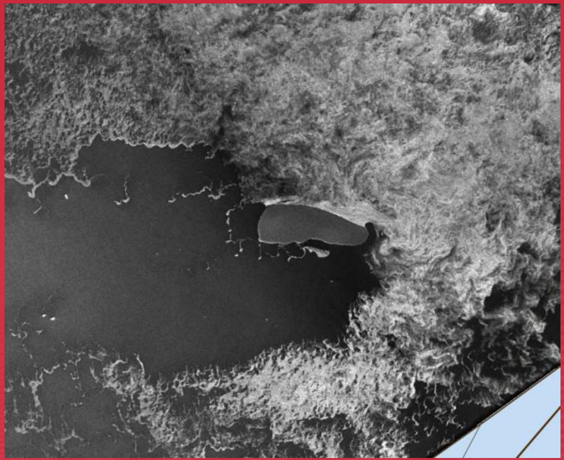
SAR imagery: an asset to the sea ice altimetry communauty

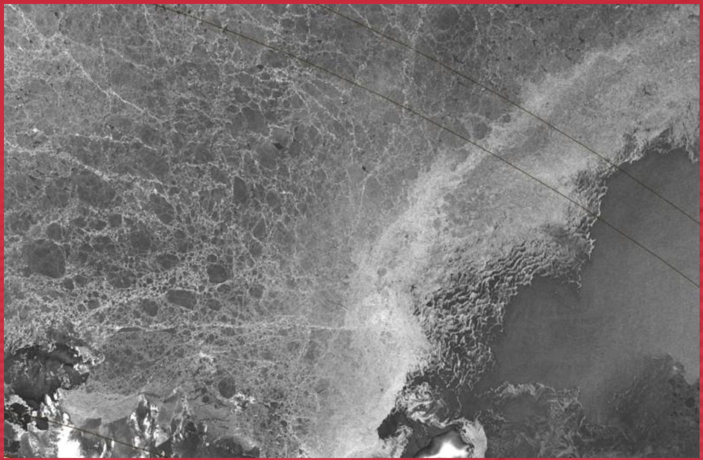
Altimetry and glaciology CNES workshop

June 25, 2015

N. Longépé, P. Vincent, G.Hajduch, R. Husson (CLS)

A. Mouche (IFREMER)



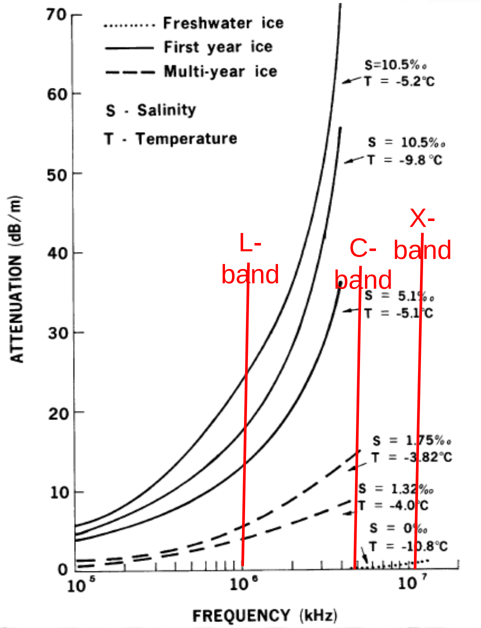


Foreword on sea ice backscattering from single-pol SAR images (L-C-X bands)

Sea ice varies according to many parameters:

- EM parameters such as the dielectric properties of brine inclusion and of ice depending on salinity
- Geo-physical parameters such as the sea ice thickness, its top surface roughness, its porosity, the size/shape of scatterers (brine inclusions, air particles…).
- Potential snow cover (dielectric constant of 1.5 for dry snow – varying also with density, frequency and wetness)

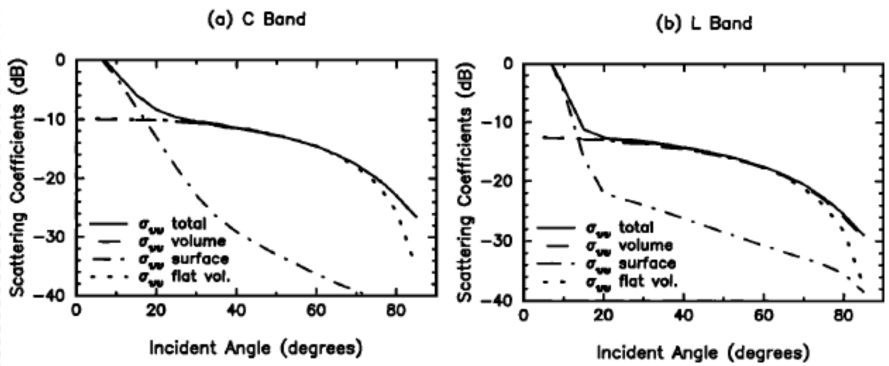
⇒ Large number of parameters impacting sea ice backscattering, potential ambiguities between open water and thin ice in leads with single-pol SAR imagery



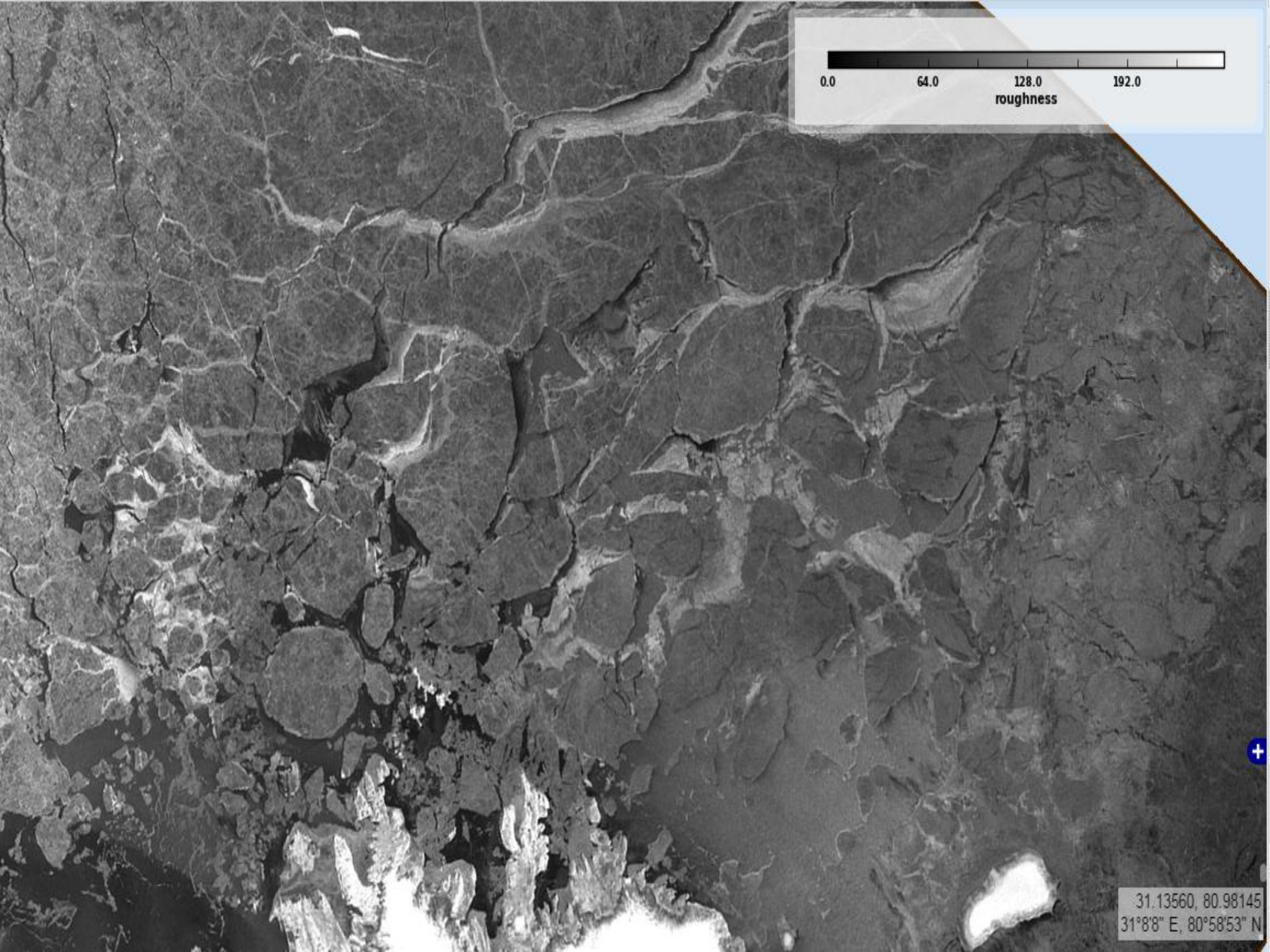
Attenuation by sea ice depending on the frequency of EM microwaves (from Fingas and Brown)

<u>**Surface vs volume backscattering at 20-50°**</u>

- Average thickness of FYI about 1.5 meter (MYI: 2.5 m)
- **FYI: Limited volume backscattering from C-band and higher frequencies**
- **MYI: Limited volume backscattering from L-band and higher frequencies**



Contribution of surface and volume contributions from MYI at L-band (Left) and C-band (from Nghiem et al. 1995)


