INFORMATION SYSTEMS

InSAR Monitoring of Urban Infrastructure: Mitigating Land Deformation Risk

presented by Vivienne WU

www.mdacorporation.com

Outline

- Intro to Land Deformation Monitoring in Urban Context
- Intro to INSAR
- Monitoring Solution Overview
- Case#1: Seattle SR99 Bored Tunnel
- Case#2: Canadian Cases

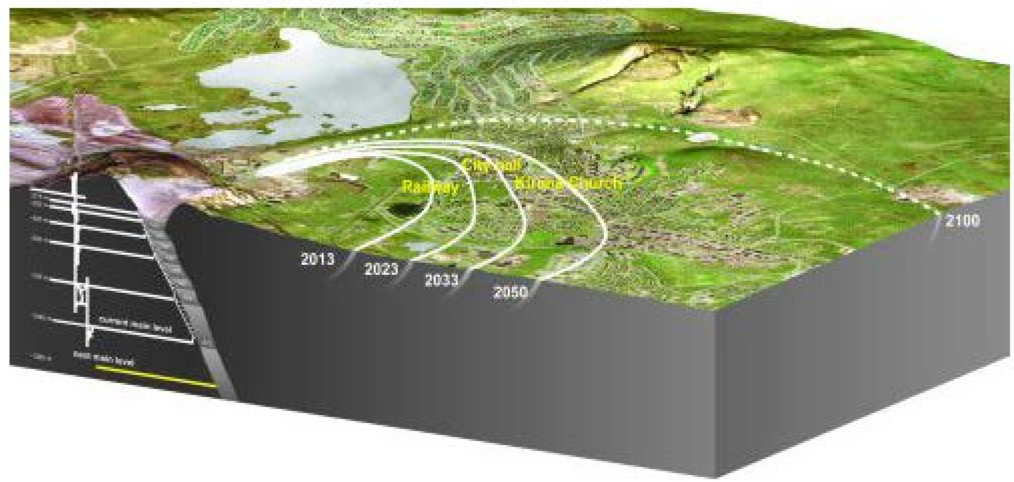
Land Deformation – In Urban Areas

Sinking or soaring?

by The China Watch on March 7, 2012

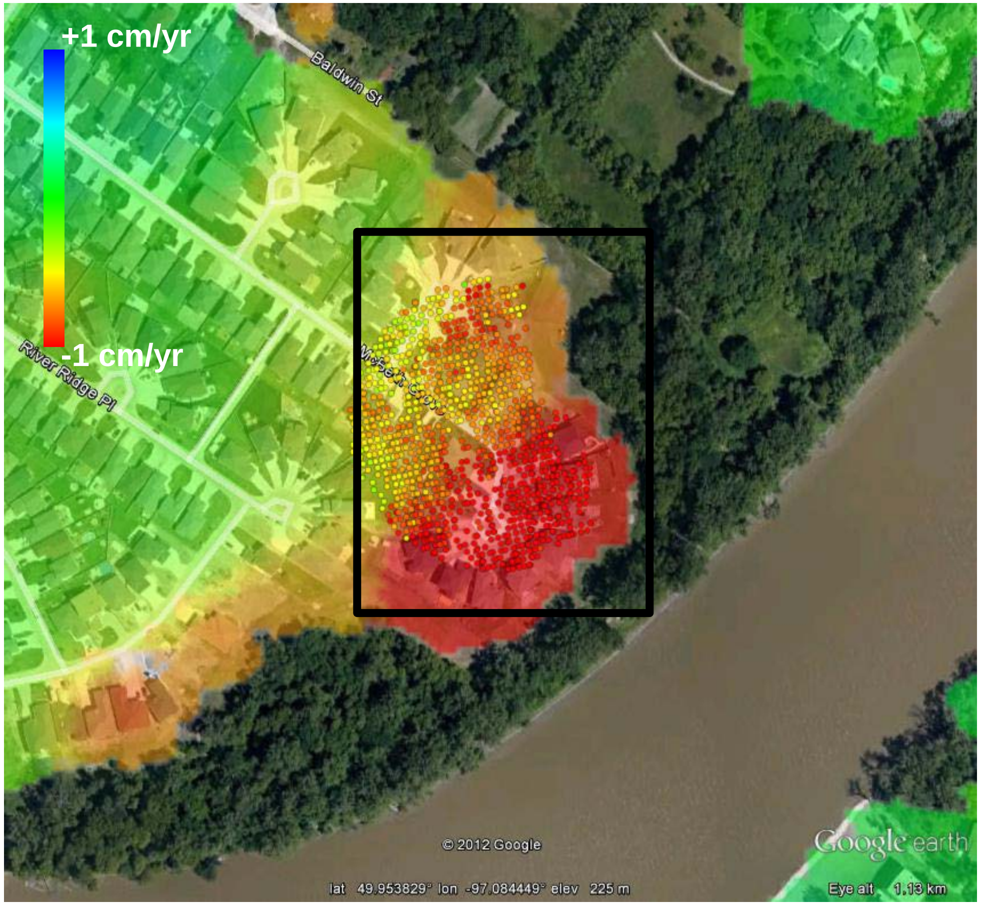
This hole appeared near Shanghai Railway Station ... to have been caused by subsidence because of mov... underground water table. Photo: Cai Xianmin/GT

Kiruna: The Town That Moved

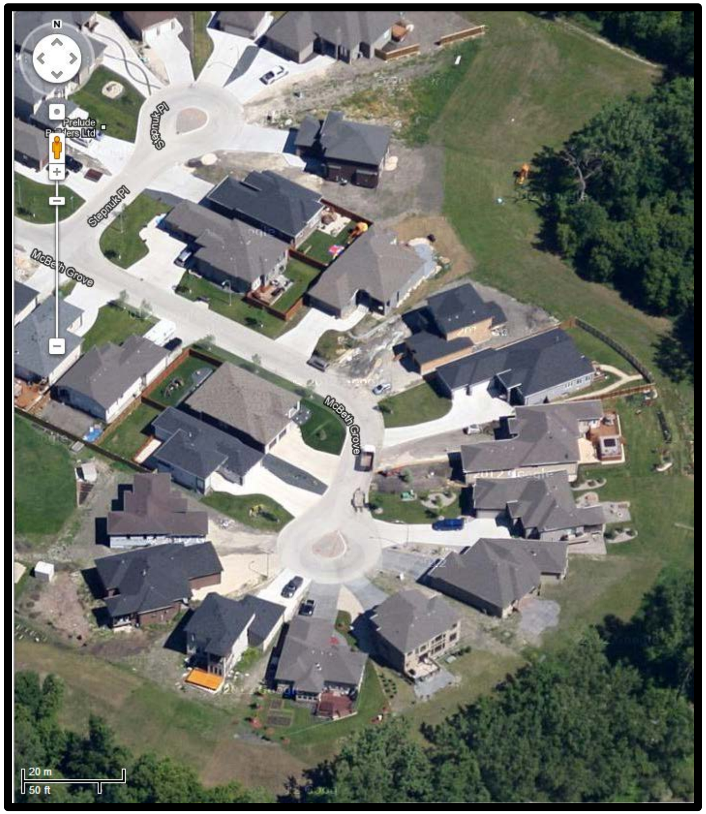


The collapse differs in each of the six structures and buildings that make up the T-2, variations airport authorities compensated by ramps, baseboards and gravel.

Winnipeg, New Residential Development



Linear rate



Source: GoogleEarth Streetview

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

Infrastructures and Urban Land Deformation

Urban Infrastructure

Construction related subsidence

'Big Bertha' TBM Repair

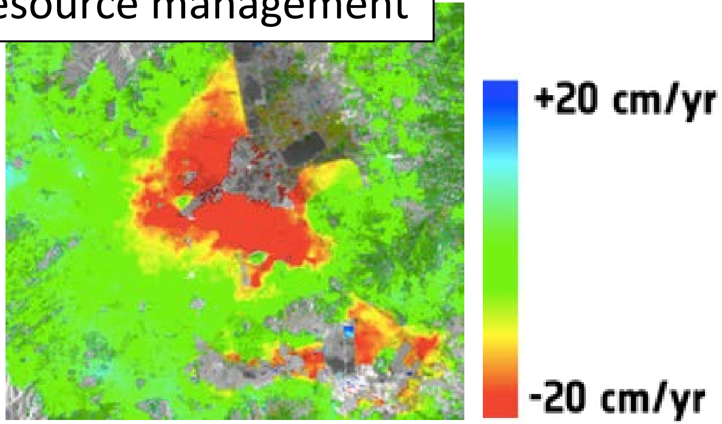
Structural failures

I-35W Minneapolis Bridge Collapse

Natural hazards

Karst sinkhole, Florida, USA

Resource management



Mexico City subsidence

Infrastructure Types

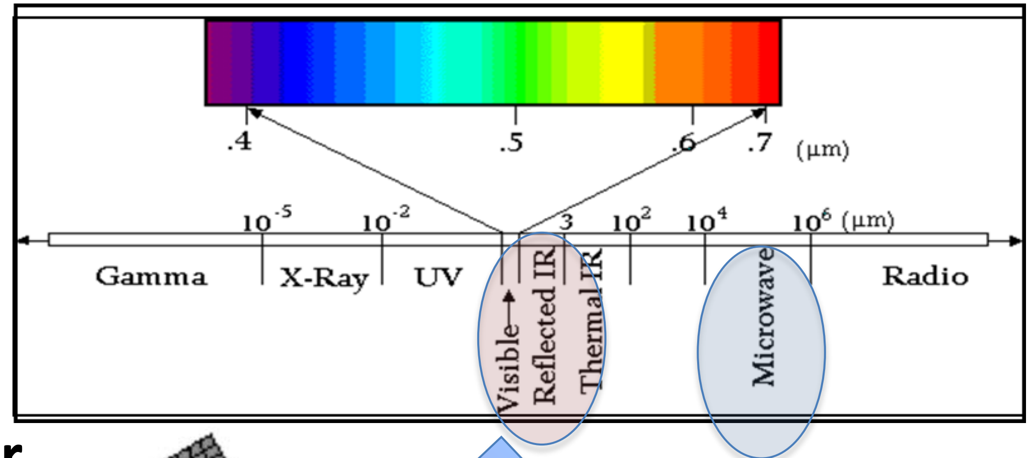
Type	Characteristics
Buildings	• Vertical surfaces -> layover, cast radar shadows • Thermally active (vertical elongation of tall buildings, horizontal spreading of metal roofed industrial buildings)
Bridges	• Multiple deformation sources (thermal expansion, vehicle loading, wind) • Complex radar return (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 (aquifer depletion)	Mexico City, California
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
Structural failure	Aging infrastructure

