

Supplementary Material

Atmospheric dust and respiratory emergency department visits in Ica, Peru, 2023–2026

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Supplementary Table S1. Model diagnostics and MERRA-2 interpolation by province.

Province	Quasi-Poisson dispersion	ACF lag 1	Max ACF , lags 1–30	Max PACF , lags 1–30	Interpolated days	Interpolated, %
Chincha	3.05	0.335	0.335	0.394	1	0.08
Ica	1.90	0.152	0.152	0.149	1	0.08
Nazca	3.26	0.168	0.168	0.191	1	0.08
Palpa	1.98	0.038	0.126	0.145	1	0.08
Pisco	2.26	0.176	0.176	0.216	1	0.08

Note. ACF, autocorrelation function; PACF, partial autocorrelation function. ACF values are based on Pearson residuals and PACF values on deviance residuals. One isolated MERRA-2 DUSMASS day per province was interpolated before model fitting; the interpolation indicator was retained for auditing.

Supplementary Table S2. Cumulative relative risks at all prespecified MERRA 2 DUSMASS percentiles, relative to the province-specific median.

Province	Percentile	DUSMASS, $\mu\text{g}/\text{m}^3$	Reference median, $\mu\text{g}/\text{m}^3$	Cumulative RR (95% CI)
Chincha	P10	10.90	19.15	0.99 (0.84–1.16)
Chincha	P25	14.43	19.15	0.96 (0.90–1.03)
Chincha	P50	19.15	19.15	1.00 (1.00–1.00)
Chincha	P75	24.95	19.15	1.11 (0.99–1.25)
Chincha	P90	30.05	19.15	1.22 (1.01–1.47)
Chincha	P95	34.33	19.15	1.31 (1.05–1.64)
Chincha	P97.5	37.85	19.15	1.39 (1.07–1.79)
Chincha	P99	42.54	19.15	1.49 (1.09–2.03)
Ica	P10	26.07	43.17	1.03 (0.92–1.15)
Ica	P25	33.99	43.17	0.98 (0.94–1.02)
Ica	P50	43.17	43.17	1.00 (1.00–1.00)
Ica	P75	54.09	43.17	1.09 (1.01–1.17)
Ica	P90	66.04	43.17	1.21 (1.07–1.38)
Ica	P95	76.12	43.17	1.34 (1.15–1.57)
Ica	P97.5	84.28	43.17	1.47 (1.23–1.75)
Ica	P99	101.63	43.17	1.79 (1.39–2.31)
Nazca	P10	15.42	22.91	1.08 (0.89–1.31)
Nazca	P25	18.87	22.91	1.01 (0.91–1.11)
Nazca	P50	22.91	22.91	1.00 (1.00–1.00)
Nazca	P75	27.89	22.91	1.04 (0.89–1.22)
Nazca	P90	32.08	22.91	1.08 (0.87–1.33)
Nazca	P95	35.58	22.91	1.10 (0.86–1.41)
Nazca	P97.5	38.63	22.91	1.13 (0.83–1.53)
Nazca	P99	42.62	22.91	1.15 (0.72–1.85)
Palpa	P10	10.12	16.79	0.72 (0.40–1.29)
Palpa	P25	12.75	16.79	0.77 (0.58–1.02)
Palpa	P50	16.79	16.79	1.00 (1.00–1.00)
Palpa	P75	21.76	16.79	1.42 (0.98–2.07)
Palpa	P90	26.44	16.79	1.61 (0.95–2.75)
Palpa	P95	28.92	16.79	1.60 (0.89–2.88)
Palpa	P97.5	32.13	16.79	1.48 (0.73–3.03)
Palpa	P99	37.28	16.79	1.16 (0.37–3.67)
Pisco	P10	24.20	42.25	1.01 (0.84–1.23)
Pisco	P25	32.38	42.25	0.97 (0.91–1.04)
Pisco	P50	42.25	42.25	1.00 (1.00–1.00)

Province	Percentile	DUSMASS, $\mu\text{g}/\text{m}^3$	Reference median, $\mu\text{g}/\text{m}^3$	Cumulative RR (95% CI)
Pisco	P75	53.93	42.25	1.10 (0.96–1.25)
Pisco	P90	67.68	42.25	1.22 (0.96–1.55)
Pisco	P95	77.65	42.25	1.32 (0.99–1.77)
Pisco	P97.5	87.27	42.25	1.42 (1.01–1.99)
Pisco	P99	104.06	42.25	1.60 (1.03–2.49)

Note. RR, relative risk; CI, confidence interval. Relative risks are cumulative over lags 0–14 days and centered at the province-specific median DUSMASS concentration.

Supplementary Table S3. Lag-specific relative risks at the 90th, 95th, and 97.5th percentiles of the province-specific DUSMASS distribution.

Province	Percentile	DUSMASS, $\mu\text{g}/\text{m}^3$	Lag, days	Lag-specific RR (95% CI)
Chincha	P90	30.05	0	1.025 (0.998–1.052)
Chincha	P90	30.05	1	1.022 (1.000–1.045)
Chincha	P90	30.05	3	1.017 (1.002–1.033)
Chincha	P90	30.05	5	1.013 (0.998–1.029)
Chincha	P90	30.05	7	1.010 (0.994–1.027)
Chincha	P90	30.05	9	1.009 (0.994–1.024)
Chincha	P90	30.05	11	1.009 (0.994–1.024)
Chincha	P90	30.05	14	1.010 (0.984–1.037)
Chincha	P95	34.33	0	1.034 (1.001–1.068)
Chincha	P95	34.33	1	1.030 (1.004–1.058)
Chincha	P95	34.33	3	1.023 (1.004–1.043)
Chincha	P95	34.33	5	1.018 (0.998–1.037)
Chincha	P95	34.33	7	1.014 (0.993–1.034)
Chincha	P95	34.33	9	1.012 (0.993–1.031)
Chincha	P95	34.33	11	1.012 (0.994–1.031)
Chincha	P95	34.33	14	1.015 (0.983–1.048)
Chincha	P97.5	37.85	0	1.042 (1.004–1.081)
Chincha	P97.5	37.85	1	1.037 (1.006–1.069)
Chincha	P97.5	37.85	3	1.028 (1.006–1.051)
Chincha	P97.5	37.85	5	1.021 (0.999–1.043)
Chincha	P97.5	37.85	7	1.016 (0.993–1.040)
Chincha	P97.5	37.85	9	1.014 (0.993–1.037)
Chincha	P97.5	37.85	11	1.015 (0.994–1.037)
Chincha	P97.5	37.85	14	1.019 (0.983–1.056)
Ica	P90	66.04	0	1.020 (1.002–1.040)
Ica	P90	66.04	1	1.018 (1.003–1.034)
Ica	P90	66.04	3	1.014 (1.004–1.025)
Ica	P90	66.04	5	1.011 (1.001–1.022)
Ica	P90	66.04	7	1.010 (0.999–1.021)
Ica	P90	66.04	9	1.010 (1.000–1.020)
Ica	P90	66.04	11	1.011 (1.001–1.022)
Ica	P90	66.04	14	1.015 (0.996–1.033)
Ica	P95	76.12	0	1.028 (1.005–1.052)
Ica	P95	76.12	1	1.026 (1.007–1.045)
Ica	P95	76.12	3	1.022 (1.009–1.036)
Ica	P95	76.12	5	1.019 (1.006–1.032)
Ica	P95	76.12	7	1.017 (1.003–1.031)

