Appraisal of the hypocentral location of the L'Aquila main shock

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Abstract

This work addresses the location of the hypocenter of the l'Aquila, M6.3 April 6, 2009, main shock. A thorough analysis of the earthquake focus and its uncertainties is carried out using both a linearized standard, and a grid search methodology for earthquake location. To assess the robustness of the location, different velocity models and independently picked phase data sets (2) are tested. All the resulting solutions are comprised within a radius of less than 1 km horizontally whereas depth depends on the velocity model used. The solutions obtained using only the 30 closest stations and a locally calibrated velocity model resulting from the application of the Velest procedure feature final RMS residual values close to 0.07 s or less. The depth of the hypocenter is close to 8.8 km with a largest semi-axis of 0.7 km for the1-σ ellipsoid . No significant change in the location (~150 m and ~200 m horizontally and vertically, respectively) is found when using the two data sets both adopting the 30 closest stations. The location difference, however, increases when additional stations are included.

The initial energy release at the hypocenter is comparable to that of a M4 foreshock, which occurred a few days earlier. The first burst of larger seismic energy is picked on some of the available data - it is found to occur about 0.8-1.0 s from OT, it locates up-dip (~2 km) from the initial nucleation and it is shifted the E-NE. This location is consistent with a ~50º SW dipping plane for the main rupture.

Observations

The data used for the location consist of the picks performed on the waveforms provided by the stations of the Italian National Seismic Network (INSN, international code IV), the accelerometers of the "Rete Accelerometrica Nazionale" (RAN, code IT), and the Abruzzi regional network.

The phase readings of the INSN and RAN networks have been picked independently by two groups of researchers. In contrast, the Abruzzi picks (26) are common to both data sets and they have been provided by the Abruzzi network operators.

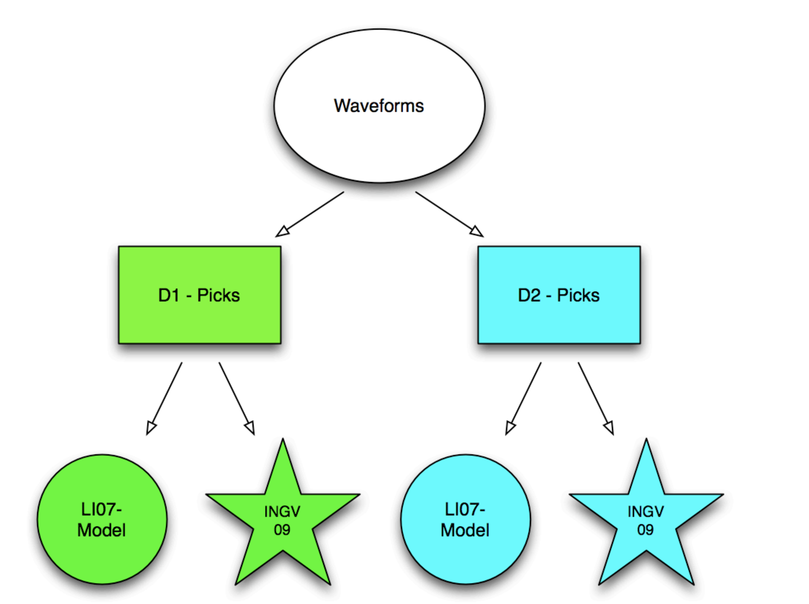


Figure 1. Flow diagrams that summarizes data sets and symbols used to represent the locations.

