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The April 6, 2009, Mw 6.3, L'Aquila sequence: weak-motion and strong-motion data recorded by the RAIS temporary stations

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ABSTRACT

The aim of this study is the sharing of waveforms recorded by several Istituto Nazionale di Geofisica e Vulcanologia (INGV) temporary stations (managed by the Milan-Pavia section; INGV MI-PV). These stations were installed after the April 6, 2009, Mw 6.3, L'Aquila earthquake (central Italy). The work synthesizes the activities conducted in the field by the INGV MI-PV working group over the three months following the mainshock. The field activities were developed in four different phases that were defined according to their time periods. Starting from April 7, 2009, for the first phase, the temporary stations were installed in correspondence with the more damaged areas. The scope was to record the strongest aftershocks in the days that followed the mainshock. In this phase, the stations were composed of a six-component acquisition system that was coupled with both a weak-motion and a strong-motion sensor. After the first month, the last three phases of installation investigated the seismic responses of sites located in the epicentral area, involving villages within a radius of about 20 km from the epicenter of the April 6 mainshock. In this way, over four specific time-period phases, the stations were installed in sites with different lithological and geomorphological conditions. The instruments worked from April 7 to July 14, 2009; in this period, 9,155 aftershocks (134,262 accelerometric waveforms and 133,242 velocimetric waveforms), with ML ≤5.3 were recorded. This study describes the dataset of these earthquake waveforms recorded with both velocity and acceleration transducers. Selected waveforms are available through ftp://ftp.mi.ingv.it/download/RAIS-TS_rel01/, with their corresponding information concerning instrumental characteristics, installation sites, and earthquakes recorded.

Introduction

On April 6, 2009, a Mw 6.3 normal faulting event struck close to the city of L'Aquila in the Abruzzo region, central Italy [Ameri et al. 2009, Anzidei et al. 2009, Cirella et al. 2009]. Soon after the mainshock, the first emergency structure of the Centro Nazionale Terremoti (National earthquake centre) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV-CNT; http://cnt.rm.ingv.it/) was activated, for the installation of a real-time temporary seismic network in the epicentral area [Chiarabba et al. 2009], with the aim of capturing the migration of the hypocenters of the aftershocks. In the meantime, the INGV Milan-Pavia section (INGV MI-PV) made available the mobile stations of the Rete Accelerometrica in Italia Settentrionale (RAIS; the strong-motion network of northern Italy, http://rais.mi.ingv.it) [Augliera et al. 2009], to set up a high-density temporary network of stations (the RAIS-TS). In this way, INGV MI-PV operated together with the INGV Rome1 section (http://www.roma1.ingv.it/) and the Helmholtz Centre, Potsdam, Germany (http://www.gfz-potsdam.de/portal/gfz/home) in the framework of a coordinated experiment [Cultrera et al. 2009].

A relevant number of stations were installed in the area surrounding the town of L'Aquila (in the upper Aterno valley), near to or inside the most damaged villages [Galli et al. 2009] and where co-seismic surface effects have been observed [Emergeo Working Group 2010].

In the first month after the April 6, 2009, Mw 6.3, L'Aquila mainshock (first phase), the RAIS-TS were mainly installed corresponding to villages that had experienced the greatest damage. In this phase, the RAIS-TS were installed also with the aim of recording the more energetic aftershocks and to evaluate the presence of possibile nonlinear effects; in particular, accelerometric sensors were used to avoid signal saturation.

In the last three phases, the RAIS-TS were moved to several areas up to 20 km from the town of L'Aquila (see Figure 1), to evaluate the local site responses using ambient noise and/or earthquake recordings. These phases of installation was carried out in agreement with the research groups operating in the area, with the aim of investigating a relevant number of areas, while avoiding superimposition of recording stations.

The present study describes the features of the data collected by RAIS-TS in the epicentral area of the L'Aquila mainshock (Mw 6.3) during these four phases over the three months following the April 6, 2009, mainshock. The RAIS-TS recorded more then 267,000 waveforms that

