Requirements for a space mission for DInSAR and PS analysis based on past and present missions

Claudio Prati, Fabio Rocca
Dipartimento di Elettronica e Informazione
Politecnico di Milano
Milano, Italy
rocca@elet.polimi.it

Alessandro Ferretti
Tele-Rilevamento Europa – T.R.E.
www.treuropa.com
Milano, Italy
alessandro.ferretti@treuropa.com

***Abstract*— The aim of this paper is to highlight some important issues that should be taken into account when designing and planning a SAR mission dedicated to differential SAR interferometry (DInSAR) and Permanent Scatterers (PS) analysis. Special attention is paid to the impact of different design parameters on the information that can be retrieved, namely: (1) different wavelengths; (2) repeat cycle; (3) polarization modes; (4) platform stability; (5) state vectors accuracy. The impact of satellite dead band at different frequencies is discussed as well, taking into account DEM estimation issues and the problem of atmospheric effects. It will be shown how very small baselines are not always the best design solution at least for PS analysis. PS results obtained processing 3 multi-temporal data-sets acquired by JERS, ERS and Radarsat over Tokyo are presented and discussed.**

Keywords: DInSAR, Permenent Scatterers, SAR sensors, baseline optimization, atmospheric effects, DEM generation.

I. INTRODUCTION

The use of satellite mounted radars for Synthetic Aperture Radar Interferometry (InSAR) and Differential Interferometry (DInSAR) has been made operational with several platforms (ERS 1 - 2, ENVISAT, Radarsat, JERS-1) [1]-[8]. We study the effects on coherence of different wavelengths and repeat cycles, as resulting from the experience in processing many images in L and C bands. We highlight the impact of the use of the so called Permanent Scatterers (PS) [3][4] on Digital Elevation Models determined using InSAR and on DInSAR. We evaluate the effects of the centre radar frequency in connection with atmospheric disturbances and the limited signal-to-noise ratio (SNR) available. Finally, we show examples obtained by processing of real data-sets.

II. A MODEL FOR COHERENCE

First, we start with the usual equation that states [8]:

$$\gamma_{tot} = \gamma_{time} \cdot \gamma_{space} \cdot \gamma_{noise}$$

Then, indicating with σ_m^2 the dispersion of the motion of the scatterer and with σ_ϕ^2 the variance of its phases, supposing that the motion variance grows linearly with time, we observe that [8]:

$$\gamma_{time} = e^{-\sigma_\phi^2/2}; \quad \sigma_\phi^2 = \left(\frac{4\pi}{\lambda}\right)^2 \sigma_m^2; \quad \sigma_m^2 = \sigma_{day}^2 \cdot T$$

$$\gamma_{time} = \exp\left\{-\frac{1}{2}\left(\frac{4\pi}{\lambda}\right)^2 \sigma_{day}^2 \cdot T\right\} = e^{-\frac{T}{\tau}}$$

In the case of C band, τ=30 days, approximately [5]-[7]. Thus we can predict the coherence for all time intervals and frequencies, indicating with *m* the number of months in the time lapse:

$$\gamma(\lambda, m) \approx \exp\left(-m\frac{\lambda_C^2}{\lambda^2}\right)$$

This formula tells that natural targets show exponential decrease of coherence with time; the exponent is inversely proportional to the wavelength squared. In fact, in [7] we show L band 44-day results that look like C band 3 days; the ratio of the wavelengths squared is about 18. This ratio would lead to 550 days as L band decorrelation time, consistent with what has been shown by Dr. M. Shimada on JERS data (CEOS SAR WGCV 2004, Opening presentation, Ulm). X band data would decorrelate in about 1 week. Furthermore, if we consider the *SNR* that is needed to achieve a given sensitivity to motion (say 1mm), longer wavelengths, while staying coherent for longer time, need a larger SNR to achieve the same motion sensitivity. Approximately we have:

$$\sigma_\varphi = \frac{4\pi}{\lambda}\sigma_m \le \frac{1}{\sqrt{SNR}}; \quad SNR \ge \left(\frac{\lambda}{4\pi\sigma_m}\right)^2$$

In the cases of X, C, L band, this formula yields for SNR the values 6, 12, 24 dB. Since the effects of atmospheric delays should not change with the wavelength, possible implications for future missions are that L band revisiting times could be up to six-monthly but then the Neσ0 should be rather low to maintain sensitivity to small motions. Alternatively, more frequent surveys could be combined to achieve the same goal. C band appears to be very well conditioned for long term interferometry. X band revisiting times should be close to weekly, to maintain coherence and avoid alias. An X band system designed to create without conflicts an archive could be difficult to design.