Province	Percentile	DUSMASS, µg/m³	Lag, days	Lag-specific RR (95% CI)
Ica	P95	76.12	9	1.017 (1.004–1.029)
Ica	P95	76.12	11	1.017 (1.005–1.030)
Ica	P95	76.12	14	1.019 (0.997–1.042)
Ica	P97.5	84.28	0	1.033 (1.007–1.061)
Ica	P97.5	84.28	1	1.032 (1.010–1.054)
Ica	P97.5	84.28	3	1.029 (1.014–1.045)
Ica	P97.5	84.28	5	1.026 (1.012–1.042)
Ica	P97.5	84.28	7	1.025 (1.009–1.041)
Ica	P97.5	84.28	9	1.023 (1.009–1.038)
Ica	P97.5	84.28	11	1.023 (1.008–1.037)
Ica	P97.5	84.28	14	1.022 (0.997–1.048)
Nazca	P90	32.08	0	0.991 (0.960–1.024)
Nazca	P90	32.08	1	0.995 (0.970–1.022)
Nazca	P90	32.08	3	1.003 (0.985–1.021)
Nazca	P90	32.08	5	1.009 (0.991–1.027)
Nazca	P90	32.08	7	1.012 (0.992–1.032)
Nazca	P90	32.08	9	1.011 (0.993–1.030)
Nazca	P90	32.08	11	1.007 (0.990–1.026)
Nazca	P90	32.08	14	0.999 (0.968–1.031)
Nazca	P95	35.58	0	0.999 (0.962–1.037)
Nazca	P95	35.58	1	1.001 (0.971–1.031)
Nazca	P95	35.58	3	1.004 (0.983–1.025)
Nazca	P95	35.58	5	1.007 (0.986–1.028)
Nazca	P95	35.58	7	1.009 (0.986–1.031)
Nazca	P95	35.58	9	1.009 (0.989–1.030)
Nazca	P95	35.58	11	1.009 (0.989–1.030)
Nazca	P95	35.58	14	1.009 (0.973–1.046)
Nazca	P97.5	38.63	0	1.009 (0.963–1.058)
Nazca	P97.5	38.63	1	1.008 (0.969–1.047)
Nazca	P97.5	38.63	3	1.004 (0.977–1.032)
Nazca	P97.5	38.63	5	1.002 (0.976–1.029)
Nazca	P97.5	38.63	7	1.003 (0.974–1.032)
Nazca	P97.5	38.63	9	1.006 (0.980–1.032)
Nazca	P97.5	38.63	11	1.011 (0.986–1.037)
Nazca	P97.5	38.63	14	1.021 (0.977–1.068)
Palpa	P90	26.44	0	1.022 (0.940–1.112)
Palpa	P90	26.44	1	1.030 (0.963–1.102)
Palpa	P90	26.44	3	1.045 (0.998–1.093)
Palpa	P90	26.44	5	1.054 (1.006–1.104)

Province	Percentile	DUSMASS, µg/m³	Lag, days	Lag-specific RR (95% CI)
Palpa	P90	26.44	7	1.054 (1.001–1.109)
Palpa	P90	26.44	9	1.043 (0.995–1.092)
Palpa	P90	26.44	11	1.023 (0.977–1.071)
Palpa	P90	26.44	14	0.985 (0.905–1.071)
Palpa	P95	28.92	0	1.013 (0.923–1.113)
Palpa	P95	28.92	1	1.022 (0.949–1.102)
Palpa	P95	28.92	3	1.038 (0.987–1.093)
Palpa	P95	28.92	5	1.050 (0.997–1.106)
Palpa	P95	28.92	7	1.052 (0.994–1.114)
Palpa	P95	28.92	9	1.044 (0.991–1.100)
Palpa	P95	28.92	11	1.027 (0.977–1.081)
Palpa	P95	28.92	14	0.995 (0.906–1.092)
Palpa	P97.5	32.13	0	0.995 (0.889–1.114)
Palpa	P97.5	32.13	1	1.004 (0.917–1.099)
Palpa	P97.5	32.13	3	1.021 (0.960–1.087)
Palpa	P97.5	32.13	5	1.035 (0.972–1.102)
Palpa	P97.5	32.13	7	1.042 (0.973–1.117)
Palpa	P97.5	32.13	9	1.041 (0.978–1.108)
Palpa	P97.5	32.13	11	1.034 (0.973–1.098)
Palpa	P97.5	32.13	14	1.016 (0.909–1.134)
Pisco	P90	67.68	0	1.006 (0.973–1.041)
Pisco	P90	67.68	1	1.009 (0.981–1.037)
Pisco	P90	67.68	3	1.013 (0.993–1.033)
Pisco	P90	67.68	5	1.016 (0.997–1.036)
Pisco	P90	67.68	7	1.018 (0.997–1.039)
Pisco	P90	67.68	9	1.017 (0.998–1.037)
Pisco	P90	67.68	11	1.015 (0.996–1.034)
Pisco	P90	67.68	14	1.010 (0.977–1.044)
Pisco	P95	77.65	0	1.007 (0.967–1.050)
Pisco	P95	77.65	1	1.011 (0.977–1.045)
Pisco	P95	77.65	3	1.017 (0.993–1.042)
Pisco	P95	77.65	5	1.022 (0.998–1.047)
Pisco	P95	77.65	7	1.025 (0.999–1.051)
Pisco	P95	77.65	9	1.024 (1.000–1.048)
Pisco	P95	77.65	11	1.021 (0.997–1.045)
Pisco	P95	77.65	14	1.014 (0.974–1.056)
Pisco	P97.5	87.27	0	1.007 (0.961–1.056)
Pisco	P97.5	87.27	1	1.012 (0.973–1.052)
Pisco	P97.5	87.27	3	1.021 (0.993–1.050)

Province	Percentile	DUSMASS, $\mu\text{g}/\text{m}^3$	Lag, days	Lag-specific RR (95% CI)
Pisco	P97.5	87.27	5	1.028 (1.000–1.057)
Pisco	P97.5	87.27	7	1.031 (1.001–1.062)
Pisco	P97.5	87.27	9	1.031 (1.003–1.060)
Pisco	P97.5	87.27	11	1.027 (1.000–1.055)
Pisco	P97.5	87.27	14	1.019 (0.972–1.067)

Note. Lag-specific estimates are centered at the province-specific median DUSMASS concentration. Selected lags are 0, 1, 3, 5, 7, 9, 11, and 14 days.

Supplementary Table S4. Cumulative relative risks across selected lag windows at the 90th, 95th, and 97.5th percentiles of the province-specific DUSMASS distribution.

Province	Percentile	DUSMASS, $\mu\text{g}/\text{m}^3$	Lag window, days	Cumulative RR (95% CI)
Chincha	P90	30.05	0–1	1.05 (1.00–1.10)
Chincha	P90	30.05	0–3	1.09 (1.01–1.17)
Chincha	P90	30.05	0–5	1.12 (1.01–1.23)
Chincha	P90	30.05	0–7	1.14 (1.02–1.28)
Chincha	P90	30.05	0–9	1.16 (1.01–1.33)
Chincha	P90	30.05	0–11	1.18 (1.01–1.38)
Chincha	P90	30.05	0–14	1.22 (1.01–1.47)
Chincha	P95	34.33	0–1	1.07 (1.01–1.13)
Chincha	P95	34.33	0–3	1.12 (1.02–1.23)
Chincha	P95	34.33	0–5	1.16 (1.03–1.31)
Chincha	P95	34.33	0–7	1.20 (1.04–1.38)
Chincha	P95	34.33	0–9	1.23 (1.04–1.45)
Chincha	P95	34.33	0–11	1.26 (1.04–1.52)
Chincha	P95	34.33	0–14	1.31 (1.05–1.64)
Chincha	P97.5	37.85	0–1	1.08 (1.01–1.15)
Chincha	P97.5	37.85	0–3	1.15 (1.03–1.28)
Chincha	P97.5	37.85	0–5	1.20 (1.04–1.38)
Chincha	P97.5	37.85	0–7	1.24 (1.05–1.46)
Chincha	P97.5	37.85	0–9	1.28 (1.05–1.55)
Chincha	P97.5	37.85	0–11	1.32 (1.06–1.64)
Chincha	P97.5	37.85	0–14	1.39 (1.07–1.79)
Ica	P90	66.04	0–1	1.04 (1.00–1.07)
Ica	P90	66.04	0–3	1.07 (1.01–1.13)
Ica	P90	66.04	0–5	1.10 (1.03–1.17)
Ica	P90	66.04	0–7	1.12 (1.03–1.21)
Ica	P90	66.04	0–9	1.14 (1.04–1.25)
Ica	P90	66.04	0–11	1.17 (1.05–1.29)
Ica	P90	66.04	0–14	1.21 (1.07–1.38)
Ica	P95	76.12	0–1	1.05 (1.01–1.10)
Ica	P95	76.12	0–3	1.10 (1.03–1.18)
Ica	P95	76.12	0–5	1.15 (1.06–1.25)
Ica	P95	76.12	0–7	1.19 (1.08–1.31)
Ica	P95	76.12	0–9	1.23 (1.10–1.38)
Ica	P95	76.12	0–11	1.27 (1.12–1.45)
Ica	P95	76.12	0–14	1.34 (1.15–1.57)
Ica	P97.5	84.28	0–1	1.07 (1.02–1.12)

