# Complexity of the Mw6.3 2009 L'Aquila (central Italy) earthquake:
# 1. Multiple finite-extent source inversion
**ELECTRONIC SUPPLEMENT**

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## Introduction

Here we present two additional synthetic tests of the MuFEx source inversion. The approach we have taken is exactly the same as in the main text (see, e.g., the inversion flowchart in Figure 2). Thus we concentrate only on the explanation of the tested input model and comment the major outcomes from the inversion results. Note that synthetic test #1 (mimicking the result from the real data application, but without the deep-asperity time delay) is presented in the Appendix of the main text, thus we start with synthetic test #2.

## Synthetic test #2 - Bilateral rupture model

The synthetic data are produced for a bilateral rupture model with two asperities located on the sides of the fault (see Figure E1, panels A and B). The rupture propagates at a constant rupture velocity of 2 km/s, which makes the model even more different from the others.

The locations and sizes of the MuFEx subsources are based on the result of the TSVD and ISOLA inversions (Figure E1, panels C and D). Note that both TSVD and ISOLA resolve correctly the bilateral character of the rupture, but (unlike ISOLA) the TSVD result underestimates the right asperity, despite the very high fit of the data (variance reduction VR=0.99 for TSVD and VR=0.97 for ISOLA). This effect is similar in all three synthetic tests and can perhaps be attributed to the station coverage (see stations AQV and AQK present above the well-resolved part of the fault).

The MuFEx source model consists of three subsources (see Figure E1, panel C). The best fitting model (together with the input model) is shown in Figure E2, showing also the locations of the trial nucleation points. This model (VR=0.99, same as for TSVD) resolves the slip values of the asperities better than TSVD. This is further confirmed by the uncertainty analysis shown in Figure E3: The slip value of Subsource 1 can attain zero value even with only a very small decrease of the overall VR, and both subsources at the sides of the fault (2 and 3) require relatively large slip values. Nevertheless, Subsource 3 can also attain very small slip values if VR is allowed to drop down to 0.95. The rupture velocities of the subsources are not well constrained, with a very minor preference of smaller values (<~2 km/s). The same applies to the trial nucleation point positions and the nucleation times. As for the latter, nucleation times of up to 3-4 seconds are allowed, but not required. The total seismic moment of the best models are around the correct values (2.4e18Nm).

## Synthetic test #3 – Complementary unilateral rupture model

In this case the model to be inverted consists of two asperities located at the fault areas, where no significant slip was found in the real data inversion (compare Figure E4 and Figure 5 in the main text). That is why we call it 'a complementary model'. The rupture propagates from the

same nucleation point as in synthetic test #1 at a constant velocity of 3 km/s, but the top right asperity is delayed by two seconds. Figure E4 (panels C and D) shows the result of the TSVD and ISOLA inversions. Areas of high values of inverted slip velocity (and/or location of major ISOLA subevents) are used for the preliminary setup of the two MuFEx subsources. In addition, we introduce a third MuFEx subsource located in a questionable part of the fault (see the smallest subsource in Figure E4) to test what happens when such a spurious subsource is tested in the MuFEx analysis. Note that the fit is excellent (VR=0.99 for TSVD and VR=0.98 for ISOLA) although again the right asperity is underestimated (in this case both by the TSVD and ISOLA approaches).

Figure E5 shows the best-fitting MuFEx source model (VR=0.98) in comparison with the input model. Note that the slip values are again better balanced than in the preliminary TSVD and ISOLA analysis. Nevertheless, the spurious Subsource 3 has been assigned a non-zero value. However, the uncertainty analysis (Figure E6) suggests that this subsource can be neglected already when a negligibly small decrease of the fit (with respect to the best value) is allowed. The other two subsources require slip values of 0.3-0.6 meters. Interestingly, the best models are characterized by smaller seismic moments (by 20%) compared to the input model although the correct moment (2.4e18Nm) is allowed. Well resolved is the nucleation point of Subsource 1 (#1 in Figures E5 and E6). The rupture velocities are again not well resolved as in the previous tests.
