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Cost efficient SAGD heave monitoring: New generation radar technology

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Abstract

Oil sands operators are required to present regular performance reviews to the Energy Resources Conservation Board (ERCB), including heave monuments or other surface monitoring programs.
Heave monitoring is an efficient method to monitor steam chambers and to guarantee safety for SAGD operations and infrastructure.

This presentation illustrates the most recent advancements in Interferometry for Synthetic Aperture Radar (InSAR), the cost-efficient heave monitoring technique using radar satellites, with a specific focus on new generation X-band satellite technology and the technology's impact on reservoir monitoring.

In 2007 and 2008 **new generation X-band radar satellites** were launched with the following technical advantages:

- **Redundancy of satellites:** New generation X-band satellites are a satellite constellation, which mitigates the risk of satellite failure during the project period.

- **Frequency of images:** A new image with the same incidence angle is available every 8 days. As a consequence, in case of emergency it is possible to increase measurement frequency to a weekly rhythm.

- **Measurement precision:** With a shorter wavelength, measurement sensibility is higher (precision of 1 mm).

- **Size of Corner Reflectors:** The required size of Corner Reflectors (might be installed to guarantee measurement points) is smaller, giving it a lower visual impact and reducing production and installation costs.

- **Higher resolution:** Higher density of natural measurement points and the possibility to build up a very dense Corner Reflector network.

The new technology advancements will be illustrated with case studies and the discussion will focus on how InSAR can be combined with traditional heave monitoring techniques such as GPS-measurements.

Introduction

Oil sands operators are required to present regular performance reviews to the Energy Resources Conservation Board (ERCB). One of the content requirements for annual commercial schemes within the section of Geology/geosciences is: “Heave monuments or other surface monitoring programs: Discuss results from ongoing monitoring and how those results are being applied to the scheme operation and design.”

In addition to being a requirement of the ERCB, heave monitoring is an efficient method of monitoring steam chambers, especially in shallow SAGD reservoirs, in order to identify potential pressure excess, and to guarantee safety for SAGD operations and infrastructure.

This presentation illustrates the most recent advancements in Interferometry for Synthetic Aperture Radar (InSAR), the cost-efficient heave monitoring technique using radar satellites, with a specific focus on new generation X-band satellite technology and the technology's impact on reservoir monitoring.

1. Introduction to InSAR technology

ALTAMIRA INFORMATION is an experienced earth observation company that provides ground movement measurements with millimetric precision and mapping solutions using radar satellite images.

The technology that is used to detect millimetric ground motion is called "Interferometric Synthetic Aperture Radar", with its abbreviation InSAR.
The "Synthetic Aperture Radar" is a high-resolution satellite based radar system, and "Interferometric" means superimposition of waves to detect differences over time in fractions of wavelength.
These satellites capture images with precisely recorded travel phase between ground surface and sensor. If several measurements are compared over time, the difference between measurements indicates ground movement over time. This is a very simplified explanation since additional effects have to be filtered such as atmospheric changes, position of the satellite etc.

1.1 The radar satellites

A radar satellite is orbiting continuously on a fixed path around the globe. It takes more or less 100 min to orbit the globe. Since the earth is rotating below the satellite, its path successively moves, meaning that over time satellites build up complete images of the whole globe. The satellite returns to the initial orbit after some 8 to 45 days, depending on the satellite.

ALTAMIRA INFORMATION is able to use all available radar satellites depending on project needs and characteristics:

For ground motion studies of movement in the past, satellites with availability or archive images such as Envisat and ERS owned by the European Space Agency (ESA) or Radarsat-1 and Radarsat-2 owned by the Canadian Space Agency (CSA) or ALOS owned by the Japanese Space Agency (JAXA) are used.

