Jet Propulsion Laboratory
California Institute of Technology

NASA - ISRO SAR Mission

SNWG SAR TUTORIAL

Radar Interferometry and Applications

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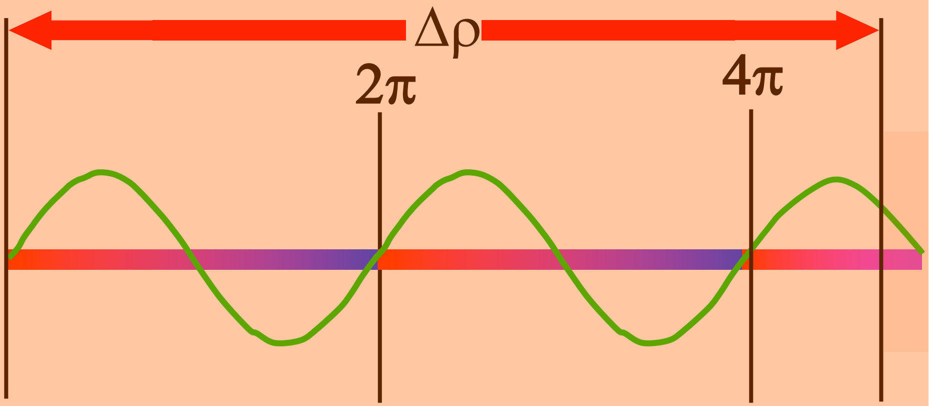
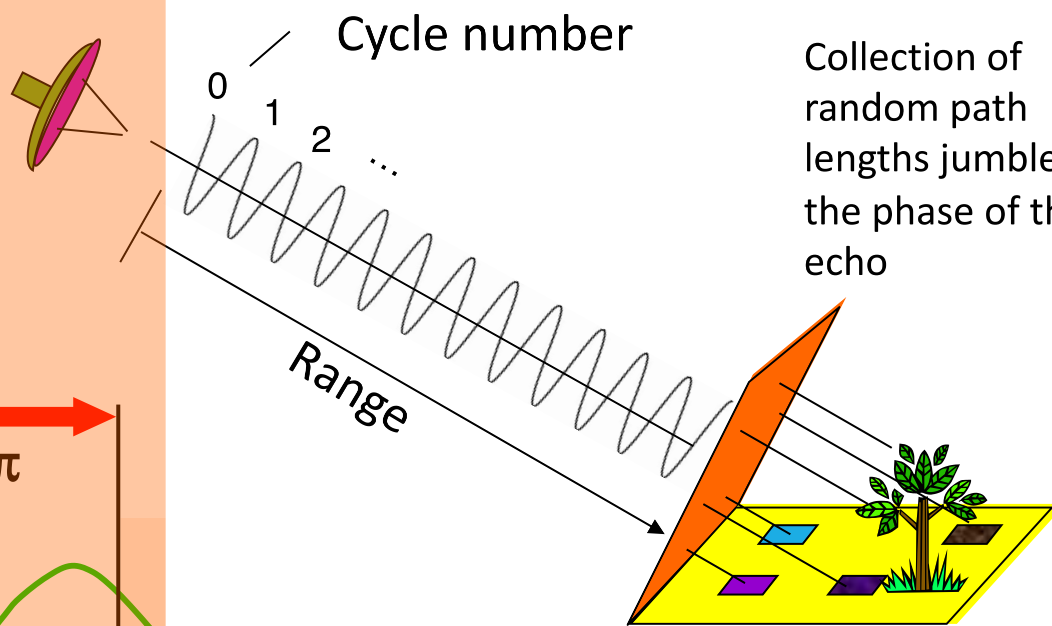
March 17, 2020

Phase and Radar Interferometry

The phase of the radar signal is the number of *cycles of oscillation* that the wave executes between the radar and the surface and back again.



$$\phi = \underbrace{2\pi}_{\text{Radians per wavelength}} \; \underbrace{\frac{\Delta\rho}{\lambda}}_{\text{Number of wavelengths}}$$

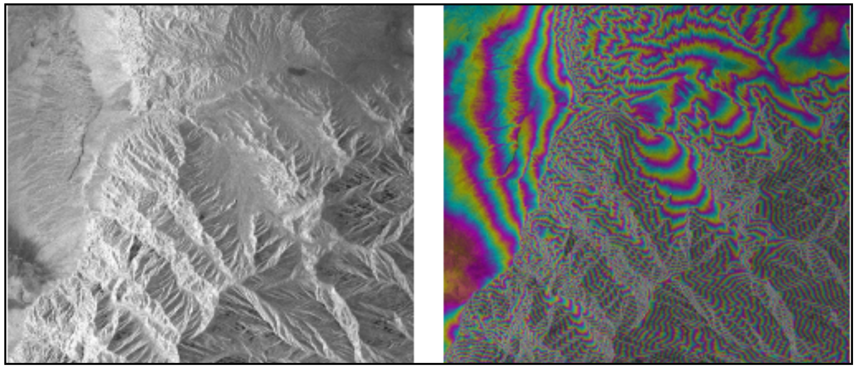


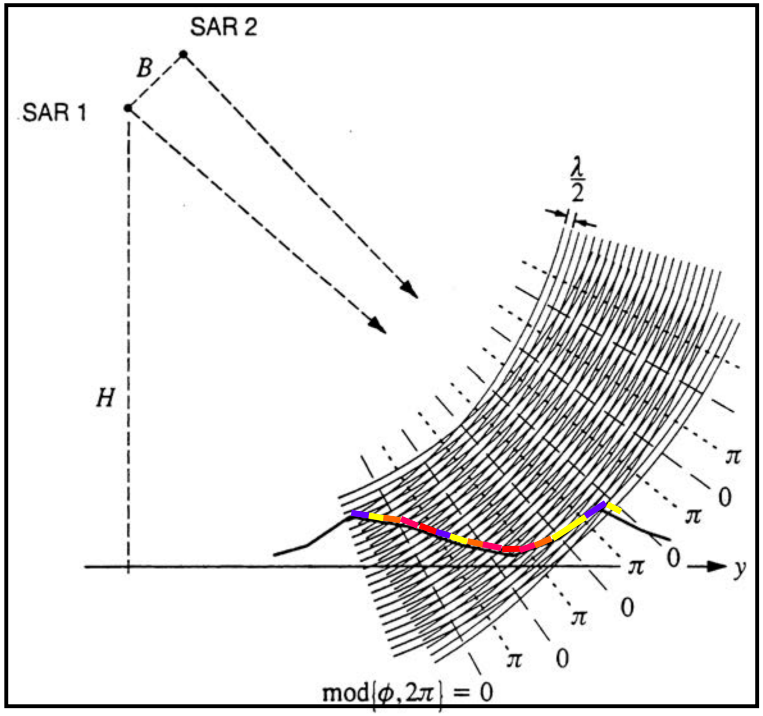
The total phase is two-way range measured in wave cycles + random component from the surface

Radar Interferometry for Topography

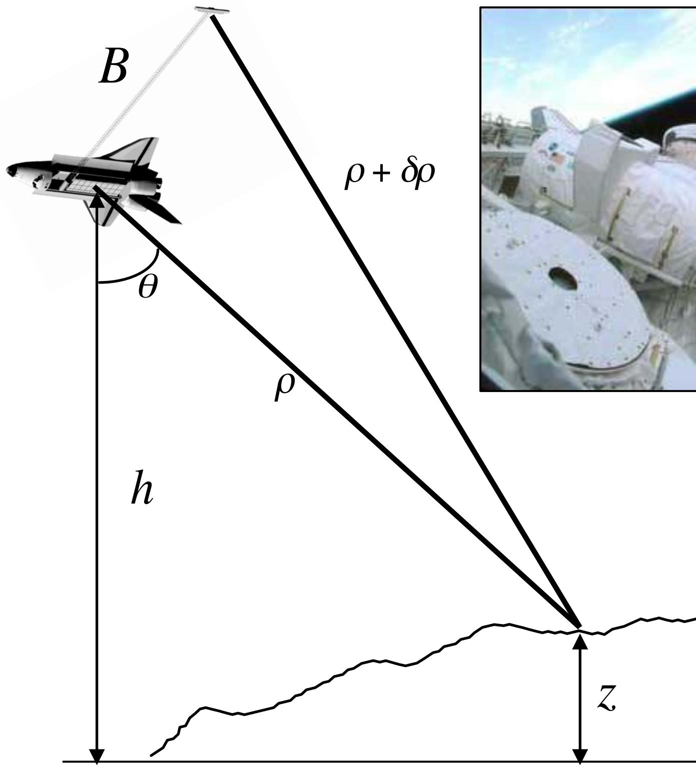
- The two radar (SAR) antennas act as coherent sources
- When imaging a surface, the phase fronts from the two sources interfere
- The surface topography slices the interference pattern
- The measured phase differences record the topographic information

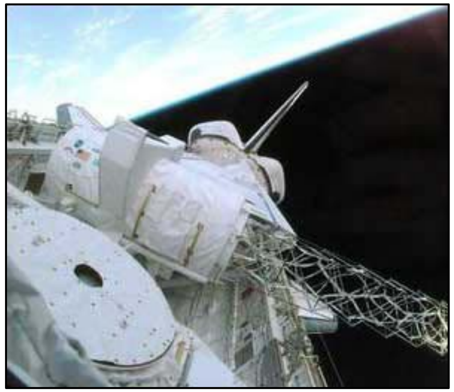
$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(s_1) - \rho(s_2)) = \frac{4\pi}{\lambda}\Delta\rho_{\text{topo}} + \text{noise}$$





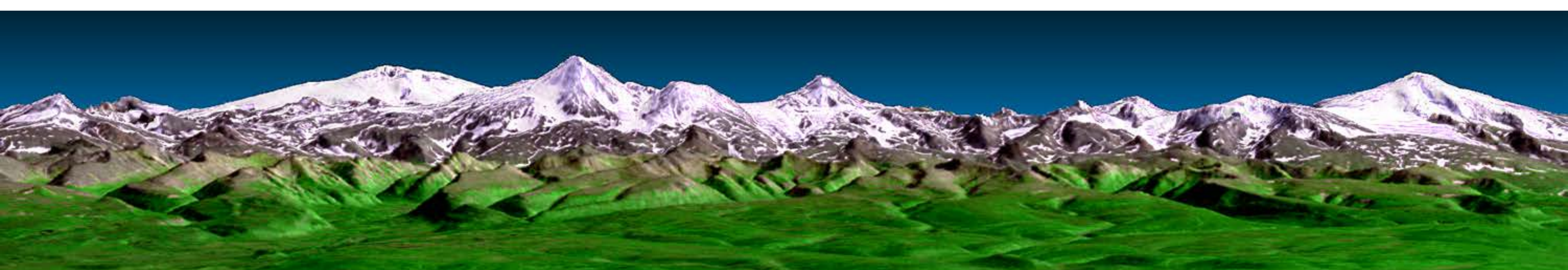
Shuttle Radar Topography Mission (SRTM)



