OPERATIONAL VALIDATION OF THE ACCURACY OF INSAR MEASUREMENTS OVER AN ENHANCED OIL RECOVERY FIELD

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ABSTRACT

This brief note presents a preliminary confirmation of a methodology for monitoring fast, strong ground deformation in a difficult environment with the RADARSAT-2 satellite.

The original aim of the monitoring was to capture the ground change present due to an aggressive enhanced oil recovery program. The ground deformation was expected to be on the order of a few centimetres per month with a spatial extent of hundreds of metres. The analysis shows that the deformation was much higher than expected. To understand the surface expression, multiple tracks of RADARSAT-2 were used to assess the error between observations. This effort confirms the use of multiple tracks of RADARSAT-2 data to increase the temporal sampling of a field.

Key words: InSAR; Multi-Track; Corner Reflectors; Enhanced Oil Recovery.

1. INTRODUCTION

In early 2010, a field of corner reflectors was installed over the oil field to be monitored in Northern Alberta. The spatial gradient of the ground change was originally assumed to be less than 2.5 cm/500 m (in one twenty-four day observation period) and the field of reflectors was installed with this assumption in mind. With observations, however, it has been shown that the spatial gradient can exceed this by three to four times. This has a serious impact on the ability to unwrap (demodulate on $[-\pi, \pi)$) the deformation observations.

If a single track of data (even with observations every 8 days) had been employed in the monitoring, then the true extent of the ground change could not have been known using the corner reflector measurements alone. Because of the spatially and temporally localized (small area extent and fast moving) deformation, the spatial distribution of the corner reflectors would have had to have been increased or the number of observations increased. (The latter is the case here.) The spatial reconstruction of the ground expression is a key factor in the design of a corner reflector field. To reconstruct a ground deformaiton signal, the spatial and temporal density must be close enough that no part of the signal is missed. In essence the change in reflector height from one reflector to the next cannot be larger than the unambiguous unwrapping distance in the time span that is being monitored. The line of sight distance that a corner reflector can be moved before the measurement is ambiguous is approximately 2.8 cm for RADARSAT-2.

Table 1. RADARSAT-2 beam modes, incident angles, and timing offset for repeated measurements. (RADARSAT-2 provides a 24 day repeat.)

Beam	Incident Angle (°)	Time Delay from t_0
MF22	34	0
U20	45	3
U79	30	7
MF2	41	10
U10	38	17
MF6N	48	20

In order to categorize the field shown here, a series of 6 beam modes from the RADARSAT-2 satellite were used. The tracks, all ascending, are shown in Table 1. The resulting time series of images provides interferometric measurements that are spaced over very short periods of time. That is, each series of images (each beam mode or track) provides an interferometric measurement over a period of 24 days but the image acquisition from each time series is staggered by approximately 4 days thus providing multiple observations of the same deformation signal.

The observations were made over a field of corner reflectors (see Figure 1). The corner reflectors have been installed on a raised pedestal and covered with a fibreglass snow cover. Each pedestal is sunk into the bedrock, so that the motion observed at the corner reflector is only due to the movement of the cap-rock (see for instance

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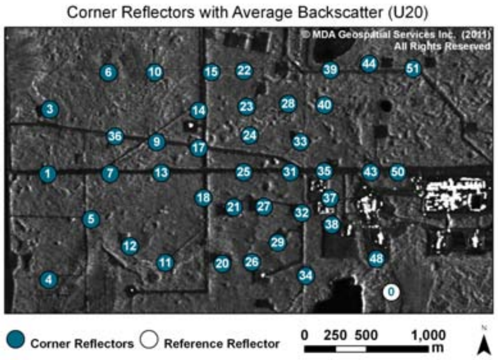


Figure 1. Map of corner reflectors with raised reflectors attached to a pedestal installed into the bedrock and covered with a fibreglass snow cover.

Kampes & Van der Kooij (2008)).

