

1 **A stochastic view of the 2020 Elazığ  $M_w$  6.8 earthquake**

2 **Théa Ragon<sup>1</sup>, Mark Simons<sup>1</sup>, Quentin Bletery<sup>2</sup>, Olivier Cavalié<sup>2</sup>, Eric**  
3 **Fielding<sup>3</sup>**

4 <sup>1</sup>Seismological Laboratory, California Institute of Technology, Pasadena, CA, USA.

5 <sup>2</sup>Université Côte d'Azur, IRD, CNRS, Observatoire de la Côte d'Azur, Géoazur, France.

6 <sup>3</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

7 **Key Points:**

- 8 • We infer a stochastic model for the distribution of subsurface fault slip associated  
9 with the 2020 Elazığ earthquake
- 10 • We account for uncertainties in both the depth-dependence of the assumed elas-  
11 tic structure and the location and geometry of the fault
- 12 • Our models are characterized by two primary patches of fault slip where distri-  
13 bution appears to be controlled by geometrical complexities

---

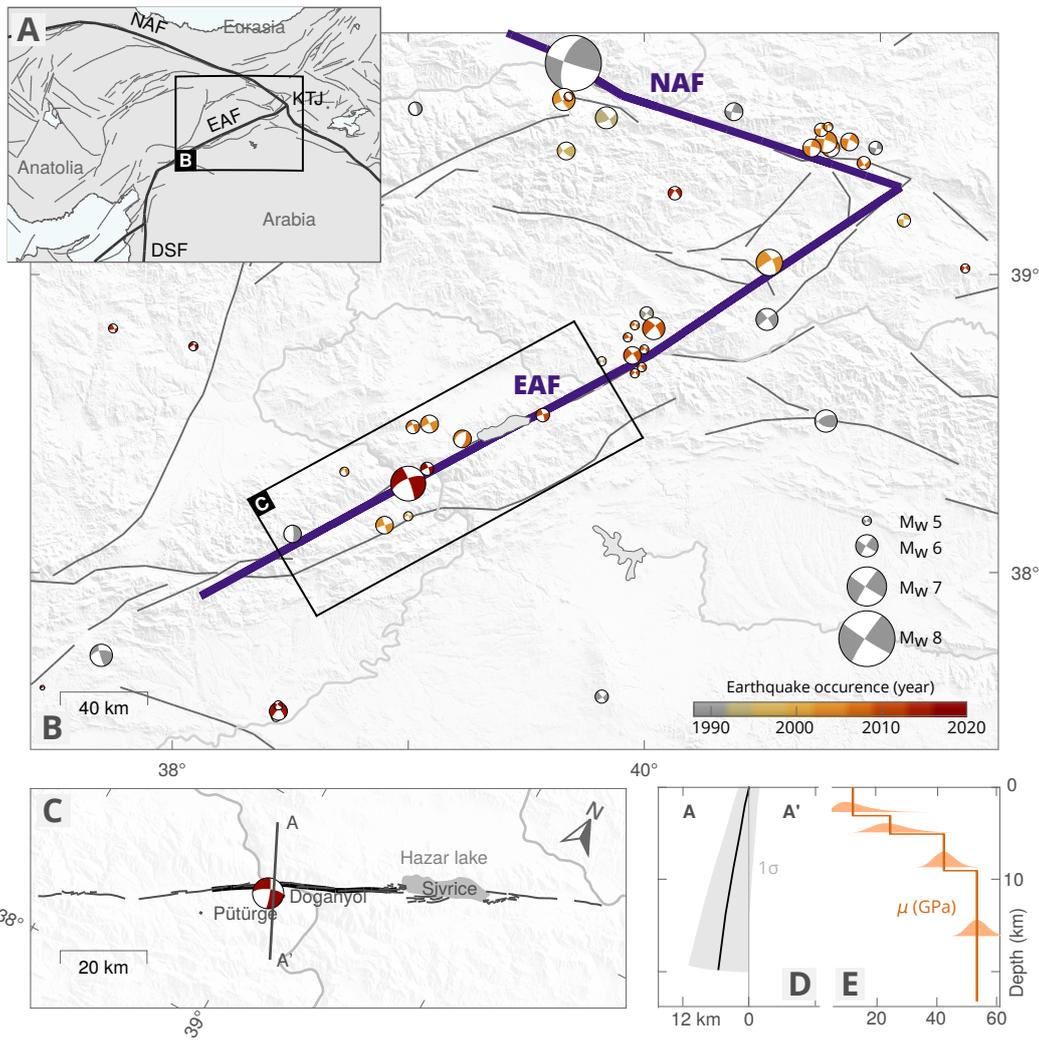
Corresponding author: Théa Ragon, [tragon@caltech.edu](mailto:tragon@caltech.edu)

## 14 **Abstract**

15           Until the  $M_w$  6.8 Elazığ earthquake ruptured the central portion of the East Ana-  
16           tolian Fault (EAF) on January 24, 2020, the region had only experienced moderate mag-  
17           nitude ( $M_w < 6.2$ ) earthquakes over the last century. Here, we use geodetic data to con-  
18           strain a model of subsurface fault slip. We adopt an unregularized Bayesian sampling  
19           approach relying solely on physically justifiable prior information and account for un-  
20           certainties in both the assumed elastic structure and fault geometry. The rupture of the  
21           Elazığ earthquake was bilateral, with two primary disconnected regions of slip. This rup-  
22           ture pattern may be controlled by structural complexity. Both the Elazığ and 2010  $M_w$   
23           6.1 Kovancilar events ruptured portions of the central EAF that are believed to be cou-  
24           pled during interseismic periods, and the Palu segment is the last portion of the EAF  
25           showing a large deficit of fault slip which has not yet ruptured in the last 145 years.

## 26 **Plain Language Summary**

27           The Elazığ earthquake ruptured the central portion of the East Anatolian Fault  
28           (EAF), a major strike-slip fault in eastern Turkey, on January 24, 2020. Before this event,  
29           the region had only experienced moderate magnitude earthquakes over the last century.  
30           We aim at understanding the rupture of this earthquake, and how it relates to the his-  
31           torical ruptures of the EAF. To do so, we use geodetic observations of the deformation  
32           at the surface to image the subsurface slip on the fault that occurred during the earth-  
33           quake. As the characteristics of the crust are poorly known, we make realistic assump-  
34           tions on the fault geometry and Earth structure, and build on novel approaches to ac-  
35           count for the possible biases of our assumptions and to characterize the uncertainties of  
36           the imaged slip. We suggest that the Elazığ earthquake rupture may be controlled by  
37           structural complexity of the fault, and that two main regions of slip surround the fault  
38           bend responsible for the nucleation of the rupture. We also suggest that the fault seg-  
39           ment located between Lake Hazar and the city of Palu is the last portion of the central  
40           EAF, showing a large deficit of the fault slip, which has not yet ruptured in the last 145  
41           years.



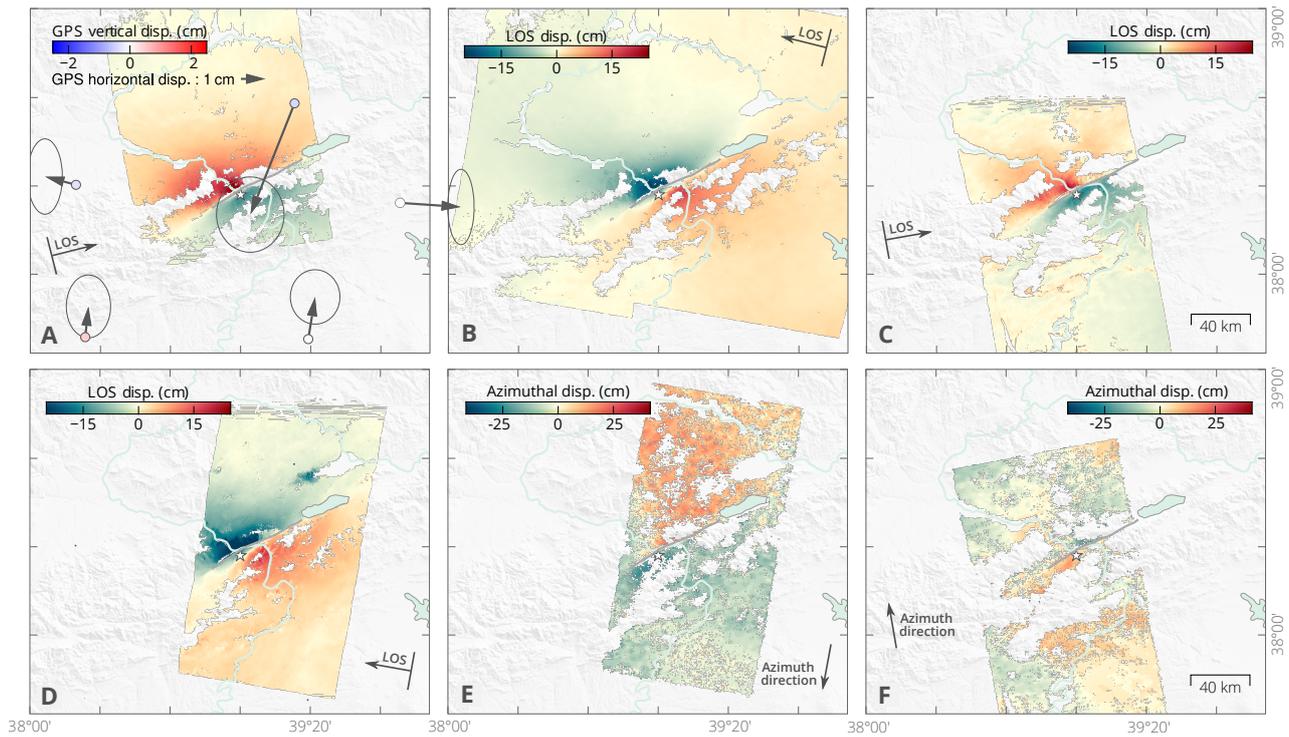
**Figure 1.** Tectonic setting and assumed characteristics for the Elazığ earthquake. (a) Tectonic setting of the area, plate boundaries are shown in thick black lines. East and North Anatolian Faults are labelled (EAF and NAF), as well as the Dead Sea fault (DSF) and Karlıova Triple Junction (KTJ). (b) Active fault traces (Basilic et al., 2013) and seismicity since 1976 (GCMT, Dziewonski et al., 1981) around the EAF and NAF. The Elazığ earthquake focal mechanism (GCMT) is in red. (c) Details of assumed (black) and mapped (gray) fault trace at the surface. (d) Assumed fault geometry at depth and associated uncertainty (standard deviation of  $5^\circ$  around the assumed dip and 1 km around the fault surface trace). (e) Assumed shear moduli with depth (derived from Maden, 2012; Ozer et al., 2019) and associated uncertainties.

