Slide 1 – Title Slide

Hello and welcome to Week 4, Part 3 of EGM703: Principles of InSAR. In this lesson, we'll learn the basics of how we can use SAR data to measure topography and movement on the Earth's surface.

Slide 2 – Phase

As we have seen, the phase of a signal is the fraction of a period – the fraction of a full cycle, or wavelength, of the signal. In our example here, we see that between our sensor and our target, we have one two three full wavelengths, and a small portion leftover. The phase that is recorded by the sensor has two components – the first is a deterministic component based on the range, R, between the sensor and the target. This is effectively the bit that's left over if we divide the range by the wavelength. The second component is the random component based on the contributions from all of the subpixel scatterers – this is the part that changes based on the surface conditions. Because phase is limited to be between 0 and 2π, the phase of an individual SAR image appears to be totally random noise. There's a lot of information in there, including about the topography, but it's difficult to see without some additional processing.

Slide 3 – Interferometric SAR: the basic idea

That additional processing is known as interferometric SAR, or InSAR. The basic idea here is that we have two images, image 1 and image 2, separated either by a baseline distance B, or separated by time. Then, the phase of the first image is the combination of the deterministic component determined by the range, R, and the random component contributed by each of the subpixel scatterers. In the second image, the phase of this pixel is equal to the deterministic component determined by the range of the second image (which is R plus ΔR, the distance from where the perpendicular baseline intersects the sight line to the satellite), and the random component contributed by the subpixel scatterers. If we then construct an interferogram, by effectively differencing the phases of the two images, what we are left with is the phase owing to the extra distance between the two satellites, ΔR. Of course, this only works if we have coherence between the two images – that is, the random phase in image 1 is approximately equal to the random phase in image 2. If they are substantially different, this doesn't quite work out.

Slide 4 – The interferogram

So, if we have two images, u_1 and u_2, the way we form the interferogram is by taking the dot product of image 1 with the complex conjugate of image 2. Given image 1, which has amplitude and phase that looks like this, and image 2, which has amplitude and phase that looks like this, if we do this multiplication, we end up with this – notice what the phase of the interferogram looks like now. Rather than random noise, we have a very clear interference pattern – if you've ever seen a thin film of oil on water, or wet pavement, you have seen a pattern like this. This image is what contains the information about the difference in range between the two images, which we can use to work out the topography, or the ground motion.

Slide 5 – Flat Earth (phase)

Even on flat terrain, the phase in an interferogram will very from the near-range to the far-range – this is known as the “flat Earth” phase. In order to see what we want to see, such as the topographice phase or the deformation phase, we need to correct this. In the example shown here, which is based on the images used in this week’s practical, we see how removing the flat earth phase from the interferogram changes the picture – what we’re left with, at least in this case, is the combination of the ground displacement due to an Earthquake, and the phase due to the different topography in the image.

Slide 6 – Coherence

As mentioned, the assumption that the random phase components are approximately equal (and therefore zero out when we form the interferogram), depends on whether we have coherence between the two images. Remember that another way to think about this is that the phase is time-independent – that we can treat the phase contributions of all of the subpixel scatterers as stationary vectors, and add them together. By measuring the coherence between two images, we can learn about the accuracy of our measured topography or estimated deformation or displacement. If we have high coherence, it means that we can trust the estimated elevation or displacement from our interferogram; if we have low coherence, it tends to mean that our estimates are less reliable. With shorter wavelengths, it tends to be harder to keep coherence between images. In the example here, anywhere we have high coherence, we can see the interferometric fringes; anywhere we see gray, the coherence is quite low. This example is for C-band radar with a wavelength of 5.6 cm; the second example here is for L-band radar with a wavelength closer to 25 cm; you can see how much more dense the fringes are – we have significantly better coverage of our interferogram.

Slide 7 – Differential InSAR

What do we do if the ground is moving? In that case, our interferometric phase has two components, related to the topography and the deformation. To isolate the deformation, if we only have two images, then we need an accurate external DEM in order to estimate the topographic phase and remove it, leaving only the deformation phase. If the topography is changing, or we don’t have an accurate DEM, we can use 3 or more SAR images to accomplish the same thing. In this case, we would take one pair separated by a longer amount of time – for example, several days or weeks, in order to measure the deformation. A second pair separated by a shorter amount of time, but where the satellite paths are separated by distance, will enable use to estimate the topographic phase, and subtract it from the interferometric phase of the first pair. This technique, where we subtract out the topographic phase in order to study displacement, is known as “differential InSAR,” or just “dInSAR”

Slide 8 – Limitations

InSAR and dInSAR are incredibly powerful tools, but they do not hold unlimited power. For starters, with dInSAR, we can only see deformation or displacement in the satellite’s line of sight – if we want to see the 2D or 3D displacement field, we need to have multiple look directions. Fortunately, SAR satellites acquire in both ascending and descending orbits. For example, if we have a glacier here, we would need a descending pass, where the satellite is typically traveling from Northeast to Southwest, and an ascending pass, where the satellite is moving from Southeast to Northwest. Unfortunately, we're not always lucky enough to have these passes acquired close together in time, which means we can't always get multiple looks in order to estimate the full displacement field. The surface also has to be coherent. In the example here, we can see nice, clear interferometric fringes in some areas on this glacier, but very noisy fringes in other spots. If the motion is too slow, the surface can end up decorrelating due to seasonal changes, and we can't actually measure any motion. Similarly, we can't measure very fast changes using dInSAR, because if the surface is moving quickly it will also end up decorrelating – we're typically limited to measuring motion that is less than the sensor resolution in the time between images.

We're also limited by the spatial baseline – the fringe density increases as the baseline increases, meaning that if the images are too far apart, we end up with multiple fringes per pixel, and we end up being unable to measure anything.

We also have to consider atmospheric effects – small delays in the return time due to water vapor in the atmosphere or ionopsheric influence actually change the phase measured by the sensor, which makes it even more difficult to correlate the two images.

Finally, we also need to worry about orbit errors – part of the process requires that we know where our two satellites are at the time of acquisition. This is less of a problem for more modern satellite missions, but this can be a considerable issue for some of the older SAR satellites.

Slide 9 – Summary

In this lesson, we've covered how SAR sensors record phase, which contains information about the distance to the target, and the subpixel scatterers.

If we have at least 2 SAR images, we can create an interferogram to measure topography and deformation, though the accuracy of this technique depends on the level of coherence between the two images.

With 3 or more SAR images, or 2 images plus an external DEM, we can subtract the topographic phase from our interferogram and measure the deformation, or surface displacement, between the two images.

In short, InSAR is a powerful technique that can provide highly accurate measurements of topography and motion, though like all things it is not without limitations.

Slide 10 – Additional resources

You can read more about the topics we've discussed here in the textbooks – Lillesand, Kiefer & Chipman, Chapter 6.9, or Cambpell & Wynne, Chapter 7.12.

I've linked to an ESA training manual – this is a free e-book that covers the theory of InSAR in quite a bit of detail. I've also linked to a video produced by Michigan Tech University that also covers the concepts included in this lesson. This paper by Bamler and Hartl also covers the theory of InSAR in quite a bit of mathematical detail, if that’s something you are interested in.

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!