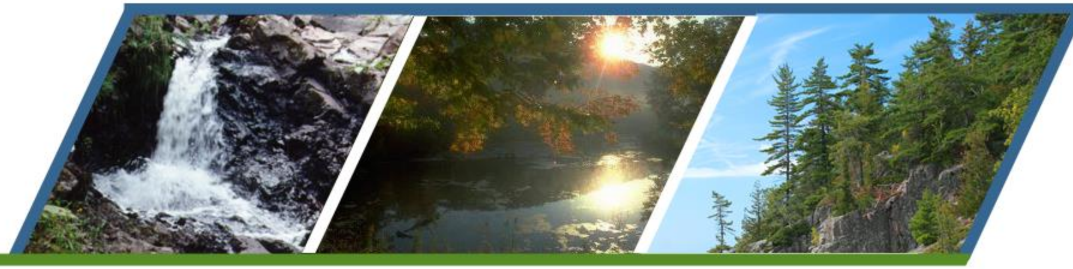
Feb 2019



Radar Interferometry 101

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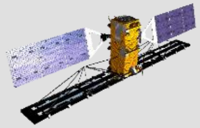
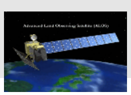
Contents

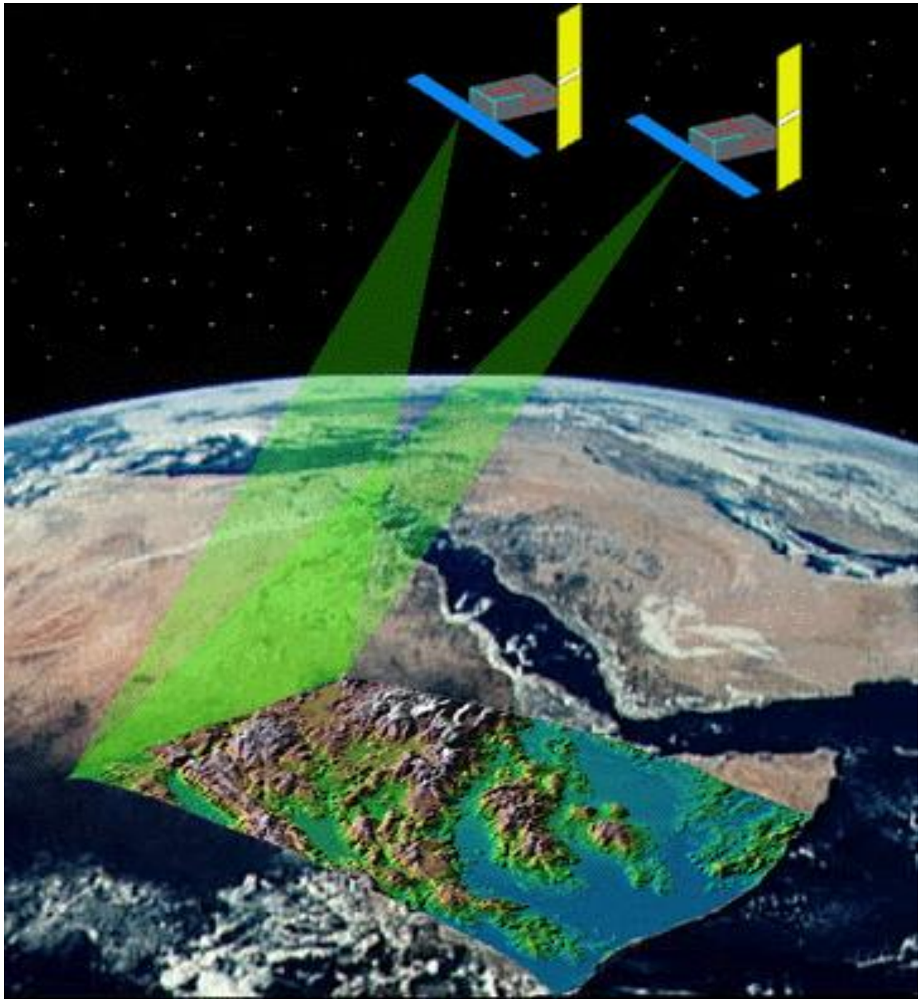
- Radar Interferometry
- RADAR Satellites
- Viewing geometry, revisit time and coherence
- Why we need high resolution and rapid revisit
- InSAR examples and interpretation

	Design Life	Imaging frequency	Spatial resolution	Polarization	Look direction	Status
RADARSAT-2 	7 years	C-Band, 5.405 GHz	3 to 100 meters	Single (HH, VV, VH, HV) Dual (HH/ HV, VV/VH) Polarimetric	Left- and right-looking	Launch 2007 Dec
RSAT-1 	5 years	C-Band, 5.3 GHz	25 to 100 m	Compact Pol HV	Right-looking	In operation (Since 12)
Sentinal 1 	7 years	C-Band, 5.331 GHz	30 to 1000 meters	Single (HH, VV) Alternating (VV/HH, VV/VH, HH/HV)	Right-looking	In operation (Since 14
TerraSAR-X  TandemX	5 years	X-Band, 9.650 GHz	1 to 15 meters	Single (HH, VV) Dual (VV/HH, VV/VH, HH/HV)	Left- and right-looking	Launch 2007 2011
ALOS PALSAR 	5 years	L-Band, 1.27 GHz	10 to 100 meters	Single (HH, VV) Dual (HH/ HV, VV/VH) Polarimetric (exp.)	Right-looking	Launch 2014
COSMO-Skymed 	5 years	X-Band, 9.6 GHz	1 to 100 meters	Single (HH, VV, VH, HV) Polarimetric	Left- and right-looking	2 Launch in 2007

Current Radar Satellites:

- Canadian RCM will be launched in the Summer 2019

Radar Interferometry



Drawing courtesy of Prof. Howard Zebker, Stanford University

- Two or more satellite image the Earth's surface of the same area
- Repeat visit with the same viewing angle of the same SAR satellite or constellation
- The phase difference of the two images is processed to obtain detailed height and/or motion information.

SAR Interferometry-Principles

- Takes advantage of phase difference between two scenes, taken at different times (similar to time lapse photography)
- The phase difference between corresponding pixels in two radar images produce an interference pattern (interferogram)
- If the scene on the ground changes slightly between two scans, the phases of some pixels in the 2nd image will shift.

Satellite InSAR - Measuring Motion 1

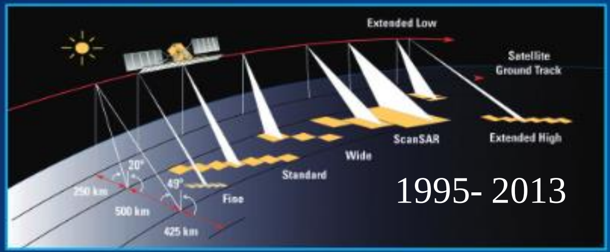
- To measure motion, the following must apply:
  - The *satellite revisit* must be appropriate e.g SAR Constellation)
  - Coherence must be high enough (Vegetation= poor coherence, Cities= high coherence)
  - Small baseline and high resolution DEM improve accuracy.
  - More than three passes must be used.(Time series InSAR)

Canadian Space Agency / Agence spatiale canadienne

Rapid Revisit and Viewing Geometry

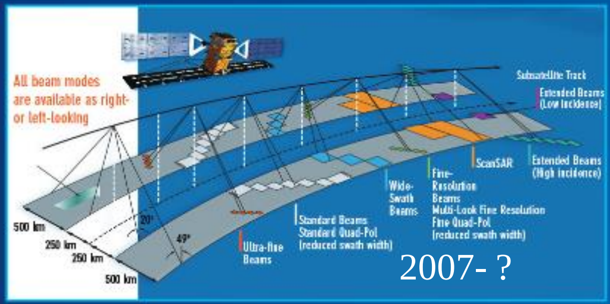
BEAM MODES

RADARSAT-1



Beam Modes	Nominal Swath Width (km)	Nominal Resolution (m)
Fine	45	8
Standard	100	30
Wide	150	30
Scansar narrow	300	50
Scansar wide	500	100
Extended high incidence	75	18-27
Extended low incidence	170	30

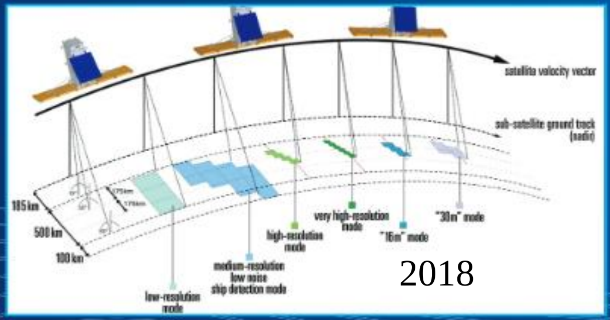
RADARSAT-2



Beam Modes		Nominal Swath Width (km)	Approximate Resolution (m) *1
Selective Polarization Transmit H or V receive H and/or V	Fine	50	10 x 9
	Standard	100	25 x 28
	Low incidence	170	40 x 28
	High incidence	75	20 x 28
	Wide	150	25 x 28
	ScanSAR narrow	300	50 x 50
	ScanSAR wide	500	100 x 100
Polarimetric Transmit H and V on alternate pulses / receive H and V on any pulse	Fine Quad-pol	25	11 x 9
	Standard Quad-pol	25	25 x 28
Selective Single Polarization Transmit H or V receive H or V	Ultra-Fine	20	3 x 3
	Spotlight	18	3 x 1
	Multi-Look Fine	50	11 x 9

*1. Ground range by azimuth

RADARSAT Constellation



Beam Modes	Nominal Swath Width (km)	Approximate Resolution (m)
Low Resolution	500	100 x 100
Medium Resolution (Maritime)	350	50 x 50
Medium Resolution (Land)	30	16 x 16
Medium Resolution (Land)	125	30 x 30
High Resolution	30	5 x 5
Very High Resolution	20	3 x 3
Ice/Oil Low Noise	350	100 x 100
25 m ship mode	350	Variable
Spotlight mode	5	1 x 3

3 satellites, Dual/Compact/Quad Polarization, Right looking
4 days repeat cycle, Lifetime: 7 years 300,000 scenes/yr

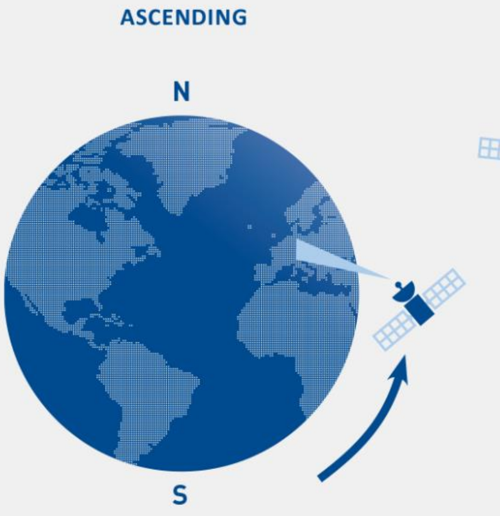
www.asc-csa.gc.ca

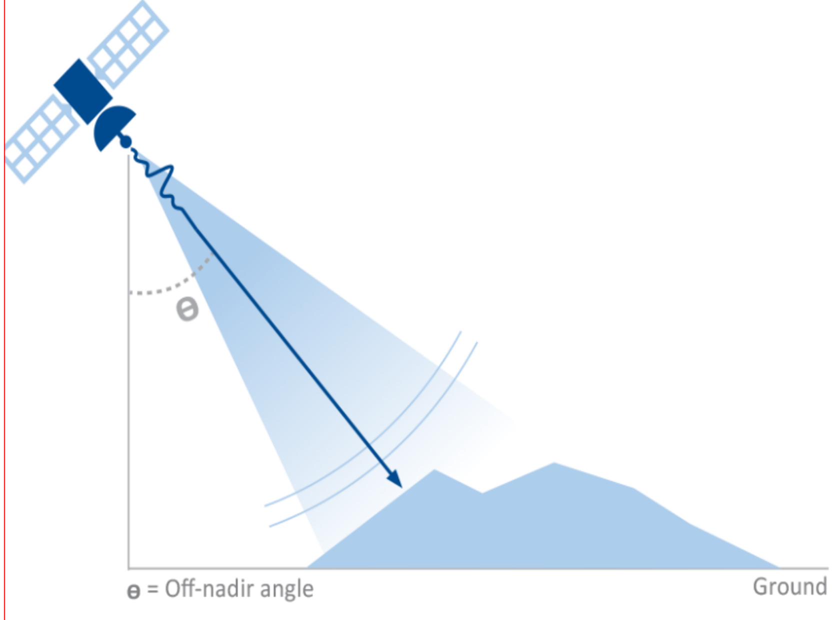
Canada

SAR satellites

Synthetic Aperture Radar (SAR) satellites acquire images of the Earth's surface by emitting electromagnetic waves and analysing the reflected signals.

