A European L-Band SAR for Environmental Monitoring

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Abstract – The Phase B definition study of the TerraSAR-L mission concluded with a solid baseline design for a future European L-Band Synthetic Aperture Radar (L-SAR). Besides a major contribution to applications in the area of climate change, the system design responds specifically to requirements from interferometric applications. Most important applications of L-band SAR are monitoring of seismic and volcanic activities and of landslides and subsidence over vegetated terrain, mapping of glacier and ice stream velocities, generation of forest change maps for Kyoto inventory and monitoring of inundation patterns for wetlands. Being conceived as operational, the mission scenario is aiming at maximizing the exploitation of this SAR system.

Keywords: L-Band SAR, Systematic Global Monitoring, Surface Deformation, Terrestrial Carbon Cycle Science.

1. INTRODUCTION

The TerraSAR-L system characteristics have been derived from a careful analysis of the mission objectives [1] and the resulting product requirements. The novel snapdragon platform [2] is optimized for and built around the 11 m x 2.9 m active phased array antenna of the L-SAR. The L-SAR [3] (center frequency 1.2575 GHz) provides standard Stripmap and ScanSAR imaging configurations as well as a Wave Mode with a maximum bandwidth of 85 MHz within the available frequency allocation. Its capabilities include full polarimetry and repeat-pass ScanSAR interferometry. Key mission characteristics are a 14-day repeat cycle in a Sun-synchronous dawn-dusk orbit (635 km altitude), tight orbit control (orbital tube of 100 m), high pointing accuracy (10 mdeg) and high precision orbit determination (around 5 cm) based on a dual-frequency GNSS receiver as well as a precise burst synchronization (better than 5 msec). The nominal right-looking configuration is supplemented by a limited left-looking capability, the orbit is optimized for a global coverage within the 14-day repeat cycle. 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 L-SAR instrument can be operated in either a Stripmap, a ScanSAR or a sampled Stripmap (Wave) mode imaging configuration. Data acquisition is possible in a single, dual or quad polarization scheme. Six combinations out of all possible imaging and polarization configurations have been defined as the nominal L-SAR imaging modes as summarized in Tab. 1. For an operational mission based on a systematic acquisition scenario it is crucial to identify and design one main mode of operation, which can serve a number of applications simultaneously. For the L-SAR this main mode is the Interferometric Wideswath Mode, which will cover the major share of the instrument operations.

2. L-BAND SAR APPLICATIONS

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, terrestrial carbon cycle science 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 surfaces, on global scale. Monitoring seismic and volcanic activities, landslides, subsidence and glacier/ice motion are the main INSAR applications.

Such a sensor will be an important complement to current and future X- and C-band SAR sensors and can serve a number of highly relevant applications, which can be categorised under the following major areas.

2.1 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 [4]. Beyond the detection of changes, biomass estimates as such are required for global carbon cycle science.

