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Comment on"Geodetic investigation of the 13 May Kozani-Grevena (Greece) earthquake" by Clarke et al.

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In a recent paper, Clarke et al. [1997] try to describe the coseismic displacement field of the 1995, Grevena (Northern Greece) earthquake by comparing triangulation surveys of a geodetic network made in 1984-1986 and a post-earthquake survey of the same network with GPS made in 1995. The composite triangulation-GPS horizontal displacement obtained and the model proposed are inconsistent with important tectonic, seismological and geodetic observations that Clarke et al. [1997] have ignored in their inversion procedure.

Concerning the tectonics the Clarke et al. [1997] paper is internally inconsistent. On the one hand Clarke et al. [1997] postulate that "no obvious surface break was found so it was not possible to locate the fault plane *a priori*" (p. 707), but on the other hand they incorporate in their map (their Fig. 1), without appropriate citation, the approximate location of the surface break along the Palaeochori Fault described by Meyer et al. [1996]. This break and the other active faults in the area have been identified with modern morphological techniques using the SPOT satellite imagery and the field evidence for Holocene slip [Meyer et al., 1996]. The tectonic results ignored by Clarke et al. [1997] are as follows. The 1995 surface break was mapped in detail for 8 km along the pre-existing Palaeochori normal fault, a feature with topographic relief of about 50 m clearly seen in the SPOT images (see Fig. 1a in Meyer et al. [1996]). The fault strikes N70°E with near-surface dip of 70° to the northwest and the 1995 break was a continuous strand formed by open fissures and small scarps with 2-4 cm down-to-the-northwest normal slip (see Figs. 1, 2a and 2b in Meyer et al. [1996]). There is no evidence in the SPOT satellite imagery nor in the field, of significant surface faulting southwestward beyond the mapped southwest tip of the Palaeochori Fault. Several smaller segments, however, are found stepping NE and splaying SE of the northeast tip of the Palaeochori fault. The presence of numerous small slumps over the surface traces of these fault segments suggests that they also ruptured during the main event. One important result was to establish that the much more prominent Servia and Paliuria faults did not break, in spite of the clear evidence for Holocene activity (see Figs. 1, 2c and 2d in Meyer et al. [1996]). Selectively, Clarke et al. [1997] use this tectonic information to fix the position of the fault plane, not the upward nor the lateral extent of the rupture.

The model by Clarke et al. [1997] is consistent with the fault plane solution of the main shock [Hatzfeld et al., 1997] but it proposes that the rupture extended 27 km along strike, far beyond the observed tips of the Palaeochori Fault, WNW across the Vourinos Range and especially ESE into the Mesohellenic Trough. This gives a seismic scalar moment of 16.3×10^{18} Nm, twice that of the Harvard's CMT solution (7.6×10^{18} Nm); improbable though not impossible.

Finally, the composite triangulation-GPS vectors and the model by Clarke et al. [1997] are in serious conflict with geodetic information provided by the SAR interferometry, a technique that has now proved to be of prime importance in resolving the coseismic [e.g., Massonnet et al., 1993] and even the more subtle postseismic displacement fields [Peltzer et al., 1996]. For the 1995 Grevena event the basic SAR information is given by Meyer et al. [1996]. To summarize, the SAR interferograms obtained with the ERS-1 satellite scenes covering two-years intervals including the date of the earthquake reveal 11 well-defined concentric fringes outlining a kidney-shaped area of subsidence of 400 km^2 with maximum of about 30 cm (Fig. 1a). The model by Clarke et al. [1997] implies many more fringes (20), corresponding to about 53 cm subsidence (Fig. 1c), and a longer along-strike subsidence zone of 50 km compared to the about 25 km observed in the interferograms. The surface displacement field seen in the interferograms can be modelled using a dislocation embedded in an elastic half space, incorporating the tectonic constraints and increasing progressively the complexity of the model to fit quantitatively, by trial and error, the details of the SAR information (Fig. 1b). These details allow for modelling with some precision the faulting complexities of the NE end of the rupture zone [Meyer et al., 1996]. The overall model is consistent with the tectonic constraints, the hypocenter, the fault plane solution and the CMT scalar moment in addition to the inference that the surface deformation seen in the interferograms is mostly coseismic. The horizontal displacement field derived from this model (Fig. 1b) can be compared with the composite triangulation-GPS vectors (Fig. 1c). The corresponding vectors are roughly comparable in the small area close to the Palaeochori Fault, but they are completely inconsistent in the far field. The horizontal vectors predicted from the model by Clarke et al. [1997] fit somewhat better the triangulation-GPS vectors in the near field, but important discrepancies persist in the far field. Overall the fit is, in our opinion, unsatisfactory. The large composite displacements (10-20 cm) seen with the triangulation-GPS technique at significant distance from the Palaeochori fault cannot be explained by any reasonable coseismic model (Fig

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1c). Thus, the composite triangulation-GPS displacement vectors include either very substantial interseismic strain and/or large bias and error, apparently unexpected by Clarke et al. [1997].

We conclude that GPS resurveying of old triangulation networks may give much less accuracy than supposed and is thus inadequate to solve for an earthquake dislocation. The tectonic and the SAR information cannot be ignored. In a more general way, modelling through "blind" inversion techniques that do not easily incorporate widely different data sets can be misleading for these strongly non-linear problems.

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References

Clarke, P.J., D. Paradissis, P. Briole, P.C. England, B.E. Parsons, H. Billiris, G. Veis and J.C. Ruegg, Geodetic investigation of the 13 May 1995 Kozani-Grevena (Greece) earthquake, *Geophys. Res. Lett.*, *24*, 707-710, 1997.

