

## **“Wave Processes in Arctic Seas, Observed from *TerraSAR-X*”**

Susanne Lehner  
German Aerospace Center  
Maritime Safety and Security Lab  
Henrich-Focke-Str. 4  
28199 Bremen  
Germany  
phone: 0049 421/ 24420-1850 fax: 0049421/59702421 email: [Susanne.lehner@dlr.de](mailto:Susanne.lehner@dlr.de)

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### **LONG-TERM GOALS**

The reduction of the sea ice coverage during the boreal summer will lead to an increased importance of wind waves for the dynamic processes of the Arctic Seas. The large ice free areas lead to longer fetch and thus longer and higher sea state. Wind waves will enhance upper-ocean mixing, may affect the breakup of ice sheets, and will likely lead to increased coastal erosion.

The primary long-term goal is a better understanding of the two-way interaction of waves and sea-ice, in order to improve wave models as well as ice models applicable to a changing Arctic wave/ and ice climate.

This includes observation and information retrieval from various data sources, in particular from spaceborne SAR imagery. Such retrieval methods of sea state in the MIZ will complement and validate modelling data for the spatial and temporal evolution of sea state in the MIZ. Further goals are the development of near-real time wave field observations and their delivery to marine operations in the Arctic.

### **OBJECTIVES**

Over the ocean, synthetic aperture radar is capable of providing wind and wave information by measuring the roughness of the sea surface, as well as information on ice coverage.

In particular, TerraSAR-X data have been used to investigate the highly variable wave climate in coastal areas (e.g. Lehner et al., 2013). However, the use of these data at the sea ice boundary is still to be utilized in full detail. In addition, TerraSAR-X data provide accurate estimates of the wind field over the ocean as well as the position (and change) of the ice edge, ice drift estimates, and ice floe size distributions.

The main objectives of the proposed work are to adapt existing TerraSAR-X wave parameter and ice motion retrieval algorithms for the marginal ice zone in order to:

- analyze the spatial and temporal variability of the wave field in the emerging ice-free regions;

- investigate wave damping in sea ice and the related ice breakup;
- test/develop formulae of wave development (such as fetch laws) for the marginal ice zone;
- provide wave field characteristics and wind data to other research groups within this DRI
- provide ice field characteristics to other research groups within this DRI;

## APPROACH

This work is in collaboration with J. Gemmrich at UVIC. We are using data from the X-band high resolution SAR satellite TerraSAR-X (TS-X), which was launched in June 2007, and its twin, TanDEM-X (TD-X), launched in June 2010. TS-X and TD-X operate from 514km height at sun-synchronous orbits, the ground speed is  $7\text{km}\cdot\text{s}^{-1}$  (15 orbits per day). Both satellites are orbiting in a close formation with typical distances between satellites of 250m to 500m. They operate with a wavelength of 31mm. The repeat-cycle is 11 days, but in polar regions the same region can be imaged with different incidence angles after 12 h to 3 days dependent on scene latitude. The coverage and resolution depends on satellite mode: *Wide ScanSAR* mode covers 450km by 250km and *ScanSAR* mode covers 100km strip, with resolution of about 40m. *StripMap* mode covers 30km by 50km with a resolution of about 3m, and *Spotlight* covers 10km by 10km with resolution of about 1m. Retrieval of wind parameters from TS-X data is based on the *XMOD-2* algorithm, which takes the full nonlinear physical model function into account. At the same time the corresponding sea state can be estimated from the same image. The empirical model for obtaining integrated wave parameters is based on the analysis of image spectra, and uses parameters fitted with collocated buoy data and information on spectral peak direction and incidence angle. The *XWAVE-2* algorithm derives significant wave height, wave direction and wave length directly from TS-X SAR image spectra without using a-priori information.

Size distributions of ice floes are calculated based on brightness thresholds and automated object recognition. Retrieved floe parameters are area, major and minor axis length and orientation.

## WORK COMPLETED

Several TSX scenes overlapping with the *in-situ* wave observations of the MIZ DRI in the Beaufort Sea were obtained and analyzed.

