

The Magnitude–Frequency Kink in the 2020–2024 Noto Peninsula Earthquake Swarm

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Research Article

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Abstract

The 2020–2024 earthquake swarm beneath the northeastern Noto Peninsula, central Japan, preceded the 1 January 2024 Mw 7.5 earthquake and has been linked to deep fluid supply, aseismic slip and fault-valve behaviour. Using the published double-difference relocated catalogue of Yoshida et al. (2024; 31,158 events, 2003–2024), we examine the magnitude–frequency distribution (FMD) of the 2021–2023 swarm (14,810 events, $M_{\text{JMA}} \geq 1.2$) in three depth bands. Completeness is $M_{\text{c}} \approx 1.2$ in all bands. Shallow events (< 10 km) follow a single Gutenberg–Richter (GR) law. Middle (10–13 km) and deep (≥ 13 km) events do not: for the deep band a broken GR model ($b_1 = 1.57$ below and $b_2 = 0.75$ above a break at $M_{\text{k}} = 1.9$, 95% interval 1.8–2.3) and a two-population GR mixture are preferred over a single GR law by $\Delta\text{BIC} \approx -107$ and -112 , with parametric-bootstrap $p < 0.005$; the deep band contains 37 events of $M \geq 3$ against 7 (95% range 2–14) expected from its single-GR fit. The departure persists after nearest-neighbour declustering and when only JMA velocity magnitudes are used ($\approx 98\%$ of events across the break). The break magnitude is similar at all depths ($M \approx 1.8\text{--}2.1$), but the departure is much stronger at depth. The departure was first indicated by a GR-conditioned residual of magnitude dispersion (Z_{C}), which measures dispersion beyond that implied by the b-value. Because a common break magnitude is also the expected signature of non-linear scaling between amplitude-based magnitude and seismic moment for small events, we do not interpret the break physically; we show that the documented direction of the known JMA small-event bias would oppose the observed shape, and identify the comparison with moment magnitudes as the decisive test. The results caution against interpreting single b-values from this catalogue without specifying the magnitude range and depth.

Key points

- In the relocated catalogue of the 2020–2024 Noto swarm, the magnitude–frequency distribution of events deeper than 13 km is statistically inconsistent with a single Gutenberg–Richter law: it is steep below $M_{\text{JMA}} \approx 1.9$ ($b \approx 1.6$) and flatter above ($b \approx 0.75$), with about five times more $M \geq 3$ events than the small-event slope predicts.
- The departure survives a common completeness threshold, nearest-neighbour declustering and restriction to a single JMA magnitude type; the break magnitude is similar at all depths, but its strength increases strongly with depth.
- Whether the break reflects earthquake physics or the scaling of amplitude-based magnitudes for small events cannot be decided from the catalogue alone; we state this open question and the test that would resolve it.

Plain-language summary

Small earthquakes are much more common than large ones, and the standard rule says that their numbers fall by a fixed factor for each step up in magnitude, which appears as a straight line on a logarithmic graph. In the earthquake swarm that preceded the 2024 magnitude 7.5 Noto earthquake, we

find that deeper earthquakes do not follow one straight line: very small events are relatively abundant, but above magnitude about 2 there are several times more larger events than the small ones would predict. This pattern passes several statistical checks, but it occurs at nearly the same magnitude at all depths, which could also be produced by the way the magnitudes of very small earthquakes are calculated. We therefore report it as a robust feature of the catalogue whose physical meaning still needs to be tested.

1. Introduction

The Gutenberg–Richter (GR) law, $\log_{10} N(M \geq m) = a - b m$, describes the decrease in earthquake numbers with magnitude (Gutenberg & Richter, 1944). The b -value is widely used as an indicator of differential stress (Scholz, 1968; Schorlemmer et al., 2005) and has been proposed as a basis for distinguishing foreshocks from aftershocks (Gulia & Wiemer, 2019). These applications assume that a single straight line describes the FMD above the completeness magnitude. Departures from a single line are frequently reported; they can arise from changes in magnitude scaling for small events (Deichmann, 2006; Uchide & Imanishi, 2018), from incompleteness, from mixing of populations with different b -values, or from genuine physical processes. Distinguishing these possibilities requires explicit statistical tests and catalogue audits.

