Homework 2 - Radar Imaging SAR Interferometry (InSAR)

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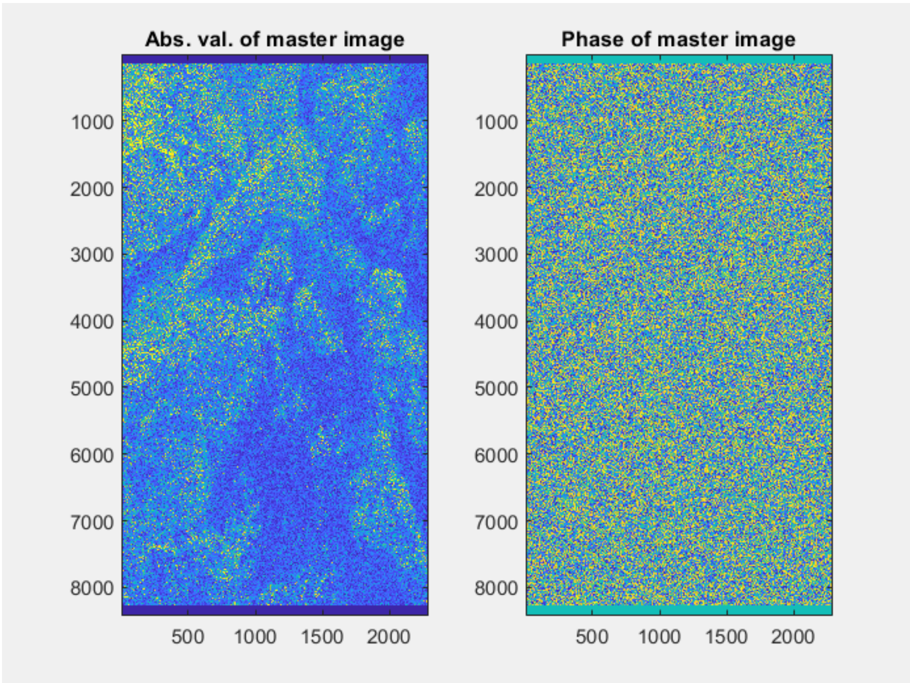
1 Introduction

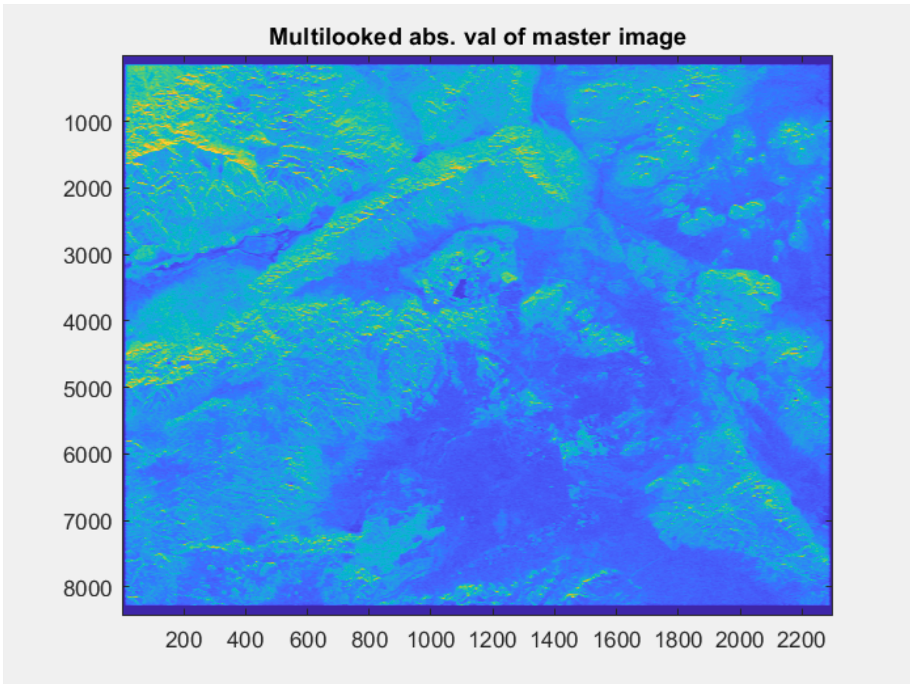
The goal of this homework activity is that of evaluating the deformation field of the terrain caused by the earthquake that hit Ridgecrest, California on July 5th 2019 by means of the Synthetic Aperture Radar (SAR) interferometry, computed on satellite radar images taken before and after the earthquake.

