TerraSAR-X for Oceanography – Mission Overview

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1. INTRODUCTION

TerraSAR-X is a new generation, high resolution radar satellite to be launched at the end of 2005. The objective of the mission is the setup of an operational spaceborne X-Band synthetic aperture radar (SAR) system in order to produce remote sensing products for commercial and scientific use. TerraSAR-X is the scientific and technological continuation of the highly successful Space Shuttle missions Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) in 1994 (Evans and Plaut, 1996) and Shuttle Radar Topography Mission (SRTM) in 2000 (Werner, 2000). After an in-orbit commissioning period of approximately 5 month, in which the instrument will be calibrated and the system performance will be verified, TerraSAR-X will be fully operational for an active lifetime of 5 years.

The German Aerospace Center (DLR) and the ASTRIUM GmbH have agreed on an innovative co-operation scheme for the implementation of Earth observation satellites by realizing Germany's first Earth observation space project based on public-private partnership with considerable contributions from industry.

The TerraSAR-X mission will serve two main objectives:

- to provide the scientific community with high-quality, multi-mode X-band SAR-data for scientific research and applications
- to support the establishment of a commercial EO-market; and
- to develop a sustainable EO-service business in Europe, based on TerraSAR-X derived information products.

The broad spectrum of scientific applications, include: Hydrology, Geology, Climatology, Oceanography, Environmental- and Disaster Monitoring as well as Cartography. The scientific potential of TerraSAR-X is based on a combination of unprecedented features of the SAR instrument, which have never before been operational in space (Roth et al., 2002, Suess et al., 2002, Mittermayer et al., 2003).

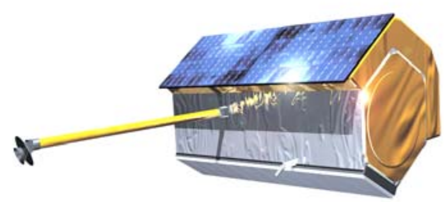

Fig. 1: Artist view of the TerraSAR-X satellite.

- High geometric and radiometric resolution with an experimental very high resolution (~ 1 m) in 300 MHz mode
- Single-, Dual- and Full- Polarization modes
- Long term observation with the opportunity for multi-temporal imaging
- Precise attitude and orbit control and determination as well as phase stability e.g. for Repeat-Pass interferometry
- High synergy potential with other frequency bands (L-band: ALOS, TerraSAR-L, C-band: ENVISAT ASAR, RADARSAT-1 and 2 SAR)
- New imaging modes like ScanSAR, sliding/staring Spotlight and Dual Receive Antenna Mode
- the possibility of Repeat-pass as well as Along Track Interferometry (ATI) for moving target indication, and
- Full operator access to the highly flexible active phased array antenna for the realization of new imaging modes (like Along-track interferometry, Moving Target Identification, etc.) and the acquisition of custom designed image products

These technical features of TerraSAR are of strong interest for oceanography. In this paper several promising applications concerning wind, wave and current measurements as well as monitoring of morphodynamic changes are discussed.

2. SPACECRAFT

The TerraSAR-X satellite constitutes a mission-tailored *Flex*Bus design with a total wet mass of

Product	Coverage [az x rg]	Resolution [az x rg]	Polarization	Full Performance Range
HR SpotLight	**5 x 10 km^2**	**1.0 m x (1.5 – 3.5 m)**	**single, dual, quad**	**20 – 55 °**
Spotlight	**10 x 10 km^2**	**2.0 m x (1.5 – 3.5 m)**	**single, dual, quad**	**20 – 55 °**
StripMap	**≤1650 km x 30 km**	**3.0 m x (1.7 – 3.5 m)**	**single**	**20 – 45 °**
StripMap (polarimetric)	**≤1650 km x 15 km**	**6.0 m x (1.7 – 3.5 m)**	**dual, quad**	**20 – 45 °**
ScanSAR	**≤1650 km x 100 km**	**16.0 m x (1.7 – 3.5 m)**	**single, dual, quad**	**20 – 45 °**
300 MHz Exp.-Mode Spotlight	**5 x 10 km^2**	**1.0 m x (0.6 – 1.5 m)**	**single, dual, quad**	**20 – 55 °**
Dual Receive StripMap	**≤1650 km x 30 km**	**1.5 m x (1.7 – 3.5 m)**	**single, dual, quad**	**20 – 45 °**
ATI		**Acc. 15-60 km/h**		

Table 1: Parameters of TerraSAR-X imaging modes. The blue color indicates experimental modes.

approximately 1025 kg related to 1350 kg total lift capability of the Dnepr-1 launch vehicle for the intended mission orbit. The body-mounted solar array delivers an orbit average power of ~800 W under EOL and worst case solar illumination conditions. A standard S-band TT&C System with 360° coverage in uplink and downlink is used for satellite command reception and telemetry transmission.

