

Supplementary Table 2: U-series dating report for novel Vanuatu corals.

Sample*	²³⁸ U	²³² Th	$\delta^{234}\text{U}$	$[\frac{^{230}\text{Th}}{^{238}\text{U}}]$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	Age (kyr ago)	Age (ka)	$\delta^{234}\text{U}_{\text{initial}}$
ID	10 ⁻⁹ g/g ^d	10 ⁻¹² g/g	measured ^a	activity ^c	atomic (x 10 ⁻³)	uncorrected	corrected ^{c,d}	corrected ^b
11-TVS-B	2530.3 ± 2.7	1538.3 ± 7.6	143.0 ± 1.8	0.04218 ± 0.00011	1.1457 ± 0.0063	4.103 ± 0.013	4.028 ± 0.015	144.7 ± 1.8
05-AR-I	2627.7 ± 4.7	17 ± 24	144.6 ± 2.3	0.07341 ± 0.00041	190 ± 270	7.229 ± 0.044	7.172 ± 0.044	147.6 ± 2.4
19-TV-J	2358.4 ± 2.4	153.1 ± 2.1	140.7 ± 1.4	0.11970 ± 0.00022	30.41 ± 0.43	12.062 ± 0.028	11.991 ± 0.028	145.6 ± 1.5
19-TV-K	2320.0 ± 2.3	10.2 ± 2.2	138.1 ± 1.5	0.12266 ± 0.00040	460 ± 100	12.407 ± 0.047	12.337 ± 0.047	143.0 ± 1.6
19-TV-2	2618.7 ± 2.6	847.9 ± 2.6	134.9 ± 1.2	0.14652 ± 0.00025	7.461 ± 0.025	15.032 ± 0.033	14.955 ± 0.033	140.8 ± 1.3

*Chemistry was performed in October 2011 for 11-TVS-B, January 2007 for 05-AR-I, October 2019 for 19-TV-2, and January 2020 for 19-TV-J and -K.

Analytical errors are 2σ of the mean.

$\delta^{234}\text{U} = ([\frac{^{234}\text{U}}{^{238}\text{U}}]_{\text{activity}} - 1) \times 1000$.

^a $[\frac{^{238}\text{U}}{^{235}\text{U}}] = [\frac{^{238}\text{U}}{^{235}\text{U}}] \times 137.77 (\pm 0.11\%)$ (Ref 134); $\delta^{234}\text{U} = ([\frac{^{234}\text{U}}{^{238}\text{U}}]_{\text{activity}} - 1) \times 1000$.

^b $\delta^{234}\text{U}_{\text{initial}}$ corrected was calculated based on ²³⁰Th age (T), i.e., $\delta^{234}\text{U}_{\text{initial}} = \delta^{234}\text{U}_{\text{measured}} \times e^{\lambda_{234} \times T}$, and T is corrected age.

^c $[\frac{^{230}\text{Th}}{^{238}\text{U}}]_{\text{activity}} = 1 - e^{-\lambda_{230}T} + (\delta^{234}\text{U}_{\text{measured}}/1000)[\lambda_{230}/(\lambda_{230} - \lambda_{234})](1 - e^{-(\lambda_{230} - \lambda_{234})T})$, where T is the age.

Decay constants used for age calculation are $2.8215 \times 10^{-6} \text{ yr}^{-1}$ for ²³⁴U from Hu et al. (2025; Ref 52) and others available in Cheng et al. (2013; Ref 53).

^d Age corrections, relative to 1950 AD, were calculated using an estimated atomic ²³⁰Th/²³²Th ratio of $4 (\pm 2) \times 10^{-6}$ (Ref 135)..

Supplementary Table 3: Observational products in this study.

Product	Resolution	Variable(s)	Years (CE)	Length (years)	References
COBE	1° x 1°	SST	1850–2025	176	61
ERSSTv5	2° x 2°	SST	1854–2025	172	56
HadCRUT4.6G	5° x 5°	SSTA	1850–2017	168	63
HadCRUT5	5° x 5°	SSTA	1850–2025	176	64
HadCRUT5inf	5° x 5°	SSTA	1850–2025	176	64
HadISST	1° x 1°	SST	1870–2025	156	65
KaplanSSTv2	5° x 5°	SSTA	1856–2022	167	66
ORA-20C (reanalysis)	1° x 1°	SST, SSS	1900–2009	110	54
SODA (reanalysis)	0.5° x 0.5°	SST, SSS	1871–2010	140	55
Delcroix	1° x 1°	SSS	1950–2009	60	57

HadCRUT, HadSST, and KaplanSST products are available as monthly anomalies from the global mean. Local monthly anomalies were computed using a 1961–1990 CE climatological reference period. The ORA-20C, SODA, and Delcroix products were used to compute the forward-modelled $\delta^{18}\text{O}$ annual cycle at Kiritimati (see Extended Data Fig. 9b).

Supplementary Table 4: Vanuatu and Kiritimati coral data in this study.