0.0
64.0
128.0
192.0
roughness
31.13560, 80.98145
31°8'8" E, 80°58'53" N

Overview

On the automatic detection of leads with thin ice or open water

Benefit of polarization diversity to characterize sea ice and leads

Assessment of sea surface roughness in leads

Few words on Sentinel-1

On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

On the automatic detection of leads with thin ice or open water

Benefit of polarization diversity to characterize sea ice and leads

Assessment of sea surface roughness in leads

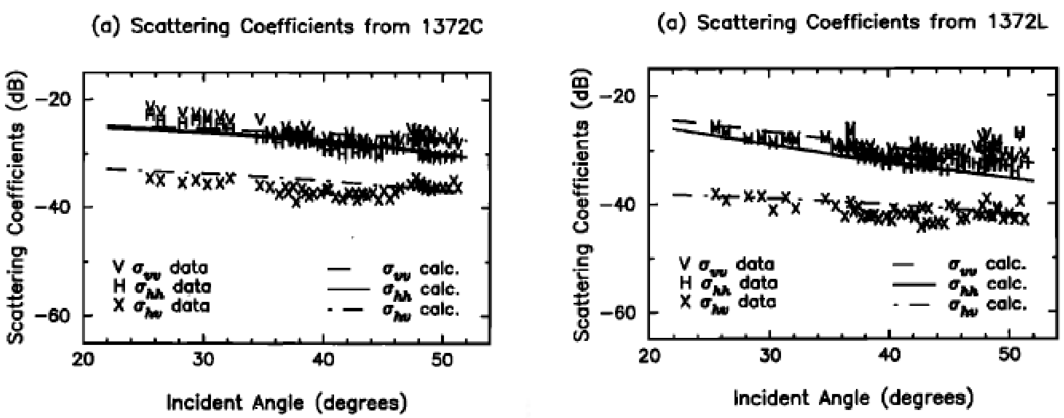
Few words on Sentinel-1

On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

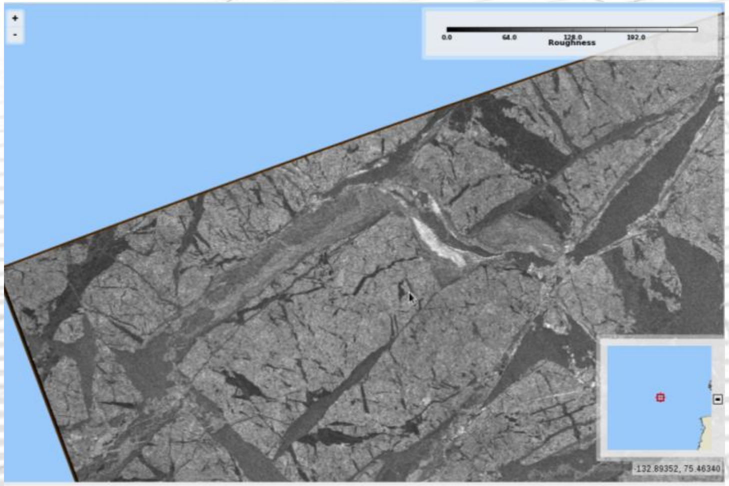
Thin ice lead

- Open water rapidly freezes (directly exposed to the cold air temperatures) -> thin ice skim hence formed followed by black ice
- Backscattering close to NESZ of current available sensors

⇒ Potential ambiguity with open water in leads (limited fetch -> very calm sea surface)

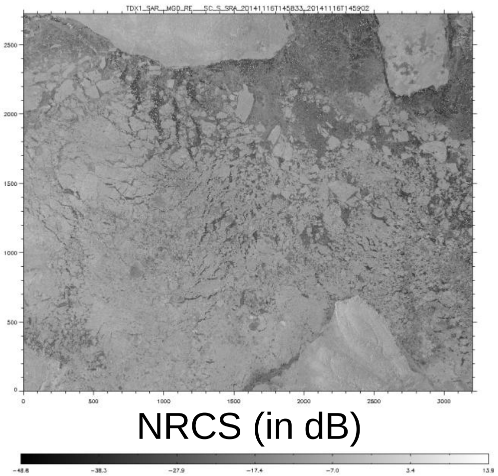


Simulations and measurements of EM backscattering at C-band (Left) and L-band (Right) from thin lead ice (from Nghiem et al. 1995)

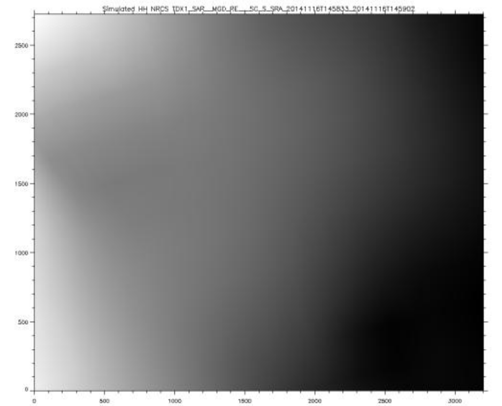


ENVISAT image 01/06/2008

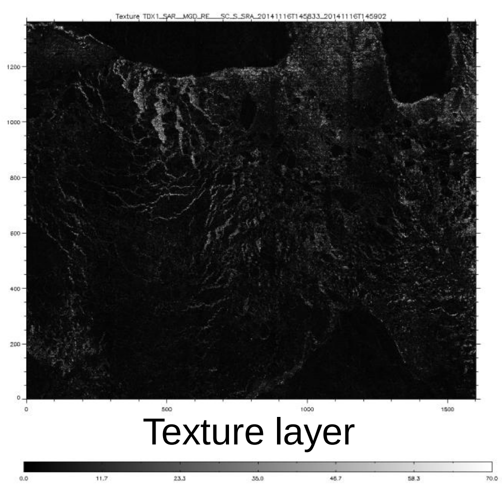
Automatic lead detection with single-pol X-band data



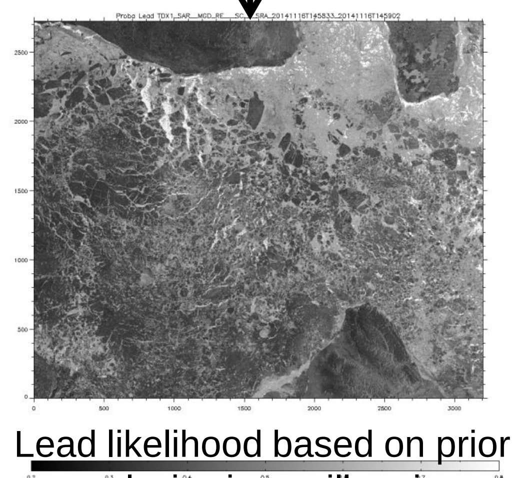
NRCS (in dB)



Simulated NRCS with CMOD or XMOD (assuming open water everywhere)

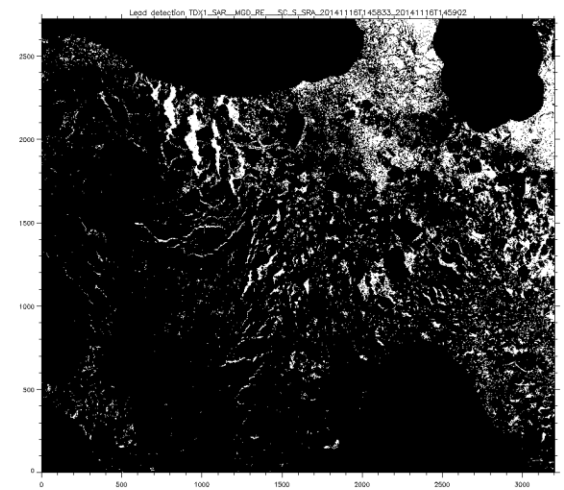


Texture layer



Lead likelihood based on prior analysis via ancillary ice concentration information

Iterative threshold with morphological filter



Lead detection

On the automatic detection of leads with thin ice or open water

Benefit of polarization diversity to characterize sea ice and leads

Assessment of sea surface roughness in leads

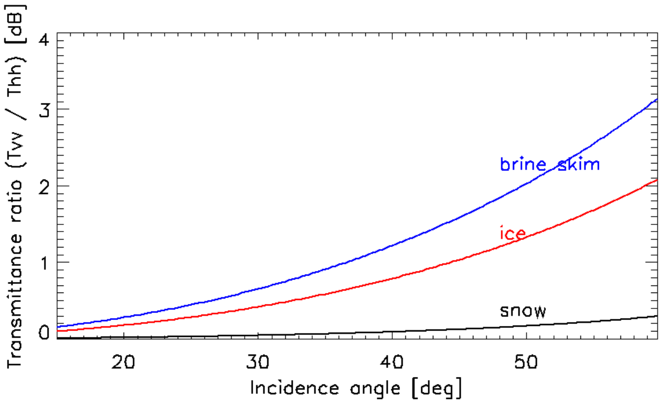
Few words on Sentinel-1

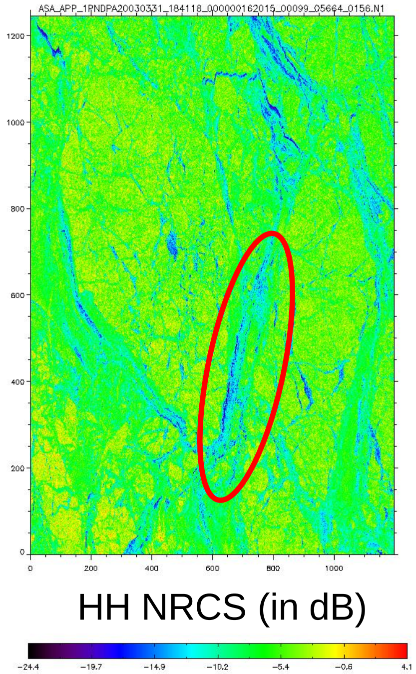
On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

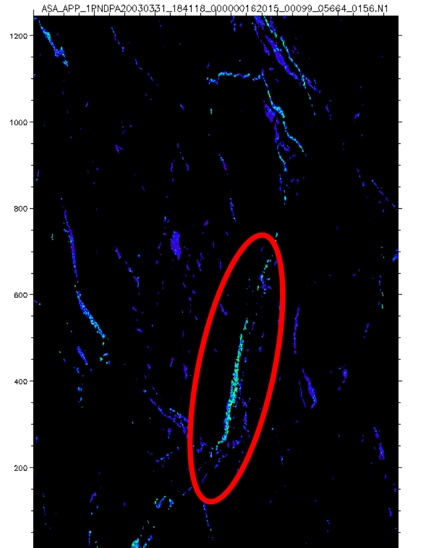
Benefit of dual-pol HH and VV C-band

New thin ice:
Slushy layer of the order of millimetre thick and composed of ice and brine with salinity as high as 100% exists on the top of new ice

High VV/HH Polarization Ratio (PR) first observed by Nghiem et al. 1995




HH NRCS (in dB)


Ratio meas. and sim. PR (dB)
Over detected leads

New thin ice detection
- Ratio between measured and simulated PR (Mouche et al. 2007) assuming open water
  - If very high, potential new thin ice

⇒ Thin ice generates high PR values for a large set of ice/radar configurations ?

