Time-Lapse Monitoring with Satellite Data for Reservoir Management*

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Abstract

Reservoir monitoring improves our understanding of reservoir behaviour and helps achieve more effective reservoir management and prediction of future performance with obvious economic benefits. It relies on an integrated approach involving both surveillance (well or surface based; seismic, electrical, leakage, flow and deformation measurements etc.) and modeling.

Volumetric changes in reservoirs due to fluid extraction and injection can induce either subsidence or uplift which could trigger fault reactivation and threaten well integrity; deformation may also be detectable at the surface.

The occurrence of surface displacements related to reservoir operations depends on its depth and the reservoir/overburden rheology. One of the most recent applications presented in this paper is relevant to the Tengiz giant oil field, Kazakhstan; in this case the top of the reservoir is about 3900 m deep.

Surface deformation monitoring can provide valuable constraints on the dynamic behaviour of a reservoir enabling the evaluation of volumetric changes in the reservoir through time. Whatever the surveying technique, the detection of millimetre level surface deformation is required to monitor small surface displacement rates, which could impact risk evaluation and land use planning.

Mapping surface effects accurately requires hundreds of measurement points per square km which cannot be delivered by traditional monitoring methods without unacceptably large expenditure. SqueeSAR™ is one of the most valuable and cost-effective techniques capable of providing high precision and high areal density displacement measurements over long periods of time, free of atmospheric

artifacts. Moreover, the availability of surface displacement data from different orbits enables the estimation of both vertical and E-W horizontal displacement fields.

Some case studies (e.g. Oman, Kuwait, Kazakhstan) demonstrating the effectiveness of measuring surface deformation with satellite data for the calibration of reservoir geomechanical models will be presented.

References

Chambers, K.T., W.S. Hallager, C.S. Kabir, and R.A. Garber, 1997, Characterization of a Carbonate Reservoir With Pressure-Transient Tests and Production Logs: Tengiz Field, Kazakhstan: SPE #38657-MS, 16 p.

Hilley, G., R. Bürgmann, A. Ferretti, F. Novali, and F. Rocca, 2004, Dynamics of slow-moving landslides from permanent scatterer analysis: Science Magazine, v. 304/5679, p. 1952-1955.

Klemm, H., I. Quseimi, F. Novali, A. Ferretti, and A. Tamburini, 2010, Monitoring horizontal and vertical surface deformation over a hydrocarbon reservoir by PSInSAR: EAGE First Break, v. 28, p. 29-37.

Teatini, P., N. Castelletto, M. Ferronato, G. Gambolati, C. Janna, E. Cairo, D. Marzorati, D. Colombo, A. Ferretti, A. Bagliani, and F. Bottazzi, 2011, Geomechanical response to seasonal gas storage in depleted reservoirs: A case study in the Po River basin, Italy: Journal of Geophysical Research, v. 116/F02002, 21 p. doi:10.1029/2010JF001793.

Vasco, D.W., A. Rucci, A. Ferretti, F. Novali, R.C. Bissell, P.S. Ringrose, A.S. Mathieson, and I.W. Wright, 2010, Satellite-based measurements of surface deformation reveal fluid flow associated with the geological storage of carbon dioxide: Geophysical Research Letters, v. 37/3, p. 1-11.

Time-lapse monitoring with satellite data for reservoir management

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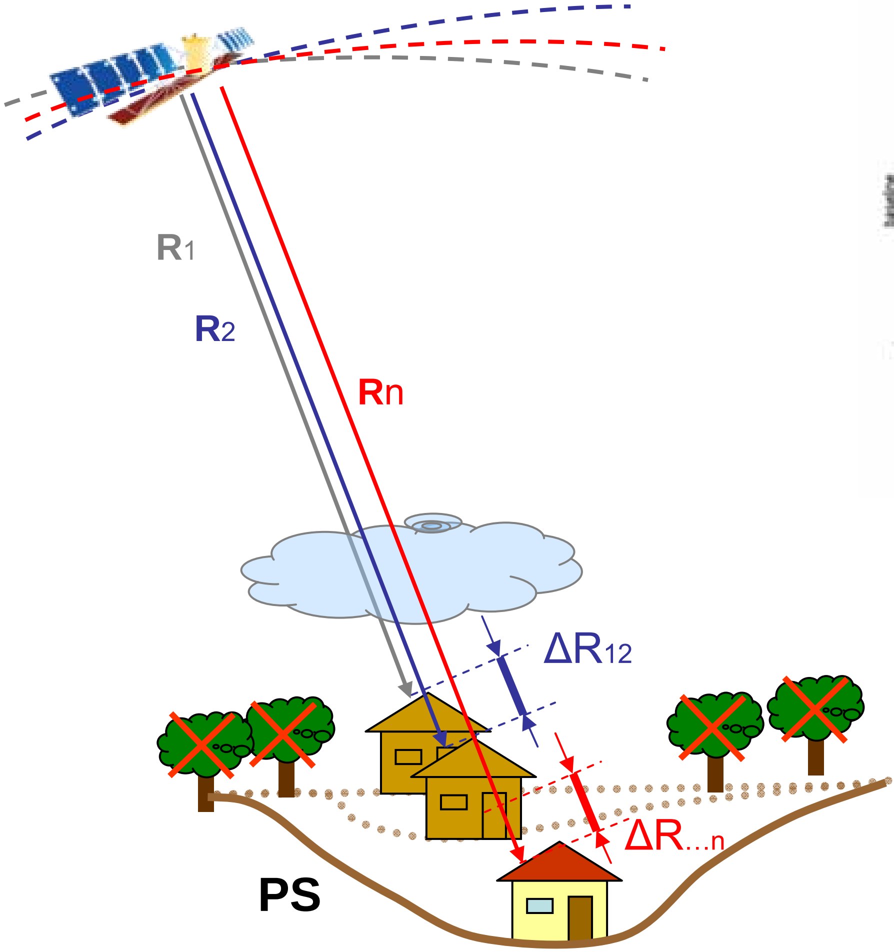
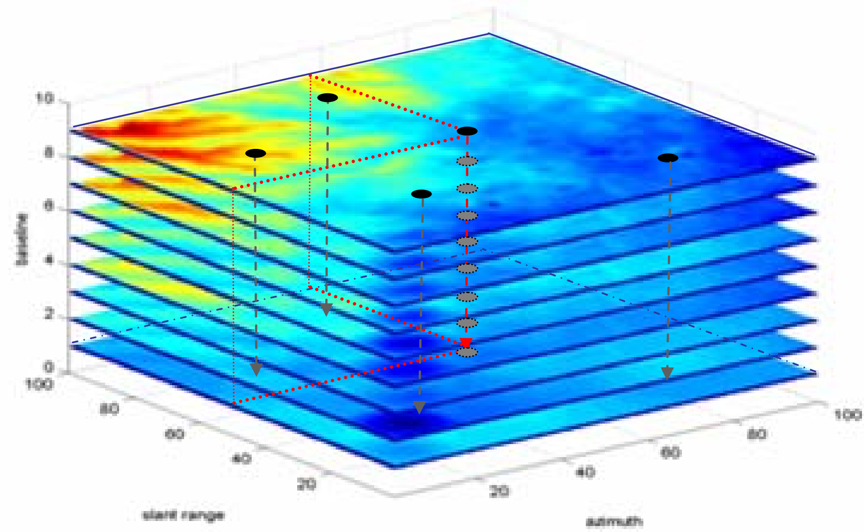
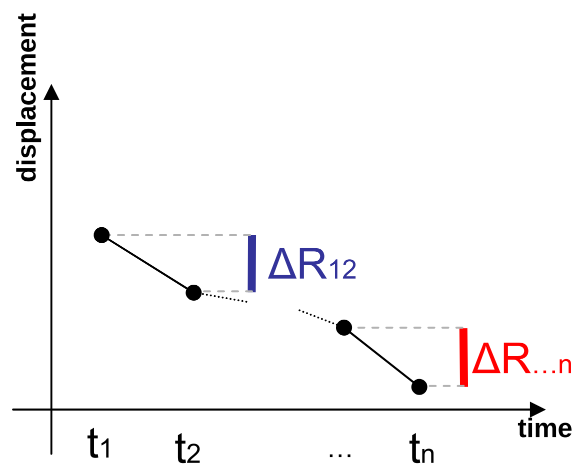
Outline

- **Monitoring surface displacements**: the SqueeSAR^{TM} technique
  - Operating principle
  - 1D to 2D surface displacement measurement
  - Available SAR Satellites
  - Examples
- **Case studies**
  - Middle East
  - In Salah (Algeria)
  - Tengiz (Caspian Region)
  - Northern Italy UGS site
  - Algeria, star dunes
- **Conclusions**