## 1 Introduction

A large portion of Turkey is located on the Anatolian Plate (AP), which is slowly extruding westward as a result of the north-south collision between the Arabian and Eurasian tectonic plates (e.g., Mckenzie, 1970; McKenzie, 1972; McClusky et al., 2000). The westward motion of the AP is predominantly accommodated along the North and East Anatolian faults (NAF and EAF, Fig. 1). The NAF experienced a sequence of destructive earthquakes that struck within the last eighty years (e.g., A. Barka, 1996; Stein et al., 1997; Armijo et al., 1999; Şengör et al., 2005). In contrast, the EAF is generally assumed to be less active, and has only experienced small to moderate events over the last century, although large ( $M > 7$ ) earthquakes have occurred in the historic past (e.g., Ambraseys, 1970; Ambraseys & Jackson, 1998; Hubert-Ferrari et al., 2020).

The EAF is a left-lateral 600-km-long strike-slip fault linking the Dead Sea fault (DSF, Fig. 1) to the Karlova Triple Junction (KTJ, Fig. 1) where it intersects with the right-lateral NAF (e.g., Yilmaz et al., 2006; Duman & Emre, 2013). The EAF has a complex geometry divided into several main segments, each of them characterized by bends, pull-apart basins or compressional structures (e.g., Duman & Emre, 2013), and also comprises multiple secondary sub-parallel and seismically active structures delineating a 50-km-wide fault zone (e.g., Bulut et al., 2012). The EAF accommodates a displacement of 9 to 15 mm/yr (Cetin et al., 2003; Reilinger et al., 2006; Cavalié & Jónsson, 2014; Bletery et al., 2020), with creep dominantly at depths greater than 5 km (Cavalié & Jónsson, 2014; Bletery et al., 2020), while shallower portions of the fault are characterized by a moderate to large inter-seismic slip deficit (Bletery et al., 2020).

The January 24 2020  $M_w$  6.8 earthquake ruptured the EAF between the Hazar Pull-apart Basin and the city of Pütürge (Fig. 1). Although no coseismic surface rupture has been observed, the main fault has been mapped as sinusoidal and interrupted by small bends and step-overs whose widths do not exceed a kilometer (Duman & Emre, 2013). In this study, we investigate the subsurface rupture of the Elazığ earthquake and its relationship to fault geometry and inter-seismic slip deficit. While assuming a fault structure with a realistic geometry, we also account for its inherent uncertainties, as well as uncertainties related to assumptions on the crustal structure. We adopt a Bayesian sampling approach which allows us to sample a large panel of possible slip models and to estimate the posterior uncertainty on the inverted slip distribution.



**Figure 2.** Observations used in this study. (a) Surface displacement in the satellite line-of-sight (LOS) direction from a Sentinel-1 ascending interferogram (01/21/2020-01/27/2020), overlaid with coseismic GNSS offsets (Melgar et al., 2020). (b) Surface displacement from a Sentinel-1 descending interferogram (01/22/2020-01/28/2020). (c) Surface displacement from an ALOS-2 ascending interferogram (01/03/2020-01/31/2020). (d) Surface displacement from an ALOS-2 descending interferogram (03/03/2019-01/03/2020). (e) Pixel-offset surface displacement in the satellite along-track (azimuth) direction from the ALOS-2 descending pair (03/03/2019-01/03/2020). (f) Pixel-offset surface displacement in the satellite azimuth direction from the ALOS-2 ascending pair (01/03/2020-01/31/2020). The surface projection of the satellite LOS direction is positive in the ground-to-satellite direction.

74 **2 Bayesian Inference framework**

75 **2.1 Data**

76 We derive the earthquake surface displacement from four Synthetic Aperture Radar  
 77 (SAR) interferometric pairs and two SAR pixel offsets images (summarized in Table S2  
 78 and Fig. 2). We computed two ALOS-2 ascending and descending interferograms, and  
 79 two Sentinel-1 ascending and descending interferograms. Copernicus Sentinel-1 data have  
 80 been acquired by the European Space Agency (ESA) and processed with the NSBAS soft-

ware (Doin et al., 2012). ALOS-2 data are collected by the Japan Aerospace Exploration Agency (JAXA) and have been processed using the InSAR Scientific Computing Environment (ISCE) software (Rosen, 2012) augmented with an additional module for processing ALOS-2 data (Liang & Fielding, 2017a).

We also applied pixel offset tracking analysis to ALOS-2 images on both tracks (Liang & Fielding, 2017b). Resulting surface displacements have lower precision and higher noise than LOS measurements, but provide useful information on the deformation along the satellite track (azimuthal) direction. Due to snowy conditions in January, both L-band ALOS-2 and C-band Sentinel-1 data decorrelate at higher topographic elevations. Note that surface displacements derived from the InSAR data contain from 3 to 7 days of post-seismic deformation, which might affect our modeling of the coseismic phase (Ragon, Sladen, Bletery, et al., 2019; Twardzik et al., 2019). InSAR and dense pixel offsets from the ALOS-2 descending track cover 1 year of preseismic and 1 month of postseismic deformation, and thus also include long-term deformation. To improve computational efficiency, we resample InSAR observations based on model resolution (Lohman & Simons, 2005) with quadtree regions ranging from 12 km to 1.2-2 km wide. We remove data points that are within 500 m of the fault trace to prevent artifacts due to its approximate location. We estimate measurement uncertainties following Jolivet et al. (2012, Fig. S1). We also use 3 components coseismic GNSS offsets at 6 stations located within 120 km of the rupture (Fig. 2). These offsets have been processed by Melgar et al. (2020) and extracted from high-rate GNSS displacements.

## 2.2 Fault geometry and elastic structure

Duman and Emre (2013) mapped the main surface trace of the Pütürge segment as a relatively continuous sinusoidal trend interrupted by small bends and step-overs whose width do not exceed the kilometer. Over the Lake Hazar releasing bend (Fig. 1c), the fault trace divides into multiple parallel lineaments that outline a 10 km wide fault zone (e.g., Garcia Moreno et al., 2011). Around Doğyanol, the fault strike abruptly changes by  $10^\circ$ . West of the rupture area, two major bends affect the Pütürge segment before it links to the Erkenek segment. The strike change around Doğyanol has been well outlined by InSAR data as well (Fig. 2), although the rupture did not reach the surface. We build on these observations, as well as on the location of the aftershocks and previous seismicity (Bulut et al., 2012; Melgar et al., 2020) to define the trace (surface projection)

113 and position of the causative fault. Hereafter, we will refer to the two bends of the Pütürge-  
 114 Sivrice segment as the main bend (bend of  $\sim 10^\circ$  around the city of Doganyol, refer to  
 115 Fig. 1c) and the second bend (east of the main bend).