The attitude control system is based on reaction wheels for fine-pointing with magnet torquers for wheel desaturation. A mono propellant propulsion system is implemented to facilitate attitude control maneuvers necessary to achieve rapid rate damping during initial acquisition. Attitude measurement is performed with a GPS/Star Tracker system during nominal operation and a Coarse Earth and Sun Sensor in safe mode situations and during the initial acquisition.

3. SAR INSTRUMENT

The spacecraft will be equipped with a X-band SAR instrument with the following characteristics: The instrument is an active phased array X-band system with 384 transmit/receive (T/R) modules capable of operation in two polarizations, H and V. Beam steering is possible in azimuth (0.75°) and elevation (20°). Acquired SAR data are stored in a Mass Memory Unit of 256 Gbit capacity before they are down linked via a 300 Mbit/s X-band link. The antenna is body fixed and its approximate dimensions are 4.8 m in length, 0.7 m in width and 0.15 m in depth.

The instrument is designed for multiple imaging modes like Spotlight, Stripmap and ScanSAR operating with either single-, dual- or full polarization (Fig. 2). In addition it will enable an experimental high-resolution

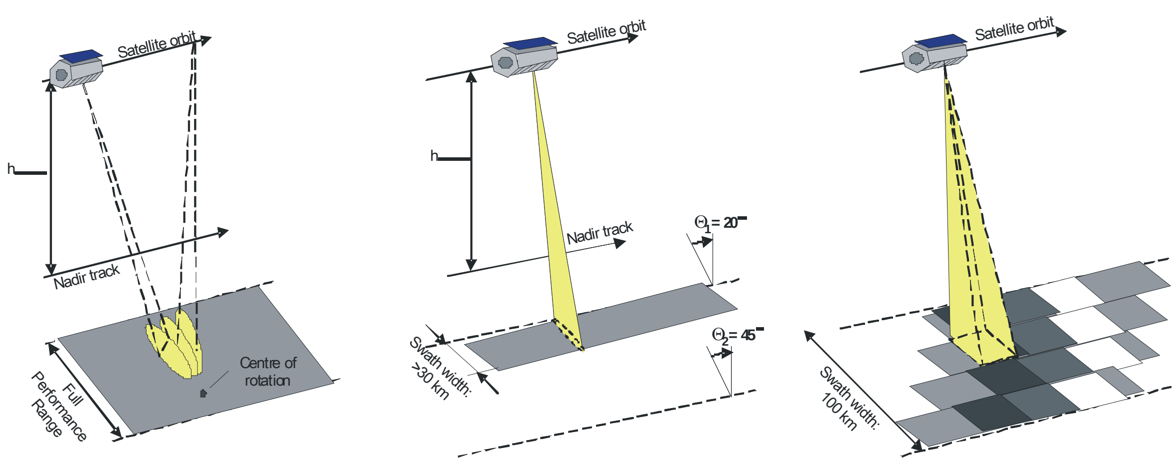

Fig. 2: Schematic sketch of the different imaging modes, which will be available for TerraSAR-X: Spotlight, Stripmap, and ScanSAR (from left to right).

300 MHz mode as well as the so-called Dual Receive Antenna Mode, which is based on the usage of the antenna in two azimuth halves and utilizes the redundant electronics set as a second Receiver channel. Main applications of the Dual Receive Antenna Mode will be

- Along-track interferometry, e.g. for ocean surface current measurements, and
- a full polarimetric mode, by simultaneously receiving H and V with the two subapertures.

In addition, it also allows an improvement of azimuth resolution as well as new calibration strategies.

An overview of the different TerraSAR imaging modes with the key parameters is given in Table 1, where the modes highlighted in blue are experimental modes.

