Surface monitoring using radar satellite images to measure ground deformation: applied to Coal Seam Gas production areas to comply with regulatory requirements

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Abstract

The objective of this presentation is to introduce radar satellite reservoir monitoring technology (InSAR) and its main applications for monitoring Coal Seam Gas (CSG) production areas and its surroundings.

InSAR technology detects ground motion with millimetric precision. Measurements are taken remotely from space, a very efficient tool for ground motion measurement even in large and remote areas where land-based measurement techniques are inconvenient and costly. Altamira Information has developed an advanced differential interferometric chain (Stable Point Network SPN) which is able to process radar images achieving millimetric measurements.

In the field of Coal Seam Gas activities, ground motion monitoring with radar images is an efficient technology that allows to comply with regulatory requirements. These regulatory requirements specify the obligation for CSG operators to monitor subsidence starting with a baseline and continuing with ongoing monitoring in order to quantify deformation at the land surface within the proponents tenures.

Furthermore InSAR technology is the only technology able to measure ground deformation in the past due to the availability of archive radar images. These measurements in the past allow establishing baselines to determine vulnerable zones affected by subsidence (before CSG production) or subsidence induced by CSG or other activities. Monitoring requirements for the present and future can be covered with high-resolution satellites with precise measurement results (up 1mm). These satellites can be programmed.

This presentation includes some case studies with historical data processed over the Surat and southern Bowen Basin CSG developments, as well as some preliminary analysis regarding a possible correlation between CSG and non-CSG induced surface deformations.

1. INTRODUCTION

1.1 InSAR technology

Space borne Synthetic Aperture Radar (SAR) sensors are active systems on board satellites that operate in the microwave domain (cm to dm wavelength) providing global acquisitions that are almost independent from the meteorological conditions and during day or night. These radar satellites provide high resolution images which have a wide range of applications and are very suitable for operational monitoring tasks.

SAR interferometry (InSAR) is one of the main applications of radar imagery because it fully exploits the geometric precision of the SAR systems (in the order of the sensor wavelength). These radar satellite images, unlike optical satellite images, provide an accurate measurement of the distance between the satellite and the ground. The principle of interferometry is based on the superposition of waves from two images in order to detect differences in distance measured in wavelength fractions.
For ground motion monitoring projects several satellite images taken at different times are compared. By means of the analysis of the evolution of the distance between the sensor and the ground of the different acquisitions, information regarding the topographical relief and ground deformation can be extracted. These two main components are superimposed in the interferometric signal jointly with other unwelcome contributions, the most critical one being the one due to the variations in the state of the atmosphere during the image acquisition. It is very important to properly filter these unwanted variations in order to avoid possible errors when interpreting the InSAR data.

The Stable Point Network (SPN) is an advanced differential interferometric software developed by Altamira Information in order to process stacks of 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.

Figure 1: Performance of InSAR technology to measure the ground deformation from the comparison of the evolution of the distance between the sensor and the ground in repeat satellite passes.

The application of SPN is very suitable for Coal Seam Gas (CSG) reservoir monitoring as it can cover wide areas at a very high resolution and with millimetric precisions. The availability of archive SAR data also offers a unique opportunity to look into the past and to perform historical studies. CSG operators can accomplish regulatory requirements in the monitoring of subsidence, starting with a baseline and continuing afterwards with ongoing monitoring to quantify deformation at the land surface within the proponents tenures.

1.2 Coal Seam Gas reservoirs

Coal Seam Gas is the natural gas generated by the microbial or thermogenic processes that occur during and after the formation of coal from organic matter. The gas is trapped in microscopic fractures (cleats) within the coal by the pressure exerted by the groundwater within the coal seams. CSG is produced by extracting groundwater to reduce the pressure to allow the gas to flow. During the early production of a well water production rates are relatively high. When the water pressure is reduced below a critical point, dependent on gas content and saturation, gas begins to flow and the water production rate begins to decline. Over time the pressure within the gas reservoir is reduced to about 50PSI above the top of the coal measures, by which time there should be little water production.
The CSG reservoir in this study is the Jurassic-aged Walloon Coal Measures of the Surat Basin, Queensland. Within the study area, the top of the WCM is between approximately 200m and 1,000m below ground level (mbgl). The WCM is generally between 300m and 350m thick, contains around 10% (35m) of actual coal, with the intervening material being mostly siltstones and mudstones. Individual coal seams rarely exceed 0.5m thick.

