ELECTRONIC SEISMOLOGIST

# Introducing the European Rapid Raw Strong-Motion Database

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## ABSTRACT

We present the European Rapid Raw Strong-Motion database (RRSM), a new Europe-wide system that provides parameterized earthquake ground-motion information, as well as access to waveform data, within minutes of the occurrence of any earthquake with $M \geq 3.5$ occurring in the European–Mediterranean region. The RRSM is different from traditional platforms for disseminating earthquake strong-motion data in Europe, which focus on providing reviewed, processed strong-motion parameters, typically with significant delays. The RRSM provides rapid open access to raw waveform data and metadata and does not rely on manual waveform processing. The RRSM targets seismologists and strong-motion data analysts, earthquake and geotechnical engineers, international earthquake response agencies, and the educated general public. The database is accessible online (see Data and Resources). Users can query earthquake information, peak ground-motion parameters, and select and download earthquake waveforms. The RRSM database is populated using the waveform processing module *scwfparam*, which is integrated in SeisComP3. Processing is triggered using earthquake parameters provided by the European–Mediterranean Seismological Center and uses all significant waveform data that are available in the European Integrated waveform Data Archive (EIDA). EIDA consists of broadband and strong-motion data from across Europe, and the majority of these data are available in near real time. All relevant, on-scale open EIDA data are processed for the RRSM. As the EIDA community is continually growing, the already significant number of strong-motion stations is also increasing and the importance of the RRSM database is expected to grow further in time. Real-time RRSM processing started in September 2014, whereas offline reprocessing was carried out for all $M4.5+$ events that occurred since January 2005.

## INTRODUCTION AND MOTIVATION

The advent of digital seismometry and the rapid development of information technologies over the last three decades have dramatically improved the quantity and quality of seismic monitoring stations worldwide. Seismology, engineering seismology, and earthquake engineering today benefit from open databanks that offer researchers and practitioners large amounts of earthquake waveform data associated with event and station metadata. These databanks are typically maintained by the national institutions in charge of seismic monitoring, and/or governmental agencies with a research or civil protection mandate. Data are usually available via online interfaces often requiring user registration. Data policies are generally open though usage is sometimes restricted to research and education. Proper acknowledgment of the data providers is encouraged but not enforced (see Evans *et al.*, 2015).

An example is the portal managed by the National Research Institute for Earth Science and Disaster Prevention (NIED) in Japan (see Data and Resources). Notable efforts in the greater European region that focus on strong-motion data are the Italian Accelerometric Archive (ITACA, Pacor *et al.*, 2011, see Data and Resources) and the Strong Ground Motion Database of Turkey (Akkar *et al.*, 2010, see Data and Resources).

Regional and global datasets have also been consolidated and homogenized in an effort to provide the community with a single source of high-quality data. Examples include (see Data and Resources): (1) the European Strong-Motion Database (ESMD) (Ambraseys *et al.*, 2004); (2) the Pacific Earthquake Engineering Research Institute ground-motion database (Ancheta *et al.*, 2014); (3) the Center for Engineering Strong-Motion Data; (4) the European Integrated waveform Data Archive (EIDA, Clinton *et al.*, 2014); and (5) the Incorporated Research Institutions for Seismology Data Management Center.

EIDA was established within Observatories and Research Facilities for European Seismology (ORFEUS) in 2012, building on the success of the ORFEUS Data Center (ODC, see Data and Resources) and it operates today as a coordinated, distributed data archive system across Europe. EIDA has the primary task of providing a long-term archive of seismic waveform data associated with standardized metadata. EIDA ensures open and transparent access to this archive for the research community. EIDA is the key infrastructure within ORFEUS, and in the long term will provide access to seismic waveform data for the European Plate Observing System (see Data and Resources), the European integrated research infrastructure for solid-Earth sciences that is currently being implemented.

EIDA differs from the strong-motion databanks mentioned above as it is generally populated in near real time; that is, data are available within a few tens of seconds of being recorded at the seismic stations. EIDA is primarily composed of waveforms recorded by broadband seismological instrumentation, that is, either high-gain broadband seismometers or broadband force-balance accelerometers, often collocated, continuously sampled by high dynamic range analog-to-digital converters (ADC) and low-noise dataloggers (see Sleeman *et al.*, 2006; Bormann, 2012; Cauzzi and Clinton, 2013).

Conversely, waveform archives like ITACA and ESMD are collections of accelerometric event data only, and include, due to their engineering importance, time series from earthquakes recorded on analog narrowband, low-gain instrumentation operated in triggered mode. These collections of waveform data and metadata are generally referred to as engineering strong-motion databases and are tailored to the needs of earthquake engineering scientists and practitioners. Until recently (Faccioli *et al.*, 2004; Priestley *et al.*, 2007; Sullivan and Calvi, 2013), the preferred strong-motion parameters in engineering practice were peak ground acceleration (PGA) values and short (-to-mid)-period (e.g., 2–3 s or less) response spectra. Waveform data from these archives are usually provided as filtered (often called corrected) acceleration, velocity and displacement time series. Some databanks provide uncorrected (unfiltered) acceleration as well, although already converted to physical sensor units (e.g., $cms^{-2}$) through simple application of the band-pass gain (sensitivity) of the recording station. As archive completeness is a key requirement of strong-motion databases, research in previous decades focused on developing optimal signal processing techniques that can be applied to the old band limited, as well as to the newer, higher-quality earthquake data (see Douglas, 2003). Emphasis has recently been placed on recovering intermediate-to-long period components of the ground motion (Koketsu and Miyake, 2008), which are often excellently recorded by modern strong-motion instruments (Cauzzi and Clinton, 2013; Ringler *et al.*, 2015). The reader is referred to the works of Boore (2001, 2005), Boore *et al.* (2002, 2012), Boore and Bommer (2005), Akkar and Bommer (2006), Paolucci *et al.* (2008, 2011), and Akkar and Boore (2009) for a comprehensive and up-to-date discussion on the topic.

