Correlating earthquake static stress drop values with fault complexity in the 2016 Amatrice-Norcia earthquake sequence, Central Italy

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Abstract

The 2016 Amatrice-Norcia seismic sequence in central Italy activated a system of normal faults in the central Apennines and ruptured the surface along the Monte Vettore normal fault. Due to the complex rupture behavior, including antithetic faults and the proposed reactivation of an old thrust front, the Amatrice-Norcia seismic sequence offers a unique opportunity to study the relationship between fault complexity, surface ruptures, and earthquake source properties. Here, we focus on the first two months of the Amatrice-Norcia seismic sequence, including the 30 October 2016 Mw 6.5 mainshock near Norcia and more than 25000 aftershocks. Using continuous waveform data from 94 seismic stations with epicentral distances of up to ~100 km, we estimate source parameters of all cataloged earthquakes that exceed specific quality control criteria in a time period ranging from 24 October – 29 November 2016. Displacement spectral corner frequency and seismic moment values are fit using individual earthquake spectra, and corner frequency estimates are refined using spectral ratios. Constrained spectral parameters then provide input for static stress drop estimates based on a circular crack model. Preliminary results suggest the majority of earthquakes have static stress drop values between 1 and 10 MPa and self-similar scaling. Due to the high quality and quantity of available data, including precise earthquake locations, manually reviewed phase arrivals, and detailed mapping of surface ruptures, the Amatrice-Norcia earthquake sequence represents an opportunity to link earthquake source parameters to geological structures and surface rupture complexity. Preliminary results show correlations between high stress drop values and areas with increasing fault complexity, such as fault intersections at depth (inferred from precise earthquake hypocenters) or the mapped tip of the Monte Vettore normal fault, relative to other fault patches with fewer intersections or mapped surface trace terminations. Future work will examine whether the correlation of stress drop and fault complexity holds using refined stress drop estimates obtained using spectral ratio approaches.

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References + Supplementary
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What and Why?

- Investigate Static Stress Drop Values
  - Single spectrum + Spectral Ratio Methods
- Scaling and Distribution of Stress Drop
- Spatio- and Temporal Evolution of Stress Drop
  - Relationship to Large Earthquakes and Mapped Faults
- Insights into the Stress Field and its Evolution

Where?