Improvements and further testing of the wave retrieval algorithm were performed. Software was developed for automated calculation of ice floe size distributions from ScanSAR and from Wide ScanSar images.

We will coordinate the shore support for the field campaign in October-November 2015. The required hardware and software for the communication and data exchange protocols between the research vessel and shore support has been installed and tested during two test runs in July and September. The system is a mixture of automated collecting various forecast products, and ordering and processing satellite images with a minimal lead time.

We participated in the DRI planning meetings in November and May, and the ONR review meeting in October.

I attended additionally the workshop on the Sea State MIZ Project at SAMS in Oban, Scotland, organized by Phil Hwang and showed the joint work in progress with UVIC.

We organised an automatic ftp push system to provide the Sikuliaq team with NRT TerraSAR data and wind and wave information (it worked).

## RESULTS

Wind, wave and ice information has been retrieved from TS-X data in the marginal ice zones and open water conditions in the Beaufort Sea.

Figure 1 shows an example from the Beaufort Sea, taken on August 9, 2014. At that time, an ice-free corridor had opened up along the entire width of the southern Beaufort Sea, allowing for long fetch conditions during easterly winds. *In-situ* wind and wave observations in the vicinity (taken by J. Thomson) indicate that the SAR images were taken during the decay phase of a substantial wave event with maximum significant wave heights of up to 3 m, which had decayed to about 2m during the time of our observation.

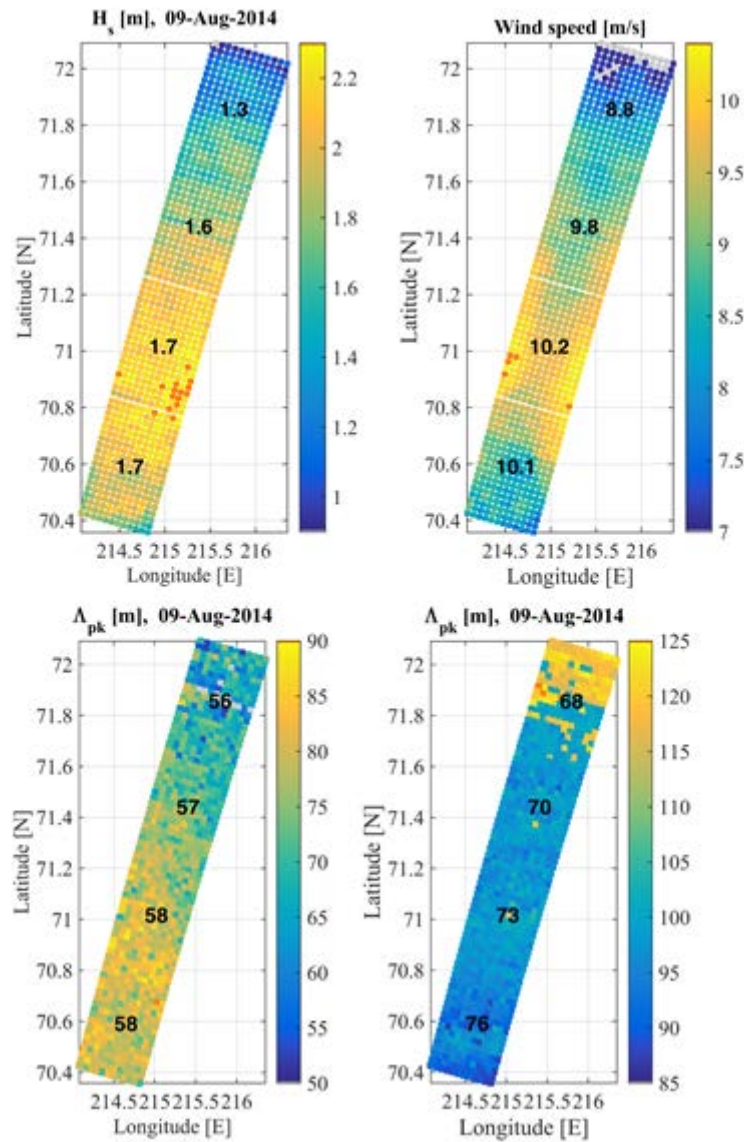
The satellite swath includes open water in its centre part, whereas the northern and southern ends are close to the retreating ice edges. The significant wave height (Fig 1a) shows a wide range from about 1m closer to the northern ice edge to 2.3 m in the middle of the ice-free water section. Model results show a similar, but less pronounced trend. The vicinity of the ice can limit the fetch (the distance over which wave generation occurs), resulting in lower wave heights. This is likely the reason for the somewhat reduced wave heights in the southern region of the swath. The most pronounced drop in wave height is observed in the northern part of the satellite swath, most likely due to a combination of wave dampening in partial ice covered water, and short fetch conditions, and potentially somewhat weaker winds (Fig 1b). The dominant wave length is extracted from the peak of the 2-d wavenumber spectrum of the SAR image, and is therefore a direct observation. Similar to the overall pattern of wave height, we see a slight gradient in wave length, from >80m in the south to <70m at the northern edge. The wave model gives shorter wave lengths, at approximately 60m, and no variability. Dominant wave lengths (Fig 1c) from the model are calculated in the frequency space, and converted via the dispersion relation for short gravity waves to wave length:  $\omega^2 = gk$ , where  $\omega$ ,  $k$  are the wave frequency and wave number, respectively, and  $g$  is the acceleration due to gravity. This method has the inherent tendency of shorter dominant wave length obtained from the frequency space compared to values obtained from the wavenumber space, even for identical conditions [Gebhardt, et al.2015]. However, the expected difference is less than the differences observed here.

