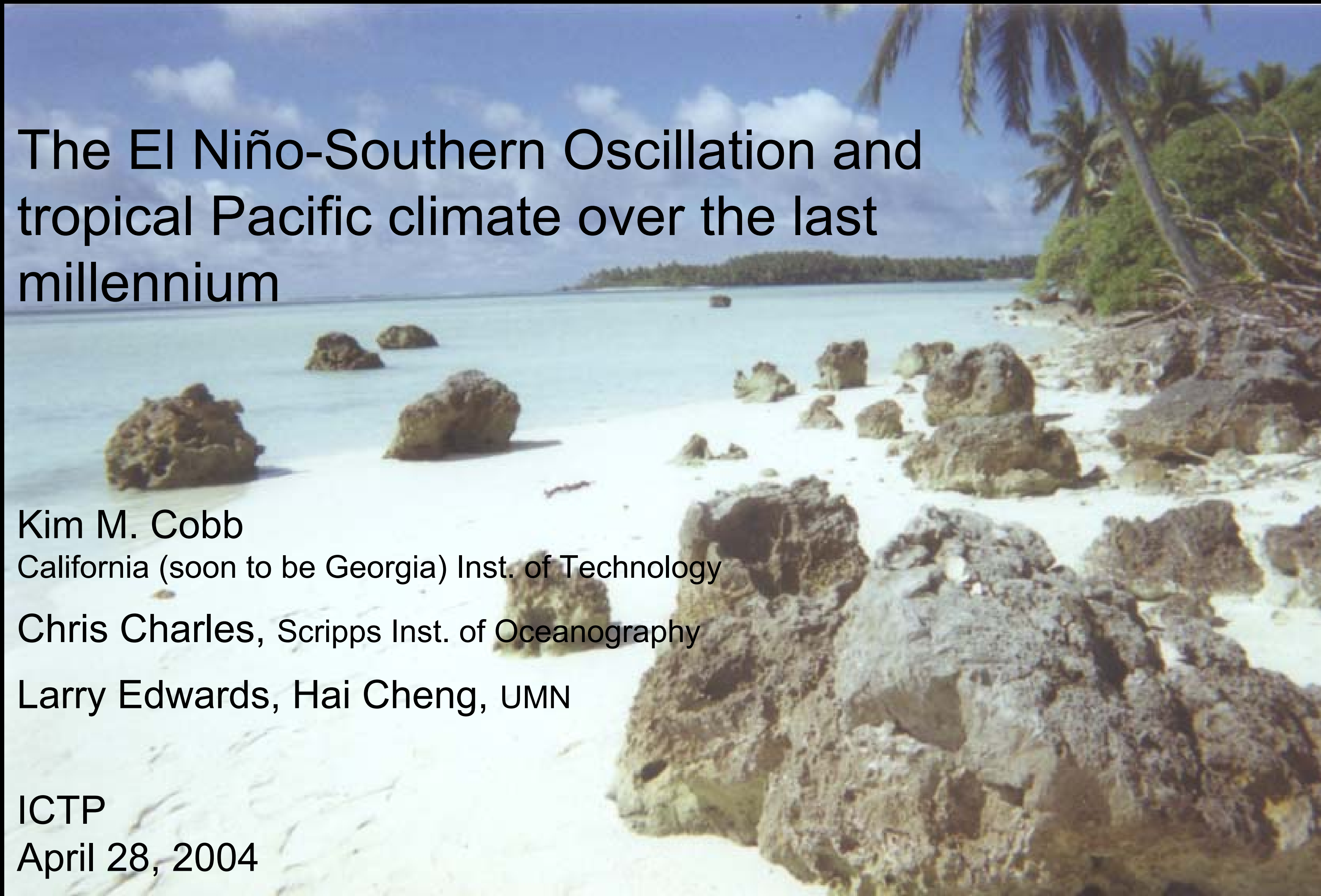

The El Niño-Southern Oscillation and tropical Pacific climate over the last millennium