Waveforms in engineering strong-motion databases are accompanied by reviewed documentation of earthquake and station metadata, often including geophysical and geotechnical characterization of the recording sites. In Europe, the most recent compilation of this kind is the RESORCE database (Akkar, Sandıkkaya, Şenyurt, *et al.*, 2014; see Data and Resources), assembled within the framework of the (industry-funded) project SeIsmic Ground-Motion Assessment (see Data and Resources). RESORCE, a substantial update of ESMD, features uniform processing of the acceleration time histories and improved magnitude, site characteristics, and source-to-site distance information. RESORCE was peer reviewed to provide expert-verified accelerometric data and metadata, and has been used to derive a new generation of predictive models for peak ground motion and response spectra in Europe (see Douglas *et al.*, 2014). Although a public release of the database is still pending to date, RESORCE is already superseded by the release of the demo version (July 2015) of the European Commission (EC)-funded ESM (see Data and Resources) (Luzi *et al.*, 2016). The Engineering Strong-Motion (ESM) database includes, among other data, the ESMD, ITACA, the Strong Ground Motion Database of Turkey, and the HEllenic Accelerogram Database, as well as reviewed waveform data collected from EIDA. All filtered and unfiltered waveform data contributing to the ESM can be retrieved online.

Engineering strong-motion databanks suffer from delays in disseminating waveforms and derived strong-motion parameters following an earthquake. In most cases, the delay is due to the peer-review process that involves visual inspection and scrutiny of the waveforms and associated metadata. The delay is often attributed to ensuring quality, though this may be better attributed to ensuring expert revision and validation, as the quality of a seismic signal mainly depends on the characteristics of the sensor, the digitizer, and the site conditions, and there is little that signal processing techniques can offer to recover the input ground motions if they were not recorded with sufficient signal to noise across the frequency range of interest. Moreover, until recently, data providers often restricted the distribution of waveform data until event analysis was completed, typically following scientific publications. Whatever the cause of this delay, it is a reality that waveform data of engineering interest are often unavailable for a long time to engineers, or restricted to selected research groups. This is a disadvantage for both analysts and scientists.

The quality of the broadband and strong-motion seismic data and metadata now being recorded in Europe ensures that automated processing routines can produce high-quality and reliable parameter data. Through EIDA, there is a substantial and continually growing amount of open seismic data available in near real time. As we are convinced that the scientific and engineering communities will benefit from rapid access to strong-motion data and associated parameters, we conceived and developed the European Rapid Raw Strong-Motion database (RRSM). The design and implementation of the RRSM (the website is listed in Data and Resources) builds on the existing EIDA infrastructure to provide rapid event-triggered access to high-quality earthquake data. The RRSM development was partly supported through the EC-funded project Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (see Data and Resources) and is hosted and maintained at ODC. The RRSM is the first European system that delivers open access to earthquake waveforms and derived engineering parameters within minutes of an earthquake occurrence. The RRSM partly builds upon the experience gained in work package NA5 of project Network of Research Infrastructures for European Seismology (see Data and Resources), that proposed a prototype for unified accelerometric data exchange in Europe (Péquegnat *et al.*, 2011). The key features of the RRSM are that: (a) it is automatically populated in near real time and (b) it processes all waveforms recorded on scale, whether they are from acceleration or velocity sensors. Once an earthquake is reported by the European–Mediterranean Seismological Center (EMSC; see Data and Resources), all open waveform data from EIDA (which includes substantial sets of unrestricted continuous accelerometric data) close to the epicenter are processed. EIDA only includes waveform data with up-to-date high-quality (i.e., compliant with international seismological standards) station metadata. Although station density is heterogeneous in the European region, the magnitude distribution of the EMSC catalog indicates completeness down to magnitude ∼3 (see e.g., Godey *et al.*, 2014). The RRSM only includes events with EMSC magnitude above 3.5 from 2012 onward; before only above 4.5. In addition to the basic station and event information, peak ground-motion parameters and elastic 5%-damped response spectral amplitudes over a broad frequency range are computed and displayed.

## DATA GATHERING, PROCESSING, AND DISSEMINATION

The RRSM relies on the raw waveform data and basic station information available in EIDA and basic earthquake information (location and magnitude) provided by the EMSC within 5–20 min of an earthquake origin time (OT). EIDA currently consists of 10 nodes that collect and archive data from permanent and temporary seismic networks (see Data and Resources). The ODC is a primary EIDA node. Technically, EIDA is currently based on an underlying architecture developed by GeoForschungsZentrum (GFZ) (German Center for GeoSciences, Potsdam, Germany, see Data and Resources).

