

Why Bandung heard the September 2026 Anak Krakatau eruption and Jakarta did not: eruption timing, ray tracing and search-interest evidence, compared with April 2020

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Abstract

During the night of 4–5 September 2026, residents of the Bandung area, 240–300 km from Anak Krakatau, reported repeated booms and rattling windows, while Jakarta, 150 km from the volcano, reported almost none. The Indonesian meteorological agency (BMKG) first judged the volcano too distant and the winds unfavourable, then attributed the booms to the eruption. We test the volcanic explanation with three independent lines of open evidence. Timing: the volcanological agency (PVMBG) recorded continuous eruption tremor from 23:07 WIB on 4 September to 00:04 WIB on 6 September, and Darwin VAAC advisories show the ash column rising from about 2 km to 13.7–15.2 km between 23:20 and 01:10 WIB; the booms, reported from about 23:30 to 05:00 WIB, fall within this high-intensity phase and are consistent with atmospheric travel times. Propagation: ray tracing through ERA5 extended upward with the HWM14 wind and NRLMSIS atmosphere models, with 200 random gravity-wave realisations, returns sound to Bandung in 88 % of ensemble members at the eruption hour and in 84–97 % in every hour of the reported window, mostly through eastward winds near the stratopause (about 55–60 km), whereas Bogor (11 %), Jakarta (3 %) and Serang (0 %) lie in a shadow zone; with a windless upper atmosphere the shadow zone persists but the return to Bandung is thermospheric, a path along which absorption would leave only sub-audible infrasound. Search behaviour: all 26 cities with measurable Google search interest in “dentuman” (boom) lay 206–371 km from the volcano, with 96 % of the interest at 200–300 km, while every large city within 200 km showed none; searches for “krakatau” instead declined with distance from the volcano and peaked a day later. Applied to a 2025 meteor of known location, the same measure placed 96 % of “dentuman” interest within 100 km of it. For the April 2020 eruption, whose volcanic origin PVMBG rejected in favour of thunderstorms, eastward stratopause winds also favoured returns, at about 150–210 km; 70 % of “dentuman” interest lay at 100–200 km, and rain within thunder range of Jakarta was light during the reported booms, although a thunderstorm had passed close to Jakarta about two hours earlier. A matched-control analysis of eleven boom reports shows that low-level acoustic ducts occur on most nights and cannot by themselves explain when booms are heard. Long-range sound and infrasound from sustained explosive eruptions, returning beyond a shadow zone, explain both episodes, the 2020 case with less certainty.

Plain-language summary

On the night of 4–5 September 2026, people around Bandung heard loud booms for hours, although the erupting volcano, Anak Krakatau, is about 260 km away and people in Jakarta, much closer, heard little. The booms began just after the eruption became violent; a model of how sound travels through the atmosphere sends it up to about 55–60 km, where winds blew towards Bandung, and back down around Bandung while skipping Jakarta; and internet searches for “dentuman” (boom) came almost entirely from the Bandung area. Much of what people noticed may have been low-pitched pressure waves that rattle windows rather than sound in the usual sense. The same pattern, but closer to the volcano, explains booms heard around Jakarta during the April 2020 eruption.

Keywords: volcanic infrasound; long-range sound propagation; shadow zone; ray tracing; Google Trends; Anak Krakatau; dentuman; Indonesia

1 Introduction

Loud unexplained booms, known in Indonesia as *dentuman*, are reported several times a year and often cause public alarm. Agencies have attributed them to thunder trapped under temperature inversions, meteors, ceremonial explosions or volcanoes, usually without event-specific evidence (Antara, 2021; Kompas TV, 2021). Volcanic eruptions are a well-established source of sound heard far away: the 1883 Krakatau explosion was heard about 4800 km away on Rodrigues, and long-range infrasound from eruptions is routinely detected by monitoring arrays. Sound from a surface source returns to the ground where the effective sound speed aloft, the adiabatic sound speed plus the wind component along the path, exceeds its value at the ground; returns from the stratosphere and lower thermosphere typically arrive 150–350 km from the source, beyond a quieter shadow zone (Drob et al., 2010; Negraru et al., 2010; Waxler and Assink, 2019). In the tropics, whether sound travelling east or west returns from the upper stratosphere depends on the direction of the winds near the stratopause, which reverse with the season. Absorption increases with frequency and with decreasing air density, so audible sound rarely survives returns from far above about 60 km, and thermospheric arrivals are dominated by infrasound below a few hertz (Sutherland and Bass, 2004). Audible booms reported thousands of kilometres from the 2022 Hunga eruption have been attributed to nonlinear generation of higher frequencies along the path (Matoza et al., 2022).

Anak Krakatau entered a continuous eruptive phase late on 4 September 2026 (Komdigi, 2026). That night, booms and vibrating windows were reported across the Bandung area. BMKG’s Bandung geophysics station initially stated that Bandung was too far away to hear the volcano and that the wind direction was unfavourable (Liputan6, 2026a; Kompas, 2026a); after further analysis BMKG concluded that the booms most likely came from seismic-acoustic waves from the eruption, citing eruption-timed signals at its Lampung Selatan, Serang, Sukabumi and Tretes stations (Kompas, 2026b; detikINET, 2026). A similar episode occurred during the April 2020 eruption, when booms were reported in Jabodetabek (Kompas TV, 2020a; Medcom, 2020). PVMBG then stated that the rumble was not from Anak Krakatau: the eruptions were relatively small, observers at its post 42 km from the volcano heard nothing, its infrasound sensor

recorded activity at frequencies below human hearing, and observers at the Gede and Salak posts attributed the rumbling they heard to thunderstorms (The Jakarta Post, 2020b).

Here we test the volcanic explanation for both episodes using only openly available data: the timing of the eruption against the reports, propagation modelling with empirical upper-atmosphere models, a gravity-wave ensemble and an estimate of absorption, and the geography and timing of Google search interest, which acts as an unsolicited, independent record of where people noticed something unusual. As a contrast, we examine whether low-level acoustic ducts, the mechanism usually invoked for *dentuman*, distinguish boom nights from ordinary nights.

2 Data

Table 1. Data used.

