2 on JAXA's GCOM-W



AMSR2 Channel Set					
Center Freq.	Band width	Pol.	Beam width	Ground res.	Sampling interval
GHz	MHz		degree	km	km
6.925/7.3	350	V/H	1.8	35 x 62	10
10.65	100		1.2	24 x 42	
18.7	200		0.65	14 x 22	
23.8	400		0.75	15 x 26	
36.5	1000		0.35	7 x 12	
89.0	3000		0.15	3 x 5	5



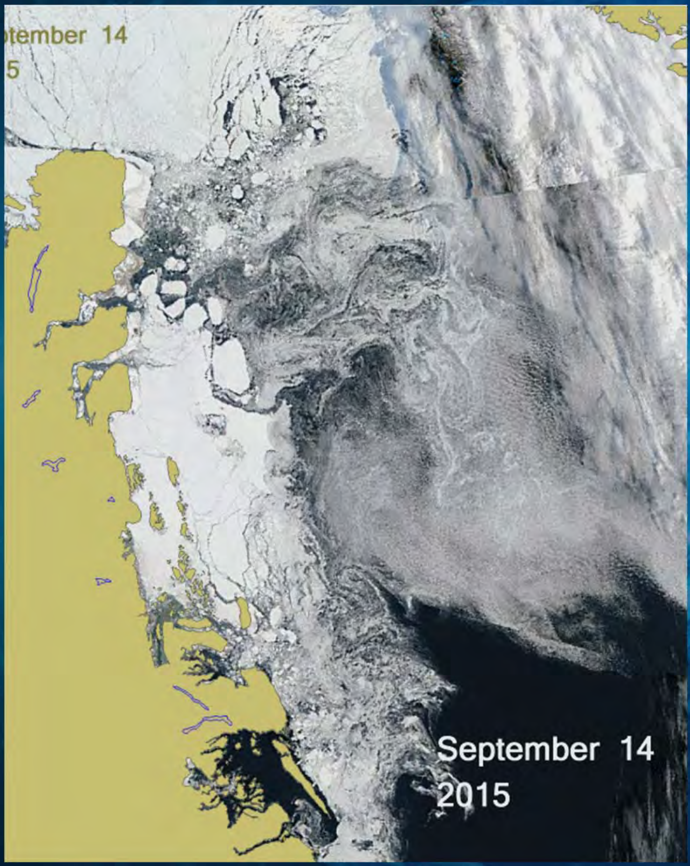
Signature - Summary

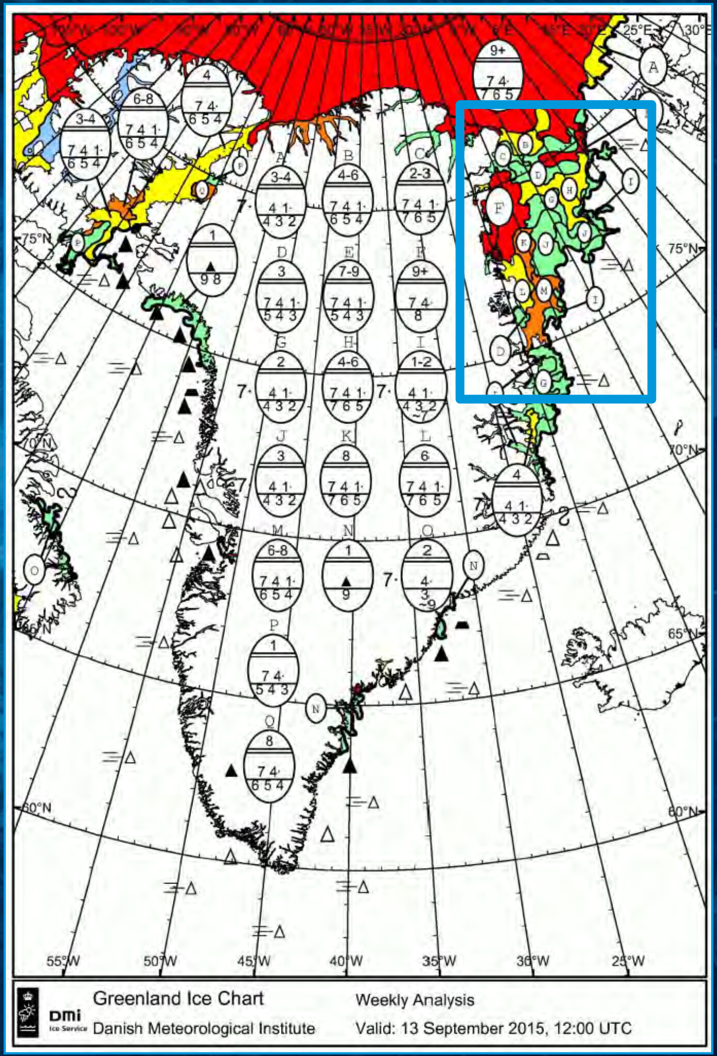


End of part 1

Thank you ☺

Icecharts


September 14
2015


Greenland Ice Chart
Weekly Analysis