Earthquake swarms associated with crustal fluids often have high b -values and complex magnitude statistics (Shelly, 2024, and references therein). The 2020–2024 Noto swarm offers an exceptional opportunity to study such statistics: it preceded an M_w 7.5 earthquake, its fluid-related evolution has been documented in detail (Nakajima, 2022; Amezawa et al., 2023; Nishimura et al., 2023; Yoshida, Uno, et al., 2023; Kato, 2024; Yoshida et al., 2024), and a high-precision relocated catalogue is publicly available.

This study arose from work on magnitude compression, $C = 1 - \sigma_W/\sigma_0$, a measure of the dispersion of recent magnitudes relative to a reference. Because dispersion and b are linked for a GR distribution, we examined the residual of dispersion after conditioning on the window b -value (Z_C). In the Noto catalogue this residual was negative and strongest at depth, which led us to examine the full FMD by depth. Here we (1) document the resulting departure from a single GR law, (2) test it against completeness, declustering and magnitude-type explanations under protocols fixed before each analysis, and (3) discuss the remaining magnitude-scaling explanation and the test needed to resolve it.

2. Setting and the 2020–2024 sequence

The Noto Peninsula lies on the eastern margin of the Japan Sea, where Miocene extensional faults are reactivated as reverse faults under present-day compression (Kato, 2024). Large earthquakes include an M 6.6–7.0 event in 1729 on the Wajima-Oki fault (Hamada et al., 2016) and the 2007 M_w 6.7 Noto Hanto earthquake beneath the western coast (Kato et al., 2008).

The swarm beneath the northeastern tip began in late 2020 in a deep cluster at about 18 km depth above an S-wave reflector interpreted as a fluid reservoir, then expanded upward and into several clusters (Yoshida, Uno, et al., 2023). A low-velocity lower crust suggests deep fluid supply (Nakajima, 2022), hypocentres migrated diffusively (Amezawa et al., 2023), and geodetic data indicate tensile opening at ~ 16 km followed by aseismic slip (Nishimura et al., 2023). An Mw 5.2 (M_JMA 5.4) event occurred on 19 June 2022 and an Mw 6.2 (M_JMA 6.5) event on 5 May 2023; the latter ruptured a $\sim 45^\circ$ SE-dipping fault and was followed by up-dip aftershock migration at ~ 20 km/h, interpreted as fault-valve behaviour (Kato, 2024). The 1 January 2024 Mw 7.5 earthquake initiated on the previously unrecognised Suzu blind fault at the front of a two-year westward swarm migration, after M 5.5 and M 4.6 foreshocks (Yoshida et al., 2024), and ruptured more than 100 km (Okuwaki et al., 2024).

3. Data

We use the relocated catalogue of Yoshida et al. (2024), available from Zenodo (<https://doi.org/10.5281/zenodo.12799165>; licence CC BY 4.0). It contains 31,158 events from 11 March 2003 to 31 March 2024, obtained by double-difference relocation of JMA unified-catalogue events with $M_{\text{JMA}} \geq 1$ (mean 95% location uncertainties ≈ 0.1 km). Our copy (hypocenter.out) has MD5 checksum a5a994e039832ccda3aed53903bcefb5, identical to the published value. Times were converted from JST to UTC (UTC = JST – 9 h). Magnitudes are M_{JMA} rounded to 0.1; a value of 0.0 denotes an undetermined magnitude.

We analyse the main swarm phase, 1 January 2021–31 December 2023, before the Mw 7.5 earthquake, using events with $M_{\text{JMA}} \geq 1.2$ (Section 4.1): 14,810 events, of which 1,787 are shallow (< 10 km), 9,993 middle (10–13 km) and 3,030 deep (≥ 13 km), using relocated depths. For the magnitude-type audit we use the JMA unified hypocentre catalogue for the Noto region ($36.8\text{--}38.2^\circ\text{N}$, $136.5\text{--}138.3^\circ\text{E}$, $M_{\text{JMA}} \geq 1.5$, 2000–2023), which records the magnitude type, a second magnitude where available and the number of stations for each event.

