A RE-APPRAISAL OF THE 1992 LANDERS EARTHQUAKE INSAR DATA USING THE AMBIGUITY SEARCH METHOD

M. A. Warren, A. Sowter, R. M. Bingley

IESSG, University of Nottingham, University Park, Nottingham NG7 2RD,
Email: andrew.sowter@nottingham.ac.uk

ABSTRACT/RESUME

The 1992 Landers earthquake is perhaps the most famous earthquake for InSAR, having been the subject of many different scientific journal, magazine and newspaper articles. This plethora of papers means that the site is very well known and any attempt to process the data should be able to confidently predict the results. The ambiguity search method, proposed in 2003, offers a potential procedure for DINSAR that appears to have some benefits when there is no terrain model or when ground control is sparse, even over mountainous terrain. In this paper, an attempt to re-create the classic Landers results using the new process is described. The results are compared with previous results and also with GPS data of the region.

1. INTRODUCTION

Current methods for the derivation of differential InSAR data use methods based on phase flattening to generate their results [1]. Sowter [2] has proposed an alternative method based on the characterisation of the full phase through the solution of the integer phase ambiguity parameter [3]. This method was demonstrated in a laboratory experiment [4].

This paper describes the method used and evaluates its capability using InSAR data from the ERS satellites. Data from the 1992 Landers earthquake will be used for the demonstration.

2. THE INSAR MODEL

In an error-free differential interferometry scenario, an entirely feasible methodology would be to calculate the full 3-d positions of the same target in two interferograms and to examine its displacement. However, this is impossible in the real world, mainly due to the pseudo-range approximation, and therefore it is usual to examine the interferometric phase change between the interferograms and to infer target motion from that value alone [5].

The interferometric phase is related to the baseline declination angle by:

$$\frac{4\pi}{\lambda}\cos\beta = \frac{1}{B}\left(\phi + 2\pi\Delta n^{ij} + \frac{4\pi}{\lambda}\delta e\right) \qquad (1)$$

where λ is the radar wavelength, β is the baseline declination angle, B is the orbital baseline, ϕ is the interferometric phase, Δn^{ij} is the integer phase ambiguity and δe is the far field correction.

The phase deviation between two interferograms, Φ, is defined by [1]:

$$\begin{aligned}\Phi = &\frac{1}{B_{12}}\left(\phi_{12} + 2\pi\Delta n^{12} + \frac{4\pi}{\lambda}\delta e_{12}\right)\\ &-\frac{1}{B_{13}}\left(\phi_{13} + 2\pi\Delta n^{13} + \frac{4\pi}{\lambda}\delta e_{13}\right)\\ &-\frac{8\pi\sin\frac{1}{2}\gamma}{\lambda}\sin\left(\beta_{12} + \frac{1}{2}\gamma\right)\end{aligned} \qquad (2)$$

where the *12* and *13* sub- and super-scripts relate to the topography and deformation interferometric pairs respectively and γ is the angle between the two baselines. Note that Φ is zero when there has been no differential change in target position.

An objective of differential InSAR is to calculate the phase deviation, Φ, for all pixels in the two interferograms. Any deviation from zero indicates an error or a change in one of the phase values, possibly indicating a change in target position at the third acquisition. If there has been a change in position, the range to the target T will be shorter or longer than anticipated and therefore the phase value will be different from the anticipated value.

This method outlined above is an extremely precise method for the derivation of the differential phase change. The assumptions are:

- The baseline is known very accurately;
- The phase must be unwrapped;
- Coarse ground control is available.

If all of these assumptions are satisfied, precise differential interferometry can be performed without

recourse to using a DSM or using the far-field approximation.

3. APPLICATION

3.1 The Landers Site

The magnitude M7.3 Landers earthquake of 1992 occurred near to the town of Landers, California. This area is situated near the San Andreas fault and is of great geodetic interest. The area is mainly arid desert land.

The data used in this paper is ESA ERS SLC data of the following 3 dates: 24th April 1992, 3rd July 1992 and 7th August 1992.

Fig. 1, the interferogram magnitude, shows the area of interest with GPS sites marked. GPS coordinate data has been used, made available from the Scripps Orbit and Permanent Array Centre (http://sopac.ucsd.edu/).