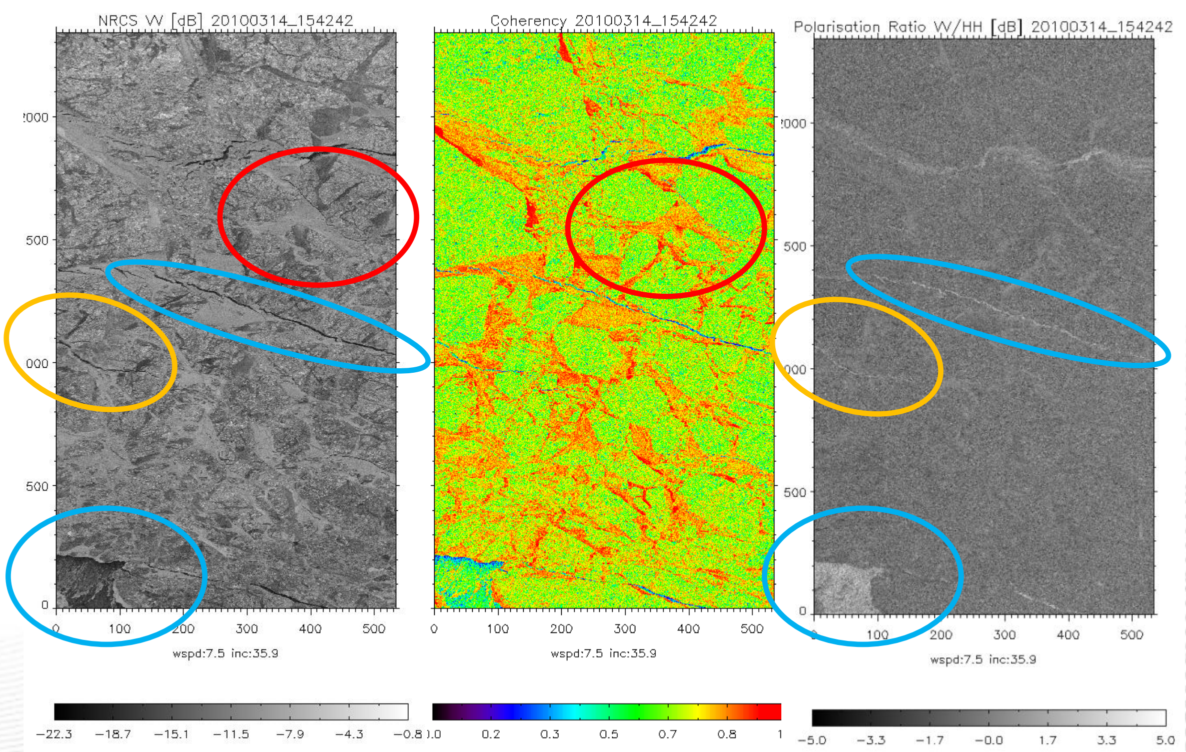
Nghiem S.V, Kwok R., Yueh S.H., Drinkwater M.R., “Polarimetric signatures of sea ice 2. Experimental observations”, Journal of Geophysical Research, Vol. 100, no. C7, pp. 13,681-13,698, 1995

Dual-pol HH/VV analysis in X-band: study cases

In (Nghiem et al. 1995), about VV-HH coherency over sea ice -> Valid for long EM waves (penetrating L-band data, and to a lesser extend C band)

- MYI: high correlation between HH/VV with spherical air inclusions
- FYI: Decorrelation due to ellipsoidal shape of brine inclusion, and preferred vertical orientation
- Thin Lead ice: same as FYI, with additional decorrelation due to noise

What about higher frequency data ?…. Below X-band VV/HH TSX data

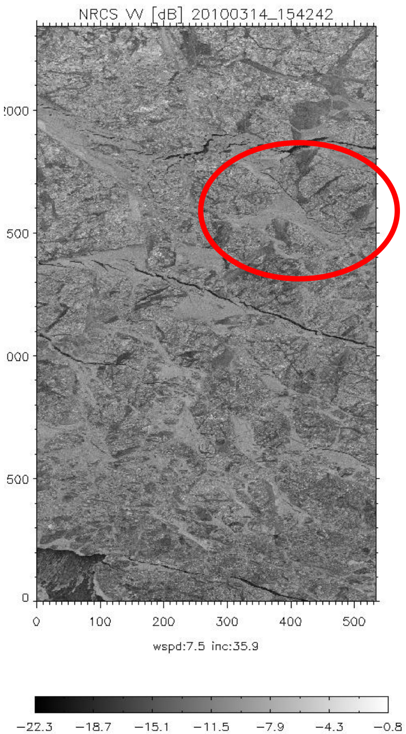


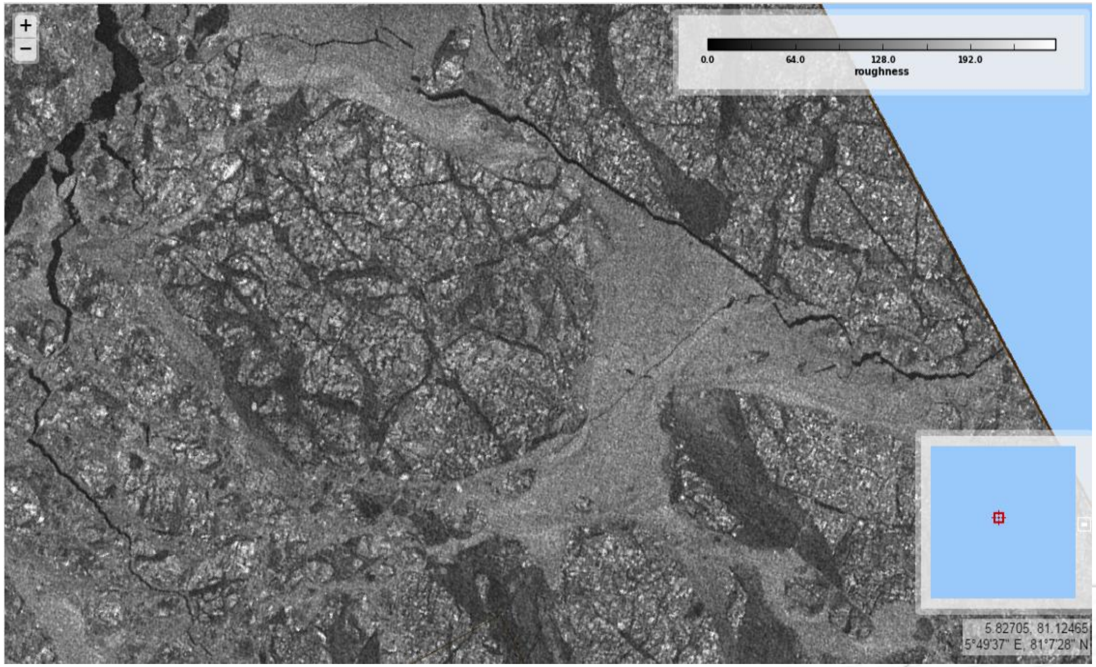
High Polarisation Ratio over leads with possibly thin ice (open water otherwise)

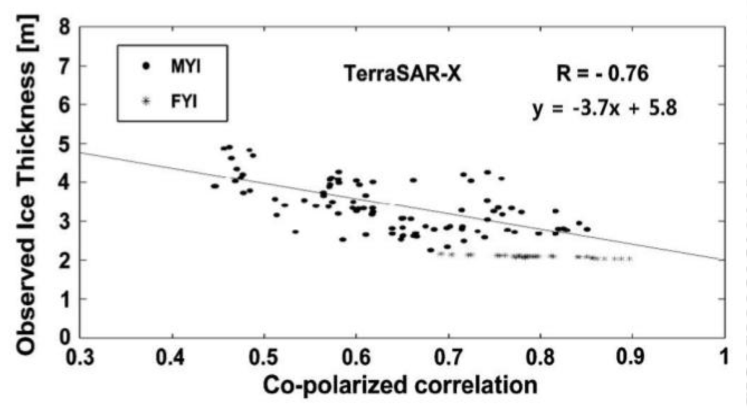
High co-pol coherency over homogenuous FYI ice

Deformed ice / fragment of MYI induces lower coherency at X-band

Dual-pol HH/VV analysis in X-band: study case







Potential indirect effect from top ice roughness ?

