

Supporting Information for

Meteorological Drivers of Extreme Swells on the Peruvian Coast

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Introduction

This Supporting Information provides additional figures and tables that complement the main text by (i) documenting the full three-level synoptic composite anomaly structure (SLP, Z500, and Z250) for Southern Hemisphere (E1–E5) and Northern Hemisphere (E6–E11) extreme-swell events (Figures S1 and S3), (ii) illustrating links between large-scale climate modes and near-surface wind variability through detrended Pearson correlation maps (SAM, PDO, and ENSO 3.4; Figures S2, S4, and S6) and ENSO modulation of analogue-day distributions (Figure S5), and (iii) summarizing the statistical robustness of the jet-diagnostic signals and the analogue-based attribution tests (Tables S1–S4). All

analyses are based on ERA5 reanalysis fields used in the manuscript (daily SLP, geopotential height, 10-m winds, and 250-hPa winds), with anomalies defined relative to the 1991–2020 seasonal climatology and event-centered lead windows consistent with estimated swell travel times (D–4 to D–3 for SH; D–11 to D–8 for NH). Statistical significance is assessed using two-sided non-parametric tests (Mann–Whitney U and Kolmogorov–Smirnov), and correlation maps display only values significant at the 5% level. Known limitations include uncertainty inherent to reanalysis near-surface winds/waves, and the small event sample size, which can affect the spatial extent of significance and the stability of some composite features.