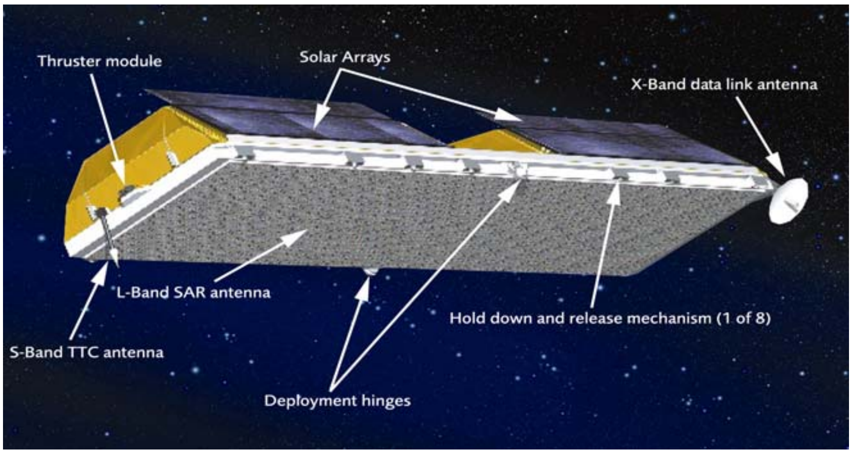

Fig. 1: Annotated View of the TerraSAR-L Spacecraft

Mode	Incidence Angle	Swath Width	Resolution Az x Rg	DTAR	Radiometric Accuracy (3 σ)	NESZ
Quad Pol Stripmap	20 – 36 deg	40 km	5 m x 9 m	-23 ...-20 dB	1 dB	-35 ... -30 dB
Dual Pol Stripmap	20 – 45 deg	70 km	5 m x 9 m	-20 dB	1 dB	-30 dB
Interferometric Stripmap	20 – 45 deg	70 km	5 m x 5 m	-20 dB	1 dB	-27 dB
Dual Pol Wideswath	20 – 45 deg	> 200 km	50 m x 50 m (15 looks)	-20 dB	1.5 dB	-30 dB
Interferometric Wideswath	20 – 45 deg	> 200 km	20 m x 5 m	-20 dB	1.5 dB	-27 dB
Wave	20 – 45 deg	20 km x 20 km	5 m x 9 m	-20 dB	1 dB	-30 dB

Tab. 1: Nominal L-SAR Imaging Modes (highlighted: Interferometric Wideswath Mode as the main mode of operation)

Another important and unique application of L-band SAR is wetland monitoring [5]. 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.

2.2 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 [6] allowing extending the successful C-band applications to global scales (see Fig. 2). Therefore the L-SAR is well suited to serve Solid Earth applications like monitoring of seismic and volcanic activities. Furthermore our system will provide important contributions to subsidence and landslide monitoring, especially for vegetated surfaces (see Fig. 2) 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 L-SAR system are well suited for most glaciers and ice streams.

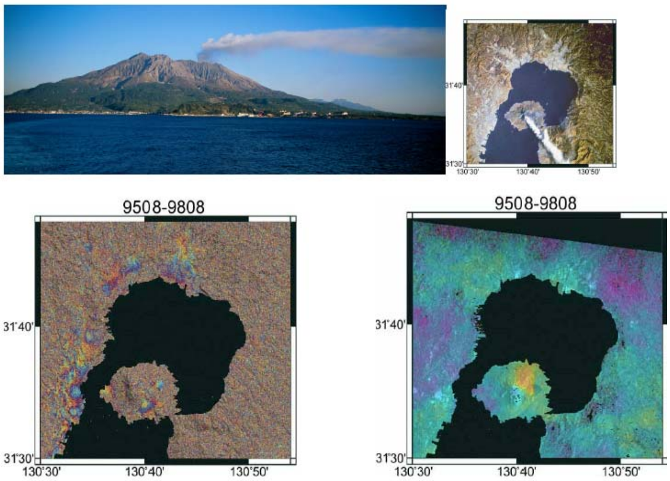

Fig. 2: Comparison between ERS (lower left) and JERS (lower right) interferogram over Sakurajima volcano (Japan) indicating increased levels of coherence especially on the lower vegetated areas (courtesy Univ. of Oxford).

2.3 Mission Objectives

These capabilities of L-band SAR enable the generation of higher-level information products as the basis for achieving mission objectives like e.g.:

- Improved understanding of the seismic cycles of accumulation and release of strain due to tectonic movements
- Better insight into the dynamics of magma chambers as a pre-requisite for potential future prediction of volcanic eruptions
- Rate and variability of ice discharge and its relation to sea level rise and climate change
- Seasonal inundation patterns of wetlands as input to greenhouse gas accounting models
- Biomass and Land Cover change maps as contribution to Terrestrial Carbon Cycle Science
- Afforestation, Reforestation and Deforestation (ARD) maps for Kyoto inventory

3. OPERATIONAL EXPLOITATION CONCEPT

All the mission objectives listed above have a global dimension and require long-term repetitive acquisitions, which can be implemented in a systematic operations strategy. A systematic acquisition scenario and the resulting consistent data archives are the first important elements in the chain of our exploitation concept. But in order to achieve the mission objectives we have to ensure that not only the data will be collected and archived but also that the relevant information will be systematically extracted. Therefore a consistent and systematic processing to higher-level products has to be implemented. The resulting operations strategy and the systematic processing are described in more detail in the following chapters.

