Tandem-L: Global Monitoring the Earth's Dynamics with Differential and Polarimetric SAR Interferometry

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ABSTRACT

Tandem-L is a German mission proposal for an innovative interferometric L-band radar mission that enables the systematic monitoring of dynamic Earth processes using advanced techniques and technologies. The Tandem-L mission concept consists of two cooperating satellites flying in close formation. The single-pass imaging mode for polarimetric SAR interferometry and the repeat-pass acquisition mode for differential interferometry provide a unique data source to observe, analyse and quantify a wide range of mutually interacting processes in the bio-, geo-, hydro- and cryosphere. The systematic observation of these processes benefits from the high data acquisition capacity and the novel high-resolution wide-swath SAR imaging modes that combine digital beamforming with a large reflector antenna. This paper provides an overview of the Tandem-L mission concept and its main application areas.

1. INTRODUCTION

Tandem-L is a German proposal for an interferometric and polarimetric SAR mission at L-band for mapping dynamic Earth processes. The motivation for this mission proposal comes from the increasing science requirements for a continuous and global monitoring of climate and environmental variables with high resolution and on a reliable way. Examples of the essential variables to be measured by Tandem-L in a systematic way are (see fig. 1):

- Above ground forest biomass and its 3-D vertical structure distribution. Observation of changes in forest height and biomass (e.g. due to deforestation or afforestation), changes in biodiversity, etc.
- Earth surface deformation (e.g. due to seismic movements, volcano eruptions, land slides, subsidence, uplift, etc.).
- Retreat and accumulation in ice and snow covered regions, velocity field estimation of land ice movement within a high velocity range variation.
- Changes in surface soil moisture and land use (high resolution maps).
- Measurements of ocean surface currents.

In order to achieve the ultimate goal to estimate these essential variables in a systematic and reliable way, the following requirements are posed on the SAR mission concept:

- Single-pass interferometry for estimation of forest height, biomass and 3-D structure by means of multi-baseline polarimetric SAR interferometry (Pol-InSAR).
- Repeat-pass acquisition mode for estimation of surface deformation with differential interferometry (D-InSAR).
- L-Band as the most appropriate frequency for Pol-InSAR and D-InSAR acquisition modes due to the following reasons:
  - high bandwidth of the available frequency allocation (85 MHz).
  - penetration capability in vegetated areas allowing the forest biomass estimation up to 500 tons/ha.
  - high coherence values in repeat-pass mode.
  - low RF interference and ionospheric perturbations when compared to lower frequency bands.
- Short revisit cycle for small temporal decorrelation.
- High data rate acquisition and downlink capability to allow a systematic acquisition of dynamic processes (acquired data volume larger than 1 TB/day).

In section 2 the measurement and mission concept will be presented based on these requirements. Due to the need of having Pol-InSAR and D-InSAR modes in the mission concept, one satellite should have a nearly circular and polar orbit within a narrow tube of a few hundred meters for D-InSAR operation, while the second satellite should have an orbit which provides the required baselines for Pol-InSAR.

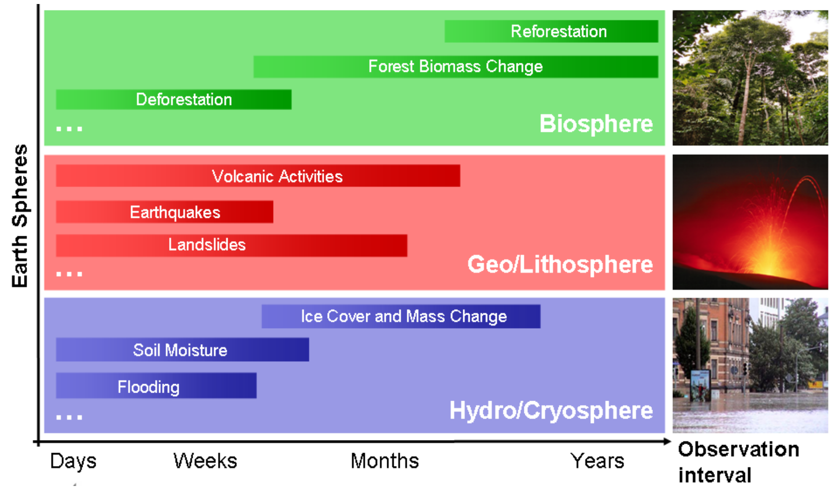

Figure 1: Dynamics of different Earth spheres and the requested interval for sampling the corresponding process in an unambiguous way.

The same helix orbit concept as in the TanDEM-X mission is adopted for the second satellite where a small eccentricity offset and a shift of the ascending node allows for a flexible adjustment of the desired baselines [2].

2. Mission Concept

The estimation of dynamic processes on Earth surfaces requires systematic, long term and continuous observation strategies in order to detect short and long term changes with a sufficient accuracy. Depending on the environmental and/or anthropogenic process to be observed there is a need for having different time intervals in the acquisition plan.