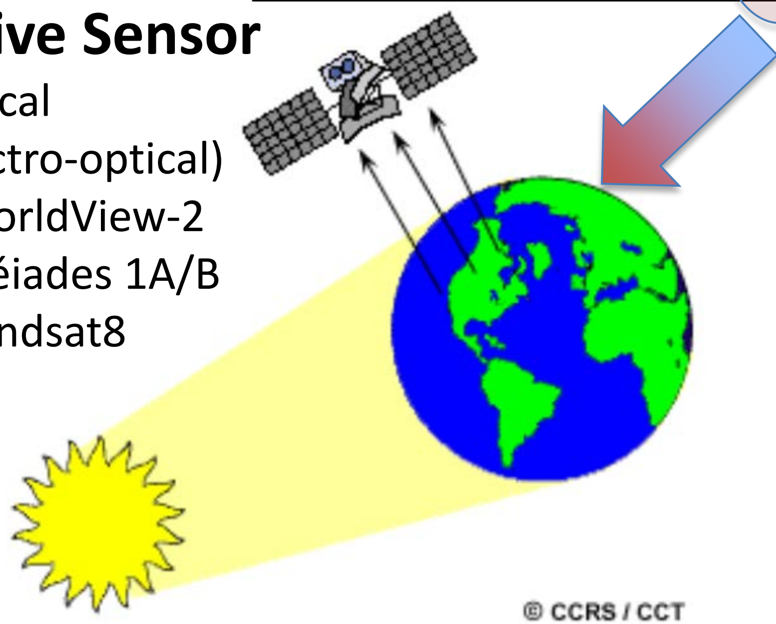
Introduction to InSAR

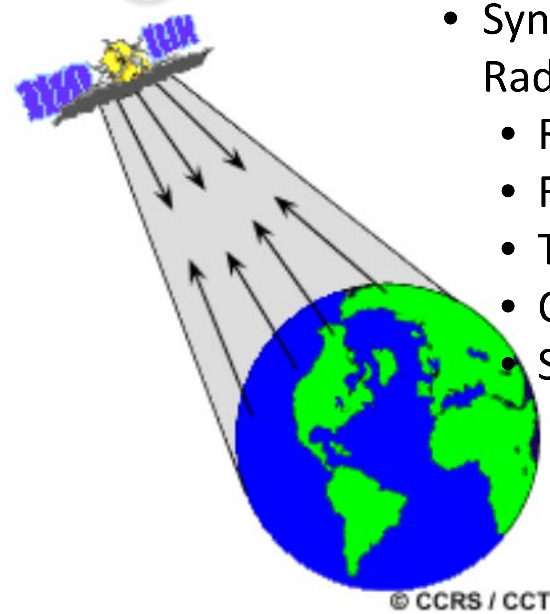
Information From Satellites



Passive Sensor

- Optical (Electro-optical)
  - WorldView-2
  - Pléiades 1A/B
  - Landsat8

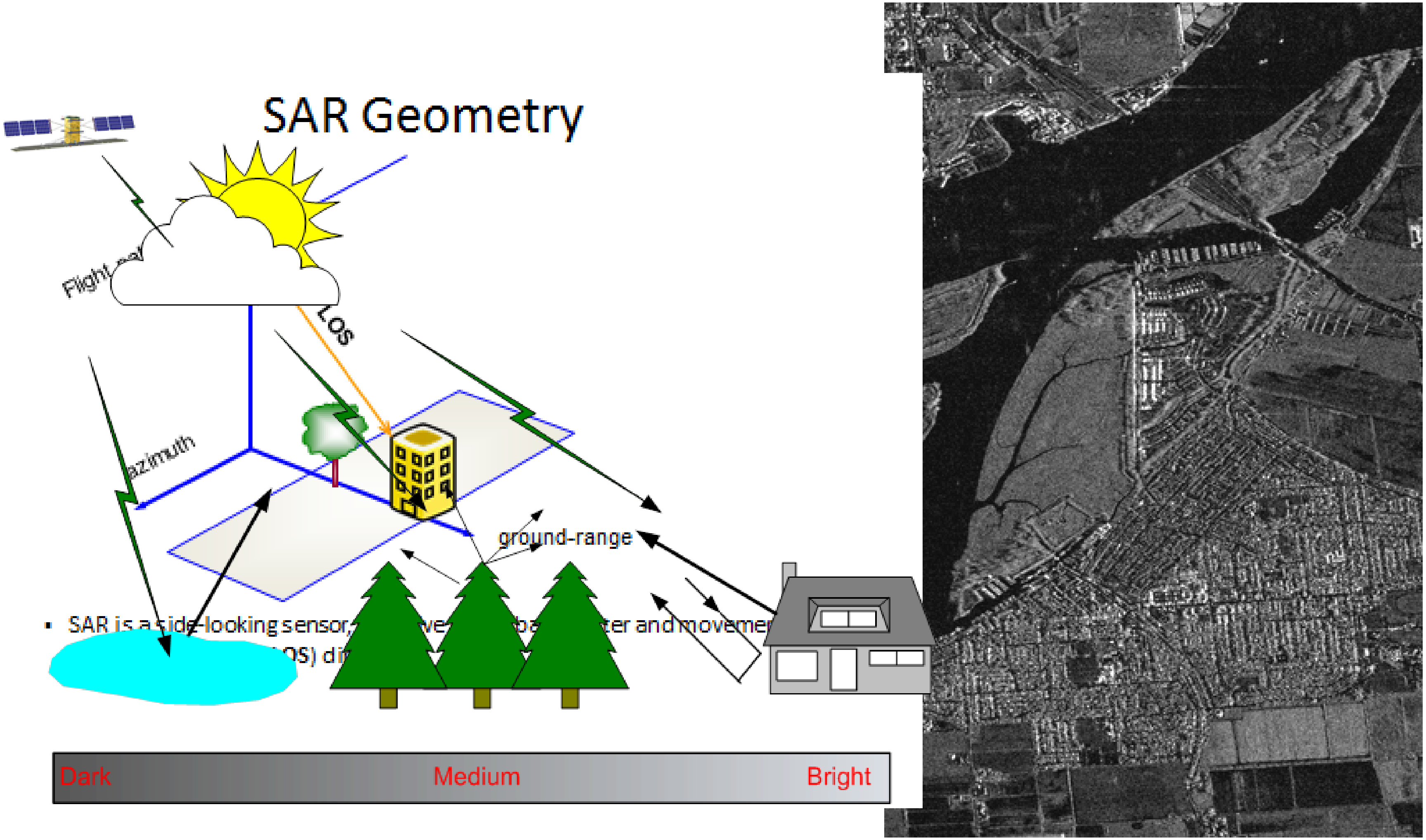




Active Sensor

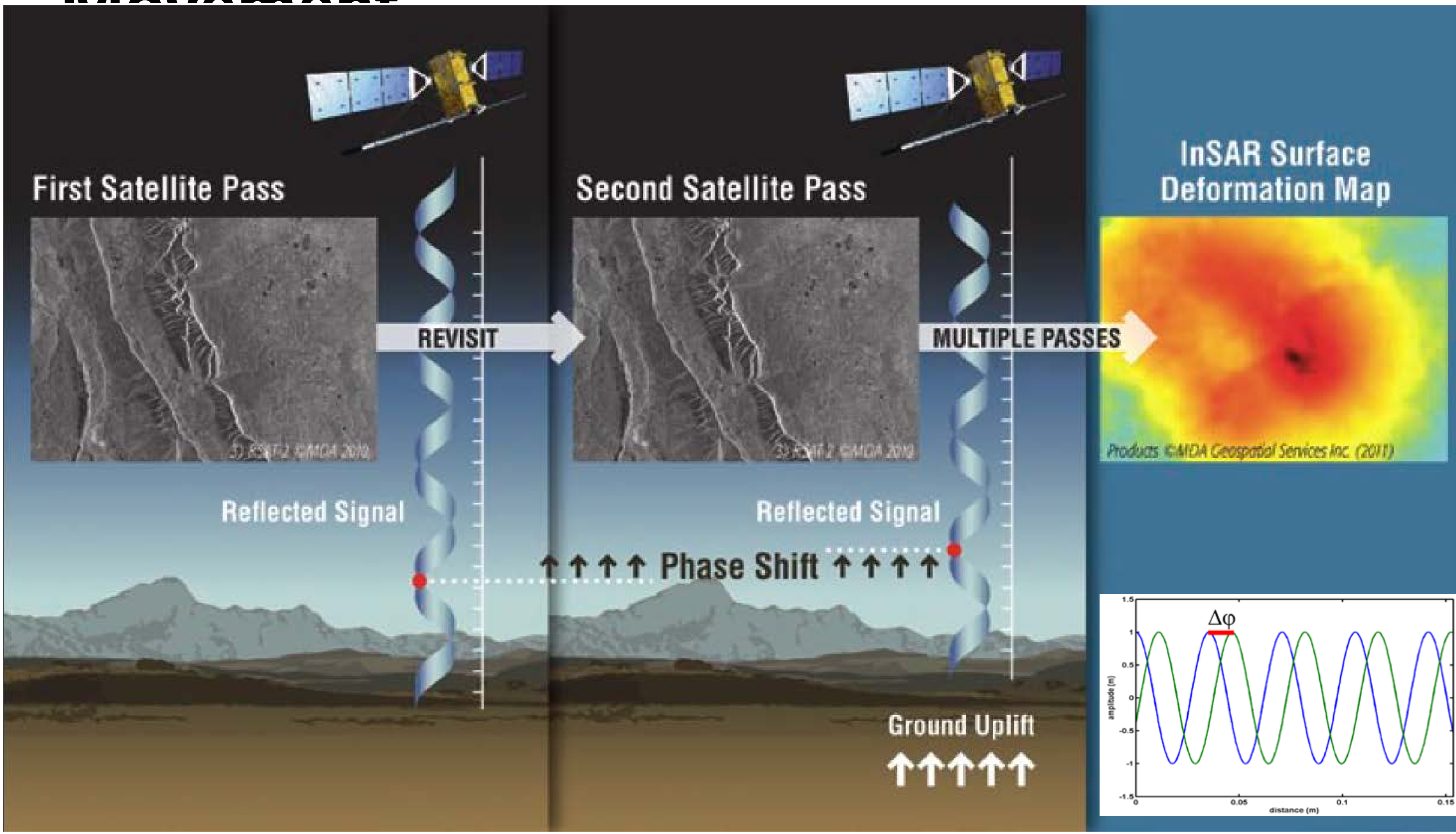
- Synthetic Aperture Radar (SAR)
  - RADARSAT-2
  - RISAT
  - TerraSAR-X
  - COSMO-SkyMed
  - Sentinel-1

What does a SAR Sensor See?



