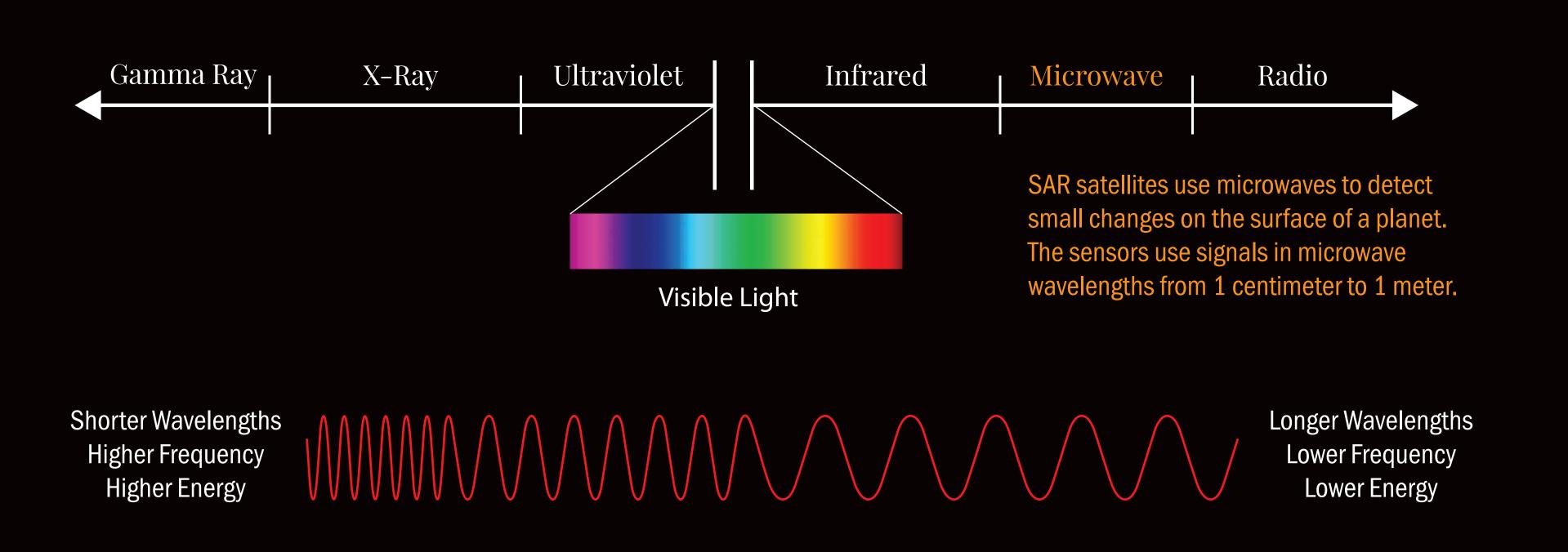
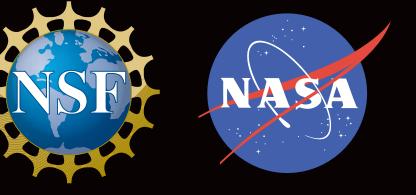
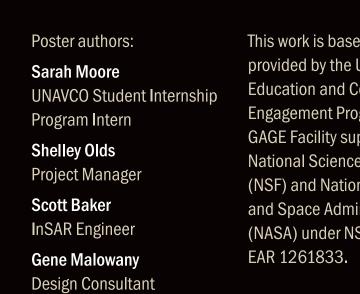
Interferometric Synthetic Aperture Radar: A remote sensing tool for measuring Earth's surface deformation

n Interferometric [uses wave interference]

InSAR is a remote sensing geodetic technique for measuring topography and deformation using Synthetic Aperture Radar (SAR) satellites. InSAR is used to measure surface change from multiple types of processes such as: volcanic deformation, earthquakes, landslides, fluid extraction from oil, gas and groundwater pumping, glacier motion, ice loss, and many other processes.