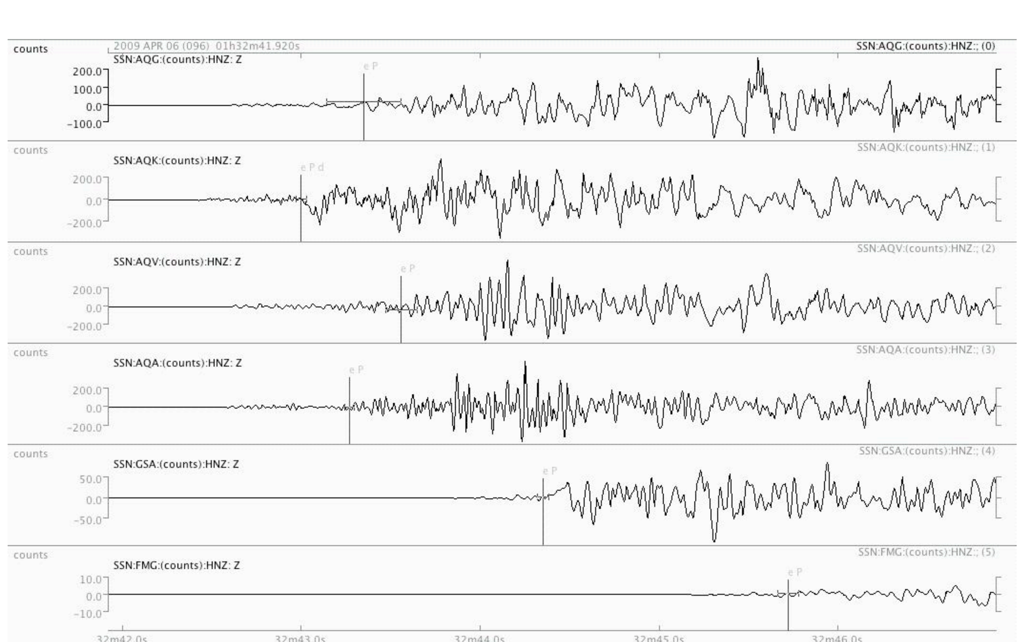


Figure 2.Example of the waveform traces recorded for the L'Aquila earthquake. The vertical bars indicate the readings for the larger burst of energy that followed the rupture inception.