### Real Time and Delayed Waveform Extraction Based on Magnitude, Location, and Distance

The RRSM database is populated via a waveform processing module, *scwfparam* (Cauzzi *et al.*, 2013), which is integrated in the earthquake monitoring software SeisComP3 (see Data and Resources; Hanka *et al.*, 2010), that is open source, free, and openly available to interested users. *scwfparam* is accompanied by an extension of the SC3 data model to accommodate peak-motion data and information of engineering interest. This RRSM data model can include rupture characteristics and finite-fault information if these are available (see Data and Resources)—currently, we do not routinely populate these fields.

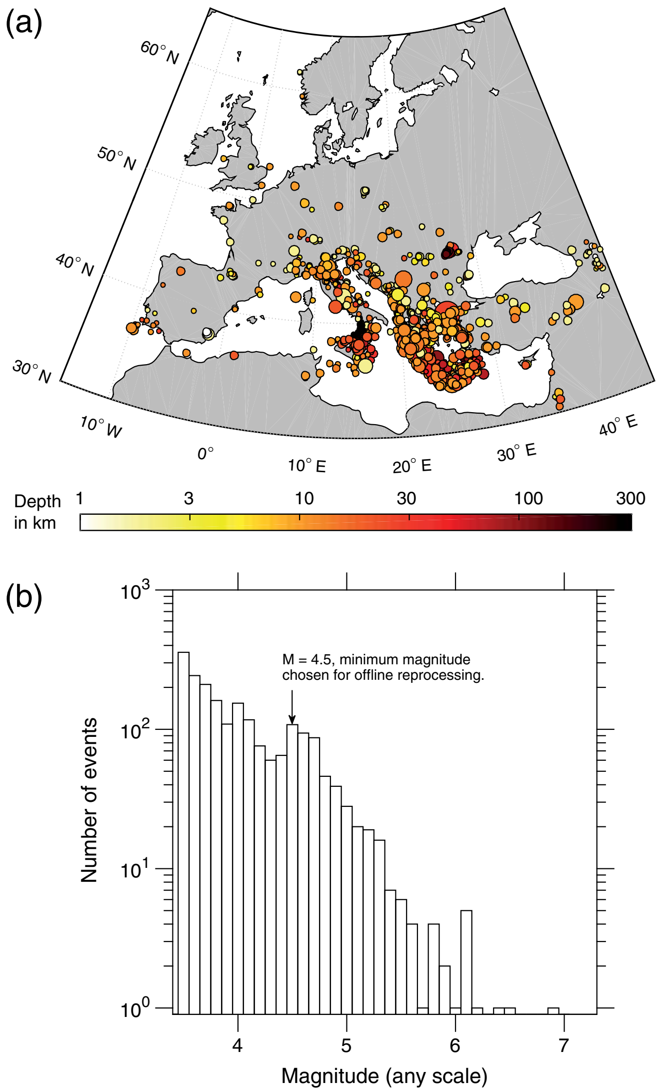
The RRSM waveform processing is triggered by an earthquake alert from the EMSC. Earthquake data are processed if the earthquake magnitude $M$ (any scale) exceeds 3.5 and the EMSC location is within the greater European region (27° ≤ latitude ≤ 81°, −32° ≤ longitude ≤ 51°).

Waveforms are immediately requested from all seismic stations installed within a given distance from the epicenter, using the EIDA core module *ArcLink* (see Data and Resources). The requested maximum epicentral distance and waveform duration are a function of magnitude, as detailed in the information page of the RRSM (see Data and Resources). The initial time-window length accounts for 20 s of pre-event window and two times the predicted significant duration of motion (based on Bommer *et al.*, 2009, their fig. 5) starting from the *P*-wave onset. Each earthquake is reprocessed at predefined time stamps after OT to ensure late arriving data in EIDA are also included; reprocessing is also particularly useful when waveforms from triggered strong-motion stations are manually added to EIDA data centers. Significant earthquake datasets can be reprocessed offline at any time, if new waveforms become available through EIDA or event parameters change. The RRSM at ODC has been automatically populated since September 2014. Offline reprocessing was carried out for all $M$4.5+ events that occurred since January 2005, and all $M$3.5+ events since January 2012, which ensures that the RRSM includes all data in EIDA for the most important European events. The geographic distribution of the events in the RRSM is shown in Figure 1a, whereas Figure 1b displays the magnitude distribution of the earthquakes. Because of the automatic population of the RRSM, the number of events will continue to increase with on-going seismicity. All figures in this article are based on the contents of the RRSM on 19 February 2016. Earthquakes are only included in the RRSM if there is at least one on-scale seismic record available. The total number of earthquakes is about 2045. If we restrict the dataset to only include events with magnitude greater than 4.5 (traditionally the limit of engineering interest), there are about 490 events. The largest event is the 24 May 2014 $M_w$ 6.9 Aegean Sea earthquake. Currently, ∼1475 stations are available to the RRSM for processing; there are ∼620 accelerometer stations, including those collocated with velocity sensors. The strong-motion component of the current EIDA is dominated by stations in Italy, France, and Switzerland.

### Waveform Processing

Waveform data processing in the RRSM is not restricted to accelerometric channels. Rather, all available seismic time histories within a given distance from the source (see Data and Resources) are evaluated. Processing occurs only if the waveforms match the following selection criteria that apply to both acceleration and velocity traces.

