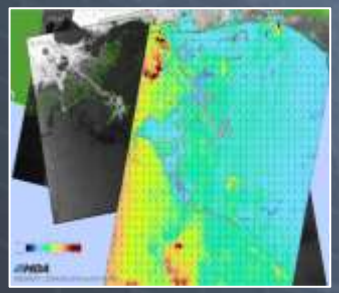




INSAR Monitoring of Land Deformation

- Infrastructure Risk Assessment and Mitigation

GWF Hyderabad, January 2018

MDA Geospatial Services Inc. / DigitalGlobe

www.mdacorporation.com

Background

- Space-borne INSAR as effective, reliable monitoring technology to detect ground movement
- Movement detected at cm / mm level at both horizontal and vertical directions
- Such land deformation poses risk to infrastructure assets, such roads, bridges, buildings
- Alert of movement allows organizations opportunity of early mitigation

Outline

- Intro to Land Deformation in Infrastructure Context
- Intro to INSAR
- Case#1: Seattle SR99 Bored Tunnel
- Case#2: High Speed Railway China

Infrastructures and Urban Land Deformation

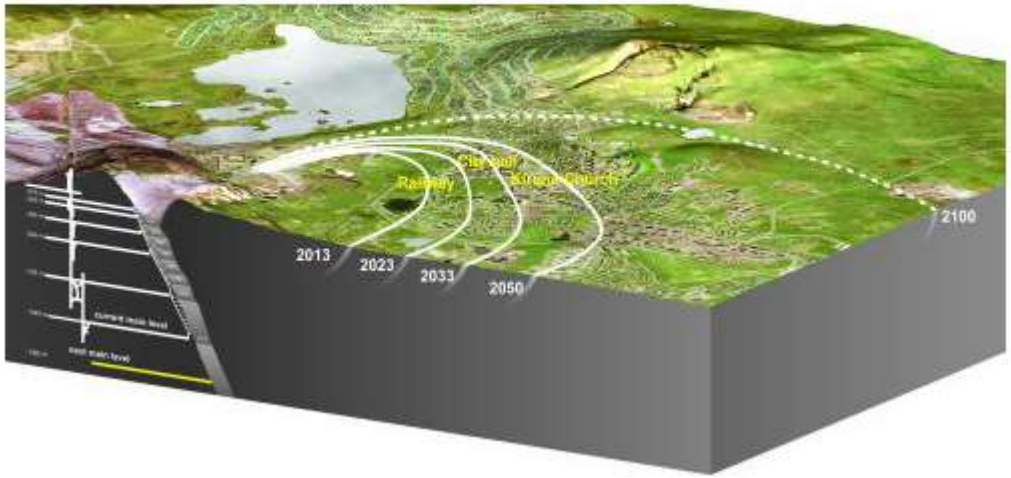
Land Deformation – In Context of Infrastructure

Sinking or soaring?

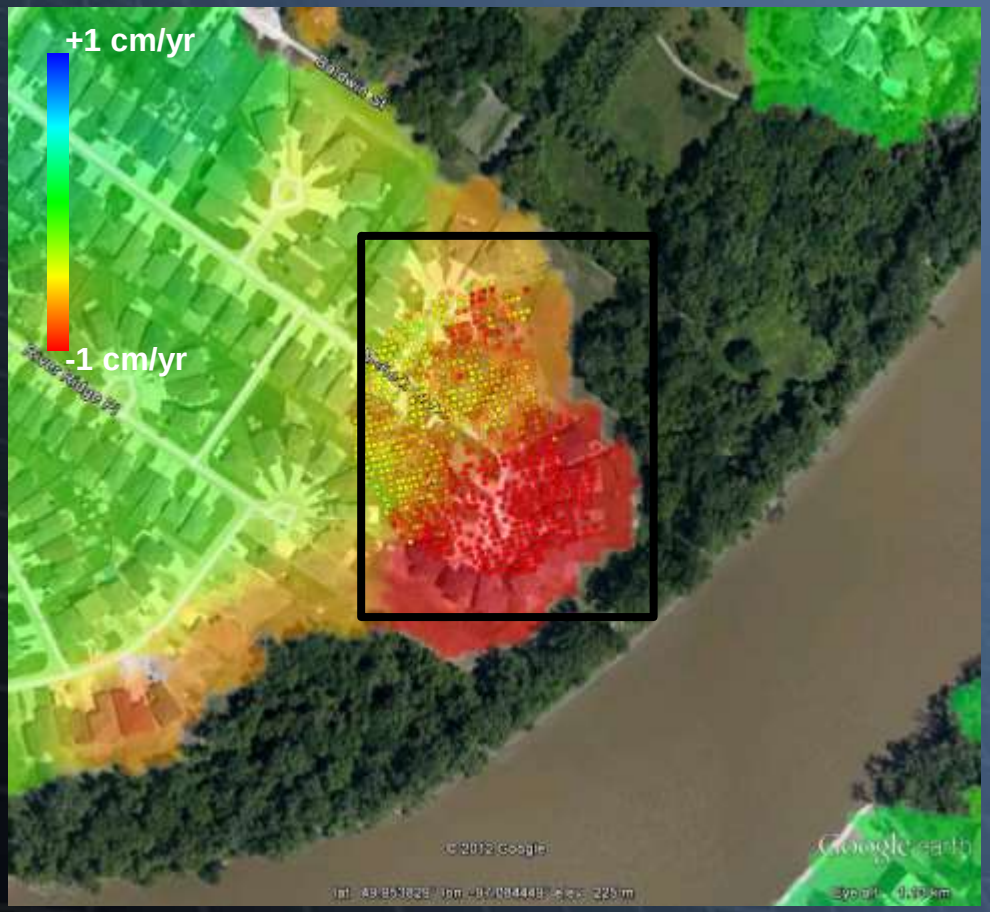
by The China Watch on March 7, 2012

This hole appeared near Shanghai Railway Station
to have been caused by subsidence because of mov
underground water table. Photo: Cai Xianmin/GT

Kiruna: The Town That Moved



Winnipeg, New Residential Development



Linear rate

Source: GoogleEarth Streetview

Extreme subsidence in a Winnipeg residential area, consistent with slumping of the riverbank.

Infrastructure Types

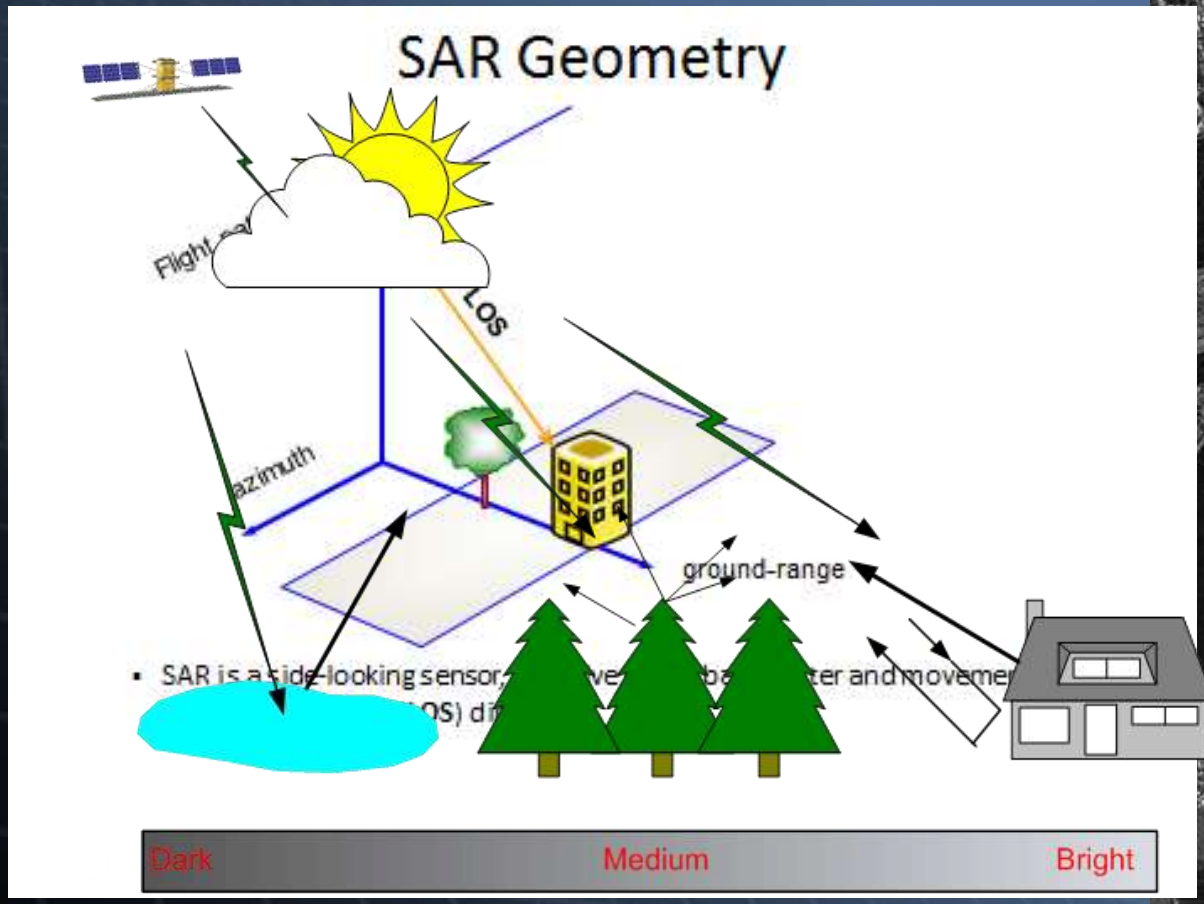
Type	Characteristics
Buildings	• Vertical surfaces -> layover, cast radar shadows • Thermally active (vertical elongation of tall buildings, horizontal spreading of metal roofed industrial buildings)
Bridges	• Multiple deformation sources (thermal expansion, vehicle loading, wind) • Complex radar return (e.g. double bounce off water)
Roads	• Low radar backscatter from asphalt -> increases measurement noise -> requires filtering • May be cluttered by traffic parked cars, trees
Tunnels	• Not directly observable • Overburden relaxation, groundwater removal may result in deformation of surface infrastructure within zone of influence
Others	• Rail, dikes, airports, port facilities, …