The Surat Basin is a major constituent of the Great Artesian Basin (GAB). The GAB underlies approximately one-fifth of the Australian continent is heavily utilised for water supplies in an area where surface water resources are scarce and unreliable. The majority of water is used for stock purposes. The WCM lie approximately mid-way through the GAB sequence. The GAB comprises alternating aquifers and aquitards and reaches a maximum thickness of about 2,500m in the study area. Groundwater use by landholders is generally extract from the shallow aquifers. The deeper aquifers are generally only used when large volumes of water are required.

2. GROUND MOTION MEASUREMENTS

This section presents and discusses some results based on the historical analysis of 530 images over the Surat Basin in Queensland. The whole study covers an area of 45,000 Km² studied during the period December 2006 - February 2011. The SPN processing of these data stack allows the retrieval of more than 30 millions of measurements point which represents a mean density of 600 points/Km². In consequence, consistent measurements of the historical ground motions are obtained over the site. The global analysis of the results allows the identification of many small field areas of uplift and subsidence which are found heterogeneously distributed throughout the site.

In particular, several field areas at the riverbanks present an important uplift of more than 20 mm during 2010. This deformation might result from an increase of rainfall values over the area, known to have happened in 2010. The annual climate statement of 2010 by the Bureau of Meteorology of the Australian government stated that based on preliminary numbers, 2010 was the wettest year on record for Queensland. A mean rainfall total of 690mm well above the long-term average of 465mm was measured. Figure 2 shows an example of correlation between the floodplain map generated by the Department of Environment and Resource Management for the Queensland Reconstruction Authority for the period 2010/2011 and the measured uplift motions at the surrounding of Taroom.

Another interesting example of subsidence can be found at the walls of some pond or irrigation pools, providing an example of how InSAR is also valuable for infrastructure management in this type of application field.
2.1 Correlation of ground motion with CSG activities.

Some CSG fields belonging to Origin were already active during the historical ground motion analysis. In our experience in previous works with injection and production in oil and gas fields, the surface deformation is associated with the location where the fluid is being produced with high relative flow (subsidence), or alternatively where there is low relative flow and thus pressure build-up. According to this the pressure changes which result in deformation changes are reflecting hydrodynamic flow variations. Well injection locations themselves are not necessarily where the deformation will occur, unless they happen to be adjacent to a flow barrier (injection) or high flow unit (production). However, deformation adjacent to wells should be able to be correlated with production or injection rates.

Based on this initial discussion an initial qualitative comparison between CSG operations and surface ground motion has been performed with the aim of retrieving a possible relationship between these two factors. In particular, a correlation analysis between the extracted water and the measured motion with InSAR for several wells was carried out. This relationship will certainly change with the depth of burial, the permeability of the formation (also related to the water production rates, but will affect the rate of depressurisation of the surrounding area), and the geomechanical properties of the overlying rock.

The correlation analysis was based on the comparison of the evolution of the rates of extracted water against the ground motion for the surrounding InSAR points of each well. The preliminary analysis shows interesting relative variations of both magnitudes in some cases. However in other examples where the water extraction levels were high there is no measurable ground motion. Figure 3 illustrates two examples of this analysis with and without an apparent correlation. In several cases, the InSAR measurement point which gives the best correlation with the water production variation is not necessarily the nearest one regarding the well location.
Figure 3: Example of correlation analysis between the evolution of the surface motion over time and the extracted water (lilac line) at two different CSG active wells. The bolded InSAR time series are the ones that give the best correlation index within a radius of 200 meters around the well. On top (a) there is an example of very high correlation between both curves. On bottom (b) there is an example of a well with an important extracted water amount without measurable motion.

3. CONCLUSIONS

The conducted historical analysis demonstrates that InSAR data is very suitable for the detection and monitoring of ground motion in the energy sector. InSAR technology gives a relevant amount of measurements data (600 points/Km2) covering a very wide area with millimetric precisions.

Several small areas in open fields affected by ground motion were detected and analysed. Subsidence patterns are also identified over the walls of ponds or irrigation pools. Additionally, several uplift patterns are observed along some riverbanks, possibly related with the heavy rains occurred during 2010. Those areas are not related to CSG operations since they are located in non-active fields.

In active CSG fields the amount of extracted water was compared with the measured ground motion at the surrounding of each well. The correlation analysis shows interesting correspondence of the evolution of the ground motion through time with the variations of the amount of extracted water. The best correlation it is not always achieved with the nearest InSAR points with respect to the well location. However, the results also show areas without motion at the surrounding of active wells. Further analyses will be conducted in order to understand the possible relationship between the CSG production activities and the surface motion.

It is clearly concluded that InSAR data is able to track the motion on the ground with a coverage and precision that will be a valuable tool with potential great use for understanding the behavior of the land motion in active CSG fields.