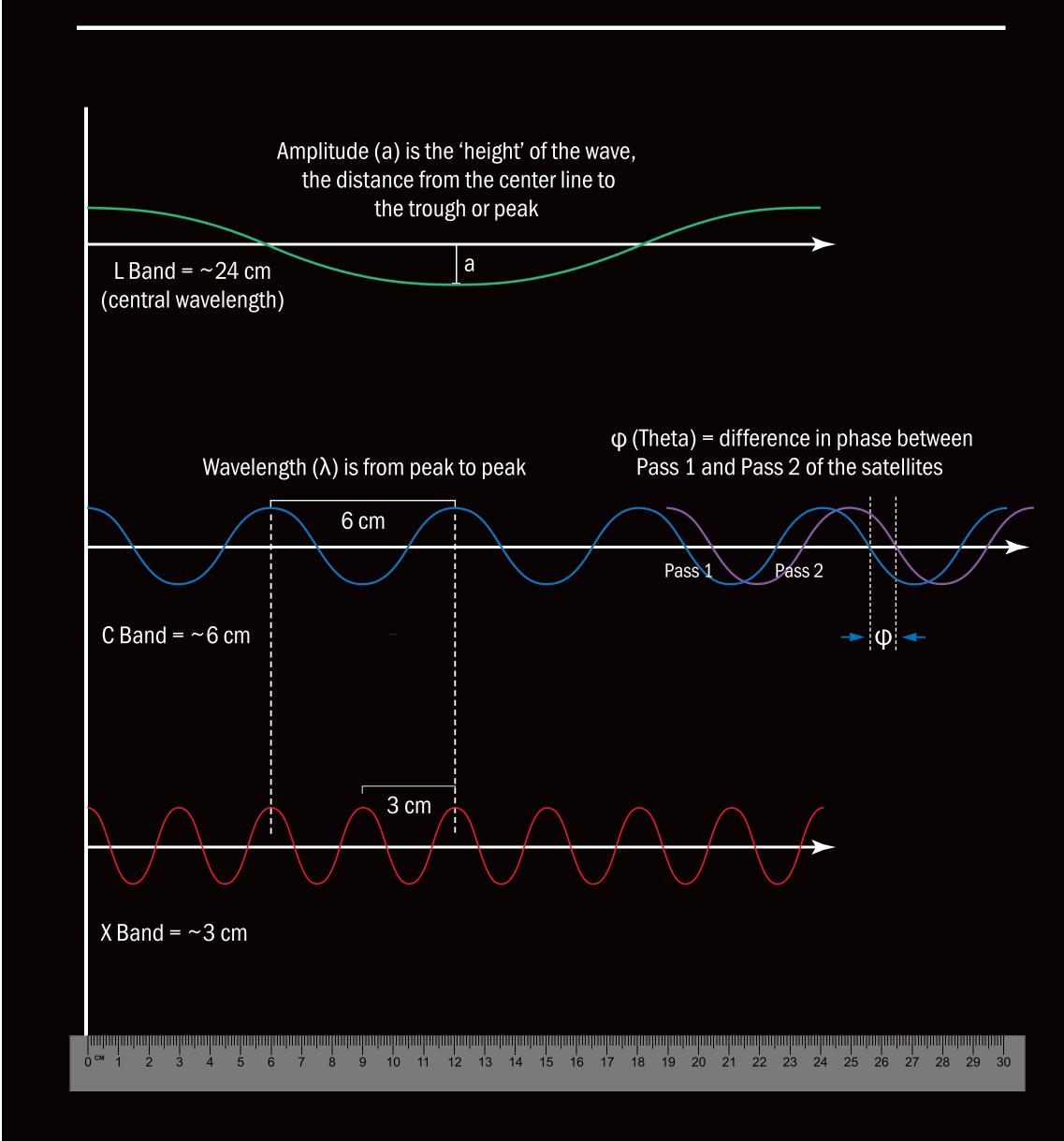




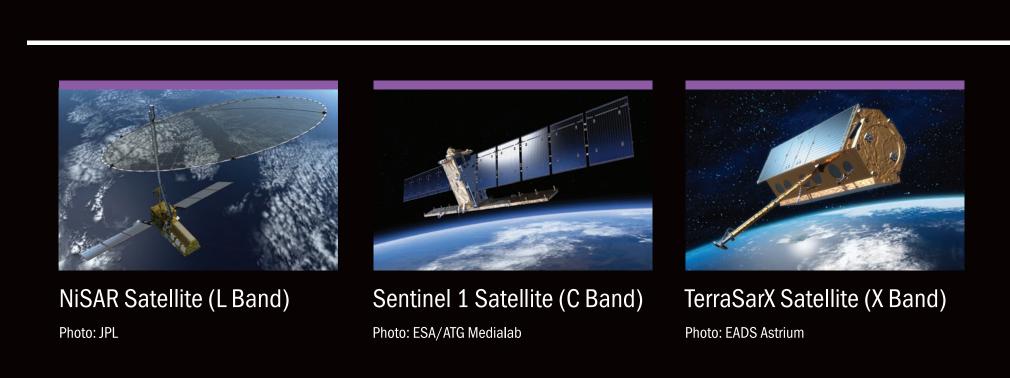