Deformation Drivers

Deformation driver	Examples
Dewatering (underground water extraction)	Beijing, China
Dewatering (construction related)	Vancouver water filtration tunnel, Seattle SR99 tunnel
Sinkhole formation	Limestone karst region of Pennsylvania, USA
Excavation	Cut-and-cover sections of Vancouver 'Canada Line' project
Construction induced loading	New construction in alluvial areas
Unstable slopes	Urbanized hillsides – e.g. La Paz Bolivia

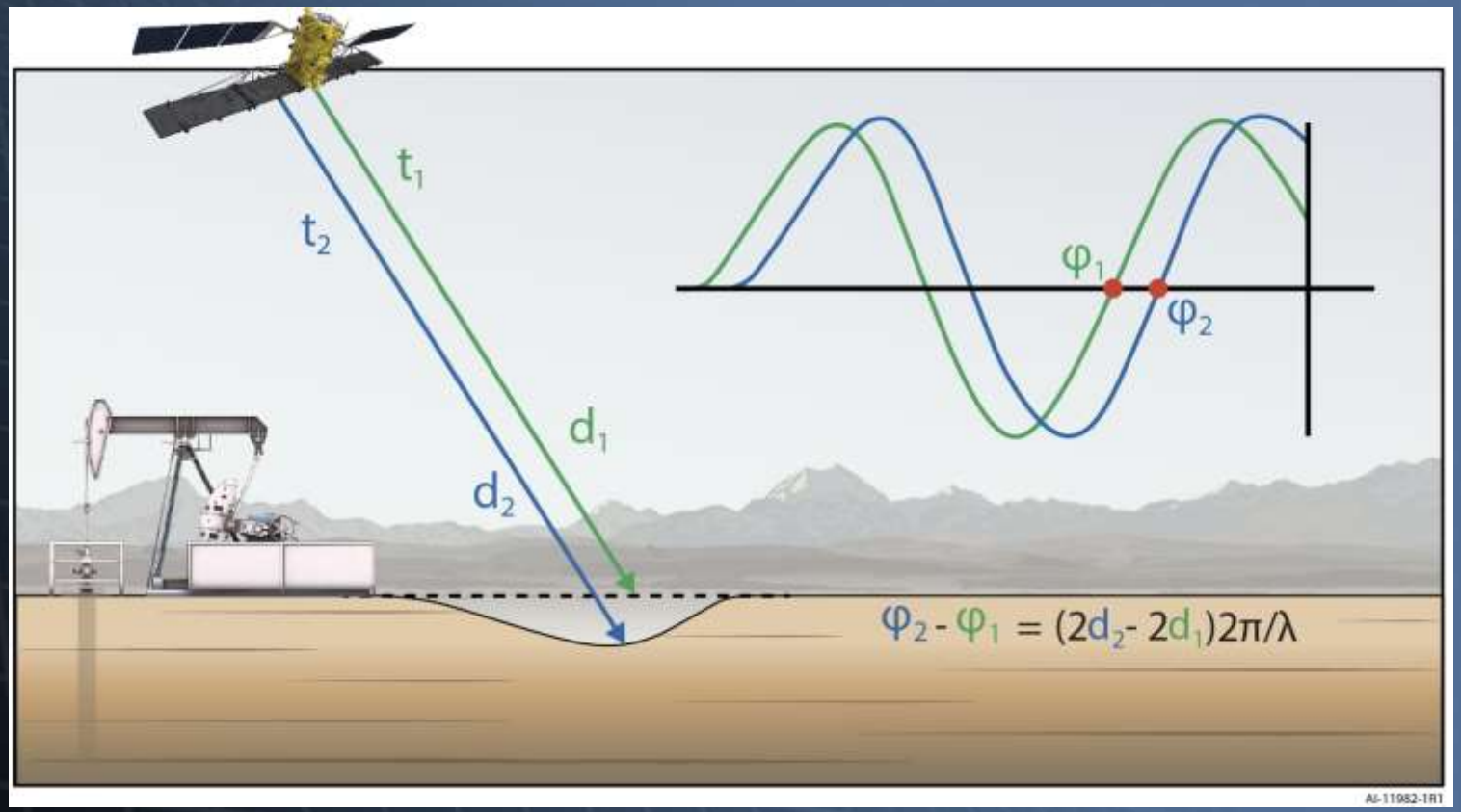
Introduction to InSAR

What does a SAR Sensor See?



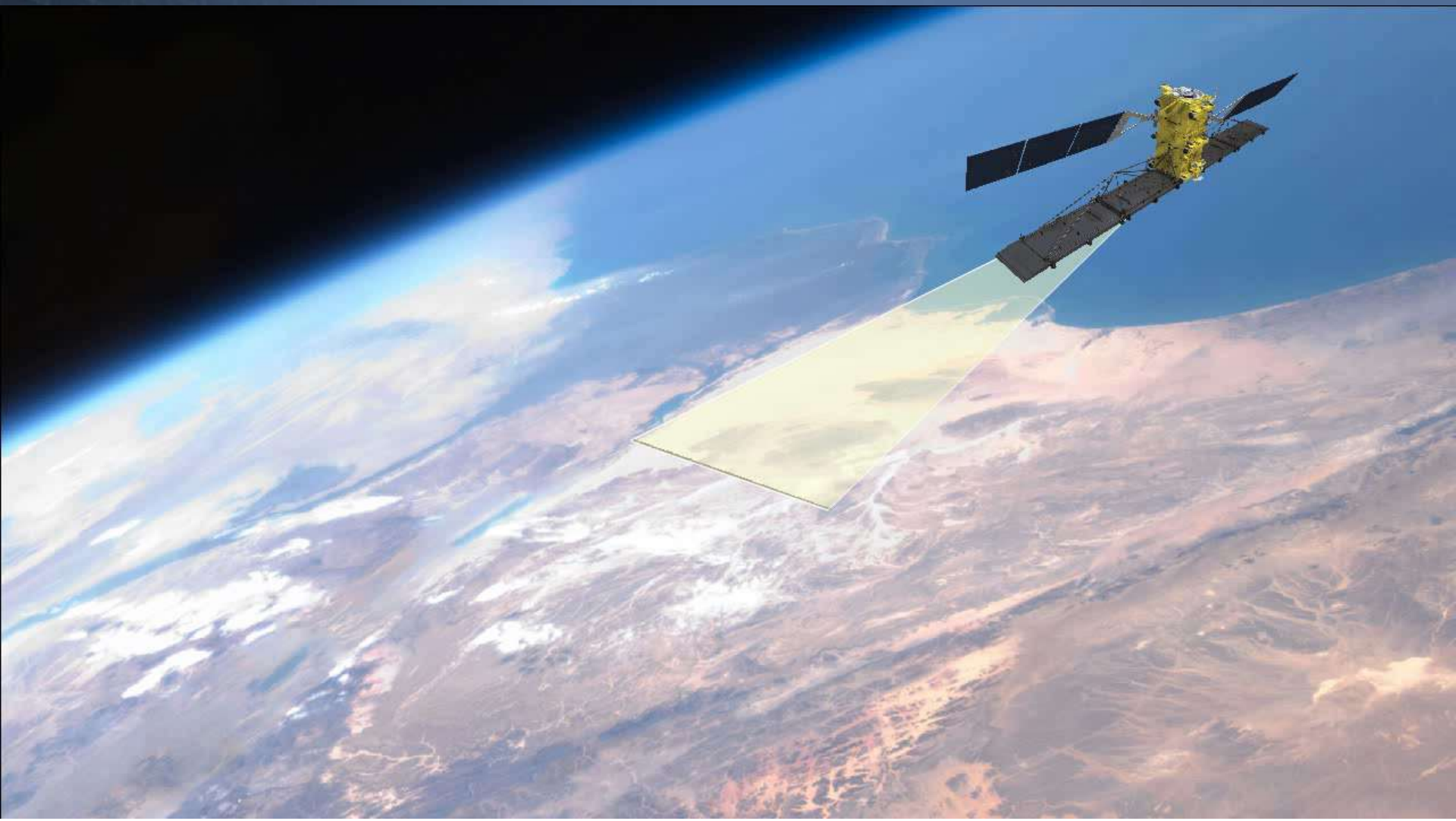
How SAR Detects Ground Movement?

InSAR calculates the change in surface height between two imaging times, by using radar to measure the distance from the satellite to the surface.