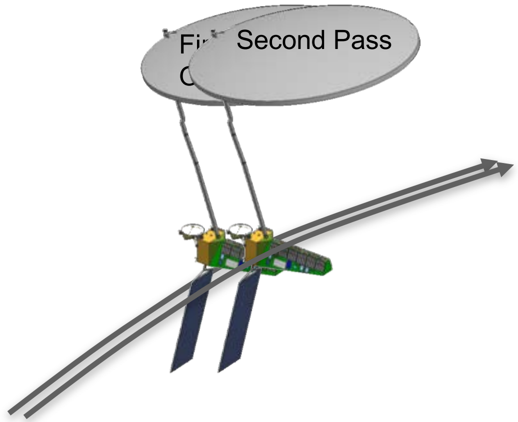


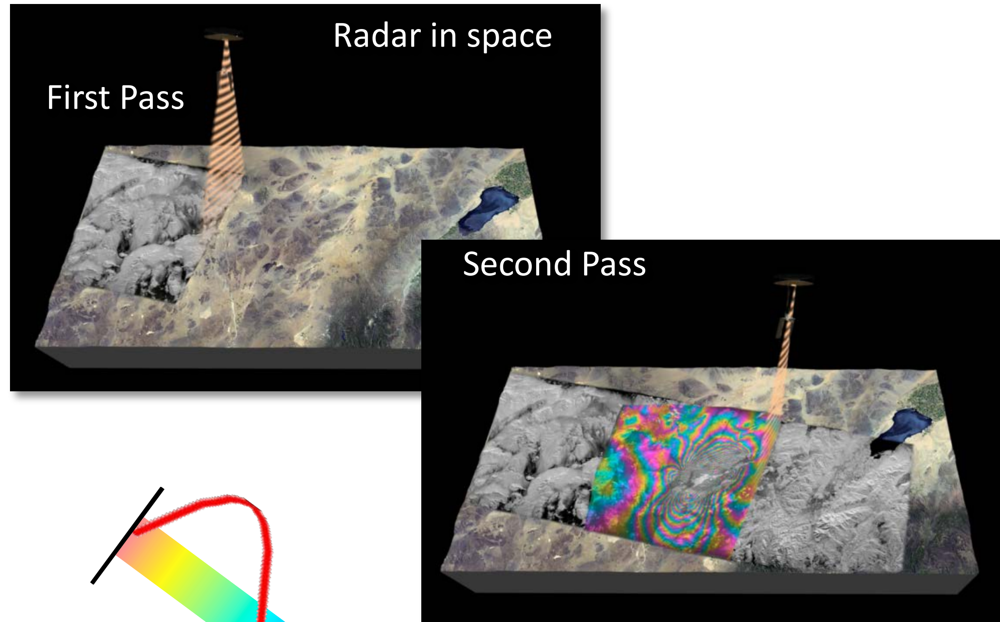
3-dimensional SRTM view of Los Angeles (with Landsat overlay) showing San Andreas fault

- Mapped 80% of Earth's Land Surface
- 30 m horizontal data points
- < 10 m vertical accuracy



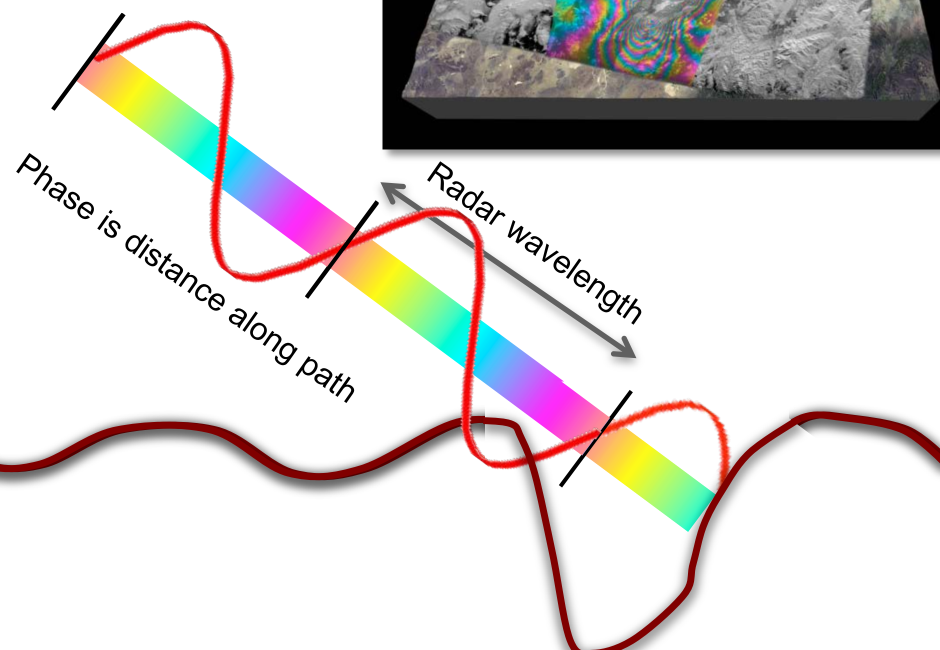
Interferometry for Surface Change





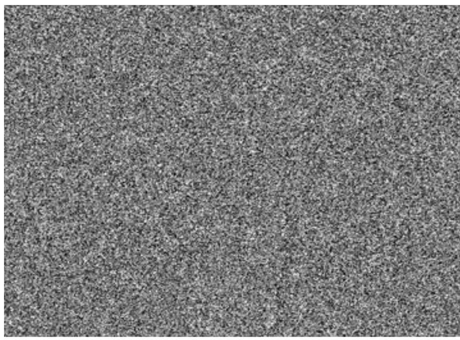
Radar flies over a patch of ground to measure reflection

Radar flies again over the patch of ground to measure new reflection and change of distance through *phase* change

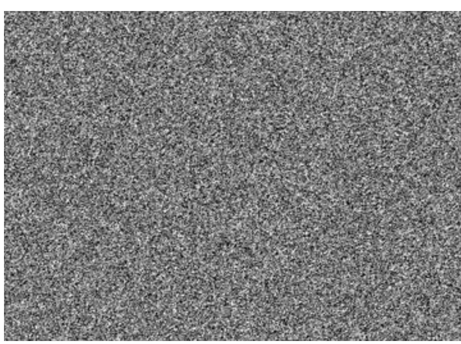


Radar Interferometry Workflow

Satellite Observation

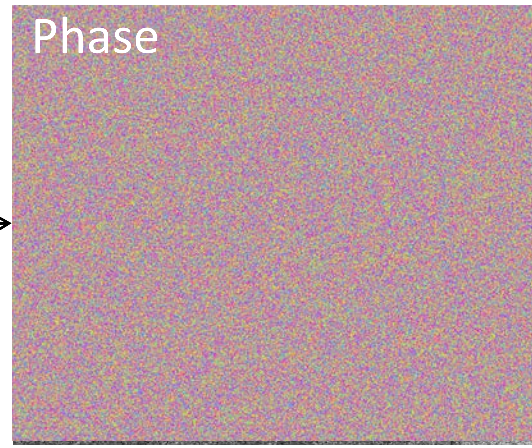


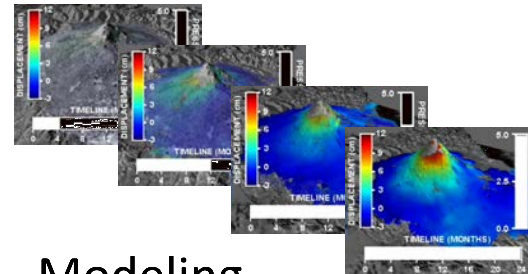
First Time



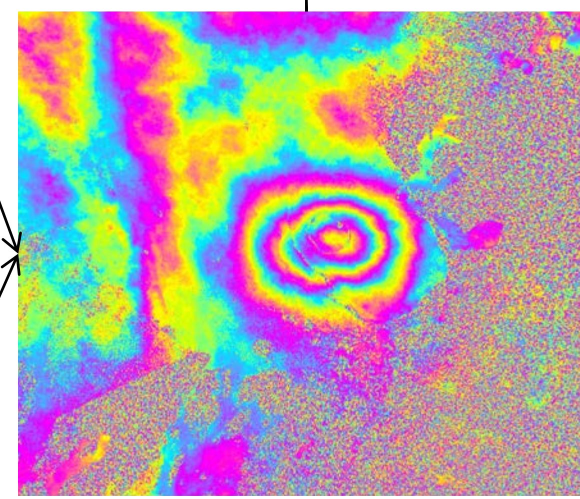
Next Time

Magic of imaging





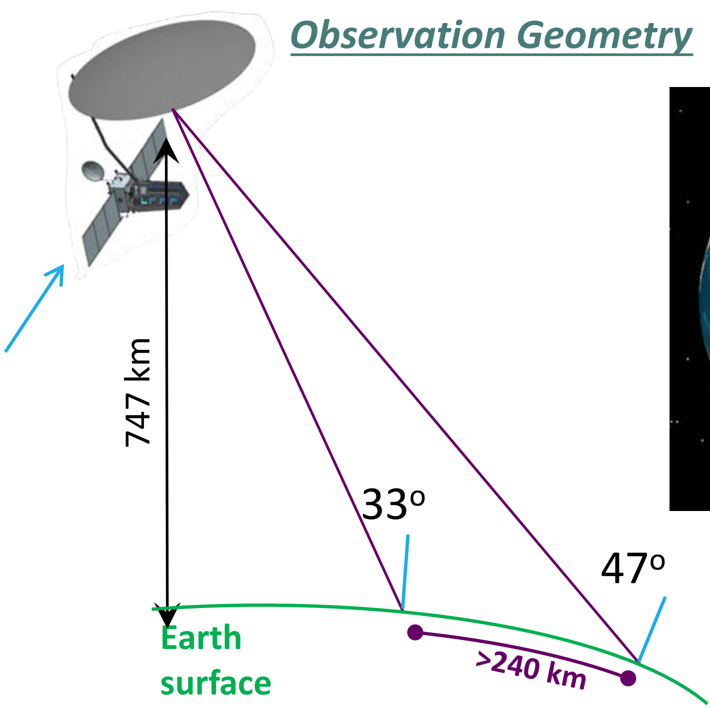
Modeling

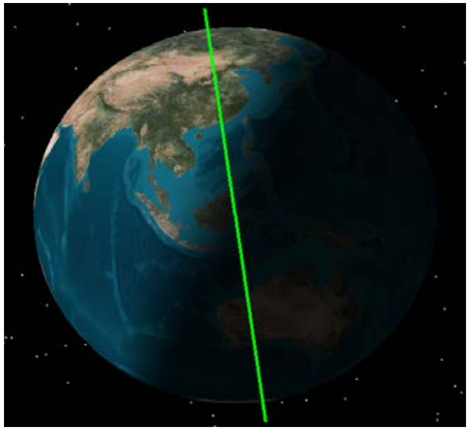


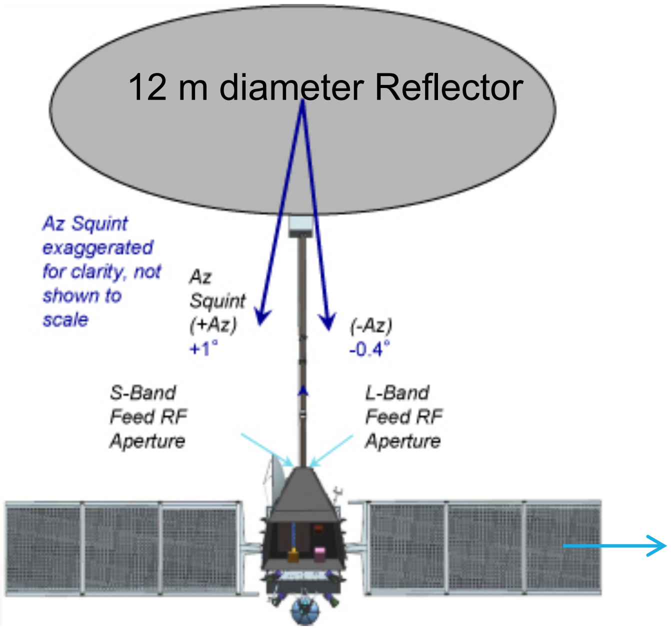
Magic of interferometry

NISAR Imaging and Orbit Geometry

- Wide swath in all modes for global coverage at 12 day repeat (2-5 passes over a site depending upon latitude)
- Data acquired ascending and descending
- Left/Right Pointing Capability (Right nominal)