116 InSAR data show largest amplitudes north of the fault (Fig. 2), suggesting that  
 117 the fault is slightly dipping northward, as confirmed by the aftershocks (Melgar et al.,  
 118 2020; Pousse-Beltran et al., 2020). We thus assume a fault dipping of  $80^\circ$  northward, from  
 119 its south-western end to 30 km eastward, the dip angle increases to  $85^\circ$  further east. We  
 120 discretize the fault into 203 triangular subfaults whose side range from 1.5 km at the sur-  
 121 face to 4-5 km at depth. We also assume a layered crustal model (Tab. S1) derived from  
 122 the seismic velocity models for NE Turkey proposed by Maden (2012) and by the  $V_p/V_s$   
 123 ratio proposed by Ozer et al. (2019), and calculate the surface displacement following  
 124 Zhu and Rivera (2002).

### 125 **2.3 Bayesian Sampling of the inverse problem**

126 In this study, we explore the full solution space of co-seismic slip distributions com-  
 127 patible with geodetic observations in order to sample the range of plausible models. The  
 128 sampling is performed with a Bayesian approach implemented in the AlTar2 package,  
 129 originally formulated by Minson et al. (2013). AlTar combines the Metropolis algorithm  
 130 with a tempering process to iteratively sample the solution space. A large number of sam-  
 131 ples are tested in parallel at each transitional step, which is followed by a resampling step,  
 132 allowing us to select only the most probable models. The probability of each sample to  
 133 be selected depends on its ability to fit the observations  $\mathbf{d}_{\text{obs}}$  within the uncertainties  
 134  $\mathbf{C}_\chi = \mathbf{C}_d + \mathbf{C}_p$ , where  $\mathbf{C}_d$  represents the observational errors and  $\mathbf{C}_p$  the epistemic  
 135 uncertainties introduced by approximations of the forward model (e.g., Minson et al.,  
 136 2013; Duputel et al., 2014; Ragon et al., 2018; Ragon, Sladen, & Simons, 2019).

137 The solution space is evaluated through repeated updates of the probability den-  
 138 sity function (PDF) of each sampled parameter

$$p(\mathbf{m}, \beta_i) \propto p(\mathbf{m}) \cdot \exp[-\beta_i \cdot \chi(\mathbf{m})], \quad (1)$$

139 where  $\mathbf{m}$  is the sampled model,  $p(\mathbf{m})$  the prior information on this sample,  $i$  corresponds  
 140 to each iteration and  $\beta$  evolves dynamically from 0 to 1 to optimize the parameter space  
 141 exploration (Minson et al., 2013).  $\chi(\mathbf{m})$  is the misfit function which quantifies the dis-  
 142 crepancies between observations and predictions within uncertainties described by the

143 covariance matrix  $\mathbf{C}_\chi$  (Tarantola, 2005; Minson et al., 2013, 2014; Duputel et al., 2014)

$$\chi(\mathbf{m}) = \frac{1}{2}[\mathbf{d}_{\text{obs}} - \mathbf{G}(\mathbf{m})]^T \cdot \mathbf{C}_\chi^{-1} \cdot [\mathbf{d}_{\text{obs}} - \mathbf{G}(\mathbf{m})]. \quad (2)$$

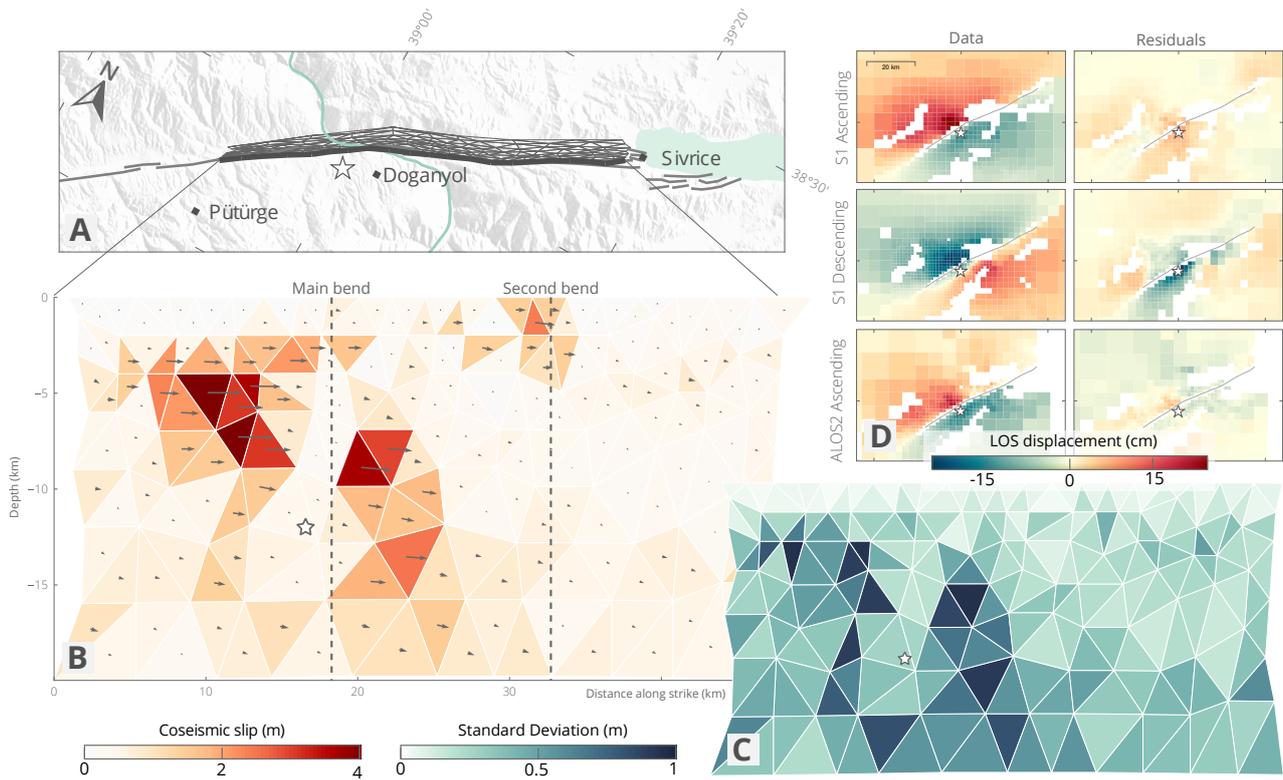
144 We use an unrestrictive positive uniform prior distribution  $p(\mathbf{m}) = \mathcal{U}(0 \text{ m}, 20 \text{ m})$   
 145 for the strike-slip parameters, and a restrictive Gaussian prior distribution centered on  
 146 zero for the dip-slip parameters  $p(\mathbf{m}) = \mathcal{N}(0 \text{ m}, 1 \text{ m})$ . We solve for both slip ampli-  
 147 tude and rake.

148 Ad-hoc choices of regularization, such as smoothing or moment minimization, ar-  
 149 tificially restrict the range of possible models and strongly bias the inferred slip distri-  
 150 butions towards simplistic overly-smoothed solutions (e.g., Du et al., 1992; Causse et al.,  
 151 2010). In our approach, we do not impose any type of prior regularization and explore  
 152 the entire solution space, i.e. the entire range of possible slip models.

#### 153 **2.4 Accounting for epistemic uncertainties**

154 Our estimates of fault slip are driven by the quality and quantity of observations,  
 155 but also by the way we build the forward model and any other prior information we in-  
 156 clude in the problem. Any prior choice made to evaluate the Green’s function (includ-  
 157 ing problem parameterization and description of the Earth interior) will have a signif-  
 158 icant impact on inferred model parameters (e.g., Beresnev, 2003; Hartzell et al., 2007;  
 159 Yagi & Fukahata, 2008; Razafindrakoto & Mai, 2014; Duputel et al., 2014; Gallovič et  
 160 al., 2015; Diao et al., 2016; Mai et al., 2016). So-called epistemic uncertainties stem from  
 161 our imperfect description, or simplification, of the parameters describing the Earth in-  
 162 terior, such as crustal properties (e.g., rheology), fault geometry or regional character-  
 163 istics (e.g., topography, Langer et al., 2020). In this study, we account for the epistemic  
 164 uncertainties caused by our poor knowledge of the fault dip, the fault position, and the  
 165 elastic layered crustal structure, following the methodologies presented by Duputel et  
 166 al. (2014); Ragon et al. (2018); Ragon, Sladen, and Simons (2019).

167 We assume 1 km uncertainty ( $1\sigma$ ) in the location of the surface projection of the  
 168 fault, and  $5^\circ$  uncertainty ( $1\sigma$ ) in the fault dip, the fault rotating as a whole around its  
 169 assumed dip (Fig. 1). We assume uncertainties on the shear modulus for every layer (Pois-  
 170 son’s ratio is held constant within each layer), the uncertainty decreasing with depth (Fig. 1,  
 171 Tab. S1).