Data	Content	Source	Use
Eruption chronology	Continuous tremor 23:07 WIB 4 Sep – 00:04 WIB 6 Sep 2026; 2020 eruptions 21:58 and 22:35 WIB, activity until 05:44 WIB 11 Apr	PVMBG/Badan Geologi via official releases and news	Timing
Volcanic ash advisories	32 Darwin VAAC advisories for Krakatau, 4–7 Sep 2026	Darwin VAAC, Bureau of Meteorology	Eruption intensity
ERA5 hourly reanalysis	Temperature, wind and humidity on 37 levels to 1 hPa	ECMWF via Google Earth Engine and Copernicus CDS (Hersbach et al., 2020)	Propagation
HWM14 and NRLMSIS 2.1	Wind, temperature and density above the ERA5 top, to 150 km	Drob et al. (2015); Emmert et al. (2021)	Propagation, absorption
US Standard Atmosphere 1976	Windless alternative above the ERA5 top	NOAA et al. (1976)	Sensitivity test
Google Trends	“dentuman” by city, 3–8 Sep 2026 and 8–14 Apr 2020; “krakatau” by city, 3–8 Sep 2026; daily interest by region	trends.google.com	Where and when people searched
Other boom events	11 events 2020–2026 with reported windows and causes	News and agency statements (Table A1)	Matched controls
GPM IMERG, IGRA v2, FDSN	Rainfall, radiosondes, open seismic records	NASA; NOAA NCEI; GEOFON, EarthScope, Raspberry Shake	Matched controls

3 Methods

3.1 Timing

For a source active between t_1 and t_2 at distance d , sound can arrive between $t_1 + d/0.35 \text{ km s}^{-1}$ and $t_2 + d/0.18 \text{ km s}^{-1}$, the span of celerities of known atmospheric waveguides (Negraru et al., 2010; Nippress et al., 2014). Reports are consistent with the source if their window overlaps this interval. The test reproduces the 1883 Krakatau arrival on Rodrigues.

3.2 Propagation modelling

ERA5 profiles at the eruption hour and the following hour were averaged over the source, the path midpoint and the receiver, with heights obtained hypsometrically. Effective sound speed along the source-to-receiver

azimuth θ is $c_{\text{eff}} = 20.05 \sqrt{T_v} + u \sin \theta + v \cos \theta$, with T_v the virtual temperature. Above the ERA5 top (about 47 km) we used two upper atmospheres. The main one follows the HWM14 horizontal wind model (Drob et al., 2015) and NRLMSIS 2.1 temperature and density (Emmert et al., 2021), joined to ERA5 by interpolation across 8 km, with solar and geomagnetic inputs for each night from the GFZ Potsdam index record (Matzka et al., 2021): observed F10.7 of the preceding day, its 81-day centred mean and daily Ap were 108.2 sfu, 114.2 sfu and 3 for 2026 and 70.3 sfu, 69.6 sfu and 4 for 2020, both geomagnetically quiet nights. The alternative, a sensitivity test, follows the US Standard Atmosphere 1976 with winds tapered to zero. Because smooth profiles lack the small-scale structure that often enables returns (Drob et al., 2013), 200 random realisations of vertical gravity-wave perturbations were added to the along-path wind, with root-mean-square amplitude increasing with height to 15 m s^{-1} . Rays were traced in the effective-sound-speed approximation for launch angles of $1\text{--}60^\circ$; a receiver counted as reached by an ensemble member if a ground return landed within 10 km of it. Because tides change the stratopause winds within hours, the HWM14 calculation was repeated for every hour of the reported windows (23:00–05:00 WIB on 4–5 September 2026 and 21:00–03:00 WIB on 10–11 April 2020), each with its own ERA5 profile and the same 200 gravity-wave realisations, so that differences between hours reflect the atmosphere rather than sampling.

To judge which frequencies could survive each path, absorption was integrated along every arriving ray, with $\alpha = 1.6 \times (2\pi^2 f^2 / \rho c^3)(4/3 + (\gamma - 1)/\text{Pr})\mu$, an approximate classical-plus-rotational coefficient with viscosity μ from Sutherland’s law, $\gamma = 1.4$ and Prandtl number $\text{Pr} = 0.72$. This order-of-magnitude estimate stands in for the full model of Sutherland and Bass (2004), which it probably exceeds in the thermosphere, and it ignores geometric spreading, so it shows which frequencies are removed rather than predicting amplitudes.

3.3 Search interest

Google Trends gives, for each city, the share of searches for a term relative to all searches there, scaled so that the highest city is 100; cities with too little volume are left blank. Cities were placed at approximate centres and their distance from Anak Krakatau computed. We compare the distance distribution of “dentuman” interest with the modelled ground returns, contrast it with “krakatau”, which should reflect awareness of the eruption rather than hearing, and compare the daily timing of the two terms. Because each value is a share of a city’s own searches, small towns can reach high values from few searches, and users are located by internet address, so locations are approximate. To test whether search interest locates a boom, we applied the same analysis to the meteor that exploded near Cirebon on 5 October 2025, whose location and time are known. Trends exports were made on 4 October 2026 with the account time zone set to Asia/Jakarta (UTC+7).

3.4 Thunder check for 2020

To test PVMBG’s thunderstorm explanation for 2020 we found the maximum GPM IMERG rain rate within 25 km of Jakarta, Bogor, Bandung, the volcano and PVMBG’s Gede and Salak observation posts,

since thunder is seldom heard beyond about 25 km (National Research Council, 1986), together with the location of the heaviest rain within 150 km of Jakarta. This was done for the whole night (21:00–03:00 WIB on 10–11 April 2020 and 23:00–05:00 WIB on 4–5 September 2026) and, near Jakarta, for the reported boom window with one hour added either side. A half-hourly series of the same quantity from 18:00 to 06:00 WIB on 10–11 April 2020 gives the timing of rain near Jakarta and the posts.

3.5 Low-level ducts on boom nights

For eleven boom events (Table A1), each event night was compared with 12–16 control nights at the same place, season and clock time. A night counted as strictly ducted if ERA5 showed an effective-sound-speed excess of at least 1 m s^{-1} , at least 100 m deep and able to trap frequencies down to 20 Hz, in any direction or along the source direction (the known source, or the strongest IMERG rain cell within 100 km). Radiosonde and seismic checks and a power analysis are documented in the archived notebook.