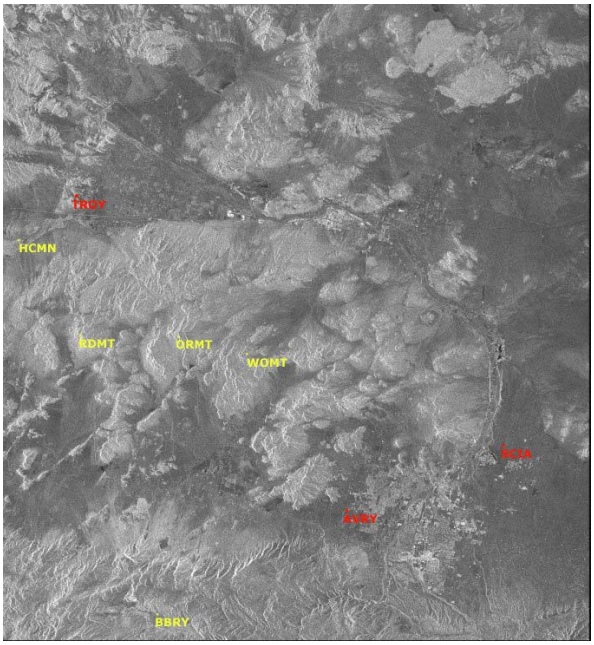

Fig.1 Interferogram magnitude showing locations of GPS stations

3.2 Data Processing

The data has been processed in the following way. First two interferograms are formed from the 3 SAR images. These are then unwrapped and the phase is converted to the absolute phase, by finding the integer ambiguity value. The phase deviation can then be calculated using equation (2), which in turn gives the differential phase if we multiply it by $-B_{13}$. This is shown in the flow diagram below, fig. 2.

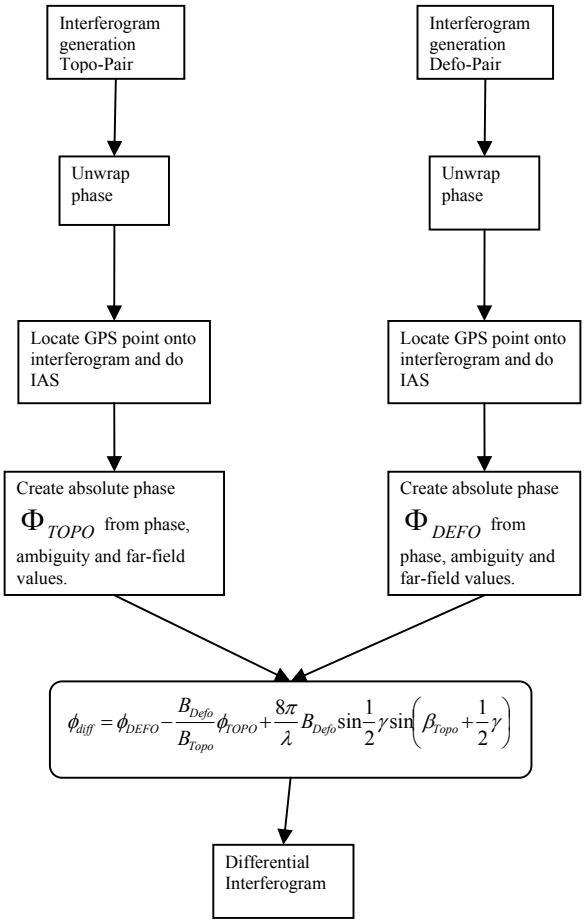

Fig. 2. Flow diagram of the DInSAR processing chain

The processing stages will be discussed in turn below.

A Generating the interferograms

Interferogram generation has been performed using ERS data by the DORIS software provided by the Technical University of Delft in the Netherlands [6]. The software performs all the main stages of interferogram generation, from coregistration of the SAR images to calculating the coherence map and filtering. The two interferograms have been formed using the same master image (7th August 1992) for both. The final result has been multilooked by factors 10 in azimuth and 2 in range, to give an approximate pixel size of 40m x 40m in ground range.