4. Methods

Each analysis was specified in a written protocol, fingerprinted with SHA-256 before execution; changes (for example, replacement of an unsuitable declustering method) were recorded in new protocols before the corrected analysis was run. Withdrawn results are retained and labelled in the data package.

4.1 Completeness

For each depth band we estimated M_c by maximum curvature (most frequent 0.1 bin + 0.2) and by the goodness-of-fit method (lowest M_c at which the residual between observed and GR cumulative counts is $\leq 10\%$; Wiemer & Wyss, 2000):

$$R = 100 \cdot \sum |N_{\text{obs}}(m) - N_{\text{GR}}(m)| / \sum N_{\text{obs}}(m)$$

4.2 b-value

The maximum-likelihood b-value (Aki, 1965) with the rounding correction of Utsu (1965) and the uncertainty of Shi and Bolt (1982) are

$$b = \log_{10} e / [\bar{M} - (M_c - \Delta M/2)], \quad \sigma_b = 2.30 b^2 \sqrt{[\sum (M_i - \bar{M})^2 / (N(N-1))]}$$

with $\Delta M = 0.1$ and $\bar{M}$ the mean magnitude above M_c .

4.3 Magnitude dispersion and the GR-conditioned residual Z_C

Magnitude compression compares the standard deviation σ_W of the last W magnitudes with a reference value σ_0 : $C_{\text{raw}} = 1 - \sigma_W / \sigma_0$. For an exponential (GR) distribution the standard deviation equals the mean excess above the threshold, $\sigma \approx \log_{10} e / b$, so C_{raw} and b are linked. To isolate dispersion beyond that implied by b , we simulated 300,000–400,000 windows of W binned GR magnitudes above the same M_c (true b uniform in 0.5–2.2), re-estimated $\hat{b}$ in each with the same formula, and tabulated the mean $\mu_\sigma(\hat{b}, W)$ and standard deviation $sd_\sigma(\hat{b}, W)$ of σ in bins of $\hat{b}$ (width 0.02). For an observed window,

$$Z_C = (\mu_\sigma(\hat{b}, W) - \sigma_W) / sd_\sigma(\hat{b}, W)$$

$Z_C > 0$ indicates magnitudes more tightly grouped, and $Z_C < 0$ more dispersed, than a GR distribution with the same estimated b . Statistics were computed on non-overlapping windows, $W = 30$ –150.

4.4 Models of the magnitude–frequency distribution

Treating rounded magnitudes as continuous above $m_0 = M_c - 0.05$, we compared three survival functions $S(m) = P(M > m)$:

Single GR: $S_1(m) = 10^{(-b(m - m_0))}$

Broken GR: $S_2(m) = 10^{(-b_1(m - m_0))}$ for $m < M_k$; $10^{(-b_1(M_k - m_0) - b_2(m - M_k))}$ for $m \geq M_k$

Two-population mixture: $S_3(m) = w \cdot 10^{(-b_a(m - m_0))} + (1 - w) \cdot 10^{(-b_b(m - m_0))}$

The probability of a 0.1 bin centred at v is $P(v) = S(v - 0.05) - S(v + 0.05)$, and the binned log-likelihood is $\ln L = \sum_v n_v \ln P(v)$, where n_v is the number of events in bin v . Parameters were obtained by numerical maximisation; for the broken model M_k was searched from 1.8 to 3.5 in steps of 0.1. Models were compared by the Bayesian information criterion, $BIC = k \ln N - 2 \ln L$, with k the number of parameters (1 or 3). Because M_k is searched, significance of the broken model was assessed by a parametric bootstrap: 200 catalogues of N events were simulated from the fitted single GR, both models were

refitted (including the full M_k search), and the observed likelihood-ratio statistic $LR = 2(\ln L_2 - \ln L_1)$ was compared with the simulated distribution. The 95% interval of M_k was obtained by refitting 200 resampled catalogues. Note that the binned-likelihood single-GR b differs slightly from the Aki–Utsu estimate (1.46 versus 1.45 for the deep band).

4.5 Excess of larger events

The expected number of events above magnitude t under the single-GR fit is $N_{\text{exp}}(M \geq t) = N \cdot 10^{-(b(t - 0.05 - m_0))}$. Predictive 95% intervals for $t = 3$ and 4 were obtained from 2,000 simulated catalogues of N events, with b drawn from its sampling distribution.