4 Results

4.1 The booms coincide with the paroxysmal phase

The eruption intensified abruptly on the night of 4 September 2026 (Figure 1). PVMBG recorded continuous eruption tremor from 23:07 WIB and an eruption signal lasting 21 600 s (Komdigi, 2026; Liputan6, 2026b). The Darwin VAAC reported ash to about 2 km in the advisory issued at 23:20 WIB, a high-level eruption to 13.7 km at 23:50, 14.6 km at 00:10 and 15.2 km from 01:10, after which emission to that height continued until the high cloud detached from the volcano on 6 September. Booms were reported in the Bandung area from about 23:30 WIB, and BMKG’s analysis covered reports from about 00:30 to 05:00 WIB (detikINET, 2026). Sound could have arrived from 23:19 on 4 September until 00:27 on 6 September, so the reports are consistent with the source throughout (Table 2). For April 2020, activity continued until 05:44 WIB on 11 April (Medcom, 2020), rumbling was heard on Sebesi Island near the volcano from 23:10 until morning (Mongabay, 2020), and the Singapore infrasound array recorded the eruptions (Earth Observatory of Singapore, 2020); the booms reported around 01:30–02:30 WIB are likewise consistent.

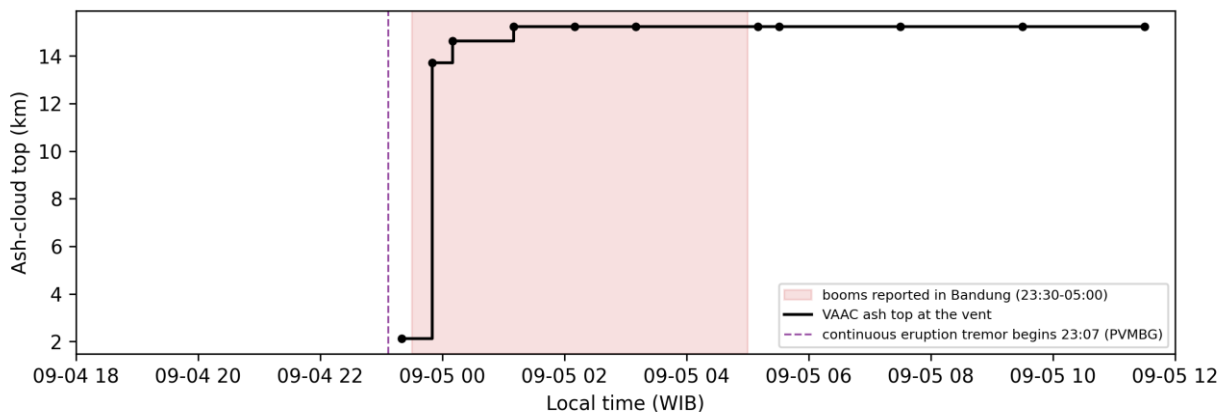


Figure 1. Eruption-column height at the vent from Darwin VAAC advisories (black, at advisory issue time), the start of continuous eruption tremor recorded by PVMBG (dashed), and the period over which booms were reported in the Bandung area (shaded), 4–5 September 2026, local time (WIB = UTC+7).

Table 2. Timing test. Possible arrivals assume celerities of 0.18–0.35 km s⁻¹.

Case	Distance	Source activity (local time)	Possible arrivals	Reported
Anak Krakatau → Bandung, 2026	259 km	continuous 23:07 4 Sep – 00:04 6 Sep	23:19 4 Sep – 00:27 6 Sep	23:30 4 Sep – 05:00 5 Sep
Anak Krakatau → Jabodetabek, 2020	154 km	21:58 10 Apr – 05:44 11 Apr	22:05 10 Apr – 05:58 11 Apr	about 01:30–02:30 11 Apr
Krakatau → Rodrigues, 1883	4781 km	10:02 27 Aug (source clock)	13:49–17:24	about 14:02 (0.332 km s ⁻¹)

4.2 A return zone over Bandung and a shadow over Jakarta

The winds near the stratopause differed between the two eruptions (Figure 2). On 10 April 2020, ERA5 had winds blowing towards Jakarta of about 25 m s⁻¹ at its top (1 hPa, about 48 km), and the effective sound speed there nearly equalled its ground value (ratio 0.999), so returns from the upper stratosphere were close to possible even without perturbations. On 4 September 2026 ERA5 instead had winds of 13–26 m s⁻¹ blowing against the path to Bandung at 5 and 1 hPa (about 36 and 48 km), and the ratio peaked at only 0.969. Above the ERA5 top, HWM14 places eastward winds of 24–35 m s⁻¹ at 55–60 km on both nights, raising the ratio to 1.004 in 2026 and 1.007 in 2020, whereas the windless alternative allows returns only from the thermosphere. The return path to Bandung therefore depends on winds between 48 and 65 km, which neither ERA5 nor any routine observation resolves.

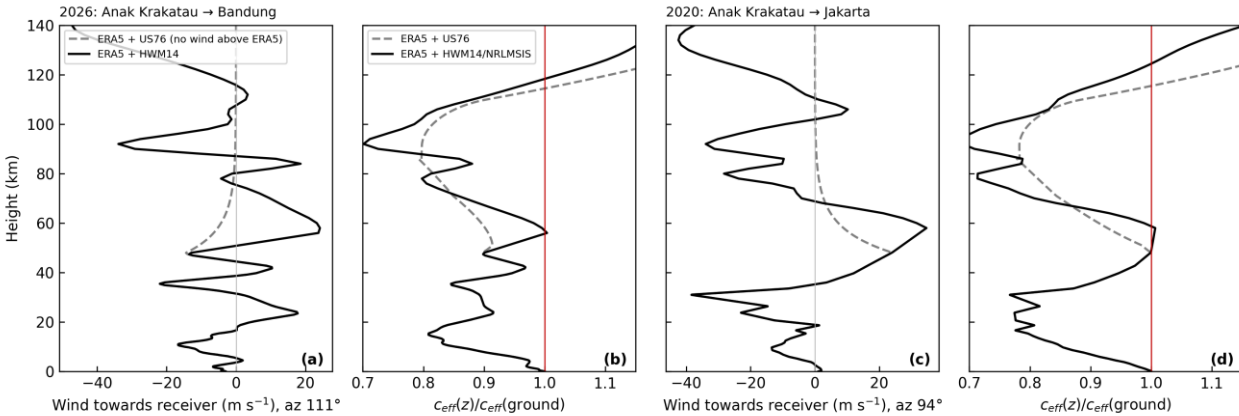


Figure 2. Along-path wind towards the receiver and effective sound speed relative to its ground value for (a, b) 4 September 2026, Anak Krakatau to Bandung, and (c, d) 10 April 2020, Anak Krakatau to Jakarta, averaged over profiles at the source, path midpoint and receiver. Below about 47 km both curves are ERA5; above it, solid lines use HWM14 and NRLMSIS 2.1 and dashed lines the windless US Standard Atmosphere. Sound can return to the ground where the ratio exceeds 1 (red line). Profiles at 15–16 UTC (2026) and 14–15 UTC (2020).