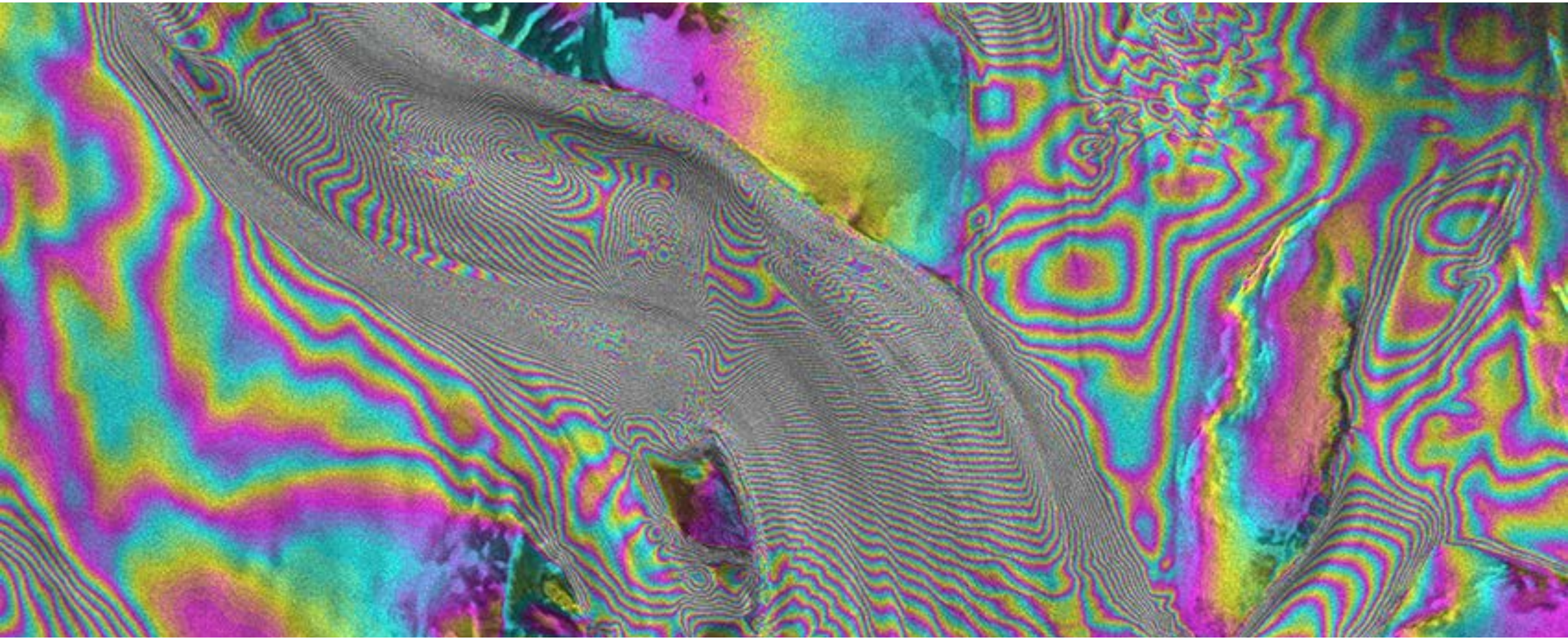






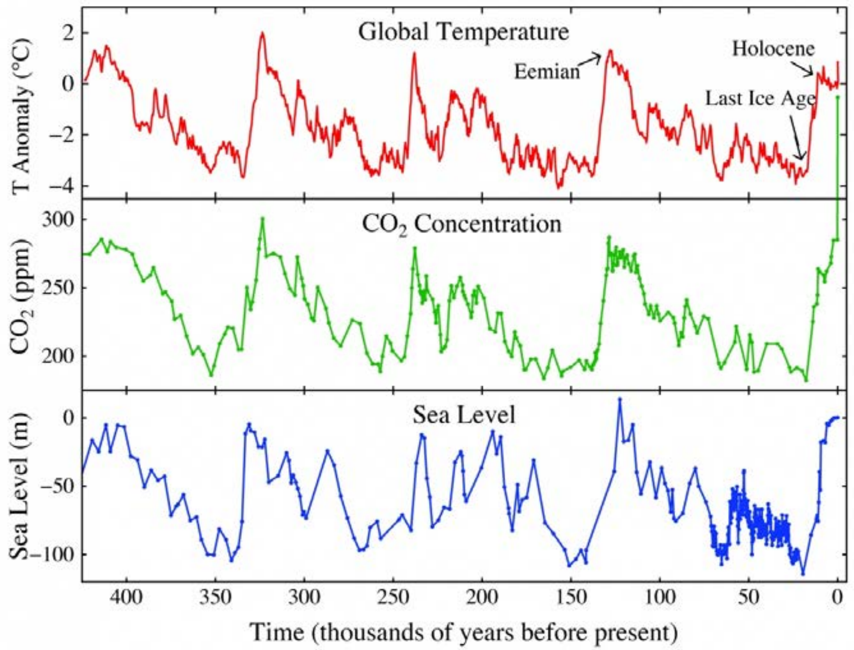
6 AM / 6 PM Orbit
98.5° inclination
Arctic Polar Hole: 87.5R/77.5L
Antarctic Polar Hole: 77.5R/87.5L

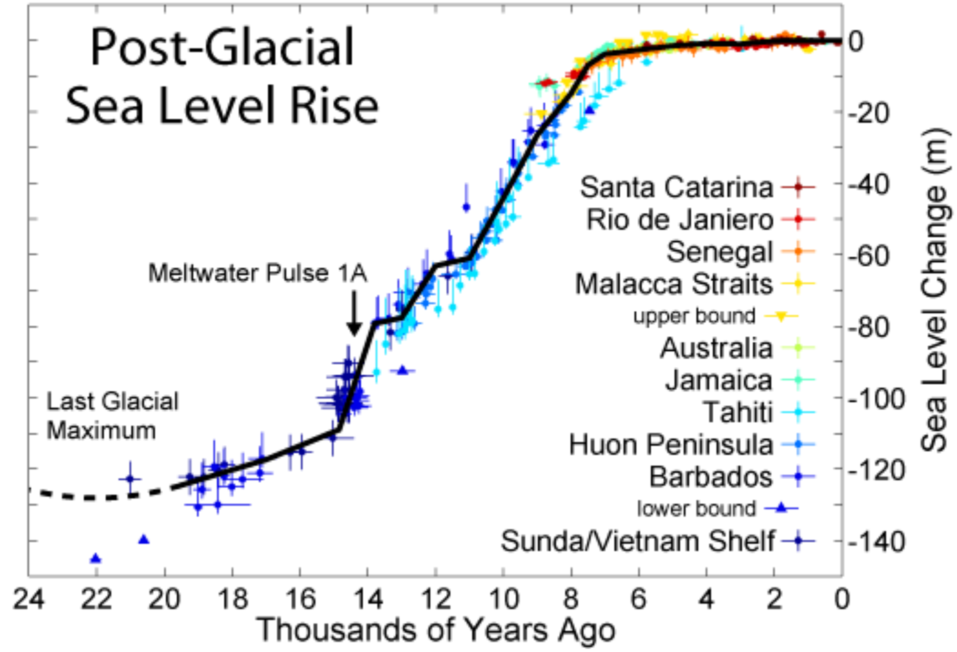
Cryosphere Science with NISAR



- Material from Prof. Eric Rignot
- University of California Irvine and Caltech's Jet Propulsion Laboratory.

Sea level and ice ages





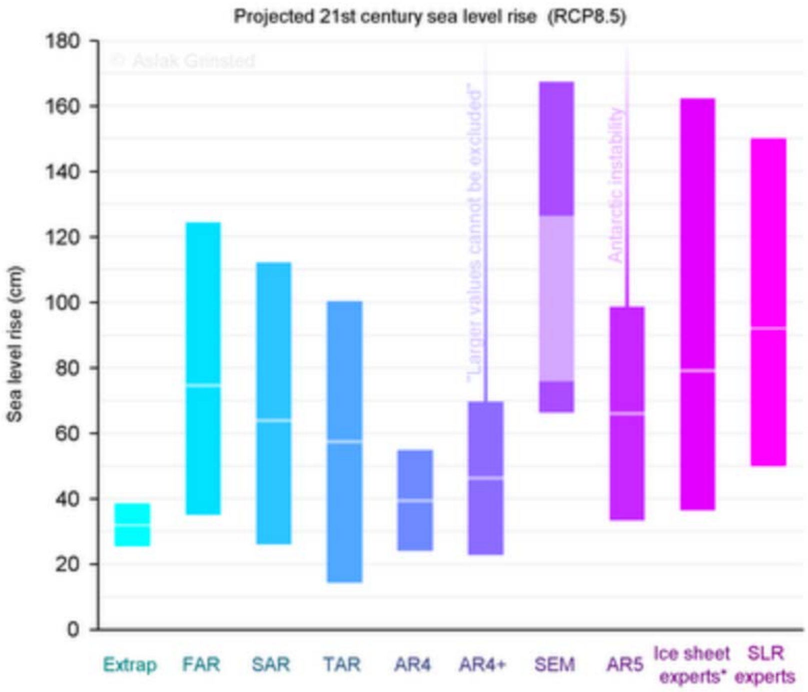
Waxing and waning of ice sheets changed sea level by ±120 m.

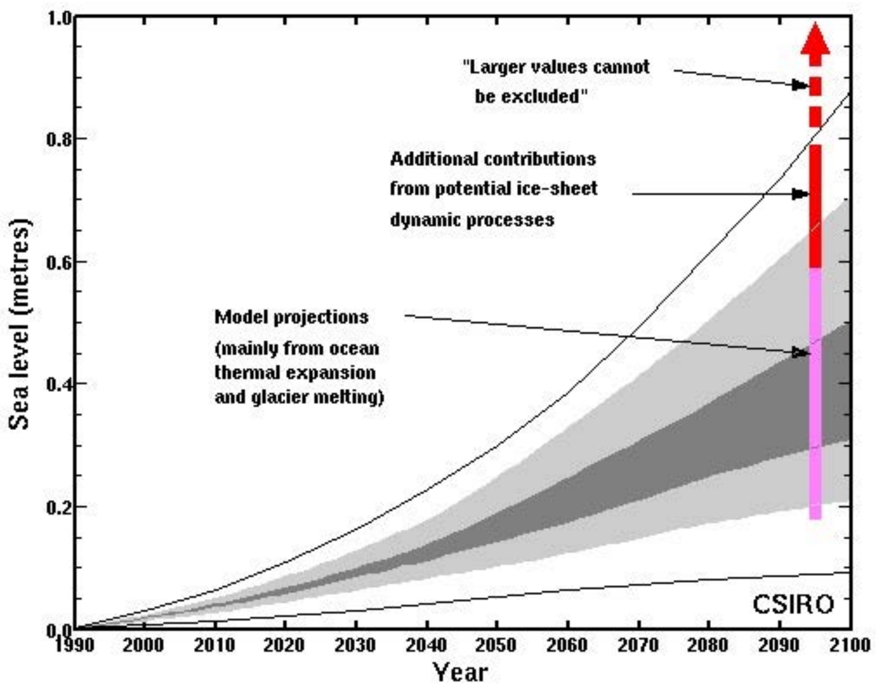
Every 1^{o}C warming induces 20 m SLR.