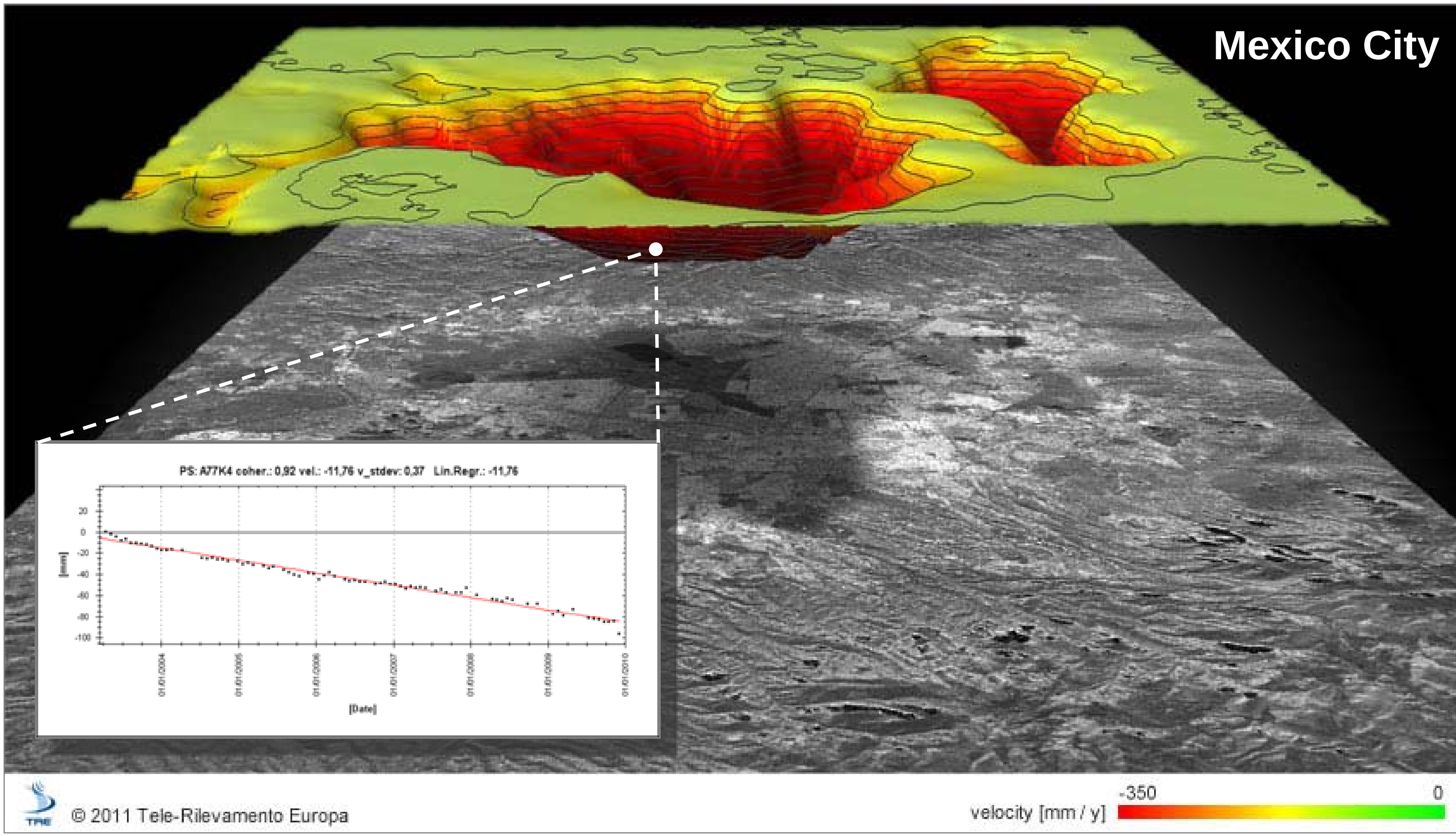
SqueeSAR™: multi image approach





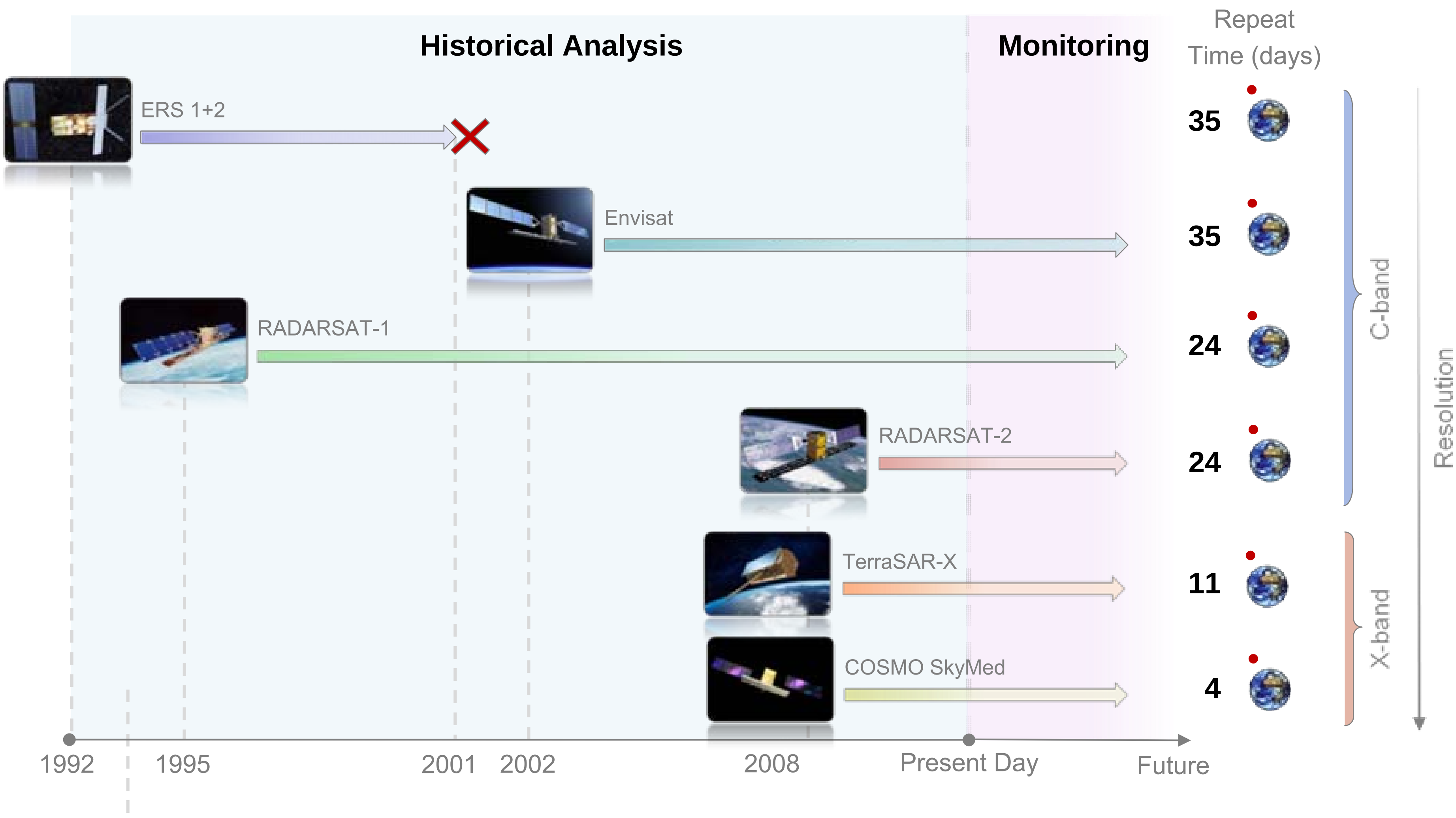


SqueeSAR™ outputs

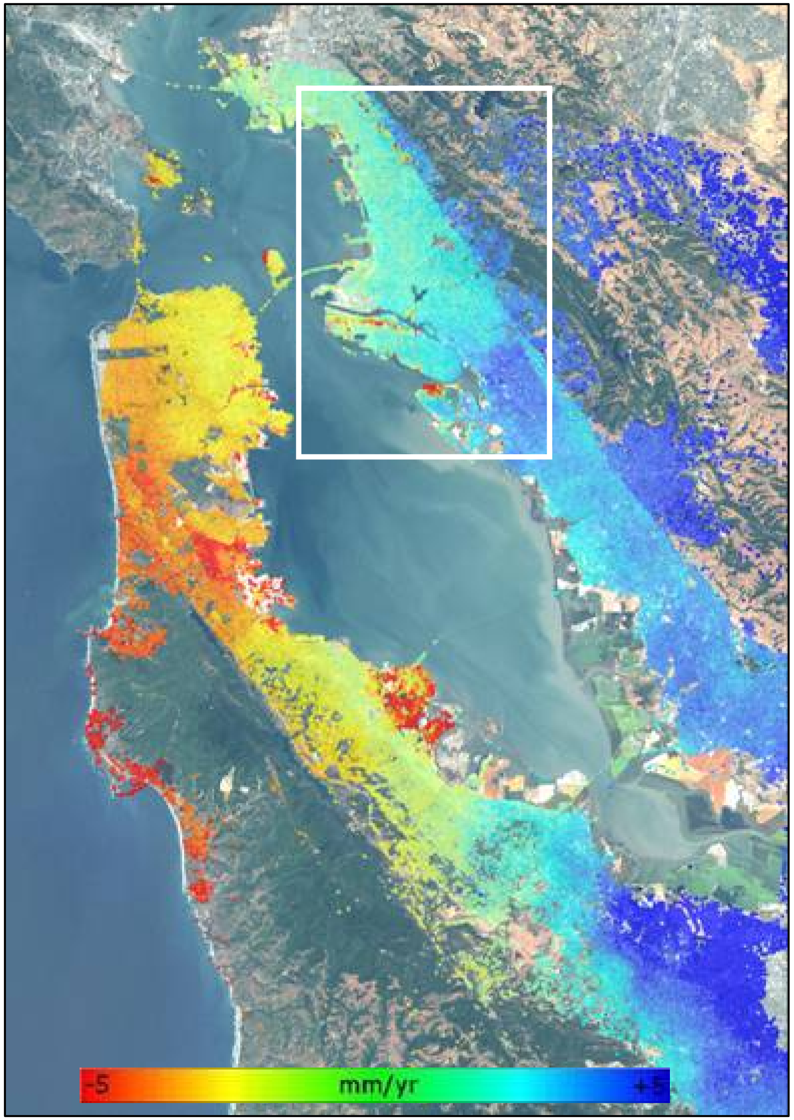


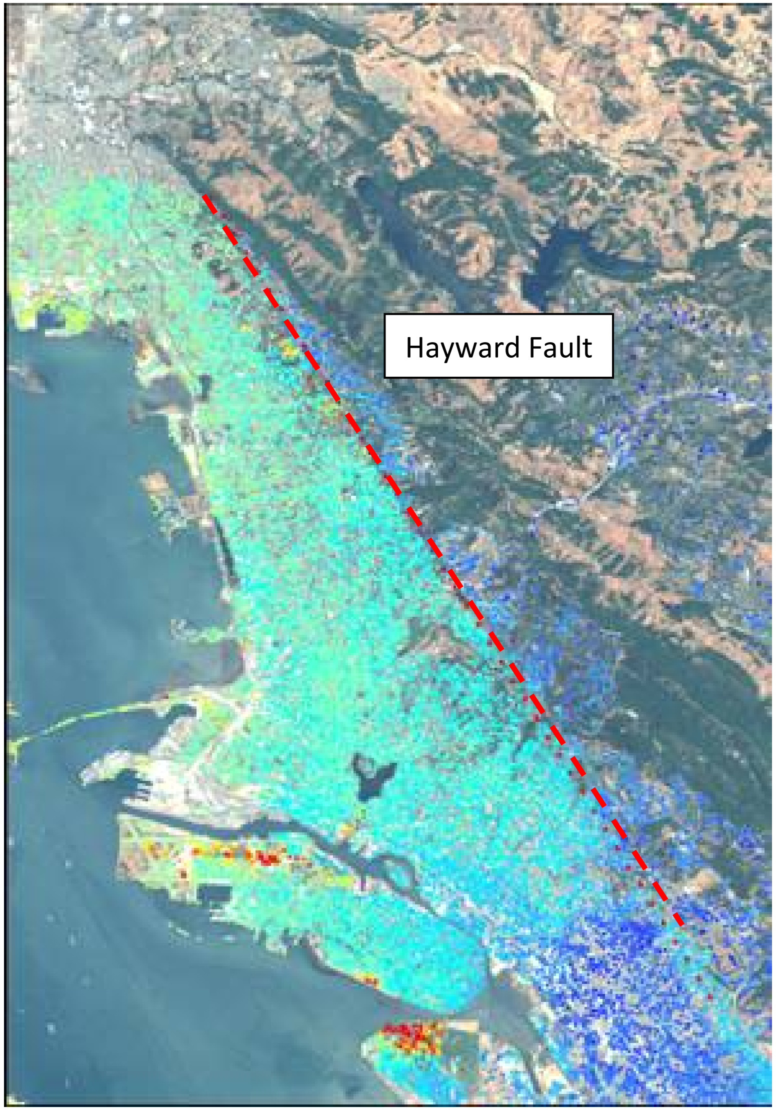
Data: Cumulative displacement from Mar. 2003 – Oct. 2007

