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Supporting Information for

Equatorial Undercurrent influence on seawater $\delta^{18}O$ values in the Galápagos

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Introduction

This document contains supporting figures and tables discussed in the main manuscript. It is also contains supporting discussion of freshwater pulsing and temporal variability in the $\delta^{18}O_{sw}$-salinity relationship at Galápagos.

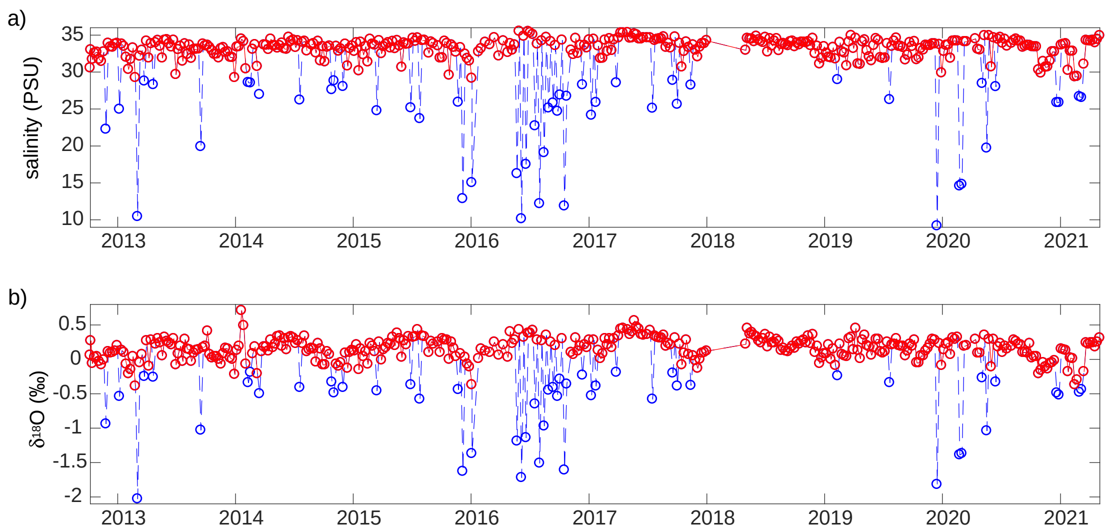

Figure S1: Weekly a) Galápagos salinity and b) $\delta^{18}O_{sw}$ values. Blue colored symbols represent freshwater pulses that are removed from calculated monthly averages.

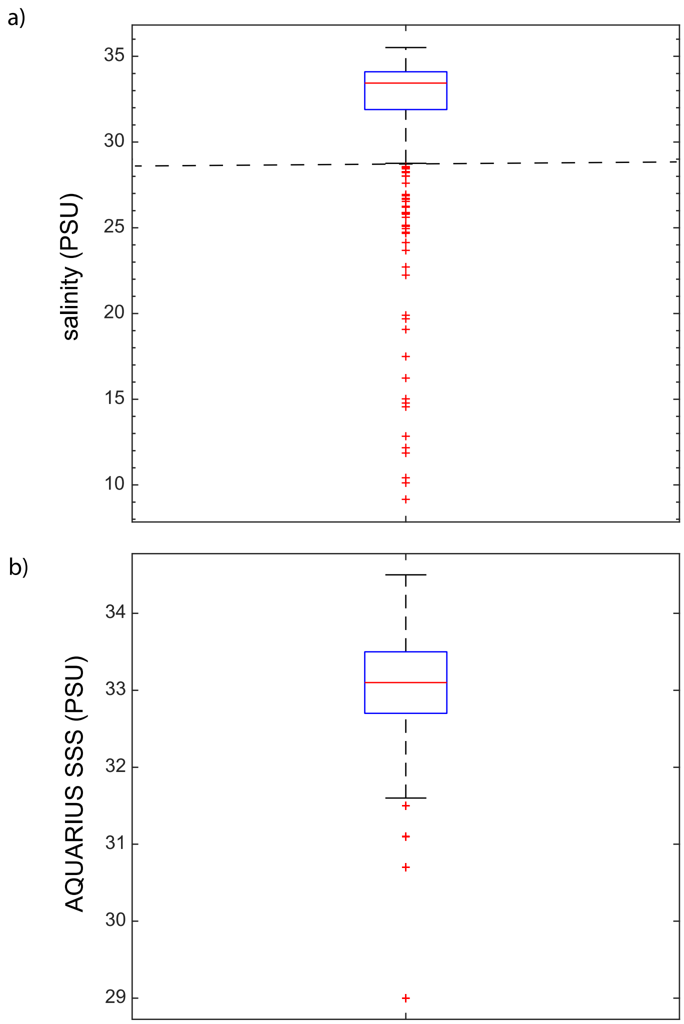

Figure S2: a) Box and whisker plot of weekly salinity measurements from October 2012 to May 2021. Values lower than 29 PSU (dashed line) that are indicated as outliers (red asterisks) are classified as coastal freshwater pulses. b) Daily NASA Aquarius v4 sea surface salinity data, 8/25/2011 to 6/7/2015, for the closest unmasked grid to the sample site (0.5°N 90.5°W).

