What can and what cannot be reconstructed from coral records: Cross-validation of corals δ^{18}O and ship-based sea surface temperatures.

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The goal of this work is the systematic mutual verification of two collections of data: all available long records of coral δ^{18}O and ship-based historical records of sea surface temperature (SST). Not only does this verification add validity to both kinds of data being compared, but it also helps to understand which type of climate information and with what expected accuracy can be objectively extracted from coral δ^{18}O records. This understanding is especially important for doing sensible reconstructions of past climates using coral data. In the future we will compare the coral results with similar verifications of other types of proxies (tree rings, ice cores) in order to characterize better the climate-recording features of each.

Our source of SST data is the recently produced analysis (Kaplan et al. 1997) of the MOHSST5 (Parker et al. 1994) product of the U.K. Meteorological Office. MOHSST5 is a $5^o \times 5^o$ monthly compilation of historical (1856-1991) ship-based observations of SST, and the analysis employs the newly developed technique of the reduced space optimal smoother to objectively extract large scale variations of SST from incomplete spatial and temporal observations. Large-scale features of the SST field are reproduced in the near-global analyzed solution, within estimated error bars, whose reliability has been verified. The small scale details (amounting to $(0.3\text{-}0.4)^2(^oC)^2$ of the local intermonthly variance) which are not constrained by the observed data are filtered out. We use annual (April to March) means for the period 1856-1990 from this SST analysis for comparisons with the coral data.

Beginning with the work of Weber and Woodhead (1972), much empirical evidence indicates that variability in the δ^{18}O of coral aragonite is a function of sea surface temperature in which the coral accreted its skeletal material. Additional δ^{18}O variability may be due to variability in the δ^{18}O of sea water, which depends on the net evaporation-precipitation balance (Gat 1996) However, derivation of the empirical relationship between δ^{18}O and SST has largely been based upon short intervals of δ^{18}O and local SST observations. We use 9 coral δ^{18}O records: all 7 long (longer than 40 years) records available from the World Data Center - A for Paleoclimatology (ftp://ftp.ngdc.noaa.gov/paleo/coral/), the Cebu record by J. Pätzold, and the record from Kiritimati atoll by M. Evans et al. (1997). These records are listed in Table 1. Resolution of the records change from monthly (TAR, KIR) to biannual (ABR). We interpolate all of them on the annual (April to March means) time grid, centralize and normalize them and compare these with like averages of the Kaplan et al. (1997) analysis of the global SST fields.

Table 1. Coral δ^{18}O records used in this work

#	Core name	Site	Location	Time period	Reference
1	AQ18	Aqaba	29.5N, 35E	1788-1992	Heiss (1994)
2	AQ19	Aqaba	29.5N, 35E	1886-1992	Heiss (1994)
3	CEB	Cebu	10N, 124E	1859-1979	Pätzold (1984)
4	ABR	Abraham Reef	22S, 153E	1635-1957	Druffel and Griffin (1993)
5	ESP	Espiritu Santo	15S, 167E	1806-1979	Quinn et al. (1993)
6	TAR	Tarawa atoll	1N, 172E	1894-1989	Cole et al. (1993)
7	KIR	Kiritimati	2N, 157W	1938-1993	Evans et al. (1997)
8	UR[86-7]	Urvina Bay	0.4S, 91.2W	1607-1953,62-81	Dunbar et al. (1994)
9	PP	Punta Pitt	0.7S, 89W	1936-1983	Shen et al. (1992)

Table 2. Comparison of coral data with SST (1856–1990): N_t, number of time points available, correlations with local SST (SST_{loc}) and with NINO3, correlations with the same when all variables are smoothed by 5- or 11-year running means filter, and correlations with timeseries found in the SVD analysis.

