ACHIEVING THE EVINSAR OBJECTIVES WITH TERRASAR-L

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ABSTRACT

An L-band InSAR mission, EVINSAR, was proposed to ESA's Earth Explorer Opportunity Mission programme in 2002 that would measure the strain cycles associated with earthquakes/tectonism and volcanoes. Although not funded the concept was encouraged by ESA and the EVINSAR Science Team was asked to study how the science requirements of EVINSAR could be met by the proposed TerraSAR-L mission. The EVINSAR concept emphasises the collection of a frequent time series of repeat-pass SCANSAR interferograms of the world's areas of active tectonism and volcanism from an inclined orbital plane and a narrow orbital tube. Left- and right-viewing would alternate with each repeat cycle. These characteristics would obviate baseline decorrelation, minimise topographic noise and maximise the ability to recover the 3D motion vector. L-band radar is needed to reduce temporal decorrelation over vegetation and give the mission a global capability. We have studied TerraSAR-L's Phase 0 specifications in relation to distributed scatterer differential InSAR. TerraSAR-L goes a considerable way to meeting the EVINSAR science needs. Under ideal conditions it could approach a target minimum strain rate sensitivity of 1mm/10km/year. However, the polar orbit of TerraSAR-L and only limited capability for left-sided viewing reduces the ability to retrieve the 3D motion vector from multiple views.

1 INTRODUCTION

There has not been a spaceborne satellite mission dedicated to measuring ground motion by radar interferometry (InSAR). Such missions have been proposed to NASA (e.g. ECHO) and to ESA (EVINSAR), but remain unfunded. The practical application of InSAR for measuring ground motion has been achieved using multi-purpose spaceborne radars, particularly ERS-1 and -2 [1]. A growing user community has been both excited by this capability and frustrated by its limitations. One such multi-purpose SAR mission is TerraSAR-L, proposed for launch in 2008. In many respects it comes closest of any of the existing and planned SAR missions to meeting the InSAR needs of the communities who measure deformation associated with earthquakes and volcanoes. Here we present a brief overview of how closely TerraSAR-L might meet those needs as set out in the EVINSAR mission concept.

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2 EVINSAR

The EVINSAR mission, "Understanding Earthquake and Volcano strain using InSAR", was proposed to ESA in 2002 under the Earth Explorer Opportunity Mission programme.. The scientific rationale is to test the ability of differential InSAR to measure fully the strain cycles at faults and volcanoes on a global scale. One important outcome of this would be to specify the technical character of a future operational system for global monitoring. The decision to restrict the science to earthquakes and volcanoes was taken because they share the same physical framework: the brittle (and ductile) parts of the upper crust, as the setting for their signals, though their forcing mechanisms are different. As a result, the requirements for the measurement of ground motion are similar. The other two main science applications of surface motion measured by InSAR, in glaciology and subsidence and landsliding, have more varied physical settings and needs.

EVINSAR emphasises strongly the need to produce a "guaranteed" stream of high quality interferograms at short, regular intervals. At C-band InSAR is largely restricted to non-vegetated targets. There are many hazardous volcanoes and faults that are vegetated and so for global applicability an L-band system is required. In order to ensure that baseline decorrelation does not prevent interferometry and to minimise topographic errors, a very narrow orbital tube (10m diameter) was proposed. There are few volcanoes and active faults in the polar regions. This fact, coupled with the need to improve the retrieval of the 3D ground motion vector with InSAR, led to the 70° inclined orbit specification for EVINSAR. This gives a more favourable selection of viewing geometries. The global mission would alternate between left- and right-viewing after every repeat cycle of 11 days.

3 TERRASAR-L

Table 1 Comparison of the EVINSAR and TerraSAR-L missions

	EVINSAR	**TerraSAR-L**
Prime mission	Dedicated InSAR	Multi-purpose radar
Launch + duration (years)	? + 3 (5)	2008? + 3(5)
InSAR imaging mode	L-band SCANSAR	L-band SCANSAR
Repeat period (days)	11	16(14)
Incidence angles (degrees)	30-46	23-45
Orbital inclination (degrees)	70	97
Altitude (km)	634	629
Coverage	75°N/S	global
One-look resolution (m)	10	2.8
Bandwidth (MHz)	28	70-80
Ionospheric correction	No	Yes
Orbit knowledge	GNSS	GNSS
Orbital tube diameter (m)	10	100
Left-, right-viewing	Yes	Partial