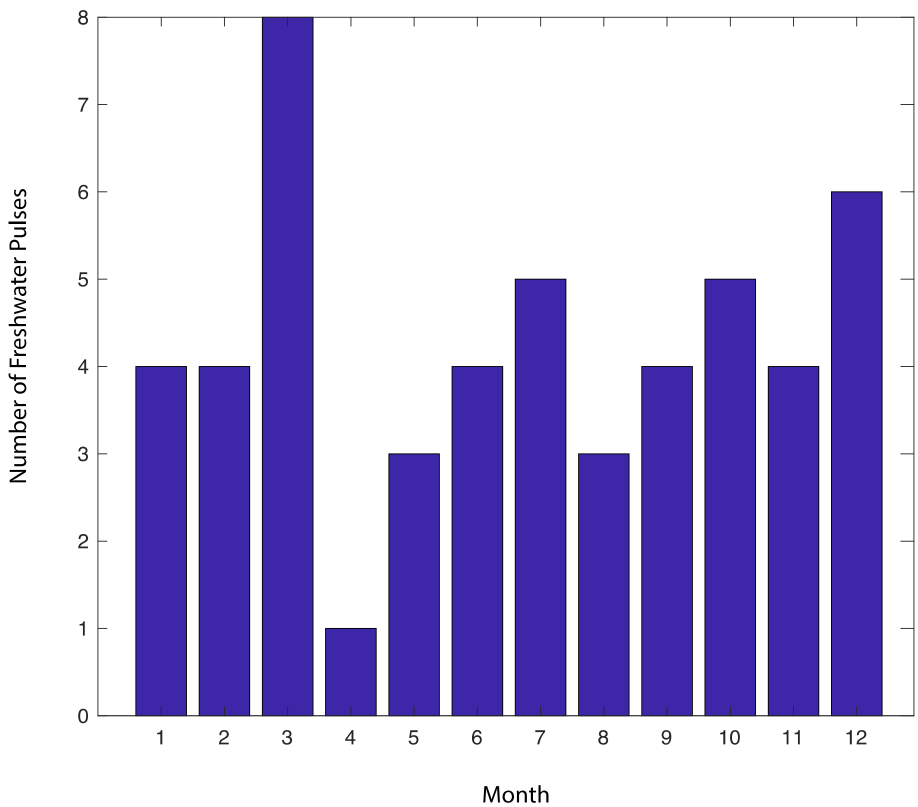

Figure S3 The number of weekly measured freshwater pulses per month during the observation period.

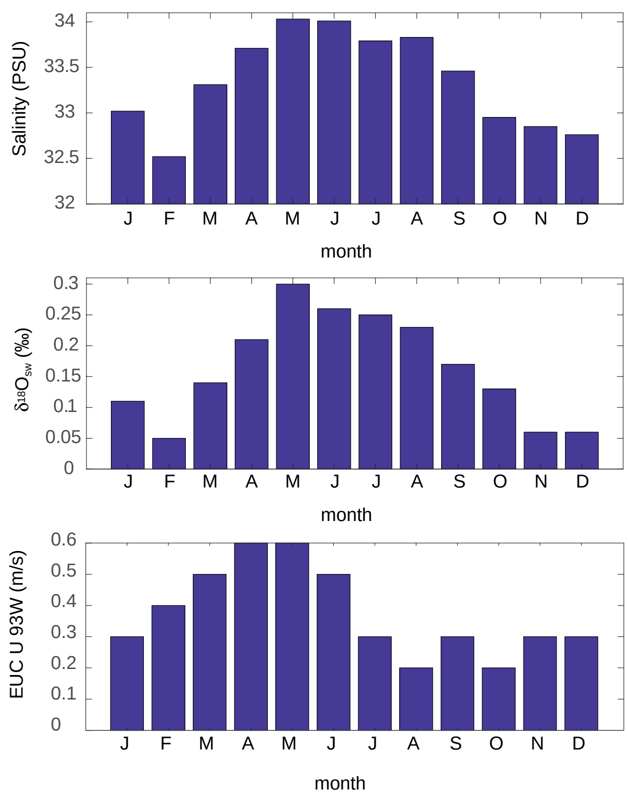

Figure S4: Seasonal cycle of monthly averaged (top panel) salinity and (middle panel) $\delta^{18}O_{sw}$, excluding freshwater pulses. Bottom panel: Seasonal cycle of monthly averaged zonal current speed at 93°W, 0.67°S-0.75°, 47 to 55 m depth.