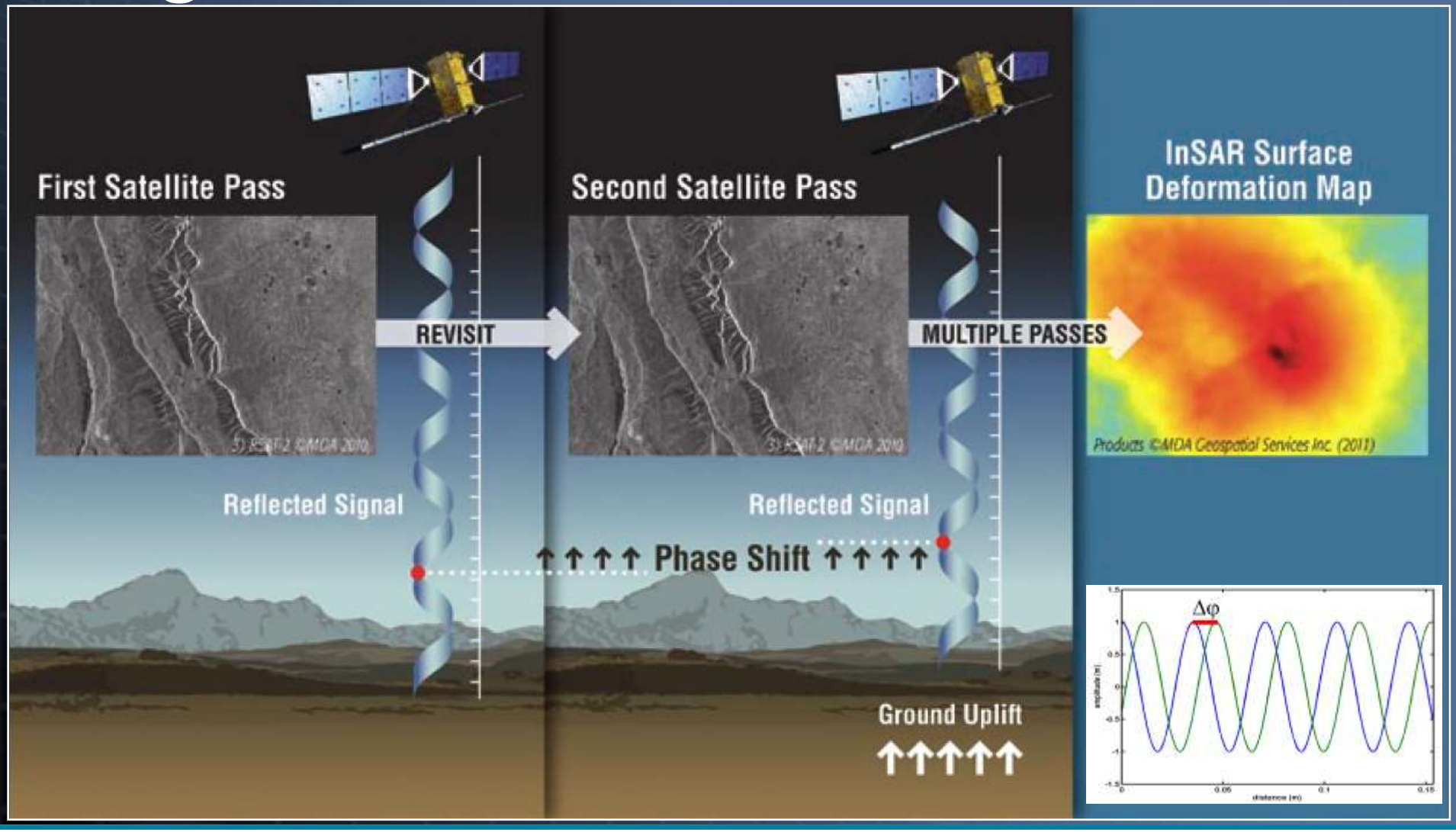


InSAR can measure surface changes of a few millimeters using SAR phase information.

InSAR concept



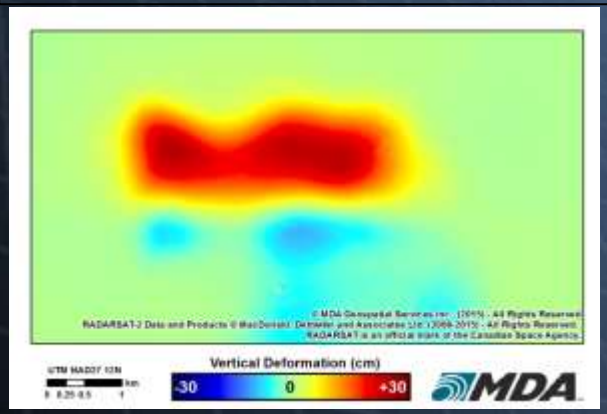
Using SAR to Measure Surface Movement

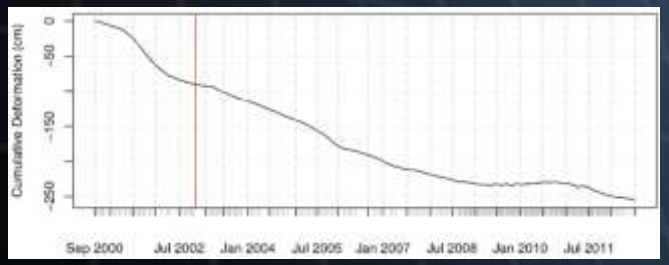


Phase and amplitude change analysis
Phase and amplitude change analysis

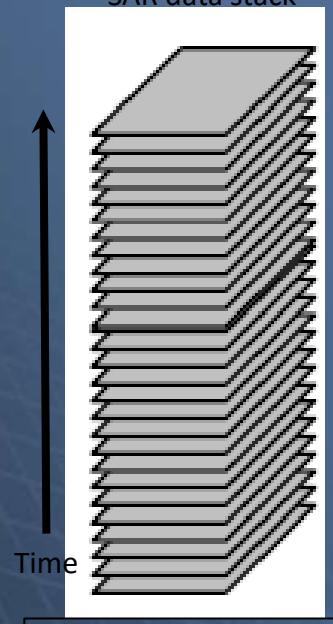
Phase Change Analysis (InSAR)

Analysis of the **phase change** of each pixel over time provides a time series of surface movement measurements with mm accuracy.





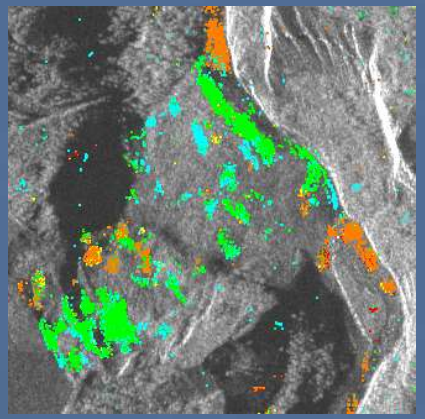
SAR data stack



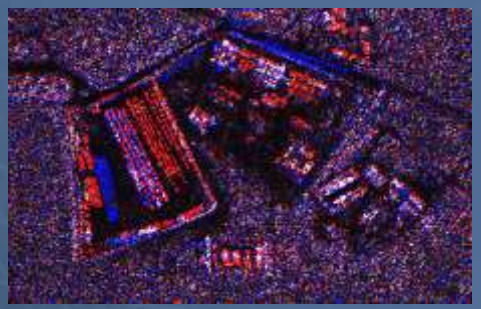
A series of SAR images collected with the same viewing geometry is used to perform either phase change or amplitude change analysis.

Amplitude Change Analysis

Analysis of the **amplitude change** of each pixel information about the appearance or disappearance of objects and features.