Fig. 1: Radar satellites owned by the European Space Agency (ESA) : ERS-2 launched in 1995 and Envisat launched in 2002

Fig. 2: Radar satellites owned by the Canadian Space Agency (CSA): Radarsat-1 launched in 1995and Radarsat-2 launched in 2007

For ground motion monitoring in the future, mainly the newer radar satellites are used. These satellites can be new generation X-band satellites, such as the TerraSAR-X satellites owned by EADS and the German Space Agency (DLR) and COSMO-SkyMed owned by the Italian Space Agency (ASI).
Section 3, "Recent advancements in InSAR technology: New generation X-band satellites" elaborates on the advantages using new generation X-band satellite.
Another option for ground motion monitoring is the use of the C-band satellite, Radarsat-2.

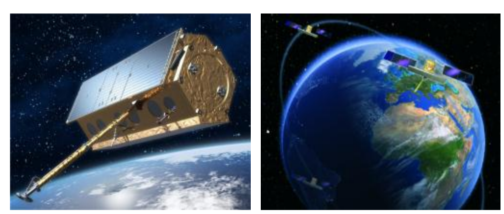

Fig. 3: Radar satellite TerraSAR-X owned by EADS and the German Space Agency launched in 2007 and COSMO-SkyMed owned by the Italian Space Agency launched between 2007 and 2010

1.2 Ground motion measurements

To measure ground motion with millimetric precision, several satellite images covering different dates are acquired and compared.

These satellites capture images with precisely recorded travel phase between ground surface and sensor in fractions of wavelength.

If several measurements are compared over time, the difference between measurements indicates ground motion over time.

Additional effects have to be filtered such as atmospheric changes, position of the satellite etc.

Ground motion measurement results are delivered in the form of a ground motion map where every identified measurement point is shown and where colours indicate the average yearly ground motion rate during the period of analysis.
Furthermore for each measurement point, time series are delivered indicating the exact ground motion evolution over time for this measurement point.

1.3 Natural versus artificial measurement points

Radar measurement points can be twofold: So-called **"natural measurement points"** are existing radar signal reflection points, such as roofs, metallic structures or arid zones.

Fig. 6: Natural measurement points

The advantage of these measurement points is that measurements can take place without any installation, since pre-existing measurement points are taken as radar reflectors. There is even the possibility to measure ground movement in the past, since archive images are available for most areas worldwide.
Measurement updates are every 4 to 45 days (depending on the satellite used).
The limitation for measurement with natural points is that at least an amount of 12-20 images is required to localise measurement points and to get reliable measurement results.

In areas where there is an absence of natural measurement points such as forests, vegetation, snow: which is characteristic of the areas of heavy oil production in Alberta, Canada, the alternative is the installation of **"Artificial Corner Reflectors"**. These reflectors are aluminium trihedrals that are installed on the ground and oriented towards the satellite to guarantee measurement points.

Fig. 7: Artificial Corner Reflectors

The advantage of Artificial Corner Reflectors is that they guarantee measurement points in areas lacking a presence of natural measurement points. First measurement results can be achieved after the acquisition of 2 or 3 images, since the measurement point location is known.

Most projects for ground motion monitoring in heavy oil extraction areas in Alberta measure mainly with Artificial Corner Reflectors due to an absence of natural measurement points due to a number of factors. The areas of interest are mainly populated by trees and include non-constructed areas. Heavy snow fall in winter also hinders the possibility of identifying natural measurement points.

1.4 The Stable Point Network (SPN) chain

The Stable Point Network is an advanced differential interferometric processing technique developed by ALTAMIRA INFORMATION. It is the result of three years of research projects in the DInSAR data analysis field for the CNES (French Space Agency) and ESA (European Space Agency). The SPN tool was the first advanced interferometric processor capable to merge the new Envisat data with the historical ERS1/2 [1]. The SPN software uses the DIAPASON interferometric chain for all the SAR data handling, co-registration work and interferogram generation. The DIAPASON processing software has become, since its creation in 1992, one of the leading differential interferometric tools. More than 100 companies and research laboratories around the world use it.

The Stable Point Network procedure generates three main products for a subsequent set of radar images: The average displacement rate, which can be derived using only 6 images. A DEM error map, produced at any resolution. Finally, the extraction of subsidence time series, that requires from 15 to 30 images, depending on the velocity of displacement in relation the intervals between image acquisition. In all cases, an increase in number of images improves the quality of the estimate.