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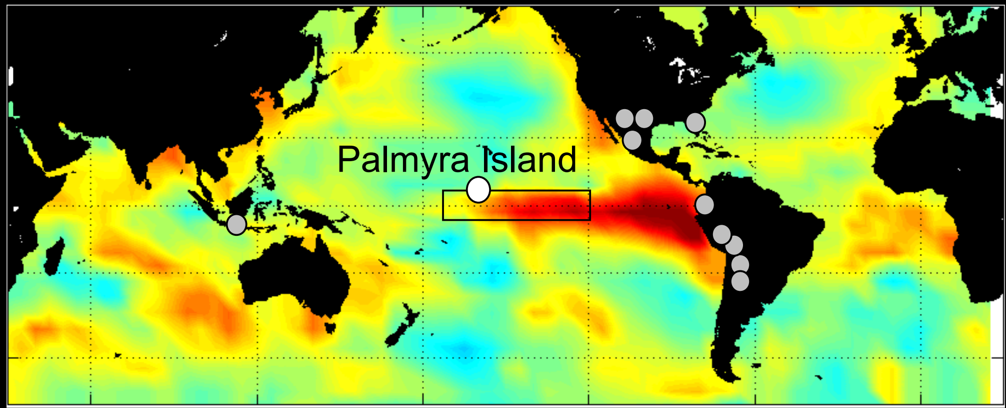
Chris Charles, Scripps Inst. of Oceanography

Larry Edwards, Hai Cheng, UMN

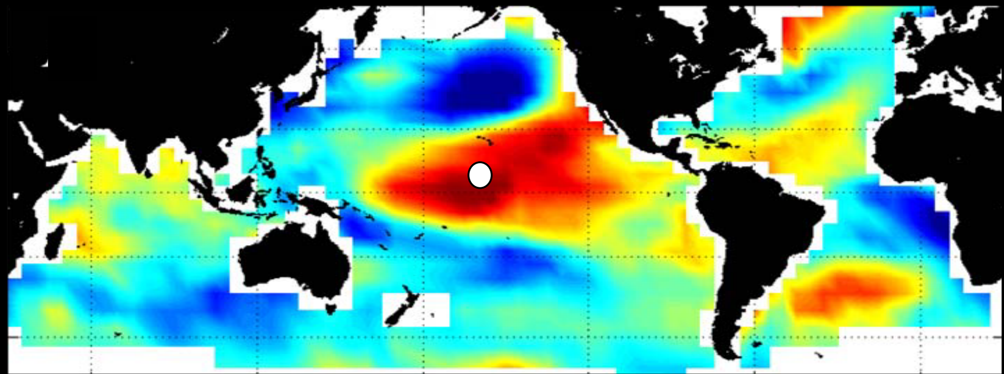
ICTP
April 28, 2004



ENSO
“El Niño-Southern Oscillation”

December 1997 SST Anomalies

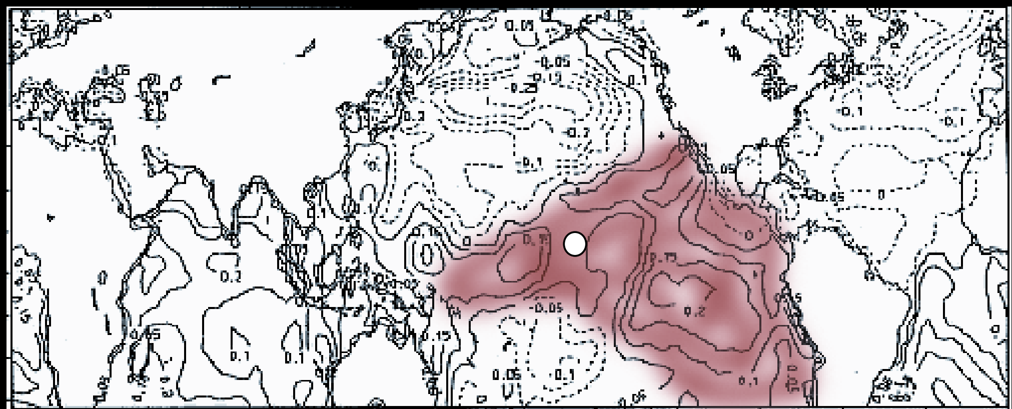
● Locations of annually-resolved climate proxy records in the tropics that extend to 1500A.D.



“ENSO-like” Decadal Variability?

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

Zhang et al, 1997
Mantua et al, 1997



ENSO-like “Global Warming”??