MWP1a: 20 m SLR in 400 years from ice sheet dynamics in both north and south hemispheres.

Numerical ice sheet models do not know how to replicate the speed and magnitude of MWP1a.

What sea level for year 2100?





Largest uncertainty in SLR is from ice sheets.

AR5 projections disagree with more than 50% of ice sheet experts.

Progress since FAR is limited or misleading.

AR5 projects 20 cm to 60 cm SLR from thermal expansion and glacier melt.

Ice sheet dynamics could add 40 cm to more than 100 cm SLR.

Why is it hard to predict the future of ice sheets?

- Past records of marine ice sheet retreats have been bulldozed by ice sheet re-advances. We do not know how fast marine-based ice sheets may retreat.

- Boundary conditions at the base (interaction of water flow, sediment, heat flow) and at the seaward margins (interactions of ocean circulation, heat flow, wind forcing, sea ice cover, sea floor bathymetry) are complex and unexplored.

- Detailed observations of ice sheet dynamics are new and sparse, evidence for marine ice sheet instability is recent and not taken seriously.

- New high resolution numerical ice sheet models with full physics, coupled with ocean and atmosphere, with data assimilation (DA) capabilities are becoming available but ice observations are few, not continuous, and do not cover long time scales.

- Think of making meteorological forecasts without weather observations (Vaughan, Science 2007).

Physical processes of importance

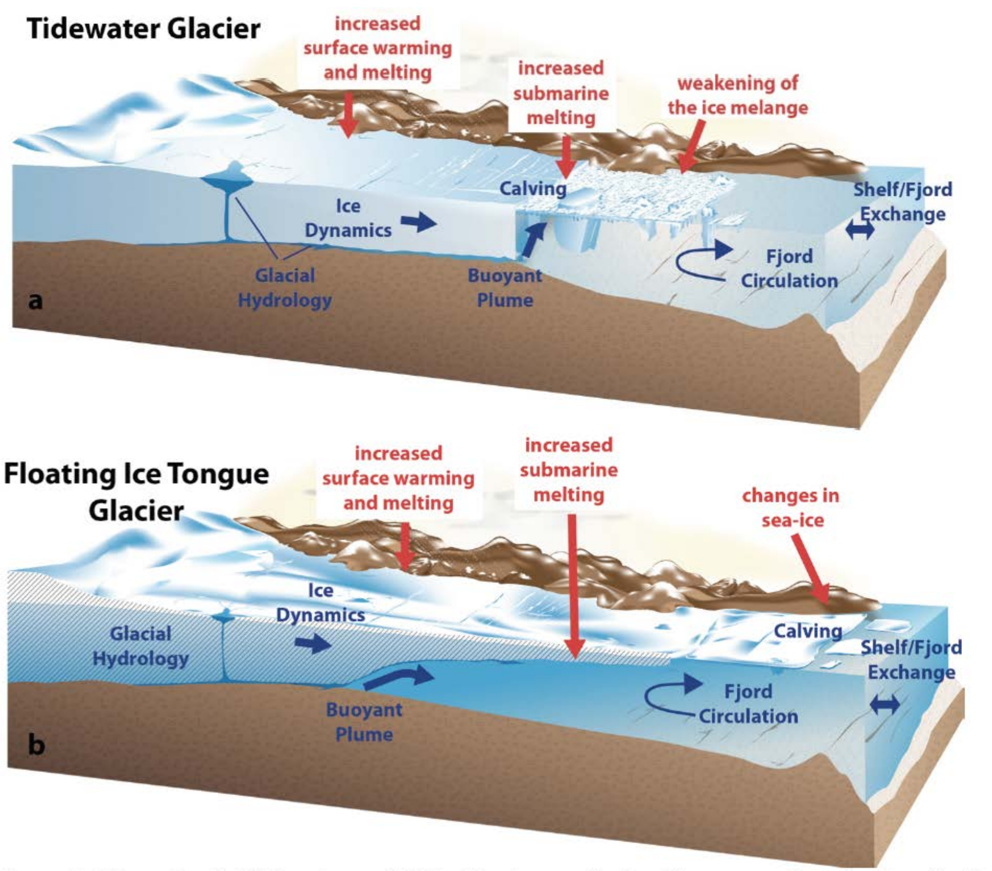


Figure 4: Schematic of a) Tidewater and b) Floating tongue Glacier. The proposed mechanisms for the glacier retreat and ensuing glacier acceleration are shown in red (section 2.3). The key processes needing to be addressed are identified in blue (section 3).

1. Surface mass balance (snowfall minus surface melt) is now reasonably well reconstructed and even projected by regional atmospheric climate models.

2. Iceberg calving (50% of loss) is poorly represented in numerical ice models because relatively un-observed.

3. Ice-ocean interactions (50% of loss) are poorly constrained by observations (ocean temperature, bathymetry, grounding line position, ice shelf melt).

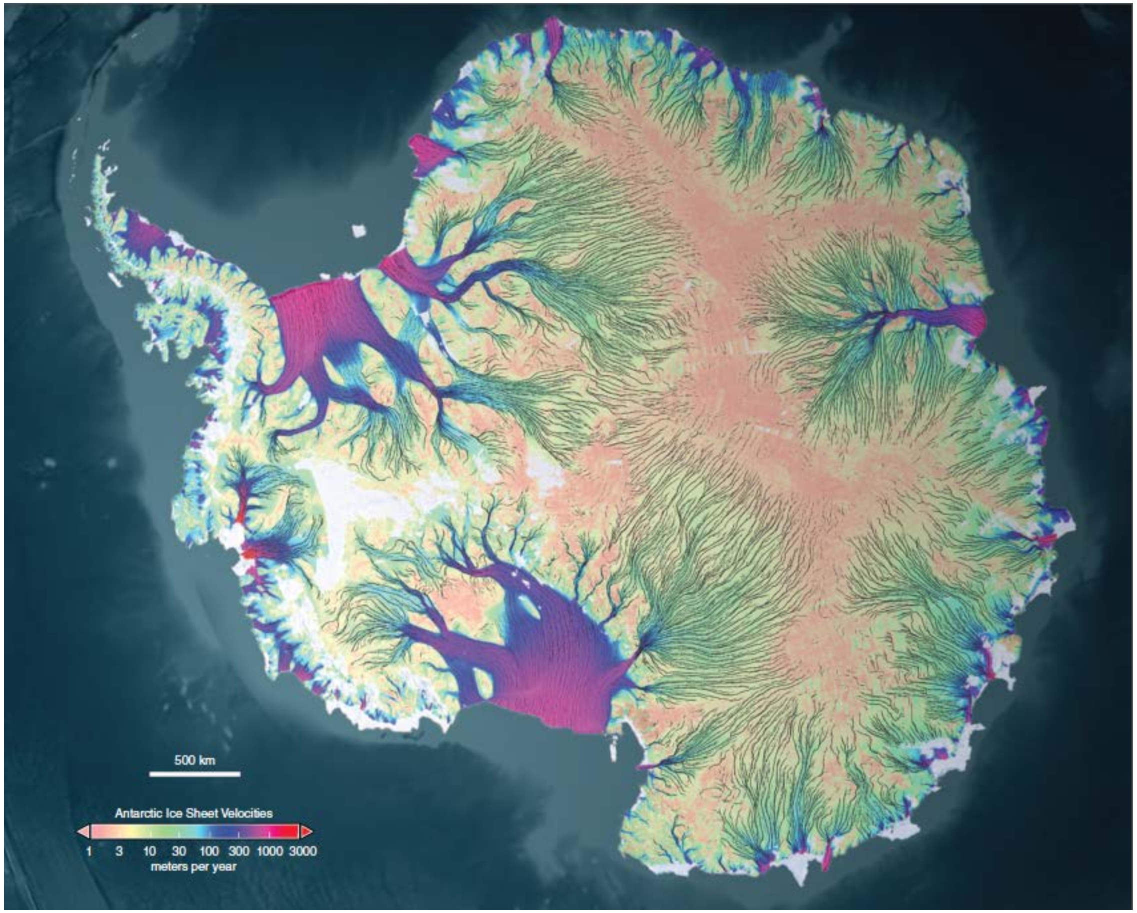
4. Basal friction is inferred (DA), but not observed; geothermal flux is un-observed.

NISAR will help 2, 3 and 4.

What NISAR does best: Observe ice dynamics

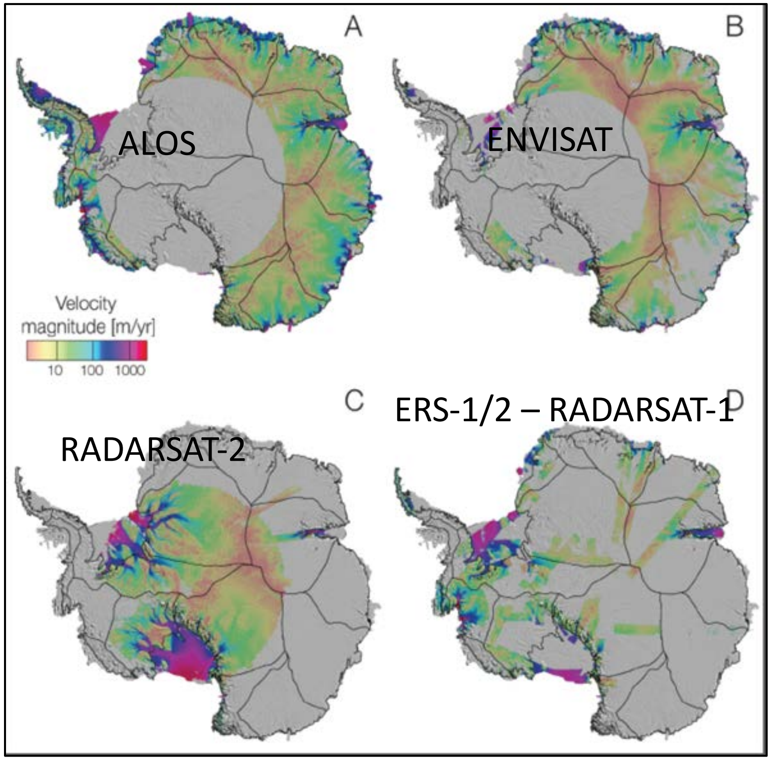
- Ice motion controls mass transport, expresses basal constraints and interactions at seaward margins, and documents the impact of climate change on ice loss.
- InSAR is the most powerful technique for observing ice dynamics.