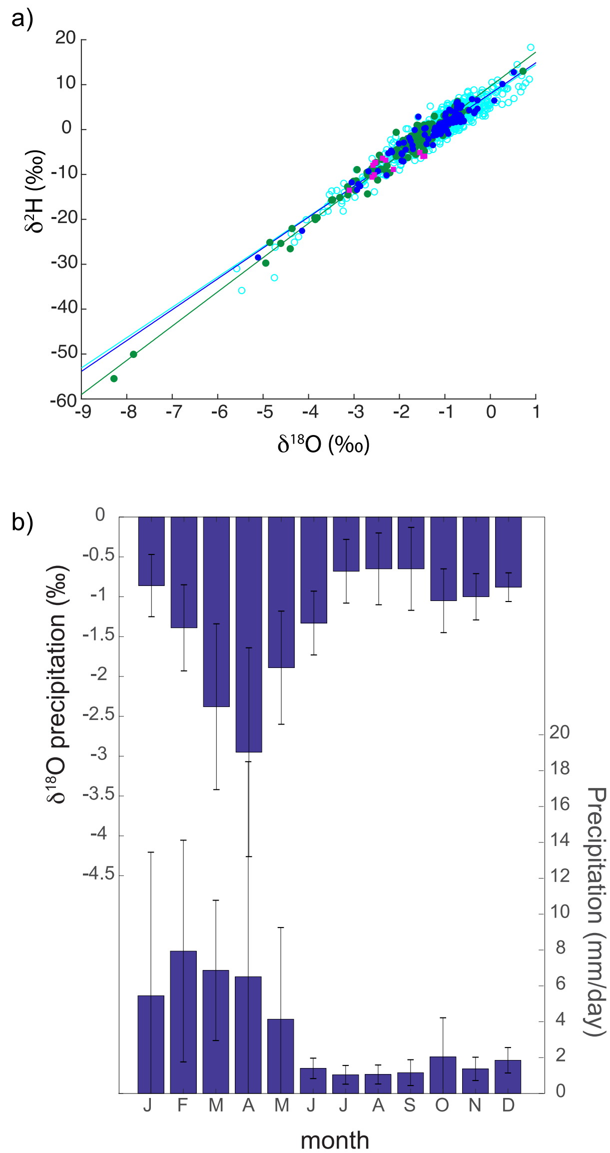

Figure S5: a) Meteoric water line of Galápagos daily (open cyan circles) and amount-weighted monthly averages (filled blue circles) from October 2012 to January 2021. Prior monthly GNIP data from Bellavista (September 1995- January 2009) are filled green circles (IAEA, 2022). Santa Cruz Island groundwater samples from Warrier et al. (2012) and this study are pink squares. b) seasonal mean precipitation $\delta^{18}O$ and precipitation rates, with 1s error bars.

Table S1: Groundwater salinity, $\delta^{18}O$, and $\delta^{2}H$ values

Sample ID	lon E	lat N	elevation	salinity	δ18O	δ2H	Date	Notes
G12i-47	-90.316	-0.757	0	13.42	-1.55	-5.09	10/9/12	Las Grietas
G15i-96	-90.312	-0.743	0		-1.44	-5.90	1/18/15	Muelle de los Pescadores
sz-1	-90.302	0.738	0		-2.13	-8.85		Warrier et al., 2012 Santa Cruz
sz-2	-90.319	-0.746	0		-2.55	-10.06		Warrier et al., 2012 Santa Cruz
sz-3	-90.326	-0.704	160		-2.6	-10.57		Warrier et al., 2012 Santa Cruz
sz-4	-90.403	-0.641	500		-3.1	-13.5		Warrier et al., 2012 Santa Cruz
G22gw-03	-90.314	-0.739	18	1.99	-2.58	-7.93	11/17/21	Escuela Crevice, sampled by bailer deep below street
G22gw-04	-90.321	-0.742	22	1.58	-2.54	-7.39	11/17/21	Pamapas Coloradas, sampled by pump, saw crevice though
G22gw-05	-90.326	-0.704	157	1.57	-2.52	-7.28	11/17/21	Pozo Profundo, sampled by pump, unclear if this is water from highland aquifer or pumped up from town
G22gw-06	-90.326	-0.704	157	1.57	-2.30	-6.80	11/17/21	Pozo Profundo, sampled by pump, unclear if this is water from highland aquifer or pumped up from town
G22gw-07	-90.302	-0.742	10	4.37	-2.37	-6.38	11/21/21	FCD dorm tap, ran bathroom sink for 30sec before sampling

