ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

CLASSIFICATION AND BACKSCATTERING STATISTICS OF THIN SEA ICE BY SAR

Markku Similä, Wolfgang Dierking*
Marko Mäkynen, Jakob Niemeyer*,
Kathrin Einzmann*, Juha Karvonen

Finnish Meteorological Institute
Ice Research Unit

***Alfred Wegener Institute for Polar- and Marine Research**

Dragon 2 Symposium   20-24 June 2011

Outline

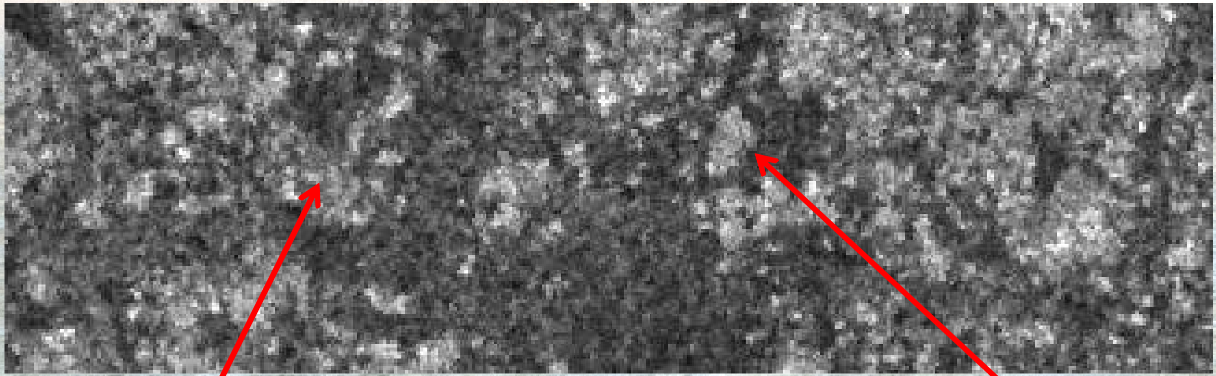
- Complements the Dragon 2 presentation of Dr. Yonggang Ji et al.
- Classification of thin sea ice using high resolution and a two-frequency polarimetric SAR data (AWI).
- Examination of thin sea ice σ° variation when the source data consists of Wide Swath Mode (WSM) images. The spatial resolution of WSM data is downsampled to 500 m to enable a daily monitoring of large sea areas (FMI).

Background

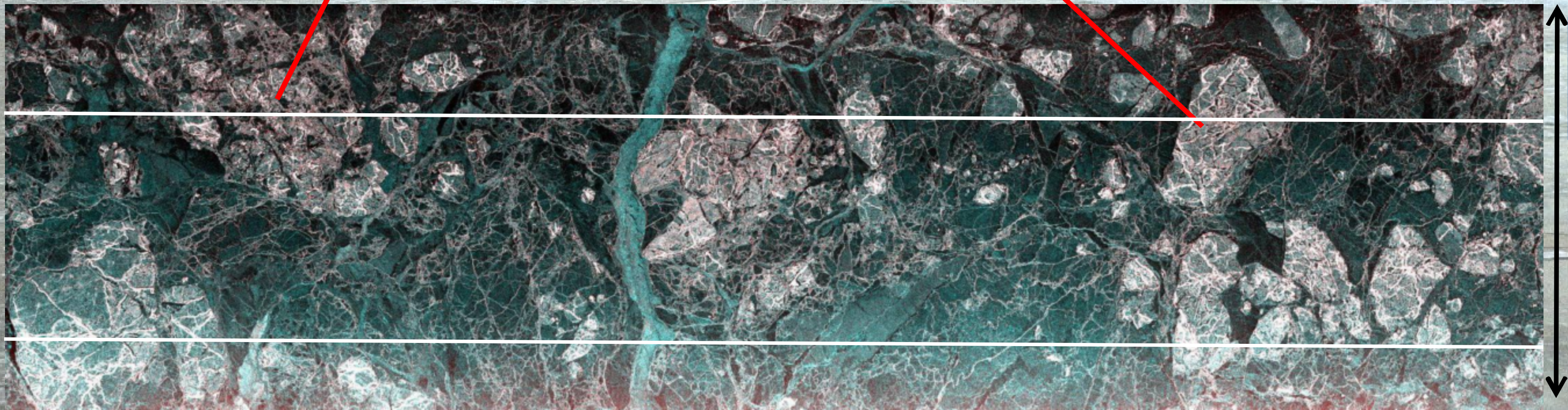
- Large thin sea ice areas are prevalent in the seasonal ice zone during the freeze-up period in the fall and early winter.
- During the polar winter large thin ice areas occur mainly in the marginal ice zone (MIZ) which is a very dynamic ice regime about 100 km from ice edge towards pack ice. Large thin ice areas inside ice pack arise in the connection of polynyas.
- The divergent events in the pack ice create continuously leads with varying width which are almost immediately covered by thin ice during the Arctic winter.
- Thin ice fields are also typical for seasonal ice areas in the marginal seas like in the Bohai Sea or in the Baltic Sea. Depending on the severity of the winter the thermodynamic ice growth may remain in these seas rather limited (less than 0.5 m).
- For many purposes ranging from global atmosphere-ocean surface heat balance and deep water circulation to the winter shipping the identification of thin ice areas is important. The SAR based detection is, however, difficult.

The accuracy of ice type classification depends on the spatial resolution of the images!

spatial
resolution
150 m



ASAR WSM image, HH -polarization, incidence angel 26°, acquired over Fram Strait on March 19, 2007 at 11:22 UTC.
Airborne SAR image (R-VH, G-VV, B-VV) acquired at 12:26 UTC.



Airborne C-Band SAR

3km

spatial
resolution
2m

Optical Scanner, ca. 12:20 UTC

Classification of different thin ice types using high resolution multi-frequency multi-polarization data

Satellite:

- high resolution modes are available (down to 1-5 m), but with narrow swath widths (10-30 km)

- also polarimetric imaging modes are (were) operational (e. g. Radarsat-2, ALOS-PALSAR)

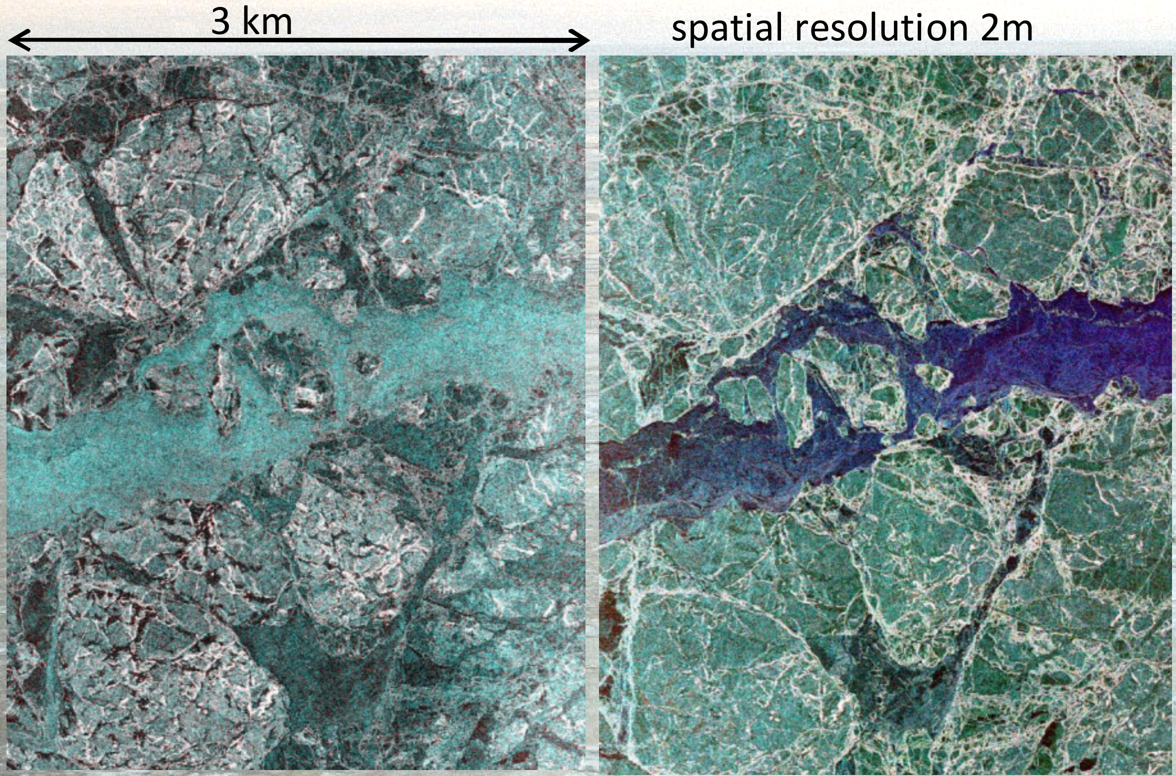
- combination of diffent frequencies is difficult (it means to acquire images from two different satellites with only a small time gap between them)

Airplane:

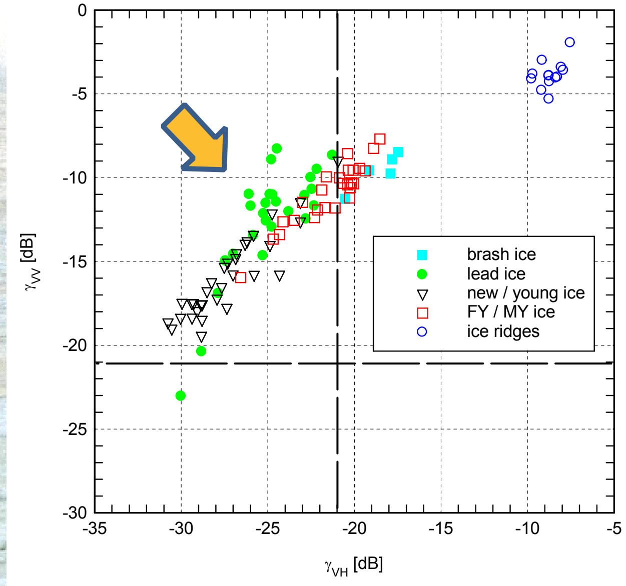
- airborne multi-frequency multi-polarization data (such as from the Danish EMISAR or the German ESAR) acquired over sea ice are useful for assessing the capabilities of satellite SAR missions and validating their data products for sea ice mapping

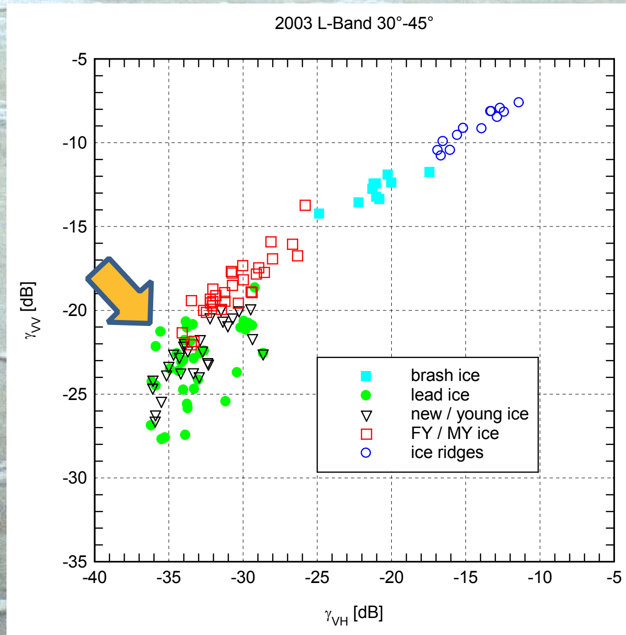
- airborne data (fine spatial resolution, low noise level): more ice types can be visually separated, and optimal radar configurations for ice classification can be found

The combination of different frequencies and polarizations improves ice type classification!



C-Band L-Band





In this example, the identification of frost flowers on thin lead ice is demonstrated: L-band is not as sensitive to frost flowers as C-band.

- In the following viewgraphs, the optimal SAR configurations for separating thin ice types from other ice classes are presented.

- Data are from EMISAR flights carried out north of Svalbard in 1998.

- Analyses were carried out by students (Kathrin and Jakob) in 2009 and 2011.