Province	Percentile	DUSMASS, µg/m³	Lag window, days	Cumulative RR (95% CI)
Ica	P97.5	84.28	0–3	1.13 (1.05–1.22)
Ica	P97.5	84.28	0–5	1.19 (1.08–1.31)
Ica	P97.5	84.28	0–7	1.25 (1.12–1.41)
Ica	P97.5	84.28	0–9	1.31 (1.15–1.50)
Ica	P97.5	84.28	0–11	1.37 (1.18–1.59)
Ica	P97.5	84.28	0–14	1.47 (1.23–1.75)
Nazca	P90	32.08	0–1	0.99 (0.93–1.05)
Nazca	P90	32.08	0–3	0.99 (0.90–1.09)
Nazca	P90	32.08	0–5	1.00 (0.89–1.13)
Nazca	P90	32.08	0–7	1.03 (0.89–1.18)
Nazca	P90	32.08	0–9	1.05 (0.90–1.23)
Nazca	P90	32.08	0–11	1.07 (0.89–1.28)
Nazca	P90	32.08	0–14	1.08 (0.87–1.33)
Nazca	P95	35.58	0–1	1.00 (0.93–1.07)
Nazca	P95	35.58	0–3	1.01 (0.90–1.12)
Nazca	P95	35.58	0–5	1.02 (0.89–1.17)
Nazca	P95	35.58	0–7	1.03 (0.88–1.21)
Nazca	P95	35.58	0–9	1.05 (0.87–1.27)
Nazca	P95	35.58	0–11	1.07 (0.87–1.32)
Nazca	P95	35.58	0–14	1.10 (0.86–1.41)
Nazca	P97.5	38.63	0–1	1.02 (0.93–1.11)
Nazca	P97.5	38.63	0–3	1.03 (0.89–1.18)
Nazca	P97.5	38.63	0–5	1.03 (0.87–1.23)
Nazca	P97.5	38.63	0–7	1.04 (0.84–1.28)
Nazca	P97.5	38.63	0–9	1.05 (0.82–1.33)
Nazca	P97.5	38.63	0–11	1.07 (0.82–1.39)
Nazca	P97.5	38.63	0–14	1.13 (0.83–1.53)
Palpa	P90	26.44	0–1	1.05 (0.91–1.22)
Palpa	P90	26.44	0–3	1.14 (0.90–1.45)
Palpa	P90	26.44	0–5	1.26 (0.94–1.70)
Palpa	P90	26.44	0–7	1.40 (0.99–1.99)
Palpa	P90	26.44	0–9	1.54 (1.03–2.30)
Palpa	P90	26.44	0–11	1.62 (1.03–2.55)
Palpa	P90	26.44	0–14	1.61 (0.95–2.75)
Palpa	P95	28.92	0–1	1.04 (0.88–1.23)
Palpa	P95	28.92	0–3	1.11 (0.85–1.45)
Palpa	P95	28.92	0–5	1.22 (0.87–1.69)

Province	Percentile	DUSMASS, $\mu\text{g}/\text{m}^3$	Lag window, days	Cumulative RR (95% CI)
Palpa	P95	28.92	0–7	1.35 (0.91–1.98)
Palpa	P95	28.92	0–9	1.48 (0.94–2.31)
Palpa	P95	28.92	0–11	1.57 (0.95–2.59)
Palpa	P95	28.92	0–14	1.60 (0.89–2.88)
Palpa	P97.5	32.13	0–1	1.00 (0.82–1.22)
Palpa	P97.5	32.13	0–3	1.03 (0.75–1.43)
Palpa	P97.5	32.13	0–5	1.10 (0.74–1.65)
Palpa	P97.5	32.13	0–7	1.19 (0.74–1.91)
Palpa	P97.5	32.13	0–9	1.30 (0.75–2.24)
Palpa	P97.5	32.13	0–11	1.39 (0.76–2.56)
Palpa	P97.5	32.13	0–14	1.48 (0.73–3.03)
Pisco	P90	67.68	0–1	1.02 (0.95–1.08)
Pisco	P90	67.68	0–3	1.04 (0.94–1.15)
Pisco	P90	67.68	0–5	1.07 (0.94–1.22)
Pisco	P90	67.68	0–7	1.11 (0.96–1.29)
Pisco	P90	67.68	0–9	1.15 (0.96–1.37)
Pisco	P90	67.68	0–11	1.18 (0.97–1.44)
Pisco	P90	67.68	0–14	1.22 (0.96–1.55)
Pisco	P95	77.65	0–1	1.02 (0.94–1.10)
Pisco	P95	77.65	0–3	1.05 (0.93–1.19)
Pisco	P95	77.65	0–5	1.09 (0.94–1.28)
Pisco	P95	77.65	0–7	1.15 (0.96–1.38)
Pisco	P95	77.65	0–9	1.20 (0.97–1.49)
Pisco	P95	77.65	0–11	1.26 (0.99–1.61)
Pisco	P95	77.65	0–14	1.32 (0.99–1.77)
Pisco	P97.5	87.27	0–1	1.02 (0.94–1.11)
Pisco	P97.5	87.27	0–3	1.06 (0.92–1.22)
Pisco	P97.5	87.27	0–5	1.11 (0.93–1.33)
Pisco	P97.5	87.27	0–7	1.18 (0.96–1.47)
Pisco	P97.5	87.27	0–9	1.26 (0.98–1.62)
Pisco	P97.5	87.27	0–11	1.33 (1.00–1.77)
Pisco	P97.5	87.27	0–14	1.42 (1.01–1.99)

Note. Cumulative relative risks are centered at the province-specific median DUSMASS concentration and accumulate the lag-specific contributions from lag 0 through the upper limit shown.

Supplementary Table S5. Respiratory emergency department visits attributable to DUSMASS concentrations above the province-specific median, backward and forward perspectives.

Province	Perspective	Attributable fraction, % (95% CI)	Attributable visits (95% CI)	Days > median
Chincha	Backward	6.32 (0.76–11.22)	1663 (200–2953)	623
Chincha	Forward	5.98 (0.61–10.27)	1573 (162–2703)	623
Ica	Backward	6.64 (2.93–9.98)	2091 (924–3146)	623
Ica	Forward	6.14 (2.66–9.11)	1935 (838–2870)	623
Nazca	Backward	2.19 (-4.14–7.62)	470 (-888–1636)	623
Nazca	Forward	2.12 (-4.31–7.17)	454 (-925–1539)	623
Palpa	Backward	12.37 (-2.16–22.40)	371 (-65–672)	623
Palpa	Forward	11.32 (-5.08–19.44)	340 (-152–584)	623
Pisco	Backward	6.40 (-0.57–12.61)	785 (-70–1546)	623
Pisco	Forward	6.01 (-0.80–11.40)	737 (-98–1398)	623

Note. The counterfactual was the province-specific median DUSMASS concentration. Backward attribution is the primary observed-burden estimate; forward attribution is shown as a complementary estimate and underlies the additive exposure-band decomposition in the main manuscript. These estimates do not represent the total burden attributable to mineral dust.

Supplementary Table S6. Sensitivity analysis using maximum lags of 7 and 14 days.

Province	Maximum lag, days	RR at P90 (95% CI)	RR at P97.5 (95% CI)
Chincha	7	1.12 (0.99–1.25)	1.20 (1.02–1.42)
Chincha	14	1.22 (1.01–1.47)	1.39 (1.07–1.79)
Ica	7	1.11 (1.03–1.20)	1.24 (1.11–1.40)
Ica	14	1.21 (1.07–1.38)	1.47 (1.23–1.75)
Nazca	7	0.98 (0.85–1.13)	0.91 (0.73–1.13)
Nazca	14	1.08 (0.87–1.33)	1.13 (0.83–1.53)
Palpa	7	1.40 (0.97–2.01)	1.15 (0.71–1.87)
Palpa	14	1.61 (0.95–2.75)	1.48 (0.73–3.03)
Pisco	7	1.09 (0.94–1.26)	1.12 (0.91–1.39)
Pisco	14	1.22 (0.96–1.55)	1.42 (1.01–1.99)

Note. The 14-day lag is the primary specification; the 7-day lag is a sensitivity analysis. All other model components were held constant.

Supplementary Table S7. Sensitivity analysis for long-term and seasonal time-trend flexibility.