#	Core	N_t	Correlations		Correlations with SST_{loc} after running means filter				Correlations with SVD timeseries	
					5-year		11-year		1st	2nd
			SST_{loc}	NINO3	SST_{loc}	NINO3	SST_{loc}	NINO3	(ENSO)	(trend)
1	AQ18	135	-0.19	-0.11	-0.56	-0.01	-0.68	0.11	0.17	-0.40
2	AQ19	105	-0.16	0.10	-0.17	0.21	-0.15	0.27	0.14	-0.71
3	CEB	116	-0.22	0.06	-0.18	0.17	-0.23	0.25	0.04	-0.72
4	ABR	102	0.06	0.10	0.31	0.14	0.36	0.09	-0.44	-0.05
5	ESP	124	-0.08	0.28	0.18	0.21	0.38	-0.12	-0.50	0.48
6	TAR	97	-0.57	-0.71	-0.46	-0.60	-0.53	-0.58	0.82	0.09
7	KIR	55	-0.72	-0.79	-0.28	-0.70	-0.04	-0.71	0.89	0.30
8	UR	113	-0.37	-0.36	-0.28	-0.17	-0.37	-0.07	0.70	0.35
9	PP	48	-0.72	-0.71	-0.48	-0.59	-0.53	-0.64	0.76	0.15

Table 2 displays the number of available annual data points in coral records (inside the comparison period) and correlations of coral data with analyzed SSTs from the corresponding 5x5 degree grid box. Corals from the equatorial oceans provide the best correlations with SST: the last four δ^{18}O-SST correlations are significant at the 1% level. Among the other five stations, only AQ18 and CEB correlate marginally significantly at the 5% level with SST. In addition, maps of the correlation coefficient computed between δ^{18}O time series and the SST field show that all corals give maximum correlation to SST at locations removed from the coral site. These patterns can have real physical bases. For example, net precipitation lowers the δ^{18}O content of sea water. This makes TAR and KIR records better correlated with NINO3 (average over [150W-190W, 5S-5N], the area to the east of both sites) than with local temperature. At Tarawa (Figure 1), coral δ^{18}O variability is dominated by precipitation variability associated with ENSO (cf. Cole et al. 1993). This example suggests that proxy data may provide an integrated record of both SST and SST-covariant rainfall, which surprisingly may provide more information on large-scale features of tropical SST variability than the local SST would.

Additional, low-frequency or secular features in the δ^{18}O records may originate in non-climatic influences on the δ^{18}O of coral aragonite. The evidence for this (Table 2) is that smoothing the data does not increase their correlations with SST, with the exception of AQ18. Smoothing should rule out possible errors in coral age models as the reason for low annual correlations, as all of age models considered here have estimated uncertainties of less than ± 5 years. Nevertheless, high correlations for equatorial sites considerably decrease after switching to 5- or 11-year running means and lose their statistical significance. The influence of *very local* climate effects (e.g. the difference between pointwise SST value and averages for $5^o \times 5^o$ boxes which we use for the comparison) is unlikely, as it is not expected to be dominating on the long time scales. We are left with the conclusion that low frequency variability in coral δ^{18}O may be a function of variability in the mean disequilibrium between coral δ^{18}O and sea water δ^{18}O, which may have a complex, biological or ecological origin. These non-climatic effects start to dominate when strong interannual ENSO variability is filtered out by smoothing.

This reasoning suggests that the *individual* coral records are best for SST extraction in the limited interval of ENSO frequencies, provided the site location is right for this. However, non-climatic influence can be expected to be uncorrelated between individual cores, and thus to be eliminated in the analysis when the records are combined. We test this hypothesis by performing EOF and SVD analyses of coral and SST data. Since there are no established procedures for these kinds of analyses when there are missing data in the samples, we first reanalyze the set of coral records by