Table 1 shows a comparison of some of the technical InSAR capabilities of the EVINSAR and TerraSAR-L missions. Both will use an L-band radar in repeat-pass SCANSAR mode to obtain the interferograms over 3 (to 5) years. The similar repeat cycles (11 days for EVINSAR and 16 days for TerraSAR-L) and narrow orbital tubes enable both systems to obtain a dense time series of effective global observations. The orbit of TerraSAR-L has been revised to 14 days, but this report uses the earlier 16 day figure. TerraSAR-L has a sufficiently wide bandwidth to enable a dual-band measurement of ionospheric variability in wave delay. However, the principal difference between the two missions lies in the orbital viewing characteristics. TerraSAR-L's sun-synchronous, polar orbit, whilst giving global coverage, will mean inferior viewing angle characteristics compared to EVINSAR. In particular, the retrieval of the N-S component of ground motion is much worse and the ability to perform left- and right-looking is reduced.

4 TERRASAR-L MEASUREMENT UNCERTAINTIES

The rates of strain amenable to measurement by InSAR depend on techniques and targets. Here we focus on differential InSAR measurement of distributed targets. The needs of inter-seismic strain measurement across large fault system [2] provides the most stringent requirements here, of the order of 1mm/10km/year. This is a useful benchmark against which to measure mission measurement uncertainties for TerraSAR-L.

4.1 Thermal Noise

L-band is less sensitive to motion relative to C-band in inverse proportion to the wavelength of the radar pulses (~24 and ~6 cm respectively). Phase measurement accuracy for a single look image will be about 35-15^o for TerraSAR-L. To achieve a 1 mm measurement capability (3-2^o) would require significant multi-looking (~64). This could be supplied by the high spatial resolution imaging.

4.2 Ionospheric Noise

The latter part of the TerraSAR-L mission will coincide with the next solar maximum (2011). For an L-band radar the effects of variable electron density in the ionosphere will be considerable occasionally, decreasing with spatial scale. At the scale of 10 km, observations suggest that relative delay differences of about 3 cm can be expected. We could reduce this level considerably by splitting the TerraSAR-L bandwidth (~ 80 MHz) to form two channels and using the dispersive character of radio waves to calculate electron densities. This should reduce the extremes of ionospheric noise to about 2 mm over 10 km.

4.3 Tropospheric Effects

As for C-band radars, the variability of water vapour in the troposphere at L-band will be the main source of measurement uncertainty for TerraSAR-L with path delays of over 10 cm/10km over mountains. Temporal averaging of a time series of interferograms by stacking will reduce the noise in proportion to the square root of the number of interferograms if the assumption of spatial non-stationarity of water vapour contents holds true. Fig.1 shows how long it would take a TerraSAR-L mission to reduce the atmospheric noise to the level of 1mm/year over the length scale between 10 and 100 km by

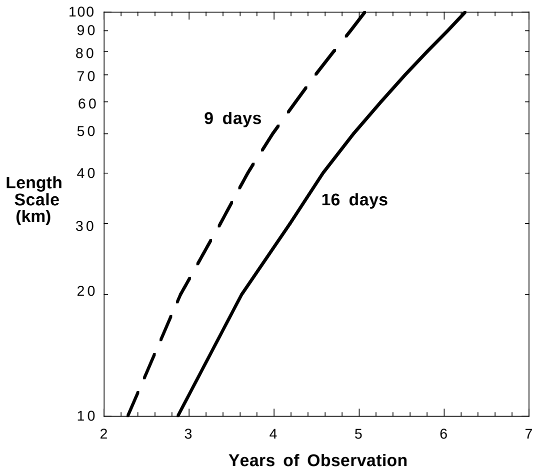

Fig.1 Duration of observation required for TerraSAR-L repeat orbits to reduce atmospheric noise levels to the equivalent rate of 1mm/year over length scales from 10 to 100 km.

stacking. This is specifically for the atmosphere of southern California [3]. The curve for a more humid climate would be displaced to the right [4].

