



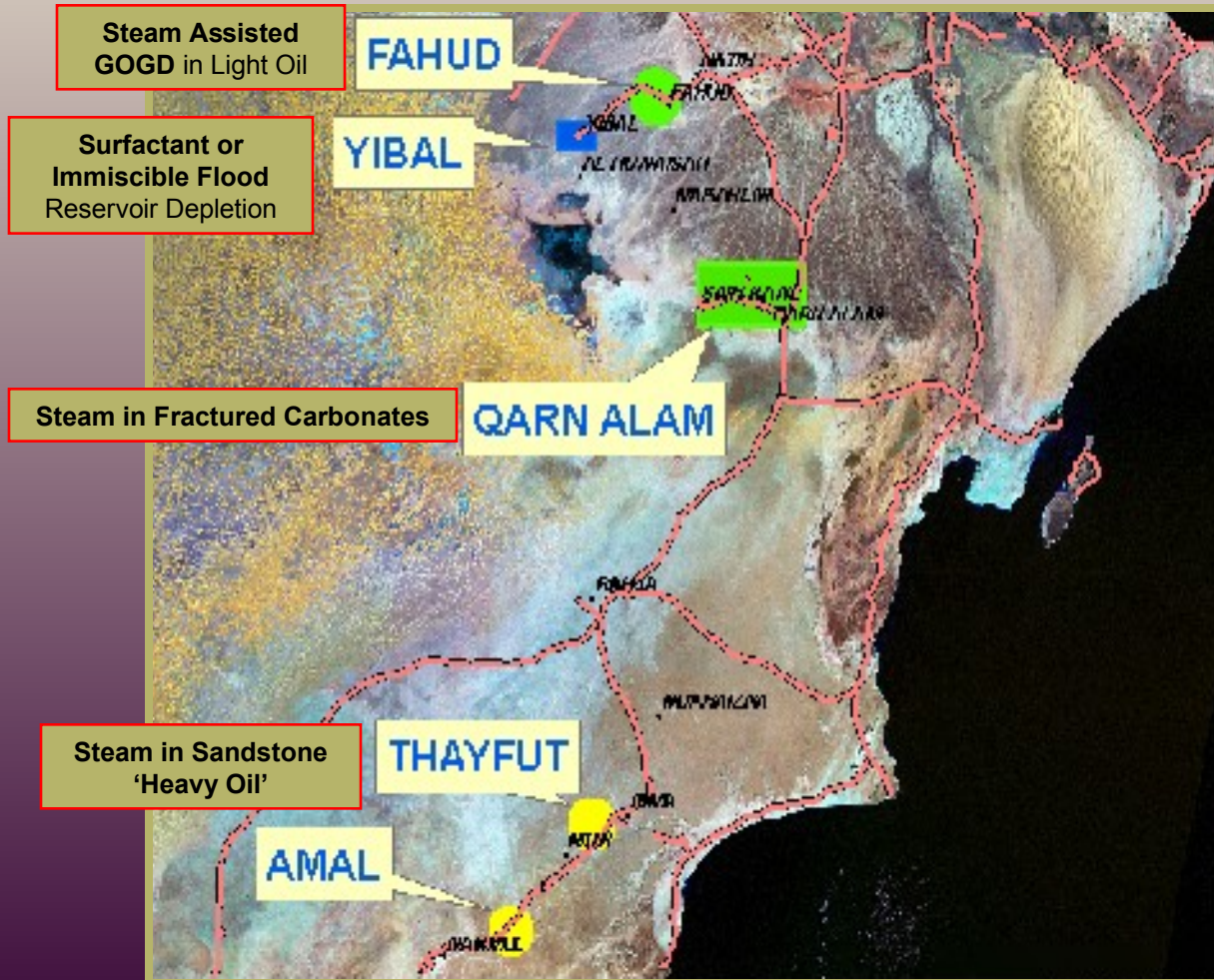
SURFACE DEFORMATION MONITORING

part of geophysical reservoir monitoring technologies
applied in Enhanced Oil Recovery projects

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PDO



CURRENT & FUTURE GEOPHYSICAL MONITORING AREAS



Enhanced Oil Recovery projects are main PDO's mid and long term strategy (Particularly steam injection projects)



Objectives of Geophysical Reservoir Monitoring

- 1. *Map the 3D progression of the heat front***
- 2. *Map expansion of the reservoir***
- 3. *Identification of fracture/fault reactivation***
- 4. *Measure stress changes in the caprock to assess caprock integrity***

Geophysical Monitoring Techniques includes;

- ***Micro Seismic.***
- ***Surface Deformation.***
- ***Time Lapse Seismic.***



Surface Deformation Techniques

Aims to detect deformation at the surface expressed as a change of slope, a horizontal movement, a subsidence, or an uplift.