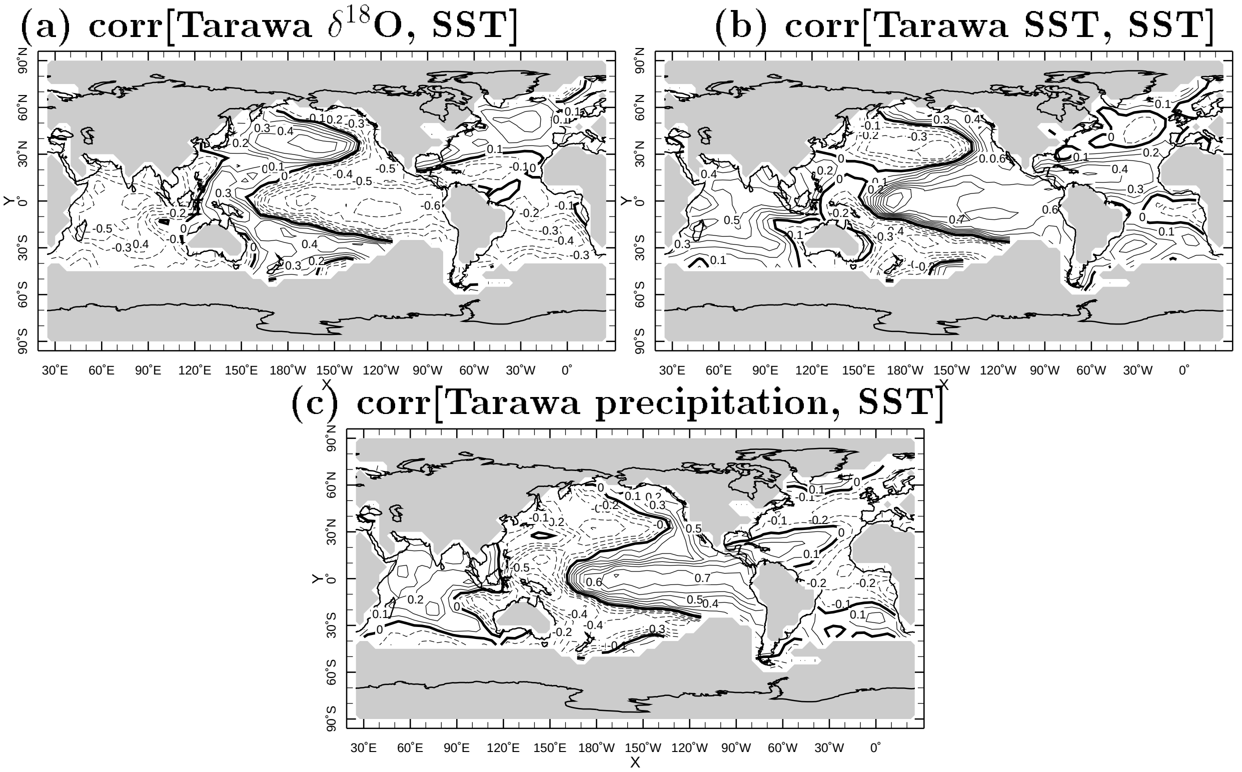

Figure 1: Correlation of Tarawa values of (a) δ^{18}O, (b) SST and (c) precipitation with global SST anomalies

performing an OI analysis on it. We estimate a location×location covariance matrix for all coral δ^{18}O data available for the comparison period (1856-1990) and use it to produce the OI solution assuming (very conservatively) the observational error in coral records of 0.5 standard deviation. This level of error also guarantees larger than 0.9 correlation of the OI solution with the original records. For the time points where there is no coral data available, the OI analysis emphasizes common cross-site features, and this is consistent with our general purpose of using the available coral data to reconstruct broad-scale features of SST variability.

We performed EOF analyses of the OI interpolated coral records and of the standardized SST timeseries for coral locations. For coral δ^{18}O records, only two leading modes of variability were found significant by Preisendorfer's ruleN and those two were easily interpretable as the ENSO mode and the "trend" mode of Cane et al. (1997). Standardized SST records had three significant EOF patterns, of which the first was that of ENSO; VARIMAX rotation was required to reveal the "trend" mode as a linear combination of the other two. The SVD analysis between coral records and SST fields retrieved the same characteristic patterns of SST variability even more clearly (Figure 2). The contributions of individual cores towards these two SVD modes are also interpretable and shown in Table 2.

Despite individual coral δO^{18} records being dominated by non-climatic influences on the long time scales, the two leading principal components of the set are similar to those of SST, although the second of them manifests a strong trend. This demonstrates the potential of objective reconstruction of SST fields from the coral data. This potential will only increase as long coral records become more abundant.