In the unperturbed profiles no ray reached any receiver, consistent with BMKG’s initial reasoning from the winds. With gravity-wave perturbations the picture changes (Table 3, Figure 3). With HWM14 and NRLMSIS, 87.5 % of ensemble members returned sound to Bandung, almost all turning near the stratopause at about 55–60 km (thermospheric returns in 1 %), at celerities of 0.21–0.30 km s⁻¹; Bogor (11 %), Jakarta (3 %) and Serang (0 %) were largely silent. With the windless upper atmosphere the shadow

179 zone was similar (Bogor 8.5 %, Jakarta 1.5 %, Serang 0 %), and 82 % of members still reached Bandung,
 180 but mostly through the thermosphere (77.5 % of members). For 2020, 55 % (HWM14) and 49 % (windless)
 181 of members delivered stratospheric returns to Jakarta. In every configuration the latest predicted arrival was
 182 within about 20 minutes of the eruption (23:27 at Bandung for the 23:07 onset).

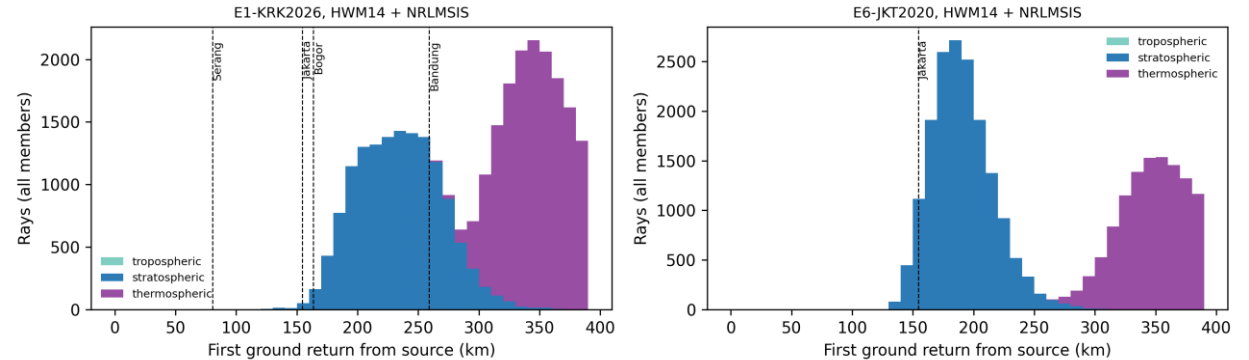
183 The two return paths differ sharply in what they could carry (Table 4). Along rays turning near the
 184 stratopause, approximate absorption was below 0.1 dB at 0.5–2 Hz and about 2 dB at 10 Hz and 9 dB at 20
 185 Hz, so audible frequencies could survive. Along thermospheric rays absorption exceeded 1000 dB even at
 186 0.5 Hz in our approximation, which probably overestimates thermospheric absorption but leaves no doubt
 187 that any thermospheric arrival would contain only infrasound. A thermospheric return could therefore rattle
 188 windows and be felt as pressure pulses, but would be audible only through nonlinear effects of the kind
 189 proposed for Hunga (Matoza et al., 2022).

190 **Table 3.** Share of 200 gravity-wave ensemble members delivering a ground return within 10 km of each receiver,
 191 for the two upper-atmosphere choices.

Eruption	Receiver	Distance	HWM14 + NRLMSIS: any (stratospheric / thermospheric)	Windless US76: any (stratospheric / thermospheric)	Latest arrival (HWM14)
2026	Bandung (booms reported)	259 km	87.5 % (87.5 / 1)	82 % (16.5 / 77.5)	23:27
2026	Bogor	163 km	11 % (11 / 0)	8.5 % (8.5 / 0)	23:17
2026	Jakarta	154 km	3 % (3 / 0)	1.5 % (1.5 / 0)	23:17
2026	Serang	80 km	0 %	0 %	–
2020	Jakarta (booms reported)	154 km	55 % (55 / 0)	49 % (49 / 0)	22:45

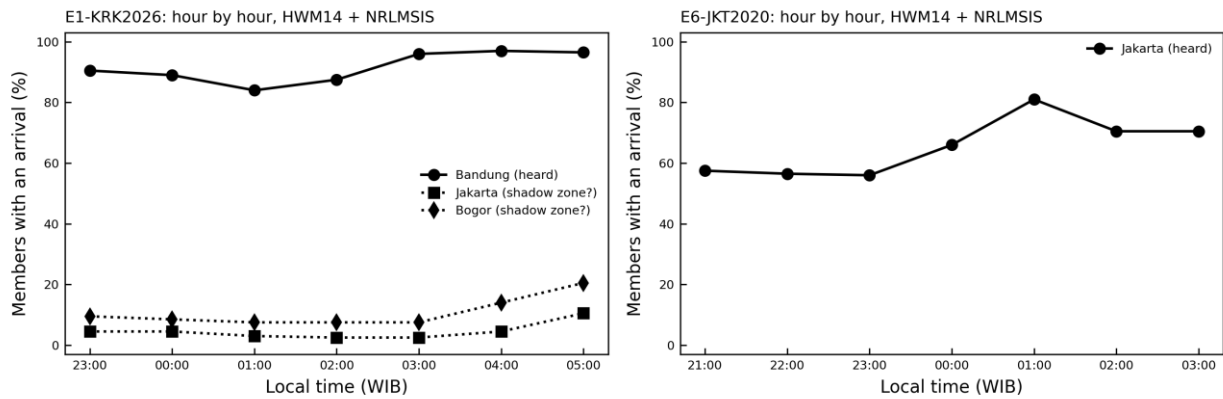
192 **Table 4.** Approximate absorption (dB) along rays arriving at each receiver, median over ensemble members, by
 193 path. Geometric spreading is not included.

