# Preliminary investigation of Zagros thrust-fold-belt deformation using SAR interferometry

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## ABSTRACT

Most of the Zagros deformation resulting from the convergence of Arabia and Eurasia takes place in the Southeast Zagros. To apply the SAR interferometry geodetic technique, a few ERS 1 & 2 satellite images were used to map this continuing deformation proven by GPS. Interferograms over 7 years show surprisingly high coherence. The unwrapped phases display a high correlation with topography reflecting atmospheric noise in addition to the desired tectonic signal. We estimate two simple linear trends and remove them from interferograms. The preliminary results show local uplift rates with a likely minimum of 1-2 mm/yr. These early crude results will be tested by more data in project No. 3174.

## INTRODUCTION

The Zagros Mountains in southwest of Iran with their high seismicity accommodate a significant portion of the 25 mm/yr [1,2] convergence between Arabia and Eurasia (fig. 1).

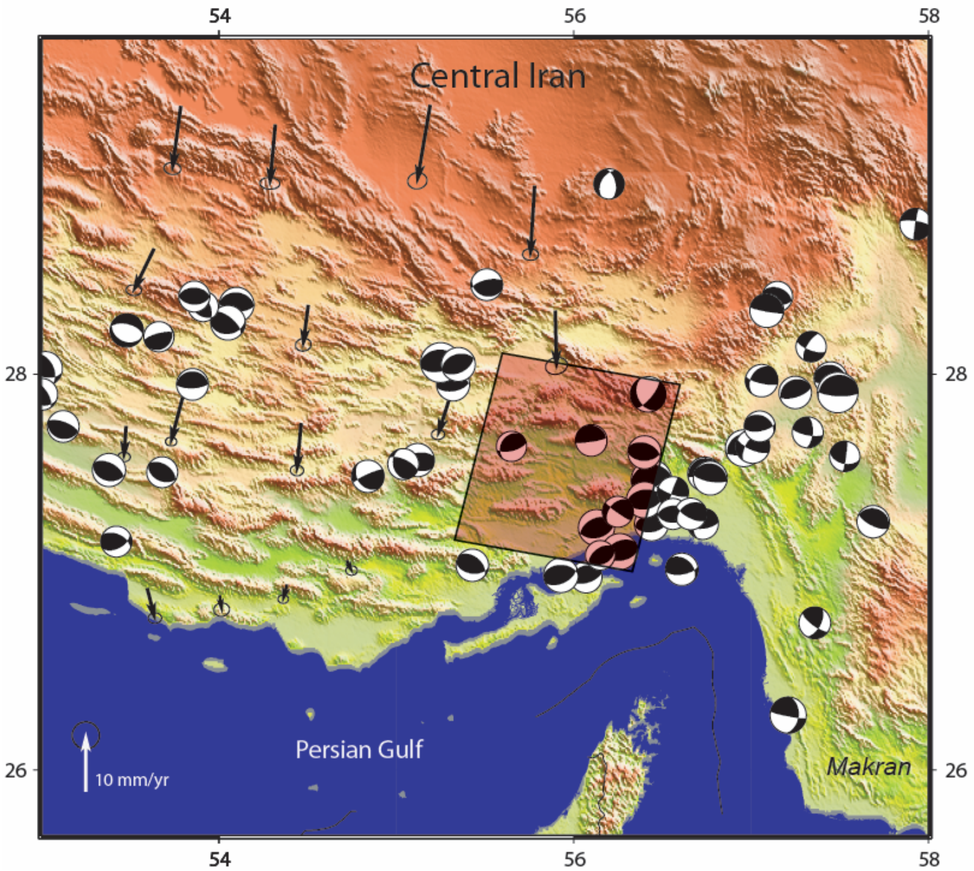


Fig. 1. Part of Zagros with its earthquakes > 4 (Harvard till 2005). The arrows are GPS velocities [2] relative to an Arabia-fixed reference frame. The study area is outlined.