All SAR satellites travel from the north pole towards the south pole for half of their trajectory (descending orbit) and from the south towards the north pole for the other half (ascending orbit). As a consequence, the same area of interest is revisited along the two orbits with ascending and descending imageries collected over it through time.





SAR signal

Each SAR image incorporates two fundamental properties: phase and amplitude.

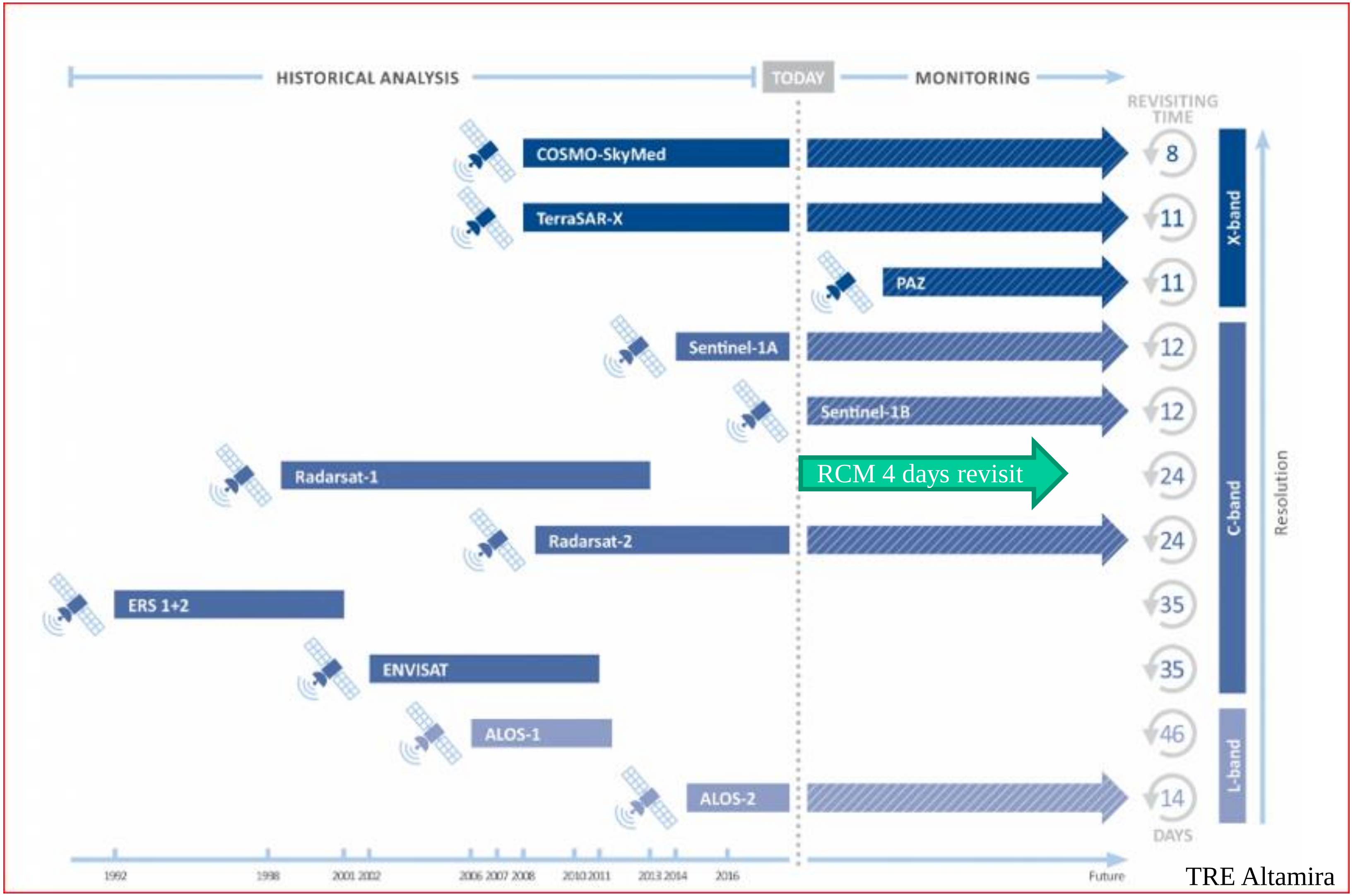
The phase contains information about the sensor-to-target distance that is used in interferometric applications (InSAR or SAR Interferometry) to measure ground surface motion over time. The amplitude is related to the energy of the backscattered signal and it is used in speckle/pixel tracking applications and ground change detection.

No ground equipment is needed. SAR satellites detect targets already existing on the ground (e.g. buildings, linear structures, rocky outcrops, uncultivated lands, debris, etc.) and register their backscattered signals.

TRE

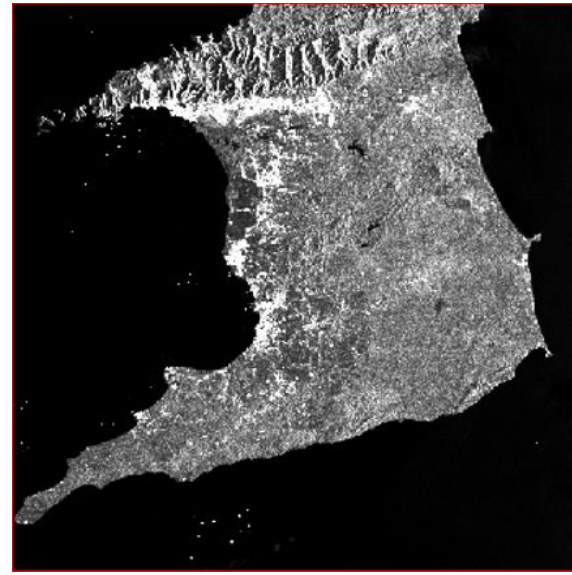
InSAR Viewing Geometry

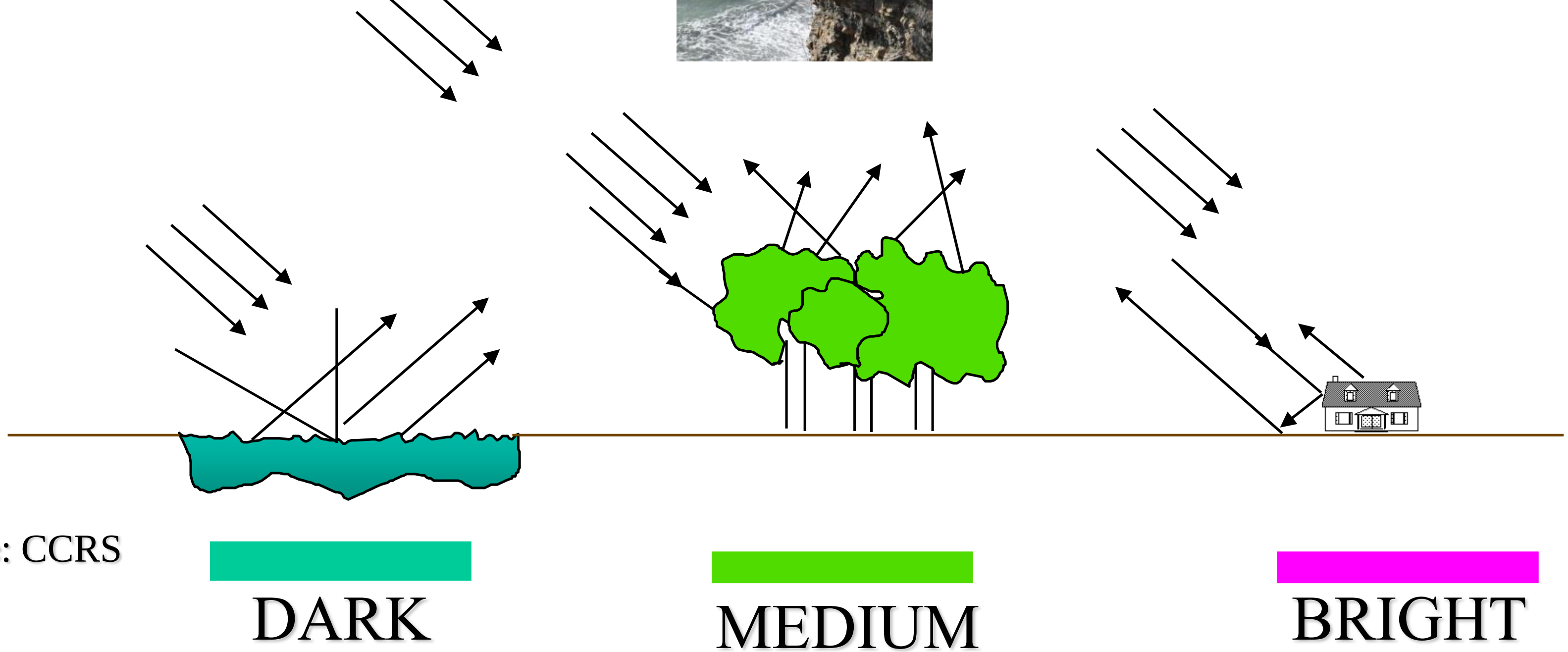
InSAR and revisit time



Different geophysical process requires different revisits

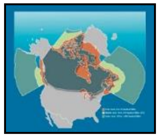
Image tone and coherence





Source: CCRS

RCM Improvements over previous RADARSAT missions



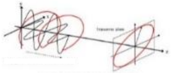
Average daily revisit of any point over Canada’s land and maritime approaches

Daily access to 90% of the world’s surface (except around the South Pole)

Secondary payload on board - Automatic Identification System (AIS) for ship detection and identification

