Operational applications for the Oil and Gas industry measuring ground motion with radar satellites

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ALTAMIRA INFORMATION

is an experienced earth observation company

that provides ground movement measurements

with millimetric precision using satellite images.
ALTAMIRA INFORMATION & CLS Group
Providing integrated services for industry, environment and security.
Altamira Information brings together a team engineers experts in InSAR technology. The company’s head office is in Barcelona (Spain), with branch offices in 14 other countries and expanding with agents in more areas.
Millimetric ground deformation measurements
Introduction to Altamira Information
InSAR leader in the different industrial sectors

**Infrastructures**
- Infrastructures (railway, ports…) monitoring
- Planning, construction and maintenance

**Mining**
- Open pit mines and slopes
- Underground mines
- Infrastructures

**Oil & Gas**
- Reservoirs, pipelines and gas storage monitoring
Introduction to Altamira Information
Leader in InSAR R&D projects

ESA Terrafirma:
biggest GMES terrain motion hazard information service

Service coverage 2009-2011

The current (third Stage) of the project is lead by Altamira Information;
it has a budget of 4M€ over 3 years.
The German space agency (DLR) has certified that the PSI processing of Altamira Information was conformed to the Terrafirma Validation Project standards.

**Leader in InSAR technology**

**Advantages of using the Altamira Information PSI’s processing chain**

- **Technique developed in-house**
  Continuous investment in internal developments in PSI. Adaptation of the technology to the project needs

- **Multidisciplinary team**
  Experts in SAR signal processing, geologists, mathematics, software developers, commercial division

- **Chain multi-satellite**
  The processing chain is able to handle all the current satellite SAR missions and all the acquisition modes (Spotlight, StripMap, ScanSAR, TOPSAR)

- **Quality controls**
  Different QCs (certified by DLR) are applied during the processing

- **Validation**
  Validated results with external measurements: precise leveling, GPS, geodesic measurement, extensometers
Analysis of the title:

Operational applications for the Oil and Gas industry measuring ground motion with radar satellites
Operational applications for the Oil and Gas industry measuring ground motion with radar satellites
Travel phase between ground and sensor gives millimetric distance.

Ground movement is measured with radar satellites, comparing the satellite distance from the Earth surface at different moments in time.
Travel phase between ground and sensor gives millimetric distance.

Ground movement is measured with radar satellites, comparing the satellite distance from the Earth surface at different moments in time.

**Introduction to PSI technology**

- **Radar satellites**
  - **Interferometric Synthentic Aperture Radar (InSAR)**
  - Superimposition of waves to detect differences
  - High resolution radar system

- **First measurement**
  - Travel phase between ground and sensor gives millimetric distance

- **Second measurement (afterwards)**
  - Difference between two measurements indicates ground movement over time

- **Results**
  - Ground motion measurements map
  - Time series for each point

**For a specific measurement point**

- Cm / year
  - +1 cm
  - +0.5 cm
  - +0 cm
  - -0.5 cm
  - -1 cm
Operational applications for the Oil and Gas industry measuring ground motion with radar satellites
## Applications for the Oil and Gas industry

| Reservoir monitoring | Safety of reservoir and infrastructure: Prevent reservoir compaction  
| CH₄ / CO₂ storage | Extraction efficiency: Ground motion measurements can deliver information about gas distribution and pressure in the reservoir  
| Pipeline monitoring | Quality and safety control of natural gas and CO₂ storage sites with uplift and subsidence monitoring  
|                      | Monitoring stability for storage sites with seasonal pressure changes  
| Platform monitoring | Detection of pipeline leakages  
|                      | Prevention of potential leakage risks by measuring ground motion on pipeline tracks  
| Monitoring of LNG terminals | Monitoring of sea-anchored offshore platforms  
|                      | Information until when platform will continue  
| Refinery monitoring | Safety of storage sites  
|                      | Ground motion monitoring for LNG terminals, in coastal areas  
| Mapping | Safety of production installations (refineries)  
|                      | Ground motion monitoring for refineries that might be affected by subsidence or ground motion  
|                      | 3D and structural mapping, especially in remote areas  
|                      | Digital Elevation Models can be updated efficiently with new data  

*altamira*
Gas Storage: CH\textsubscript{4} and CO\textsubscript{2}

InSAR surface monitoring for reservoir characterization

**Pre injection phase**

- **Historical analysis** of the selected site to get ground motion information of the surface and detect vulnerable areas.
- **SAR Structural Image & DEM** to enhance textural surface information to provide structural maps.