SST trend from 1949-1991, in degrees/decade (*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

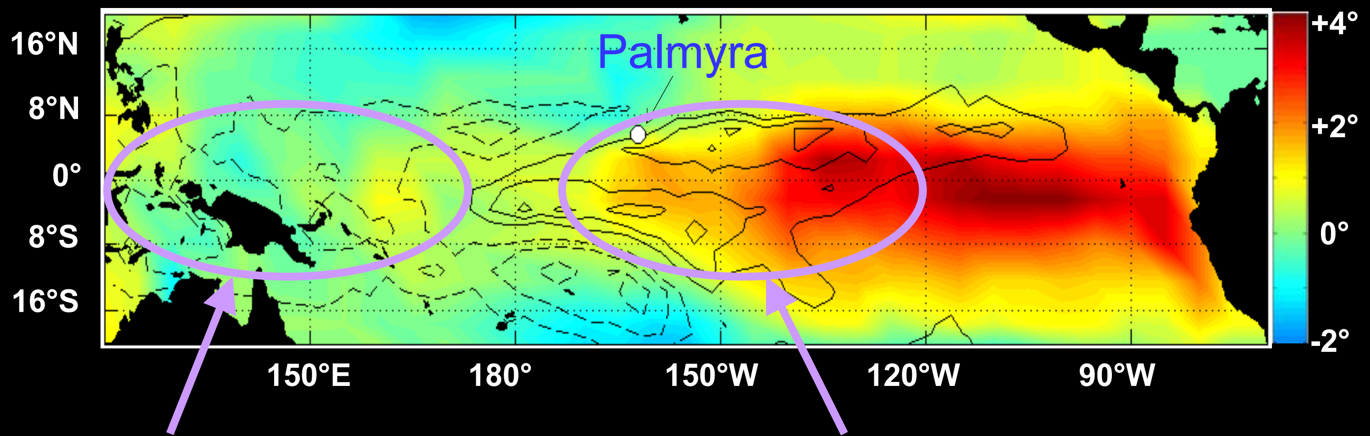
Methods: Dating: U-Th

Climate proxy: Coral skeletal $\delta^{18}O \rightarrow f(SST, \delta^{18}O_{sw})$

ENSO and coral $\delta^{18}O$ at Palmyra

SST and rainfall anomalies for the 82-83 El Niño event

Color = SST anomaly (°C), contours = rain anomaly (CI 10 cm/month)