Eruption	Receiver	Path	0.5 Hz	2 Hz	10 Hz	20 Hz
2026	Bandung	stratopause	0.0	0.1	2.2	8.8
2026	Bandung	thermospheric	1300	2×10^4	$> 10^5$	$> 10^5$
2026	Jakarta, Bogor	stratopause	0.0	0.0	0.3–0.4	1.3–1.4
2020	Jakarta	stratopause	0.0	0.0	0.5	2.2



194 **Figure 3.** Distance of the first ground return from Anak Krakatau for all rays of the 200-member ensemble with
 195 HWM14 and NRLMSIS above ERA5, by turning layer: (left) 4 September 2026, path to Bandung; (right) 10 April
 196 2020, path to Jakarta. Dashed lines mark receivers.
 197

198 The result does not depend on the hour chosen (Figure 4). In every hour from 23:00 to 05:00 WIB, 84–97
 199 % of members returned sound to Bandung, while Jakarta (2.5–10.5 %) and Bogor (7.5–20.5 %) remained
 200 largely in shadow. Along the Bandung path the stratopause wind varied between 19 and 33 m s⁻¹ and the
 201 effective-sound-speed ratio near 56 km between 0.987 (01:00) and 1.026 (05:00); stratospheric returns
 202 persisted in 84–92 % of members even when the unperturbed ratio fell below 1, because the gravity-wave
 203 perturbations bridge a margin of this size, and thermospheric returns became common after 02:00 (43–64
 204 % of members from 03:00). In 2020, 56–81 % of members reached Jakarta in every hour from 21:00 to
 205 03:00 WIB, with the highest values (70.5–81 %) at 01:00–03:00, when booms were reported.



206
 207 **Figure 4.** Share of the 200 gravity-wave ensemble members delivering a ground return within 10 km of each receiver,
 208 hour by hour, with each hour’s ERA5 profile and HWM14 and NRLMSIS above: (left) 4–5 September 2026, Bandung
 209 (booms reported) and Bogor and Jakarta; (right) 10–11 April 2020, Jakarta (booms reported).

210 4.3 Where and when people searched

211 Search interest in “dentuman” during 3–8 September 2026 was confined to the predicted return zone
 212 (Figures 5 and 6, Table 5). All 26 cities with reportable interest lay 206–371 km from the volcano, on
 213 azimuths of 102–117°, with an interest-weighted distance of 256 km and 96 % of the interest at 200–300
 214 km. The highest values were in the western and southern Bandung basin (Cililin 100, Ciwidey 91,
 215 Padalarang 58, Batujajar 55), about 240–250 km out, near the inner edge of the modelled return zone. Every
 216 large city closer than 200 km, including Cilegon, Serang, Bandar Lampung, Tangerang, Jakarta, Depok,
 217 Bogor and Bekasi, had no reportable interest. Searches for “krakatau” in the same week behaved differently:
 218 they were highest close to the volcano (Kota Agung 100, Cilegon 81, Bandar Lampung 73, Pandeglang 72)
 219 and declined with distance, with 75 % of the interest within 200 km.

220 For 8–14 April 2020, “dentuman” interest was concentrated at 135–175 km, in Bogor (100), Depok (83),
 221 South Tangerang (65), Bekasi, Tangerang and Jakarta, with 70 % of the interest at 100–200 km and a
 222 smaller group around Bandung at 240–290 km, matching the two modelled return zones for that night
 223 (Figure 6). Daily series show that “dentuman” searches peaked on 5 September 2026 nationally and in West
 224 Java, a day before the “krakatau” peak on 6 September, when ash dispersal and airport disruption dominated
 225 the news; in 2020 “dentuman” peaked on 11 April in Indonesia, Jakarta, Banten and West Java alike (Figure
 226 7). Applied to the Cirebon meteor of 5 October 2025, the same analysis placed 96 % of “dentuman” interest
 227 within 100 km of the meteor, at an interest-weighted distance of 63 km, with the highest values in Slawi

(100, 70 km), Brebes (96, 51 km) and Gunungjati (34, 8 km); only seven cities had reportable interest, as expected for a single short boom. Search interest thus located a boom of known origin to within about 100 km, although one test is a small sample.