**Injection and future monitoring**

- **HR Ground deformation monitoring** when injection starts with monthly or even weekly updates.
- **Installation of Corner Reflectors** where measurement points are not guaranteed (*optional*).
- **Combination** of ground motion monitoring results with other monitoring technologies: micro-seismic, ground-level gas measurements, temperature, pressure.
Applications for the Oil and Gas industry

CO₂ injection monitoring (Northern Africa)

CO₂ storage at 1900m depth.

Areas of uplift (5mm/year) have been detected surrounding the injection wells. (Blue areas on the images).

Areas of subsidence (2.5 mm/year) in the extraction area have been detected affecting gas field facilities.
Product example: High resolution

High resolution product – Overview

A high resolution product identifies ground motion with a very high measurement point density and precision.
1. Steam injection to dissolve heavy oil
2. Surface uplift as a consequence of steam chamber formation
3. Ground motion measurements using radar satellites
4. Measurement results: Uplift
5. Measurement results: Subsidence
Applications for the Oil and Gas industry
Oil sands in Canada: Installation of corner reflectors

Monitoring:
Monthly and bi-weekly update with a new images every 1-3 days.
Flexibility to increase monitoring to weekly rhythm.
Case study 3
Oil sands in Canada: Installation of corner reflectors

Steam injection at highlighted well

Uplift appearing in well center
Analysis of the title:

Operational
Definition: Operational

Thesaurus:

Adj.

1. *operational* - pertaining to a process or series of actions for achieving a result;

   Relevant measurement points

   Accurate motion measurement

2. *operational* - *ready* for or in condition to undertake a destined function.

   Reliable source

   Delivered or Triggered in time
Reliable sources
Radar satellites used by Altamira Information

ERS-1
Launch: July 1991
Owner: European Space Agency
Frequency: C-band

ERS-2
Launch: April 1995
Owner: European Space Agency
Frequency: C-band

Radarsat-1
Launch: November 1995
Owner: Canadian Space Agency
Frequency: C-band

ENVISAT
Launch: March 2002
Owner: European Space Agency
Frequency: C-band

ALOS
Launch: January 2006
Owner: JAXA
Frequency: L-band

Radarsat-2
Launch: December 2007
Owner: Canadian Space Agency
Frequency: C-band

TerraSAR-X (x 2)
Launch: June 2007
Owner: German Space Agency
Frequency: X-band

COSMO-SkyMed (x 4)
Owner: Italian Space Agency
Frequency: X-band

New satellites
New generation X-band satellites are satellite constellations: Working with several similar satellites mitigates the risk of satellite failure.
Example of combination of sensors

X band Monitoring

Original monitoring

Backup solution
Example of combination of sensors
Cross-sensor coregistration quality check

TSX images have been coregistered to CSK geometry
RGB amplitude image shows the coregistration quality:
Green and blue colors are CSK / Red is TSX

The coregistration quality is good except in layover areas
➢ the distortions are too big and the resolution too poor
The radar backscattering is very similar in most of the areas
**Example of combination of sensors**

**Cross-sensor coregistration quality check**

**Interferograms with similar characteristics show areas with the same quality**

<table>
<thead>
<tr>
<th></th>
<th>Interferometric coherence</th>
<th>Interferogram</th>
<th>Topography and atmospheric phase cleaned interferogram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Terrasar-X with COSMO-SkyMed</strong></td>
<td><img src="image1" alt="Interferogram" /></td>
<td><img src="image2" alt="Interferogram" /></td>
<td><img src="image3" alt="Interferogram" /></td>
</tr>
<tr>
<td>Bp: 156m, Br: 22 days</td>
<td><img src="image4" alt="Interferogram" /></td>
<td><img src="image5" alt="Interferogram" /></td>
<td><img src="image6" alt="Interferogram" /></td>
</tr>
</tbody>
</table>