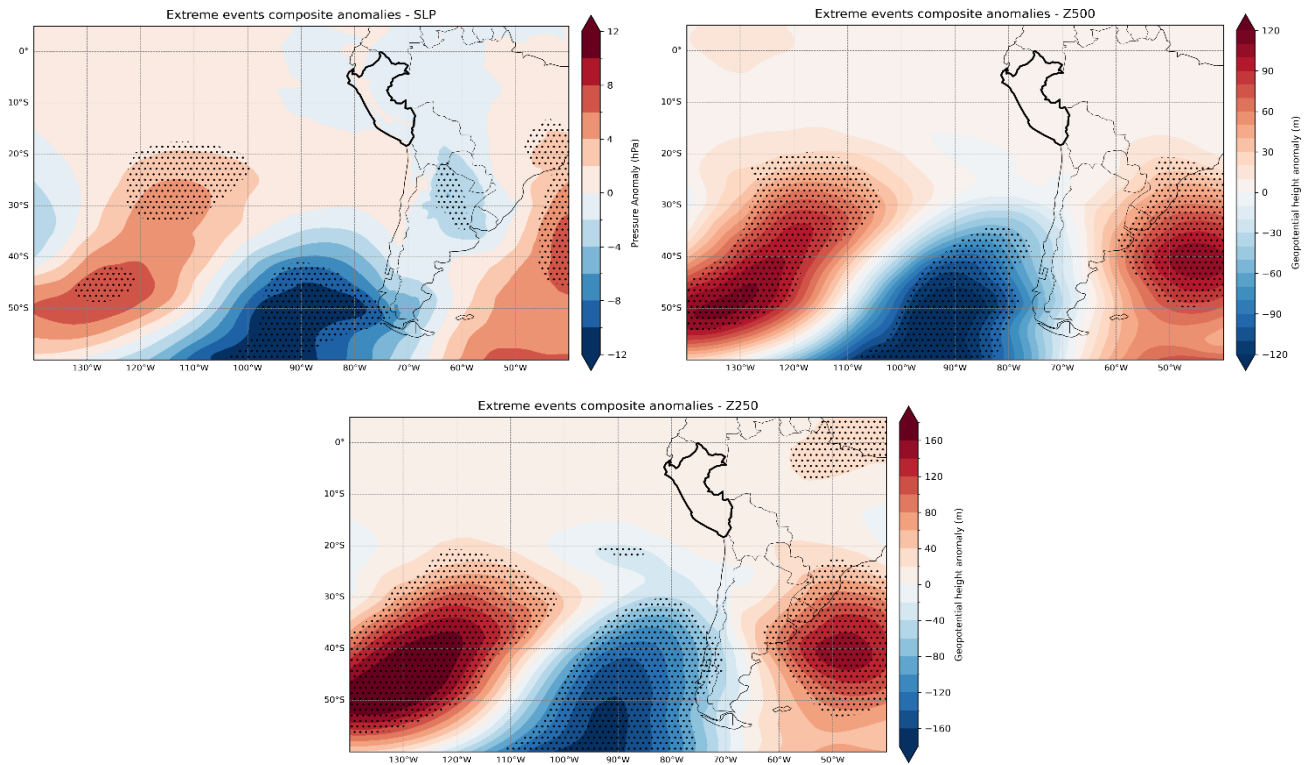


Figure S1. Southern Hemisphere composite anomalies for extreme-swell events E1–E5 (MJJAS). (a) (top left) Sea-level pressure (SLP, hPa), averaged over days D–4 to D–3 relative to each event day (D0). (b) (top right) Z500 geopotential height, same lead window. (c) (bottom), Z250 geopotential, same lead window. Anomalies are referenced to the 1991–2020 seasonal climatology (May–September). Dashed contours indicate grid points significant at $p < 0.05$ (two-sided Mann–Whitney U). The Peru outline is emphasized to indicate the coastal sector analyzed.

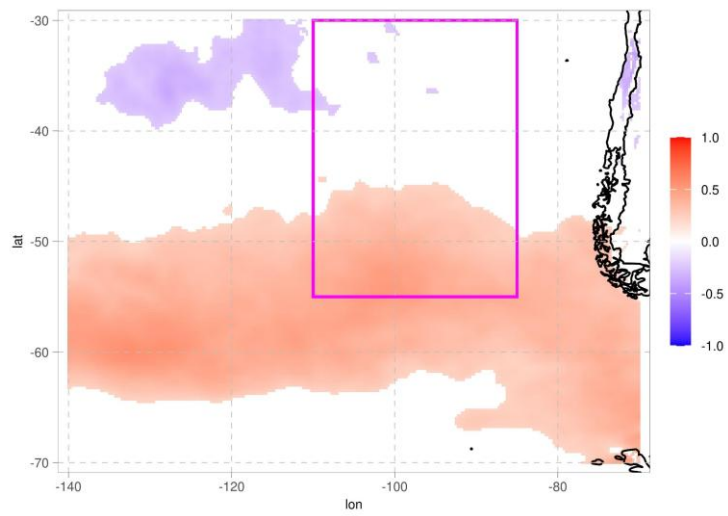


Figure S2. *SAM conditions.* Pearson correlation between the detrended SAM index and detrended 10m wind speed in MJJAS. Only correlations that are significant at the 5% level are shaded. The box indicates the wind analysis region for event E1.