The software is also able to give the exact UTM coordinates of the analyzed points with a final geocoding precision of about 2 meters

One important characteristic of the chain is its flexibility: the software can work at any resolution and with extracted pieces of images.

2. Project examples and case studies

Ground movement measurement studies are employed in a number of aspects of the oil and gas sector, however the most frequent application is in reservoir monitoring. In both the case of oil recovery areas, as well as gas storage sites, identifying, measuring and monitoring ground movement using InSAR technology has proven to be extremely effective.

Pre injection phase

- Historical analysis of the selected site to obtain ground motion information of the surface and detect vulnerable areas.
- Installation of Artificial Corner Reflectors to measure zero-motion baseline before injection starts

Injection phase and ongoing monitoring

- High resolution ground deformation monitoring when injection starts, with monthly or even weekly updates.
- Installation of Artificial Corner Reflectors where measurement points are not guaranteed.
- Combination of ground motion monitoring results with other monitoring technologies

2.1 SAGD steam injection area in Canada

The first application example is a SAGD steam injection area in Canada, Alberta. The objective of ground motion measurements in this project is to maximize steam injection efficiency while minimising the risks for the extraction area.

A network of more than 100 measurement points has been installed in the area of interest.
Now that the reflectors are installed, ground motion monitoring measurements can be made remotely without any intervention on the site.
The following illustration shows how the reflectors are detectable on the radar image:

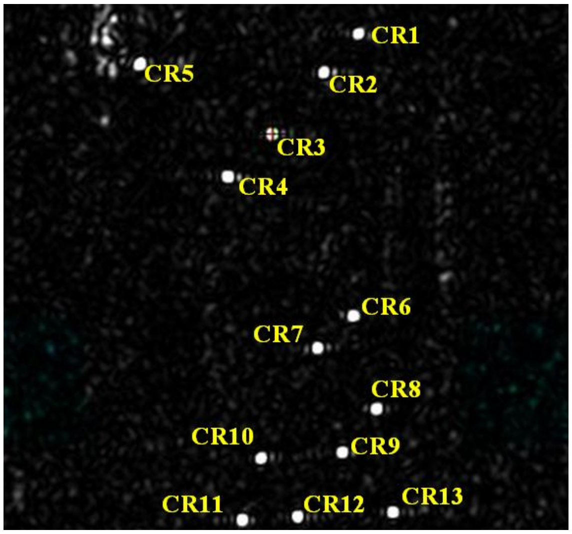

Fig. 7 : Radar image after installation of reflectors

For each Corner Reflector, quality control measurements are conducted to check the reliability of installed reflectors over time.

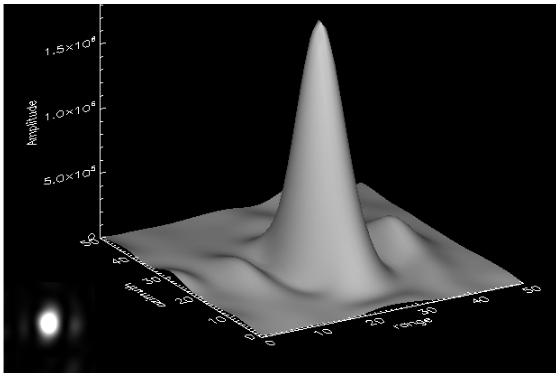

Fig. 8 : Quality Control

Ground motion updates are delivered to the client on a monthly basis.

The output of this project is an overview map with isolines 3 months after installation, indicating in red colours where uplift is occurring and in blue colours subsidence. Green colours indicate stable behaviour.