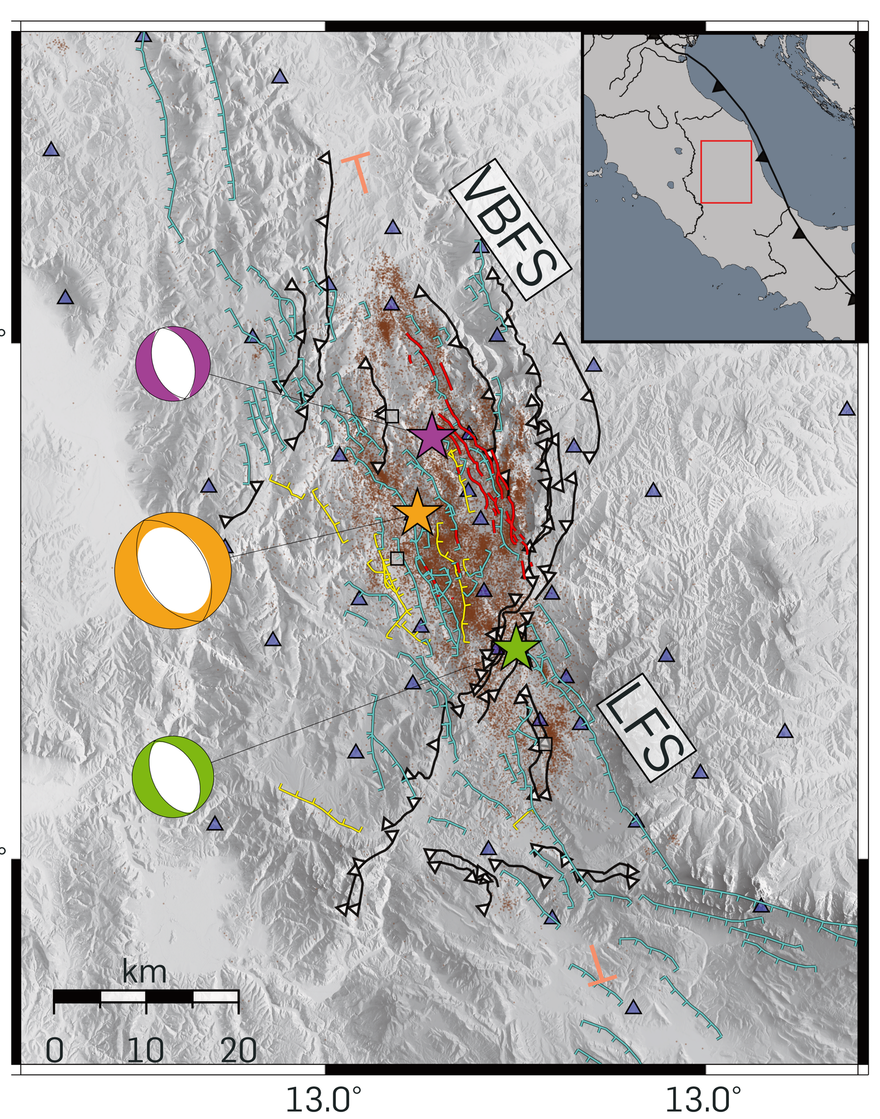


Figure 1: Epicentral area of the Amatrice-Visso-Norcia (AVN) seismic sequence with all earthquakes used in this study. Mapped active normal faults are marked with yellow (E-dipping) and cyan (W-dipping) colored lines. Miocene-Pleistocene thrust fronts are denoted with black barbed lines, and mapped surface ruptures are marked with red lines (modified after Villani et al. 2018). VFBS – Vettore-Bove fault system, LFS – Laga fault system.

- 2016-06-01 – 2016-11-31
- Three "Mainshocks"
  - Amatrice M_W 6.0
    - 2016-08-24
  - Visso M_W 5.9
    - 2016-10-26
  - Norcia M_W 6.5
    - 2016-10-30

