KiK-net and K-NET flatfile with automatically processed ground motions

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1 Licence

2 Citation

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3 Data Description

Ground-motion flatfiles are commonly used to develop ground motion models (GMMs) and for systematical analysis of ground motions over a wide range of distances and earthquake magnitudes. A flatfile is organized as a table of properties and various intensity measures of earthquake waveforms, including data processing parameters. Here we present a comprehensive processed ground-motion flatfile containing data from the Kyoshin (K-NET) and Kiban-Kyoshin (KiK-net) networks operated by National Research Institute for Earth Science and Disaster Resilience (NIED) (2019) in Japan (Okada et al., 2004; Aoi et al., 2011). This flatfile contains 914,628 ground motions from 18,018 events recorded by 1,749 stations. Out of these, 434,898 ground-motions are from KiK-net and 479,730 from K-net. The events were recorded between June 1996 and September 2024, covering distances up to 1200 km and magnitudes between 2.5 and 9. The ground motions have been automatically processed, and metadata describing each event and record are provided in the flat file.

An overview of the flatfiles and the processing steps to derive the reported ground-motion parameters is provided in this report. Further details and discussion about the flatfile compilation can be found in the corresponding publication:

Loviknes, K., von Specht, S., Lilienkamp, H., Händel, A., and Cotton, F. (2025). Harmonized KiK-net and K-NET flatfile for systematic analysis of earthquake ground motions (submitted to *Seismica*, February 2025).

3.1 Data sources

All data are collected from publicly available data archives hosted by NIED and the JMA (Japan Meteorological Agency) and are listed in Table 1.

Table 1: Data sources and last access dates.

Data type	**URL**	**Last Accessed**
Raw acceleration waveforms	`https://www.kyoshin.bosai.go.jp/`	October 10, 2024
JMA unified hypocenter catalog	`https://www.data.jma.go.jp/svd/eqev/data/bulletin/index_e.html`	March 14, 2024
F-net moment tensor catalog	`https://www.fnet.bosai.go.jp/event/mcata/index.php`	October 10, 2024
JMA travel-time table	`https://www.data.jma.go.jp/svd/eqev/data/bulletin/catalog/appendix/trtime/tjma2001.zip`	August 25, 2021

3.2 Processing Steps

1. Each event is matched with the JMA and F-net earthquake catalogs using origin time and magnitude. Events within 1 minute, 0.3 magnitude, and three times the estimated surface

rupture length of each other are considered matches. Since the JMA catalog is available only up to March 2023 and not all events are included in the F-net catalog, events are matched with both catalogs. Events that are not matched with either of the catalogs are omitted.

2. Focal mechanisms are determined based on moment tensor solutions from F-net following Boore and Atkinson (2007), as shown in Table 2.

Table 2: Fault-type definitions from Boore and Atkinson (2007).

P-axis plunge	**T-axis plunge**	**Focal mechanism**
$\leq 40^\circ$	$> 40^\circ$	Reverse (R)
$\leq 40^\circ$	$\leq 40^\circ$	Strike-slip (S)
$> 40^\circ$	$\leq 40^\circ$	Normal (N)
$> 40^\circ$	$> 40^\circ$	Undefined

3. Epicentral (R_{epi}) and hypocentral (R_{hypo}) distances are computed for all recorded ground motions, while the Joyner-Boore (R_{JB}) and rupture plane (R_{rup}) distances are only calculated for events matched with the F-net catalog.

4. Records with $\text{M}_{\text{JMA}} < 2.5$ or $R_{\text{hypo}} > 1200$ km are omitted.

5. The three waveform components are processed together using the following steps:

   (a) Metadata and waveforms for each component are read from the `.txt` files downloaded from the Kyoshin webpage.

   (b) Units are converted from cgs to SI (i.e., gal to m/s^2).

   (c) Waveforms are detrended using a first-order polynomial.

   (d) Theoretical P- and S-wave arrival times at the recording station are calculated from the JMA origin time and travel-time table. Records starting after the theoretical S-wave arrival are omitted.

   (e) To assess whether a waveform is contaminated by multiple event arrivals, the energy ratio between the P- and S-wave window and the entire waveform is calculated using the following steps:

      i. The theoretical duration of the S-wave window is computed following the Brune (1970) model and the approach of Perron et al. (2018).

      ii. The energy ratio, defined as the sum of squared accelerations within the P- and S-wave window relative to the entire waveform, is computed.

      iii. If the energy ratio is less than 80%, indicating that more than 20% of the energy lies outside the main P- and S-wave window, the record is flagged as potentially containing multiple arrivals. Flagged records remain in the flatfile but should be used with caution.