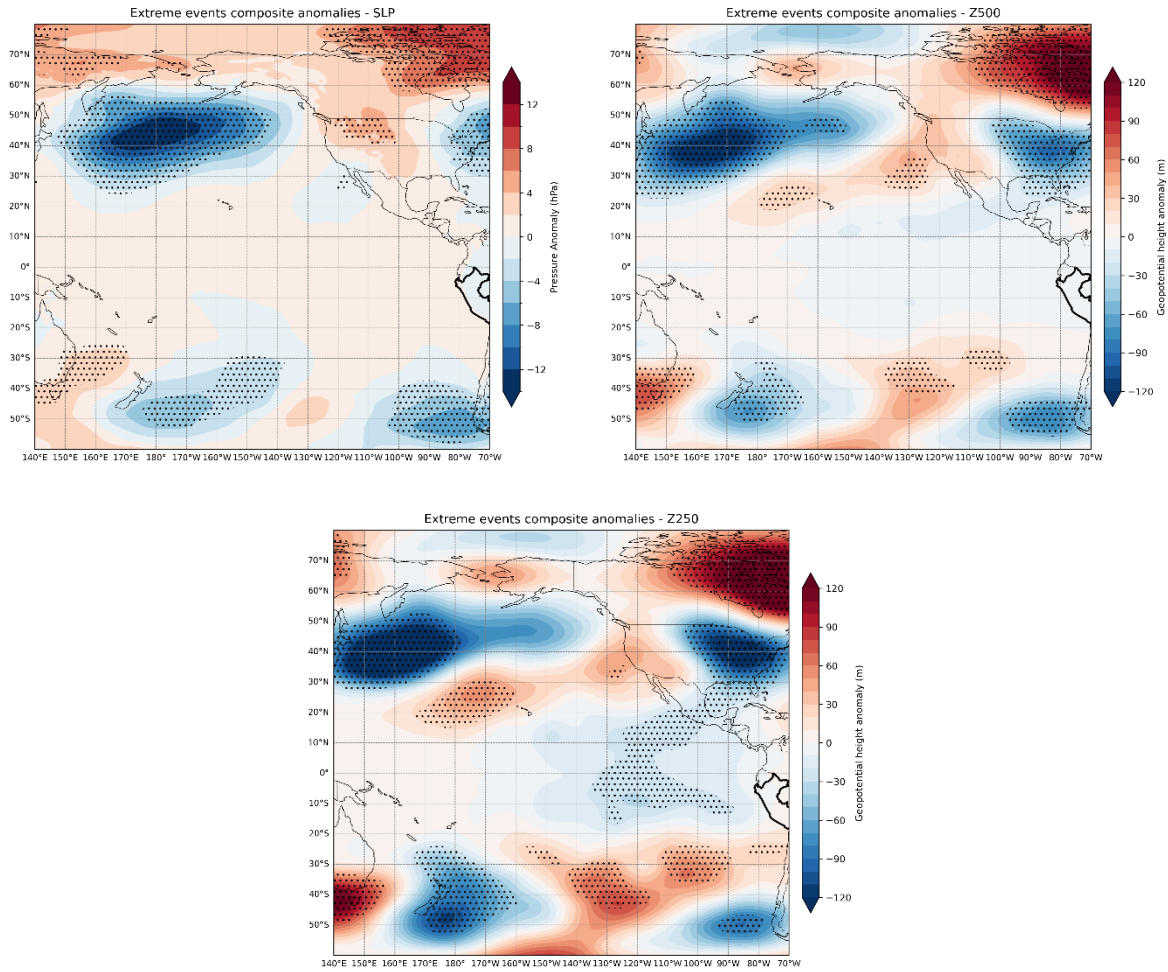


Figure S3. Northern Hemisphere composite anomalies for extreme-swell events E6–E11 (DJFM). (a) (top left) Sea-level pressure (SLP, hPa), averaged over days D–4 to D–3 relative to each event day (D0). (b) (top right) Z500 geopotential height, same lead window. (c) (bottom), Z250 geopotential height, same lead window. Anomalies are referenced to the 1991–2020 seasonal climatology (December–March). Dashed contours indicate grid points significant at $p < 0.05$ (two-sided Mann–Whitney U). The Peru outline is highlighted for reference.

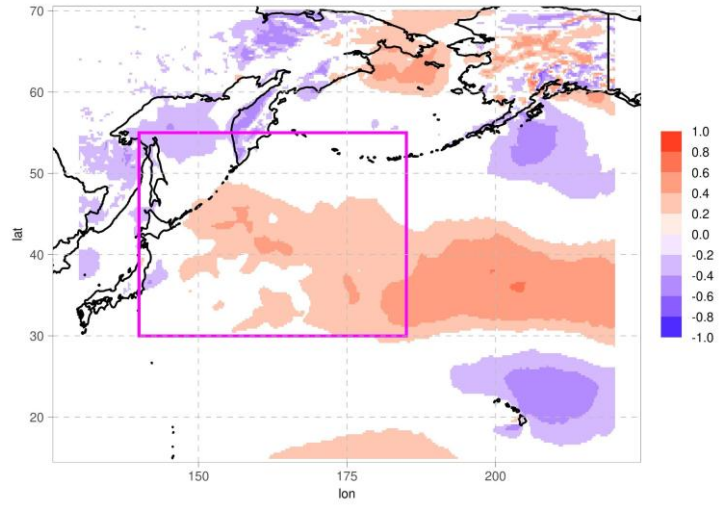


Figure S4. PDO conditions. Pearson correlation between the detrended PDO index and detrended 10m wind speed in NDJFM. Only correlations that are significant at the 5% level are shaded. The box indicates the wind analysis region for event E9.

