Reconciling InSAR and seismic observations of moderate size earthquakes

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Investigations undertaken

The primary focus of this work was to identify a set of moderate size earthquakes observable using interferometric synthetic aperture radar (InSAR) and then determine the source characteristics by modeling of the observed deformation. These results were then compared with source characteristics determined from seismic data. Primary results of the work were published in *Mellors et al*., (2004).

The purpose of the work was to test the use of InSAR as a source of calibration of source parameters derived from seismic data. For example, hypocentral depth often varies among seismic catalogs even in a well-instrumented area such as Southern California due to station geometry, variations in velocity structure, and location algorithm. The focal mechanism of these events also varies among catalogs, in part due to depth dependence. By using InSAR, we can test the accuracy of the locations and may be able to use InSAR constraints for 'ground truth' for improved station corrections or velocity models. An important part of the work was verifying the detection level of InSAR.

A secondary justification was to test the use of InSAR, which measures surface deformation, to set additional constraints on the source physics such as moment release and focal plane geometry. We chose moderate size earthquake as they are more numerous. They may be likely to possess simpler source physics than large earthquakes because the rupture area is smaller and does not intersect the free surface or brittle/ductile transition.

We address the following questions:

- *What are realistic InSAR detection limits and problems?*
- *How many events can we see with InSAR?*
- *Are the seismic data and InSAR data consistent? If not, why not?*
- *Are the differences within likely errors or does it reflect differences in source physics?*

The estimated line-of-sight surface deformation (as would be seen by InSAR) was calculated for all M > 4.0 events in the Southern California seismic catalog. Rupture areas were assumed to be square, with slip scaled to fault size. The seismic depth was assumed to be at the center of the fault with focal mechanism parameters taken from the seismic catalog. The catalogs of *Hauksson* (2000) (first-motion focal mechanisms and hypocenters) and *Zhu and Helmberger* (1996) (source parameters from waveform modeling) were used. We kept the events with deformation large enough to likely be detectable by InSAR. These were filtered to remove the events near the rupture of large events (e.g. Landers, Hector Mine, or Northridge) and in areas of low correlation. This left a set of 5 events with magnitude less than 6.0.

InSAR data was acquired (from the WINSAR archive) and processed to cover all events (Table 1). Multiple scenes and both ascending and descending data were used where possible, in order to discriminate between small events and artifacts from atmospheric water vapor, unwrapping, or incorrect topography. A matched filter based on seismic catalog focal mechanism was used to evaluate detection. Processing used

ROIPAC software with 90 m topographic DEM and the Delft orbits (*Scharroo and Visser*, 1998).

After identification of the events, modeling was done to estimate the source parameters. A grid-search algorithm was implemented which ranged over strike, dip, slip, depth, and moment to determined the optimal source characteristics and estimated range of error as constrained by the InSAR data. Synthetic data was originally used to calibrate the grid-search algorithm. As before, a square fault with slip scale to fault length was used. Several algorithms were used: a point-source in an elastic half-space, a finite source in an elastic half-space, and a reflectivity algorithm which yields the static point source solution.

Solutions were found for three events: the Dec. 4, 1992, Fawnskin event; the July 5, 1992 Pisgah event; and a set of aftershocks from October 21 and 22, 1999 of the Hector Mine event. In parallel with the InSAR effort, locations and focal mechanism were re-calculated using a 3D location algorithm. This was done to determine the error range of the locations for comparison with the InSAR results.

dates	***Sat.orbit***	***Sat,orbit***	***frame***	***track***	***Dir.***	***Bperp***	***days***
991020-000621	E2 23528	E2 27035	2907	127	desc	-28	245
920703-930129	E1 05053	E1 08059	2907	399	desc	126	210
920703-950402	E1 05053	E1 19425	2907	399	desc	59	1003
950402-980706	E1 19425	E2 16786	2907	399	desc	-31	1191
970127-970616	E2 09271	E2 11275	2907	399	desc	-299	140
951007-951216	E1 22109	E1 23111	0693	077	asc	-200	70
951216-991226	E1 23111	E2 24480	0693	077	asc	-64	1471

Table 1. List of pairs used for analysis of earthquakes.

Results

Events as small as M 5.2 were observable, but it is difficult to distinguish noise (especially atmospheric noise) from signal at the low levels. In particular, areas with high coherence were required. Only a fraction of the theoretically observable events presented a clear signal. However, 3 events (only one of which had been previously reported) were observed suggesting that moderate size events are a reasonable target for InSAR detection and analysis.

The seismic data and the InSAR data were consistent (Table 2). In fact, the InSAR results closely matched the results of careful 3D location algorithms and waveform-based locations. It suggests that the 1D seismic location (especially in depth) were biased. Given the range of errors in the InSAR estimates, no clear differences in source physics were resolvable. There were suggestions that it may be possible to resolve active fault planes of these events, which is potentially useful.