3.1 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 the 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 L-SAR, 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. As already mentioned, 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. In this process we rely on the important lesson learnt from ERS and ENVISAT experience, to design a main mode of operation, which is able to serve a number of applications simultaneously. In the L-SAR case this main mode is the Interferometric Wideswath (IW) Mode with the following characteristics:

- Resolution (Rg x Az): 5 x 20 m (comparable to ERS/ASAR Image Mode resolution)
- Swath Width: 200 km (providing global coverage from the 635 km orbit in a 14-day repeat cycle)
- ScanSAR repeat-pass interferometric capability enabled by precise acquisition start (burst) synchronisation and 3 sub-swath ScanSAR operation with maximum burst duration (single-look ScanSAR)

Over land most of the operations will be in this IW mode and in HH polarization covering all interferometric applications and some of the land cover classification themes like wetland monitoring. Once per year a global data set will be acquired in the dual polarization IW option (HH & HV) to serve specific land cover classification applications (biomass change and Kyoto ARD monitoring). Over open ocean the instrument will operate in Wave Mode and over sea ice in the Dual Pol Wideswath Mode.

The above-described maximum duty cycle of 20 minutes/orbit in high-rate modes is driven by the data volume and downlink capacity, assuming a network of three ground stations and a downlink rate of 300Mbit/s. Instrument thermal and power constraints allow more than 30 minutes of operation per orbit.

3.2 Systematic Generation of Higher-Level Information Products

With the implementation of the outlined systematic operations concept we will be able to acquire the required data and to build-up consistent archives for our applications. The acknowledgement of the importance and the value of long-term archives is one of the major achievements of the ERS mission. But the compilation of consistent archives has to be complemented by dedicated efforts to systematically process the L-SAR data to high-level information products required to achieve our mission objectives. This concept is schematically presented in Fig. 3 and outlined in the following.

As a first step towards a systematic generation of higher-level products, the ground segment design includes a systematic processing of all acquired data to Level 1b (L1b) products. In addition the family of L1b basic products is restricted to Single-look Slant-range Complex (SSC) products for all operational modes. This decision is justified by the following considerations:

- SSC products are required by most applications including interferometry, polarimetry, sea surface imaging, etc.
- Processing algorithms for derivation of higher-level information products can be consistently based on SSCs as input.