4.6 Declustering

Gardner–Knopoff (1974) space–time windows were tested first but withdrawn: their windows (e.g. ~ 30 km and ~ 41 days for $M \geq 4$) exceed the extent of the swarm and removed 97–99.7% of events. We used instead the nearest-neighbour method of Zaliapin and Ben-Zion (2013). For each event j and every earlier event i ,

$$\eta_{ij} = t_{ij} \cdot r_{ij}^{d_f} \cdot 10^{(-b m_i)}$$

with t in years, r the hypocentral distance in km (minimum 0.05 km), $d_f = 1.6$ and $b = 1$. The parent of j is the earlier event minimising η ; the link is classified as clustered if $\eta < \eta_0$, where $\log_{10} \eta_0 = -6.98$ is the equal-posterior point of a two-component Gaussian mixture fitted to $\log_{10} \eta$ (component means -8.07 and -5.70). This classified 32% of 2021–2023 events as clustered. We analysed catalogue A (all events), catalogue B (all clustered descendants of every $M \geq 4$ event removed, the $M \geq 4$ events retained) and catalogue C (background events only). Declustered catalogues are treated as sensitivity analyses, because cluster-initiating events tend to be larger and background-only catalogues are therefore slightly biased towards larger magnitudes.

4.7 Magnitude-type audit

JMA magnitudes are computed from displacement amplitudes (types D, d) or velocity amplitudes (types V, v), the lower-case types using fewer stations, and occasionally as moment magnitude (type W). Events of the Yoshida catalogue with $M_{\text{JMA}} \geq 1.5$ were matched one-to-one to the JMA catalogue by origin time ($|\Delta t| \leq 1$ s, JST) and magnitude ($|\Delta M| < 0.05$). For each 0.1 bin and depth band we computed the share of each type, and refitted the FMD models using only type-V events. The protocol defined, in advance, attribution to magnitude construction as either a change of ≥ 30 percentage points in the dominant-type share across M 1.6–2.4 or the absence of the break in a single-type subset.

4.8 Magnitude variogram

To test whether consecutive events have similar magnitudes, we computed $\gamma(\tau) = \frac{1}{2} E[(M_{\{i+\tau\}} - M_i)^2]$ for event lags $\tau = 1-100$ and compared it with 200 random permutations, and computed γ for random event pairs grouped by time separation and hypocentral distance.

5. Results

5.1 Completeness and b-values

Maximum curvature gives $M_c = 1.2$ for all three depth bands (the most frequent bin is $M = 1.0$ in each; for the deep band 1,218 events), and the goodness-of-fit method gives 1.0; we therefore use a common $M_c = 1.2$. Aki–Utsu b-values above M_c are 0.92 ± 0.02 for the shallow band and 1.45 ± 0.03 for the deep band.

5.2 Departure from a single GR law

Shallow events follow a single GR line over the full magnitude range (Figure 1). Middle and deep events depart from it: the distribution is steep at small magnitudes and flattens above $M \approx 2$, so that the cumulative counts at $M = 4$ exceed the single-GR line by more than a factor of 30 in the deep band.

Depth band	N	b (single)	b_1 / b_2	M_k (95%)	ΔBIC broken / mixture	Bootstrap p
Shallow < 10 km	1,787	0.92	—	—	+12.5 / +15.0	0.49
Middle 10–13 km	9,993	—	1.11 / 0.84	1.8 (search edge)	-96.8 / -67.1	—
Deep ≥ 13 km	3,030	1.46	1.57 / 0.75	1.9 (1.8–2.3)	-107.3 / -111.8	< 0.005

Table 1. Model comparison, catalogue A, $M_c = 1.2$. Negative ΔBIC favours the broken or mixture model; b (single) from the binned likelihood.

For the deep band the single GR is rejected decisively (Table 1; Figure 2): the broken model improves the log-likelihood by 61.7 units ($LR = 123.3$), none of 200 bootstrap catalogues simulated without a break reached this value ($p < 0.005$), and the best mixture comprises 94.4% of events with $b_a = 1.71$ and 5.6% with $b_b = 0.43$. The deep band contains 37 events of $M \geq 3$ against 7 expected (95% predictive range 2–14) and 12 of $M \geq 4$ against 0 expected (range 0–2). The shallow band shows no excess (45 observed vs 39 expected for $M \geq 3$; range 27–54).