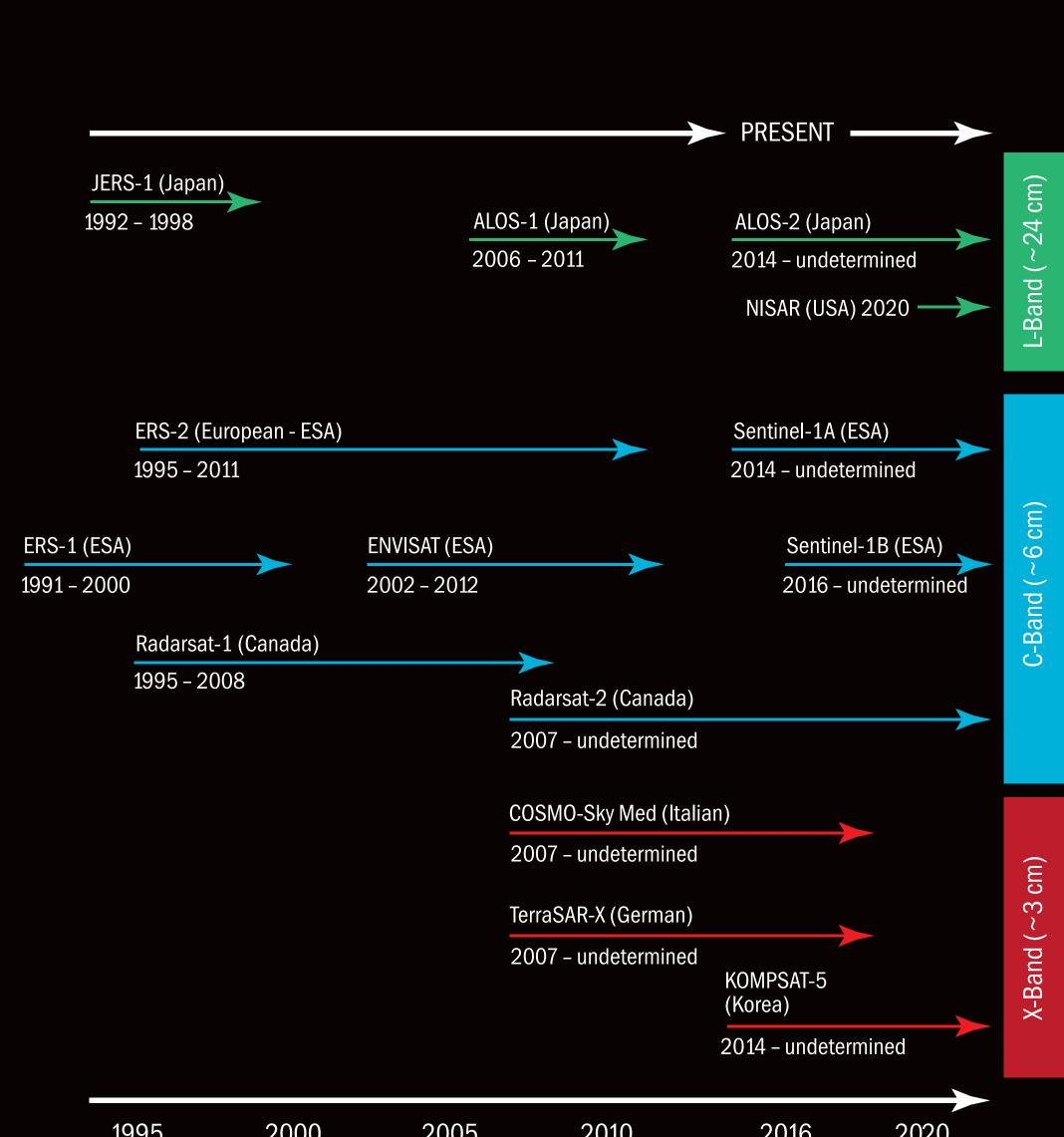


Different wavelengths provide different levels of detail.