1. *Pretesting*
   - *Sensor quality*: only broadband acceleration and velocity stations with sufficiently high sampling rates (80–250 samples per second) are considered for processing.
   - *Saturation*: the waveform is processed only if the maximum amplitude is below a saturation threshold (Fig. 2a), defined as a fraction (80%) of the full scale (FS) = ($2^{24-1}$) of a 24-bit digitizer, in digital counts. The benefit of this approach is that saturation is checked based on unprocessed data, so static offsets are included. It is assumed here that all recording systems use a 24-bit ADC, and that dataloggers with

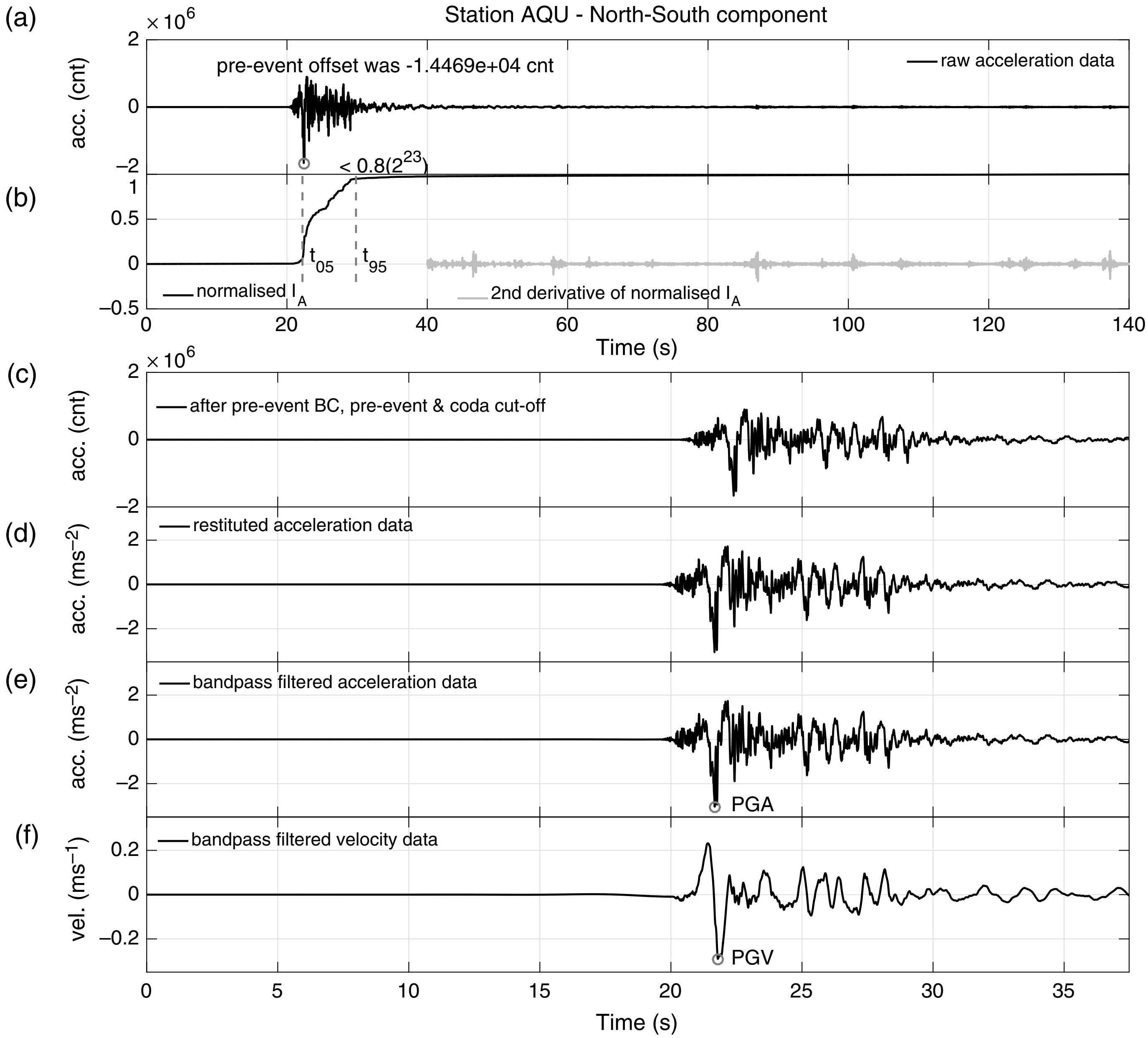



▲ **Figure 1.** (a) Geographic distribution of earthquakes in the Rapid Raw Strong-Motion database (RRSM). Symbols are proportional to magnitude from 3.5 to 6.9. The database is dominated by shallow crustal seismicity but include deep events along the Calabrian (Italy) and Hellenic (Greece) Arcs, and in the Vrancea (Romania) region. (b) Magnitude distribution of the events in the RRSM. The color version of this figure is available only in the electronic edition.

lower dynamic range do not clip. We also assume the dynamic range of the sensor is at least similar to that of the datalogger.