The processing of Tokyo JERS data was self-financed by TRE.

III. EFFECTS OF PS ON INTERFEROMETRIC SURVEYS

We consider a set of points (PS) that have a radar signature unchanged with time. The measured phase for the *j-th* point at the *i-th* passage is:

$$\phi_{i,j} = \beta_i \frac{4\pi B_{RF} q_i}{c\cos\theta} + \alpha_{i,j};\quad i = 1,...N$$

$$\beta_i = \frac{B_i}{B_{CR}};\ q_j = \frac{c\cos\theta}{4\pi B_{RF}} \frac{\left(\phi_{i,j} - \alpha_{i,j}\right)}{\beta_i}$$

where q_j is the elevation, B_i the baseline at the *i-th* passage measured normally to the radar LOS, B_{CR} the critical baseline, B_{RF} the radio frequency bandwidth, and $\alpha_{i,j}$ the Atmospheric Phase Screen, APS. Its variance σ^2_α is dependent on the variability of the two-way delay of the electromagnetic waves in the atmosphere, mostly due to water vapour [2] and is given in terms of the variance of the additional two-way travel path σ^2_m, approximately wavelength independent, and posed to be equal to about $1cm^2$. Additive phase noise be it due to clutter, electronic noise, ambiguities, etc. contributes another σ^2_n .This contribution is in general negligible with respect to that due to the atmospheric effects, but it will also be considered since it may become significant for lower frequencies. The dispersion of the elevation of the stable scatterers $\sigma^2_{\varepsilon,q}$ and the variance of the error of the APS estimate $\sigma^2_{\varepsilon,\alpha}$ can be determined as a function of the number N of takes and of the variance of the perpendicular baselines σ^2_β [7]:

$$\sigma^2_{\varepsilon,q} = \left(\frac{f_0\cos\theta}{2B_{RF}}\right)^2 \frac{\sigma^2_m}{N\sigma^2_\beta};\ \sigma^2_{\varepsilon,\alpha} = \sigma^2_\alpha \frac{\beta^2_i}{N\sigma^2_\beta}$$

The more dispersed are the baselines, the better is the estimate of the elevations. Then, if the PS elevations are well determined, one gets there a good estimate of the APS as residual phase. The smaller the current baseline, the better the current APS estimate. For L band systems we have a PS elevation error lower than with X band systems, since the ratio f_0/B_{RF} is smaller. However, in order to achieve, with a new archive, error estimates 5 dB greater than the ones of a 100-image archive, takes about 1,5 years with fortnightly surveys.

IV. THE EFFECTS OF ADDITIVE NOISE

We discuss now the impact of possible additional noise component n_{ij}. We suppose that, after averaging over the area of interest, populated by *M* PS, the effect of the additive noise is equal to the atmospheric one. The additive noise is independent from one PS to the next, whereas the atmospheric contribution stays practically the same, so that we can average over *M*. Thus we have [6]:

$$\frac{1}{2M \bullet SNR} \approx \left(\sigma_m \frac{2\pi}{\lambda}\right)^2 \frac{\beta^2_i}{N\sigma^2_\beta}$$

$$\lambda < \sigma_m \frac{2\pi\beta_i}{\sigma_\beta}\sqrt{\frac{2M \bullet SNR}{N}} = 0.01 \bullet 2\pi\sqrt{\frac{2 \bullet 30}{50}}\sqrt{M}$$

Posing $\beta_i \approx \sigma_\beta$ and for a limit SNR equal to 15dB then $\lambda < 7$cm for $M = 1$ i.e. when the area of interest contains just one PS.