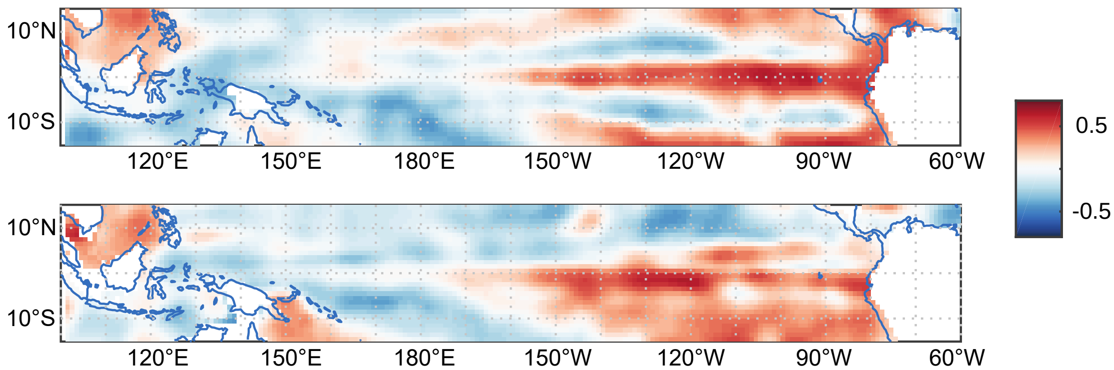

Figure S6: a) Correlation map of monthly $\delta^{18}O_{sw}$ and EN4.2.2 surface (5 m depth) salinity. b) Correlation map of monthly $\delta^{18}O_{sw}$ and 50-100 m average EN4.2.2 salinity.

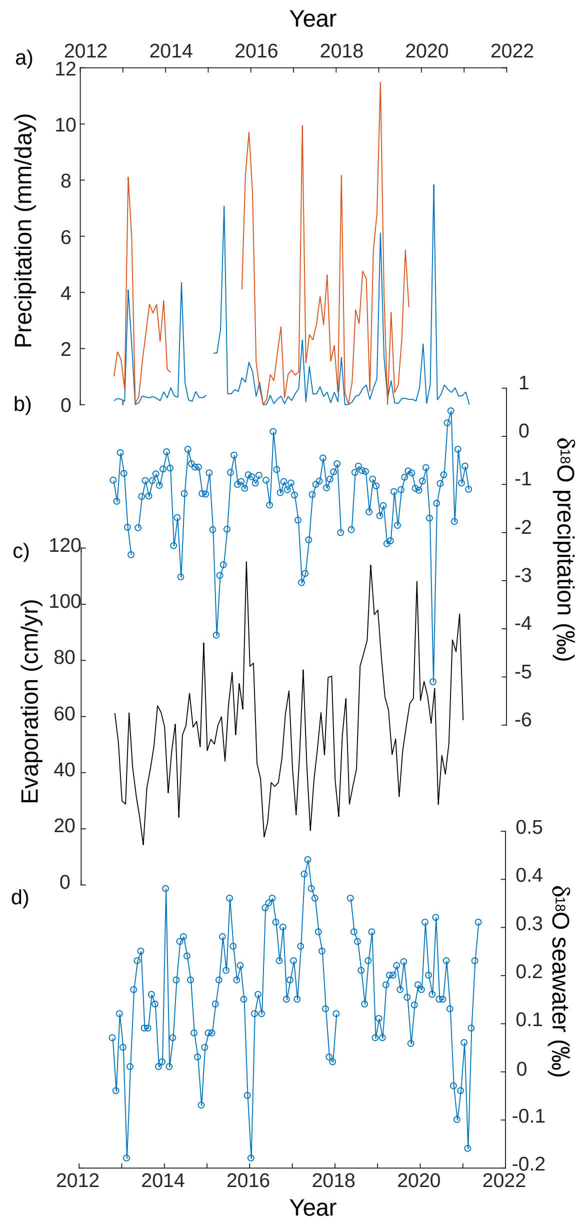

Figure S7: Monthly averaged Galápagos $\delta^{18}O_{sw}$ time series with key hydroclimatic variables a) Puerto Ayora (sea level) precipitation (blue), and Bellavista (191 masl) precipitation (orange, mm/day) b) Puerto Ayora amount-weighted precipitation $\delta^{18}O_{p}$ values (‰) c) WHOI OAflux evaporation (cm/yr) for 0.75°S, 90.3°W, d) $\delta^{18}O_{sw}$ (‰)