2 Execution and results

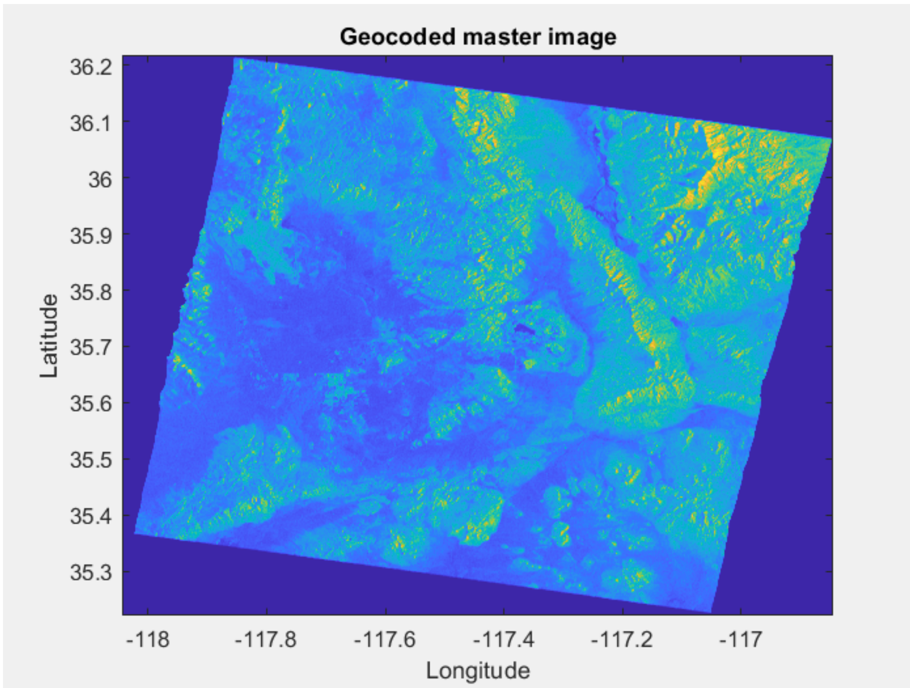
The homework activity is structured in a sequence of subsequent tasks, each one built upon the previous ones. Radar images are represented in MATLAB as complex matrixes, and it is thus possible to plot absolute value and complex phase of each radar image in two separate plots. Since those images are very heavy they are subsampled in MATLAB before further processing for memory efficiency reasons. After subsampling some peaks have to be removed in order to have an image that is clearly visible in MATLAB using the imagesc() function. The peaks above the 98th percentile of the amplitude of the image are satured by using a crest reductor (this is a nonlinear operation). The phase of the complex image is left unchanged by this operation.
So the image that we obtain is:



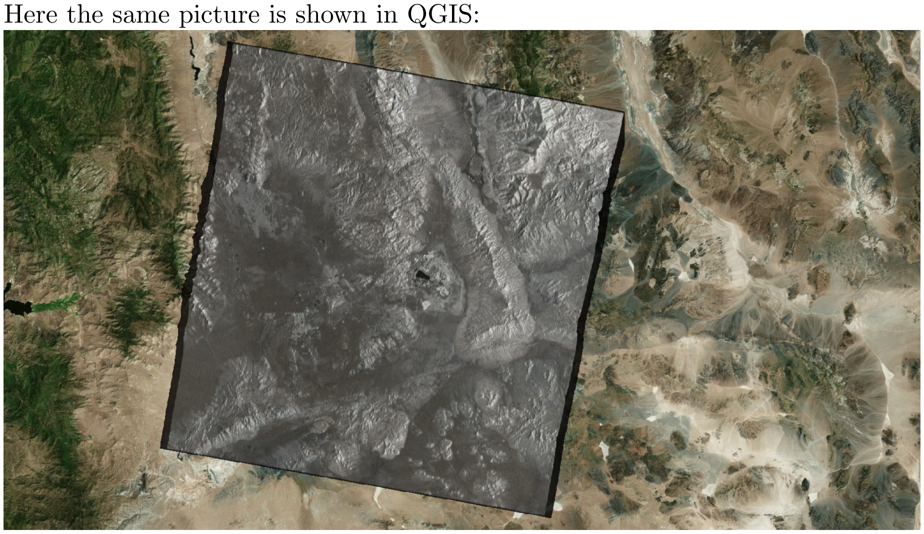
As we can see the image is very noisy, even if some shapes of the depicted territory can be identified, this noise is due to speckle interference in the capture image, as well as image degradation due to aliasing. Both these issues can be mitigated by multilooking (low pass filtering).
After multilooking with a 9x9 rectangular low pass filter, the absolute value of the image that is obtained is a much clearer picture, in which the altimetric profile and geographic features of the zone can be clearly recognized:



After geocoding the master image we obtain this picture, in which it can be seen that there is some shadowing, specially on the easternmost part of the picture, and that the direction of such shadowing is parallel to the direction of the motion of the satellite, i.e. on the E-W axis:



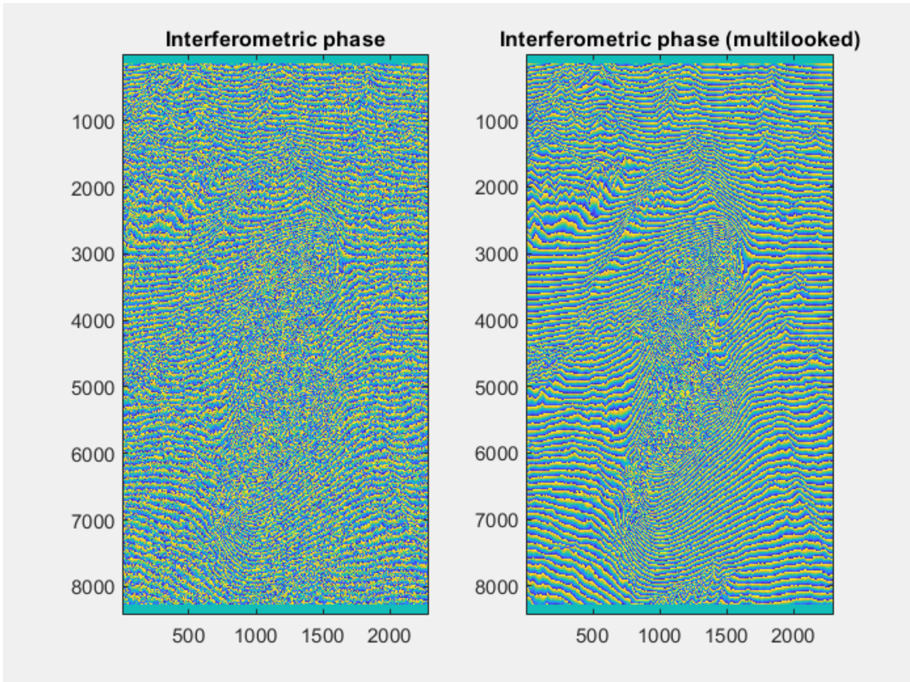
Here the same picture is shown in QGIS:



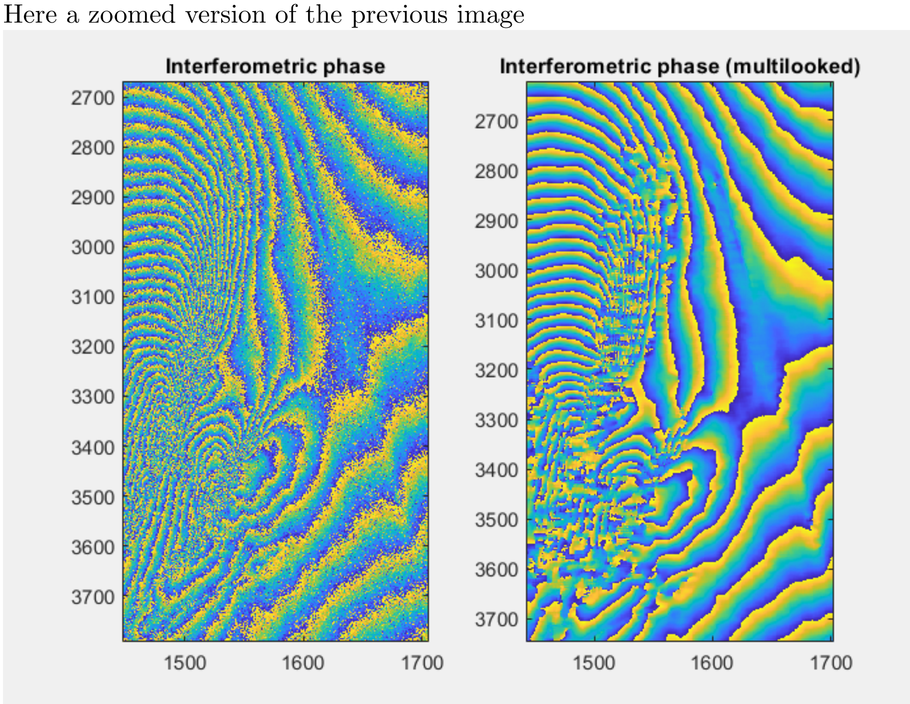
After computing the master image the same procedure is performed for the slave image (i.e. the one after the earthquake happened), and the interferogram is computed as:

```
interferogram = master.*conj(slave);
```

The complex phase of the interferogram, before and after multilooking is shown below:

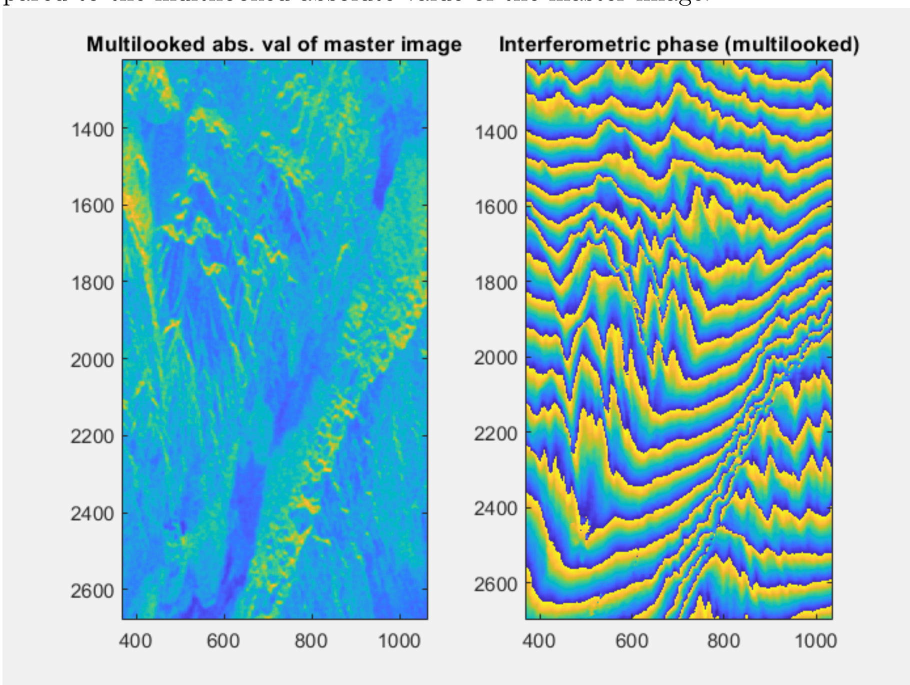


Here a zoomed version of the previous image



Both with and without multilooking the phase images have fast fringes that are

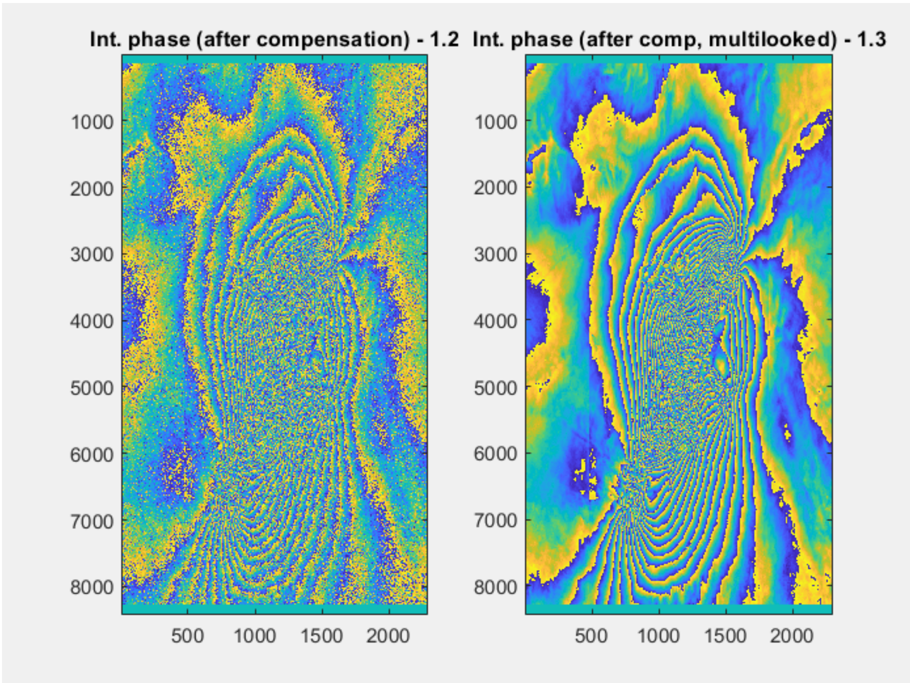
due to the topography of the area, the presence of such fringes is due to the fact that the exact distance between each pixel and the satellite at the moment of capturing the image is not taken into account into the images.
This is evident when looking at a zoomed part of the interferometric phase compared to the multilooked absolute value of the master image:



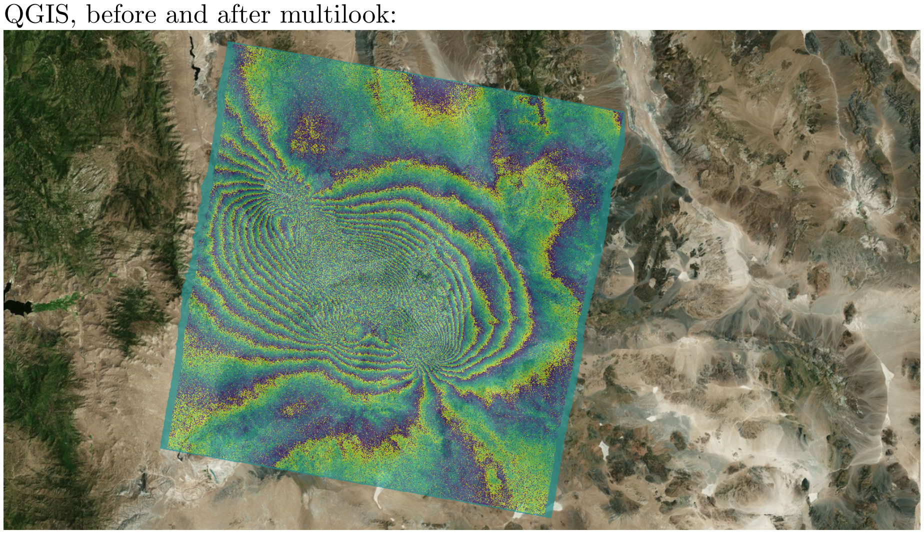
It can be clearly seen in the previous image that the fringes follow the altimetric profile of the area, in the parts in which the altitude changes rapidly the interferometric phase follows suit.
In order to remove the dependance of the interferometric phase from the distance between the satellite and each pixel the following operation is carried out:

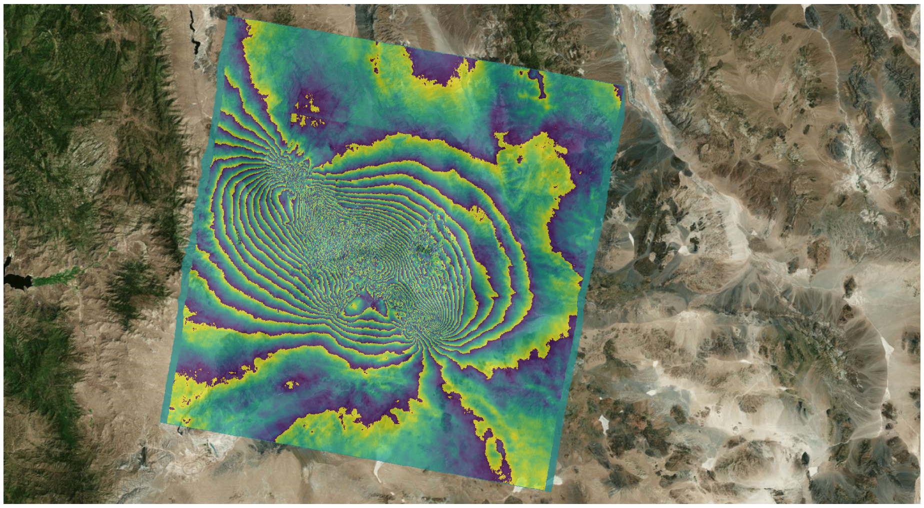
```
master = master.*exp(1j.*(4*pi*f/c)*distancesMaster);
```

in which f is the operational frequency, c is the speed of light and distancesMaster is a real valued matrix containing the distance from the satellite at the moment of acquisition for each pixel of the image, computed by knowing the trajectory of the satellite and the altimetric profile of the area.
The results of this operation (before and after multilooking) are here shown:



It can be seen that the image is much more clearer, and the fringes are much faster in the central part of the image than in the outer parts, meaning that the deformation hit the central part of the area harder than the other parts.
Below the same images representing the interferometric phase can be seen in QGIS, before and after multilook:

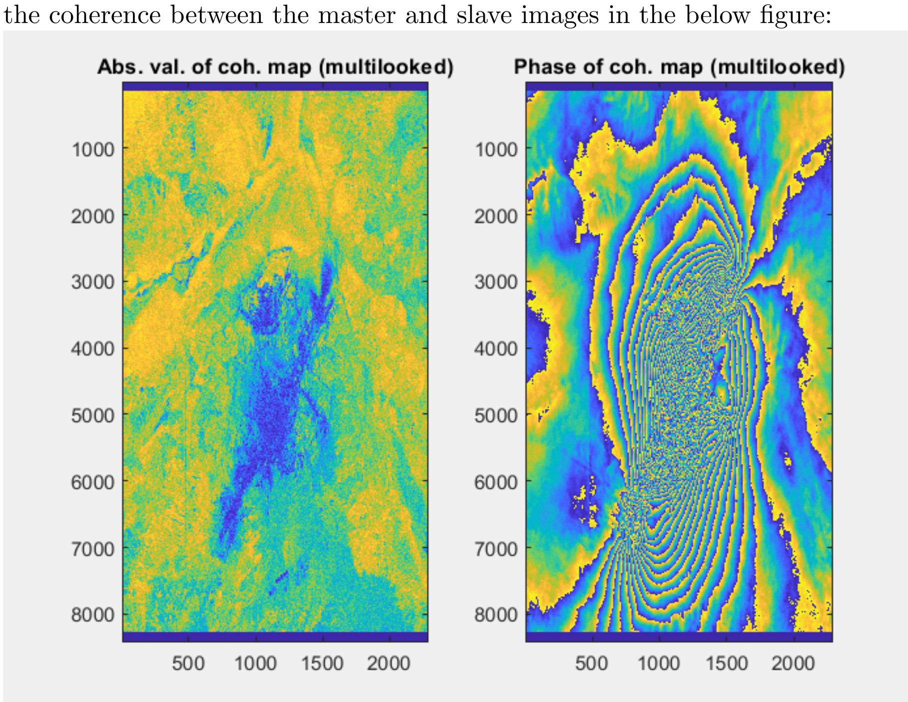




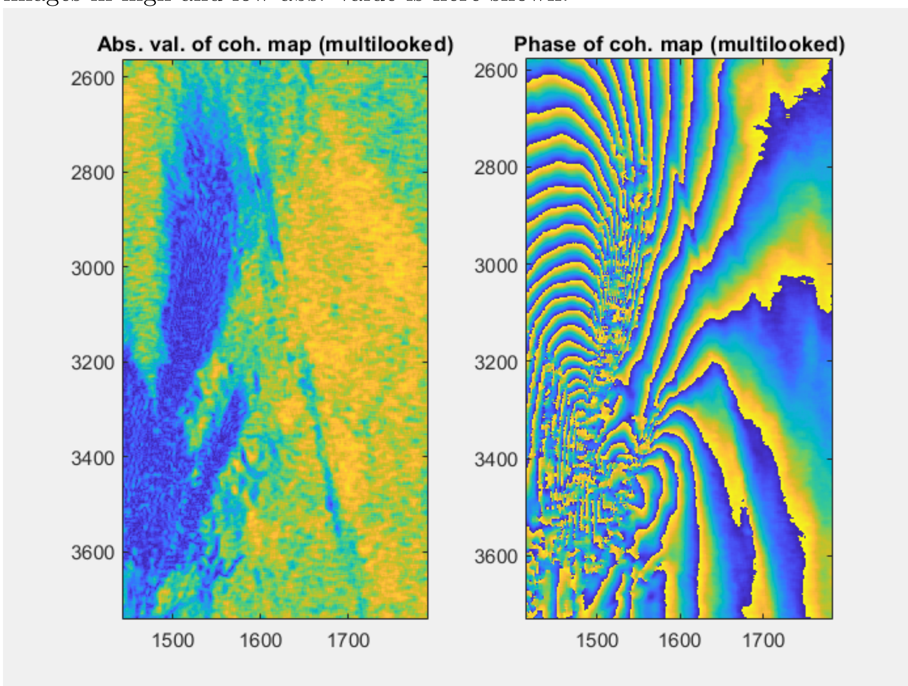
The coherence map is computed as:

```
coherenceMap = master.*conj(slave)./
        ((master.*conj(master).*slave.*conj(slave)).^0.5)
```

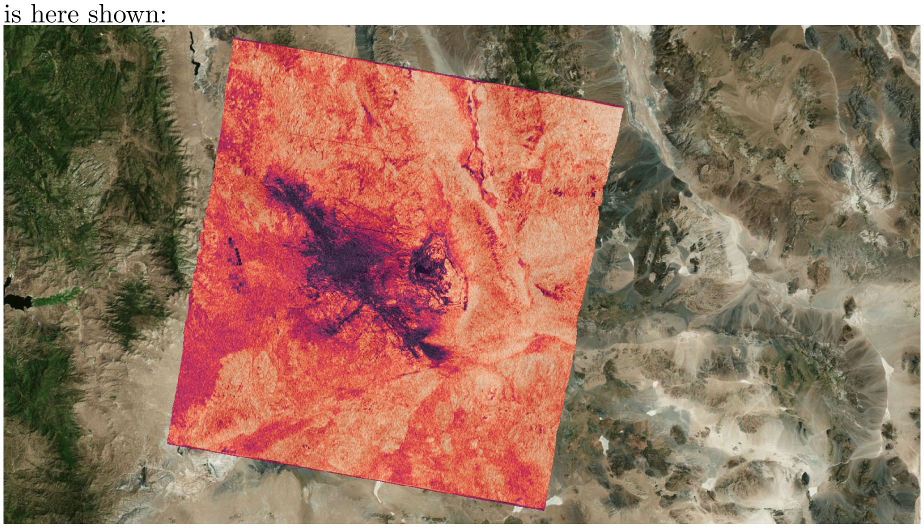
The coherence map is a complex image whose phase is equal to the one of the interferogram, while its absolute value tells us how much the noise is causing corruption of the phase. We can see the absolute value and complex phase of the coherence between the master and slave images in the below figure:



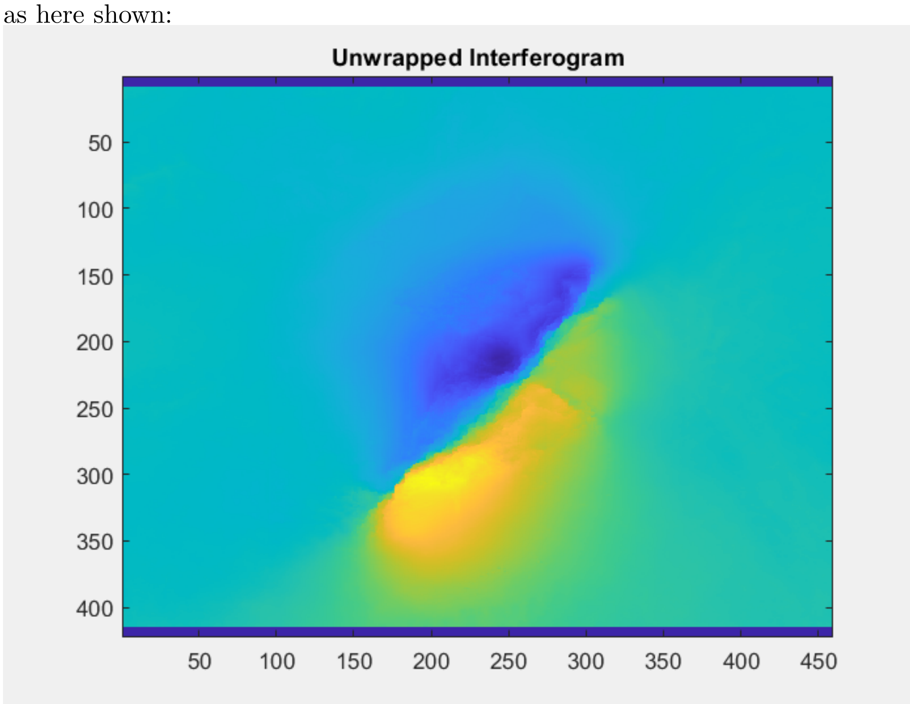
As we can see the absolute value of the coherence is lower in some part of the central area of our map. A zoomed detail of the difference between the phase images in high and low abs. value is here shown:



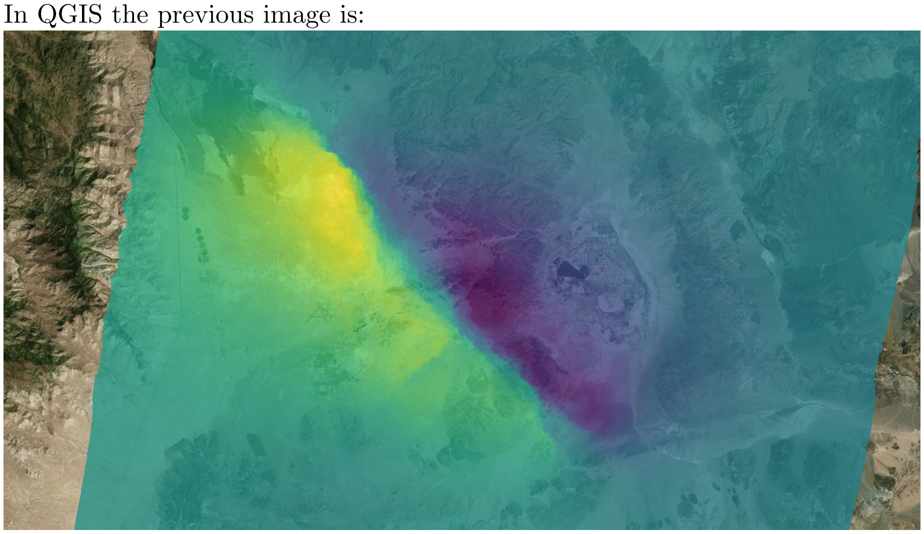
As we can see where the abs. value of the coherence is low (blue in the image, as opposed to yellow) the phase in the right subplot appears more fuzzy.
The absolute value of the coherence between master and slave images in QGIS is here shown:



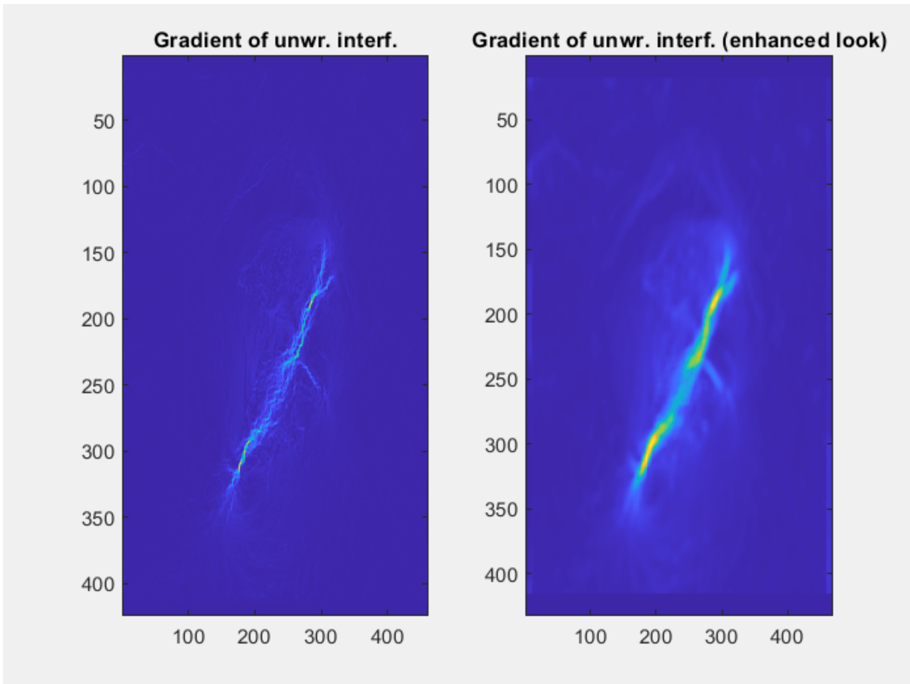
By using the unwrap_IRLS() function it is possible to unwrap the interferogram thus obtaining a clear picture of the deformation field caused by the earthquake, as here shown:



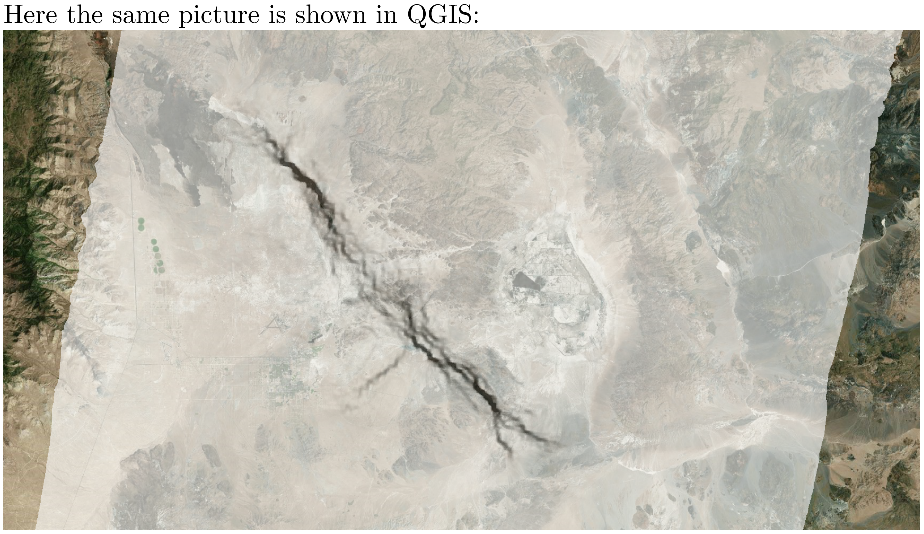
In QGIS the previous image is:



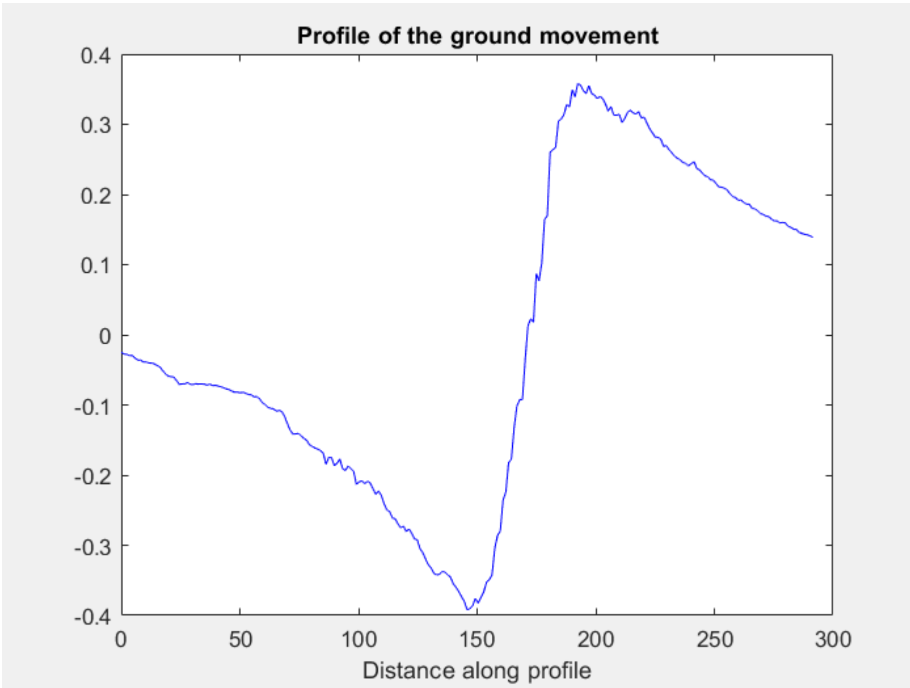
The gradient of this deformation field shows the precise location of the fissures caused by the earthquake. The gradient has been computed with the Pythagorean Theorem starting from the gradients computed in the x and y directions, and is here shown:



Here the same picture is shown in QGIS:



A profile of the ground movement, in a direction perpendicular to the main fissure caused by the earthquake, is below reported:



This has been obtained by using the improfile() MATLAB function, going from point (150, 100) to (300, 350) of the previous figure. It can be seen that the ground displacement has reached peaks of more than 40 cm, with differences of more than 80cm between highest and lowest point of the displacement profile. The profile of the ground movement clearly shows how the two tectonic plates involved in the earthquake went in opposite directions: one upwards and the other downwards.

3 Conclusion

This activity shows that with the use of Synthetic Aperture Radar imagery a lot of information about environment can be extracted, providing useful and detailed insights about a lot of use cases, in this case natural disaster. Interferogram proves to be an effective tool at evaluating differences in images of the same area taken at different times, enabling users to detect ground movement, human activity, natural phenomena or signs of animal life.