4.4 Topographic Uncertainties

Any uncertainty in knowledge of topography will leave range errors in TerraSAR-L interferograms that will scale according to $0.00275\sigma_z B_{\perp}$, where σ_z is the height error and $B_{\perp}$ is the perpendicular baseline. The 3 arc second SRTM dataset will provide the main source of global topographic data for TerraSAR-L InSAR. We would expect very different levels of accuracy in these data over bare rock surfaces (~ 3-4 m rms) compared to those over forests (~ 22 m rms). As a result the requirements for orbital tube diameter to restrict baselines will show a similar ratio over these different surfaces: a diameter of about 400 m for bare rocks would be required compared to 70 m for forests to achieve 3 mm range error over 10 km (at 1σ).

4.5 Orbital Position Uncertainty

Assuming a GNSS-tracking capability of a quality equivalent to Topex-Poseidon (~2 cm radial, ~6 cm cross track) would enable range errors to be restricted to about 6 mm over a scale of 100 km.

4.6 3D Motion Retrieval

Multiple views by the TerraSAR-L radar to help measure the 3D motion of the ground could come from three sources:

- ascending/descending passes
- near/far ranges of overlapping swaths
- left-/right-viewing

Combined use of ascending and descending pass data provides the most beneficial improvement to a single line of sight vector measurement [5]. As Table 2 shows, additional improved retrieval capability is supplied by left- and right-looking data. However, the TerraSAR-L performance is significantly worse than that of EVINSAR because the crossing angles of the swaths from polar orbits are more acute.

Table 2 Relative errors in the vector components for estimated TerraSAR-L line of site ground displacements ($\sigma = 1$) at varied viewing combinations (A/D = ascending/descending, O = overlapping swaths, L/R = left- and right-viewing)

Component	**A/D + O**	**A/D + L/R**	**A/D + L/R + O**	**A/D + L/R (EVINSAR)**
East	0.9	1.0	0.7	1.2
North	11.7	4.8	3.1	2.0
UP	1.6	0.6	0.4	0.4

5 OPERATIONAL CAPABILITIES

5.1 Area of Interest

The mission must be able to image all the world’s active subaerial volcanoes and faults likely to produce measurable displacements during each orbital cycle. The information to generate a suitable area of interest map for volcanoes is relatively straightforward . For active faults the situation is more difficult because of the local variability of interpretation and availability of data. We have spent a considerable effort in compiling such data. Fig. 2 is the resultant combined volcano/fault area of interest mask. Unsurprisingly it is dominated by the Alpine-Himalayan belt and the circum- Pacific zones associated with plate subduction.