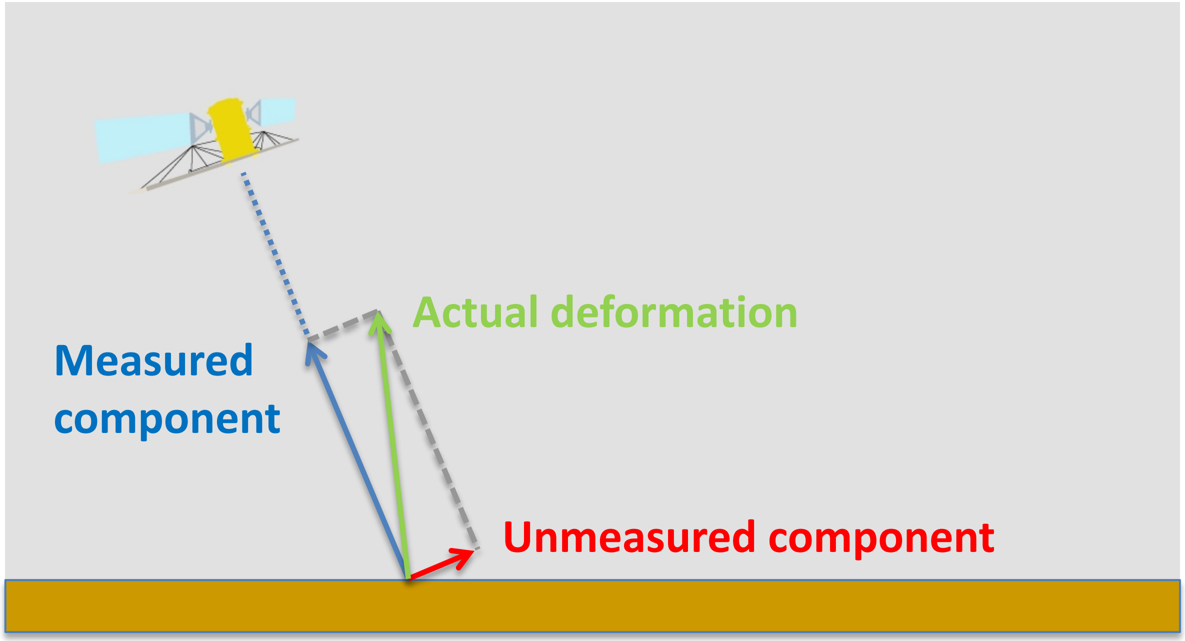
InSAR concept

Using Satellite SAR to Measure Surface Movement

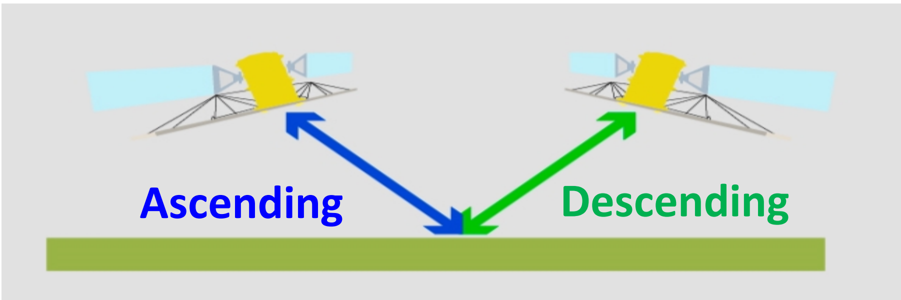


Line-of-sight measurements

- 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

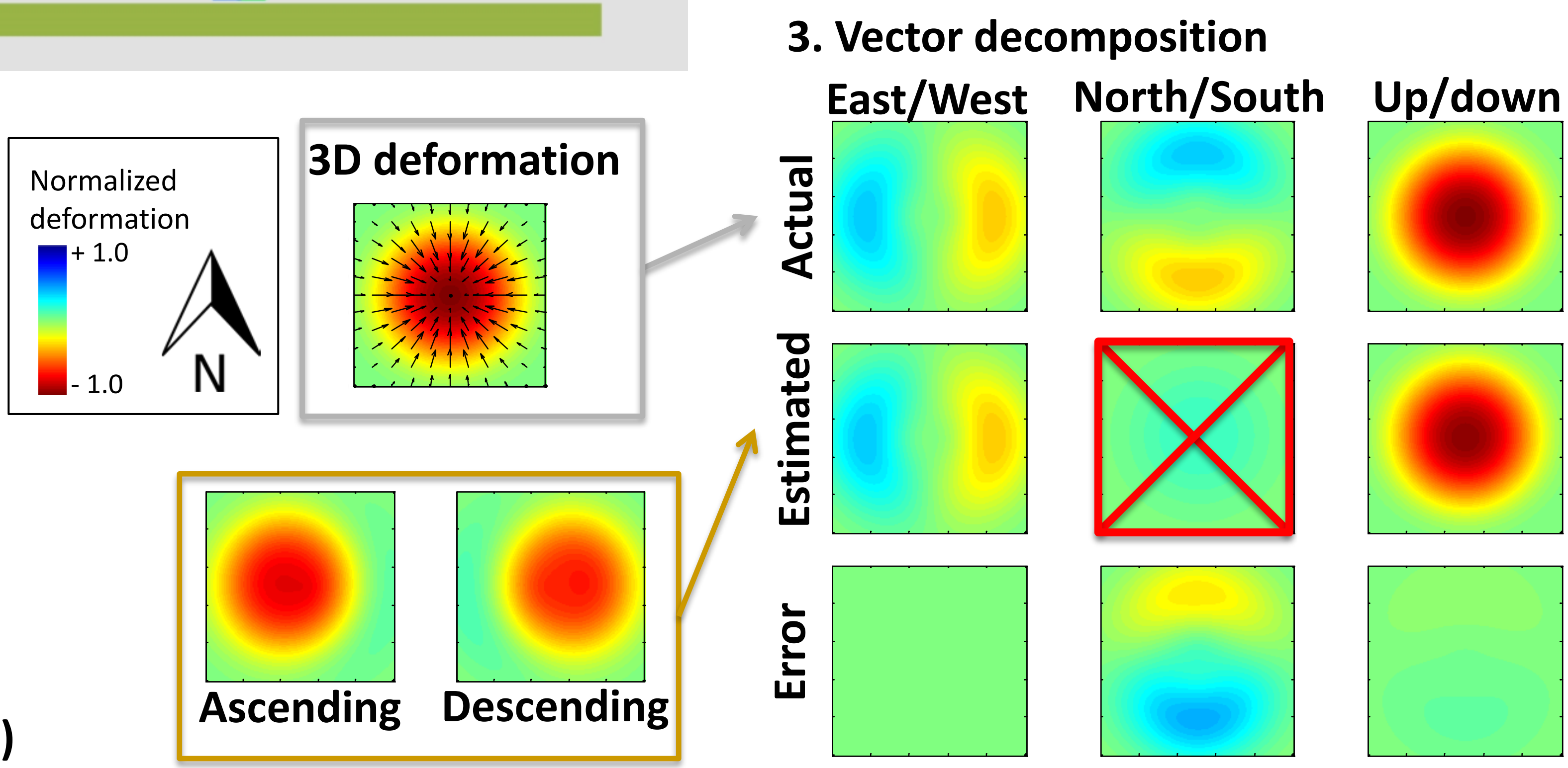


Estimating 2D deformation with InSAR

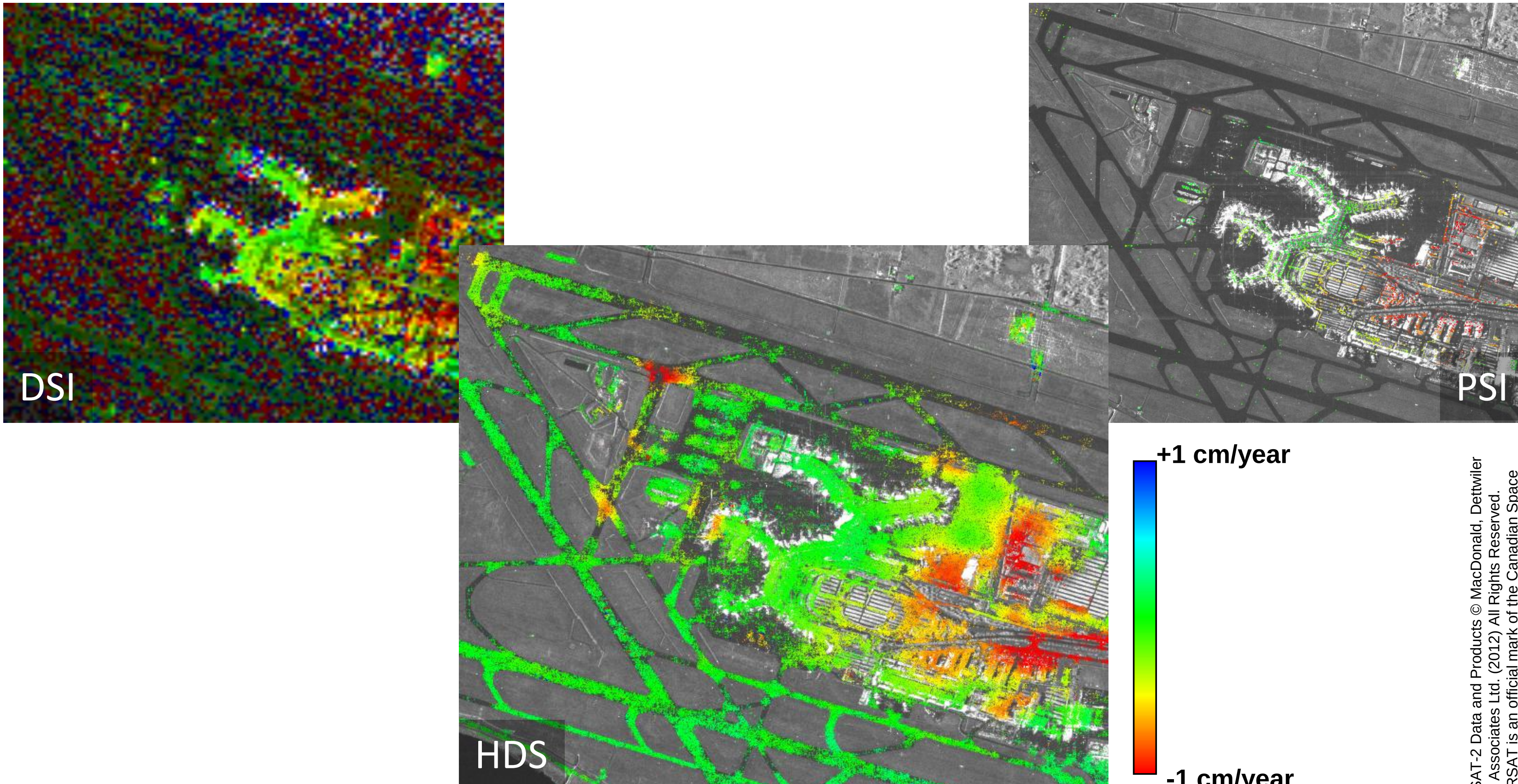


1. Simple example of dewatering deformation

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



InSAR Methods



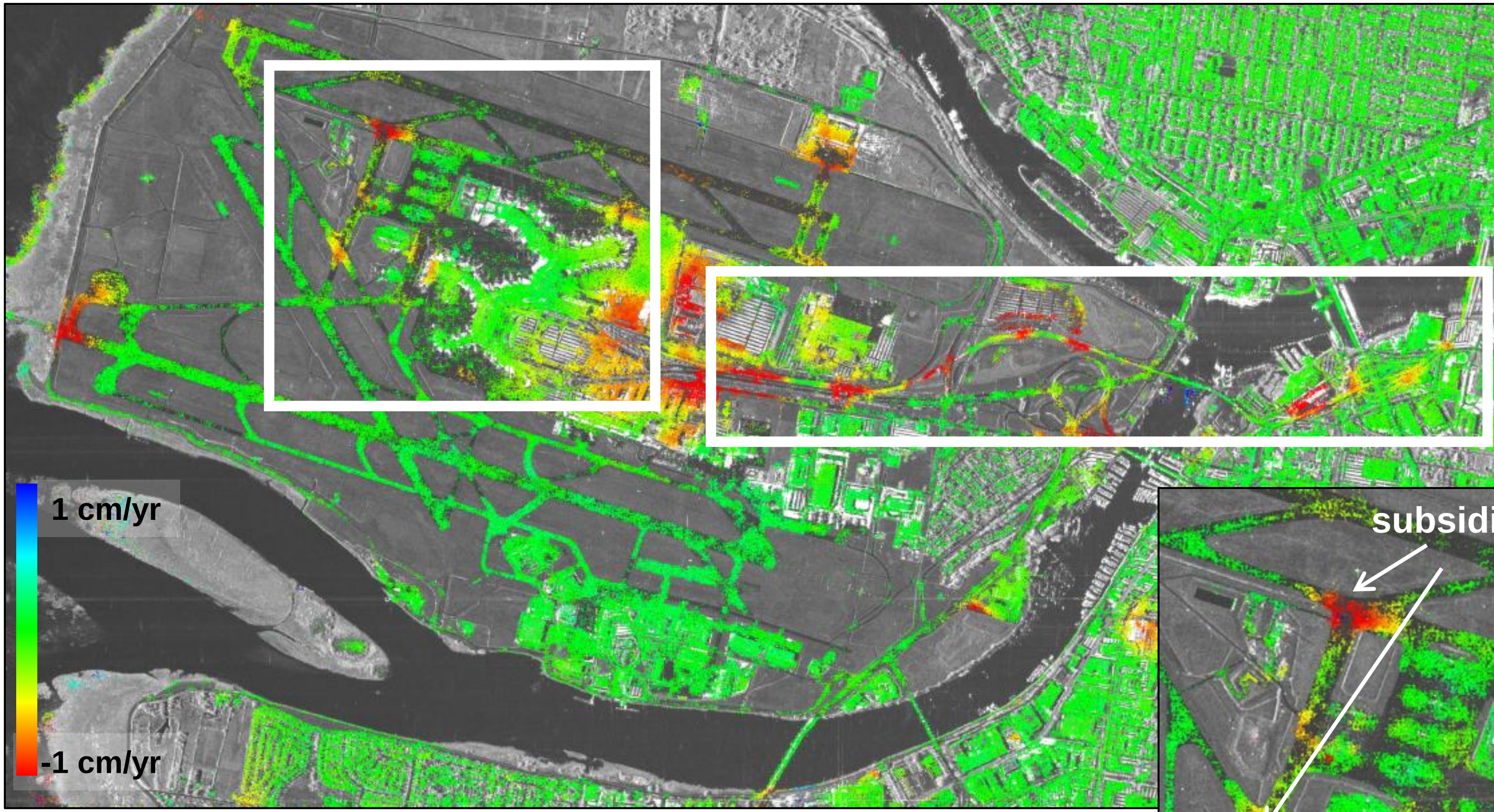
Linear deformation rate maps of Vancouver's YVR airport (RADARSAT-2, Ultra-Fine, 40 scenes)

InSAR Methods

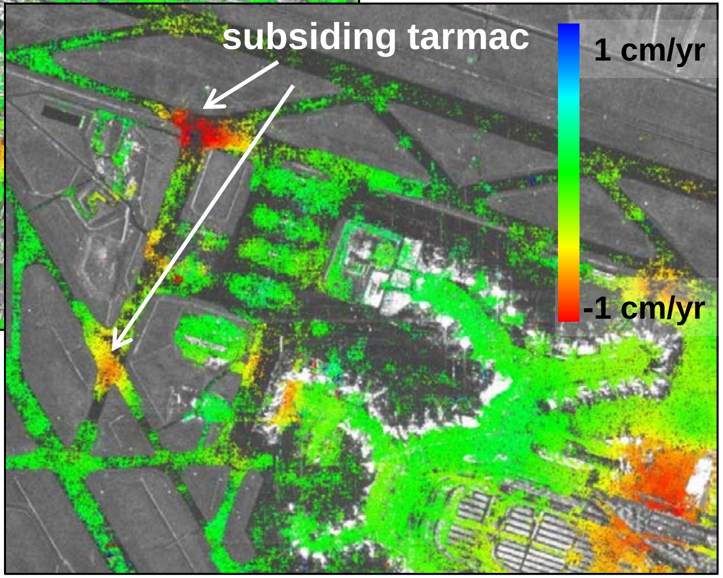
Method for Reducing Noise	Characteristics	Weakness
1st Gen DSI (Distributed Scatterer InSAR)	Averaging over rectangular grid to reduce noise.	• Resolution loss • Contaminate good points
2nd Gen PSI (Persistent Scatterer InSAR)	Identify low noise points and form sparse grid.	• Throw out most data • Poor spatial coverage • N_scenes > 15
3rd Gen HDS (Homogeneous Distributed Scatterer)	Adaptive spatial filtering based on temporal intensity distributions* Optimizes SNR/ resolution tradeoff	• N_scenes > 15

*Parizzi, A. and Brcic, R. (2011). Adaptive InSAR stack multilooking exploiting amplitude statistics: A comparison between different techniques and practical results. IEEE Geosci. Remote Sens. Lett., 8(3):441-445.

Vancouver airport (YVR)



Adaptive multi-looking recovers tarmac signal while preserving spatial resolution over terminal buildings