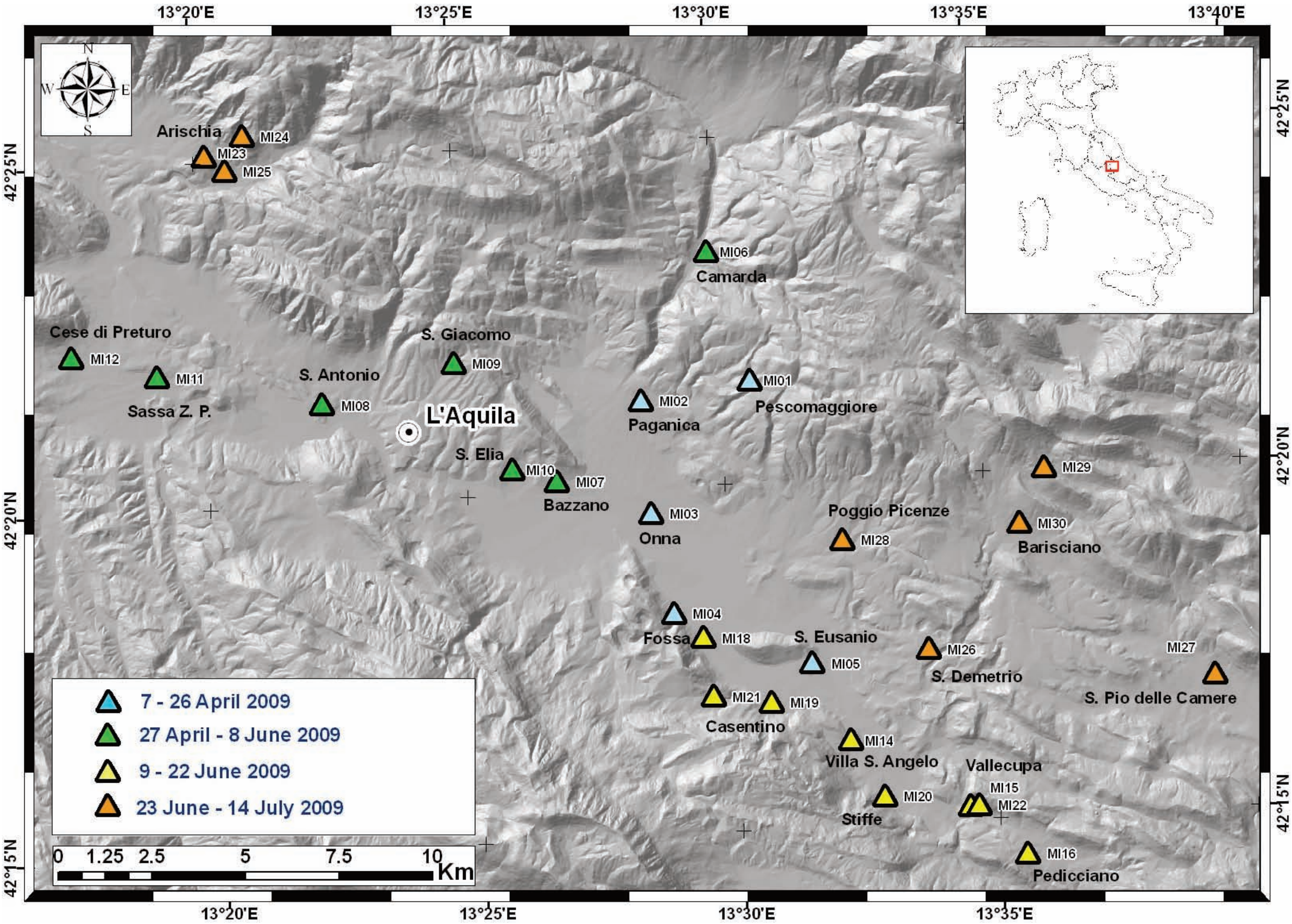

Figure 1. The RAIS-TS stations. The coloured triangles indicate the locations of the temporary stations installed in the different periods (as indicated).

Event ID	Data	Origin Time (GMT)	Latitude (° N)	Longitude (° E)	Depth (Km)	ML
20090407092628	2009-04-07	09:26:28	42.342	13.388	10.2	4.7
20090407174737	2009-04-07	17:47:37	42.275	13.464	15.1	5.3
20090407213429	2009-04-07	21:34:29	42.380	13.376	7.4	4.2
20090408225650	2009-04-08	22:56:50	42.507	13.364	10.2	4.3
20090409005259	2009-04-09	00:52:59	42484	13.343	15.4	5.1
20090409031452	2009-04-09	03:14:52	42.338	13.437	18.0	4.2
20090409043244	2009-04-09	04:32:44	42.445	13.420	8.1	4.0
20090409193816	2009-04-09	19:38:16	42.501	13.356	17.2	4.9
20090413211424	2009-04-13	21:14:24	42.504	13.363	7.5	4.9
20090414201727	2009-04-14	20:17:27	42.530	13.288	10.4	4.1
20090423151408	2009-04-23	15:14:08	42.247	13.492	9.9	4.0
20090423214900	2009-04-23	21:49:00	42.233	13.479	9.3	4.0
20090622205840	2009-06-22	20:58:40	42.446	13.356	14.2	4.5
20090703110307	2009-07-03	11:03:07	42.409	13.387	8.8	4.1
20090712083851	2009-07-12	08:38:51	42.338	13.378	10.8	4.0

Table 1. Earthquake list for the present study (ML ≥4.0). The focal parameters come from the ISIDE bulletin (http://iside.rm.ingv.it/iside/standard/index.jsp; last accessed on December 4, 2009).

Code	Locality	Lon (° E)	Lat (° N)	EL (m)	V. Sens.	A. Sens.	S. Time (d/m/y hh:min)	E. Time (d/m/y hh:min)	S
MI01	Pescomaggiore	13.5098	42.3580	740	Le3D-Lite	FBA ES-T	07/04/09 07:14	27/04/09 11:14	R
MI02	Paganica	13.4743	42.3545	648	Le3D-5s	FBA ES-T	07/04/09 08:38	29/04/09 07:38	S
MI03	Onna	13.4757	42.3274	581	Le3D-5s	FBA ES-T	07/04/09 11:35	09/06/09 09:00	S
MI04	Fossa	13.4814	42.3031	612	Le3D-Lite	-	07/04/09 15:03	27/04/09 09:14	R
MI05	S. Eusanio Forconese	13.5252	42.2895	585	Le3D-5s	FBA ES-T	07/04/09 16:49	28/04/09 08:05	S
MI06	Camarda	13.4979	42.3894	807	Le3D-Lite	FBA ES-T	27/04/09 14:18	09/06/09 08:48	S
MI07	Bazzano	13.4459	42.3362	662	Le3D-Lite	FBA ES-T	27/04/09 17:14	09/06/09 08:14	S
MI08	Sant'Antonio	13.3713	42.3574	650	Le3D-Lite	FBA ES-T	28/04/09 13.12	09/06/09 10:12	S
MI09	San Giacomo	13.4144	42.3658	782	-	FBA ES-T	28/04/09 15.20	09/06/09 08:20	S
MI10	Sant'Elia 1	13.4307	42.3368	607	Le3D-5s	FBA ES-T	29/04/09 11:32	08/06/09 14:53	S
MI11	Sassa Zona Polivalente	13.3183	42.3659	657	Le3D-5s	-	29/04/09 15:58	08/05/09 11:00	S
MI12	Cese di Preturo	13.2910	42.3716	672	-	FBA ES-T	29/04/09 17:00	09/06/09 11:49	S
MI13	Sassa Zona Polivalente	13.3183	42.3659	657	-	FBA ES-T	08/05/09 15:12	08/06/09 13:12	S
MI14	Villa Sant'Angelo	13.5365	42.2706	587	Le3D-5s	-	09/06/09 15:15	24/06/09 07:15	S
MI15	Vallecupa	13.5740	42.2532	680	Le3D-5s	FBA ES-T	10/06/09 15:46	22/06/09 15:46	S
MI16	Pedicciano	13.5916	42.2411	749	Le3D-5s	-	10/06/09 17:52	25/06/09 09:08	S
MI18	Fossa	13.4904	42.2970	622	Le3D-5s	-	11/06/09 08:14	22/06/09 13.14	S
MI19	Casentino	13.5114	42.2806	579	-	FBA ES-T	11/06/09 09:56	24/06/09 08:56	S
MI20	Stiffe	13.5464	42.2567	609	-	FBA ES-T	11/06/09 11:24	24/06/09 08:24	S
MI21	Fossa	13.4928	42.2827	741	Le3D-5s	-	11/06/09 15:54	22/06/09 13:54	R
MI22	Vallecupa	13.5767	42.2534	692	Le3D-5s	FBA ES-T	12/06/09 17:20	25/06/09 07:55	R
MI23	Arischia	13.3370	42.4185	862	Le3D-5s	FBA ES-T	23/06/09 16:30	14/07/09 09:30	S
MI24	Arischia	13.3498	42.4228	1052	Le3D-5s	-	23/06/09 13:40	14/07/09 08:30	R
MI25	Arischia	13.3437	42.4146	810	Le3D-5s	-	23/06/09 10:10	14/07/09 09:15	S
MI26	S. Demetrio ne' Vestini	13.5630	42.2914	697	-	FBA ES-T	24/06/09 12:06	14/07/09 11:06	S
MI27	San Pio delle Camere	13.6552	42.2819	807	-	FBA ES-T	24/06/09 14:29	14/07/09 12:29	S
MI28	Poggio Picenze	13.5370	42.3186	715	Le3D-5s	-	24/06/09 16:14	13/07/09 08:14	S
MI29	Barisciano	13.6035	42.3354	1191	Le3D-5s	FBA ES-T	25/06/09 12:50	14/07/09 11:50	R
MI30	Barisciano	13.5944	42.3205	899	Le3D-5s	-	25/06/09 14:50	13/07/09 15:50	S

