RESERVOIR MONITORING USING RADAR SATELLITES

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Key words: *Reservoir monitoring, InSAR, radar, satellite, heavy oil, enhanced oil recovery, EOR, SAGD, ground motion, subsidence, uplift, Artificial Corner Reflectors, Altamira Information*

Summary

The objective of the presentation is to provide an introduction to InSAR technology and its applications for reservoir monitoring.

InSAR (Interferometry for Synthetic Aperture Radar) technology is a spaceborne measurement method, able to detect ground motion with millimetric exactness using radar satellite images. Measurements are taken remotely from the space. Therefore it is a very cost efficient tool to measure ground motion in even remote areas in most parts of the world.

ALTAMIRA INFORMATION has developed its own advanced differential interferometric chain (Stable Point Network SPN) able to process several raw radar images to achieve millimetric ground motion measurements. Results are provided in GIS format and can be received and analysed by reservoir engineers remotely without the need for site visits.

Ground motion monitoring with radar images can contribute to oil & gas reservoir monitoring in several ways: For oil & gas extraction areas, InSAR ground motion results support site safety since risk areas can be identified at an early stage. For Enhanced Oil Recovery, millimetric ground motion monitoring is able to contribute to production efficiency: By mapping ground motion elevation changes over the whole area, InSAR measurements can aid the assessment of whether the pressure of injection is correctly distributed over the area. For gas storage areas, InSAR can contribute to an evaluation of the storage stability, since millimetric surface uplift could be one of the indicators for a potential storage leak.

Radar image based measurements can be conducted standalone at reservoir monitoring sites; it is also possible to combine InSAR measurements with GPS measurements or ground levelling methods.

In order to illustrate the value added of this spaceborne technology with concrete examples, the paper includes case studies, representing ALTAMIRA INFORMATION's InSAR experience with major oil & gas companies.

1. Introduction to radar satellite technique (InSAR)

ALTAMIRA INFORMATION is an experienced earth observation company providing 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.

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 satellite builds up complete images of the whole globe. The satellite returns to the initial orbit after some 11 to 45 days, depending on the satellite.

ALTAMIRA INFORMATION uses radar satellites from space agencies, for example 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). ALTAMIRA INFORMATION also uses the TerraSAR-X satellite owned by EADS and the German Space Agency (DLR).

These satellites are taking images with precisely recorded travel phase between ground 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.

The interferometric processing algorithm Stable Point Network (SPN) owned and developed by Altamira Information

The Stable Point Network is an advanced differential interferometric processing technique developed at ALTAMIRA INFORMATION. It is the result of three years of research projects inside the DInSAR data analysis field for 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 most important 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 versus the intervals between image acquisitions. In any case, an increase in number of images improves the quality of the estimate.

If a DEM of the area is available, 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 point of the chain is its flexibility: the software can work at any resolution and with extracted pieces of images.

2. Oil & Gas applications with radar satellite images

Ground movement measurements are applied to different Oil & Gas areas, in upstream, downstream and finally for economical estimation of remaining reserves.

One of the most relevant PRODUCTION areas is reservoir monitoring: Ground movement information can increase extraction efficiency especially in Enhanced Oil Recovery areas, since information about surface uplift can deliver valuable information about injection distribution and impact. Ground movement measurement can also contribute to security to protect infrastructure owned by the oil company and its surroundings.
The following chapters will enter more in detail in reservoir monitoring.

Another application that is becoming more and more important is CH_4 and CO_2 sequestration. Millimetric ground movement, specifically millimetric uplift in sequestration areas can contribute to quality control at a very early stage.

Surface monitoring with radar satellite images is also used to measure offshore sea-anchored platform subsidence. A point on the nearest land mass is used to reference the motion.

Regarding DOWNSTREAM, radar ground movement monitoring is used for pipelines, to provide warnings about potential risks, for example in areas suffering from landslides or subsidence.

Thanks to its huge and cost efficient images, radar satellite imagery is also used for EXPLORATION purposes: The radar satellite can detect offshore oil slicks, e.g. oil seepages as an indicator of hydrocarbon existence. Also 3D mapping and structure mapping as well as slope maps can support exploration activities, especially in remote areas with difficult access.

Finally, radar satellite ground motion can be applied on a large scale to ESTIMATE REMAINING RESERVES for large oil extraction areas. Measuring ground motion and its recent historical evolution can support remotely the estimation of remaining oil reserves in the reservoirs, and therefore contribute to an economical evaluation of oil reservoirs.

3. Why measure ground motion? - Example: Enhanced Oil Recovery

Reservoir monitoring, especially the case of SAGD is one of the most valuable applications for ground motion measurements.
One of the main SAGD objectives is to optimise steam extraction efficiency with high steam pressure, but at the same time minimise risks for accidents.
Ground motion measurement can contribute to reach these objectives in the following way:
Uplift is an indicator for potential steam excess and therefore elevated risk for accidents.