Surface measurements are carried out using ;

- ***Tiltmeter;***
- ***Optical Precise Levelling;***
- ***Precise Global Positioning System (GPS);***
- ***Satellite Remote Sensing Radar technique known as Interferometric Synthetic Aperture Radar (InSAR)***



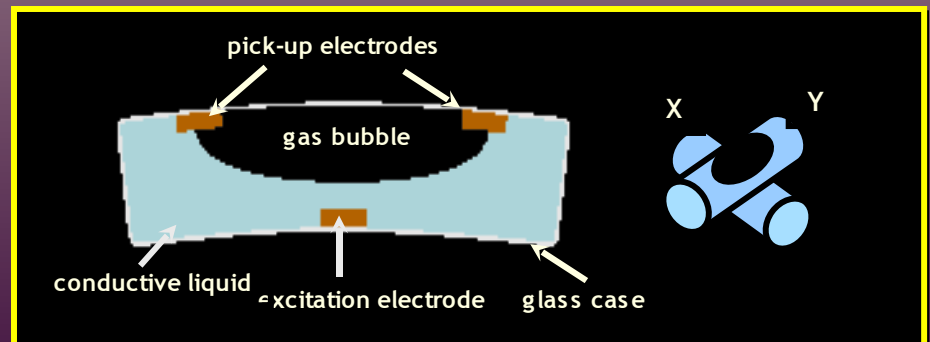
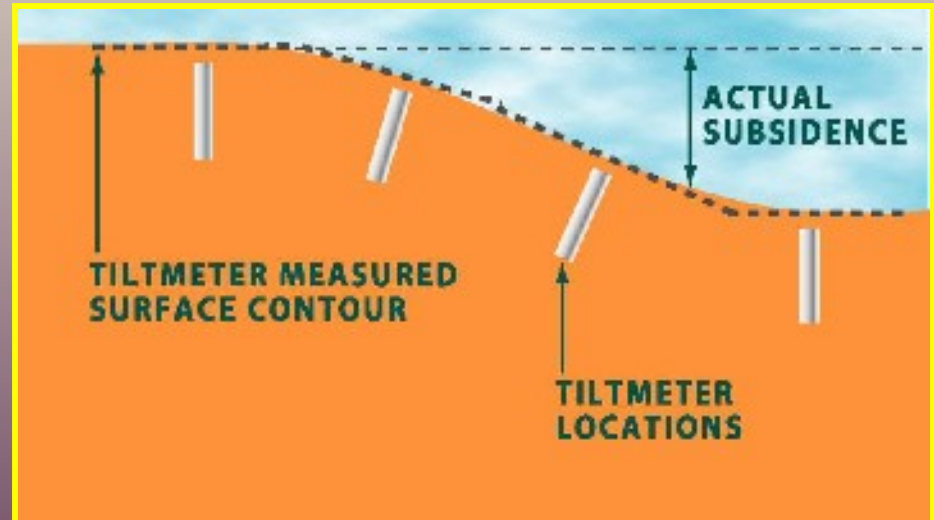
Tiltmeter

Advantage;

- *Can resolve tilt as small as one billionth of a radian corresponding to sub-millimeter precision across a typical array*

Disadvantage;

- *Too much sensitivity and too little long-term stability*
- *Only Vertical Component.*





Optical Precise Levelling (PL)

Advantage;

***Sub/One millimeter Precision
and most reliable***

Disadvantage;

- ***HSE (Tedious under the sun)***
- ***Long time which might not be suitable for steam monitoring requirement***
- ***Only Vertical Component.***





Precise GPS

Advantage;

- *One to several millimeter Precision*
- *both horizontal and vertical displacements*
- *Faster than PL*
- *Real Time Continuous Data*

Disadvantage;