Danish Meteorological Institute
Valid: 13 September 2015, 12:00 UTC
DMI

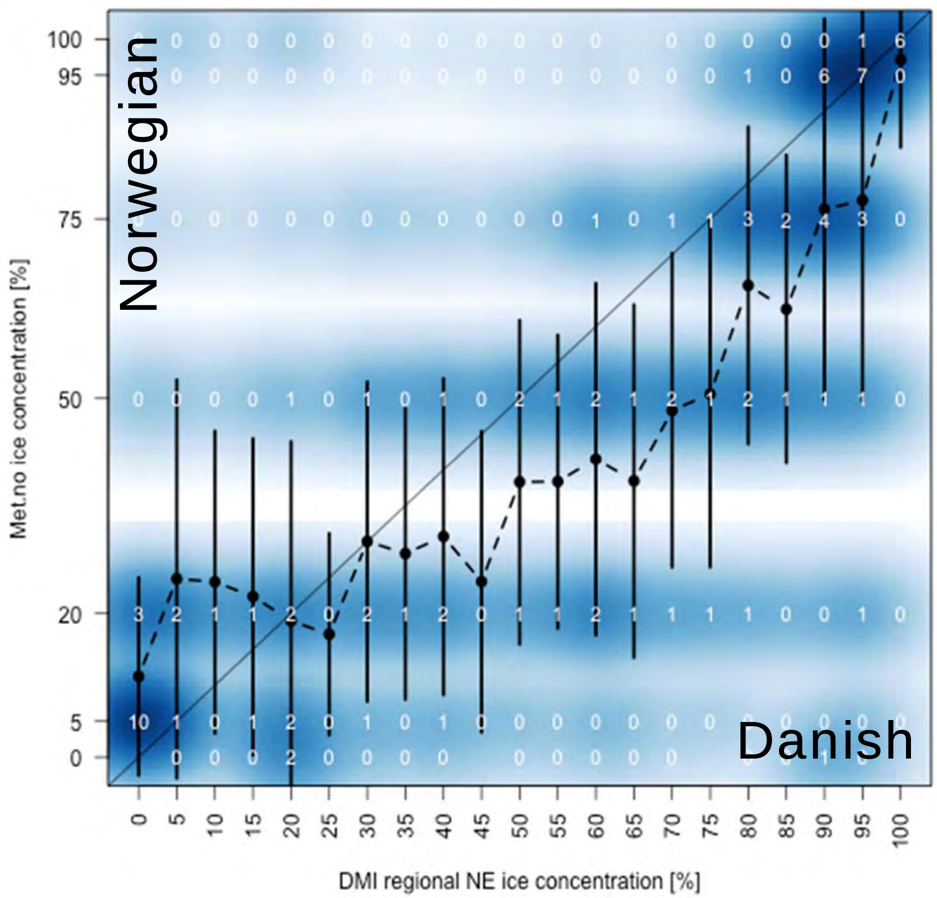
Include volume scattering

$$T_B = \frac{1}{\cos(\theta)} \int_{-(hice+hsnow)}^{0} T(z)\kappa_a(z)e^{-\tau(z,hsnow)}dz + \frac{1}{\cos(\theta)} \int_{-(hice+hsnow)}^{0} T_{DN}(z)\kappa_s(z)dz$$

$$\tau(z_1, z_2) = \frac{1}{\cos(\theta)} \int_{z_1}^{z_2} (\kappa_a(z) + \kappa_s(z))dz$$

$$T_{DN}(z) = T_{DN}(0)e^{-\tau(0,z)} + \frac{1}{\cos(\theta)} \int_{z}^{0} T(z)\kappa_a(z)e^{-\tau(z,hsnow)}dz$$

