Interferometric point target analysis of RADARSAT-1 data for deformation monitoring at the Belridge/Lost Hills oil fields

Bernhard Rabus
MacDonald Dettwiler
13800 Commerce Parkway
Richmond B.C.
Canada V6V 2J3
brabus@mda.ca

Charles Werner, Urs Wegmueller
GAMMA Remote Sensing
Thunstrasse 130
CH-3074 Muri / Bern
Switzerland
gamma@gamma-rs.ch

Adrian McCardle
Radarsat International
13800 Commerce Parkway
Richmond B.C.
Canada V6V 2J3

Abstract—**Interferometric Point Target Analysis using Gamma Remote Sensing's IPTA module has been applied to two interferometric stacks of RADARSAT-1 FINE mode data over the Belridge/Lost Hills oil fields in California. The stacks (~30 images each) are both from descending orbits and span the same 2 year time period (2002/02 – 2004/02) but incidence angles are different (F1 vs. F3F). An IPTA analysis is carried out on each stack separately and results are then compared in terms of achieved density of the scatterers and residual errors of the motion analysis. We verify the accuracy of our methods indirectly by studying the subtle difference in line-of-sight motion caused by the different incidence angles of the data stacks (38.4 vs. 43.1 degrees at the study site).**

(interferometry, point targets, RADARSAT-1, subsidence)

I. Introduction

Interferometric point target analysis (IPTA) has become an established method to measure spatio-temporal patterns of subsidence and other forms of surface motion. Input is a stack of interferometric SAR images. Provided that the acquisition times and the interferometric baselines between the images of the stack are not too unevenly distributed, the method allows separating the surface motion trend from atmospheric, topographic, and orbit contributions to the interferometric phase. The statistical separation becomes more accurate with stack thickness; depending on the precise implementation of the method at least 15-20 images are required. For urban areas with high densities of interferometric point targets, accuracies exceeding 1 millimetre of surface motion per year have been previously attained [1],[2],[3]

Goal of this paper is to demonstrate applicability and accuracy of Gamma Remote Sensing's implementation of the IPTA method for RADARSAT-1 FINE mode data. The method has been previously demonstrated for ERS data [3]. For the present study the method was modified to handle the lower orbit accuracy and higher bandwidth of RADARSAT-1 FINE mode (ground resolution 8 meter) compared to ERS (ground resolution 20 m).

As study area we chose the Belridge/Lost Hills oil fields near Bakersfield (California, U.S.A.), where long-lasting surface subsidence of up to 0.5 meter per year has been previously documented [4],[5],[6]. The areas affected by subsidence are about 20 x 5 km and 15 x 5 km for the Belridge and the Lost Hills field, respectively. In the present paper we mainly concentrate on the smaller Lost Hills field.

II. Data Preparation

The RADARSAT F1 and F3F data stacks were focused from RAW into SLC format. Reference scenes in the middle of the temporal stack (04 Apr 2003 and 22 Feb 2003 for F1 and F3F respectively) and all SLCs of a stack were resampled to the respective reference scene geometry. Regular repeat pass interferograms were formed with the reference SLC and used to carry out the necessary coarse baseline calibration. Figure 1

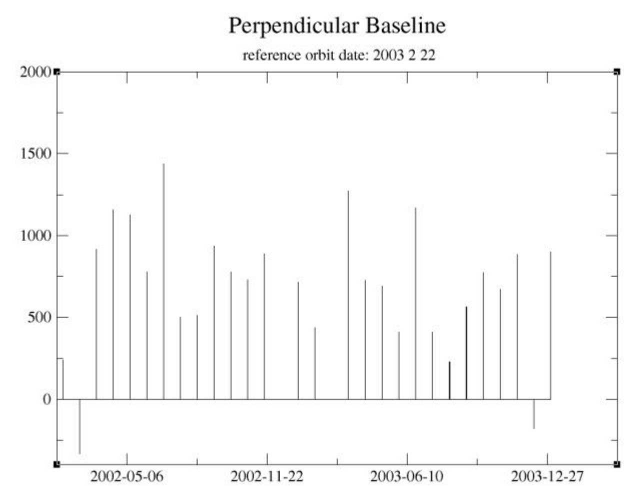

Figure 1. Perpendicular baselines for the F3F stack (in meter).

shows the adjusted baseline distributions for the example of the

F3F stack. Subsequently we coarsely flattened the topographic contribution to the interferograms using the SRTM 90 meter resolution DSM.