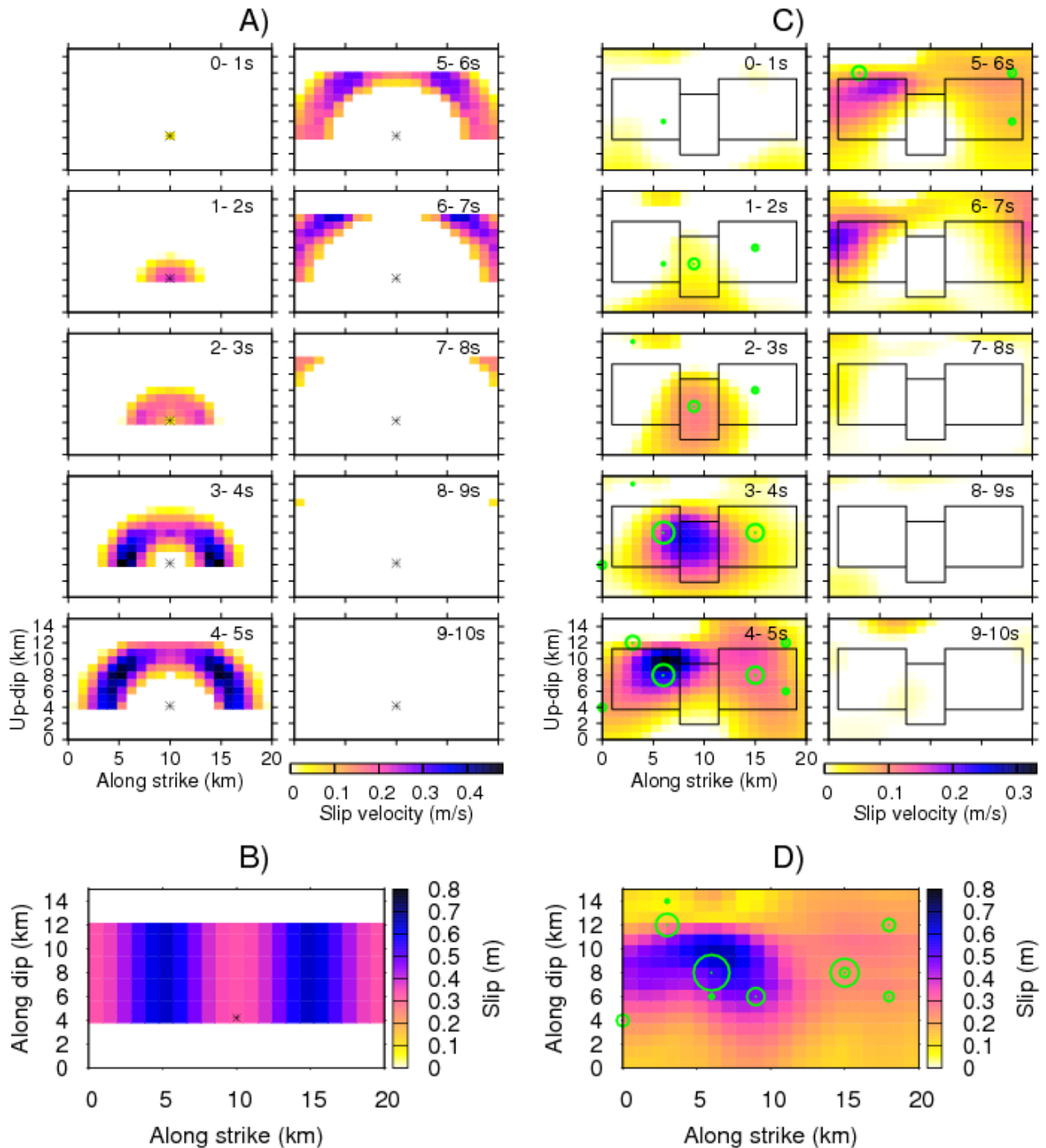
**Figures**

Figure E1. Setting up the MuFEx source model for synthetic test #2 (bilateral rupture). A) Slip velocity snapshots of the input model with assumed constant rupture propagation (2 km/s) from the hypocenter (asterisk). B) Final slip of the input model. C) Snapshots of the model inverted by the TSVD approach with truncation at 1/10 of the largest singular value. The truncation level is dictated by the application of TSVD when applied to the real data. The fit of the seismograms is almost perfect (variance reduction VR=0.99). The multiple point-source (ISOLA) inversion is shown by green circles proportional to the moment (the largest circle corresponding to $4.9 \times 10^{17}$ Nm, VR=0.97). Here it is in good agreement with TSVD. Areas with large slip velocities (or locations of largest ISOLA point sources) are used for the first setup of the MuFEx subsources. The final MuFEx subsources are shown as rectangles. D) Final slip of the inverted model. Note that the slip map is highly biased due to the effect of the truncation (regularization) during the inversion. The right asperity is highly underestimated in TSVD.
