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Assimilation of D-InSAR and sub-pixel image correlation displacement measurements for coseismic fault parameter estimation

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Extended abstract:

The displacement field induced at the Earth's surface by the Kashmir earthquake of October 8th, 2005, has been analyzed by using sub-pixel correlation of SAR images [1] as well as optical images [2]. So far, the application of differential interferometry has not been successful in measuring the displacement of this earthquake because of the coherence loss due to decorrelation noise. Only few isolated areas of deformation signal are detected, which makes the phase unwrapping extremely difficult. In this paper, we apply both differential interferometry (D-InSAR) and sub-pixel image correlation on a series of ENVISAT images from October 2004 to June 2006 (Table 1) in order to map the deformation due to this earthquake. On one hand, in near field of the fault, with presence of a large magnitude deformation, the measurement with sub-pixel correlation is robust. On the other hand, in far field of the fault, where the deformation magnitude is small, the differential interferometry can provide precise information. As a result, the combination of these 2 methods allows us to obtain, at the same time, reliable information in near field and in far field. The strategy of combination will be discussed thereafter.

In regard to sub-pixel image correlation method, we calculate the offset in range and azimuth direction from the single look complex (SLC) images with the ROIPAC software [3]. Some post-processings, such as the filtering and some particular corrections are carried out to obtain the displacements only due to the earthquake in range and in azimuth directions.

Given the difficulty of phase unwrapping, we develop a particular chain which can take prior information on the displacement field into account. The estimation of phase gradient, corresponding to the instantaneous

Orbit Direction	No. Track	Acquisition Date	$B_\perp$ (m)	B_t (year)
Descending	191	20041018 - 20051107	18.5252	1.0532
	234	20051006 - 20060608	-42.0326	0.6721
	463	20041106 - 20051126	-21.9210	1.0548
		20041106 - 20060311	12.1250	1.3470
		20040724 - 20051022	-52.8583	1.2445
		20050917 - 20051126	113.1981	0.1913
Ascending	227	20050309 - 20060118	17.5586	0.8679
	270	20050625 - 20051112	72.4898	0.3811
	499	20050815 - 20051128	42.0463	0.2856
		20050815 - 20060313	42.4986	0.5779
		20050919 - 20051024	-268.0392	0.0970

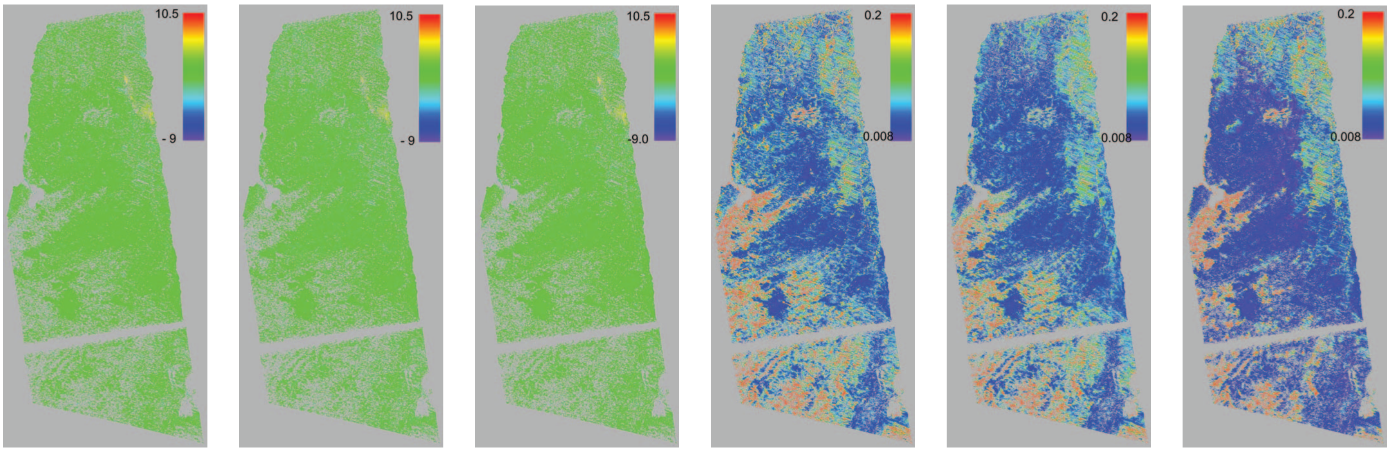
Table 1: Available data set for the measurement of Kashmir earthquake displacement field.