Hatzfeld, D., et al., The Kozani-Grevena (Greece) earthquake of May 13, 1995, A seismological study, *Bull. Seism. Soc. Am.*, *in press*, 1997.

Meyer, B., R. Armijo, D. Massonnet, J.B. de Chabalier, C. Delacourt, J.C. Ruegg, J. Achache, P. Briole, and D. Papanastassiou, The 1995 Grevena (Northern Greece) earthquake: Fault model constrained with tectonic observations and SAR interferometry, *Geophys. Res. Lett.*, *23*, 2677-2680, 1996.

Massonnet, D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl and T. Rabaute, The displacement field of the Landers earthquake mapped by radar interferometry, *Nature*, *364*, 138-142, 1993.

Peltzer, G., P. Rosen, F. Roger, K. Hudnut, Postseismic rebound in fault step-overs caused by pore fluid flow, *Science*, *273*, 1202-1204, 1996.

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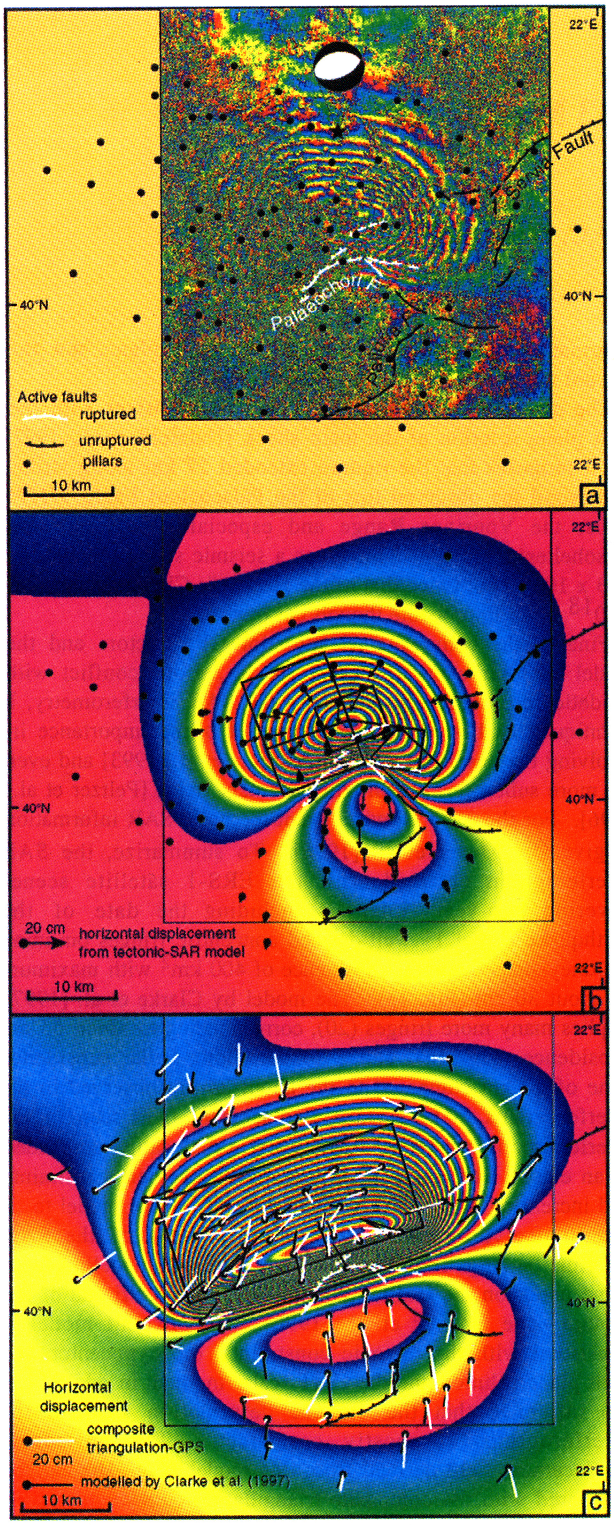

Figure 1. Observed coseismic displacement field and two alternative models for the 13/05/1995, Grevena (Ms = 6.6) earthquake. According to Meyer et al. [1996] the Grevena earthquake activated the small Palaeochori Fault (and the small segments at its NE end, white) and not the larger Servia and Paliuria Faults (black). Black dots represent the location of the pillars of the Greek geodetic network. **a.** Interferogram describing the surface displacement between 16/11/93 and 05/10/95 (from Meyer et al. [1996]). Each fringe represents 28-mm displacement between the ground and the ERS-1 satellite (unit vector [east, north, up] is [0.402, -0.083, 0.912]). **b.** Synthetic fringes generated with the preliminary model of the SAR interferograms using the tectonic information (from Meyer et al. [1996]). The horizontal coseismic displacement predicted for the pillar network is represented by the black arrows. The rectangles represent the fault model. **c.** The horizontal displacement between 1984-1986 and 1995 (white lines) as deduced with the composite triangulation-GPS technique by Clarke et al. [1997]. The black lines represent the horizontal displacement deduced from the inversion of the triangulation-GPS composite information by Clarke et al. [1997], fixing the fault geometry and position but ignoring other *a priori* information. The rectangle and the parallel straight line represent the corresponding fault model and the projected surface trace which is close to that of the Palaeochori Fault. The synthetic fringes are generated here with the model parameters given by Clarke et al. [1997]. They imply a subsidence area with about twice the number of fringes and about twice the along-strike length observed in the interferogram shown in (a) and modelled in (b). The corresponding scalar seismic moment is also twice that of the Harvard's CMT solution.