Figure 2 shows a series of differential interferograms over the region. The series shows why corner reflectors are necessary in the area: the spatial coherence is routinely too low to provide reliable distributed scatterers. In fact, the temporal coherence in the region is so rapidly changing that few persistently coherent scatterers are available even on a short time period. There are coherent scatters available from the infrastructure installed in the region but this does not give a spatial sampling region that will allow a reconstruction of the surface expression caused by the enhanced recovery operation.

When the coherence is sufficient (as in the top graphic of Figure 2), the ground observations may be used to confirm the highly localized rapid deformation. It is rarely the case that the ground response provides any spatial coherence. The intereferogram shown in the lower graphic of Figure 2 is the normally observed case. There are no permanent scatters, other than the installed reflectors in the scene.

Figure 3 shows the impact of multi-track, temporal unwrapping of the information from a particular corner reflector. The phase unwrapping errors in the top panel of Figure 3 are repeated in each of the tracks where the spatial and temporal sampling was clearly too low for the signal to be captured when one track is considered at a time. By using the multiple track observations, we were able to capture and reconstruct the real deformation signal at each corner reflector. Without multiple track observations, the strength and spatial localization of the surface expression would not have been captured by the field design.

The agreement between the observed data provides an excellent characterization of the accuracy of the measurements made. In Figure 4 and Figure 5 we show a representative error estimate for each of the corner reflectors based on the variation of each of the observations from a trend estimated by a temporally varying Lowess filter (see for instance Cleveland & Devlin (1988)). Each of the estimates have been projected into the vertical direc-

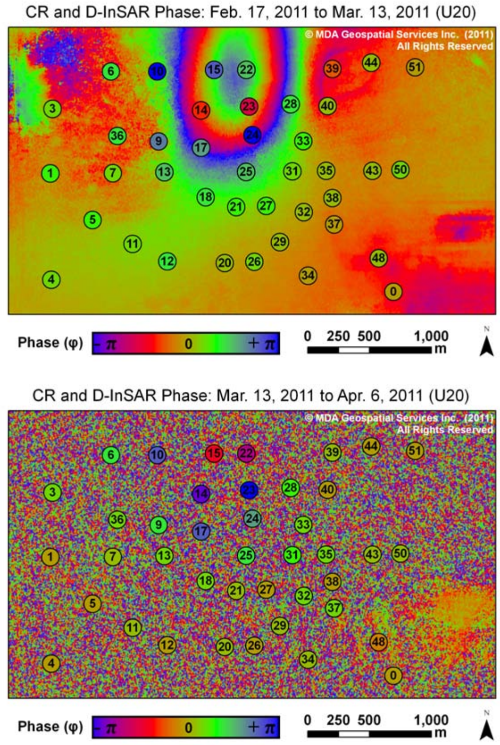


Figure 2. Examples of the wide area phase over two interferogram pairs.

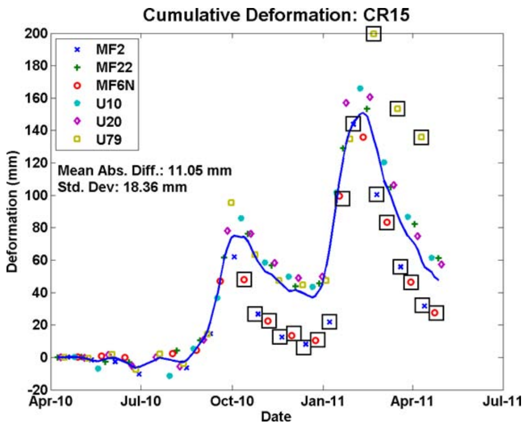
tion. As there is as much as 14° difference between the nominal incident angles between the beams and no estimation of horizontal velocity has been made, it is possible that a closer approximation to the true signal can be made. The point of this note, however, is to show the operational validity of the measurements via multiple track approximation and a mean absolute error of less than 5 mm in 180 mm of signal is of clear operational value.