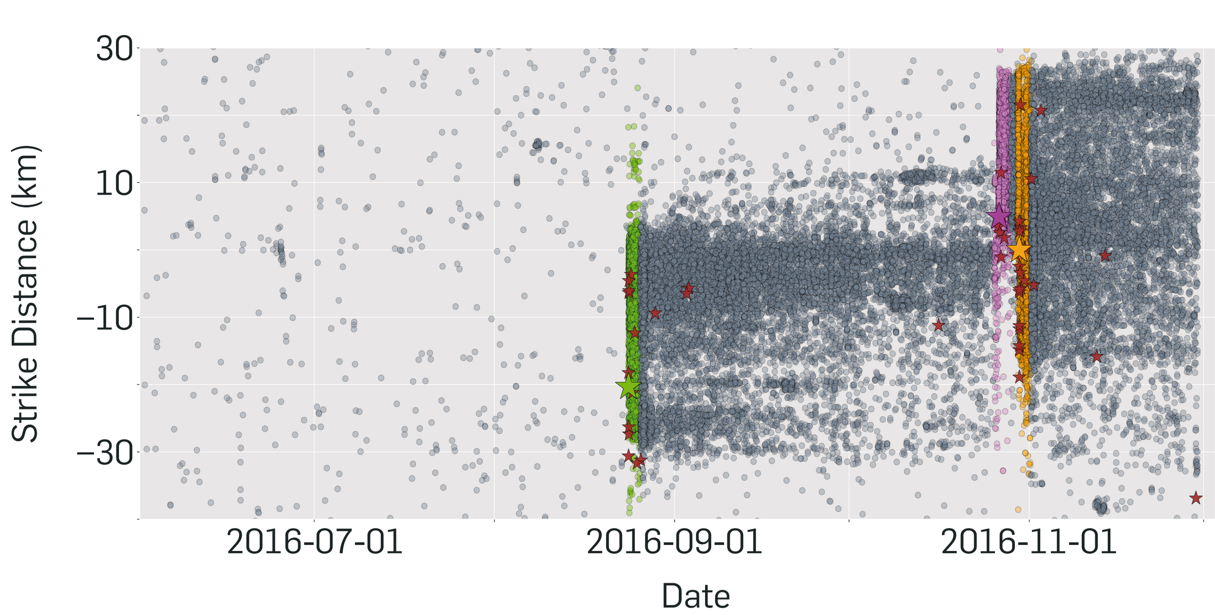
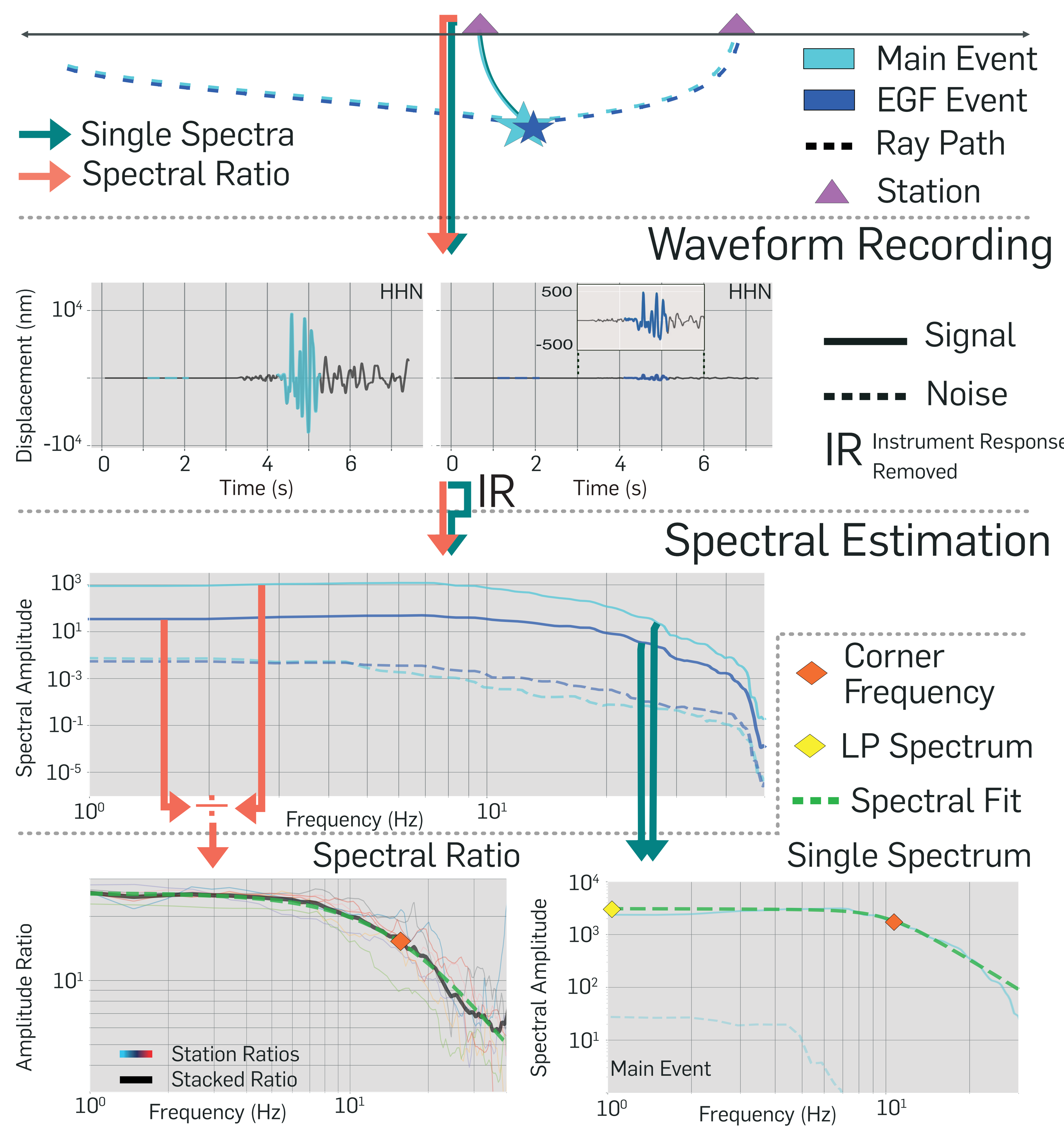