The Zagros includes a variety of geological structures like strike-slip faults (Kazerun, Sabzpooshan, Servestan), folds, thrusts, and salt diapirs. These structures and their deformation mechanisms have been discussed in several studies using earthquake locations, satellite images and analogue models to infer ongoing deformation in Zagros. A local GPS network in the Zagros Mountains [2], also estimates that about half of the deformation involved with Arabia-Eurasia convergence is taken up in this young active thrust-fold-belt and shows extension along the belt and shortening and thickening across it.
Earlier application of InSAR to the Zagros focused on deformation associated with small earthquakes [3]. They inverted the observed deformation seen by InSAR to constrain earthquake locations (from Harvard CMT and International Seismological Center catalogs) and fault parameters.
This study will use InSAR to look for possible uplift rates due to the high rate of shortening across the Southeast Zagros. To start studying this deformation, we use 3 pairs of ERS 1& 2 satellite images and the SRTM global DEM, to implement 2-pass SAR interferometry with the free software SAR Processor (DORIS). Our attempt to map the uplift rates in part of the Zagros is complicated by water vapor content which varies with height and introduces significant atmospheric errors [4, 5]. Preliminarily interferograms for SE Zagros near the Persian Gulf have been generated from 3 pairs of descending ERS1 and 2 images taken in 1992, 1996 and 1999. The correlations between topography and unwrapped phases are shown in one part of image to illustrate a linear trend which can be removed from the interferograms. We finally estimate these linear trends and refine the signal.

## DATA SET AND PROCESSING

The existing InSAR images from the ERS 1 & 2 satellites provide sparse temporal and spatial coverage over the Zagros Mountains. So far we have used 4 ERS 1 & 2 descending images as follows:

| No | Frame | Orbit | P⊥ | Satellite | Date | Repeat (days) |
|---|---|---|---|---|---|---|
| 1 | 3051 | 5089 | 0 | ERS1 | 92-07-06 | 0 |
| 2 | 3051 | 7594 | -171 *0* | ERS1 | 92-12-28 | 175 *0* |
| 3 | 3051 | 21331 | 59 | ERS2 | 99-05-20 | 2509 |
| 4 | 3051 | 5800 | *-100* | ERS2 | 96-05-30 | *1249* |

Table 1. SAR images used for this study. **P⊥** is perpendicular baseline (in meters) between image pairs

We used both SRTM and 10m local DEM (provided by National Cartographic Center of Iran) to carry out 2-Pass SAR Interferometry using DORIS free software developed by the Delft Institute for Earth-Oriented Space Research. SNAPHU was used for phase unwrapping and MATLAB, GMT and ENVI also were used for some data analysis and visualization.
Differential interferograms of the same scene in part of the Zagros Thrust-fold-belt for three periods, ~0.5, 3.5, and ~7 years between 1992/07/06 and 1999/05/20 are shown in figs. 2 and 3. It's interesting to see that the signal remains coherent over exposed mountains even after 7 years.

