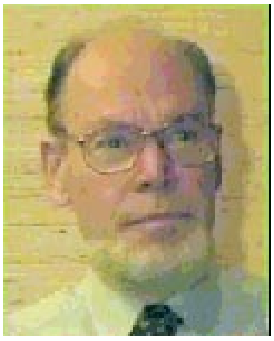
# Two Envisat projects related to Nordic applications, sea ice and boreal forest



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Microwaves, not sensitive to cloud cover or sun illumination, are important for remote sensing at Nordic latitudes. The Arctic ice cover and the boreal forests are extensive areas important for the living conditions and sensitive to climate changes at these latitudes. Envisat offers new possibilities to detect and follow possible changes e.g. due to the greenhouse effect.

## Variability of polynyas and ice concentration in the Arctic

The ERS SAR was considered to be a pre-operational tool for sea ice monitoring. Sea ice is highly variable and information is needed as fast as possible for support of ice breakers and ships. Remote sensing of sea ice has also with the cloud independent SAR and the fast delivery product of ERS-1/2 developed to an operational service where images are used regularly e.g. in the Baltic Sea. For the Arctic area the basic need for remote sensing in this hostile and remote area is partly in support of ice routing. However, due to various alarming reports concerning the melting sea ice in the Arctic the focus has to an increasing extent concentrated on the question of climate change and the Arctic. So far the passive microwave sensor SSM/I has been our basic tool to follow changes of the Arctic sea ice cover and such investigations have also pointed in the direction of a diminishing ice cover. However SSM/I has a resolution of tenths of kilometres and like any sensor problems in the interpretation occurs. SAR has a resolution of the order of tenths of meters and can show details of the ice surface like no other sensor since optical sensors are too much affected by the adverse cloud and fog conditions in the Arctic as well as the Arctic night during large parts of the year. We have carried out experiments in conjunction with the expeditions to the Arctic Ocean using the Swedish ice breaker Oden in 1991, 1996, and this summer with the goals to increase our knowledge of remote sensing of the sea ice. Based on experience from the 1991 and 1996 expeditions we have found that during the period of the expeditions (summer melt to the early freeze up period) the sea ice signatures are quite complex. For a limited range of wind speeds, the SAR may have problems but within a few percent we have obtained agreement between ice concentration estimates from the bridge of i/b Oden and helicopter observations in the vicinity. However studies of SSM/I shows differences of ice concentration up to 35% depending on what algorithms are used. If the weather sensitive 85 GHz channel of the SSM/I is used an improvement is obtained also showing the importance of spatial resolution. Such differences illustrate the importance of having radar coverage of the Arctic area and with the forecasts from global models of the effects of the increased atmospheric $CO_2$ we need improved estimates of ice cover and ice concentration. Envisat was designed to offer solutions to this need by giving on-board data storage for full coverage of the Arctic using the so called global mode with 1 km resolution and coverage of all sensitive areas according to global models using the wide swath coverage with 150 m resolution. With the increased capacity of the data recording on-board Envisat it may also be possible to regularly cover the Arctic area with 150 m resolution.

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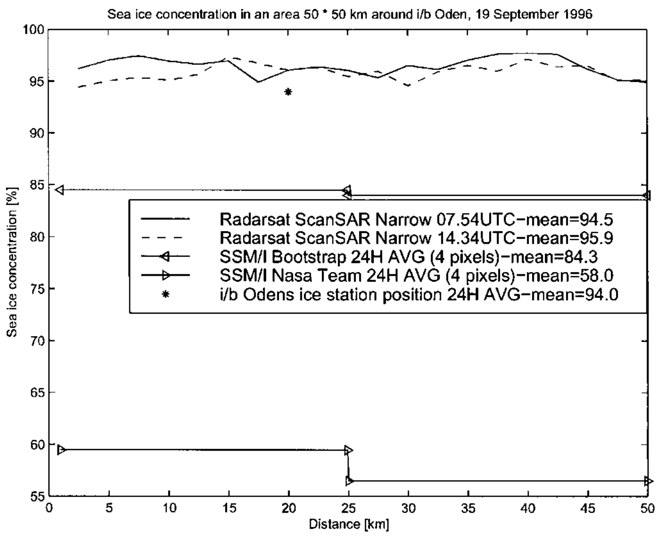