Location	Sample name	Age (ka BP)	Length (yrs)	References
Sabine Bank, Vanuatu	06-SB-A	-0.025†	164	24,117
Tasmaloum, Vanuatu	11-TM-S	0.848†	100	24
Tavovusvus, Vanuatu	11-TVS-B	4.028	43	This study
Araki, Vanuatu	05-AR-I	7.172	42	This study
Tavovusvus, Vanuatu	19-TV-J	11.991	59	This study
Tavovusvus, Vanuatu	19-TV-K	12.337	38	This study
Tavovusvus, Vanuatu	19-TV-2	14.955	64	This study
Kiritimati, Kiribati	Mult. records*	-0.062	10	81
Kiritimati, Kiribati	Mult. records**	-0.049	26	23
Kiritimati, Kiribati	PP7-3	0.016	55	80
Kiritimati, Kiribati	Mult. records***	0.020	15	79
Kiritimati, Kiribati	Compilation	-0.020††	93	This study
Kiritimati, Kiribati	M2	0.457††	45	22
Kiritimati, Kiribati	P49	1.277††	18	22
Kiritimati, Kiribati	P2	1.716	20	22
Kiritimati, Kiribati	P37	2.311	25	22
Kiritimati, Kiribati	X12-D2-5	2.510	17	23
Kiritimati, Kiribati	X13-FS21-36	2.914	10	23
Kiritimati, Kiribati	XM1	2.928	18	129
Kiritimati, Kiribati	X12-D1-6	3.248	13	23
Kiritimati, Kiribati	X12-D1-4	3.414	21	23
Kiritimati, Kiribati	P26	3.498	43	22
Kiritimati, Kiribati	XM9	3.585	32	129
Kiritimati, Kiribati	X12-D2-1	3.765	20	23
Kiritimati, Kiribati	P43	3.862	43	22
Kiritimati, Kiribati	P40	3.998	47	22
Kiritimati, Kiribati	X13-FS21-51	4.118	14	23
Kiritimati, Kiribati	P34	4.144	67	22
Kiritimati, Kiribati	XM35	4.419	176	25
Kiritimati, Kiribati	X13-FS21-14	4.534	7	23
Kiritimati, Kiribati	X13-FS21-38	4.737	7	23
Kiritimati, Kiribati	X13-FS27-2	4.798	16	23
Kiritimati, Kiribati	P382	4.996	36	22
Kiritimati, Kiribati	P381	5.033	26	22
Kiritimati, Kiribati	X13-FS21-15	5.036	18	23
Kiritimati, Kiribati	X13-FS21-40	5.049	10	23
Kiritimati, Kiribati	P11	5.108	22	22
Kiritimati, Kiribati	X13-FS21-22	5.103	8	23
Kiritimati, Kiribati	X13-FS21-45a	5.136	8	23
Kiritimati, Kiribati	X13-FS21-45b	5.141	5	23
Kiritimati, Kiribati	X13-FS21-16	5.224	17	23
Kiritimati, Kiribati	X13-FS22-8	6.322	24	23

*Multiple records: X16C-D3, X16C-D4, X16C-D5, X16C-D10, X16A-D1, and X16A-D2, spliced and averaged as published.

**Multiple records: X12-6, X12-3, X14-1, X14-14, X14-7, and X14-9, spliced and averaged as published.

***Multiple records: X13-FS17-8 and X14-FS28-10, spliced with the annual cycle of PP7-3 (Ref 80) in the January 1929 CE to February 1930 CE interval.

GPS coordinates for coral collection sites are in Supplementary Table 1. Compilation at Kiritimati combines and replaces the four published records above it (Methods). Grey shading denotes coral records included in the extreme-event frequency analysis in Fig. 4. The † symbol denotes coral records included in the 1.5–0-ka reference interval for Vanuatu in Fig. 4b. The †† symbol denotes coral records included in the 1.5–0-ka reference interval for Kiritimati in Fig. 4c.

Supplementary Table 5: Background conditions and durations in CESM1.2 simulations.

Simulation	Duration (years)	Relative sea level (m)	CO₂ (ppm)	CH₄ (ppm)	N₂O (ppb)	Freshwater forcing (Sv)
2xCO2	400	0	560	760	270	0
PI control	1500	0	280	760	270	0
3 ka	500	0	275	580	270	0
6 ka	500	0	265	600	260	0
9 ka	500	-20	260	665	260	0
12 ka	500	-60	250	475	245	0
12-ka FWF	500	-60	250	475	245	0.2
15 ka	500	-100	230	475	240	0
15-ka FWF	500	-100	230	475	240	0.2

Ice sheet topography and land surface glacier extent were prescribed based on the ICE-6G_C reconstruction^{136, 137}.

Changes in vegetation are documented in Thirumalai et al.²¹ (2024). Freshwater forcing (FWF) simulations were imposed at the ocean surface of the gridded quadrant at 50–70°N, 80°W–20°E.

Supplementary Table 6: Reference intervals and thresholds for extreme El Niño frequencies.

Source data	Site	Reference interval	Variable	Percentile	NDJ threshold (units)
CESM1.2	Niño 3.4	PI control	SST	93rd	2.50 (°C)
Coral	Vanuatu	1.5-0 ka	$\delta^{18}\text{O}$	93rd	0.19 (‰)
CESM1.2	SWP	PI control	$\delta^{18}\text{O}_{\text{PSM}}$	93rd	0.23 (‰)
Coral	Kiritimati	1.5-0 ka	$\delta^{18}\text{O}$	7th	-0.19 (‰)
CESM1.2	CEP	PI control	$\delta^{18}\text{O}_{\text{PSM}}$	7th	-0.37 (‰)

The southwest Pacific (SWP; 14.5–16.5°S, 162.5–165.5°E) in CESM1.2 is the area most representative of modern Vanuatu climate conditions (Methods). The central equatorial Pacific (CEP; 2°N, 157.5°W) in CESM1.2 is the model representation for Kiritimati. Extreme El Niño frequency is the number of events century⁻¹ where the NDJ average of anomalies exceeds the threshold tailward, i.e., above the 93rd percentile threshold for Niño 3.4 and Vanuatu/SWP and below the 7th percentile threshold for Kiritimati/CEP.

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