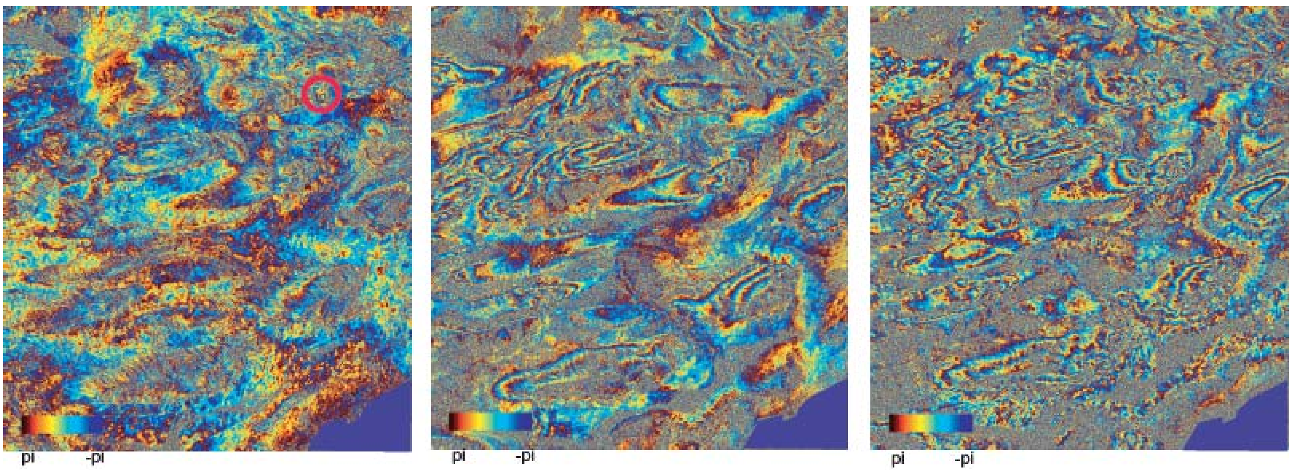


Fig. 2. Differential filtered Interferograms for ~0.5 year (left), 3.5 years (middle) and ~7 years (right). Red circle (to left) shows a few fringes over a salt dome. High deformations limits coherency after a few years in most salt domes. The dark blue patch in lower right corner is part of the Persian Gulf which we have masked.

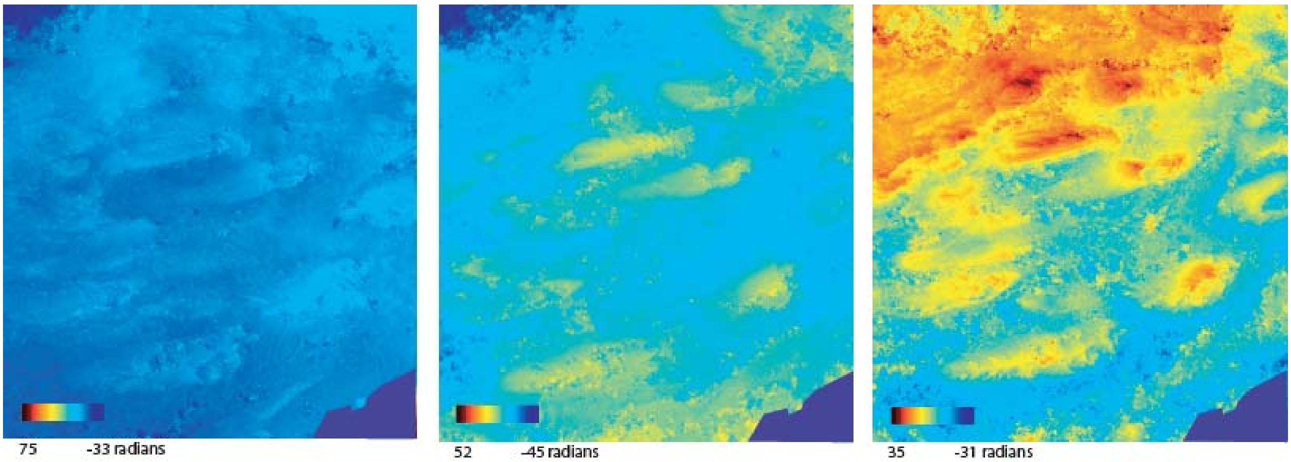


Fig.3. Differential unwrapped Interferograms for ~0.5 year (left), 3.5 years (middle) and ~7 years (right). The dark blue patch in lower right corner is part of the Persian Gulf which we have masked.

In order to investigate correlation of the results with atmospheric effects, we make some scatter plots of unwrapped phases with respect to radar coded heights (fig. 4). It has been proved that atmospheric effects correlate with topography and is bigger in higher mountains [4,5]. Since atmospheric effects are not uniform in the whole area and vary with space and time, so we consider part of image (figs. 5) with good coherence and make some scatter plots to see these correlations. The results (containing the tectonic signal and other sources of errors, mainly atmospheric delays) correlate strongly with the topography as shown in fig. 6. To measure the LOS changes we consider a north south profile crossing the anticline (figs. 7 and 8) and measure the unwrapped phases.

