# Measurement and Modeling of Interseismic Deformation Near Parkfield, CA Using Radar Interferometry

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## Investigations undertaken

We have just begun this study at the beginning of last summer, therefore most of this report consists of plans for the completion of the work. Where possible we have indicated which parts of the study have been completed to date. The remainder of the investigation will be undertaken over the next eight monts.

## Summary of planned approach

In this study we are investigating the degree to which interferometric synthetic aperture radar interferometry may produce reliable measurements of crustal deformation at fine spatial scale, over wide areas, and without requiring field equipment at all potential sites. Our intent is to show that interseismic small motions such as creep may be identified and analyzed using InSAR. Our test area is at Parkfield, CA, because of the known creeping section north of Parkfield and the wealth of ancillary data available here.

Because of the fine spatial scale of the measurements and their continuous coverage, these data may also be used in inverse problems to determine the slip distribution on the fault at depth, such as in identification and mapping of locked and slipping zones. While over the past 20 years geodetic measurements such as GPS have led to major advances in modeling crustal deformation quantitatively, even these precise measurements are limited for many deformation fields. They lack spatial continuity and require field equipment at each study site. The radar methods offer solutions to these shortcomings, and yield complementary data that in turn lead to more complete models.

We proposed to extend the radar technique to detect displacements of a few cm/yr across a 100 km wide area, and to apply it to the observation of strain fields near Parkfield, CA.

Our objectives include investigating the limitations of SAR interferometry in determining small strain accumulations over terrain typical of the San Andreas fault region, and modeling these observed motions for structure at depth. This section of the fault zone contains a transition from a creeping segment to the north to a locked zone in the south, thus there will be a wide variety of strain rates and strain gradients present in the area, permitting an objective analysis of strain visibility. Because Parkfield is monitored extensive by ongoing programs, these data will provide a cross-comparison and add to the research already underway at Parkfield. While direct tests of the SAR approach in important urban regions are desirable, it is much more difficult to observe and understand instrumental effects and limitations in a geologically complex region such as the Bay Area. Thus Parkfield represents a good first step in our assessment of the applicability of radar interferometry to seismic hazard analysis.

**Experimental Task List**

To meet the budget constraints as recommended by USGS, we replaced the original list of tasks by the following, eliminating several parts of the study while maintaining the principal science objective of characterizing the slip on the San Andreas Fault using a combination of SAR interferometry measurements and inverse theory.

Our revised approach is to 1) acquire interferometric quality ERS-1 and ERS-2 data over Parkfield, 2) process the data into interferograms, 3) stack interferograms to achieve the largest region of reliable surface displacement maps and verify the results, 4) invert the results and analyze for consistency with models of fault structure.

1. ERS Data Acquisition. Since we have already been selected as investigators for the ESA AO3 program, archival ERS-1 and ERS-2 data are available at no cost for our research. This data-only proposal insures that we will be able to obtain 120 radar scenes over the next year or two, sufficient to study the Parkfield segment and any other areas along the San Andreas fault that would be relevant to this study.

In cases where appropriate, we will also be requesting data acquisitions from the NASA/JPL TOPSAR airborne radar system. These data provide somewhat higher resolution elevation data than the USGS 30 m data, and can give a more precise topographic correction. These data also are available through other programs and we do not need to cover their costs here. When available, we will also be using data from existing ground based geodetic (including GPS) networks to serve as verification and constraint points.

2. Data Processing and Verification. We will request raw data samples rather than processed products in order to minimize distortions and decorrelation in the final interferograms. We wish to process the data in the specialized ERS-1 data processor we have developed at Stanford. While this step is tedious and time consuming, we need to conduct the processing to insure consistent data quality. Verification activities include comparison of topographic products with existing digital elevation models and heights derived from the in situ GPS networks, as well as comparison of inferred motions with

those determined by GPS techniques. Preliminary data reduction of the ERS data will include interferogram correlation map formation. If correlation is acceptably high, topographic and surface deformation products will be generated.

3. Stacking. Because system noises such as decorrelation and atmospheric propagation effects are random processes, only averaging of the data sets will reduce the level of the noise. Fortunately, radar data were acquired over Parkfield every 35 days for much of the ERS mission, so that many passes are available. Our plan is to develop methods to stack several interferometric-quality data sets, which must be scaled by repeat time interval or fit overall with a weighted least-squares approach to compensate for the different temporal periods. Here we will determine a useful approach to stacking and use it.

4) Inverse theory and modeling. We will model the results using a dislocation model that varies along the fault in order to investigate possible structural changes with position. In this proposal, we will employ limited inverse methods conditioned on consistency with pre-defined forward models of slip distribution. We will use least-squares approaches to solving the integral equations, probably using Okada's (1985) analytical solution to the Volterra equation.