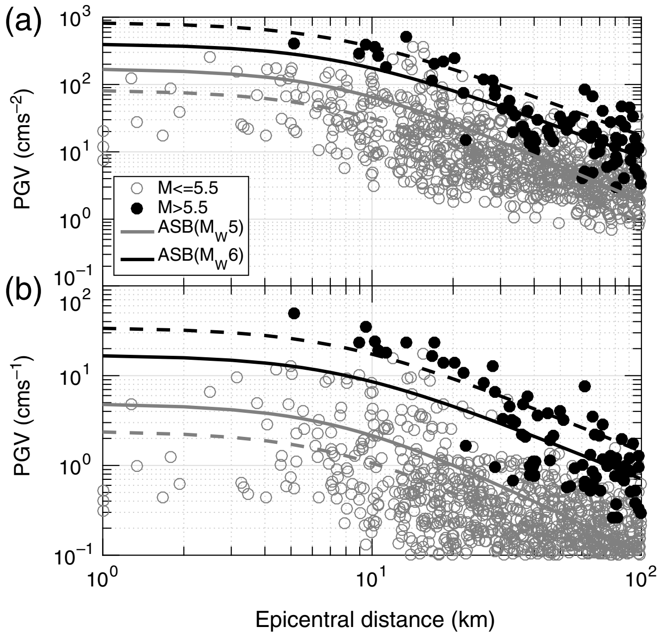
- *Noise*: the waveform is processed when the amplitude of the short-term average/long-term average (STA/LTA) ratio around the predicted *P*-wave onset exceeds a given threshold (presently five). The length of time windows for the STA and the LTA are 1 and 20 s, respectively.
- *Collocation*: if two sensors at one site are available and on-scale (e.g., collocated broadband and strong motion), only the velocity sensor data are processed (clipped stations are removed in Saturation step). The distinction between acceleration and velocity traces is based on the sensor input units (e.g., $ms^{-1}$ or $ms^{-2}$) available in the EIDA station inventory.

2. *Restitution to ground motion:* The instrument response is removed from the recorded signal by means of spectral division in the frequency domain, and subsequent inverse transformation to the time domain (Fig. 2d). This full instrument deconvolution is basically equivalent to a simple band-pass gain correction for modern force-balance accelerometers. As deconvolution using a full instrumental response is mandatory, only channels with full response description can be used. Waveforms with gaps are discarded. To have homogeneous processing irrespective of the channel type, all records passed to the subsequent stages should be in the units of acceleration. Velocity waveforms are therefore differentiated in the time domain to acceleration at this stage. The signal processing workflow is described in the following paragraphs and illustrated in Figure 2, in which the north–south component of the accelerometer recording of the $M_w$ 6.3 L'Aquila 2009 (central Italy) earthquake at MedNet station AQU (epicentral distance 2.5 km) is used as an example.
3. *Pre-event and coda cutoff, aftershock removal*: pre-event and coda cutoff are necessary to avoid processing of very large time windows that extend beyond the significant earthquake signal and to remove any aftershock signals. The current *scwfparam* configuration for the RRSM retains only 20 s of data preceding the expected *P*-wave onset as defined by OT and the epicentral distance (Fig. 2c). Aftershocks on the waveform coda should be removed and processed separately because they can alter the amplitudes of the mainshock response spectra, especially at short periods. *scwfparam* checks for the presence of aftershock signals (and noise spikes) in the coda of the time series by monitoring the polarity and amplitude of the second derivative of the normalized Arias (1970) intensity $I_A = \frac{\pi}{2g}\int_0^{Td} a^2(t)dt$, in which $Td$ is the length of the time window, $a(t)$ is the ground acceleration, and $g$ is the acceleration due to gravity. The normalized Arias intensity $I_A/\max(I_A)$ is often used to compute the significant duration ($D$) of an earthquake signal as the time span between its 5% ($t_{05}$) and 95% ($t_{95}$). Because $I_A$ normally exhibits a sigmoid variation with time, the presence of a strong (presently $>5$) positive curvature following a stable plateau is used as a proxy for the detection of a significant aftershock (Fig. 2b) in the coda of the acceleration trace (Figini, 2006; Paolucci *et al.*, 2008). If an aftershock is detected, the waveform is cut 5 s before its onset. Even without aftershocks, a coda cutoff is necessary before the response spectra computation is performed. In this latter case, the cutoff time can be determined by a multiple (presently 2) of $D$.
4. *Baseline correction*: a default baseline removal (zeroth order correction, Boore, 2005) is applied to all waveforms based on the average amplitude of the pre-event time window (Fig. 2a,c).
5. *Acausal (zero-phase) band-pass filtering*: all restituted accelerograms are band-pass filtered to remove potential noise




▲ **Figure 2.** North–south recording at MedNet station AQU (L'Aquila, central Italy) for the April 2009 $M_w$ 6.3 L'Aquila mainshock. (a) Original waveform extraction and saturation check—the amplitude of the pre-event offset, though large, is not visible in the image, as it is two orders of magnitude smaller than the peak value of the acceleration trace in raw digital counts. (b) Computation of normalized Arias intensity ($I_A$) and its second derivative, the variation of the second derivative of $I_A$, corresponding to small disturbances (possibly aftershocks) on the coda of the original signal; the ~8 s duration of the signal ($D$) defined as the time between $t_{05}$ and $t_{95}$. (c) Acceleration signal in raw counts after pre-event baseline correction, pre-event and coda cutoff; coda cutoff was based in this case on the significant duration of the signal, as no relevant aftershock was detected. (d) Restitution to ground acceleration after spectral division between the Fourier transform of the raw acceleration data and the frequency response function of the recording station. (e) Zero-phase band-pass (0.05–40 Hz) filtered acceleration (after 5% tapering and zero-padding following Boore, 2005). (f) Velocity time history obtained through integration of zero-phase band-pass filtered acceleration data. (c–f) Focus on the portion of the waveform used to compute peak ground acceleration (PGA), peak ground velocity (PGV), and the response spectra; zero padding is omitted.