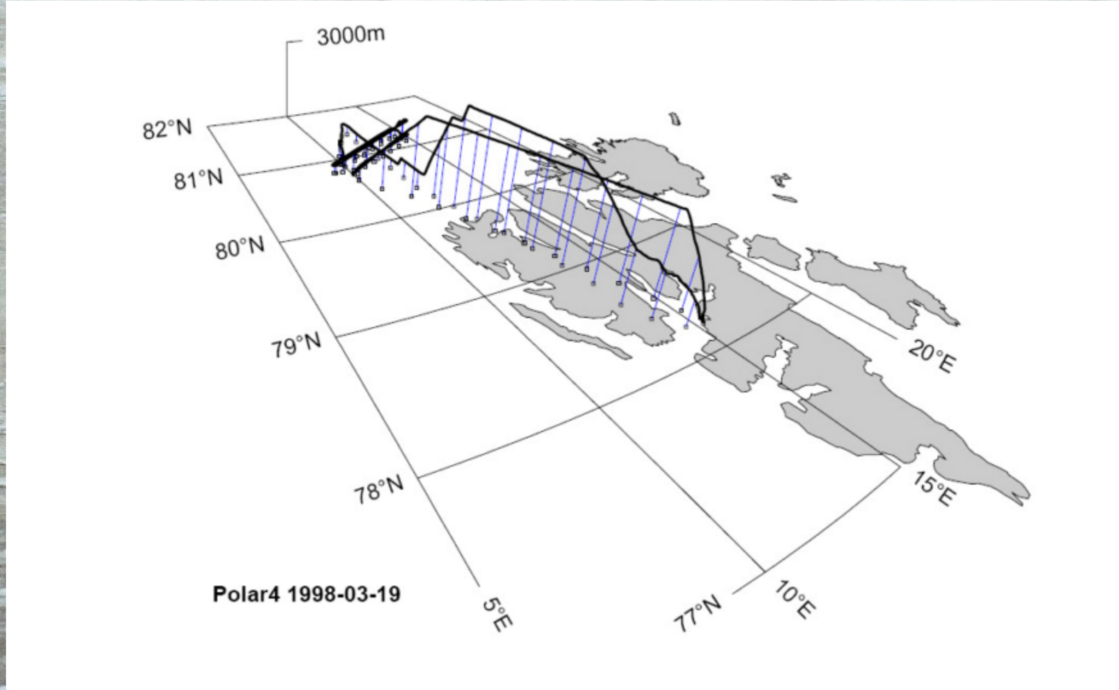
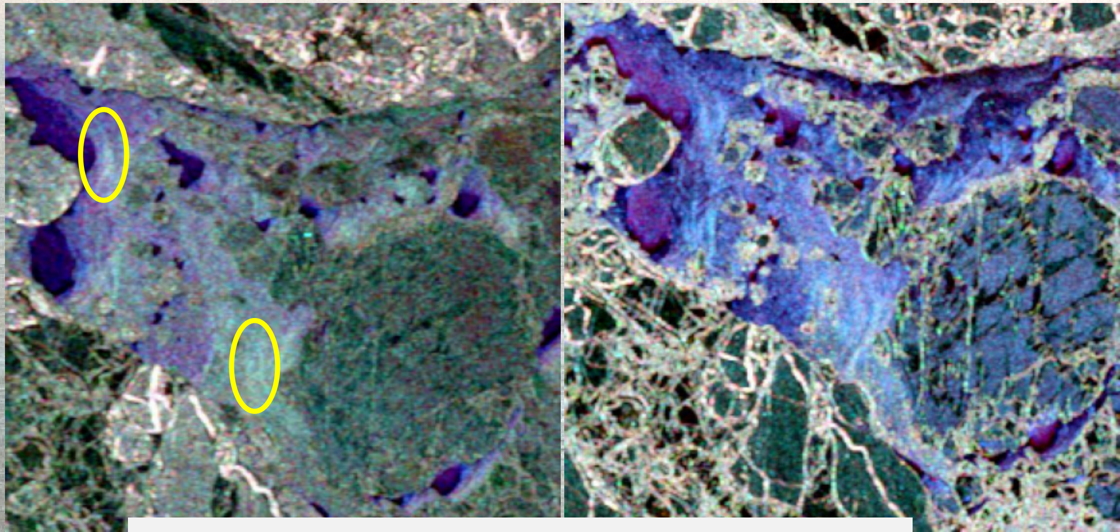
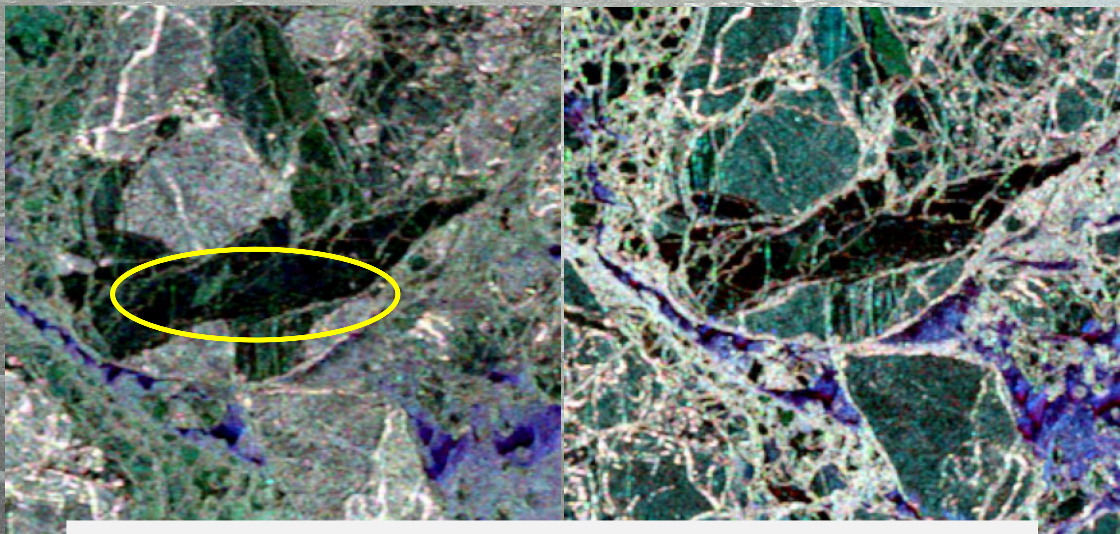


Fig. 1. The upper north-eastern strips depict the research area north of Svalbard (Hartmann et al., 1999, p. 25)

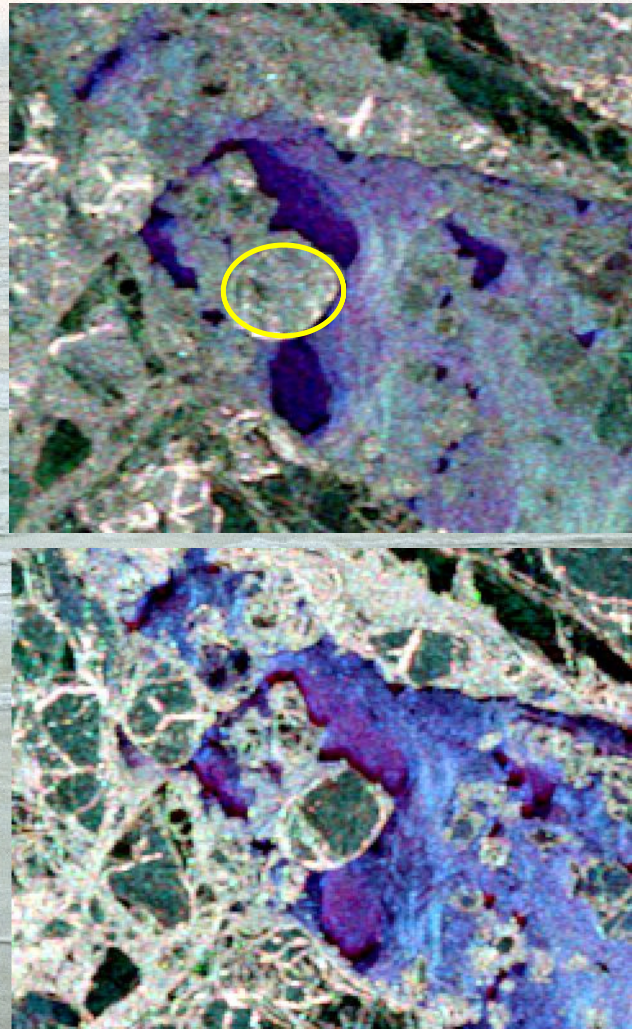
Examples for classes of thin sea ice:



compacted frazil ice, left: C-, right: L-band

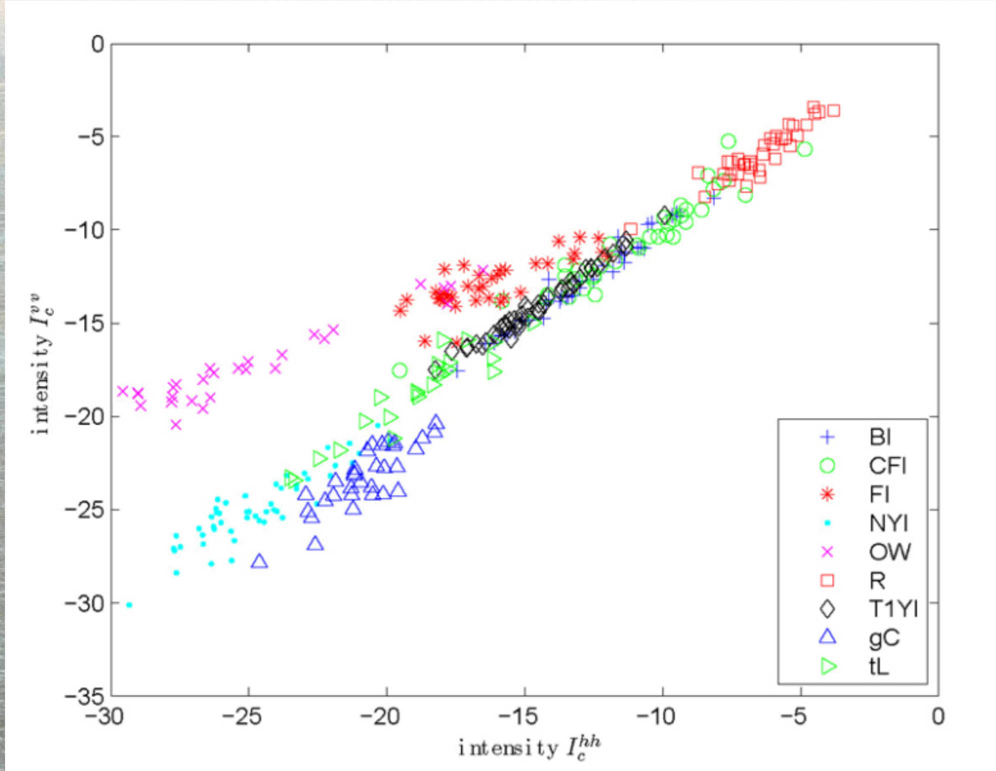


nilas and grey ice, left: C-, right: L-band, rafting visible



thin first-year ice,
top: C-, bottom: L-band

Optimal detection of class "frazil FI":



Best combinations:

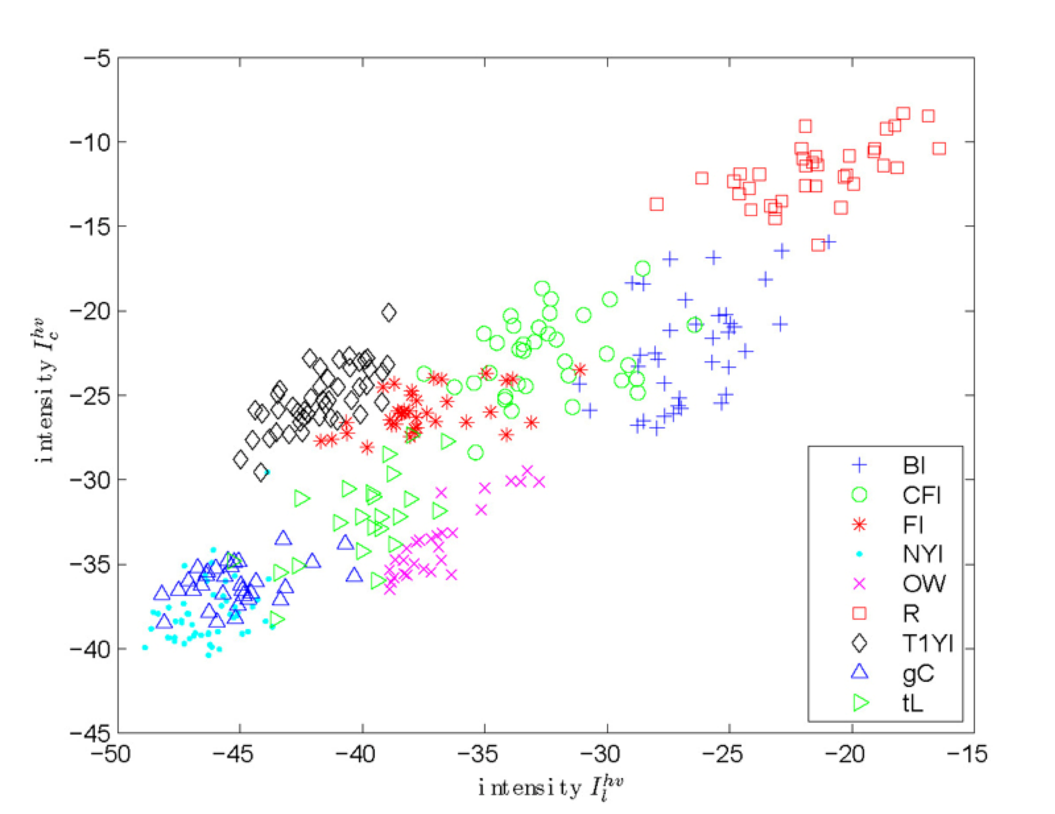
$\sigma^0_{VV\text{-}C}$ and $\sigma^0_{HH\text{-}C}$

$\sigma^0_{HV\text{-}C}$ and $\sigma^0_{VV\text{-}C}$ / $\sigma^0_{HH\text{-}C}$

$\sigma^0_{VV\text{-}C}$ /$\sigma^0_{HH\text{-}C}$ and
$\sigma^0_{HV\text{-}C}$ / ($\sigma^0_{HH\text{-}C}$ +$\sigma^0_{VV\text{-}C}$)

Frazil ice can be best separated with C-band like-polarization channels.

Optimal detection of class "compacted frazil CFI":



Best combinations:

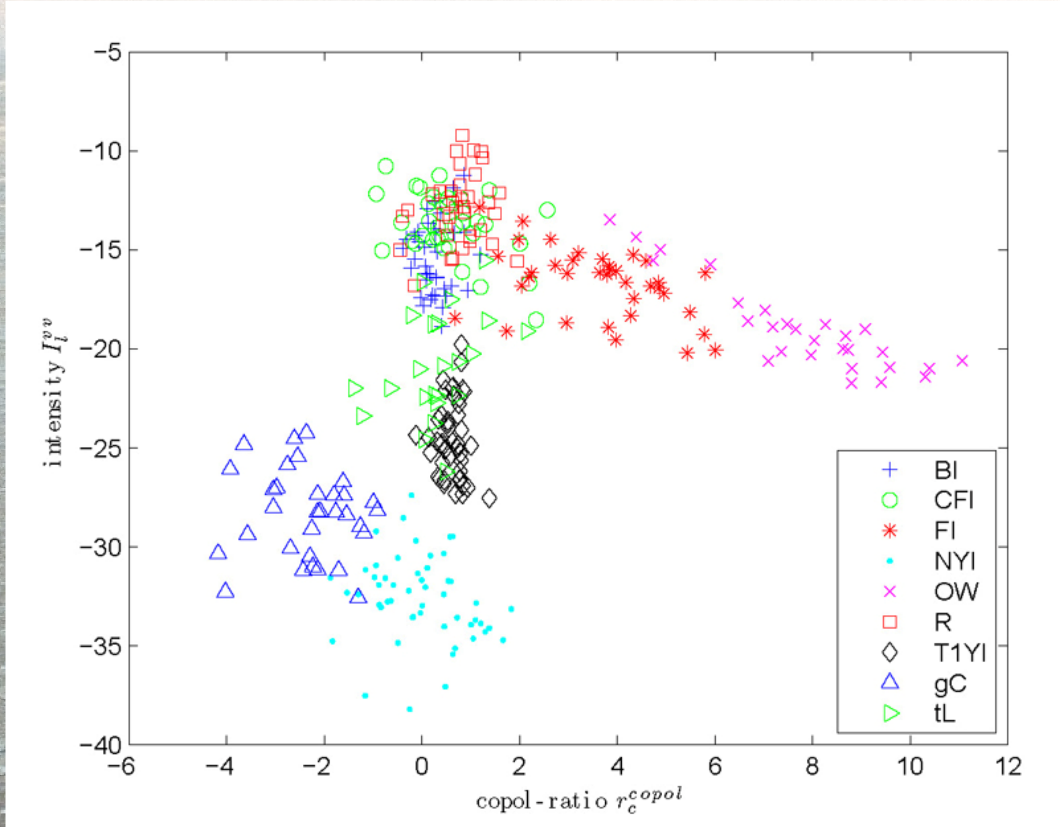
$\sigma^0_{HV\text{-}C}$ and $\sigma^0_{HV\text{-}L}$

$\sigma^0_{HV\text{-}L}$ and
$\sigma^0_{HV\text{-}C} / (\sigma^0_{HH\text{-}C} + \sigma^0_{VV\text{-}C})$

$\sigma^0_{HV\text{-}L}$ and
$\sigma^0_{HV\text{-}L} / (\sigma^0_{HH\text{-}L} + \sigma^0_{VV\text{-}L})$

For compacted frazil ice, a combination of C- and L-band is optimal. However, the overlap with other ice classes is relatively large.

