The TanDEM-X Acquisition Timeline and Mission Plan

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Abstract

This paper introduces the TanDEM-X data acquisition plan that fulfils the requirements of deriving a global DEM according to the emerging HRTI-3 quality standard within three years mission time. Therefore, a joint TerraSAR-X & TanDEM-X data acquisition concept is introduced. Taking this concept into account, a TanDEM-X data acquisition timeline is calculated. The performance with respect to height of ambiguity is optimised. By assuming a ground station network, mass memory states of both satellites are calculated to guarantee enough free space onboard both satellites for the TerraSAR-X mission. Finally, the TanDEM-X Mission Plan is presented.

1 Introduction

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) is an innovative spaceborne radar interferometer that is based on two TerraSAR-X radar satellites flying in close formation [1]. The primary objective of the TanDEM-X mission is the generation of a consistent global digital elevation model (DEM) with an unprecedented accuracy, which equals or surpasses the HRTI-3 specification. This will be achieved by bi-static data acquisitions in a HELIX formation. Because the TanDEM-X mission is based on the TerraSAR-X mission [1], it must be ensured that both missions will achieve their mission goals simultaneously. To assure this, all TerraSAR-X data takes will be distributed almost homogenously onto the two satellites. This will leave enough satellite resources free to fulfil the TanDEM-X mission goals. For data acquisition, an already accepted concept is introduced in Section 2. Based on this concept, a TanDEM-X DEM data acquisition timeline is generated in Section 3, respecting the constraints of the TerraSAR-X mission and fulfilling the mission objective of the TanDEM-X mission.

2 Joint TerraSAR-X & TanDEM-X Acquisition Concept

In this concept, TanDEM-X DEM data takes are planned well in advance for a long time span (e.g. one year) and are set to high priority. These data takes are summarized in the so-called DEM acquisition timeline. To achieve the goal of deriving a consistent HRTI-3 quality DEM, the height of ambiguity for all data takes should be homogeneous. The HELICES are optimized accordingly for this time span with respect to each region that has to be mapped. To keep fuel as low as possible, the vertical displacement $a\Delta e$, described by the semi-major axis a and the difference in eccentricity Δe, shall be small and may be kept fixed for the whole time. The horizontal displacement $a\Delta i$, described by the difference of their inclination vectors Δi, will start with a small value and will be increased to larger values as time evolves. This may be achieved by a small inclination offset of the TanDEM-X satellite, resulting in a fuel consumption free drift of the right ascension of the ascending node of the TanDEM-X satellite, hence increasing Δi. As a consequence, the height of ambiguity is changing slowly for a given beam and latitude, allowing for recording data in subsequent repeat cycles due to data loss. TerraSAR-X data takes are planned around the already calculated TanDEM-X DEM acquisition timeline, and a small number, x %, of data takes may even overwrite the TanDEM-X data takes or cut holes into long TanDEM-X data takes. The percentage is calculated as a number of disturbed TanDEM-X data takes versus the total number of TanDEM-X data takes over the long-term acquisition timeline. To avoid a concentration of overwritten and/or cut data takes in specific orbits, no more than y % of TanDEM-X data takes for each of the 167 orbits in the long-term acquisition timeline shall be disturbed. Individual orbits occur n times, with n being the number of repeat cycles of the long-term acquisition timeline. Furthermore, to prevent an overwriting and / or cutting of long data takes (which are required to reach the HRTI-3 quality standard), a long data take weighting factor applies to all TanDEM-X data takes that are longer than e.g. 50 s. These overwritten and / or cut TanDEM-X data takes or missing parts are replanned in the next possible repeat cycle. Here, these acquisition requests are set to highest priority and cannot be overwritten / cut anymore. Also lost TanDEM-X data takes, e.g. due to dump failure, may be recovered over several adjacent repeat cycles. Due to the fact of slowly changing HELICES, the height of ambiguity will be almost equal and due to the increasing baseline no quality loss would occur but processing and especially phase unwrapping might

become increasingly difficult and erroneous.
The advantages of this approach are manifold. It is easy to implement, is very robust and is based on existing design. Therefore, the complete order scheme must only be changed at very few places, and the TanDEM-X acquisition timeline is well known in advance. Through this it is possible to order TerraSAR-X data takes around the TanDEM-X data takes. Also the HELICES can be optimized to the specific data takes and the DEM performance will improve by minimizing the height of ambiguity variations. Furthermore, special maintenance phases, manoeuvres, and calibration data takes might be planned well in advance without constraining TanDEM-X data takes.