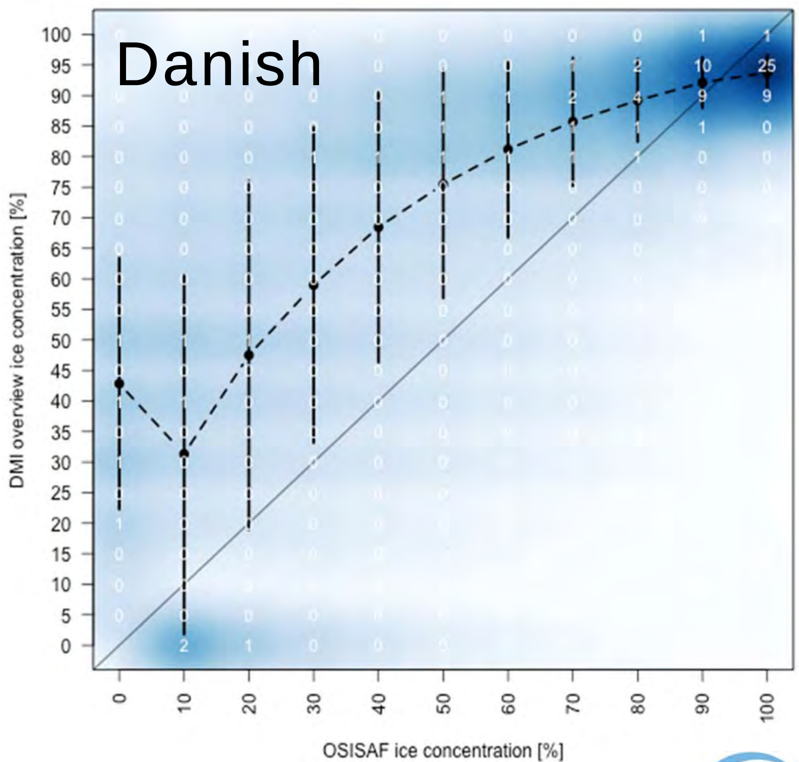
Icechart to OSISAF SIC intercomparison

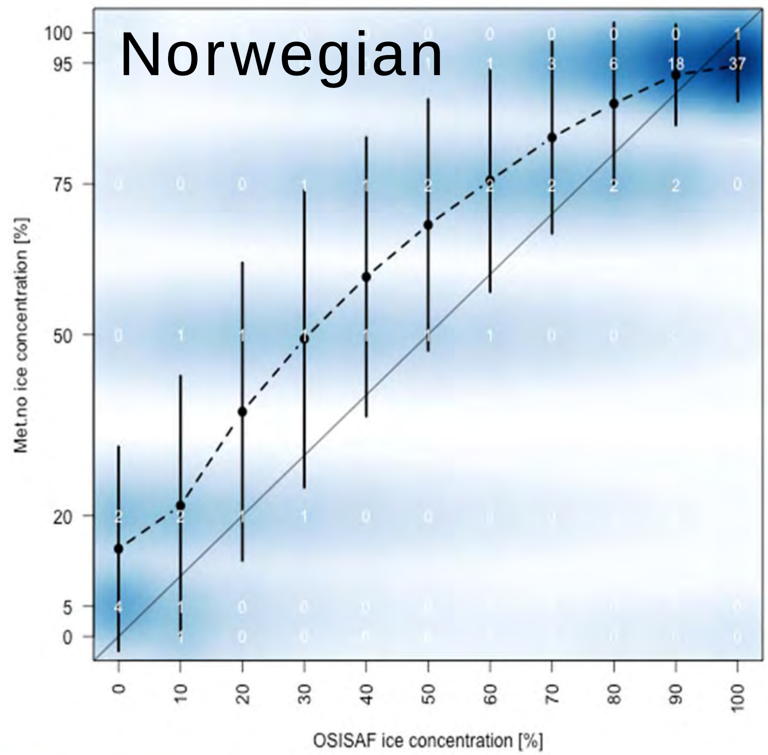


East Greenland Area

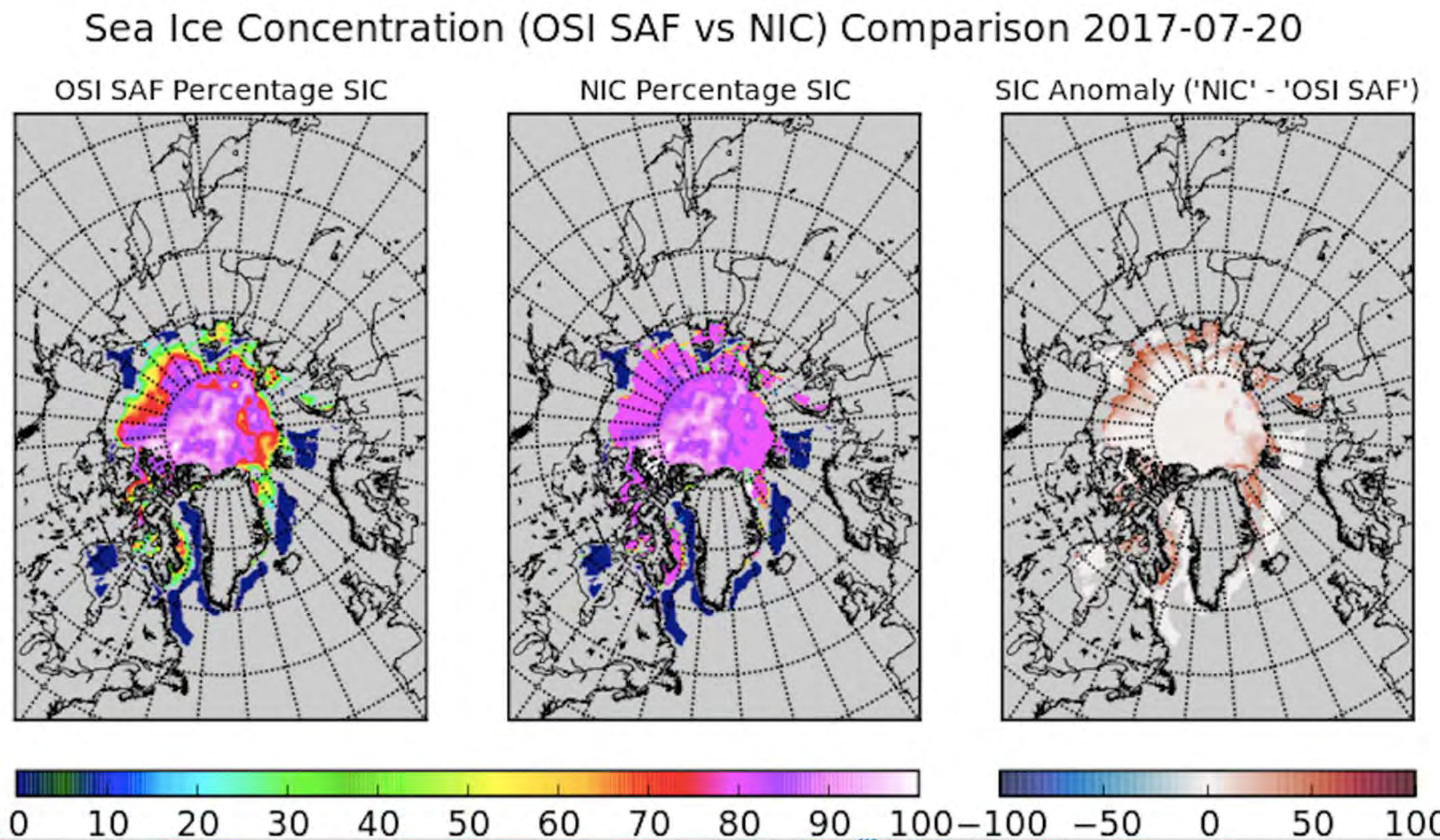
See also:
Karvonen, Juha, Jouni Vainio, Marika Marnela, Patrick Eriksson, and Tuomas Niskanen, *A Comparison Between High-Resolution EO-Based and Ice Analyst-Assigned Sea Ice Concentrations,* IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 8, NO. 4, APRIL 2015