Table 2. The RAIS temporary stations. In the last column a preliminary soil (*S*) classification is reported (*R* = rock and *S* = soft). *V. Sens.* and *A. Sens.* indicate velocimetric and accelerometric sensors respectively. *S. Time* is the starting time, *E. Time* is the ending time. *Lon*, *Lat* and *EL* indicate Longitude, Latitude and Elevation.

related to 9,155 aftershocks. In general, the selected waveforms refer to earthquakes with epicentral distances up to 65 km, 93% of which were recorded at distances <30 km. In particular, 15 aftershocks with magnitudes >4.0 were recorded in the first month, two of which had magnitudes >5.0 (Table 1). The aftershocks were recorded by 29 sites, corresponding to 25 localities inside the province of L'Aquila (Table 2). The main scope of the present study is the dissemination of the data for these collected waveforms, to stimulate further research associated with the April 6, 2009, L'Aquila earthquake, and with the sincere belief that it will be useful for both the safety and awareness of the population.

Data acquisition

Starting from April 7, 2009, several instruments of the RAIS-TS (Figure 1) were installed in the epicentral area of the April 6, 2009, L'Aquila mainshock (Mw 6.3), to achieve the above-mentioned tasks regarding both seismic monitoring and local site-effect investigations. Due to the limited number of instruments available, a particular four-phase installation strategy was adopted to set up different network configurations during the evolution of the sequence. The stations were working globally from April 7 to July 14, 2009, and were installed in sites with different lithological and geomorphological conditions, according to four different phases of network configurations that corresponded to the following time periods:

April 7-26, 2009:

in this first phase, five RAIS-TS stations were installed corresponding to the more damaged villages [Galli et al. 2009]. Four six-component stations (with three-component velocimetric and three-component accelerometric transducers) and one three-component station (with a three-component velocimetric sensor) were installed near the municipalities of Pescomaggiore, Paganica, Onna, Fossa, Sant'Eusanio Forconese (Figure 1).

April 27 - June 8, 2009:

during this second phase, the RAIS-TS were increased to seven stations (four with six-component and three with three-component instruments), which were installed in selected areas located in the municipality of L'Aquila (near to the source): Camarda, Bazzano, Sant’Antonio, San Giacomo, Sant'Elia, Sassa Zona Polivalente, and Cese di Preturo (Figure 1). The new configuration of the network was set up to investigate the seismic responses of these areas, assessing the soil resonance frequencies through empirical analysis of the events recorded: the horizontal to vertical spectral ratios (H/V) of earthquakes [Lermo and Chavez-Garcia 1993] and receiver functions [Borcherdt 1970].

June 9-22, 2009:

in this third phase, the network was composed of eight stations (two with six-component and six with three-component instruments) that were installed in areas of the Aterno valley, between 10 km and 20 km SE of the town of L'Aquila, between the municipalities of Fossa and Pedicciano (Figure 1). The instrumentation was installed inside the municipalities of Fossa (two stations), Fagnano, Casentino, Villa S. Angelo, Stiffe, Vallecupa, and Pedicciano.

June 23 - July 14, 2009:

in this last period, the RAIS-TS were moved in both NW and SE directions, to complete the geophysical characterization of the Aterno valley. This last phase included a total of eight installations, five of which were in the municipalities of Poggio Picenze, San Demetrio ne' Vestini, Barisciano (two stations) and San Pio delle Camere (sites located SE of L'Aquila), and three corresponding to the municipality of Arischia, located about 10 km NW of L'Aquila (Figure 1).

In general the seismic stations (see Table 3) were equipped with 5-s or 1-s Lennartz velocimetric sensors and Kinemetrics Episensors (strong-motion sensors), coupled

Seismic sensors					
type	**name**	**natural frequency (Hz)**	**sensitivity**	**poles**	**zeros**
Velocimeter	Lennartz LE-3D/5s	0.2	400 V/m/s	-0.888 + 0.888j -0.888 - 0.888j -0.220 + 0.000j	Triple zero at the origin
Velocimeter	Lennartz LE-3Dlite	1.0	400 V/m/s	-4.444 + 4.444j -4.444 – 4.444j -1.083 + 0.000j	Triple zero at the origin
Accelerometer	Kinemetrics Episensor FBA ES-T	200	10 V/g		

Seismic recorder
Reftek 130-01
3 or 6 Channel recording
Resolution 24 bit
Clock: GPS
Sampling 100 Hz

Table 3. Instrumentation.