using a fourth-order Butterworth filter. The filter corner frequencies depend on the earthquake magnitude, as listed in the information page of the RRSM (see Data and Resources). Lower corner frequencies are consistent with the findings of Cauzzi and Clinton (2013) who showed that regional earthquakes with $M \sim 3.5$ can be clearly recorded above the station noise of a modern accelerometer station at periods lower than 2–3 s (see also Cauzzi and Faccioli,




▲ **Figure 3.** Attenuation of (a) PGA and (b) PGV with epicentral distance for events with minimum European–Mediterranean Seismological Center (EMSC) magnitude > 4.5. The solid curves are the median predictions of Akkar, Sandıkkaya, and Bommer (2014) for $M_w$ 5 (gray) and $M_w$ 6 (black) strike-slip events and $V_{S30} = 800$ ms$^{-1}$. The dashed curves represent the $1\sigma$ bounds of the predictions.

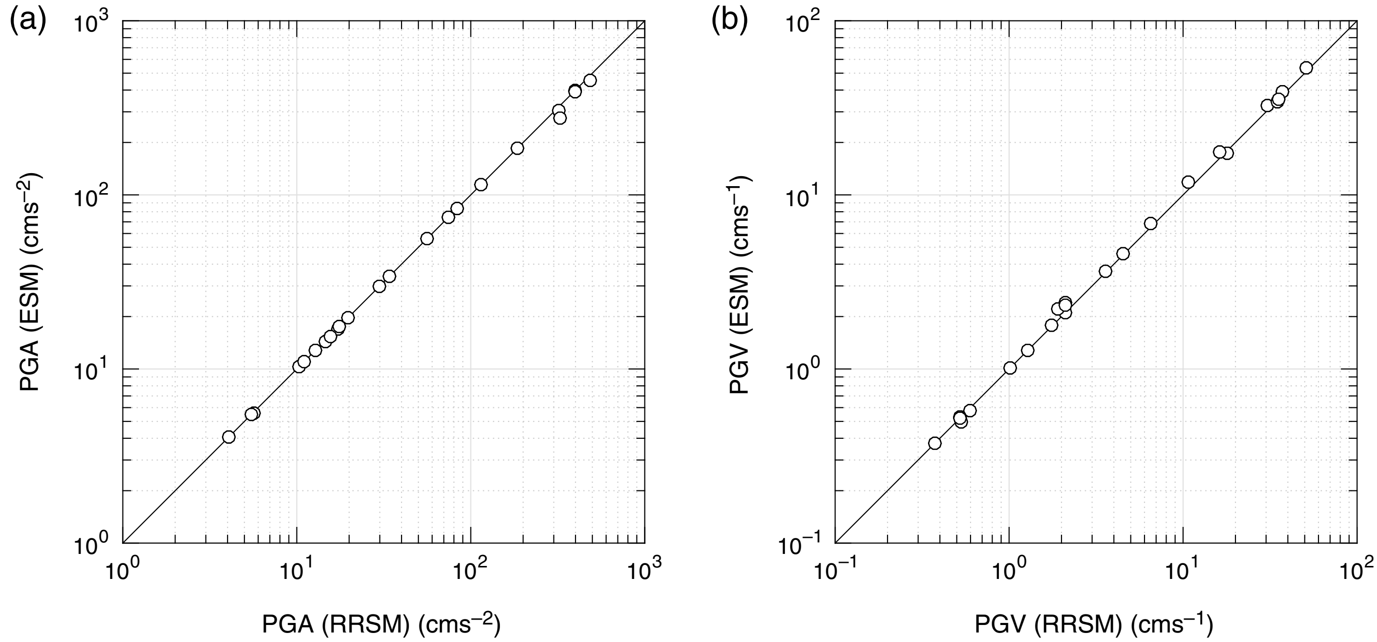
2008; Cauzzi, Faccioli, *et al.*, 2015). Following Converse and Brady (1992) and Boore (2005), cosine tapering (5% of the pre-event time window is applied at start and end of the waveforms) and zero padding is applied to the waveforms before filtering.

6. Computation of PGA (Fig. 2e), time domain integration of the waveforms, and subsequent computation of peak ground velocity (PGV) (Fig. 2f).

We do not automatically compute peak ground displacements as we believe their computation requires human inspection of the waveforms and their Fourier spectra. We internally compute the $I_A$ and the significant duration of motion with the only aim of automating the coda cutoff procedure. Although algorithmically identical, this is conceptually different from computing the $I_A$ and the significant duration on filtered waveforms and time windows already cut around the earthquake shaking, as done in engineering databanks. We believe that publishing our values of $I_A$ and significant duration would be misleading for the users.

