TerraSAR-X for Oceanography – Mission Overview

S. Lehner, A. Roth, M. Eineder
DLR, Oberpfaffenhofen, 82230 Wessling, Email:Susanne.Lehner@dlr.de

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/technological continuation of the highly successful missions X-SAR (1994) and SRTM (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 with Interferometry. 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 (Mittermayer, 2003).

- High geometric and radiometric resolution with an experimental very high resolution 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: ASAR, RadarSAT)
- 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

Most of the technical TerraSAR features are of great 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 FlexBus design with a total wet mass of 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°). Generated 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 4800 mm in length, 700 mm in width and 150 mm in depth.

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

4. OCEANOGRAPHIC APPLICATIONS

Due to its polarimetric and interferometric capabilities as well as the high spatial resolution TerraSAR-X is a very interesting tool for various oceanographic applications. In this paper 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. SAR is the only system which provides a synoptic view of wind fields over the ocean covering large areas (Lehner et al., 1998). An example is given in Fig. 2. 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 atmospheric boundary rolls.

For a future TerraSAR-X wind algorithm it is necessary to translate existing C-band algorithms to X-band. This can to some extent be done with existing X-band data from both airborne and spaceborne systems.

<table>
<thead>
<tr>
<th>Product</th>
<th>Coverage [az x rg]</th>
<th>Resolution [az x rg]</th>
<th>Polarization</th>
<th>Full Performance Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR Spotlight</td>
<td>$5 \times 10 \text{ km}^2$</td>
<td>$1.0 \text{ m} \times (1.5 - 3.5 \text{ m})$</td>
<td>single, dual, quad</td>
<td>$20 - 55^\circ$</td>
</tr>
<tr>
<td>Spotlight</td>
<td>$10 \times 10 \text{ km}^2$</td>
<td>$2.0 \text{ m} \times (1.5 - 3.5 \text{ m})$</td>
<td>single, dual, quad</td>
<td>$20 - 55^\circ$</td>
</tr>
<tr>
<td>StripMap</td>
<td>$\leq 1650 \text{ km} \times 30 \text{ km}$</td>
<td>$3.0 \text{ m} \times (1.7 - 3.5 \text{ m})$</td>
<td>single</td>
<td>$20 - 45^\circ$</td>
</tr>
<tr>
<td>StripMap (polarimetric)</td>
<td>$\leq 1650 \text{ km} \times 15 \text{ km}$</td>
<td>$6.0 \text{ m} \times (1.7 - 3.5 \text{ m})$</td>
<td>dual, quad</td>
<td>$20 - 45^\circ$</td>
</tr>
<tr>
<td>ScanSAR</td>
<td>$\leq 1650 \text{ km} \times 100 \text{ km}$</td>
<td>$16.0 \text{ m} \times (1.7 - 3.5 \text{ m})$</td>
<td>single, dual, quad</td>
<td>$20 - 45^\circ$</td>
</tr>
<tr>
<td>300 MHz Exp.-Mode Spotlight</td>
<td>$5 \times 10 \text{ km}^2$</td>
<td>$1.0 \text{ m} \times (0.6 - 1.5 \text{ m})$</td>
<td>single, dual, quad</td>
<td>$20 - 55^\circ$</td>
</tr>
<tr>
<td>Dual Receive StripMap</td>
<td>$\leq 1650 \text{ km} \times 30 \text{ km}$</td>
<td>$1.5 \text{ m} \times (1.7 - 3.5 \text{ m})$</td>
<td>single, dual, quad</td>
<td>$20 - 45^\circ$</td>
</tr>
<tr>
<td>ATI</td>
<td></td>
<td></td>
<td>Acc. 15-60 km/h</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Parameters of TerraSAR-X imaging modes. The pink color indicates experimental modes.
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. 3). These measurements are e.g. important for harbour protection, offshore wind parks, or 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 are less important than they are for the ERS or ENVISAT case (Hasselmann and Hasselmann, 1991). This makes the retrieval of ocean wave information like e.g. the two-dimensional ocean wave spectrum easier.

Furthermore the polarimetric information is known to improve 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 et al. (this issue).

4.3 Current measurements

The split antenna mode of TerraSAR-X enables along track interferometry and thus the estimation of current fields (Goldstein, 1987). A first analysis of this application has shown that the retrieved current fields have to be smoothed quite heavily 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 2 shows a current field in the river Elbe estimated from SRTM data.

Also interesting is the combination of wave and current measurements in order to analyze ocean wave current interaction. This interaction is known to play an important role in the generation of extreme waves and has risen a lot of attention (Nieto-Borge et al., 2003), e.g. at weather centers.

4.4 Monitoring of Morphodynamic processes

Due to its high spatial resolution and polarimetric capabilities TerraSAR data are also ideally suited to observe morphodynamic processes, e.g. in river estuaries. These processes play a big economical role and are hard to measure with traditional in situ instruments.

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, which is basis for the method. It might also be possible to use some information about scene coherence taken from the along track data to improve the land-water classification.

Figure 4 shows an ERS-2 image acquired over the river Elbe with the land-water boundary extracted by wavelet techniques.
5. Outlook and Conclusions

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 high spatial resolution, which makes it a valuable tool for wave, wind 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 events 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 SRTM mission, exist.

REFERENCES


Niedermeier, A., Romaneessen, E., Lehner, S., 2000, Coastlines In SAR Images Using Edge Detection By Wavelet Methods, IEEE GRS, Vol. 3 8, No. 5, Pp. 2270-2281