Optimal detection of class "nilas and grey ice NYI+gC":



Best combinations:

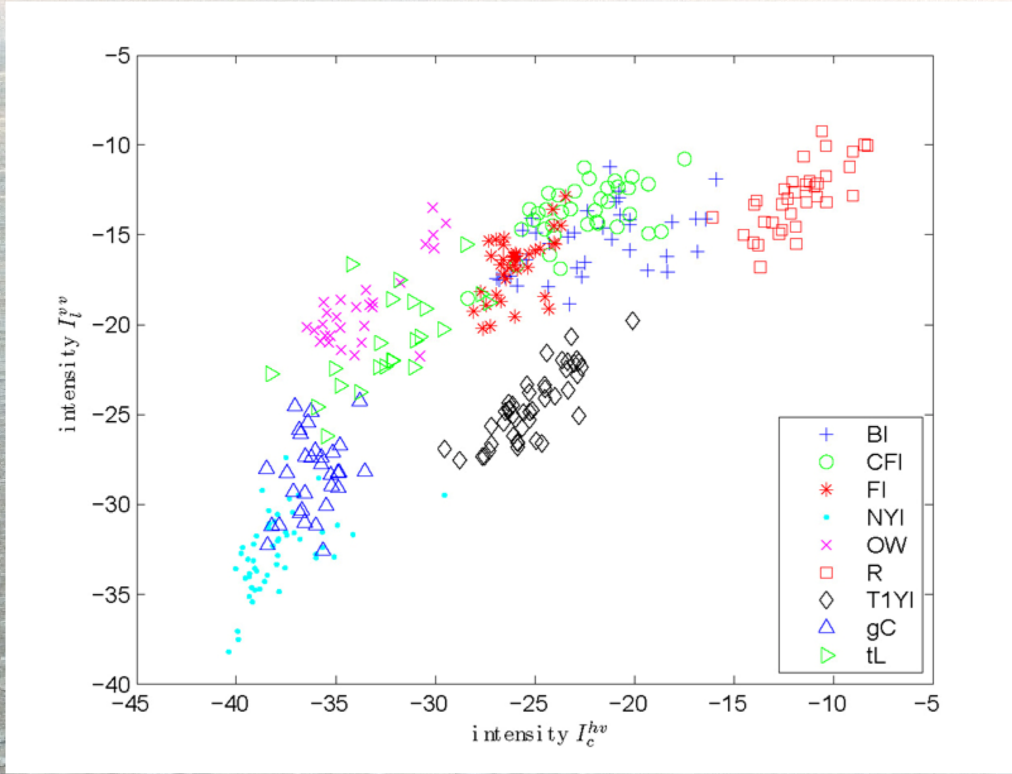
$\sigma^0_{VV\text{-}L}$ and $\sigma^0_{VV\text{-}C}$/ $\sigma^0_{HH\text{-}C}$

$\sigma^0_{HH\text{-}L}$ and $\sigma^0_{VV\text{-}C}$ / $\sigma^0_{HH\text{-}C}$

$\sigma^0_{VV\text{-}L}$ and $\sigma^0_{VV\text{-}C}$

Also nilas and grey ice can be optimally separated when combining C- and L-band. (Note: airborne SAR systems provide a much better signal-to-noise ratio than satellite SAR.)

Optimal detection of class “thin first-year ice T1YI“:



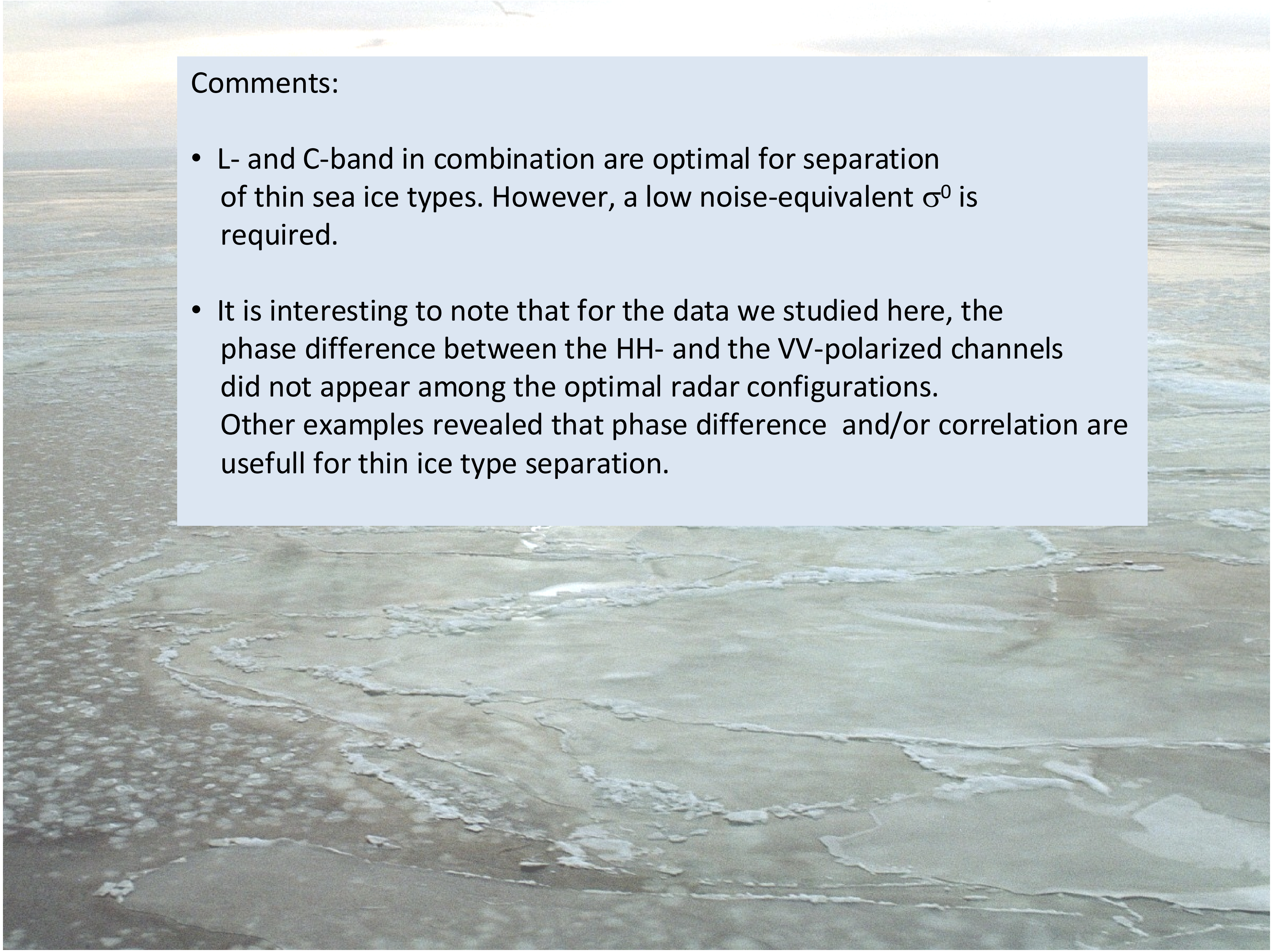
Best combinations:

$\sigma^0_{VV\text{-}L}$ and $\sigma^0_{VH\text{-}C}$

$\sigma^0_{VV\text{-}L}$ and $\sigma^0_{HH\text{-}C}$

$\sigma^0_{VV\text{-}L}$ and $\sigma^0_{VV\text{-}C}$

Thin first-year ice (30-70 cm) can be best separated when combining C- and L-band.



Comments:

- L- and C-band in combination are optimal for separation of thin sea ice types. However, a low noise-equivalent σ^0 is required.

- It is interesting to note that for the data we studied here, the phase difference between the HH- and the VV-polarized channels did not appear among the optimal radar configurations.
  Other examples revealed that phase difference and/or correlation are usefull for thin ice type separation.

Thin ice backscattering statistics from WSM data

- **Goal:** To study the variation of the backscattering at C-band when the scattering occurs at thin ice regime with the estimated mean ice thickness staying below 30 cm.
- **Approach:**

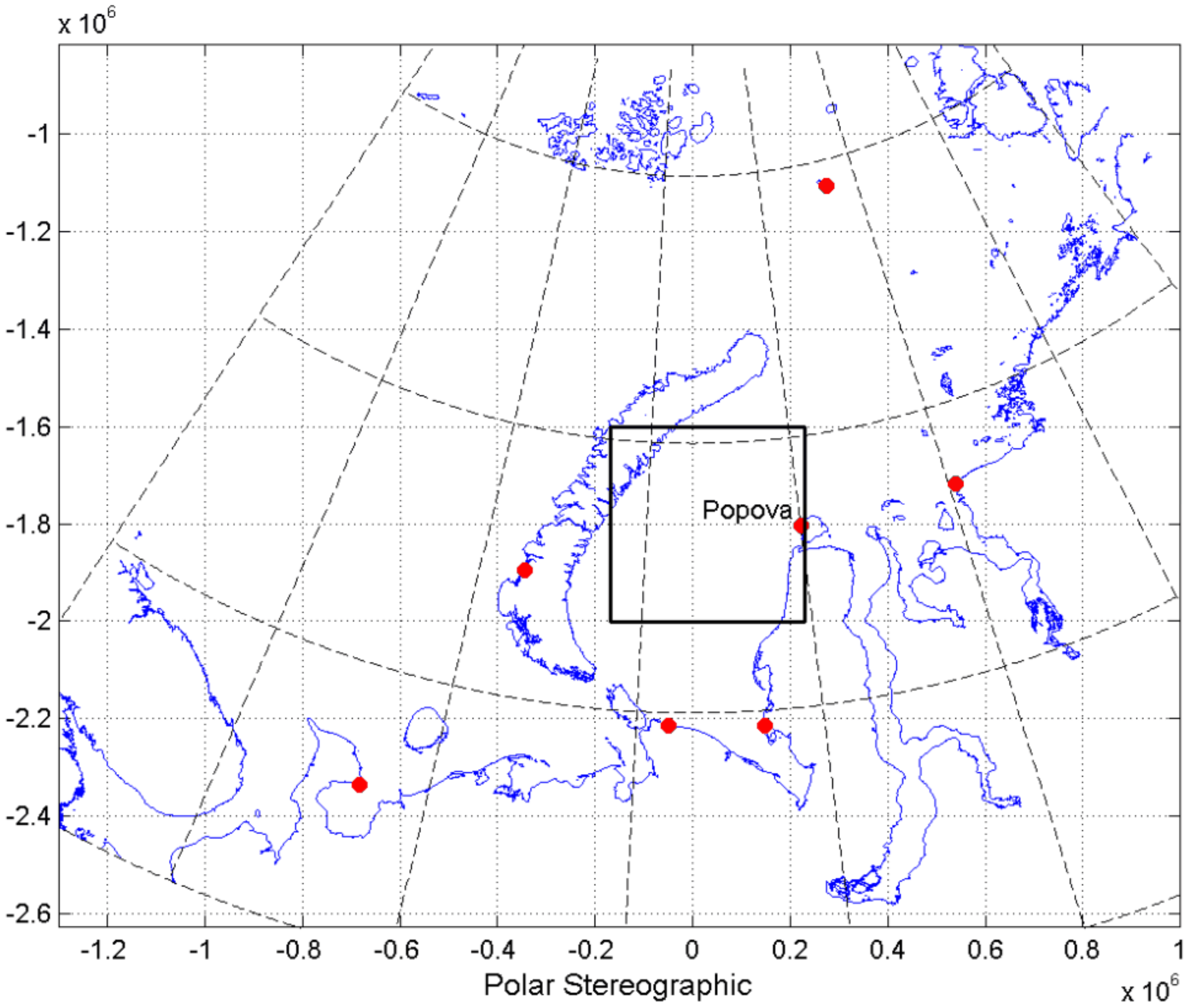
(1) Collocate a MODIS based ice thickness chart and a nearly simultaneously acquired SAR image.

(2) The local mean ice thickness category corresponding a selected SAR window is determined from the ice thickness chart. A multitude of SAR windows for each ice category are collected. In some cases (MODIS data missing) we use the visual interpretation in determining the ice class for a SAR window. The visual interpretation is aided often by the knowledge of ice conditions before and/or after the SAR image acquisition.

Data Sets

- From acquired ENVISAT WSM images we have formed an image mosaic which covers our test area.
- Each image mosaic consists mostly of SAR images acquired during the last 2-3 days and has a resolution of 500 m.
- The SAR image mosaics have been collected throughout the whole ice season from freeze-up up to melting period.
- To reduce the effect of incidence angle variation all SAR images are scaled to 35 degrees.
- All cloud-free nighttime MODIS images over the test area were acquired.
- The retrieval of ice thickness utilizes the MODIS based surface temperature. All other parameters necessary to solve the surface heat balance equation (air temperature, wind speed, humidity etc) are obtained from the HIRLAM.

Main test area in the Kara Sea



Thin ice thickness from MODIS thermal imagery

- Physical basis: The surface of thin ice is warmer than the surface of thick ice layer due to the stronger heat flow from the ocean. The presence of snow layer complicates the determination of the surface temperature (T_s) vs. ice thickness relationship.
- Requirement: The approach works only under **cold cloud-free weather conditions** (air temperature T_a < -10°C).
- Using only nighttime data: Uncertainties related to the effects of the solar shortwave radiation and surface albedo are excluded.
- HIRLAM as weather forcing data.