V. THE TOKYO DATA-SETS

An in depth analysis of real data acquired by different sensors over the same target area has also been made. This allows a better understanding of possible future scenarios with new SAR sensors operating at different frequencies and polarizations. The test area used in this paper is the city of Tokyo, selected for data availability. 30 ERS (C Band, VV, 35-day repeat-cycle), 30 Radarsat (C-band, HH, 24-day, ERS-like acquisition mode) and 46 JERS (L band, HH, 44-day) scenes were available and were processed by means of the PS processing chain developed by TRE. After PS analyses, results were geo-coded and superimposed on an optical image for comparison purposes. In Fig. 1 the sparse grid of PS exhibiting phase coherence greater than 0.8 are reported for all data-sets. Some observations are now in order:

- Unfortunately, data were gathered neither simultaneously nor with regularity; the impact of temporal decorrelation is then very different on the 3 data-sets.
- PS density ($\gamma > 0.8$) turned out to be: 240 PS/km^2 for JERS, 270 for ERS and 680 for Radarsat. Apart from the JERS density, not comparable with the other 2 data-sets due to the different number of scenes, an important result is the remarkable difference in ERS vs. Radarsat, although standard (not fine) beam acquisitions were used in the analysis. This result points out - once more - the importance of a regular acquisition of SAR data and the effects of a shorter (24 days vs 35) repetition cycle.
- Baseline errors were estimated for all acquisitions using an iterative (blind) algorithm exploiting the PS population. Results are reported in (Fig. 2) as a fraction of B_{CR}. The temporal correlation of baseline errors in Radarsat and JERS is interesting and deserves further analyses (especially the periodical behavior of Radarsat).
- The estimated atmospheric components have shown a very good agreement with what is expected for C and L band data. The mean dispersion of the APS was 1.89 rad for Radarsat, 1.5 rad for ERS and 0.37 rad for JERS acquisitions. Since $\lambda_{JERS}/\lambda_{ERS} \approx 4$ the impact of the atmospheric delay on phase measurements is about 4 times lower in L band with respect to C band.
- An in depth comparison of both elevation and velocity fields derived from the three data-sets will be carried out in the next few months. Since the temporal baseline values and the time span of the data-sets are significantly different, we started analyzing the elevation fields (Fig. 1), that should be easier to compare. Preliminary results are consistent and show a good agreement (Fig. 4), although it is hard to identify PS common to all three sensors and the availability of ground truth (e.g. LIDAR data) would be extremely important for the analysis.