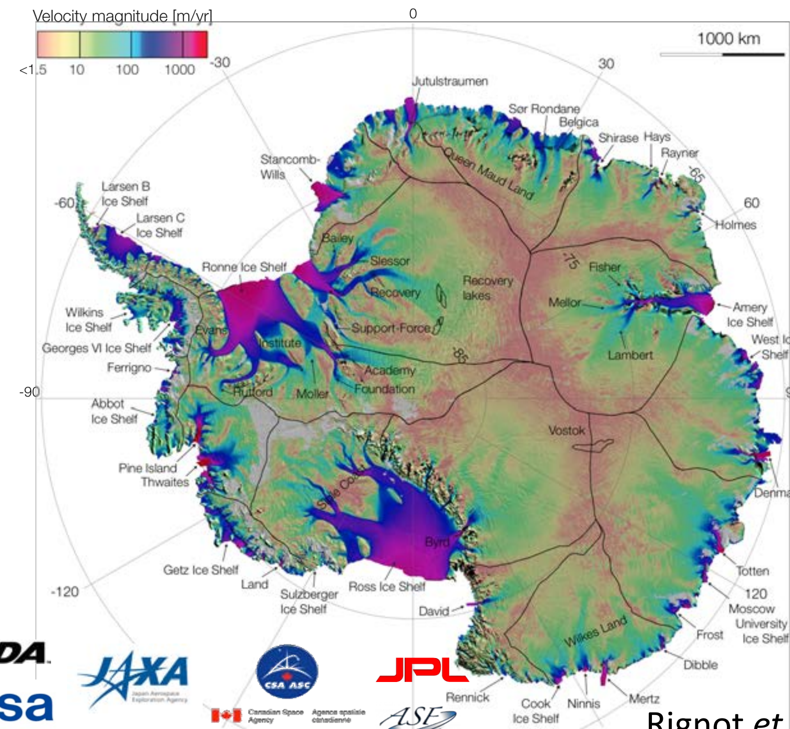
- Velocity map of Antarctica took many years of arduous work from a range of international satellites to construct
  - Error-prone
  - No time-variability of flow



Ice Velocity mapping in Antarctica

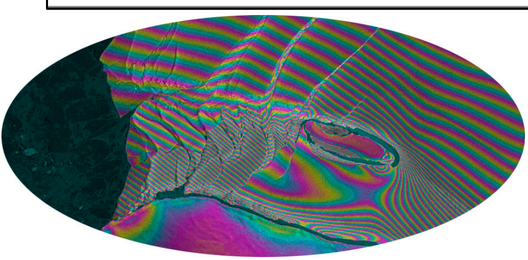
NASA - ISRO SAR Mission

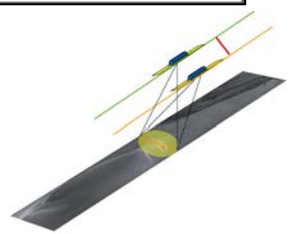




MDA esa JAXA CSA ASC Canadian Space Agency / Agence spatiale canadienne JPL ASF

Rignot *et al.*,, 2011.

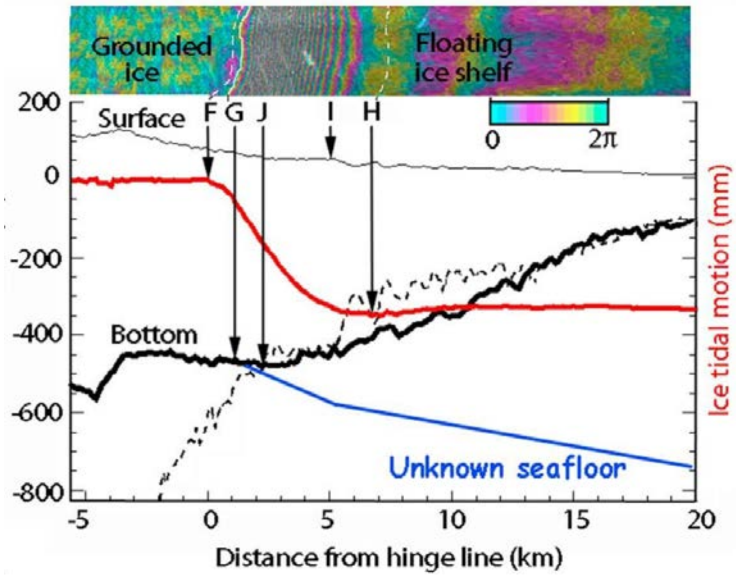


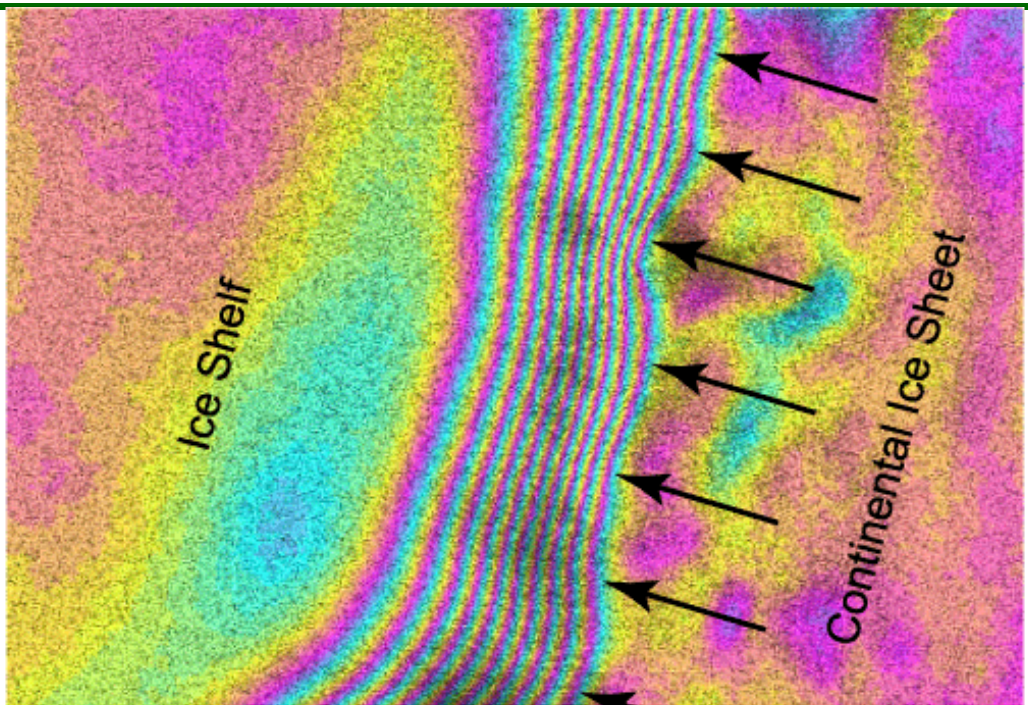


First map of Antarctic ice motion from 3 years of data, 6 satellites, 4 space agencies, 6 years of coordination.

Numerical models require time series (sub-annual) of comprehensive (no gap) ice motion on long time scales (decades) with sufficient temporal (daily) and spatial (1 ice thickness) resolution to observe glacier changes (speed up, calving, instability). This is not possible from any single SAR satellite.

NISAR will image grounding line positions: the hinge line of ongoing and future instabilities

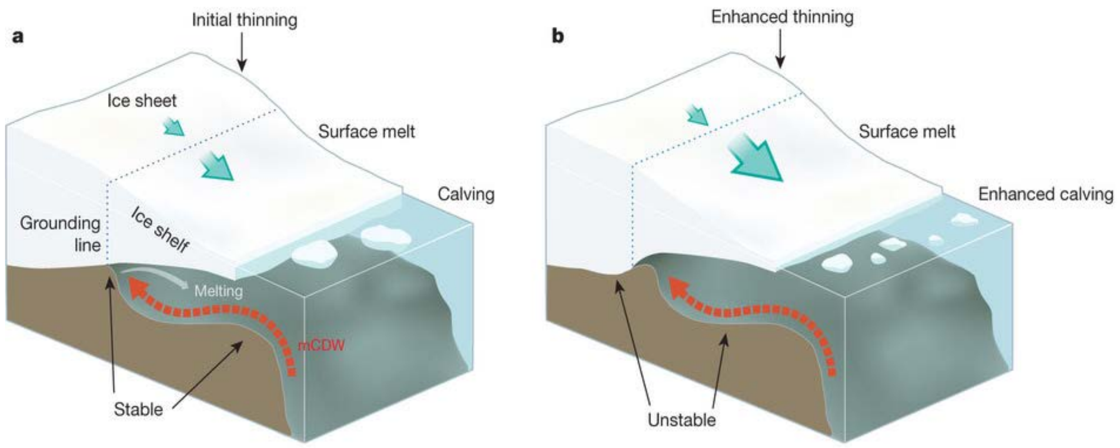




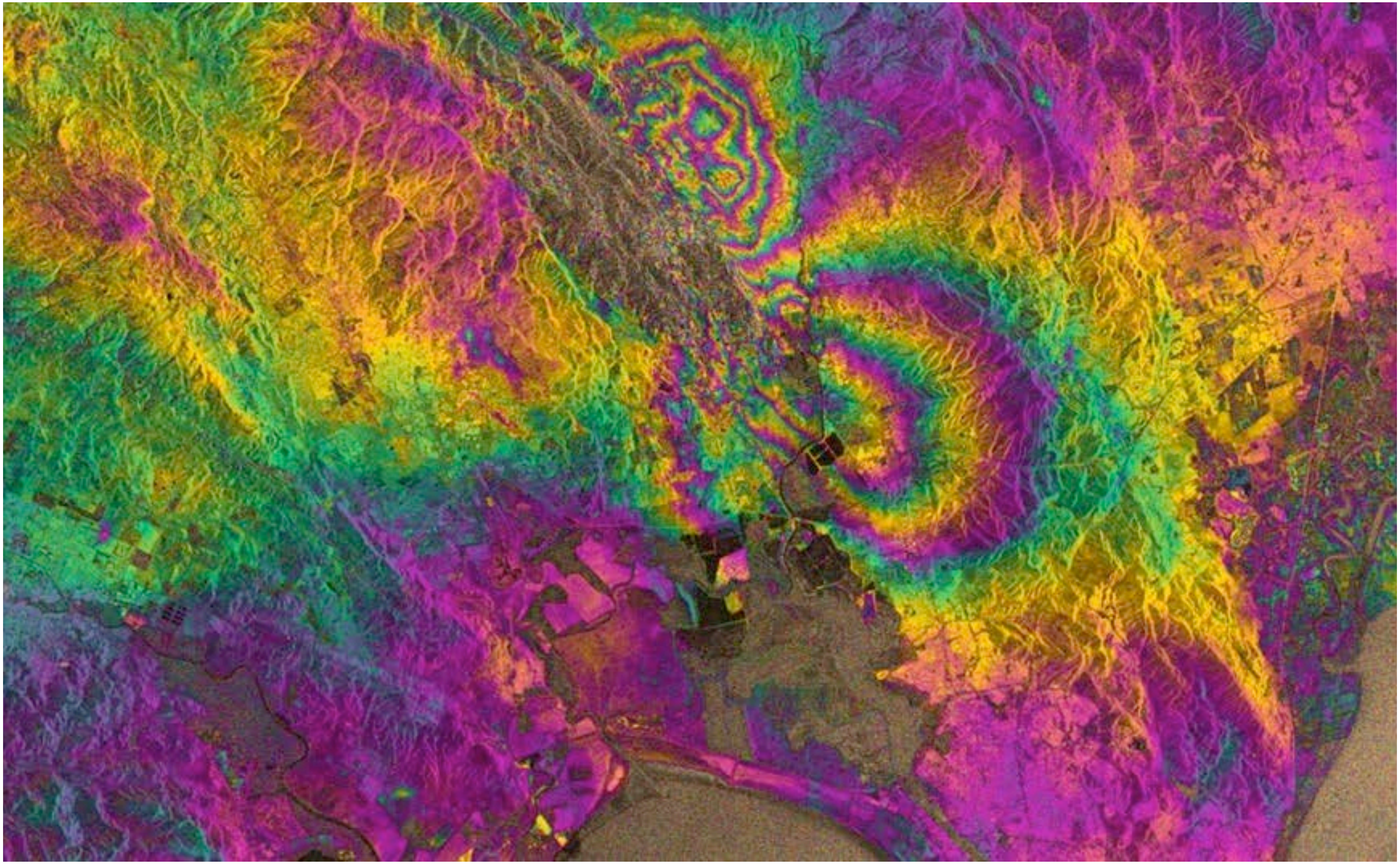
Grounding lines (G) are imaged by InSAR with 100 m horizontal precision (10 km with visible image; 1 km with laser altimetry).