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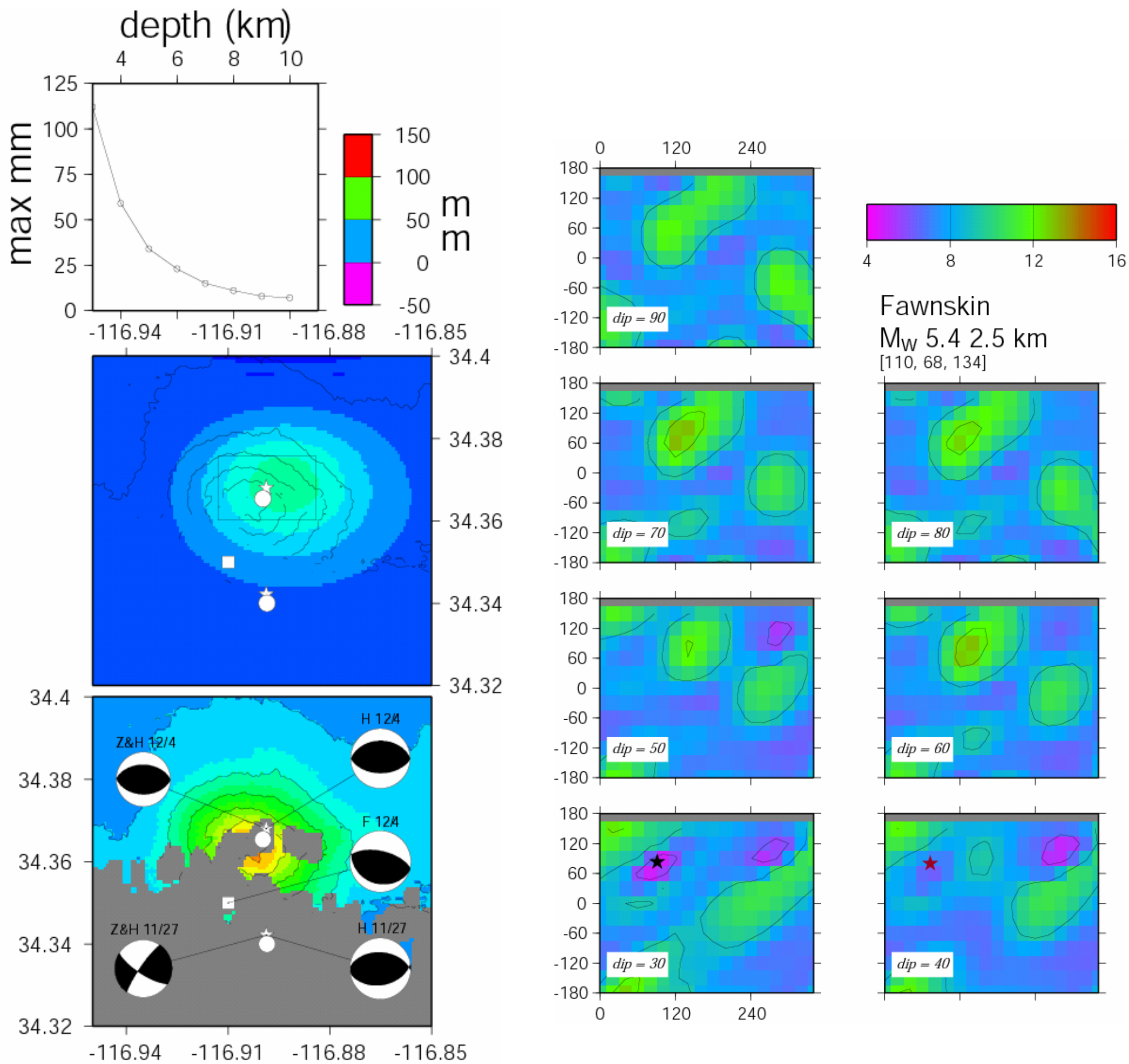

Figure 1. InSAR data compared with focal mechanisms and results of grid search of the Dec. 4 Fawnskin event. The bottom left map shows the unwrapped InSAR data with focal mechanism from *Hauksson* (2000) (denoted by H) and *Zhu and Helmberger* (1996) (denoted by Z&H). The focal mechanism marked F is from an InSAR study by *Feigl et al*.,(1995). Above the observed InSAR data is a model showing the predicted deformation (shaded) with contours representing the observed deformation. At top left is a graph of the predicted surface deformation versus depth for the best-fitting focal mechanism. A match of the observed deformation clearly requires a shallow depth. On the left is the results of a grid search match of the observed deformation over strike, dip, and slip with fixed moment and depth. The best fit is shown in purple.