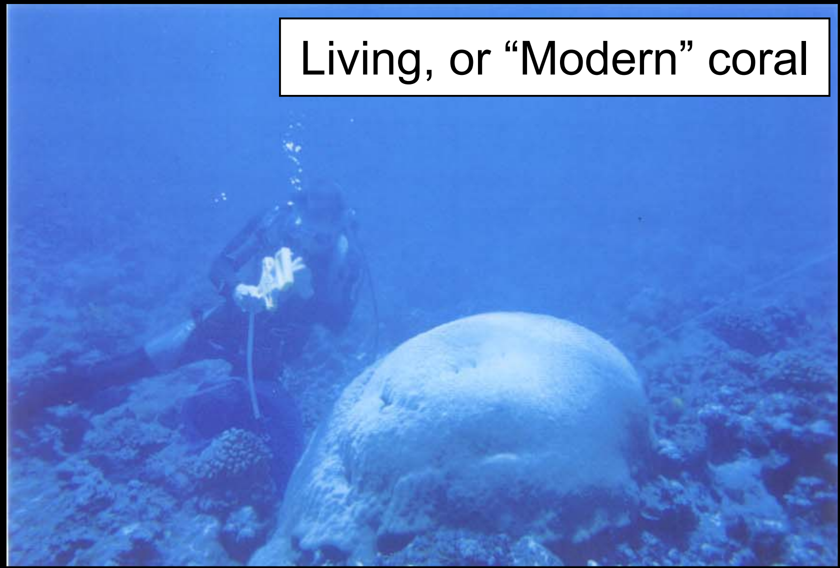
Warm Pool

Little SST change (~0‰)
- precip. (+$\delta^{18}O$)
Net: +$\delta^{18}O$

Central tropical Pacific

+ SST change (-$\delta^{18}O$)
+ precip. (-$\delta^{18}O$)
Net: -$\delta^{18}O$

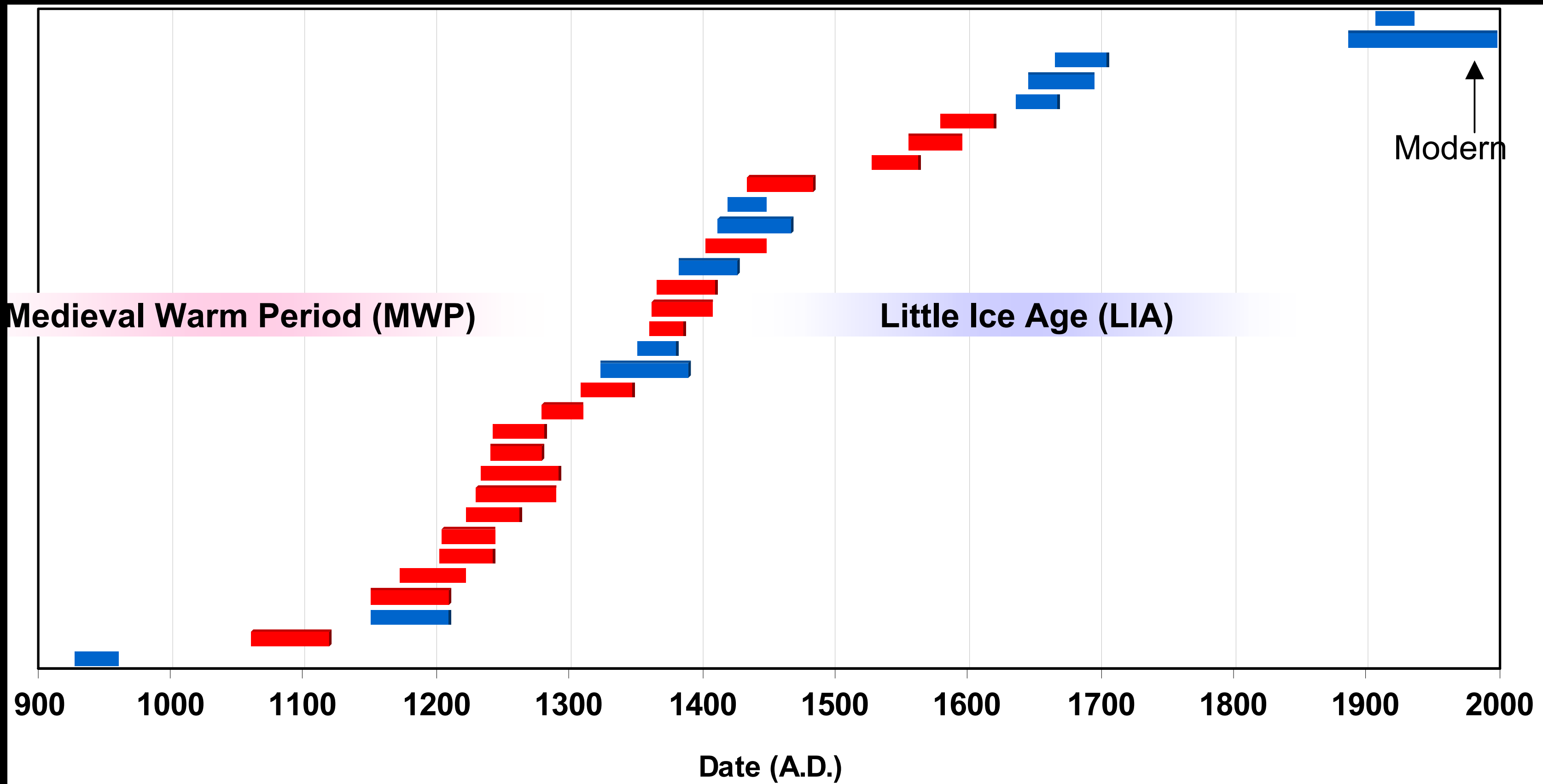
Palmyra experiences positive SST and rainfall anomalies during El Niño events, which both lead to lower coral $\delta^{18}O$ values.



Most corals at Palmyra grow in ~10m water depth.

Large fossil coral heads are strewn on ocean-facing beaches.

The Palmyra Island Coral Collection



Research Questions:

1) How well does the Palmyra modern coral $\delta^{18}O$ reflect 20th century tropical Pacific climate variability?