Existing SAR sensors could already demonstrate that radar plays an important role in the parameter estimation related to essential environmental, climate and anthropogenic processes. Today, SAR sensors are mostly covering only small and selected areas and do not acquire data in a long term and systematic way in order to make reliable statements about Earth's processes changes. In some cases large areas are being acquired, but the required sampling interval as shown in fig. 1 is not fulfilled.

One important feature of Tandem-L is therefore to achieve observation intervals of weeks to several months on a global scale with an appropriate sampling to characterise dynamic processes. A second important feature is a systematic acquisition strategy with a global coverage that allows generating consistent time series over at least 5-7 years of mission lifetime. The combination of short observation intervals and systematic data acquisition will enable to observe short term highly dynamic processes like seismic movements as well as long term processes with yearly cycle change like forest biomass growth changes.

The main scientific focus of Tandem-L is placed on two application areas, the biosphere and geosphere. However, with the requirements for a systematic and global mapping with short repeat times Tandem-L will be also very useful for other application areas in hydro- and cryosphere. The Tandem-L mission will provide a new insight and will increase the information content in bio- and geo-sciences and represents therefore a unique concept that will provide a step forward towards a holistic view of global land processes.

For the data acquisition an innovative concept has been worked out. The satellite system as it is planned up to now will operate in two basic data acquisition modes:

1) The *3-D structure mode* employs fully-polarimetric single-pass SAR interferometry (Pol-InSAR) to acquire structural parameters and quasi-tomographic images of volume scatterers like vegetation, sand, and ice.

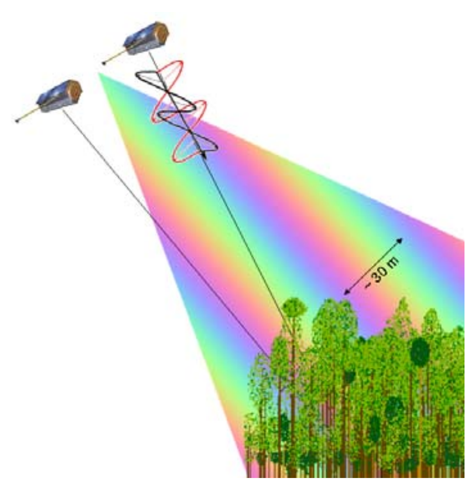

Figure 2: 3-D structure mode using single-pass SAR interferometry

2) The *deformation mode* employs repeat-pass interferometry (InSAR) in an ultra-wide swath mode in order to measure small shifts on the Earth surface with millimeter accuracy in short repetition intervals.

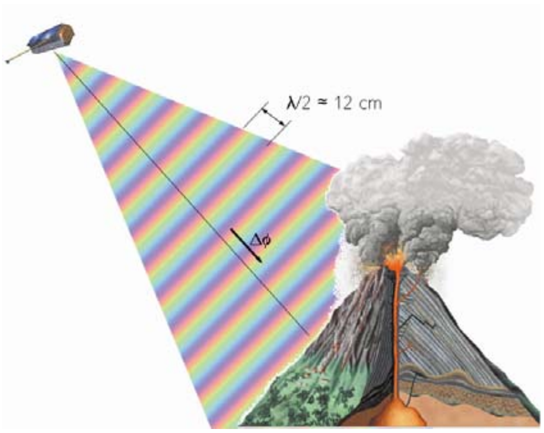

Figure 3: Deformation mode using repeat-pass SAR interferometry

Both acquisition modes (cf. fig. 4) enable a systematic and global mapping of the Earth with a high spatial resolution due to the use of digital beamforming techniques. The deformation mode requests a short orbital repeat cycle, whereas the 3-D structure mode needs only a repeat pass time of one month due to slower changes in the vegetation cover.

In case of critical events and hazards (earthquakes, flooding, volcano eruption, dike breaks etc.) it will be possible to adapt the satellite acquisition plan to a certain area of interest that can then typically be mapped within one or two days.

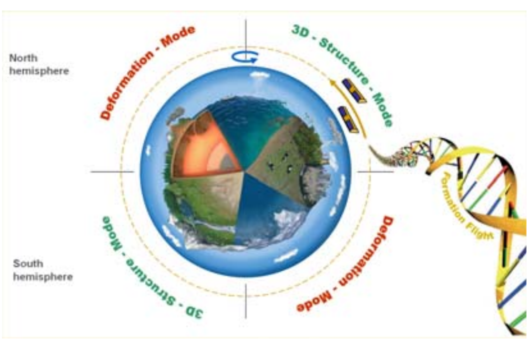

Figure 4: Tandem-L mission concept with two acquisition modes.