III. IPTA ANALYSIS

Phase and amplitude based statistical selection techniques were used vertically through the stack to select 'point scatterer (PS) candidates', i.e. to identify pixels, which are dominated by a single scatterer that is much smaller than the pixel dimension and which is evident in each of the stack images. Our selection techniques deviate significantly from the ones described in [1] and [2]: results for the PS masks have been shown to be similar for large (>40 scene) stacks; for smaller data stacks our methods of PS selection seem produce more robust results [3].

The selection process attributes each identified PS candidate with a quality measure. A subset of PS with high quality is used to initialize the model-based separation of surface motion and topography (relative to the reference DEM). A linear deformation model was used, which is adequate for the given type of subsidence. In subsequent iterations the separation is refined, to take into account the atmospheric water vapor contribution. At the same time PS with lower initial quality are assimilated to add density to the model.

In the final step results for both stacks were geocoded to UTM coordinates to facilitate comparison

IV. COMPARSION OF THE F1 AND F3F IPTA RESULTS

In the following we present some preliminary results of the comparison of the IPTA analysis results achieved for both stacks. More detailed results of the comparison will be published elsewhere.

Figure 2 compares the line-of-sight (LOS) deformation maps for the F1 and F3F cases. Due to the smallness of the incidence angle difference results are as expected very similar. The two epicenters of the subsidence at the Lost Hills oil field have

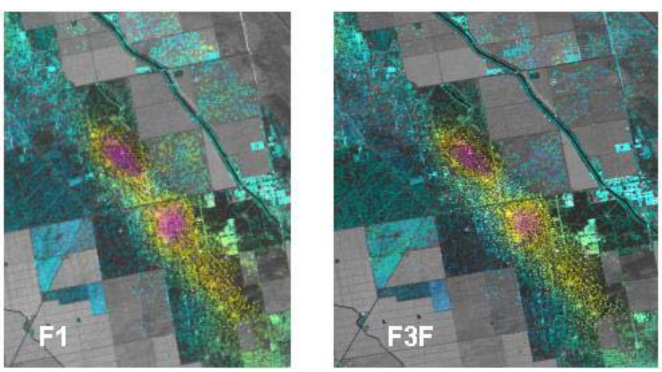

Figure 2. Line-of-sight deformation maps for the Lost Hills oil field superimposed on the average amplitude of the stack. Left: F1; right: F3F. Color scale; blue: 0 m per year; red: 0.15 m per year.

maximum displacement rates of >0.12 m per year. Residuals not explained by the model (including, topography, linear deformation, and atmosphere) are less than 4 mm throughout.

Because results are geocoded the PS sets found for both stacks can be directly compared. Within the mask chosen around the Lost Hills oil field (see Fig.2) 44,974 and 37,086 PS have been identified for the F1 and F3F stacks respectively. Of these 10433 are present in both PS sets. Figure 3 identifies PS present in the F1 set only, F3F set only, and both sets for a small subset around the subsidence epicenter.

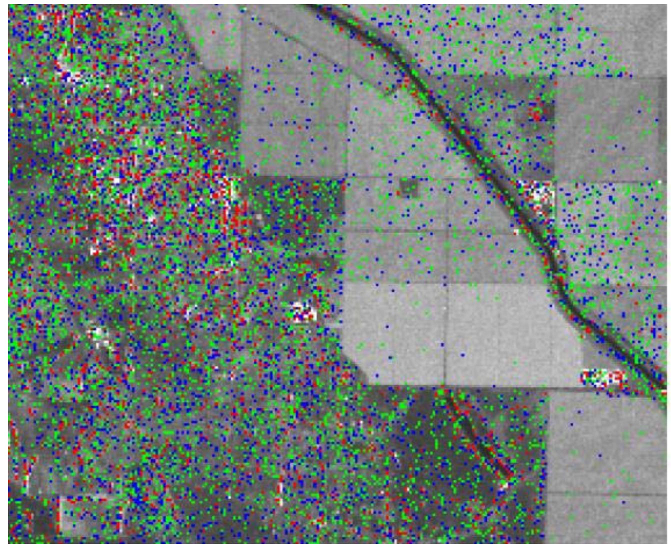

Figure 3. Interferometric point scatterers.for a small area immediately north of the Lost Hills subsidence epicenters. Green: F1 only, blue: F3F only, red :present in both stacks