Table S2: Pearson correlation coefficients of monthly averaged $\delta^{18}O_{sw}$, without freshwater pulses, with select oceanic and atmospheric time series. U and V currents are surface GLORYS12 data and represent the grid cell containing the sampling site; regional correlation maps are in Figure 2 of the main manuscript. Bold values are significant ($p<0.05$). Precipitation and precipitation isotope correlations are Spearman rank (ρ) as the data are not normally distributed.

	salinity	**E**	**SST station**	**Pto Ayora Precip**	**Bellavista Precip**	**$\delta^{18}O_p$**	**U current**	**V current**	**Pto Ayora Sea level**	**20C isotherm**	**NINO1+2**
$\delta^{18}O_{sw}$	**0.86**	**-0.29**	0.10	-0.10	-0.25	-0.07	0.04	0.01	0.10	0.05	0.16

Table S3: Lagged precipitation correlation coefficients (Spearman Rank, ρ) between monthly averaged $\delta^{18}O_{sw}$ with Puerto Ayora and Bellavista precipitation. Monthly average $\delta^{18}O_{sw}$ values exclude freshwater pulses. Anomaly columns are coefficients when the long-term monthly means are removed from both the precipitation and $\delta^{18}O_{sw}$ time series. Bold values are significant at the 95% confidence value, with the Bonferroni method.

Lag (month)	**Pto Ayora- $\delta^{18}O_{sw}$**	**Bellavista- $\delta^{18}O_{sw}$**	**Anomaly: Pto Ayora- $\delta^{18}O_{sw}$**	**Anomaly: Bellavista- $\delta^{18}O_{sw}$**
0	-0.10	-0.24	-0.11	0.01
1	-0.01	-0.28	-0.08	-0.03
2	0.05	-0.30	-0.14	-0.11
3	0.01	-0.21	-0.24	-0.10
4	0.09	-0.10	-0.22	-0.19
5	-0.04	-0.12	-0.24	**-0.35**
6	-0.16	-0.04	-0.13	-0.24

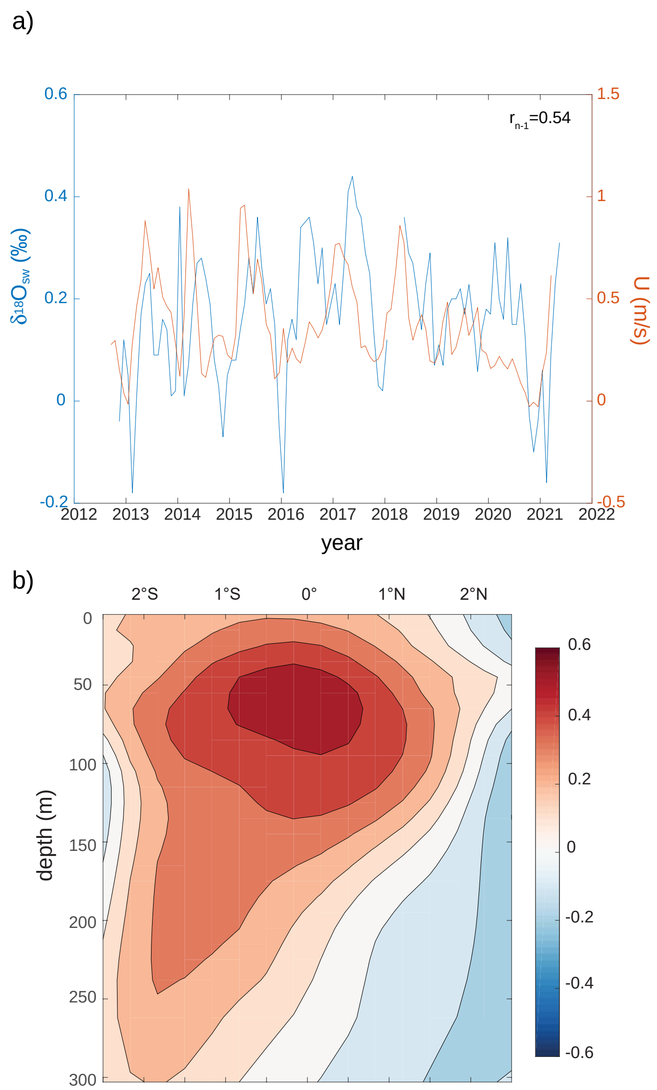

Figure S8: a) Monthly $\delta^{18}O_{sw}$ and GODAS zonal velocity averaged over 1°S-0°, 100-90°W, 55 to 105 m depth. 1 month lag applied to $\delta^{18}O_{sw}$ data. b) Correlation coefficients between monthly $\delta^{18}O_{sw}$ and GODAS zonal velocity averaged over 95.5°W from October 2012 to May 2021. 1 month lag applied to $\delta^{18}O_{sw}$ data.