   (f) Observed P- and S-wave arrivals are automatically detected using the Short-Term Average over Long-Term Average (STA/LTA) technique (Akazawa, 2004).

   (g) A sufficiently long, uncontaminated noise window is selected for SNR estimation using the following criteria:

i. If at least 11 seconds of pre-event noise is available, it is used as the noise window (preferred).
ii. If the pre-event noise window is too short, a 20-second window at the end of the signal is used.
iii. If the energy ratio between the selected noise window and the waveform is too high (> 0.01) and the waveform is long enough, a new noise window is selected between the end of the signal and the end of the waveform.

(h) The running Arias Intensity ($I_A(t)$, Bommer and Martínez-Pereira, 1999) is calculated as the summed squared acceleration and used to derive the 5-75%, 5-95% and 5-97.5% significant durations (D_{5-75}, D_{5-95}, $D_{5-97.5}$). The end of the main signal is selected as the maximum of $D_{5-97.5}$ and the theoretical S-wave window duration D_S (Perron et al., 2018).

(i) The waveform is cut from 5 seconds before the observed first arrival (P- or S-wave) to the selected end of the signal.

(j) A first-order polynomial detrending is applied again.

(k) Cutoff frequencies for filtering are selected using the following steps:
i. Signal and noise spectra are smoothed using LOESS (locally estimated scatterplot smoothing) regression (Hastie et al., 2009).
ii. The signal-to-noise ratio (SNR) is computed.
iii. The usable frequency band is identified as the range where most SNR values exceed 3.
iv. Cutoff frequencies for filtering are set as the minimum and maximum frequencies within the usable range.
v. The lower cutoff frequency ($f_{c,0}$) is constrained between $1/D_{\text{noise}}$ and 0.5 Hz, while the upper cutoff frequency ($f_{c,1}$) is constrained between 20 Hz and 30 Hz.
vi. The most conservative values are selected for the horizontal components: $f_{c,0} = \max[f_{c,0,\text{EW}}, f_{c,0,\text{NS}}]$ and $f_{c,1} = \min[f_{c,1,\text{EW}}, f_{c,1,\text{NS}}]$.

(l) A 2.5% cosine taper is applied to the waveform.

(m) The waveform is padded with zeros to prevent spectral leakage.

(n) The waveform is filtered using the selected cutoff frequencies with an acausal 4th-order Butterworth filter.

(o) The zero-padding is removed.

(p) A baseline correction is applied following Boore et al. (2012); Ancheta et al. (2014):
i. The acceleration time series is double-integrated to obtain displacement.
ii. A 6th-order polynomial (with 0th- and 1st-order term coefficients constrained to zero) is fitted to the displacement trace.
iii. The second derivative of the polynomial is subtracted from the acceleration trace.
iv. The corrected acceleration trace is integrated to obtain the corrected velocity and displacement time series.

(q) The baseline-corrected acceleration, velocity, and displacement traces are oversampled to 400 Hz using Whittaker–Shannon interpolation (also called sinc interpolation, Shannon, 1949).

(r) Peak ground-motion amplitudes are taken as the absolute maxima of the oversampled time series for each horizontal component:

- Peak ground acceleration (PGA)
- Peak ground velocity (PGV)
- Peak ground displacement (PGD)

(s) Ground-motion intensity parameters are calculated from the final processed waveforms:

- Pseudo-spectral acceleration (PSA)
- Fourier amplitude spectrum (FAS)
- Arias intensity (IA)
- Cumulative absolute velocity (CAV)

4 File Description

The processed data are provided in eight flatfiles, i.e., parametric tables containing metadata and intensity measures of processed earthquake waveforms. The name and content of each flatfile are outlined in Table 3.

Table 3: File description.

File Name	**Content**
2025-001_Loviknes-et-al_1997_2024_kik_META.csv	Metadata of the KiK-net ground-motion records
2025-001_Loviknes-et-al_1997_2024_kik_SA.csv	ROTD50 pseudo-spectral amplitudes of KiK-net ground motions (surface recordings)
2025-001_Loviknes-et-al_1997_2024_kik_SA_B.csv	ROTD50 pseudo-spectral amplitudes of KiK-net ground motions (borehole recordings)
2025-001_Loviknes-et-al_1997_2024_kik_FAS3c.csv	Three-component Fourier amplitudes of KiK-net ground motions (surface recordings)
2025-001_Loviknes-et-al_1997_2024_kik_FAS3c_B.csv	Three-component Fourier amplitudes of KiK-net ground motions (borehole recordings)
2025-001_Loviknes-et-al_1996_2024_knet_META.csv	Metadata of the K-NET ground-motion records
2025-001_Loviknes-et-al_1996_2024_knet_SA.csv	ROTD50 pseudo-spectral amplitudes of K-NET ground motions (surface recordings)
2025-001_Loviknes-et-al_1996_2024_knet_FAS3c.csv	Three-component Fourier amplitudes of K-NET ground motions (surface recordings)

