ABSTRACT
The interest in the monitoring of sea ice masses has increased greatly over the past decades for a variety of reasons. These include:

- Navigation in northern latitude waters;
- transportation of petroleum;
- exploitation of mineral deposits in the Arctic, and
- the use of icebergs as a source of fresh water.

The availability of ERS-Envisat 28 minute tandem acquisitions from dedicated campaigns, covering large areas in the northern latitudes with large geometrical baseline and very short temporal separation, allows the precise estimation of sea ice displacement fields with an accuracy that cannot be obtained on large scale from any other instrument. This article presents different results of sea ice dynamic monitoring over northern Canada obtained within the “ERS-Envisat Tandem Cross-Interferometry Campaigns: CInSAR processing and studies over extended areas” project from data acquired during the 2008-2009 Tandem campaign.

1. INTRODUCTION
The very short temporal separation (about 28 minutes) of the ERS-2 and ENVISAT satellites is very attractive to obtain almost-simultaneous acquisitions, appealing for SAR Interferometric applications both for the very high correlation (possibly resulting in very precise DEMs), for the strong reduction of atmospheric artefacts, and for monitoring fast displacements. The problem of the interferometric combination of such data arises from the difference of 31MHz in the Centre Frequency of the AMI (ERS-2) and ASAR (ENVISAT) instruments. As shown in 0, this difference, overcoming the range bandwidths of the instruments (respectively 15.5 and 16MHz), results in completely uncorrelated range spectra of the two acquisitions, and hence in no possible interferometric combination, if not for close-to-ideal point targets.

The European Space Agency has carried out in the last years two ad-hoc EET Campaigns with a specific orbit configuration of a normal baseline between ERS and ENVISAT of around 2.1 Km, tuned according to the principles shown in [1] to compensate the Centre Frequency shift and allow interferometric combination of the data, at least in areas with moderate slope of the topography.

Data acquired with this configuration is hence of particular interest for monitoring fast displacement of sea ice in the northern regions.

2. DATA AVAILABILITY
ESA has carried out the second EET campaign in the period November 18th 2008 – April 7th 2009. A summary of the resulting available frames suitable for Cross-Interferometry is shown in Figure 1 for the northern latitudes in the American continent.

![Figure 1. Availability of ERS-ASAR frames over the northern latitudes from the second EET campaign.](image)

Here only the frames that correspond to ERS-ASAR pairs with proper baseline area shown. Furthermore, the screening discarded also the pairs that are characterised by small difference of the Doppler Centroid. This condition is necessary to discard all the acquisitions characterised by too large values of the Doppler Centroid in the ERS acquisition, case that happens quite often in the current gyro-less functioning mode of the ERS-2 platform.

From Figure 1 it is possible to notice how some areas of this region are particularly well covered, like the areas of the Beaufort and Baffin seas. Furthermore, thanks to the large overlap at these latitudes of the ground tracks and to the duration of the campaign of more cycles, many areas are covered more than once during the campaign, allowing to compare results obtained at
different dates and to perform monitoring of the sea ice dynamic.

The interferometric phase of one ERS-ASAR pair is shown in Figure 2. A constant ellipsoidal height has been used to compensate for the flat earth phase component of the original interferogram. Here it is therefore possible to identify the following areas:

- Areas of topography over land (Southern and Northern edge of the frame). Here, due to the large height sensitivity (~5m for every $2\pi$ cycle), the phase variations are very large. The possibility of exploiting this phase for DEM generation depends on the local slope of the terrain.

- Areas of too fast ice displacement (Eastern edge of the frame). Here very low values of coherence can be obtained, hence not allowing to obtain useful interferometric results.

- Coherent areas over see (most of the frame). Here the high coherence is maintained thanks to the flat topography (as first approximation) of the sea ice and to the moderate displacement rate during the 28 minutes of separation between the ERS-2 and the ASAR acquisition. Different phase components can then be identified in this area, some due to fast displacements and, mostly in this case, others due to atmospheric artefacts. Nevertheless, the absolute phase variation that can be expected for such effects is often negligible respect to the phase values due to the LOS displacements. Hence, very accurate results can be expected for the estimation of the displacement of different sea ice areas.

3. IDENTIFICATION OF THE GROUNDED ICE BORDER

Figure 3 shows the differential phase over an area of the North-west passage obtained from three different pairs, acquired in short time separation on January 4th, 7th and 10th 2009.

Here it is possible to distinguish two areas: one close to the land, showing moderate or no displacement, and another area, in the sea, showing different amounts of displacement, up to large enough to destroy the interferometric coherence. The common line that can be identified in the three frames dividing these two regions can be interpreted as the border separating the grounded ice from the sea ice.

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4. MEASUREMENT OF THE 2D COMPONENTS OF THE DISPLACEMENT

The large displacements of the sea ice occurring within the 28 minutes of separation between the ERS and ASAR acquisitions (up to several kilometers per hour) can be estimated in their 2D components by exploiting different techniques. Offset tracking can be for example exploited, but much better results can be obtained in coherent areas by exploiting Multi-Aperture Interferometry approaches, as proposed originally in [3]. In both cases, coregistration strategies shall be updated to handle large space-varying offsets.

Some results are shown in Figure 4 over the same area covered in Figure 3. Here the upper image shows the conventional differential phase (resulting in one $2\pi$ cycle for every 2.8 cm of displacement in Line Of Sight), while the lower image shows the MAI phase obtained by splitting the original Doppler bandwidths of the ERS and ASAR SLC data in sub-bands and forming differential interferograms between the interferograms generated from the different sub-bands. Here the sensitivity of the differential phase to the azimuth displacements is of around 5m every $2\pi$. Although reduced respect to the accuracy of the LOS displacement estimation, this allows to estimate the full 2D displacement field of the sea ice patches.
5. PROCESSING APPROACH

Due to the large extent of the shifts occurring in the sea ice areas in these regions, and to the high coherence of the ice patches, the conventional coregistration approaches show some limitations. One example of this is shown in Figure 5. Here the location of the coregistration windows used during the offset estimation has been manually selected, once over the land area and once over the sea ice.

This two-step approach results in the estimation of accurate coregistration polynomials with local validity inside a frame: the boundaries of the regions of the validity of the single coregistration polynomials are estimated with the help of the analysis of the interferometric fringes instantaneous frequency, as shown in Figure 6.

Results of this approach are shown in Figure 7, that presents the MAI differential phase of the whole frame showed in Figure 5. Here, despite the large difference of the estimated shifts of different ice and land patches, it has been possible to fine coregister the two input SLC images for almost the whole area, obtaining accurate estimates of the ice 2D displacement field also in case of large displacements.
6. CONCLUSIONS

EET CInSAR data show a great potential for monitoring sea ice dynamic at Northern latitudes, for example for the identification of the grounded ice line. The exploitation of data in the same areas from future EET campaigns will allow to compare the results obtained in different years and hence to monitor the evolution of the grounded ice over the years.

In case of large displacements, the 2D components of the displacements can be estimated from the data, in particular by exploiting sub-aperture techniques in the azimuth direction.

Due to the large value of the displacements, updated strategies for coregistration shall be exploited to allow to obtain measurements for different areas of the frames, characterised by different amount of displacement.

7. ACKNOWLEDGEMENTS

This work has been carried out within the “ERS-Envisat Tandem Cross-Interferometry Campaigns: CInSAR processing and studies over extended areas“ ESA project.

The ERS-ASAR data have been provided under the AO 6440.

8. REFERENCES