Observed ice thickness with respect to co-pol coherence with TSX X-band data (from Kim et al. 2012)

On the automatic detection of leads with thin ice or open water

Benefit of polarization diversity to characterize sea ice and leads

Assessment of sea surface roughness in leads

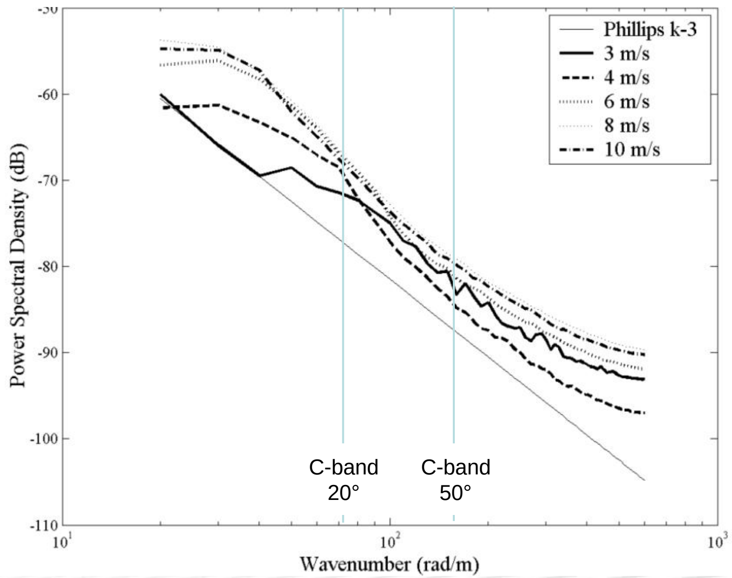
Few words on Sentinel-1

On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

Effect of fetch in leads / melt ponds

- **Wind stress: primary forcing mechanism on the variability and magnitude of small-scale wind-waves**
  - Perturbation of wind roughened open sea surface in ice to wavelengths that are resonant to C-band SARs is driven by upwind fetch and wind speed.
  - Morphology of leads (size, orientation) with respect to wind contributes to the availability of fetch (i.e distance from ice edge)

Measured wavenumber in melt pond with mean size [10-30 meters] for different wind speed (Scharien and Yackel 2004)



(Small?) dependancy to wind speed at C-band

Variable	Pearson's Correlation to σ° (HH, VV) [a]			
	20°	*30°*	*40°*	*50°*
Wind Speed	.298 (.012)	.346 (.003)	.327 (.006)	.317 (.007)
Pond Fetch	.479 (.000)	.500 (.000)	.508 (.000)	.502 (.000)
Pond Depth	.452 (.000)	.454 (.000)	.469 (.000)	.477 (.000)

a. Correlation does not change as a function of polarization.

Wind speed, upwind fetch length, and depth contribute to C-band σ° from a FYI sea ice melt ponded surface

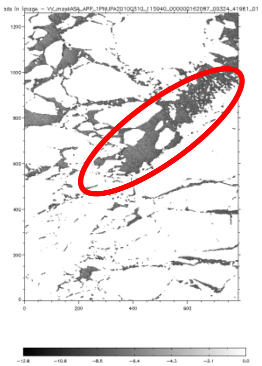
Even at low wind speeds (e.g., 3 m/s): decametric ponds are reactive to Bragg scattering at C-band.

* Fetch: Waves are formed by wind blowing along the water's surface. Surface roughness is dependent on wind speed, fetch length and duration of time the wind blows consistently over the fetch. Wind "fetch" is the distance the wind blows over water with similar speed and direction.

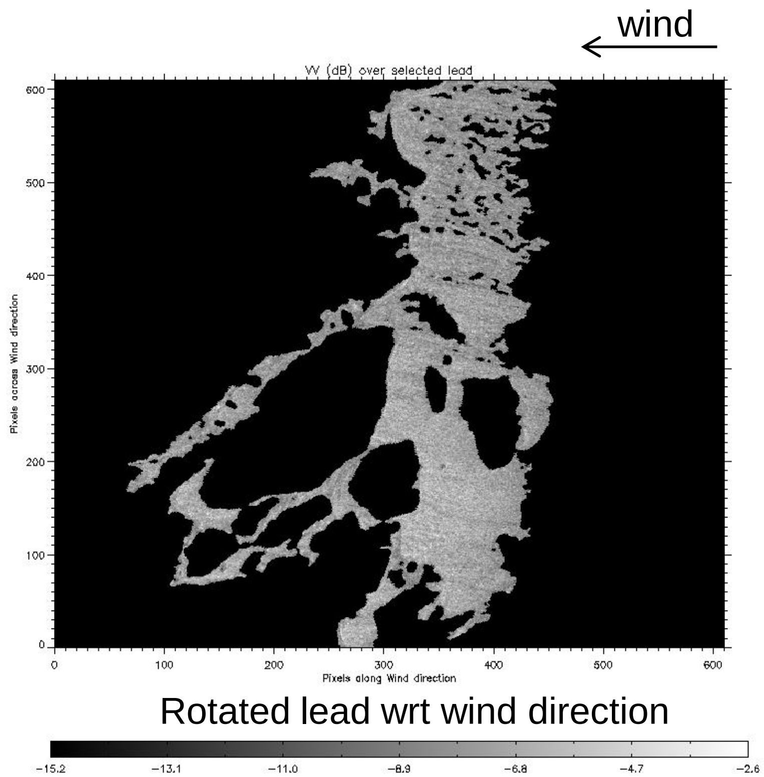
(Scharien and Yackel 2004): "Analyses of C-band microwave backscatter to windroughened first-year sea ice melt ponds"

Measurement of fetch effect in lead with open water

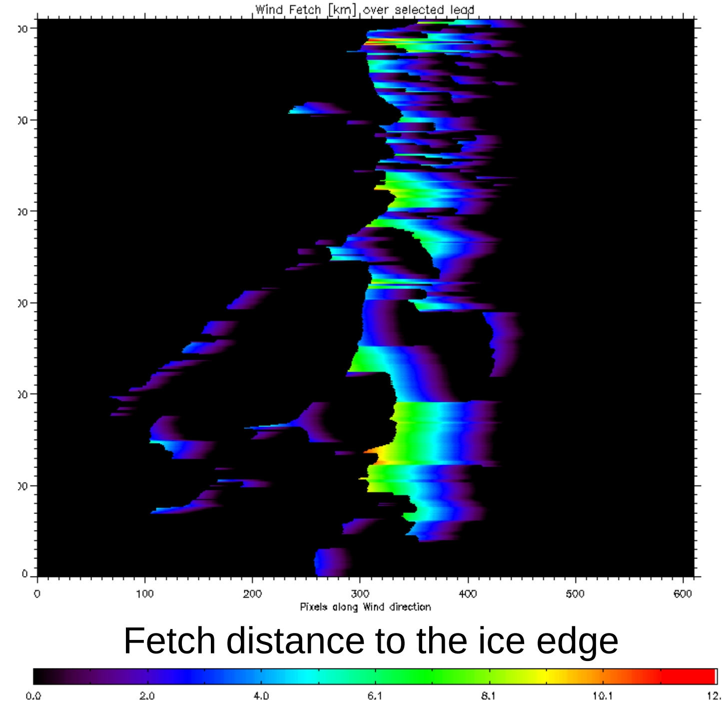
- **Automatic fetch assessment**
  - Automatic lead detection then followed by lead identification
  - Lead is rotated wrt to upwind direction, and NRCS analyzed upon distance to the ice edge (wrt wind direction)



APP ENVISAT
10/03/2010

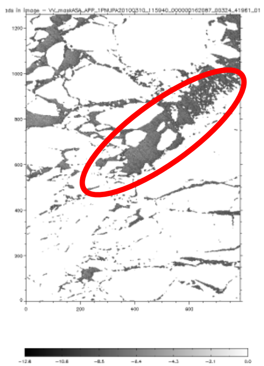


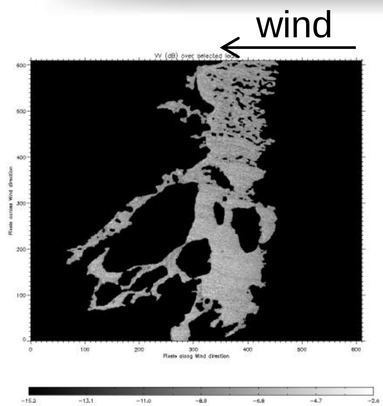
Rotated lead wrt wind direction



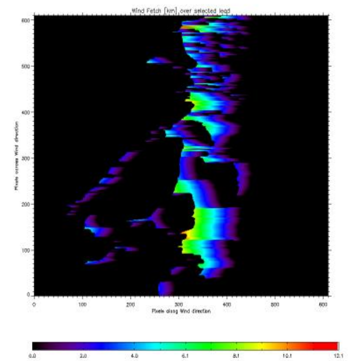
Fetch distance to the ice edge

Measurement of fetch effect in lead with open water (#1)