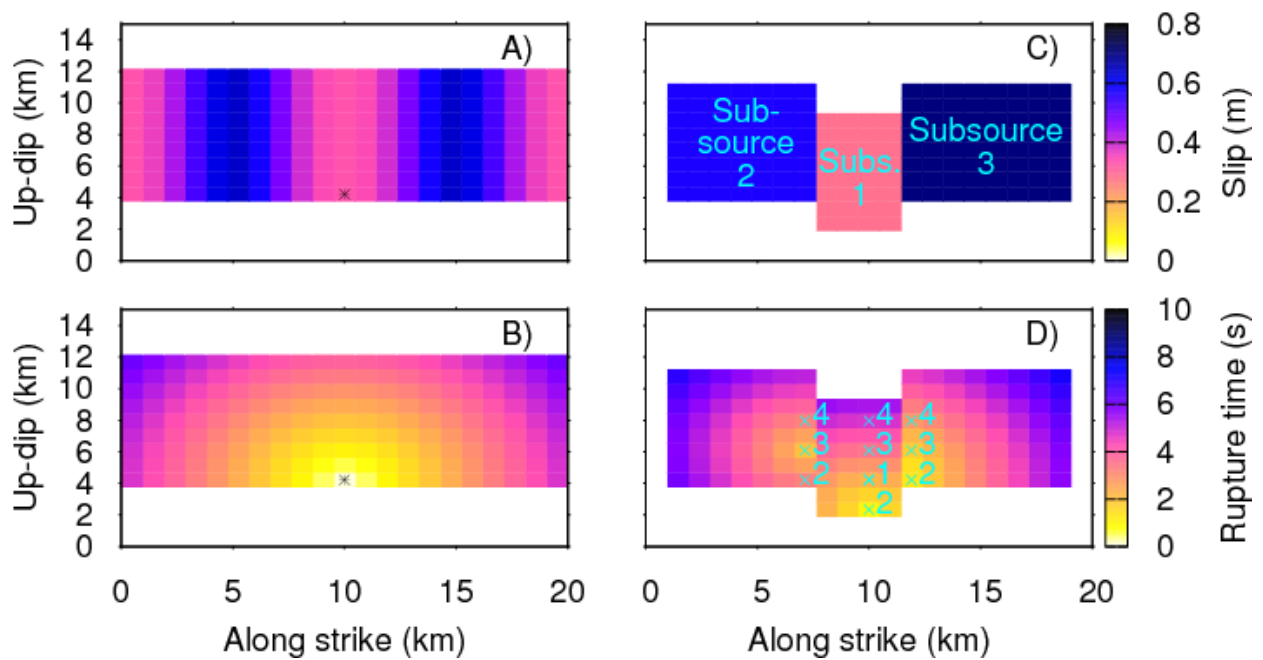
Figure E2. Synthetic test #2 of the inversion by the MuFEx source model. A) Final slip (same as in Figure E1B), and B) rupture times of the input test model. The setup of the MuFEx subsources is based on the TSVD and ISOLA inversions (see Figure E1). The asterisk denotes the hypocenter. Panels C) and D) show the best-fitting (grid-searched) MuFEx model in terms of the final slip and rupture times, respectively (VR=0.99). The numbered points represent the trial nucleation points of the subsources; these are different for the different subsources, except for trial nucleation point #1, common to all the subsources. Panels C) and D) are to be compared with panels A) and B), respectively. Note that the slip model corresponds better to the input model than in the case of the TSVD inversion (panel B in Figure E1) – the right asperity is not underestimated.