RADAR Satellites and revisiting time

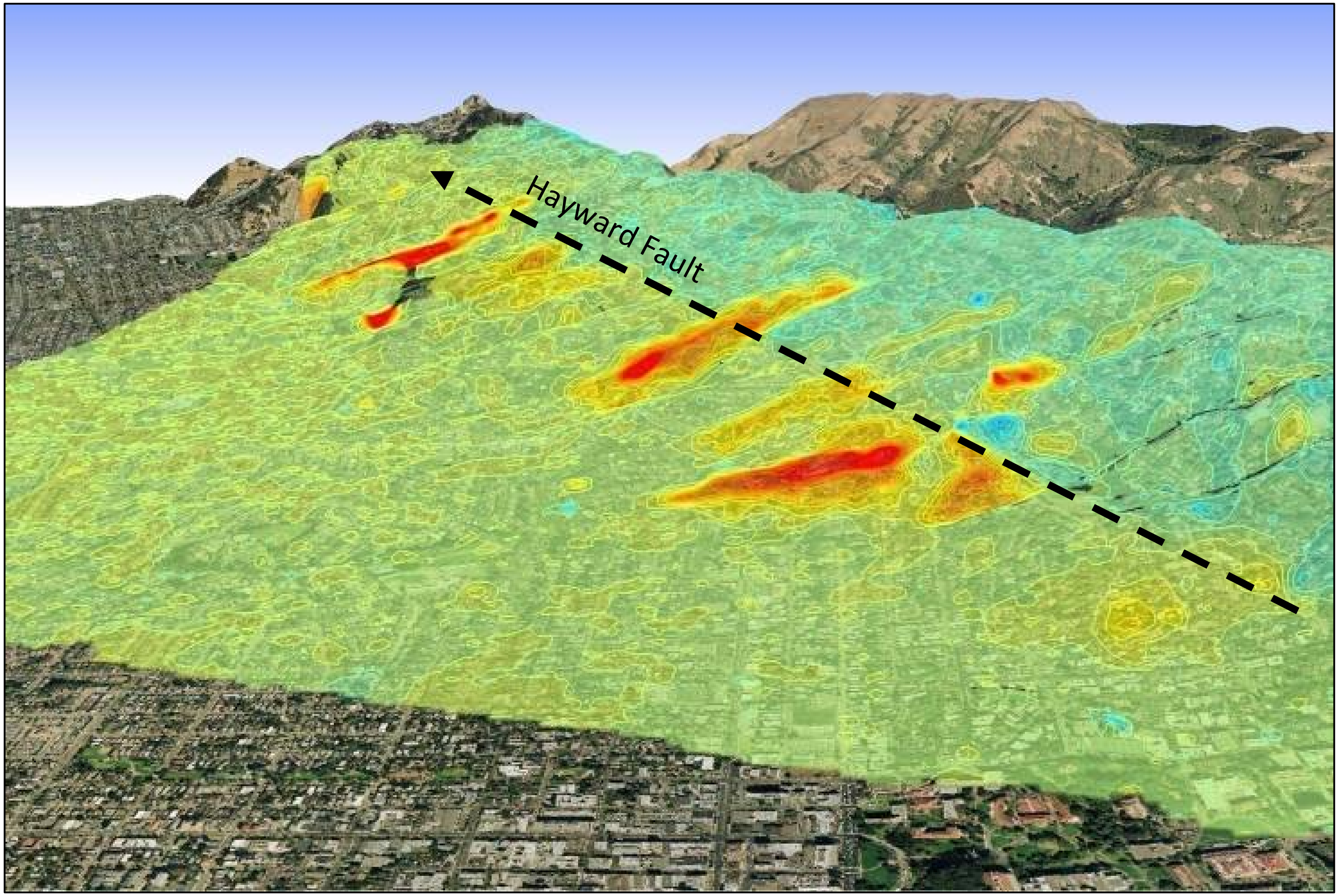


San Francisco Bay area



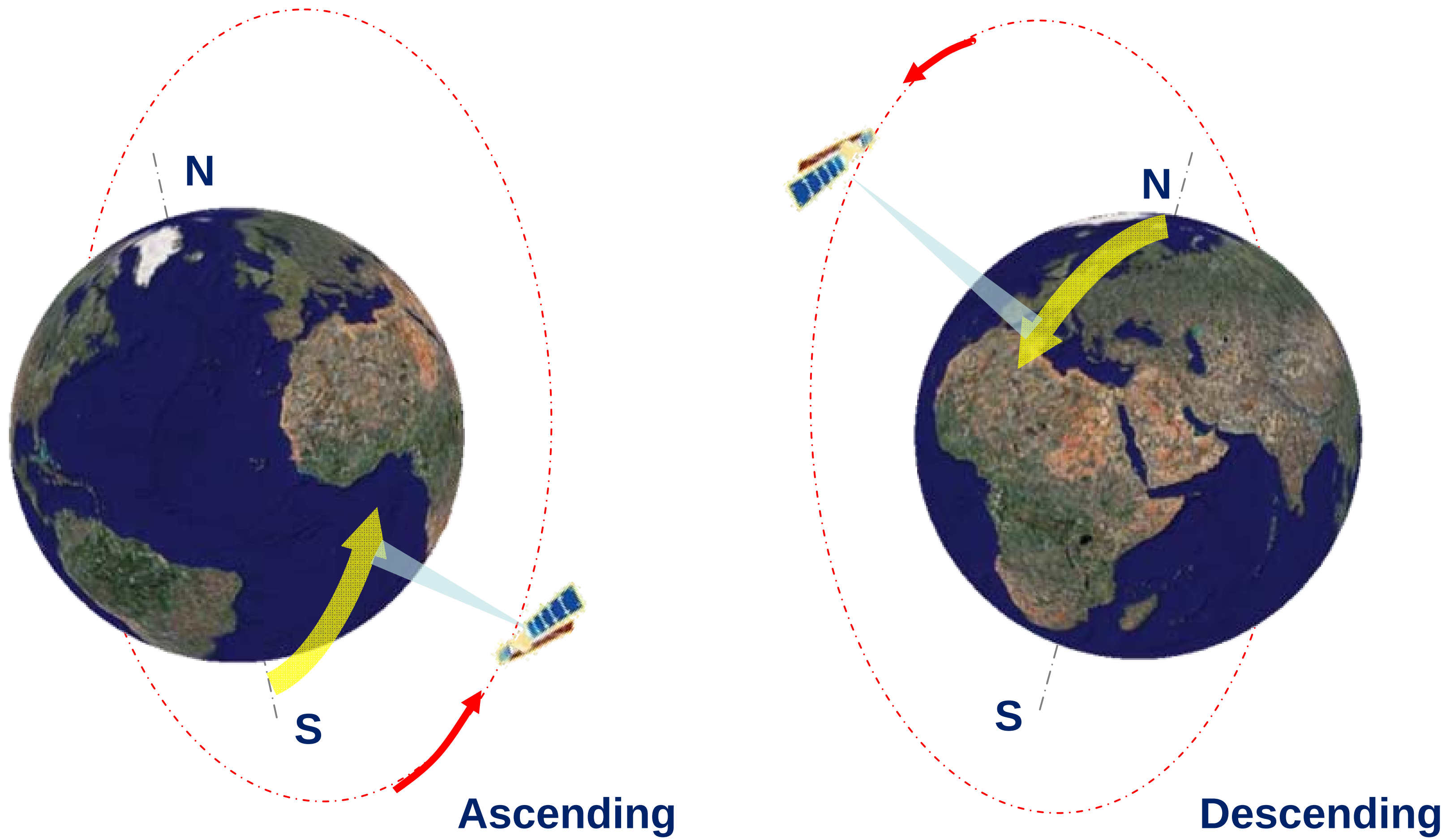


Berkeley Landslides



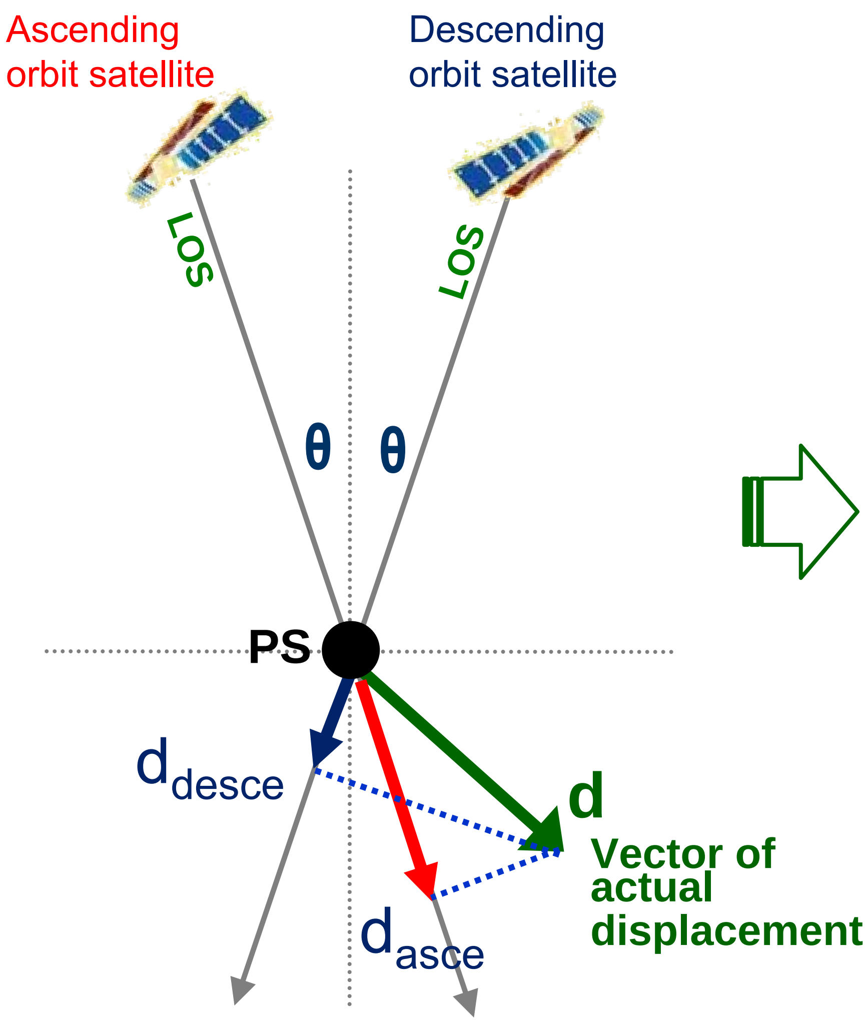
G. Hilley, R. Bürgmann, A. Ferretti, F. Novali, F. Rocca - *Dynamics of Slow-Moving Landslides from Permanent Scatterer Analysis*
SCIENCE MAGAZINE, June 2004

Ascending and Descending Geometries



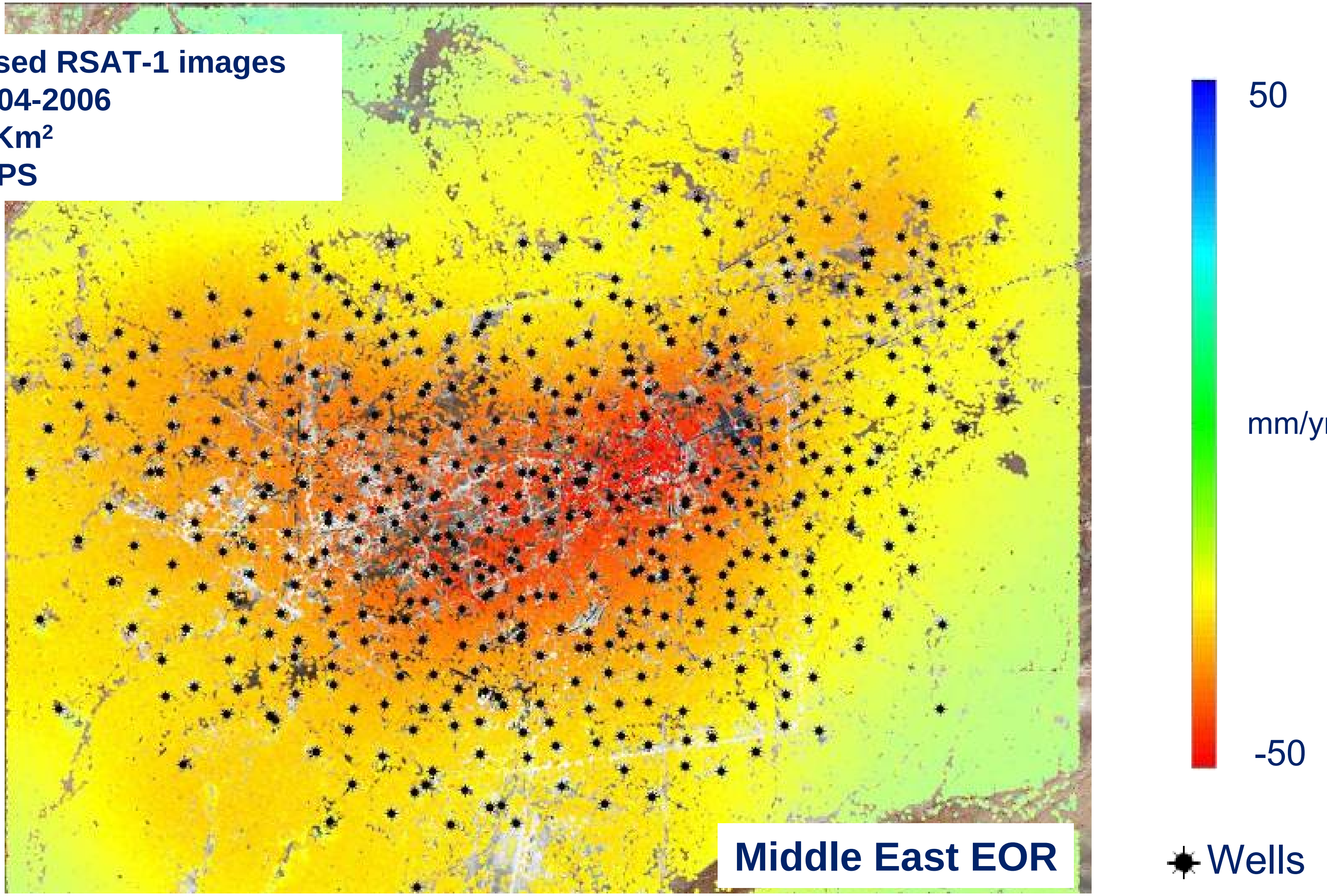
By combining the rotation of the Earth and the orbital paths of the satellites, the entire surface of the Earth is illuminated by two different satellite geometries.

Combining Ascending and Descending

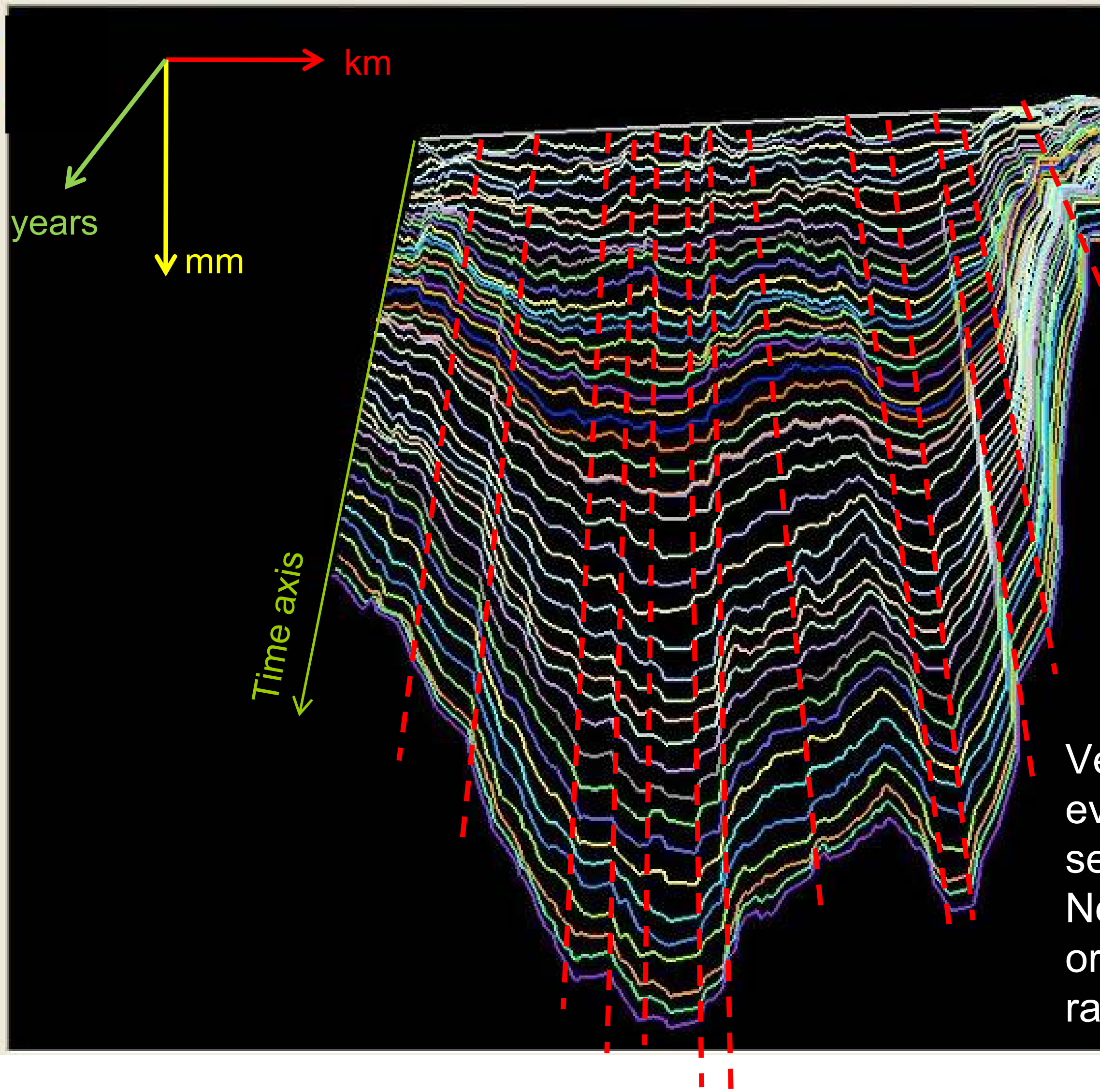


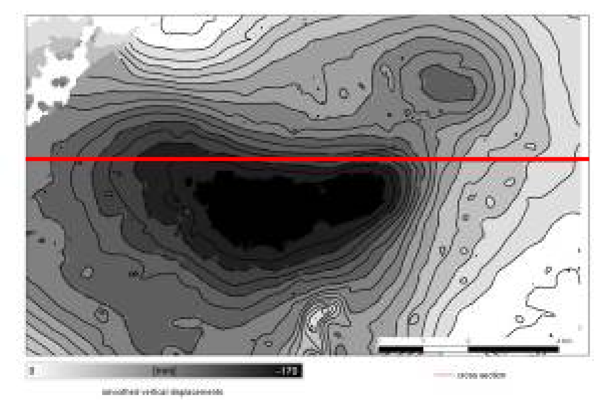
Middle East EOR: fault recognition

28 processed RSAT-1 images
period: 2004-2006
area: 120 Km^2
~ 200.000 PS



Does vertical displacement evolution show evidences of fault reactivation?

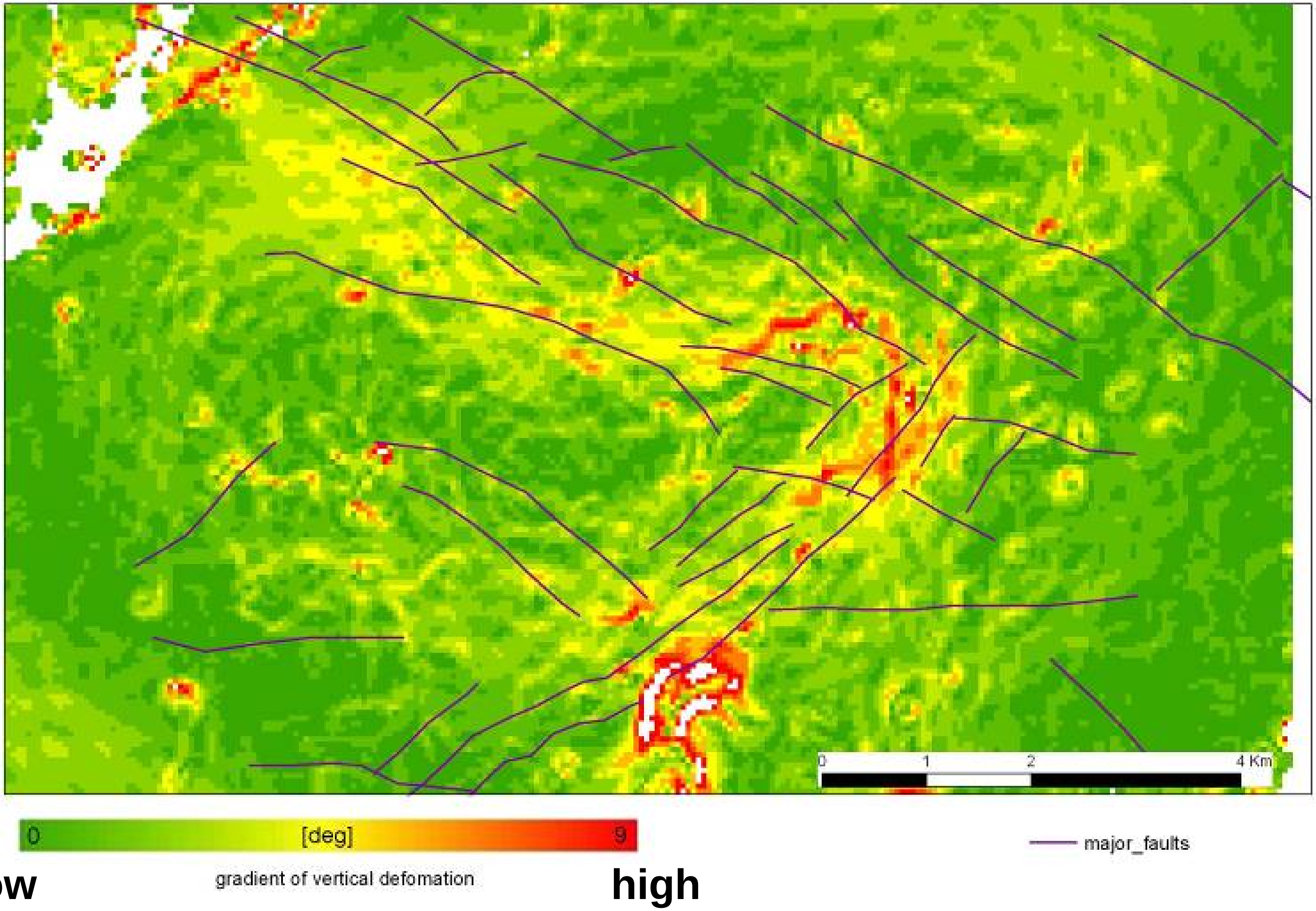




Vertical displacement evolution along an E-W cross section

Neighbourhood statistics on original data (mean ~ 200 m radius)