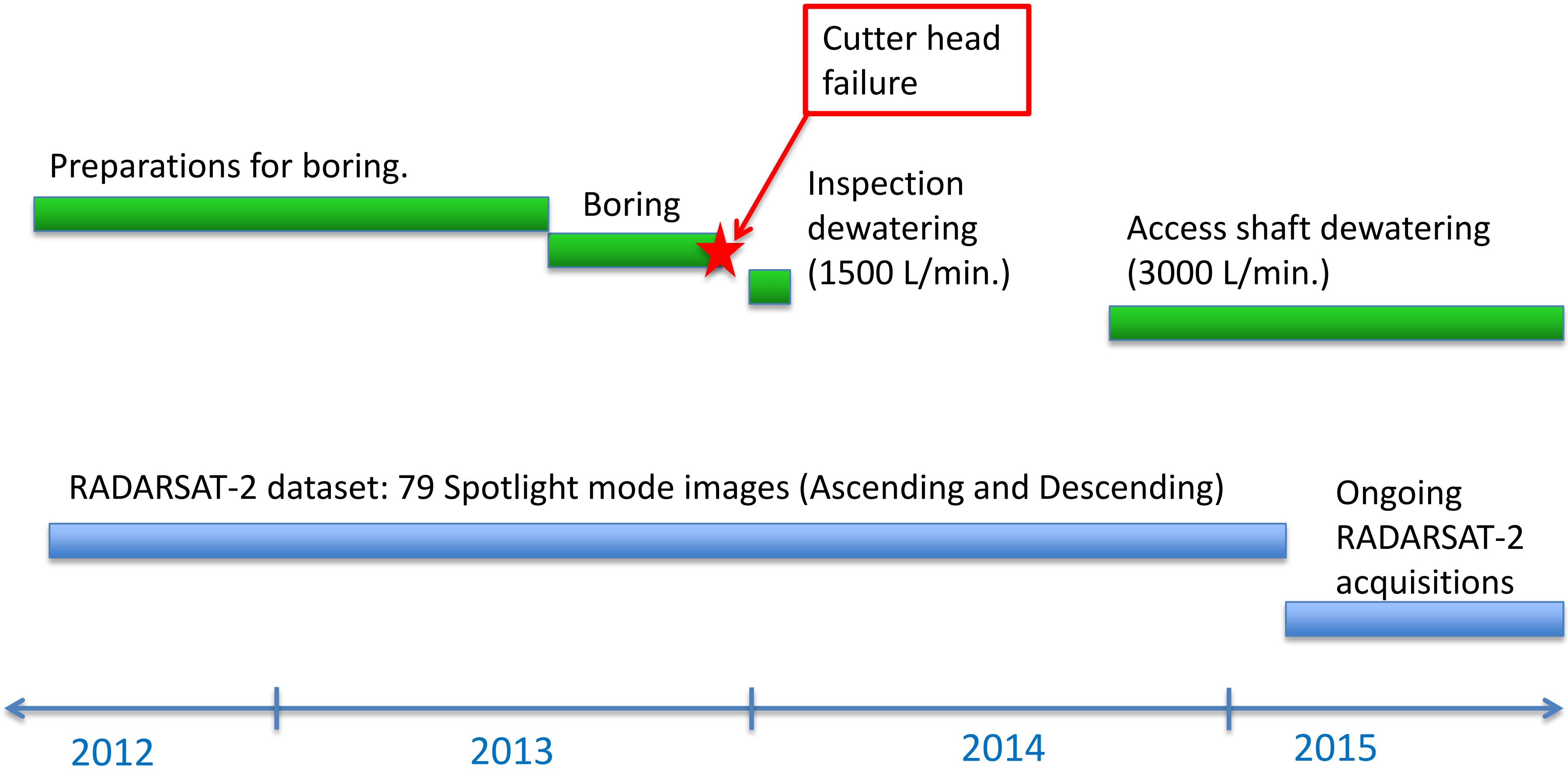


Case Study: Seattle Tunneling Project

SR99 Tunnel Project

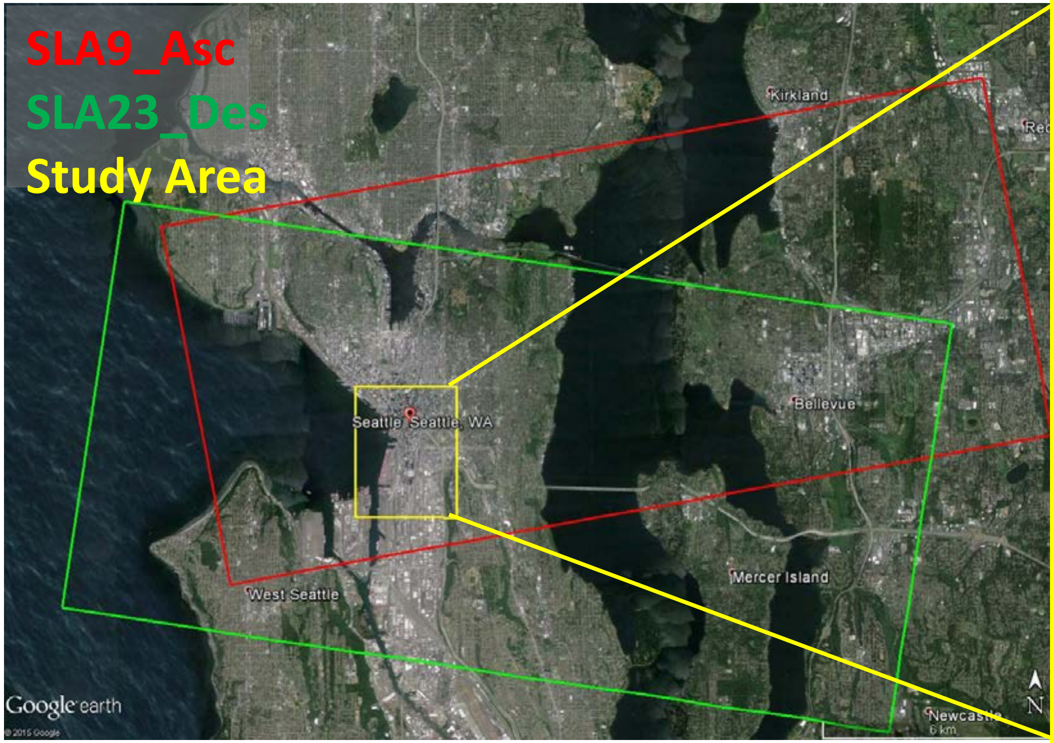
- 3.2 km bored tunnel under downtown Seattle, U.S.A.
- 17.5 m diameter tunnel boring machine → ‘Big Bertha’
- TBM failed after 10% completion of tunnel
- Repair involves 24 m wide x 37 m deep rescue shaft with significant dewatering required → potential for surface displacement