Subsidence is an indicator for limited steam injection, but also for a potential reservoir compaction because of extraction activities.
Finally ground stability indicates that no risk could be identified on the surface.

Radar measurement points can be twofold: First of all with so-called “Natural measurement points”, meaning that measurement points are existing radar signal reflection points, such as roofs, metallic structures or arid zones.

Fig. 1: 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 11 to 35 days (depending on the satellite used).
The limitation for measurement with natural points is that at least an amount of 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 (forests, vegetation, …), the alternative is the installation of Artifical Corner Reflectors. These reflectors are aluminium trihedrals that are installed on the ground and oriented towards the satellite to guarantee measurement points.

Fig. 2: Artificial Corner Reflectors

The advantage of Artificial Corner Reflectors is that they guarantee measurement points in areas without presence of natural measurement points. First measurement results can be achieved after the acquisition of 2 or 3 images, since measurement point location is known.
Typical projects start with a first analysis based on natural measurement points, and the densification of measurements points with the installation of corner reflectors.

4. Project examples

Example 1: Monitoring with Natural Measurement Points

The first project example is a heavy oil reservoir monitoring project. In this case monitoring has been conducted using only natural measurement points since the main interest was to know ground motion in the past.
In this area of interest there were some areas with good natural point density (thanks to existing infrastructure, and rocky surfaces), whereas in vegetated areas, no measurement results could be achieved. The following illustrations show measurement points in the global area and with a zoom on the main area:

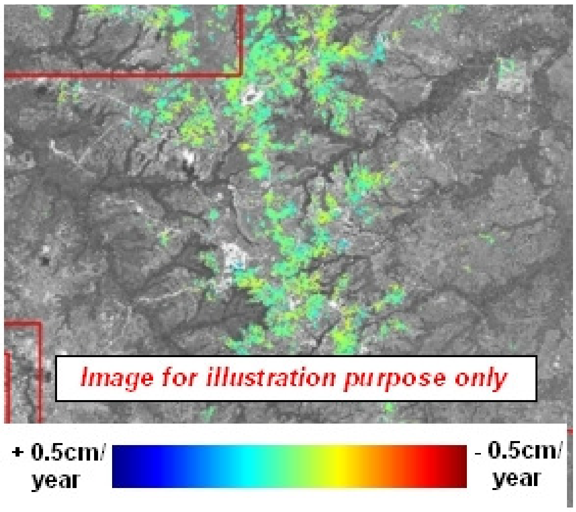

Fig. 3: Measurement with natural points (global area)

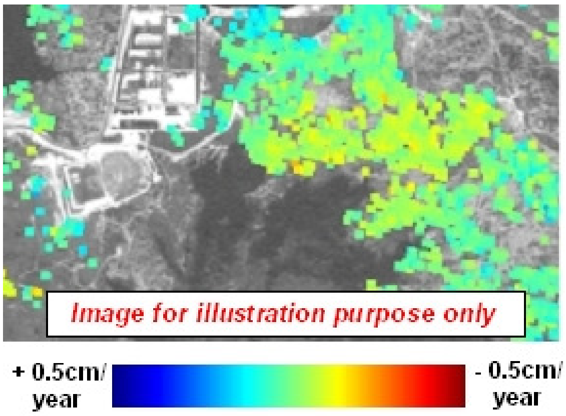

Fig. 4: Measurement with natural points (zoom)

This example shows that an analysis with only natural points can be conducted in reservoirs which have limited vegetation and arid areas.
In such a case, a good measurement density is achieved without any installation works.

Example 2: Monitoring with Corner Reflectors

The second application example is a SAGD steam injection area in Canada. 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.
Once 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:

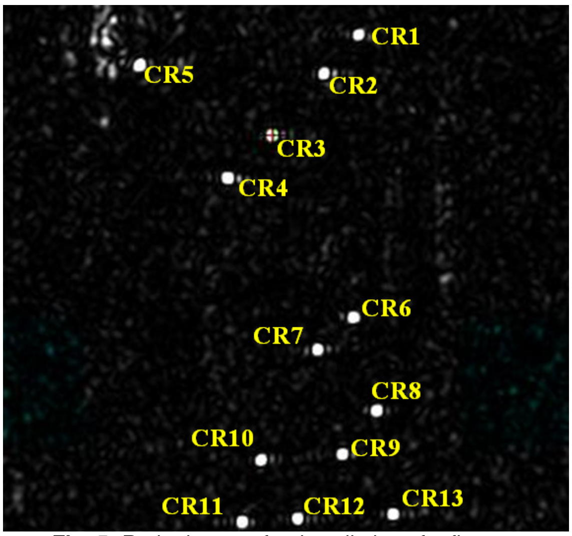

Fig. 5: Radar image after installation of reflectors

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

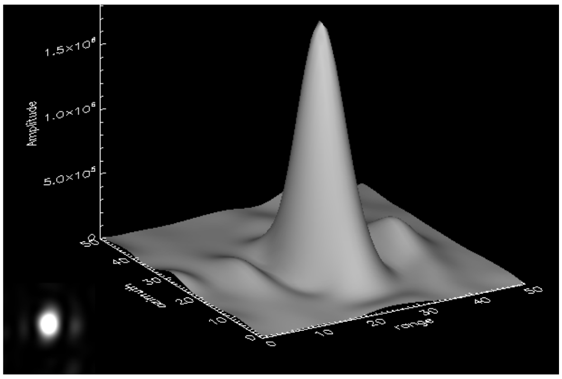

Fig. 6: Quality control

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

The output of this project is an overview map with isolines 2 months after installation, indicating in red colours where uplift is occurring and in blue colours subsidence. Green colours indicate stable behaviour.