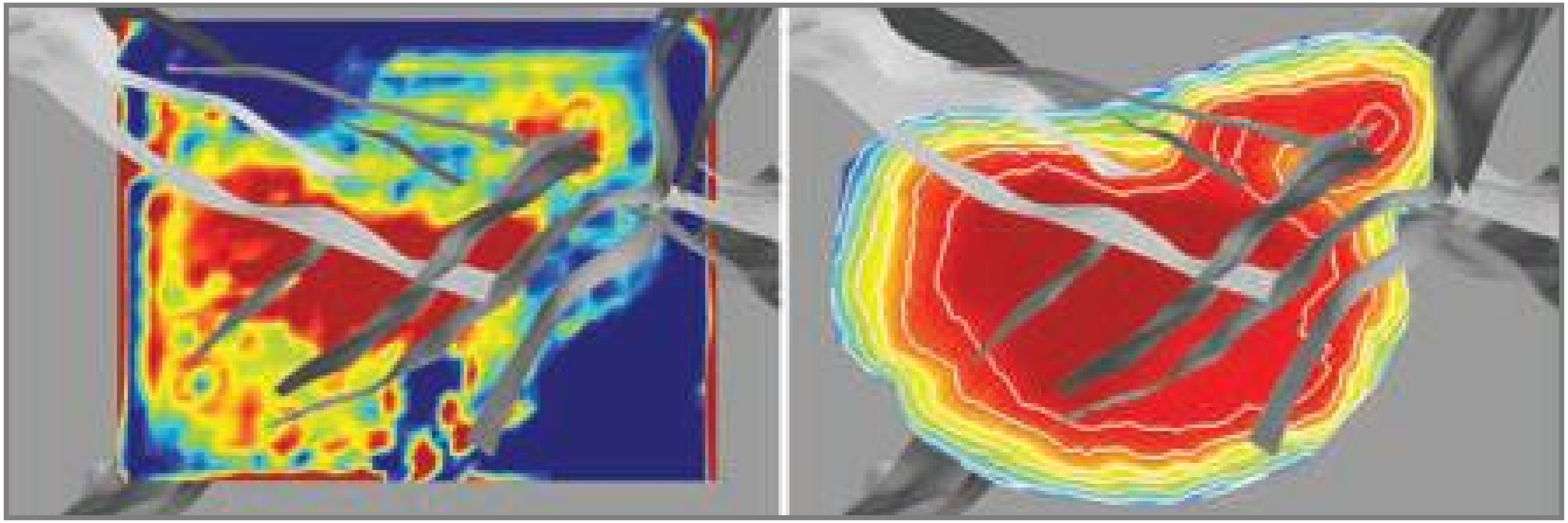
Gradient field of vertical displacements



low

high

Geomechanical Model calibration

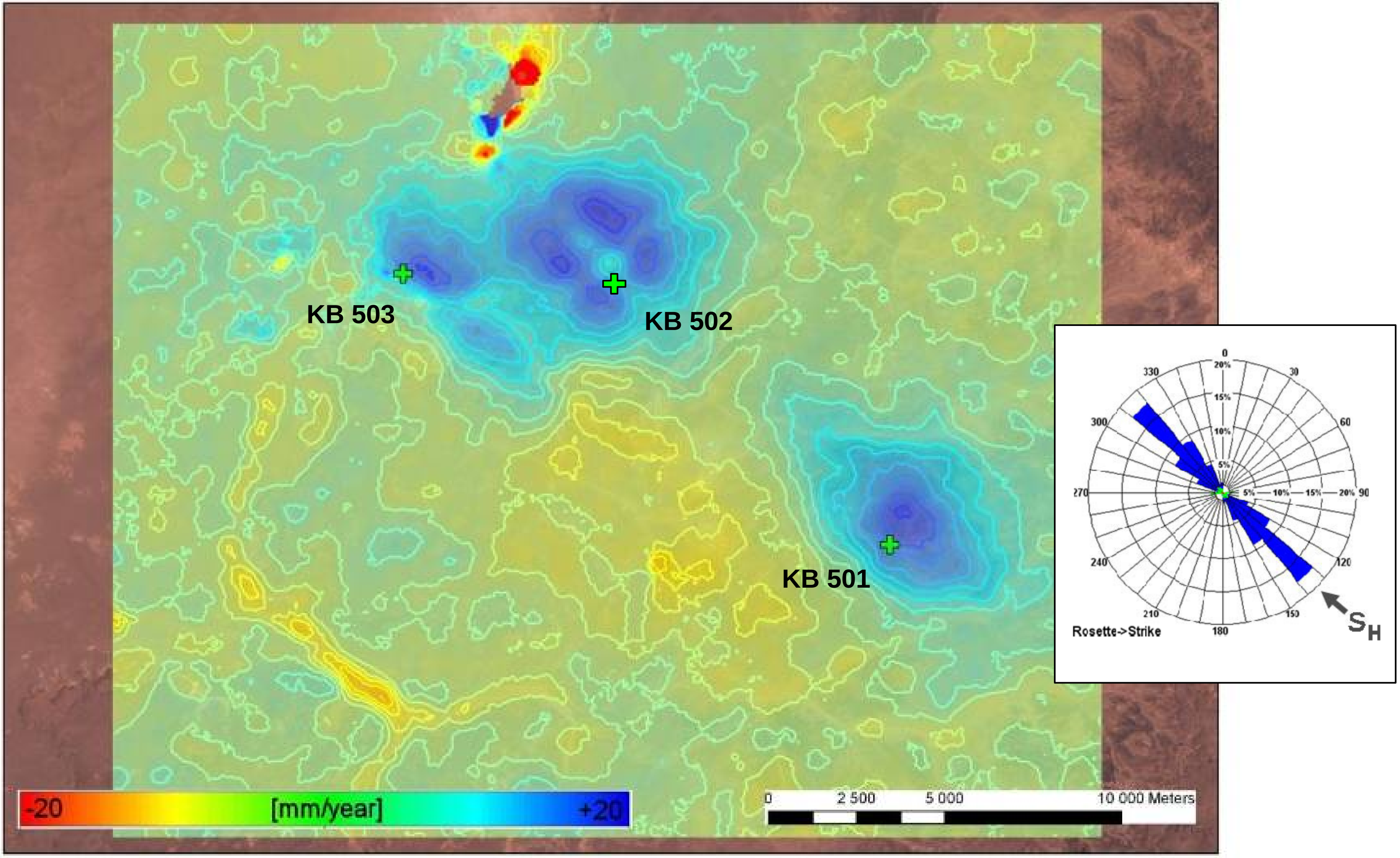


Inversion of surface data with linear poroelasticity model

Geomechanical model prediction

Klemm et. al.
Monitoring horizontal and vertical surface deformation over a hydrocarbon reservoir by PSInSAR
EAGE First Break, volume 28, May 2010