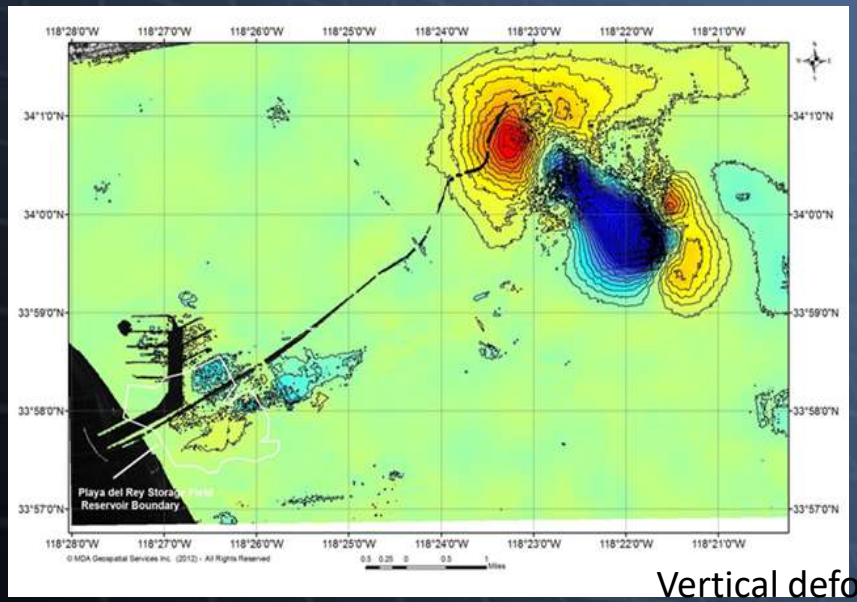
Changes at different times

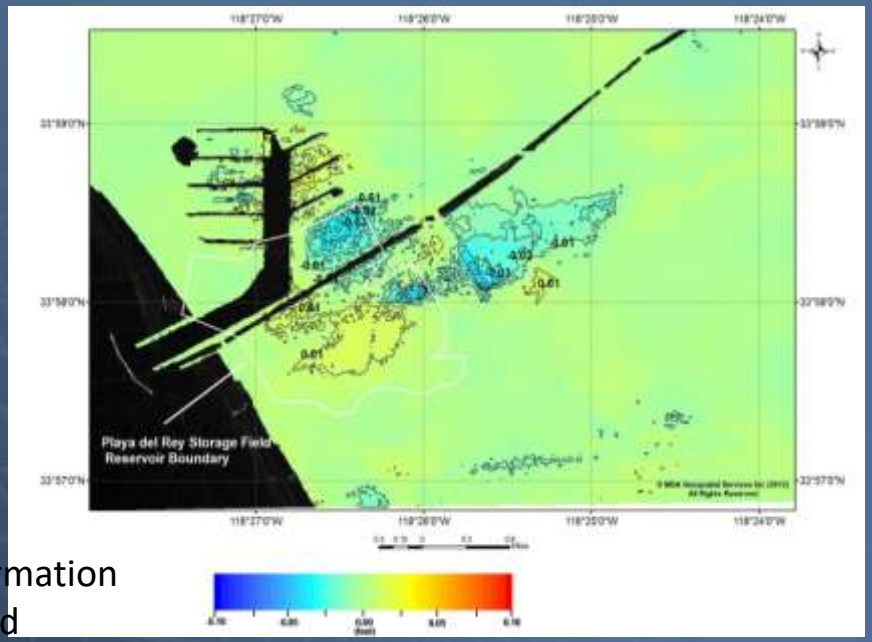


New or missing objects

Demonstrate Absence of Deformation

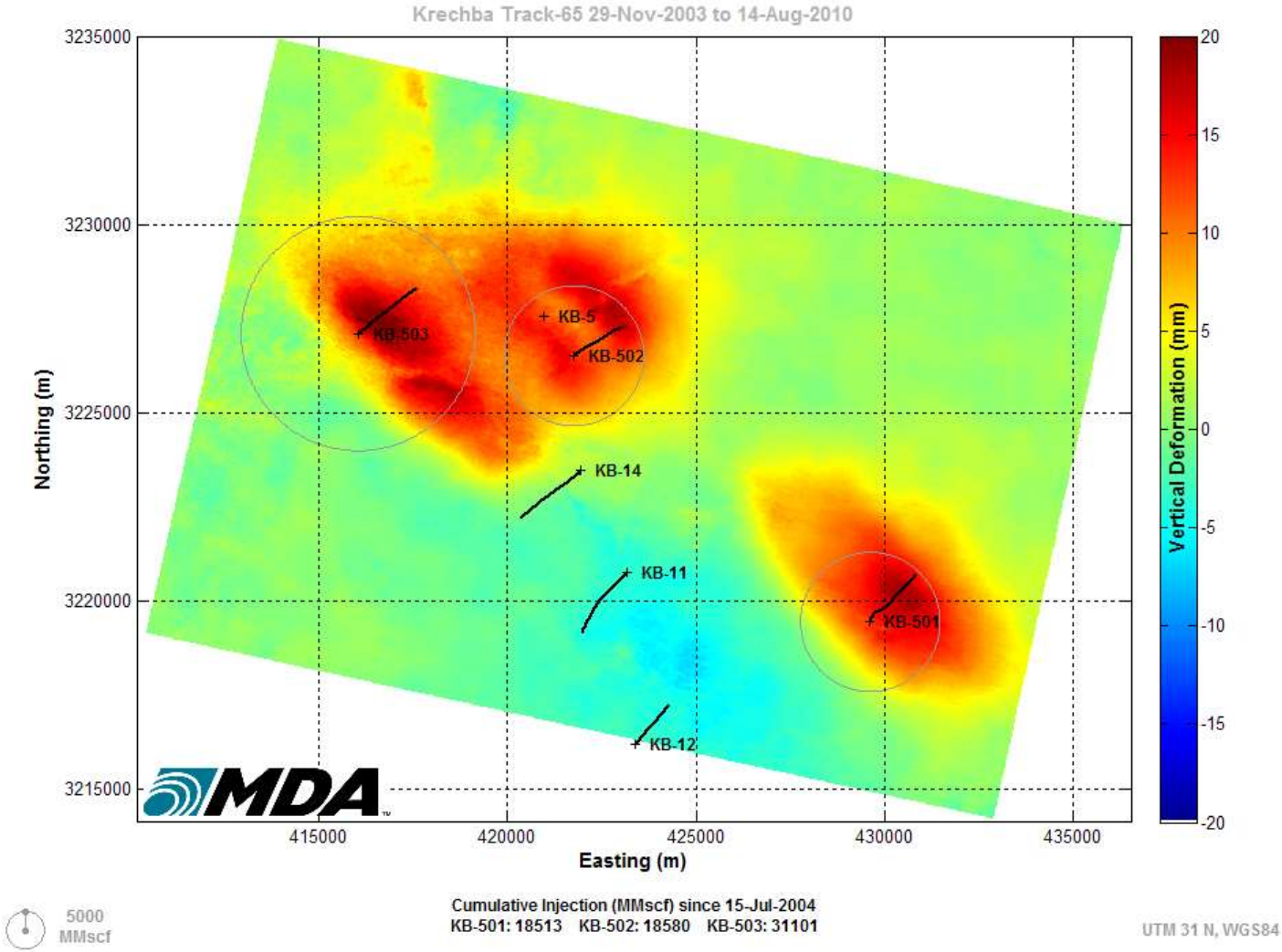
- Analysis over a five year period using natural targets
- InSAR used to confirm absence of deformation over gas storage reservoir field
- Showed that technology worked by measuring ground movement in adjoining EOR field
- Ground movement at gas storage field very small and related to moisture variations during rainy/dry conditions





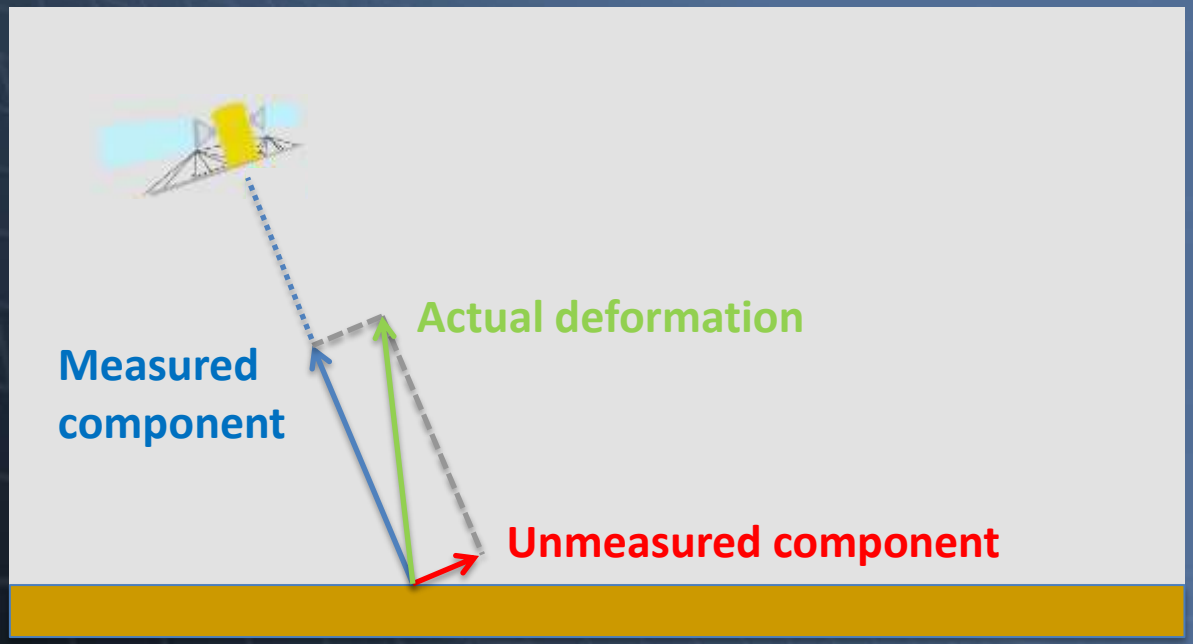
Vertical deformation
~4 year period

Monitoring Trends Over Time

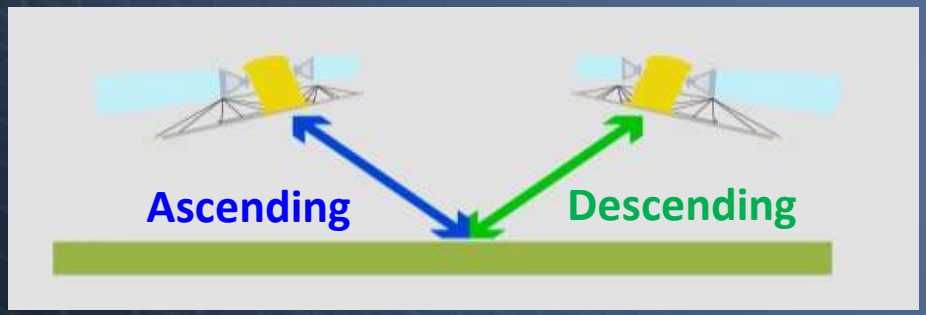


Line-of-sight measurements

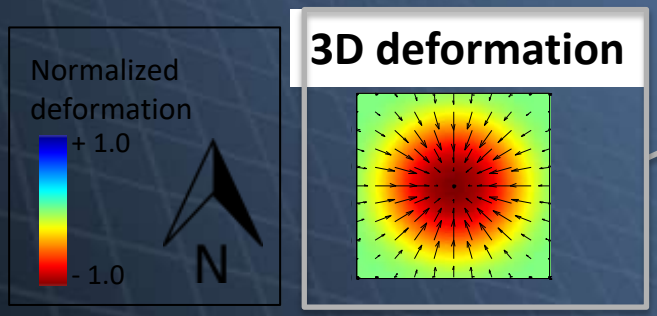
- Actual deformation is a 3D vector quantity
- InSAR measures projection of deformation along sensor line-of-sight → a 1D quantity
- 2 (or more) view geometries can be combined to measure other dimensions