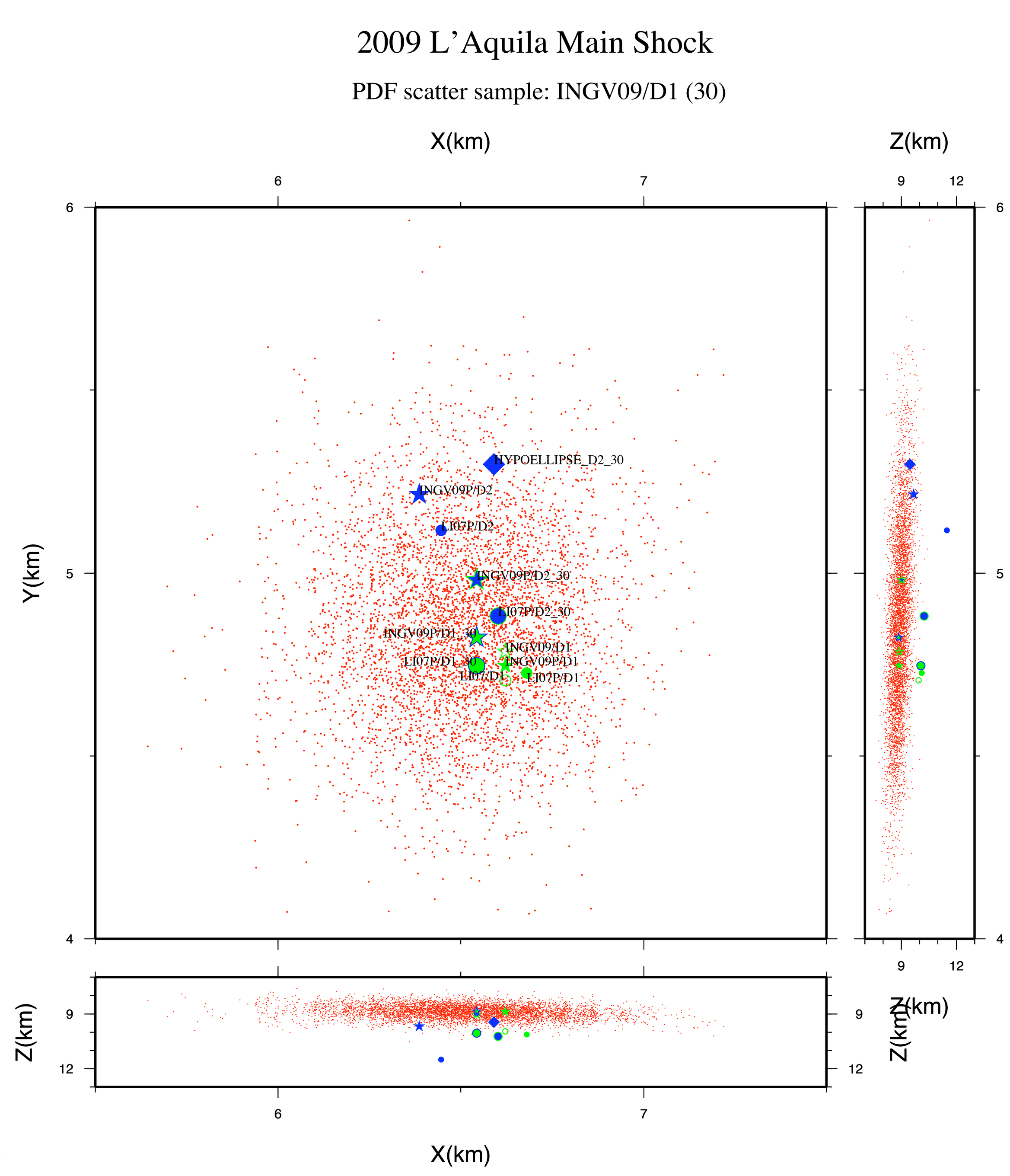


Figure 3. L'Aquila main shock locations. The green and the blue symbols refer to the locations obtained using the D1 and D2 data sets, respectively. The stars refer to locations obtained using the INGV09 model whereas the circles to the LI07 model. The solid blue diamond corresponds to the location obtained with HYPOELLIPSE. The filled symbols refer to locations obtained using the P phases only (the open symbols represent location obtained using also the S-wave readings). The solid blue star with a green contours refers to the INGV09P/D2 (30 phases) location. Conversely, the green star with blue contours corresponds to the the INGV09P/D1 (30 phases) location. The red dots are the probability density function (pdf) scatter points. The scatter points are associated to the location INGV09P/D1 (30 phases) of Table 2. Note that large asymmetry between horizontal and vertical scale is due to vertical exaggeration. It gives the false impression that the pdf is flattened horizontally in the vertical cross-sections whereas it is true the contrary, eventually.