Critical to know GL position for ice stream stability and modeling.

Present observations are sporadic.

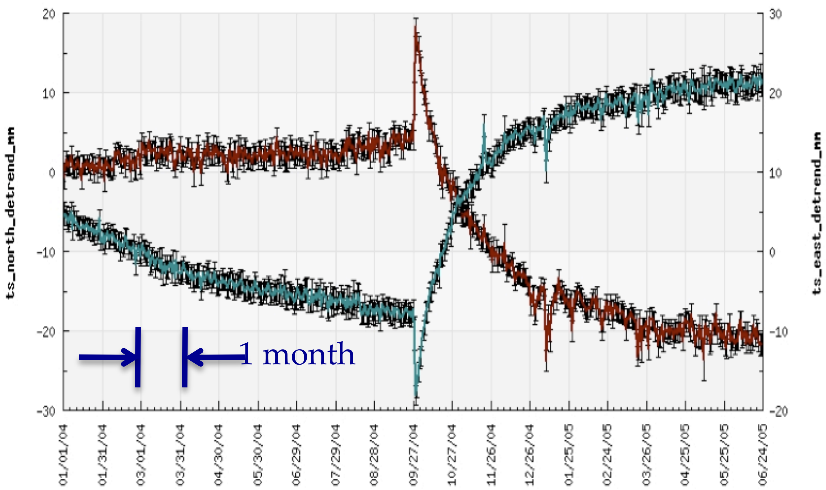


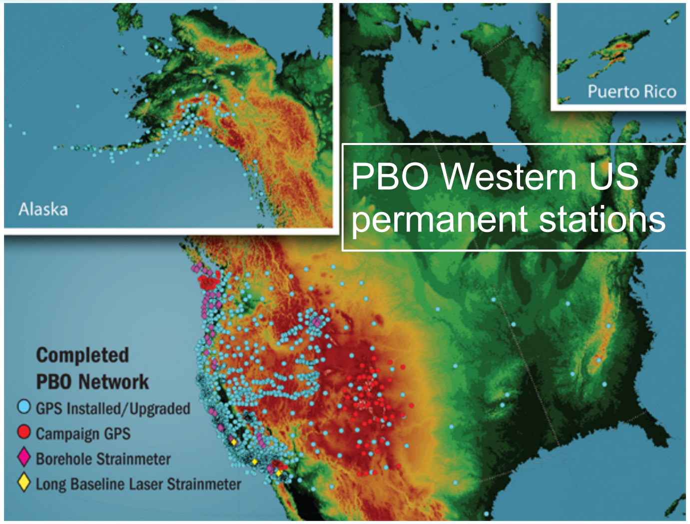
Solid Earth Deformation Science

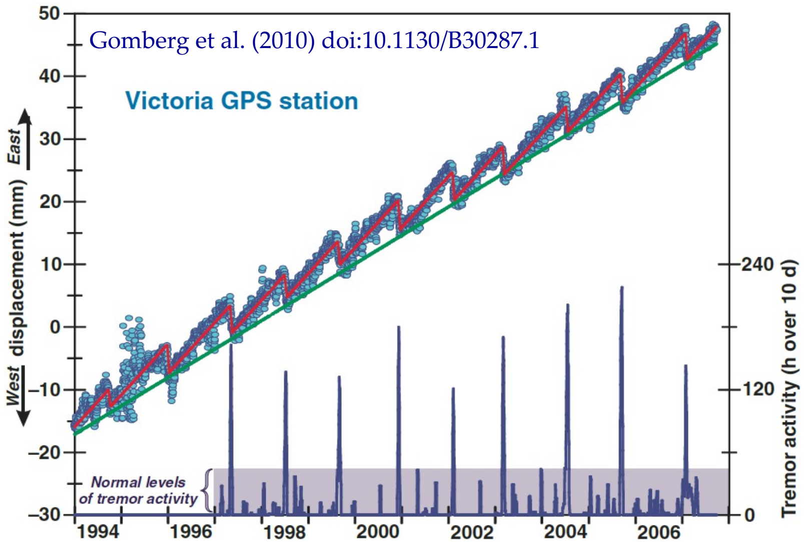


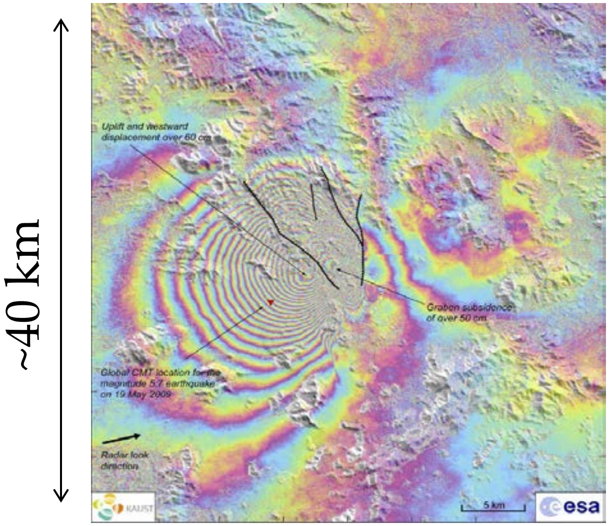
Dense Sampling in Space and Time to Understand Solid Earth Mechanisms

Parkfield CARH GPS Station



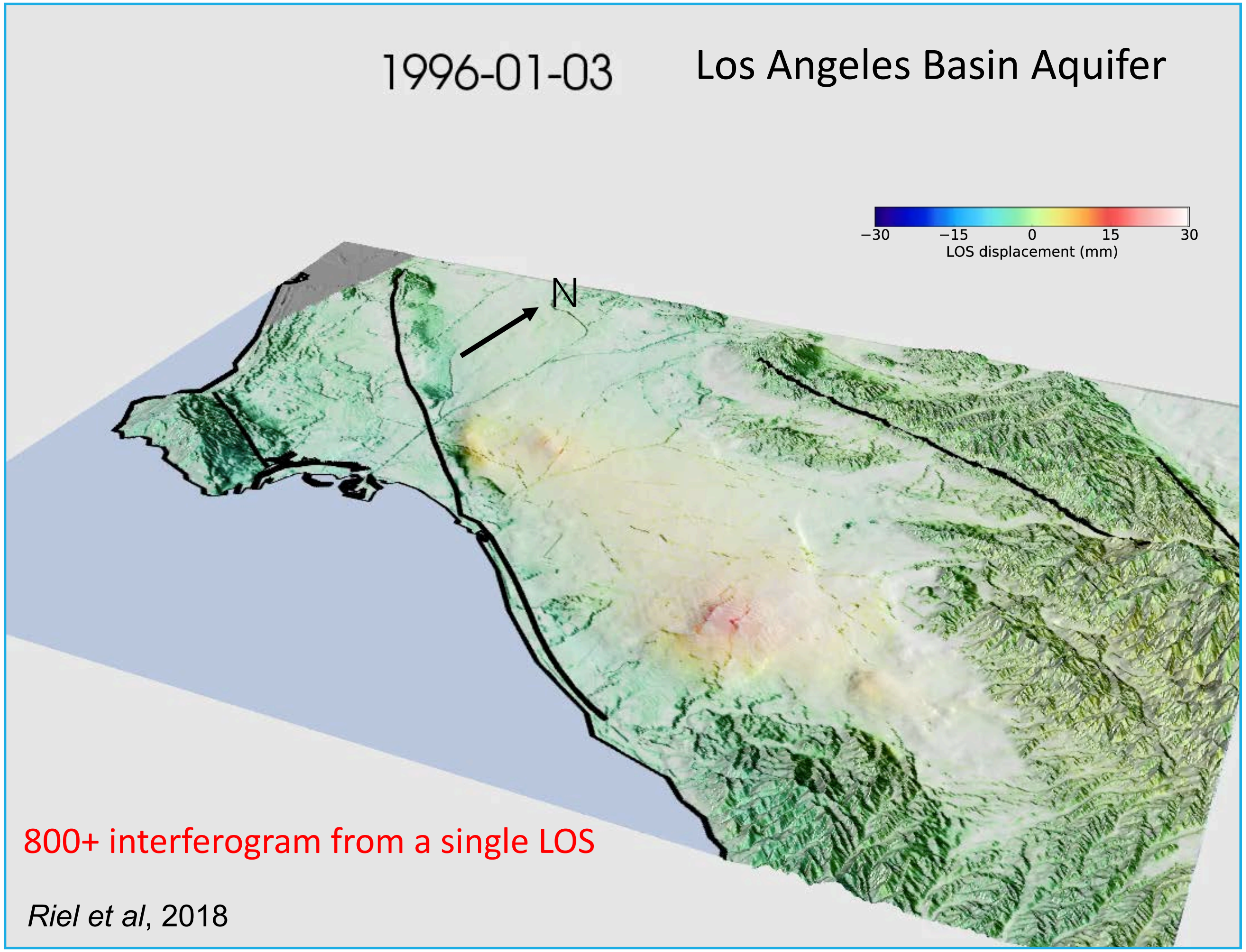






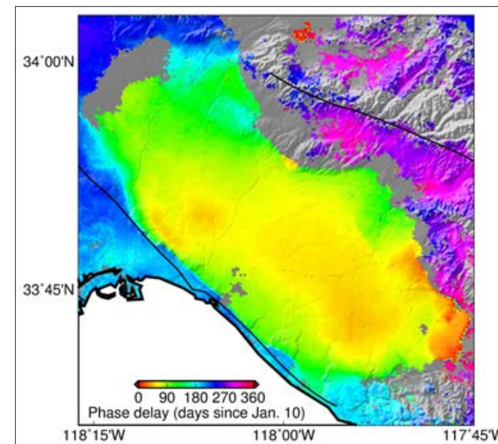
Millions of "GPS-like" points in each image frame.