SAR Satellites Over Time



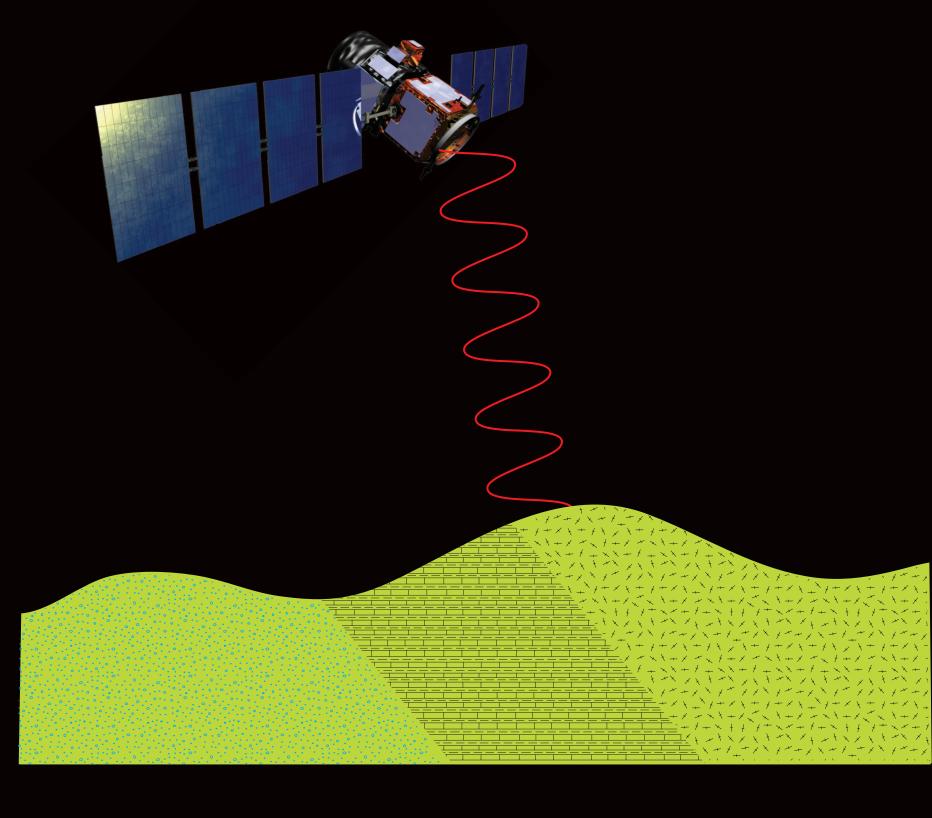


How does InSAR detect changes in the landscape?

Multiple satellites passes are needed to measure changes.

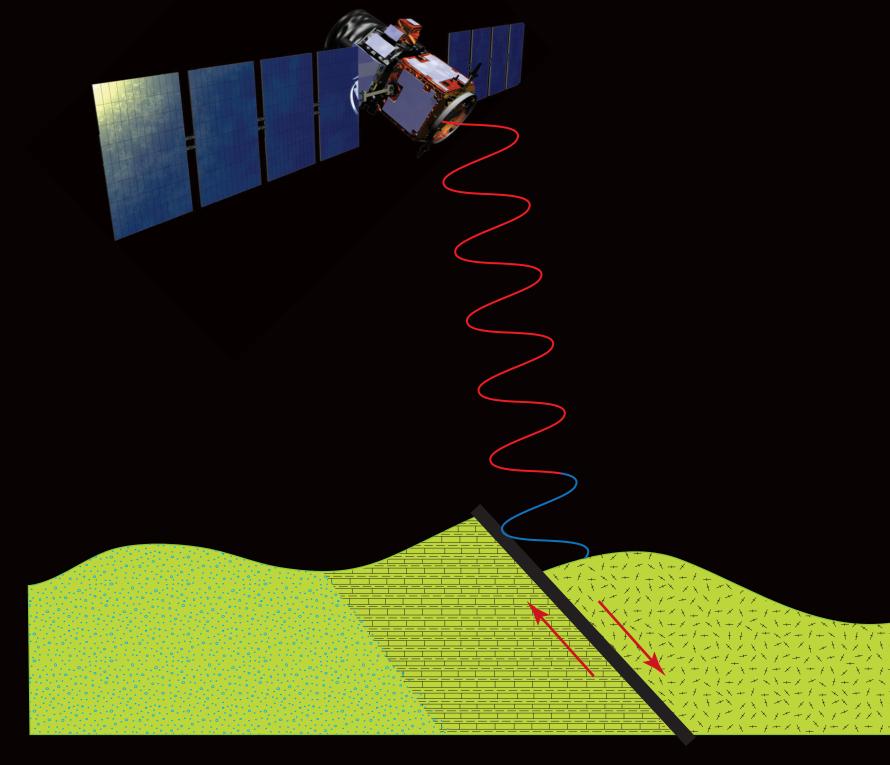
(April 6, 2009 L'Aquila, Italy Earthquake, Mw 6.3)

Satellite Pass #1 — April 27, 2008



- The SAR satellite emits a microwave signal (in red above) then receives the reflected signal from the surface of the planet (or other object).
- Distance is measured by the time it takes for the signal to reach the surface and reflect back.
- > The phase of the return wave depends on the distance to the ground and will consist of a number of whole wavelengths plus some fraction of a wavelength.
- Phase is a particular point in the cycle of the wave.
- Because the satellite produces the transmitted wave, the phase is known, and can be compared to the phase of

Satellite Pass #2 — April 12, 2009



- After an event that deforms the surface of the earth (such as an earthquake or volcanic eruption), the SAR satellite passes over the same spot and collects another image (the change is depicted with the blue line above.)
- The satellite data (time and phase) from before and after the event are compared.
- The interferogram is created by subtracting the phase differences from the first pass and the second pass; and the resulting color fringes depict the distance the ground moved. The full color fringe is called the interferometric
- In this example, the second pass of the satellite measures a longer path length (shown in blue) to the same surface, which indicates that the ground has moved away from the satellite.
- InSAR scientists call this motion positive because the path length has increased between the satellite and surface.