Figure 2: Earthquake occurence along strike (Norcia mainshock at position zero). Brown stars denote earthquakes with M ≥ 4. The standard catalog from INGV is used before the Amatrice mainshock. Afterwards, the catalogs from Chiaraluce (2017) and Improta (2019) are combined. Colored earthquakes denote the early aftershock sequences of each mainshock.

How? – Spectral Workflow



Results

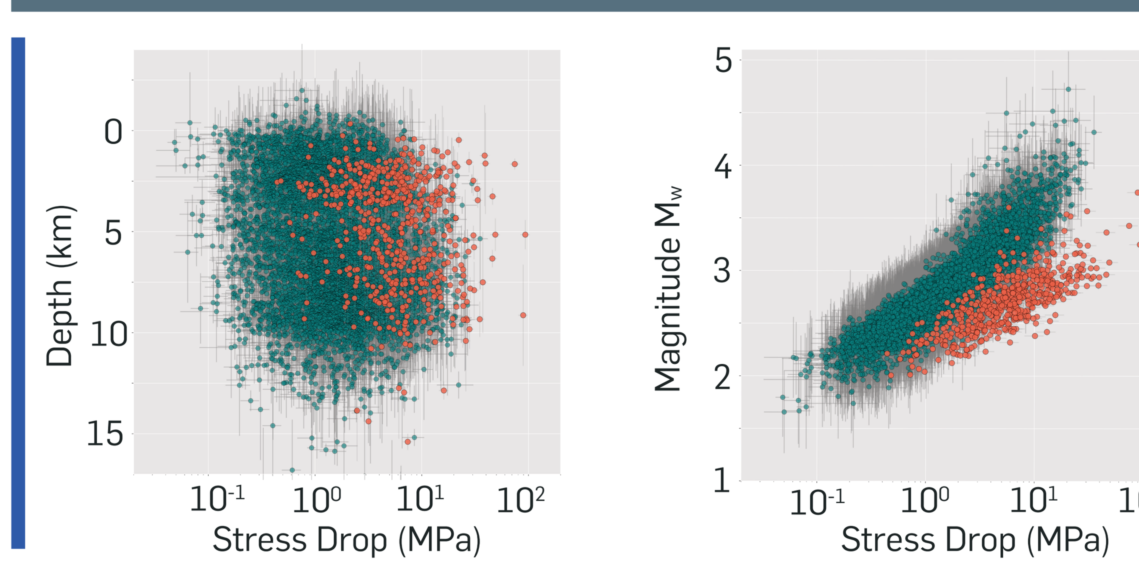


Figure 3: Stress drop vs. depth and magnitude. Orange and teal colored points denote estimations from single spectra and spectral ratios, respectively.

