

Supplement of: El Niño-Southern Oscillation Dynamical Response to Volcanic Forcing During the Last Millennium

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Table S1: Selected volcanic eruptions between 850–1849 CE, obtained from Sigl et al., 2024

Eruption Year	Eruption Month	Eruption Day	Eruption Latitude	VSSI
939	4	1	63.6	16.23
946	11	1	42	1.72
1257	7	1	-8.4	59.42
1477	2	1	64.6	5.12
1510	7	25	64	2.3
1585	1	10	19.5	8.51
1595	3	1	4.9	8.87
1600	2	17	-16.9	18.95
1640	12	26	6.1	18.68
1667	9	23	42.7	3.48
1673	5	20	1.4	4.67
1707	12	16	35.4	1.08
1721	5	11	63.6	0.81
1739	8	19	42.7	3.44
1755	10	17	63.6	1.18
1766	4	5	64	2.52
1783	6	15	64.4	20.81
1815	4	10	-8.0	28.08
1822	10	8	-7.3	2.02
1831	7	1	46.9	12
1835	1	20	13	9.48

Table S2: Ranking of proxy reconstructions by type based on composite score metrics

Rank	Series	Frac. Valid	IAV Ratio	Var. Stability	Med. Corr. Within	Composite Score
<i>Coral</i>						
1	Zhu et al. (2022) Li13b6	0.7895	0.5751	0.8468	0.8838	0.7009
2	Zhu et al. (2022) Ocn2kCorals Li13b6	0.7895	0.4992	0.8626	0.8838	0.6776
3	Zhu et al. (2022) Corals Li13b6	0.7895	0.5014	0.8606	0.8853	0.6771
4	Wilson et al. (2010) Nino34 COAPCR	0.2558	0.5524	0.9044	0.9974	0.5644
5	Wilson et al. (2010) Nino34 COACPR	0.2558	0.5524	0.9044	0.9974	0.5644
6	Freund et al. (2019) Nino4 DJF	0.2400	0.5823	0.8907	0.8496	0.5474
7	Freund et al. (2019) Nino3 DJF	0.2421	0.5636	0.8548	0.8496	0.5099
8	Wilson et al. (2010) Nino34 zscoreCOA	0.3263	0.5555	0.7800	0.9947	0.4885
9	Freund et al. (2019) NWP DJF	0.2432	0.6055	0.8297	0.6020	0.4854
10	Freund et al. (2019) NCT DJF	0.2432	0.5612	0.8109	0.8586	0.4743
11	Tierney et al. (2015) East	0.2547	0.5285	0.8685	−0.0119	0.4233
12	Zhu et al. (2022) Corals	0.7895	0.2403	0.6369	0.4493	0.3268
13	Tierney et al. (2015) West	0.2442	0.2200	0.8331	−0.0119	0.2434
<i>Tree-ring</i>						
1	Li et al. (2011) NADA PC1	1.0000	0.8603	0.8810	—	0.8490
2	D'Arrigo et al. (2005) Nino3	0.4653	0.6837	0.8996	—	0.5954
3	Stahle et al. (1993)	0.1579	0.7804	0.9428	—	0.5709
4	Stahle et al. (1998)	0.1516	0.7513	0.9410	—	0.5534
5	Torbenson et al. (2019) eMEIall	0.1842	0.5407	0.9386	0.8935	0.5517
6	Torbenson et al. (2019) eMEIstable	0.1842	0.5334	0.9395	0.8935	0.5489
7	Li et al. (2013) Tree-rings PC1	0.5779	0.5570	0.8550	—	0.5373
<i>Multi-proxy</i>						
1	Liu et al. (2024) PCR	0.6947	0.8487	0.8574	0.5392	0.7736
2	Dätwyler et al. (2020) ENSO DJF	0.8947	0.3944	0.8449	—	0.5606
3	Geay et al. (2013) Nino3	0.7368	0.4911	0.8450	—	0.5524
4	Braganza et al. (2009) Multiproxy R5	0.3421	0.4477	0.9067	0.9470	0.5410
5	Liu et al. (2024) DD	0.6947	0.2914	0.8896	0.5392	0.5335
6	Dätwyler et al. (2019) FullPeriod PC1	0.8947	0.3607	0.7822	—	0.4933
7	Braganza et al. (2009) Multiproxy R8	0.1295	0.3671	0.9436	0.9470	0.4592
8	Wilson et al. (2010) Nino34 zscoreTEL	0.2547	0.4450	0.7989	0.9766	0.4246
9	Wilson et al. (2010) Nino34 TelecPCR TEL	0.3263	0.5077	0.7301	0.9766	0.4232
10	Mann et al. (2000)	0.2105	0.4931	0.9038	—	0.4199
11	McGregor et al. (2010)	0.2105	0.5206	0.8144	—	0.3602
12	Falster et al. (2023)	0.6842	0.1282	0.7380	—	0.2736

IAV Ratio = interannual variance ratio; Var. Stability = variance stability; Med. Corr. Within = median correlation within proxy network; — = not available

Table S3: Statistical significance of ENSO transition probability differences between eruption years and baseline conditions