What is an interferogram and how is it read?

The number of fringes and color sequence tells the story of deformation.

Sentinel-1A Path 128 Tops Mode

2015/05/06 - 2015/06/23

L. The scale represented by the fringe is 3 cm (half of

2. Movement starts near this purple-blue border.

Reading the fringe color sequence, the color spectrum goes from purple to red indicating a

3. Approximately 7 to 8 fringes; total of 21 to 23 cm of deflation.

Sentinel-1A's central wavelength.

downward, or deflationary, motion.

Interpreting an Interferogram

Parts of Interferometric Phase

The interferometric phase is the difference in the distance to the ground between two passes. This difference is depicted on an InSAR image as color ringes. One fringe is one cycle of the spectrum colors from purple to red. The displacement represented by one color fringe (scale shown below the InSAR images) is half the wavelength of the band of the SAR instrument. The total displacement is calculated by counting the number of color fringes multiplied by

Galapagos Islands – May 6, 2015 to June 23, 2015

Volcanic Caldera

Ground is moving away from the satellite, e.g. deflation. >>>>

<><< Ground is moving toward the satellite, e.g. inflation.

Sierra Negra Volcano

	:	•	
Deformation	Topographic	Baseline (orbital)	Error and
is the surface	phase	phase	atmospheric
change that	contribution	contribution can	effects can be
occurred	can be	be removed with	partially remove
between the two	removed.	knowledge of	through local
SAR acquisitions.		satellite orbits.	tropospheric

Determine the scale represented by each color fringe on the interferogram.

- First identify the SAR satellite and the band used. Divide the central wavelength of the band in half. Example using the Galapagos Islands image:
- The satellite is Sentinel-1A, and uses the C Band. The central wavelength = 6 cm. Half-wavelength is 3 cm. The scale should go from 0 to 3 cm.
- 2 Determine sense of motion shown in the interferogram. Look at the color sequence from the outside edge where the color fringe begins to the center of the fringe pattern.
 - If the fringe color sequence goes through the spectrum of colors from purple to red, the ground has moved away from the satellite indicating that the ground has moved down for volcanic deformation (a positive phase change).
 - If the fringes goes through the spectrum of colors from red to purple, the ground the movement is toward the satellite indicating that the distance between the ground and the satellite has decreased (a negative phase change). In this example, the fringe goes from purple to red and the ground has moved down through deflation.

3 Determine the total displacement.

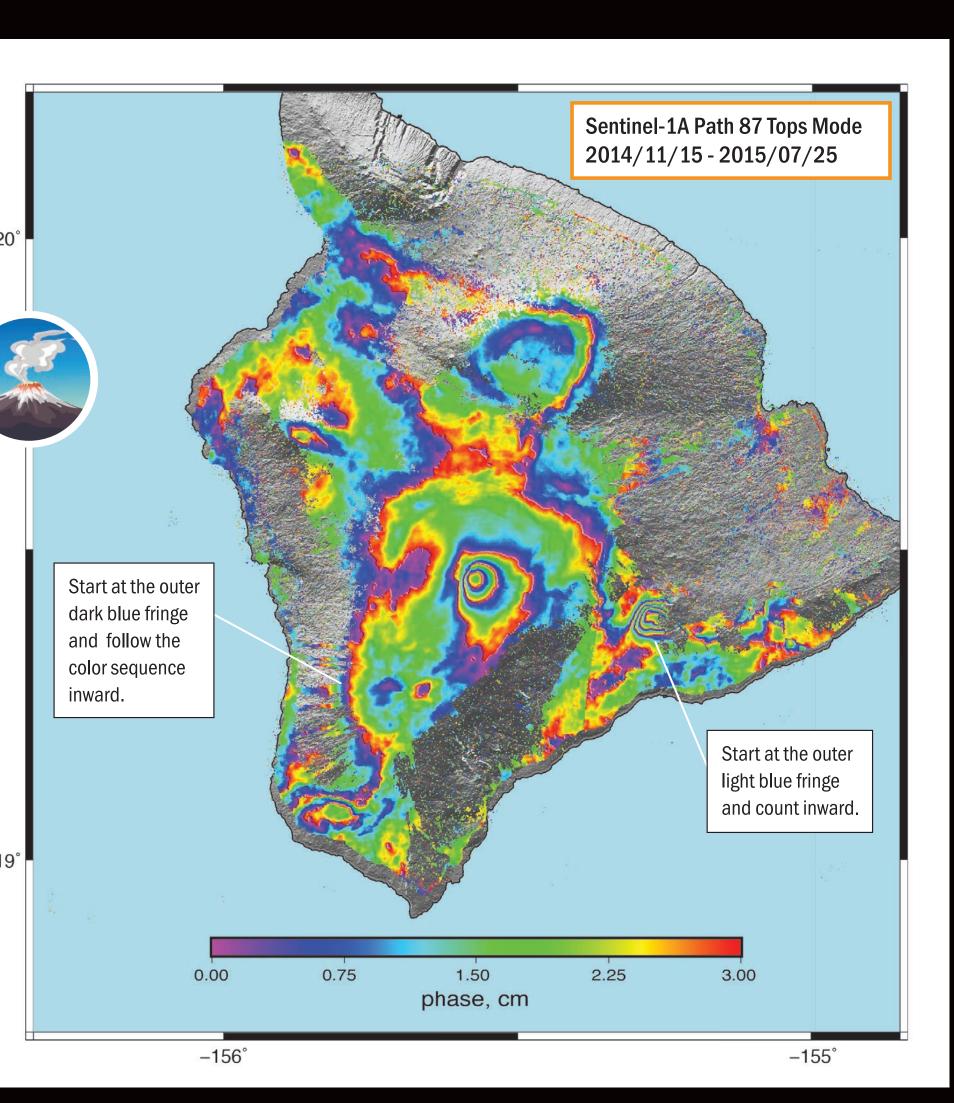
Count the total number of color fringes from the label, Movement starts near ..." to the top of volcano and multiply by the scale. There are approximately 7 1/3 fringes, indicating ~ 21 to 23 cm of motion.

