

Steam Chamber Monitoring using Surface Deformation from Radar (PS-InSAR) and Tiltmeter Measurements

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Summary

Monitoring of bitumen in-situ production is essential to optimize production and to do it in a safe way.

Traditional monitoring techniques are based on production and injection rates, pressure and temperatures. The surface deformation measurement is an additional mean to assess and visualize what is going on in the overburden and in the reservoir. Radar telemetry and tilt measurements were used on our SAGD field case to quantify the deformations, enhance safety and understand the limitations of such techniques. The measured deformations are consistent with geomechanical modeling.

Introduction

Most of currently produced bitumen in Athabasca is produced by surface mining. However a large part of the bitumen reserves will be produced by in-situ techniques, requiring injection of steam in the reservoir at high temperature and fairly high pressure.

Our SAGD plant is located in northern Alberta. The reservoir is in the McMurray Formation of Lower Cretaceous age. The depth of the reservoir is between 60 to 80 meters. Monitoring of the steam injection is necessary to optimize production while producing in a safe way.

Field monitoring is traditionally based on steam injection rates, oil and water production rates, pressure and temperatures. Seismic may give an areal view of the steam chamber growth but requires the ground to be frozen and acquisition is therefore limited to winter periods. Surface deformation monitoring is an other technique to assess the spatial expansion of the steam. In our case, it is particularly adapted as the reservoir is very shallow. Stancliffe, 2001, discussed the

advantages of the different techniques to measure the deformation. We based our measures on the latest available techniques: radar interferometry and tiltmeters.

Deformation Measurement by Radar Stable Point Interferometry

Ground deformation measurement by radar interferometry has been described on other fields (Stancliffe 2001, Mei 2007). When we started our study, only satellites working in the C-band (0.055 m) were available. The interferometry with these satellites is usually performed on dry or urban areas where 'stable' landmarks are present. In Northern Alberta, mostly covered by trees with the addition of snow in the winter, correlation between consecutive images is poor. The use of artificial corner reflectors (ACR) can solve this problem, and gives very precisely identified locations where the deformation is measured. However, the satellite is flying over the same location every 35 days which is sufficient for monitoring purposes but not for surveillance purposes. We therefore used several satellite tracks with different vertical incidences. This makes the computation of the displacement more complex but gives access to 2D surface deformation (Y and Z) instead of a 1D (Z) assumed deformation when using a single satellite track.

Over a six months period, maximum surface deformation is around 2 cm and is well correlated with injection, production and pressure. Second order movements in the order of one cm are also observed both above the well pairs and at some reference ACR locations and will be compared to soil nature and other environmental parameters for a full understanding.

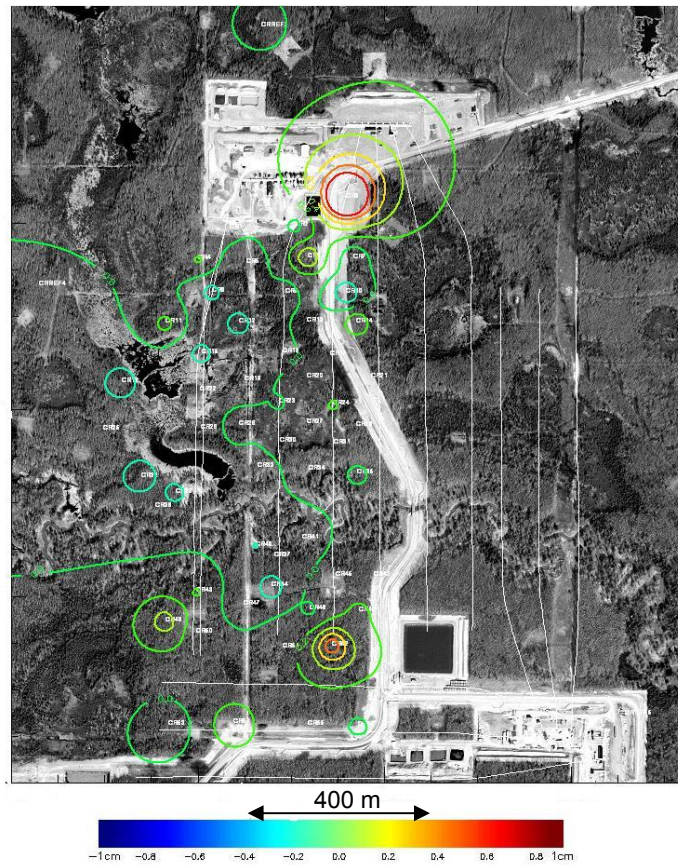


Figure1: Surface deformation over a 5 months period as measured by Radar Interferometry