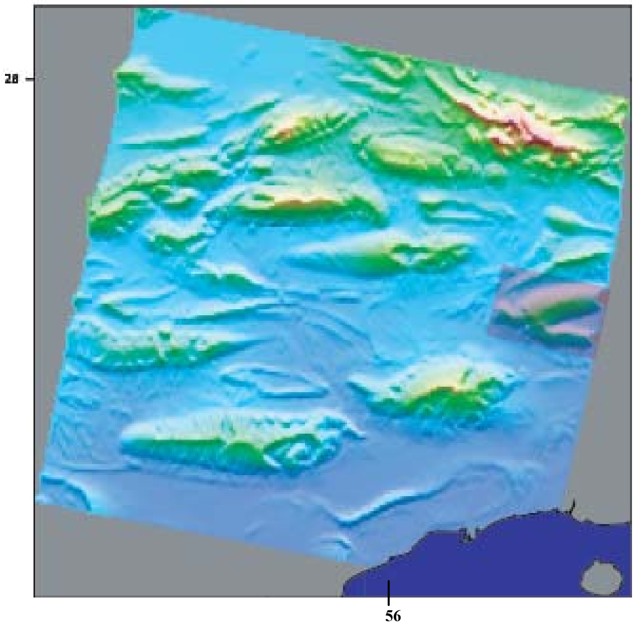


Fig. 4. Radar coded heights are converted to geocoordinates (WGS84) The area chosen for atmospheric analysis is outlined.

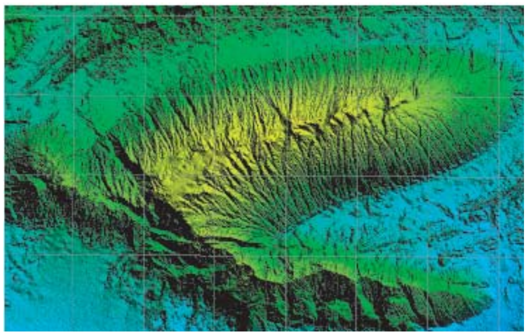

Fig. 5. Part of Initial DEM (10 m) used to remove the topographic phase

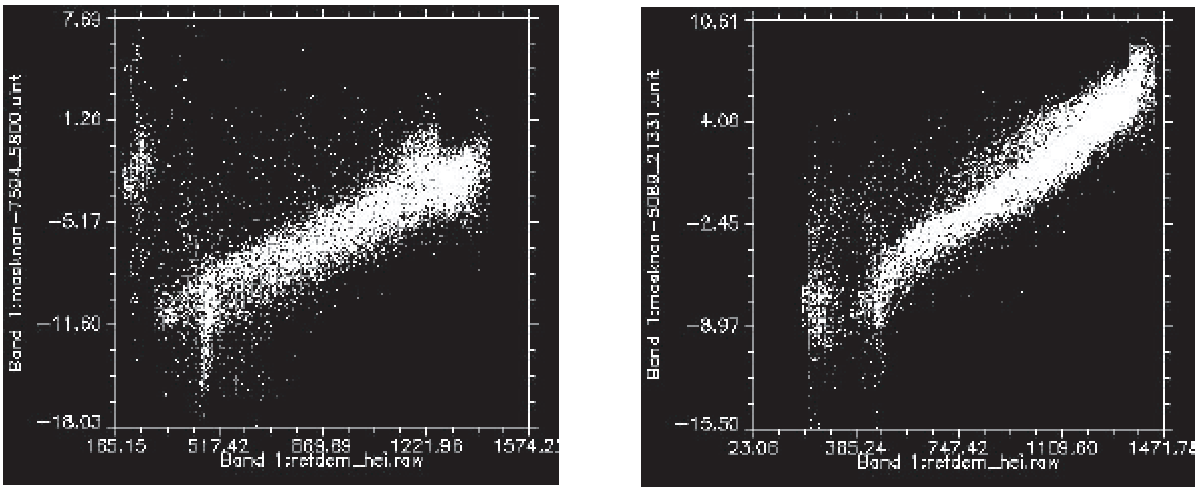


Fig. 6. Scatter plots of unwrapped phases (Left: after 3.5 years, Right: after ~7 years) over heights for sample area shown in fig 5. Two simple linear trends $d\varphi = 0.007*h-4\pi$ and $d\varphi = 0.01*h-4\pi$ are estimated for left and right plots respectively where $d\varphi$ is differential unwrapped phase in radians and $h$ is height in meters.