**Figure 1: Example on ice concentration estimates from Radarsat SAR (Technique: threshold+wavelet), and from SSM/I (NASA and Bootstrap algorithms) compared with visual observations from ship bridge and helicopter observations**

Of the various properties, which can be related to global change, the ice concentration is rather important. Sometimes large openings, called polynyas, occur in the Arctic ice cover. They are caused by the wind mainly and also by upwelling of warmer weather. The heat exchange in such large openings (having a mean diameter of 6 km) between the water and the atmosphere is extensive. Therefore it is rather important to know the extent of polynyas. In the polynyas large amounts of ice is formed and salt is released from the ice and contributes to the halocline, which is very important to maintain in order for the water circulation in the Arctic Ocean and the surrounding oceans not to be disturbed.

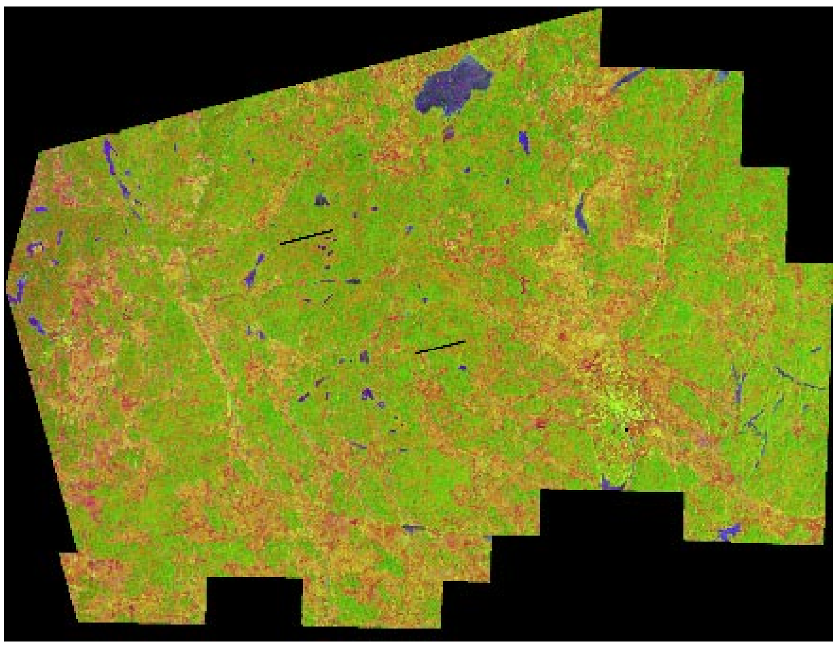
Sverre T. Dokken has in his PhD-thesis (Dokken, 2000) shown different techniques to estimate ice concentration and polynyas using ERS and RADARSAT SAR. He has also analysed the differences relative SSM/I and the importance to use SAR in the future for ice concentration and polynyas. He has also compared high resolution numerical modelling with SAR estimates of ice concentration indicating a need to improve numerical modelling. Obviously Envisat will play a very important role for future changes of the ice cover. For sea ice 150 m resolution is considered to be sufficient and the wide swath coverage very useful in order to cover special regions or all of the Arctic area. With the VV/HH polarisation ratio the ice water contrast will be high. Areas, where polynyas are expected, can if necessary be covered with the higher resolution modes. Probably wide swath SAR sensors like Envisat and Radarsat will take over as the workhorse of Arctic remote sensing.

Envisat is a satellite designed to combine a large number of sensors and due to this being able to combine simultaneous measurements. However, combination of many sensors also increases the complexity and the sensitivity to technical faults. The general trend today is more towards specialised satellites. For the Arctic ice concentration is one of the important parameters but for a changing sea ice cover we would also like to be able to determine the sea ice thickness. In fact a specialised satellite for this purpose, CryoSat, is just now under construction by ESA and will also be one of the major steps for the coming surveillance of the Arctic area. This satellite will use an advanced radar altimeter design. Together with the area coverage of ASAR we will have a much better picture of the changes of the Arctic ice cover and to be able to complement the observations of a long-term decrease in ice concentration as observed by SSM/I. The project in collaboration with SMHI and others is aiming towards testing and developing the algorithms of ASAR in order to reach this goal.