5.3 Sensitivity to declustering

Catalogue	Band	N	b_1 / b_2	M _k	$\Delta\text{BIC (best)}$	p	M $\geq$ 3 obs / exp
B: M $\geq$ 4 descendants removed	Deep	2,521	1.66 / 0.67	2.0	-102.9 (mixture)	< 0.005	23 / 4
B	Shallow	1,160	1.03 / 0.71	2.1	-1.5 (broken)	< 0.005	36 / 20
C: background only	Deep	2,156	1.76 / 0.99	1.8	-34.2 (broken)	< 0.005	13 / 2
C	Shallow	1,050	1.06 / 0.65	2.1	-10.9 (broken)	< 0.005	35 / 16

Table 2. Declustered catalogues (nearest-neighbour method).

The deep departure persists in both declustered catalogues with similar slopes and break magnitudes (Table 2). After declustering, the shallow band also shows a break at a similar magnitude ($M_k = 2.1$), although much weaker ($\Delta\text{BIC} -1.5$ and -10.9 , compared with -34 to -103 at depth). Thus the location of the break is common to all depths, whereas its strength is strongly depth-dependent.

5.4 Magnitude-type audit

Of 6,437 matched events, about 98% between M 1.7 and 3.5 carry type V at all depths; across M 1.6–2.4 the type-V share changes by at most 9.7 percentage points (Figure 3). Reduced-station type v is more common only at M 1.5–1.6, below the break, and displacement magnitudes appear only above $M \approx 3.6$. Restricted to type-V events ($M \geq 1.5$), the deep band still rejects a single GR (mixture $\Delta\text{BIC} -35.5$, $p < 0.005$, $M_k = 1.8$, 95% interval 1.8–2.2; 26 events of $M \geq 3$ against 8 expected), whereas the shallow band is consistent with a single GR ($p = 0.045$ for the broken model; BIC prefers the single law). Neither pre-specified attribution criterion is met, so switching between JMA magnitude types does not explain the break. A second magnitude exists only for 57 large events (M 3.6–6.5), where it agrees with the primary magnitude (median difference 0.00), preventing a direct comparison of magnitude types near M 2.

5.5 GR-conditioned dispersion and temporal behaviour

Band	Z _C (W = 50)	Z _C (W = 30)
Shallow	+0.09 (-0.33, +0.53)	+0.02 (-0.30, +0.35)
Middle	-0.28 (-0.43, -0.12)	-0.19 (-0.31, -0.06)
Deep	-0.71 (-1.22, -0.22)	-0.26 (-0.58, +0.06)

Table 3. Mean Z_C with 95% bootstrap intervals, $M_c = 1.2$, non-overlapping windows.

Z_C orders the bands as the FMD does (Table 3), but is much weaker than the FMD departure and depends on window length, because a window of 30–50 events rarely contains one of the rare larger events. At $M_c = 1.5$ the deep mean had been -2.77 ; our pre-set robustness criterion (deep $Z_C < -1$ with interval excluding 0 at the common M_c) was not met, and we therefore use the full FMD as the primary diagnostic. Within each depth band Z_C showed no significant persistence ($W = 50$), while the persistence found in the full catalogue ($W = 30-150$) is explained by the swarm moving between depth populations as it migrated upward. Consecutive events have more similar magnitudes than random ($\gamma(1) = 0.199$ versus $0.234-0.247$ for permutations), whereas pairs within one day are less similar than random pairs ($\gamma \approx 0.26-0.31$ versus 0.196), reflecting sequences that combine a large event with small aftershocks; hypocentral distance has little effect.

6. Discussion

6.1 What is established

The FMD of the deeper part of the Noto swarm is statistically inconsistent with a single GR law. The result does not depend on completeness (common M_c at all depths, and incompleteness would flatten rather than steepen the small-magnitude part), on aftershock sequences (nearest-neighbour declustering) or on switching between JMA magnitude types (audit). It is best described as a two-slope or two-population distribution, with the break at $M \approx 1.8-2.1$ and a strongly depth-dependent strength.