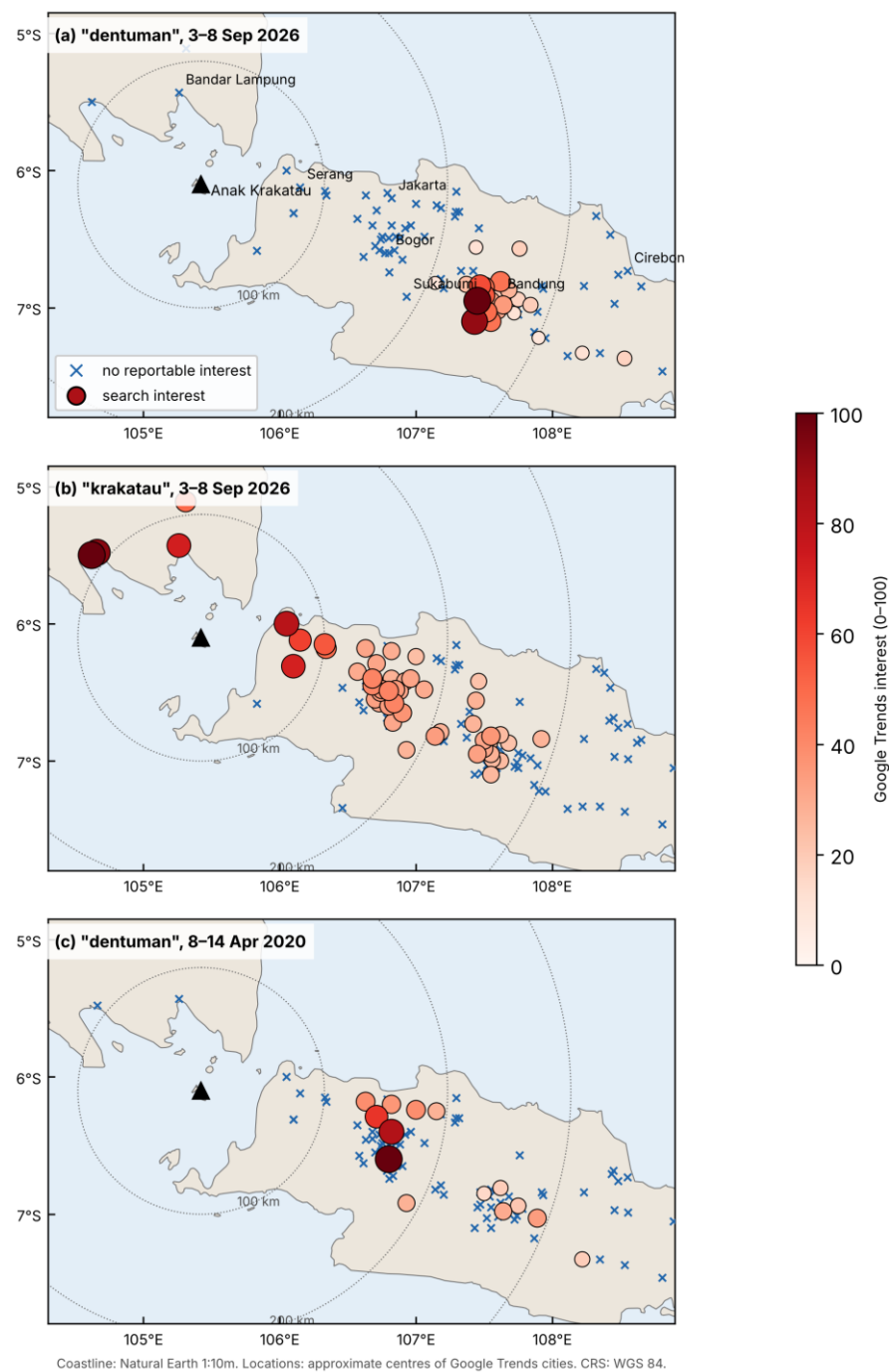


Figure 5. Google Trends search interest by city: (a) “dentuman”, 3–8 September 2026; (b) “krakatau”, same week; (c) “dentuman”, 8–14 April 2020. Crosses: cities without reportable interest. Rings every 100 km from Anak Krakatau (triangle).

Table 5. Distribution of Google Trends interest with distance from Anak Krakatau.

Term and period	Cities with interest	Median distance	Interest-weighted distance	0–100 km	100–200 km	200–300 km	> 300 km
“dentuman”, Sep 2026	26	257 km	256 km	0 %	0 %	96 %	4 %
“krakatau”, Sep 2026	50	166 km	156 km	18 %	57 %	25 %	0 %
“dentuman”, Apr 2020	16	218 km	216 km	0 %	70 %	20 %	10 %

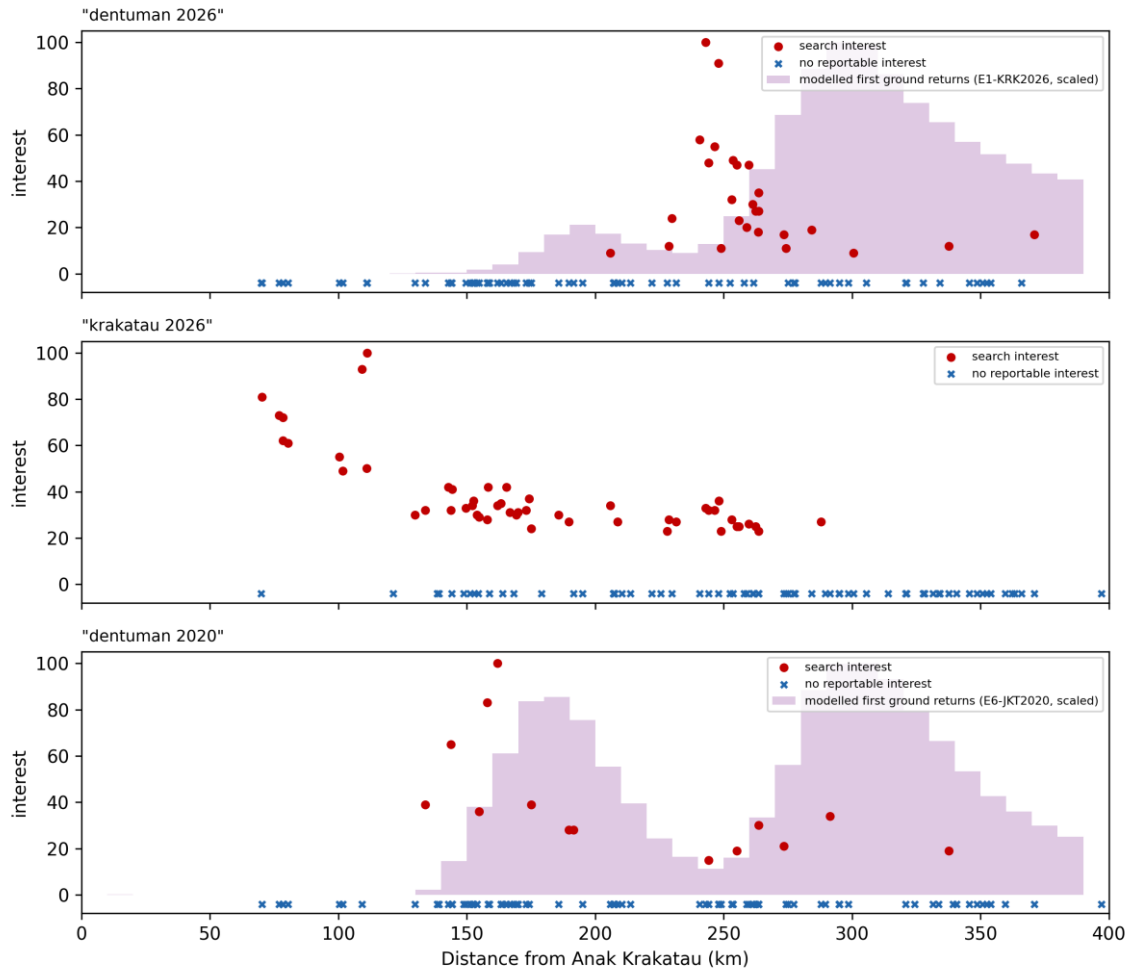


Figure 6. Search interest against distance from Anak Krakatau (red), cities without reportable interest (blue crosses) and modelled first ground returns from the windless-upper-atmosphere sensitivity run (purple, scaled) for 2026 along the path to Bandung and for 2020 along the path to Jakarta.