4. OCEANOGRAPHIC APPLICATIONS

Due to its polarimetric and interferometric capabilities as well as the high spatial resolution TerraSAR-X is an interesting measurement tool for various oceanographic applications. In the following a short overview is given of some applications, which are of both scientific and commercial interest.

4.1 High resolution wind fields

In particular for applications like offshore wind farming a high spatial resolution of the SAR system is important (Lehner and Horstmann, 2001). SAR is the only system, which provides a synoptic view of wind fields over the ocean covering large areas (Lehner et al., 1998, Horstmann et al., 2002, Horstmann and Koch, this issue). An example wind field of the southern North Sea, acquired with the SAR aboard the European remote sensing satellite ERS-2, is given in Fig. 3. To analyze detailed wind field structures like e.g. wind blocking by a wind farm or wind shadowing within the grid of turbines, it is essential to look at finer spatial scales. A more detailed description of this application is given in Schneiderhan et al. (this issue).

It is also expected that the polarimetric capabilities of TerraSAR-X will help to discriminate between atmospheric and oceanic features, which is e.g. important for the retrieval of wind direction from wind induced streaks.

Near grazing incidence it has been demonstrated that X-band radars are capable of measuring high resolution wind fields with an accuracy of up to 0.85 m/s in wind speed and 15° in wind direction (Dankert et al., 2003). For a future TerraSAR-X wind algorithm it is necessary to translate existing C-band wind speed algorithms to X-band. This can to some extent be done with existing X-band data from both airborne and spaceborne systems.

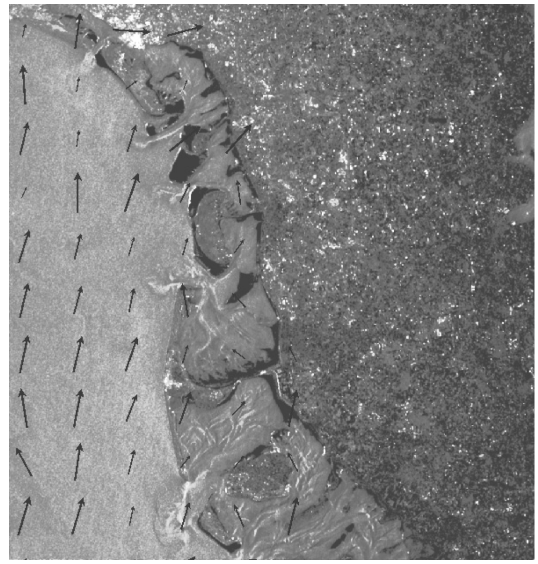

Fig. 3: ERS-2 SAR image mode scene (100 by 100 km) with imprinted derived wind field acquired on July 11, 2002, at 10:24 UTC.

Airborne X-band data suitable for such studies were e.g. acquired in the SINEWAVE (SAR Interferometry Experiment for validation of ocean wave imaging models) experiment (Schulz-Stellenfleth et al. 2001, Schulz-Stellenfleth and Lehner, 2001) and the Gijon experiment (Lehner et al., 2002).

In the Gijon experiment, which was carried out in the framework of the EUROROSE project, a three antenna airborne X-band InSAR system with about 1 m spatial resolution acquired data near the harbour of Gijon with simultaneous wind, wave and current measurements taken by HF radar and nautical radar.

4.2 High resolution ocean wave fields

Another interesting application of TerraSAR-X is the measurement of high resolution ocean wave fields in particular in coastal areas (compare Fig. 4). These measurements are especially important for applications dealing with harbour protection, offshore wind parks as well as wave farming.

Apart from the high spatial resolution the relatively low flight altitude of the satellite is beneficial for ocean wave measurements, especially because nonlinear effects (Hasselmann and Hasselmann, 1991) are less important than they are for the ERS or ENVISAT case. This improves the retrieval of ocean wave information as for example the measurement of the two-dimensional ocean wave spectrum (Schulz-Stellenfleth et al., this issue) or of the two-dimensional sea surface elevation fields (Schulz-Stellenfleth and Lehner, 2004) easier.

Furthermore, it is known that the availability of polarimetric information will improve the ocean wave measurements, as it gives some independent estimation of the ocean to SAR transfer functions (Engen et al., 2000). It is also expected that a statistical analysis of polarimetric TerraSAR-X data will give some new insight into the SAR ocean wave imaging process, e.g. the relative role of Bragg scattering and specular reflection.
A summary of the state of the art of wave measurements with SAR systems is given in Lehner and Ocampo-Torres (this issue).

