The TerraSAR-L System and Mission Objectives

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ABSTRACT

TerraSAR-L is the new imaging radar mission of the European Space Agency. The platform, based on the novel Snapdragon concept, is built around the active phase array antenna of the L-band Synthetic Aperture Radar (L-SAR). Specification of the L-SAR has been guided by careful analysis of the product requirements resulting in a robust baseline design with considerable margins.

Besides having a commercial role for the provision of geo-information products, TerraSAR-L will contribute to the Global Monitoring for Environment and Security (GMES) initiative and serve the scientific user community. Major application areas are: Kyoto inventory and wetland monitoring, solid earth science including seismic and volcanic activity as well as land slides and subsidence, land cover classification in different levels of detail and marine applications. The TerraSAR-L operations strategy is based on a long-term systematic and repetitive acquisition scenario to ensure consistent data archives and to maximise the exploitation of this very powerful SAR system.

1 INTRODUCTION

ESA's new imaging radar mission, TerraSAR-L, is currently being studied in a Phase B and the preliminary design review is planned for December 2004. The TerraSAR-L system will provide Europe with its most powerful SAR programme to date. Key features of the 5-year mission are a short (14-day) repeat cycle in a Sun-synchronous dawn-dusk orbit, global imaging coverage, tight orbit control and high precision orbit determination. The L-SAR is build around an active phased array antenna and provides full polarimetric capabilities, 85 MHz bandwidth, and repeat-pass ScanSAR interferometry.

Such a system can serve a number of applications and will be an important complement to current and future X- and C-band SAR sensors. Because of its penetration into vegetation canopies L-band SAR has strong capabilities in land cover classification. This feature is important for applications related to Climate Change like the Kyoto inventory and wetland monitoring and in combination with X-band data for commercial services in the area of agriculture, forestry and cartography. The capability to penetrate vegetation and to interact with the mechanically more stable lower parts of the canopy is also the main reason for increased coherence levels in L-band over vegetated surfaces and facilitates applications based on differential interferometry, which up to now have been limited to urban areas and bare surface, on global scale. Monitoring seismic and volcanic activities, landslides, subsidence and glacier ice motion are the main INSAR applications. Besides standard stripmap and ScanSAR modes the system also features a Wave mode similar to the one on ENVISAT and ERS.

This paper provides an overview of the TerraSAR-L system and its mission objectives including a detailed discussion of the interferometric capabilities. Important considerations for the operations strategy and a summary of the main mission features conclude the publication.

2 THE TERRASAR-L SYSTEM

The TerraSAR-L system comprises a spacecraft carrying a large, fully polarimetric L-Band SAR, and a complementary ground segment architecture.