2. CONCLUSION

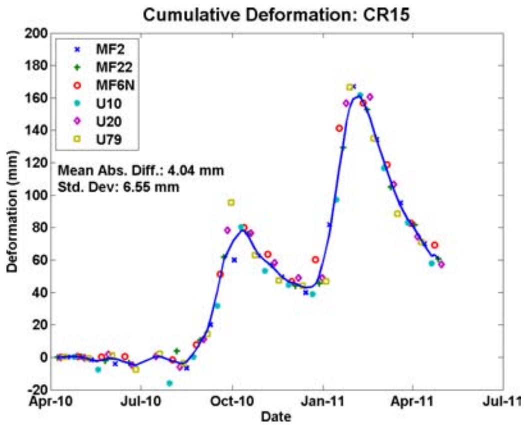
Even in challenging conditions with rapid deformation greater than a fringe per spatial and temporal observation, multiple tracks of observations provide high accuracy measurements of the ground change.

The residual errors reported in the final analysis are due to 1) the modeling of the signal, 2) the assumption of only vertical movement, and 3) errors inherent in the InSAR analysis. The non-linear nature of the ground deformation makes a simple modelling of the signal difficult. A Lowess filtering approach has been used to approximate the true deformation signal. The residual error resulting from 1) and 2) is thought to be larger than the residual differences from 3).

The collection of coincident information from multiple beams provides further confirmation of the efficacy of InSAR measurements.



(a) Before temporal unwrapping



(b) After temporal unwrapping

Figure 3. The cumulative deformation calculated at one corner reflector.

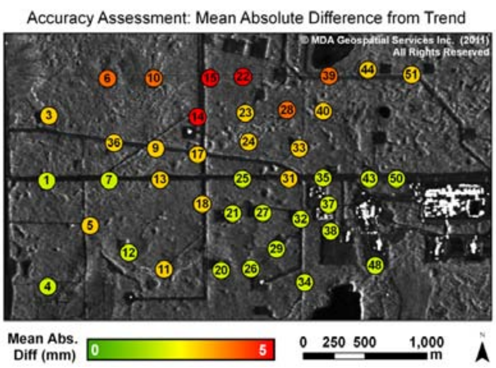


Figure 4. The mean absolute error from a trend identified at each corner reflector by a Lowes filtering method.

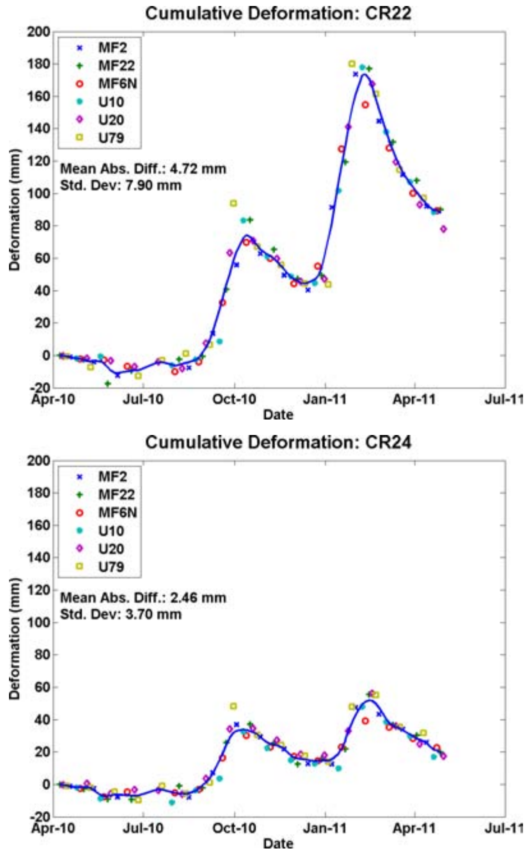


Figure 5. Time series of all observations at three representative corner reflectors.

Multi-track InSAR provides a highly accurate, operational monitoring system to fully categorize the ground movement over a very dynamic field.

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