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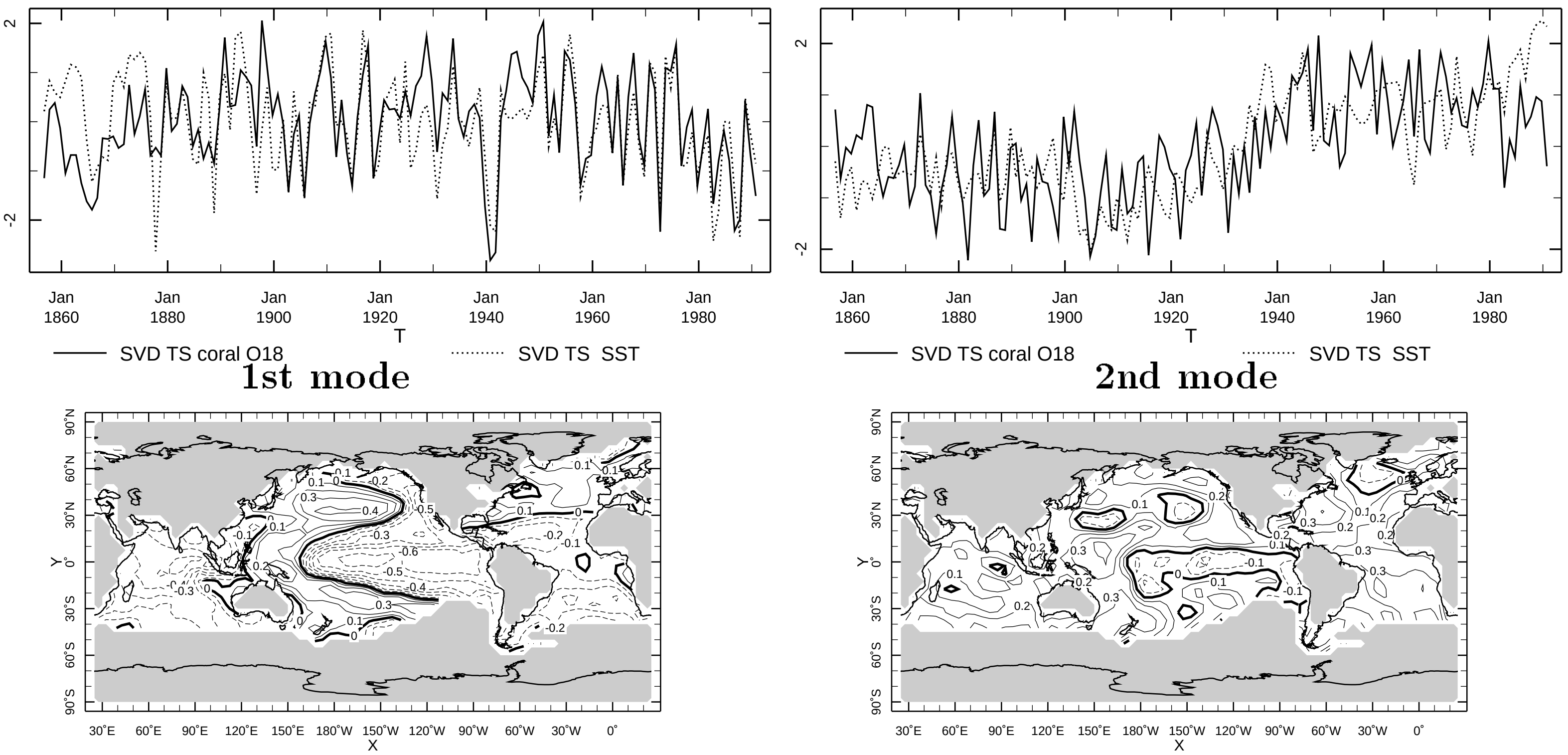

Figure 2: First two leading SVD modes of coral δ^{18}O records vs. global SST. Top panel show timeseries for these modes, while bottom ones display heterogeneous correlation SST patterns

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