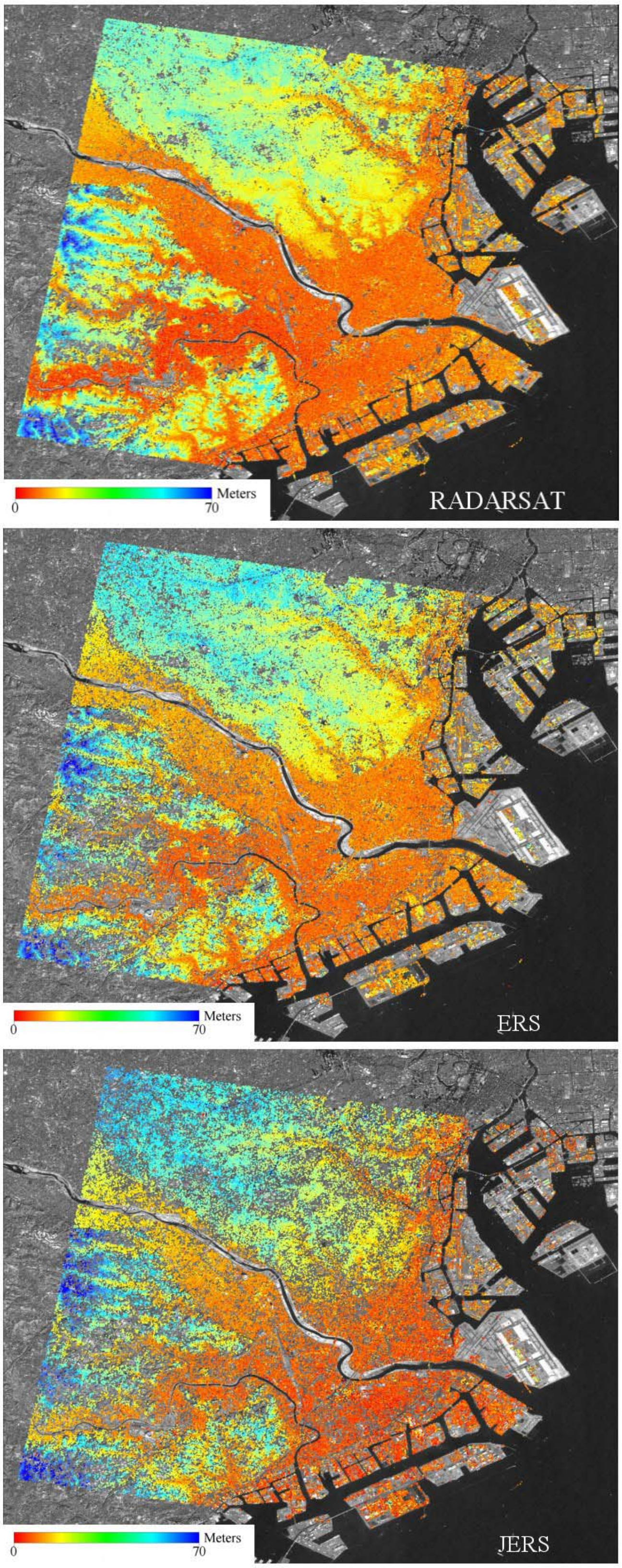

Figure 1: Comparison of PS results over Tokyo. Colored dots correspond to PS. Color is related to PS elevation.

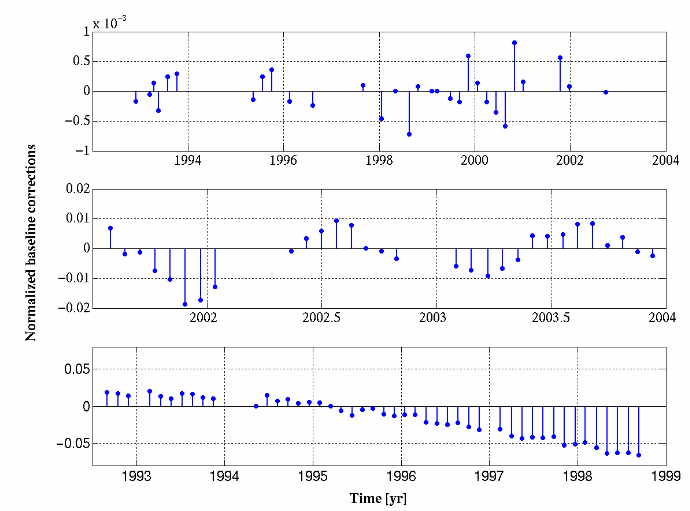

Figure 2: Baseline errors estimated in the 3 data-sets: ERS (up), Radarsat (middle), JERS (bottom). Data are reported normalized with respect to B_{CR}.

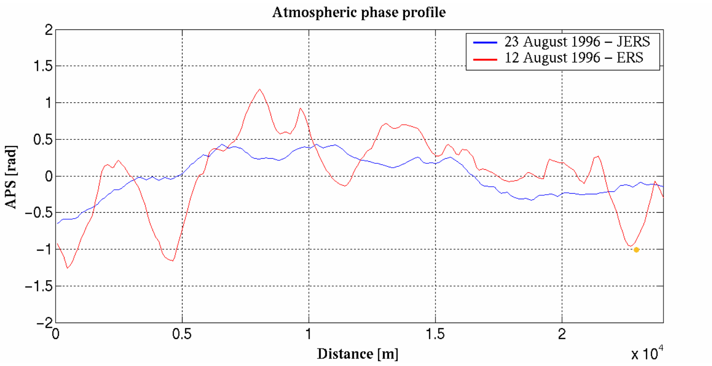

Figure 3: Visual comparison of two profiles of APS estimated over Tokyo (in radians). Red: ERS data. Blue: JERS data. This picture is just to highlight qualitatively the different signal powers found in C and L band data.