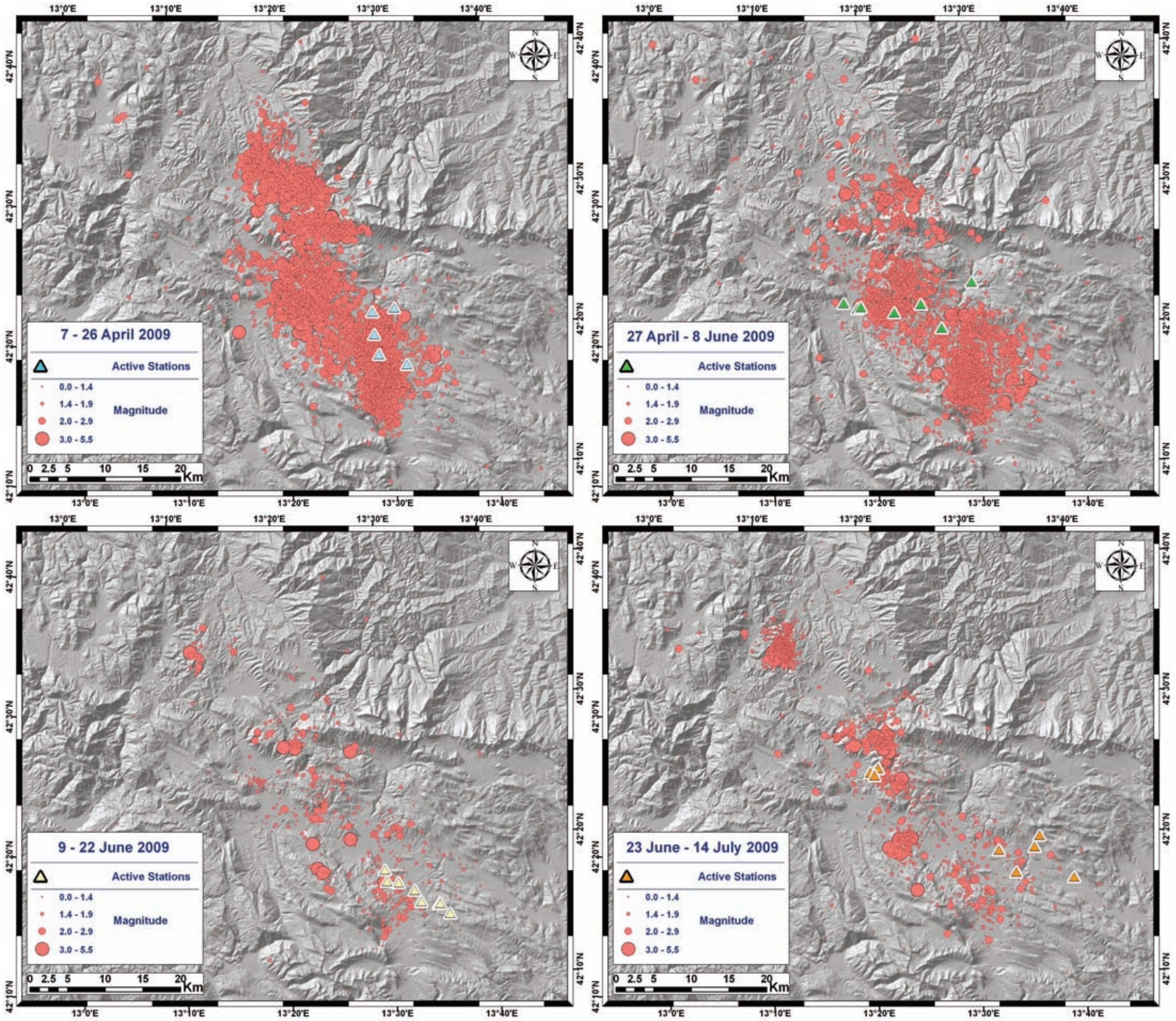

Figure 2. The RAIS-TS recorded events. Each panel shows the seismicity and the station distribution for each period considered (as indicated).

with 24-bit Reftek 130 digital recorders (of both three and six channels). The time code adopted was based on the global positioning system (GPS), and the electricity supplies were assured by solar panels with service batteries. Where possible, the sensors were buried 30 cm below the soil. The seismic data were recorded on local memory cards and the instruments were sheltered in watertight boxes. Figure 2 shows the seismicity recorded by the RAIS-TS over the whole of the above-mentioned periods.

Data selection

All of the stations recorded in continuous mode (the data were stored in 1-hour-long data files), so it was possible to recover the time series related to each event from continuous signals. To extract the waveforms recorded from the RAIS-TS over the whole period considered, we refer to the hypocenters reported in the INGV official seismic bulletin (Italian Seismological Instrumental and Parametric Database; ISIDE; http://iside.rm.ingv.it/iside/standard/index.jsp; last accessed, December 4, 2009).

The ISIDE reference location file is composed of quasi-real-time precise locations, data that came from the Italian National Seismic Surveillance, an advanced real-time system for seismic data analysis operated by the INGV-CNT in Rome, Italy. This provides the first location estimate of any Italian earthquake within 40 s of its origin time, starting from a minimum ML of 1.8, along with a definitive location within 5 min. Although all of the events detected by the Italian National Seismic Network are located automatically, the ISIDE only reports the list of locations as revised by the seismologist who is in charge of the seismic surveillance activity when the earthquake occurs. This localization is the best evaluation of the hypocenter parameters during the evolution of a seismic sequence.

Magnitude Class	Pre-event time (s)	Post-event time (s)	Number of Events
M >= 4.0	30	240	15
3.0 <= M < 4.0	30	150	131
2.0 <= M < 3.0	30	90	1505
1.0 <= M < 2.0	30	60	6984
M < 1.0	30	30	520

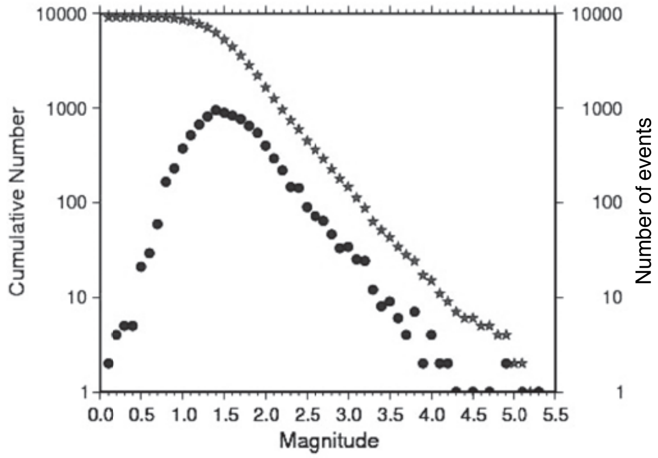

Table 4 (left). Selection criteria for waveform extraction. The increasing post-event times are related to the increasing ML. **Figure 3** (right). All the selected earthquakes. The magnitude distribution (circles) and cumulative number of events according to magnitude (stars).