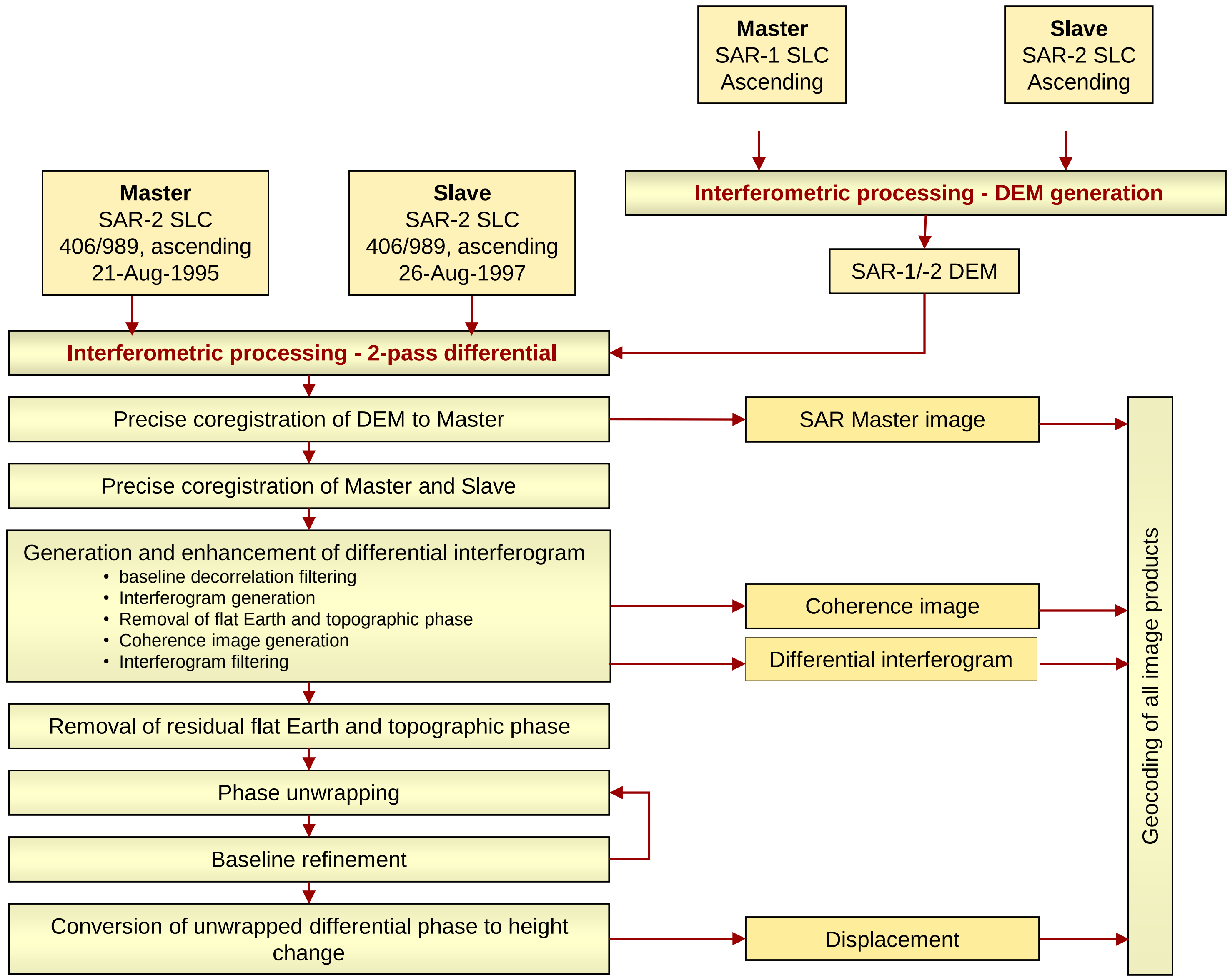
4-day exact repeat (as opposed to 24 days with RADARSAT-1 and 2) for Coherent Change Detection

Circular Compact Polarization for better detection, measurement, and discrimination of surface features and characteristics



Circular transmit-linear receive
Provide more polarimetric information.
Improved characterization of vegetation, ocean and sea ice
RCM-CP 350 km swath (R2 50 km)

Data Processing Flowchart - Differential Interferometry



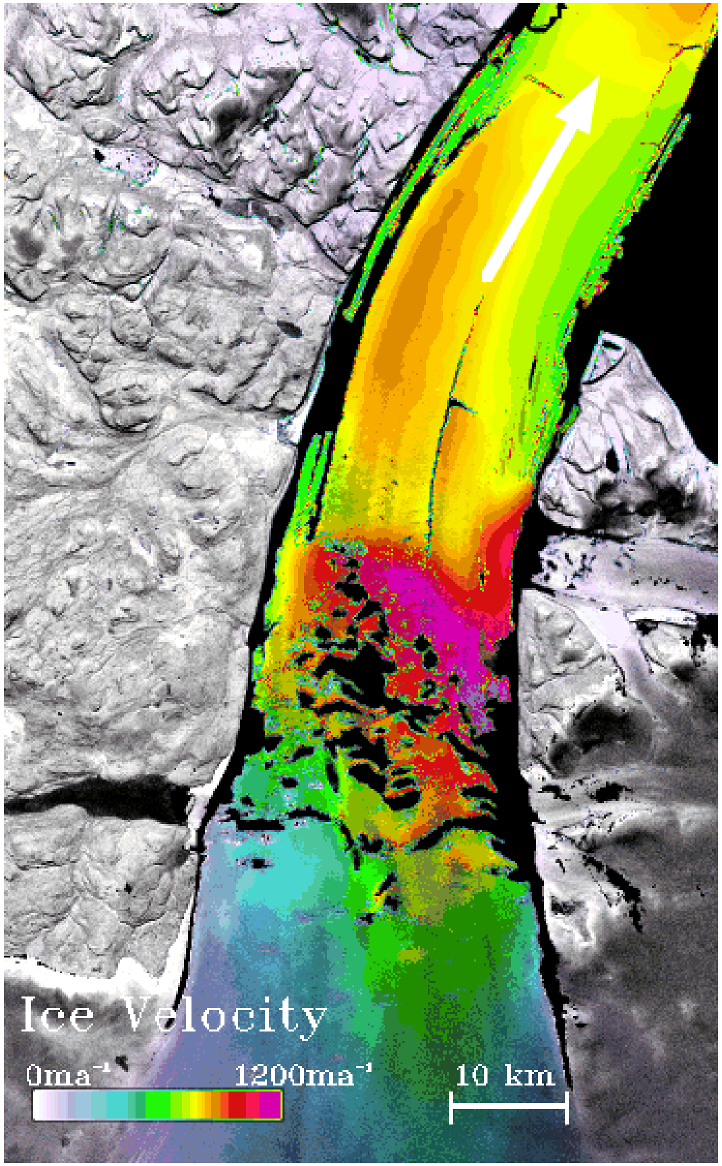
The need for high resolution and rapid revisit InSAR monitoring provided by SAR Constellations

- The high-resolution InSAR images with a short temporal acquisitions are critical for active surface deformation monitoring.
- The high resolution allows high InSAR coherence on the non-vegetated areas
- High resolution images consistently produce excellent results
- Rapid revisit produces better stack products and reliable results with better signal to noise ratios .

SAR Interferometry-Applications

- Radar satellites can monitor minute earth movements
- Measure slow movement of glaciers: Canada, Antarctica
- Map volcanic movements and lava flows. Mt Etna,(Italy)
- Map the motion of geological faults during earthquakes Landslides e.g Nepal, Haiti etc
- Monitor land subsidence related to oil extraction.
- Map terrain elevation /topography

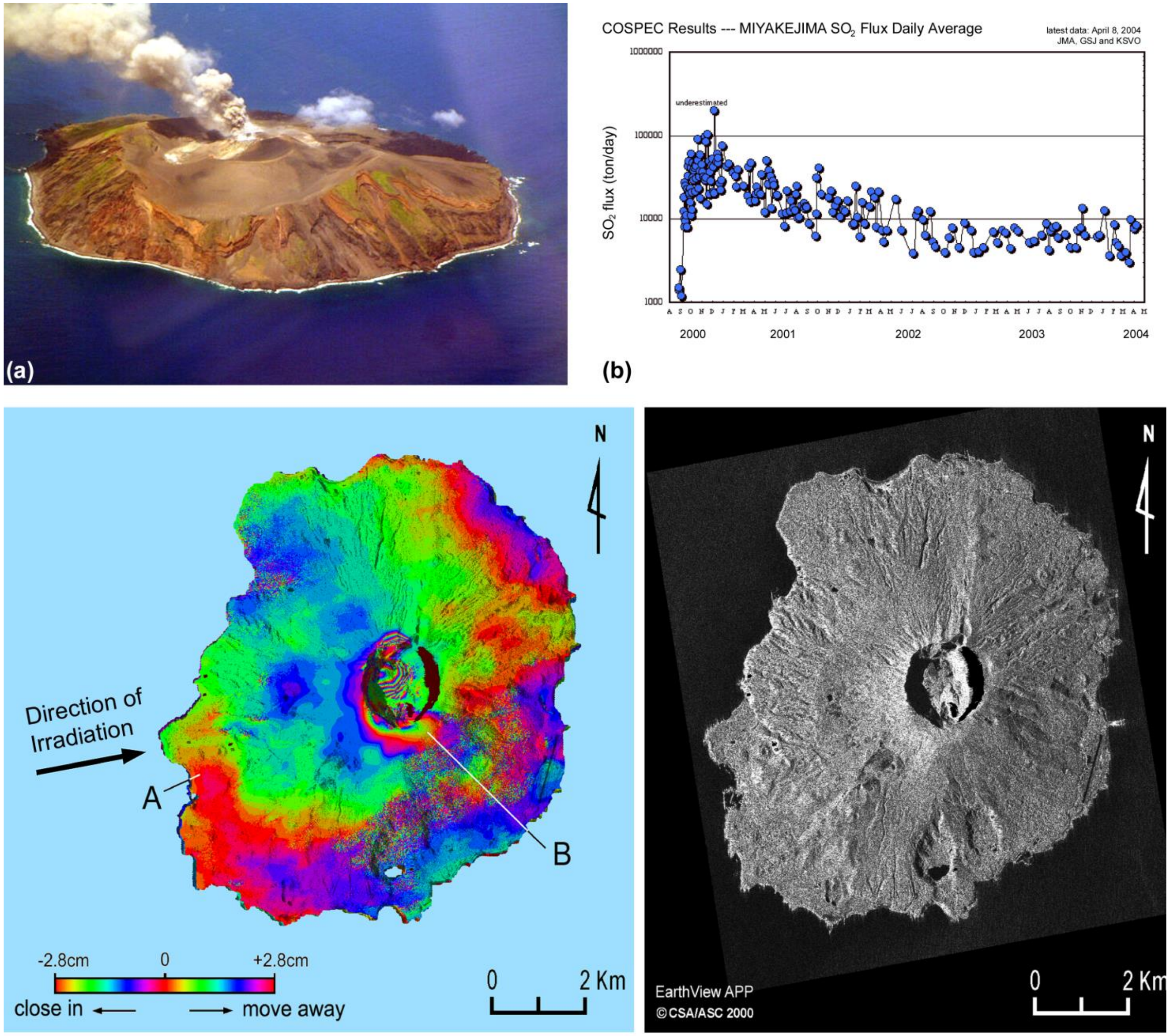
Glacier / Ice Stream Velocity Measurement



An outlet glacier in North-Eastern Greenland.

Only the moving parts of the scene have been colored. The black areas are areas where the coherence was too low to process.

Image courtesy of
Prof. Howard Zebker,
Stanford University



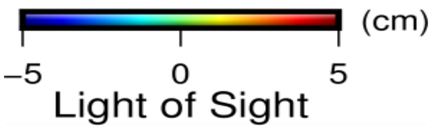
RADARSAT D-InSAR 2000 11/10 & 2000 12/04