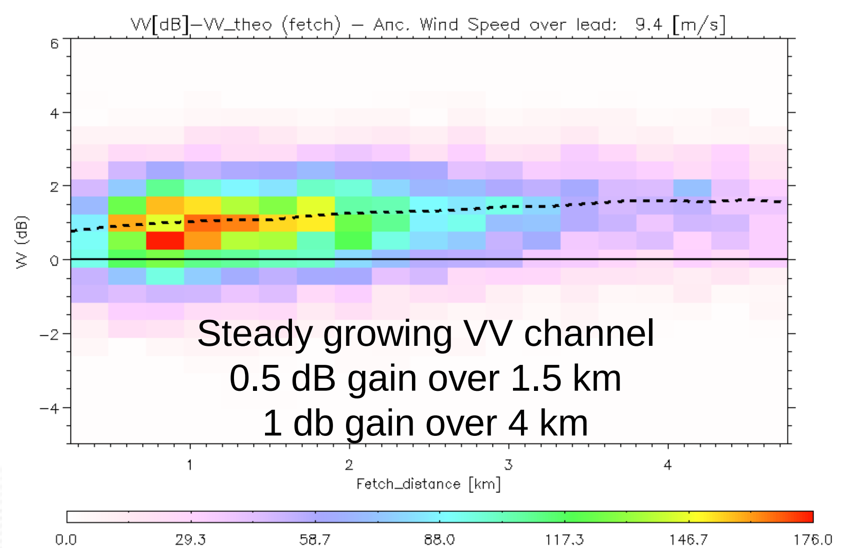


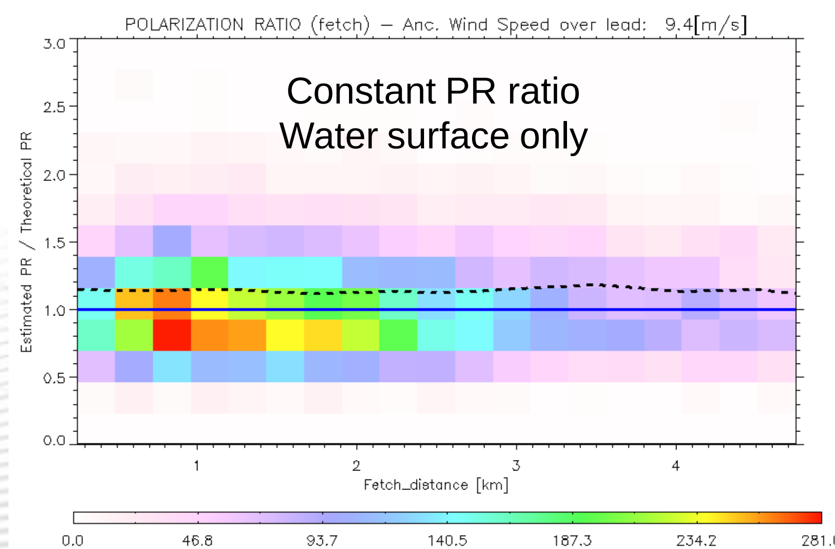


Rotated lead wrt wind direction



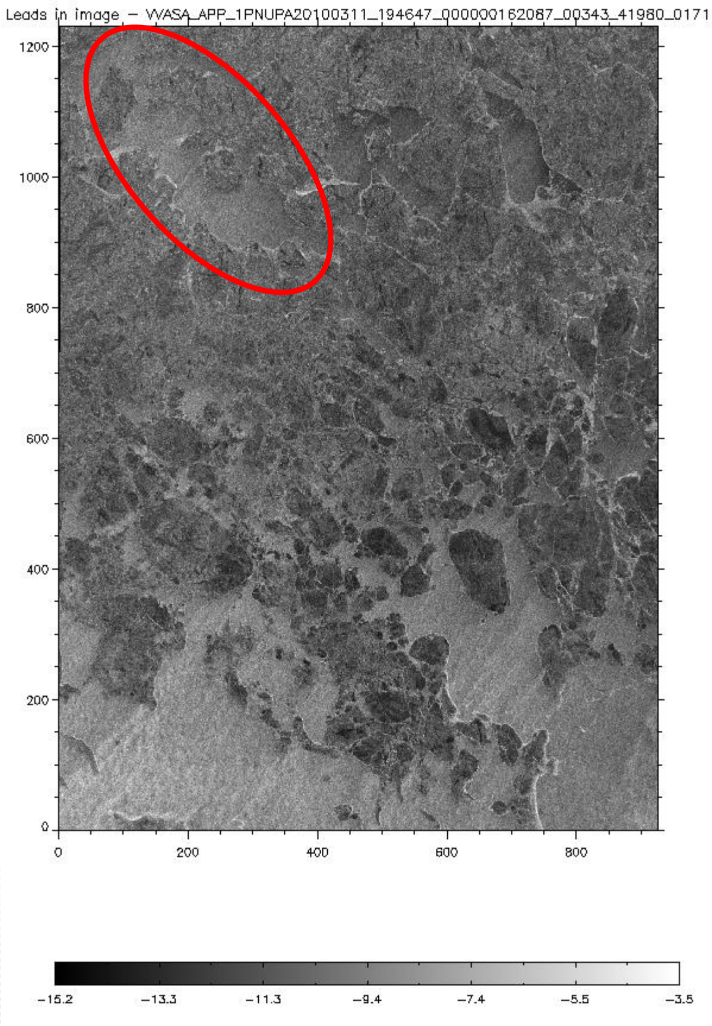
Fetch distance to the ice edge

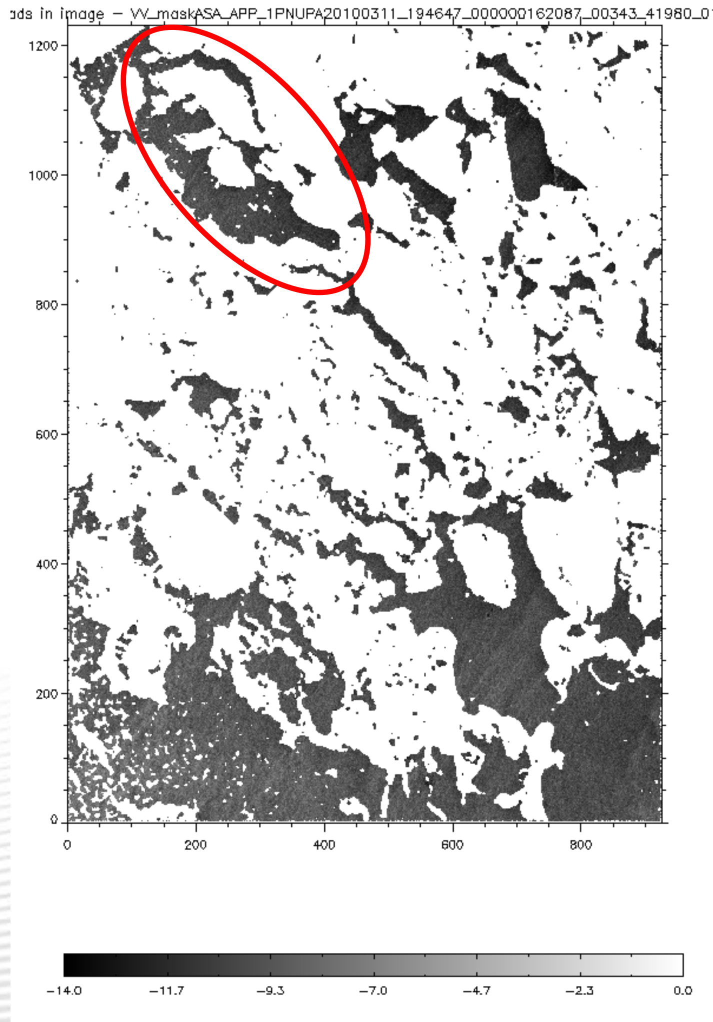




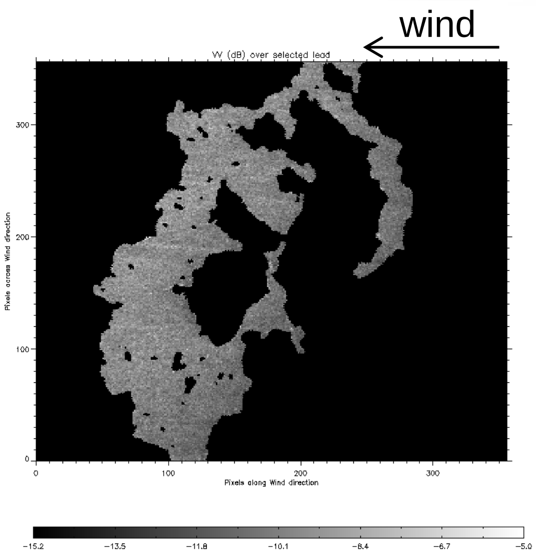
For this specific case, wind-wave equilibrium with about 3.8 km fetch distance

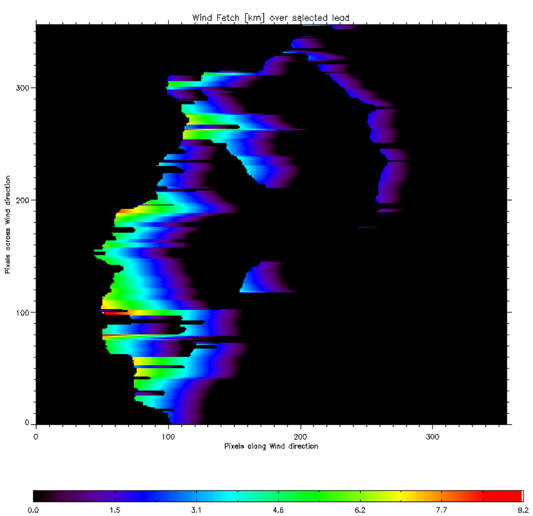
Measurement of fetch effect in lead with open water (#2)

