What we can say (or not) about the seismic sequence of the November 9th 2022, Mw 5.5, earthquake in the Marche offshore: an analysis of the Italian Seismic Bulletin on phase interpretation, velocity models and uncertainties of earthquake locations

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Introduction

In November 2022 a seismic sequence occurred in the Marche offshore, about 29 km from the coast and the city of Fano. The sequence started on November 9 (06:07:25 UTC) with a M_L=5.7 earthquake (Mw=5.5 from TDMD computation, Scognamiglio et al., 2006), immediately followed by a M_L=5.2 earthquake (06:08:29 UTC) located about 8 km to the south. The two mainshocks activated a seismic sequence with about 400 aftershocks lasting the first week, 13 of them with M_L>= 3.5 (Fig. 1).

Few hours after the occurrence of the mainshock, the BSI ("Bollettino Sismico Italiano") working group started to manually analyze P and S phase arrival times and seismogram amplitudes of earthquakes with magnitude M_L>= 3.5 recorded by the the Italian National Seismic Network (Rete Sismica Nazionale, hereafter RSN) in order to better constrain hypocenter locations previously provided by the seismic surveillance room of the INGV in Rome for rapid communication to the Italian Civil Protection (Dipartimento Protezione Civile, DPC). Later, the BSI working group analyzed the seismicity of the sequence of the first weeks of seismic activity by revising hypocentral parameters of more than 500 events.

The 2022 Marche offshore sequence took place along the Adriatic outer front of the northern Apennines in central Italy. Offshore seismic reflection profiles image a shallow thrust-and-fold system striking WNW–ESE to NNW–SSE. Along the coastal Adriatic area, active blind thrusts deform Plio-Quaternary siliciclastic turbidites that are few hundreds of meters to more than 2 km thick in correspondence of ramp anticlines and synclines, respectively. In a recent work, through the analysis of high-quality background seismicity data, De Nardis et al. (2022) identified two lithospheric-scale active thrusts deepening westward under the Adriatic outer front from upper- to lower-crustal depths. These new data support previous thick-skinned interpretations of seismic commercial profiles and CROP03 deep reflection data (Lavecchia et al., 2003). Focal mechanisms of weak to moderate (M_L < 4.8) local earthquakes occurred between 2009-2017 at upper- to deep-crustal depths show prevailing reverse and reverse/oblique solutions (De Nardis et al., 2022) and subordinate strike-slip faulting (Mazzoli et al., 2014).

The analysis of the 2022 Marche offshore sequence opens again the discussion on the uncertainties related to the hypocenter locations of earthquakes that occur in the Adriatic offshore domain (e.g., Di Stefano et al., 2022) and the limits of our present capability to provide an accurate seismotectonic interpretation of the instrumental seismicity in this region. Actually, the 2022 sequence area is only covered on land by RSN, with the closest seismic station located at about 28 km from the epicentral location of the mainshock. The particular geometry of the network along the Italian coast makes it difficult to correctly constrain hypocenter locations compared with other regions of Italy. Taking into account this configuration, although the INGV is able to obtain coherent earthquake information for Civil Protection purposes into the limits of the communication threshold, we note that data provided by the seismic surveillance room in terms of both seismic phase readings of arrival times for hypocenter location and waveform amplitudes for magnitude computation need to a more accurate analysis if the main goal is the correct reconstruction of the active structures involved in the sequence. This analysis should include a) a careful revision of the arrival time pickings to reduce the errors due to seismic phase misinterpretations, b) an accurate study to constrain earthquake locations with appropriate velocity models, and c) the hypocenter solution assessment through adequate tests that define which information can be inferred from earthquake location results.

Data analysis and phases interpretation

Through the interpretation of the seismic records, the BSI analysts have identified refracted first arrivals of P and S phases at epicentral distances of about 60 km, smaller than those expected for Pn/Sn refracted phases at the Moho discontinuity (e.g., Di Stefano and Ciaccio, 2014) whose arrivals should be observed at distances of about 90-100 km in this area. Since possible systematic misinterpretation of P and S arrivals can strongly affect the correct hypocenter locations, we have carefully revised the phase pickings provided by the INGV surveillance room by discriminating direct from refracted phases at stations located at distances greater than 60 km. This is mainly important for interpretation of weak S refracted phases that are often hidden into the arrivals after the P phase. We have taken into account these characteristics in the earthquake location process by only using clear direct/refracted S phases in our inversion procedure. The comparison of the M_L>= 3.5 hypocenter locations performed by the BSI and the INGV surveillance room (Figs. 1 and 2) shows how an accurate analysis of the pickings is necessary to obtain robust earthquake locations for seismotectonic interpretation: even using the same hypocenter location code and velocity model, we observe that the mislocation of the hypocenters in this area can range from few to about 10 kilometers (Fig. 1) while the formal errors are strongly reduced after the BSI picking revision (Fig. 2)

The velocity model issue

Events location in the Adriatic Sea suffers from the lack of a specific velocity model for the seismic sequence area. The use of inadequate velocity parameters during the location process can introduce systematic errors, which may result in incorrect seismotectonic interpretations. We therefore built and tested different velocity models from both available geophysical data and our inversion of the velocity structure using the arrival time readings revised by the BSI working group.