Province	Time spline, df/year	RR at P90 (95% CI)	RR at P97.5 (95% CI)
Chincha	7	1.26 (1.05–1.50)	1.46 (1.14–1.89)
Chincha	8	1.22 (1.01–1.47)	1.39 (1.07–1.79)
Chincha	9	1.16 (0.97–1.40)	1.28 (0.99–1.65)
Chincha	10	1.10 (0.92–1.32)	1.22 (0.94–1.58)
Ica	7	1.16 (1.03–1.31)	1.39 (1.17–1.66)
Ica	8	1.21 (1.07–1.38)	1.47 (1.23–1.75)
Ica	9	1.09 (0.96–1.25)	1.27 (1.06–1.53)
Ica	10	1.11 (0.98–1.27)	1.30 (1.08–1.56)
Nazca	7	1.03 (0.84–1.27)	1.07 (0.80–1.44)
Nazca	8	1.08 (0.87–1.33)	1.13 (0.83–1.53)
Nazca	9	1.04 (0.84–1.29)	1.04 (0.75–1.44)
Nazca	10	1.01 (0.81–1.26)	0.99 (0.71–1.37)
Palpa	7	1.68 (1.02–2.76)	1.62 (0.82–3.21)
Palpa	8	1.61 (0.95–2.75)	1.48 (0.73–3.03)
Palpa	9	1.49 (0.87–2.55)	1.36 (0.66–2.81)
Palpa	10	1.55 (0.87–2.76)	1.33 (0.63–2.82)
Pisco	7	1.11 (0.88–1.41)	1.28 (0.91–1.79)
Pisco	8	1.22 (0.96–1.55)	1.42 (1.01–1.99)
Pisco	9	1.10 (0.86–1.42)	1.20 (0.84–1.71)
Pisco	10	1.04 (0.81–1.34)	1.20 (0.84–1.73)

Note. The primary model used 8 df/year. Alternative models used 7, 9, or 10 df/year while retaining the same exposure, lag, meteorological, day-of-week, and holiday specifications.

Supplementary Table S8. Sensitivity analysis with and without relative-humidity adjustment.

Province	Adjustment	Percentile	Cumulative RR (95% CI)
Chincha	With humidity	P90	1.22 (1.01–1.47)
Chincha	With humidity	P95	1.31 (1.05–1.64)
Chincha	With humidity	P97.5	1.39 (1.07–1.79)
Chincha	Without humidity	P90	1.22 (1.02–1.46)
Chincha	Without humidity	P95	1.30 (1.05–1.62)
Chincha	Without humidity	P97.5	1.38 (1.07–1.76)
Ica	With humidity	P90	1.21 (1.07–1.38)
Ica	With humidity	P95	1.34 (1.15–1.57)
Ica	With humidity	P97.5	1.47 (1.23–1.75)
Ica	Without humidity	P90	1.18 (1.04–1.34)
Ica	Without humidity	P95	1.30 (1.12–1.51)
Ica	Without humidity	P97.5	1.41 (1.19–1.68)
Nazca	With humidity	P90	1.08 (0.87–1.33)
Nazca	With humidity	P95	1.10 (0.86–1.41)
Nazca	With humidity	P97.5	1.13 (0.83–1.53)
Nazca	Without humidity	P90	1.07 (0.87–1.31)
Nazca	Without humidity	P95	1.08 (0.85–1.37)
Nazca	Without humidity	P97.5	1.10 (0.81–1.48)
Palpa	With humidity	P90	1.61 (0.95–2.75)
Palpa	With humidity	P95	1.60 (0.89–2.88)
Palpa	With humidity	P97.5	1.48 (0.73–3.03)
Palpa	Without humidity	P90	1.55 (0.91–2.62)
Palpa	Without humidity	P95	1.54 (0.86–2.77)
Palpa	Without humidity	P97.5	1.46 (0.72–2.96)
Pisco	With humidity	P90	1.22 (0.96–1.55)
Pisco	With humidity	P95	1.32 (0.99–1.77)
Pisco	With humidity	P97.5	1.42 (1.01–1.99)
Pisco	Without humidity	P90	1.25 (0.99–1.57)
Pisco	Without humidity	P95	1.35 (1.01–1.80)
Pisco	Without humidity	P97.5	1.45 (1.05–2.02)

Note. The primary model included daily mean relative humidity as a natural cubic spline with 3 df. Other model components were unchanged.

Supplementary Table S9. Sensitivity analysis with and without national-holiday adjustment.

Province	Adjustment	Percentile	Cumulative RR (95% CI)
Chincha	With national holidays (main)	P90	1.22 (1.01–1.47)
Chincha	With national holidays (main)	P95	1.31 (1.05–1.64)
Chincha	With national holidays (main)	P97.5	1.39 (1.07–1.79)
Chincha	Without national holidays	P90	1.22 (1.01–1.46)
Chincha	Without national holidays	P95	1.31 (1.04–1.64)
Chincha	Without national holidays	P97.5	1.38 (1.07–1.79)
Ica	With national holidays (main)	P90	1.21 (1.07–1.38)
Ica	With national holidays (main)	P95	1.34 (1.15–1.57)
Ica	With national holidays (main)	P97.5	1.47 (1.23–1.75)
Ica	Without national holidays	P90	1.21 (1.07–1.38)
Ica	Without national holidays	P95	1.34 (1.15–1.57)
Ica	Without national holidays	P97.5	1.47 (1.23–1.75)
Nazca	With national holidays (main)	P90	1.08 (0.87–1.33)
Nazca	With national holidays (main)	P95	1.10 (0.86–1.41)
Nazca	With national holidays (main)	P97.5	1.13 (0.83–1.53)
Nazca	Without national holidays	P90	1.07 (0.87–1.33)
Nazca	Without national holidays	P95	1.10 (0.86–1.41)
Nazca	Without national holidays	P97.5	1.13 (0.83–1.54)
Palpa	With national holidays (main)	P90	1.61 (0.95–2.75)
Palpa	With national holidays (main)	P95	1.60 (0.89–2.88)
Palpa	With national holidays (main)	P97.5	1.48 (0.73–3.03)
Palpa	Without national holidays	P90	1.63 (0.95–2.77)
Palpa	Without national holidays	P95	1.60 (0.89–2.89)
Palpa	Without national holidays	P97.5	1.47 (0.72–3.01)
Pisco	With national holidays (main)	P90	1.22 (0.96–1.55)
Pisco	With national holidays (main)	P95	1.32 (0.99–1.77)
Pisco	With national holidays (main)	P97.5	1.42 (1.01–1.99)
Pisco	Without national holidays	P90	1.22 (0.96–1.55)
Pisco	Without national holidays	P95	1.32 (0.98–1.76)
Pisco	Without national holidays	P97.5	1.42 (1.01–1.98)