To make the recorded waveforms of the L'Aquila sequence available in a short period, we extracted the data from April 7, 2009 at 07:10 (GMT) to July 14, 2009 at 15:50 using the ISIDE. We considered all of the events, without any magnitude selection, that occurred within a rectangular area limited between 42.15˚ and 42.70˚ North in latitude and between 13.00˚ and 13.80˚ East in longitude. For all of the events, the reference time was set to the origin time of the earthquake. We considered a pre-event window for data extraction of 30 s, and a post-event window with a duration that depended on the magnitude of the event (see Table 4). The final events listed include a total of 9,155 earthquakes with ML ≤5.3 (Figure 3). Table 1 reports an example of the event list for the earthquakes with magnitude >4.0. The complete list of the extracted dataset is available on the ftp site.

The dataset is composed of a total of 267,504 waveforms, 134,262 of which are strong-motion waveforms, and 133,242 of which are velocimetric data. Figure 4 shows the magnitude versus epicentral distance distribution of the whole dataset. The selected earthquakes were recorded by a variable number of stations, depending on the network configuration at the time. The coincidence list in Table 5 shows an example for the events with magnitudes >4.0. Even if in the present study we operated a selection based on ISIDE, since the waveforms were recorded in continuous mode, further time series can, however, be recovered on demand from continuous recordings.

Dataset structure and data format

The earthquake waveforms were at first extracted from continuous signals, and then converted into Little-endian SAC binary files (http://www.iris.washington.edu/software/sac/) [Tapley and Tull 1992]. Each time series was individually written into the SAC file data section as an evenly sampled data sequence. Consequently, the SAC header variables LEVEN and IFTYPE were set to TRUE and ITIME, respectively. All of the data were sampled at 100 sps and the data values are expressed in counts. Ground motion units can be obtained through the SAC header variables USER0 and USER1, respectively set as sensitivity (V/m/s and V/g for velocimetric and accelerometric sensors, respectively), and digitization constant (V/count) and KUSER0 (gain). The extracted waveforms were baseline corrected using the SAC command RTREND, which removes any linear trend from

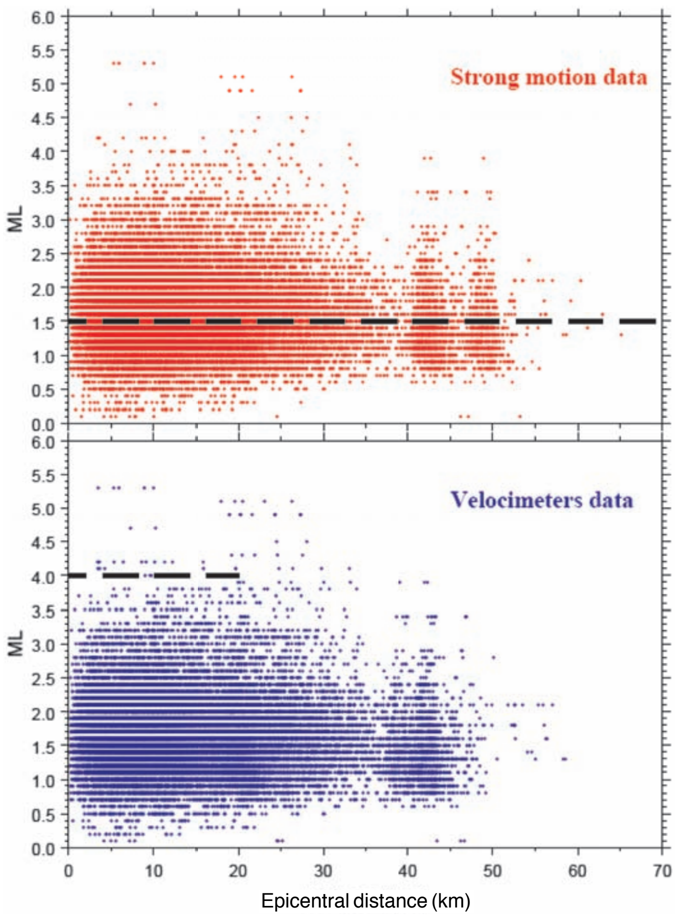

Figure 4. Magnitude *versus* epicentral distance distribution of the events recorded. Top panel: records from the strong-motion sensors. Bottom panel: records from the weak-motion sensors. In both panels, the data located above and below the dashed lines indicate records with low signal-to-noise ratio (top panel, for the accelerometers) and possible signal saturation (bottom panel, for velocimeters).

# STATION	M01a	M01v	M02a	M02v	M03a	M03v	M04a	M04v	M05a	M05v	M06a	M06v	M07a	M07v	M08a	M08v	M09a	M09v	M10a	M10v	M11a	M11v	M12a	M12v	M13a	M13v	M14a	M14v
# COMPONENT	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ
20090407092628	+++	+++	+++	+++																								
20090407174737	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090407213429	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090408225650	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090409005259	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090409031452	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090409043244	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090409193816	+++	+++	+++	+++	+++	+++		+++	+++	+++																		
20090413211424	+++	+++	+++	+++				+++	+++	+++																		
20090414201727	+++	+++	+++	+++				+++	+++	+++																		
20090423151408	+++	+++	+++	+++				+++	+++	+++																		
20090423214900	+++	+++	+++	+++				+++	+++	+++																		
20090622205840																												+++
20090703110307																												
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	M15a	M15v	M16a	M16v	M18a	M18v	M19a	M19v	M20a	M20v	M21a	M21v	M22a	M22v	M23a	M23v	M24a	M24v	M25a	M25v	M26a	M26v	M27a	M27v	M28a	M28v	M29a	M29v	M30a	M30v
# COMPONENT	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ	NEZ		
20090407092628																														
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20090414201727																														
20090423151408																														
20090423214900																														
20090622205840							+++		+++				+++	+++																
20090703110307															+++	+++		+++		+++	+++		+++			+++	+++	+++		+++
20090712083851															+++	+++		+++		+++	+++		+++			+++	+++	+++		+++

Table 5. Coincidence list of the dataset events for M ≥4.0. STATION: a = accelometer; v = velocimeter. COMPONENT: N = North-South; E = East-West; Z = Up-Down. For each event and for each station the existing components are marked as «+».

the data and media removed using the SAC command RMEAN. The waveforms were not corrected for the instrument response and were not filtered. The SAC header parameters were generally set according to the conventions adopted by the SAC Users Manual (http://www.iris.edu/manuals/sac/manual.html), with a certain number of variables customized for the present dataset. The complete description of the SAC header variables is reported in the Appendix.