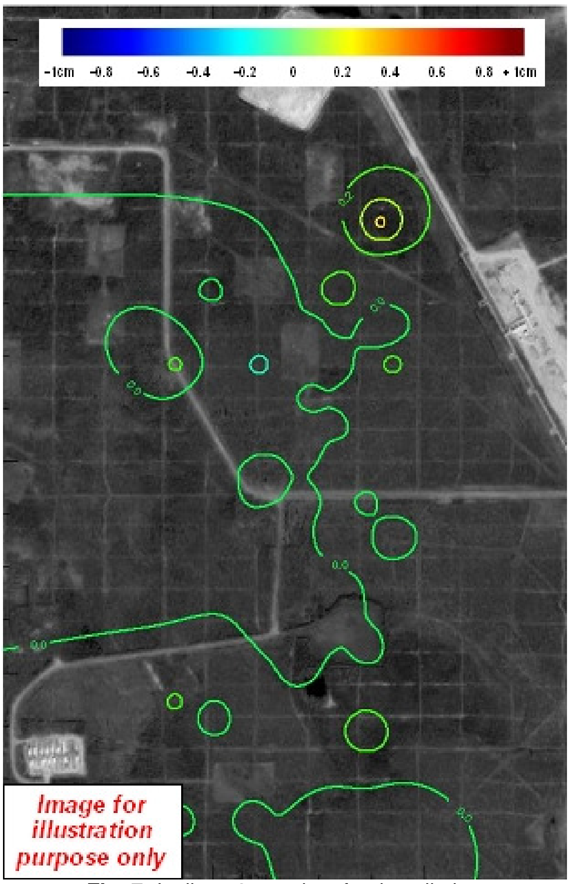

Fig. 7: Isolines 2 months after installation

The following illustration shows the same area, this time 7 months after installation of corner reflectors:

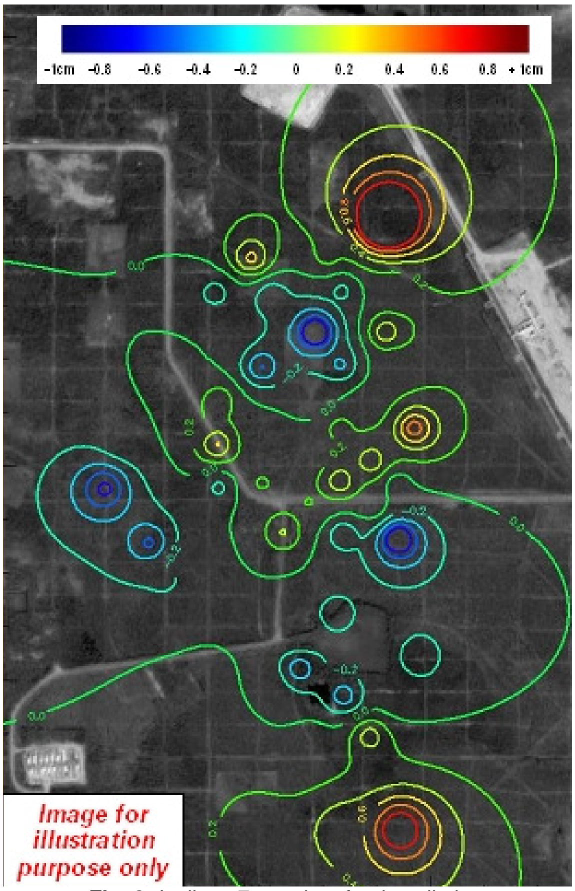

Fig. 8: Isolines 7 months after installation

A clear uplift can be identified, that was already beginning after 2 months.

5. Conclusions

Ground motion measurements are highly precise (millimetric) thanks to the interferometric processing algorithm Stable Point Network (SPN).

Depending on surface conditions, measurements can be made on natural measurement points or – if there are not enough natural measurement points available using Corner Reflectors.

Ground motion can be measured with updated data ("Ground motion monitoring") or with archive data, to obtain ground motion for the past.

The main application of the technology in the Oil & Gas sector is for reservoir monitoring. Other Oil & Gas related applications for radar satellite ground motion monitoring area:

- CO_2 sequestration
- Platform monitoring
- Pipeline monitoring
- Oil slicks detection
- Mapping (3D, structural mapping, slopes)
- Estimation of remaining reserves.

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.