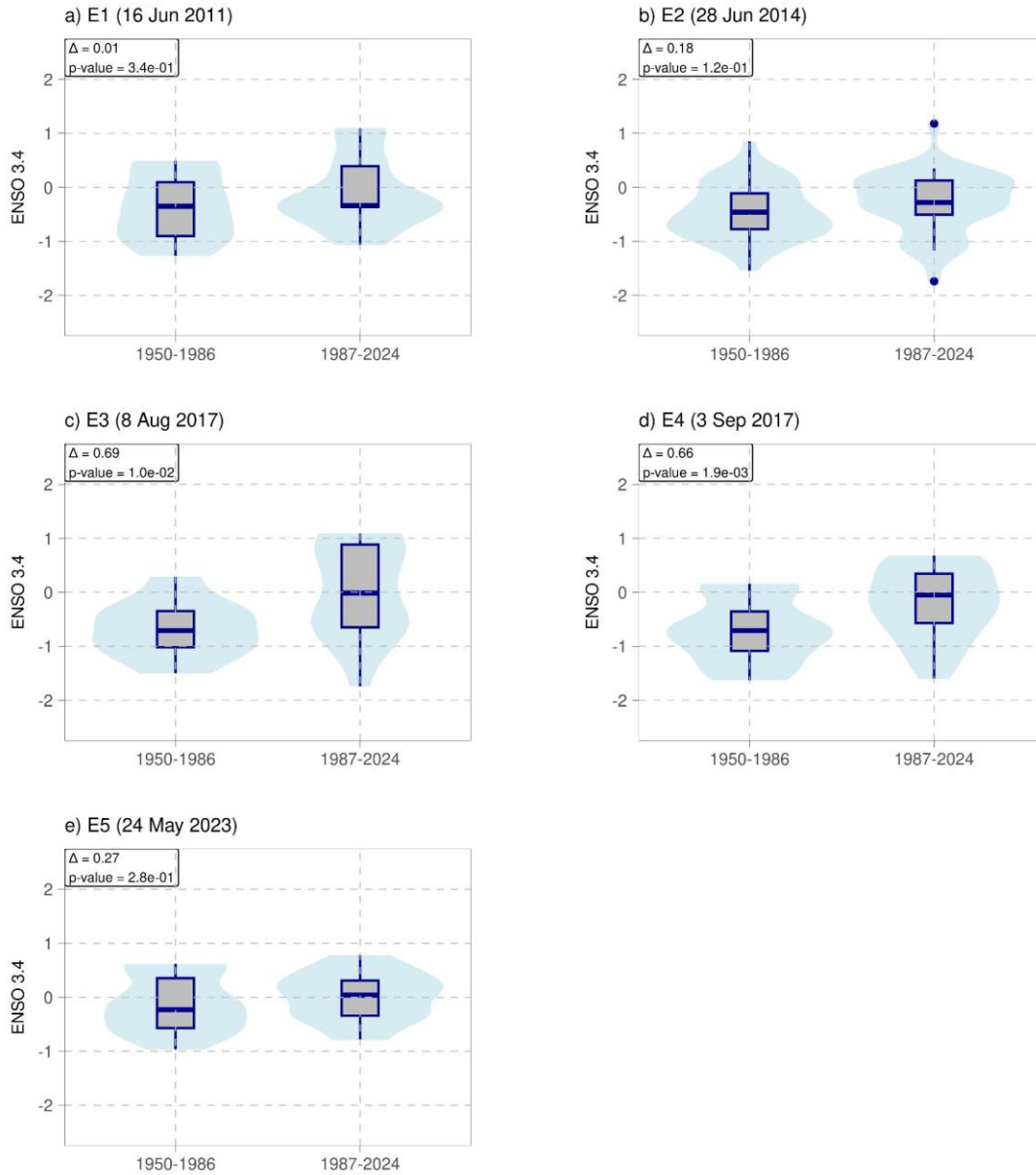


Figure S5. ENSO modulation to analogues. Monthly ENSO 3.4 index associated with days with flow analogs for the past and present periods for each event. The difference between medians for both periods and statistical significance is indicated in the box.