C-band HH-pol SAR signature

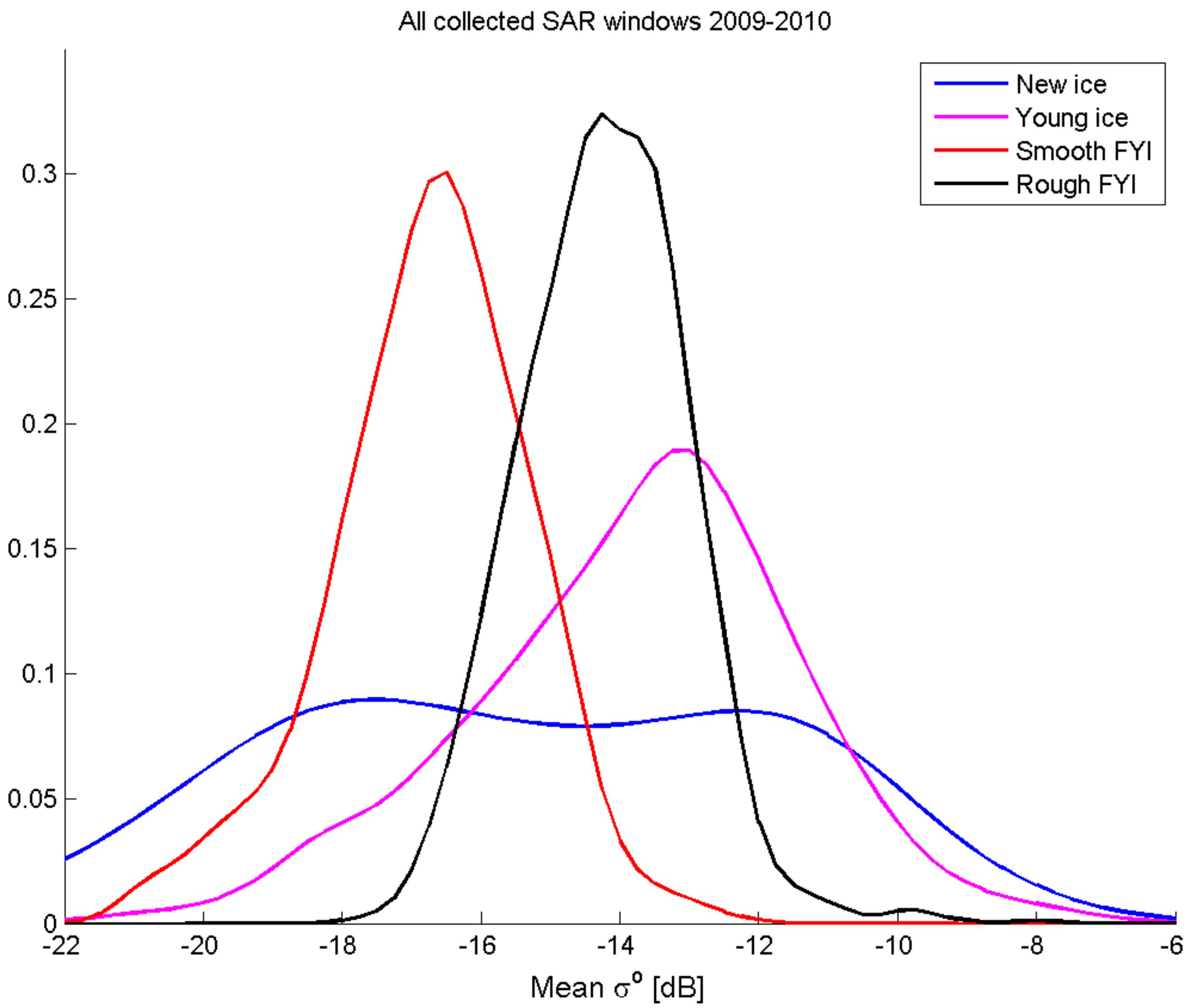
- The dynamic range of σ° in the ENVISAT WSM images is typically quite narrow in the Kara Sea for the thicker ice (>30 cm).
- On the other hand, the σ° response from thin ice exhibits a large variation and may change rapidly (500 m resolution).
- Factors affecting on thin ice σ°:

  - Wave conditions when the ice is forming. In relatively calm conditions nilas is formed, later it thickens to gray (tends to raft when deforms) and gray-white ice (tends to ridge when deforms). Jointly the last two ice types are called young ice.

  - In turbulent wave conditions the frazil ice develops to grease ice which then becomes consolidated young ice. Often the formed ice is pancake ice with relatively large small scale roughness.

  - Waves, wind and ice pressure govern the formation of brash ice in ice edge or inside ice matrix.

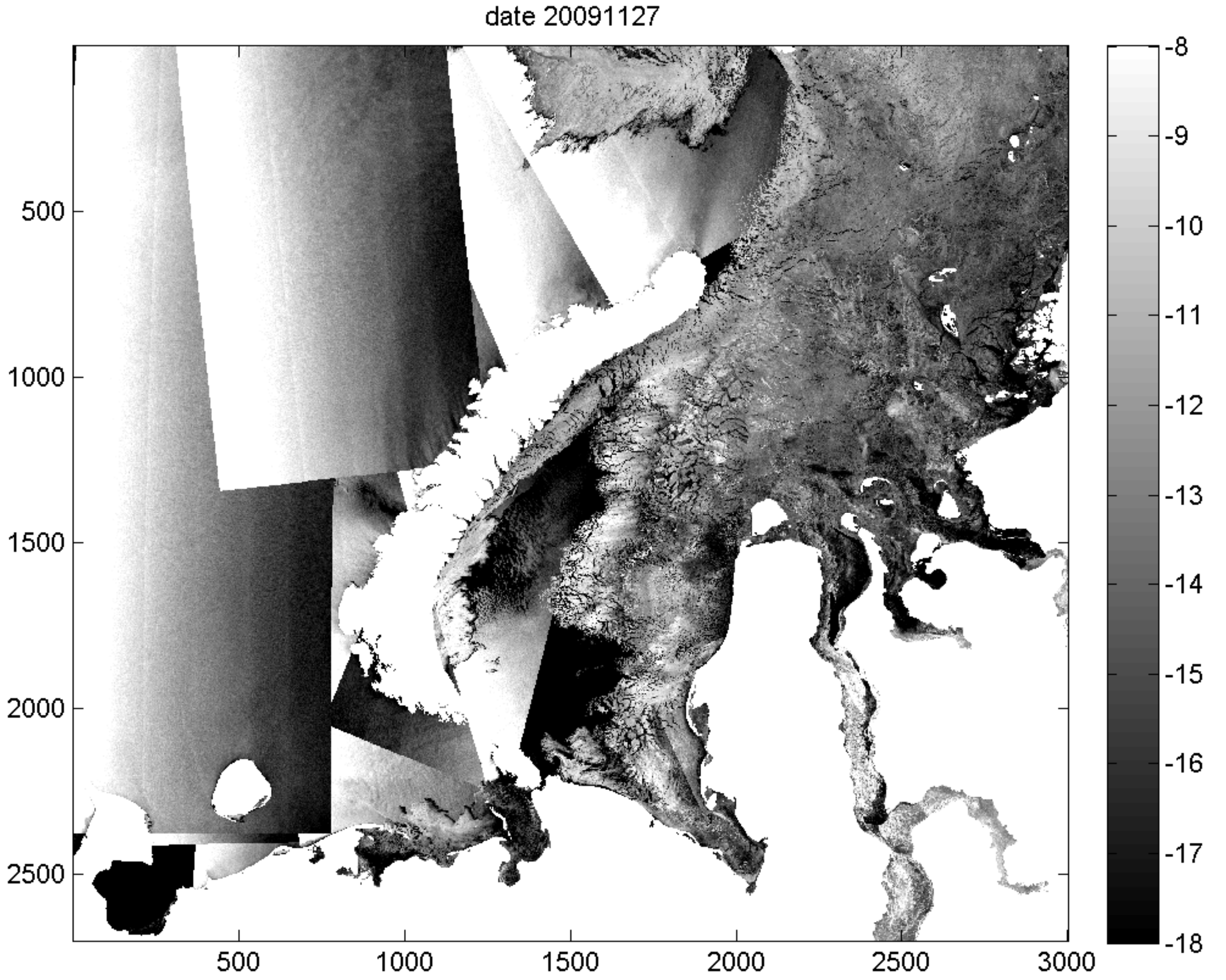
All collected σ° windows for different ice regimes 2009-2010



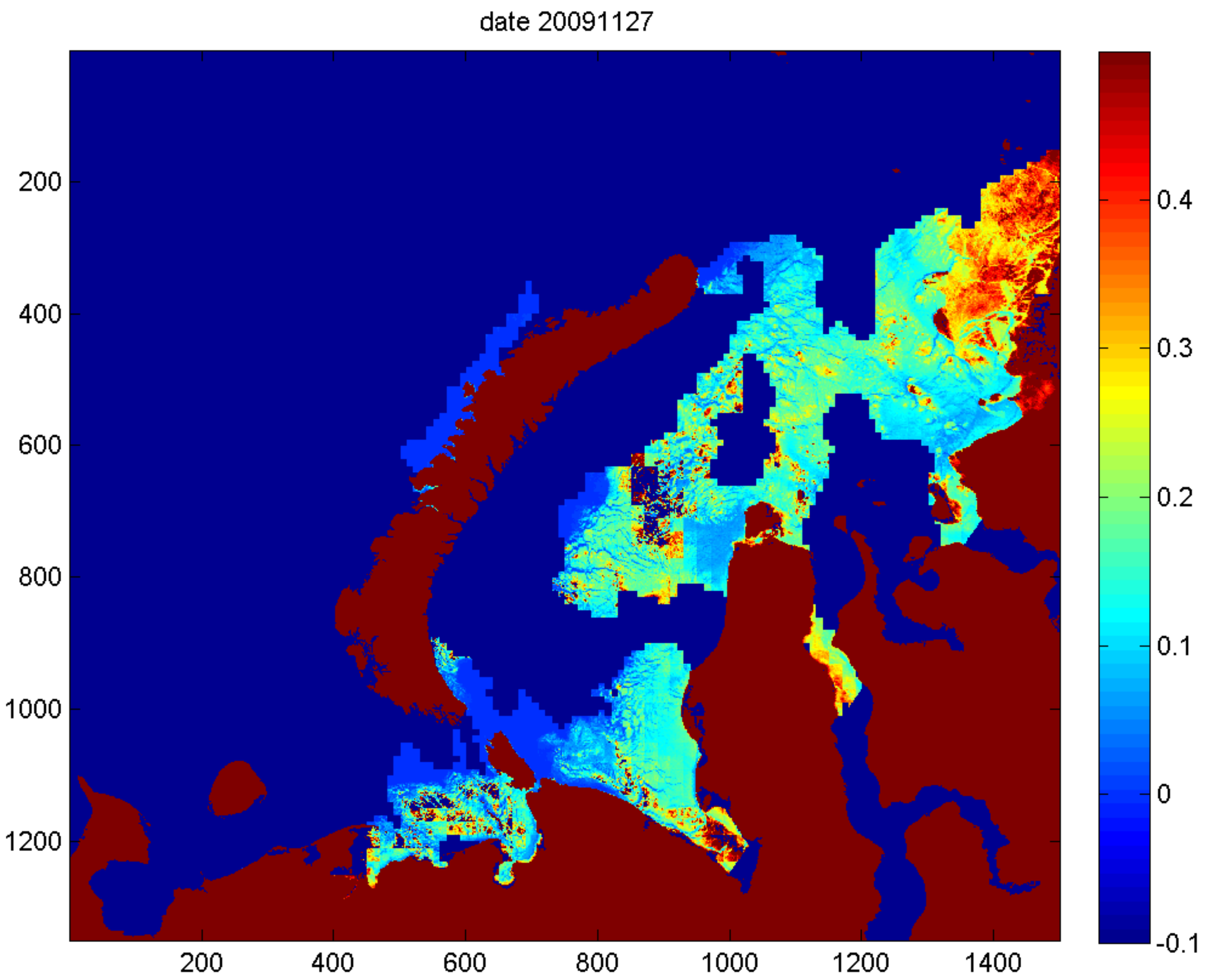
Rapid changes in σ°

- In the following we demonstrate that in some specific cases the SAR signature statistics can change rapidly (in 1-5 days) although the mean ice thickness remains according to our estimation the 30 cm limit. This is in contrast with the results over a thick ice where the SAR signature characteristics are relatively stable if the degree of deformation remains at the same level.
- Note that mean ice thickness may be less than 30 cm even if there has occurred some rafting or ridging in the area of interest. This depends on the sea ice concentration.
- One of the most important cases is the development of SAR signature in the polynya.