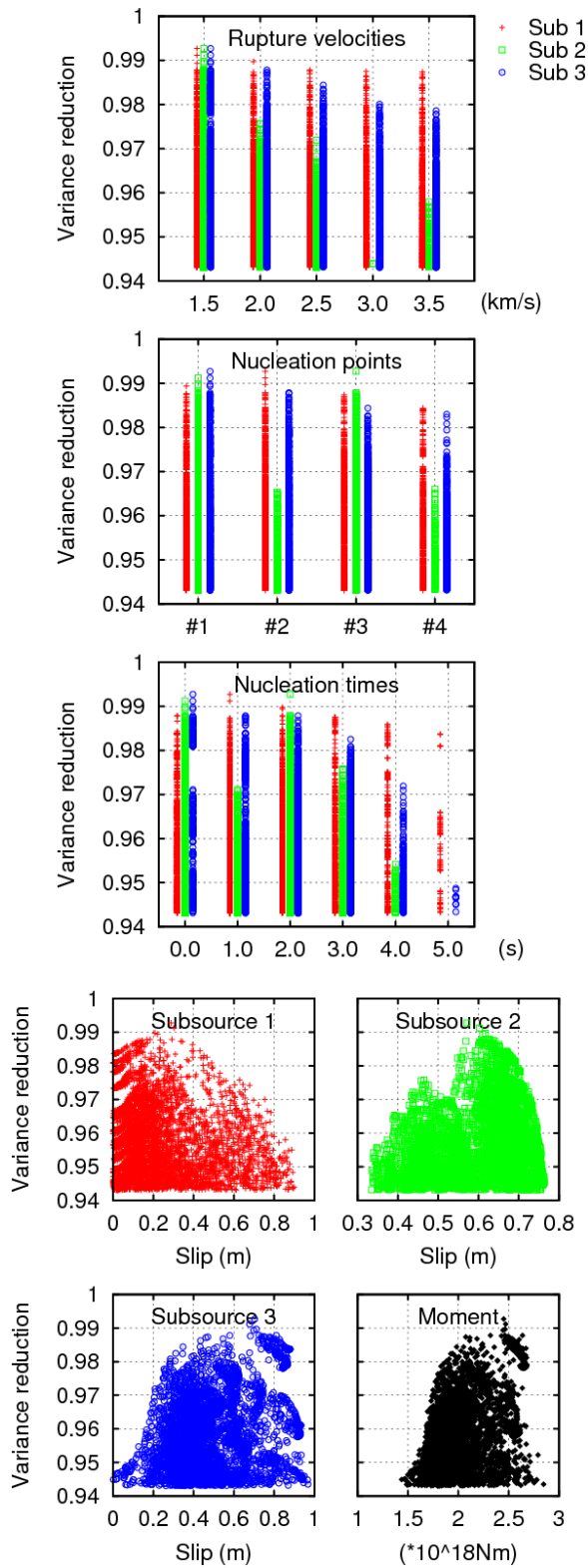
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Figure E3. The uncertainty analysis of the whole population of the grid-searched MuFEx source models with VR>0.94 for synthetic test #2. The analyzed set consists of approximately 4400 models out of ~2 million trial ones. The first three plots from the top show the sensitivity of the data to the trial parameters of the MuFEx model, namely the rupture velocities, nucleation points and nucleation times. For the locations of the tested nucleation points see Figure E2. The remaining four plots analyze the slip distribution of the three subsources individually and the total seismic moment. Note that the seismic moment of the best-fitting model corresponds to the input model (2.4e18Nm), but already a small drop in the VR value yields a significant variation of the moment value. The rupture velocity of 2km/s in the input model is not well constrained.