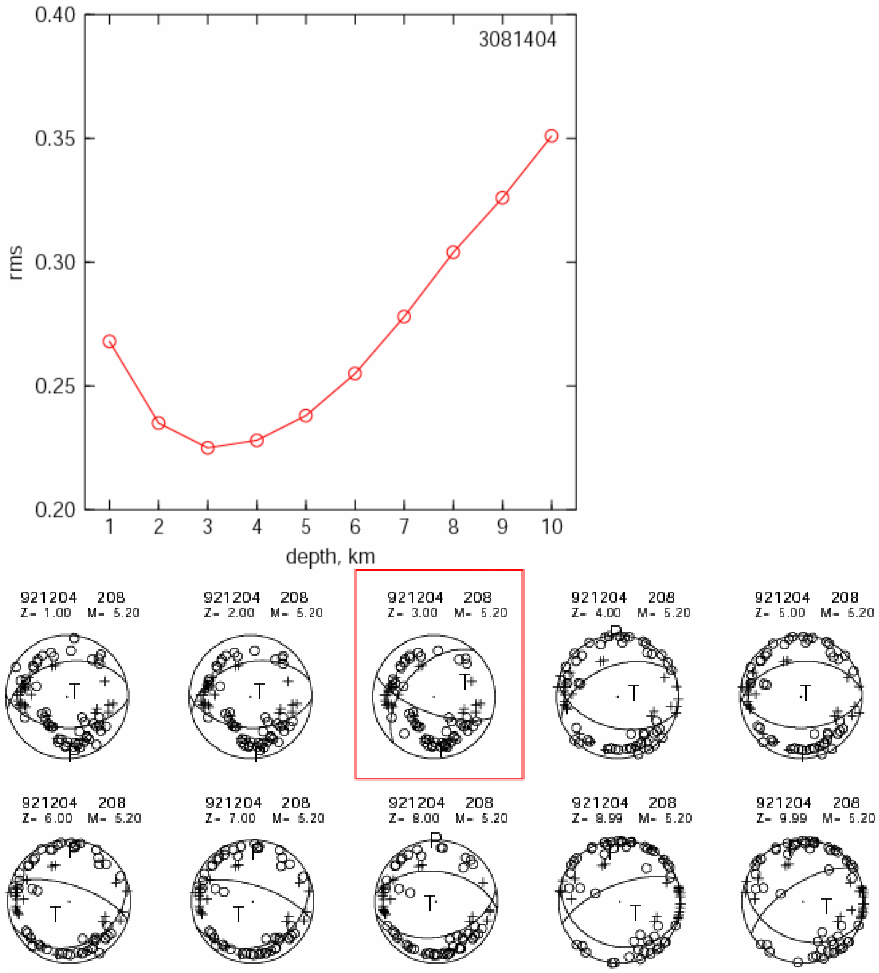

Figure 2. Depth constraints and focal mechanisms from a 3D location of the earthquake shown in figure 1 derived from seismic data. The top graph shows the error as a function of depth and the bottom shows the focal mechanisms as a function of depth. The red box outlines the best fitting depth.

Table 2. Comparison of InSAR locations and seismic.

Date	*Time*	*Long*	*Lat*	*Dep*	*erz*	*S*	*D*	*R*	*Ml*	*Mw*	*Source*
Pisgah											
92/07/05	21:18:27	-116.322	34.584	1.14	0.4	190	50	60	5.43		H
92/07/05	21:18:27	-116.322	34.584	1.14	0.4	75	75	170	5.43		H
92/07/05	21:18:27	-116.316	34.582	0.96	1.08						RD&S
92/07/05	21:18:27	-116.32	34.58	9.6	0.7	73	64	33		5.20	Z&H
92/07/05	21:18:27			> 5.0							M
Fawnskin											
92/12/04	02:08:57	-116.899	34.368	3.21	0.3	180	50	90	5.37		H
92/12/04	02:08:57	-116.900	34.365	0.53	0.21						RD&S
92/12/04	02:08:57	-116.900	34.37	4.3	0.8	91	44	90		4.81	Z&H
92/12/04	02:08:57	-116.91	34.35	2.6		106	28	98		5.4	F
92/12/04	02:08:57			< 4.0							M
Calico											
97/03/18	15:24:48	-116.825	34.970	0.8	1.3	145	70	-20	5.27		H
97/03/18	15:24:48	-116.824	34.977	7.61	1.30						RD&S
97/03/18	15:24:48	-116.825	34.970	6.6	0.5	59	65	9		4.76	Z&H
97/03/18	15:24:48			> 4.0							M
Hector Mine aftershock											
99/10/21	01:54:34	-116.407	34.878	-0.14	0.4				5.08		H
Hector Mine aftershock											
99/10/21	01:57:39	-116.402	34.861	2.97	0.04	70	75	10	4.95		H
99/10/21	01:57:39	-116.402	34.861	2.97	0.04	330	50	-170	4.95		H
Hector Mine aftershock											
99/10/22	16:08:48	-116.407	34.859	1.83	0.4	255	85	10	5.04		H
99/10/22	16:08:48	-116.407	34.859	1.83	0.4	350	35	180	5.04		H
Hector Mine aftershock (composite)											
				3.5	1.0	258	81	-12	5.3		M

Non-technical summary

Medium size earthquakes in California were located and identified using space-based radar. The results were compared to traditional methods of location using seismic data. We found that the radar was effective at locating and characterizing some of the earthquake but was not as sensitive or as comprehensive as the seismic data. This suggest that space-based radar may be a partially effective substitute in areas difficult to access with traditional means.

Availability of data

The results of the InSAR analysis and seismic catalog are available. The InSAR data itself is subject to constraints of the WINSAR archive, as the original data is copyright by the European Space Agency.

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