- *Can be an HSE issue*
- *Point Measure*
- *Initially could be Costly*





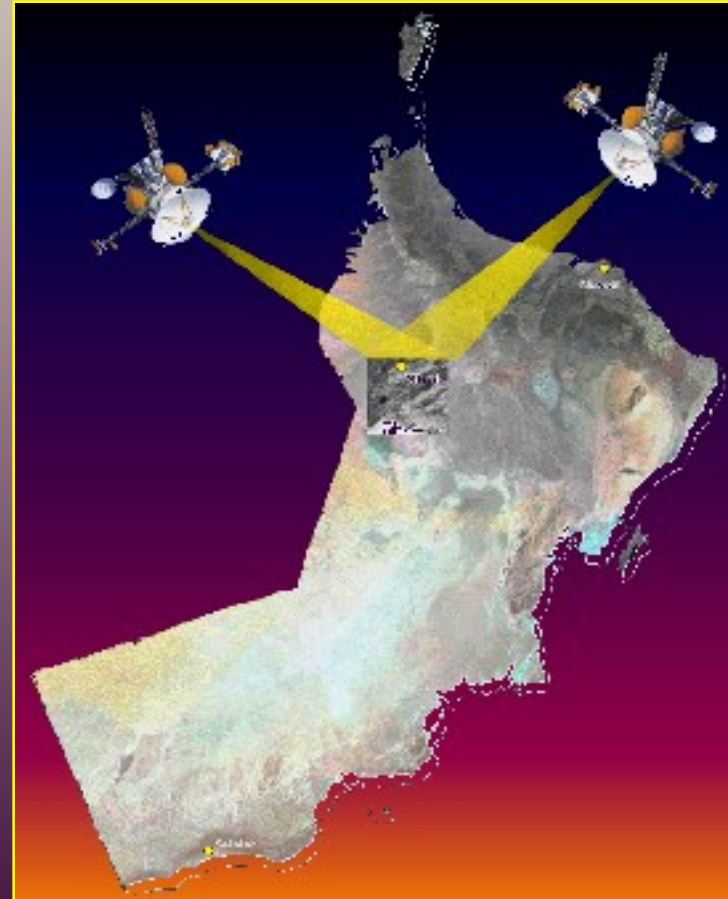
Interferometric Synthetic Aperture Radar (InSAR)

Advantage;

- *Wide Area Coverage*
- *Several millimeter Range Precision*
- *100% Remote*
- *Low Cost*