In order to define deterministic 1D models suitable for earthquake location (Vp and Vp/Vs), we integrated sonic logs from local deep wells (ViDEPI Project, 2005) with literature data that include: seismic commercial profiles, deep seismic refraction surveys, the CROP03 crustal profile, Receiver Function and regional seismic tomography models, Vp/Vs reference values for mid- and lower-crustal crystalline rocks (Coward et al., 1999; Ponziani et al., 1995; Lavecchia et al., 2003; Spada et al., 2013; Di Stefano et al., 2009, Christiansen and Mooney, 1993).

In order to obtain the velocity structure from our revised dataset, we first determined the Vp/Vs ratio by using the arrival time pickings of selected P and S phases. The mean velocity ratio Vp/Vs was computed through the cumulative Wadati diagram. Then, by collecting all the *a priori* available information regarding the structure of Adriatic Sea (velocities, layer thicknesses and Moho depth), we applied the VELEST software (Kissling, 1995) to compute a new 1D velocity model for earthquake location.

Conclusions

In this work we present our first analyses of the sequence and the accurate study of the velocity models that we obtained from both a revision of available data and the inversion of arrival time pickings analyzed by the BSI analists. Moreover, we will discuss our preliminary earthquake locations with a particular attention to resolution analysis and hypocenter location assessment.

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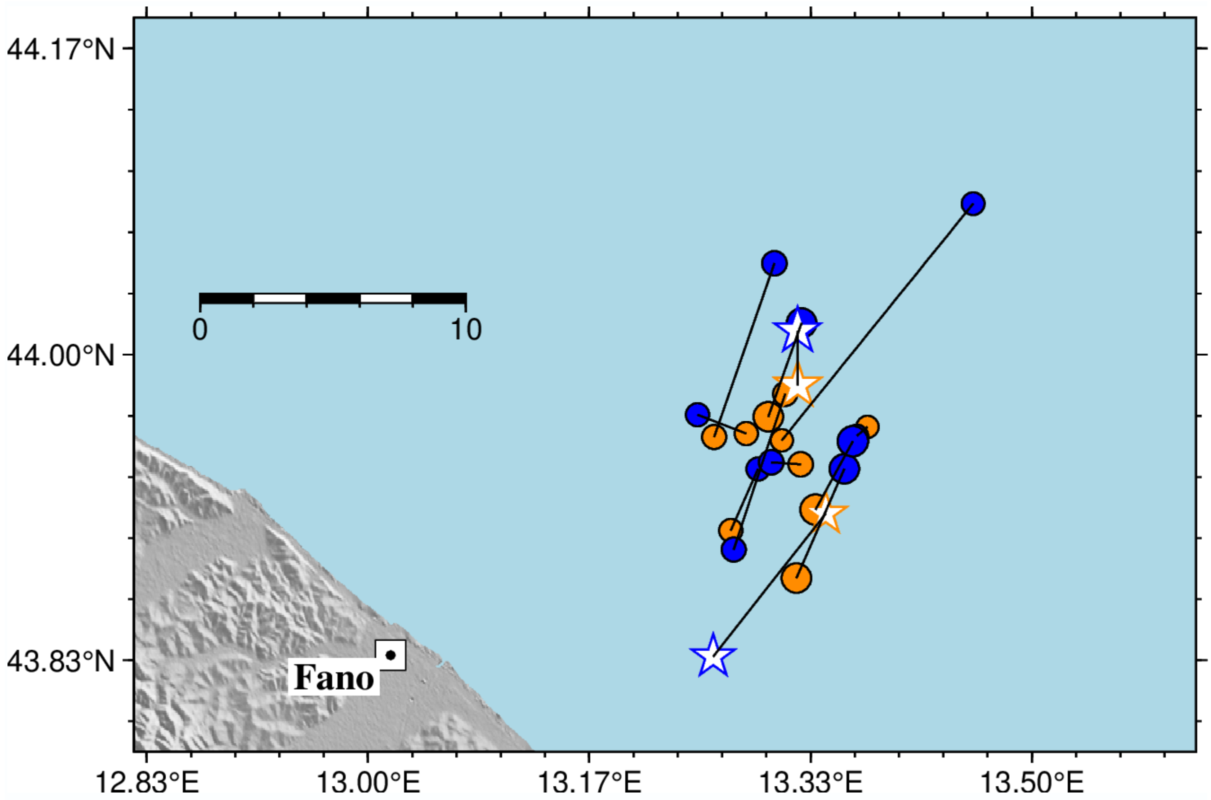
Captions