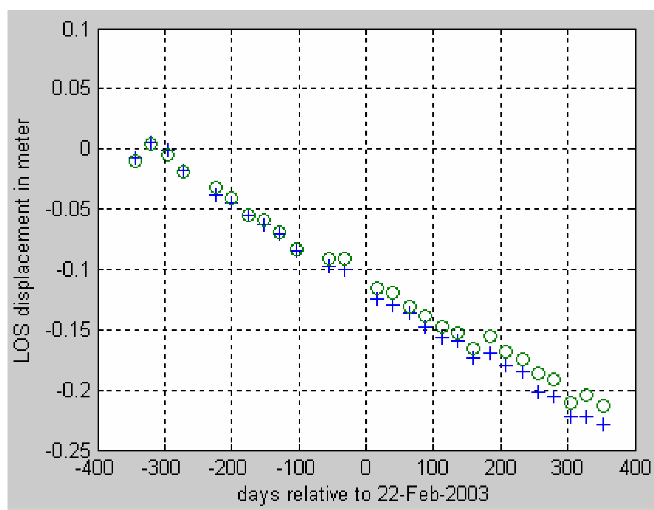

Figure 4. Example of a interferometric point scatterer time series near the northern one of the two Lost Hills subsidence epicenter. Blue pluses: F1; green circles: F3F

Figure 4 shows an example of a time series for a PS, which occurs in both data sets. The PS is located at the northern epicenter of the subsidence (Figure 2). Mean LOS displacement rates for F1 and F3F are –0.124 and –0.116 m per year, respectively

V. Discussion

The fact that only 25 per cent of the PS occur in both stacks implies that the majority of the identified PS are phase-stable only over a limited range of incidence angles. One reason for this is that the baseline distributions (Fig. 1) are biased towards baselines much smaller than the critical baseline (ranging about 4 km for both stacks). This will lead to inclusion of PS, which loose their phase stability for larger baselines.

The difference in the linear trend of the F1 and F3F time series in Figure 4 is consistent with the 4.7-degree incidence angle difference between the two image stacks. The F3F LOS displacement rates are thus expected to be about 7 per cent smaller than the corresponding F1 rates. More quantitatively, incidence angles near the Lost Hills subsidence epicenter are 38.35 and 43.05 degrees for the F1 and F3F look geometry, respectively. Therefore, the expected ratio between the LOS displacement rates is $\cos 43.05^{o}/\cos 38.05^{o} = 0.932$, which agrees well with the ratio 0.115/0.124=0.935 calculated for PS time series shown in Fig. 4.

VI. Conclusion

We have demonstrated the Gamma Remote Sensing IPTA technique for RADARSAT-1 fine mode data. Two stacks over the same area but slightly different viewing angle (F1: 38.4 degrees; F3F: 43.1 degrees) were compared. Similar numbers of interferometric point scatterers were identified for each stack of which 25 per cent are common to both stacks., i.e. are phase-stable over an incidence angle range of > 5 degrees

The LOS displacement time series derived from the F3F stack consistently show a 7 per cent smaller slope than the corresponding F1 time series, which agrees well with what is expected from the incidence angle difference. This check proves that we can achieve an accuracy of 3-4 mm per year of line-of sight motion with the Gamma IPTA tool.

Acknowledgment

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References

[1] ADAM N. et al., “The Development of a Scientific Permanent Scatterer System “, ISPRS Proceedings 2003, Hannover, Germany

[2] FERRETTI A., C. PRATI AND F. ROCCA, “Analysis of Permanent Scatterers in SAR Interferometry”, IEEE 2000

[3] WERNER, C. WEGMÜLLER, U. STROZZI, T. WIESMANN, A., “Interferometric point target analysis for deformation mapping”, Geoscience and Remote Sensing Symposium, 2003. IGARSS '03. Proceedings.2003 IEEE International