The waveforms datasets were organised following an event code, which was defined by the origin time of the earthquake (expressed as year, month, day, hour, minute and second), as reported in ISIDE. The dataset was structured into directories with names that correspond to the event codes. Each directory contains SAC files with the waveforms related to the stations that recorded the corresponding earthquake. The file names are composed of four different sections: extraction time (year, month, day, hour, minute and second, defined according to the above-mentioned pre-event time, which was selected to be 30 s before the origin time of the earthquake); station code (four characters); channel (according to the SEED-format conventions; see below); and file type (e.g. *.sac*).

The SEED-format convention for the channel naming adopts three characters, each of which describes a single aspect of the data. The first character specifies the general sampling rate and the response frequency band of the instrument: for example *E* stands for «extremely short period instrument with a sample rate in the range of 80-250 Hz and a corner period <10 s». The second character specifies the sensor family: *H* stands for «high-gain seismometer» and *N* for accelerometer data. The third character specifies the orientation code (Z, N, E for traditional vertical, North-South, East-West). For more information, please refer to Appendix A of the SEED reference manual (Incorporated Research Institute for Seismology; IRIS, 2009; http://www.iris.washington.edu/manuals/SEED_appA.htm). For example, following the ISIDE origin time, an event that occurred on April 9, 2009 (at 19:38:16) and recorded by station MI01 (equipped with a Lennartz Le3D-Lite velocimetric sensor, corner period 1 s and sampling 100 sps) was extracted at 19:37:46: in this case the name of the related file (included in the folder /20090409193816/) will be 20090409193746_MI01.EHZ.sac.

All of the extracted SAC waveforms are included in the section */waveforms/* of the dataset in which the directories are grouped according to four magnitude classes that correspond to the different earthquakes: 3.0 ≤ML <5.5 (146 events); 2.0 ≤ML <3.0 (1,505 events); 1.5 ≤ML <2.0 (3,673 events); 0.0 ≤ML <1.5 (3,831 events). Each class corresponds to a uncompressed tar archive file, which also includes the information files of the whole dataset. The information files are subdivided into sections */maps/* and into */files/*, the former of which includes KML files to display the stations and epicentres in an Earth browser such as Google Earth (http://earth.google.com). The section */files/* includes bulletin files, coincidence files, station books, and instrument information. The complete structure of the datasets is summarized in Figure 5.

Conclusions

The dataset presented in the present study consists of more than 267,000 waveforms related to 9,155 aftershocks that occurred after the April 6, 2009, Mw 6.3, L'Aquila earthquake, and were recorded by the RAIS-TS over the period of April, 7 - July 14, 2009. The selected waveforms are

Figure 5. Dataset structure (see text for explanation).

all available in SAC format, and they correspond to events with a maximum epicentral distance of 65 km. In particular, the dataset includes 15 events with ML >4, two of which have an ML >5, which were recorded at epicentral distances of <30 km (Table 1).

The waveforms have been extracted from signals recorded in continuous mode after selection of the corresponding time windows, based on the origin times reported in the ISIDE bulletin. The localizations used for this dataset corresponded to the best evaluations of hypocenter parameters available in December, 2009. Minimal pre-processing was applied to all of the records, which basically consisted of linear-trend removing. The location parameters and other information about the recorded events, station characteristics and instrumental settings are included in the SAC file headers. It is worth noting that in the case of energetic events recorded by stations close to the epicenter, the weak-motion channels (velocimetric sensor) show saturated waveforms (see Figures 4 and 6, dashed lines in the bottom panels). In contrast, the strong-motion stations that recorded all of the strongest aftershocks can show low-quality data (in terms of signal-to-noise ratios) related to weak motions (ML ≤1.5), especially if they were recorded at distances greater than about 20 km. In any case, the database described in the present study includes all of the records. It will be the responsability of the final users to focus their attention on these considerations.

The maximum recorded peak ground acceleration was 0.69 g at 5.4 km of epicentral distance (station MI05) during the April 7, 2009, ML 5.3, earthquake (Figure 7).

As is usual in seismic sequences, the first period of activity was characterized by a high seismic rate, with a large number of events over short time periods. The waveforms belonging to the different earthquakes often overlapped within the same time windows (Figure 8).

The 267,504 selected waveforms and the corresponding information relating to the instruments, installation sites and recorded earthquakes are all downloadable from ftp://ftp.mi.ingv.it/download/RAIS-TS_rel01/

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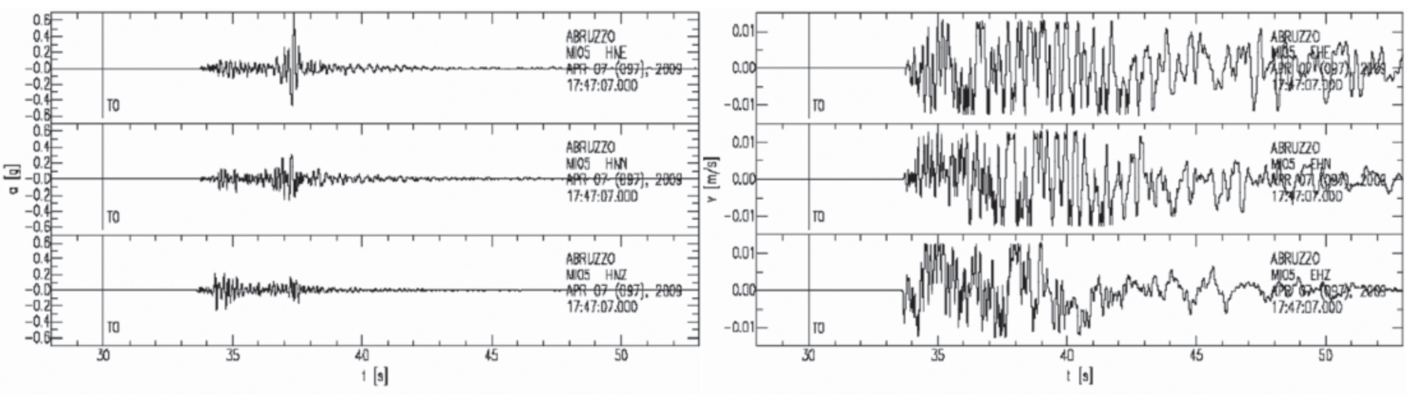