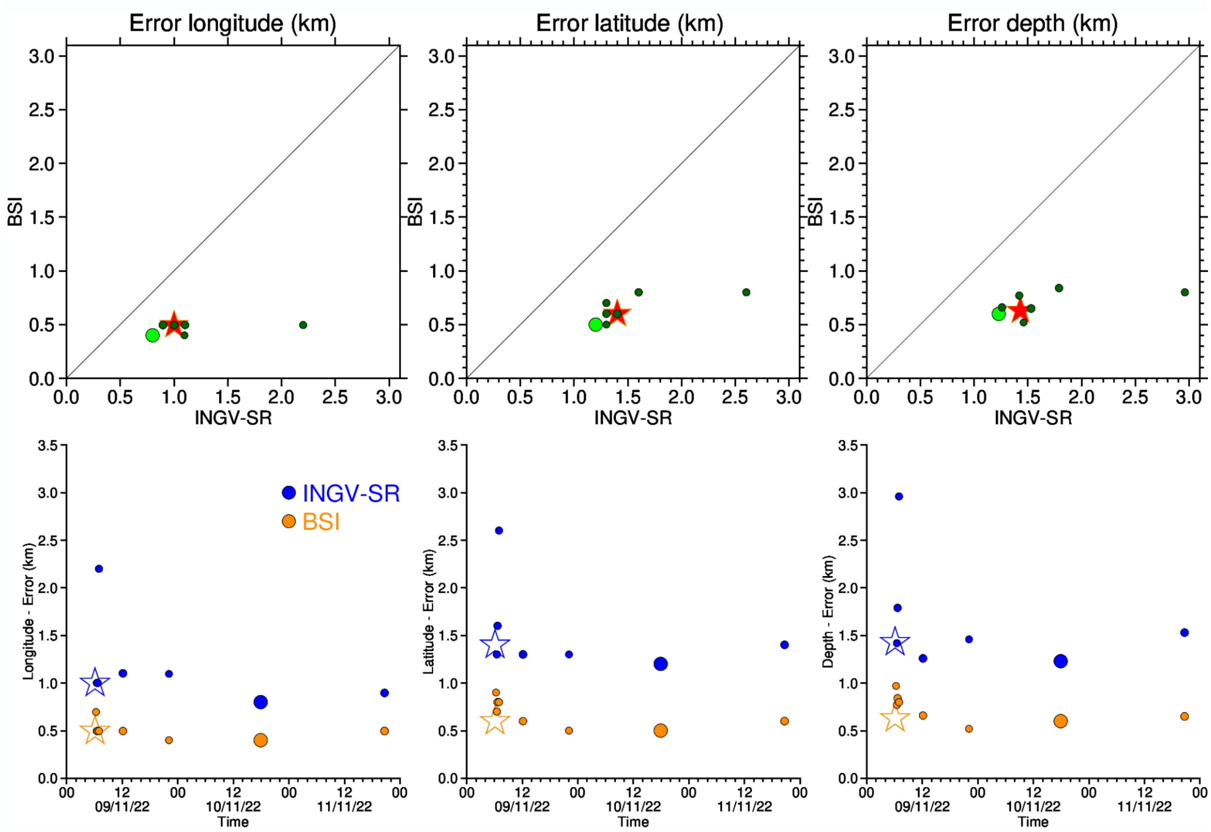
Fig. 1: Epicentral map of 12 earthquakes with ML ≥ 3.5 occurred in the first hours after the mainshock and revised by the BSI (orange symbols) compared to the epicenters of the same events localized by the INGV seismic surveillance room (blue symbols). The stars (blue and orange) are the events with ML=5.7 and ML=5.2 (color code is the same).

Fig. 2: Hypocenter location formal errors for parameters of longitude, latitude and depth. Color code is the same as Fig. 1. BSI are formal hypocentral errors from BSI analysis and INGV-SR are formal hypocentral errors from the INGV seismic surveillance room analysis



44.17°N
44.00°N
43.83°N
12.83°E
13.00°E
13.17°E
13.33°E
13.50°E
0
10
Fano

Fig. 1



Error longitude (km)
Error latitude (km)
Error depth (km)
BSI
INGV-SR
INGV-SR
BSI
Longitude - Error (km)
Latitude - Error (km)
Depth - Error (km)
09/11/22
10/11/22
11/11/22
Time

Fig. 2