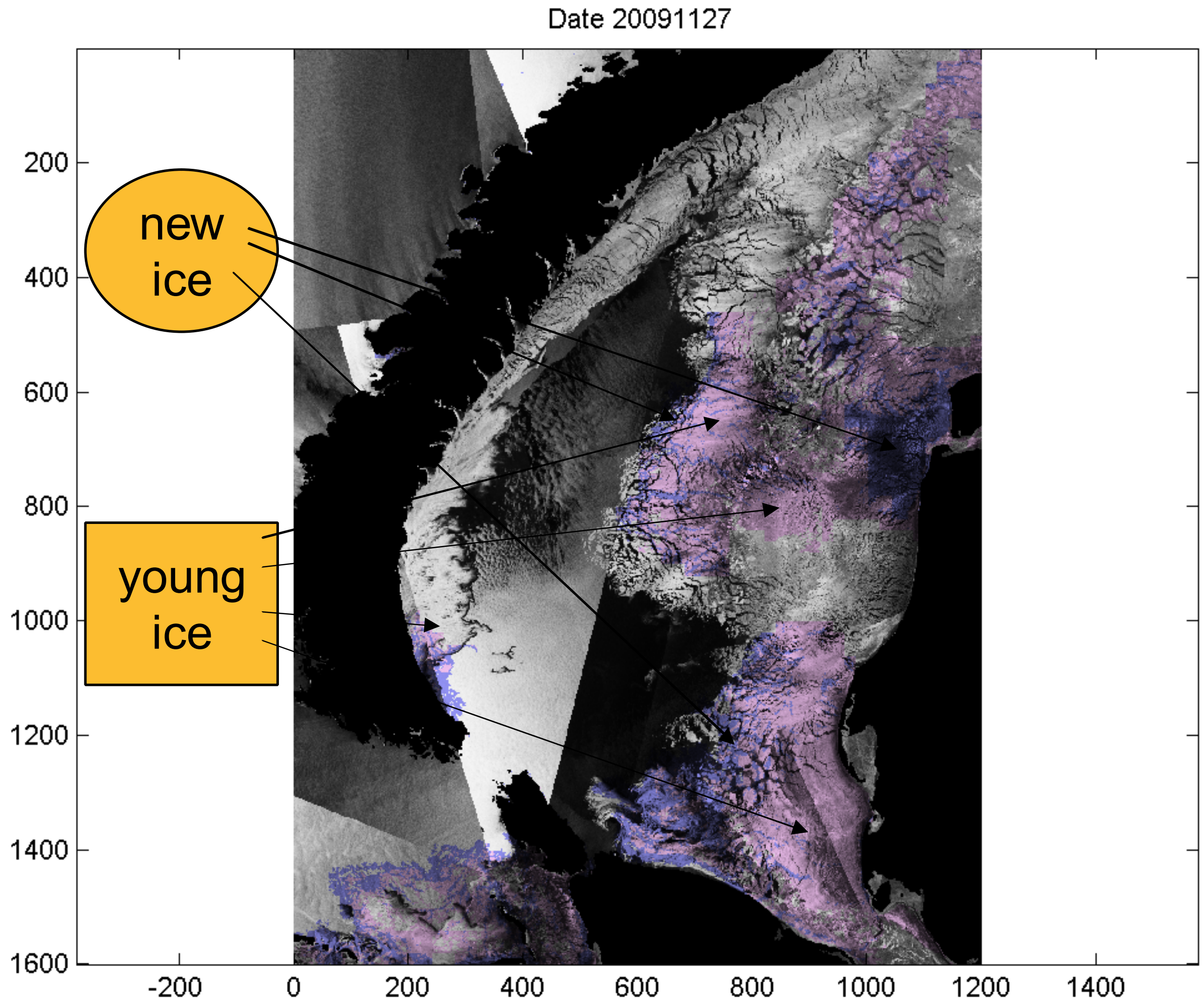
The whole
SAR mosaic
on 27 Nov 2009



MODIS based ice thickness chart on 27 Nov 2009



MODIS thickness chart overlayed on the SAR mosaic



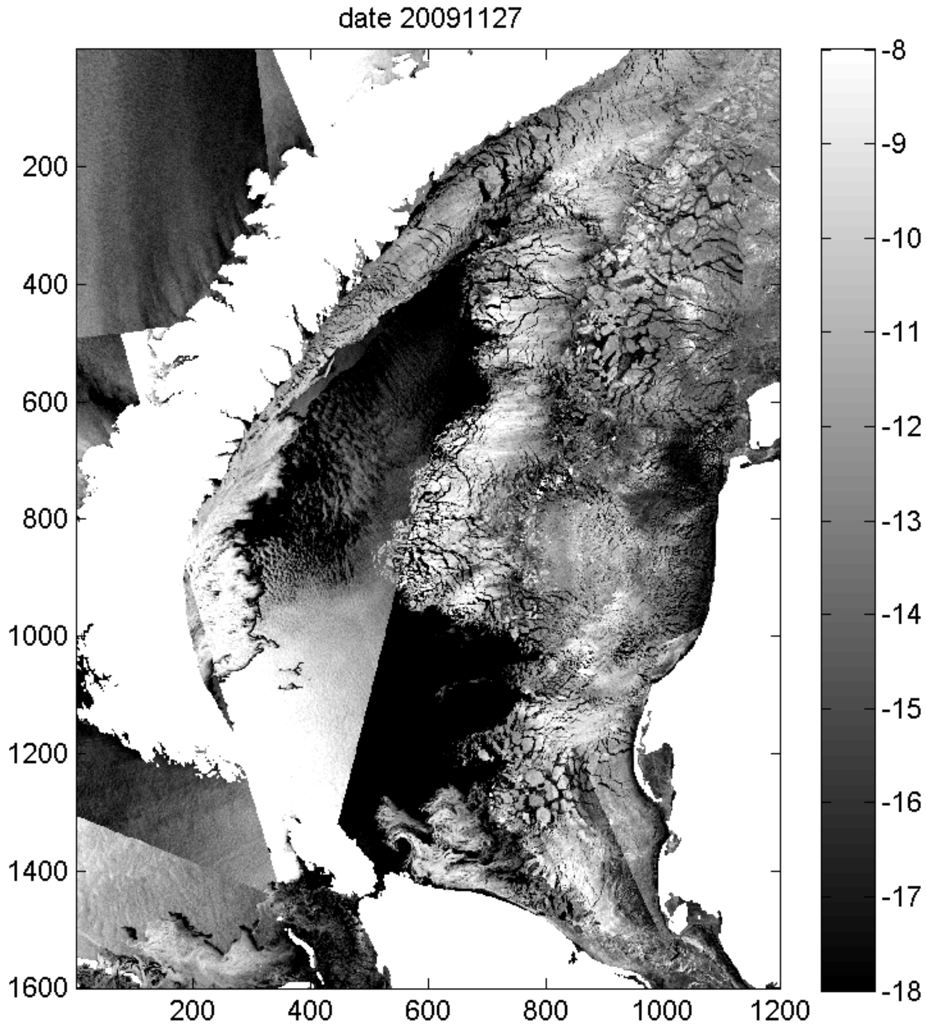
The region of interest,
27 Nov 2009.

Ta **= -21°C**

Color code:
blue= new ice,
magenta = young ice

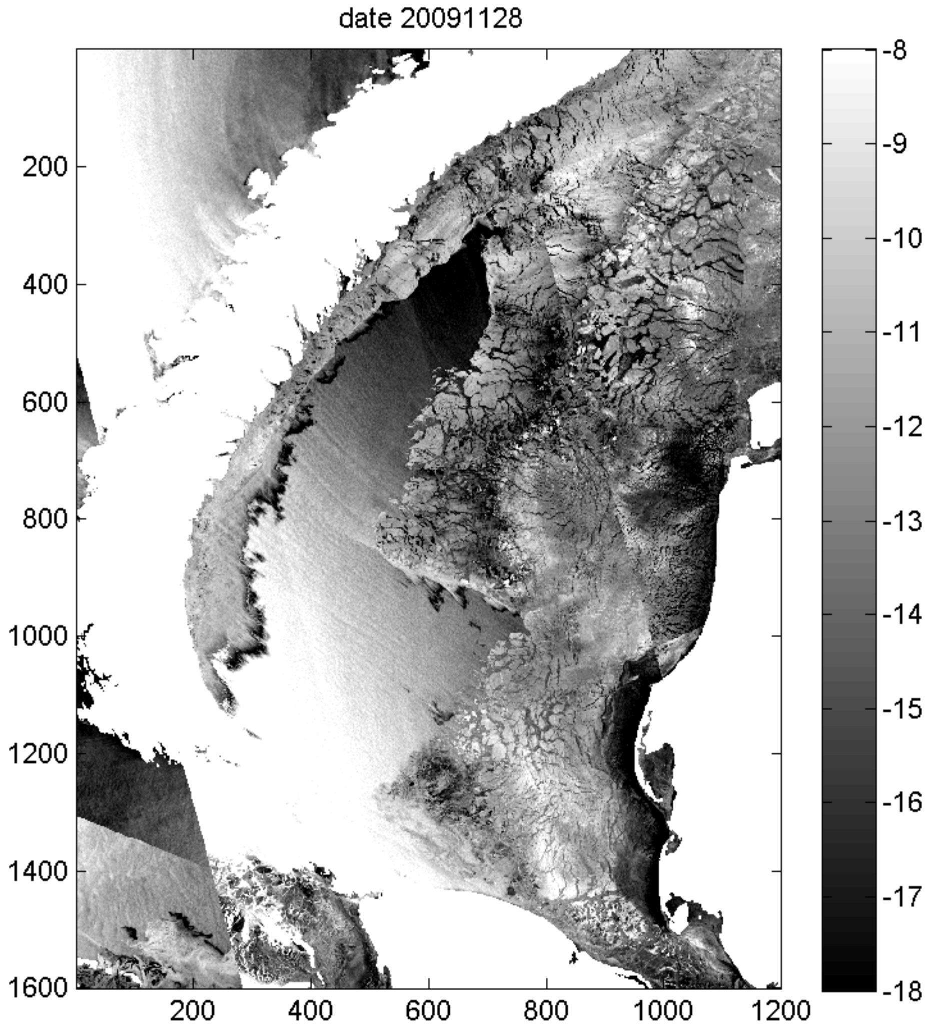
The region of interest,
27 Nov 2009.

***Ta* = -21°C**

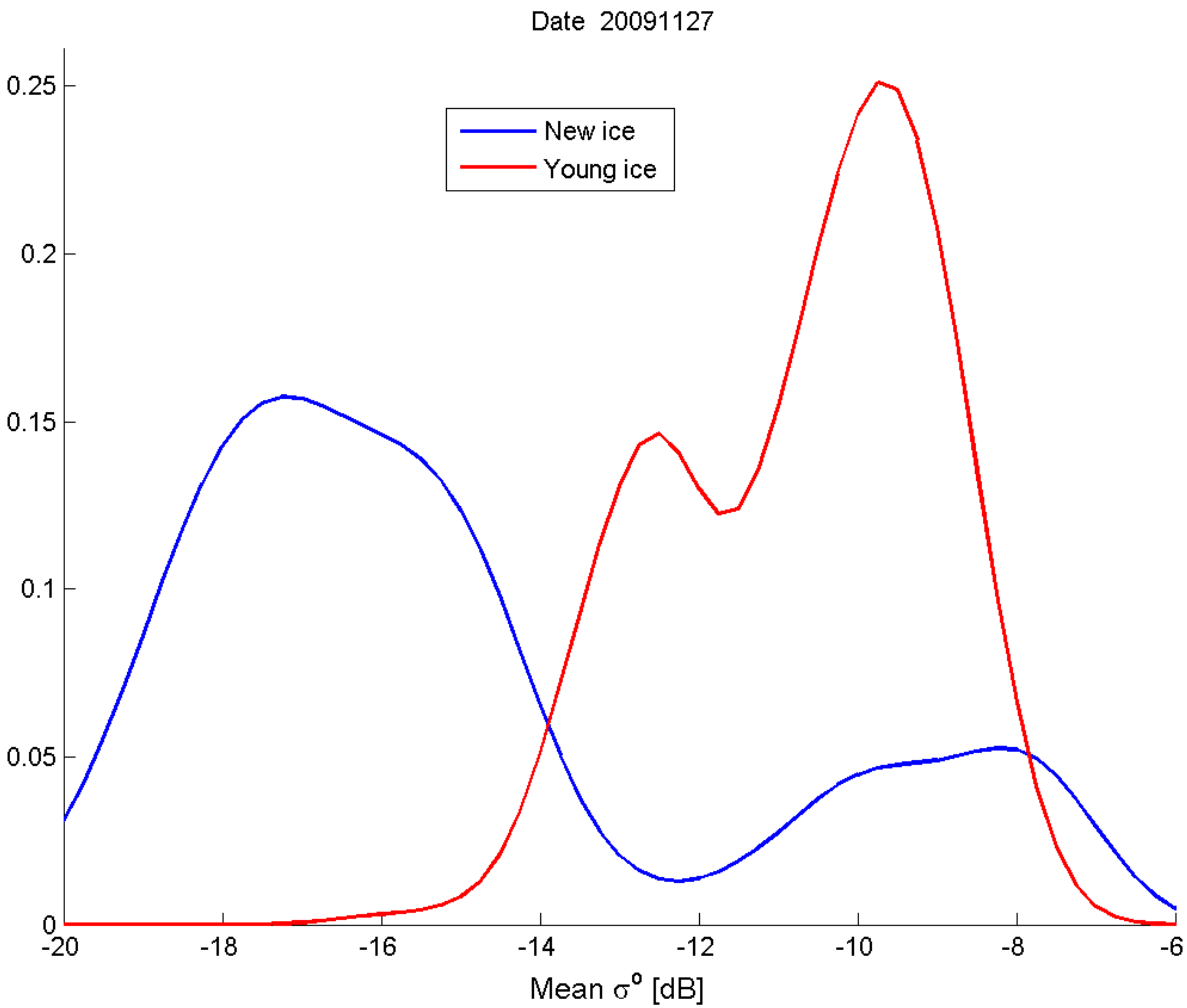


The region of interest,
28 Nov 2009.

***Ta* = -32°C**

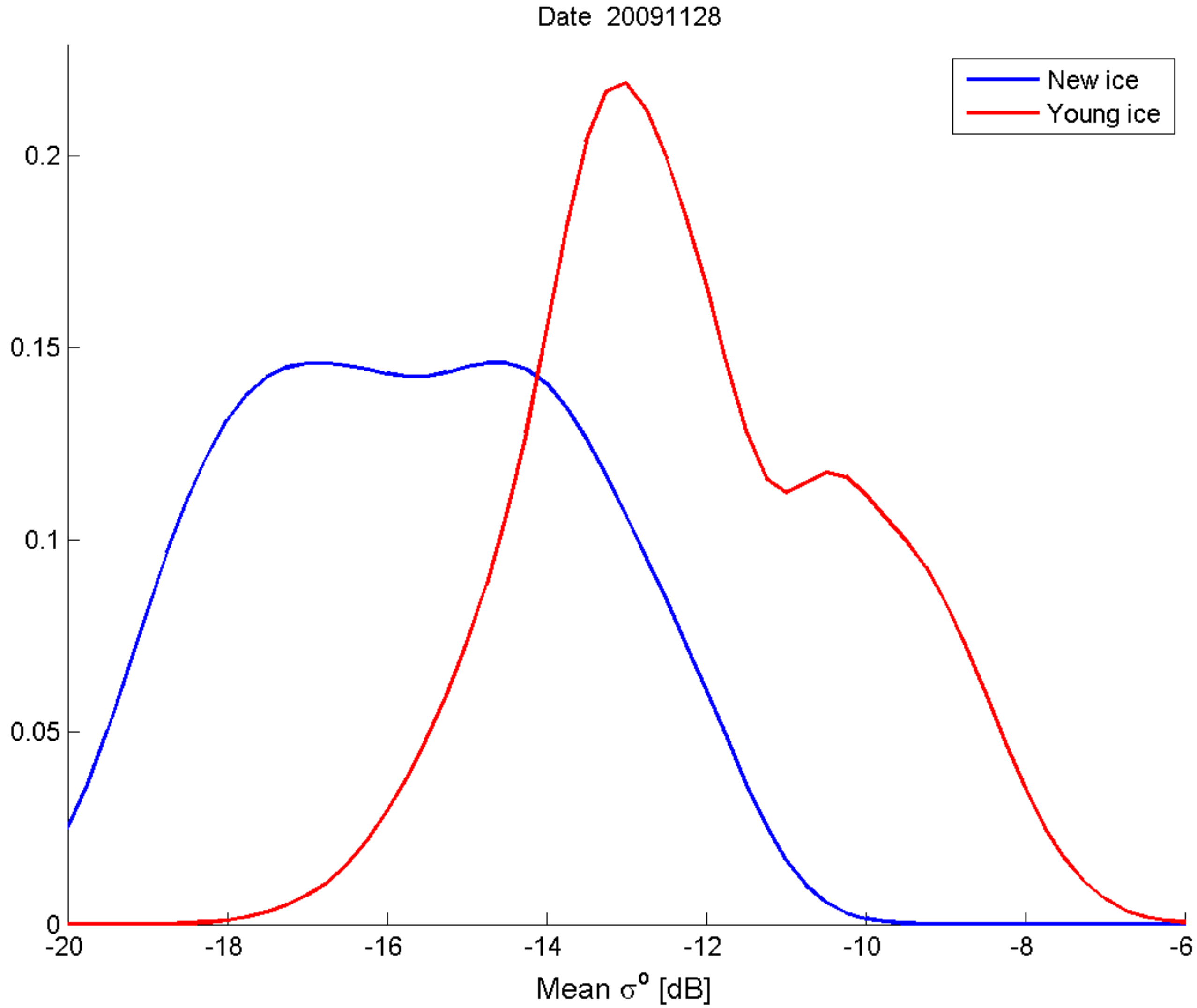


Thin ice σ° statistics on 27 Nov 2009 (region of interest)