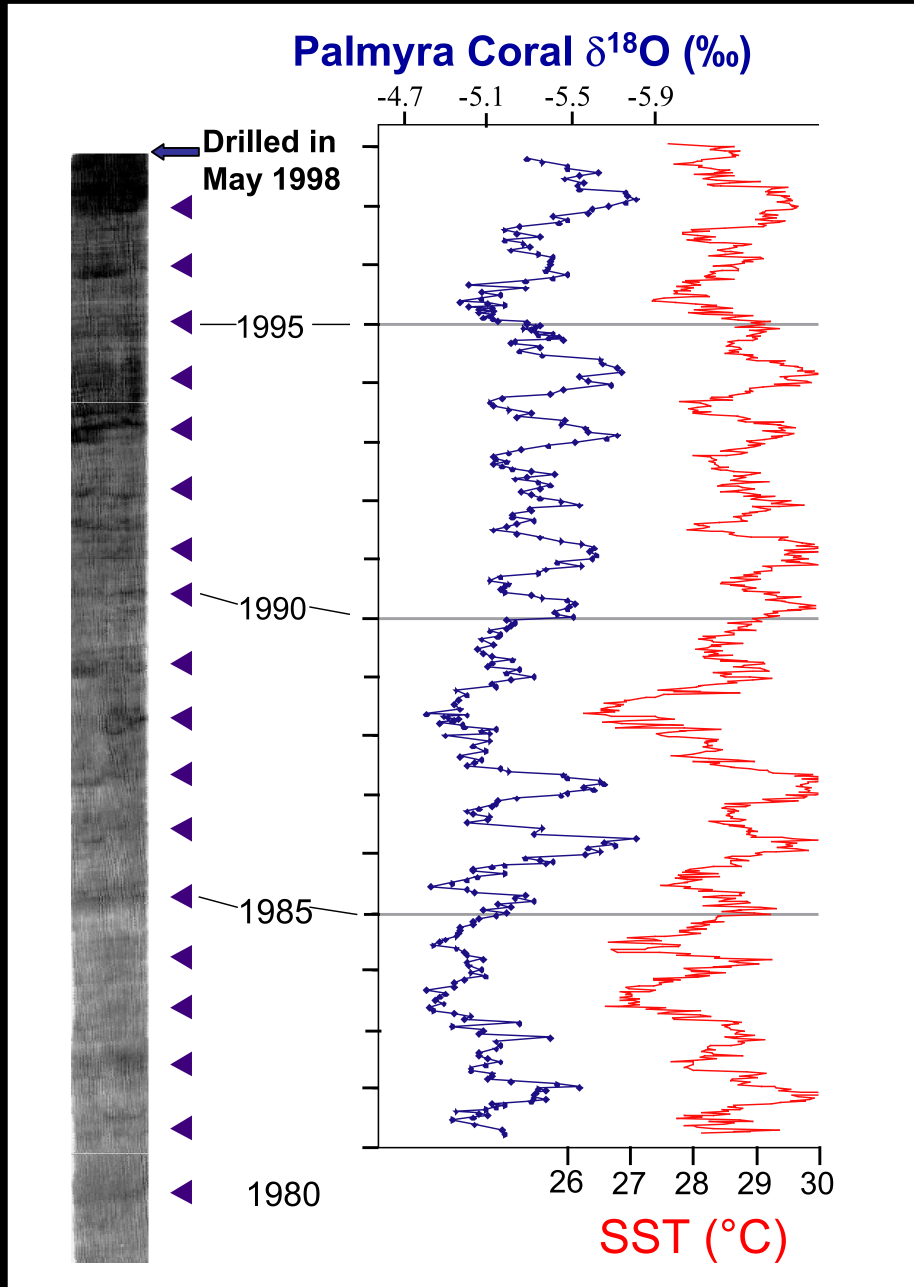
2) Can we splice fossil coral sequences together to generate longer records?
   Requires: i. accurate, precise dating of fossil corals
   ii. high reproducibility of fossil coral $\delta^{18}O$

3) What is the natural range of tropical Pacific climate variability on interannual to centennial timescales over the last millennium and how does it relate to extratropical climate variability?

Climate Proxy: Coral $\delta^{18}O$

$$\delta^{18}O = \left[\frac{\left({}^{18}O/{}^{16}O\right)_{spl} - \left({}^{18}O/{}^{16}O\right)_{std}}{\left({}^{18}O/{}^{16}O\right)_{std}}\right] x1000$$