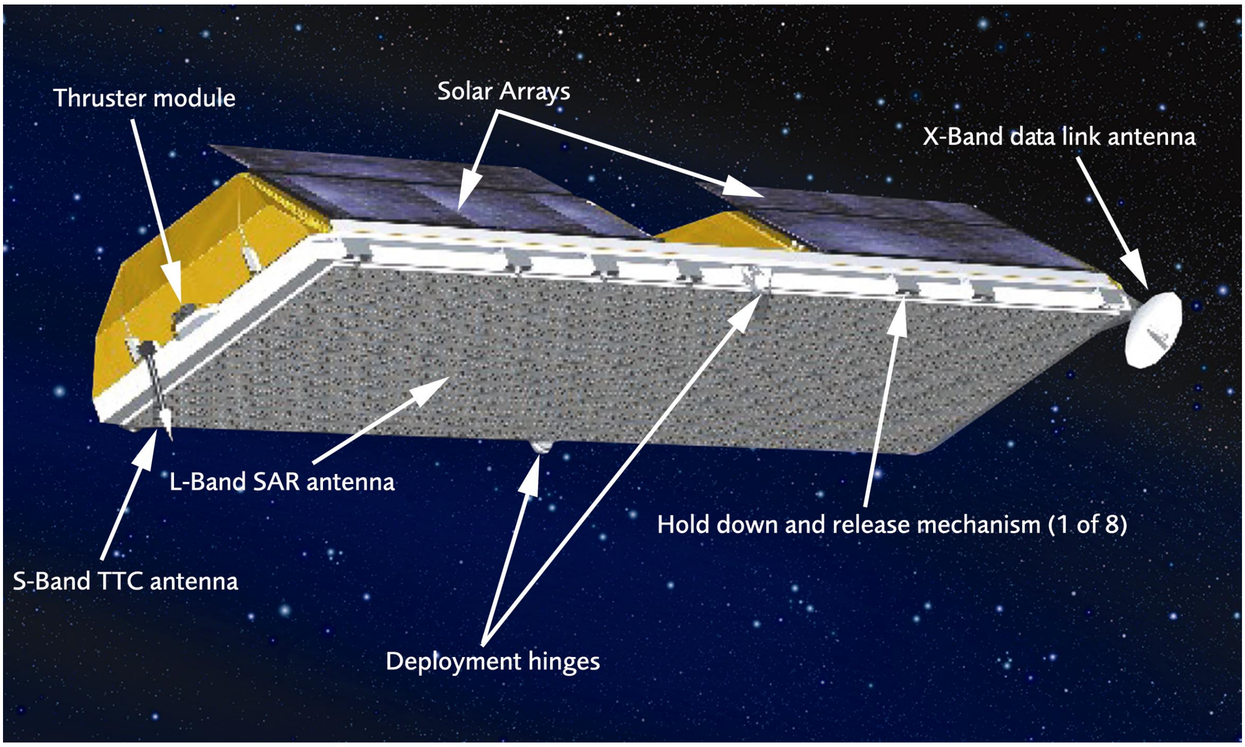

Fig. 1. Annotated View of the TerraSAR-L Spacecraft

2.1 Snapdragon Configuration

The TerraSAR-L spacecraft (Fig. 1), based on the novel snapdragon configuration, is optimised for and build around the large L-SAR antenna. One single deployment (see Fig. 2) of the whole spacecraft deploys the 11m by 2.86m SAR antenna. The snapdragon architecture retains the modularity of conventional platforms, offers ample space for equipment accommodation and simplifies the payload design and AIT of a large spacecraft. It furthermore permits verification by testing at high levels of integration and overall reduces the risk, costs and schedule. The spacecraft has a high agility due to low roll inertia and a low aerodynamic coefficient (lower than GOCE). A simple solar array and a simplified thermal design are further advantages of the snapdragon concept.

With a total launch mass of 2.8 tons (including contingencies and system margin), the Soyuz Fregat launcher has ample margins in volume to accommodate the stowed snapdragon and in mass to place TerraSAR-L into its ~630km orbit. The solar array provides more than 5kW power for an average L-SAR consumption of 4kW during data acquisition. Consequently, the TerraSAR-L spacecraft has margins in all aspects of its design.

2.2 The TerraSAR-L Orbit

TerraSAR-L will operate from a ~635km Sun-synchronous dawn-dusk orbit with a mean local solar time of 18:00 hours on the ascending and 06:00 on the descending orbits respectively. The short revisit time of only 14 days is optimised with respect to ensuring global coverage (no gaps at lower latitudes), effort and performance of the orbit maintenance manoeuvres and is a key feature of this mission, especially for INSAR applications.