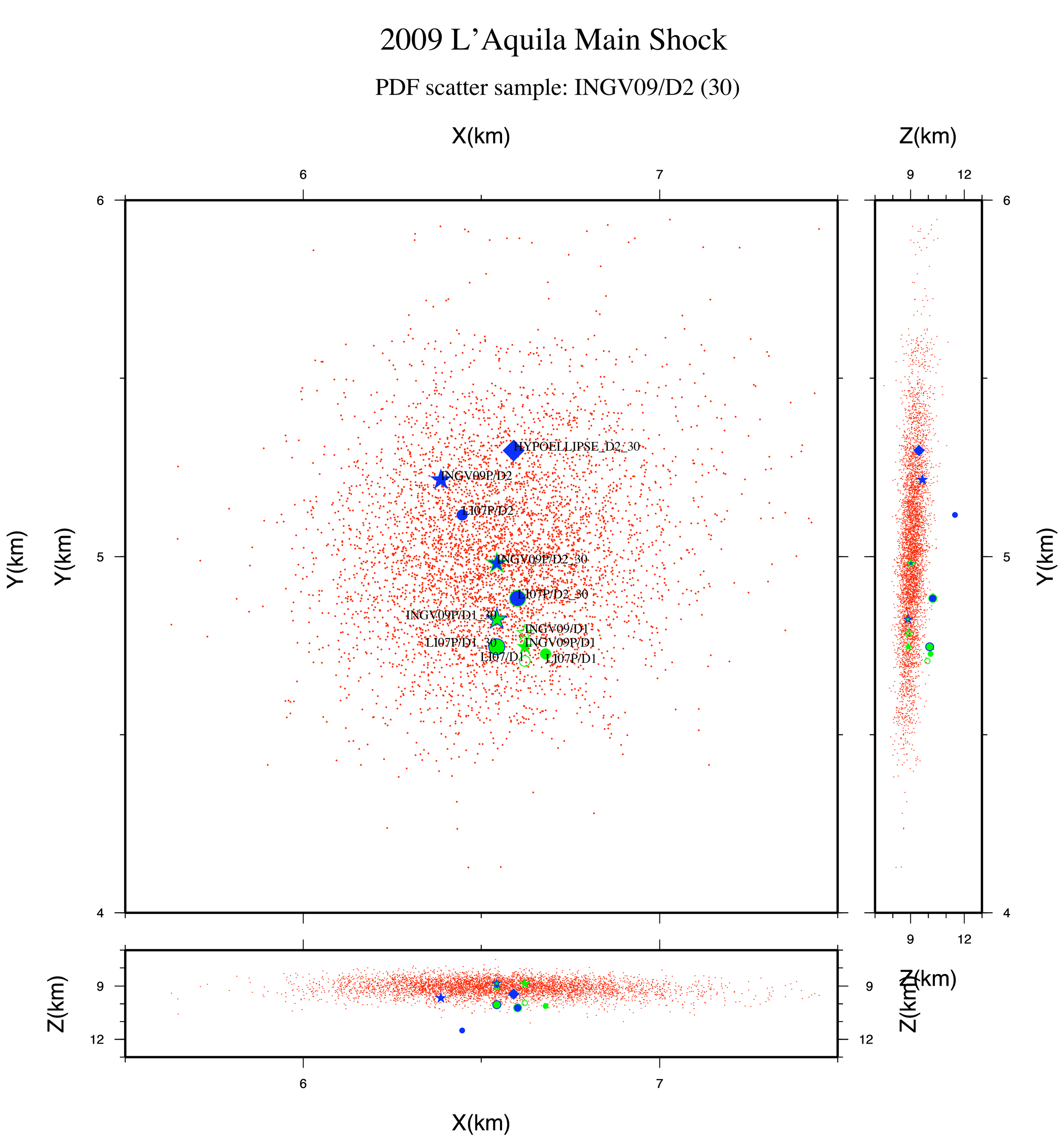


Figure 4. L'Aquila main shock locations. Same format as Fig. 3. The scatter points are associated to the location INGV09P/D2 (30 phases) of Table 2.

Model/Data	OT (h,m,s)	Lat (º)	Lon (º)	Dep (km)	N	RMS (s)	GAP (º)	EL1 (km)	EL2 (km)	EL3 (km)
LI07/D1	01 32 40.439873	42.34235	13.38036	9.954	49 (4)	0.132	34	0.43	0.51	0.87
LI07P/D1	01 32 40.423480	42.34253	13.38107	10.122	45	0.124	34	0.42	0.52	1.11
LI07P/D1 30 phases	01 32 40.431504	42.34271	13.37941	10.056	30	0.070	45	0.39	0.41	0.78
INGV09/D1	01 32 40.703546	42.34306	13.38036	8.884	49 (4)	0.135	31	0.43	0.49	0.88
INGV09P/D1	01 32 40.705111	42.34270	13.38036	8.870	45	0.131	33	0.42	0.49	0.98
INGV09P/D1 30 phases	01 32 40.708957	42.34341	13.37941	8.855	30	0.065	45	0.38	0.41	0.75
LI07P/D2	01 32 40.253070	42.34605	13.37823	11.499	51	0.133	21	0.49	0.60	1.46
LI07P/D2 30 phases	01 32 40.400391	42.343936	13.380124	10.239	30	0.078	45	0.40	0.49	0.86
INGV09P/D2	01 32 40.616443	42.34693	13.37752	9.675	51	0.100	20	0.36	0.44	0.76
INGV09P/D2 30 phases	01 32 40.685015	42.34482	13.37941	9.031	30	0.071	45	0.40	0.45	0.83
INGV09P/D2 HYPOEL	01 32 40.78	42.34767	13.38000	9.46	30	0.095	40	0.1	-	0.2

Table 2. Summary of the inversion results obtained using the NLLoc algorithm and with HYPOELLIPSE (last row). The green shaded rows indicate the locations that used the D1 data sets and the light blue shaded evidences the locations obtained using the D2 data set. The dark green rows indicate the locations obtained using also the S-wave phases.

Velocity Models

Vel (km/s)	Dept	Vp/Vs
5.0	0.0	1.86
5.9	3.5	1.86
6.3	9.0	1.86
7.0	18.0	1.86
8.0	33.0	1.86

Vel (km/s)	Dept	Vp/Vs
5.48	0.0	1.86
6.16	4.0	1.86
6.45	8.0	1.86
6.87	12.0	1.86
7.06	16.0	1.86

Table 1. Velocity models. LI07 (*top*); INGV09 (*bottom*).