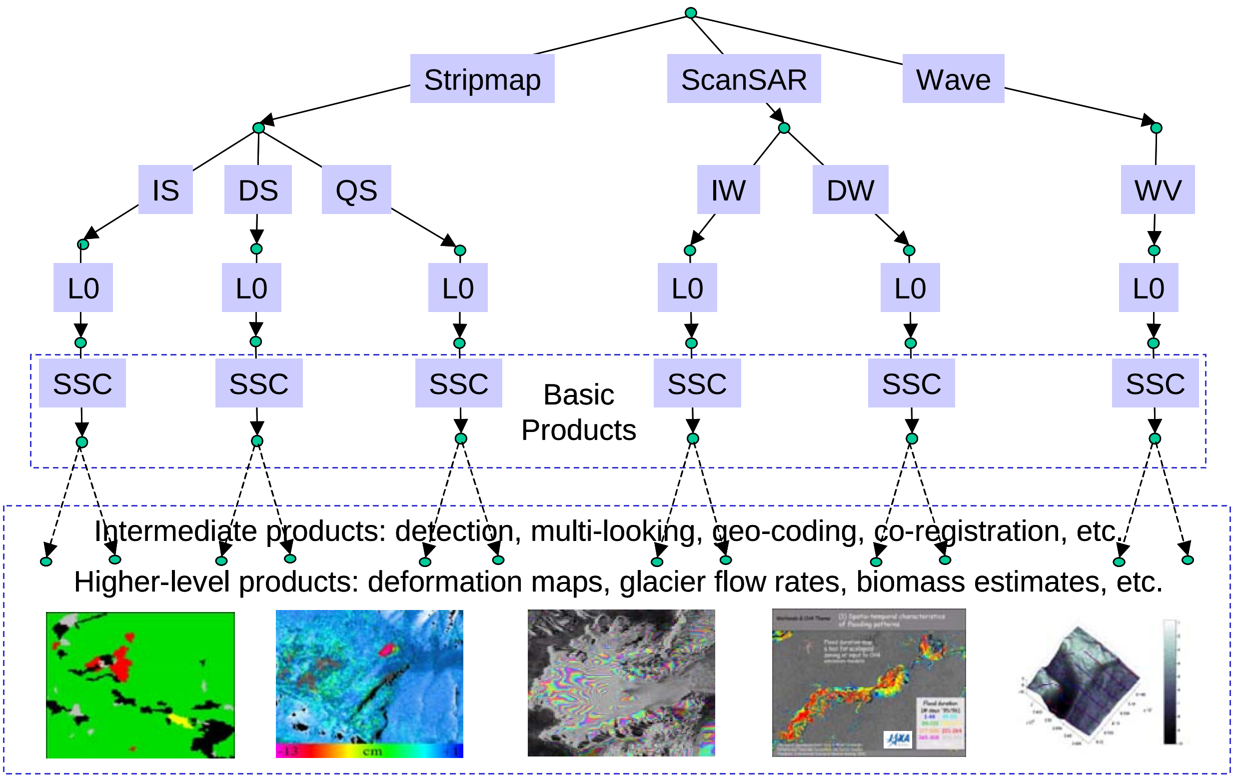

Fig. 3: L-SAR Product Tree

- The L1b processor design simplifies, because a minimum number of algorithmic variants can be implemented in a well-structured and modular architecture.
- Verification and maintenance of a flat basic product tree requires less effort.

The required steps of detection, multi-looking and geo-referencing to various projections will be provided as post-processing algorithms in a consistent tool set implementation. These algorithms will be able to ingest the best available DEM for geo-coding and allow a certain level of output product customisation (e.g. optimise geometric versus radiometric resolution or vice versa in the multi-look detection process).

Furthermore the geo-coding algorithms will include the option of keeping the original SSC product and only generating the lat/long (or northing/easting) matrices corresponding to each individual image pixel. Using this so-called enumeration files, all higher-level data processing (e.g. polarimetric classification) can be performed directly on the SSC data and only the result will be mapped onto the selected projection via the lat/long co-ordinates. This option is especially important for processing of full-polarimetric products, but in general enables algorithms based on the original full-resolution SSC products.

Intermediate products of different level, like the above detected and geo-coded images or co-registered images and interferograms, are the basis for higher-level information product generation. Well-established and robust processing algorithms can be integrated into the above tool set to generate for example surface deformation maps, glacier flow rates, wetland inundation patterns, biomass estimates, etc.

3.3 L-SAR Basic Product Tree

The identification of Single-look Slant-range Complex (SSC) products as the only constituent of the basic product portfolio and the requirement for a systematic level 1 processing lead to the definition of a product hierarchy introducing consistent layers of Level 0 (L0) and SSC products as depicted in Fig. 3. All L-SAR data received on-ground are processed into L0 products for long-term archival. Any level 1 data processing starts from these L0 products and produces SSCs. Post-processing algorithms for derivation of higher-level information products are consistently based on these SSCs as input. This is a novel concept for SAR ground segments, which has been developed first in the frame of the TerraSAR-X Payload Ground Segment [8].

Only in the recent years, the generation and the use of complex ScanSAR products has been demonstrated in the field of interferometry [9,10]. Following a strong user request, the ENVISAT/ASAR is the first mission to introduce a complex phase-preserving ScanSAR product ASA_WSS (availability expected for end of 2004) as part of the user product portfolio [11]. However, this product is a specific add-on to the ASAR product tree and its implementation was only initiated after the commissioning phase.

4. CONCLUSIONS

The robust design of the TerraSAR-L, based on the snapdragon architecture, provides a solid baseline for future European L-Band SAR. Repeat-pass ScanSAR interferometry, 85MHz bandwidth and full polarimetric capabilities are the key characteristics of the L-SAR. A 14-day repeat cycle provides global coverage and enhanced performance for INSAR applications.

Such a L-band mission will serve the scientific user community and will also be valuable for the Global Monitoring for Environment and Security (GMES) initiative. 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.

An operational exploitation concept will ensure optimum use of the system resources, consistent data archives and maximised exploitation of the L-SAR mission. Key elements of this concept are a systematic acquisition scenario using the Interferometric Wideswath Mode as the main operational mode and a systematic generation of higher-level information products.

It is planned to provide processing algorithms for higher-level information products as a tool-set, which includes also intermediate steps of detection, multi-looking, geo-referencing, co-registration, etc. These algorithms will be consistently based on SSCs as input. As a consequence the basic product tree can be limited to SSC products for all imaging modes and the processor architecture can be simplified.

5. REFERENCES

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