Dominant wave direction (Fig 1d) is from the East, with about 20° discrepancy between the direction retrieved from the SAR image and the model output. The apparent jump of about 30° within the northernmost 15 km of the satellite swath is not supported by the model result and might indicate contamination by remnant ice floes.

## IMPACT/APPLICATIONS

This effort will provide detailed information on wave-ice interaction on a scale that is difficult to achieve with in-situ observation but at a high-resolution commonly not achieved by other satellite-based remote sensing methods. These information, which can be obtained independently of local

weather conditions, can guide the development of wave and ice prediction models required for safe marine efforts in the emerging Arctic Ocean. The development of near real time wind and wave products and their delivery onboard vessels in the Arctic can improve safe operation of arctic shipping.



**Figure 1: An example of fields of wave and wind parameters, retrieved from TS-X StripMap images (preliminary results), indicating significant spatial variations, likely due to variable fetch, and ice damping. Black numbers give wind speed input values and calculated wave heights for WavewatchIII model results (courtesy of E. Rogers). Panels from left to right show: significant wave height, wind speed (top), and dominant wave length, dominant wave direction (bottom).**

## RELATED PROJECTS

This project is related to several other projects within this DRI. In particular:

1. “Storm Flux: Heat and Momentum Transfer in the Arctic Air–Sea–Ice System” by Thomson. This project will provide in-situ wave observations which will serve for ground-truthing the TS-X wave products.
2. “Radar Remote Sensing of Ice and Sea State and Boundary Layer Physics in the Marginal Ice Zone”, by Graber. This project will provide high resolution spatial wave and ice information during the field campaign. These results will be compared to the larger field of view data from TS-X.
3. “Wave–Ice Interaction in the Marginal Ice Zone: Toward a Wave–Ocean–Ice Coupled Modeling System” by Rogers. This project will provide modelled wave and wind fields, which will serve as a cross check for the spatial variabilities of the wind and wave fields retrieved from the TS-X image swaths.
4. “Wave Climate and Wave Mixing in the Marginal Ice Zones of Arctic Seas, Observations and Modelling”, by Babanin, Young and Zieger. This project proposes to investigate wave climate in the Beaufort and Chukchi Sea and its trends by means of satellite altimetry

## REFERENCES

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