Icechart vs OSISAF - SIC intercomparison

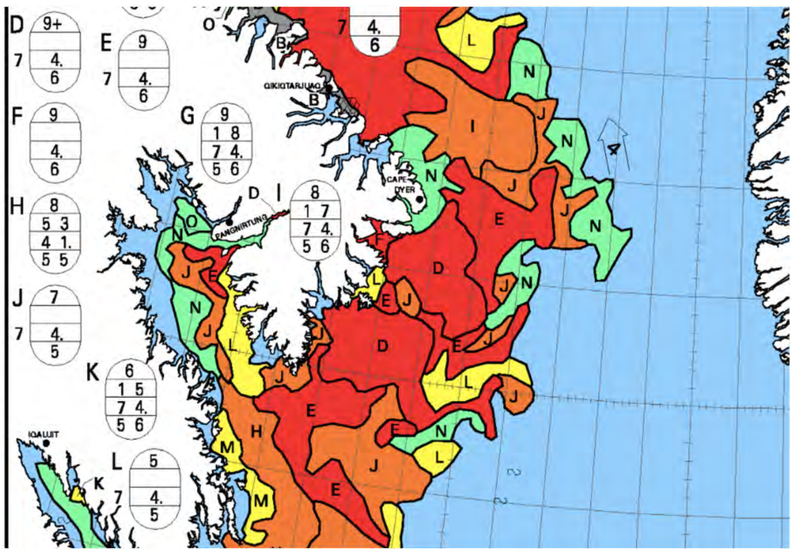




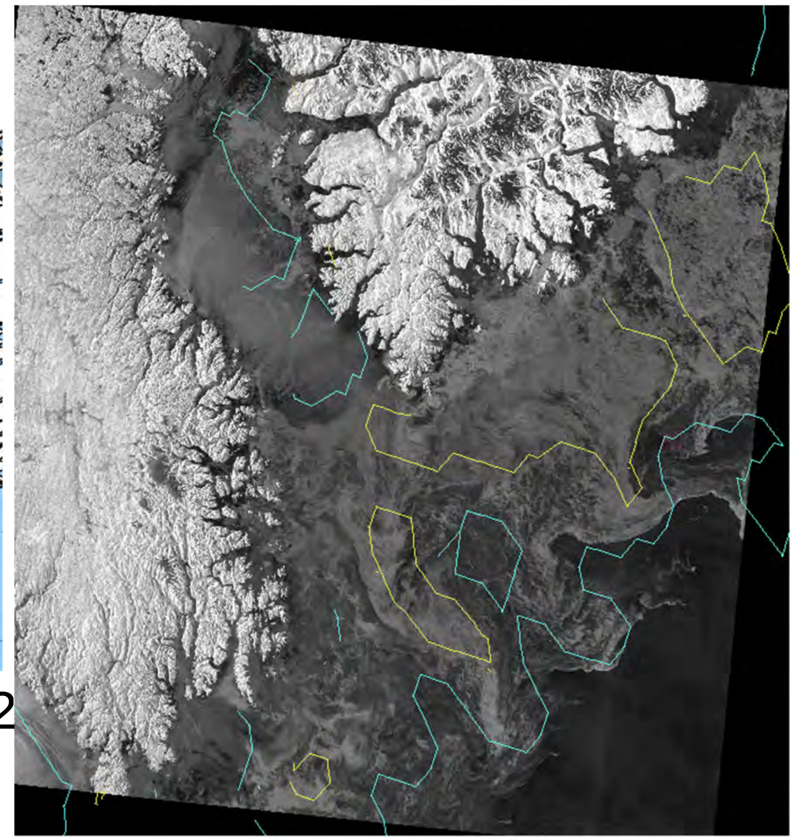
Icechart vs OSI-SAF ice concentration



CIS Icechart vs Sentinel-1 SAR



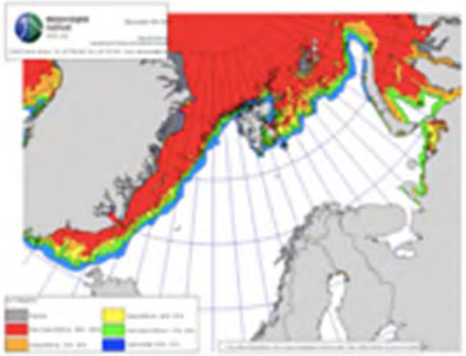
CIS daily ice chart on July 2



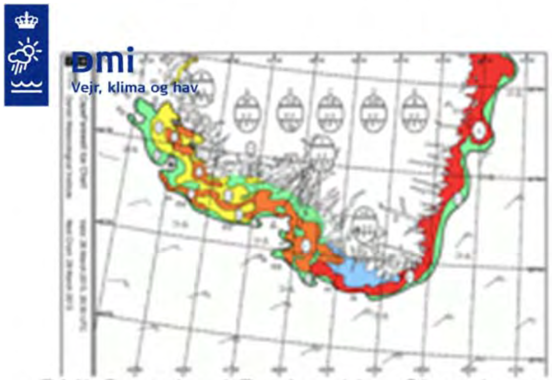
Sentinel-1 SAR on July 20, 2017