Deformation Measurement by Tiltmeters

Tiltmeters measure the surface tilt. They have been used for decades to measure deformations of volcanoes to follow magma movements. Today's tiltmeters derived from military technology can measure angles as small as a few nanoradians. They are so sensitive that they record the Sun and Moon influences on the Earth surface. This makes them also sensitive to human nearby activities and to surface conditions. This was observed on the edges of our layout.

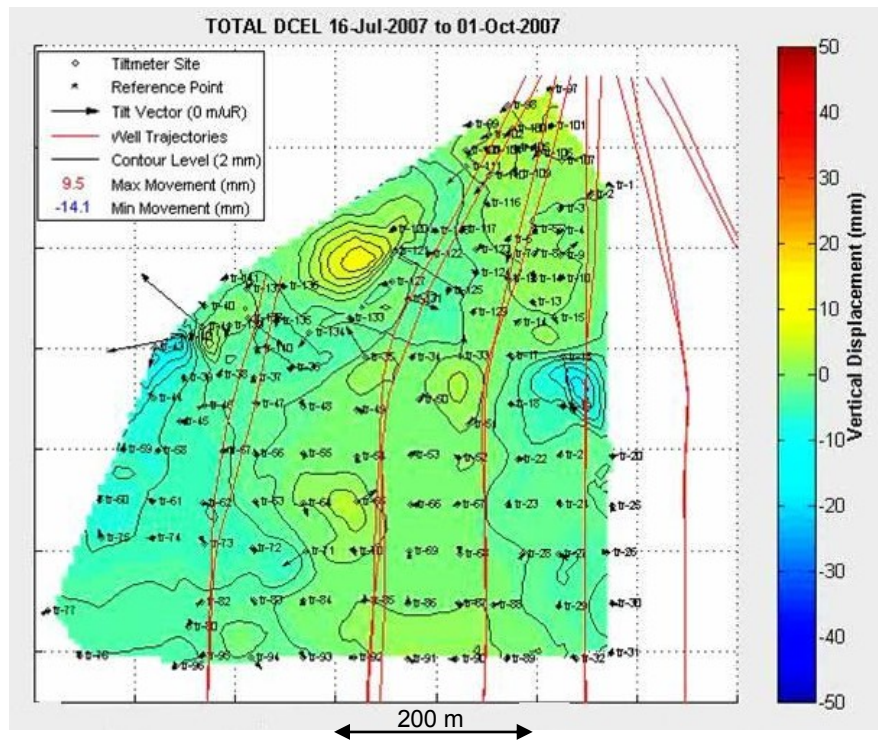


Figure 2: Surface deformation over a 3.5 months period as computed from tiltmeter measurements

Radar Interferometry vs Tiltmeters

Our ACR layout is covering three well pairs and consists in 60 double corner reflectors. This system is well adapted to cover a large area. Displacements are measured every 2 to 3 days. Our tiltmeters layout consist of about 100 tiltmeters and is more concentrated in the vicinity of the well heads and therefore give a sharper but currently noisier image of the deformation. Tiltmeter measurements are continuous in time.

Both data are showing the same areas of elevation along a SW-NE axis and subsidence in the West and East. Over the first six months of measurement, the deformation is no more than 2 cm, consistent with geomechanical modeling that we performed.

Conclusions

PS-InSAR and tiltmeter measurements allow to measure the surface deformation of bitumen in-situ production and are important tools both for safety and monitoring purposes. However, measurements are sensitive to environmental factors and human activity and need to be carefully QCed and validated to avoid false alarms.

Acknowledgements

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