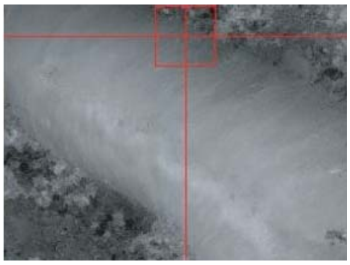

Fig. 7. Part of unwrapped interferogram showing location of NS profile over an anticline (flipped Fig 5) analyzed for atmospheric errors.

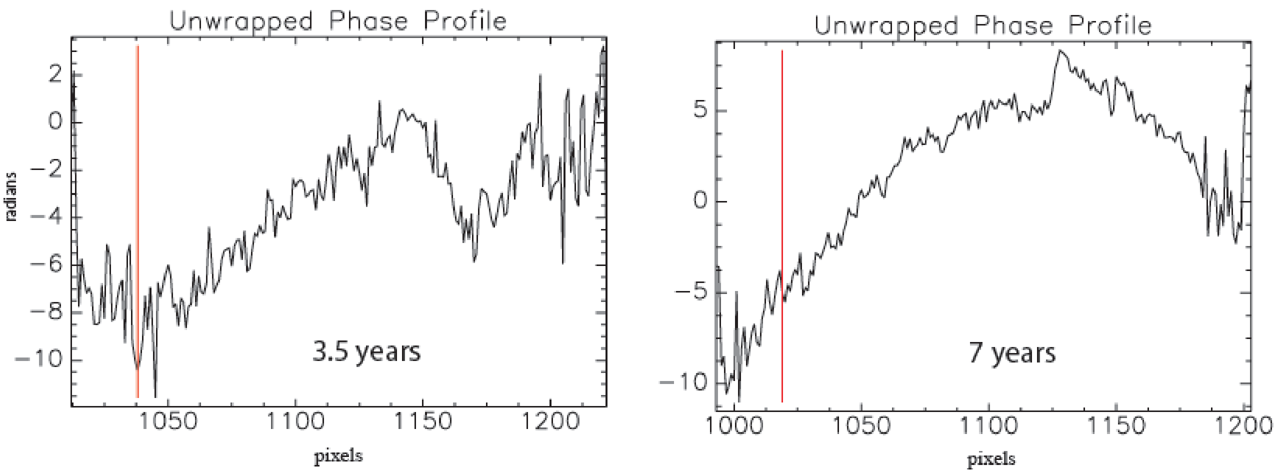


Fig. 8. North South profile extracted from unwrapped interferogram. Location of red line is shown by a cross in fig 7.

We estimate two trends from these two scatter plots (fig. 6) of phase vs. elevation. Figs. 8 and 9 show 4 measurements before (fig. 8) and after (fig. 9) removal of the elevation-phase trends in our unwrapped phases for two periods of 3.5

and 7 years deformation. Assuming the same elevation-phase trends in different parts of interferograms, we remove them from two interferograms (fig. 10).