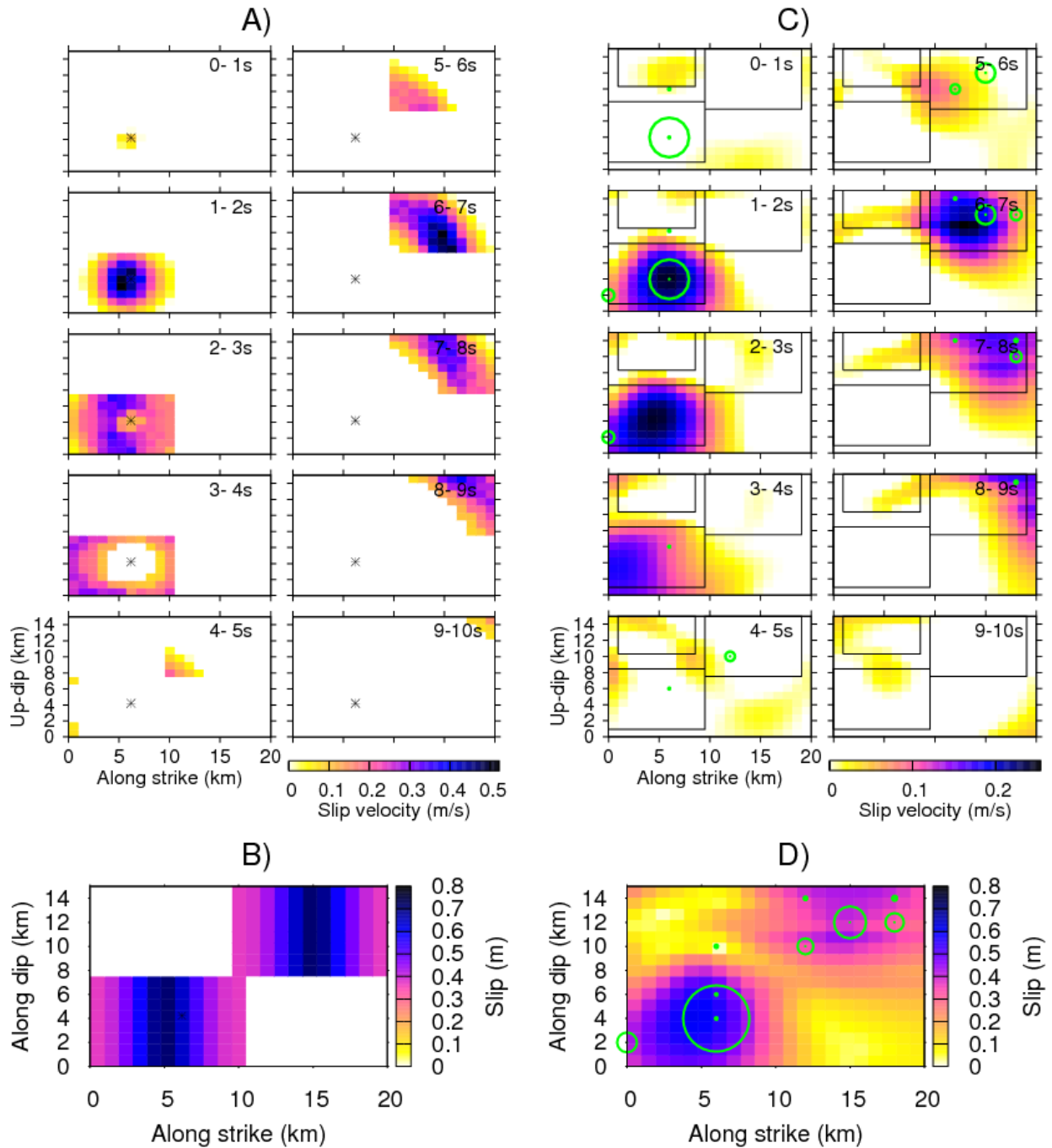
Figure E4. Same as Figure E1 but for synthetic test #3 (unilateral rupture with different position of asperities and including the 2s time delay of the shallow asperity with respect to the constant speed of 3 km/s). VR=0.99 for the TSVD inversion, while VR=0.98 for the ISOLA inversion (the moment of the largest circle corresponds to $9.0 \times 10^{17}$ Nm). Note that the slip map is again biased due to the effect of the truncation (regularization) during the inversion. The top right asperity is underestimated by both TSVD and ISOLA. Note that the smallest Subsource 3 (top left in panels C) is located at a position where no slip is present in the input model. It merely serves to illustrate how the MuFEx analysis treats such a spurious subsource in the inversion (see Figures E5 and E6).