**Figure 3.** Inferred average slip model and associated posterior uncertainty for the Elazığ earthquake. (a) Map view of the fault trace and local setting, the epicenter is the white star. (b) Depth view of the average total slip amplitudes and directions. (c) Standard deviation of the inferred strike-slip parameters. (d) Observed and predicted surface displacement in the LOS direction from Sentinel-1 ascending and descending, and ALOS-2 ascending InSAR.

### 172 3 Results

173 We infer primarily strike-slip fault slip (Fig. 3). Most of the slip is imaged around  
 174 the main bend (localized around the city of Doganyol, Fig. 3a). The maximum slip am-  
 175 plitudes (up to 4 m) are reached within two slip patches located around the main bend  
 176 and from 2 to 10 km depth. Associated posterior uncertainty for these patches can reach  
 177 up to ~1 m for highest amplitudes (Fig. 3c). The westernmost slip patch extends down  
 178 to greater depths (7 - 15 km) with moderate slip amplitudes of ~2 m. At depth, the pos-  
 179 terior model uncertainty reaches up to 1 m. The posterior marginal distributions all show  
 180 well-delineated Gaussian shapes (Fig. S2), even for the smallest slip amplitudes. The pos-  
 181 terior PDFs on subfaults in between these two main slip patches indicate well resolved  
 182 very low slip amplitudes (Fig. S2), suggesting that the two patches are disconnected (Fig. 3c).

183 One other narrow slip patch can be observed west of the main bend, at the loca-  
184 tion of the second bend. Slip is imaged from the surface to 4-km-depth, with maximum  
185 amplitudes reaching 2.5 m at the surface, and with relatively small posterior uncertainty.  
186 This patch is not connected with the main slip patches, and does not seem to correspond  
187 to any  $M_w > 4$  aftershock (relocated by Melgar et al., 2020; Pousse-Beltran et al., 2020).  
188 This slip may be coseismic or afterslip (given that the InSAR data span a period up to  
189 one month after the mainshock).

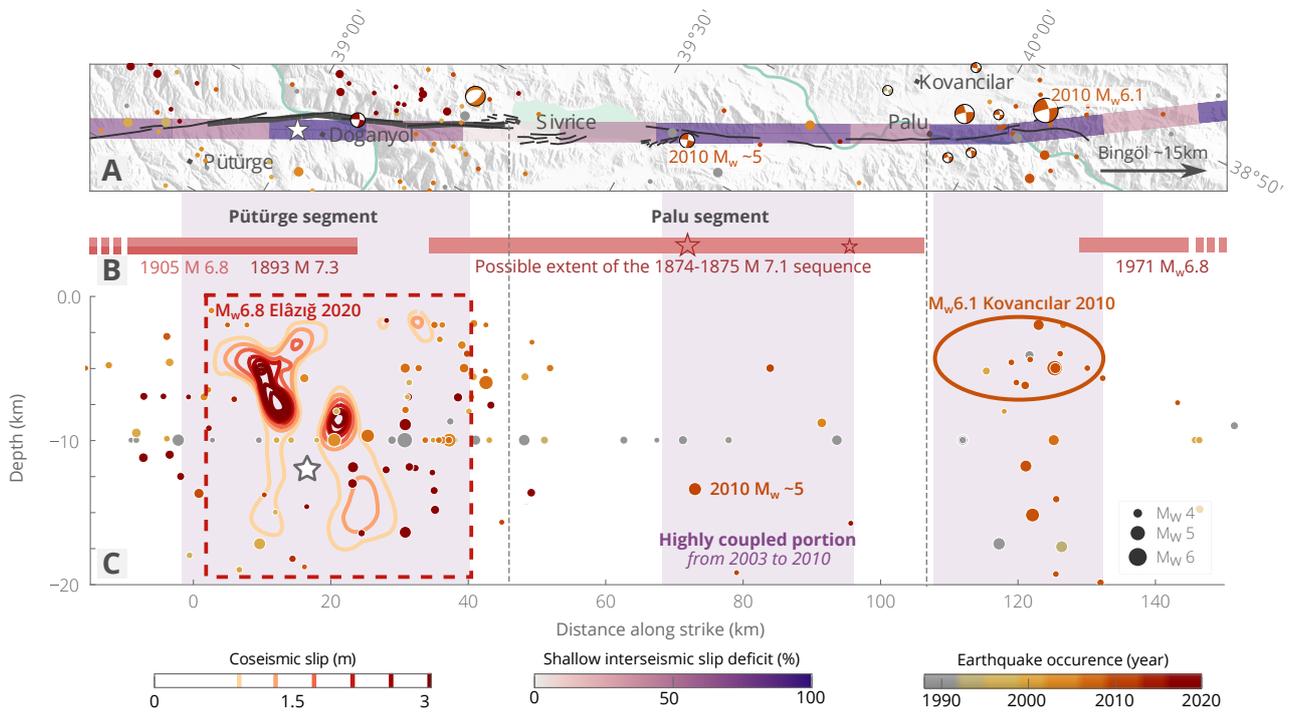
190 Observations are well fit by the predictions of our model (Figs. 3(d), S4, S5, S6 and  
191 S7 for the InSAR and GNSS data respectively), within the assumed uncertainties and  
192 possible remaining noise (in particular for the pixel-offset data). Accounting for epistemic  
193 uncertainties mitigates overfitting (Ragon et al., 2018). Residuals are expected to be larger  
194 than if epistemic biases are neglected. The descending interferograms present larger resid-  
195 uals (Figs. S4, S5, S6) because the assumed fault geometry is primarily constrained by  
196 ascending data, and the descending imaging geometry is not oriented favorably.

197 We also infer the slip distribution of the Elazığ earthquake assuming a planar fault  
198 structure dipping of  $85^\circ$  towards the north and embedded within a homogeneous half  
199 space, without introducing any epistemic uncertainty (Fig S8). Unlike our preferred model,  
200 the slip is concentrated in a single shallow and extended slip patch with low posterior  
201 uncertainty. Highest amplitudes (up to 3.5 m) are reached above the main bend, from  
202 1.5 to 9 km depth. Low slip values are inferred at depths greater than 10 km and lower  
203 than 1.5 km. Some slip is also inferred around the second bend. As expected, the fit of  
204 the predicted displacement to the observations is good (Figs. S9, S10, S11 and S12), and  
205 slightly better than with our preferred inference.

## 206 **4 Discussion and Conclusion**

### 207 **4.1 A stochastic view of the 2020 Elazığ coseismic rupture**

208 Assuming a realistic fault geometry and crustal structure, and accounting for re-  
209 lated epistemic uncertainties, we estimate the slip distribution of the 2020 Elazığ earth-  
210 quake with a Bayesian inference approach. We show that the coseismic rupture affects  
211 almost the full width of the Pütürge-Sivrice segment, down to 15 km depth. Two dis-  
212 connected slip patches host most of the slip: one patch extends from  $\sim 2.5$  to  $\sim 12$  km  
213 depth east of the main bend, reaching up to 4 m in amplitude, while the second extends



**Figure 4.** Comparison between the spatial distributions of the 2020 Elazığ earthquake rupture, historical earthquakes, and highly coupled sections of the EAF. (A) Map view of three segments the East Anatolian Fault (black lines), overlaid with historical and recent seismicity from 1900 to January 2020 (Retrieved from AFAD, 2020; NEIC, 2020), shallow interseismic slip deficit (Bletery et al., 2020) and our assumed fault trace for the 2020 Elazığ event (thick black line). (B) Possible rupture extents for the 4 most recent  $M_w > 6.5$  earthquakes that struck the mapped segments of the EAF before the Elazığ event, inferred from Ambraseys (1989); Hubert-Ferrari et al. (2020). Red stars denote the locations of the mainshock and aftershock of the 1874 sequence (Ambraseys, 1989). Fault segments of the central EAF are indicated, from Duman and Emre (2013). (C) Depth extent of the slip amplitude inferred for the 2020 Elazığ event (Fig. 3), along with the highly coupled sections of the EAF between 2003 and 2010 (Bletery et al., 2020), and the possible extent of the 2010  $M_w$  6.1 Kovancilar earthquake estimated from the spatial coverage of aftershocks and basic scaling laws (Wells & Coppersmith, 1994; Tan et al., 2011), as well as historical and recent seismicity from 1900 to January 2020.

214 down to 15-km-depth just west of the main bend (Fig. 3). A large shallow slip (0-5 km,  
215 2.5 m in amplitude) is also imaged around the second bend. Although the location of  
216 the epicenter, as estimated from different institutions and authors (e.g., Jamalreyhani  
217 et al., 2020), comes with a few kilometers uncertainty, it is probably located around the  
218 main bend. Our inferred model thus suggests the rupture of the Elazığ earthquake is bi-  
219 lateral, starting at a geometrical complexity and propagating on both sides.