Figure 3 summarizes the current content of the RRSM databank. The horizontal PGA and PGV values are shown for all records within 100 km epicentral distance from events with $M > 4.5$. Only PGA $> 0.1$ cms$^{-2}$ and PGV $> 0.1$ cms$^{-1}$ are included in the figure. The largest events contributing to the dataset of Figure 3 are the mainshocks of the L'Aquila 2009 and Emilia (northern Italy) 2012 earthquake sequences, with moment magnitudes ranging between 6 and 6.3 (see the European–Mediterranean Regional Centroid Moment Tensors Catalog in Data and Resources), and the $M_w$ 6.9 Aegean Sea event that occurred on 24 May 2014. In the figure, peak-motion data are separated in two magnitude classes ($M \le 5.5$ and 5.5); the ground-motion predictions of Akkar, Sandıkkaya, and Bommer (2014), Akkar, Sandıkkaya, and Bommer (ASB) are included for reference, for $M_w$ 6 (black curves) and $M_w$ 5 (gray curves) strike-slip scenarios at rock-like sites with $V_{S30} = 800$ ms$^{-1}$. ASB was calibrated using the peer-reviewed RESORCE databank and therefore is representative of ground-motion attenuation in the greater European region. Strike slip is the reference style-of-faulting (SOF) term in ASB; the amplitude of the prediction changes by 10% at most, if normal or reverse SOF is used. The use of $V_{S30} = 800$ ms$^{-1}$, that is, the boundary between ground types B and A in the Eurocode 8 (2004), is justified by the fact that the majority of the stations in the RRSM are installed at low-noise rock-like sites optimized for seismological observations, though this is certainly not always the case. The dashed curves represent the $1\sigma$ (i.e., the standard deviation) bounds of the predictions: $+1\sigma$ and $-1\sigma$ are shown for $M_w$ 6 and 5, respectively. Apparent from Figure 3 is that the automatically processed RRSM data are in good agreement with the ASB model, both as to the rate of attenuation with distance and the saturation of peak-motion values in the proximity of the earthquake source. Although the comparisons shown in Figure 3 should not be overemphasized, they suggest the fully automated processing in the RRSM performs well. This is also confirmed by comparing the peak-motion values provided by the ESM and the RRSM for the events and stations available in both databases. One significant example is shown in Figure 4, where we depict the PGA and PGV values generated by the second shock of the Emilia (Italy) sequence (29 May 2012, 07:00:02) and delivered by both databanks; minor deviations from a 1:1 relationship are due to the different corner frequencies of the filters used in the automatic and manual processing.

The acceleration traces are used at this stage to compute elastic response spectra. Though different damping levels can be used in *scwfparam*, only 5%-damped spectra are calculated in the RRSM. Spectral values are obtained through numerical integration of the equation of motion of the single-degree-of-freedom system (SDOF), using the Newmark (1959) unconditionally stable algorithm with parameters $\beta = 0.25$ and $\gamma = 0.5$. Readers interested in a comprehensive overview of alternative algorithms are referred to Chopra (2012). The elastic 5%-damped pseudo-spectral acceleration spectrum (PSA) ($T$;5%) is obtained from the elastic 5%-damped displacement response spectrum (DRS) ($T$;5%) as PSA($T$;5%) = DRS($T$;5%) $\times (4\pi^2/T^2)$, in which $T$ is the vibration period of the SDOF, in seconds. The RRSM displays only the spectral amplitudes computed at vibration frequencies higher than the low-cut of the band-pass filter applied. The reader is referred to Akkar and Bommer (2006) for a comprehensive discussion on the maximum usable vibration period of a response spectrum given the low-cut corner frequency of the filter applied to the acceleration trace.




▲ **Figure 4.** Comparison of (a) PGA and (b) PGV values delivered by the RRSM and the European Strong-Motion (ESM) for the second shock of the Emilia (Italy) sequence that occurred on 29 May 2012 at 07:00:02 (EMSC magnitude 5.8).

### A Web Interface for Data Dissemination

The RRSM is openly available (see Data and Resources), without user registration. This interactive web interface is based on OpenCMS (see Data and Resources), and users can download raw waveform data (in digital counts via redirection to EIDA), automatically processed waveforms (in physical units), peak ground-motion values, and response spectra computed as described in the Waveform Processing section. For manually selected and processed waveforms, the users are referred to the ESM, mentioned in Introduction and Motivation. The RRSM interface supports three different request types:

- *Select Events* allows querying the RRSM earthquake catalog by event time, magnitude, and location; the query returns events, streams, and peak-motion values fulfilling the search criteria.
- *Select Peak-Motions* allows searching recorded waveforms based on peak-motion criteria; the query returns events, streams, and peak-motion values fulfilling the search criteria.
- *Combined Selection* performs earthquake search by peak-motion criteria, station location, distance from and magnitude of the causative earthquake; the output of the query is events, streams, and peak motions fulfilling the criteria.

After submitting the search constraints, the earthquakes/streams are shown on a Results page (display of the actual raw and processed waveforms may be part of a future implementation). From there, the user can navigate through an Event detail page and/or a Station detail page. Peak ground-motion values are shown on all page levels. The interface provides plots of peak amplitude versus distance for a selected earthquake, and response spectra for selected stations. In addition, the user can select a set of events/stations/streams to download raw waveforms or metadata (Standard for Exchange of Earthquake Data [SEED], IRIS [2012]) from the EIDA web interface. The XML input files for U.S. Geological Survey ShakeMap are also available for download, as well as automatically processed waveforms in SEED format. Peak ground-motion parameters and response spectra, earthquake, and station metadata are available for download in various human-readable formats (e.g., plain ASCII, CSV, and PDF).