SR99 Tunnel Project Timeline



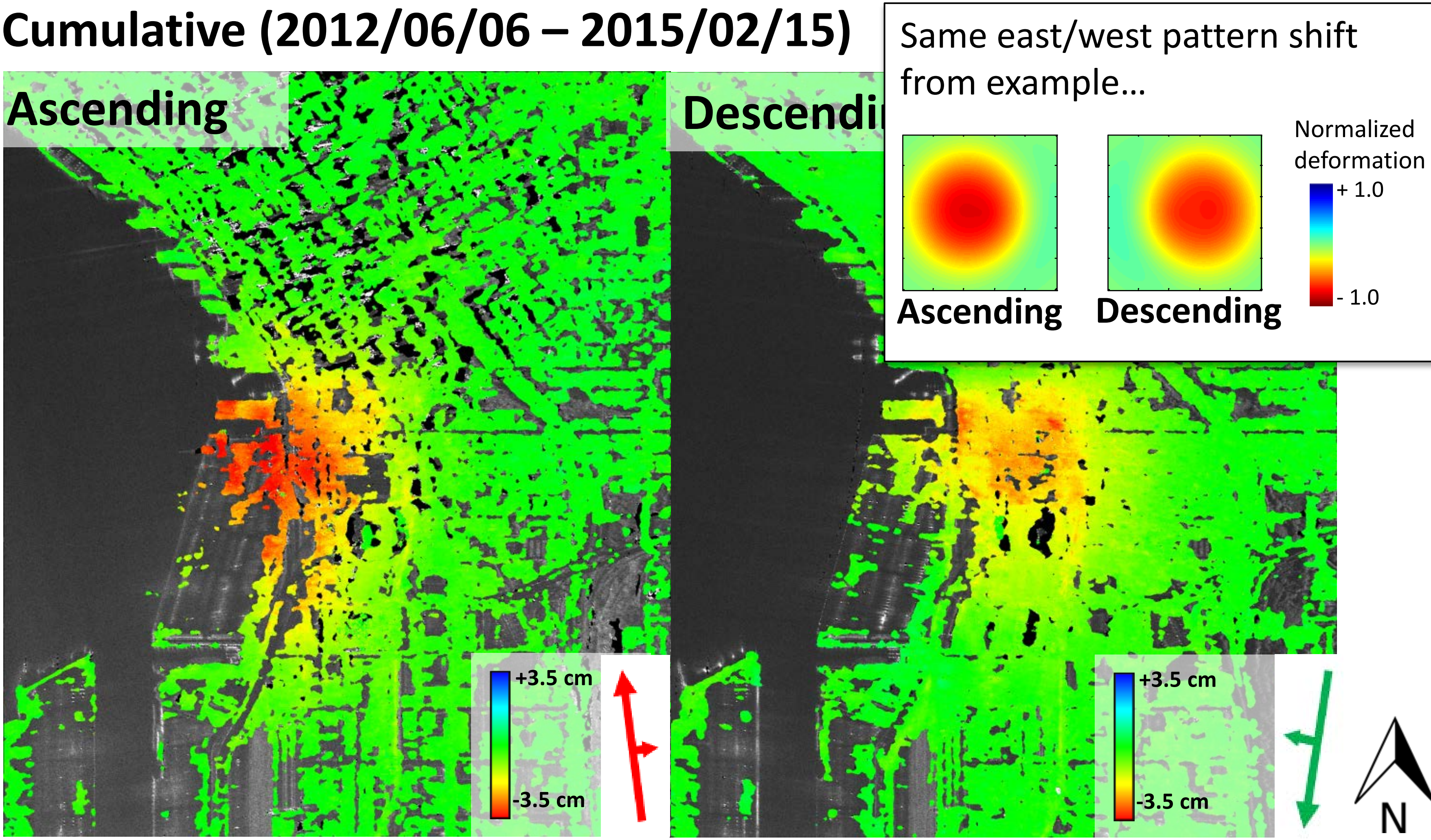
RADARSAT-2 data

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



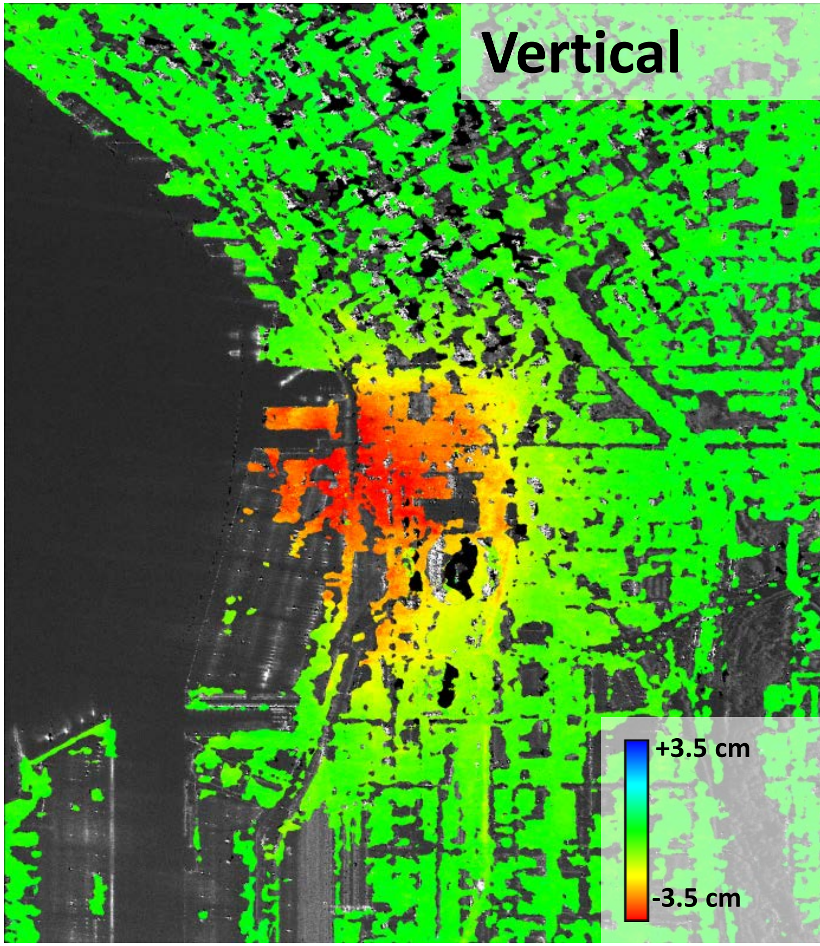
Line-of-sight deformation

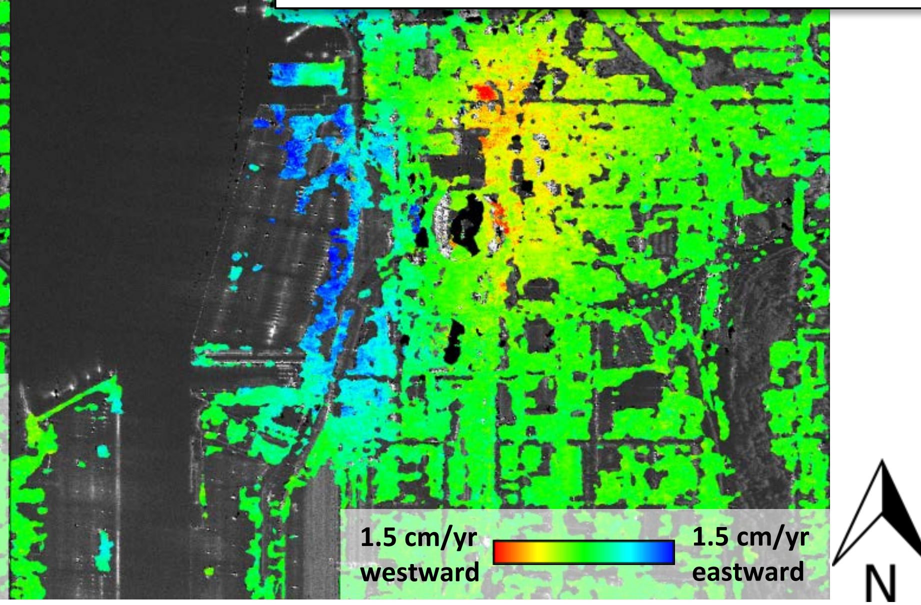
Cumulative (2012/06/06 – 2015/02/15)



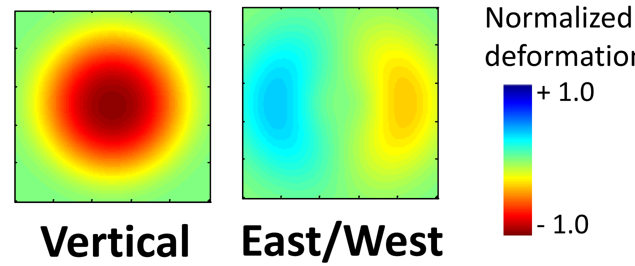
2D deformation

Cumulative (2012/06/06 – 2015/02/15)