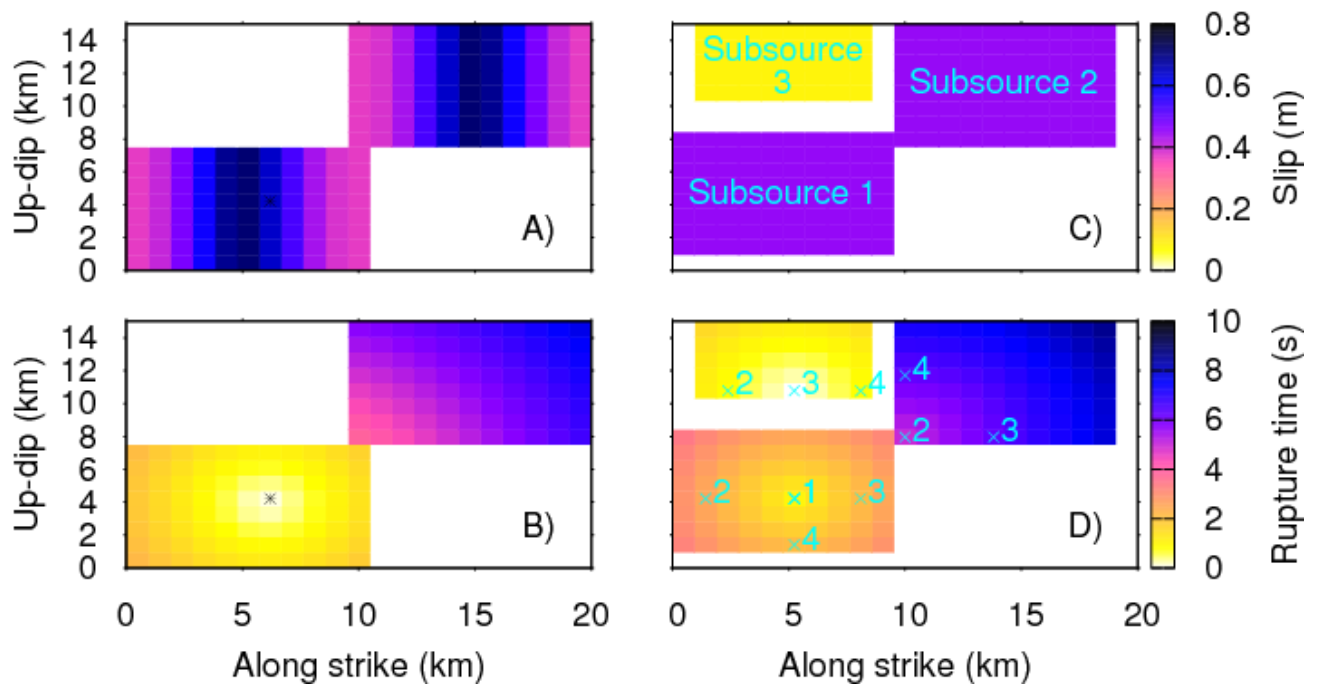
Figure E5. Same as Figure E2 but for synthetic test #3 (VR=0.98). The relative strength of the Subsources 1 and 2 is balanced better than in the preliminary inversion by the TSVD technique. Furthermore, the spurious asperity (Subsource 3) is relatively weak.