The deformation mode can be operated in any position of the orbit cycle, while the 3-D structure mode requires adequate interferometric baselines that are only present within two quadrants of each orbit cycle (assuming a fixed right looking direction). Hybrid operation modes in connection with digital beamforming will allow resolving the conflicts in the acquisition mode due to different user requirements [5].

3. Radar Technology: Digital Beam Forming

One most challenging task in the Tandem-L realisation is the development of two identical satellites with a cost effective implementation approach and at the same time having a high performance in order to fulfil the demanding scientific needs. However, besides an innovative mission concept also new imaging techniques and technologies are needed for fulfilling the science requirements.

Figure 5: Artistic view of a Tandem-L formation with two satellites (preliminary design achieved during a joint DLR and NASA/JPL pre-phase A study [4], [5]).

One key technology of Tandem-L is the use of a large reflector antenna and the use of digital beamforming in the feed array that illuminates the reflector (see fig. 6 and fig. 7). While all feed elements are used during transmission, allowing the illumination of a large image swath, 2-3 feed elements are activated during the receive window. The feed element positions are periodically shifted in synchrony with the systematic variation of the direction of arrival from the swath echoes. The advantages of this concept are manifold. First, the use of a large reflector antenna in connection with digital beamforming allows the reduction of the transmit power by a factor of 3-4 in comparison to the traditional SAR concept for the same imaging parameters. Second, it allows the mapping of a much wider swath (ca. 350 km) in high resolution stripmap mode [4], [5]. The fully polarimetric acquisition in stripmap mode with a wide swath is possible without the constraints of conventional SAR systems. This leads, however, to a large data rate and requires the implementation of advanced technologies for high data rate downlink. The downlink requirements can however be alleviated by employing new hybrid SAR modes suggested in [5]. These modes enable variable resolutions within a single scene and allow by this for an optimum adaptation to the non-homogeneous resolution requirements from the different science disciplines.

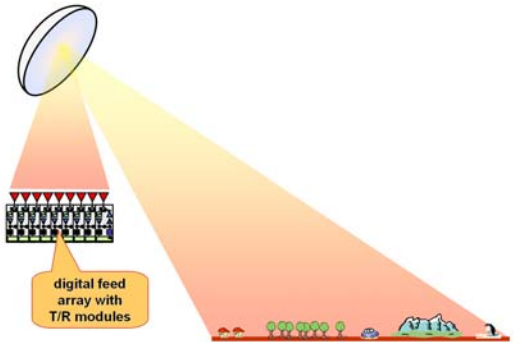

Figure 6: Concept of digital beamforming for high resolution, wide-swath radar systems: Transmit event

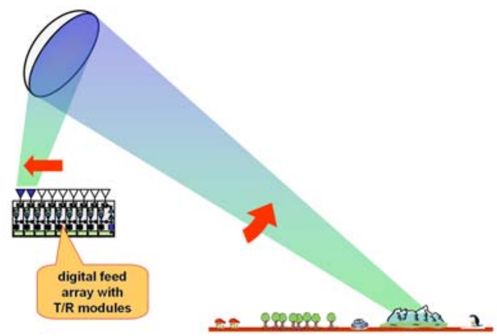

Figure 7: Concept of digital beamforming for high resolution, wide-swath radar systems: Receiving event

The Tandem-L mission is currently in the pre-phase A study and is being performed in cooperation with NASA/JPL. The study shall demonstrate a concept for a joint realisation of a Tandem-L/DESDynI type of mission. Currently, the mission proposal is scheduled for a mission operation time of five to seven years with a launch in 2015. A positive decision for a joint mission realization is expected in the next 1-2 years.

Table 1: Tandem-L Time Schedule

Year	Planning
2008-2009	Pre-Phase A (1 Year)
2009-2010	Phase A (1 Year)
2010-2011	Phase B (1 Year)
2011-2014	Phase C/D (3 Years)
2015	Launch of satellites
2015-2020	Nominal mission duration

4. Summary

Tandem-L is an innovative mission proposal for mapping Earth's dynamics with an unprecedented accuracy and capability. Advanced measurement techniques like single-pass Pol-InSAR allow the estimation of new essential environmental and climate variables. The instrument concept includes the innovative technology of digital beamforming in connection with a large reflector antenna which allows fulfilling the so far contradicting user requirements for a fully polarimetric imaging mode with wide swath and high resolution.

In addition to the science objectives described in this paper, Tandem-L has the potential for allowing many other applications and products due to its global and systematic acquisition plan. As an example, single-pass Pol-InSAR can also be used to estimate the bare soil topography as complementary information to the surface DEM that will be provided with the TanDEM-X mission with HRTI-3 standard [2].

5. Acknowledgement

I would like to thank the Tandem-L science and project team for their great work and outstanding achievements in the pre-phase A study. In addition I like also to thank the DESDynI science team for sharing their expertise in ecology and geo-sciences and the NASA/JPL research/engineering team for the constructive discussions and valuable contributions.

6. References

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