4.1 Column Descriptions of Metadata (*_META.csv* files)

The *_META.csv* files contain columns describing each record, event, and station. The record metadata are related to the distance and processing, while the event metadata are from either the waveform metadata (suffix *_Meta*), the JMA catalog (prefix *JMA_*), or the F-net catalog (prefix *fnet_*).

The only station metadata included in this flatfile are from the waveform metadata and describes the station code, height, and location. Users requiring additional site parameters (e.g., shear-wave velocity, depth to bedrock, geology) should refer to the site database of Zhu et al. (2021).

Although not included in the following column explanation, the KiK-net *_META.csv* file also contain columns with subscript **_B** describing the borehole sensor and the properties of ground motions recorded by the borehole sensor.

4.1.1 Event Metadata

- **EQ_Code**: Event identifier (date and time of event in time format: YYYYMMDDhhmmss)
- **NumberofStations**: Number of stations that recorded the event

Metadata from Waveform Files

- **Origin_Meta**: Event origin time from waveform metadata (adjusted for 15-second trigger delay), in time format: YYYY-MM-DD hh:mm:ss
- **evLat._Meta**: Event latitude from waveform metadata
- **evLong._Meta**: Event longitude from waveform metadata
- **Depth. (km)_Meta**: Event depth from waveform metadata
- **Mag._Meta**: Event magnitude from waveform metadata

Metadata from JMA

- **JMA_match**: Boolean flag indicating whether the event is matched with the JMA catalog
- **JMA_UTC**: Event origin time (UTC) from the JMA catalog (YYYY-MM-DD hh:mm:ss.fff format)
- **JMA_JST**: Event origin time in JST (Japan Standard Time, UTC + 9 h) from the JMA catalog
- **JMA_Lat**: Event latitude from the JMA catalog
- **JMA_Lon**: Event longitude from the JMA catalog
- **JMA_Depth**: Event depth from the JMA catalog (km)
- **JMA_Mag**: Event magnitude from the JMA catalog, according to the type specified in **JMA_Magtype**
- **JMA_Magtype**: Magnitude type used by JMA (see Table 4)

Table 4: JMA magnitude type (from `www.data.jma.go.jp/svd/eqev/data/bulletin/data/format/hypfmt_e.html`, last accessed 22.01.2025)

Code	Magnitude	Description
J	MJ	JMA magnitude
D	MD	JMA displacement magnitude
d	MD	JMA displacement magnitude, but for two stations
V	MV	JMA velocity magnitude
v	MV	JMA velocity magnitude, but for two or three stations
W	MW	Moment magnitude
B	mb	Body wave magnitude from USGS
S	MS	Surface wave magnitude from USGS

Metadata from F-net

- **Fnet_match**: Boolean flag indicating whether the event is matched with the F-net catalog
- **fnet_Region_Name** Name of the region where the event occurred
- **fnet_Latitude(deg)**: Event latitude from F-net
- **fnet_Longitude(deg)**: Event longitude from F-net

  Hypocenter information obtained from JMA (also included in the flatfile as events after March 2023 are not matched with JMA)
- **fnet_Origin_Time(UT)** Event origin time in UTC time (same as in the JMA catalog) in time format YYYY-MM-DD hh:mm:ss.fff
- **fnet_JMA_Depth(km)** Event depth from the JMA catalog (km)
- **fnet_JMA_Magnitude(Mj)** JMA magnitude (M_{JMA})

  The focal mechanism solution are estimated by F-net (Fukuyama, 1998) as described on their webpage: `https://www.fnet.bosai.go.jp/event/dreger.php` (last accessed 29.01.25)
- **fnet_MT_Magnitude(Mw)**: Moment magnitude (M_w) from F-net
- **fnet_MT_Depth(km)** Event depth from the F-net catalog (km)
- **fnet_Mo(Nm)**: Seismic moment (Nm)
- **fnet_Strike_0, fnet_Strike_1**: Fault strike angles for two possible fault planes
- **fnet_Dip_0, fnet_Dip_1**: Fault dip angles for two possible fault planes
- **fnet_Rake_0, fnet_Rake_1**: Fault rake angles for two possible fault planes
- **fnet_Var._Red.**: Variance reduction, representing the quality of the focal mechanism solution
- **fnet_Number_of_Stations** Number of stations used to obtain the focal mechanism solution