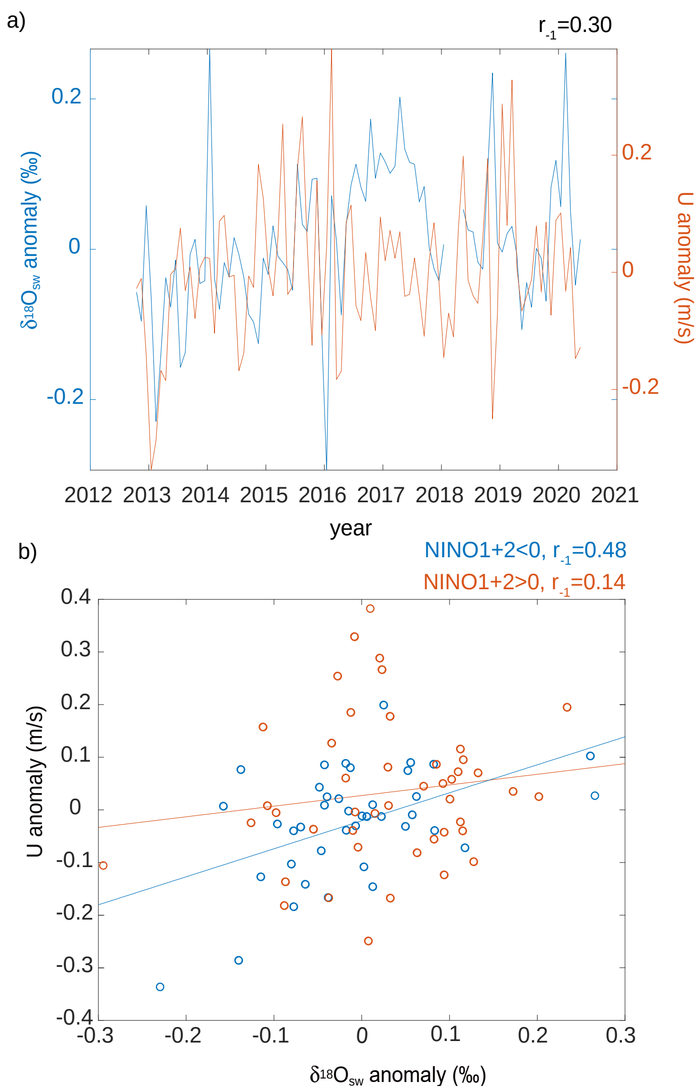

Figure S9: a) Time series of monthly anomalies of Galápagos $\delta^{18}O_{sw}$ (blue) and GLORYS12 zonal current velocity at 93°W, 0.67°S-0.75°, 47 to 55 m depth. b) Scatterplot and best linear fits of relationship between anomalies of Galápagos $\delta^{18}O_{sw}$ and GLORYS12 zonal current velocity at 93°W, 0.67°S-0.75°, 47 to 55 m depth during months when NINO1+2 values are > 0° (El Niño months, red) and < 0°C (La Niña months, blue).

Freshwater pulsing

Groundwater discharge to the coastal sea, in a volume sufficient to dilute the salinity of seawater, is an important influence on nutrient availability, carbonate geochemistry, and coastal ecosystems (Moore 1999; Garcia et al., 2017). As there is no surface runoff or drainage channels near our sample collection site, we presume that aperiodic measurements of very low salinity and $\delta^{18}O_{sw}$ are due to such groundwater discharge. The intercept of the $\delta^{18}O_{sw}$-salinity linear relationship is referred to as the 'freshwater endmember,' and theoretically should, to a degree, reflect the $\delta^{18}O$ value of the freshwater source to the ocean (Benway and Mix, 2004). The Galápagos freshwater endmember for monthly averaged data excluding the pulses is lower than measured groundwater $\delta^{18}O$ values (-4.03±0.49‰), but the freshwater endmember of the weekly $\delta^{18}O_{sw}$ -salinity data, including the pulses (-2.70±0.07‰), closely approximates measured Santa Cruz groundwater $\delta^{18}O_{sw}$ values (Table S1).