Figure 6. April 7, 2009, ML = 5.3, aftershock recorded at station MI05 by a six-component acquisition system equipped with both strong-motion (left panel; HNE, HNN and HNZ for East-West, North-South and vertical components) and weak-motion (right panel; EHE, EHN and EHZ for East-West, North-South and vertical components) sensors. It is worth noting that the strong-motion sensor (time sequences on the left) recorded the event without saturation.

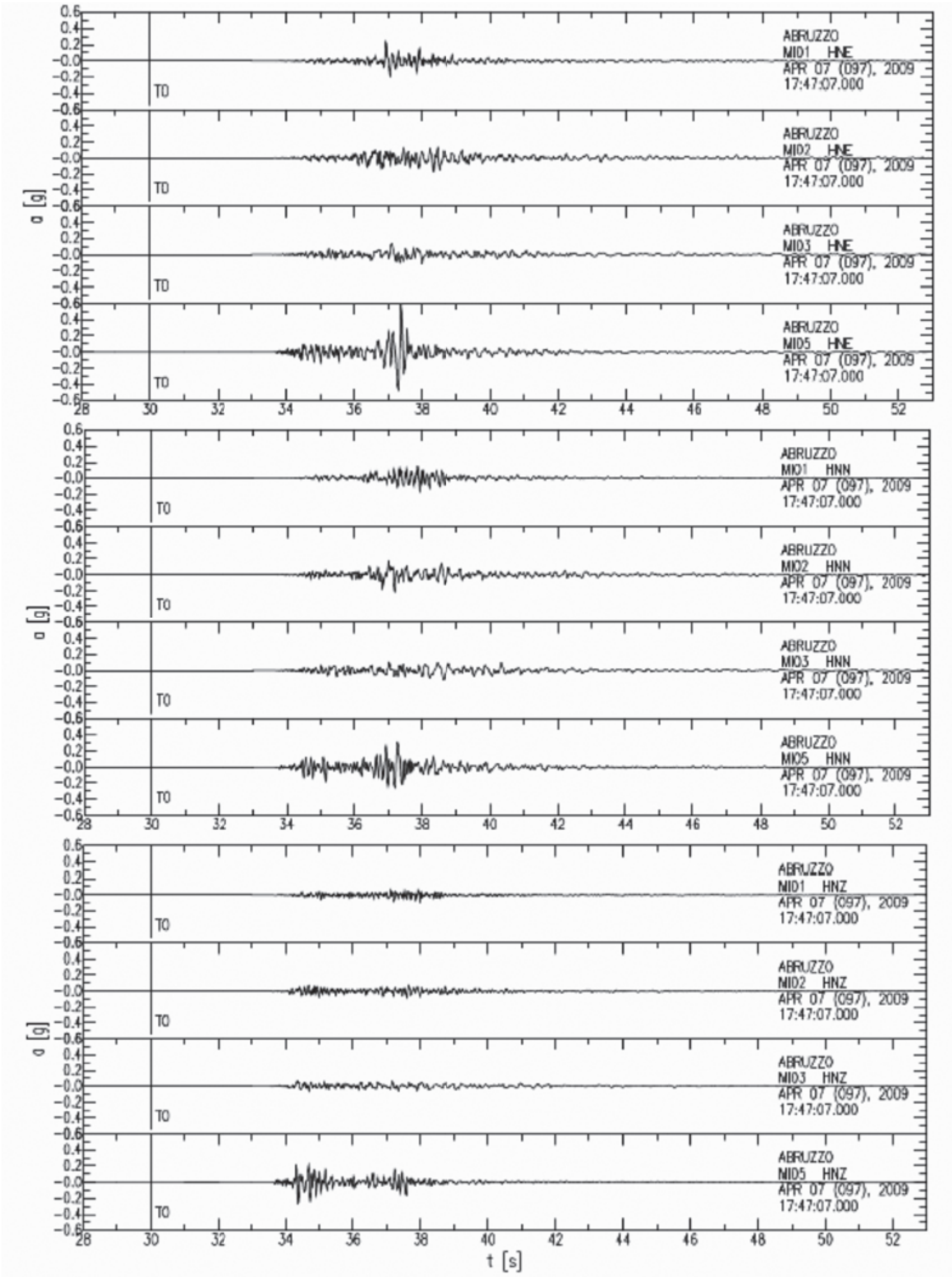

Figure 7. April 7, 2009, ML = 5.3, aftershock recorded at strong-motion stations MI01, MI02, MI03 and MI05 (top panel, East-West; middle panel, North-South; and bottom panel, vertical components) in the near source (epicentral distances <10 km).