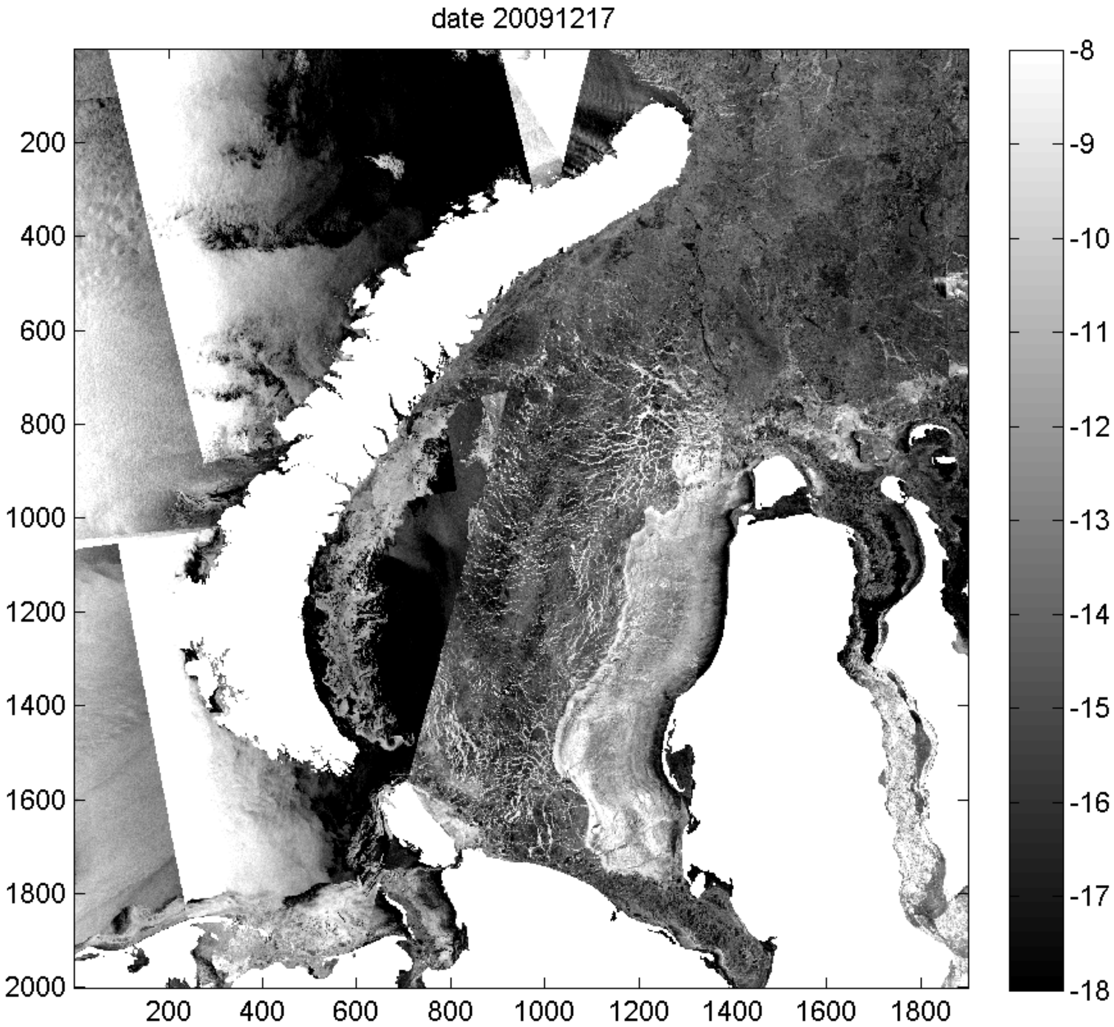
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Thin ice σ° statistics on 28 Nov 2009 (region of interest)