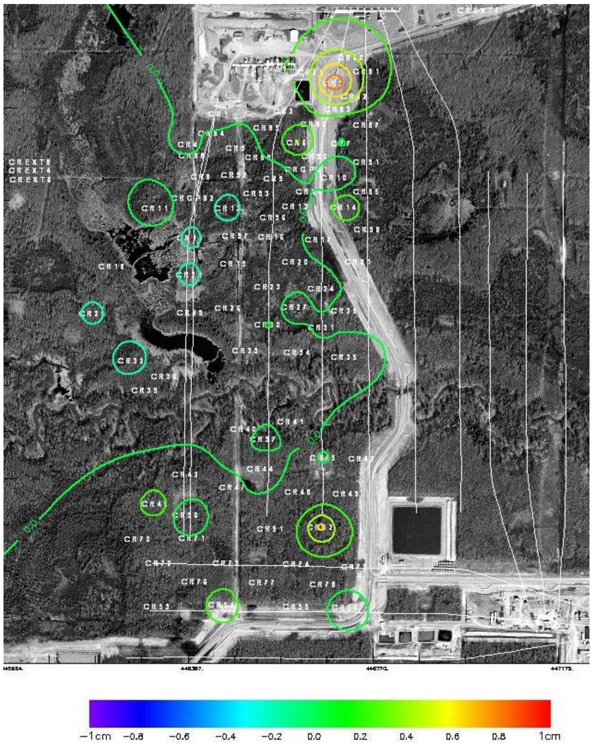

Fig. 9: Isolines 3 months after installation

The following illustration shows the same area, this time 10 months after installation of corner reflectors:

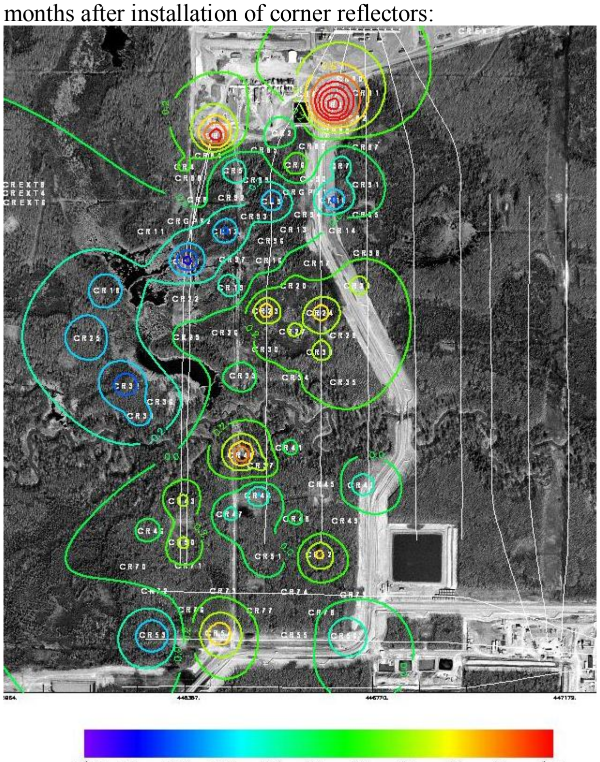

Fig. 10: Isolines 10 months after installation

A clear uplift can be identified in the Northern part that was already beginning after 3 months.

2.2 CO_2 storage in Algeria

The second application example is the CO_2 storage site in In Salah in Algeria:

The arid conditions of this location make it an ideal test site for ground deformation monitoring using InSAR technology.

This analysis is based on 46 Envisat images covering the period between 2003 and 2010.

Despite the depth of 1900 m of this CO_2 storage site, ground deformation was detected with millimetric precision. Areas of uplift (5 mm/year,) were identified surrounding the injection wells, while areas of subsidence (2.5 mm/year) were detected in the extraction area near the gas field facilities (Fig.8).

For CO_2 storage sites, the historical study of ground deformation during the pre-injection phase identifies areas that are vulnerable to ground deformation, thus contributing to early warnings and operations planning to help prevent damages in the future. Ground deformation monitoring during the injection phase then delivers updated information on the impact of operations as they evolve.