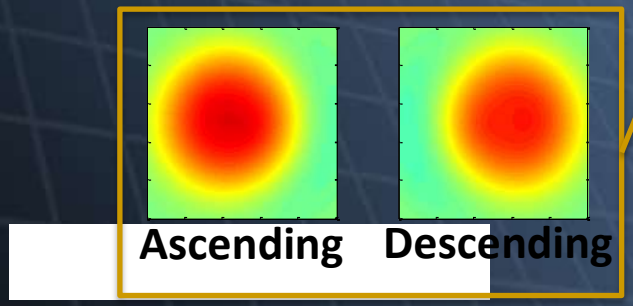
Estimating 2D deformation with InSAR



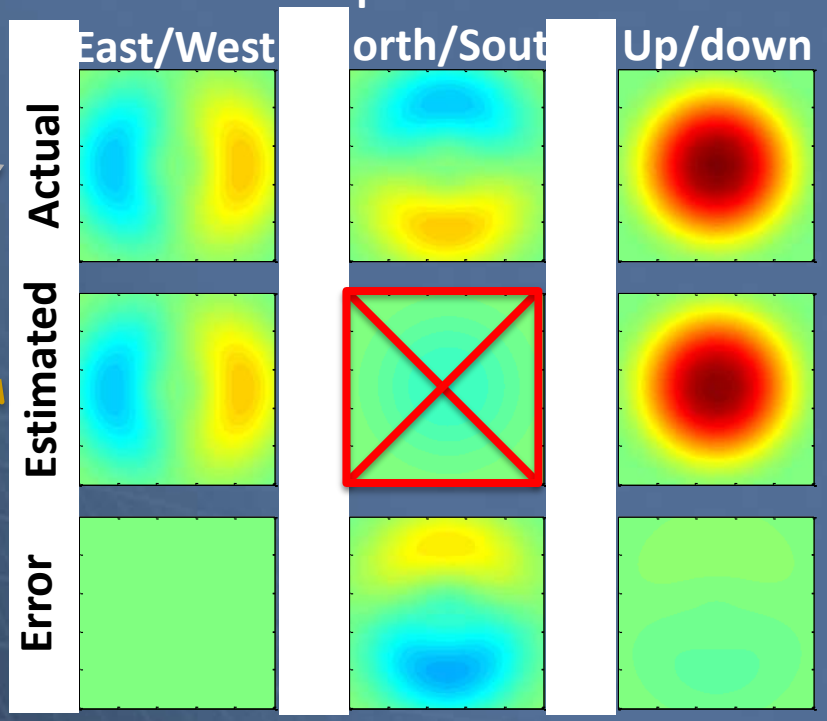
1. Simple example of dewatering deformation



2. Line-of-sight InSAR measurements (apparent east/west shift)



3. Vector decomposition

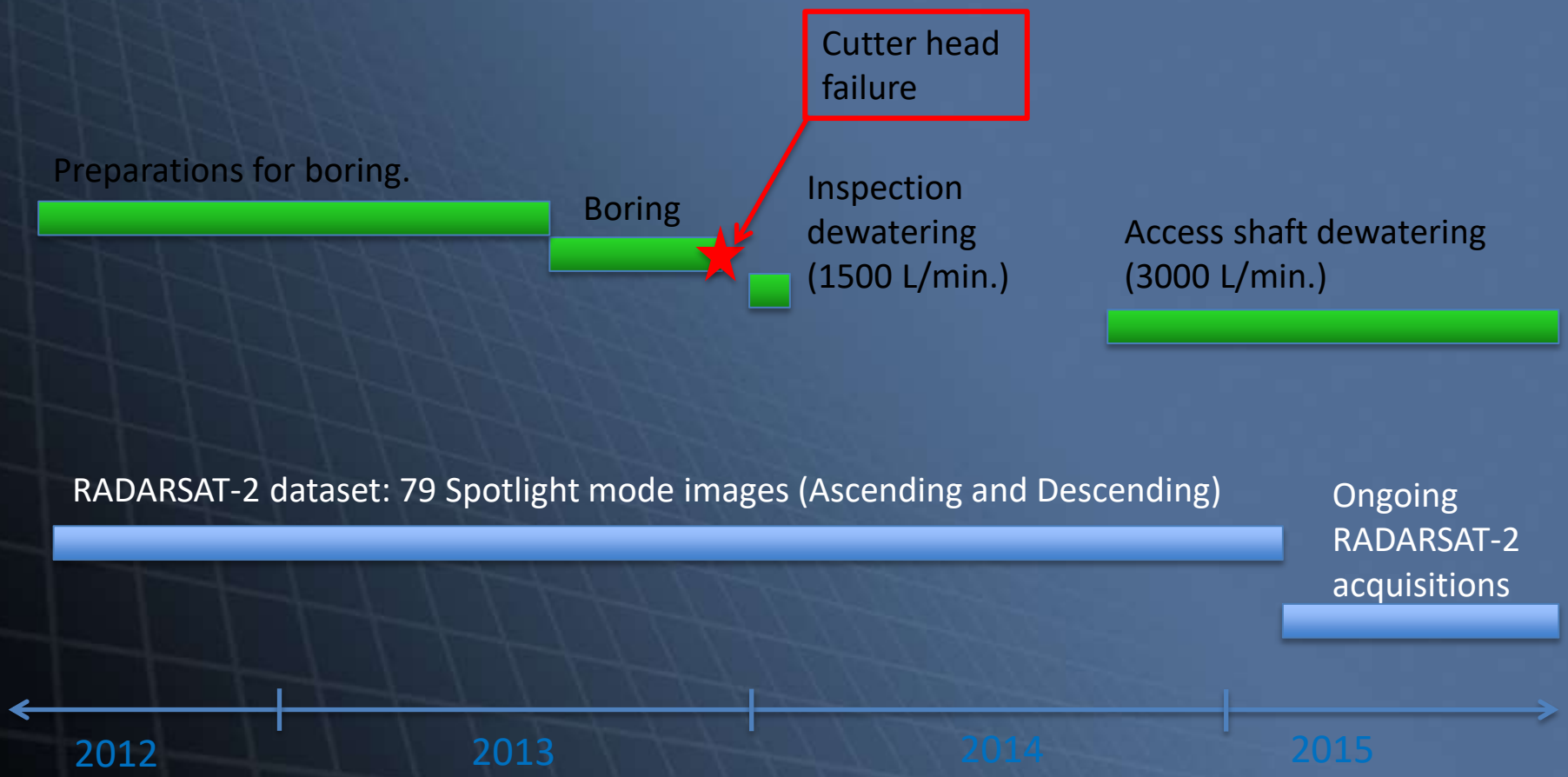


Case Study: Seattle Tunneling Project

SR99 Tunnel Project

- 3.2 km bored tunnel under downtown Seattle, U.S.A.
- 17.5 m diameter tunnel boring machine → 'Big Bertha'
- TBM failed after 10% completion of tunnel
- Repair involves 24 m wide x 37 m deep rescue shaft with significant dewatering required → potential for surface displacement