The 51 freshwater pulses identified in our dataset occur in every month of the year, but peak in March, at the height of the warm and rainy season. However, the pulses are not the direct result of rain events at the time of sampling (i.e., due to a freshwater film). Rather, we hypothesize the frequency of these pulses may be tied to increased groundwater fluxes following months with higher precipitation. Over three-month, discrete periods, there is a strong, negative relationship with three-month averaged ERA5 reanalysis SLP in the grid cell containing Santa Cruz Island ($\rho=-0.64$, $p<0.001$, $N=35$), with a lag of 4 (Figure S10). That is, periods of low SLP appear to coincide with more freshwater pulses about a year later. This may be due to enhanced precipitation over the island or platform during periods of low SLP, or pressure-induced changes in hydraulic head, or a mixture of both factors. Periods of low tides or low sea level may also drive a larger flux of groundwater to exit into the coastal waters via changes in hydraulic head or changes in tidal forces (Moore, 1999). Yet when we assess tidal and sea level data with both weekly $\delta^{18}O_{sw}$ data and only the $\delta^{18}O_{sw}$ pulse values (N=51), we do not find a significant relationship (Table S1, Table S4).

The number of freshwater pulses in 2016 was more than double compared to other years, and is likely related to low SLP a year earlier during the 2015 El Niño event. However, it also could be partly due to a seismic event on Santa Cruz on May 1st, 2016, which had a magnitude of 4.6 on the Richter Scale, and an epicenter 14 km northwest of Puerto Ayora (Institute of Geophysics of the National Polytechnic School in Quito, data accessed via https://www.volcanodiscovery.com). This was the only recorded earthquake on the island of Santa Cruz during the measurement period and preceded the period of increased freshwater pulsing, which began May 23, 2016. Movements along key faults transporting groundwater to the coast may have thus altered the rate of groundwater flux following this seismic event.

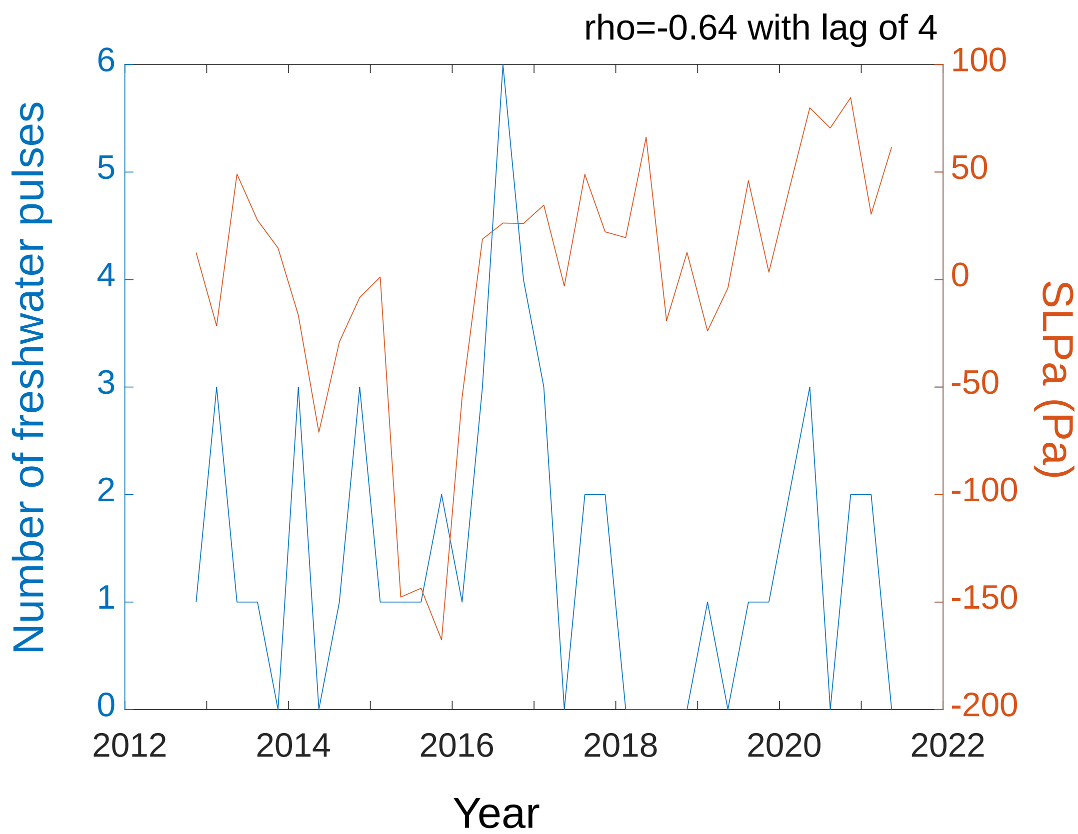

Figure S10: Number of measured freshwater pulses in discrete, 3-month periods and average ERA5 SLP anomalies over the same period.