4 Interpret the results:

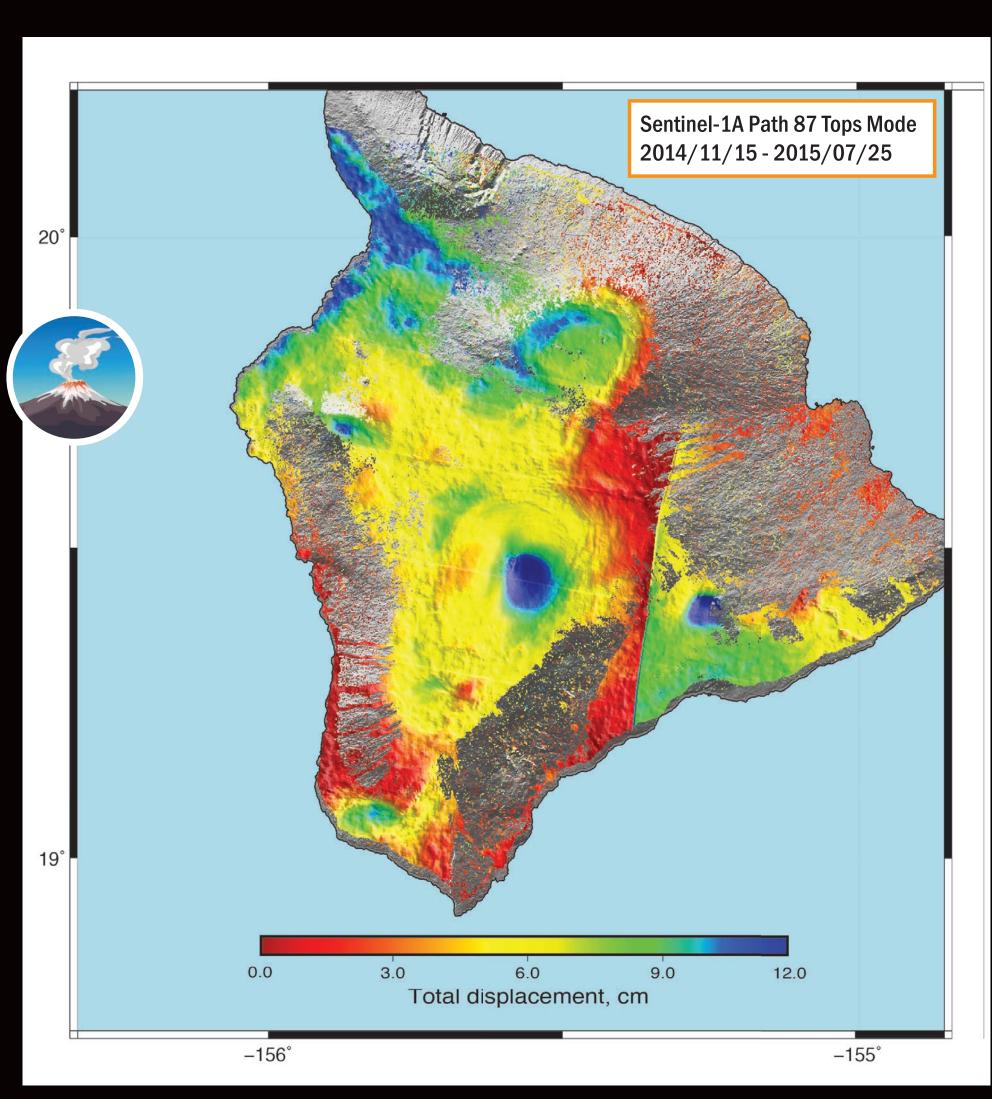
The northernmost set of fringes are around Wolf Volcano on the Galapagos Islands. Since the motion of the ground has moved away from the satellite (positive), this is a deflation event after an eruption.