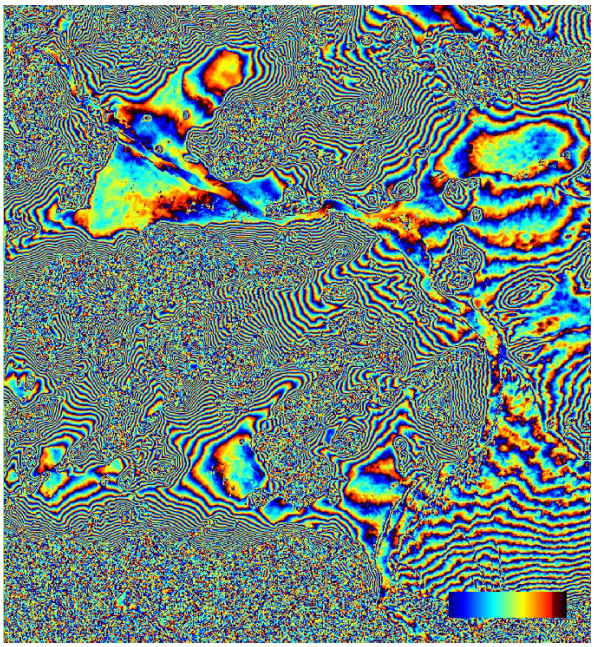

Fig. 3. Flattened topographic interferogram

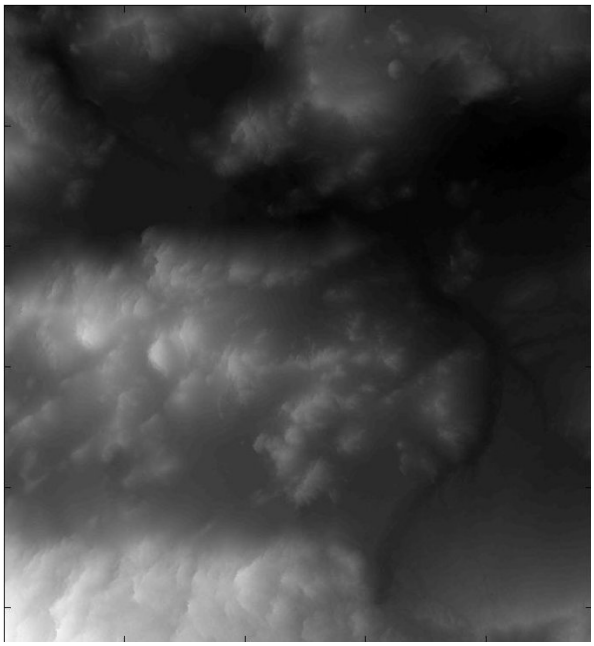

Fig. 4. Unwrapped flattened topo-interferogram

B. Phase Unwrapping

Due to the high fringe rate of the interferograms, phase unwrapping can not be performed on the full phase. This means the interferograms must be flattened first, by removing a reference phase that characterizes the phase trend. DORIS calculates the reference phase for subtraction using the available orbit data and image properties. The flattened topographic interferogram can be seen in fig. 3. This flattened interferogram is then unwrapped (see fig. 4) and the absolute reference phase is added back onto this. The phase unwrapping was performed using the SNAPHU software provided by Stanford University [7].

When the absolute reference phase is added back onto the unwrapped flattened phase the data should be checked to ensure that at some point the wrapped data agrees with the unwrapped data. The unwrapped phase plus reference phase is shown in fig. 5.

C. Integer Ambiguity Search (IAS)

For the IAS to take place a known point must be located on the interferogram. The GPS points are not visible on the images so a simple range-doppler algorithm has been used to locate the GPS points onto the master SLC image. For this method to work precise orbits are required. These are supplied by Technical University of Delft [8]. Because only position vectors are supplied, the orbits have been interpolated by fitting a 3rd order regression fit, with the first derivative giving the velocities. The GPS points can be seen located in fig. 1, although only the ones in red have been used in this study. For the seeding of the search process, GPS point AVRY has been used. This was selected on criteria due to coherence and prior knowledge of where the deformation zone was.

Once a GPS point has been located on the image, the full IAS can take place. A brief description follows (see [3] for details on the process).

1. A GPS point is selected as a seed for the search process. It is located onto the unwrapped interferogram using the range-doppler method.
2. The phase value of the pixel is interpolated to the GPS point.
3. The interferogram is "normalized" to the seed GPS point, i.e. multiples of 2π are added/subtracted to the whole unwrapped interferogram until the unwrapped phase at the GPS point agrees with the wrapped phase at the same point.
4. From the satellite positions of this point, the baseline is calculated, as are the master range, the baseline declination angle and an estimate for the far-field approximation. This gives an initial value for the integer ambiguity.

Fig. 5. The full unwrapped topo-phase.

5. This integer ambiguity value is then increased/decreased to test whether the value is applicable, with the "best" choice being selected.