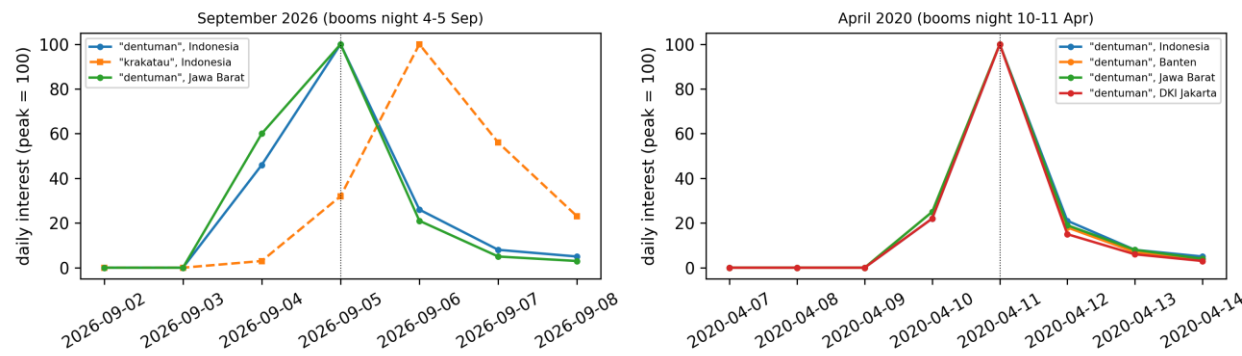


Figure 7. Daily Google Trends interest, scaled to each series' peak: September 2026 (“dentuman” for Indonesia and West Java; “krakatau” for Indonesia) and April 2020 (“dentuman” for Indonesia, Banten, West Java and Jakarta). Dotted lines mark the day after each boom night.

4.4 The 2020 episode and the thunderstorm alternative

PVMBG’s observation that its post 42 km from the volcano heard nothing is what a shadow zone predicts: in no configuration did first returns land within about 130 km of the volcano. The rain data support its thunderstorm explanation for the evening but not for the reported booms (Figure 8). Half-hourly IMERG rain within 25 km of Jakarta exceeded 5 mm h^{-1} from at least 18:00 until 23:30 WIB, peaking at 33 mm h^{-1} at 22:00–22:30 about 16 km east of central Jakarta (6.25°S , 106.95°E), and rain of $3\text{--}10 \text{ mm h}^{-1}$ fell within 25 km of the Gede and Salak posts until about 23:00, so thunder was probably audible at the posts and in Jakarta during the evening, as PVMBG reported. The rain then stopped. From 00:30 WIB the posts were dry, and during the reported booms (01:30–02:30 WIB) rain within 25 km of Jakarta was $0.2\text{--}0.7 \text{ mm h}^{-1}$, typical of control nights (86 % of which had some rain within 25 km); the heaviest rain within 100 km in that window, with an hour added either side, was 5.1 mm h^{-1} at about 7.05°S , 106.55°E , roughly 100 km south of Jakarta and beyond the usual range of thunder. The reported booms therefore followed the storm by about two hours and coincide instead with the highest modelled return rates (Figure 4). The first eruption pulses, at 21:58 and 22:35 WIB, would have arrived during the storm, when thunder and volcanic sound could not have been told apart, and IMERG can miss small convective cells, so thunder cannot be excluded entirely. On 4–5 September 2026, by contrast, IMERG shows no rain within 25 km of Bandung, Bogor or Jakarta, and nothing heavier than 1.0 mm h^{-1} within 150 km of Jakarta, so thunder can be excluded on that night. The night was also the first of Jakarta’s partial COVID-19 restrictions (The Jakarta Post, 2020b), when the city was unusually quiet and residents were at home and online, which may have increased both the noticing of faint sounds and searches about them. The 2020 case therefore supports, but less firmly than 2026, a volcanic source; lightning records would settle the thunder question.

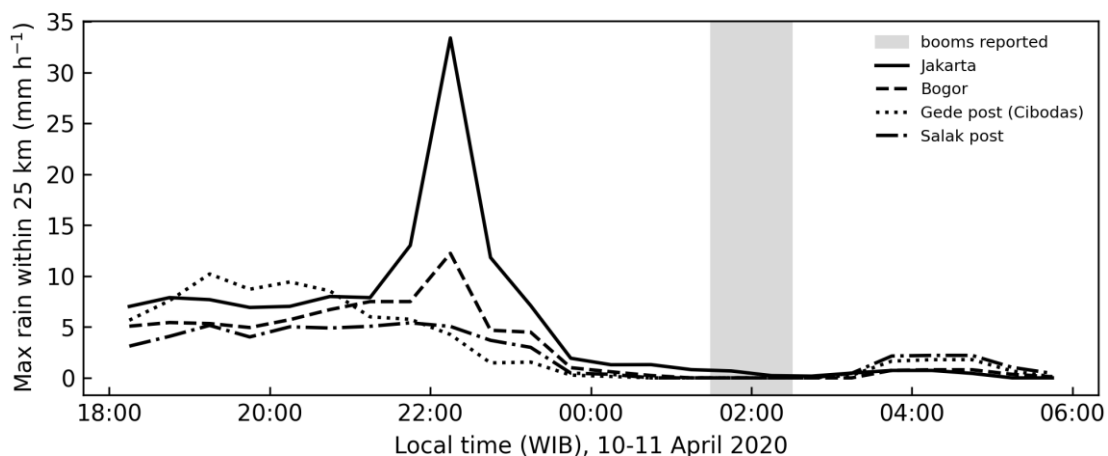


Figure 8. Half-hourly maximum GPM IMERG rain rate within 25 km of Jakarta, Bogor and PVMBG’s Gede (Cibodas) and Salak observation posts, 18:00–06:00 WIB on 10–11 April 2020, plotted at the middle of each half hour. Shading: reported boom window.

4.5 Low-level ducts do not single out boom nights

Across the eleven events of Table A1, ERA5 showed a low-level duct stronger than 0.5 m s^{-1} in some direction on 84 % of control nights and a strict duct on 70 %; requiring the duct along the source direction reduced this to 30 % of the 112 controls with a source direction. Typical waveguides were about 260 m deep and could trap frequencies down to about 5 Hz, so they could carry audible booms. Eight of eleven event nights ranked above their control medians (binomial $p = 0.23$; night-time events only, 5 of 7, $p = 0.45$), and candidate events did not differ from events whose booms had known non-ducting causes, such as the Punggur meteorite fall and a naval-academy ceremony in Surabaya. With eleven events the comparison would detect boom nights lying at the 75th percentile of their controls only about 70 % of the time. Usable radiosonde profiles existed only at Juanda and resolve two levels below 3 km, and open seismic data covered few events and showed no clear signals. Low-level ducts are therefore common, poorly constrained by the available observations, and not diagnostic of boom nights.