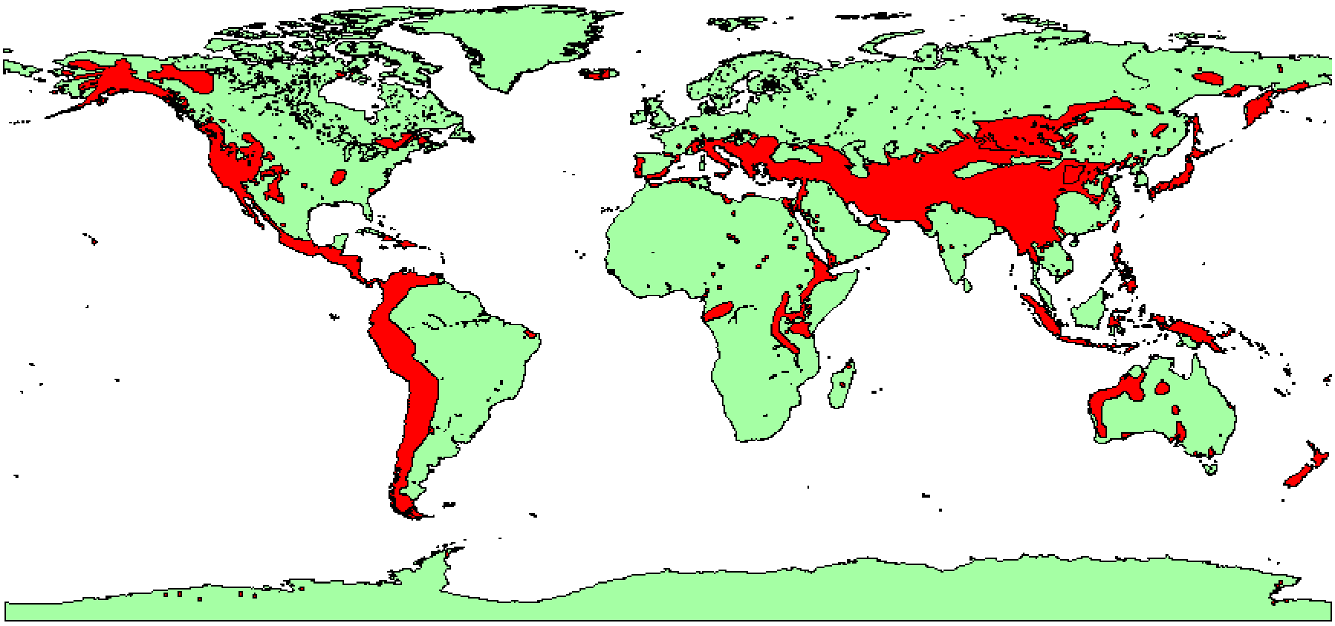

Fig.2 Global area of interest mask for combined fault/tectonics and volcanoes (red)

5.2 Observational Strategy

Two modes of observation are proposed for TerraSAR-L InSAR that approach the capability of EVINSAR. The Background Mode supplies the basic 16-day repeat cycle of right-view imaging by SCANSAR with both ascending and descending datasets for the global area of interest. The power requirements of the radar mean that it cannot have the solar panels angled away from the sun for too long. Thus left-view imaging time is much more restricted. The full alternating right- and left-viewing modes of EVINSAR cannot be met for the Background Mode of TerraSAR-L. Instead we propose a more limited Event Mode of operation during which left-view image acquisition would be made. Event Mode acquisitions would be triggered by significant earthquakes and eruptions. The data would be acquired at the next most suitable opportunities (for both ascending and descending passes) after the event. In order to permit interferometry, a preparatory archive of left-viewing data would be acquired that would form the "before-the-event" images of the left-view interferograms. We anticipate activating this mode perhaps 50 times per year.

5.3 Observational Capability

Orbit modelling using our area of interest mask for the TerraSAR-L mission carried out by Astrium UK shows that the on-board storage will be able to cope with the Background and Event Mode requirements (166 Gb maximum loading compared to a 412 Gb limit). The duty cycle permits a nominal data take of 15 minutes in SCANSAR mode. For a 16-day repeat cycle this would be exceeded several times per orbit cycle on orbits imaging the western Americas and central Asia (Fig.3). A slightly more complex or flexible strategy would be required to meet these requirements. The preparatory campaign for the Event Mode could be achieved in the first four months of the mission using only 5% of the available imaging time.

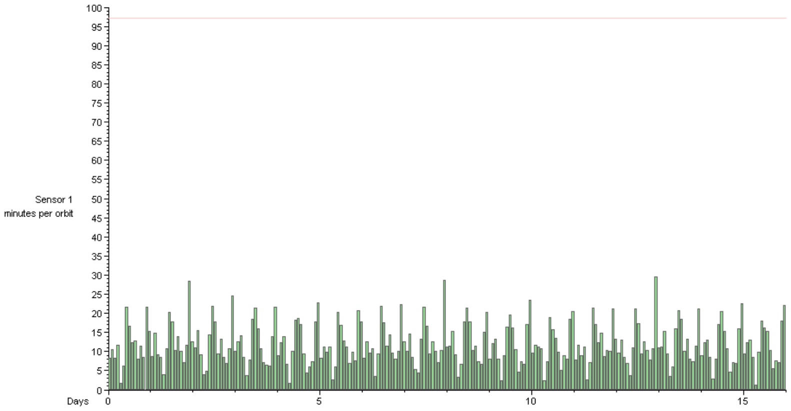

Fig.3 Number of minutes of SCANSAR operation per orbit to acquire the global area of interest over a 16 day orbit repeat cycle. 15 minutes is the nominal limit.

6 CONCLUSIONS

- The proposed TerraSAR-L mission could meet many of the experimental scientific requirements for differential InSAR by the earthquake and volcano communities as represented in the EVINSAR mission.
- Line-of-sight strain rates of the order of 1mm/10km/year could be approached by TerraSAR-L in favourable circumstances over the lifetime of the mission.
- The polar orbit and limited left-sided viewing reduces the ability of TerraSAR-L to measure the 3D ground motion vector significantly relative to EVINSAR.
- The core strategy of EVINSAR is to acquire consistently a high frequency of multiple views with minimal interferometric baselines from a global set of targets. To achieve this a multi-purpose mission like TerraSAR-L would have to replicate that operationally.

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