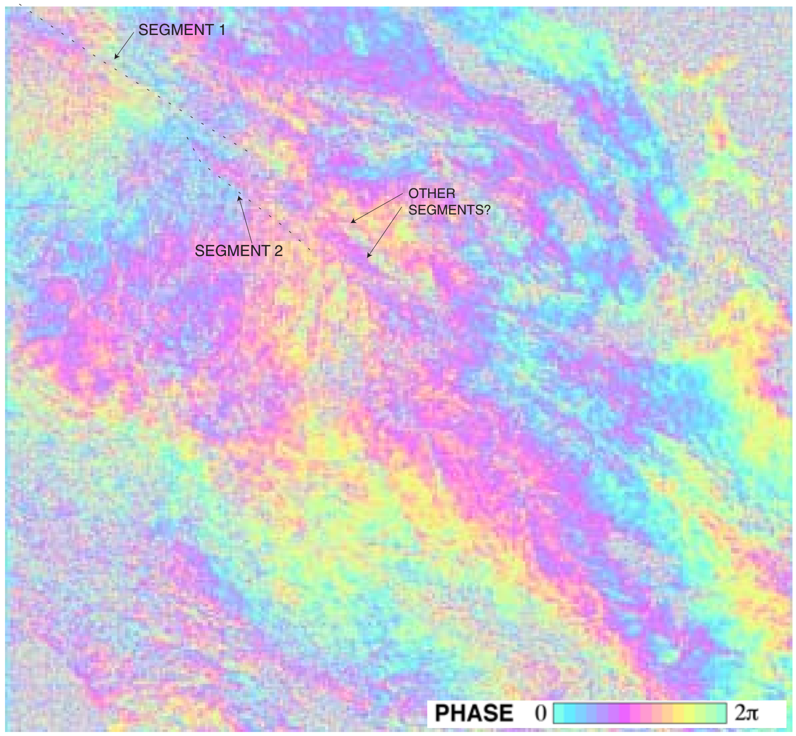
**Progress**

For task 1, we have acquired several ERS-1/2 data sets over the Parkfield region. Data we have acquired and analyzed are:

| Satellite | Orbit number | Date |
|---|---|---|
| ERS-1 | 25294 | 16 May 1996 |
| ERS-2 | 5120 | 12 Apr 1996 |
| ERS-2 | 5621 | 17 May 1996 |
| ERS-2 | 10130 | 28 Mar 1997 |
| ERS-2 | 12134 | 15 Aug 1997 |

These data were reduced to a set of interferograms according to the plans in task 2. A sample interferogram is shown below.

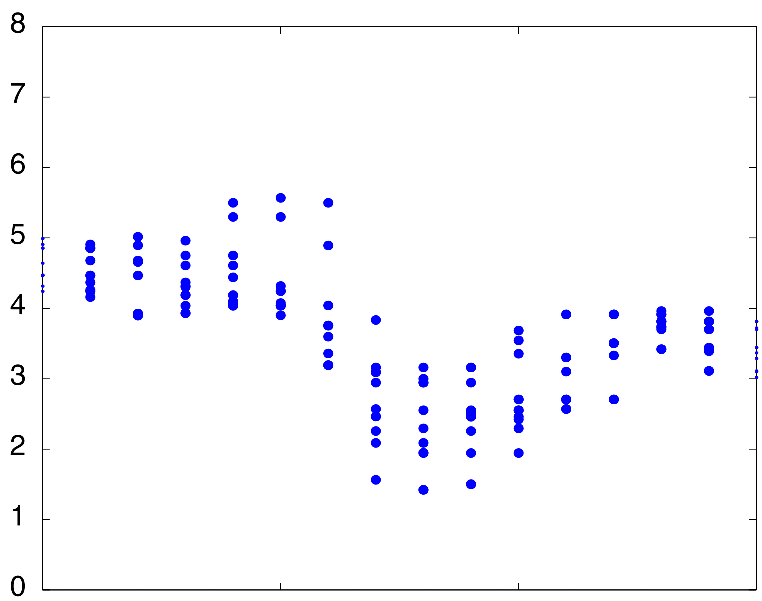
INTERFEROGRAM 12 APR 96 - 28 MAR 97




MEASURED PHASE (RAD)

We have also reduced the data along the creeping section in the northwest to estimates of displacement across the fault. These will be needed in the inversion to find the slip distribution at depth. A sample estimate of a cut across the fault, giving displacement as a function of distance from the surface trace, is:

42.4 KM



The numbers on the axis represent cm of displacement in the radar line of sight. The cut is taken at a location 42.4 km from the upper left end of the fault visible in the image. The various values at each abscissa represent the spread of data due to noise and other distortions in the data. Yet a clear jump of 2-3 cm is visible at the fault, with some increase in displacement just before the fault trace is reached. This overshoot will likely be the result of the distribution of slip at depth, which we will resolve in the remaining part of this study.

**Summary**

We have acquired and reduced InSAR data over Parkfield, CA, that clearly show the distribution of creep along the fault. We can measure creep as a function of position along the fault, and also estimate how that signal falls off with distance from the fault trace. The shape of this curve gives clues as to where the slip is occurring at depth. We will extend this approach to describe the fading of the creep signal from north to south in this area.

**Reports published**

None to date.

**Data availability**

All interferogram products and original data are available to interested users—please contact the PI at zebker@stanford.edu. Copyright restrictions on raw data may apply, but the reduced products are freely distibutable.