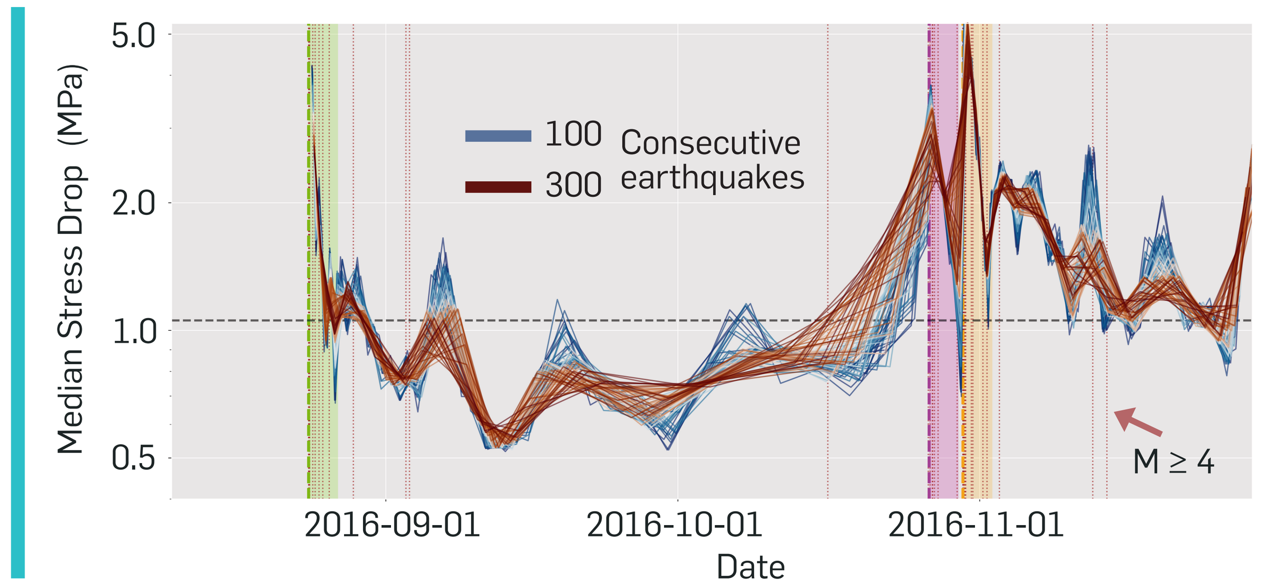


Figure 4: Moving median of the stress drop estimates with time.The heavy vertical dash-dotted lines denote the occurrence of the three largest earthquakes.