(c) INTERFEROGRAM

RADARSAT 42A F3f 2000 11/10

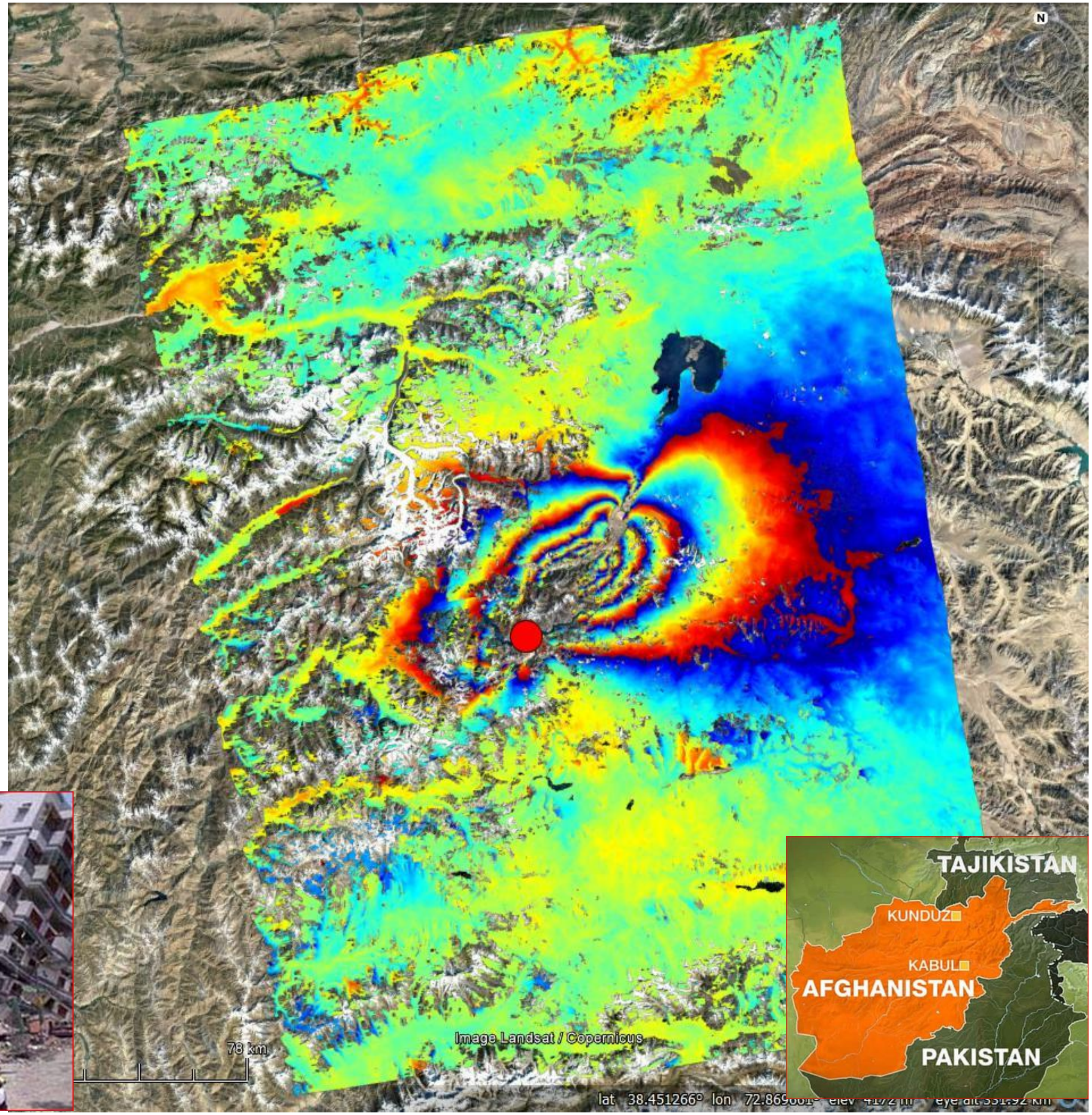
(d) MASTER IMAGE

Earthquake motion: Co-seismic interferogram from Sentinel-1: 2015 Mw7.2 Tajikistan earthquake