6.2 Magnitude scaling as the remaining explanation

A break at a common magnitude across depths is the expected signature of a change in scaling between amplitude-based magnitude and seismic moment for small events (Deichmann, 2006), which can bend an FMD even within a single magnitude type. Because the velocity-magnitude formula contains a depth-dependent term, an effect of this kind could also differ between depths, so the depth dependence alone does not exclude it. However, the direction of the documented JMA bias opposes the observed shape: Uchide and Imanishi (2018) report that M_{JMA} underestimates microearthquake size relative to moment magnitude; if this underestimation increases towards smaller events, small events are spread over a wider M_{JMA} range, which flattens the small-magnitude part of the FMD, whereas the Noto deep FMD is steeper there. The decisive test is a comparison with moment or spectral magnitudes for small swarm events: if the break persists in moment magnitude, a physical interpretation becomes justified; if it disappears, the break is a magnitude-scale effect.

6.3 Possible physical interpretations

If the break is physical, the two-population mixture provides a natural description: a dominant, steep population ($b \approx 1.7$) together with a small, flat population ($b \approx 0.4$). High b -values are typical of fluid-driven swarms and low stress, and the deep band coincides with the region where deep fluid supply, aseismic slip and the initiation of the swarm have been documented (Nakajima, 2022; Nishimura et al., 2023; Yoshida, Uno, et al., 2023; Yoshida et al., 2024). The flat population could correspond to events on

larger, more continuous fault patches. An alternative is that larger events preferentially nucleate deeper while their aftershocks are shallower; the persistence of the break after removal of the descendants of all $M \geq 4$ events argues against this as the sole explanation. These interpretations are hypotheses for future testing, not conclusions of this study.

6.4 Implications for the b-value and for dispersion measures

Because of the break, single b-values from this catalogue depend on the magnitude range: for the deep band $b = 1.45$ above $M 1.2$, but the slope above the break is ≈ 0.75 . Previously reported temporal or depth variations of b in this swarm should therefore be interpreted together with the magnitude range used; for example, the high b-values of the early swarm partly reflect the dominance of deep events at that time. Mori and Abercrombie (1997) found b decreasing with depth in California; in the Noto swarm the small-magnitude slope instead increases with depth, consistent with an unusual deep population. For dispersion measures, a mixture of GR populations is always more dispersed than a single GR population with the same mean, which explains why Z_C was negative where the break is strong: once corrected for b , dispersion acts as a detector of FMD shape. In this catalogue Z_C showed no temporal behaviour beyond that explained by depth populations, so it is not supported as a precursor.

7. Limitations and future work

- A single sequence was analysed, and the break was found by exploration rather than by testing a prior hypothesis; the statistical tests address the strength of the departure, not its novelty.
- The upper part of the deep FMD rests on 37 events of $M \geq 3$.
- Depth bands combine several clusters and faults; mapping the excess onto the clusters and the Suzu blind fault of Yoshida et al. (2024) is the next spatial step.
- Only amplitude-based JMA magnitudes were available; moment magnitudes for small events are needed to resolve the magnitude-scaling question.
- Further work: comparison with moment magnitudes; spatial mapping; the temporal evolution of the break within the deep band before the 2023 and 2024 events; and application of the same tests to other swarms and catalogues.

8. Conclusions

In the relocated catalogue of the 2020–2024 Noto swarm, the magnitude–frequency distribution of events deeper than 13 km is strongly inconsistent with a single Gutenberg–Richter law, with a break near $M_{JMA} 1.9$ and an excess of larger events. The departure survives a common completeness threshold, nearest-neighbour declustering and restriction to a single JMA magnitude type. Its break magnitude is common to all depths, but its strength increases sharply with depth. Whether it is a property of the earthquakes or of small-event magnitude scaling remains open and can be decided by comparison with moment magnitudes. Meanwhile, b-values from this catalogue should be reported with their magnitude

range and depth, and the procedures used here — GR-conditioned dispersion, a three-model likelihood comparison with bootstrap significance, and a magnitude-type audit — offer a practical check before b-values are interpreted.

Declarations

Competing interests

The author declares no competing interests.