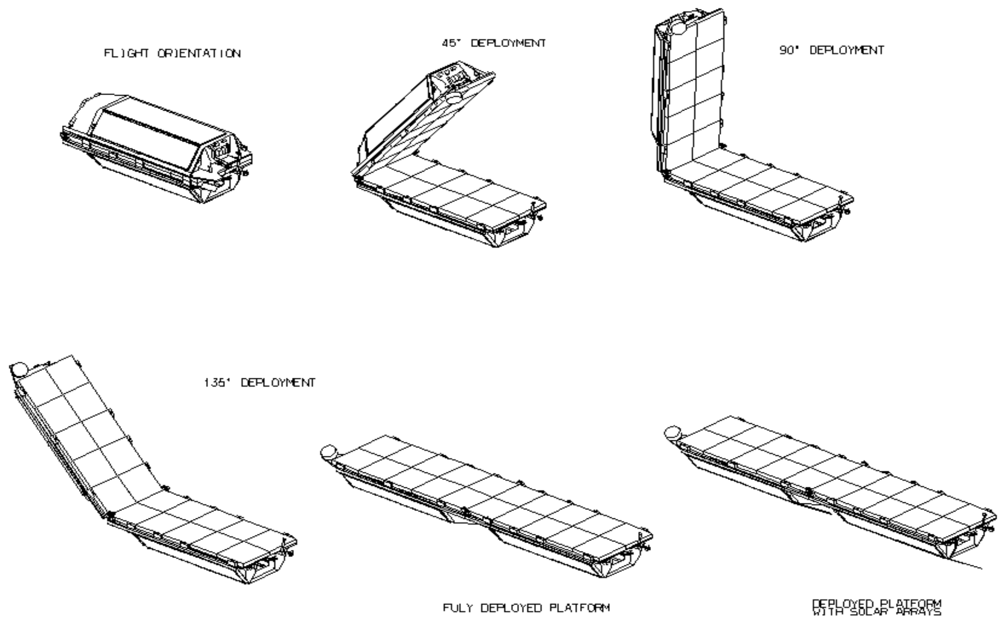

Fig. 2. Deployment sequence of the TerraSAR-L spacecraft

Tight orbit control (required to be within 100m tube) will be achieved by ground-generated manoeuvres and will reduce the topographic noise in the DINSAR applications to 1-2mm, if DEM data of the SRTM quality are available. The tight orbit control is combined with a requirement on the pointing accuracy of 10mdeg (3σ) in all axes.

A dual-frequency GNSS receiver allows for precise orbit determination to within 5cm, and a star tracker provides highly accurate spacecraft attitude (2mdeg).

2.3 L-SAR Characteristics

The L-SAR operates at a centre frequency of 1257.5MHz. Observing the ITU regulations a maximum bandwidth 85MHz is feasible in the allocated frequency band between 1215 and 1300MHz. Nominal modes are:

- Stripmap mode in single, dual and quad polarization
- Wideswath (ScanSAR) mode in single and dual polarization
- Wave mode (sampled stripmap, vignettes of 20x20km acquired every 100km)

Table 1 summarizes the main performance requirements on the L-SAR modes including the incidence angle range, swath width, azimuth and ground range resolution, Distributed Target Ambiguity Ratio (DTAR), radiometric accuracy and Noise Equivalent Sigma Zero (NESZ). The nominal look direction is right-looking, but for limited periods data can be acquired in left-looking geometry. In the high rate modes the maximum operations time per orbit is limited to 20 minutes, Wave mode data can be acquired over full orbits. The 20 minutes limit is driven by the data volume and downlink capacity, instrument thermal and power constraints allow more than 30 minutes of operation per orbit.

The ScanSAR and Stripmap Single Pol modes are especially designed for INSAR applications requiring maximum bandwidth to allow multi-looking for phase noise reduction and precise (<5ms) burst synchronization enabling repeat-pass ScanSAR interferometry.

Mode	Inc. Angle	Swath Width	Resolution azi x rg	DTAR	Rad. Accuracy (3σ)	NESZ
Quad Pol Stripmap	20-36 deg	40 km	5 x 9 m	-20 dB	1 dB	-30 dB
Dual Pol Stripmap	20-45 deg	70 km	5 x 9 m	-20 dB	1 dB	-30 dB
Interferometric Stripmap (Single Pol)	20-45 deg	70 km	5 x 5 m	-20 dB	1 dB	-27 dB
Dual Pol Wideswath	20-45 deg	>200 km	50 x 50 m	-20 dB	1.5 dB	-30 dB
Interferometric Wideswath (Single Pol)	20-45 deg	>200 km	20 x 5 m	-20 dB	2 dB	-27 dB
Wave	20-45 deg	20 km	5 x 9 m	-20 dB	1 dB	-30 dB

Tab. 1. Summary of L-SAR mode characteristics

The above performance requirements have to meet under the end-of-life assumption of 6% random module failure. Primary design driver for the L-SAR instrument and the size of the antenna aperture is not sensitivity but ambiguity performance at high incidence angles. With dimensions of 11m x 2.86m the L-SAR active phase array antenna is more than twice as big as the ASAR antenna and radiates more than twice the power of ASAR at a similar weight of ~900 kg. It consists of 160 sub-arrays fed by 160 transmit/receive modules (TRMs) arrange in 16 rows and 10 columns (panels). The antenna front-end and the snapdragon deployment mechanism are the only critical new developments of the TerraSAR-L system. Both are covered under on-going pre-development (risk retirement) activities, where in case of the antenna front-end a complete antenna panel is being designed and build.