3 TanDEM-X Acquisition Timeline

Based on the concept above, an acquisition timeline can be derived. For this, some assumptions and constraints must be taken into account:

- a "landmask" providing information of regions that have to be mapped. For this paper the CIA Worldmap II is applied.
- TerraSAR-X reference ephemeris and orbit of the TanDEM-X satellite: here, the HELIX concept is taken, which is described in detail in [1]
- Radar geometry: a right looking geometry is assumed with look angles covering ~27° . . . 44°. The look angles are defined in Table 1 with an overlap of 4 km of two adjacent beams respectively.
- Data rates for each individual beam, also given in Table 1.
- Mapping strategy: on the northern hemisphere, data will be recorded during ascending orbits and on the southern hemisphere in descending orbits. Furthermore, due to the fact that the distance between two adjacent ground projected tracks of TSX/TDX is decreasing with increasing latitude, a smaller number of swaths must be recorded with increasing latitude.
- Time: to cover all data a mean orbit usage in the order of ~180 s is assumed.

Beam ID	θ_{min} [deg]	θ_{max} [deg]	Data rate [MBit/s]
1	27.402	29.975	360
2	29.652	32.157	440
3	31.850	34.246	410
4	33.956	36.205	410
5	35.931	38.965	470
6	37.808	39.764	430
7	39.522	41.344	460
8	41.115	42.737	440
9	42.520	43.880	410

Table 1: Beam IDs, their specific look angles θ_i and corresponding data rates.

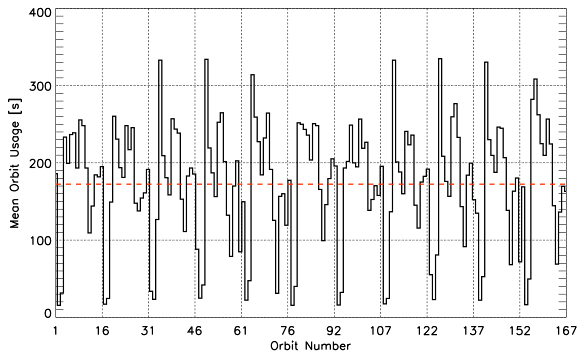

Figure 1: Mean acquisition time in [s] per orbit

Based on these assumptions and constraints, a so-called basic timeline can be derived. This basic timeline includes all required data takes and consists of e.g. start/stop times within one repeat cycle. In this paper, a basic timeline covering latitudes $-62° \ldots 70°$ is analyzed.

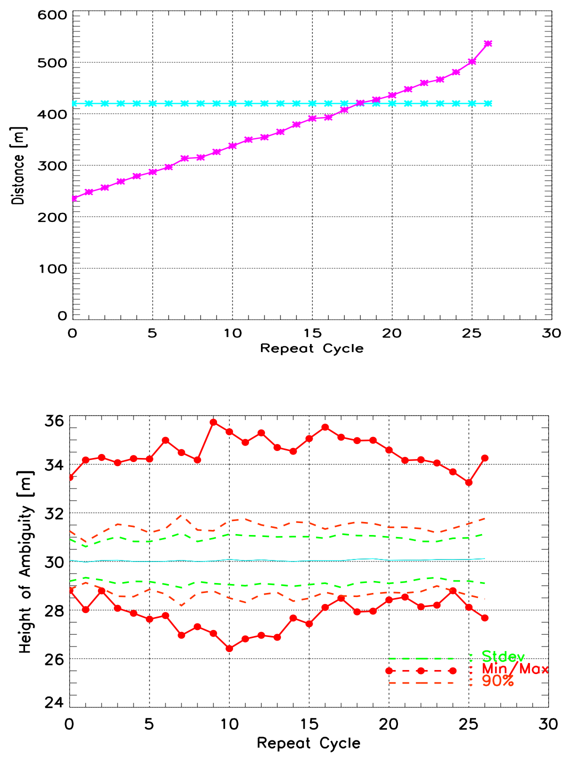

Figure 2: Upper plot: Vertical displacement between the two satellites (blue) and horizontal displacement (pink) vs. repeat cycles. **Lower plot:** Corresponding height of ambiguity vs. repeat cycles. Blue represents the mean value, green the mean value standard deviation, dashed red 90% of all values and solid red all values.

With this basic timeline, it is possible to distribute the data takes over 27 repeat cycles such that a mean orbit usage of ~175s in each orbit is achieved. The distribution of mean acquisition time of each single orbit is shown in Figure 1.