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Data availability

The relocated catalogue is available from Zenodo (<https://doi.org/10.5281/zenodo.12799165>; Yoshida et al., 2024; CC BY 4.0). The JMA unified hypocentre catalogue is available from the Japan Meteorological Agency (<https://www.data.jma.go.jp/svd/eqev/data/bulletin/hypo.html>). The exact event tables used in this study (the 14,810 analysed events with depth bands and declustering flags, the 6,437 JMA-matched events with magnitude types, and the bin counts) and all model results are provided as supplementary Excel files with checksums.

Code availability

The Python scripts used for every analysis, and the protocols fixed before each analysis with their SHA-256 fingerprints, are available from the author on request and will be deposited in a public repository.

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Figures

Noto swarm 2021–2023 (Yoshida catalogue): frequency-magnitude distributions by depth, with a Gutenberg-Richter line using each band's own b

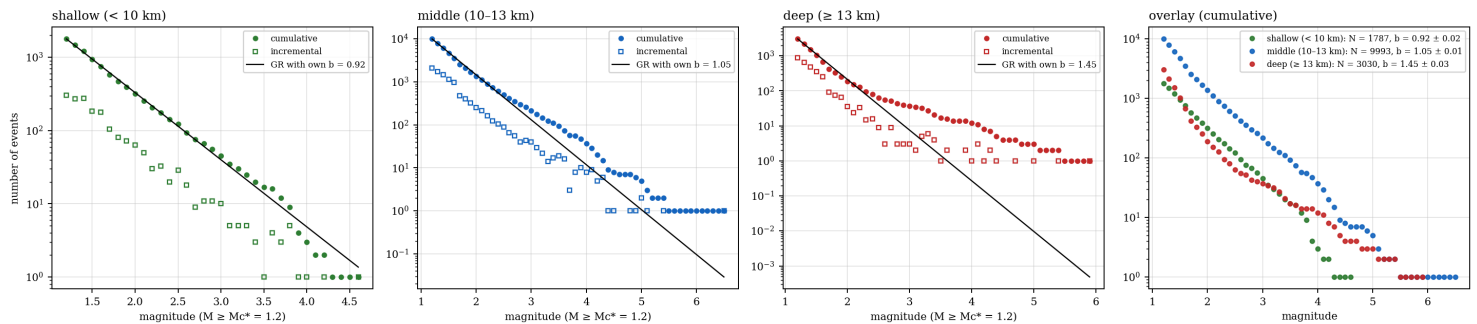


Figure 1

Magnitude–frequency distributions of the 2021–2023 Noto swarm by depth ($M_{JMA} \geq 1.2$): cumulative counts (dots), counts per 0.1 bin (squares) and the single-GR line for each band's own b (black). Right: overlay of the three bands.