- *Existing Database*

Disadvantage;

- *Atmospheric Errors*





Optimum Surface Deformation Techniques

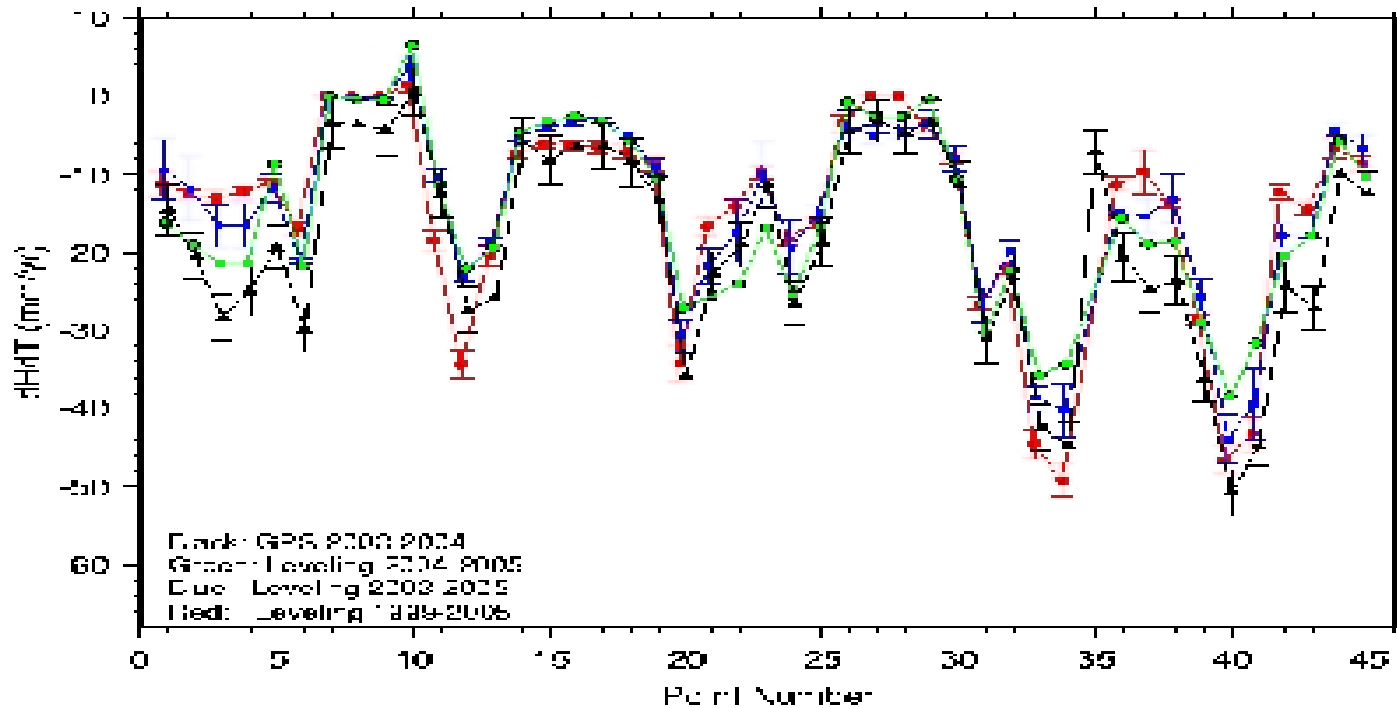
GPS is reliable and the only technology to measure horizontal surface displacements -valuable additional information for reservoir monitoring.