SR99 Tunnel Project Timeline

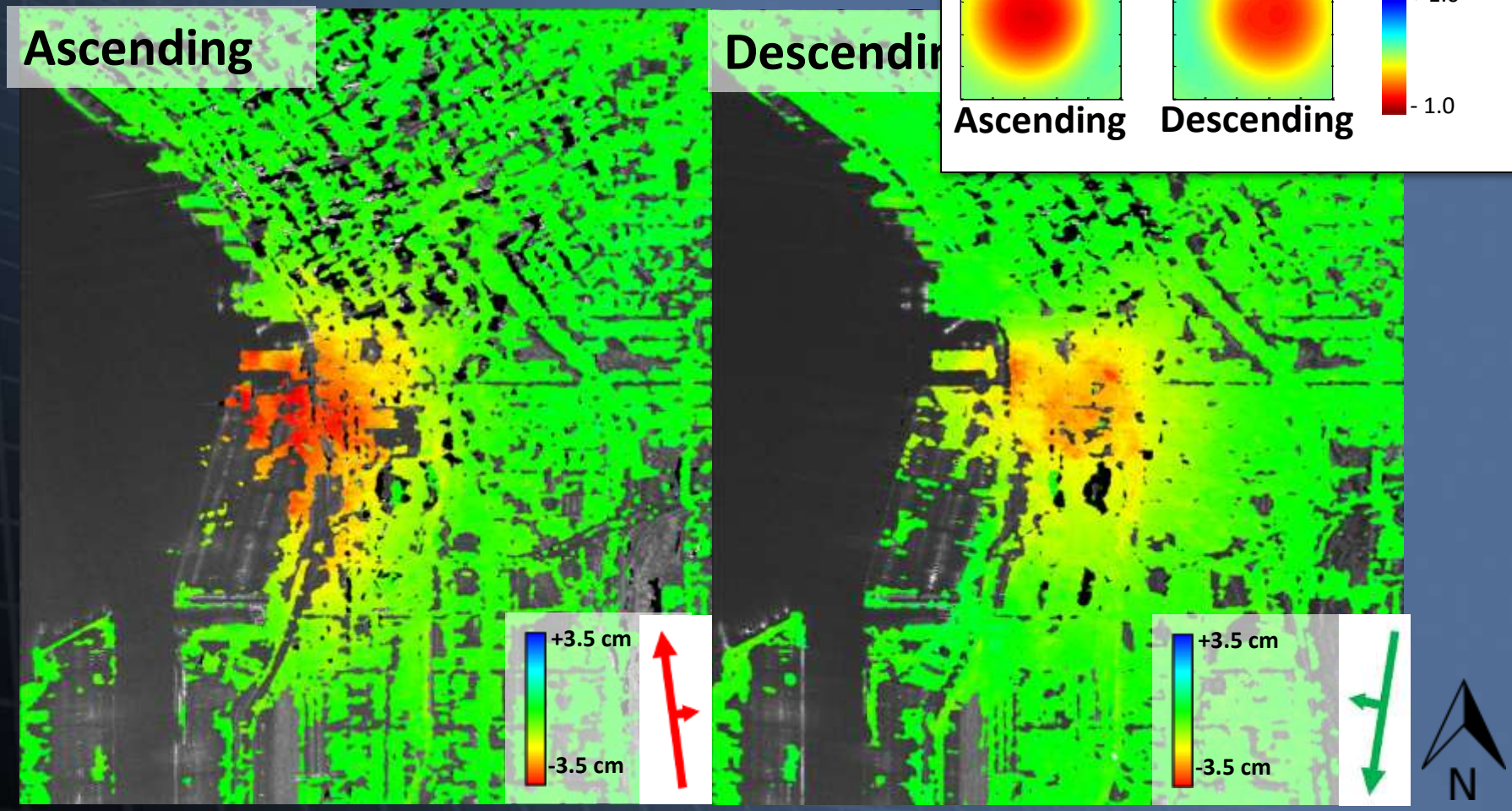


RADARSAT-2 data

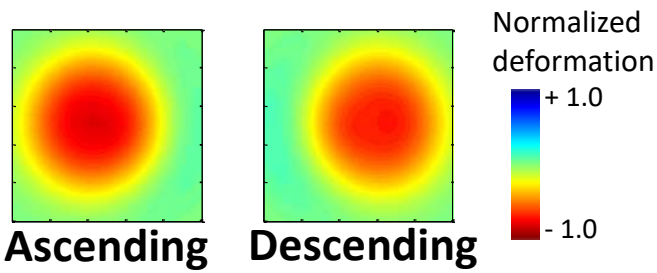
Stack	Start Day	End Day	Number of Scenes	Incidence angle (degrees)
SLA9 Ascending	2012/06/06	2015/02/15	41	37.0
SLA23 Descending	2012/06/06	2015/02/15	38	46.7

Line-of-sight deformation

Cumulative (2012/06/06 – 2015/02/15)

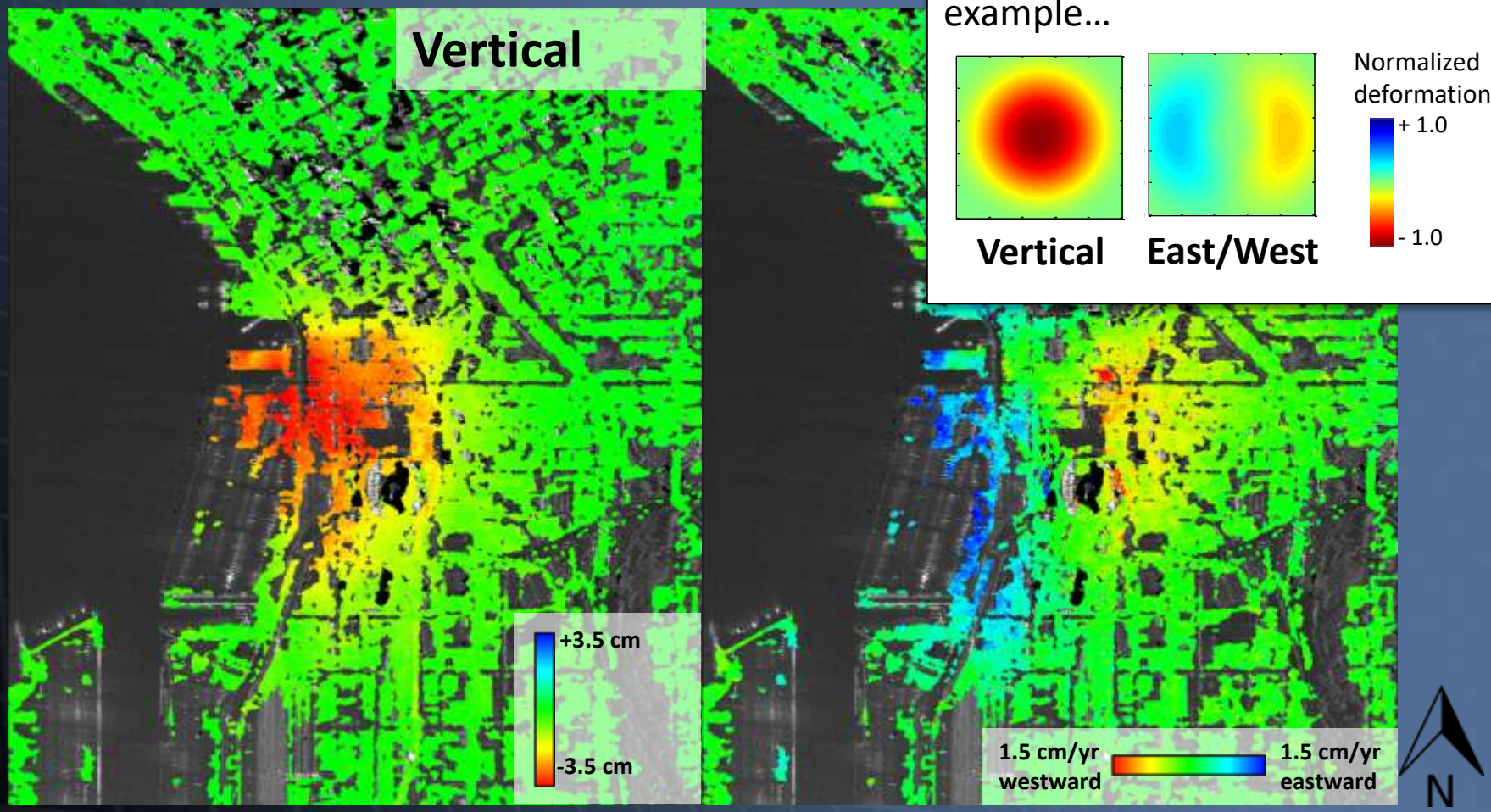


Same east/west pattern shift from example…



2D deformation

Cumulative (2012/06/06 – 2015/02/15)

