TANDEM-L: MAIN RESULTS OF THE PHASE A FEASIBILITY STUDY


German Aerospace Center, DLR
*Airbus DS, Germany
+OHB, Germany

ABSTRACT

Tandem-L is a proposal for a highly innovative SAR satellite mission for the global observation of dynamic processes on the Earth’s surface with hitherto unknown quality and resolution. Thanks to its novel imaging techniques and its unprecedented acquisition capacity, Tandem-L will deliver urgently needed information for the solution of pressing scientific questions in the areas of the biosphere, geosphere, cryosphere and hydrosphere. In this way, Tandem-L will make a vital contribution towards a better understanding of the Earth system and its dynamics. The feasibility of Tandem-L has been analyzed and confirmed in the scope of a phase A study, which has been conducted in close cooperation between the German Aerospace Center (DLR) and the German space industry. This paper provides an overview of the major results of the Tandem-L feasibility study and summarizes the actual development status.

Index Terms— Earth system, dynamic processes, SAR interferometry, tomography, digital beamforming, high-resolution wide-swath SAR imaging

1. INTRODUCTION

Tandem-L is a proposal for a highly innovative SAR satellite mission for the global observation of dynamic processes on the Earth’s surface with hitherto unknown quality and resolution. Thanks to its novel imaging techniques and its vast recording capacity, Tandem-L will provide urgently needed information for the solution of pressing scientific questions in the areas of the biosphere, geosphere, cryosphere and hydrosphere. Important mission goals are the global measurement of forest biomass and its temporal variation for a better understanding of the carbon cycle, the systematic monitoring of deformations of the Earth’s surface on a millimetre scale for the investigation of earthquakes and risk analysis, the quantification of glacier motion and melting processes in the polar regions, the fine scale measurement of variations in the near-surface soil moisture as well as observations of the dynamics of ocean surfaces and ice drift. The Tandem-L mission concept builds upon the success of TanDEM-X and utilises two formation-flying radar satellites operating in L-band. The wavelength of Tandem-L optimally fulfils the requirements for tomographically imaging the three-dimensional structure of vegetation and ice bodies, as well as the wide-area measurement of deformations with millimetre precision. Tandem-L will moreover use cutting-edge radar technology employing the latest digital beamforming techniques to map ultra-wide image swaths with high azimuth resolution. The goal of Tandem-L is to interferometrically image large parts Earth’s landmass up to twice per week. Beyond the primary mission objectives, the data set recorded with Tandem-L represents a tremendous opportunity for the development of novel scientific applications and commercial services. The feasibility of Tandem-L has been analyzed and confirmed in the scope of a phase A study, which has been conducted in close cooperation between the German Aerospace Center (DLR) and the German space industry. This paper summarizes the results of the phase A study and provides an overview of the mission objectives and requirements, the mission concept and the major innovations in the radar instrument.

2. MISSION OBJECTIVES AND REQUIREMENTS

The Earth system consists of a wide variety of components and processes that are intrinsically linked by complex interactions. For instance, changes in the biosphere (deforestation of tropical forests, land use change), the geo-/lithosphere (volcanic eruptions, earthquakes), the hydrosphere (changes in ocean currents, soil moisture) or the cryosphere (polar ice caps and snow coverage, permafrost) may impact not only their own dynamic balance, but can also precipitate lasting changes in physical and chemical processes in the atmosphere. Changes in the
atmosphere will subsequently affect the weather and climate, which in turn influence a number of processes in the biosphere, geosphere, cryosphere and hydrosphere.

Until now, many of these complex interactions are either insufficiently understood or are inadequately quantified. A major reason for this is that processes involving several spheres of the Earth are interconnected across different spatial and temporal scales, and that appropriate observational data that would enable analysis of these manifold interactions have not been acquired thus far.

Although the dynamic processes unfolding within the atmosphere are already being continuously monitored by a large number of different sensors, many of the processes occurring on the Earth’s surface are only mapped on a point-by-point basis, and often at widely separate points in time. For example, there is a lack of regular and comprehensive observations of fundamental processes such as changes in the global biomass, glacier dynamics, volcanic activity, tectonic displacements, global ocean currents, freezing and thawing cycles in permafrost, local variations in soil moisture, and so on.