Examples of Wrapped and Unwrapped interferograms

Hawaii Inflation Event, November 15, 2014 to July 25,2015



ams show deformation as multiple color sequences. For both volcanoes in this image, the spectrum of colors goes from red to purple indicating the ground is moving toward the satellite (inflation). The central volcano inflated approximately 12 cm.



Jnwrapped Interferograms show total displacement of deformation in the satellite's line of sight. An unwrapped interferogram is created by adding the fringes together from the wrapped interferogram. The total inflation of the central volcano is approximately 12 cm, agreeing with the findings of the wrapped interferogram.

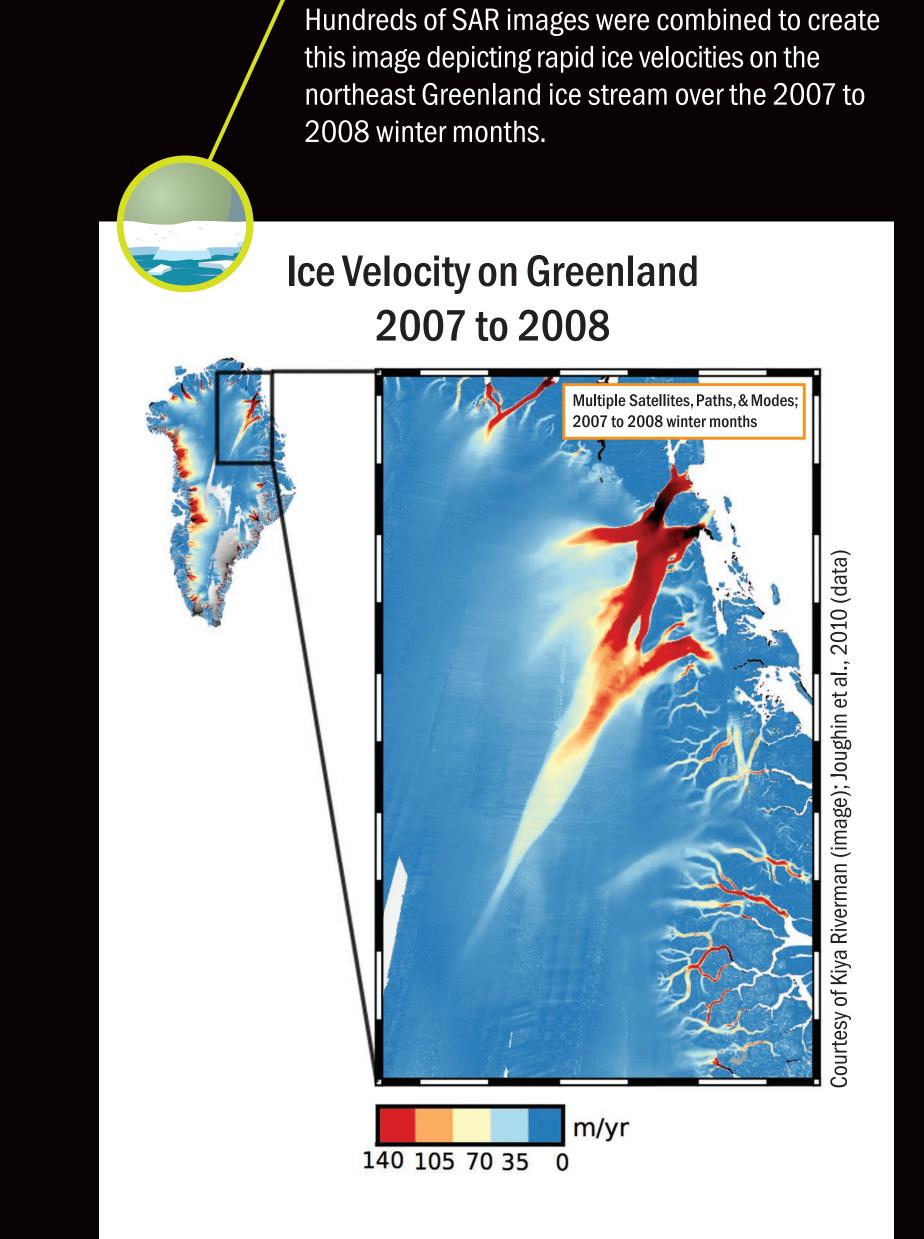
Palm Springs, California Subsidence Nepal Earthquake, Mw = 7.8 April 25, 2015 2007 to 2011 ALOS-2 Path 166 PALSAR Mode 2007/06/01 - 2011/06/01 Movement approximately starts along the blue-green border the light blue. Working through red through the spectrum back to blue. Center of subsidence in Coachella Valley. fringes, totaling \sim 80 cm Start at the light blue. Working inwards, the colors change to deep blue then continue from There are approximately 9 fringes = 104 cm upward displacement. Salton Sea