In L-band propagation disturbances and especially ionospheric effects like Faraday rotation and phase delay have to be considered and if possible corrected. Quad-pol data allow estimating and compensating the Faraday rotation from the data itself. Dual-frequency (split-band) SAR operation permits Total Electron Content (TEC) estimation and is foreseen to support the ionospheric phase screening for interferometric applications.

The principal constraint on the TerraSAR-L system is transferring data to the ground. Optimised sampling schemes and advanced encoding techniques are required to reduce overheads on the instrument data rate as much as possible. The data management subsystem provides SAR data formatting, a mass memory of more than 600 Gbit and downlink encryption. Via a single channel 300 Mbit/s X-band downlink the data are transferred to a network of 3 ground stations.

2.4 Ground Segment

The ground segment is composed of three subsystems: the flight operations segment, the payload data segment and the instrument calibration segment. A modular architecture and re-use of existing facilities wherever beneficial is required. The ground segment must be compatible with the needs for interoperability with other missions, in particular TerraSAR-X, which is being developed as a German national programme. There is provision to accommodate direct access stations that could download data from the TerraSAR-L spacecraft directly using their own receiving station.

Encryption of the X-band downlink and the S-band uplink is required, in order to prevent unauthorized access to the TerraSAR system. A data-driven approach is the baseline for the payload ground segment, removing the need for detailed scheduling of the ground segment facilities/elements beyond the contact plan for the X-band receiving stations.

3 OVERVIEW OF MISSION OBJECTIVES

An L-band SAR system provides unique contributions in several application areas and will be an important complement to future X- and C-band mission. The TerraSAR-L system has the capabilities to serve a number of highly relevant applications, which can be categorised under the following areas.

3.1 Climate Change

Monitoring of the compliance to the Kyoto Protocol requires quantification of areas subject to land use change with respect to Afforestation, Reforestation and Deforestation (ARD). L-band SAR has strong capabilities in land cover classification in general, but especially in forest/non-forest area delineation. In addition, because of increased interaction depth in forest canopies, the L-band is also more sensitive to biomass changes than shorter wavelengths and reaches saturation at biomass levels of 50 t/ha, which enables the identification of afforestation and reforestation [1]. Beyond the detection of changes, biomass estimates as such are required for global carbon cycle science.

Another important and unique application of L-band SAR is wetland monitoring [2]. Reversing the global trend of wetland degradation and destruction is the objective of the UN's Ramsar Convention. Natural and anthropogenic wetlands (rice cultivation) are also sources of methane, one of the most effective greenhouse gases.

3.2 Interferometry

Interferometry is one of the most important applications of SAR, which has been mainly developed using C-band data from the ERS missions. With the exception of the ice phase (3-day repeat) and the ERS-1/-2 tandem mission (1-day repeat) C-band interferometry is limited to urban areas and bare surfaces. The increased levels of coherence over vegetation are a key advantage of L-band [3] allowing to extend the successful C-band applications to global scales. Therefore TerraSAR-L is well suited to serve Solid Earth applications like monitoring of seismic and volcanic activities. These were the main objectives of EVINSAR, which has been proposed as an Earth Explorer mission [3]. Furthermore our system will provide important contributions to subsidence and landslide monitoring, especially for vegetated surfaces and fast motions.

Also over snow and ice coherence is better preserved at L-band than at higher frequencies. This is of relevance for monitoring ice sheet and glacier dynamics with the DINSAR technique, as well as for speckle/feature tracking. The 14-day repeat cycle and increased bandwidth offered by the TerraSAR-L system are well suited for most glaciers and ice streams.