Dataset	El Niño <i>p</i>	Neutral <i>p</i>	La Niña <i>p</i>
Climate Models			
BCC-CSM1-1	1.0000	0.6554	0.6661
CCSM4	0.8570	0.7774	0.7181
CSIRO-Mk3L-1-2	0.5918	0.1180	1.0000
GISS-E2-R	0.4235	0.4575	1.0000
IPSL-CM5A-LR	1.0000	0.8194	–
MIROC-ES2L	0.5382	0.8144	1.0000
MIROC-ESM	1.0000	0.5661	–
MPI-ESM-P	0.4255	0.2746	0.3416
MPI-ESM1-2	0.5755	0.5285	1.0000
MRI-ESM2-0	1.0000	0.3992	0.5428
Palaeoclimate ENSO Reconstructions			
Zhu et al., 2022 Li13b6	0.7464	0.8284	0.5028
Wilson et al., 2010 Niño3.4 COAPCR	0.5851	0.7827	0.2666
Freund et al., 2019 Niño4 DJF	1.0000	0.3715	0.6125
Li et al., 2011 NADA PC1	0.4618	0.9394	0.7857
Stahle et al., 1993	–	1.0000	0.2606
D'Arrigo et al. (2005) Niño3	0.4289	0.7537	0.8920
Dätwyler et al. (2019) ENSO DJF	0.6564	0.2792	0.2932
Geay et al. (2013) Niño3	0.2859	0.8311	0.4715
Liu et al. (2024) PCR	0.8297	0.9260	0.1903

Values show p-value (*p*). Statistically significant results ($p < 0.05$) are highlighted in bold.

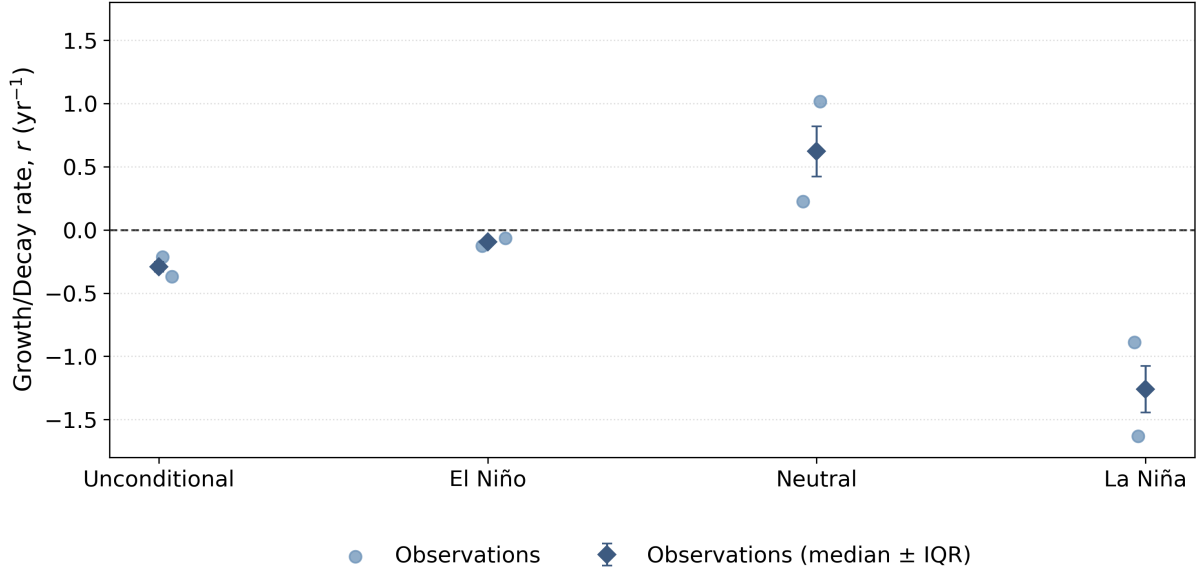


Figure S1: Observed growth/decay rate, r (yr^{-1}), for all years (Unconditional) and conditioned on the ENSO phase: El Niño, Neutral and La Niña. Circles show estimates from each observational dataset (HadISST and ERSST). Diamonds show the median across datasets, and bars show the interquartile range. The dashed line marks $r = 0$.

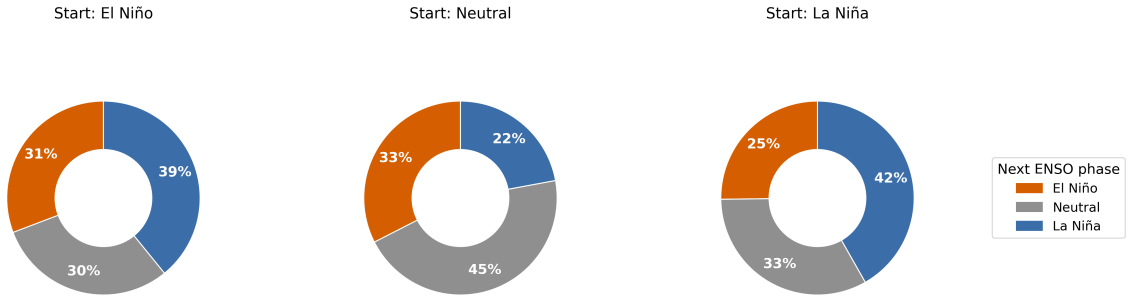


Figure S2: Observed year-to-year transition probabilities between ENSO phases. Each panel shows the percentage of years starting in (a) El Niño, (b) Neutral and (c) La Niña conditions that are followed by El Niño (orange), Neutral (grey) or La Niña (blue) conditions in the next year.