220 The inferred slip distribution changes significantly if we assume a planar fault em-  
221 bedded in a homogeneous crust and we neglect uncertainties stemming from the assump-  
222 tion of a simplified Earth interior. In particular, a single and shallower slip patch is in-  
223 ferred above the epicenter, no slip larger than 50 cm being imaged above 2 km, or larger  
224 than 80 cm below 10 km depth. The slip deficit imaged when assuming a simplified for-  
225 ward model suggests that the pronounced shallow slip deficit observed by Pousse-Beltran  
226 et al. (2020) may be an artifact deriving from modeling choices, as proposed by Xu et  
227 al. (2016) and Ragon et al. (2018).

228 Our estimates of the pattern of fault slip differ from other estimates based on sim-  
229 ilar data (e.g., Melgar et al., 2020; Pousse-Beltran et al., 2020; Cheloni & Akinci, 2020).  
230 While our preferred model is very different from Pousse-Beltran et al. (2020), it shares  
231 some characteristics with the preferred one of Melgar et al. (2020), especially for the lo-  
232 cation of largest slip and the overall shape of the ruptured areas, surrounding the epi-  
233 center. Melgar et al. (2020) preferred model being primarily driven by high-rate GNSS  
234 data and assuming a 1D crustal structure, these shared characteristics suggest that as-  
235 suming a layered crustal model is necessary to infer robust slip estimates in this region.

## 236 **4.2 Structurally driven slip on the Pütürge segment**

237 Fault segmentation and bends are thought to act as geometric barriers that can  
238 influence, or even drive, rupture initiation, termination and propagation (e.g., G. King  
239 & Nabelek, 1985; A. A. Barka & Kadinsky-Cade, 1988; Wesnousky, 2006; Duan & Oglesby,  
240 2005; Aochi et al., 2002; Perrin et al., 2016). Similarly, creeping sections might act as  
241 barriers to earthquake propagation (e.g., G. C. P. King, 1986; Chlieh et al., 2008; Per-  
242 fettini et al., 2010; Kaneko et al., 2010).

243 The coseismic rupture of the Elazığ earthquake started at the location of the main  
244 bend of this portion of the EAF (refer to Fig. 3, Melgar et al., 2020; Jamalreyhani et al.,

245 2020). Peak slip amplitudes and most of the slip are located on both sides of this bend,  
 246 which also acts as a barrier, in particular at depth, where well-resolved low slip values  
 247 separate the two main slip patches. The location of the main bend also corresponds to  
 248 the portion of the EAF that shows maximum shallow interseismic slip deficit (Fig. 4).  
 249 Inferred slip partly overlays this portion of maximum slip deficit, but the coseismic rup-  
 250 ture also extends over moderately coupled regions (30-40%) at greater depths (from 8  
 251 to 15-km-depth). The second bend, to the northeast of the main bend (Fig. 3), is also  
 252 surrounded by large slip amplitudes at shallow depths.

253 Slip slowly decreases towards Lake Hazar (Fig. 4). Aftershocks activity also declines  
 254 abruptly at the basin boundary (Melgar et al., 2020; Jamalreyhani et al., 2020). The pull-  
 255 apart basin hosting Lake Hazar might thus have acted as a geometrical barrier to the  
 256 ruptured asperity (as also observed for the Haiyuan fault, China, Liu-Zeng et al., 2007;  
 257 Jolivet et al., 2013).

258 Altogether, these observations suggest that the distribution of subsurface fault slip  
 259 during the Elazığ earthquake may largely reflect complexities in the fault geometry. The  
 260 main fault bend is not prone to aseismic slip (at least at shallow depths), and it likely  
 261 triggered the rupture. Both bends might have favored seismic rupture and large coseis-  
 262 mic slip amplitudes. The main bend might also have acted as a barrier to rupture prop-  
 263 agation, similarly to the structure responsible for the pull-apart basin of Lake Hazar. The  
 264 deepest imaged slip patch, down to 15-km-depth, confirms that the seismogenic depth  
 265 is deeper than 10 km for the central EAF (Bulut et al., 2012). Our results do not seem  
 266 to corroborate the shallow locking depth (full creep below 5 km) inferred by Cavalé and  
 267 Jónsson (2014). This behavior appears similar to the NAF, where large earthquakes oc-  
 268 cur on faults also prone to aseismic slip (Cakir et al., 2005, 2014; Schmittbuhl et al., 2016).

### 269 **4.3 Seismic potential of the Palu segment**

270 From Pütürge to Bingöl, interseismic slip deficit at shallow depths varies along strike,  
 271 as inferred from geodetic data from 2003 to 2010 (Bletery et al., 2020, Fig. 4, the city  
 272 of Bingöl is located just out of the map). Three main sections of large shallow interseis-  
 273 mic slip deficit (>70%) are clearly distinct: one on the Pütürge segment, another on the  
 274 Palu segment, and a last one west of the city of Palu. Before the Elazığ event, this por-  
 275 tion of the EAF was struck by 4 large earthquakes in the last 200 years. Two  $M \sim 6.8$

276 and  $M \sim 7.3$  occurred west of Lake Hazar in 1893 and 1905 (Ambraseys, 1989). In 1874-  
 277 1875, a sequence of two  $M \sim 7.1$  and  $M \sim 6.7$  likely struck the region between Sivrice  
 278 and Palu (Ambraseys, 1989; Cetin et al., 2003; Hubert-Ferrari et al., 2017). East of the  
 279 locality of Palu, the region around the city of Bingöl was affected by a  $M_w$  6.8 in 1971  
 280 (Ambraseys, 1989; Ambraseys & Jackson, 1998).

281 Slip deficit has accumulated on the EAF since these recent historical ruptures, and  
 282 the newly coupled portions (from 2003 to 2010) are preferably located in between the  
 283 historically ruptured segments (Bletery et al., 2020). The 2010  $M_w$  6.1 earthquake that  
 284 occurred near Kovancılar (Akkar et al., 2011) appears to have filled the possible seismic  
 285 gap between the 1874 sequence and the 1971 Bingöl event (Fig. 4B). Similarly, the ex-  
 286 tent of the Elazığ rupture well overlays with a highly coupled portion of the EAF, and  
 287 it may have filled a possible gap between the 1893/1905 earthquakes and the 1874 se-  
 288 quence (Melgar et al., 2020; Duman & Emre, 2013).

289 Although the portions of the EAF that have been affected by the Elazığ and Ko-  
 290 vancılar events show seismic activity in the 20 years preceding these events, the Palu seg-  
 291 ment is characterized by relatively low seismic activity (Fig. 4). Together with the low  
 292 slip deficit at depth (or shallow locking depth, Cavalie & Jónsson, 2014; Bletery et al.,  
 293 2020), the lack of seismicity suggests that this segment is creeping. However, this seg-  
 294 ment also shows large interseismic slip deficit in its shallow portion ( $< 5$ -km-depth), and  
 295 at greater depths even larger than for the Pütürge segment (before the 2020 event, Bletery  
 296 et al., 2020). Ground shaking maps derived from press reports and testimonies suggest  
 297 the 1874 sequence likely initiated at depth just west of Lake Hazar (Ambraseys, 1989),  
 298 near the epicenter of a  $M_w \sim 5$  earthquake that occurred in 2010. The Palu segment  
 299 is thus capable of producing large earthquakes. Cheloni and Akinici (2020) also suggest  
 300 that the Elazığ event led to an increase in the Coulomb stress of the Palu segment. Al-  
 301 together, these observations suggest that the Palu segment of the central EAF is likely  
 302 seismogenic.

### 303 **Acknowledgments**

304 We are very grateful to Diego Melgar and Brendan Crowell who calculated and provided  
 305 the GNSS offsets for the coseismic deformation, and their relocated aftershocks catalog,  
 306 which are both available in Melgar et al. (2020). GNSS data were made available from  
 307 the Turkish National Permanent GNSS/RTK Network (TUSAGA-Aktif/CORS-TR ad-