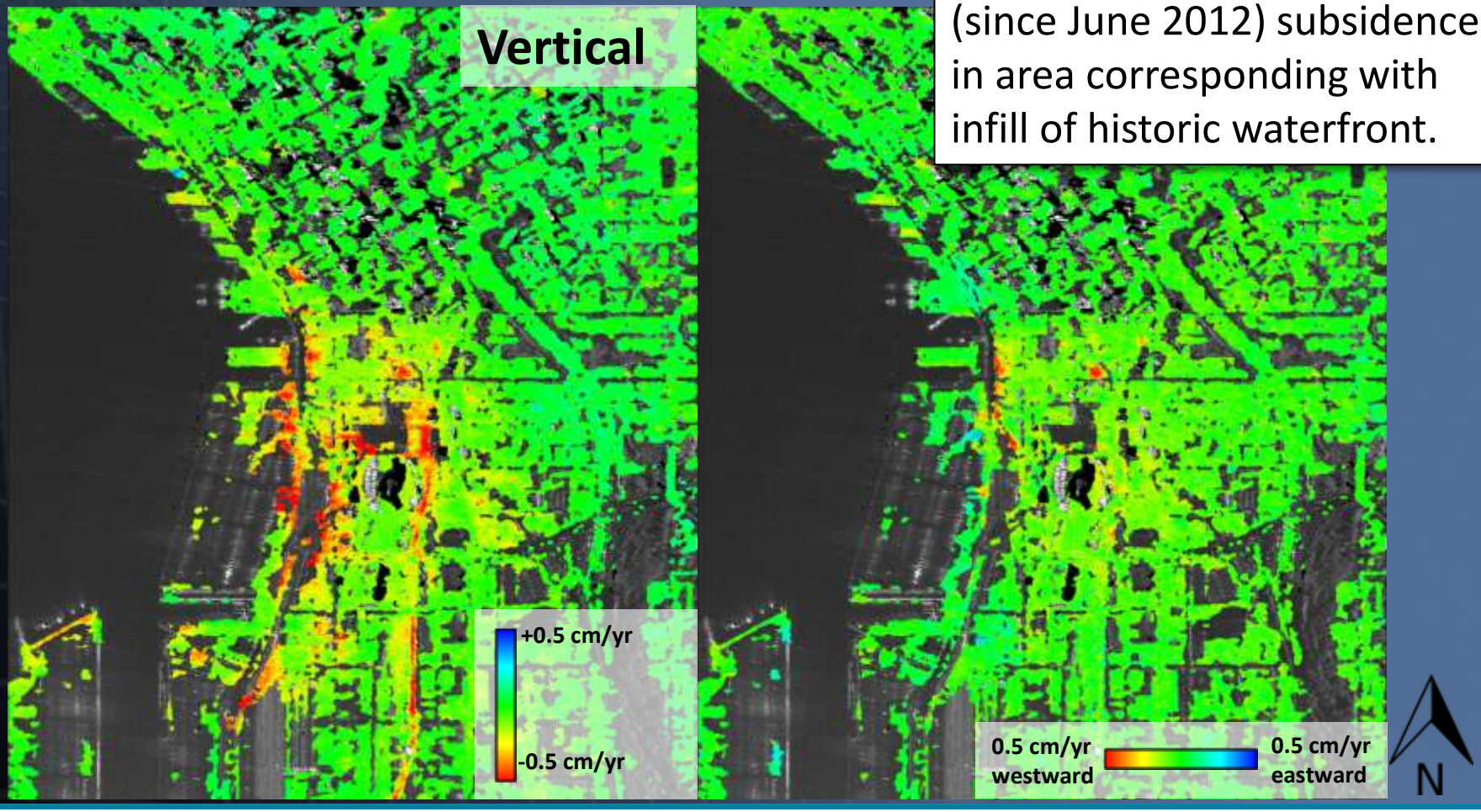


Same general patterns from example…

Pre-dewatering linear deformation

(2012/06/06 – 2014/09/24)

Significant areas of long term (since June 2012) subsidence in area corresponding with infill of historic waterfront.



Pre-dewatering linear deformation

(2012/06/06 – 2014/09/24)

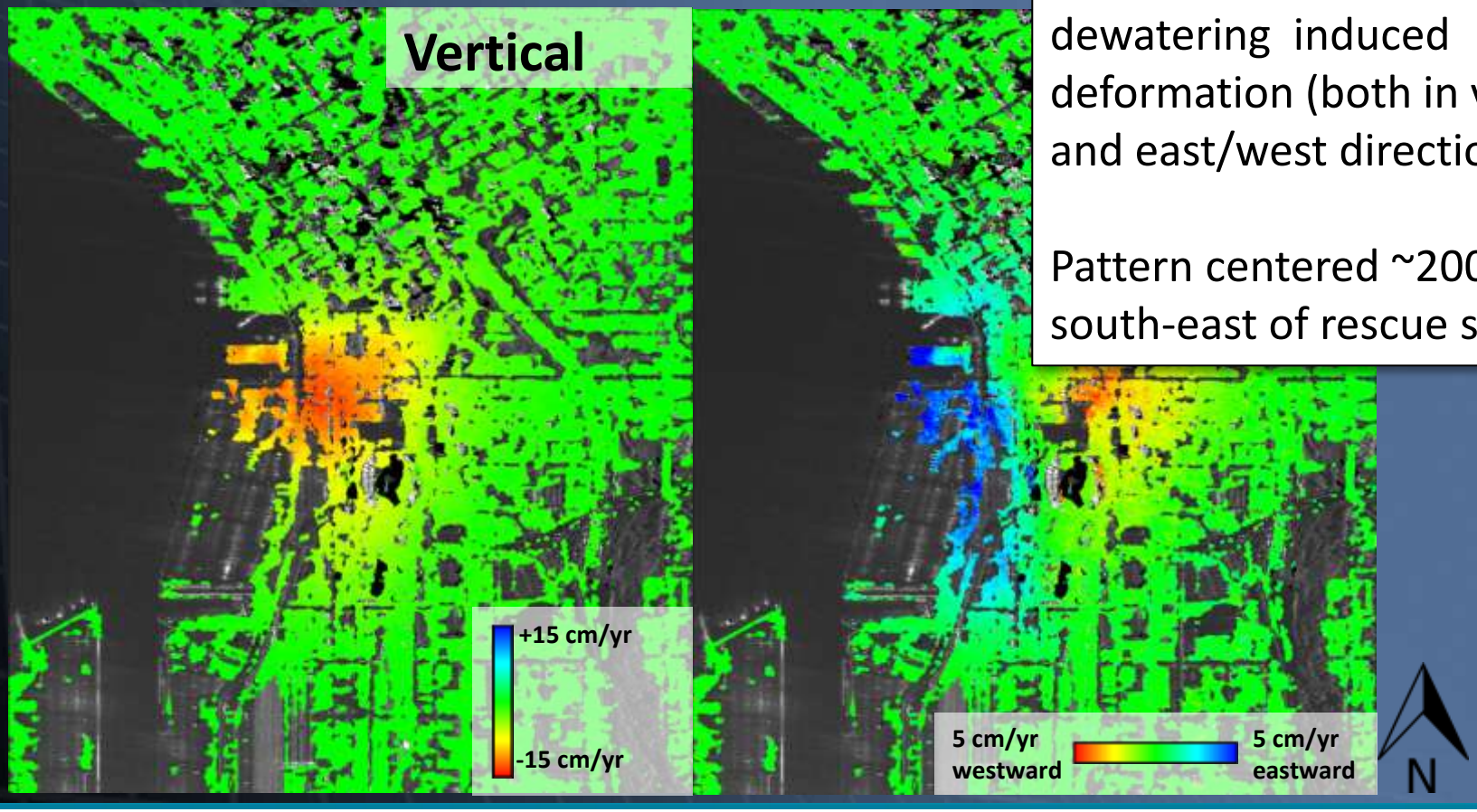
Westward deforming building shows external signs of damage and reinforcement.

Dewatering correlated deformation

2012/06/06 – 2014/11/01 : no deformatio
2014/11/01 – 2015/02/15 : linear deforma

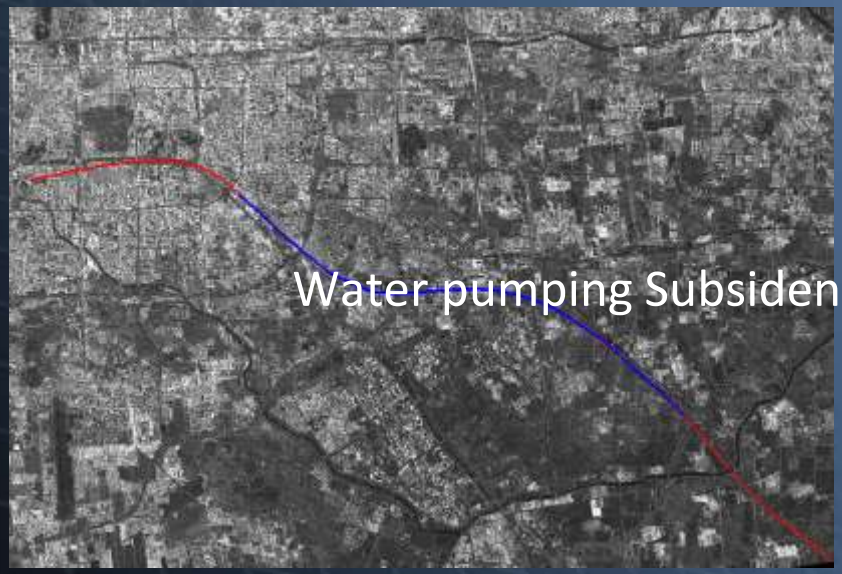
Dewatering correlated deformation is spatially consistent with localized dewatering induced deformation (both in vertical and east/west directions).

Pattern centered ~200 m south-east of rescue shaft.