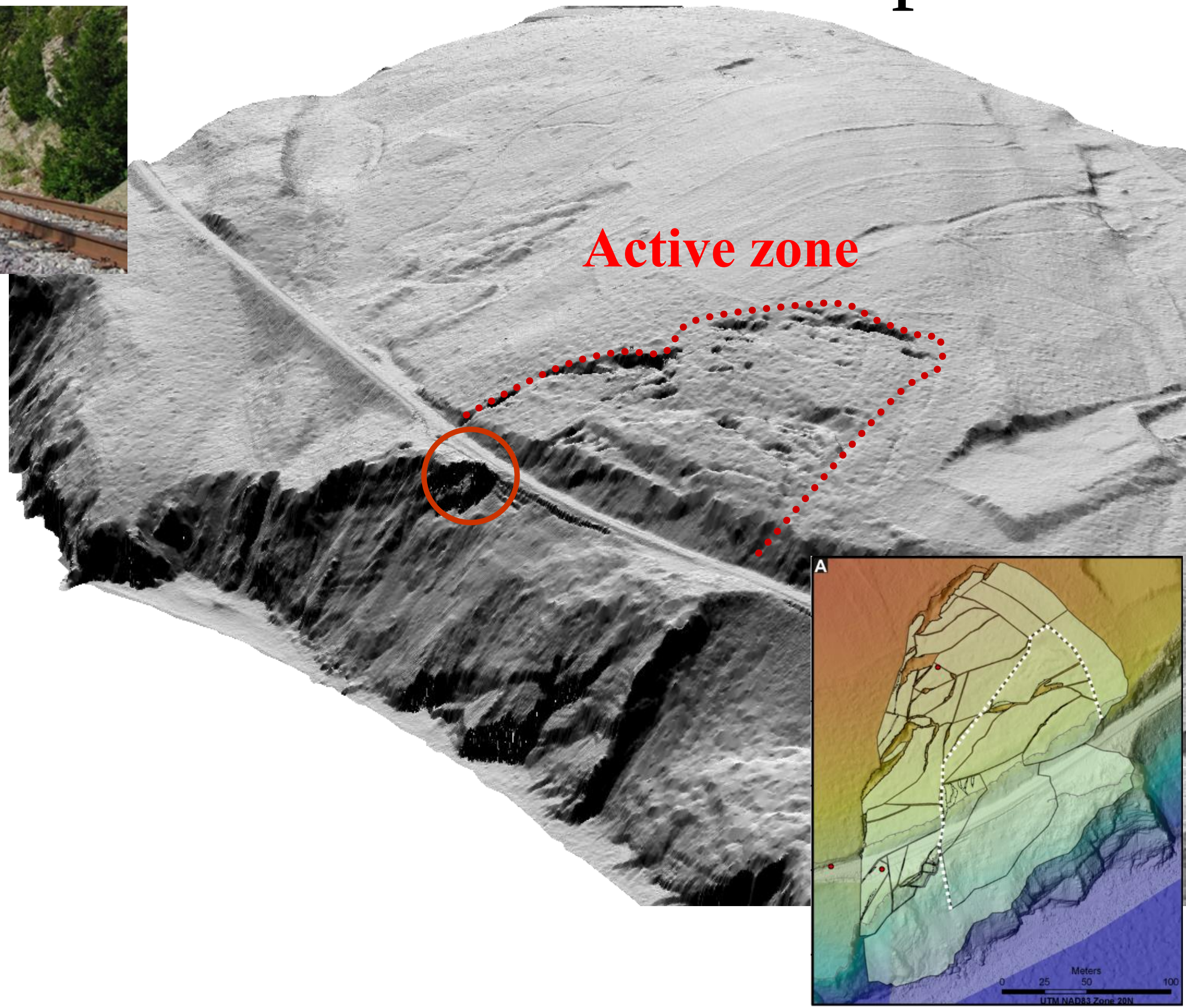


Priya and Feng 2016,AGU

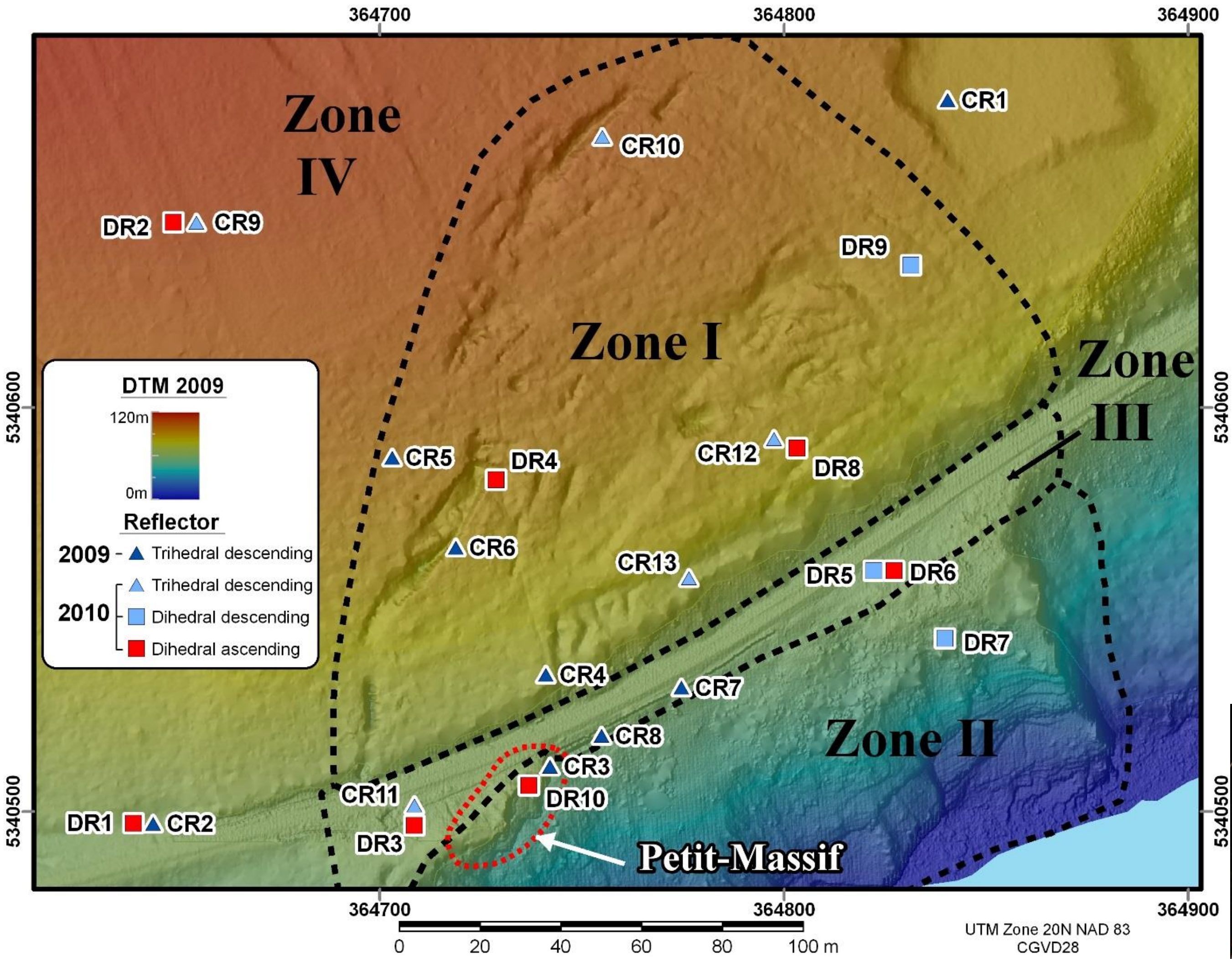
Note the surface rupture



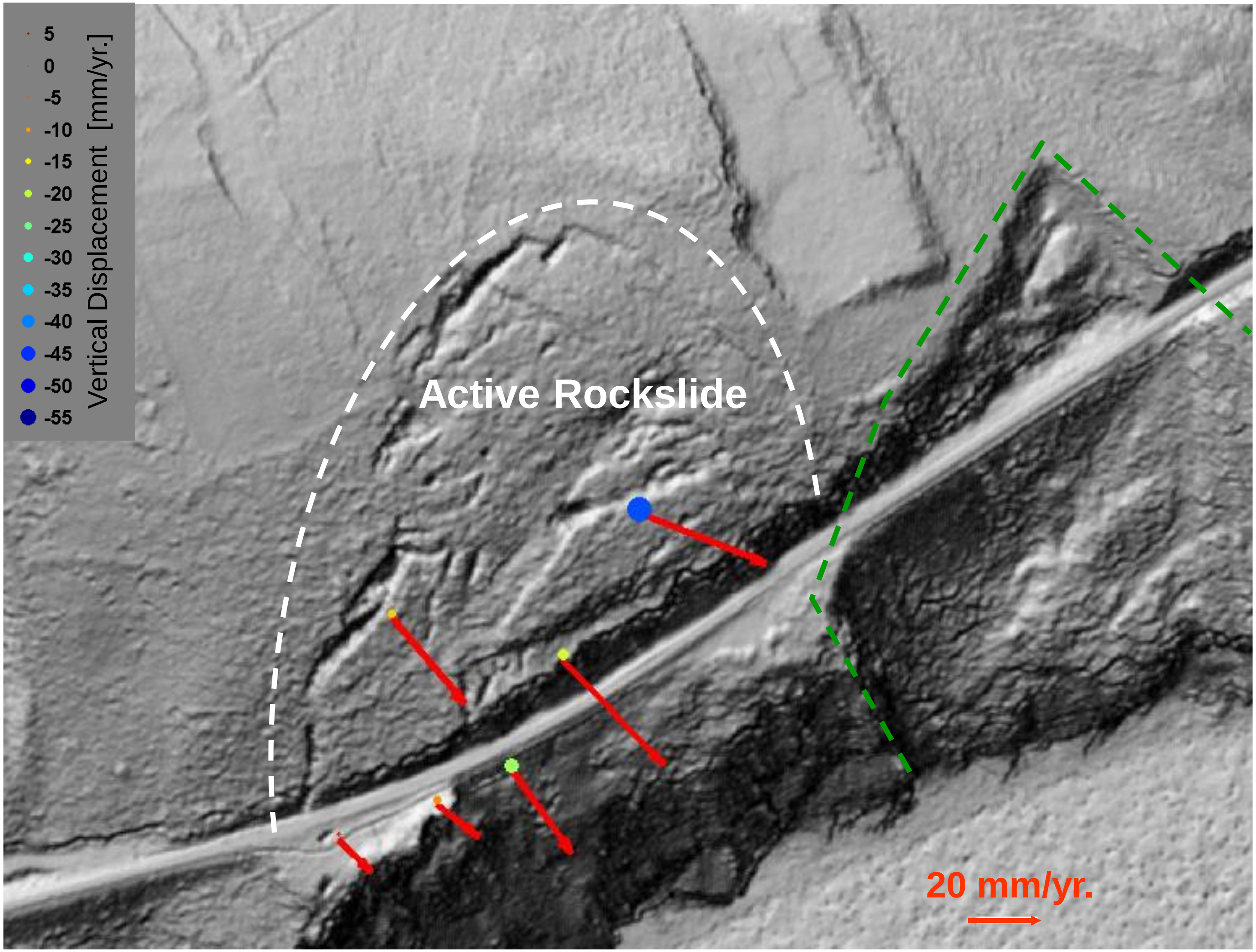
Lidar DEM of Landslide at Gaspe



Deployment of corner reflectors
Descending & Ascending

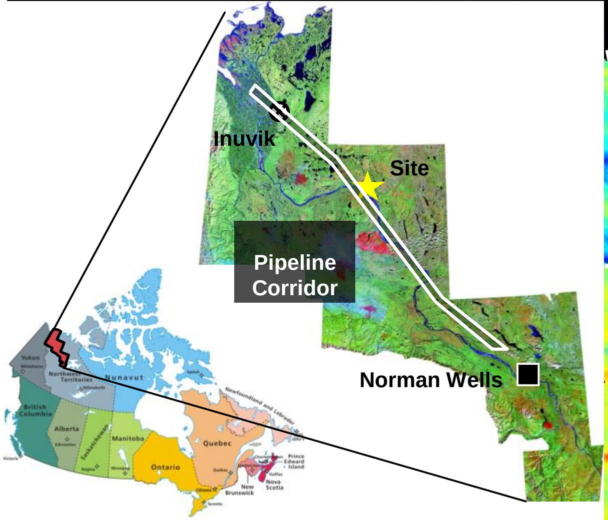


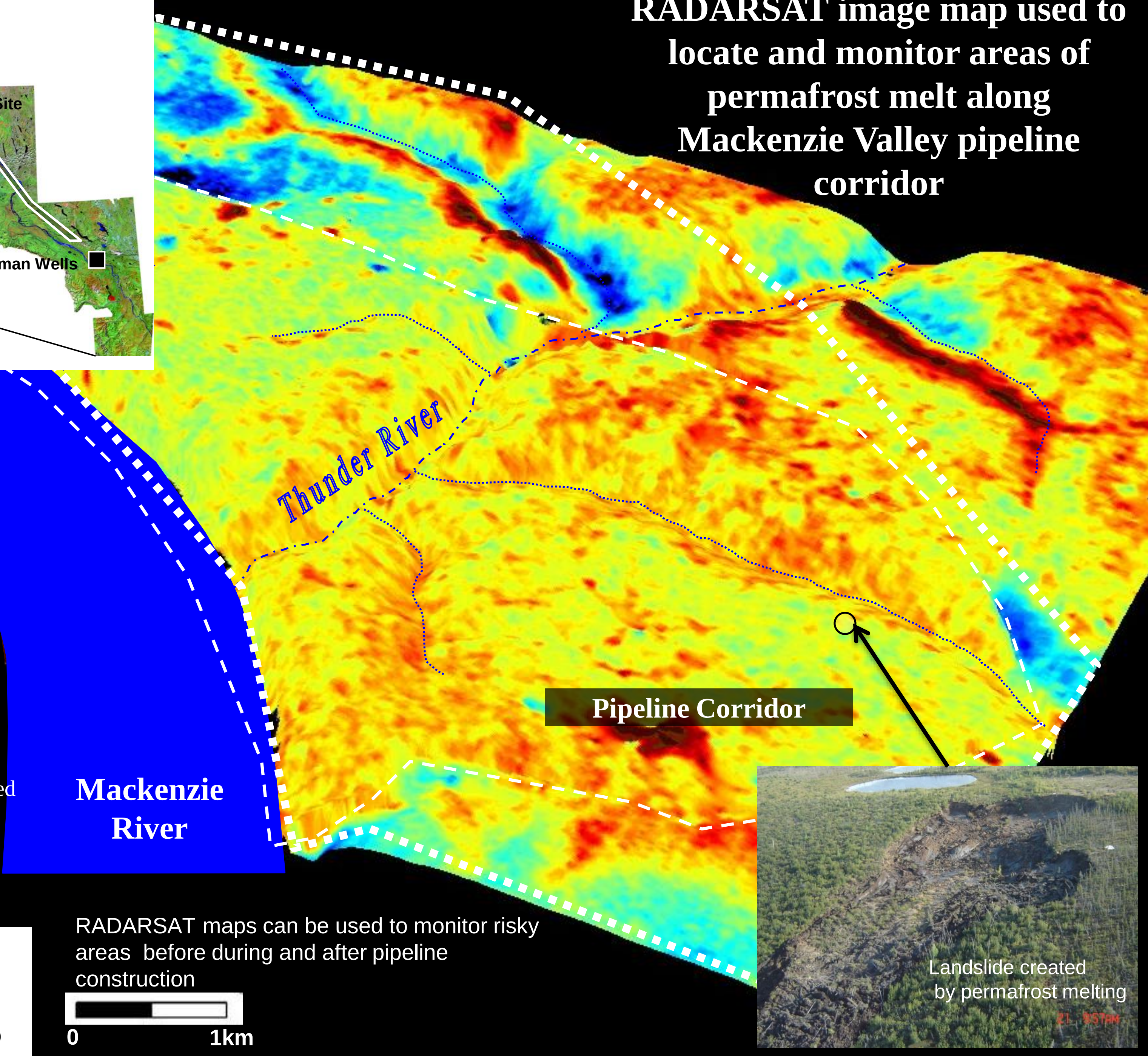
Radarsat 2 InSAR results



InSAR results have been integrated with geomechanical models

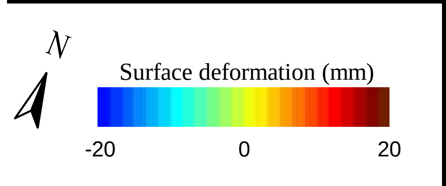
RADARSAT image map used to locate and monitor areas of permafrost melt along Mackenzie Valley pipeline corridor

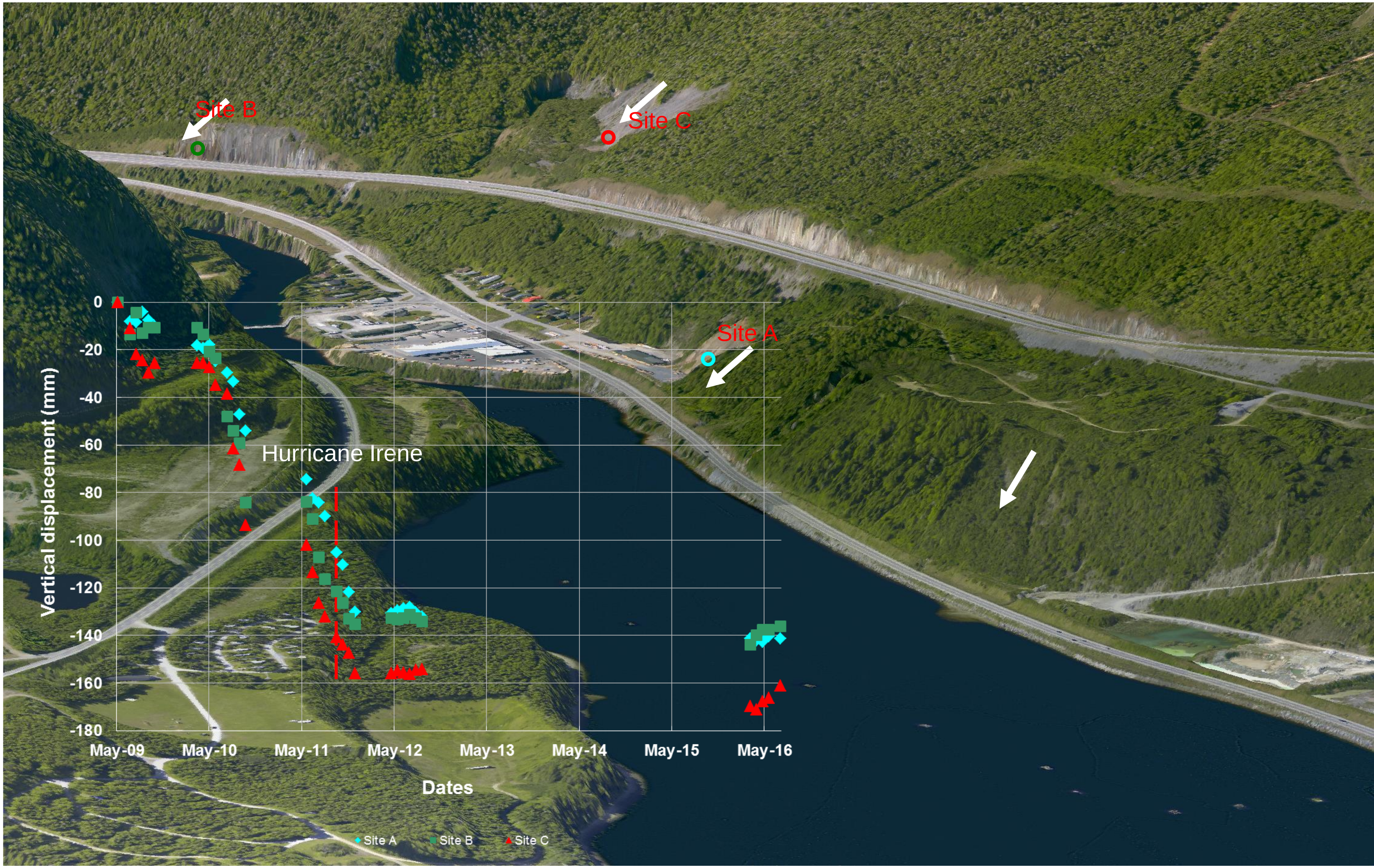




RADARSAT maps (red and blue areas) show risky ground before the pipeline is constructed These maps will be used to refine the pipeline route to prevent spills

RADARSAT maps can be used to monitor risky areas before during and after pipeline construction