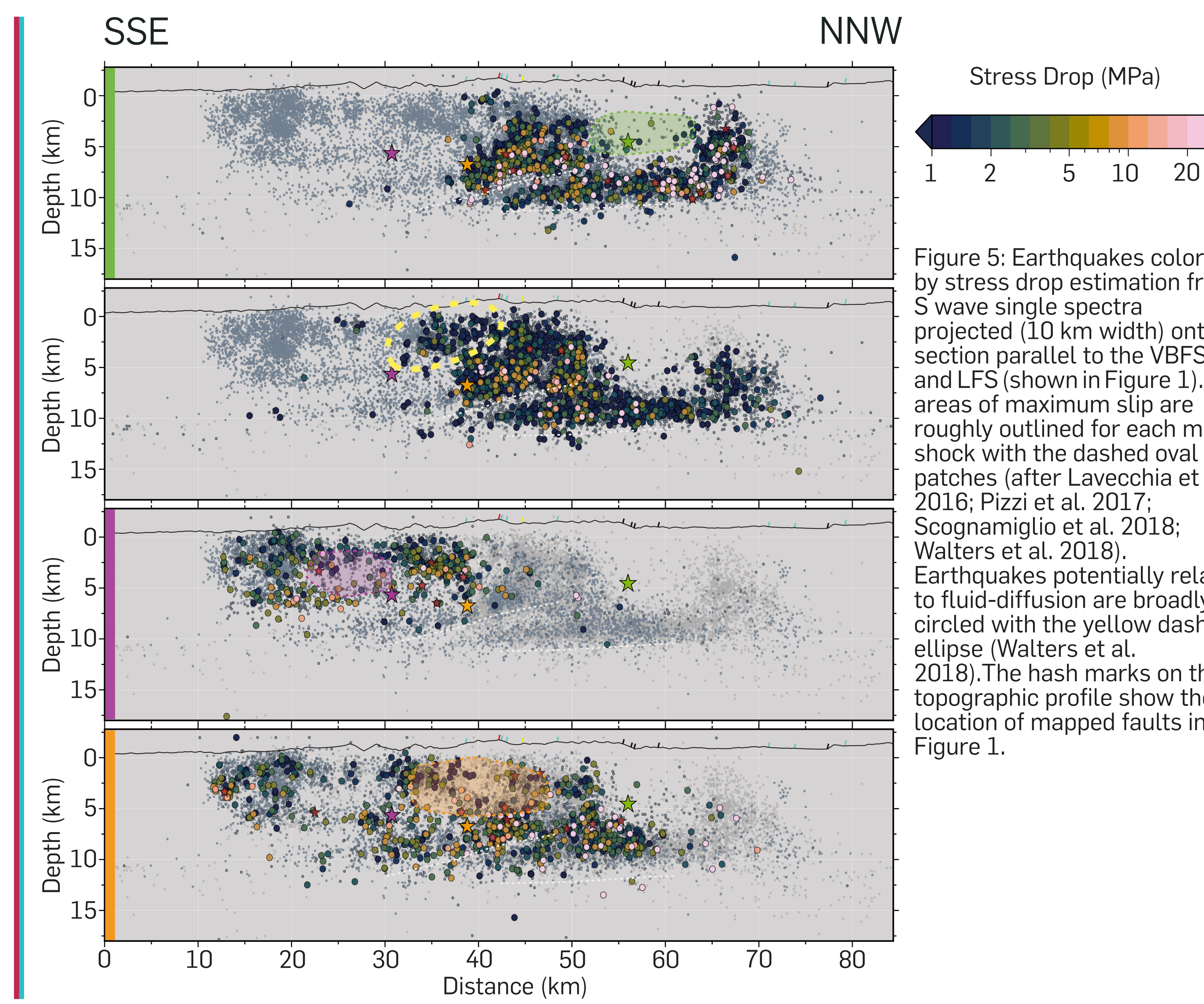


Figure 5: Earthquakes colored by stress drop estimation from S wave single spectra projected (10 km width) onto a section parallel to the VBFS and LFS (shown in Figure 1).The areas of maximum slip are roughly outlined for each main-shock with the dashed oval patches (after Lavecchia et al. 2016; Pizzi et al. 2017; Scognamiglio et al. 2018; Walters et al. 2018). Earthquakes potentially related to fluid-diffusion are broadly circled with the yellow dashed ellipse (Walters et al. 2018).The hash marks on the topographic profile show the location of mapped faults in Figure 1.

Conclusions

- **Higher** stress drops ...
  - › for early aftershocks
  - › around areas with max slip
  - › in fault intersection zones
  - › for higher magnitudes (?)
- **Lower** stress drops ...
  - › for late aftershocks
  - › during fluid diffusion
  - › during post-seismic afterslip (?)
  - › preceding large events
- › Lower stress drop events may exhibit migratory patterns between large slip events.