Icechart to OSISAF SIC intercomparison

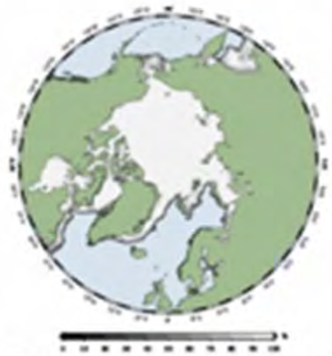
DMI Greenland Overview Ice Chart



Met.no Svalbard Ice Chart

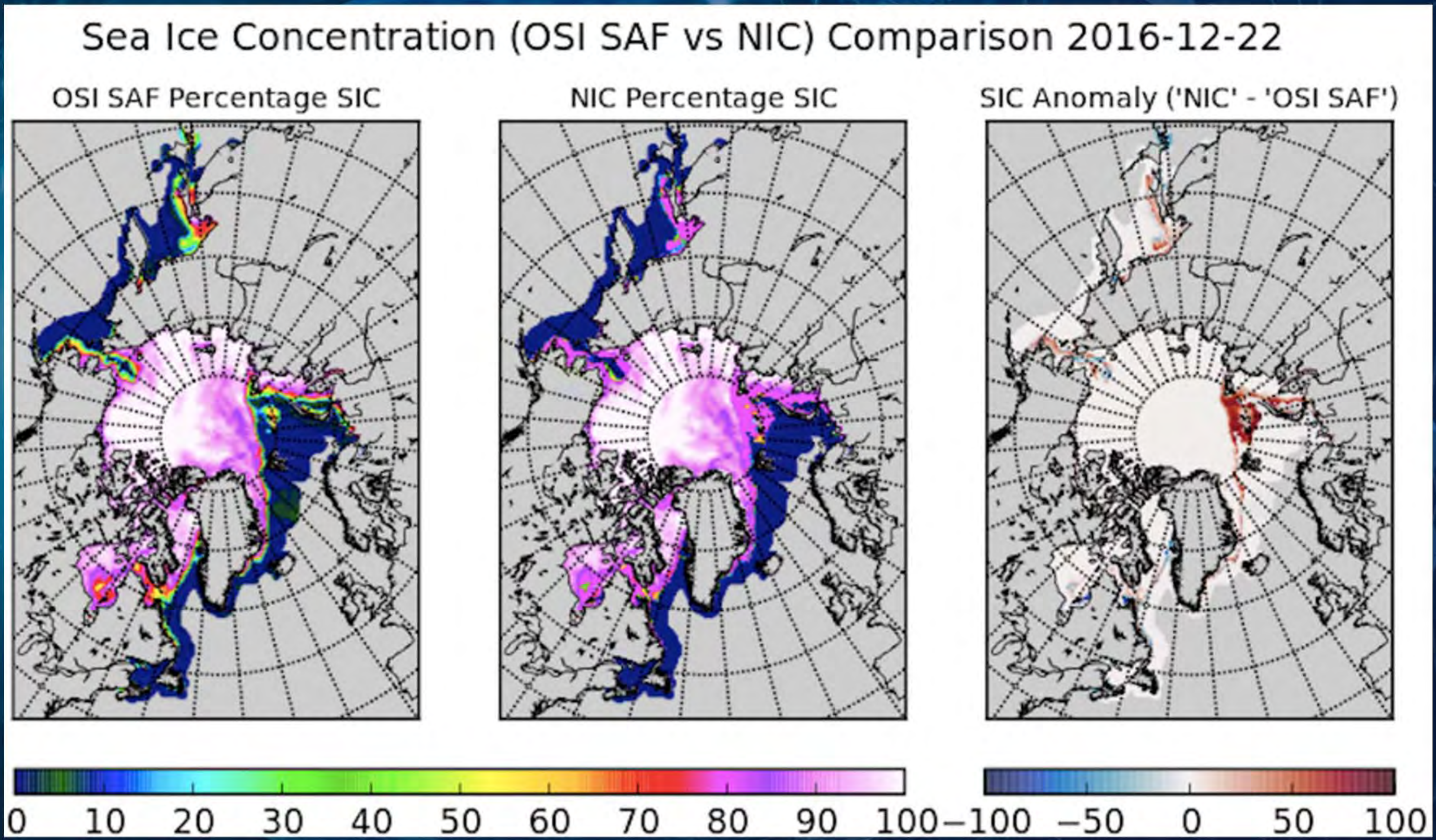


DMI Greenland Regional Ice Chart (example)



OSISAF Ice Concentration data

Icechart to OSISAF SIC intercomparison



Danmarks Meteorologiske Institut

Sentinel-1 SAR and MET Icechart 2016-12-22