308 ministrated by General Directorate of Land Registry and Cadastre-TKGM and General  
 309 Directorate of Mapping-HGM, Ankara, Turkey). Initial aftershocks and phase-arrival cat-  
 310 alog has been provided by the Disaster and Emergency Management Presidency of Turkey  
 311 (AFAD, 2020) for the period 24 January 2020 11 February 2020, and historical/background  
 312 seismicity catalog was provided by BU-KOERI ([http://www.koeri.boun.edu.tr/sismo/](http://www.koeri.boun.edu.tr/sismo/2/en/)  
 313 [2/en/](http://www.koeri.boun.edu.tr/sismo/2/en/)) for Turkey from 1992 to 2020. This work contains modified Copernicus data from  
 314 the Sentinel-1A and -1B satellites provided by the European Space Agency (ESA) that  
 315 are accessible at [earth.esa.int/eogateway/](http://earth.esa.int/eogateway/). Original ALOS-2 data and products are  
 316 copyright JAXA and provided under JAXA ALOS Research Announcement 6 (RA6) project  
 317 3278, and will be made available upon acceptance at [aria-share.jpl.nasa.gov](http://aria-share.jpl.nasa.gov). The  
 318 Bayesian simulations were performed with the AlTar2 package ([github.com/AlTarFramework/](https://github.com/AlTarFramework/altar)  
 319 [altar](https://github.com/AlTarFramework/altar)). The Classic Slip Inversion (CSI, [github.com/jolivetr/csi](https://github.com/jolivetr/csi)) Python library (Jolivet  
 320 et al., 2014) was used to build inputs for the Bayesian algorithm, in particular to com-  
 321 pute Green’s functions. The python module PyDistMesh has been used to build the fault  
 322 geometry (Persson & Strang, 2004). Figures were generated with the Matplotlib and Seaborn  
 323 ([doi:10.5281/zenodo.1313201](https://doi.org/10.5281/zenodo.1313201)) Python libraries and with the Generic Mapping Tools  
 324 library (Wessel et al., 2019). MS was partially supported by the National Aeronautics  
 325 and Space Administration under Grant No. 80NSSC19K1499. EF was partially supported  
 326 by the National Aeronautics and Space Administration Earth Surface and Interior fo-  
 327 cus area under Grant No. 80NM0018D0004. QB work has been supported by the French  
 328 government, through the UCA JEDI Investments in the Future project managed by the  
 329 National Research Agency (ANR) ANR-15-IDEX-01, the ANR S5 Grant No. ANR-19-  
 330 CE31-0003, and the ANR JCJC E-POST Grant No. ANR-14-CE03-002-01JCJC.

## 331 **References**

- 332 AFAD. (2020). *AFAD Earthquake catalogue (1900–Feb 2020)*,  
 333 *Prime Ministry, Disaster and Emergency Management Pres-*  
 334 <https://depem.afad.gov.tr/depemkatalogu?lang=en#>.  
 335 Akkar, S., Aldemir, A., Askan, A., Bakır, S., Canbay, E., Demirel, İ. O., . . . Yenier,  
 336 E. (2011). 8 March 2010 Elazığ-Kovancılar (Turkey) Earthquake: Observations  
 337 on Ground Motions and Building Damage. *Seismological Research Letters*,  
 338 *82*(1), 42–58. doi: 10.1785/gssrl.82.1.42  
 339 Ambraseys, N. N. (1970). Some characteristic features of the Anatolian fault zone.

- 340 *Tectonophysics*, 9(2), 143–165. doi: 10.1016/0040-1951(70)90014-4
- 341 Ambraseys, N. N. (1989). Temporary seismic quiescence: SE Turkey. *Geophysical*  
 342 *Journal International*, 96(2), 311–331. doi: 10.1111/j.1365-246X.1989.tb04453  
 343 .x
- 344 Ambraseys, N. N., & Jackson, J. A. (1998). Faulting associated with historical and  
 345 recent earthquakes in the Eastern Mediterranean region. *Geophysical Journal*  
 346 *International*, 133(2), 390–406. doi: 10.1046/j.1365-246X.1998.00508.x
- 347 Aochi, H., Madariaga, R., & Fukuyama, E. (2002). Effect of normal stress during  
 348 rupture propagation along nonplanar faults. *Journal of Geophysical Research:*  
 349 *Solid Earth*, 107(B2), ESE 5-1-ESE 5-10. doi: 10.1029/2001JB000500
- 350 Armijo, R., Meyer, B., Hubert, A., & Barka, A. (1999). Westward propagation  
 351 of the North Anatolian fault into the northern Aegean: Timing and kine-  
 352 matics. *Geology*, 27(3), 267–270. doi: 10.1130/0091-7613(1999)027<0267:  
 353 WPOTNA>2.3.CO;2
- 354 Barka, A. (1996). Slip distribution along the North Anatolian fault associated with  
 355 the large earthquakes of the period 1939 to 1967. *Bulletin of the Seismological*  
 356 *Society of America*, 86(5), 1238–1254.
- 357 Barka, A. A., & Kadinsky-Cade, K. (1988). Strike-slip fault geometry in Turkey and  
 358 its influence on earthquake activity. *Tectonics*, 7(3), 663–684. doi: 10.1029/  
 359 TC007i003p00663
- 360 Basilic, R., Kastelic, V., Demircioglu, M. B., Garcia Moreno, D., Nemser, E. S.,  
 361 Petricca, P., ... Wössner, J. (2013). The European Database of Seismogenic  
 362 Faults (EDSF) compiled in the framework of the Project SHARE.  
 363 doi: 10.6092/INGV.IT-SHARE-EDSF
- 364 Beresnev, I. A. (2003). Uncertainties in Finite-Fault Slip Inversions: To What Ex-  
 365 tent to Believe? (A Critical Review). *Bulletin of the Seismological Society of*  
 366 *America*, 93(6), 2445–2458. doi: 10.1785/0120020225
- 367 Bletery, Q., Cavalié, O., Nocquet, J.-M., & Ragon, T. (2020). Distribution of In-  
 368 terseismic Coupling Along the North and East Anatolian Faults Inferred From  
 369 InSAR and GPS Data. *Geophysical Research Letters*, 47(16), e2020GL087775.  
 370 doi: 10.1029/2020GL087775
- 371 Bulut, F., Bohnhoff, M., Eken, T., Janssen, C., Kılıç, T., & Dresen, G. (2012).  
 372 The East Anatolian Fault Zone: Seismotectonic setting and spatiotemporal

- 373 characteristics of seismicity based on precise earthquake locations. *Journal of*  
 374 *Geophysical Research: Solid Earth*, 117(B7). doi: 10.1029/2011JB008966
- 375 Cakir, Z., Akoglu, A. M., Belabbes, S., Ergintav, S., & Meghraoui, M. (2005).  
 376 Creeping along the Ismetpasa section of the North Anatolian fault (Western  
 377 Turkey): Rate and extent from InSAR. *Earth and Planetary Science Letters*,  
 378 238(1), 225–234. doi: 10.1016/j.epsl.2005.06.044
- 379 Cakir, Z., Ergintav, S., Akoğlu, A. M., Çakmak, R., Tatar, O., & Meghraoui, M.  
 380 (2014). InSAR velocity field across the North Anatolian Fault (eastern  
 381 Turkey): Implications for the loading and release of interseismic strain accumu-  
 382 lation. *Journal of Geophysical Research: Solid Earth*, 119(10), 7934–7943. doi:  
 383 10.1002/2014JB011360
- 384 Causse, M., Cotton, F., & Mai, P. M. (2010). Constraining the roughness degree of  
 385 slip heterogeneity. *Journal of Geophysical Research: Solid Earth*, 115(B5). doi:  
 386 10.1029/2009JB006747
- 387 Cavalié, O., & Jónsson, S. (2014). Block-like plate movements in eastern Anato-  
 388 lia observed by InSAR. *Geophysical Research Letters*, 26–31. doi: 10.1002/  
 389 2013GL058170@10.1002/(ISSN)1944-8007.GRLeditorhghlts2014
- 390 Cetin, H., Güneçli, H., & Mayer, L. (2003). Paleoseismology of the Palu–Lake Hazar  
 391 segment of the East Anatolian Fault Zone, Turkey. *Tectonophysics*, 374(3),  
 392 163–197. doi: 10.1016/j.tecto.2003.08.003
- 393 Cheloni, D., & Akinci, A. (2020). Source modelling and strong ground motion simu-  
 394 lations for the January 24, 2020, Mw 6.8 Elazığ earthquake, Turkey. *Geophys-  
 395 ical Journal International*. doi: 10.1093/gji/ggaa350
- 396 Chlieh, M., Avouac, J. P., Sieh, K., Natawidjaja, D. H., & Galetzka, J. (2008). Het-  
 397 erogeneous coupling of the Sumatran megathrust constrained by geodetic and  
 398 paleogeodetic measurements. *Journal of Geophysical Research: Solid Earth*,  
 399 113(B5). doi: 10.1029/2007JB004981
- 400 Diao, F., Wang, R., Aochi, H., Walter, T. R., Zhang, Y., Zheng, Y., & Xiong, X.  
 401 (2016). Rapid kinematic finite-fault inversion for an Mw 7+ scenario earth-  
 402 quake in the Marmara Sea: An uncertainty study. *Geophysical Journal Inter-  
 403 national*, 204(2), 813–824. doi: 10.1093/gji/ggv459
- 404 Doin, M.-P., Lodge, F., Guillaso, S., Jolivet, R., Lasserre, C., Ducret, G., ... Pinel,  
 405 V. (2012). Presentation Of The Small Baseline NSBAS Processing Chain On A