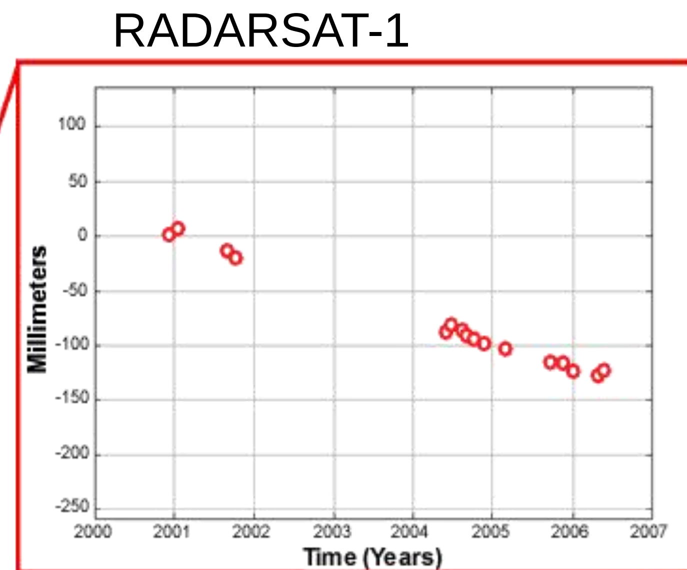


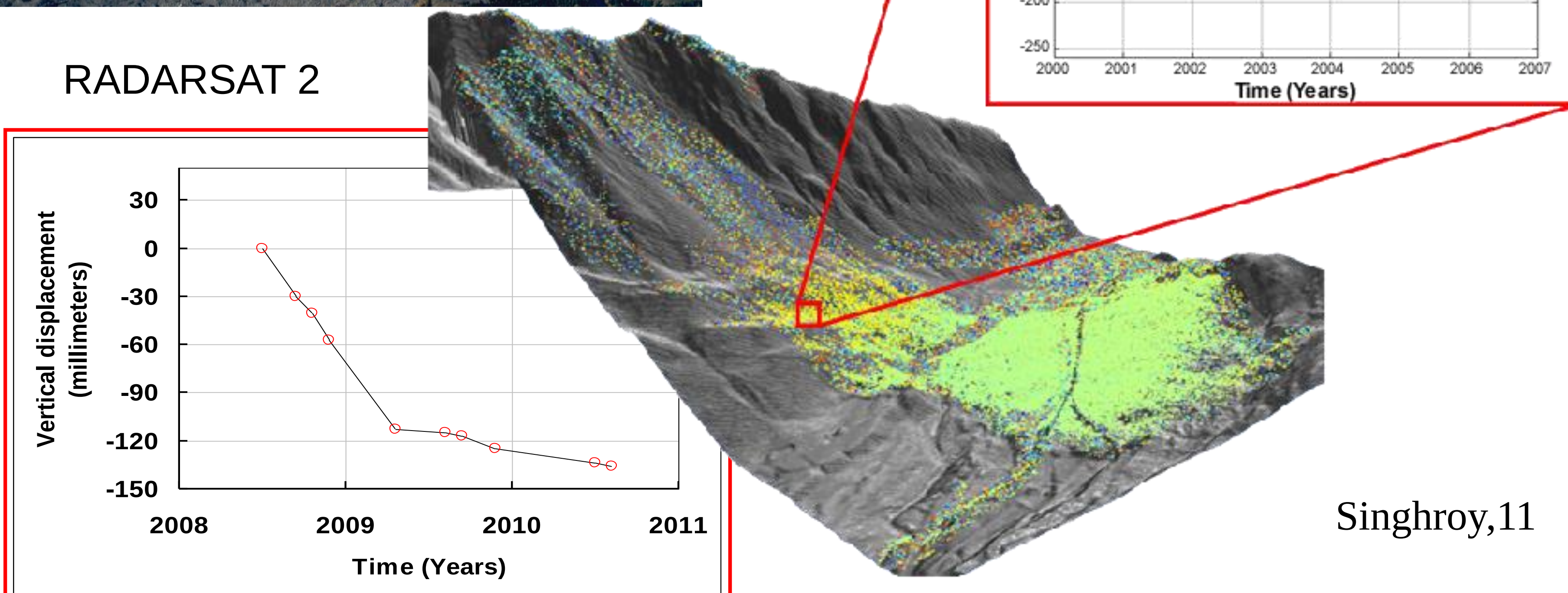


RADARSAT 2 Time series InSAR monitoring the effects of Hurricane Irene on Landslides near highway routes

Corner Brook, Newfoundland, Canada

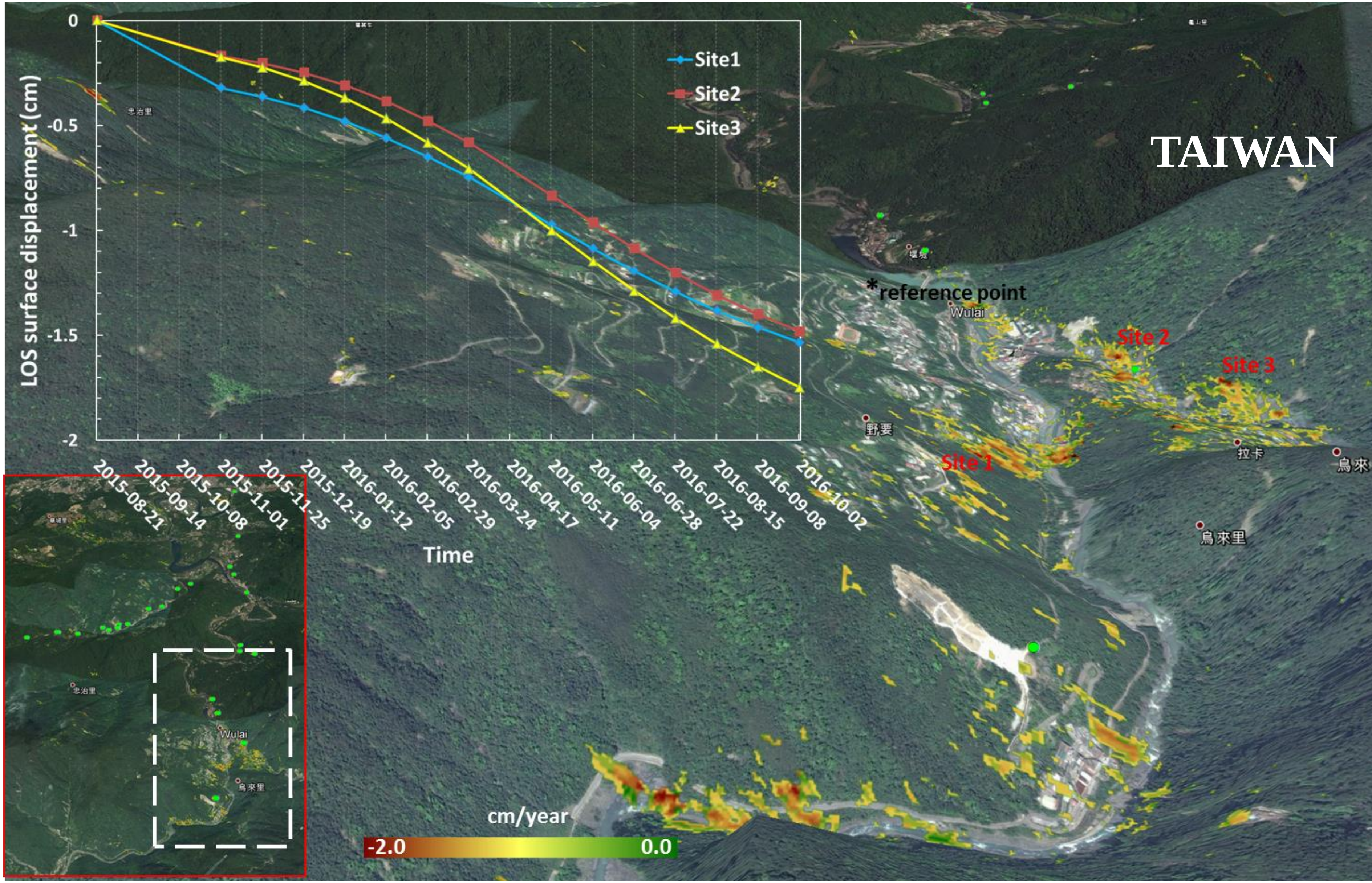
Monitoring landslide motion from RADARSAT InSAR (2000-10)