Combinations of GPS and InSAR processing are recommended to exploit the time-density of GPS data and the areal density of InSAR data



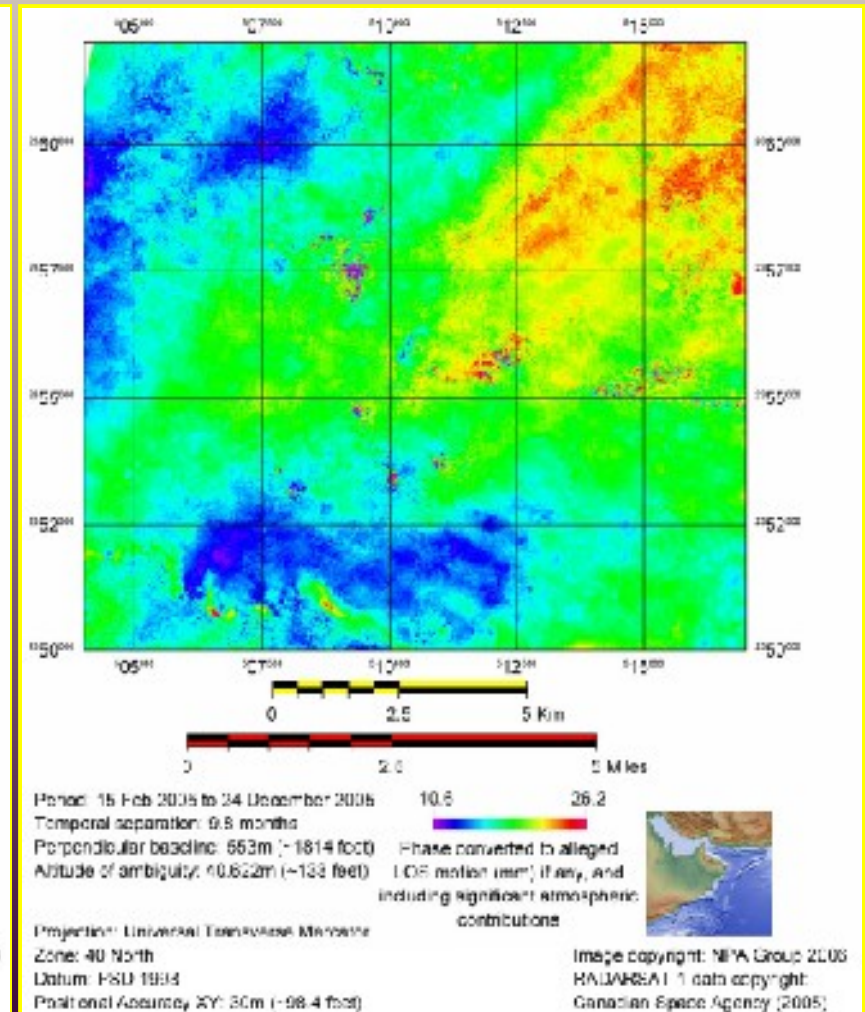
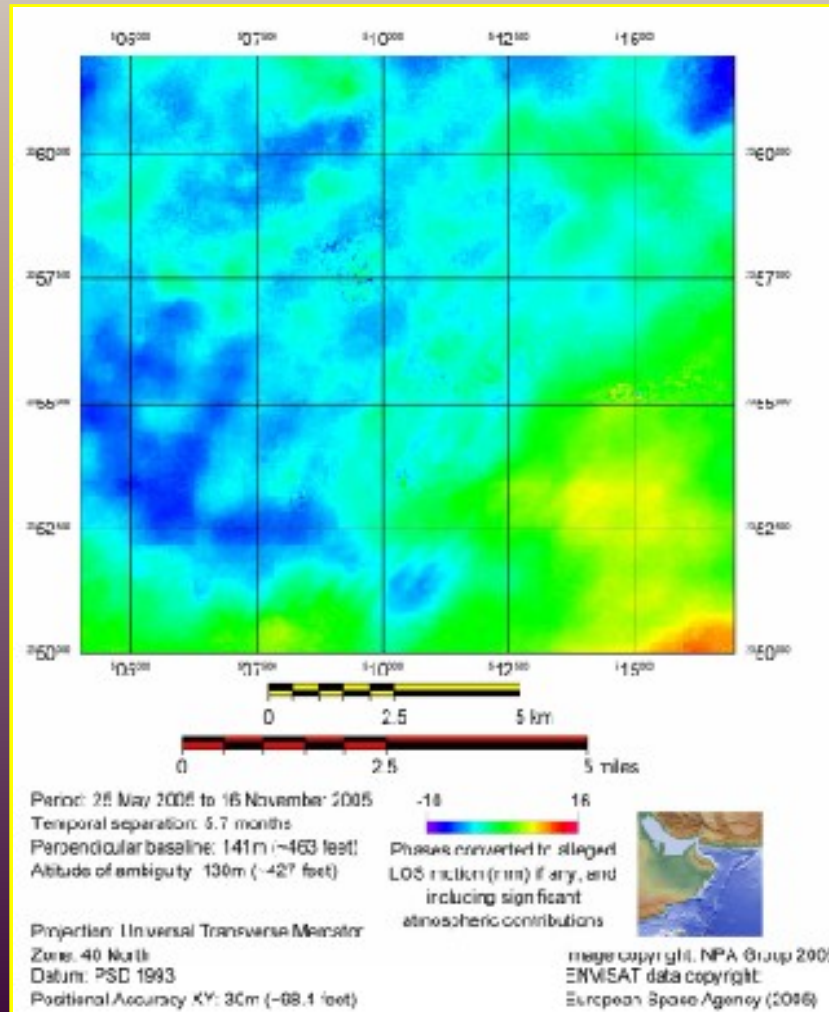
GPS/Levelling Comparison (2003-2005)