Many of these processes are directly or indirectly linked to the climate and require a continuous and systematic observation system in order to detect and quantify changes in a timely manner. Depending on the phenomenon under consideration, it is necessary to monitor changes across the entire range of spatial and temporal scales and to place these changes in relation to each other. Although the understanding of changes taking place in the Earth system has increased substantially since the introduction of satellite-based Earth observation, the imaging capability and measurement precision of current systems is often insufficient to support reliable statements on the dynamics of processes occurring over large areas. Figure 1 shows a number of selected examples to illustrate the spectrum of observation intervals needed to analyse important dynamic processes in the different Earth spheres.

Hence, an essential requirement of the Tandem-L mission is to image large areas regularly with high temporal and spatial resolution. This, together with a systematic acquisition scenario will allow to monitor the evolution of natural and/or anthropogenic processes in a consistent way. Only thus can the dynamics of the different changes in the Earth’s surface be monitored with sufficient accuracy and detail. The combination of short revisit times and data recording periods extending over several years allows the monitoring of rapidly developing, highly-dynamic processes, such as the relaxation following an earthquake, as well as slowly developing processes, like the variation of forest biomass, with the necessary precision and resolution.

Figure 1: Examples of dynamic processes within the bio-, geo-, cryo- and hydrosphere and the observation intervals required for their systematic monitoring.

A vital scientific goal of Tandem-L is the quantitative recording of dynamic processes on the Earth’s surface both systematically and on a global scale. Important mission objectives are:

- global measurement and monitoring of 3-D forest structure and biomass for a better understanding of ecosystem dynamics and the carbon cycle,
- systematic recording of small and large scale deformations of the Earth’s surface with millimeter accuracy for earthquake, volcano and landslides research as well as risk analysis and mitigation,
- quantification of glacier movements, 3-D ice structure and melting processes in the polar regions for improved predictions of future sea level rise,
- fine scale measurements of soil moisture and its variations close to the surface for a better understanding of the water cycle and its dynamics
- systematic observation of coastal zones and sea ice for environmental monitoring and ship routing,
- monitoring of agricultural fields for crop and rice yield forecasts, as well as
- generation of highly accurate global digital terrain and surface models which form the basis for a wide range of further remote sensing applications.

These objectives address subjects of great societal importance and encompass a spectrum that ranges from basic Earth system research to environmental monitoring and disaster mitigation. Moreover, in a time of intense scientific and public debate on the extent and influence of climate change, Tandem-L can provide important and currently missing information for improved scientific forecasts about which socio-political decisions can be based.
3. MISSION CONCEPT
The Tandem-L mission concept builds upon the experience with TanDEM-X and employs two formation flying radar satellites operating in L-band [1], [3], [9], [7]. The data acquisition is based on two complementary modes:

- **3-D Structure Mode** for the three-dimensional surveying and tomographic imaging of volume scatterers, such as vegetation, ice, snow and dry soil. This imaging mode is necessary to collect unambiguous data on volume scatterers (height, density, structure, etc.). The 3-D structure mode optimally fulfills the requirements of applications pertaining to the biosphere, hydrosphere and cryosphere. The basis of the 3-D structure mode is polarimetric SAR interferometry (Pol-InSAR) and tomography. Tandem-L will be the first radar mission that employs these techniques to operationally derive global 3-D structure measurements.

- **Deformation Mode** for monitoring topographic changes in the Earth’s surface with accuracies down to centimeters and millimeters. In this mode, the largest possible swath width up to 350 km will be imaged. In this way, temporal spacing between the images is minimized. The deformation mode is optimum for applications in the geosphere and lithosphere research fields.

Both measurement techniques permit systematic and global imaging of the Earth with a spatial resolution down to 7 m (a spotlight mode option even allows small areas to be imaged with 1 m azimuth resolution). While the deformation mode requires a repeat measurement cycle of one to two weeks, for the 3-D structure mode a repeat cycle of one to two months is sufficient, because of the slower fluctuations of volume scatterers.