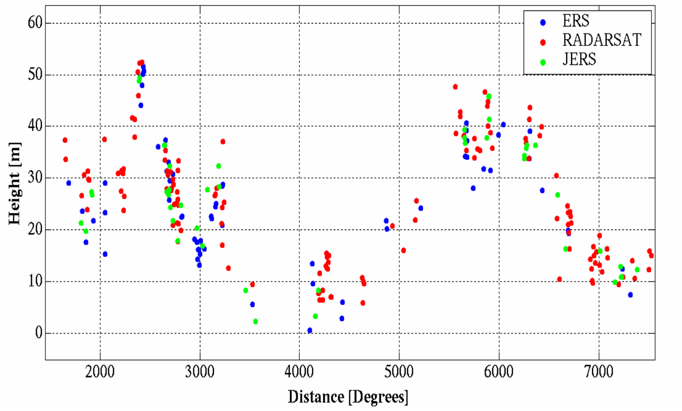

Figure 4: Comparison of three profiles (North direction – about 6 km long) of the PS elevation values over an area of Tokyo estimated from the 3 sensors. Blue (ERS), red (Radarsat), green (JERS) PS data.

VI. CONCLUSIONS

A) The quality of the retrieved topography depends mostly on the relative bandwidth. Expected dispersion of Tokyo PS elevation data (Fig. 4) is about 0.5 m for all systems, provided that orbital and atmospheric components can be estimated and removed correctly. However, cross-validation procedures (assessing the sub-metric precision locally) of these data-sets are difficult to run due to the difficulties related to the identification of common PS for all SAR systems used in the analysis.

B) From the theoretical analysis, the quality of differential interferometry should be almost independent of the carrier frequency, provided that the wavelength be shorter than, say, 7cm. Longer wavelengths require SNR proportionally higher than 15dB or averaging over sizeable areas. Shorter wavelengths are subject to alias. However, further research efforts will be devoted to the analysis of the JERS PS results over Tokyo, since there the PS density turned out to be lower than expected. Of course, forthcoming ALOS data will be very welcome.

C) The PS technique yields two advantages with respect to standard InSAR techniques: i) the selection of the stable points allows long surveys and baseline optimisation; ii) the APS estimate can be improved with respect to interferogram stacking, by exploiting the point wise character of most PS reflectors to allow a long tailed distribution of the baselines.

D) Finally, although further comparison will be carried out to better quantify the performance of ERS and Radarsat data and the impact of the different polarizations (both on urban and non-urban areas), it seems that a regular acquisition of SAR scenes (and the creation of an historical data archive) is a key factor for any future SAR missions. To that end, it seems that a careful planning of the acquisition modes will be mandatory both for ALOS, Radarsat2 and any new SAR mission.

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REFERENCES

[1] Bamler, R. and Hartl P., 1998, Synthetic Aperture Radar Interferometry, Inverse Problems, 14, R1 - R54.

[2] Hanssen, R., *Radar Interferometry*, Kluwer Academic Publishers, 2001

[3] A. Ferretti, C. Prati, F. Rocca, 2000, Nonlinear subsidence rate estimation using Permanent Scatterers in SAR interferometry, *IEEE Trans. Geosci. Rem. Sensing*,, September 2000, pp. 2202 - 2212.

[4] A. Ferretti, C. Prati, F. Rocca, 2001, Permanent Scatterers in SAR interferometry, *IEEE Trans. Geosci. Rem. Sensing*,, January 2001, pp. 8 -20.

[5] M. Arrigoni, C. Colesanti, A. Ferretti, D. Perissin, C. Prati, F. Rocca, Identification of the location Phase Screen of the Permanent Scatterers, *Fringe Meeting*, Frascati December 2003 http://earth.esa.int/fringe03/.

[6] Rocca, F., 2004, Diameters of the orbital tubes in long - term interferometric SAR surveys, *IEEE Geoscience and Remote Sensing Letters*, July 2004.

[7] Rocca F., Kenji Daito, A. Ferretti., S. Kuzuoka., and F. Novali: L-band PS analysis: JERS-1 results and TerraSAR - L predictions, Fringe Meeting, Frascati, December 2003, http://earth.esa.int/fringe03/.

[8] Zebker, H. and J. Villasenor, Decorrelation in interferometric radar echoes, *IEEE Trans. Geosci. Rem. Sensing*, 30, 950-959, **1992**.