GPS Leveling Comparison





Qarn Alam InSAR Baseline Study





Mitigating Atmospheric InSAR Error

InSAR corrected using GPS

Uses the accuracy of GPS to propagate appropriate corrections to all nearby InSAR measurements

Persistence Scatterers Synthetic Aperture Radar Interferometry (PSI)

Uses a time series of SAR images to average-out atmospheric errors over every pixel with strong radar scattering properties



Acknowledgements

Stephen, Bourne (EPT-RHS)

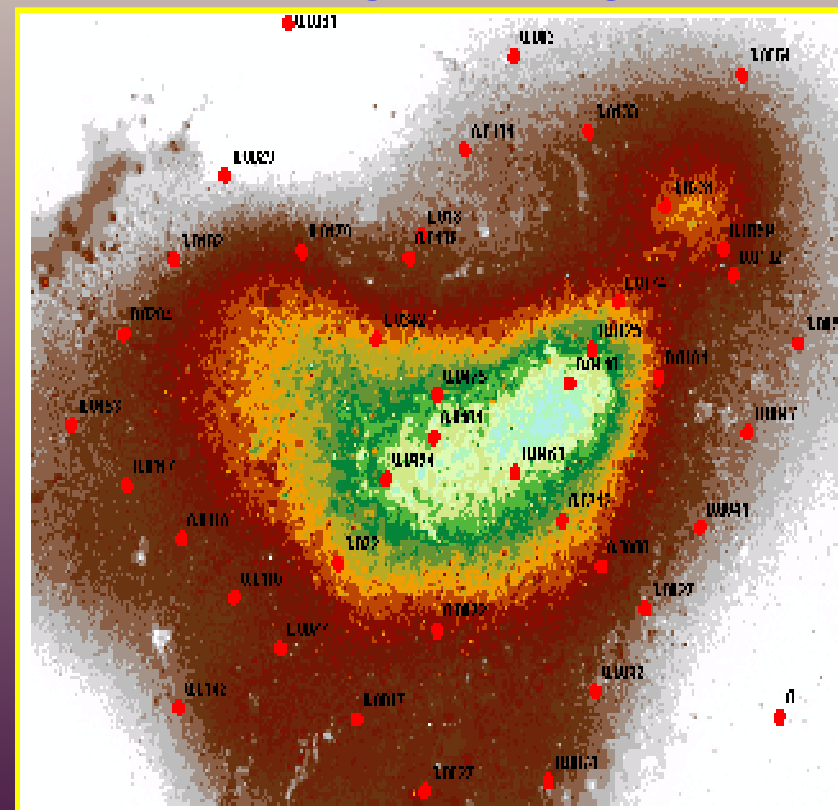
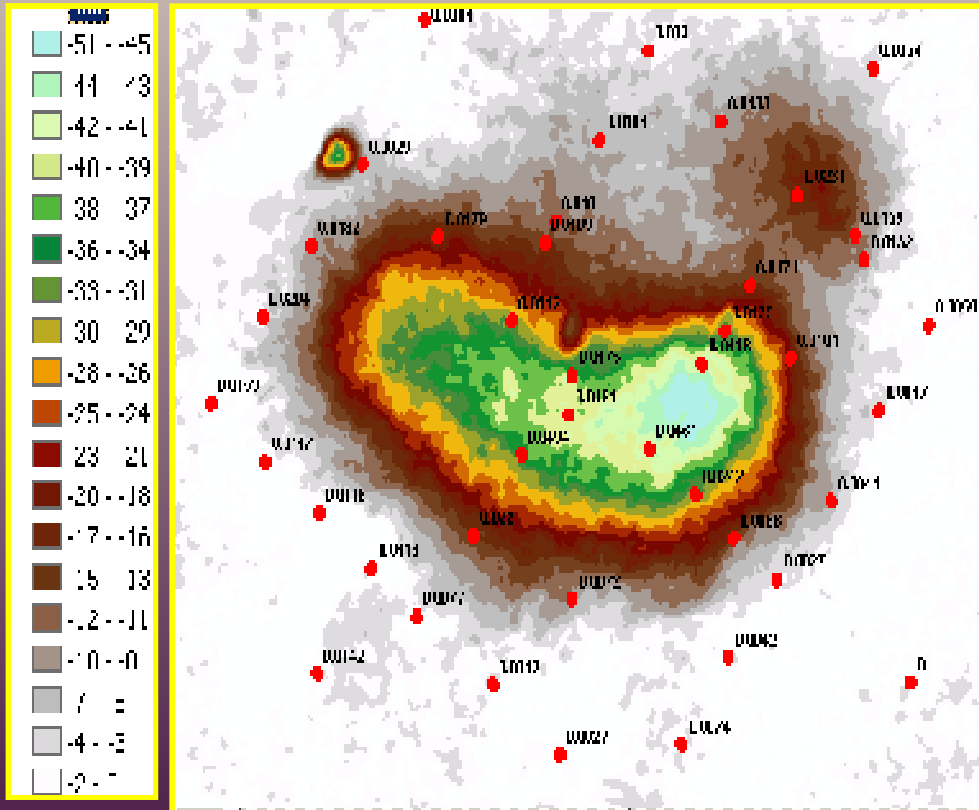


Persistence Scatterers Synthetic Aperture Radar Interferometry (PSI)



Standard InSAR Sep01/July04

PS-InSAR Aug_2004/Aug2006



	CODE	NORTH	FAST	VFL_BFRG	V_STDEV	COHERENCE	D20040817	D20040910
1	AFMRR	2454732.227000	403808.9327500	-0.62	2.20	0.85	4.57	5.48
2	AFMRR	2454731.400000	403809.1745000	-0.49	2.31	0.67	2.97	3.30