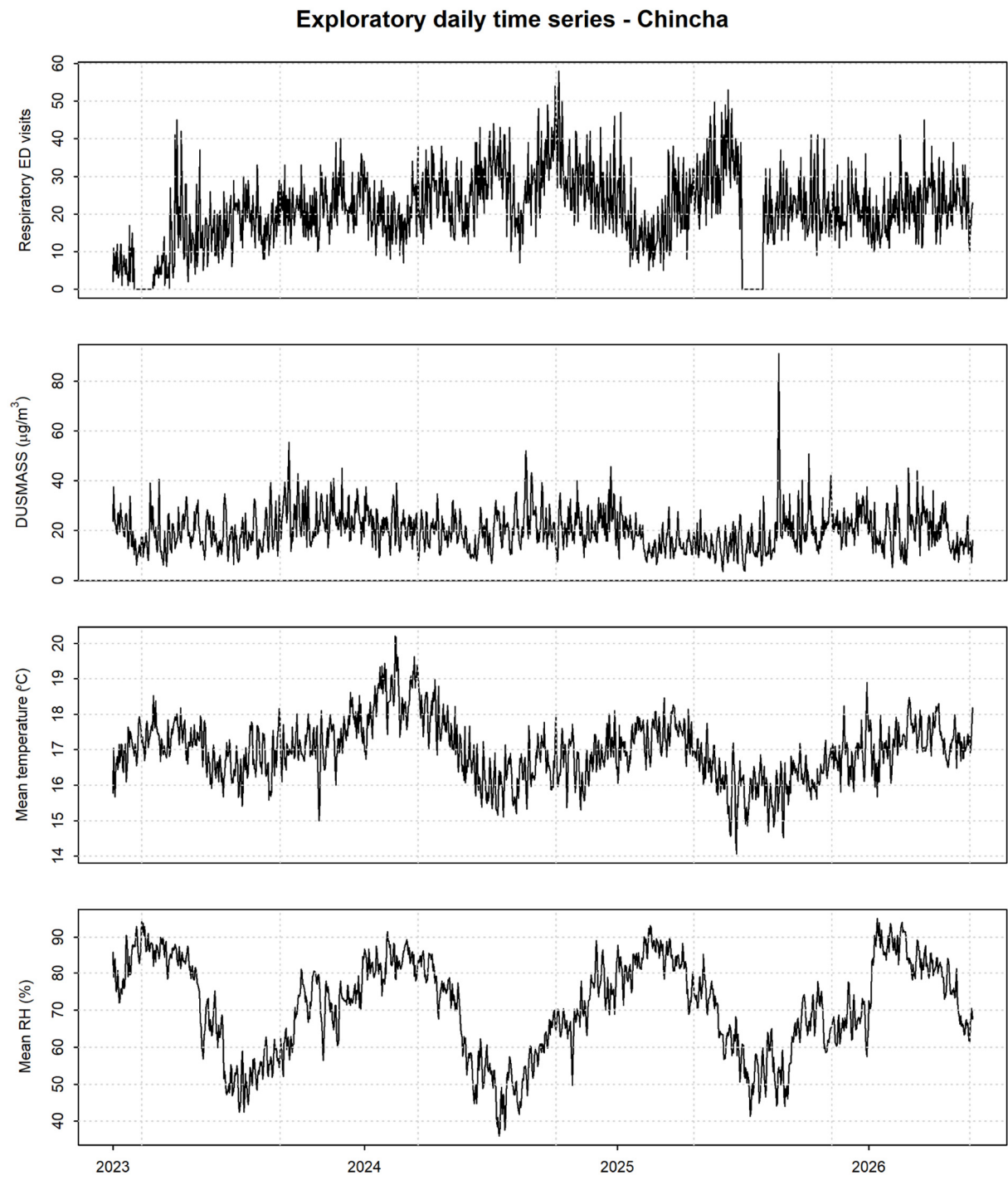
Note. The primary model included a binary indicator for Peruvian national public holidays. Other model components were unchanged.

Supplementary Table S10. Newey–West heteroskedasticity- and autocorrelation-consistent sensitivity analysis.

Province	RR at P90 (95% HAC CI)	RR at P97.5 (95% HAC CI)
Chincha	1.22 (0.94–1.58)	1.39 (0.99–1.95)
Ica	1.21 (1.04–1.41)	1.47 (1.16–1.85)
Nazca	1.08 (0.86–1.35)	1.13 (0.80–1.58)
Palpa	1.61 (0.97–2.68)	1.48 (0.74–3.00)
Pisco	1.22 (0.93–1.60)	1.42 (0.96–2.11)

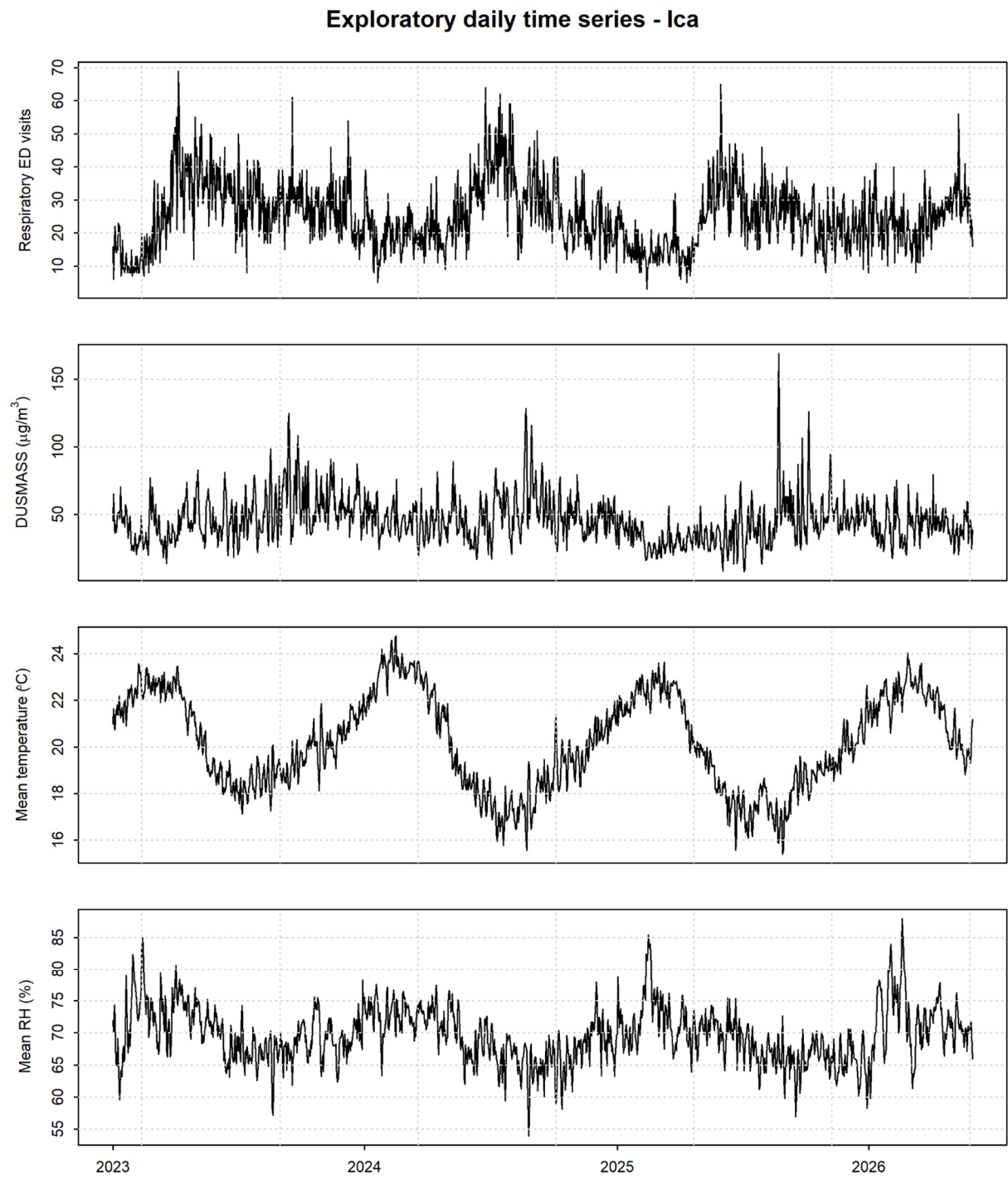
Note. HAC, heteroskedasticity- and autocorrelation-consistent. The covariance matrix was estimated using Newey–West with lag 14 and no prewhitening. Point estimates are identical to the primary model; only the confidence intervals are modified.

Supplementary Figure S1. Exploratory daily time series of respiratory emergency department visits and environmental variables in Chincha, 2023–2026.



