"Wave Processes in Arctic Seas, Observed from *TerraSAR-X*"

Johannes Gemmrich
University of Victoria
Physics & Astronomy
PO Box 1700
Victoria, BC
V8W 2Y2, Canada
phone: (250)472-5573 fax: (250)721-6200 email: gemmrich@uvic.ca

Award Number: N00014-13-1-0280
http://www.uvic.ca

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 model data for the spatial and temporal evolution of sea state in the MIZ.

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;

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **Wave Processes in Arctic Seas, Observed from TerraSAR-X**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Victoria,Physics & Astronomy,PO Box 1700,Victoria, BC V8W 2Y2, Canada,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- 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 S. Lehner and her research group at the German Aerospace Center (DLR). 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 $7 km \cdot s^{-1}$ (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 the same region can be imaged with different incidence angles after three days dependent on scene latitude. Typical incidence angles range between 20° and 55°. The coverage and resolution depends on satellite mode: *ScanSAR* mode covers 100km strip, *StripMap* mode covers 30km by 50km with a resolution of about 3m, *Spotlight* covers 10km by 10km with resolution of about 1m. A new option, particularly useful for ice coverage investigation is the *Wide ScanSAR* mode which covers 450km by 250km with resolution of about 40m.

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.

Iceberg detection is carried out through a single channel image analysis by an advancement of CFAR algorithm to detect and locate icebergs in an image. Ice type classification is obtained with a texture based approach. Ice types are classified by an artificial neural network to generate automatic ice charts.

Size distributions of ice floes are calculated base on brightness thresholds and automated object recognition.

WORK COMPLETED

Infrastructure to access and process TS-X data at the University of Vctoria has been put in place, and extensively tested. A dataset of more than 100 StripMap and WideScan images has been collected during the period mid-June to mid-September 2014, following the research vessel R/V Oden across the Arctic. The research cruise collected a comprehensive data set on atmospheric boundary layer processes, surface waves, and visual ice observations. Upon return of the vessel, these data sets will be used to validate and improve the SAR wave and wind retrieval algorithms. Furthermore, this cruise provided an oportunity to develop and test communication and data exchange protocols between the research vessel and ordering and processing of the satellite images at UVic and DLR. The experienced gained in providing satellite data to the ship will be valuable for the upcoming field experiment within this DRI.

Images were also regularly ordered to overlap with the in-situ wave observations of the MIZ DRI. However, due to conflicts in data type and coverage with this year's MIZ DRI data needs, very few images were obtained in the Beaufort Sea.

Software development for iceberg detection is in a final stage and a comprehensive validation is to be carried out during the coming Arctic iceberg season. The algorithm operates fully automatic without operator interference.

Software for ice type classification has been developed and implemented. Ice types are classified by an artificial neural network to generate automatic ice charts. Testing was carried out on a limited array of single-channel datasets. The major validation is planned for the coming Arctic winter season. As of now, the algorithm is semi-automatic, involving an operator who chooses a pre-trained classifier for an image to be classified.

Software was developed for automated calculation of ice floe size distributions from ScanSAR and from Wide ScanSar images.

We participated in the DRI planning meetings in November and June.

RESULTS

Wind, wave and ice information has been retrieved from TS-X data in the marginal ice zones and open water conditions at diverse locations in the Arctic. An example is given in Figure 1, which shows a stricing reduction in wave height in th enorthern part of th eswath, but no reduction in wind speed, or even increased wind speed. Upon data retrieval from the in-situ observations (research vessels, drifting and fixed-location buoys) the TSX–retrieved wave and wind fields will be verified and/or calibrated. Preliminary results indicate that a drifting SWIFT buoy (J. Thomson) shows similar low wave heights in the vicinity. Model results, however, show the wave damping further north (E. Rogers).

The ice classification algorithm is currently running in semi-automatic mode. First results (Figure 2, 3) show good agreements with ice charts (Ressel & Lehner, 2014). Iceberg detection is running operationally for near realtime service. Results obtained on existing datasets promise high reliability for operational purpose.

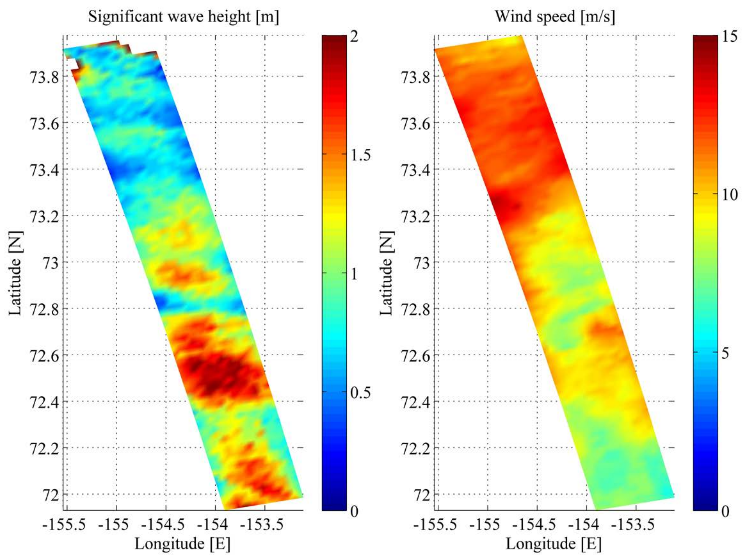

Figure 1: An example of the wave field and wind speed fields retrieved from TS-X StripMap images at the beginning of the autumn freeze-up period (preliminary results), indicating wave damping, likely due to newly formed ice coverage.