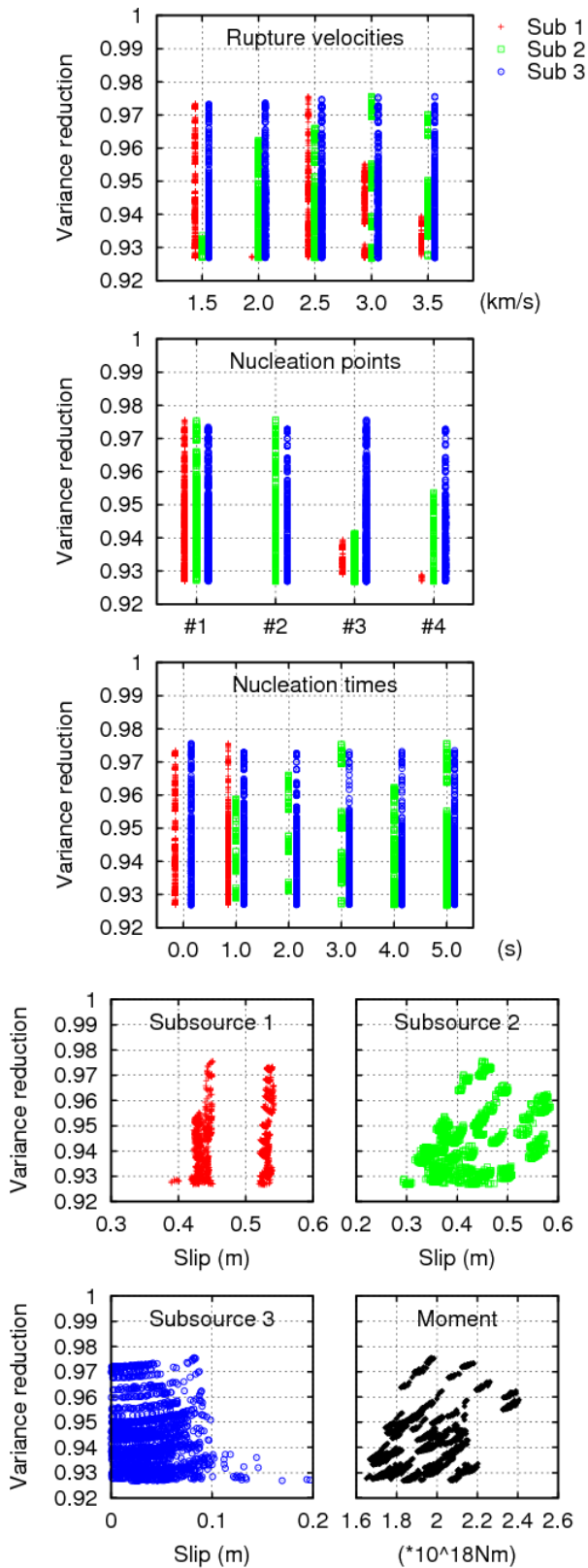
Figure E6. Same as Figure E3 but for synthetic test #3. The analyzed set consists of approximately 2000 models out of ~2 million trial ones (VR>0.93). The location of the tested nucleation points is shown in panel D in Figure E5. Note that the uncertainty analysis allows zero slip (i.e. the correct value) for the spurious Subsource 3. Rupture velocity of 3km/s in the input model is not well constrained, but a 2s time delay of the shallow asperity (approximately Subsource 2) is clearly indicated. Interestingly, in this experiment the seismic moment of the input model (2.4e18Nm) is not fitted well by the best-fitting model; nevertheless, it is included among the plausible models.