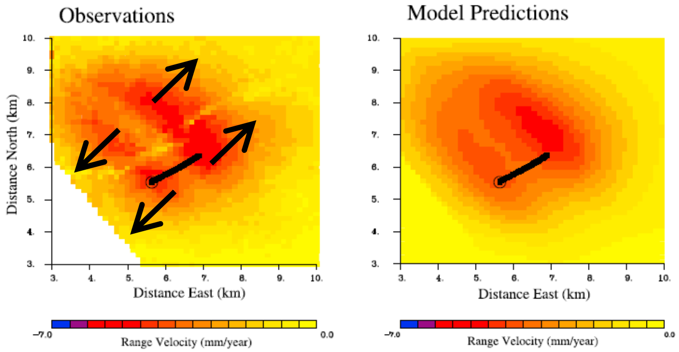
In Salah CCS project: fault opening



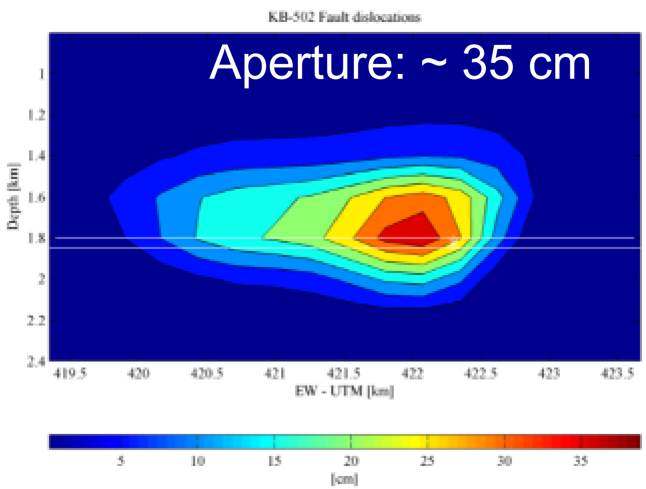
ENVISAT data

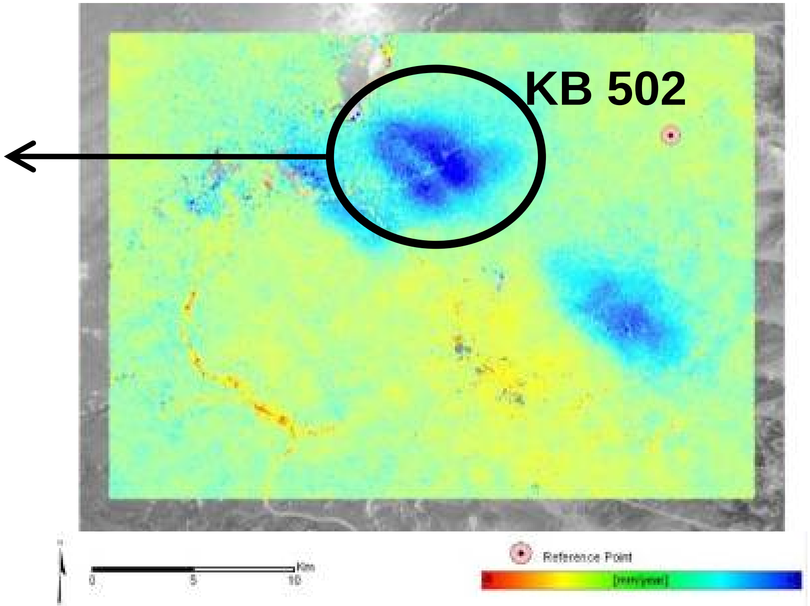
In Salah: KB 502 fault opening

Geomechanical model calibration



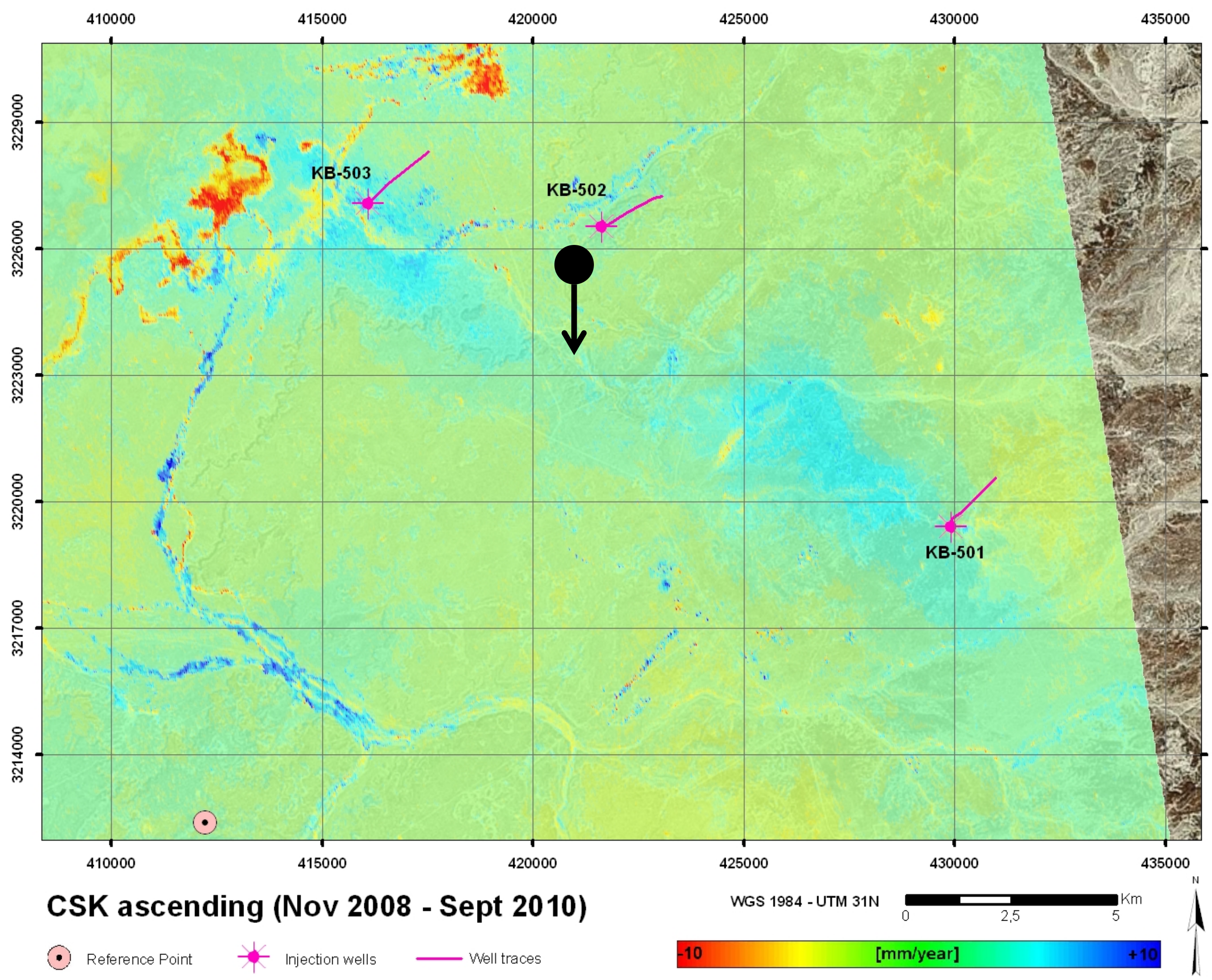
Fault opening estimation



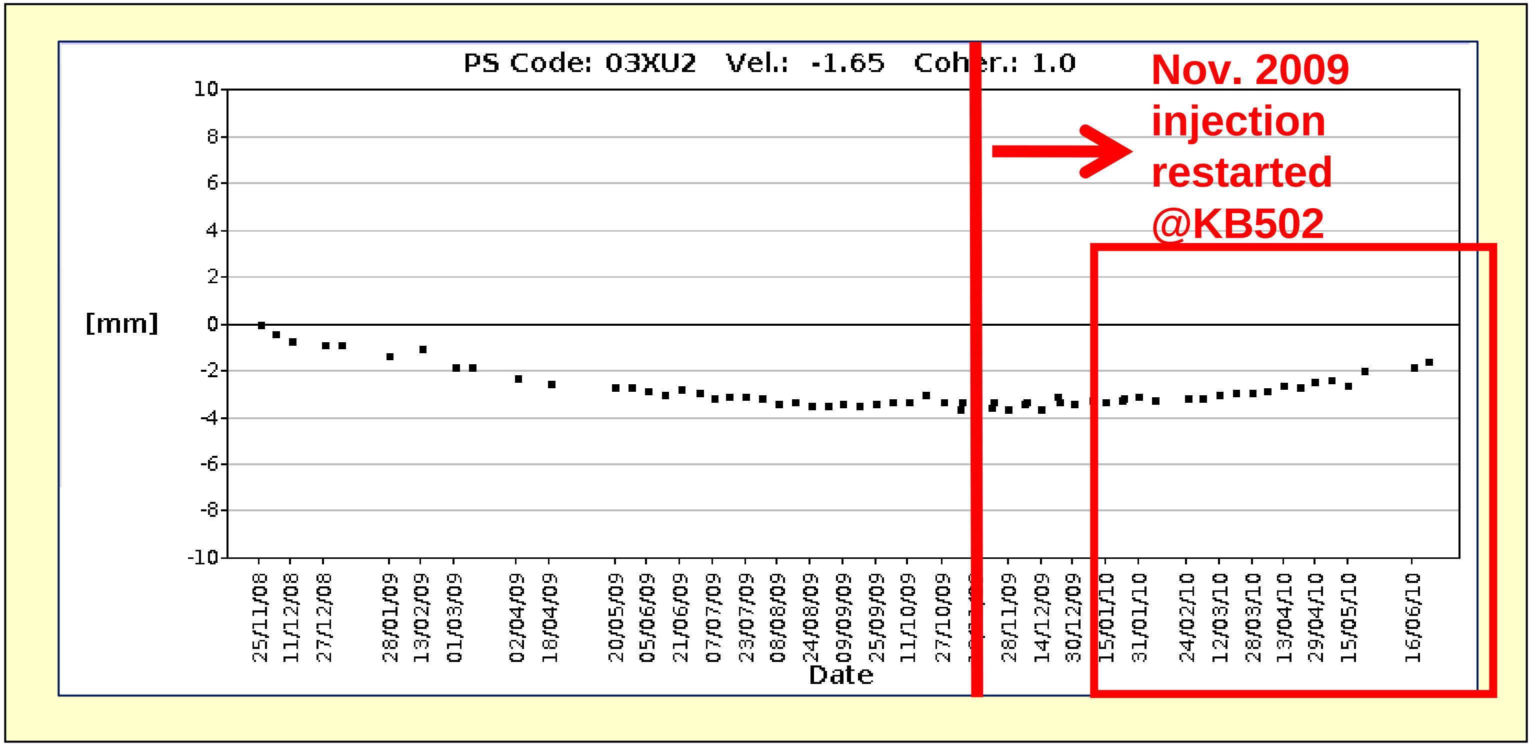


Vasco D. W., et al.
Satellite-based measurements of surface deformation reveal fluid flow associated with the geological storage of carbon dioxide.
Geophysical Research Letters, Vol. 37, Feb. 2010