Frequent temporal snapshots will reveal new processes and improve models



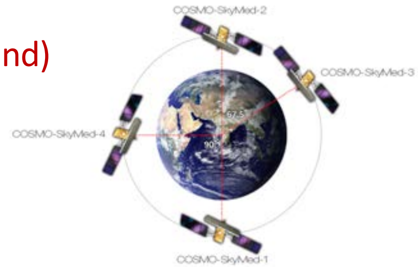
We are in the era of InSAR time series

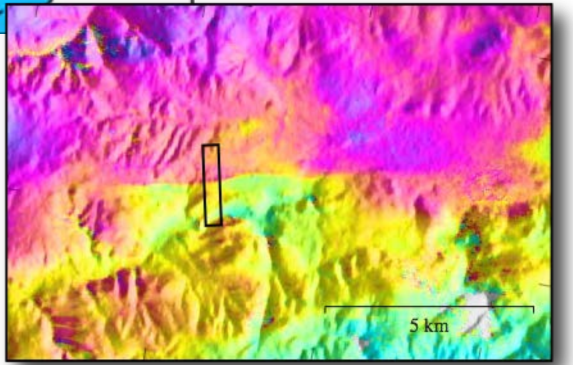
Timing of peak seasonal uplift

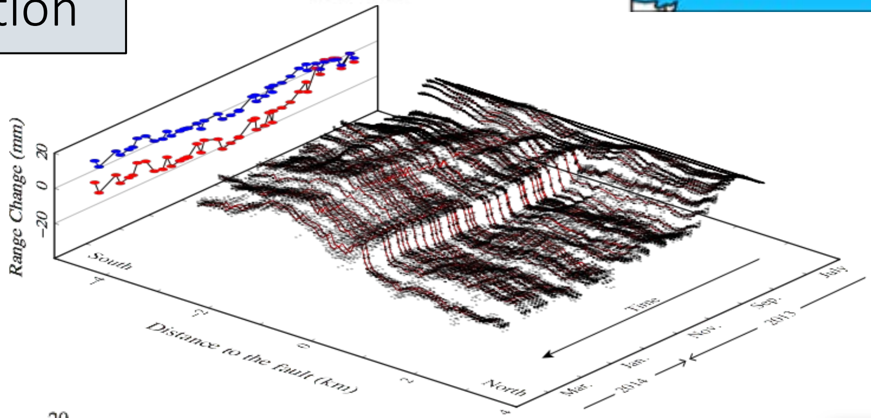


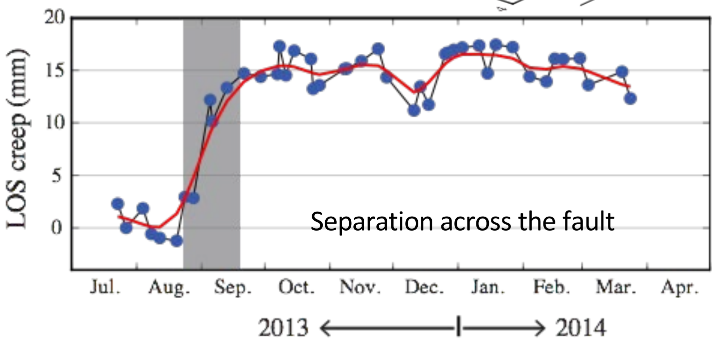
Also see:
Bawden et al., 2001
Lanari et al, 2004

Monitoring transient deformation





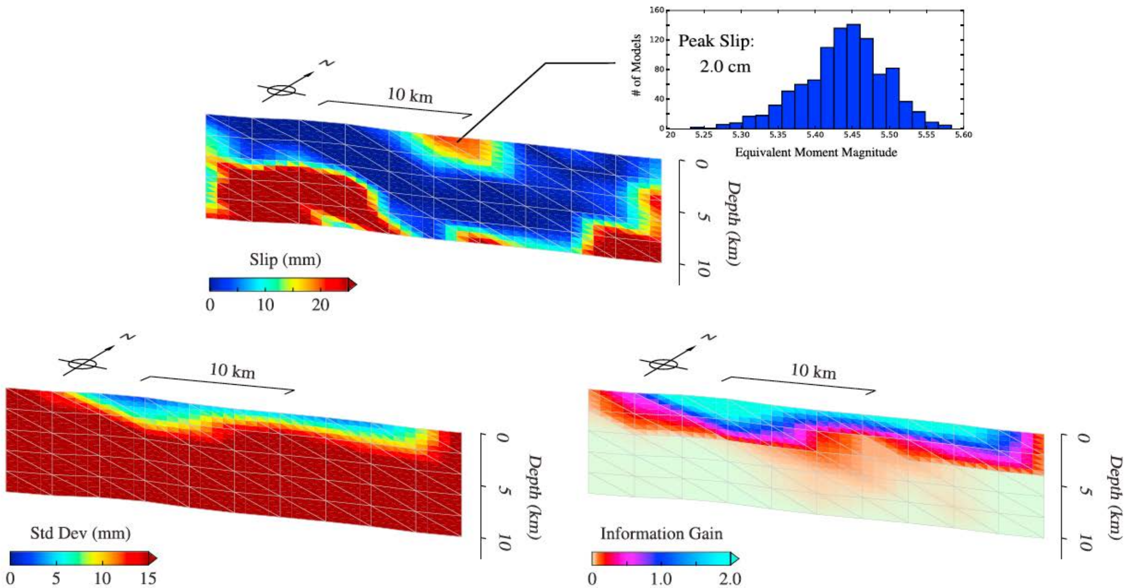




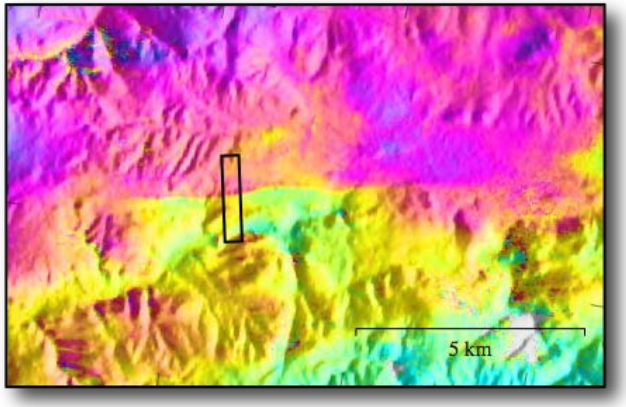
Duration: ~ 1 Month
15 mm LOS ==> 22 mm of strike slip
Equivalent to Mw 5+ or 2 years of slip
Unsteady creep confined to upper 4 km

Rousset et al., 2016

Derived subsurface fault slip model



Difference in posterior PDF and prior PDF?



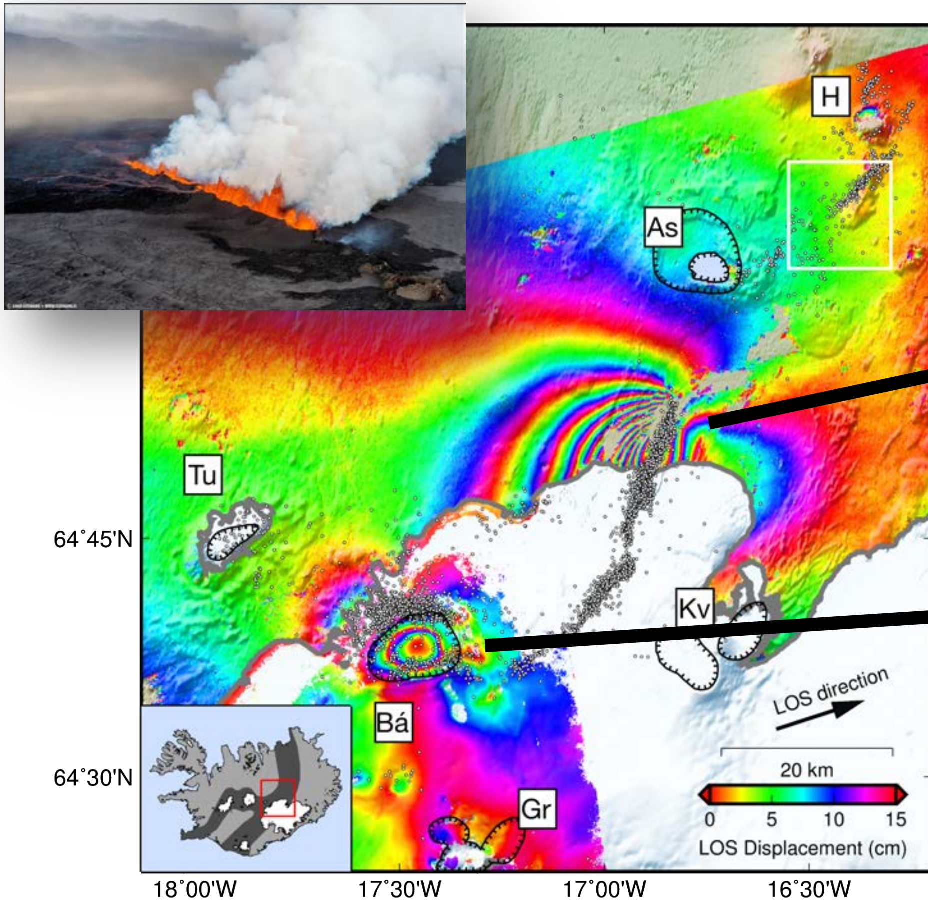
Geophysical inference limited by:

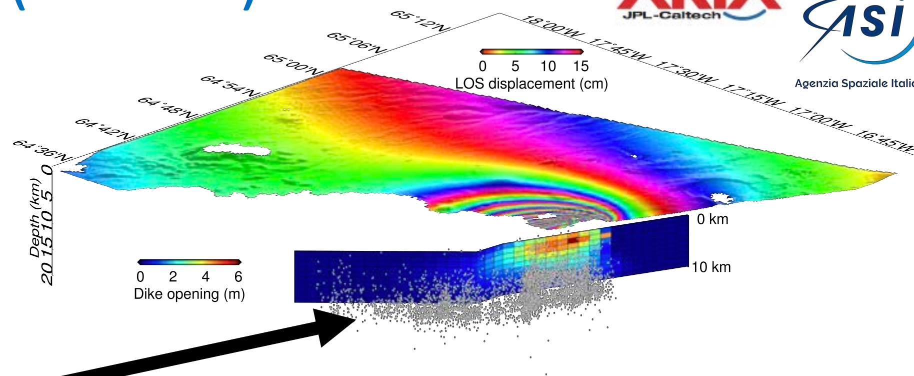
- Primarily a single LOS component
- Poor correlation
- Atmospheric noise
- Heterogeneous temporal sampling
- Need for a dedicated campaign

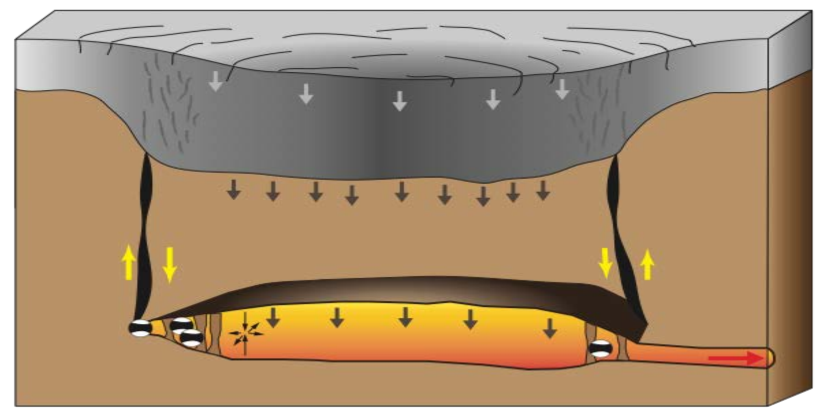
Rousset et al., 2016

Agenzia Spaziale Italiana

Caldera collapse & rifting event (Iceland)





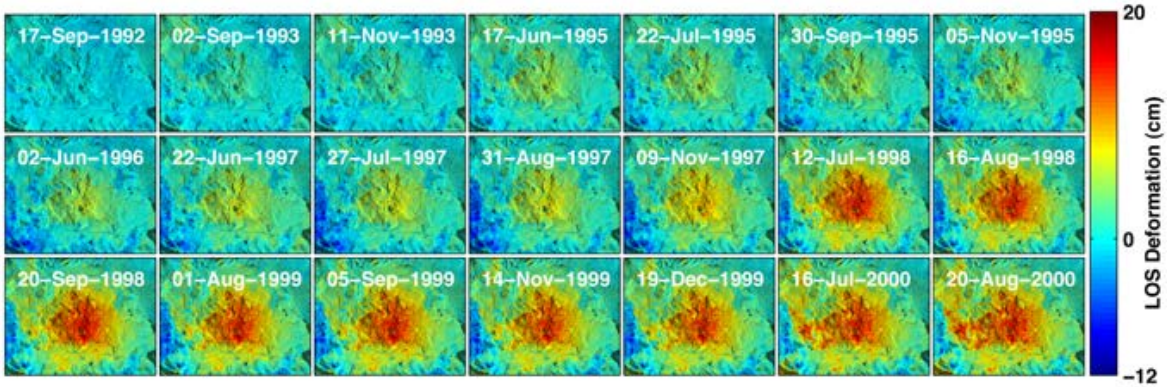


CSK (1 day) + RADARSAT 2 (24 day)