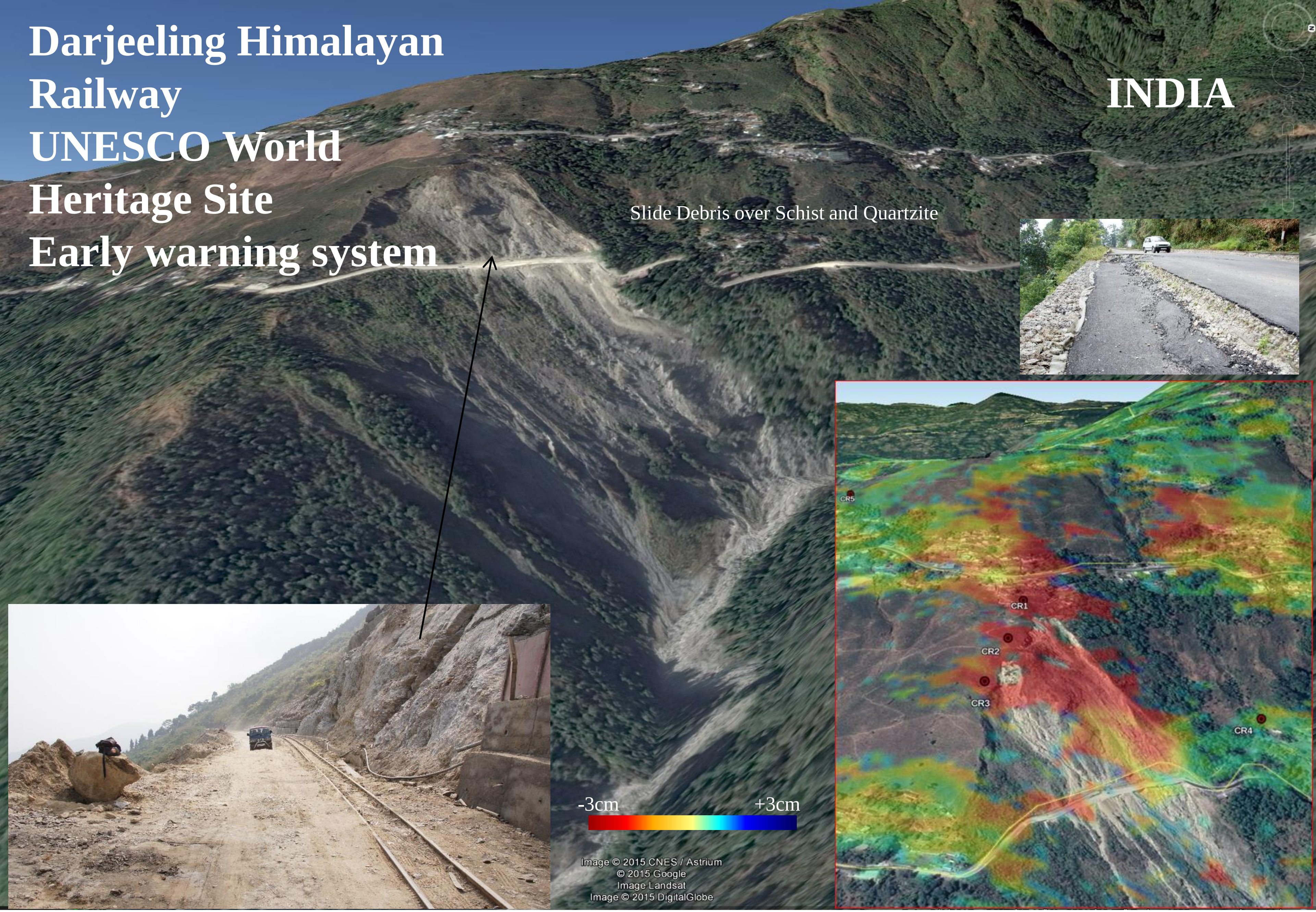
Singhroy,11

InSAR Landslide Monitoring

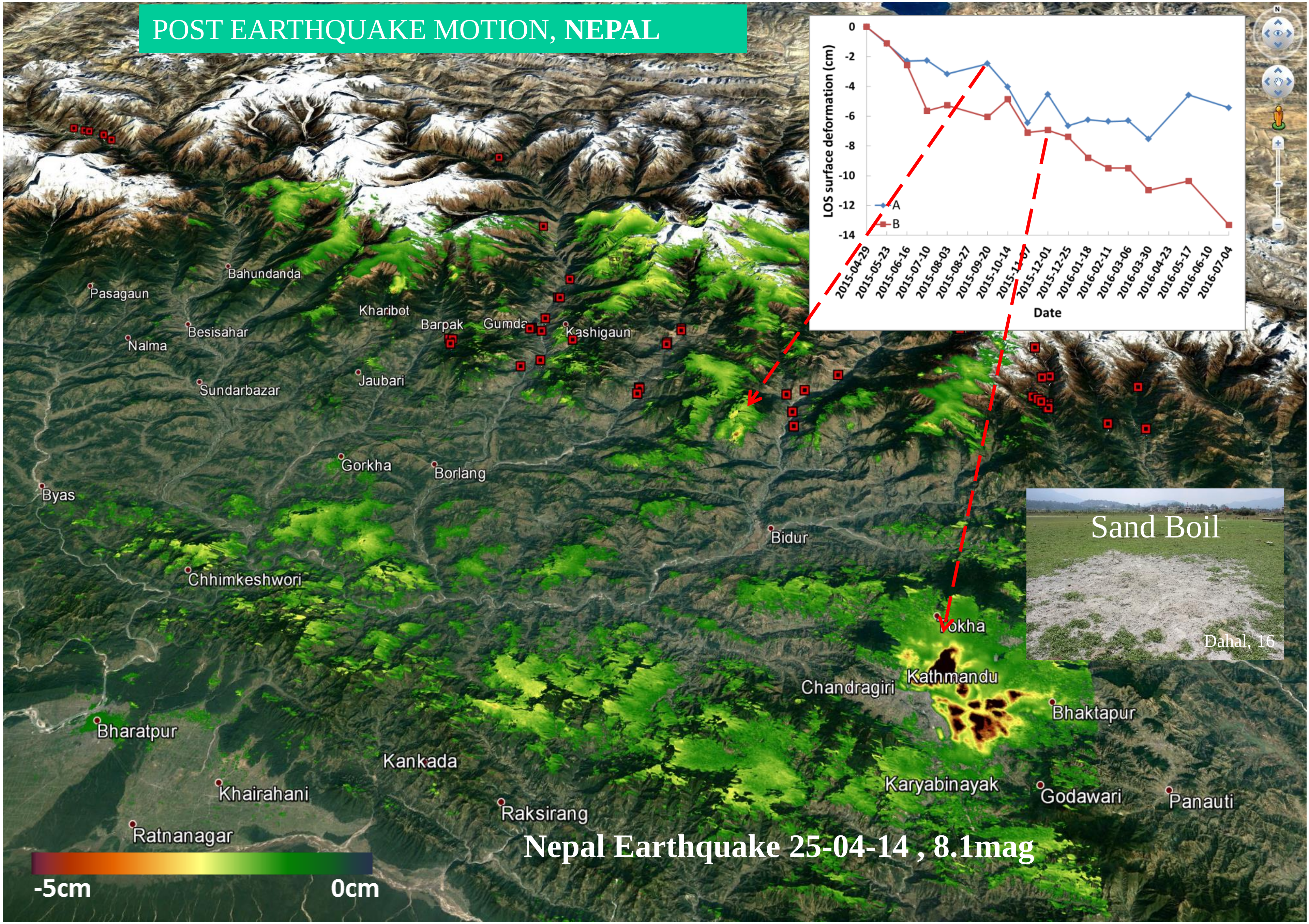


RADARSAT 2-(Extra-Fine Descending) 3m resolution for **Wulai, TAIWAN**

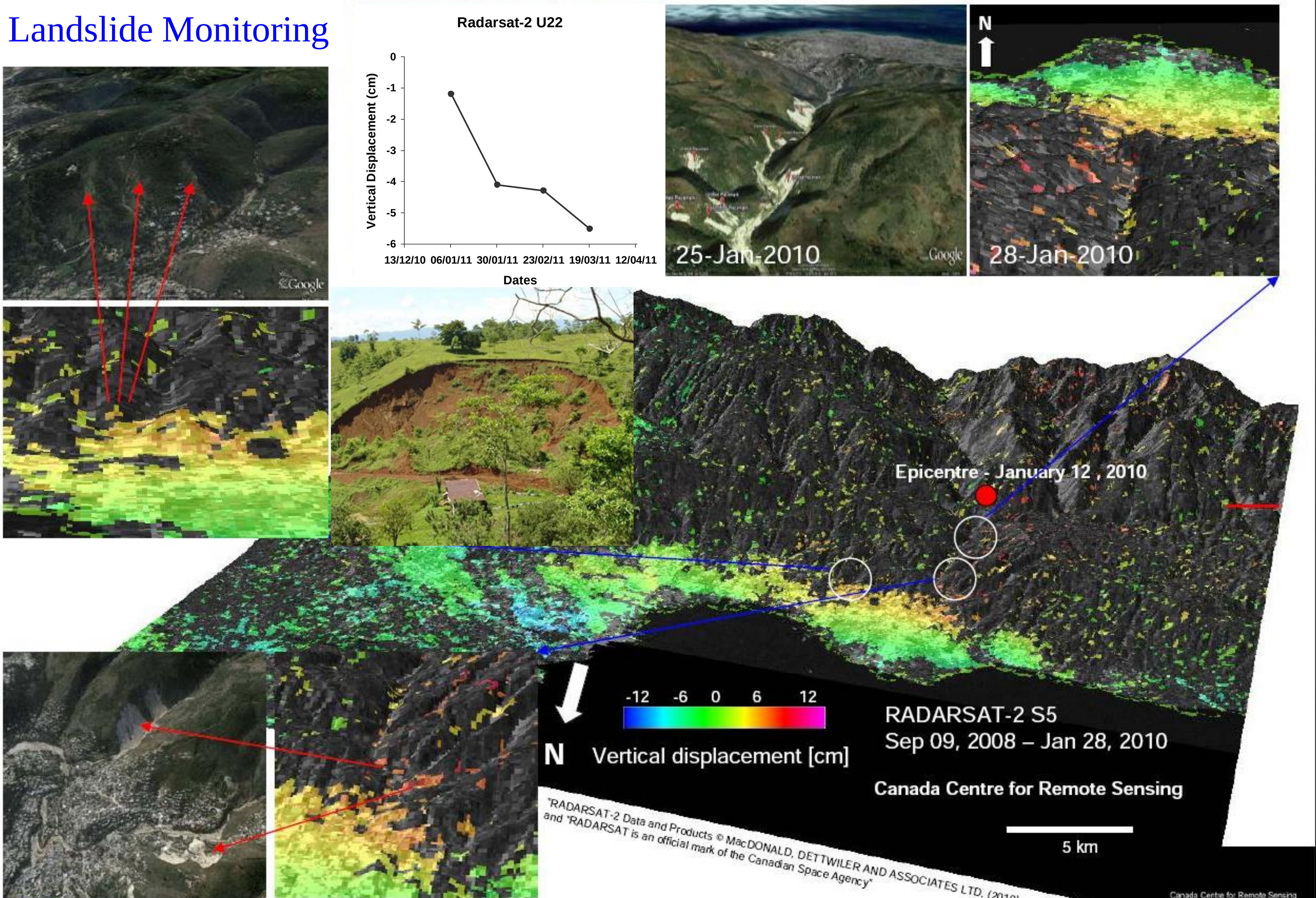
RADASAT-2 : ground movement
(2015/08-2016/10)
Time
cm/year
-2.0
0.0
Nov. 28th, 2016
landslide deposition zone
Sep. 29th, 2015(Next Media)
After typhoon Soudelor
The area affected by debris flow
Nanshi creek
Sep. 29th, 2015(Next Media)
Yun-Hsien landslide, Wulai, New Taiepi city, Taiwan
N


Darjeeling Himalayan
Railway
UNESCO World
Heritage Site
Early warning system
INDIA
Slide Debris over Schist and Quartzite
-3cm
+3cm
CR5
CR1
CR2
CR3
CR4
Image © 2015 CNES / Astrium
© 2015 Google
Image Landsat
Image © 2015 DigitalGlobe

POST EARTHQUAKE MOTION, NEPAL



Landslide Monitoring

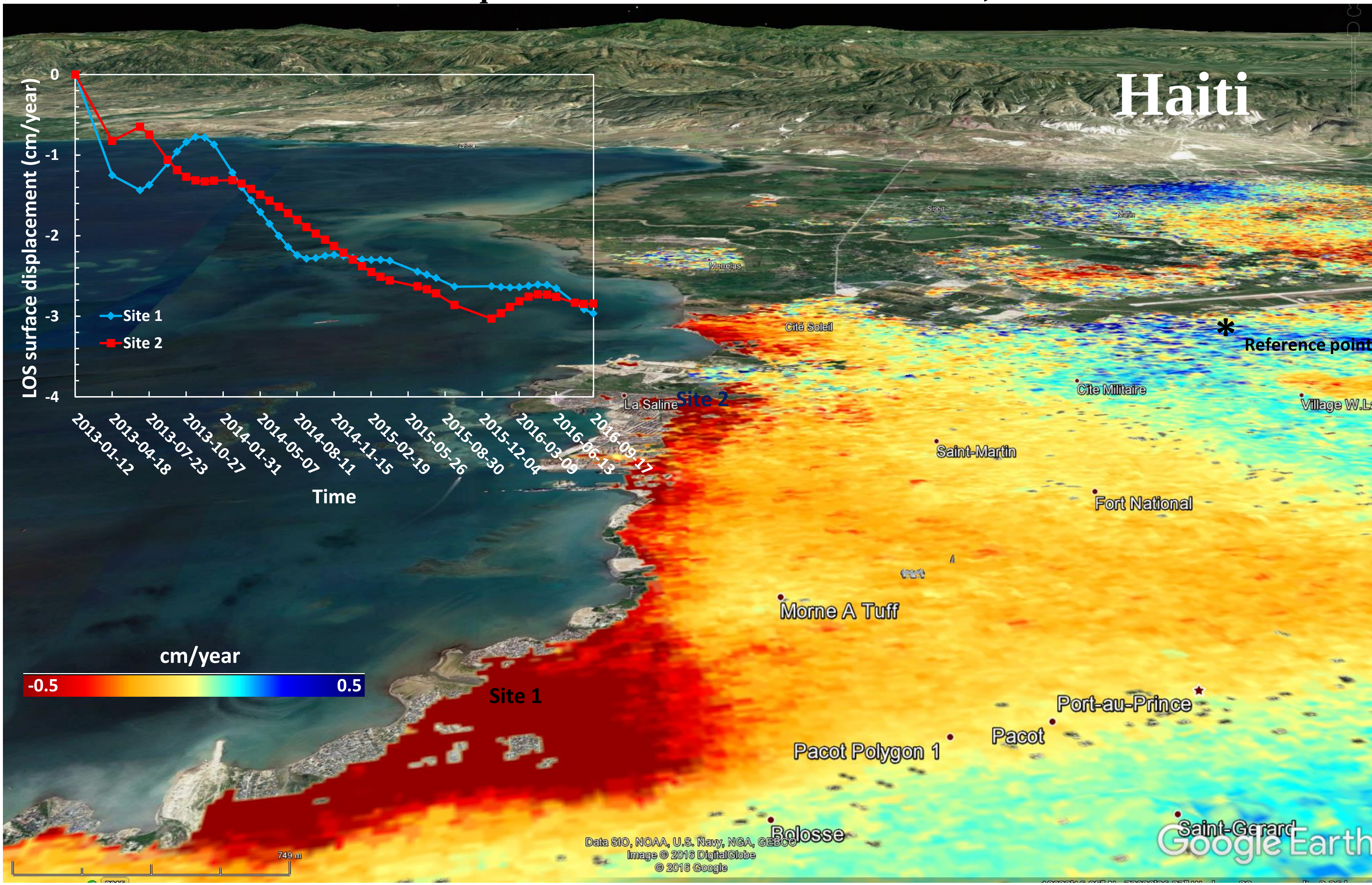


RADARSAT-2 Vertical Displacement Map – Port-au-Prince - Haiti

Singhroy and Pavlic, CCRS, Feb 2010

Canada Centre for Remote Sensing
Natural Resources Canada
Canada
Centre canadien de télédétection
Ressources naturelles Canada