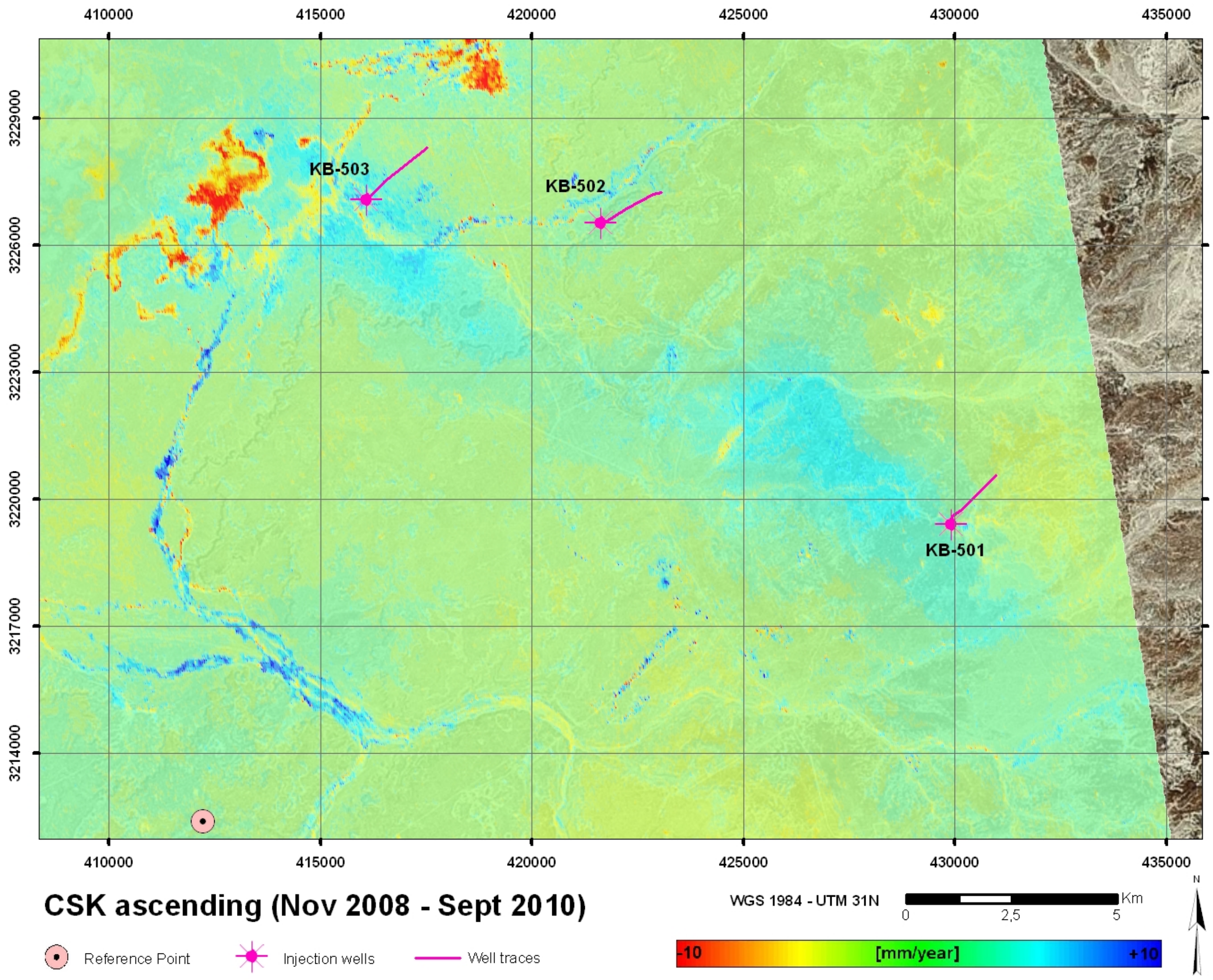
In Salah: high precision monitoring



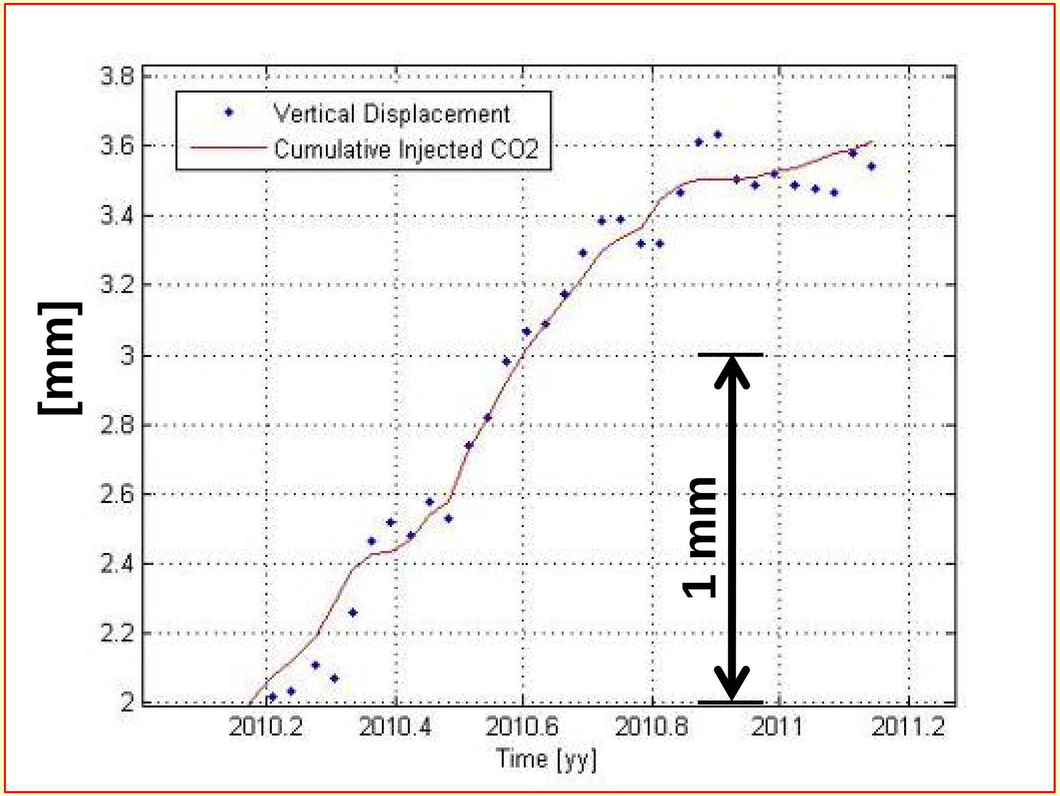
In Salah: high precision monitoring



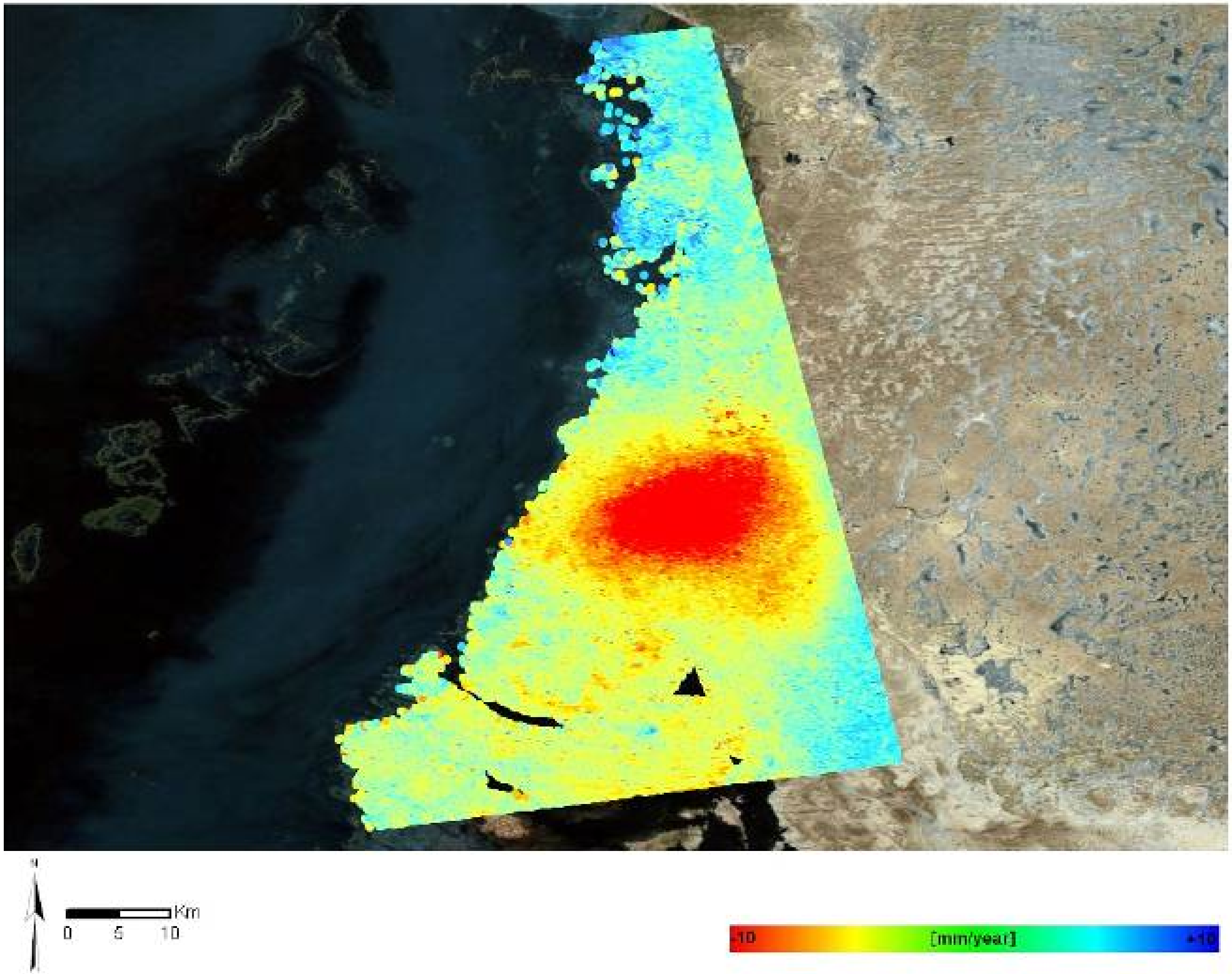
Displacement and injected volumes



Displacement and injected volumes

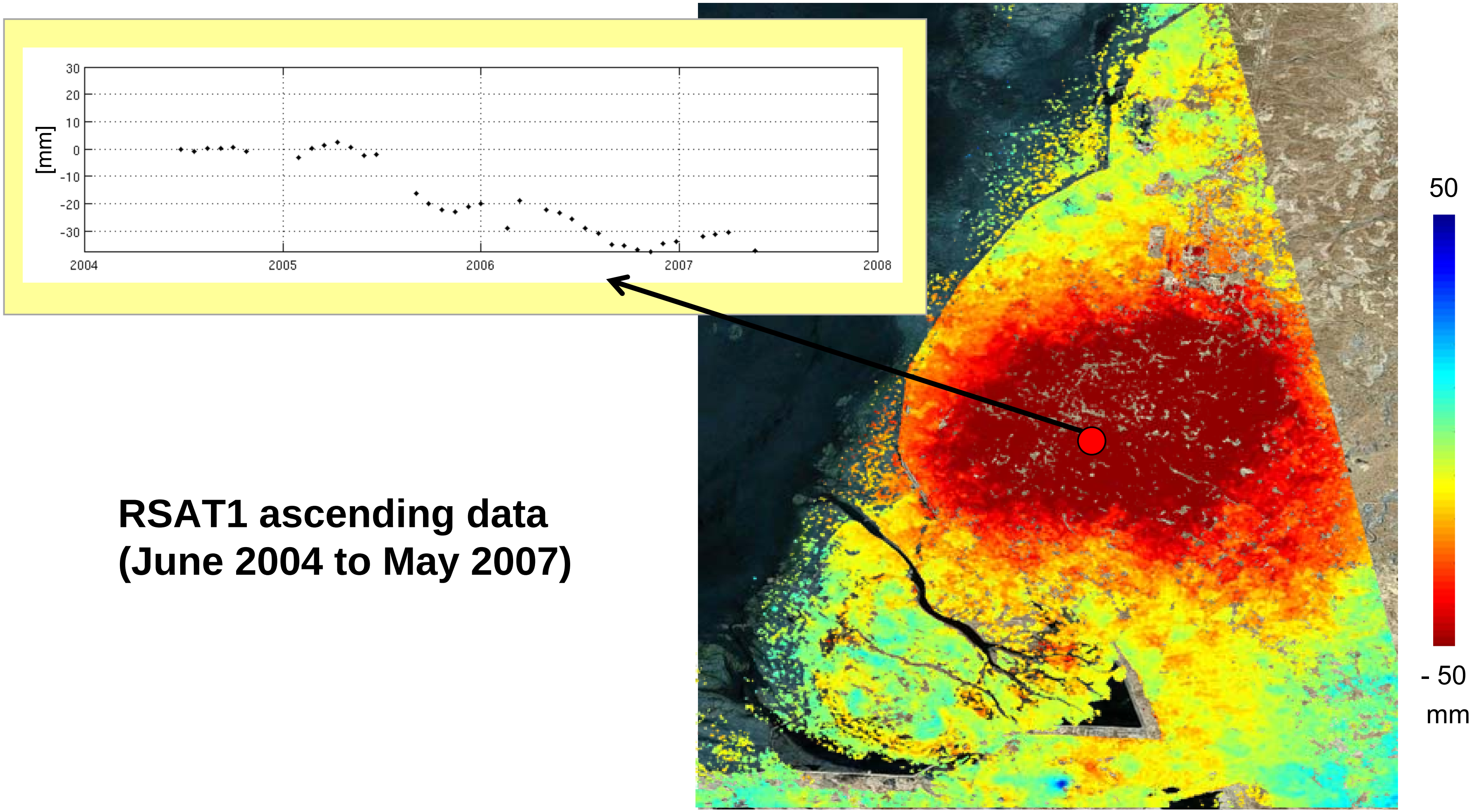


Tengiz: LOS avg yearly displacement rate



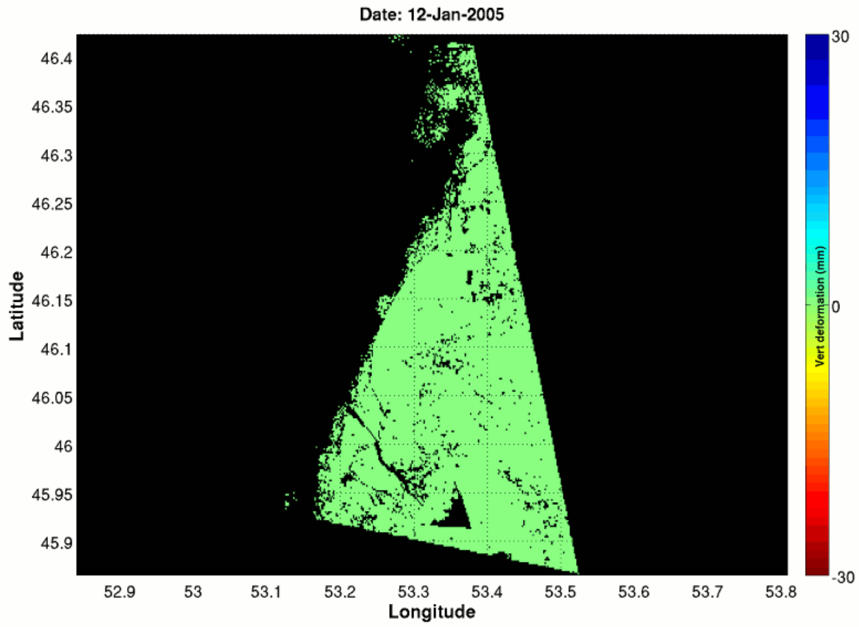
RSAT1 ascending data (June 2004 to May 2007)

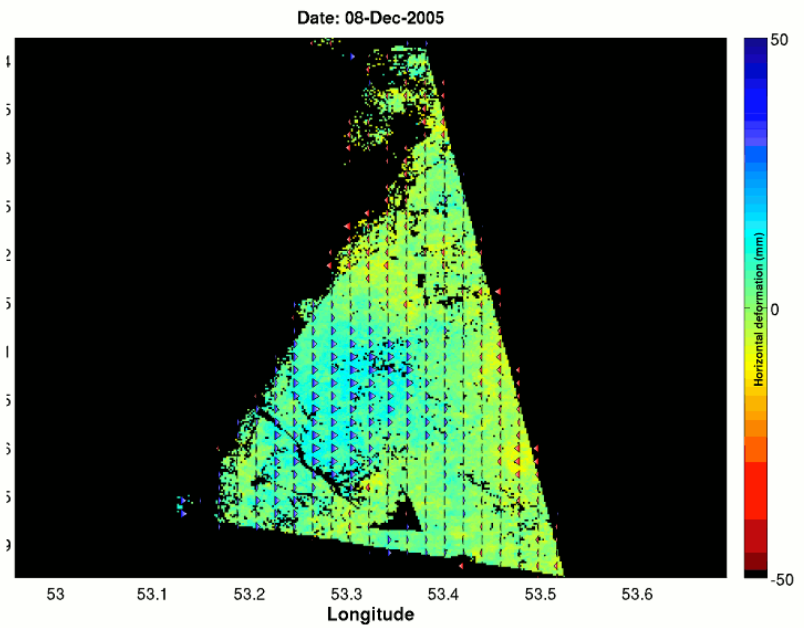
Tengiz: cumulative LOS displacements



RSAT1 ascending data
(June 2004 to May 2007)

Tengiz: Vertical and E-W displacement evolution

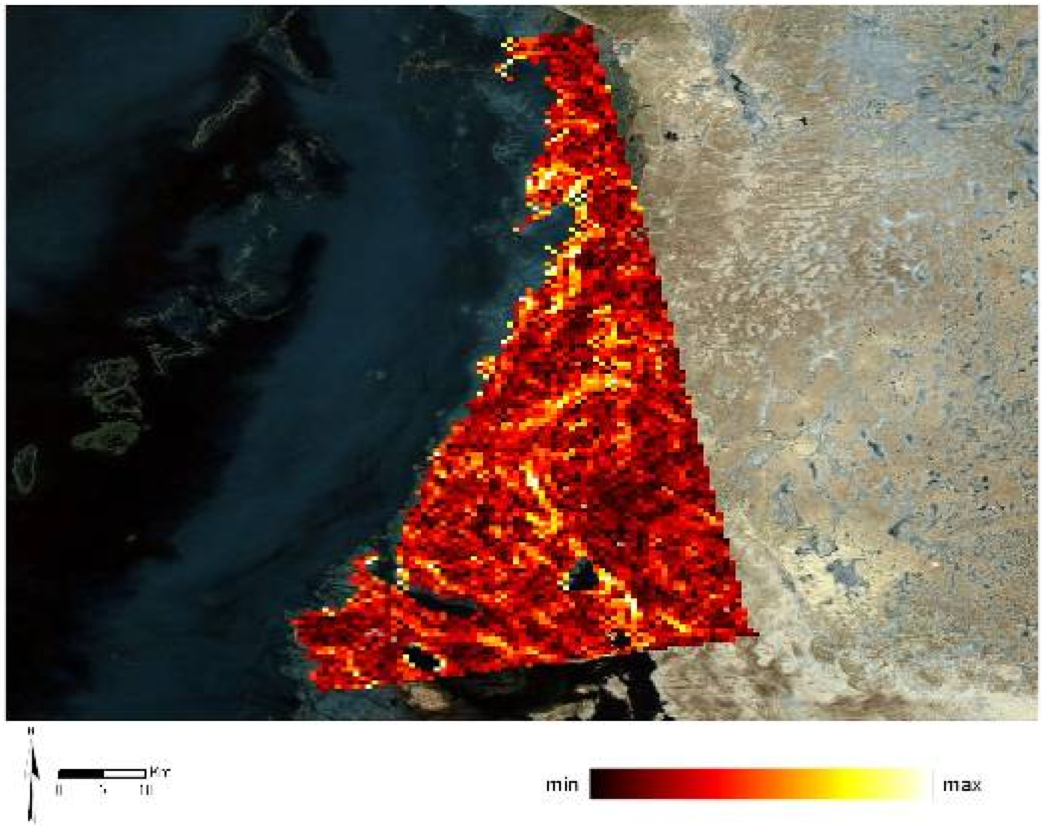




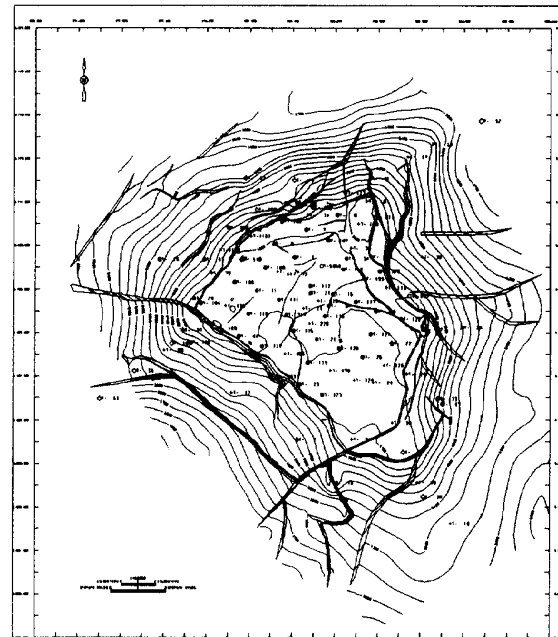
vertical

E-W horizontal

Tengiz: displacement gradient map



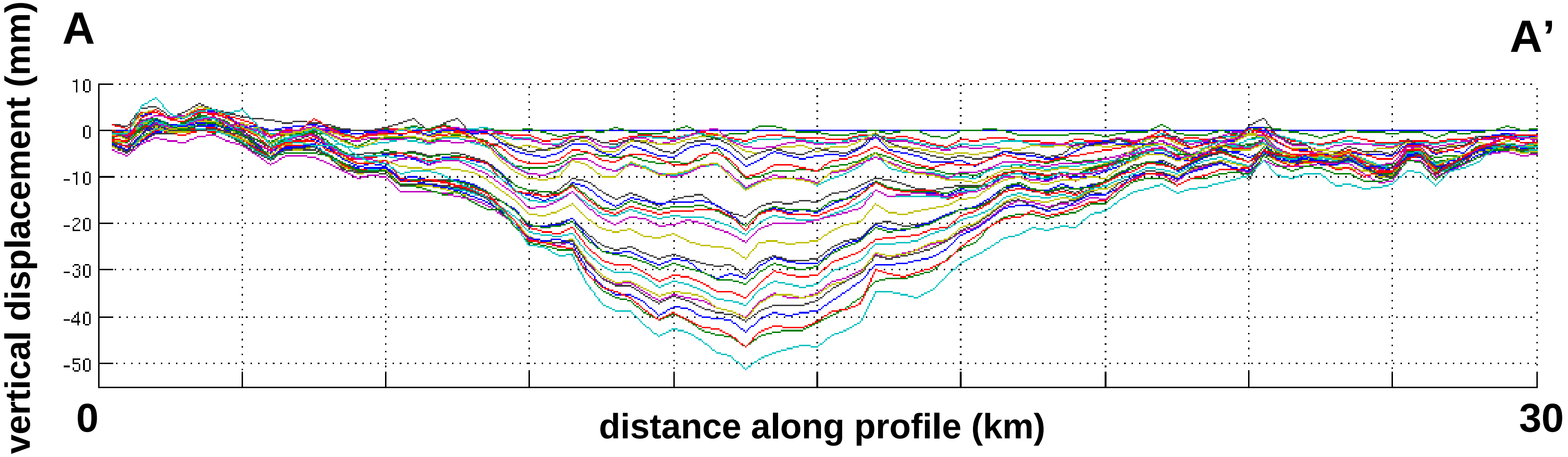
high gradient areas (yellow) probably corresponding to the buildup flanks