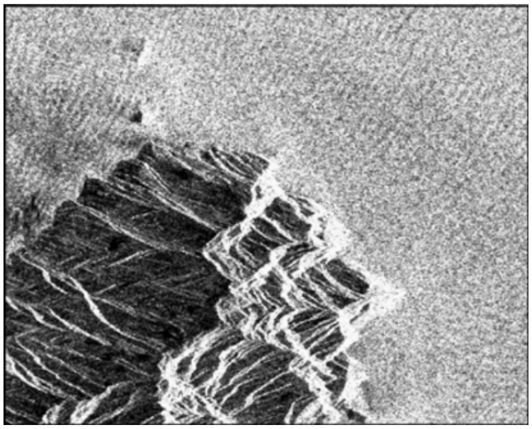

Fig. 4: ERS-2 SAR image of the north tip of the island Tenerife showing ocean surface waves.

4.3 Current measurements

High resolution current information is needed for many coastal applications like offshore operations or ship navigation. Another application, the high relevance of which has become evident in the recent Prestige disaster, is the estimation of oil slick drift in the case of ship accidents.
It has been shown in many studies that along track InSAR systems are capable of providing high resolution information on current fields (Goldstein and Zebker, 1987, Siegmund et al., 2004, Romeiser and Thompson, 2000).
The split antenna mode of TerraSAR-X enables along track interferometry and thus the estimation of current fields (Goldstein and Zebker, 1987). A first analysis of this application has shown that the retrieved current fields have to be smoothed over quite large areas in order to get reasonable signal to noise ratios (Romeiser et al., 2003). However, the achievable spatial resolution is still in the order of the promising results obtained with the SRTM system. Figure 5 shows a current field in the river Elbe estimated from SRTM data.

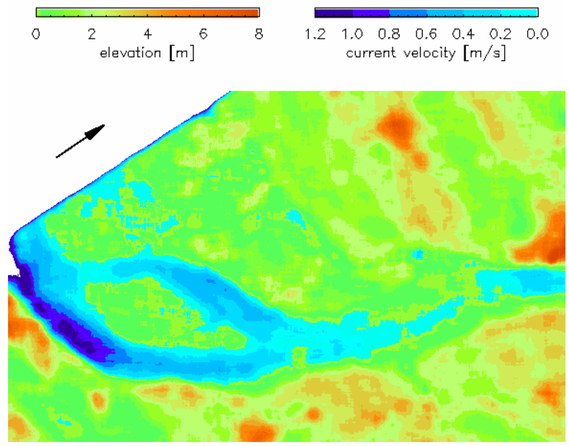

Fig. 5: Surface current field in the river Elbe derived from SRTM data

To measure jointly wave and current fields by the SAR gives a new opportunity to analyze ocean wave current interaction. This interaction is known to play an important role in the generation of extreme waves, causing many ship accidents, which was investigated in the European MaxWave project (Rosenthal et al., 2003).

4.4 Monitoring of Morphodynamic processes

Due to its high spatial resolution and polarimetric capabilities TerraSAR-X data are also ideally suited to observe morphodynamic processes, e.g. in river estuaries (Sigmund et al., 2004). These processes play a big economical role and are difficult to measure with traditional *in situ* instruments.

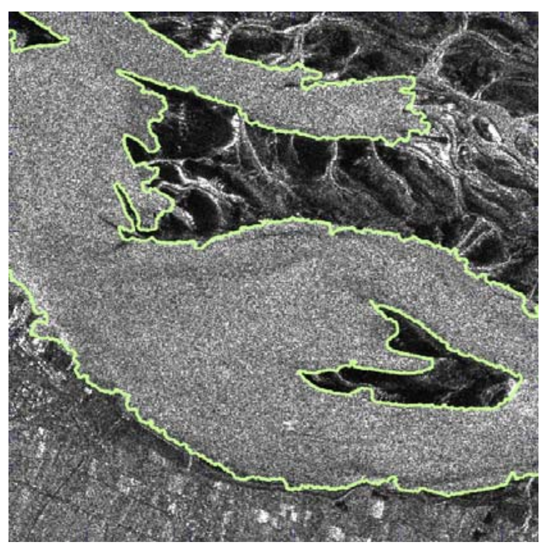

Fig. 6: Coastline in the river Elbe derived from an ERS-2 SAR image using a wavelet technique.

