Why study tropical Pacific climate?

-en: El Niño-Southern Oscillation
A coupled ocean-atmosphere phenomenon that originates in the tropical Pacific but affects global climate patterns

- December 1997 SST Anomalies

- the impacts are not confined to the tropical Pacific
- ENSO extremes carry serious economic and social costs
- improved ENSO forecasts minimize the costs
The instrumental record of ENSO

Devastation caused by the 1982 El Niño made ENSO prediction a top priority for U.S. and other countries.
I. Short-term Predictions

6-month prediction:  - requires careful monitoring of tropical Pacific ocean + atmosphere
- first ENSO model unveiled in 1987
- models wrongly predicted a weak El Nino event in 1997

The tropical Pacific observing system

http://www.pmel.noaa.gov/tao/
II. Long-term Predictions

Are severe El Niño events becoming more frequent?

How will ENSO change as the Earth warms?
The instrumental record of ENSO is too short to answer some key questions:

1. Are late 20th century El Niño events more frequent and more severe than those of the recent past?

2. Is there a correlation between average global temperature and El Niño activity?

3. How much and how fast has ENSO changed in the past?
Corals: The geologic record of ENSO

Living corals provide records for the last 200 years

Fossil corals enable us to extend the record (ex. 1320-1390 A.D.)

CORALS from the tropical Pacific record ENSO in the geochemistry of their skeletons

CORALS from 125 thousand years ago contain the signature of ENSO!
A new dot that extends back 10 centuries - Palmyra
Research Objective: To generate >100-yr-long, high-resolution, high-fidelity climate proxy records from the tropical Pacific Ocean; to extend the record of ENSO back in time

Materials: Modern and Fossil Corals

Methods: Dating: U-Th radioactive decay series
Climate proxy: Coral skeletal oxygen isotopes
Generating climate reconstructions from the Palmyra corals:

1) Recover the corals.

2) Prove that the coral geochemistry tracks large-scale climate. 
   ie. *Calibrate the modern coral record against the instrumental record of climate.*

3) Assess dating accuracy and reproducibility of climate signals in fossil corals. 
   ie. *Generate overlapping coral climate records when possible.*
The Palmyra Island Coral Collection

Medieval Warm Period (MWP)
Greenland green

Little Ice Age (LIA)
canals frozen in Europe
**Climate Proxy:**
Coral oxygen isotopes ($\delta^{18}O$)

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

Palmyra Coral Calibration

Coral $\delta^{18}O = -0.23(SST)$
R = -0.81
How well does Palmyra coral $\delta^{18}O$ record ENSO?

Red = instrumental record of ENSO
Black = modern coral $\delta^{18}O$

$R = -0.66$

$R = -0.84$
Test #1: Young fossil vs. Modern coral
Dating based on decay of $^{238}\text{U}$ to $^{230}\text{Th}$

To overlap corals, measure 2-5 ages for each coral sequence

Obtain ± <10y precision

Modern Coral – Fossil Coral Overlap

U/Th date 1= 1895+20-2
U/Th date 2= 1903+14-2
Absolute date = 1915

U/Th date 3= 1917+37-2
U/Th date 4= 1920+30-2
U/Th date 5= 1925+20-2
Absolute date = 1936

Cobb et al, EPSL, 2003
Test #2: Fossil coral vs. Fossil coral

Palmyra Island Coral Collection

Date (A.D.)
17th Century Splice

3 corals, 13 dates, 3,000 $\delta^{18}O$ measurements
14th-15th Century Splice

SB7 vs. CH9
R = 0.68

SB5 vs. CH5
R = 0.71

SB6 vs. CH5
R = 0.69

5 corals, 29 dates, 14,000 $\delta^{18}$O measurements
Palmyra Coral $\delta^{18}$O Sequences

Cobb et al., Nature, 2003
An extended history of ENSO from the Palmyra coral records

Most frequent, intense El Niño events of reconstruction can change in less than a decade.

1997 El Niño
Proxy-proxy comparison for last millennium

- Rate, magnitude of 20th century climate change unprecedented
- No simple relationship between tropical Pacific climate and NH temp, solar, or volcanic forcing
- Warm during “Little Ice Age”, cool during “Medieval Warm Period”
- Changes in the meridional temperature gradients implied (inc. during LIA, dec. during MWP)
Summary

Coral $\delta^{18}O$ is a sensitive, reliable proxy for tropical Pacific climate change.

Overlapping corals 1) enables the construction of longer records
2) increases confidence in climate reconstructions

Most intense ENSO activity occurred during 17th century, during “Little Ice Age”.

ENSO characteristics can change dramatically from decade to decade.
Food for Thought

Coral reefs are disappearing at alarming rates worldwide, due to the combined influence of rising ocean temperatures and human disturbances (pollution, dynamite fishing, etc).

Even if ENSO does not change in a “greenhouse world”, Man has perturbed the environment to the point that an El Niño event could be the “straw that breaks the camel’s back”.

Web Resources

My homepage: http://shadow.eas.gatech.edu/~kcobb

General El Niño info: http://www.pmel.noaa.gov/tao/elnino

NOVA El Niño page: http://www.pbs.org/wgbh/nova/elnino/

Data available at:
http://www.ngdc.noaa.gov/paleo/paleo.html
Gunung Buda Speleothem Project

Goal: to reconstruct annual to centennial-scale rainfall variability from an ENSO-sensitive region over the last glacial cycle

Materials: ~40 speleothems (0.1 – 1.8m long)

Dating: U-series geochemistry

Climate proxies: growth rate, $\delta^{18}$O, $\delta^{13}$C, Sr/Ca, Mg/Ca, optical properties

Approach: 1. On-site geochemical calibration  
2. High-precision U/Th dates  
3. Reproducibility tests  
4. billions and billions of datapoints
U/Th dating results to date

NOTE: stalagmites have infinite resolution (1 drop every 30 seconds to 10 minutes), temporal resolution of climate records limited only by analytical capabilities (in other words, how low can you go?)
How are precipitation changes recorded in cave dripwater geochemistry?

Borneo experiences severe drought during El Niño events.