the India plate and the Eurasia plate to the north. The InSAR approximately 7 - 10 cm over a four year period interferogram shows a typical 'butterfly' pattern. In this image (2007 to 2011) due to groundwater pumping in the the southern side of the fault moved up and the northern Coachella Valley. side moved down.

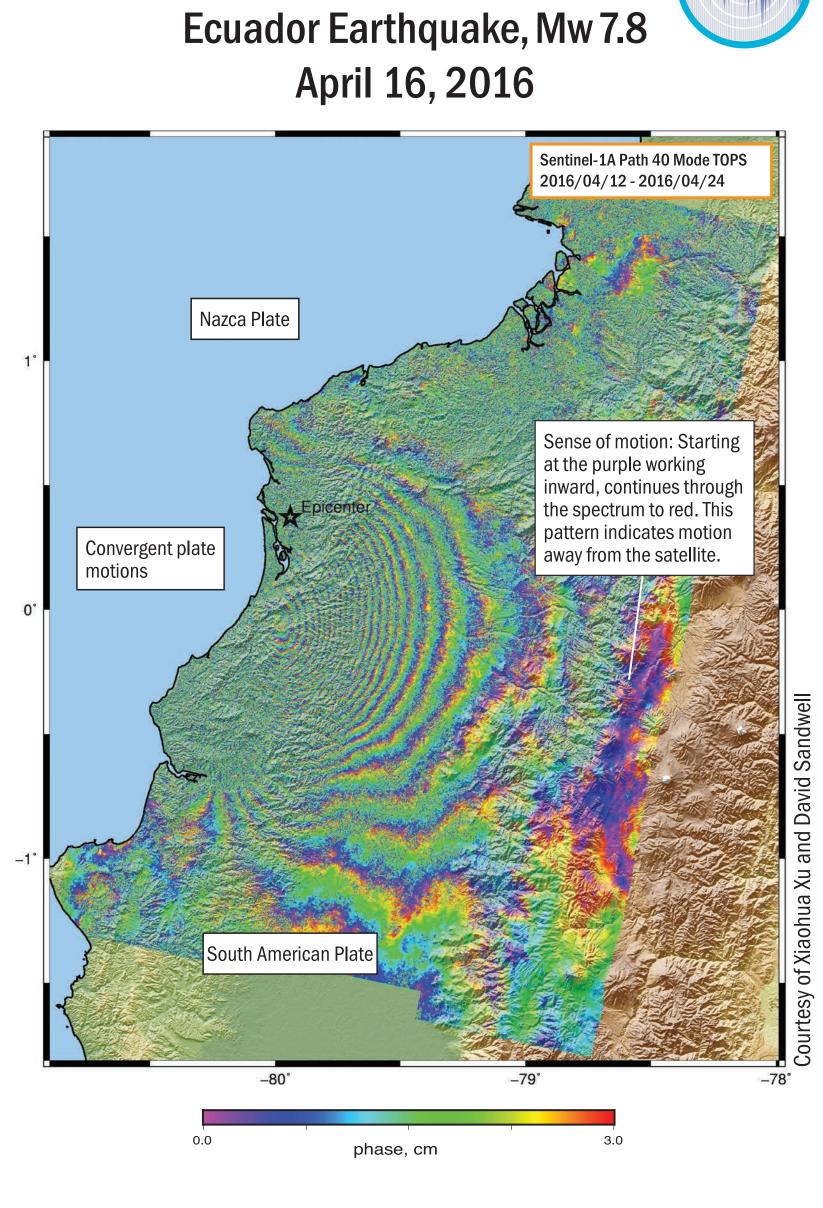
2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |

The earthquake was the result of shallow thrust faulting between the Nazca plate and the South America plate. The land imaged here moved away from the satellite due to the earthquake. As a result of the earthquake, a damaging tsunami caused 500-1,500 fatalities in the region.

The Nepal earthquake was the result of thrust faulting between



The Palm Springs, California region has subsided





Radar