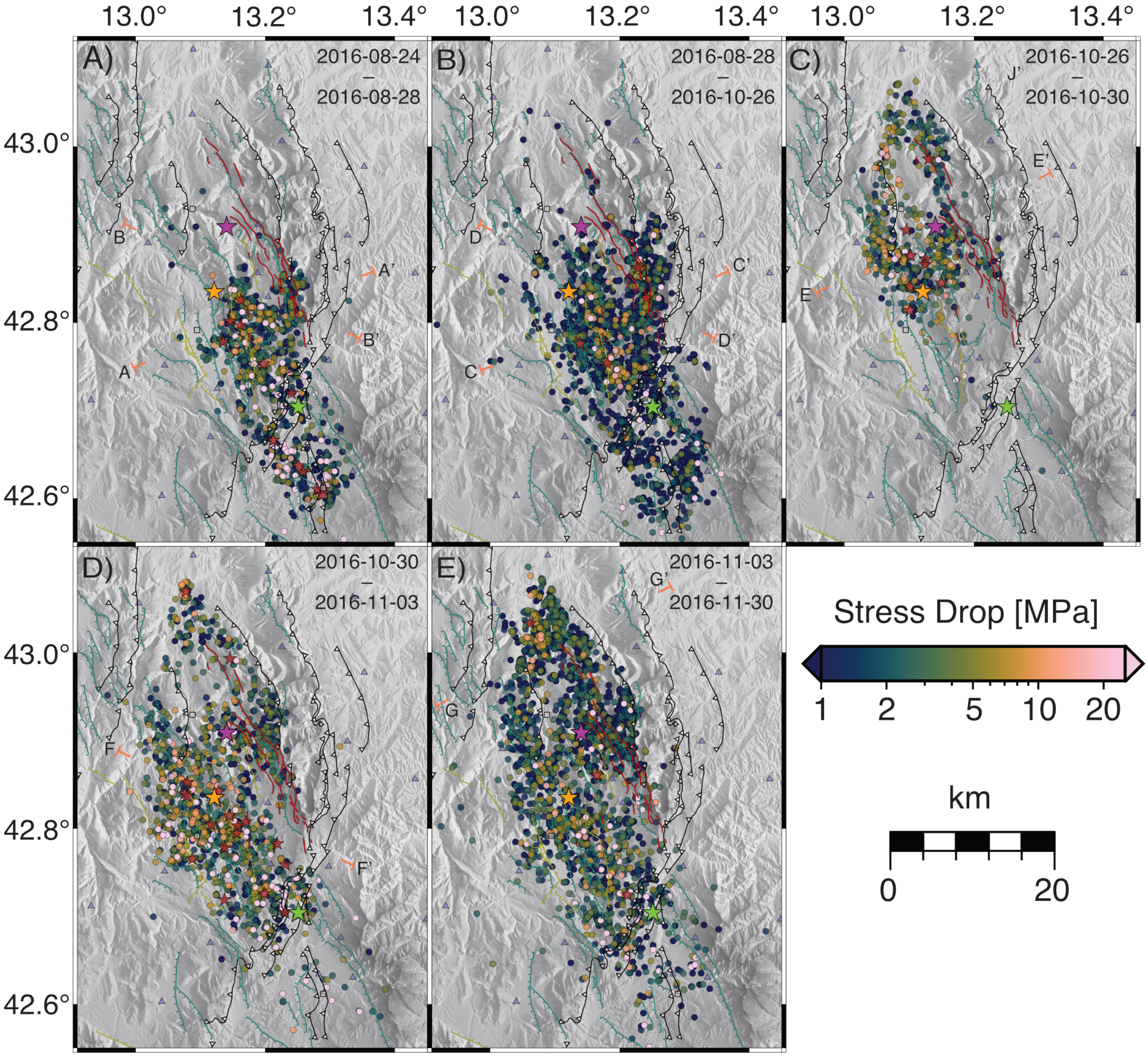


Figure S1: Map view of earthquakes for different periods colored by the stress drop estimation from S-wave single spectra. Mapped faults are marked the same as in Figure 1. Subfigures A, C, D show the aftershocks within four days after the Amatrice, Visso, and Norcia earthquake (each epicentral location of the mainshocks is marked with a star in the same color used in Figure 1), respectively. The seismicity between the Amatrice and Visso earthquakes is shown in subfigure B, and after the Norcia earthquake in subfigure E. Earthquakes with a reported magnitude $M \geq 4$ are marked with a brown star, and earthquakes without a spectral estimation with a grey circle. Mainshock locations are shown in all subfigures despite their potential occurrence after the particular time window.