## DISCUSSION AND CONCLUSIONS

We introduce the RRSM, a new fully-automated databank built from all unrestricted on-scale high-quality waveform data from EIDA. The main advantage of the RRSM is that it allows the discovery and dissemination of peak ground-motion parameters and earthquake information in near real time, and offers download for both raw and automatically processed event waveforms. The RRSM provides additional and independently-derived data compared with those available through traditional strong-motion databanks. The underlying software and architecture provides waveform information for a future European ShakeMap (Wald *et al.*, 1999, 2005; Worden *et al.*, 2010; Worden and Wald, 2016). *scwfparam* is already used to support ShakeMap generation in Switzerland (Cauzzi, Edwards, *et al.*, 2015), along with a local RRSM installation (see Data and Resources).

The RRSM concept is specifically targeted to data users who require rapid access to strong-motion parameters, raw waveform data, and metadata (including OT information) and to users who do not need to rely on manually processed and reviewed waveforms that delay availability. The RRSM uses instrument-corrected and band-pass filtered waveforms to compute peak-motion parameters and quantities of engineering interest.

We are aware that fully automatic processing might produce physically unrealistic outliers (see also Massa *et al.*, 2014), in the case, for example, of a station temporary malfunctioning or having incorrect metadata. Therefore, the RRSM implements an automatic search for outliers based on the mechanical properties of the sensors (e.g., a broadband seismometers like the STS-2 cannot record velocity larger than $\sim 1\ \mathrm{cms}^{-1}$) and the expected peak-ground motions recorded in past events (e.g., PGA $> 1g$ and PGV $> 1\ \mathrm{ms}^{-1}$). Potential outliers are not automatically discarded but prevented from display until reviewed by a seismologist.

Potential users of the RRSM are (a) seismologists and strong-motion data analysts, (b) international earthquake response agencies, (c) earthquake and geotechnical engineers, and (d) the educated general public. Engineers interested in the RRSM will note that there is a lack of geophysical and geotechnical information from the stations. This is unavoidable because the majority of EIDA stations do not provide this information, though there are some exceptions such as Switzerland (see Michel *et al.*, 2014). Efforts to collate any existing station information and integrate this with the EIDA station list are on-going, a European Station Book is also now hosted at ODC (see Data and Resources), a prototype framework that will allow EIDA contributors to share basic station characterization details if available.

By developing the RRSM, we aim to promote a concrete and durable framework useful to both engineering and seismology communities in Europe, and to further encourage the open distribution of any seismic data through EIDA. Our ultimate vision is to integrate RRSM, ESM, and the Station Book prototype; all based on the EIDA infrastructure within ORFEUS, into a single framework to rapidly serve the engineering and seismological communities with high-quality data. We hope the community will profit from our initial efforts.

## DATA AND RESOURCES

All waveforms and metadata used by the Rapid Raw Strong-Motion (RRSM) are available through European Integrated waveform Data Archive (EIDA) at http://orfeus-eu.org/eida/webdc3/. The earthquake catalog of European–Mediterranean Seismological Center (EMSC) is available at http://www.emsc-csem.org/. The web resources mentioned in this article are the RRSM (http://www.orfeus-eu.org/rrsm/index.html), the National Research Institute for Earth Science and Disaster Prevention (NIED) seismic portal (http://www.bosai.go.jp/e/activities/database/earthquake.html), Italian Accelerometric Archive (ITACA, http://itaca.mi.ingv.it), the Strong Ground Motion Database of Turkey (http://kyhdata.deprem.gov.tr), the European Strong-Motion Database (ESMD, http://www.isesd.hi.is), the Pacific Earthquake Engineering Research (PEER) strong-motion database (http://ngawest2.berkeley.edu), the Center for Engineering Strong-Motion Data (CESMD, http://strongmotioncenter.org), EIDA (http://www.orfeus-eu.org/eida/eida.html), the Incorporated Research Institutions for Seismology Data Management Center (IRIS-DMC, http://ds.iris.edu/ds/nodes/dmc), the ODC (http://www.orfeus-eu.org/data/available_data.html), the European Plate Observing System (EPOS, http://www.epos-eu.org); the RESORCE database (http://www.resorce-portal.eu), the project SeIsmic Ground-Motion Assessment (SIGMA, http://projet-sigma.com), the Engineering Strong-Motion database (ESM, http://esm.mi.ingv.it), the project Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (NERA, http://www.nera-eu.org), the project Network of Research Infrastructures for European Seismology (NERIES, http://www.neries-eu.org/), the EMSC (http://www.emsc-csem.org), the networks contributing to EIDA (http://www.orfeus-eu.org/eida/eida_network_lists.html), the GeoForschungsZentrum (GFZ) (http://www.gfz-potsdam.de/startseite), SC3 (http://www.seiscomp3.org), the QuakeML2.0 strong-motion package (https://quake.ethz.ch/quakeml/QuakeML2.0/StrongMotion), ArcLink (http://www.seiscomp3.org/wiki/doc/applications/arclink); the RRSM information page, data gathering settings (http://orfeus-eu.org/rrsm/information/index.html#datagathering), the Regional Centroid Moment Tensor (RCMT; http://www.bo.ingv.it/RCMT), OpenCMS (http://www.opencms.org/en/index.html), the Swiss RRSM installation (http://strongmotionportal.seismo.ethz.ch), the European station book (http://www.orfeus-eu.org/stationbook). All the above websites were last accessed on March 2016.

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earthquake research worldwide through open rapid dissemination data policies; numerous Ph.D. and research programs are based on these data, and this effort provides a strategic example for the wider scientific and engineering communities.

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