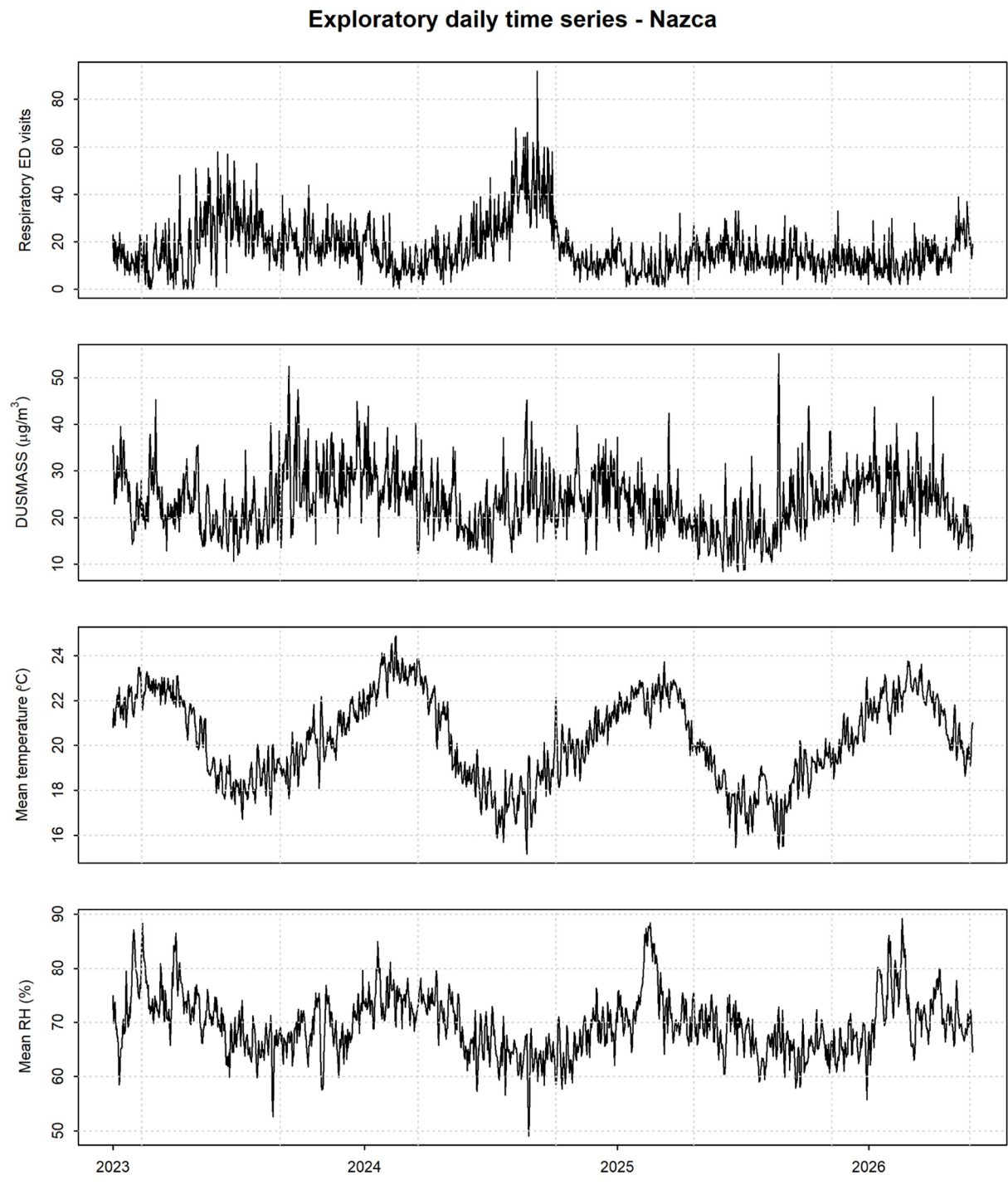
Note. The four panels show daily respiratory ED visits, daily mean MERRA-2 DUSMASS concentration, daily mean temperature, and daily mean relative humidity, respectively. These plots were used for exploratory assessment of seasonality, long-term patterns, extreme values, and potential data anomalies.

Supplementary Figure S2. Exploratory daily time series of respiratory emergency department visits and environmental variables in Ica, 2023–2026.



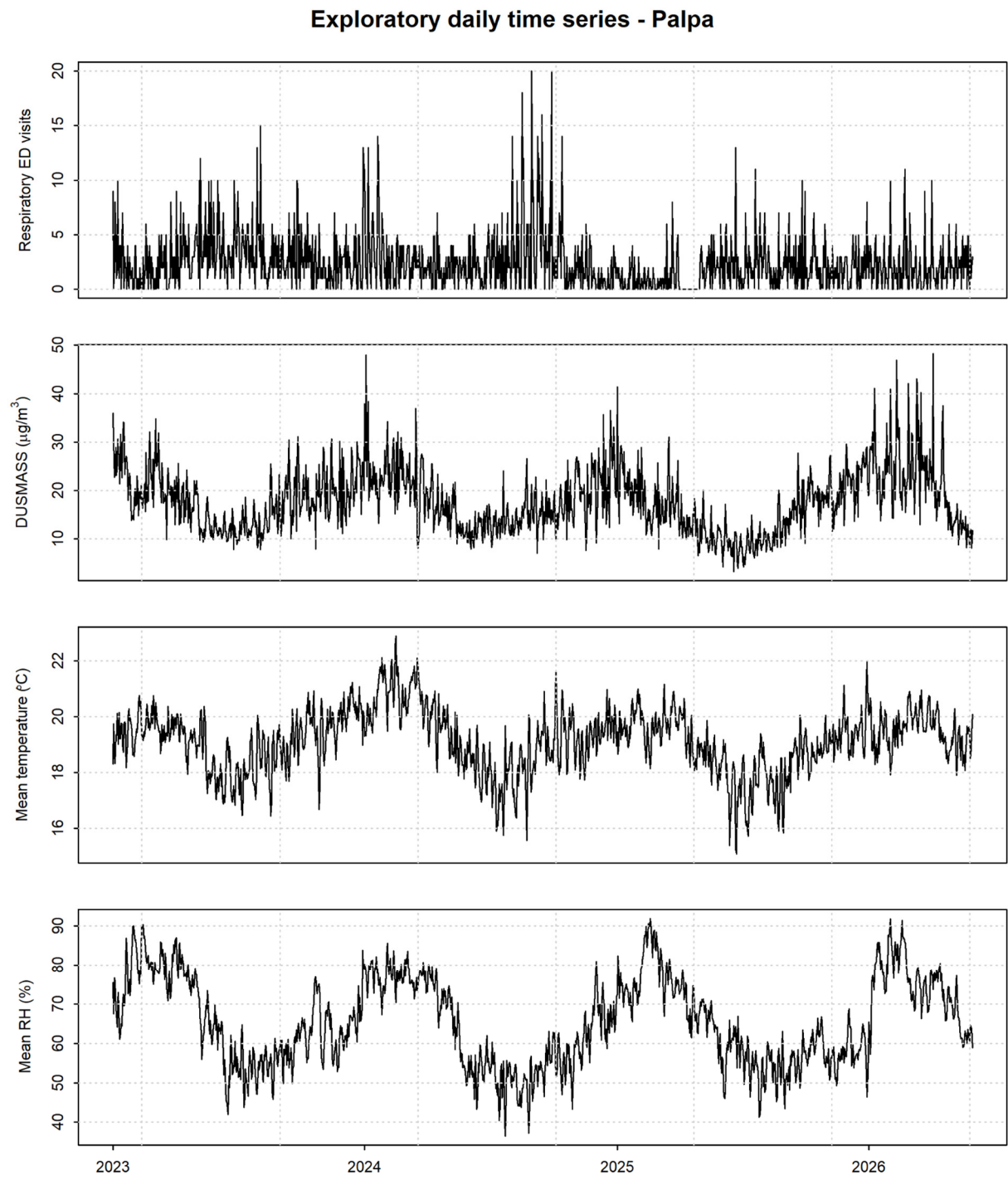
Note. The four panels show daily respiratory ED visits, daily mean MERRA-2 DUSMASS concentration, daily mean temperature, and daily mean relative humidity, respectively. These plots were used for exploratory assessment of seasonality, long-term patterns, extreme values, and potential data anomalies.

Supplementary Figure S3. Exploratory daily time series of respiratory emergency department visits and environmental variables in Nazca, 2023–2026.