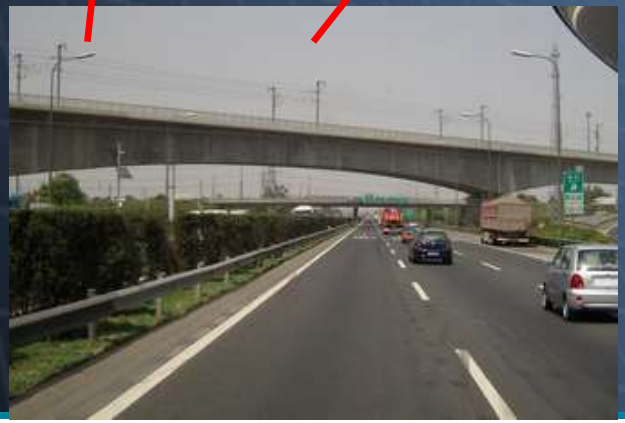


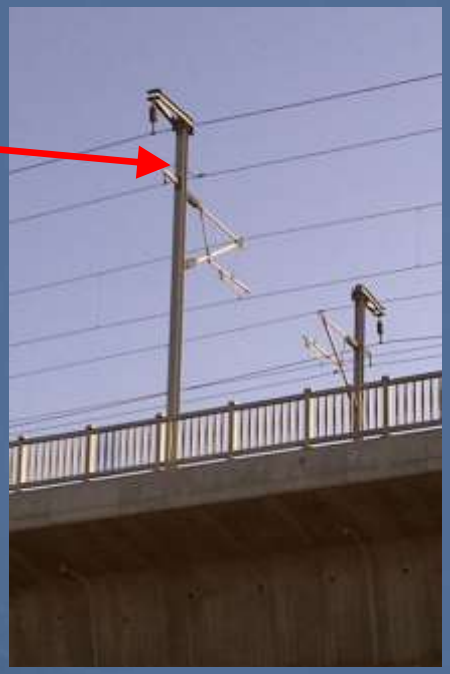
Case Study: High Speed Railway Line Subsidence

Example: JingJin High Speed Rail (HSR) China

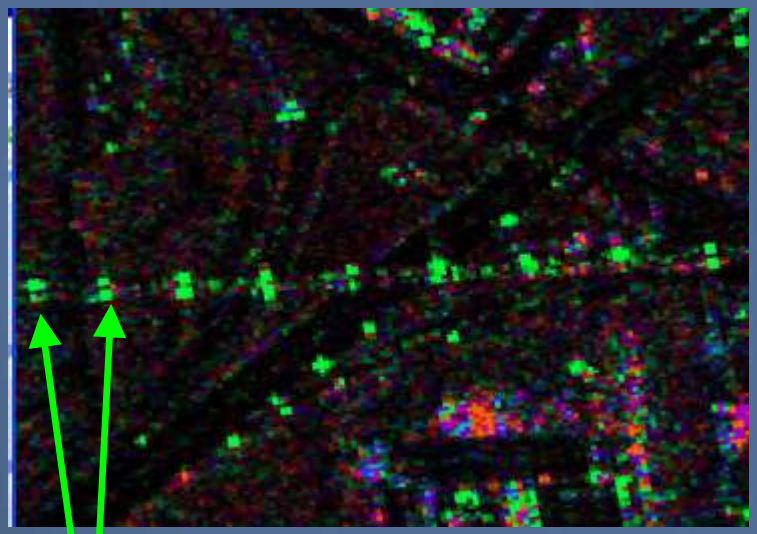


Using RADARSAT-2 High Resolution Images Allows Detection of Stable Reflections from Rail Posts

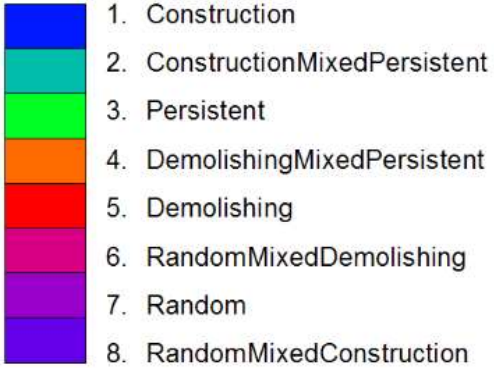




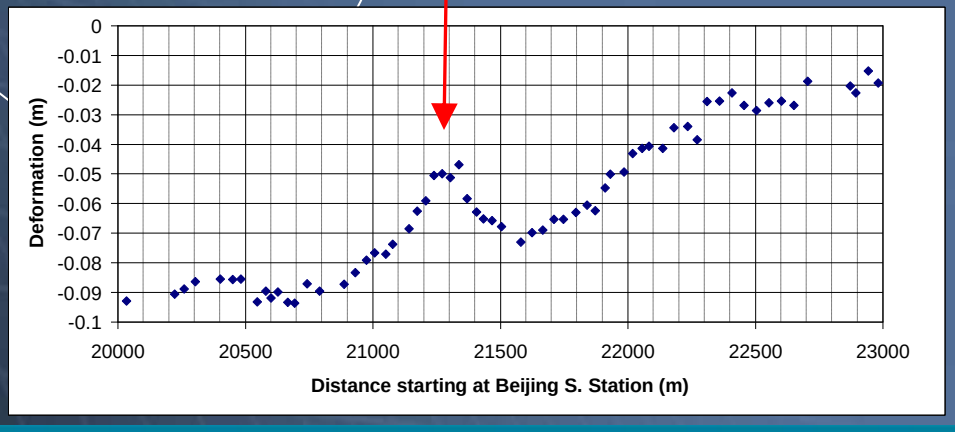
Stable Reflections from the Rail Posts as Visible in the SAR Imagery



Green: stable reflection in 5 scenes, usable for InSAR (CTM)

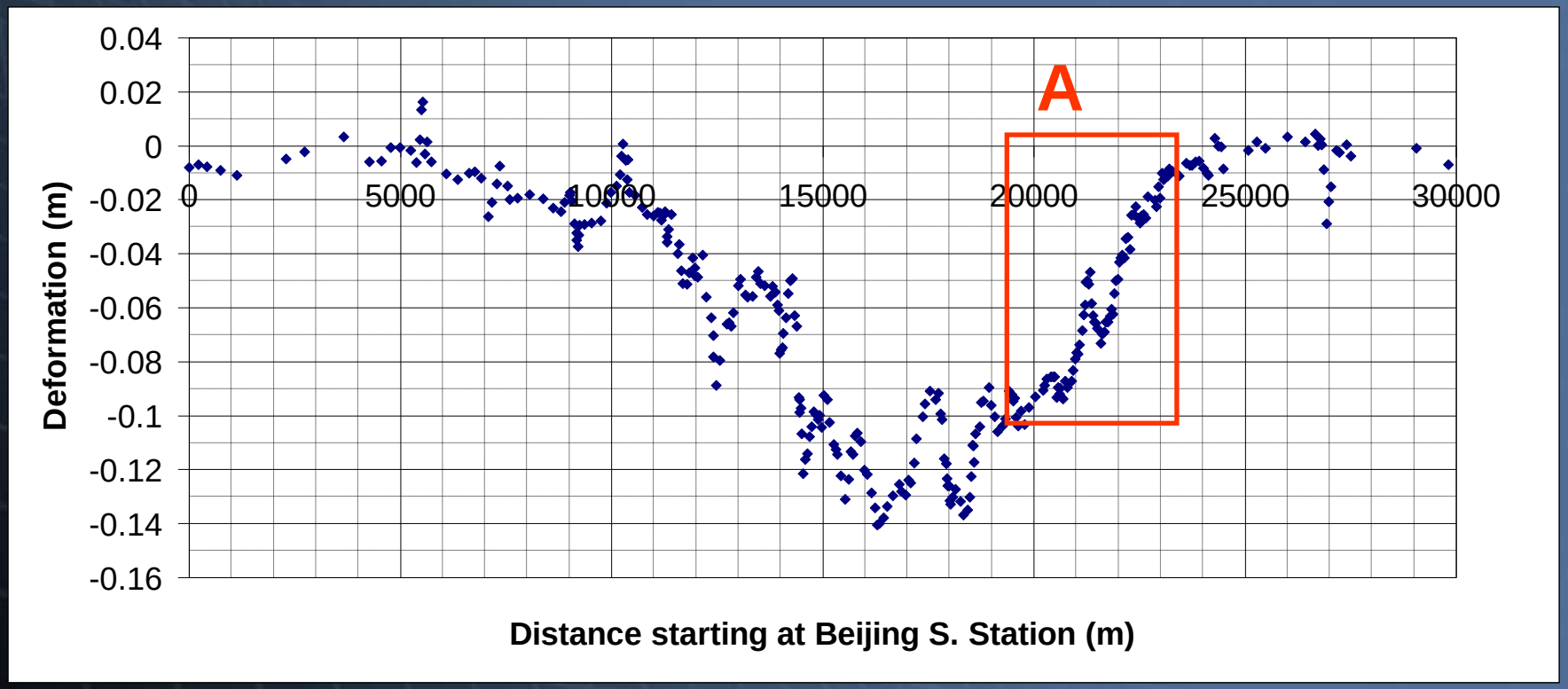


Yizhuang Railway Station (at 21.3 km)
Significant Deformation Signal (~5 cm)



Subsidence Profile Along HSR

Maximum rates of approximately 10 cm per year



Conclusion

Benefits of INSAR-based Monitoring

- Inteferometry is a proven technique which can measure mm of surface movement
- Surface movement measurements from InSAR can be readily integrated with other measurement program used such as GPS, or in-situ survey etc.
- Satellites provide wide area routine monitoring
- Regular monitoring can be used as an alert for growing subsidence problems, and targeting engineering / maitanence resources

Organizations Benefiting from the Information

- Highway / Railway companies monitoring infrastructure assets
- State / Municipality governments monitoring its areas of responsibility

Thank You

- Vivienne Wu, MDA Geospatial Services Inc., vwu@mdacorporation.com; +1 (604) 231 2607
- Srinibas Patnaik, DigitalGlobe India, spatnaik@digitalglobe.com, +91 99161 39761
- N.S. Shankaranarayana, DigitalGlobe India, shankans@digitalglobe, +91 98455 45661

Image Credits and Disclaimer Language

GENERAL ACKNOWLEDGEMENTS

Certain images contained in this document are property of third parties.