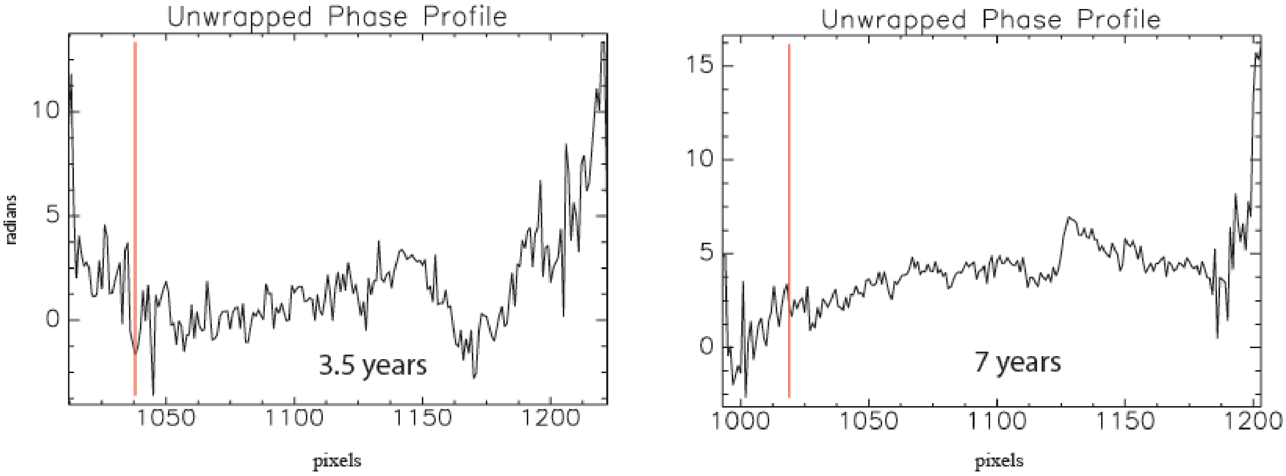


Fig. 9. North South profiles extracted from unwrapped interferogram after removing simple linear elevation-phase trends. Location of the red line is shown by a cross in fig 7.

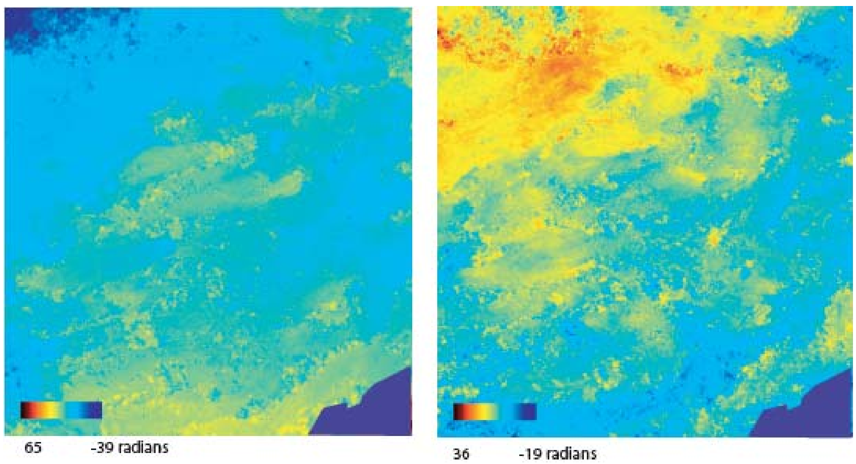


Fig. 10. Differential unwrapped interferograms after removing the elevation-phase trends for left: 3.5 years and right: ~7 years

## CONCLUSION

As the study area has a topographic relief of 3300 meters beside the extremely warm water of the Persian Gulf, the results are probably affected by water vapor contents that vary with elevation. The scatter plots of different parts of the area show that differential phases correlate strongly with heights. Changes in the atmospheric water vapor content between the acquisition times of our radar images may have generated some fringes that are mixed with any tectonic signal. Simple linear elevation-phase trends are estimated for two unwrapped interferograms (spanning 3.5 and 7 years) and removed from our unwrapped phases; this considerably reduces the atmospheric effects. This is done for part of the interferogram showing an active thrust and anticline. After removing the linear elevation-phase trends over the coherent area, the profiles of unwrapped phases show phase differences of about 3 radians which implies changes of about 13 mm of Line Of Sight (LOS) over 7 years. This suggests this anticline is rising at between 1~2 mm/yr. The other (3.5 year) interferogram is noisier but still implies some uplift. We examined phase-elevation ratios in our interferograms and found that slightly different equations fit linear elevation-phase trends in different parts. However removal of these elevation-phase trends reveals residuals that might represent the minimum tectonic signal. One salt dome shows circular fringes after 6 months but most have incoherent signals. The uplift rates reported here for part of the Zagros Mountains agree with geological studies [6, 7] but are preliminary. We will continue these investigations by analyzing more images and constraining this possible tectonic signal.


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