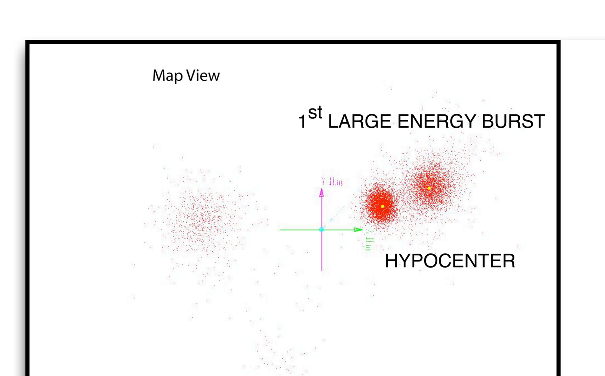
Discussion and Coclusions

The results hitherto presented indicate quite clearly that the location of the hypocenter of the l'Aquila earthquake can be pinned down to a few hundred of meters. Nevertheless, it has been observed that the locations do diverge to some extent when more distant stations are used. In practice, we have observed that the D1 data set appears to "pull" the earthquakes more to the South than the D2 set. As anticipated above, this effect can result from different interpretations of the very first onset for the farther stations. In any event, the location RMS residuals values are very low (~0.07 s) when nearest 30 stations (i.e., epicentral distance < 50 km) are used and they increase to only ~0.13 s when the station up to 75 km are used.

We have also found that the velocity models do not alter the pattern of locations horizontally but only vertically with the more regional LI07 model that locates the earthquakes slightly deeper. It is, however, difficult on the basis of the results obtained here (e.g., RMS) to select which of the two velocity models is more appropriate. We note, however, that since the INGV09 model was calibrated on the aftershocks of the sequence it is likely that this model might be more appropriate to the purpose of locating the focus of the main shock.

The final locations obtained with 30 phases did not include any S-wave onset. This follows from the difficulty to pick the S-waves for the nearby stations in the near field and, for the more distant stations, from the difficulty to identify the S-wave in the coda of the P-. For the l'Aquila main shock this was especially difficult if not impossible since the nucleation at the focus featured a very small moment rate release (i.e., low amplitudes).

The initial energy release at the hypocenter is comparable to that of a M4 foreshock, which occurred a few days earlier. The first burst of larger seismic energy is picked on some of the available data - it is found to occur about 0.8-1.0 s from OT, it locates up-dip (~2 km) from the initial nucleation and it is shifted the E-NE (see Fig. 5). This location is consistent with a ~50º SW dipping plane for the main rupture.



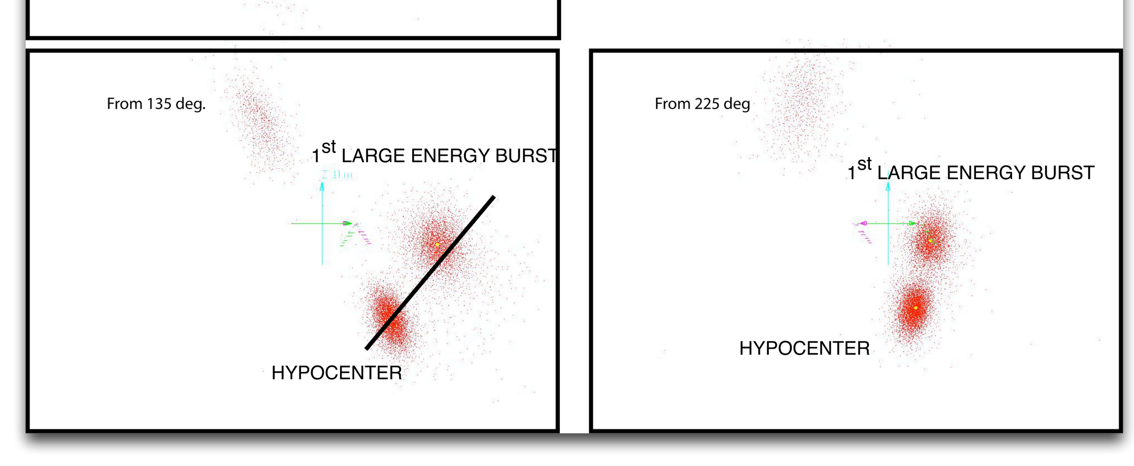


Figure 5. Location of the hypocenter and of the first larger burst of energy release. Map view (*left*). Section across the fault (*bottom left*) with indicated the 50º dip fault. Section along the fault (*bottom right*).

Acknowledgements

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