## Methods for boreal forest mapping using ASAR and MERIS

When ERS-1 was launched in 1991 there was not much hope to determine forest properties using C-band SAR images. Airborne experiments had shown that the backscatter from the forest area and the open fields were not much different and the small difference was not very sensitive to stem volume or biomass. With the long experience of ERS-1/2 we know today that multi-temporal imaging, i.e. many images over the same area will show that open fields

**Figure 2. Stem volumes between 0 and 350 m$^3$/ha have been retrieved using a multi-temporal combination of stem volume estimates from four interferometric coherence images acquired in March and April 1996 in an area of 4235 km$^2$, covering an area east Uppsala.**



are more variable than forest areas and there is a possibility to determine forest/non-forest and sometimes some more features. However, what we did not know, when ERS-1 was launched or even when Envisat was designed, was that the stability of the satellite and sensor properties was so high that interferometry would be possible. Since the ERS-1/2 missions in many aspects was "experimental" it also included features with varying orbit properties during different parts of the lifetimes, including as short as 3-day revisiting of the same area during January - March in 1992 and 1994. This 3-day orbit was motivated by the fast temporal changes of sea ice. Also temporal properties of land properties such as represented by repeat-pass coherence (interferometric correlation between two SAR images) could be investigated. Later during the tandem period, when ERS-1 and ERS-2 were used to study the same area with a one-day interval, studies for even shorter time interval could be carried out. It was now shown that the short time coherence between open fields and forest areas was much more sensitive than backscatter to differences between open fields and forest areas and that this difference could be accurately related to stem volume. This means that the coherence property is one strong candidate for mapping forest properties. Another alternative is to use lower frequencies than C-band, but experience has shown that we have to use very low frequencies, such as the airborne CARABAS system in order to have a sensitivity for dense forest areas, and such low frequencies can not be used from space. Using different polarisations, in particular at lower frequencies than C-band, also adds information.

The Envisat advanced SAR, ASAR; was designed to continue the ERS-missions with improved performance such as the possibility to also cover larger areas (however with lower resolution) and to measure different polarisations (although not fully polarimetric). The 35 day orbit of ERS which was designed in order for the SAR to cover the full globe (e.g. the 3 day orbit only covered a limited part of the globe) and this orbit was used also for Envisat in order to have continuity. With the wide swath any area at our latitudes will be covered within a time interval of approximately three days. However, SAR images acquired with the 35 day (exact repeat) orbit are not expected to show coherence for more than objects with very stable properties (such as houses, areas with low moisture variations etc) and the boreal forest areas have not been found to be stable enough. However, Envisat ASAR offers other possibilities such as using different polarisations, which will increase our possibilities to determine the differences between open fields and forest, between gaps in the forest and the trees. The multi-temporal feature and the possibility of using different incidence angles offer interesting combinations to investigate. According to the ASAR Science Advisory Group (Harris, 1998), best results for forest investigations can be expected for alternating polarisation, VV/VH in image modes 4 to 6. Perhaps the most important feature of Envisat in forestry applications will be the possibility to combine radar (image mode 1 to 5) and the medium resolution imaging spectrometer, MERIS. This instrument, with a spatial resolution of 250 m, can provide important information on canopy and land properties under cloud free conditions.

Our project is a collaborative project between the Dept. of Radio and Space Science at Chalmers University of Technology and the Department of Forest Resource Management and Geomatics at the Swedish University of Agricultural Sciences. The two groups have collaborated since 1991 on the possibilities to use radar for forest properties, in particular stem volume estimation. The goal now is to investigate the information, which can be obtained about boreal forest by using the range of possibilities offered by ASAR and by combining radar and optical properties. Important is to use reference areas with very well known forest properties, and one problem today is that we have a limited number of such areas (which also shows the need for accurate remote sensing methods). Areas in various parts of Sweden have been selected to represent the various forest properties, which can be found in Sweden.

***References:***

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Harris, J. A. (Editor)., 1998: *ENVISAT ASAR Science and Applications.* ESA, Noordwijk, NL (SP-1225). pp. 52.