- 406 Case Example: The ETNA Deformation Monitoring From 2003 to 2010 Using  
407 ENVISAT Data. , 697, 98.
- 408 Du, Y., Aydin, A., & Segall, P. (1992). Comparison of various inversion techniques  
409 as applied to the determination of a geophysical deformation model for the  
410 1983 Borah Peak earthquake. *Bulletin of the Seismological Society of America*,  
411 82(4), 1840–1866.
- 412 Duan, B., & Oglesby, D. D. (2005). Multicycle dynamics of nonplanar strike-slip  
413 faults. *Journal of Geophysical Research: Solid Earth*, 110(B3). doi: 10.1029/  
414 2004JB003298
- 415 Duman, T. Y., & Emre, Ö. (2013). The East Anatolian Fault: Geometry, segmen-  
416 tation and jog characteristics. *Geological Society, London, Special Publications*,  
417 372(1), 495–529. doi: 10.1144/SP372.14
- 418 Duputel, Z., Agram, P. S., Simons, M., Minson, S. E., & Beck, J. L. (2014). Ac-  
419 counting for prediction uncertainty when inferring subsurface fault slip. *Geo-  
420 physical Journal International*, 197(1), 464–482. doi: 10.1093/gji/ggt517
- 421 Dziewonski, A. M., Chou, T.-A., & Woodhouse, J. H. (1981). Determination of  
422 earthquake source parameters from waveform data for studies of global and  
423 regional seismicity. *Journal of Geophysical Research: Solid Earth*, 86(B4),  
424 2825–2852. doi: 10.1029/JB086iB04p02825
- 425 Gallovič, F., Imperatori, W., & Mai, P. M. (2015). Effects of three-dimensional  
426 crustal structure and smoothing constraint on earthquake slip inversions: Case  
427 study of the Mw6.3 2009 L’Aquila earthquake. *Journal of Geophysical Re-  
428 search: Solid Earth*, 120(1), 2014JB011650. doi: 10.1002/2014JB011650
- 429 Garcia Moreno, D., Hubert, A., Moernaut, J., Fraser, J., Boes, X., Van Daele,  
430 M., . . . De Batist, M. (2011). Structure and evolution of Lake Hazar pull-  
431 apart Basin along the East Anatolian Fault. *Basin Research*, 23. doi:  
432 10.1111/j.1365-2117.2010.00476.x
- 433 Hartzell, S., Liu, P., Mendoza, C., Ji, C., & Larson, K. M. (2007). Stability and  
434 Uncertainty of Finite-Fault Slip Inversions: Application to the 2004 Parkfield,  
435 California, Earthquake. *Bulletin of the Seismological Society of America*,  
436 97(6), 1911–1934. doi: 10.1785/0120070080
- 437 Hubert-Ferrari, A., Lamair, L., Hage, S., Schmidt, S., Çağatay, M. N., & Avşar, U.  
438 (2020). A 3800 yr paleoseismic record (Lake Hazar sediments, eastern Turkey):

- 439 Implications for the East Anatolian Fault seismic cycle. *Earth and Planetary*  
 440 *Science Letters*, 538, 116152. doi: 10.1016/j.epsl.2020.116152
- 441 Hubert-Ferrari, A., El-Ouahabi, M., Garcia-Moreno, D., Avşar, U., Altınok, S.,  
 442 Schmidt, S., ... Çağatay, M. N. (2017). Earthquake imprints on a lacustrine  
 443 deltaic system: The Kürk Delta along the East Anatolian Fault (Turkey).  
 444 *Sedimentology*, 64(5), 1322–1353. doi: 10.1111/sed.12355
- 445 Jamalreyhani, M., Büyükkapınar, P., Cesca, S., Dahm, T., Sudhaus, H., Rezapour,  
 446 M., ... Heimann, S. (2020). Seismicity related to the eastern sector of Ana-  
 447 tolian escape tectonic: The example of the 24 January 2020 Mw 6.77 Elazığ-  
 448 Sivrice earthquake. *Solid Earth Discussions*, 1–22. doi: 10.5194/se-2020-55
- 449 Jolivet, R., Duputel, Z., Riel, B., Simons, M., Rivera, L., Minson, S. E., ... Fielding,  
 450 E. J. (2014). The 2013 Mw 7.7 Balochistan Earthquake: Seismic Potential  
 451 of an Accretionary Wedge. *Bulletin of the Seismological Society of America*,  
 452 104(2), 1020–1030. doi: 10.1785/0120130313
- 453 Jolivet, R., Lasserre, C., Doin, M.-P., Guillaso, S., Peltzer, G., Dailu, R., ... Xu,  
 454 X. (2012). Shallow creep on the Haiyuan Fault (Gansu, China) revealed by  
 455 SAR Interferometry. *Journal of Geophysical Research: Solid Earth*, 117(B6),  
 456 B06401. doi: 10.1029/2011JB008732
- 457 Jolivet, R., Lasserre, C., Doin, M. P., Peltzer, G., Avouac, J. P., Sun, J., & Dailu,  
 458 R. (2013). Spatio-temporal evolution of aseismic slip along the Haiyuan fault,  
 459 China: Implications for fault frictional properties. *Earth and Planetary Science*  
 460 *Letters*, 377-378, 23–33. doi: 10.1016/j.epsl.2013.07.020
- 461 Kaneko, Y., Avouac, J.-P., & Lapusta, N. (2010). Towards inferring earthquake pat-  
 462 terns from geodetic observations of interseismic coupling. *Nature Geoscience*,  
 463 3(5), 363–369. doi: 10.1038/ngeo843
- 464 King, G., & Nabelek, J. (1985). Role of Fault Bends in the Initiation and Termina-  
 465 tion of Earthquake Rupture. *Science*, 228(4702), 984–987. doi: 10.1126/science  
 466 .228.4702.984
- 467 King, G. C. P. (1986). Speculations on the geometry of the initiation and termi-  
 468 nation processes of earthquake rupture and its relation to morphology and  
 469 geological structure. *pure and applied geophysics*, 124(3), 567–585. doi:  
 470 10.1007/BF00877216

- 471 Langer, L., Ragon, T., Sladen, A., & Tromp, J. (2020). Impact of topography on  
472 earthquake static slip estimates. *Tectonophysics*, 228566. doi: 10.1016/j.tecto  
473 .2020.228566
- 474 Liang, C., & Fielding, E. J. (2017a). Interferometry With ALOS-2 Full-Aperture  
475 ScanSAR Data. *IEEE Transactions on Geoscience and Remote Sensing*, 55(5),  
476 2739–2750. doi: 10.1109/TGRS.2017.2653190
- 477 Liang, C., & Fielding, E. J. (2017b). Measuring Azimuth Deformation With L-Band  
478 ALOS-2 ScanSAR Interferometry. *IEEE Transactions on Geoscience and Re-  
479 mote Sensing*, 55(5), 2725–2738. doi: 10.1109/TGRS.2017.2653186
- 480 Liu-Zeng, J., Klinger, Y., Xu, X., Lasserre, C., Chen, G., Chen, W., ... Zhang, B.  
481 (2007). Millennial Recurrence of Large Earthquakes on the Haiyuan Fault near  
482 Songshan, Gansu Province, China. *Bulletin of the Seismological Society of  
483 America*, 97(1B), 14–34. doi: 10.1785/0120050118
- 484 Lohman, R. B., & Simons, M. (2005). Some thoughts on the use of InSAR data  
485 to constrain models of surface deformation: Noise structure and data down-  
486 sampling. *Geochemistry, Geophysics, Geosystems*, 6(1), Q01007. doi:  
487 10.1029/2004GC000841
- 488 Maden, N. (2012). One-Dimensional Thermal Modeling of the Eastern Pontides Oro-  
489 genic Belt (NE Turkey). *Pure and Applied Geophysics*, 169(1), 235–248. doi:  
490 10.1007/s00024-011-0296-0
- 491 Mai, P. M., Schorlemmer, D., Page, M., Ampuero, J.-P., Asano, K., Causse, M., ...  
492 Zielke, O. (2016). The Earthquake-Source Inversion Validation (SIV) Project.  
493 *Seismological Research Letters*. doi: 10.1785/0220150231
- 494 McClusky, S., Balassanian, S., Barka, A., Demir, C., Ergintav, S., Georgiev, I., ...  
495 Veis, G. (2000). Global Positioning System constraints on plate kinematics and  
496 dynamics in the eastern Mediterranean and Caucasus. *Journal of Geophysical  
497 Research: Solid Earth*, 105(B3), 5695–5719. doi: 10.1029/1999JB900351
- 498 McKenzie, D. (1972). Active Tectonics of the Mediterranean Region. *Geophysical  
499 Journal International*, 30(2), 109–185. doi: 10.1111/j.1365-246X.1972.tb02351  
500 .x
- 501 Mckenzie, D. P. (1970). Plate Tectonics of the Mediterranean Region. *Nature*,  
502 226(5242), 239–243. doi: 10.1038/226239a0