Techniques to measure morphodynamic changes from SAR data have been developed (Niedermeier et al., 2000), but were so far limited by the system resolution of the common systems like the ERS SAR. Furthermore, it is expected that the polarimetric information will improve the land water discrimination. It has also been shown that it is possible to use some information about scene coherence taken from the along track data to improve the land-water classification (Schwäbisch et al., 1997).
In Fig. 6 an example is given, which shows an ERS-2 image acquired over the river Elbe to which the land-water boundary is superimposed, which was extracted by a wavelet based technique.
Furthermore, methods to derive information on topography from along-track data have been proposed in (Romeiser et al., 2000).

4.5 Polarimetry

An additional feature of the TerraSAR-X instrument is its polarimetric capability (see table 1). It is well known that polarimetric data contain information, which can help to

- discriminate between oceanic and atmospheric features
- improve wave measurements by providing estimates of the SAR transfer functions
- provide additional ocean wave information, e.g. on wave breaking

A polarimetric image acquired by the shuttle SIR-C/X mission over the western pacific ocean in 1994 is shown in Fig. 7. The white, curved area at the top of the image is a part of the Ontong Java Atoll, which belongs to the Solomon Islands group. The yellowish green area near the bottom of the image is an intense rain cell. This image is centered near 5.5° S and 159.5° E. The area shown is 50 km by 21 km. The colors in the image are assigned to different frequencies and polarizations as follows: Red is C-band horizontally transmitted and received; green is L-band horizontally transmitted and vertically received and blue is L-band horizontally transmitted and received.

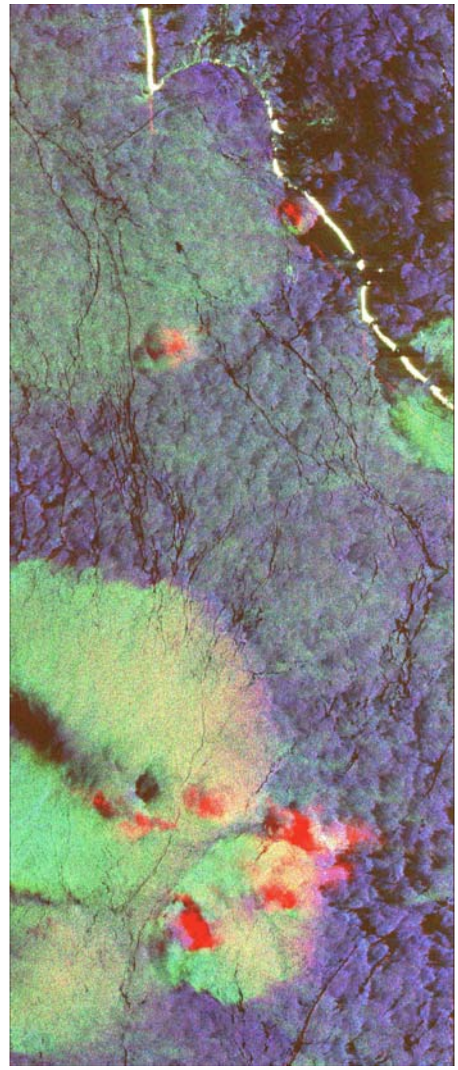

Fig. 7: Polarimetric image acquired by the shuttle SIR-C/X mission in 1994 (©NASA).

5. OUTLOOK AND CONCLUSION

A first overview of the potential of the new TerraSAR-X system for oceanographic applications has been given. The new system has polarimetric and interferometric capabilities as well as very high spatial resolution, which makes it a valuable tool for wind, wave and current measurements as well as the monitoring of morphodynamic changes. It's relatively short revisit time of 11 days (4.5 days if look direction is changed) also makes TerraSAR an interesting instrument for monitoring accidents like oil disasters.

TerraSAR-X will ensure the operational acquisition of SAR data beyond the ERS and ENVISAT era. To make it more consistent with the data products currently used at weather centres it is desirable to define additional oceanographic modes similar to the ERS and ENVISAT wave mode. Furthermore, it will be necessary to translate the existing C-Band wind and wave retrieval algorithms to X-Band. Airborne and spaceborne proxy data to start this translation, like e.g. taken during the SIR-C/X-SAR and SRTM missions, exist.

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