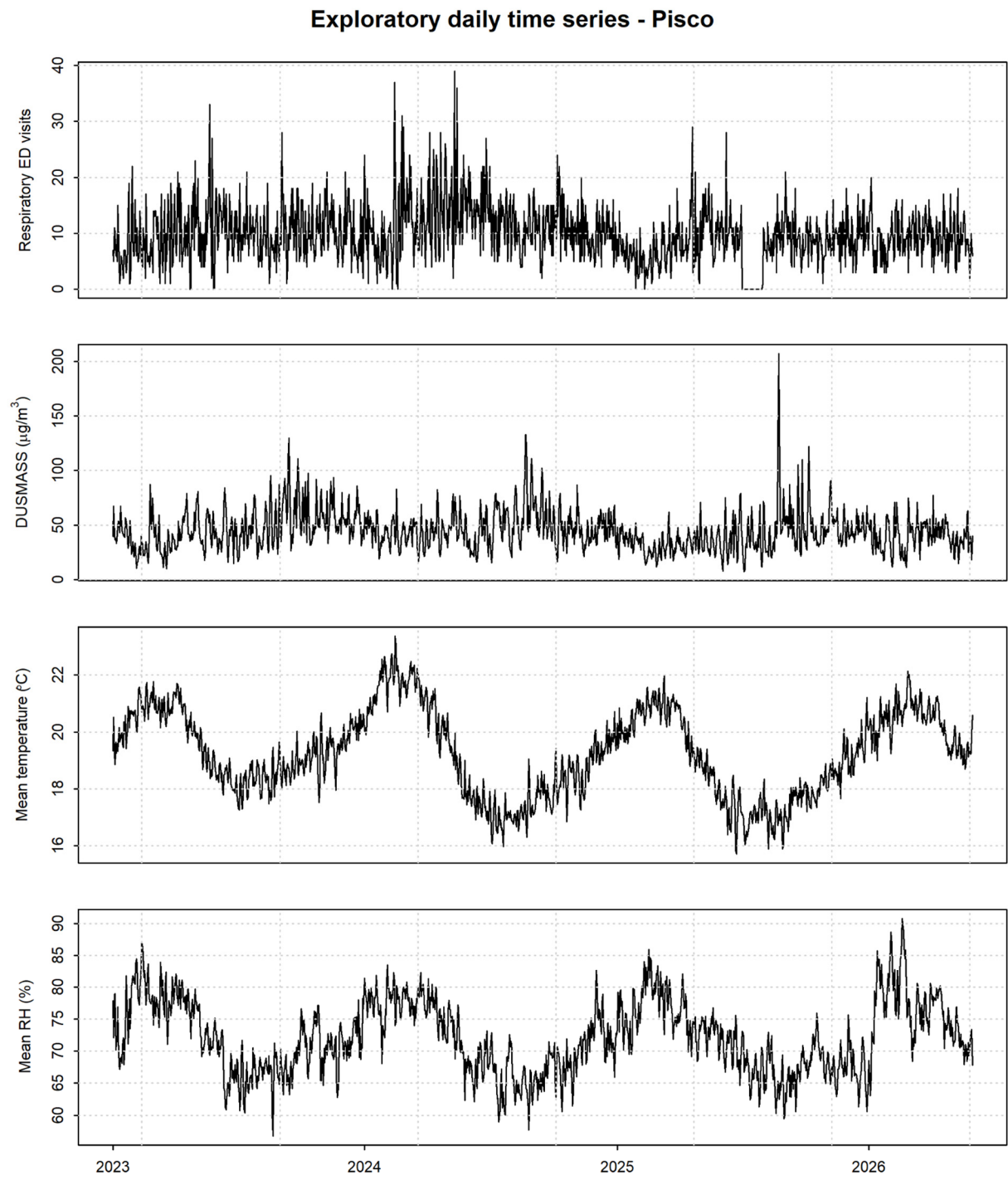
Note. The four panels show daily respiratory ED visits, daily mean MERRA-2 DUSMASS concentration, daily mean temperature, and daily mean relative humidity, respectively. These plots were used for exploratory assessment of seasonality, long-term patterns, extreme values, and potential data anomalies.

Supplementary Figure S4. Exploratory daily time series of respiratory emergency department visits and environmental variables in Palpa, 2023–2026.



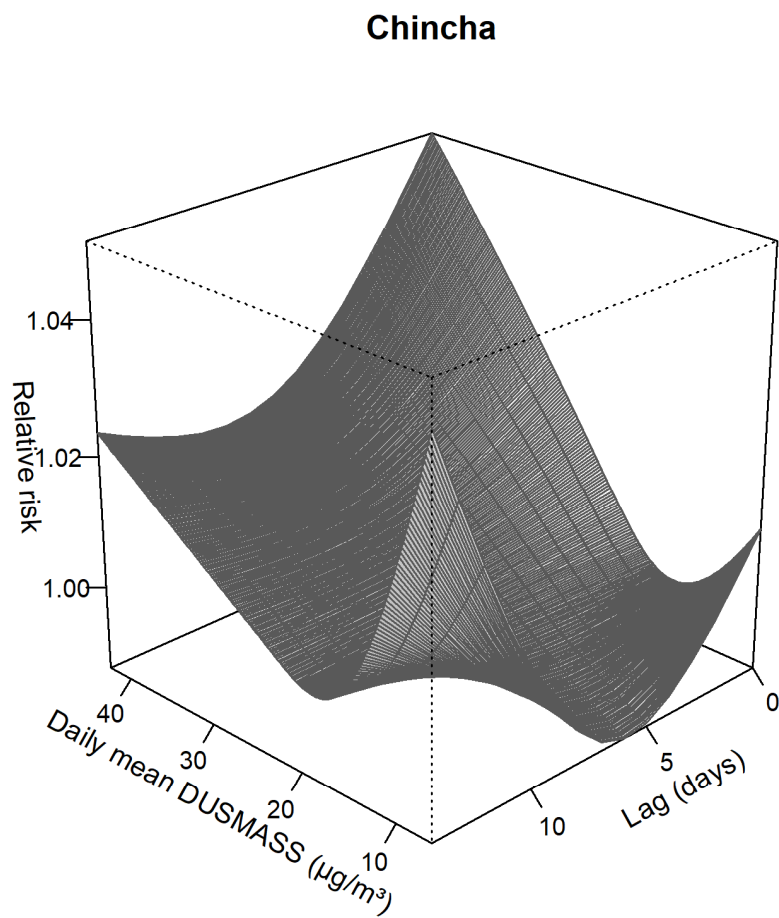
Note. The four panels show daily respiratory ED visits, daily mean MERRA-2 DUSMASS concentration, daily mean temperature, and daily mean relative humidity, respectively. These plots were used for exploratory assessment of seasonality, long-term patterns, extreme values, and potential data anomalies.

Supplementary Figure S5. Exploratory daily time series of respiratory emergency department visits and environmental variables in Pisco, 2023–2026.



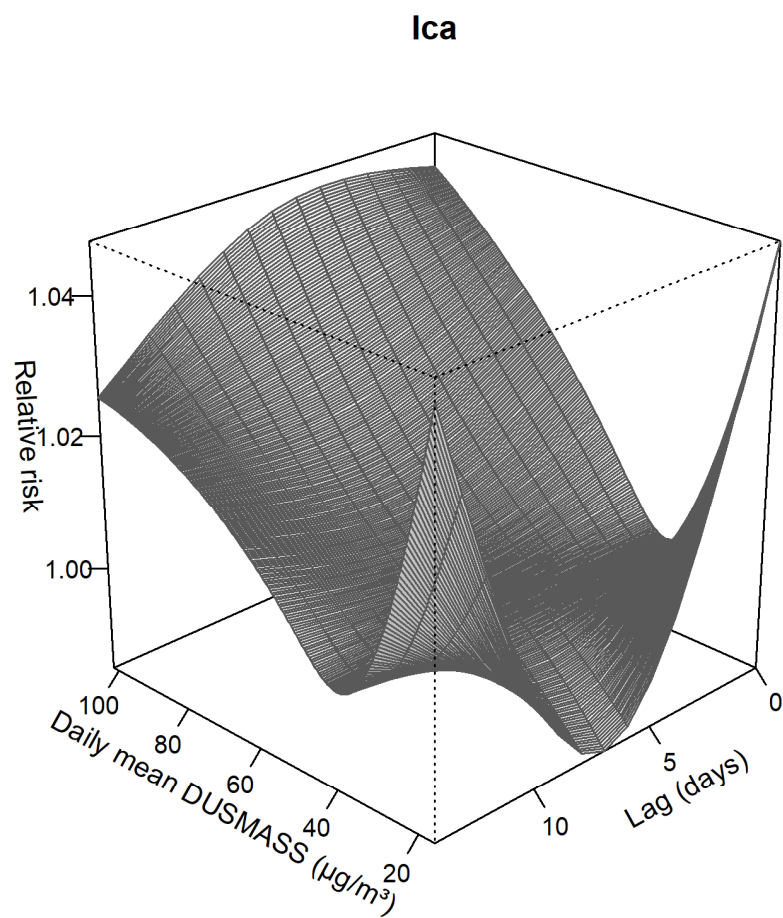
Note. The four panels show daily respiratory ED visits, daily mean MERRA-2 DUSMASS concentration, daily mean temperature, and daily mean relative humidity, respectively. These plots were used for exploratory assessment of seasonality, long-term patterns, extreme values, and potential data anomalies.

Supplementary Figure S6. Three-dimensional exposure–lag–response association between daily mean DUSMASS and respiratory emergency department visits in Chincha.



