Reconciling coral-based reconstructions of tropical Pacific SST and salinity

Diane Thompson, Julia Cole, and Sandy Tudhope

Toby Ault, Michael Evans, Julien Emile-Geay, and Suz Tolwinski-Ward
1. How can paleo proxies inform reconstructions of ENSO diversity during the instrumental epoch?

2. What are the major sources of uncertainty in the paleo proxies and reconstructions that limit our ability to characterize past ENSO diversity?
Historical SST trends (1890-1990)

ERSSTv2

ERSSTv3

HadISST1

Kaplan extended v2

SST trend (°C/100 years)
Historical SST trends
(1890-1990)

ERSSTv2

ERSSTv3

HadISST1

Kaplan extended v2

SST trend (°C/100 years)

Coral δ¹⁸O trend (%/100 years)
Coral paleoclimate reconstructions

“massive” *Porites* sp. corals

R. Dunbar and J. Cole
Pseudocoral

$$\Delta \delta^{18}O_{\text{coral}} = a_1\text{SST} + a_2\text{SSS} + \varepsilon$$

where: $a_1$ is -0.22 ‰ VPDB/° C

$a_2$ is defined by region, ‰ VPDB/PSU

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$$\Delta \delta^{18}O_{\text{coral}} = a_1 \text{SST} + a_2 \text{SSS} + \varepsilon$$

where: $a_1$ is -0.22 ‰ VPDB/°C

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Records with 90% coverage over 1850-1990 period (Ault et al., 2009)

Linear trend slope (‰/decade)

Slope (‰/decade) (1958-1990)

Coral obs

SST & SSS
SST only

± 1 std dev.

SSS only

Thompson et al. 2011
Historical salinity trends
(1958-2001)
Ranalysis salinity trends (1890-1990)

Data from Ben Giese
Onotoa Sr/Ca, $\delta^{18}O$ & $\delta^{18}O_{sw}$ (2°S, 172°E)
Onotoa Sr/Ca, $\delta^{18}O$ & $\delta^{18}O_{sw}$ (2°S, 172°E)

NCEP RMA: $-0.0812 \pm 0.0036$ mmol/mmol per °C
Onotoa Sr/Ca, δ¹⁸O & δ¹⁸Osw (2° S, 172° E)

δ¹⁸O anomaly (%) vs. Sr/Ca-SST anomaly (°C)

Warm/wet
Dry/cold
Warm
cold
Onotoa Sr/Ca, δ¹⁸O & δ¹⁸Osw (2°S, 172°E)

Graphs showing the variation in δ¹⁸O anomaly, Sr/Ca anomaly, and δ¹⁸Osw anomaly over time (1900-2000). The graphs indicate changes in temperature and precipitation, with warm/wet conditions above and dry/cold conditions below.

(after Ren et al. 2002 and Cahyarini et al. 2008)
Onotoa Sr/Ca, $\delta^{18}O$ & $\delta^{18}O_{sw}$ (2°S, 172°E)

warm/wet

-0.13 ± 0.03‰
0.59°C

dry/cold

-0.084 ± 0.01 mmol/mol
1.03°C

NCEP RMA: -0.0812 (± 0.0036) mmol/mol per °C

warm
cold

wet
dry

0.076 ± 0.02‰
0.28 PSU
Network of paired coral Sr/Ca-δ¹⁸O

- Coral sites across equator, Galapagos to New Guinea
- Sr/Ca and δ¹⁸O ➔ new histories of SST and salinity
Sensitivity of $\delta^{18}O_{sw}$ to Sr/Ca calibration

$\delta^{18}O_{sw}$ trend 1900-2000 (‰)

- NCEP OLS
- HadISST OLS
- ERSSTv2 OLS
- ERSSTv3b OLS
- NCEP RMA
- HadISST RMA
- ERSSTv2 RMA
- ERSSTv3b RMA
Sensitivity of $\delta^{18}O_{sw}$ to Sr/Ca calibration

- OLS
- RMA

NCEP OLS
HadISST OLS
ERSSTv2 OLS
ERSSTv3b OLS
NCEP RMA
HadISST RMA
ERSSTv2 RMA
ERSSTv3b RMA

$\delta^{18}O_{sw}$ trend 1900-2000 (‰)

Slope of the Sr/Ca-SST relationship

0.65 PSU
0.09 PSU
Onotoa Sr/Ca, δ¹⁸O & δ¹⁸O_{sw} (2°S, 172°E)

δ¹⁸O anomaly (%): -0.5 to 0.5

δ¹⁸Osw anomaly (%): -1 to 1

Sr/Ca–SST anomaly (°C): -3 to 3

NCEP RMA:
- δ¹⁸O: 0.076 ± 0.02‰
- δ¹⁸O_{sw}: 0.28 PSU
- Temperature: 0.59°C±0.084 ± 0.01 mmol/mol