Simultaneously with the distribution above, the HELICES are optimized to each specific data take such that the height of ambiguity of all data takes is varying as little as possible. This is reached by the HELICES shown in Figure 2 in the upper plot. For this analysis, the goal was a height of ambiguity of 30 m. It can be seen from Figure 2 in the lower plot that 90% of all data takes will be recorded with a height of ambiguity between $28\,m \ldots 30\,m$.

For the corresponding HELICES of each repeat cycle, the vertical displacement is kept constant to ~400 m while the horizontal displacement evolves almost linear from ~230 m to ~550 m.

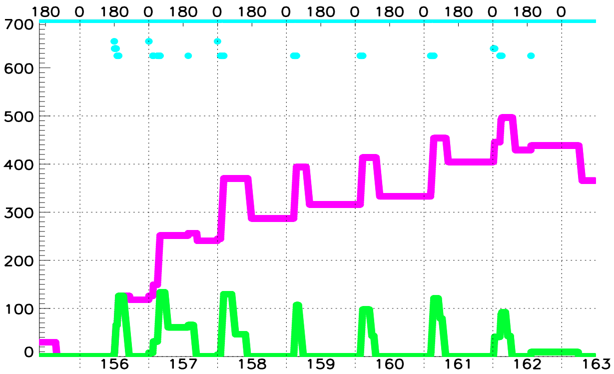

Figure 3: Mass memory vs. time. Pink represents the mass memory of TDX and green of TSX, blue shows the position of data takes. Mass memory storage is given in [GBit]

Now the mass memory states onboard both satellites can be calculated for each time of the 27 repeat cycles assuming a ground station network. Here, this network consists of Kiruna, Inuvik and O'Higgins, while each possible contact to Neustrelitz will be reserved for the TerraSAR-X mission. The latter accounts for the TerraSAR-X mission and will not be applied for TanDEM-X data takes. Furthermore, for individual peak load orbits, Chetumal will be used additionally to dump data takes. A part of the so derived memory allocation is seen in Figure 3. Here it is assumed that the mass memory of TSX is dumped firstly due to its smaller capacity of 384 Gbit - TDX has a mass memory of 768 GBit. With this derived timeline over 27 repeat cycles, it is proved that at any time there is enough mass memory available onboard both satellites to record data for the TerraSAR-X mission. Analyses show that at least 180 Gbit onboard TSX and more than 250 Gbit onboard TDX are freely available.

Another constraint to be fulfilled is that at any location of the Earth's surface there are enough opportunities to acquire TerraSAR-X data. It is essential for the TerraSAR-X mission that TanDEM-X is not blocking the same geographical position for many adjacent repeat cycles. To prove this, single orbits are analysed with respect to the repeat cycles. This can be seen in Figure 4, in which a part of Europe shall be covered by both missions.

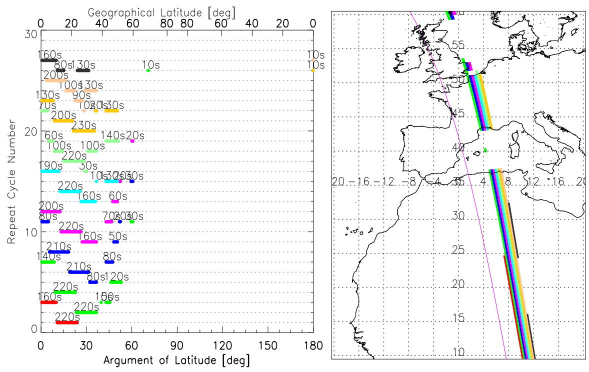

Figure 4: Left plot: Repeat cycles vs. acquisition data takes over Europe for the first year of a single orbit.Right plot: Data takes distributed on the Earth's surface. In both plots the same colours represent same beams.

From this Figure, there are some remarkable results visible. Firstly, over Europe, where it is expected that many TerraSAR-X users will require data, there are many orbits free to record these additional data. Here, between geographical latitudes of 40° and 55°, at each position 5 repeat cycles are blocked by TanDEM-X acquisitions. This means that in the remaining 22 repeat cycles TerraSAR-X users can record additional data if requested. Furthermore, as TanDEM-X will acquire data only in ascending orbits at the northern hemisphere during the first two years, all descending orbits will be additionally freely selectable for TerraSAR-X.

Of course, there are orbits in which more data will be acquired. Fortunately, these orbits are over South America and Middle Asia, leaving enough availability over Europe.