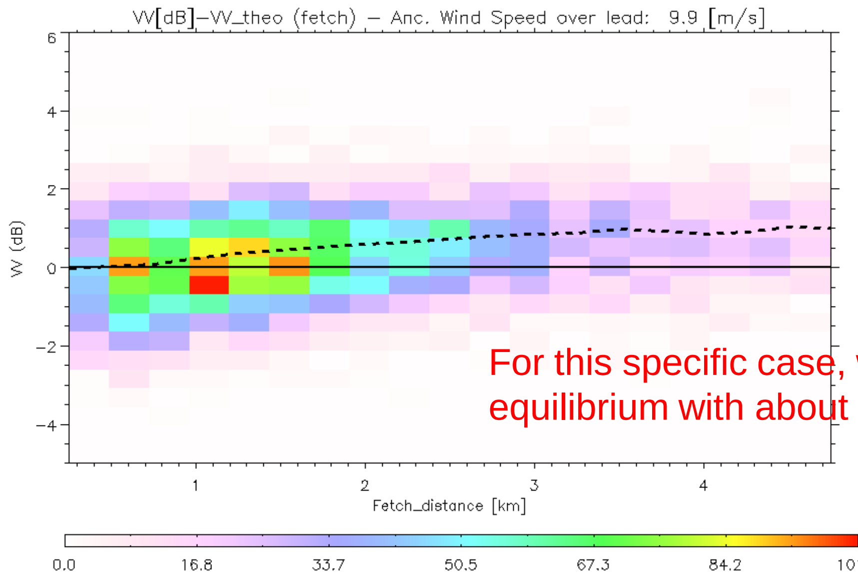




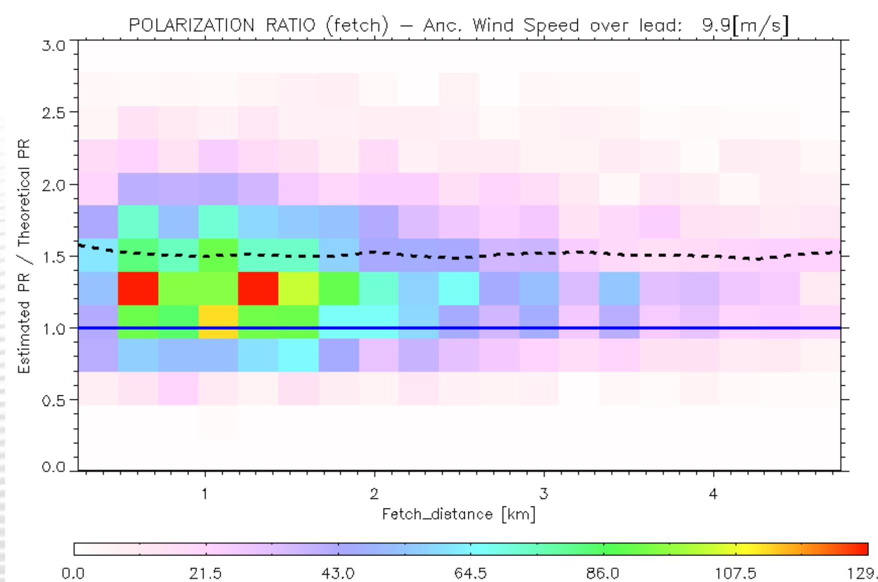
Measurement of fetch effect in lead with open water (#2)





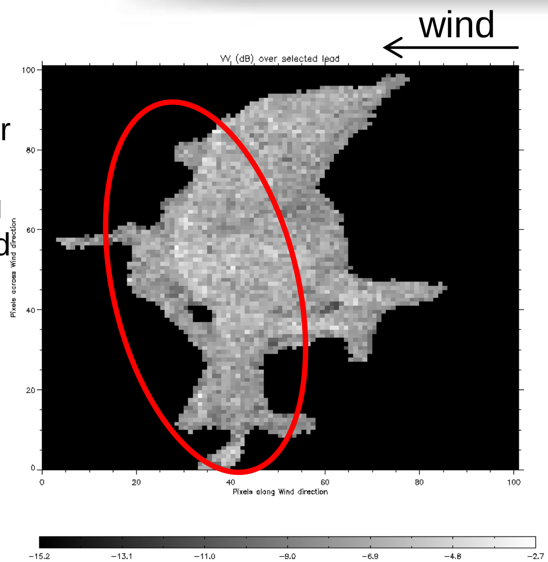


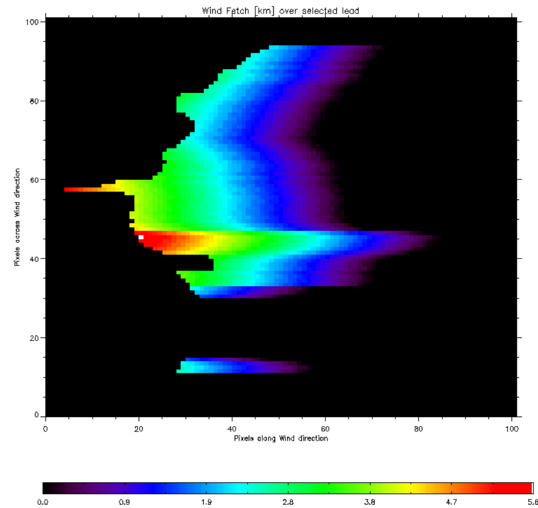
For this specific case, wind-wave equilibrium with about 3.6 km fetch distance

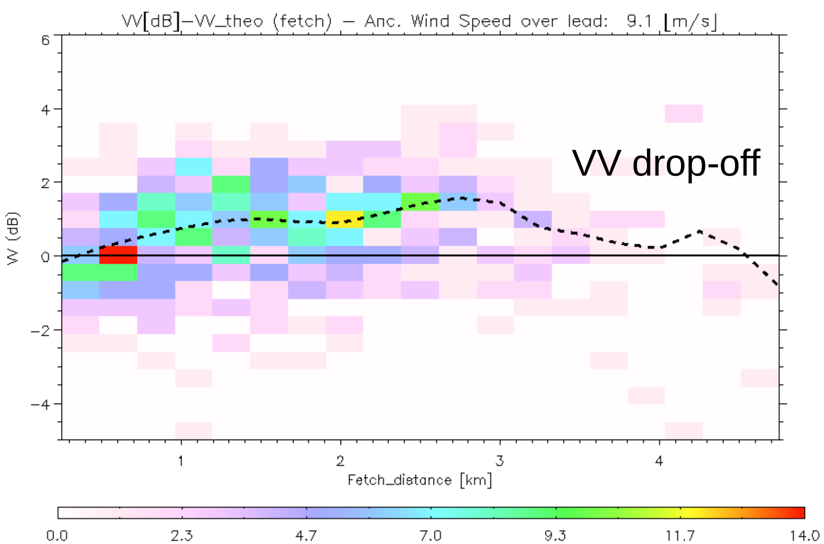


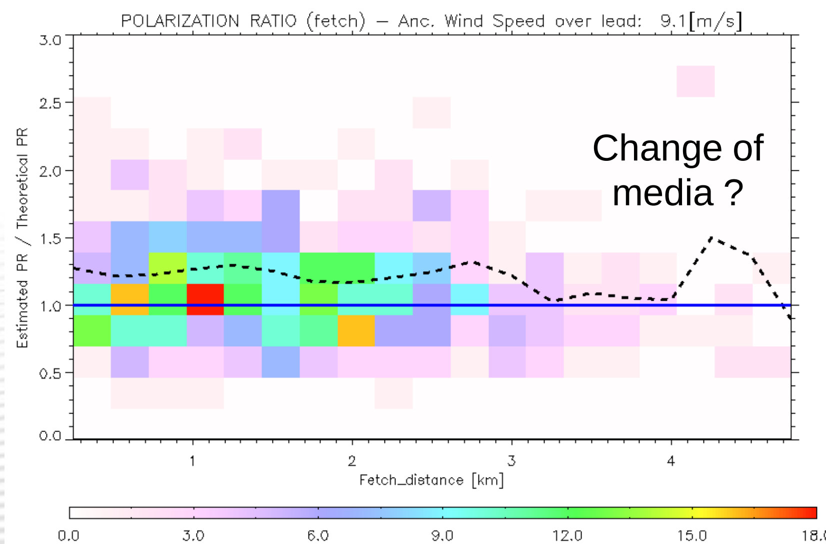
Measurement of fetch effect in lead with open water (#3)

« Unknown » lower backscattering
- Floating melting ice pushed by wind







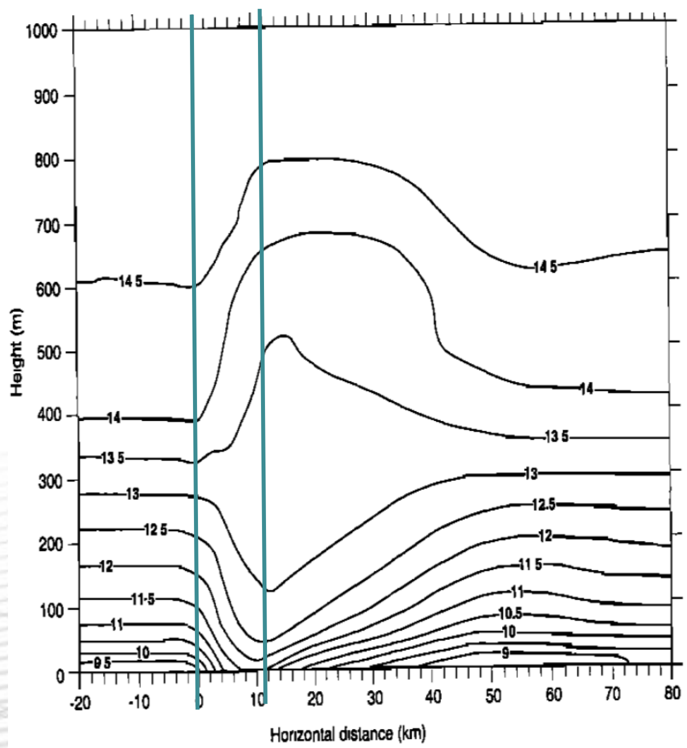


Presence of floating ice (here probably melting ice) prevents from the establishment of wind-wave equilibrium in the lead