D. Creating the absolute phase.

The absolute phase is calculated using the equation (3) below

$$\phi_{abs} = \phi_{unwrap} + 2\pi n \qquad (3)$$

where ϕ_{unwrap} is the full unwrapped phase and n is the integer ambiguity.

This process is repeated again for the deformation interferogram. When seeding the ambiguity search for the deformation interferogram, it is important to use a GPS point outside of the deformation zone. If this is not adhered to then an erroneous ambiguity value could be selected.

E. Differential phase

The phase deviation is then calculated as in equation (2) and multiplied by $-B_{13}$ to give the differential phase. The differential phase is shown in fig. 6.

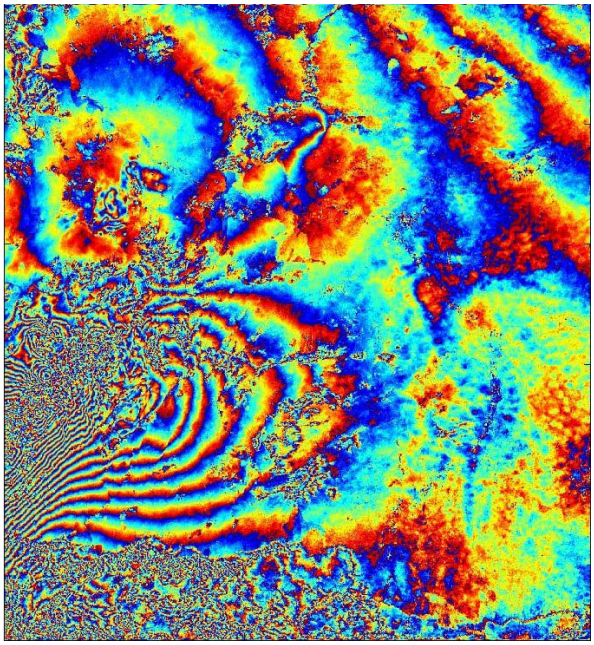

Fig. 6. The differential phase.

3.2 Results

The purpose of this paper is to show a new method for performing differential interferometry. This method is different to previous ones [1] as it uses the absolute, unflattened phase to calculate it. Fig. 7 shows the differential interferogram as calculated by the conventional 3-pass method using the DORIS software, and fig. 8 shows the difference between the two results.

There are still problems/errors with the new method described here. Before the differential phase result in fig. 6 was attained, a slope effect of a few fringes had to be modeled and subtracted from the phase. This was done by taking the 3 GPS points and setting the differential phase to zero at these points, and then fitting a plane through them to model the slope. The slope was then subtracted to give the result in fig. 6.

Putting this problem aside for a moment, comparing the two results in a qualitative way, fig. 6 and fig. 7 both show the deformation area (bottom left of the interferogram). In the top right corner of fig.6 there are 3 fringes running diagonally, this is most likely a residue of the subtracted phase slope. Examining fig. 8, the difference between the two interferograms, shows that there is a potentially non-linear centimetric-scale error in either method, that is not related to the phase slope correction. This may be due to the phase flattening performed by DORIS, where the reference

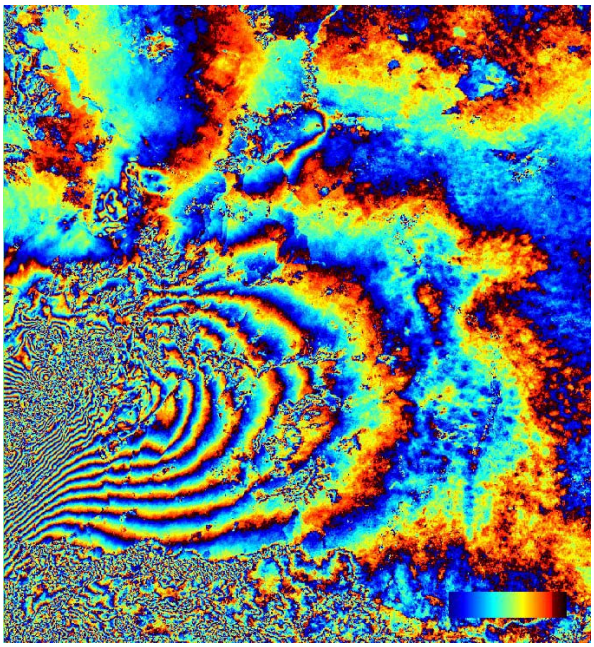

Fig 7. Conventional 3-pass differential phase.