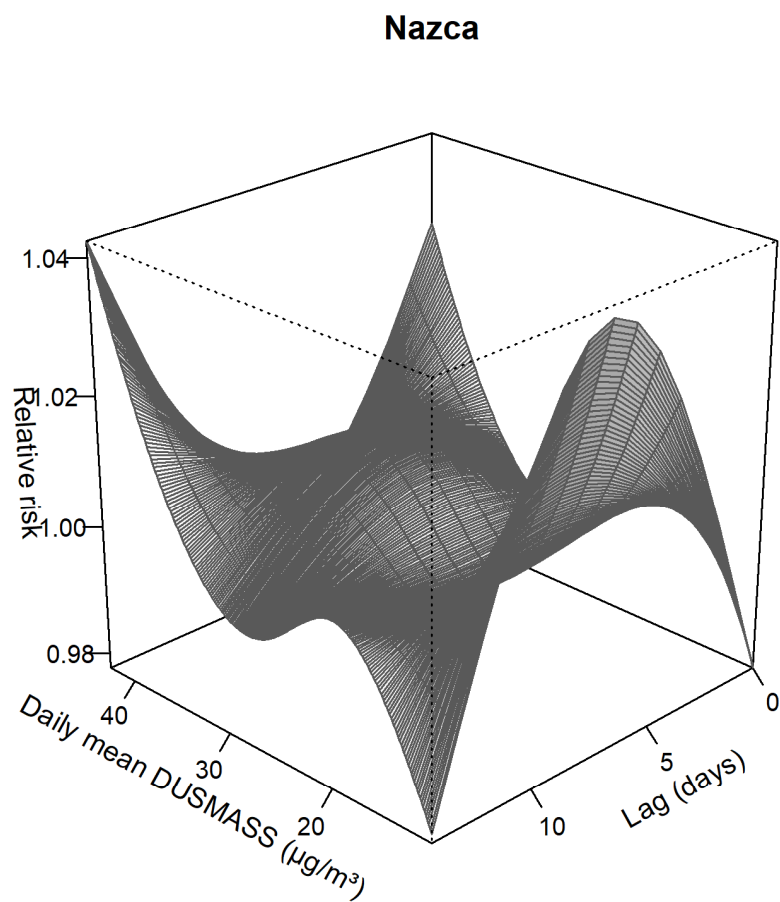
Note. The surface represents lag-specific relative risks across daily mean DUSMASS concentrations and lags 0–14 days, centered at the province-specific median DUSMASS concentration. The model used a natural cubic spline with 3 df for the exposure–response dimension and a natural cubic spline with an intercept and 3 df for the lag–response dimension.

Supplementary Figure S7. Three-dimensional exposure–lag–response association between daily mean DUSMASS and respiratory emergency department visits in Ica.



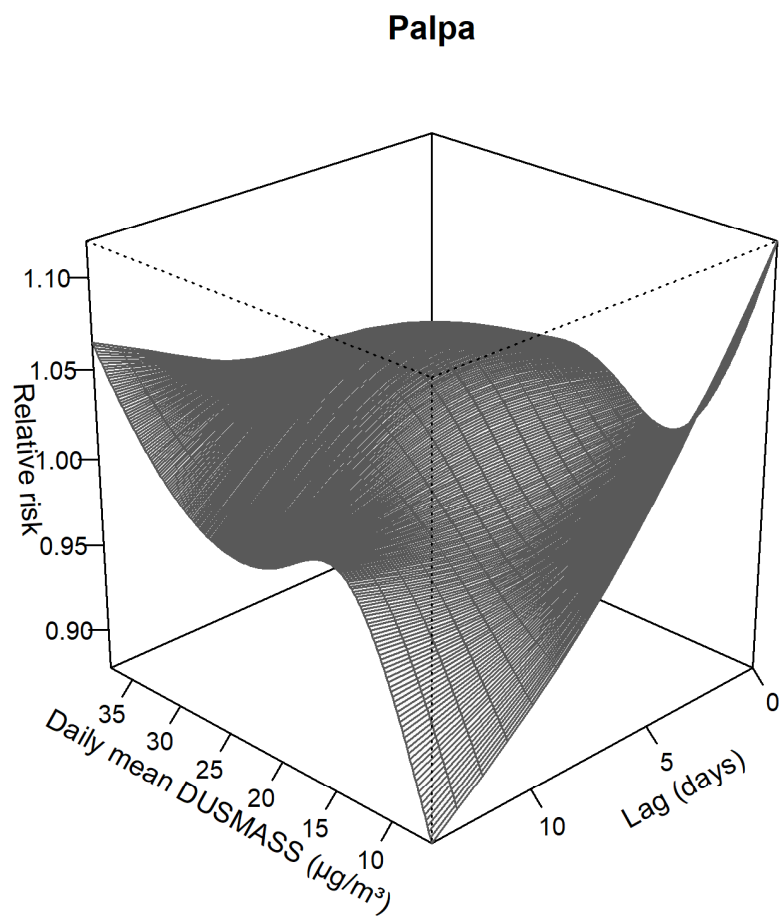
Note. The surface represents lag-specific relative risks across daily mean DUSMASS concentrations and lags 0–14 days, centered at the province-specific median DUSMASS concentration. The model used a natural cubic spline with 3 df for the exposure–response dimension and a natural cubic spline with an intercept and 3 df for the lag–response dimension.

Supplementary Figure S8. Three-dimensional exposure–lag–response association between daily mean DUSMASS and respiratory emergency department visits in Nazca.



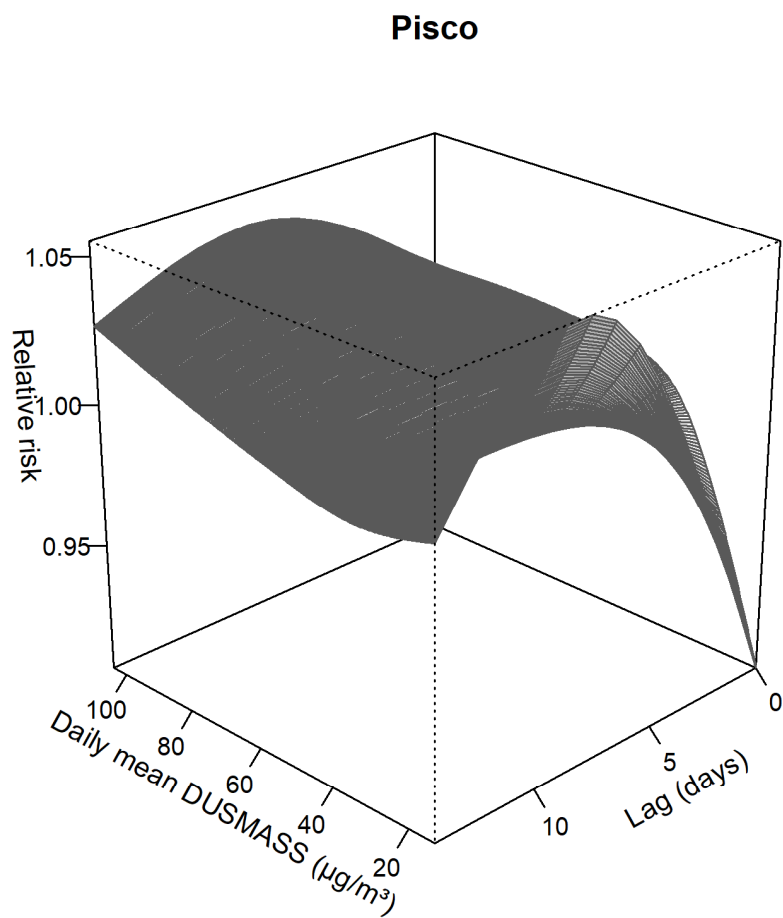
Note. The surface represents lag-specific relative risks across daily mean DUSMASS concentrations and lags 0–14 days, centered at the province-specific median DUSMASS concentration. The model used a natural cubic spline with 3 df for the exposure–response dimension and a natural cubic spline with an intercept and 3 df for the lag–response dimension.

Supplementary Figure S9. Three-dimensional exposure–lag–response association between daily mean DUSMASS and respiratory emergency department visits in Palpa.



Note. The surface represents lag-specific relative risks across daily mean DUSMASS concentrations and lags 0–14 days, centered at the province-specific median DUSMASS concentration. The model used a natural cubic spline with 3 df for the exposure–response dimension and a natural cubic spline with an intercept and 3 df for the lag–response dimension.

Supplementary Figure S10. Three-dimensional exposure–lag–response association between daily mean DUSMASS and respiratory emergency department visits in Pisco.



Note. The surface represents lag-specific relative risks across daily mean DUSMASS concentrations and lags 0–14 days, centered at the province-specific median DUSMASS concentration. The model used a natural cubic spline with 3 df for the exposure–response dimension and a natural cubic spline with an intercept and 3 df for the lag–response dimension.