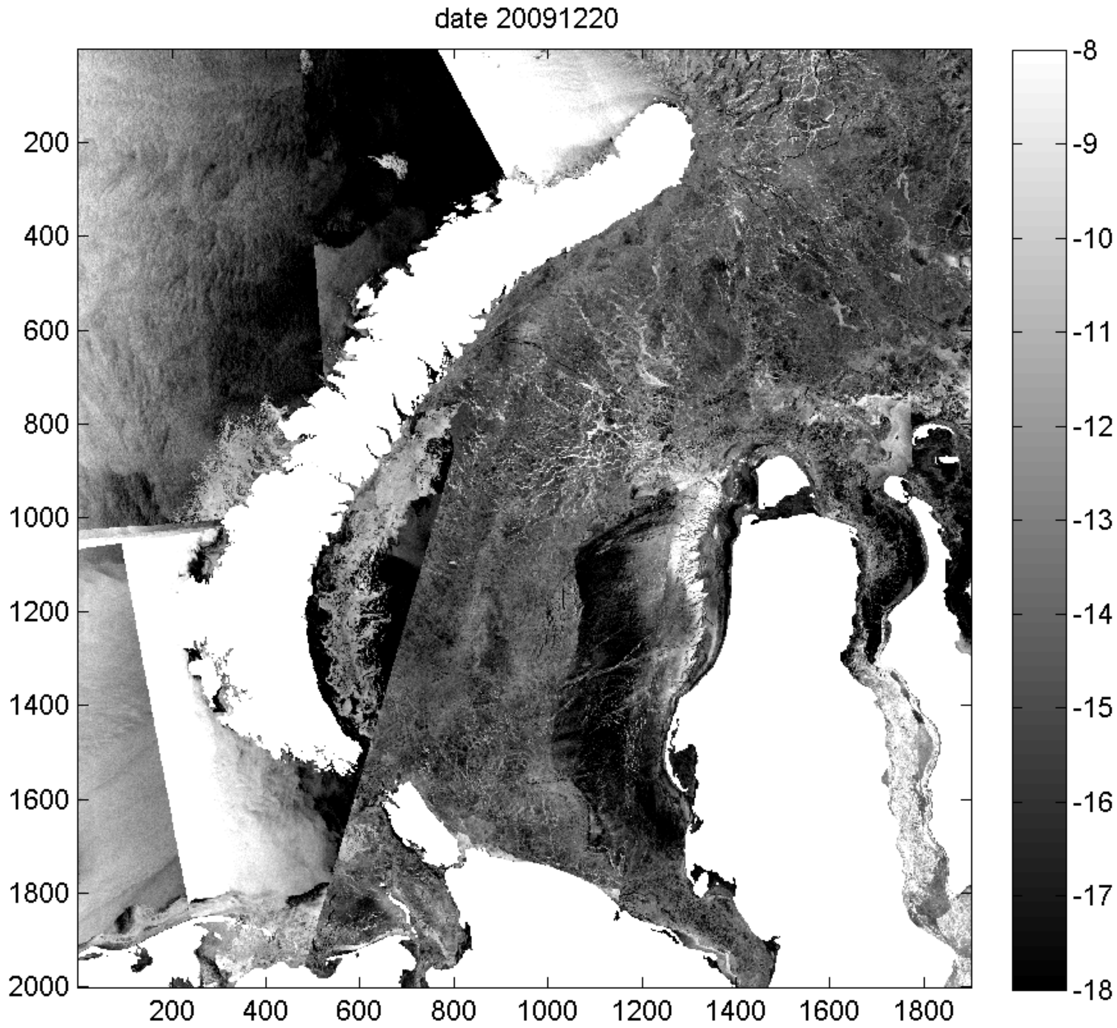
Polynya
on 17 Dec 2009

***Ta* = -31°C,**
U = 2 m/s.

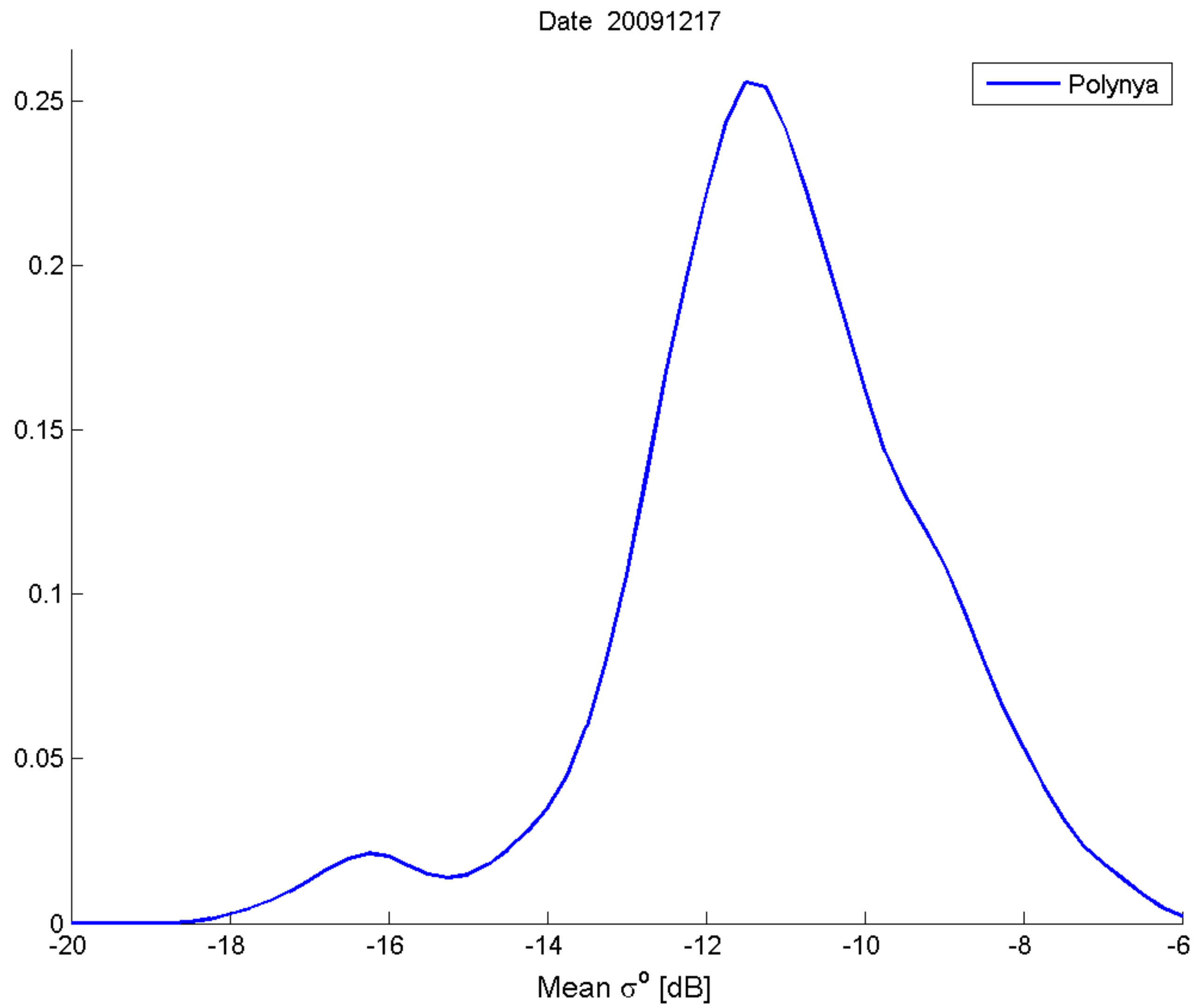


Polynya
on 20 Dec 2009

***Ta* = -33°C,**
U = 5 m/s.

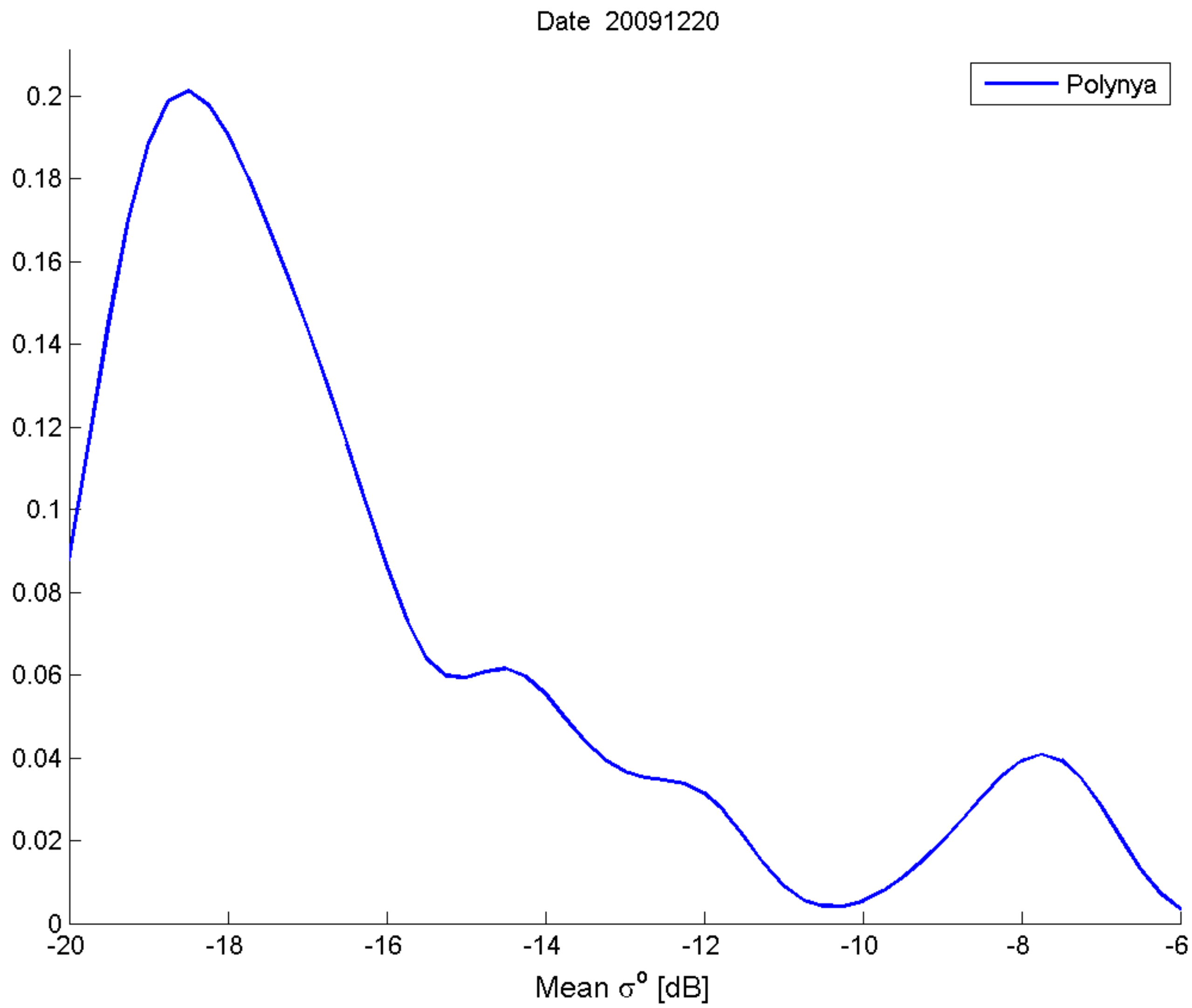


Polynya σ° statistics on 17 Dec 2009

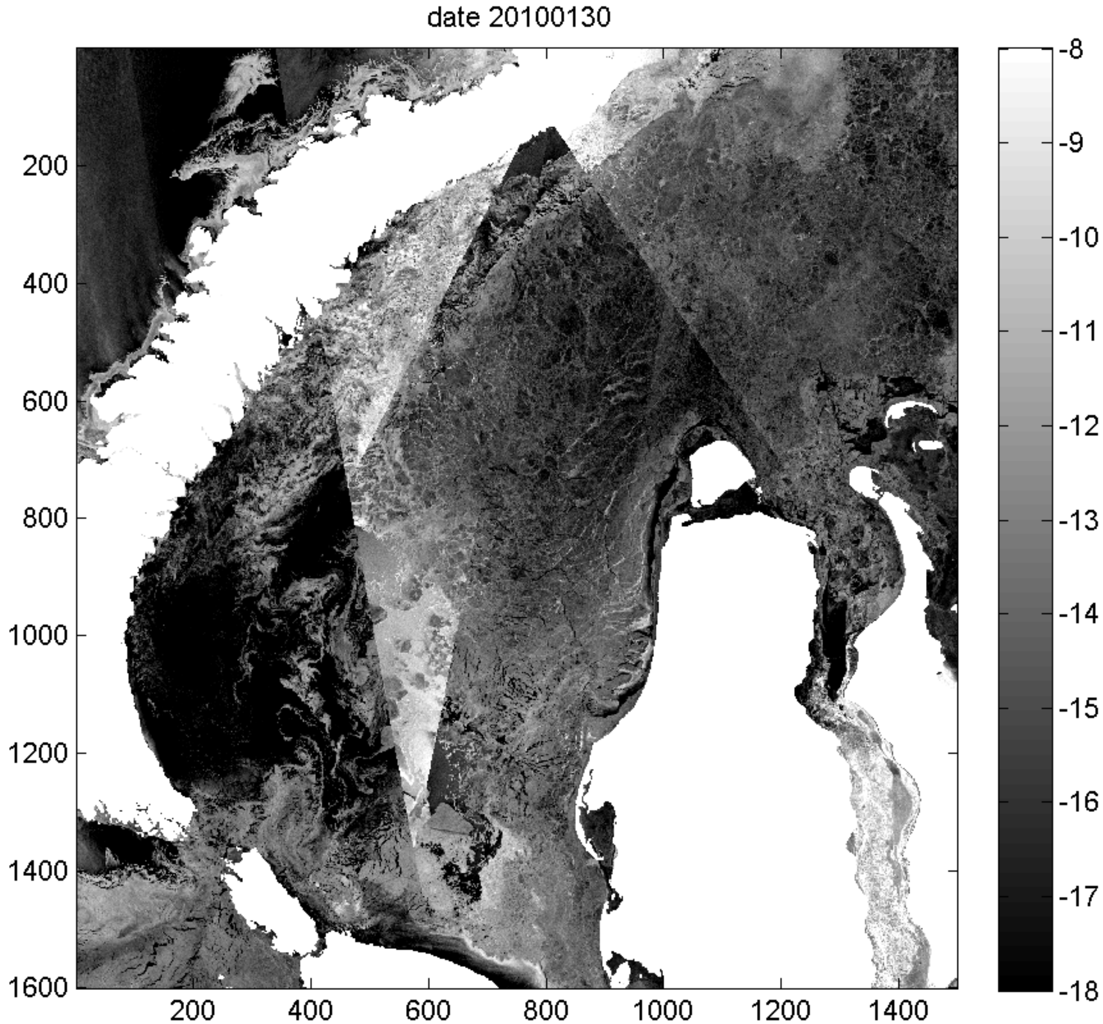


ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Polynya σ° statistics on 20 Dec 2009



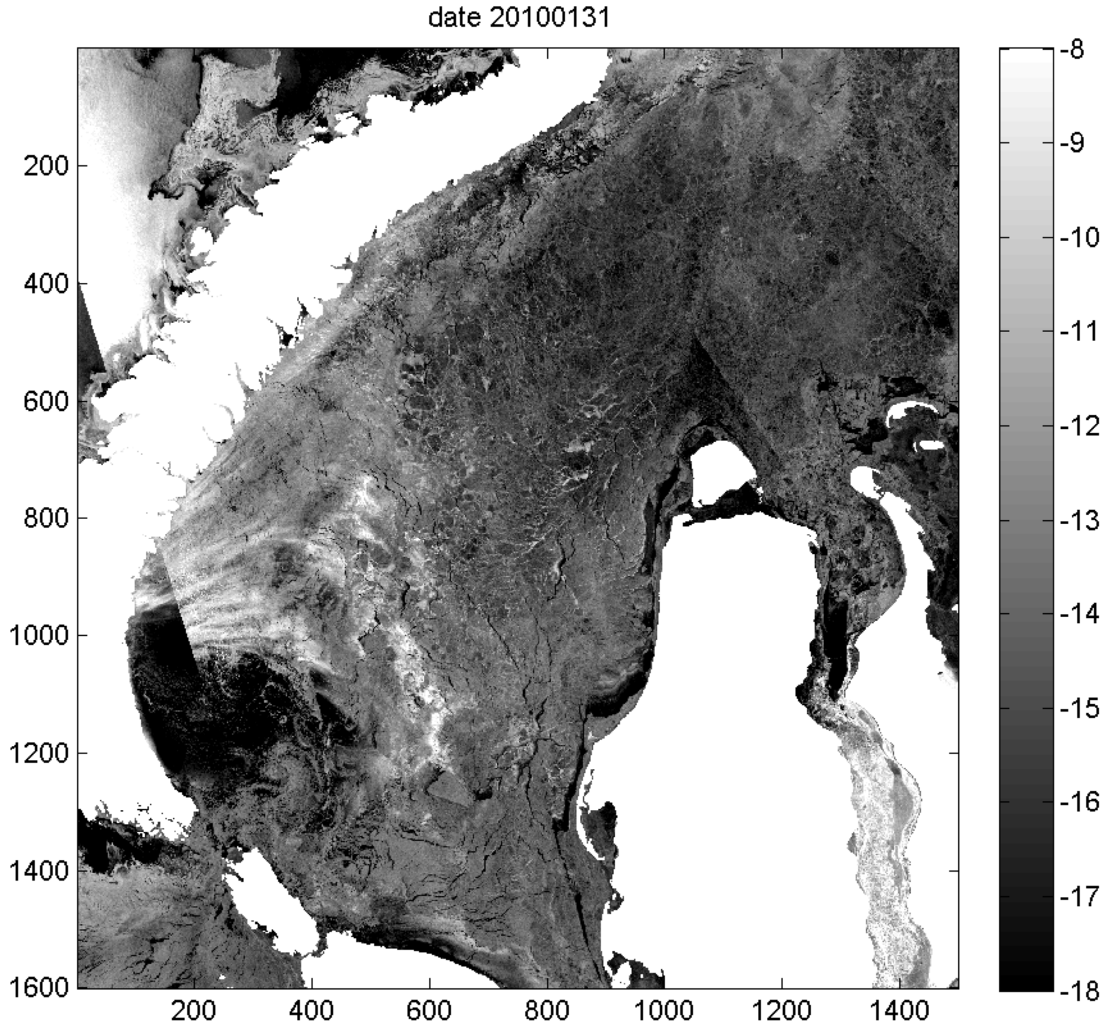
Ice conditions
on 30 Jan 2010



ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

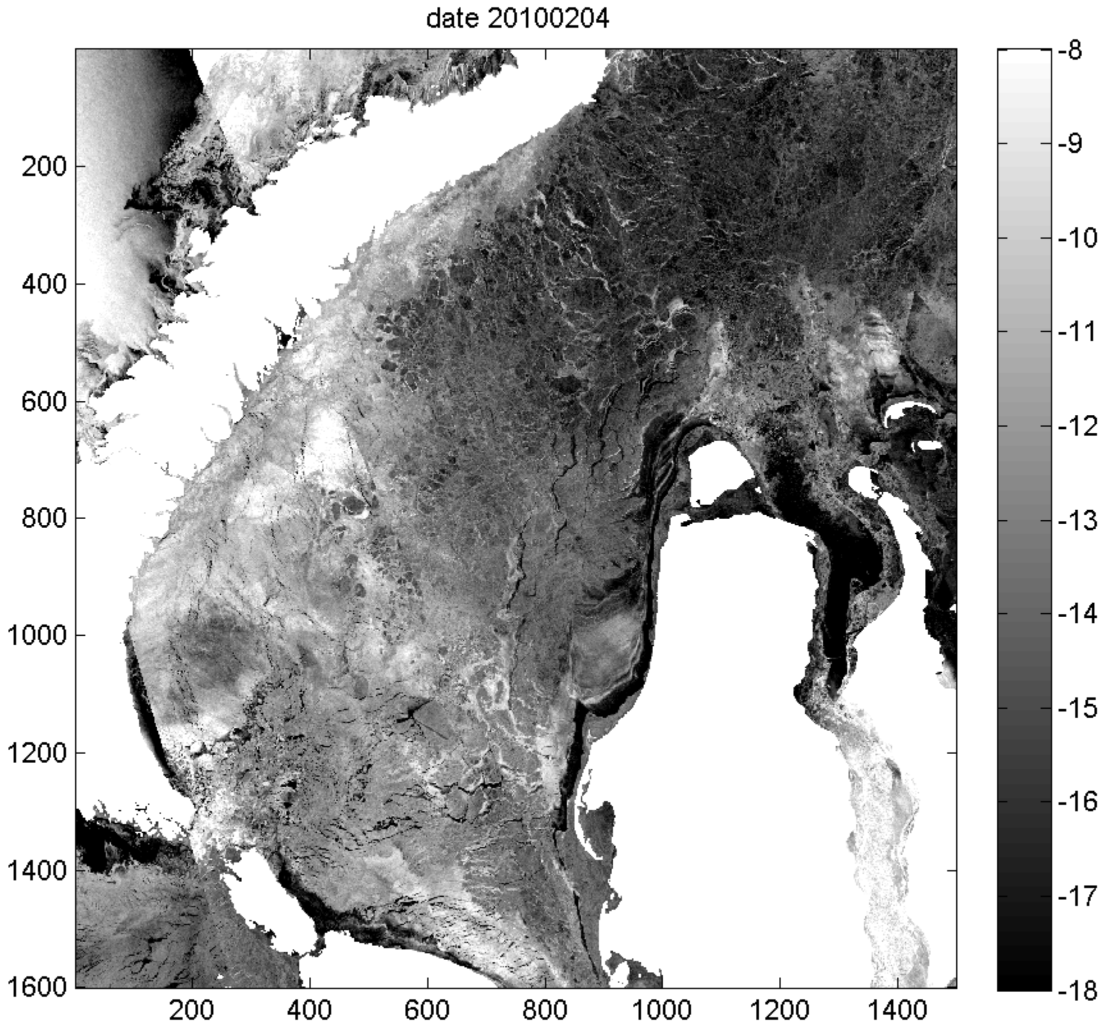
Ice conditions
on 31 Jan 2010

Ta **= -27°C,**
U = 6 m/s.