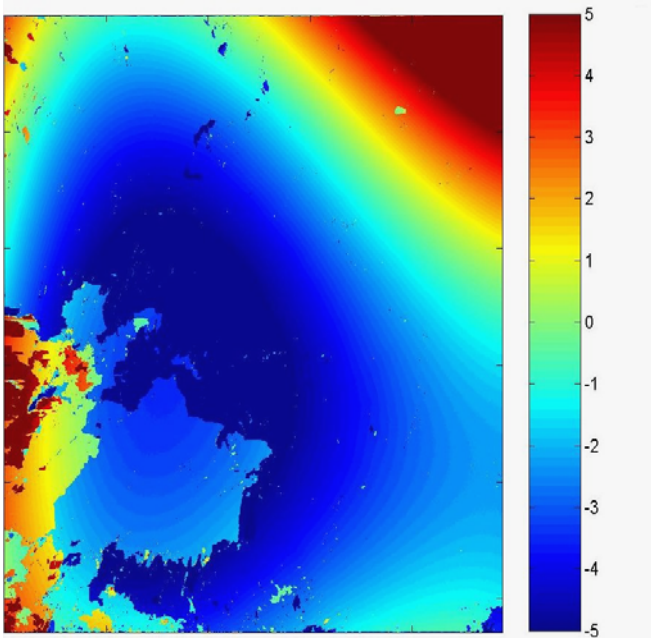

Fig 8. Difference between the two methods, scale in cm

phase may be only accurate to 0.1 radians. This requires further investigation.

In any case, a qualitative comparison shows that the deformation is similarly well-characterised in both methods and that, therefore, the new approach does seem to work.

4. CONCLUSIONS

To conclude, a new technique of performing differential interferometry has been demonstrated using ERS data. It has had a qualitative assessment against a conventional differential interferometry technique, using well known data. Initial results are promising, with the new technique clearly displaying the deformation zone, albeit after some modeling of the aforementioned slope.

Advantages of this result over the conventional 3-pass differential interferometry are [2]

1. The are no assumptions of the InSAR geometry, and hence it should be more accurate over hilly terrain
2. Reduces the need for an accurate DSM

The two main disadvantages to this technique are that:

1. the deformation phase as well as the topographic phase needs to be unwrapped
2. the residual fringe phase slope that needs to be modeled and subtracted.

It is hoped that with further work the source of error for point 2 above will be found, so that proper modeling/mitigation can be done, and then this technique will be a viable alternative to the conventional 3-pass method.

ACKNOWLEDGEMENT

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REFERENCES

1. Zebker, H.A., Rosen, P.A., Goldstein, R.M., Gabriel, A. and Werner, C.L., On the derivation of coseismic displacement fields using differential radar interferometry: The Landers earthquake. *Journal of Geophysical Research*, 99(B10), 19617-19634, 1994.

2. Sowter, A., The derivation of phase integer ambiguity from single InSAR pairs: implications for differential interferometry, *Proceedings of the 11th FIG Symposium on Deformation Measurements, Santorini, Greece,* 149-156, 2003.
3. Sowter, A., Phase Ambiguity Determination for the Positioning of Interferometric SAR Data. *Photogrammetric Record*, 18(104), 308-324, 2003.
4. Sowter and J. C. Bennett, "InSAR radargrammetry : A solution to the phase integer ambiguity problem for single interferograms," *Proc. Fringe 2003 Workshop, Frascati, Italy,* 1-5 December 2003. Available: http://earth.esa.int/fringe03/.
5 Gabriel, A.K., Goldstein, R.M. and Zebker, H.A., Mapping Small Elevation Changes over Large Areas: Differential Radar Interferometry. *Journal of Geophysical Research,* 94(B7), 9183-9191, 1989.
6. B. Kampes and S. Usai, The Delft Object-oriented Radar Interferometric software, *Proc. 2nd Int. Symp. Operational Rem. Sensing, ITC, Enschede*, The Netherlands, 16th August 1999., 4 pages (CD-ROM).
7. C. W. Chen and H. A. Zebker, Two-dimensional phase unwrapping with use of statistical models for cost functions in nonlinear optimization, *Journal of the Optical Society of America A,* vol. 18, pp. 338-351, 2001.
8. R. Scharroo, P.N.A.M. Visser, and G.J. Mets, Precise orbit determination and gravity field improvement for the ERS satellites, *J. Geophys. Res.,* 103, C4, pp. 8113-8127, 1998.