Riel et al., 2015

Time series of Deformation are Changing Our View of the Deforming Earth

- New methods for InSAR time series analysis are showing the potential of these capabilities in understanding the physics of Earth processes given the right observation conditions

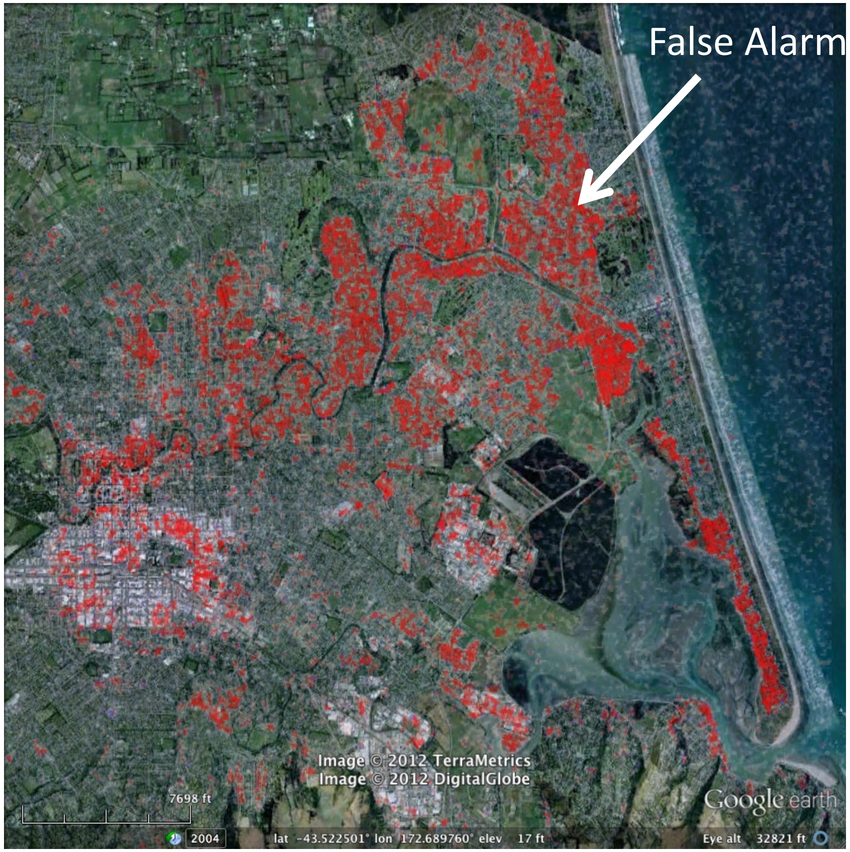


Volcano time series of deformation at Long Valley from proof of concept PS analysis

- A dedicated capability could provide major advances in quantity and quality of global events observed, properly sampled for improved modeling
  - ~100 Mw 6.5, ~30 Mw 7.0, ~10 Mw 7.5, ~3 Mw 8.0, ~1 Mw 8.5 earthquakes
  - Several tens of volcanic eruption cycles
  - Multi-scale images of strain accumulation along all major faults on Earth

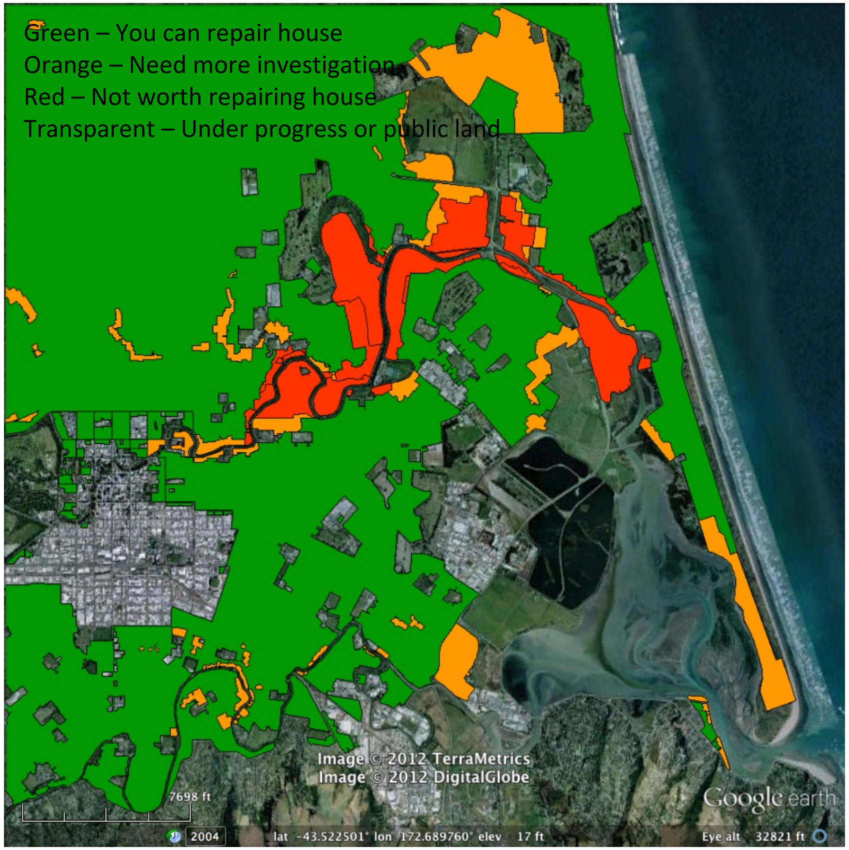
Damage Proxy Map vs Ground Truth

From radar data acquired **3 days** after EQ



Damage Proxy Map (ALOS PALSAR A335):
2010.10.10 – 2011.01.10 – 2011.02.25
Google Earth (GeoEye) Image: 2011.02.26

Zone Map first released **4 months** after EQ



2011.06.22 version
Data provided by the New Zealand Government
http://data.govt.nz

NISAR
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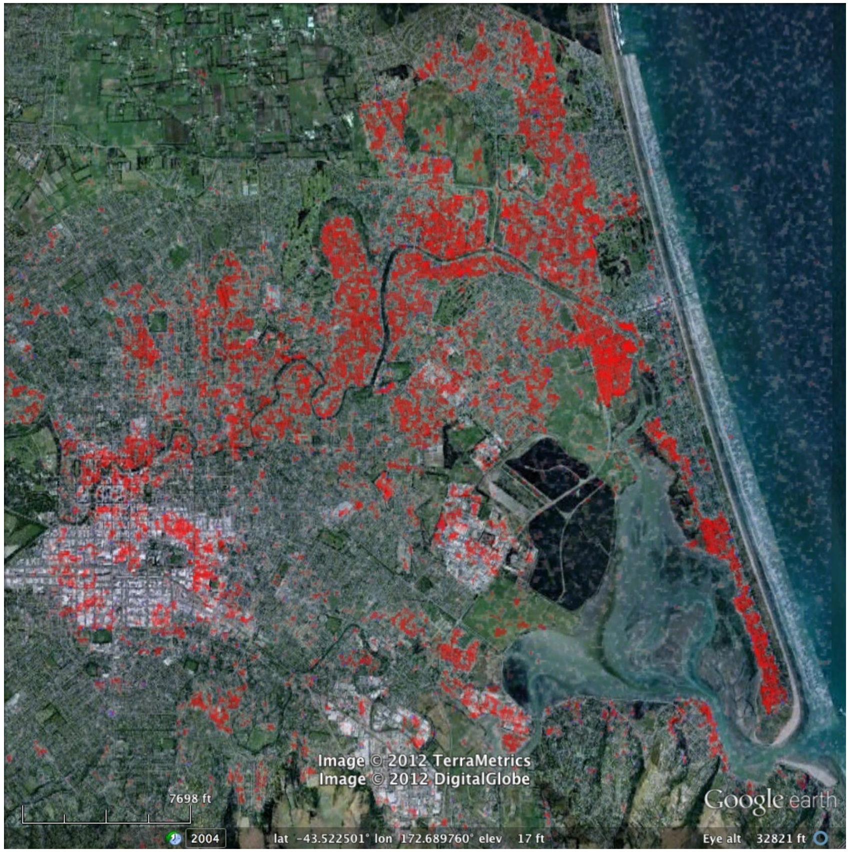
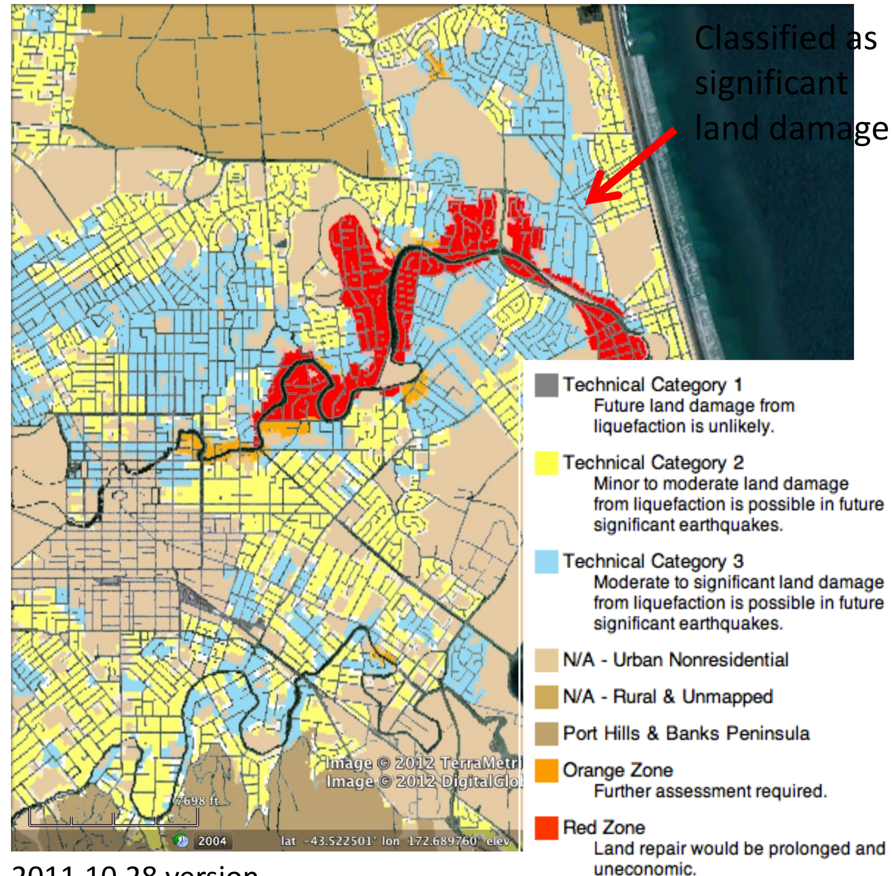
Damage Proxy Map vs Ground Truth

From radar data acquired **3 days** after EQ



Damage Proxy Map (ALOS PALSAR A335):
2010.10.10 – 2011.01.10 – 2011.02.25
Google Earth (GeoEye) Image: 2011.02.26

Technical Classification Map first released **8 months** after EQ



2011.10.28 version
Data provided by the New Zealand Government
http://data.govt.nz