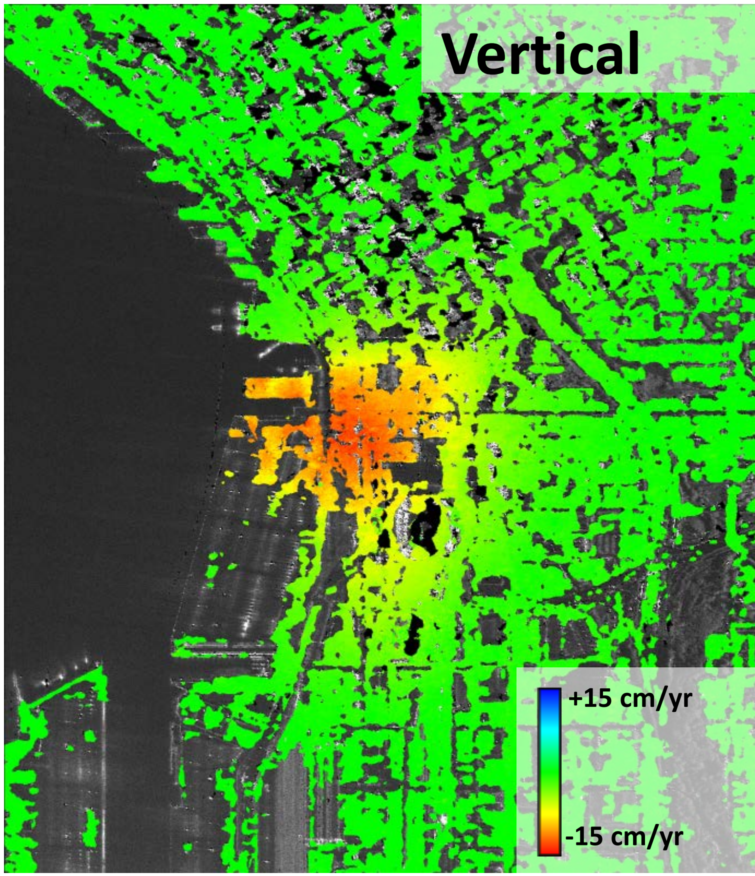
Same general patterns from example…

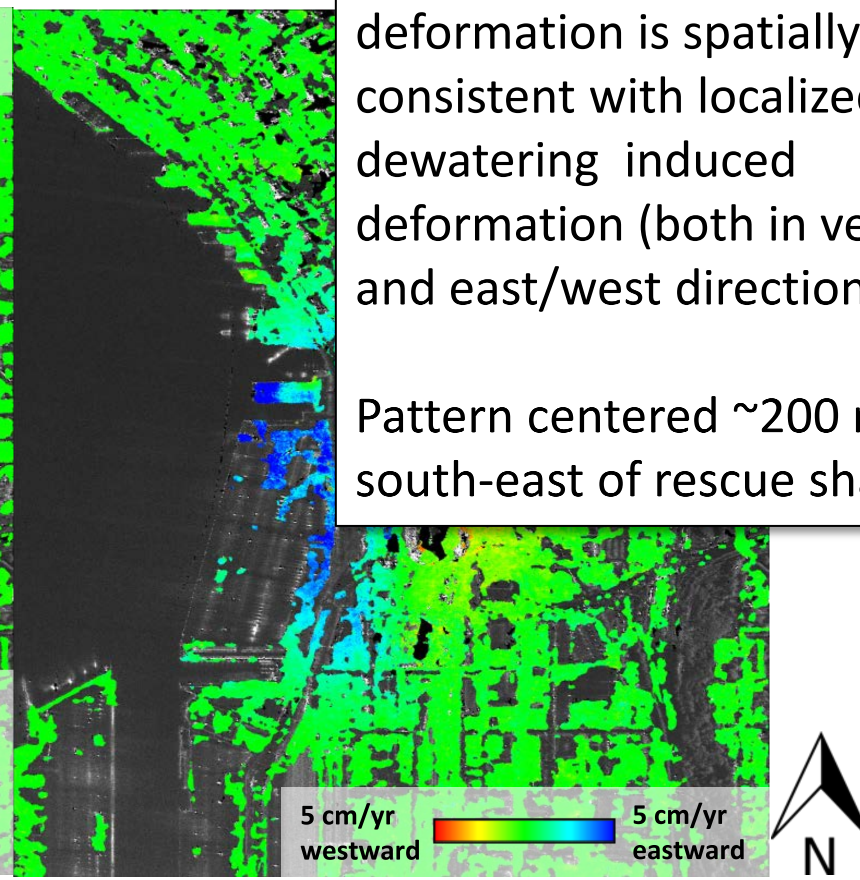


Dewatering correlated deformation

2012/06/06 – 2014/11/01 : no deformation

2014/11/01 – 2015/02/15 : linear deform





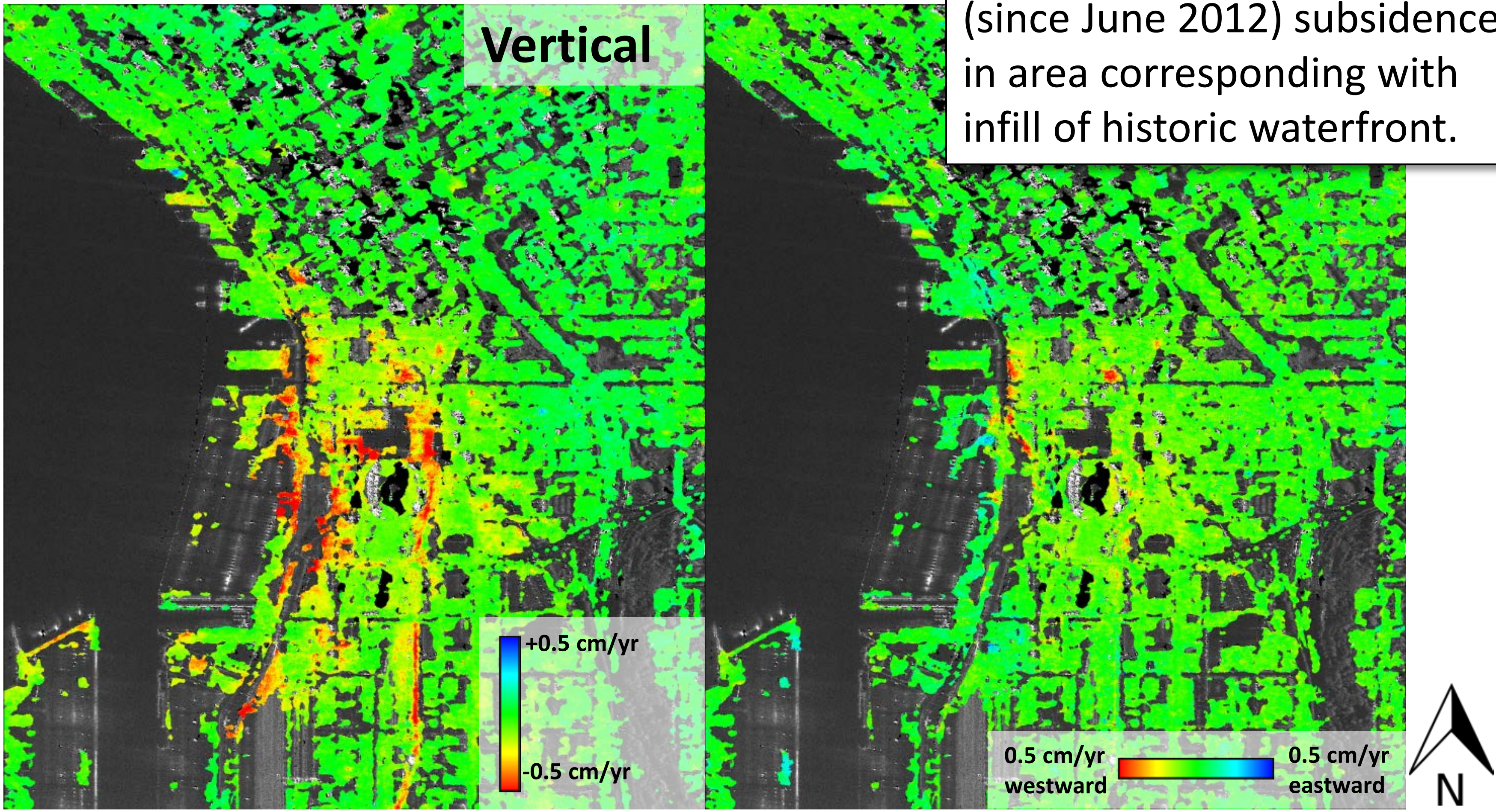
Dewatering correlated deformation is spatially consistent with localized dewatering induced deformation (both in vertical and east/west directions).