- **Focal_mechanism_BA**: Focal mechanism classification: reverse (R), strike-slip (S), normal (N), or undefined (none)

4.1.2 Station Metadata

- **StationCode**: Station name
- **StationHeight(m)**: Station height from waveform metadata (m)
- **StationLat.**: Station latitude from waveform metadata
- **StationLong.**: Station longitude from waveform metadata
- **Borehole_depth**: Depth from surface to the borehole sensor (given as **StationHeight(m)** in the borehole `.txt` file) (m)
- **Borehole_Processed** (KiK-net only): Boolean flag indicating whether the borehole records were processed (True) or not (False)

4.1.3 Record Metadata

- **Address**: Unique identifier for the record, combining **EQ_Code** and station name: EQ_Code + '/' + StationCode + '/'
- **RecordTime**: Record start time (JST) from waveform metadata in YYYY/MM/DD hh:mm:ss format (adjusted for 15-second trigger delay)
- **samplingRate**: Station sampling rate at the time of recording (usually 200 Hz for older records and 100 Hz for newer ones)

Distance Metrics

- **Repi**: Epicentral distance, calculated as the great-circle distance between the station and the earthquake epicenter
- **Rhypo**: Hypocentral distance
- **RJB_0**: Joyner-Boore distance, computed using **fnet_Dip_0**, **fnet_Rake_0**, and **fnet_Strike_0**
- **RJB_1**: Joyner-Boore distance, computed using **fnet_Dip_1**, **fnet_Rake_1**, and **fnet_Strike_1**
- **Rrup_0**: Rupture distance, computed using **fnet_Dip_0**, **fnet_Rake_0**, and **fnet_Strike_0**
- **Rrup_1**: Rupture distance, computed using **fnet_Dip_1**, **fnet_Rake_1**, and **fnet_Strike_1**

Arrival Times and Window Durations

- **tP_JMA**: Theoretical P-wave arrival time, calculated using JMA travel-time tables
- **tS_JMA**: Theoretical S-wave arrival time, calculated using JMA travel-time tables
- **WaveType**: Either "P" or "S"; "P" indicates the waveform starts before **tP_JMA**, while "S" means it starts after **tP_JMA** but before **tS_JMA**
- **tP_STA_LTA**: First arrival time (depending on **WaveType**) detected using the STA/LTA technique (Allen, 1978; Akazawa, 2004)

- **new_record_start_UTC**: In YYYYMMDDhhmmss format. If the record starts more than 80 seconds before **tP_JMA**, it is cut to begin 11 seconds before **tP_JMA**; otherwise, the same as **RecordTime**
- **new_record_start_UTC_bool**: Boolean flag indicating whether the record start time was modified compared to the original metadata (**RecordTime**)
- **duration_Noise**: Duration of the noise window in seconds
- **end_Swave**: Theoretical length of the S-wave window (in seconds), computed based on the Brune model (Brune, 1970) and Perron et al. (2018) (maximum set to 120 s)
- **noiseStart**: Start time of the noise window (relative to **RecordTime**), determined based on signal energy ratio thresholds
- **length_record_s**: Duration of the final processed waveform (in seconds)

Frequency Ranges

- **fc0**: Low cutoff frequency for filtering (minimum $1/D_{\text{noise}}$, maximum 0.5 Hz)
- **fc1**: High cutoff frequency for filtering (minimum 20 Hz, maximum 30 Hz)
- **freq_ra**: Ratio of the selected frequency range to the full available frequency range:

$$q_{\text{range}} = \frac{f_{c,1} - f_{c,0}}{f_{c,1,\max} - f_{c,0,\min}} \tag{1}$$

- **HighFreq_flag**: Boolean flag set to 1 (True) if $f_{c,1} < 20$ Hz
- **LowFreq_flag**: Boolean flag set to 1 (True) if $f_{c,0} > 0.5$ Hz
- **snrEmean**, **snrNmean**: Mean signal-to-noise ratio (SNR) for the EW and NS components, respectively.