frequency of a signal, named local frequency below, can be seen as a problem of spectral analysis on small windows. In our phase unwrapping method, the interferogram fringes are characterized by estimating their local frequency at different scales. Then the local frequencies at different scales are combined in order to eliminate the noise and to avoid the aliasing problem. Finally, the interferometric phase is unwrapped from the combined local frequencies by using a global least squares method.

All of the measurements from differential interferometry and sub-pixel image correlation are considered as projections of the surface 3D displacement field in the radar range or azimuth directions. In order to facilitate the analysis of the surface deformation, we construct the 3D surface displacement field (the E,N,Up components) by combining three or more projections from different acquisition modes (ascending and descending) through inversion. According to the availability of different measurements and possibility of inversion, we decide to perform the inversion in three cases:

1. We take 4 measurements from sub-pixel image correlation.
2. We add all of the remaining available measurements from sub-pixel image correlation.
3. We add all available measurements from D-InSAR to the 4 measurements from sub-pixel image correlation used in the first case.

Furthermore, the retrival of 3D surface displacement field is performed in two different ways. Firstly, we apply a conventional weighted least square method [4] [5] [6] [1]. In this case, the input uncertainty is the pseudo-variance of displacement for sub-pixel image correlation measurements and phase variance estimated from coherence for D-InSAR measurements. The output uncertainty is obtained through error propagation. Figure 1 shows an example of up component of 3D surface displacement estimated by conventional method in three cases. Secondly, we apply a non-weighted least square method, the displacement uncertainty is expressed by fuzzy intervals. From the displacement value and associated uncertainty in conventional method, we construct the fuzzy intervals [7] for input measurements. The output fuzzy intervals are retrieved



(a) (b) (c) (d) (e) (f)

Figure 1: Up component of surface 3D displacement (a) (b) (c) and associated uncertainty (d) (e) (f) in case with 4 measurements of sub-pixel image correlation (descending track 463 (20041106-20051126) + ascending track 270 (20050625-20051112)), all available measurements of sub-pixel image correlation and 4 measurements of sub-pixel image correlation (descending track 463 (20041106-20051126) + ascending track 270 (20050625-20051112)) plus 3 projections from D-InSAR (descending track 463 (20041106-20051126, 20041106-20060311) + ascending track 270 (20050625-20051112)). UTM geometry.

though the standard fuzzy arithmetic [8], computed by a method exposed in [9]. The results of these two methods are compared and the interest of the second approach for the experts is discussed.

In geophysical studies, we aim to retrieve, from the surface displacement field, the geophysical parameters (strike, dip, depth, length) as well as the slip distribution of the fault which ruptured and caused the earthquake. This is realised by inverting a forward mechanical deformation model describing the surface displacement field induced by a fault rupture. Inversion is performed by minimizing a misfit function which represents the difference between the surface displacements estimated by the forward model and the measurements. For the Kashmir earthquake, Pathier et al. [1] carried out such un inversion using 6 measurements from sub-pixel image correlation. In this paper, we follow the same approach, adding more measurements from sub-pixel image correlation and measurements from D-InSAR. Moreover, we investigate the improvement of displacement uncertainty due to redundant information, in particular the contribution of measurements from D-InSAR. To model the static deformation on the fault, we use a homogeneous linear elastic halfspace model known as the Okada's model [10] and assume that the fault dislocation is made of rectangular planes reaching the surface [10] [11] [12] [1]. The geometry of the fault and the distribution of the deformation are carried out by two steps. Firstly, the geometry of the fault is optimized, given the assumption of uniform slip, by looking for a global minimum misfit with the measurements from both sub-pixel image correlation and D-InSAR. Secondly, the fault plane is extended and divided into 2 km $\times$ 2 km patches, and then the deformation model is inverted on each patch for slip distribution. Finally, the feedback of the estimated parameters to the measurements combination steps is analyzed.

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