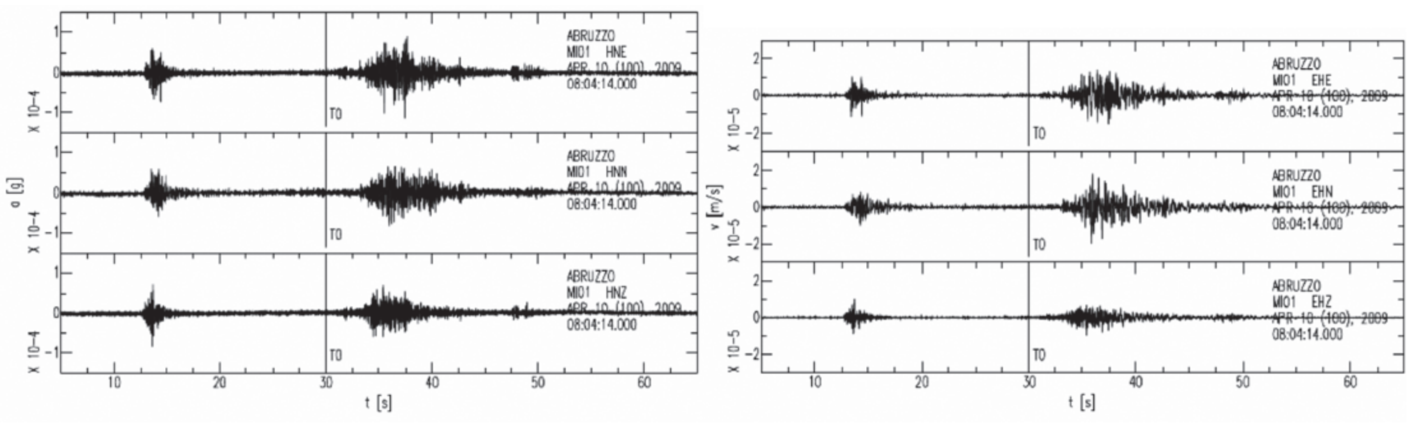

Figure 8. Waveforms of a ML = 1.5 earthquake recorded at station MI01 by a six-component acquisition system equipped with both strong-motion (left panel) and weak-motion (right panel) sensors. At least two of these events overlap between 30 s and 40 s, and a small event occurred before the selected earthquake was detected (between 10 s and 20 s).

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Appendix

SAC HEADER

EXAMPLE FILE: 20090408175805_MI02.HNZ.sac

Variable	Description	Possible Values	RAIS-TS field (*)	Typical value
NPTS	Number of points per data component.			18000
B	Beginning value of the independent variable			0.000000e+00
A	Ending value of the independent variable			1.800000e+02
IFTYPE	Type of file	= ITIME {Time series file} = IRLIM {Spectral file---real and imaginary} = IAMPH {Spectral file---amplitude and phase} = IXY {General x versus y data} = IXYZ {General XYZ (3-D) file}		TIME SERIES FILE
LEVEN	TRUE if data is evenly spaced			TRUE
DELTA	Increment between evenly spaced samples			1.000000e-02
DEPMIN	Minimum value of dependent variable			-6.655318e+04
DEPMAX	Maximum value of dependent variable			4.807683e+04
DEPMEN	Mean value of dependent variable			2.723649e-06
O	Event origin time (seconds relative to reference time.)			30
KO	Event origin time identification.			(T0)
KZDATE	Alphanumeric form of GMT reference date			APR 08 (098), 2009
KZTIME	Alphanumeric form of GMT reference time			17:58:05.000
IZTYPE	Reference time equivalence	= IUNKN (Unknown) = IB (Begin time) = IDAY (Midnight of reference GMT day) = IO (Event origin time) = IA (First arrival time) = ITn (User defined time pick n, n=0,9)		BEGIN TIME
KINST	Generic name of recording instrument.		**x**	RTF130
KSTNM	Station name		**x**	MI02
CMPAZ	Component azimuth (degrees clockwise from north)		**x**	0.000000e+00
CMPINC	Component incident angle (degrees from vertical).		**x**	0.000000e+00
STLA	Station latitude (degrees, north positive)		**x**	4.235449e+01
STLO	Station longitude (degrees, east positive).		**x**	1.347428e+01
STEL	Station elevation (meters).		**x**	6.480000e+02
KEVNM	Event name		**x**	ABRUZZO

Variable	Description	Possible Values	RAIS-TS field (*)	Typical value
EVLA	Event latitude (degrees, north positive)		x	4.236400e+01
EVLO	Event longitude (degrees, east positive).		x	1.339600e+01
EVDP	Event elevation (meters)		x	8.800000e+00
DIST	Station to event distance (km).			6.535192e+00
AZ	Event to station azimuth (degrees).			9.927607e+01
BAZ	Station to event azimuth (degrees).			2.793286e+02
GCARC	Station to event great circle arc length (degrees).			5.879549e-02
LOVROK	TRUE if it is okay to overwrite this file on disk.			TRUE
USER0	Sensitivity	Velocimetric Lennartz sensor=400; Accelerometer Kinemetrics sensor=10	x	1.000000e+01
USER1	Digitalization constant V/c	1.58997e-06	x	1.589970e-06
USER2	Trend removal	(1=rtrend on; 0=rtrend off)	x	1.000000e+00
USER3	Tapering	On=1; Off=0	x	0.000000e+00
USER4	Mean removal	(1=rmean on; 0=rmean off)	x	1.000000e+00
USER5	filtering procedure	(1=Butterworth filter on; 0= Butterworth filter off)	x	0.000000e+00
KUSER0	Sensitivity unit # gain	Velocimeter sensor=V/m/s Accelerometric sensor=V/g Gain=1 or 32	x	V/g#1
KUSER1	Trace unit	Count	x	Count
KUSER2	Sensor model	Episens=Kinemetric Episensor; LE3D-1s=Lennartz Lite 1 second; LE3D-5s=Lennartz 5 seconds	x	Episens
NVHDR	Header version number. Current value is the integer 6. Older version data (NVHDR < 6) are automatically updated when read into sac			6
NORID	Origin ID			0
NEVID	Event ID			0
LPSPOL	TRUE if station components have a positive polarity (left-hand rule).			FALSE
LCALDA	TRUE if DIST, AZ, BAZ, and GCARC are to be calculated from station and event coordinates.			TRUE
KCMPNM	Component name	HNZ= Accelerometric vertical component (Up-Down) HNN= Accelerometris orizzontal component (North-South) HNE= Accelerometris orizzontal component (East-West) EHZ=Velocimetric vertical component (Up-Down) EHN= Velocimetric orizzontal component (North-South) EHE=Velocimetric orizzontal component (East-West); SEED convention	x	HNZ
KNETWK	Name of seismic network.		x	RAIS

Variable	**Description**	**Possible Values**	**RAIS-TS field (*)**	**Typical value**
MAG	Event magnitude.		**x**	3.200000e+00
IMAGTYP	Magnitude type	= IMB (Bodywave Magnitude) = IMS (Surfacewave Magnitude) = IML (Local Magnitude) = IMW (Moment Magnitude) = IMD (Duration Magnitude) = IMX (User Defined Magnitude)	**x**	Local Magnitude

(*) The user defined parameters of the RAIS-TS network are labeled with “x”.