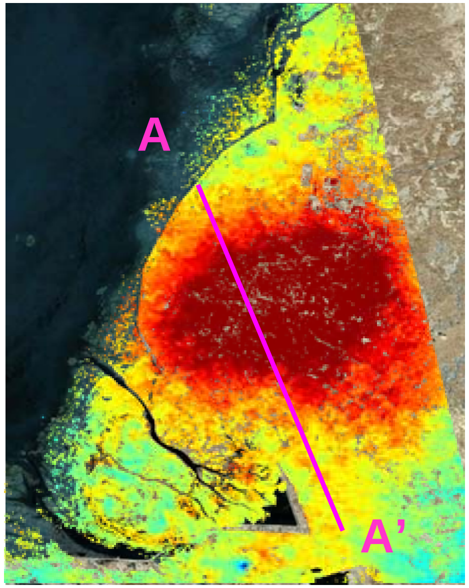
Chambers et al., 1997

top reservoir contour lines

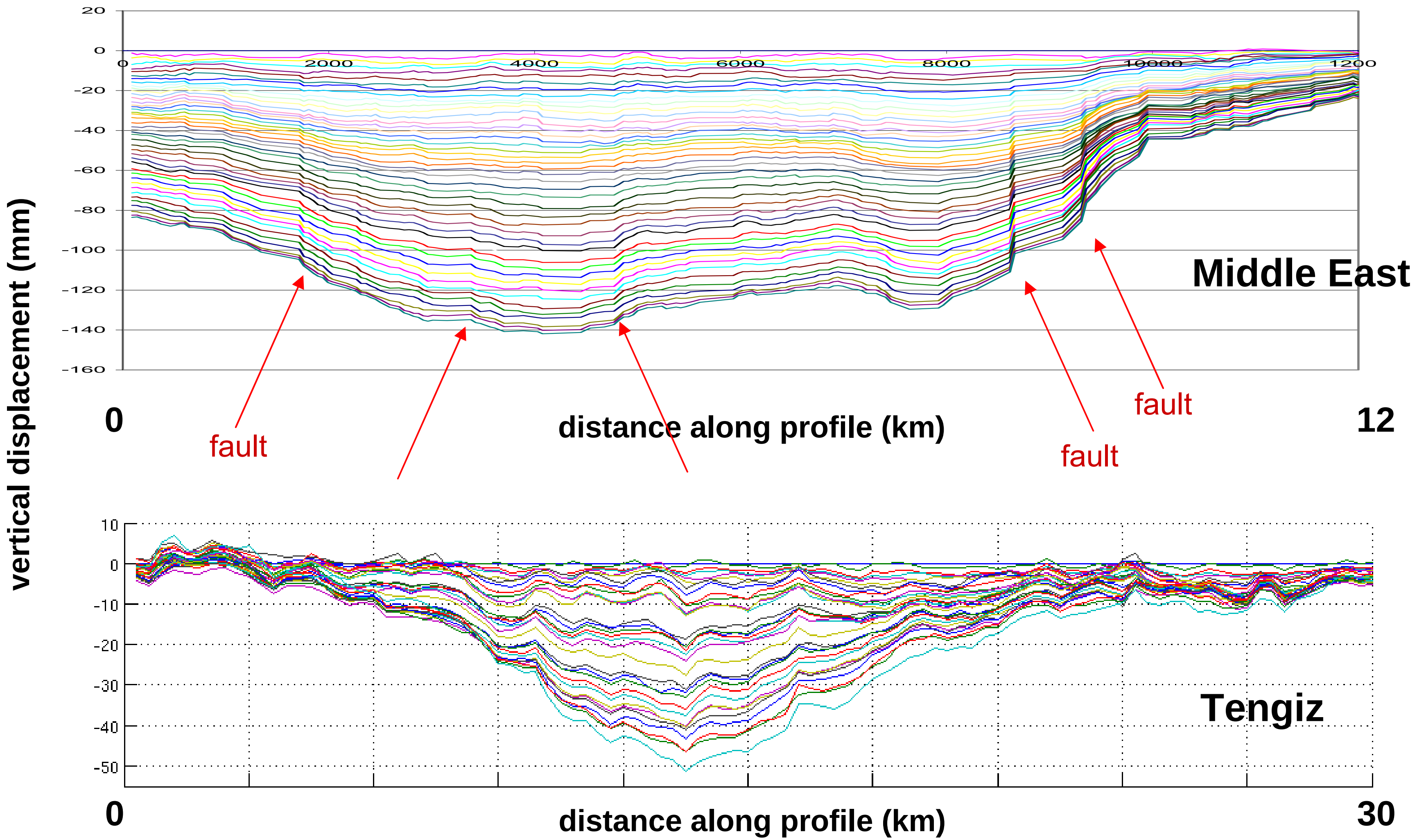
Tengiz: displacement evolution



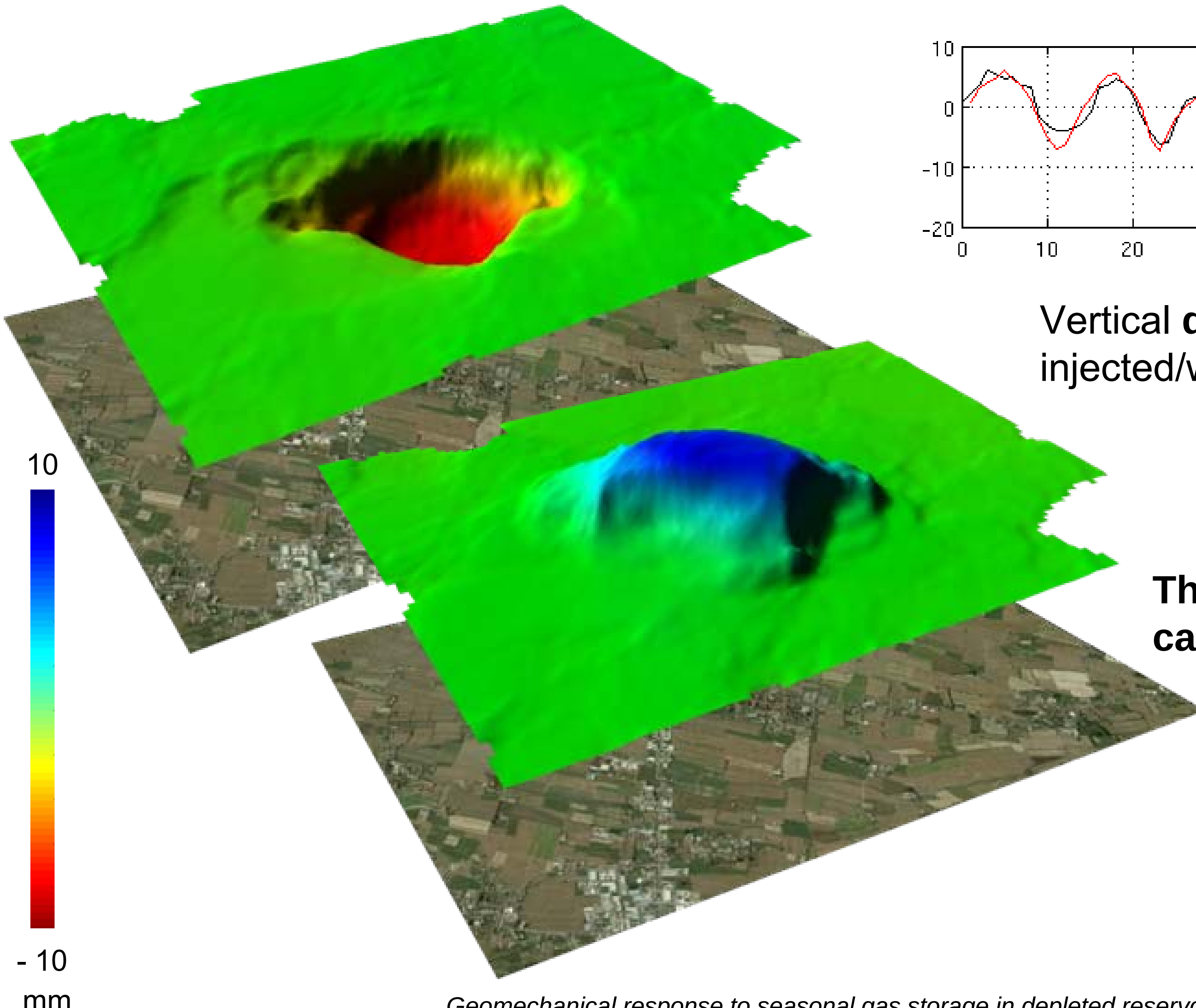
- Presence of high displacement gradient areas, probably corresponding to the structure flanks
- Isochronous displacement profiles show a continuous lateral transition from min to max
- No evidence of faults; nevertheless we can't exclude a smoothing effect on the displacement profiles related to both depth of the reservoir and plastic behaviour of the evaporite seal

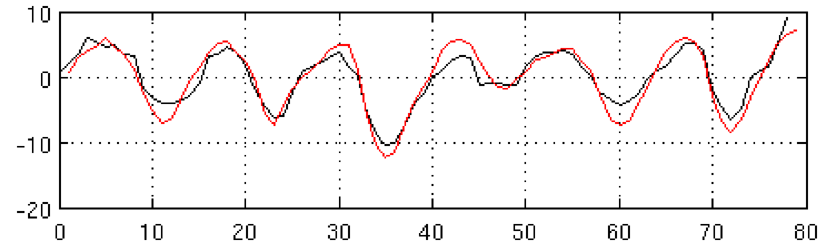


Middle East vs Tengiz displacement profiles



Northern Italy: UGS site



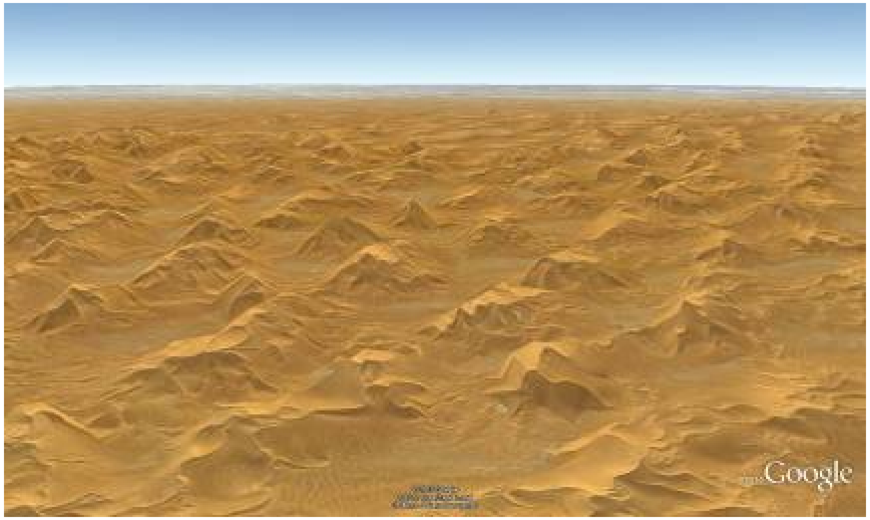


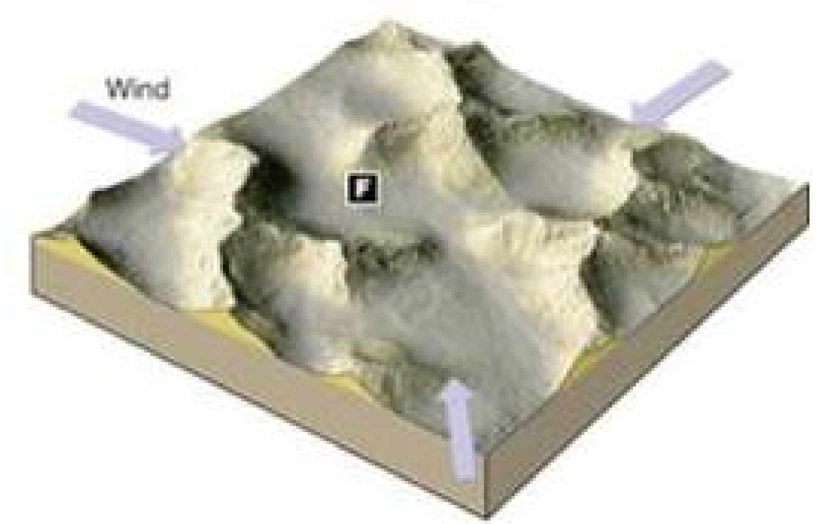
Vertical **displacements** (black) vs injected/withdrawn **gas volume** (red)

The gas pore overpressure can be pushed up to 120%p_i

P. Teatini et al.
Geomechanical response to seasonal gas storage in depleted reservoirs: A case study in the Po River basin, Italy
Journal of Geophysical Research, Vol. 116, F02002, doi:10.1029/2010JF001793, 2011