**COSMO-SkyMed**

Bp: 170m, Br: 40 days

![Interferogram](image7)  
![Interferogram](image8)  
![Interferogram](image9)
Example of combination of sensors

SPN movement detection Time Series

- **Acumulated displacement (cm)**
  - **Uplift**
    - More than +5.0
    - +3.5 a +5.0
    - +2.0 a +3.5
    - +2.0 a -2.0
    - -2.0 a -3.5
    - -3.5 a -5.0
  - **Subsidence**
    - More than -5.0

- **Displacement [mm]**
  - 5/2/2010
  - 7/1/2010
  - 8/30/2010
  - 10/29/2010

- **Displacement [cm]**
  - 5/2/2010
  - 7/1/2010
  - 8/30/2010
  - 10/29/2010

- **Graphs**
  - Time series graph showing displacement over time.
Definition: Operational
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Relevant measurement points
Measurement technology adapted to site conditions

- Natural measurement points: using coherence of dry and arid surface conditions as measurement points
- Roofs, houses and buildings used as measurement points: they reflect the radar signal during period of analysis
- Installation of artificial corner reflectors to guarantee presence of measurement points

Site conditions determine which technique will be used for measurement purposes.
### Analysis and results

- Due to arid conditions is an ideal test site for the application of InSAR technology for ground deformation monitoring for CO₂ storage at 1900m depth.
- Injection phase: period of study (2003-2010).
- 46 images have been used
- Areas of uplift (5mm/year) have been detected surrounding the injection wells. (Blue areas on the images).
- Areas of subsidence (2.5 mm/year) in the extraction area have been detected affecting gas field facilities.
Relevant measurement points

Uplift in west Berlin: Urban Area

Objective of the project

- Detection and mapping of areas affected by uplift and subsidence movements, study using ERS images 1992-2001

Analysis and results

- Strong uplift in west Berlin is attributed to underground gas storage at salt pillow location (see zoom-in analysis graphics).

- Subsidence is visible at Teufelberg, an artificial debris mountain, caused by the compaction of debris. Uneven settlement is seen at the Egelpfuhl landfill site which is experiencing uneven compaction.

"PSI is an efficient tool for vertical ground motion detection even if its rate amounts to parts of a mm per year." BGR
Relevant measurement points
Typical coverage of Natural Reflector in Rural Area

CH$_4$ Storage in Europe

CO$_2$ Storage in North America
Relevant measurement points
Natural targets analysis on Oil and Gas Infrastructure
Corner Reflectors provide reliable measurements points at the exact required place.
**Relevant measurement points**

**Accurate motion measurement – Seasonal effects**

High number of points on the center and southern area will be conserved in winter.

Almost every point on facilities and the airport are maintained.
A proper ACR installation ensures the right monitoring of the shallow reservoirs avoiding the variations due to freeze/thaw period.

Impact of ground motion due to seasonal effects
Measurement of two reflectors at nearly identical location

If piles are properly installed, the measured movement is not due to freeze/thaw of ground surface, but due to ground motion.
Conclusions

- Altamira Information is the leading company in installation of reflectors: its long-year experience is reflected in valuable best practice actions for the whole process from network design to ground motion measurements.

- Altamira Information is an InSAR provider with very reliable and high quality measurements: Quality control in all project steps is key for Altamira Information.

- Altamira Information is satellite independent: the satellite recommendation is completely adapted to project requirements.

- Altamira Information has developed and is using its own InSAR software. The technical knowledge is in-house what provides higher quality and flexibility to adapt the technology to specific project requirements.

- Altamira Information is worldwide recognized as technical leader in InSAR technology: Altamira Information won 3 out of 3 World Bank tenders and is leading the InSAR consortium Terrafirma.
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