Fossil coral snapshots of ENSO and tropical Pacific climate over the late Holocene

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with thanks to:  
Norwegian Cruise Lines  
Palmyra Research Consortium  
NOAA
“El Niño-Southern Oscillation”

(December 1997 SST Anomalies)

- Locations of annually-resolved climate proxy records that extend to 1500 A.D.

“ENSO-like” Decadal Variability?

(SST anomalies for proposed ~12-13 yr pan-tropical climate variability, from Cobb et al, 2001)

Zhang et al, 1997
Mantua et al, 1997

ENSO-like “Global Warming”??

(SST trend from 1949-1991, in degrees/decade, from Latif et al, 1997)
Research Objective: To generate >100-yr-long, high-resolution, high-fidelity climate proxy records from the tropical Pacific Ocean

Materials: Modern and Fossil Corals

Methods: Dating: U-Th
Climate proxy: Coral skeletal $\delta^{18}O \rightarrow f(SST, \delta^{18}O_{sw})$
During El Niño events, positive SST and precipitation anomalies both contribute to negative coral $\delta^{18}$O anomalies in the CTP.

Interpretation of coral $\delta^{18}$O on lower frequencies relies on assumption that warm SST drives higher precipitation in the CTP, and vice versa.
Climate Proxy: Coral $\delta^{18}O$

$$\delta^{18}O = \left[ \frac{(^{18}O/^{16}O)_{sw} - (^{18}O/^{16}O)_{std}}{(^{18}O/^{16}O)_{std}} \right] \times 1000$$

Coral $\delta^{18}O = f(SST, \delta^{18}O_{SW})$

Palmyra Coral Calibration

Coral $\delta^{18}O = -0.23(SST)$

$R = -0.81$

Drilled in May 1998
What about regional-scale SST? *Palmyra coral vs. NIÑO3.4 SST*
Modern Line Islands coral $\delta^{18}O$ records

Christmas Island (Evans et al., 1999)
Palmyra Island (Cobb et al., 2001)
Fanning Island (Dunbar et al., in prep; Nurhati et al., in prep)

Southern Line Islands (upcoming cruise, fall 2006, needed for resolving 20th century tropical Pacific climate trends)

$R(\text{Christmas, NIÑO3.4}) = 0.90$
$R(\text{Palmyra, NIÑO3.4}) = 0.84$
20th century trends in the tropical Pacific

How has anthropogenic CO2 forcing affected tropical Pacific climate?

**La Niña-like**: Clement et al., 1996; Cane et al., 1997

**El Niño-like**: Timmermann et al., 1999

Collection of evidence from tropical Pacific supports shift towards El Niño-like mean state

**KEY POINT**: understanding how
- temperature
- precipitation
- circulation
contributed to late 20th century coral $\delta^{18}O$ trend will help interpret low-frequency fossil coral $\delta^{18}O$ variability
Fossil corals collected during fieldtrips in 1998, 2000, and 2005

Beached fossil corals range from gravel-sized to 2m-diameter (~100-150yrs).

rare longer cores: ENSO & decadal variability

common short cores: mean climate
The Line Islands
Fossil Coral Collection

**Strategy**
- rare long cores (40-100y) for variability
- common short cores (10-20y) for mean climate
How reliable are young fossil corals?

Palmyra Island Coral Collection

Medieval Warm Period (MWP)

Little Ice Age (LIA)

young fossil – U/Th dated fidelity unknown

modern – absolutely dated fidelity proven

Date (A.D.)
Large errors associated with the presence of non-radiogenic $^{230}\text{Th}$ can be overcome with multiple U/Th dates and by dating samples of known age.

Coral $\delta^{18}\text{O}$ records are spliced together within dating uncertainty.
- absolute $\delta^{18}O$ values agree (give consistent picture of mean climate)
- large, well-reproduced El Niño events in mid-17th century
- low-amplitude, less well-reproduced decadal variability
14th-15th Century Splice

Appreciable error in mean climate estimates from single corals
- 1180-1245AD: most regular ENSO period of reconstruction (5y period)
Palmyra coral δ¹⁸O reconstruction to date

What controls ENSO & tropical Pacific climate variability over the last millennium?

Cobb et al., 2003
The ‘Ocean Thermostat’: heating $\rightarrow$ La Niña-like cooling $\rightarrow$ El Niño-like cooling

Can solar (heating) and volcanic (cooling) forcing shape tropical Pacific climate over the last millennium?

Cane-Zebiak model w/ uniform heating

annual mean SST, begin uniform heating

SST increases in West, but SST in East is buffered by upwelling of cool waters, zonal SST gradient increases

Bjerknes feedback: trades strengthen, zonal SST gradient increases

Clement et al., 1996
Does ENSO respond to solar and volcanic forcing?

**Combined response to Solar + Volcanic Forcing**

- Ensemble mean Nino3 (100 realizations of CZ model)
- Model mean (with ensemble spread)
- Palmyra coral isotopes (standardized to have same mean and standard deviation as Nino3 composite series)

Mann, M.E., Cane, M.A., Zebiak, S.E., Clement, A., Volcanic and Solar Forcing of the Tropical Pacific Over the Past 1000 Years, *Journal of Climate* 18: 447-456

![Graph showing combined response to solar and volcanic forcing with ensemble mean Nino3 and Palmyra coral isotopes.](image-url)
Large model ensemble spread still encompasses coral data, but large volcanic eruption in 1258AD a more direct test of ‘thermostat’ response.
Evidence of La Niña-like conditions from ~900-1250AD:
Mono Lake lowstands (Stine et al., 1994)
high Warm Pool temperatures (Sr/Ca MD81, Stott et al., 2004)
decreased Peru runoff (lithic counts, Rein et al., 2004)
cool Santa Barbara basin temperatures (G. bull. $\delta^{18}O$, Field et al., in prep)

Question: So how important were centennial-scale changes in tropical Pacific climate over the last millennium?
New sequences from Christmas and Fanning Islands

6.2 kypb: Fanning (4ºN) fossil coral

6.206.226.24
6.2 kypb Christmas (2ºN) modern coral

460-yr-old Christmas fossil coral

6.2 kypb: cooler, drier conditions?; reduced ENSO activity
0.5 kyp: statistically indistinguishable mean, ENSO variability wrt modern

GOAL: A unified tropical Pacific climate reconstruction from Line Islands fossil corals?
Late Holocene trends in ENSO variance

Equally important are reconstructions of tropical Pacific mean climate through the late Holocene….

Are corals up to the challenge?

Reduce error bar by using many small corals?

Are we up to the challenge?

Tudhope et al., 2001
Woodruffe et al., 2003
McGregor et al., 2004
Correge et al., 2000
Cobb et al., 2003, in progress
Conclusions

• 20th century trends consistent with trend towards El Niño-like mean conditions

• large range of ENSO variability observed over last millennium – governing mechanisms unclear

• cooler, drier conditions 900-1200A.D. – causes unknown (solar?), regional climate responses consistent (hydrological changes)

• tentative evidence of cooler, drier conditions and reduced ENSO at 6kybp, but significant scatter remains in mid- to late-Holocene fossil coral data

• new collections highlight potential to reconstruct ENSO and mean climate in central tropical Pacific quasi-continuously for last 6ky