Cause of the backscattering and fetch dependence

- Similar distances found with X-band data
- Possible effect of fetch/lead
  - Fetch effects on EM backscattering: wind-sea interaction is not at its equilibrium.
    - Bragg wave is instantaneous.
    - Contributing longer waves not formed yet.
  - Atmospheric effect
    - Acceleration of the wind speed over the leads as modeled by (Dare et al.) over leads and MIZ
      - Cold wind from ice (-10°C) interacts with warmer open water (-2°C) -> turbulent atmospheric layer : instability -> favor the air/water interaction

– Loss of energy due to joint fetch/atmospheric effect difficult to model



Wind profile in case of 10 km open water in MIZ with wind coming from ice area

R.A. Dare and B.W. Atkinson Numerical modeling of atmospheric response to polynyas in the Southern Ocean sea ice zone

On the automatic detection of leads with thin ice or open water

Benefit of polarization diversity to characterize sea ice and leads

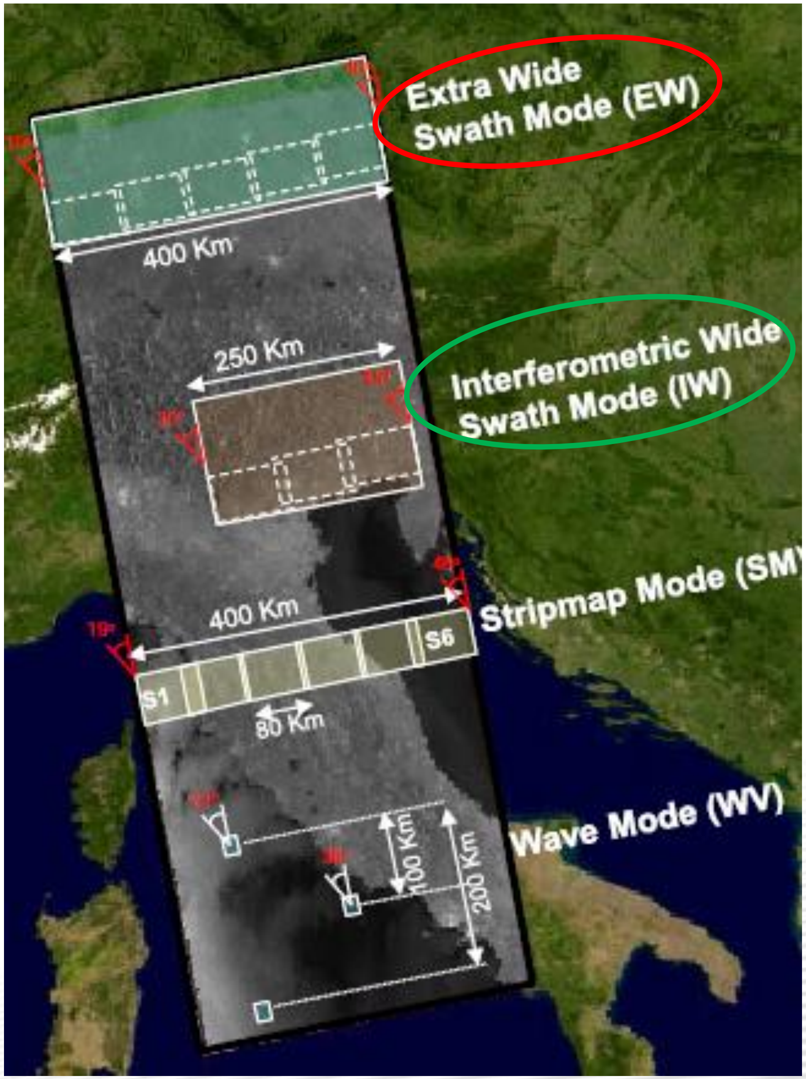
Assessment of sea surface roughness in leads

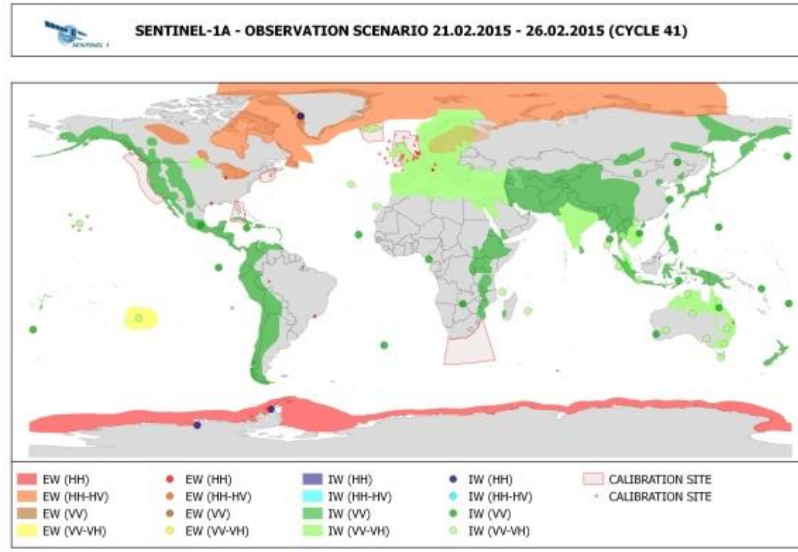
Few words on Sentinel-1

On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

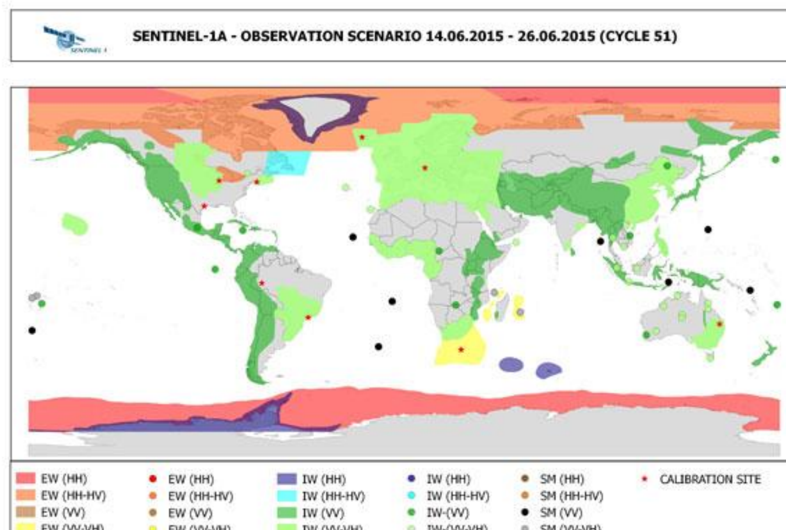
COLLECTE LOCALISATION SATELLITES

Sentinel-1 acquisition modes





End Feb 2015



June 2015

On the automatic detection of leads with thin ice or open water

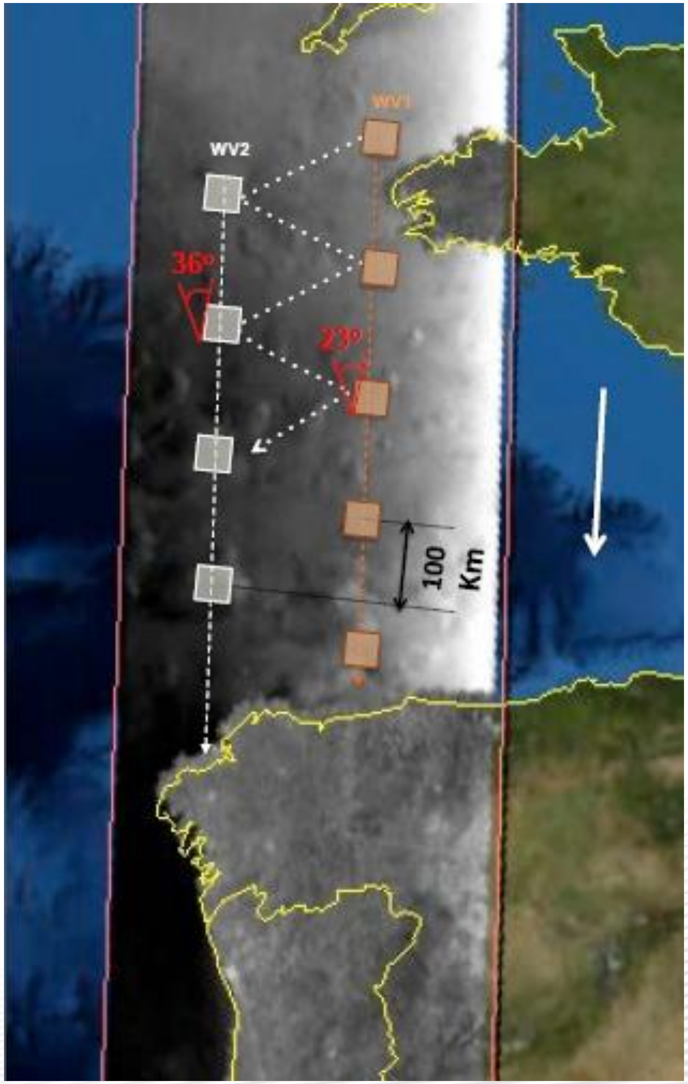
Benefit of polarization diversity to characterize sea ice and leads