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

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)

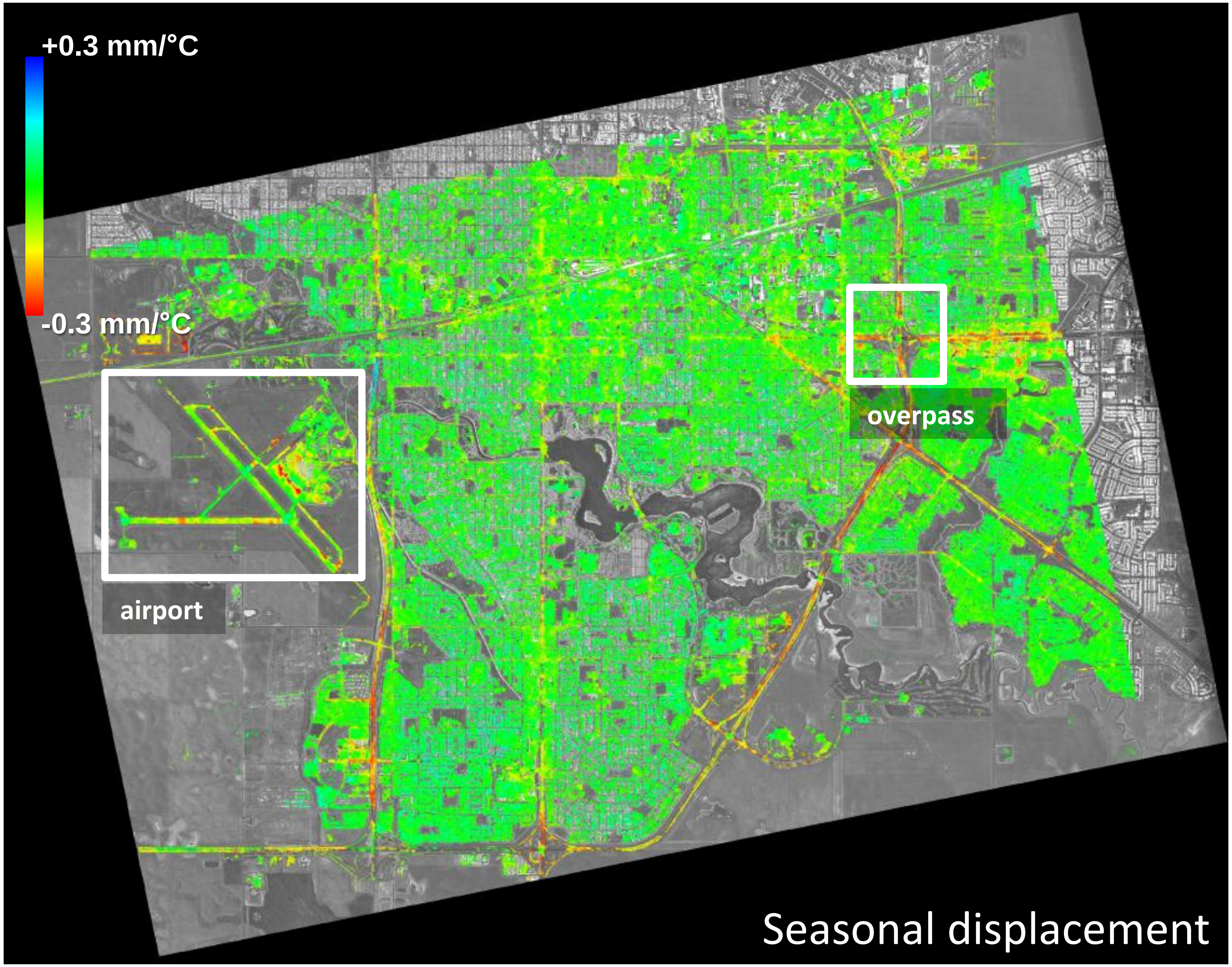
Westward deforming building shows external signs of damage and reinforcement.

Case Study: Canadian Cases

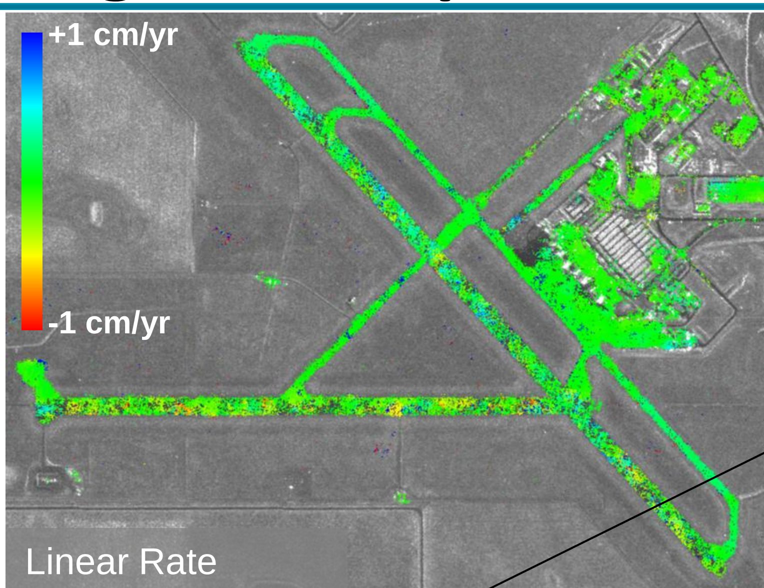
Seasonal Displacement

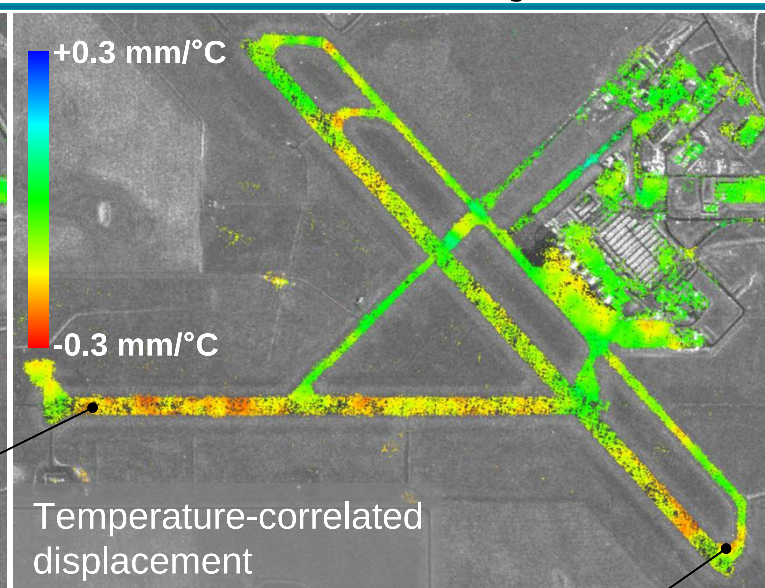
- Indicate areas with strong frost heave which will require more frequent maintenance
- Separate out seasonal effects from long-term trends
  - Seasonal/temperature-dependent effects often included in engineering design
  - Subtle long-term trends could indicate current/future problems
    - Displacement will eventually exceed tolerances