5 Discussion

5.1 *A consistent picture for both eruptions*

Three independent records agree. The booms in Bandung began within minutes of the eruption's transition to a sustained high-level column and continued through it; the propagation model, once gravity waves and the thermosphere are included, places a return zone over Bandung and a shadow over Jakarta and Banten in every hour of the reported window; and the people who searched for an unexplained boom were almost all in the return zone, while those near the volcano, who knew the source, searched for “krakatau”. The two eruptions differ in a way that supports the interpretation: in April 2020 the model returned sound at about 150–210 km and searches came from Jabodetabek, whereas in September 2026 it returned sound beyond about 240 km and searches came from the Bandung area. These differences follow from the winds near the stratopause, which were favourable along the Jakarta path in 2020 and, in ERA5, opposed along the Bandung path in 2026. The concentration of 2026 interest at about 240–250 km, at the inner edge of the return zone, is consistent with the caustic that typically forms there, where returning rays converge, although without amplitude modelling this remains a suggestion.

5.2 *What did people hear?*

Eruptions of Anak Krakatau radiate most of their acoustic energy as infrasound below a few hertz (Perttu et al., 2020), which people perceive mainly through rattling windows, doors and pressure on the ears rather than as sound. Many reports from Bandung describe exactly these effects. If the sound returned near the stratopause, as HWM14 suggests, absorption would have allowed audible frequencies to arrive as well; if it returned from the thermosphere, as the windless alternative suggests, only infrasound would have survived, and audible booms would require nonlinear generation of higher frequencies, as proposed for Hunga (Matoza et al., 2022). The present data cannot separate these possibilities, and a single low-cost infrasound sensor in Bandung would have recorded the arrivals and their frequency content.

5.3 *Why the first assessment failed*

BMKG’s initial reasoning, that Bandung was too far and the winds blew the wrong way, describes the lower atmosphere correctly: in the unperturbed ERA5 profiles no ray returns to the ground along the Bandung path. Long-range sound from strong eruptions depends instead on the upper stratosphere and lower thermosphere and on small-scale structure that reanalyses do not resolve. BMKG’s eventual conclusion, based on its own station records, agrees with ours. Rapid communication would benefit from routine infrasound monitoring and from explaining in advance that eruptions can be heard far away but not nearby.

5.4 Limitations

The modelled percentages depend on a heuristic gravity-wave ensemble, a range-independent path and a climatological model of the winds above the ERA5 top; the return path to Bandung changes with the choice of upper atmosphere, and ERA5 and HWM14 disagree in sign near 48–55 km, so the percentages indicate where returns are plausible rather than their probability. Amplitudes were not modelled: the absorption estimate omits geometric spreading and is approximate, and a parabolic-equation calculation with full absorption would be needed to predict how loud the arrivals were. Google Trends locates users by internet address, reports each city’s interest relative to its own search volume (so small towns can score highly from few searches), leaves low-volume cities blank and gives only daily resolution for these periods, and searches can be influenced by news and, in 2020, by the first day of COVID-19 restrictions, and the method has been tested against only one boom of known origin; the one-day lead of “dentuman” over “krakatau” argues against a purely news-driven pattern but does not exclude it. Hearing times come from news reports and BMKG summaries rather than a systematic collection, and VAAC times are advisory issue times. Instrumental confirmation, such as infrasound arrival times at Bandung, is not available in open archives for this night.

6 Conclusions

The booms heard around Bandung on 4–5 September 2026 are explained by long-range sound from the sustained high-level phase of the Anak Krakatau eruption, returning to the ground about 240–300 km from the volcano after passing over a shadow zone that included Jakarta and Banten; the shadow zone is robust to the choice of upper atmosphere, while the return height, and hence whether audible frequencies survived, is not. Eruption timing, ensemble ray tracing and the geography and timing of internet searches agree, and the April 2020 episode, which PVMBG attributed to thunderstorms, shows the same behaviour with a closer return zone, although its volcanic origin is less certain because a thunderstorm passed near Jakarta about two hours before the reported booms. Low-level ducts, the usual explanation for *dentuman*, are present on most nights and do not explain these events. Low-cost infrasound sensors in Bandung and Jakarta and coordinated statements by BMKG and PVMBG would allow future episodes to be identified within hours.

Data and code availability

The notebook (dentuman_event_ducting.ipynb), event table, Google Trends exports, VAAC advisories and all output tables are archived at Zenodo, doi: 10.5281/zenodo.23424259. ERA5 is available from the Copernicus Climate Data Store and Google Earth Engine, Google Trends data from trends.google.com, and Darwin VAAC advisories from the Bureau of Meteorology.

Author contributions

RAW: Conceptualization, Data curation, Methodology, Software, Formal analysis, Visualization, Writing – original draft.

Competing interests

The authors declare no competing interests.

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Appendix A Boom events in the matched-control analysis

Table A1. Events (local time) and percentile of each event night among its controls for the any-direction duct strength.

ID	Group	Place, date	Window	Cause and sources	Duct percentile
E1	case study	Bandung Raya, 4–5 Sep 2026	23:30–05:00 WIB	Anak Krakatau eruption (this study)	100
E2	candidate	Malang, 2–3 Feb 2021	23:30–04:00 WIB	Ducted thunder proposed; no lightning or seismic activity detected by BMKG Malang (Republika, 2021; Kompas TV, 2021)	71
E3	candidate	Kotabumi, Lampung Utara, 5 Feb 2021	07:28–07:40 WIB	Unknown; no rain or lightning recorded (detikNews, 2021a; iNews, 2021)	86
E4	candidate	Surakarta, Semarang, 11 May 2020	00:45–01:15 WIB	Lightning over central mountains and south coast (Kompas TV, 2020b)	57
E5	candidate	Bandung, 21 May 2020	09:00–10:00 WIB	Unknown; not volcanic (Antara Jabar, 2020)	100
E6	candidate	Jabodetabek, 11 Apr 2020	01:30–02:30 WIB	Anak Krakatau eruption (this study)	33
E7	calibration	Jakarta, 20 Sep 2020	19:30–20:00 WIB	TNT at Halim Perdanakusuma ceremony (The Jakarta Post, 2020a)	86
R1	negative	Buleleng, Bali, 24 Jan 2021	10:00–11:00 WITA	Suspected meteor (LAPAN; Times Indonesia, 2021)	50

ID	Group	Place, date	Window	Cause and sources	Duct percentile
R2	negative	Punggur, Lampung Tengah, 28 Jan 2021	21:45–22:00 WIB	Meteorite fall at 21:53 WIB, H7 melt breccia (ITERA, 2021; Gattacceca et al., 2022)	93
R3	negative	Surabaya, 30 Jan 2021	06:15–06:35 WIB	Naval academy ceremony (detikNews, 2021b)	100
R4	negative	Cirebon, 5 Oct 2025	18:35–18:40 WIB	Meteor (BRIN; Popbela, 2025)	20

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