- 503 Melgar, D., Ganas, A., Taymaz, T., Valkaniotis, S., Crowell, B. W., Kapetani-  
 504 dis, V., ... Öcalan, T. (2020). Rupture kinematics of January 24, 2020  
 505 Mw 6.7 Doğanyol-Sivrice, Turkey earthquake on the East Anatolian Fault  
 506 zone imaged by space geodesy. *Geophysical Journal International*. doi:  
 507 10.1093/gji/ggaa345
- 508 Minson, S. E., Simons, M., & Beck, J. L. (2013). Bayesian inversion for finite fault  
 509 earthquake source models I – theory and algorithm. *Geophysical Journal Inter-*  
 510 *national*, 194(3), 1701–1726. doi: 10.1093/gji/ggt180
- 511 Minson, S. E., Simons, M., Beck, J. L., Ortega, F., Jiang, J., Owen, S. E., ...  
 512 Sladen, A. (2014). Bayesian inversion for finite fault earthquake source mod-  
 513 els – II: The 2011 great Tohoku-oki, Japan earthquake. *Geophysical Journal*  
 514 *International*, 198(2), 922–940. doi: 10.1093/gji/ggu170
- 515 NEIC. (2020). *NEIC Earthquake catalogue. National Earthquake Information Cen-*  
 516 *tre, On-line Bulletin*,. <https://earthquake.usgs.gov/earthquakes/search/>.
- 517 Ozer, C., Ozyazicioglu, M., Gok, E., & Polat, O. (2019). Imaging the Crustal  
 518 Structure Throughout the East Anatolian Fault Zone, Turkey, by Local Earth-  
 519 quake Tomography. *Pure and Applied Geophysics*, 176(6), 2235–2261. doi:  
 520 10.1007/s00024-018-2076-6
- 521 Perfettini, H., Avouac, J.-P., Tavera, H., Kositsky, A., Nocquet, J.-M., Bondoux, F.,  
 522 ... Soler, P. (2010). Seismic and aseismic slip on the Central Peru megathrust.  
 523 *Nature*, 465(7294), 78–81.
- 524 Perrin, C., Manighetti, I., & Gaudemer, Y. (2016). Off-fault tip splay net-  
 525 works: A genetic and generic property of faults indicative of their long-  
 526 term propagation. *Comptes Rendus Geoscience*, 348(1), 52–60. doi:  
 527 10.1016/j.crte.2015.05.002
- 528 Persson, P.-O., & Strang, G. (2004). A Simple Mesh Generator in MATLAB. *SIAM*  
 529 *Review*, 46(2), 329–345. doi: 10.1137/S0036144503429121
- 530 Pousse-Beltran, L., Nissen, E., Bergman, E. A., Cambaz, M. D., Gaudreau, É.,  
 531 Karasözen, E., & Tan, F. (2020). The 2020 Mw 6.8 Elazığ (Turkey) Earth-  
 532 quake Reveals Rupture Behavior of the East Anatolian Fault. *Geophysical*  
 533 *Research Letters*, 47(13), e2020GL088136. doi: 10.1029/2020GL088136
- 534 Ragon, T., Sladen, A., Bletery, Q., Vergnolle, M., Cavalié, O., Avallone, A., ... De-  
 535 lousis, B. (2019). Joint Inversion of Coseismic and Early Postseismic Slip to

- 536 Optimize the Information Content in Geodetic Data: Application to the 2009  
 537 Mw6.3 L'Aquila Earthquake, Central Italy. *Journal of Geophysical Research:*  
 538 *Solid Earth*, 124(10), 10522–10543. doi: 10.1029/2018JB017053
- 539 Ragon, T., Sladen, A., & Simons, M. (2018). Accounting for uncertain fault  
 540 geometry in earthquake source inversions – I: Theory and simplified ap-  
 541 plication. *Geophysical Journal International*, 214(2), 1174–1190. doi:  
 542 10.1093/gji/ggy187
- 543 Ragon, T., Sladen, A., & Simons, M. (2019). Accounting for uncertain fault geom-  
 544 etry in earthquake source inversions – II: Application to the Mw 6.2 Amatrice  
 545 earthquake, central Italy. *Geophysical Journal International*, 218(1), 689–707.  
 546 doi: 10.1093/gji/ggz180
- 547 Razafindrakoto, H. N. T., & Mai, P. M. (2014). Uncertainty in Earthquake Source  
 548 Imaging Due to Variations in Source Time Function and Earth Structure. *Bul-*  
 549 *letin of the Seismological Society of America*, 104(2), 855–874. doi: 10.1785/  
 550 0120130195
- 551 Reilinger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., Cakmak, R., ...  
 552 Karam, G. (2006). GPS constraints on continental deformation in the Africa-  
 553 Arabia-Eurasia continental collision zone and implications for the dynamics of  
 554 plate interactions. *Journal of Geophysical Research: Solid Earth*, 111(B5). doi:  
 555 10.1029/2005JB004051
- 556 Rosen, P. A. G. (2012). The InSAR Scientific Computing Environment. In *9th Eu-*  
 557 *ropean Conference on Synthetic Aperture Radar*. Nuremberg, Germany.
- 558 Schmittbuhl, J., Karabulut, H., Lengliné, O., & Bouchon, M. (2016). Long-lasting  
 559 seismic repeaters in the Central Basin of the Main Marmara Fault. *Geophysical*  
 560 *Research Letters*, 43(18), 9527–9534. doi: 10.1002/2016GL070505
- 561 Şengör, A., Tüysüz, O., İmren, C., Sakıncı, M., Eyidoğan, H., Görür, N., ...  
 562 Rangin, C. (2005). The North Anatolian Fault: A New Look. *Annual*  
 563 *Review of Earth and Planetary Sciences*, 33(1), 37–112. doi: 10.1146/  
 564 annurev.earth.32.101802.120415
- 565 Stein, R. S., Barka, A. A., & Dieterich, J. H. (1997). Progressive failure on the  
 566 North Anatolian fault since 1939 by earthquake stress triggering. *Geophysical*  
 567 *Journal International*, 128(3), 594–604. doi: 10.1111/j.1365-246X.1997.tb05321  
 568 .x

- 569 Tan, O., Pabuçcu, Z., Tapırdamaz, M. C., İnan, S., Ergintav, S., Eyidoğan, H., ...  
 570 Kuluöztürk, F. (2011). Aftershock study and seismotectonic implications  
 571 of the 8 March 2010 Kovancılar (Elazığ, Turkey) earthquake (MW = 6.1).  
 572 *Geophysical Research Letters*, *38*(11). doi: 10.1029/2011GL047702
- 573 Tarantola, A. (2005). *Inverse Problem Theory and Methods for Model Parameter Es-*  
 574 *timation*. Society for Industrial and Applied Mathematics.
- 575 Twardzik, C., Vergnolle, M., Sladen, A., & Avallone, A. (2019). Unravelling the con-  
 576 tribution of early postseismic deformation using sub-daily GNSS positioning  
 577 —. *Scientific Reports*, *9*(1), 1775. doi: 10.1038/s41598-019-39038-z
- 578 Wells, D. L., & Coppersmith, K. J. (1994). New empirical relationships among mag-  
 579 nitude, rupture length, rupture width, rupture area, and surface displacement.  
 580 *Bulletin of the Seismological Society of America*, *84*(4), 974–1002.
- 581 Wesnousky, S. G. (2006). Predicting the endpoints of earthquake ruptures. *Nature*,  
 582 *444*(7117), 358–360. doi: 10.1038/nature05275
- 583 Wessel, P., Luis, J. F., Uieda, L., Scharroo, R., Wobbe, F., Smith, W. H. F., & Tian,  
 584 D. (2019). The Generic Mapping Tools Version 6. *Geochemistry, Geophysics,*  
 585 *Geosystems*, *n/a*(n/a). doi: 10.1029/2019GC008515
- 586 Xu, X., Tong, X., Sandwell, D. T., Milliner, C. W. D., Dolan, J. F., Hollingsworth,  
 587 J., ... Ayoub, F. (2016). Refining the shallow slip deficit. *Geophysical Journal*  
 588 *International*, *204*(3), 1867–1886. doi: 10.1093/gji/ggv563
- 589 Yagi, Y., & Fukahata, Y. (2008). Importance of covariance components in inver-  
 590 sion analyses of densely sampled observed data: An application to waveform  
 591 data inversion for seismic source processes. *Geophysical Journal International*,  
 592 *175*(1), 215–221. doi: 10.1111/j.1365-246X.2008.03884.x
- 593 Yilmaz, H., Over, S., & Ozden, S. (2006). Kinematics of the East Anatolian  
 594 Fault Zone between Turkoglu (Kahramanmaras) and Celikhan (Adiya-  
 595 man), eastern Turkey. *Earth, Planets and Space*, *58*(11), 1463–1473. doi:  
 596 10.1186/BF03352645
- 597 Zhu, L., & Rivera, L. A. (2002). A note on the dynamic and static displacements  
 598 from a point source in multilayered media. *Geophysical Journal International*,  
 599 *148*(3), 619–627. doi: 10.1046/j.1365-246X.2002.01610.x