Slide 1 – Title Slide

Hello and welcome to Week 4, Part 4 of EGM703: Applications of InSAR. In this lesson, we'll learn about a number of different scientific applications of InSAR.

Slide 2 – Applications of InSAR

One of the main applications of InSAR, for topographic mapping, is not something that we're going to cover here. Instead, we'll focus on applications that look at monitoring deformation or surface motion due to different causes, including groundwater depletion, volcanology, earthquakes, landslides, and glaciers.

Slide 3 – Groundwater pumping

Pumping groundwater out of (or into) underground aquifers for different uses can actually cause the ground to move up or down – in some cases, this actually obscures the seismic signal visible in the InSAR deformation. This study from 2001 shows the seasonal elevation changes in Los Angeles as a result of groundwater pumping and replenishment, using a series of ERS images. In the top interferograms, we see patterns of basin uplift up to 34mm in the satellite's line of sight during fall and winter months; in the bottom two, we see basin subsidence of up to 60 mm during summer months. While the changes observed are very small – less than a decimeter – dInSAR is sensitive to these small changes.

Slide 4 – Volcanology

When magma moves in the "plumbing" underneath a volcano, it causes ground deformation that can be measured using dInSAR techniques. These movements can potentially be indicative of eruptions, so InSAR is an important component of monitoring volcanic activity. When we observe motion using InSAR, for example shown here in the interferograms on the left side of this figure, we can use inverse models to infer the source mechanism and characteristics that led to the observed deformation – the "clean" interferograms on the right show the "best fit" model parameters that produced the simulated interferogram shown. There are a few example studies shown on this slide, and included in the links at the end of the lesson – on the top here, we see an example of an InSAR study of the earthquake "swarm" that occurred at Akutan Volcano in the Aleutian Islands, Alaska, in 1996. Over 3000 earthquakes were observed using temporary seismic stations on the island – though individually small, the cumulative effect of these earthquakes was approximately equivalent to a single magnitude 6 earthquake. Despite the number of cumulative power of these earthquakes, the deformation associated with the swarm did not lead to an eruption.

The second example comes from a 1995 study by Massonet et al., demonstrating the ability of ERS InSAR data to observe deformation caused during an eruption of Etna volcano, Italy, that lasted from 1991 to 1993.

Slide 5 – A word of caution

As we discussed in the lesson about the principles of InSAR, we need to be mindful of the potential limitations of InSAR – especially when it comes to atmospheric effects. As we have seen, atmospheric delays lead to a change in the phase measured by the sensor: either due to variations in humidity, temperature, or pressure; or related to elevation as a result of vertical stratification in the atmosphere. If we don't properly account for and correct these effects, our analysis can lead to incorrect interpretations – in this case, a 2020 study claimed to see a "precusor" deflation event before a fatal 2019 eruption at Whakaari/White Island, New Zealand. The analysis of the InSAR data in that study, though, did not properly take into account atmospheric delays – once these are corrected, the inferred deflation event all but disappears from the InSAR time series, as shown by the white circles.

Slide 6 – Earthquakes

As we've seen, earthquakes, especially large ones, result in a displacement of the Earth's surface. An example of this that we'll see in this week's practical is the magnitude 7.1 earthquake that occurred on 6 July 2019 near Ridgecrest, California. This dataset, which contains a number of Sentinel- 1 interferograms processed by HyP3, highlights how we can see the displacement using InSAR. We can clearly see this circular fringe pattern using an InSAR pair from before and after the earthquake – the two sides of this pattern are effectively reflected across the fault where the displacement occurred. Not only can we see the surface displacement, but we can also use the change in coherence to potentially map damage to structures in the affected area – especially if we use cross-polarized signals. The study shown here used two pairs of images: the first, from before the earthquake; the second, from before and after the earthquake (the "inter-seismic" stage). The example here highlights areas with a large change in coherence before and after the earthquake, compared to field-checked maps of structural damage. The areas where there are large changes in coherence are also the areas where there was damage to structures.

Slide 7 – Landslides

A landslide is gravity-driven ground movement that occurs due to an instability in the material – for example, soil, gravel, or rocks. The example here shows what one type of landslide looks like – we have a scarp area, where the slope has moved down; a debris flow, where the material has created, or gone through, a channel, and an accumulation zone, where the material has built up. Using InSAR, we can observe these deformation patterns – for example, here we clearly see the accumulation zone in the displacement map, represented by a shortening of the line-of-sight distance between the sensor and the slope. To study landslides, we can use ground-based sensors, as was used in the study referenced here. This example, the Gamma portable radar interferometer, has a transmitting and receiving antenna that rotate and scan in order to create an image. We can also use satellite-based sensors, as shown here – we have a number of landslides visible in this interferogram, outlined by the dotted circles. This is an example where the signal coherence, and therefore our ability to detect these landslides, depends on the wavelength of the sensor – if we switch from the L-band radar shown on the left to the C-band radar shown on the right, the coherence is lost and we have a much harder time picking out the ground motion, even when we already know where it is.

Slide 8 – Glaciology

We've seen examples of how we use SAR to measure glacier motion. We know that InSAR only gives us deformation or motion in the sensor's line of sight – as we covered in the previous lesson, if we want the full 2- or 3-dimensional displacement field, we need a combination of ascending and descending passes. We also need an accurate DEM, in order to be able to geocode the results. One example of a study using these techniques to observe glacier motion is for a surge of Monacobreen, Svalbard, which occurred from around 1991 until 1998. A glacier surge is a periodic increase of glacier speed – during a surge, the glacier velocity can increase by 10 to even 100 times the background values. However, the faster surface motion creates crevasses which break up the surface and cause a loss of coherence, meaning that InSAR is not really a suitable technique for observing the fastest parts of the glacier's motion, as we can see in the diagram here – the lower part of the glacier doesn't give usable results, and the InSAR observations are mostly limited to the upper portions of the glacier.

Slide 9 – Persistent scatterers

As we covered in the previous lesson, the InSAR signal contains phase differences that arise due to: deformation, topopgraphy, orbital errors, atmospheric delays, and noise. To help in studies of deformation using InSAR time series, we often want to focus on locations where the signal is both strong and constant, and the noise is minimal – we call these locations "persistent scatterers." We can further divide these into two different types: permanent scatterers, where the radar response is dominated by a strong reflecting object and is constant over time; and distributed scatterers, where the response is also constant over time, but is due to different small scattering objects. How well we are able to find these scatterers depends on the wavelength – the shorter the wavelength of the signal, the more persistent scatters we can usually find in an area. For example, in this image, we can see how many more scatterers are identified in the X-band image on top, compared to the C-band image on the bottom. Persistent scatterer interferometry is a useful way to analyze time series of InSAR data, especially in urban environments, as it helps us to minimize the noise that can be present in the data.

Slide 10 – Summary

In this lesson, we've discussed how the Earth's surface deforms, or moves: for different reasons, on different timescales, and on different spatial scales.

As part of that discussion, we've seen a number of examples showing how with InSAR and dInSAR, we can observe this motion, even though it's often small (on the scale of centimeters!), on large spatial scales, from space.

Slide 11 – Additional resources

As always, I’ve included links to the different articles referenced in this presentation here – they’re also available on the slide notes, and you can find PDF versions of the articles on Blackboard or in the Zotero library. I’ve also added a few additional papers to the Zotero library that weren’t covered here, so feel free to browse those as well. That’s all for this lesson – I hope you found it interesting, and you have any questions, please don’t hesitate to e-mail me or post in the discussion forum on blackboard. Bye!