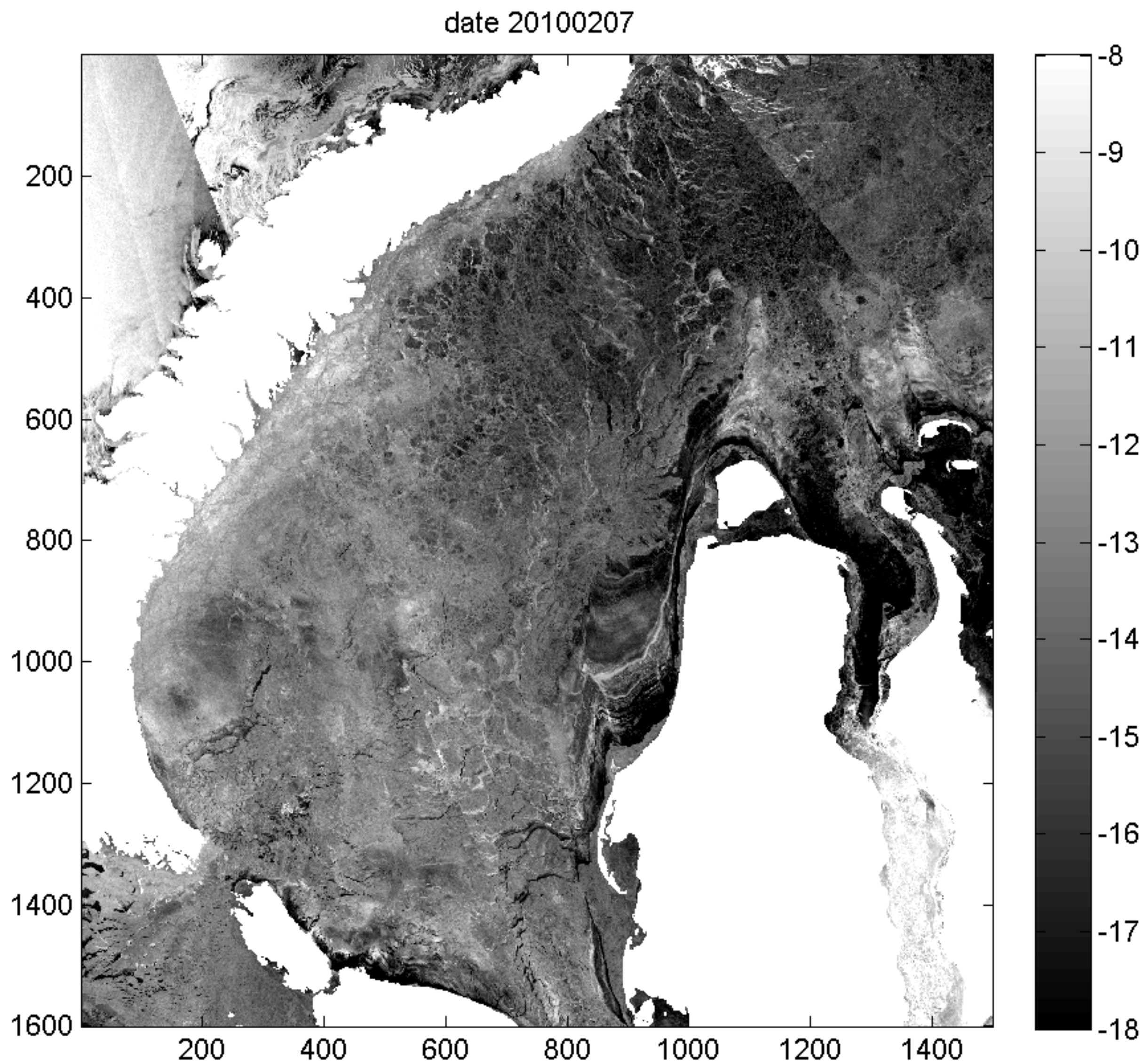
Ice conditions
on 4 Feb 2010

***Ta* = -31°C,**
U = 6 m/s.

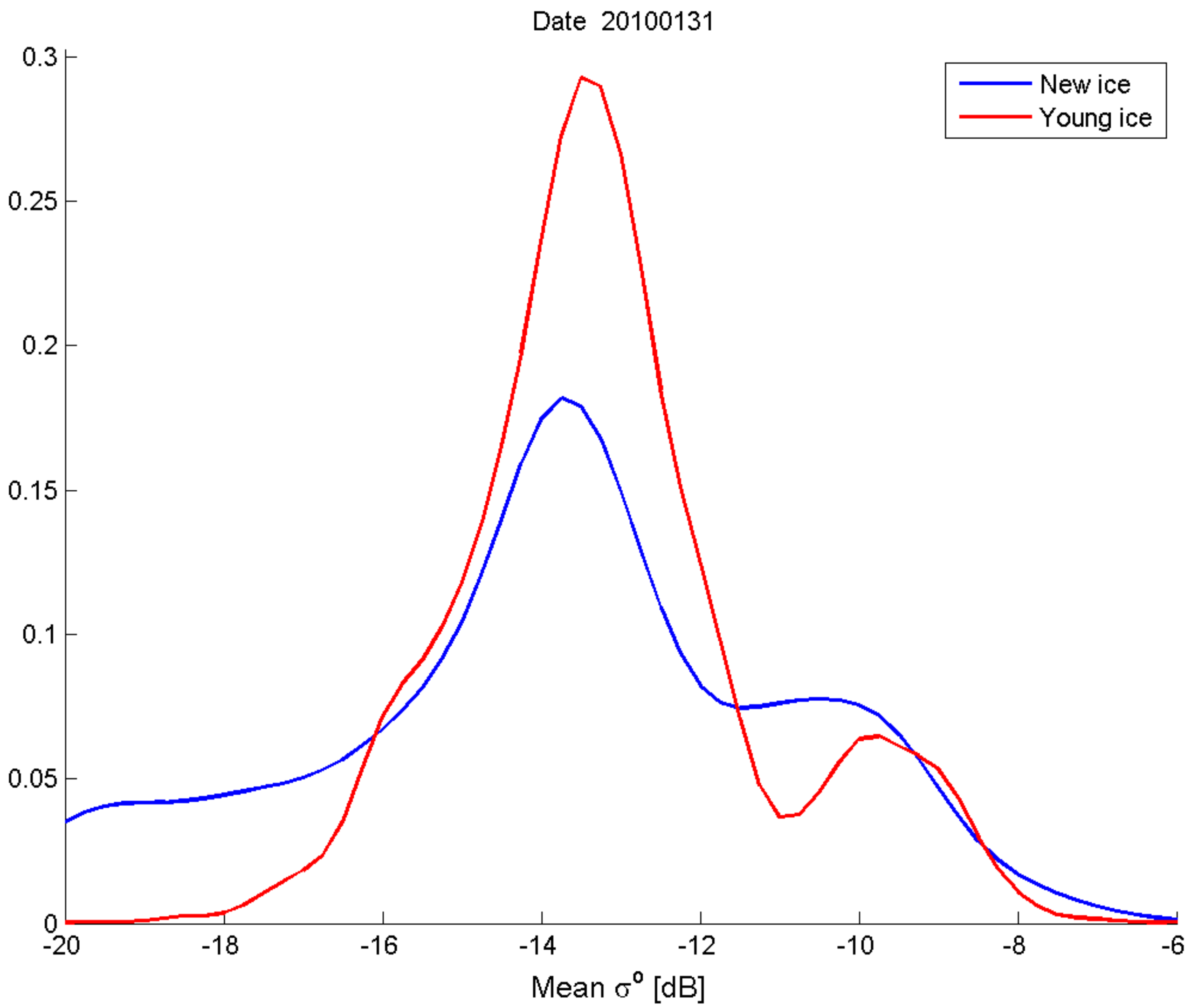


Ice conditions
on 7 Feb 2010

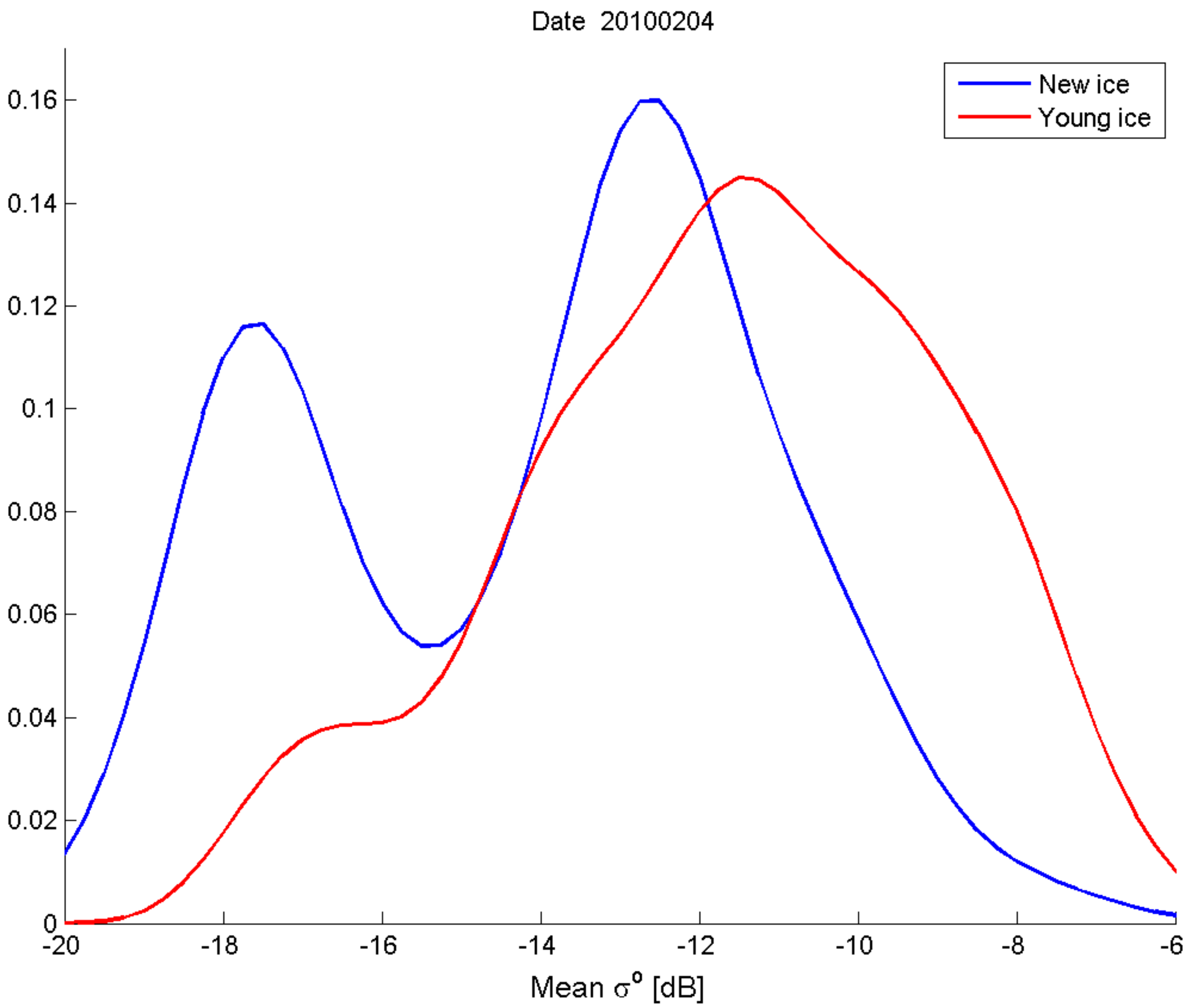
***Ta* = -35°C,**
U = 5 m/s.



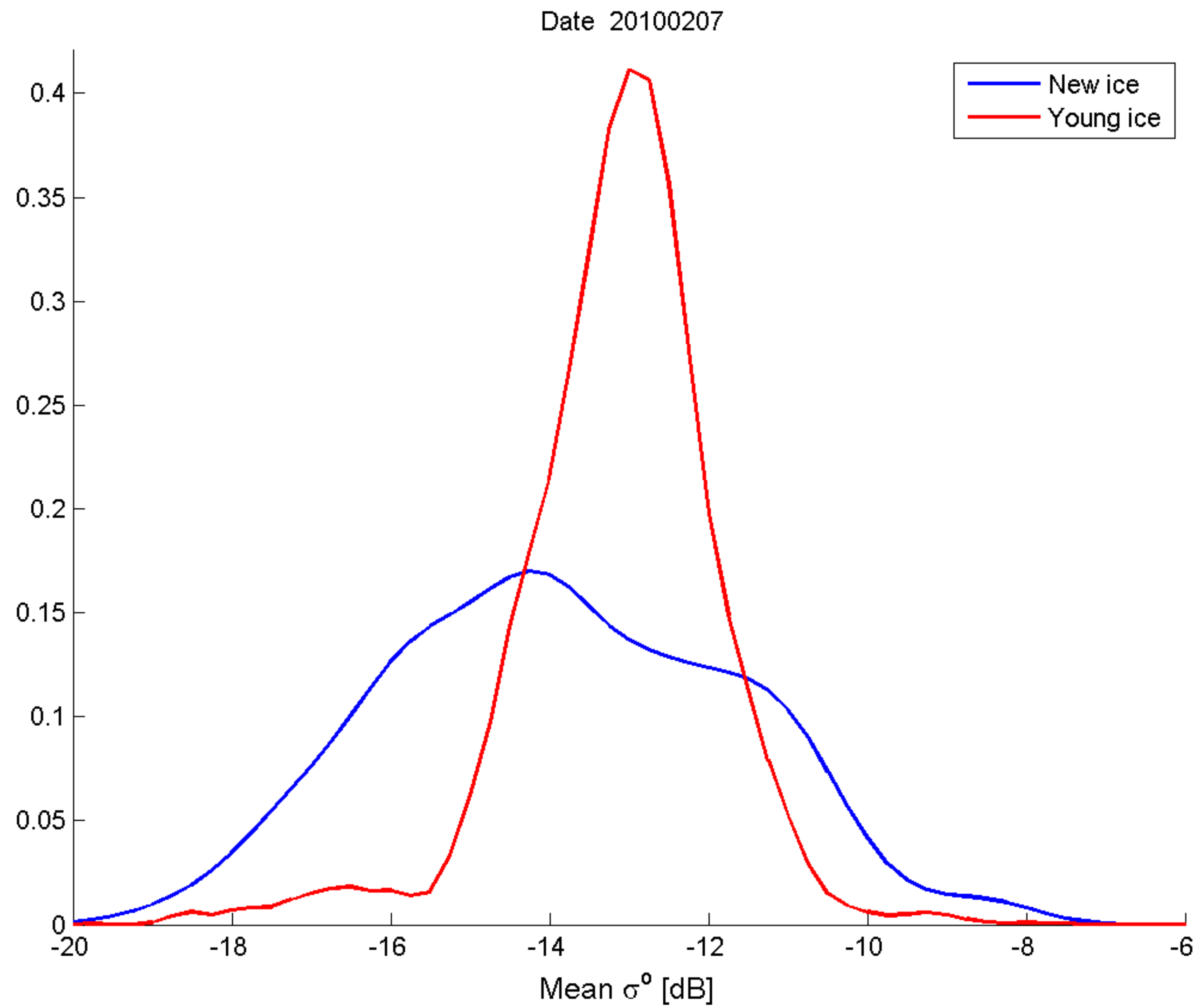
Thin ice σ° statistics on 31 Jan 2010 (region of interest)



Thin ice σ° statistics on 4 Feb 2010 (region of interest)



Thin ice σ° statistics on 7 Feb 2010 (region of interest)



Conclusions

- **Thin ice σ° statistics depend on the development stage and type of ice.**
- **Due to the uncertainties in the MODIS based ice thickness retrieval as well as the sampling procedure the resulting σ° distributions must be interpreted cautiously. However, they are indicative. The thin ice σ° distributions can exhibit significant variation when σ° is expressed at coarse scale (500 m).**
- **It is our understanding that the one of the major reasons behind the large σ° variation are changes in sea ice concentration (IC) at small (0.5-1 km) scale which are very difficult automatically or even visually detect. It is not necessary that the wind speed is high to cause a change in IC. The change in wind direction is often sufficient to cause the IC change in the MIZ.**
- **Other processes affect the SAR signature too such as deformation of thin ice (brash ice, rafting, formation of small ridges). Also the occurrence of frost flowers alters σ° for a short period.**
- **To monitor the spatial distribution and development of thin ice fields it is necessary to have an access to SAR data with high spatial resolution and, preferably, with two frequencies.**