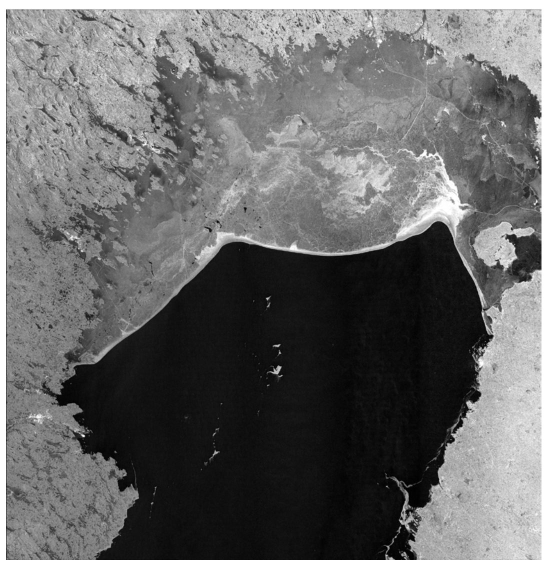
i

Figure 2: TerraSAR-X WideScanSAR image showing ice coverage in the northern Baltic Sea

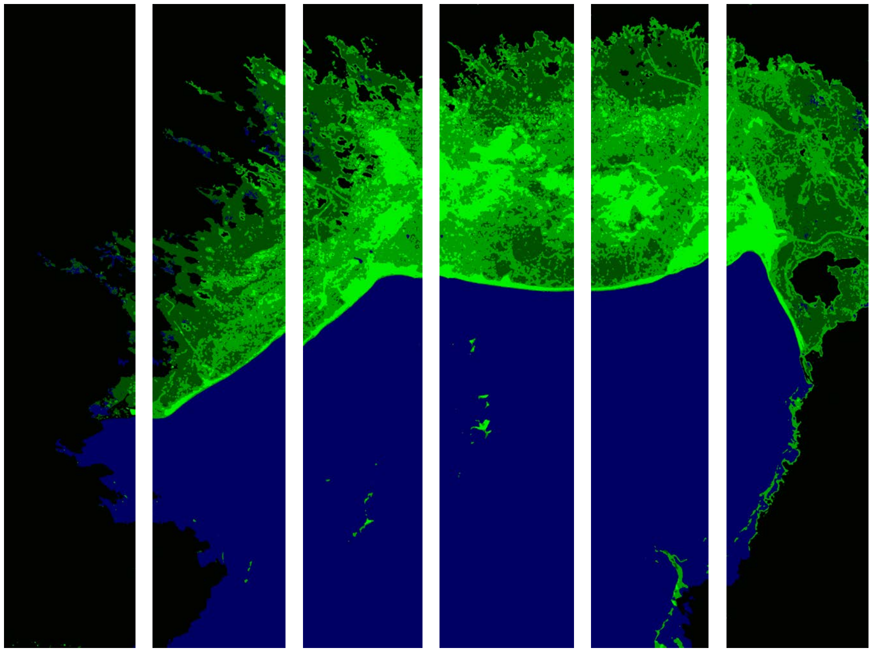

Figure 3: Classification into ice-types: Blue indicates open water, bright green is highly deformed pack ice (including ridges, brash windrows, hummocked ice), medium green is moderately deformed ice (includes portions of fast ice), dark green indicates smooth ice (mostly fast ice and fast ice floes). (From Ressel & Lehner, 2014)

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. This 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.

RELATED PROJECTS

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

1. "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
2. "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.
3. "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 form TS-X.

4. "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 variability of the wind and wave fields retrieved from the TS-X image swaths.

REFERENCES

Lehner, S., Pleskachevsky, A., Velotto, D. and Jacobsen, S.: Meteo-marine parameters and their variavbility observed by high-resolution satellite radar images.. Oceanography, 26, 81-91.

Ressel, R, and Lehner, S.: Texture-based sea ice classification on TerraSAR-X imagery. 22nd IAHR International Symposium on Ice , *Singapore, August 11 to 15, 2014*

PUBLICATIONS

Ressel, R, and Lehner, S.: Texture-based sea ice classification on TerraSAR-X imagery. 22nd IAHR International Symposium on Ice , *Singapore, August 11 to 15, 2014* [published]