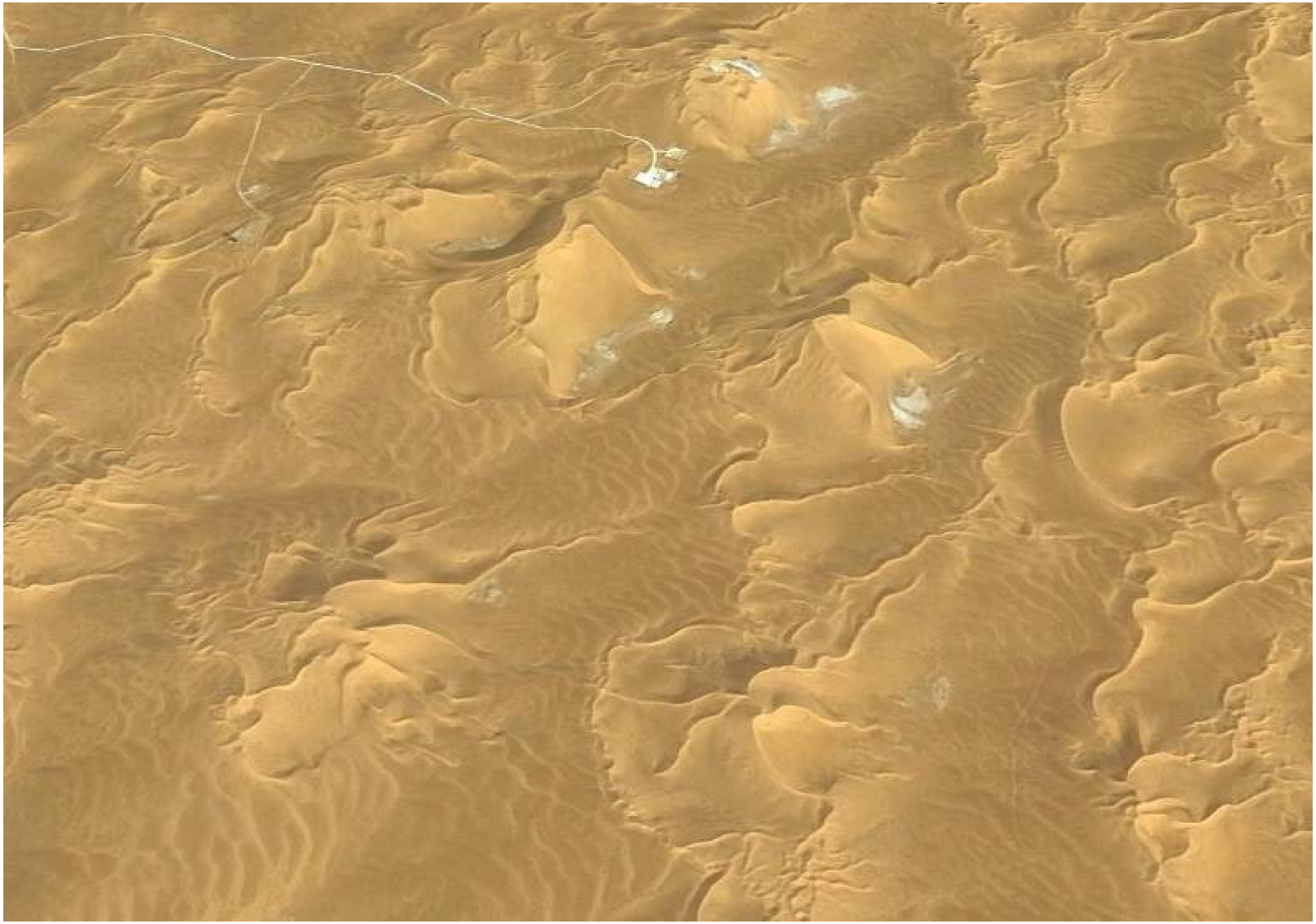
Algeria: star dunes



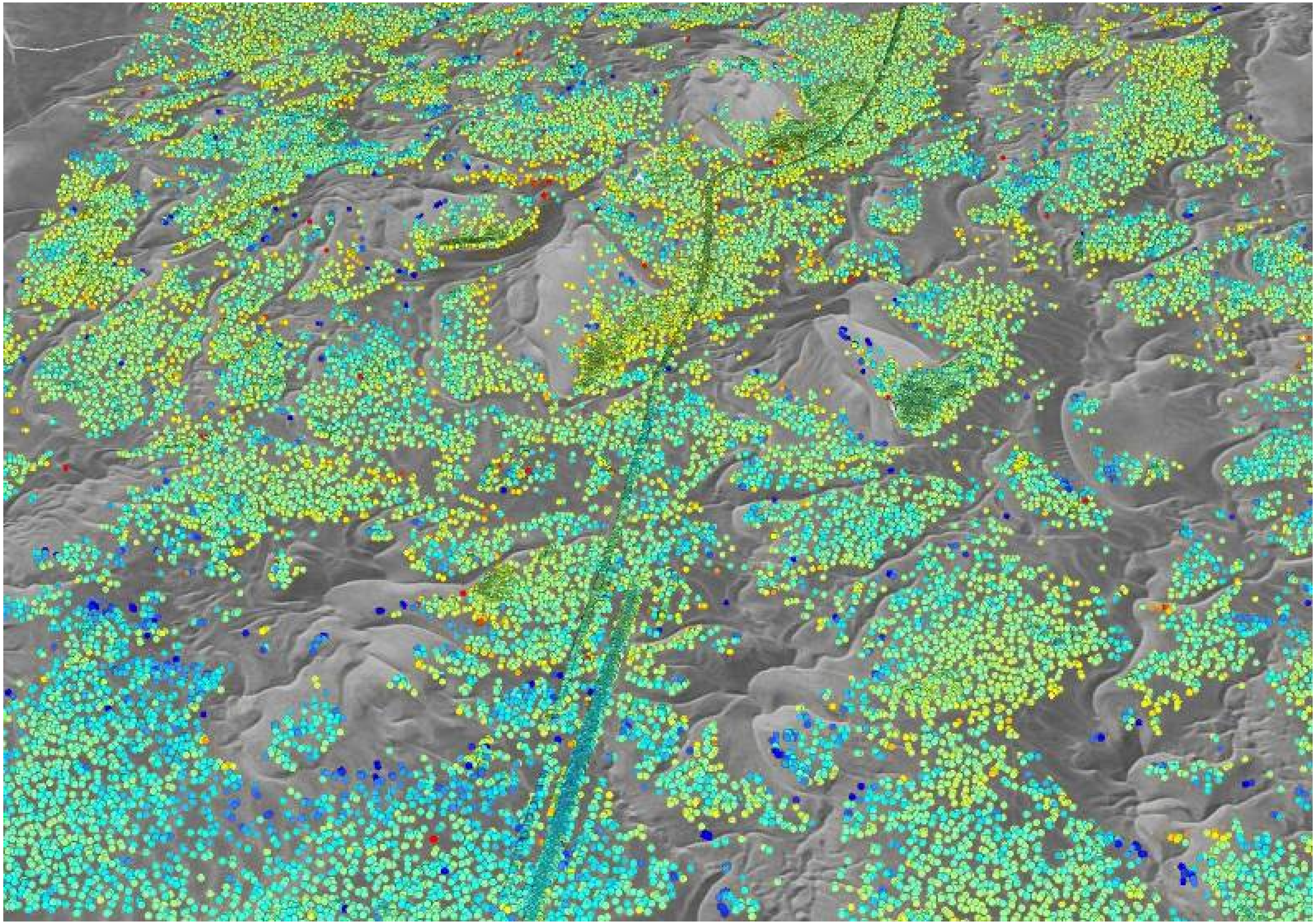


Stable radar targets in the interdune areas
(non sandy substratum or wind deflation pavement)

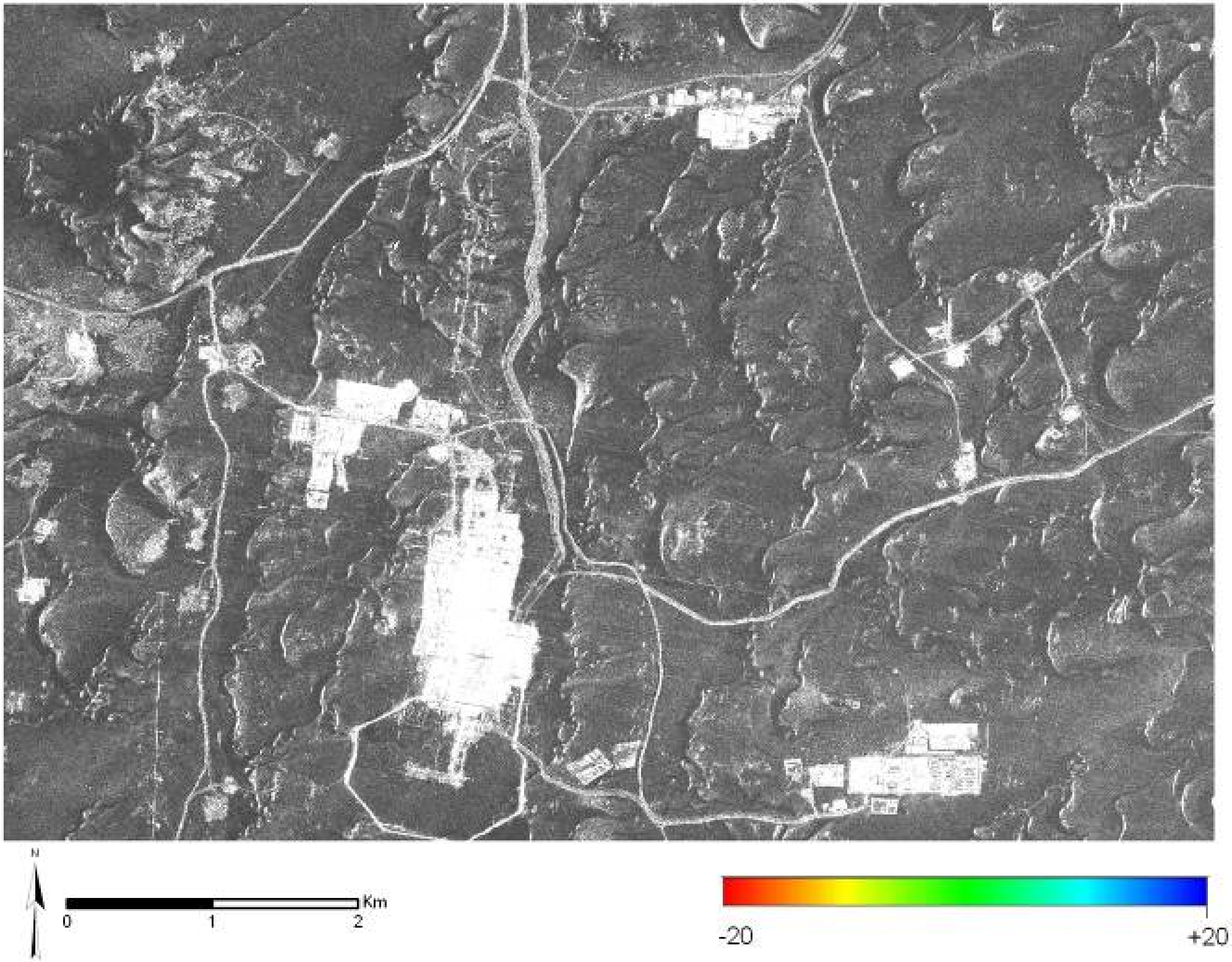
Algeria: star dunes



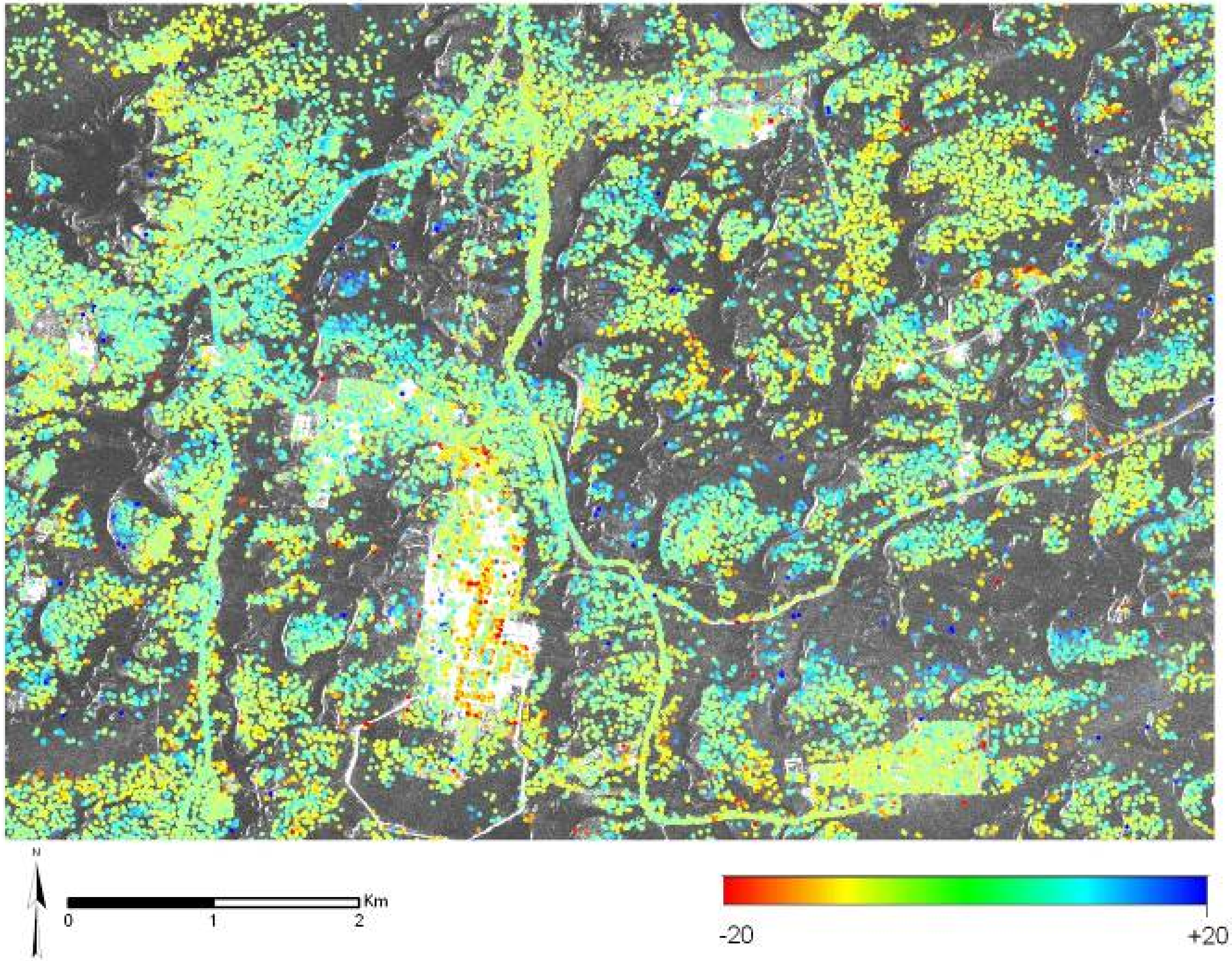
Algeria: star dunes



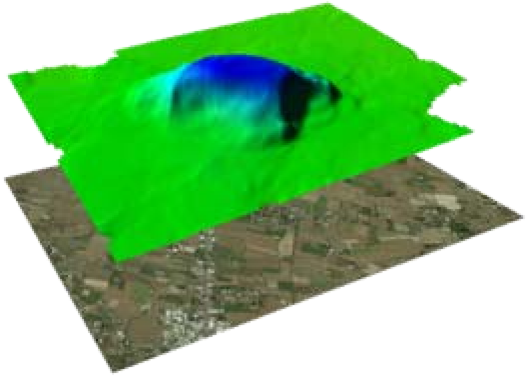
Algeria: star dunes



Algeria: star dunes

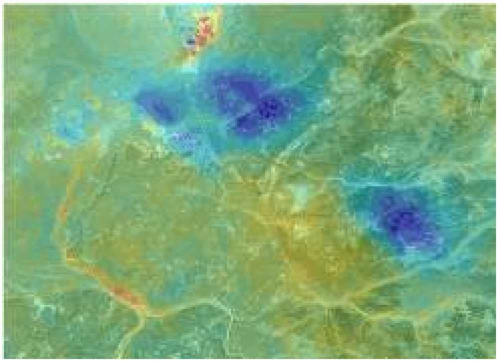


Reservoir depth and surface evidences



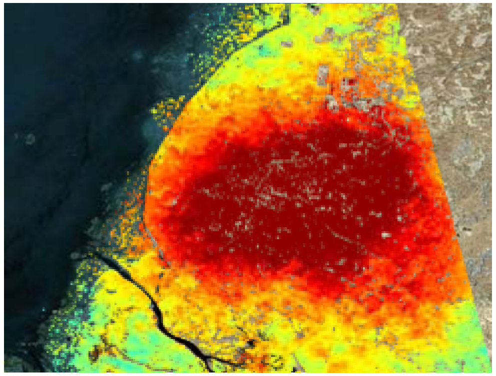
Gas Storage
Po Valley, Italy

~1200 m



CCS
In Salah, Algeria

~1900 m



Oil Field
Tengiz, Kazakhstan

~3900 m

Conclusions

- SqueeSAR™ **advantages**:
  - high measurement point density at high precision
  - low cost data over long time period
  - historical analyses and ongoing monitoring
  - remote, no field work

- Presented **case studies** (EOR, CCS and UGS) showed that measuring surface displacements can help in:
  - detecting evidence of fault reactivation at the ground surface induced by reservoir operations
  - constraining the probable subsurface deformation

- SqueeSAR™ is **complementary** to conventional techniques in performing reservoir management

- **Very favourable conditions in Middle East** for the application of SqueeSAR™

- For more info please visit our booth (Hall 1)

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