In the above example, all latitudes below $-62°$ and above $70°$ are not covered. With the same approach as above it can be demonstrated that this will require additional 4 repeat cycles. With such a complete timeline, the whole Earth will be recorded within somewhat less than one year. Because the complete mission time is three years, it is possible to map the Earth twice with two different height of ambiguities. This will alleviate phase unwrapping and will lead to the derivation of a global DEM according to the HRTI-3 quality standard. Of course, there are some regions which lay in the radar shadow within the first two years, or even have foreshortening. These regions will be identified during the first two years. Then after these two years, the satellite will be separated by ~20 km and their relative perigee will be shifted by 180°. This results in a so-called swap of the satellites, because afterwards the same scene of the Earth's surface is now recorded with a different (i.e. "left-looking") geometry. Analyses show that these regions are expected to be small [2].

Another subject besides deriving the DEM are the so-called scientific data takes or science products, with which new techniques shall be demonstrated. These science products are described in detail e.g. in [1]. Here, it is important to allocate enough time to derive these products. It is shown above that there are still two repeat cycles free, allowing for a smoother distribution of all data takes and simultaneously adding these science data takes. Furthermore, at the end of the mission, there are at least three month freely available to set up HELICES with very large baselines to record special data takes for e.g. superresolution.

4 Mission Plan

With the above timeline and science products, a complete Mission Plan can be set up:
Mission Phase A: Launch and in-orbit-injection. No data will be collected. This will last approximately one day.
Mission Phase B: Approximation of the two satellites to ~20 km in along-track. Set up of first HELIX to test and verify operation. Set up of close formation to allow for interferometric commissioning. First data takes with a small and large height of ambiguity to demonstrate the feasibility of HRTI-3 DEM generation. For this mission phase 90 days are foreseen.
Mission Phase C: Set up of starting HELIX (to be analyzed: with natural drift) to derive first global DEM with small baselines. Small baselines are selected first because of two reasons: Firstly, small baselines will result in a larger height of ambiguity for which it is easier to derive a DEM. This DEM will not hold the quality of the HRTI-3 standard, but will alleviate phase unwrapping for the next mission phase. Second, end of 2009 when the mission phase will start, solar activity is smaller and thus the forces, specially the differential forces, onto the two satellites are smaller. This implies that in the beginning controlling of the formation keeping of the two satellites will be easier than at the end of the mission during high solar activity. In this mission phase, the whole Earth will be mapped. The proposed drift and order of HELICES is also optimized to minimize fuel consumption. This mission phase will last one year.
Mission Phase D: Mapping the Earth with the second baseline. Here, the HELICES will be scaled and/or adjusted such that the HRTI-3 standard will be achieved. During Mission Phase C and D, a map of difficult terrain like e.g. shadow and foreshortening will be generated. This will serve for the next mission phase as input. This mission phase will last also one year.
Mission Phase E: Swap of satellites (shift of the relative perigee). In this phase, the two satellites will be separated by ~20 km. Then, the libration phase will be shifted by orbit manoeuvres by 180°. After these manoeuvres, the satellites are brought together again and it is possible to map regions at the northern hemisphere in descending orbits, at the southern hemisphere in ascending orbits with the same geometry as in mission phases C and D. Furthermore, in this mission phase data acquisitions may be executed in pursuit monostatic mode for calibration purposes. This will be executed within one repeat cycle.
Mission Phase F: Mapping of all terrain which requires additional coverage like e.g. mountainous regions, shadowed areas etc. Also recording of the so-called crossing orbits, which are extra long data takes at an almost fixed spacing at the equator to allow for additional calibration of the final DEM. This mission phase may be split into two sub-phases, one with a large height of ambiguity (mainly for terrain with steep gradients) and one with a small height of ambiguity (mainly for regions with shadowing/foreshortening). This mission phase and the following mission phase will last approximately one year.
Mission Phase G: Spanning of very large baselines to allow for acquiring special data to perform digital beam forming, local HRTI-4 DEM generation, bi-static experiments, and other radar data products, which have not been recorded in earlier mission phases. At the end of this mission phase, the satellites will be separated in along track, e.g. such that their respective ground tracks on the Earth's surface will be separated by one day. Then, repeat pass interferometry with one day time interval will be possible. During the along track separation, bi-static experiments with large bistatic angles might be performed.

5 Summary

A concept of bringing two satellites missions together with the potential of minimizing possible conflicts is proposed and accepted. Based on this concept, a timeline with all necessary acquisitions for deriving a global DEM according to the emerging HRTI-3 quality standard is calculated. This timeline includes a ground station network to dump recorded data and considers already satellite resources like e.g. solid state mass memory. There are still enough time and resources to place TerraSAR-X data takes and TanDEM-X science data takes. With this approach, both mission goals will be achieved.

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References

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