Energy Ratios and SNRs

- **energy_ratioSignal**: Ratio of energy (sum of squared accelerations) within the P- and S-wave window to the total waveform energy; records with values less than 0.8 should be used with caution
- **energy_ratioNoise**: Ratio of energy within the noise window to the total waveform energy; records with values above 0.01 should be used with caution
- **MultFlag**: Boolean flag indicating potential multiple event arrivals (set if **energy_ratioSignal** $< 80\%$)

Intensity Measures

- **Dur5_75_E**, **Dur5_75_N**: Significant duration (5-75% Arias intensity) for the EW and NS components, respectively (Baker et al., 2021)
- **Dur5_95_E**, **Dur5_95_N**: Significant duration (5-95% Arias intensity) for the EW and NS components
- **AriasIntensity_E**, **AriasIntensity_N**, **AriasIntensity_U**: Arias intensity (IA) for the EW, NS, and UD components, respectively
- **CAV_E**, **CAV_N**, **CAV_U**: Cumulative absolute velocity (CAV) for the EW, NS, and UD components
- **PGA_EW_Meta**, **PGA_NS_Meta**: Peak ground acceleration (PGA) of the raw waveform for the EW and NS components, respectively (m/s^2)
- **PGA_EW**, **PGA_NS**: PGA of the final processed waveform for the EW and NS components, respectively (m/s^2)
- **PGA_rotd50**: RotD50 PGA of final processed waveform (m/s^2)
- **PGV_EW**, **PGV_NS**: Peak ground velocity (PGV) of the final processed waveform for the EW and NS components, respectively (m/s)
- **PGV_rotd50**: RotD50 PGV of final processed velocity waveform (m/s)
- **PGD_EW**, **PGD_NS**: Peak ground displacement (PGD) of the final processed waveform for the EW and NS components, respectively (m)
- **PGD_rotd50**: RotD50 PGD of final processed displacement waveform (m)

4.2 Column Descriptions of Spectral Amplitude Data (*_SA.csv* files)

The *_SA.csv* files contain a subset of metadata along with RotD50 pseudo-spectral acceleration (PSA) values for each record. The following metadata columns are included:

- **Address**: Unique identifier for the record
- **EQ_Code**: Event identifier (YYYYMMDDhhmmss format)
- **Origin_Meta**: Event origin time from waveform metadata (adjusted for 15-second trigger delay), in time format: YYYY-MM-DD hh:mm:ss
- **evLat._Meta**, **evLong._Meta**: Event latitude and longitude from waveform metadata
- **Depth. (km)_Meta**: Event depth from waveform metadata
- **Mag._Meta**: Event magnitude from waveform metadata
- **StationCode**: Station name
- **StationLat.**, **StationLong.**: Station latitude and longitude from waveform metadata

- **StationHeight(m)**: Station height from waveform metadata
- **fc0**, **fc1**: Selected low and high cutoff frequencies
- **PGA_rotd50**: RotD50 PGA (m/s^2)

The remaining columns contain RotD50 PSA values for various spectral periods:

- **Sx.xxx**: RotD50 PSA for spectral periods $x.xxx$ s, where $x.xxx$ ranges from 0.01 s to 20 s

4.3 Column Descriptions of Fourier Amplitude Data (*_FAS3c.csv* files)

The *_FAS3c.csv* files contain Fourier amplitude spectra (FAS) for each record along with a subset of metadata. The included metadata columns are:

- **Address**: Unique identifier for the record
- **EQ_Code**: Event identifier (YYYYMMDDhhmmss format)
- **Origin_Meta**: Event origin time from waveform metadata (adjusted for 15-second trigger delay), in time format: YYYY-MM-DD hh:mm:ss
- **evLat._Meta**, **evLong._Meta**: Event latitude and longitude from waveform metadata
- **Depth. (km)_Meta**: Event depth from waveform metadata
- **Mag._Meta**: Event magnitude from waveform metadata
- **StationCode**: Station name
- **StationLat.**, **StationLong.**: Station latitude and longitude from waveform metadata
- **StationHeight(m)**: Station height from waveform metadata
- **fc0**, **fc1**: Selected low and high cutoff frequencies
- **PGA_EW**, **PGA_NS**: PGA for the EW and NS components, respectively (m/s^2)

The remaining columns contain three-component FAS values:

- **CCx.xxx**: Fourier amplitude spectrum for each component *CC* (EW, NS, UD) at frequency $x.xxx$ Hz, in the range from 0.1 Hz to 24 Hz and logarithmically spaced. Note that, unlike common practice (e.g., Lanzano et al., 2019; Bahrampouri et al., 2020), the FAS values are not smoothed

4.4 Borehole Data

Files with the suffix *_B* contain PSA (column names **Bx.xxx**) or FAS values (column names **B_CCx.xxx**)for ground motions recorded by the KiK-net borehole sensors. These files follow the same format as the corresponding surface-recorded data files but include borehole-specific records and metadata.

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