Table S4: Assessment of relationship between freshwater pulses and potential drivers. Correlation coefficients between weekly-resolved $\delta^{18}O_{sw}$ (top row), freshwater pulses only (bottom row), and climate and ocean variables.

	daily Tide level at 6am	**daily sea level**	**Daily SLP**	**daily precipitation Puerto Ayora**
δ^{18}Osw weekly	-0.18	0.10	0.05	-0.07
δ^{18}Osw freshwater pulses	0.21	-0.12	-0.02	-0.05

$\delta^{18}O_{sw}$-*salinity temporal relationship*

The slope of the $\delta^{18}O_{sw}$-salinity linear relationship is critical for reconstructing salinity from δ^{18}O values, but its variability in space and time remains elusive (Thompson et al., 2022). The slope (and intercept) of this relationship varies spatially across large-scale water masses (LeGrande and Schmidt, 2006) and at finer scales, such as at island sites across the tropical Pacific and even in the open ocean within a given region, such as the Panama Bight (Benway and Mix, 2004; Conroy et al., 2017). Spatial relationships appear to be less than ideal in some circumstances as a substitute for temporal relationships, as isotope-enabled ocean model $\delta^{18}O_{sw}$-salinity data and the few time series of $\delta^{18}O_{sw}$-salinity that exist show interannual variability in these values can occur (Morimoto et al, 2002; Abe et al., 2009; Conroy et al., 2017; Stevenson et al., 2018).

Overall, the Galápagos $\delta^{18}O_{sw}$-salinity slope of 0.13±0.02‰/PSU is lower than the tropical Pacific average of 0.27‰/PSU or slope values in the western tropical Pacific, which range from 0.20 to greater than 0.40‰/PSU (Conroy et al., 2017; Russon et al., 2013; Stevenson et al., 2018). This low slope is a result of low precipitation rates in the eastern tropical Pacific, with most precipitation having low $\delta^{18}O$ values as its vapor source is local and has experienced less isotopic distillation. Thus, the $\delta^{18}O_{sw}$ ‰ change per PSU is lower. A 12-month running regression to assess temporal variability in slope shows some variability, as the slope varies by 0.17‰/PSU (between 0.06 and 0.23‰/PSU, Figure S11). Intercepts also range from -7.49 to –1.89‰. The cause of the variability is still unclear, but the average 12-month running mean slope and intercept values, which closely approximate the long-term slope and intercept, have standard deviations that are not much higher than those of the long-term slope and intercept (0.13±0.04‰/PSU and -4.18±1.18‰). All calculated slope values are consistently lower than calculated western Pacific values, and suggest that a relatively low slope is a persistent feature of the eastern equatorial Pacific $\delta^{18}O_{sw}$-salinity relationship.

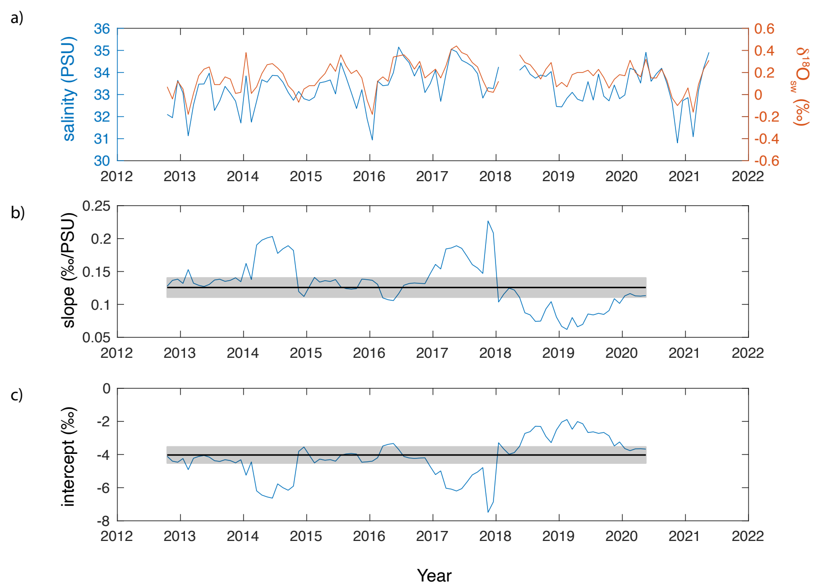

Figure S11: a) Monthly averaged $\delta^{18}O_{sw}$ (blue) and salinity (red), with freshwater pulses removed. 12-month moving calculation of $\delta^{18}O_{sw}$ w-salinity b) slope (‰/PSU) and c) intercept (‰) from monthly averaged data. Vertical line and shading in b) and c) indicate slope and intercept values and 1σ values from all monthly Galápagos data.