Table 1 summarizes some key parameters of the suggested L-band SAR system. The final paper will provide more details on the mission concept and the data acquisition plan.

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**Table 1: Key parameters and performance figures of Tandem-L.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit height</td>
<td>745 km</td>
<td>231 cycles / 16 days</td>
</tr>
<tr>
<td>Orbital tube</td>
<td>500 m (3σ)</td>
<td>refers to master satellite</td>
</tr>
<tr>
<td>Horizontal baselines</td>
<td>1 km … 18 km</td>
<td>variable horizontal baselines for bistatic mode in close formation</td>
</tr>
<tr>
<td>Radial baselines</td>
<td>0 m … 600 m</td>
<td>radial baselines are mainly for passive safety in close formation (Helix concept)</td>
</tr>
<tr>
<td>Local time</td>
<td>6 h / 18 h</td>
<td>dawn/dusk</td>
</tr>
<tr>
<td>Inclination</td>
<td>98.4°</td>
<td>sun synchronous orbit</td>
</tr>
<tr>
<td>Revisit time</td>
<td>16 days</td>
<td>the 350 km wide swath mode enables up to 4 global data acquisitions from different viewing directions every 16 days</td>
</tr>
<tr>
<td>Frequency</td>
<td>L-band</td>
<td>available frequency band: 1215 … 1300 MHz</td>
</tr>
<tr>
<td>Range bandwidth</td>
<td>up to 85 MHz</td>
<td>split frequency modes for ionospheric corrections (for reduced bandwidth modes)</td>
</tr>
<tr>
<td>Azimuth resolution</td>
<td>7 m</td>
<td>for swath widths up to 350 km (single/dual pol.) for swath widths up to 175 km (quad pol.)</td>
</tr>
<tr>
<td></td>
<td>1 m</td>
<td>spotlight mode for &gt; 50 km wide swath (all polarizations)</td>
</tr>
<tr>
<td>Downlink capacity</td>
<td>~ 8 Terabyte/day</td>
<td>use of advanced Ka-band downlink and ground station network</td>
</tr>
<tr>
<td>Look direction</td>
<td>right &amp; left</td>
<td>nominal: right looking, left-looking by horizontal satellite rotation</td>
</tr>
<tr>
<td>Reflector diameter</td>
<td>15 m</td>
<td>deployable reflector with 15 m boom</td>
</tr>
<tr>
<td>Mission lifetime</td>
<td>&gt; 10 years</td>
<td>all consumables for 12 years</td>
</tr>
<tr>
<td>Polarization</td>
<td>single/dual/quad</td>
<td>optional use of hybrid and compact pol modes</td>
</tr>
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4. SAR INSTRUMENT

A particular challenge of the Tandem-L mission is the development of two capable SAR instruments that meet the challenging mission requirements of mapping a 350 km wide swath with an azimuth resolution of 7 m or less, while maintaining for both the ambiguity-to-signal-ratio (ASR) and the noise equivalent sigma zero (NESZ) a level below -25 dB. For this, new digital antenna synthesis techniques using digital beam-forming technology have been developed that allow for the implementation of extremely powerful SAR imaging modes, which can be optimally adjusted to meet the different requirements of the 3-D structure mode and the deformation mode. For instance, the employment of variable pulse repetition frequencies in combination with multiple antenna beams enables the imaging of extremely wide swaths with hitherto unknown spatial resolution without compromising other imaging parameters [2], [5], [6]. In contrast, with conventional radar systems, the resolution worsens proportional to the swath width (or, conversely, the swath width reduces with an improvement in resolution). On top of this, the use of a large reflector antenna (see Figure 2) increases the sensitivity and allows a considerable reduction in transmit power [2], [4], [9]. In this way, the SAR instruments can be operated quasi-continuously.

Further details on the technical characteristics of the SAR instrument and its innovative modes will be provided together with the results of a detailed performance analysis in the final paper.

5. CONCLUSIONS

The final paper will provide an up-to-date overview of the Tandem-L mission including the science requirements, mission concept, observation scenario and instrument design.

6. REFERENCES