Warm/wet events:
-1900-1910: -0.13 ± 0.03‰
-1950-1960: 1.03°C

Dry/cold events:
-1900-1910: -0.084 ± 0.01 mmol/mol
Onotoa Sr/Ca, $\delta^{18}O$ & $\delta^{18}O_{sw}$ (2°S, 172°E)

**NCEP RMA**
- $0.076 \pm 0.02\%$
- 0.28 PSU

**ERSSTv3b RMA**
- $0.039 \pm 0.027\%$
- 0.14 PSU

**Sr/Ca–SST anomaly (°C)**
- $-0.13 \pm 0.03\%$
- 0.59°C

**δ18O anomaly (%)**
- $-0.084 \pm 0.01$ mmol/mol
- 1.03°C
Oonotoa Sr/Ca, δ¹⁸O & δ¹⁸O_sw (2° S, 172° E)

**NCEP RMA**

- δ¹⁸O anomaly: 0.076 ± 0.02‰
- δ¹⁸O_sw anomaly: 0.28 PSU

**ERSSTv3b RMA**

- δ¹⁸O anomaly: 0.039 ± 0.027‰
- δ¹⁸O_sw anomaly: 0.14 PSU

**NCEP OLS**

- δ¹⁸O anomaly: 0.15 ± 0.03‰
- δ¹⁸O_sw anomaly: 0.55 PSU

-0.084 ± 0.01 mmol/mol

-0.13 ± 0.03‰

0.59°C
A unified approach to $\delta^{18}O_{sw}$ reconstructions

- Reduced Major Axis regression
- 11 monthly paired Sr/Ca and $\delta^{18}O$ records
- Sr/Ca anomalies vs. NCEP SST anomalies: 1982-1992

**New Caledonia:** DeLong et al. (2012), Stephans et al. (2004), Quinn et al. (2002)

**Line Islands:** Nurhati et al. (2009) & Nurhati et al. (2001)

**Rabaul:** Quinn et al. (2006)

**Onotoa, Maiana, & Jarvis:** Thompson et al. (in prep)
1972-1992

**SSS trend (PSU, 1972-1992)**

-0.5 -0.25 0 0.25 0.5

**Coral trend (%o, 1972-1992)**

-0.3 -0.2 -0.1 0.1 0.2 0.3
1900-1997

SSS trend (PSU, 1900-1997)

Coral trend (‰, 1900-1997)
Conclusions

- Coral $\delta^{18}O$ records suggest a strong 20th-century warming and freshening trend
- Historical data products disagree regarding SSS trends
- CGCMs display weak and spatially heterogeneous SSS trends
- Paired coral $\delta^{18}O$-Sr/Ca records provide a means to address trends in mean state and ENSO diversity associated with BOTH SST and SSS
- However, $\delta^{18}O_{sw}$ reconstructions from corals are sensitive to the assumptions of the Sr/Ca-SST relationship
- Coral $\delta^{18}O_{sw}$ reconstructions suggest a highly heterogeneous response, but still limited by the number of available records
- We have more work to do, particularly with respect to SSS
Thanks to: Andrew Wittenberg, Ben Giese, Allegra N. LeGrande, Julia Tindall and all CMIP contributors for graciously sharing their data and to the organizers of the ENSO Diversity Workshop
Slope (‰/decade)

Reanalysis (SODA)
V2.2.4
V2.2.6

Pseudocorals (from 1. SST & SSS, 2. SST, 3. SSS)

Coral obs

GFDL CM2.1 control
CMIP3
CMIP5

Linear trend slope (‰/decade)
RCP 4.5 trend slope (2006-2100, per mil/decade)

Historical trend slope (1890-1990, per mil/decade)

- IPSL-CM5A-LR(4)
- CanESM2(5)
- IPSL-CM5A-mr(1)
- GISS-E2-R(5)
- inmcm4(1)
- EC-EARTH(1)
- HadGEM2-ES(1)
- CNRM-CM5(10)
- NorESM-1M(3)
- CSIRO-Mk3-6(10)
- MIROC5(1)
- HadGEM2-CC(1)
SSS trend (PSU/decade, 1958-1990)
SSS trend (PSU, 1958-1990)
NCAR CESM Runs 5-7

Historical SSS (SODA)

NCAR CESM1 Run 6

NCAR CESM1 Run 5

NCAR CESM1 Run 7