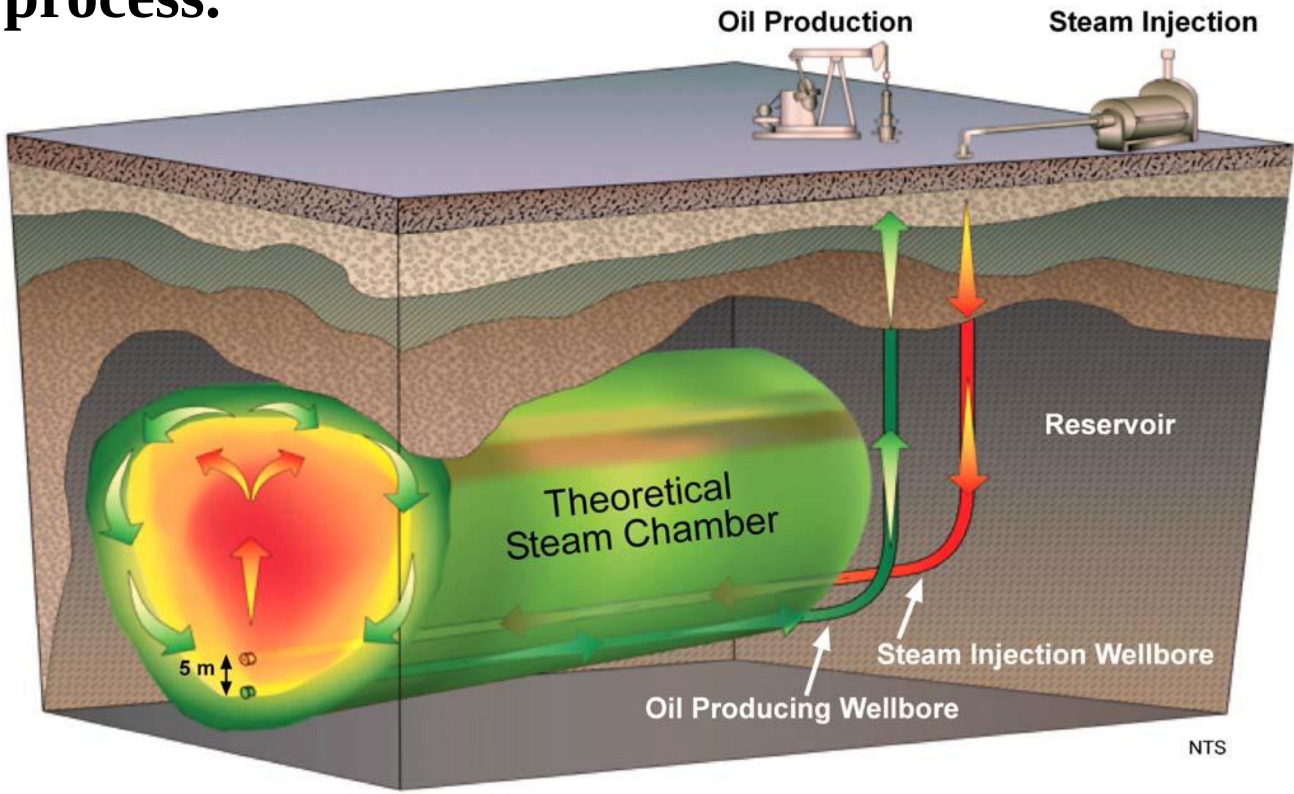
Post earthquake subsidence on marine sediments, Haiti



Radarsat-2 Standard Beam Mode 5 (S5) Descending

Steam-assisted gravity drainage (SAGD) process.

- Steam injected into upper well to reduce viscosity of heavy oil
- Oil produced from the lower well
- Injection of steam -> increase in P,T in oil sand reservoir -> surface deformation



Stratigraphic cross section of the oil sands showing variable thickness of the reservoir lithologies

Potential risks for caprock integrity are:

- Buried channels can create pathways for steam to escape
- Fracturing and faulting of the caprock from post depositional deformation.

InSAR for oil exploration in Alberta, Canada

Managing Risk

Joslyn Creek Blow Out

A stream of high-temperature water and oil shot 12 metres into the air after a wellhead blew out at Joslyn Creek. The company used steam pressures in excess of the approved levels and that's what caused the "catastrophic explosion.” (July 2010)

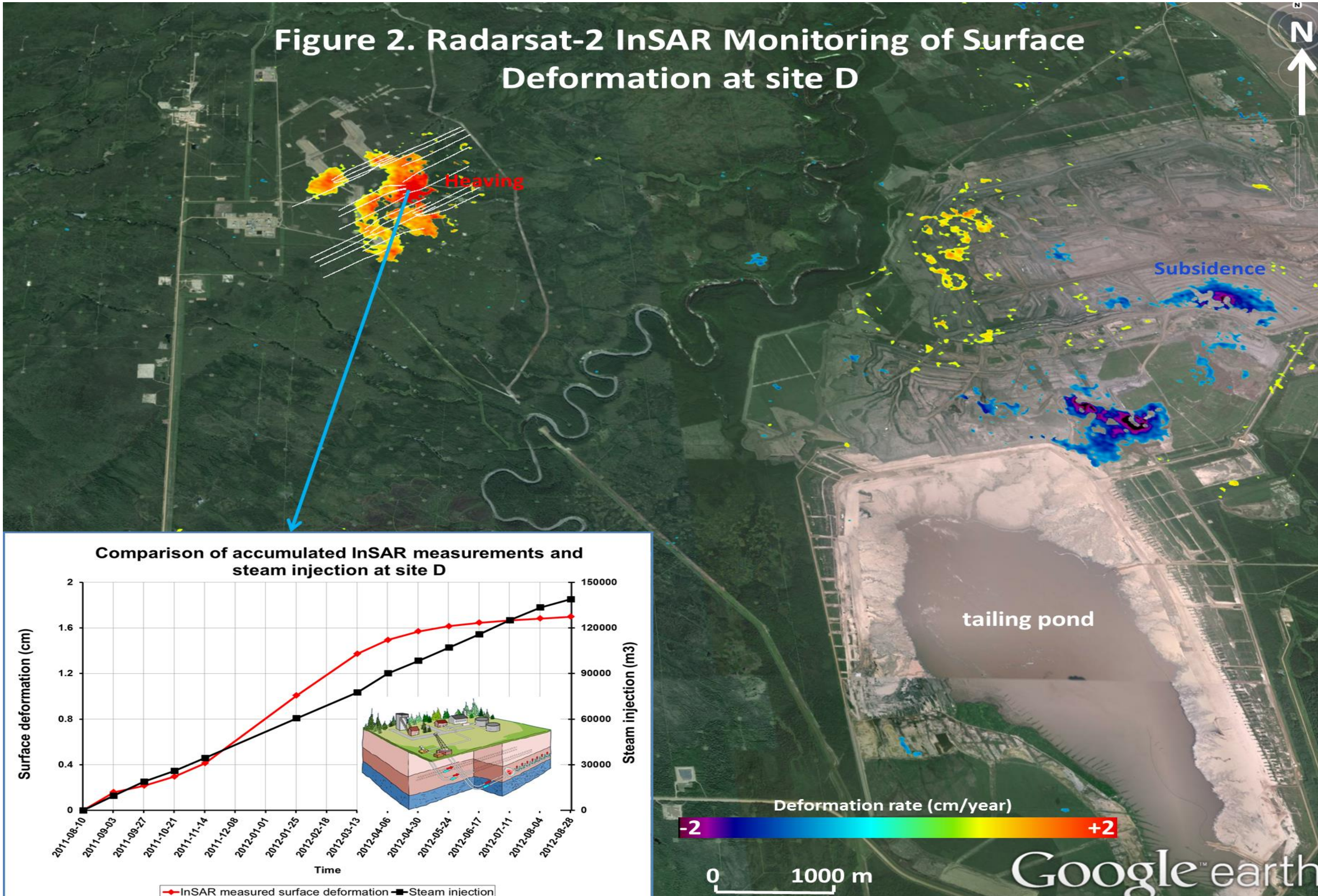
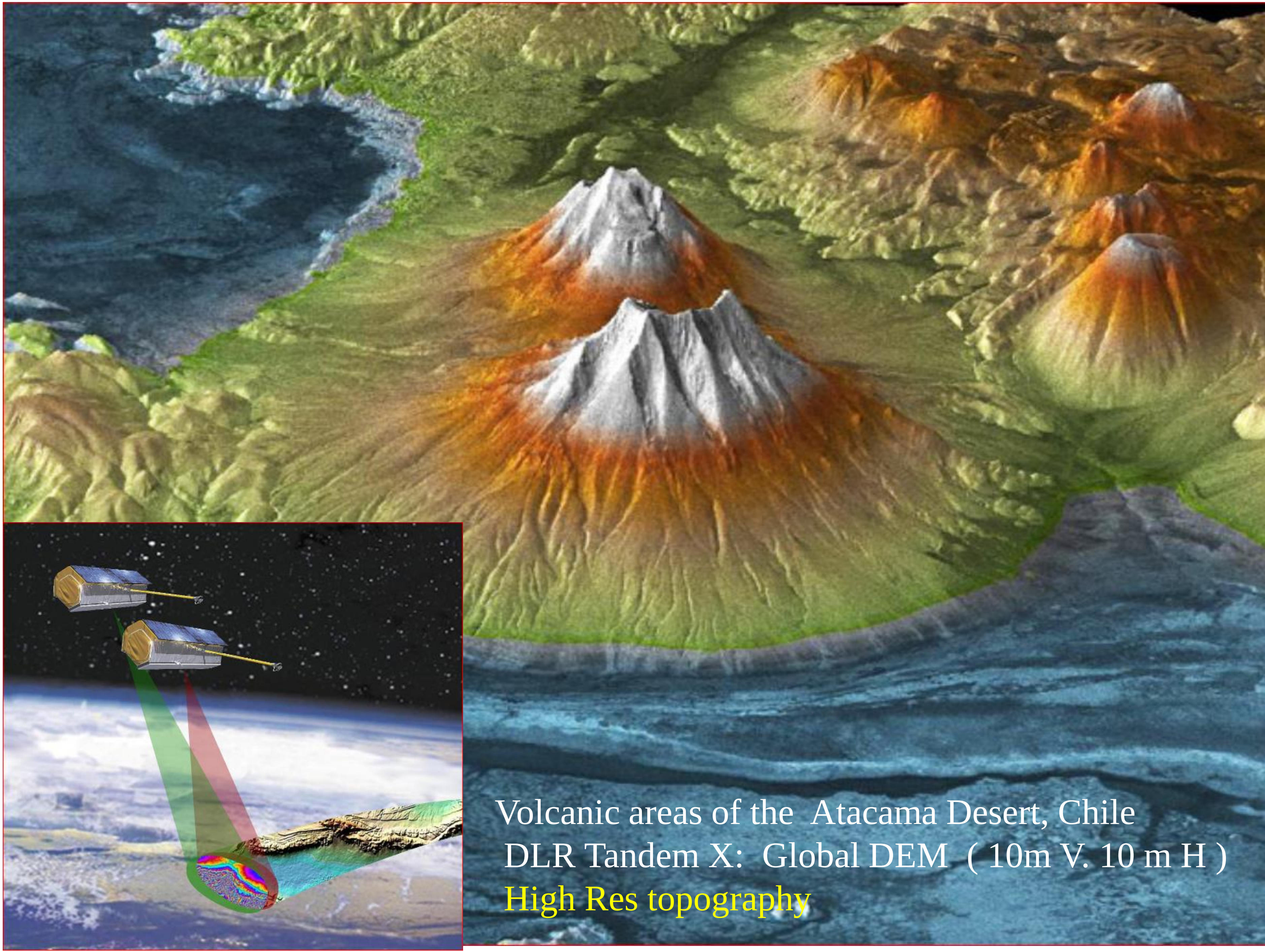


Figure 2. Radarsat-2 InSAR Monitoring of Surface Deformation at site D


Volcanic areas of the Atacama Desert, Chile
DLR Tandem X: Global DEM (10m V. 10 m H)
High Res topography

Summary

- InSAR shows motion on landslides, earthquakes, volcanoes, mining, land subsidence, permafrost melt and glacial velocity.
- RADARSAT 2 InSAR techniques are being used to monitor the spatial and temporal terrain movements in order to understand the dynamics of low velocity landslides affecting transportation corridors.
- Our InSAR measurements show different rates of motion based on favourable geological and seasonal conditions. These factors explain triggering mechanisms and deformation behaviour.
- RADARSAT and other high resolution and rapid revisit constellations are useful to monitor deformation on a weekly basis for improved mitigation measures.

References

- Singhroy, V., Li, J., & François, C. (2016) High Resolution Rapid Revisit InSAR Monitoring of Surface Deformation, *Canadian Journal of Remote Sensing*, 41:5, 458-472, DOI:10.1080/07038992.2015.1104638
- and many more