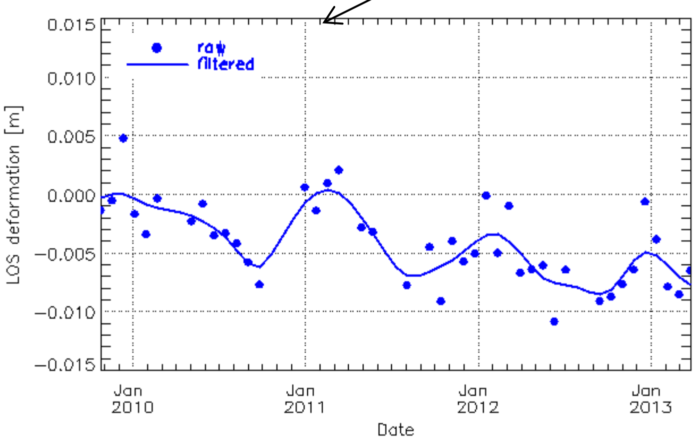
Regina Seasonal Displacement

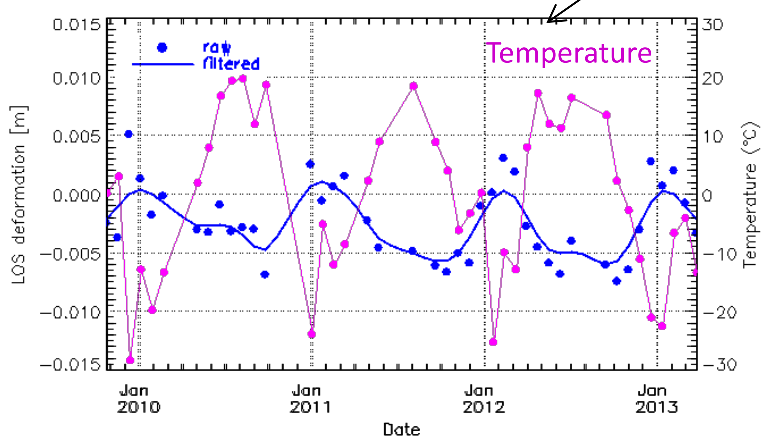


Regina, Temperature-Correlated Displacement

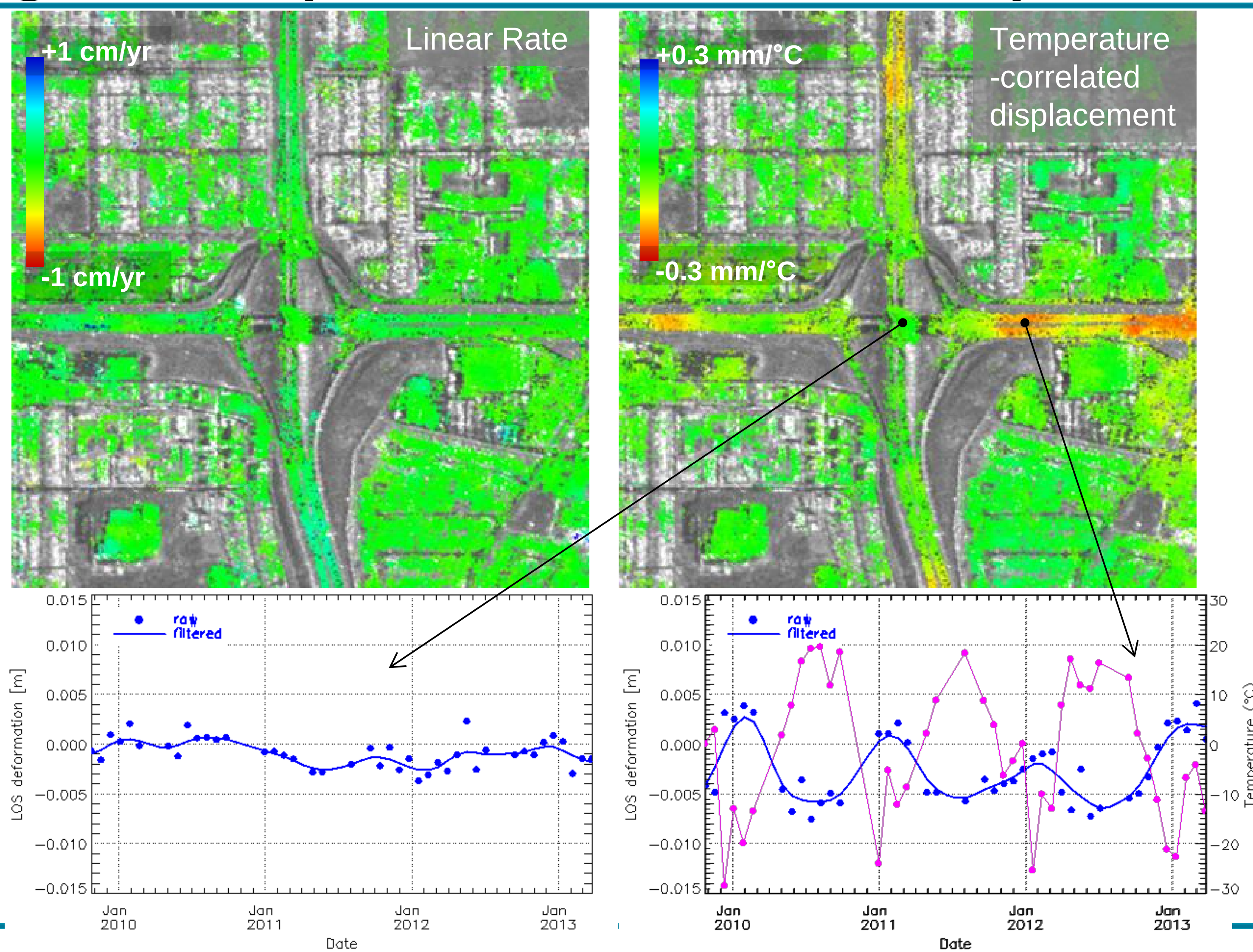








Regina, Temperature-Correlated Displacement

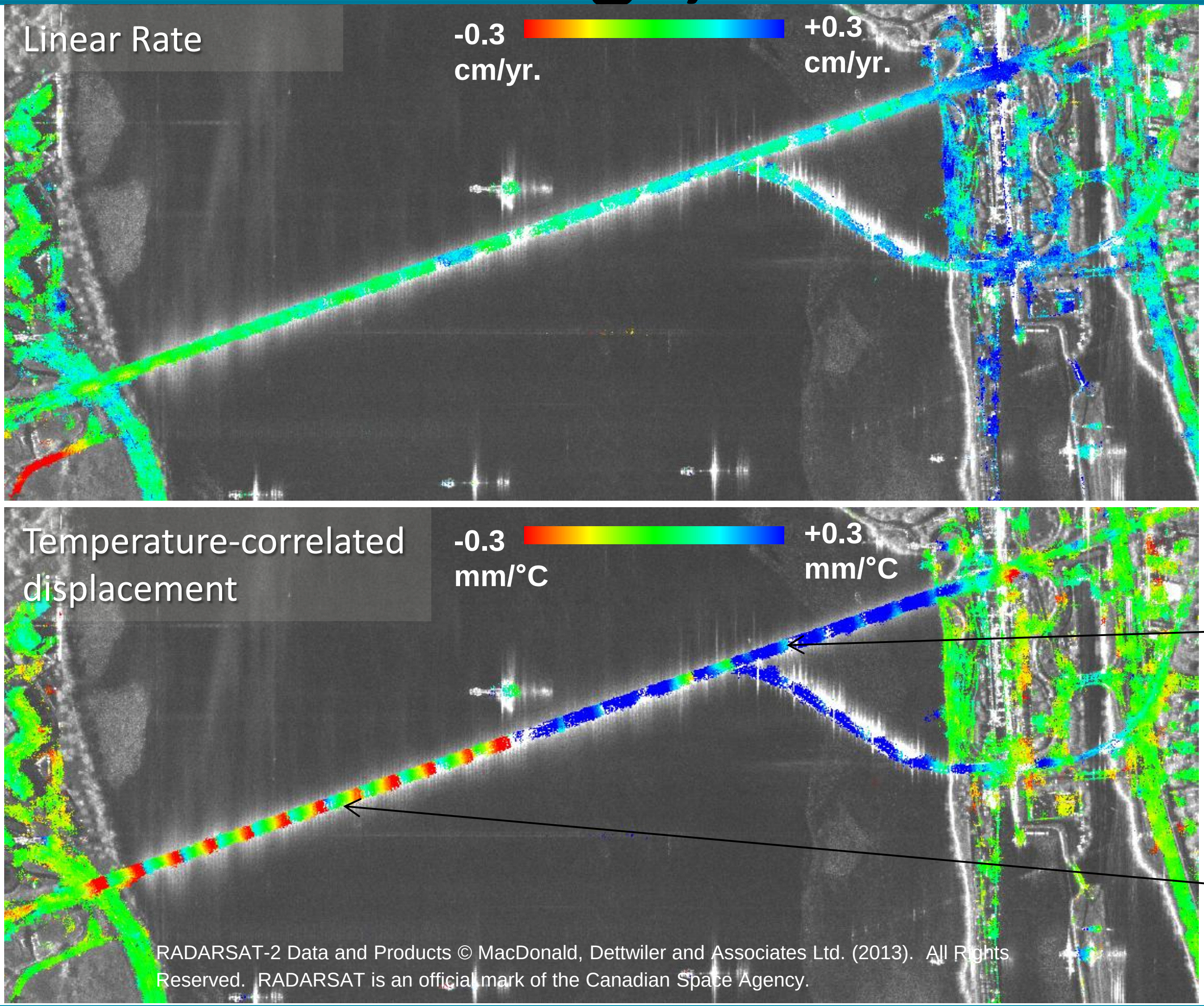


Victoria Bridge, Montreal

Source: GoogleEarth Streetview

Victoria Bridge as viewed from Montreal Technoparc (on Nuns' Island. South of bridge)

Victoria Bridge, Montreal



Minimal linear rate on majority of bridge. Some (Westward?) movement towards radar LOS on East side of bridge

Fixed joints on right-hand side allow expansion to the West only

Fixed joints on left-hand side allow expansion to the East only

Summary

Monitoring solution Summary

Monitoring Goal:

Infrastructure

\+

Construction

- Excavation
- Boring
- Dewatering
- Loading

Requirements:

High Spatial Resolution

- Resolve fine structures
- Delineate margins
- Estimate strain

Decompose vertical & horizontal deformation

Separate long term from construction related deformation

Solution:

HDS - InSAR

- Adaptively optimizes spatial resolution
- Resolve infrastructure, roads, open areas

2D view geometry

- Data from opposing look directions
- Decompose to get vertical + east/west

Temporal component modeling

- Fits multiple deformation ‘templates’

Benefits of INSAR-based Monitoring

- Inteferometry is a proven technique which can measure mm of surface movement in an urban environment
- Surface movement measurements from InSAR can be readily integrated into any other measurement program used such as GPS, or TotalStation survey methodologies
- Satellites provide wide area coverage allowing for routine monitoring
- Regular monitoring can be used as an alert for growing subsidence problems, and targeting engineering resources

Image Credits and Disclaimer Language

GENERAL ACKNOWLEDGEMENTS

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

Image of tunnel boring machine on P.[3]. http://www.nce.co.uk/features/geotechnical/alaskan-highway-tunnel-rescue-package/8685417.article. Accessed August 14, 2015.

Image of bridge failure on P.[3]. http://library.poly.edu/sites/default/files/image/2014/03/bridge_collapse.jpg. Accessed August 14, 2015.

Image of sinkhole on P.[3]. http://www.swfwmd.state.fl.us/education/watersheds/alafia/sinkholes. Accessed August 14, 2015.
Images of Greater Vancouver on P. [10], P.[11]. COPYRIGHT © 2015 Google. All rights reserved.

Image of tunnel project map on P.[11]. http://www.metrovancouver.org/services/water/construction-maintenance/ConstructionProjectPublications/SCTTFactsheet.pdf. Accessed August 14, 2015.

Image of tunneling route on P.[12]. http://www.belcarra.ca/reports/vob-report-may2011.htm. Accessed August 14, 2015.

Image of Canada Line route on P.[14]. http://www.richmond.ca/__shared/assets/Canada_Line_Overview__Aug_11_2006_PDF14827.pdf. Accessed August 14, 2015.

Image of tunnel construction on P.[15]. https://en.wikipedia.org/wiki/Cambie_Street#/media/File:Canada_Line_Construction,_Vancouver,_Cambie_Street_at_25th.jpg. Accessed August 14, 2015.

Thank You!

Vivienne WU, MDA Geospatial Services
vwu@mdacorporation.com,
Tel: +1 604 897 7822