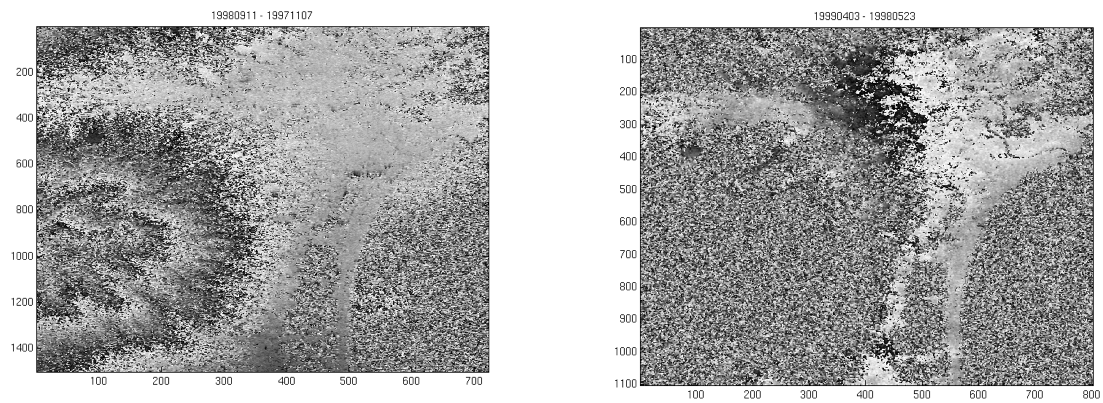

Fig. 3. Comparison of L-band (JERS-1 on the left) and C-band (ERS-1 on the right) coherence for a 10 month temporal baseline and similar height of ambiguity over the Fuji City area indicating similar coherence levels over the urban part and increased L-band coherence over the vegetated mountain slope in the left part of the images (courtesy of F. Rocca, POLIMI)

In addition to the above DINSAR applications an L-band SAR is also a favourite candidate for single-pass interferometry using a cartwheel constellation. In parallel to the main activities on TerraSAR-L a joint study team from CNES and DLR investigated the potential DEM generation performance of constellations of three receive-only micro-satellites flying in formation with TerraSAR-L [5]. The study reveals that such constellations are able to produce DEMs fulfilling the HRTI-3 (High Resolution Topographic Information) requirements: 2m/10m relative/absolute height accuracy at a 12m posting.

3.3 Land Cover Classification

Highly accurate land cover classification into a number of individual classes requires a full-polarimetric L-band sensor. Due to the complementary properties of the L- and X-band backscattering joint products from TerraSAR-L and TerraSAR-X enable even higher levels of classification performance necessary for crop monitoring and forest inventory. Dual frequency combinations are also required for cartographic maps of different thematic content and scale.

A full-polarimetric L-band SAR is the ideal sensor for soil moisture retrieval including surfaces with vegetation cover. Monitoring flood extent and supporting flood forecast in providing information on vegetation cover are further applications benefiting from TerraSAR-L products.

3.4 Marine Applications

TerraSAR-L offers a Wave mode like the one on ENVISAT or ERS for retrieving ocean wave spectra as input to meteorological models. Shallow water bathymetry and monitoring of surface current fronts and internal waves are areas, where L-band is expected to provide unique contributions.

Monitoring the extent and classification of sea ice is important for ship routing and climate change. L-band dual and quad pol data will provide improved sea ice classification capabilities.

4 SYSTEMATIC OPERATIONS STRATEGY

Providing long-term systematic and repetitive observations over large areas is one of the major strengths of remote sensing technology, in particular for microwave sensors, which are not limited by low sun angle or persistent cloud cover. Our best example is the archive of data collected by ERS-1/-2 missions. For a system with basically one mode of operation a consistent and useful archive can be achieved without major planning efforts. For a more powerful system like TerraSAR-L, which can serve a number of quite different user needs, new strategies have to be implemented to optimise the mission exploitation.

We plan to identify key driving applications early in the preparation phase and to establish a systematic observation plan. Key elements of such a systematic acquisition scenario are: adequate and consistent sensor modes, adequate repeat cycle, and adequate timing of the acquisition to account for seasonal changes. Long-term continuity is another important factor to guarantee consistent data archives. Pre-launch, this planning can be performed and potential conflicts identified and resolved, resulting in an optimised use of the system resources.

5 CONCLUSIONS

TerraSAR-L is a very powerful SAR system based on a robust design with considerable margins. The spacecraft is based on the snapdragon architecture, which is optimised for large SAR antennas. Repeat-pass ScanSAR interferometry, 85 MHz bandwidth and full polarimetric capabilities are the key characteristics of the L-SAR. The 14-day repeat cycle provides global coverage and enhanced performance for INSAR applications.

Besides major contribution to applications in areas of climate change and oceanography, the TerraSAR-L design responds specifically to requirements coming from interferometric applications. Joint products from TerraSAR-L and TerraSAR-X are important for commercial services relying on detailed land cover classification products.

A systematic operations strategy will ensure optimum use of the system resources, consistent data archives and maximised exploitation of the TerraSAR-L mission.

6 REFERENCES

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