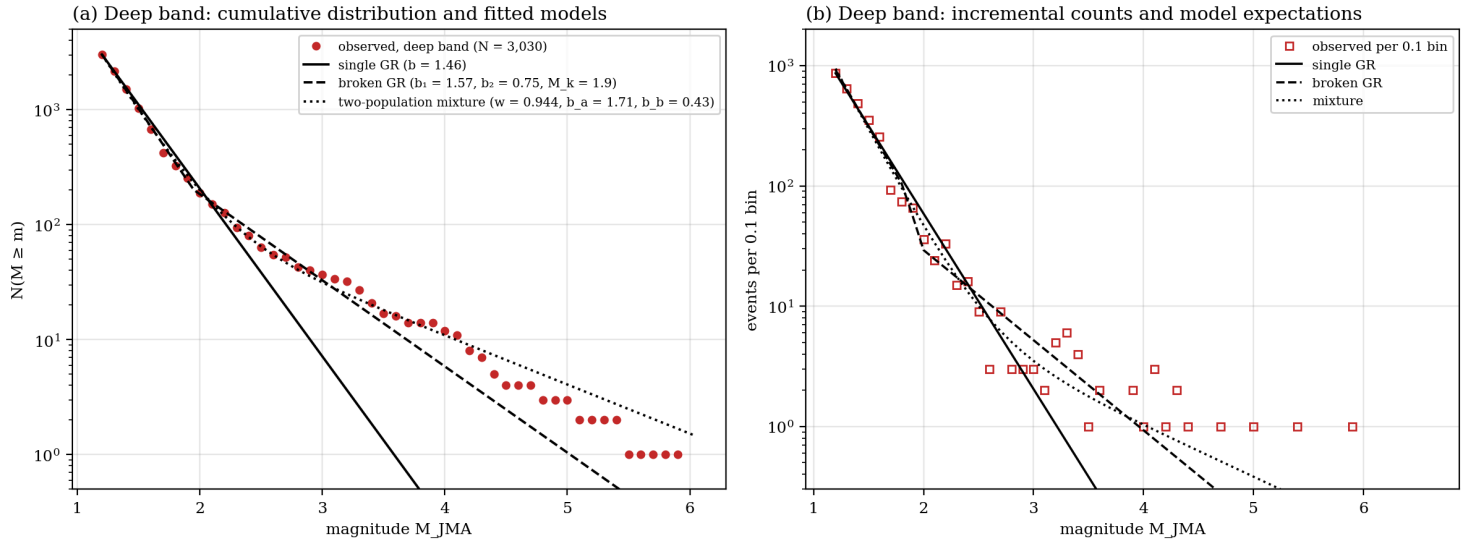


Figure 2

Deep band (≥ 13 km): (a) cumulative distribution with the fitted single GR, broken GR and two-population mixture; (b) counts per 0.1 bin with the corresponding model expectations.

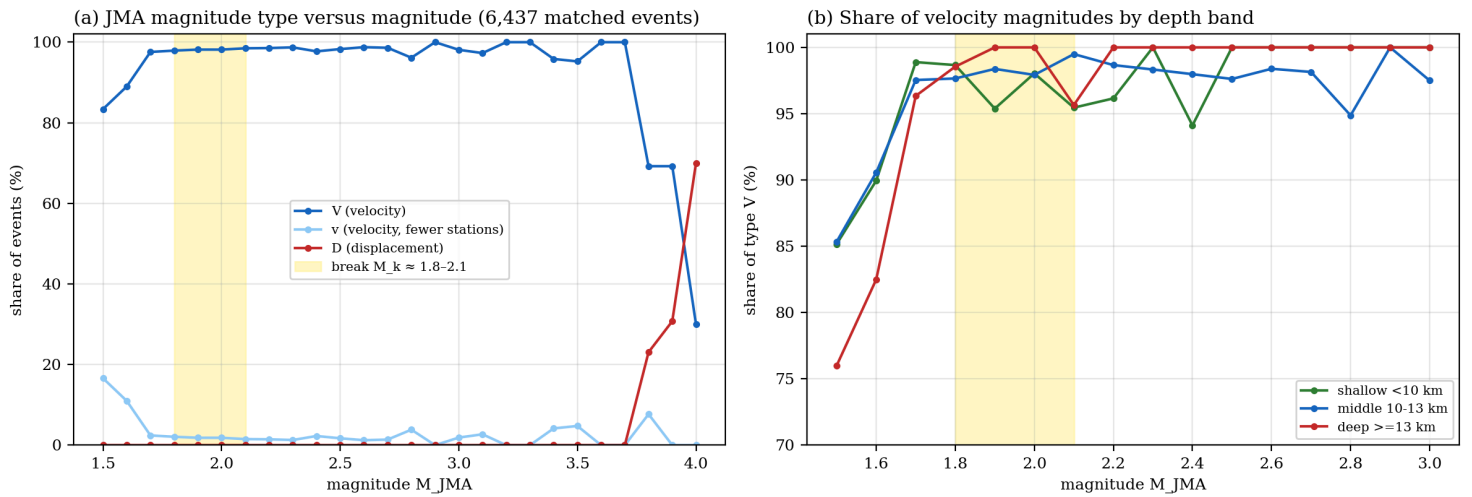


Figure 3

(a) Share of JMA magnitude types versus magnitude for 6,437 matched events; (b) share of velocity magnitudes (type V) by depth band. Shading: break magnitude range.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [S1Yoshida2024fullcatalogue.xlsx](#)
- [S2AnalysiseventsNoto20212023.xlsx](#)

- [S3Bincountsandmodelresults.xlsx](#)
- [S4JMAmatchedmagnitudetypes.xlsx](#)
- [CHECKSUMSSHA256.txt](#)
- [AppendixA.docx](#)