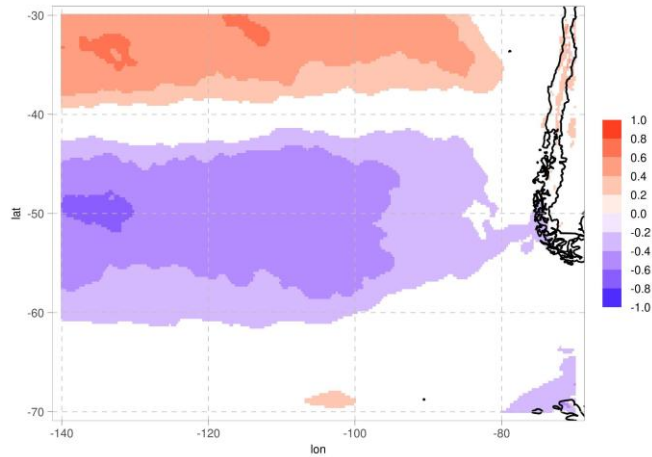


Figure S6. ENSO conditions. Pearson correlation between the detrended ENSO 3.4 index and detrended 10m wind speed in MJJAS. Only correlations that are significant at the 5% level are shaded.

	Zonal mean parameters			Total wind parameters
Climatology vs Extreme	<i>Intensity PFJ</i>	<i>Sharpness PFJ</i>	<i>Departure PFJ</i>	<i>Tilting PFJ</i>
Pvalue (Mannwhitney)	0.033	0.023	0.011	0.072
Pvalue (Ks_2samp)	0.042	0.017	0.009	0.026
Statistically significant (p<0.05)	YES	YES	YES	YES
Median difference (E-C)	7.88 m/s	7.68 m/s	-4.3 °	0.12 ° ^o

Table S1. Comparative table of significance values (p-values) between climatology and extreme events for Subtropical (top) and Polar Front (bottom) Jet parameters from Southern Hemisphere. Values were obtained using the Mann–Whitney and Kolmogorov–Smirnov tests (mannwhitneyu, ks_2samp). The last row shows the difference between medians (Extreme minus Climatology).

	Zonal mean parameters		Total wind parameters		
Climatology vs Extreme	<i>Intensity STJ</i>	<i>Tilting WB STJ</i>	<i>Lon. Ext. WB STJ</i>	<i>Intensity WB STJ</i>	<i>Intensity EB STJ</i>
Pvalue (Mannwhitney)	0.001	0.022	0.001	0.001	0.017
Pvalue (Ks_2samp)	0.002	0.015	0.002	0.001	0.002
Significative dif. (p<0.05)	YES	YES	YES	YES	YES
Median difference (E-C)	+6.2 m/s	0.059 °	15.5 °	9.15 m/s	10.96 m/s

Table S2. Comparative table of significance values (*p*-values) between climatology and extreme events for Subtropical Jet parameters from Northern Hemisphere. Values were obtained using the Mann–Whitney and Kolmogorov–Smirnov tests (mannwhitneyu, ks_2samp). The last row shows the difference between medians (Extreme minus Climatology).

	Total wind parameters		
Climatology vs Extreme	<i>Lon. Ext. WB PFJ</i>	<i>Intensity WB PFJ</i>	<i>Intensity EB PFJ</i>
Pvalue (Mannwhitney)	0.007	0.001	0.012
Pvalue (Ks_2samp)	0.028	0.001	0.040
Significative dif. (p<0.05)	YES	YES	YES
Median difference (E-C)	-11.5 °	-14.28 m/s	-5.98 m/s

Table S3. Comparative table of significance values (*p*-values) between climatology and extreme events for Polar Front Jet parameters from Northern Hemisphere. Values were obtained using the Mann–Whitney and Kolmogorov–Smirnov tests (mannwhitneyu, ks_2samp). The last row shows the difference between medians (Extreme minus Climatology). Parameters with statistically significant differences ($p < 0.05$) are shown in bold.

Event	Δ Analogs	PDO	ENSO	PNA	AO	WP	IPO
E6							
E7							
E8							
E9							
E10							
E11							

Table S4. *Effects of additional modes of internal variability in the North Pacific.* Significant changes between the past and present periods for flow analogues for each event. Arrows indicate the direction of change in the second column for 10m wind speed and in the rest for climate variability indices. The thinner arrow indicates a significant difference at 10% and the thicker one at 5%. The shading indicates how this change in climate mode affects wind speed. When there are two shades, the upper shade indicates changes in mid-latitudes and the lower shade in subtropical latitudes. The cross indicates no significant changes.