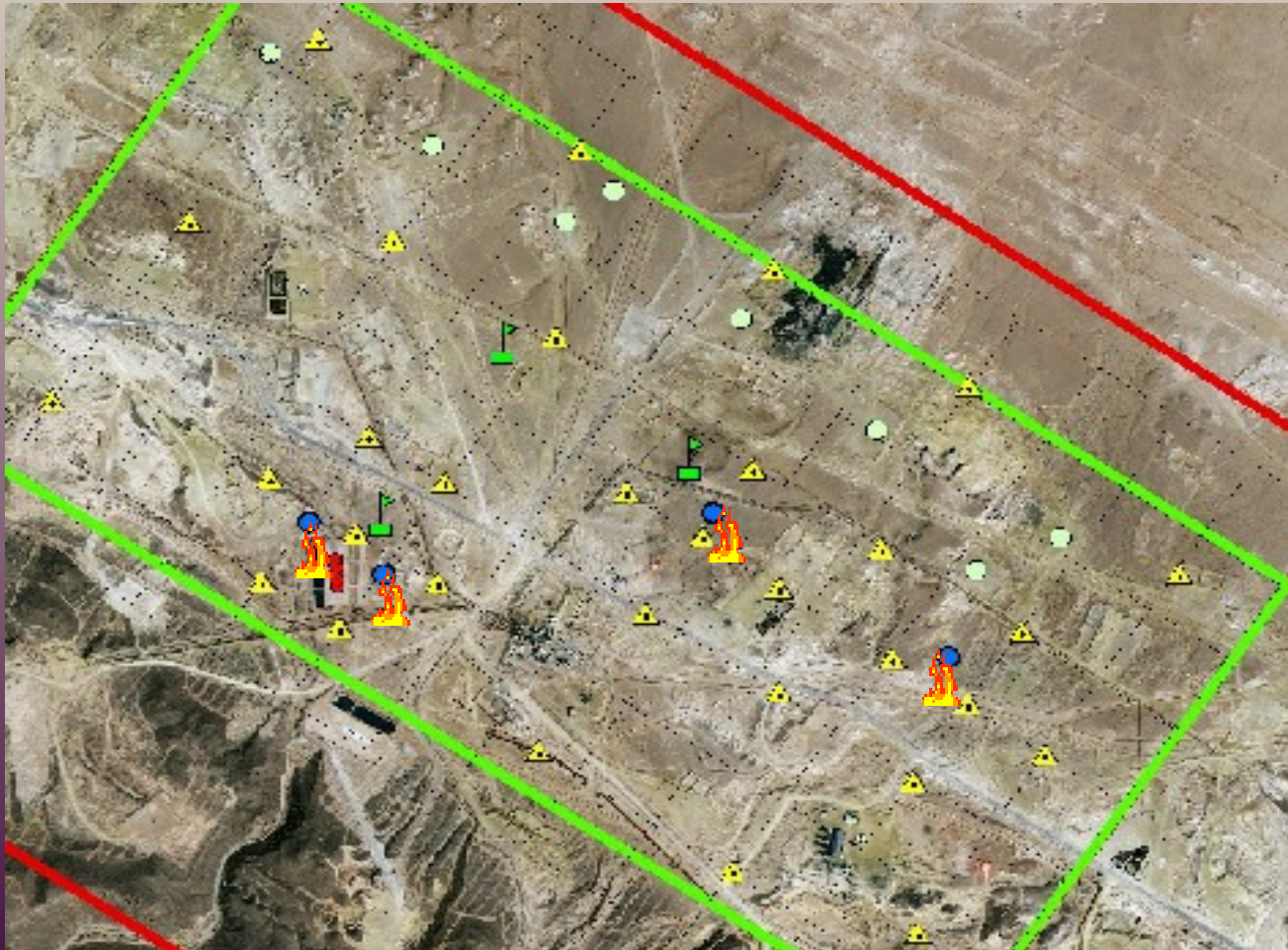


Recommendations

- ***Options for reservoir monitoring should provide the right information at the right time. The quality of information depends on the areal coverage, density, and accuracy of surface displacement measurements.***
- ***Management of steam injection operation is a dynamic process -requires more frequent (i.e. every 2-3 months) observations and expected deformation is around 1-3 cm/year.***
- ***Recommend using combined InSAR and GPS techniques (every 2-3 months). In addition, for wider aerial project coverage, PS InSAR technique is to be repeated once a year.***



Fahud Implementation Strategy Plan



- Steam Injector Wells
- Pilot Wells
- Oil Producer Wells
- SteamPhase1_2Year Heated Zone
- SteamPhase1 Reservoir Model
- ▲ Rover Location
- Continuous Location