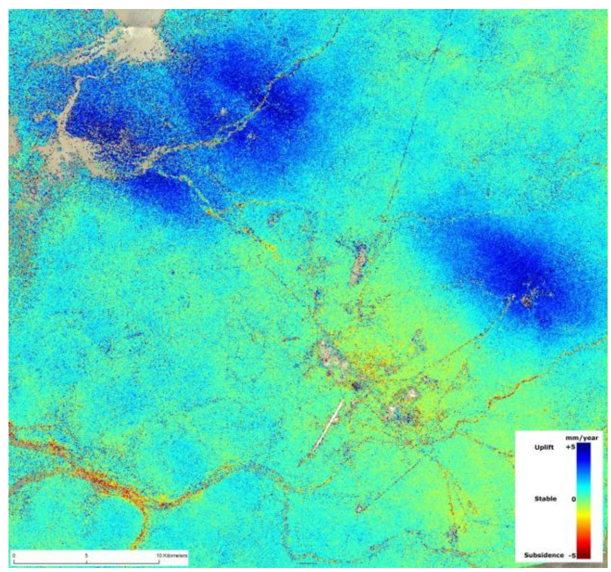

Fig. 11: Ground motion analysis of CO2 storage site using Envisat images for 2003-2010. Areas in dark blue show uplift areas.

3. Recent advancements in InSAR technology: New generation X-band satellites

New generation X-band radar satellites (TerraSAR-X and Cosmo-SkyMed) have been launched in recent years and present the following technical advantages:

Redundancy of satellites

New generation X-band satellites are a satellite constellation, not a single satellite (currently three Cosmo-SkyMed satellites and two TerraSAR-X satellites). Working with several similar satellites mitigates the risk of satellite failure during the project period.

Frequency of images

In certain SAGD project phases (e.g. during first injection or in cases of emergency), weekly heave monitoring may be required. The advantage of the new generation X-band satellites is that a new image with the same incidence angle is available every 8 days. As a consequence, monthly updates are based on 3-4 new images and in case of emergency it is possible to increase measurement frequency to a weekly rhythm.

Measurement precision

Since the wavelength of X-band satellites is shorter, their measurement sensibility is higher and as a result heave monitoring measurements have more precise results (precision of 1mm).

Size of Corner Reflectors

For steam chamber distribution monitoring, it is necessary to install aluminum Corner Reflectors (aluminum half cubes) that guarantee measurement points in snowy forest areas. The advantage of new X-band satellites is that the required size of Corner Reflectors is smaller, giving them a lower visual impact and reducing production and installation costs.

Higher resolution

Furthermore the resolution has increased to 3x3m, with the advantage of higher density of natural measurement points (infrastructure, buildings) and the possibility to build up a very dense Corner Reflector network if required: The minimum distance between Corner Reflectors could be reduced to 20 m.

4. Combination of InSAR technology with GPS measurements

InSAR measurements with artificial reflectors are very precise, they have millimetric precision.
However GPS measurements can improve InSAR measurements to reference InSAR measurements to the wider GPS network.
InSAR reference stations can be located very near to the reservoir. The location of the reference station is placed in an area that is as stable as possible. However, it is always possible that the reference station itself is moving.
An installation of a GPS-station at the same location as the reference station can measure the movements of the reference station itself contributing to a more precise calibration of corner reflectors.

Conclusions

Ground motion monitoring using InSAR technology is a cost efficient technique that assists in complying with ERCB requirements and contributes to the overall safety of heavy oil extraction operations.

Cost efficiency applies especially for the following monitoring needs and requirements:

- **Measurement results are required throughout the year**, not only during the winter season when the site can be accessed. Once the Corner Reflectors are installed, measurements are taken remotely, therefore providing the possibility to measure and monitor ground motion during the whole year. No maintenance is required for Corner Reflectors since they are passive devices with no power requirements.

- **The area that should be measured is quite large**, e.g. one to several well pads: Once the Corner Reflectors are installed, the future monitoring operative costs are partly fixed costs: therefore the larger the area the more efficient the monitoring costs.

The **technology advancements thanks to X-band satellites** offer higher reliability and precision of measurements and more flexibility due to higher image frequency. Thanks to the smaller wavelength, the size of Corner Reflector is smaller, thus having a positive impact on production and installation cost reduction.

References

1. A. ARNAUD, N. ADAM, R. HANSSEN, J. INGLADA, J. DURO, J. CLOSA, M. EINEDER: ASAR ERS interferometric phase continuity. *IGARSS 2003, Toulouse (France), 21-25 July, 2003.*