Assessment of sea surface roughness in leads

Few words on Sentinel-1

On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

Wave mode: a systematic acquisition mode for iceberg detection around Antarctica

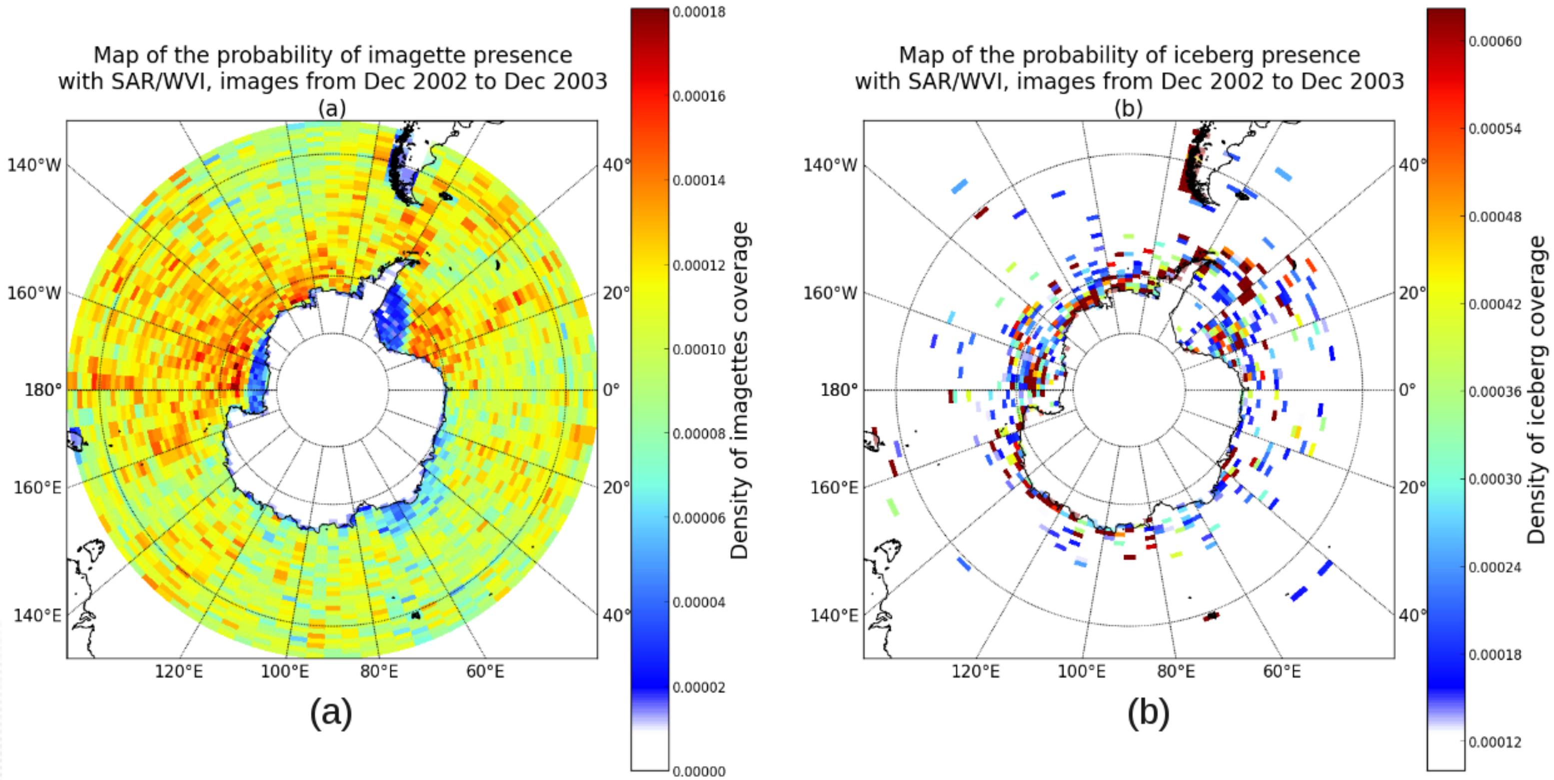


- 20 km by 20 km vignettes, at 5 m by 5 m spatial resolution, every 100 km along the orbit, acquired alternately on two different incidence angles
- VV polarization
- Quasi-systematic default mode over open ocean when not covered by EWS/IWS
- In complement of EWS (acquisition mostly during winter time over sea ice, and summer time in Weddell sea)
- Less spatial coverage than altimetry, but high resolution with potential < 10 meter detected icebergs

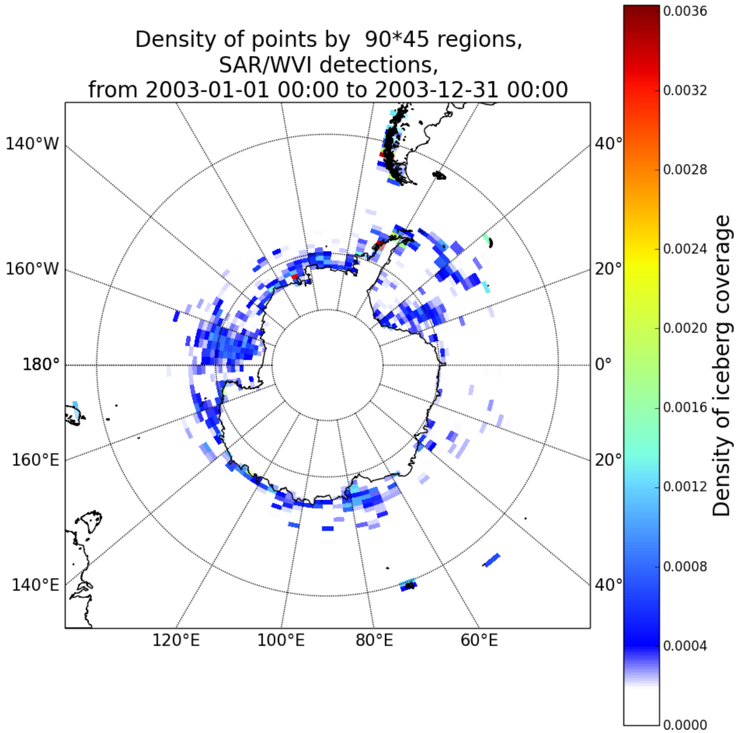
- Reconstruct the whole story of icebergs (from large tabulars to small icebergs and bergy bits) ?
  - Antarctic Iceberg Tracking Database from BYU for large tabular -> IFREMER altiberg database -> ASAR/ENVISAT & S-1 Wave mode database

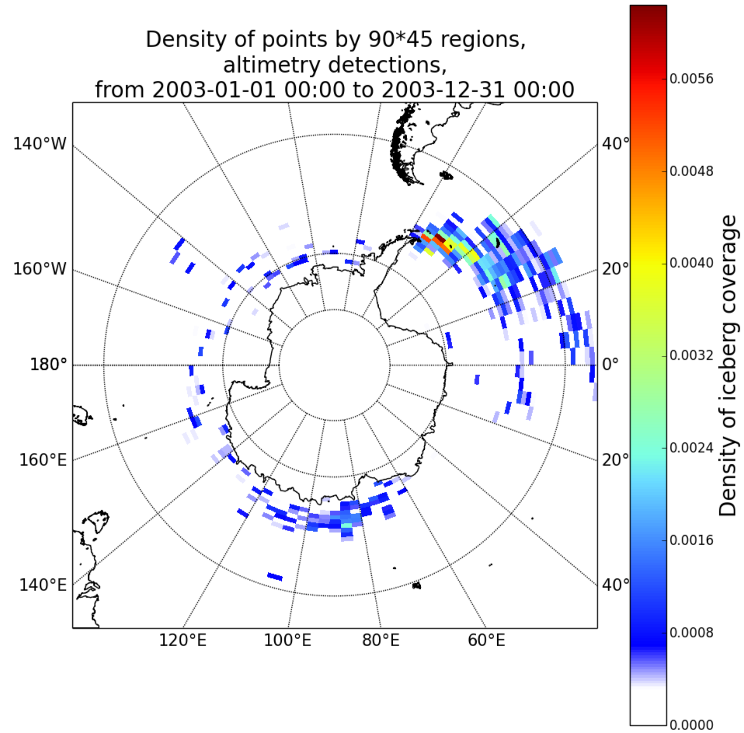
Detection comparison between ENVISAT WV mode and ENVISAT Altimeter

- First assessment between ENVISAT ASAR WV data and altiberg ENVISAT database during 2003
  - Coverage of ENVISAT WV mode between -45 and -66 was about 3% only of the ocean surface during one repeat 35 days cycle
  - Based on CFAR detector with fixed kernel size (below configured for icebergs no larger than 100 meters)



- First assessment between ENVISAT ASAR WV data and altiberg ENVISAT database in 2003
  - Coverage of ENVISAT WV mode between -45 and -66 is about 3% only of the ocean surface for one repeat 35 days cycle
  - Based on CFAR detector with fixed kernel size (below configured for icebergs no larger than 100 meters)
  - No sea ice flagging for WV mode detection





Promising agreement with same detected hot spots such as the Weddell Sea and the West Ice shelf (to a lesser extent Ross sea) … Except for the Amundsen sea

Conclusion

On the automatic detection of leads with thin ice or open water

Benefit of polarization diversity to characterize sea ice and leads

Assessment of sea surface roughness in leads

Few words on Sentinel-1

On the use of Wave mode specific acquisition mode to complement altimetry iceberg detection

SAR imagery of primary interest to analyze and complement altimetry data over sea ice … and vice versa !!!