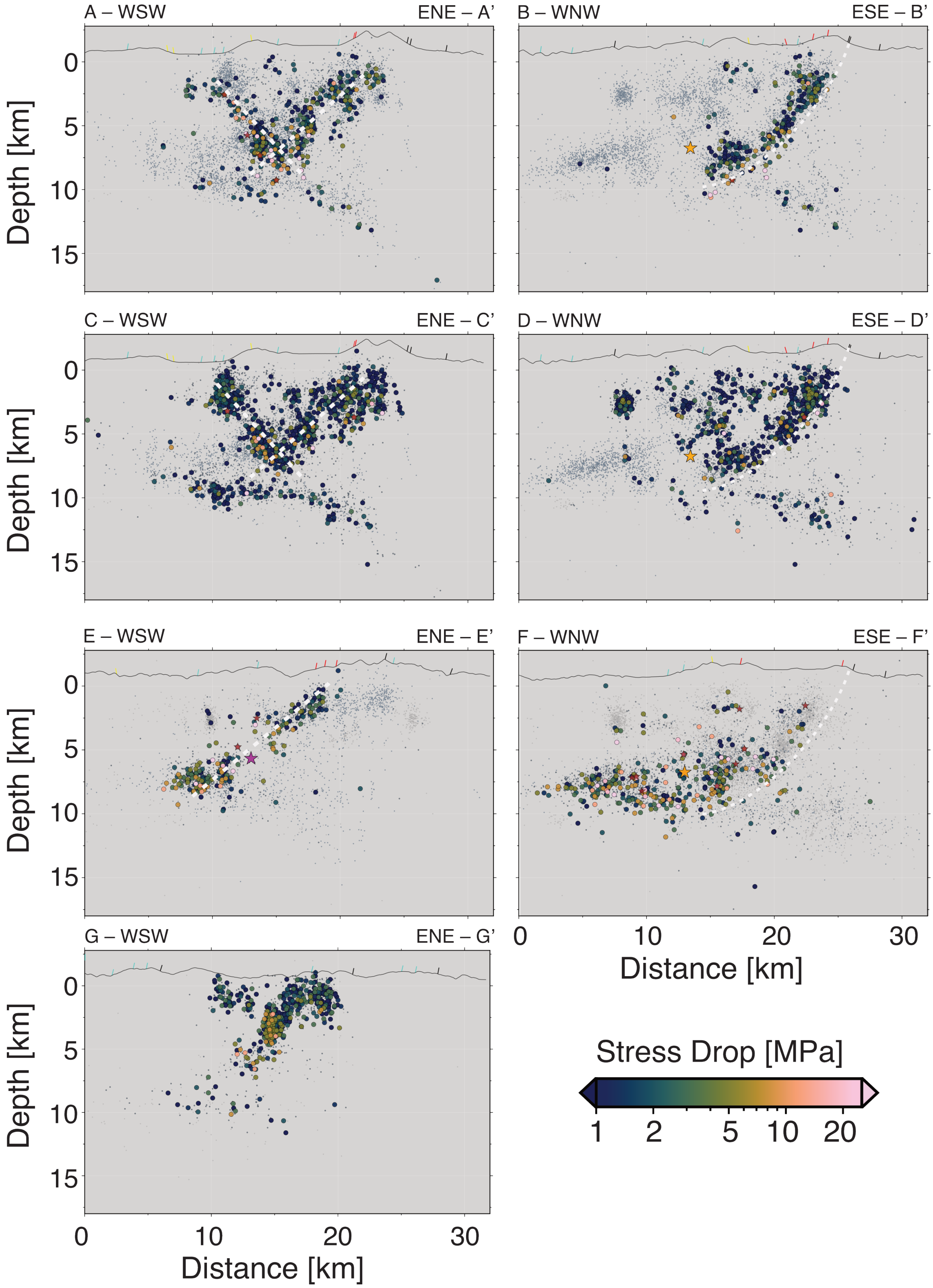


Figure S2: Earthquakes colored in their stress drop estimation from S-wave single spectra of the AVN seismic sequence projected (3 km width) onto different cross-sections, which are shown in Figure S1. Colors and symbols are the same as in Figure 5. The white dashed lines show interpretations of fault locations at depth from previous studies (Chiaraluce et al. 2017, Improta et al. 2019.)