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

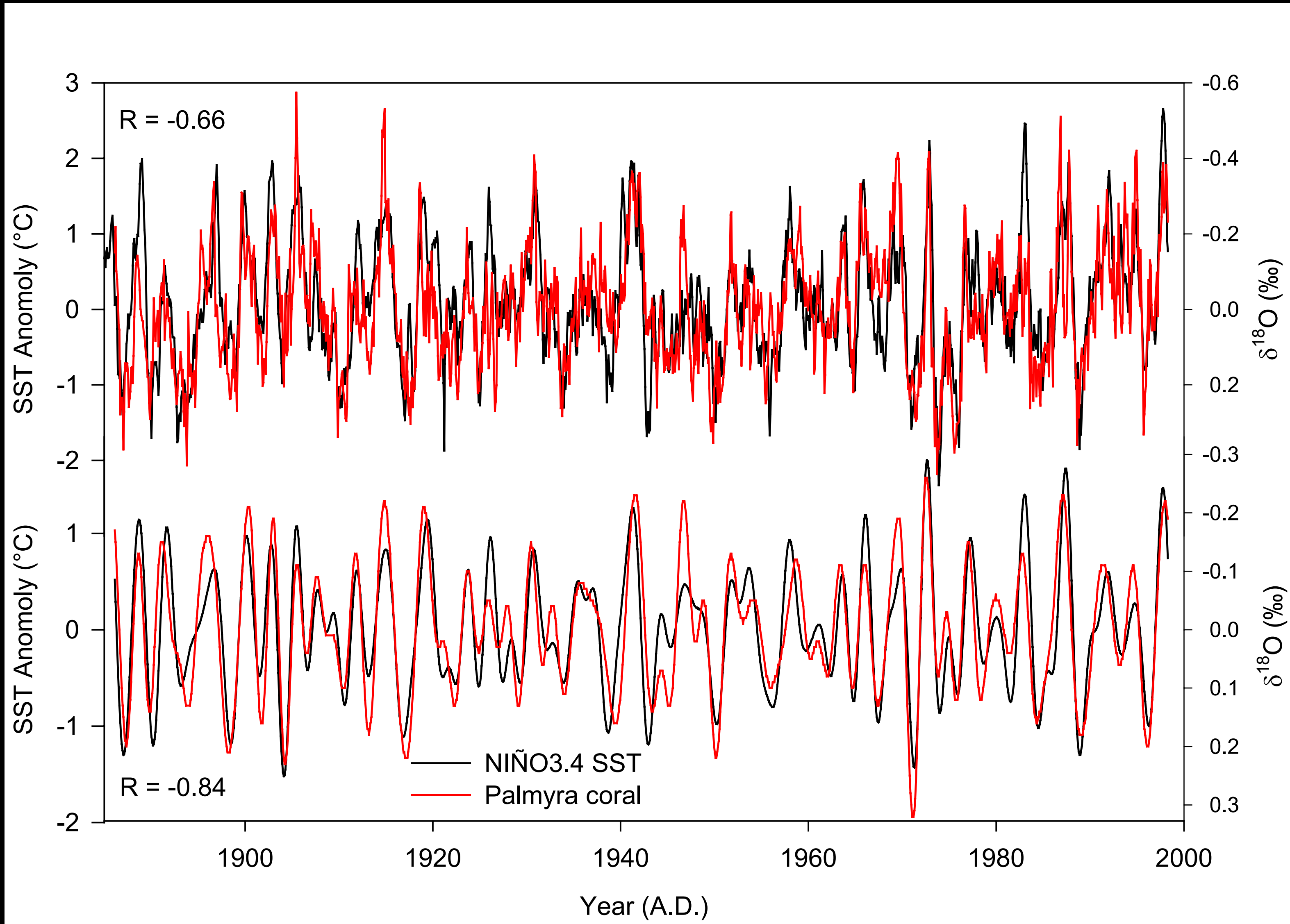


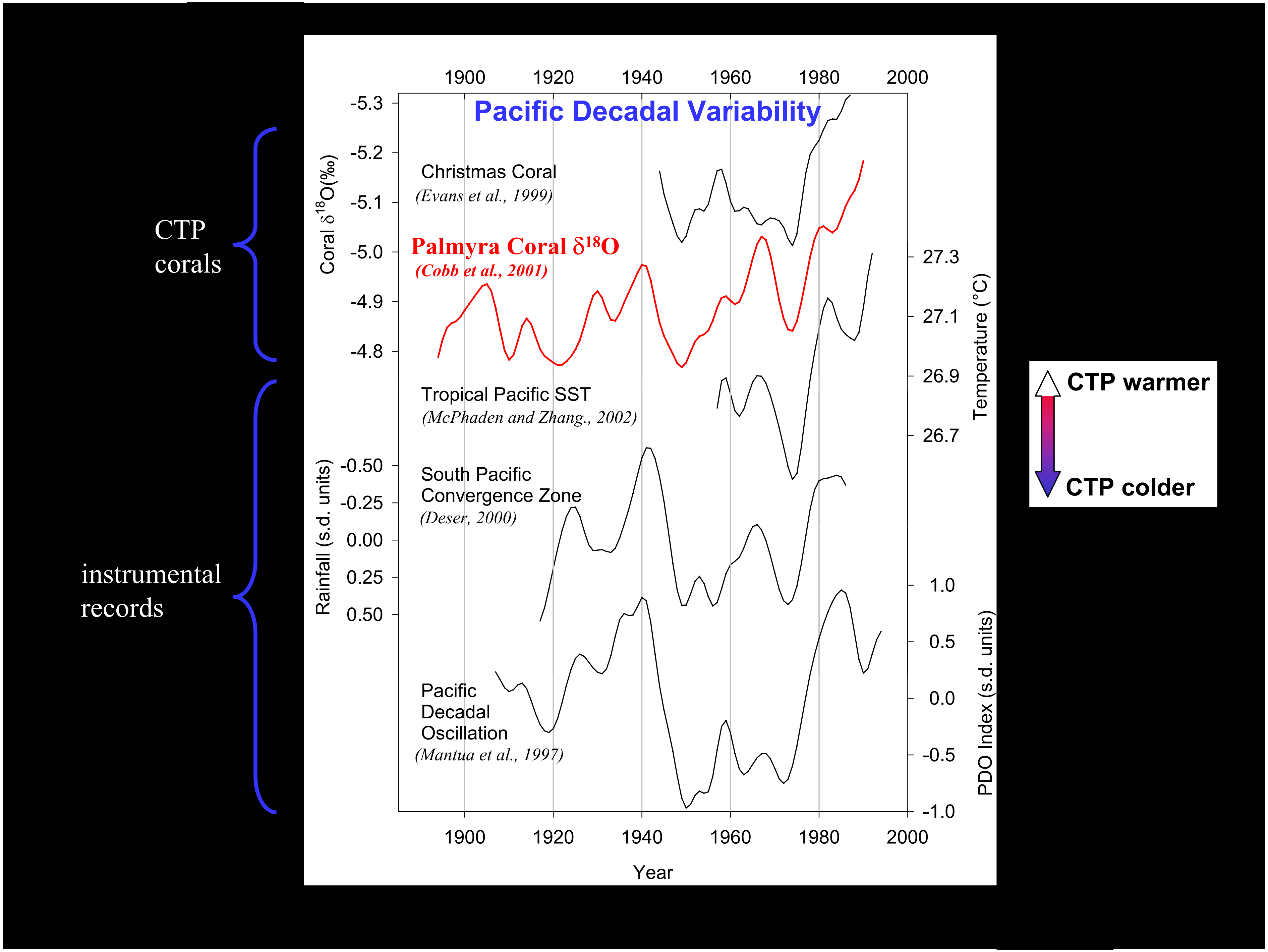
Palmyra Coral Calibration

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

$R = -0.81$

What about regional-scale SST? *Palmyra coral vs. NIÑO3.4 SST*





CTP corals
instrumental records
Pacific Decadal Variability
Christmas Coral
(Evans et al., 1999)
Palmyra Coral δ18O
(Cobb et al., 2001)
Tropical Pacific SST
(McPhaden and Zhang., 2002)
South Pacific Convergence Zone
(Deser, 2000)
Pacific Decadal Oscillation
(Mantua et al., 1997)
Coral δ18O(‰)
-5.3
-5.2
-5.1
-5.0
-4.9
-4.8
Rainfall (s.d. units)
-0.50
-0.25
0.00
0.25
0.50
Temperature (°C)
27.3
27.1
26.9
26.7
PDO Index (s.d. units)
1.0
0.5
0.0
-0.5
-1.0
1900
1920
1940
1960
1980
2000
Year
CTP warmer
CTP colder

Research Questions:

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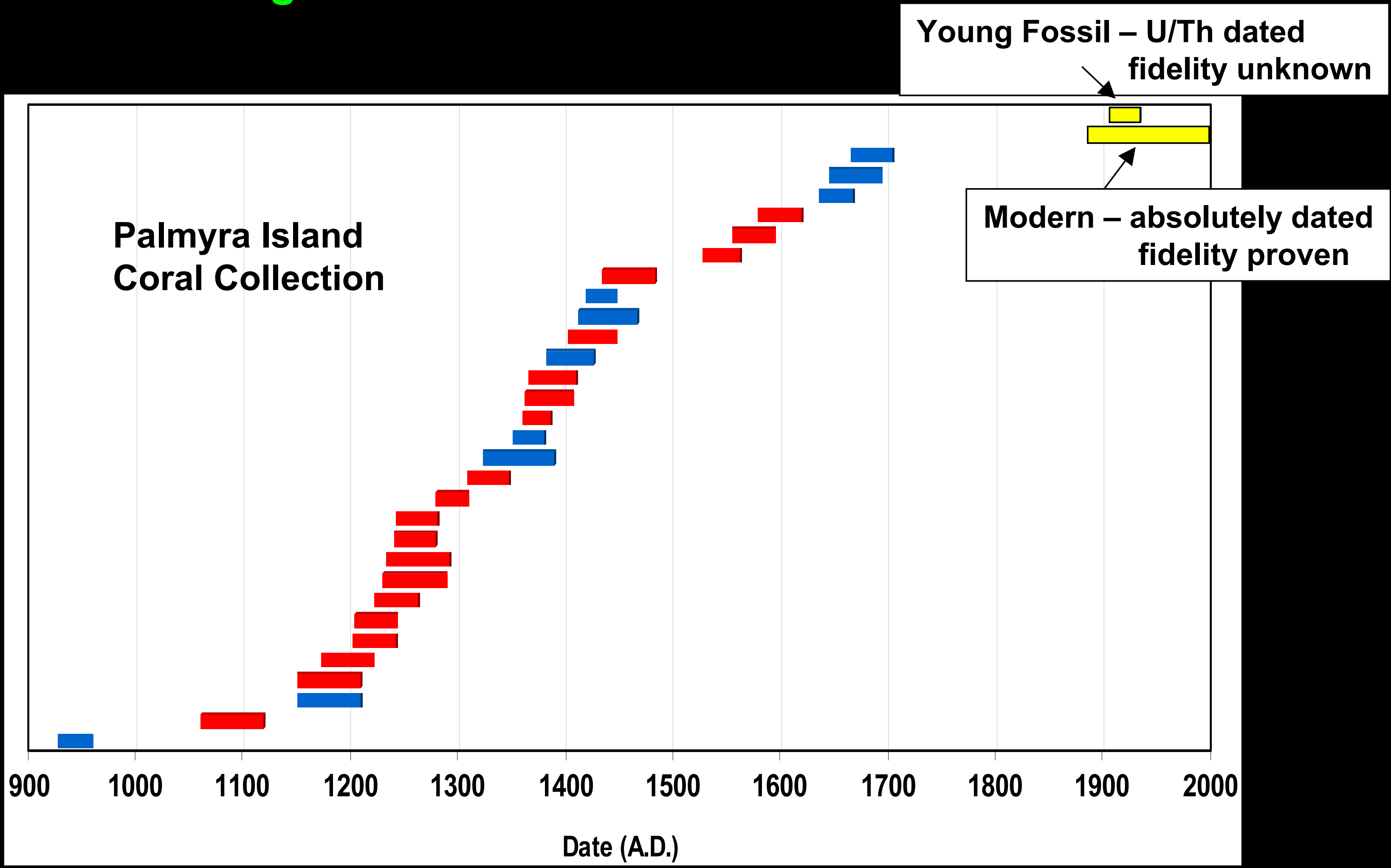
Test #1: Young fossil vs. Modern coral



Modern Coral – Fossil Coral Overlap

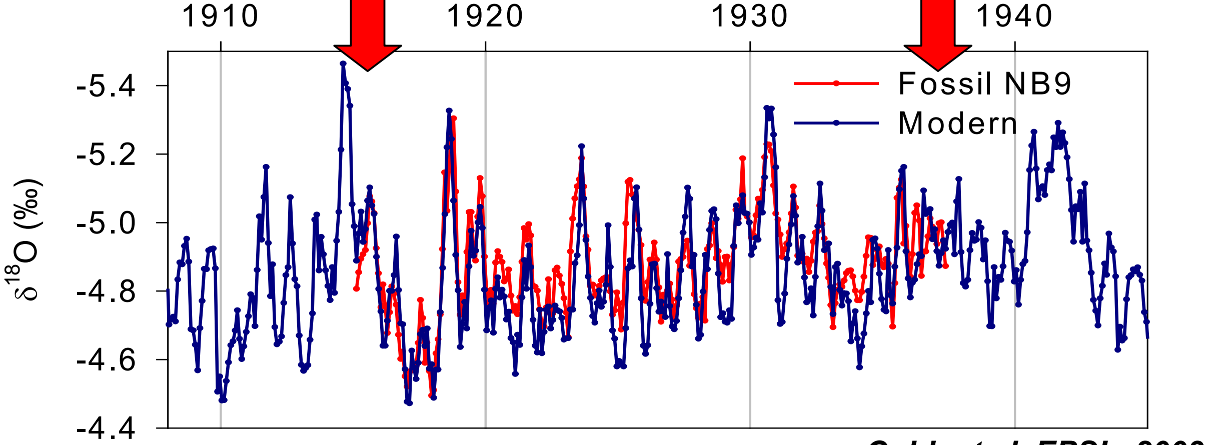
<u>Dating</u> based on decay of ^{238}U to ^{230}Th

For splicing technique, measure 2-5 ages for each coral sequence

Obtain ± <10y precision

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



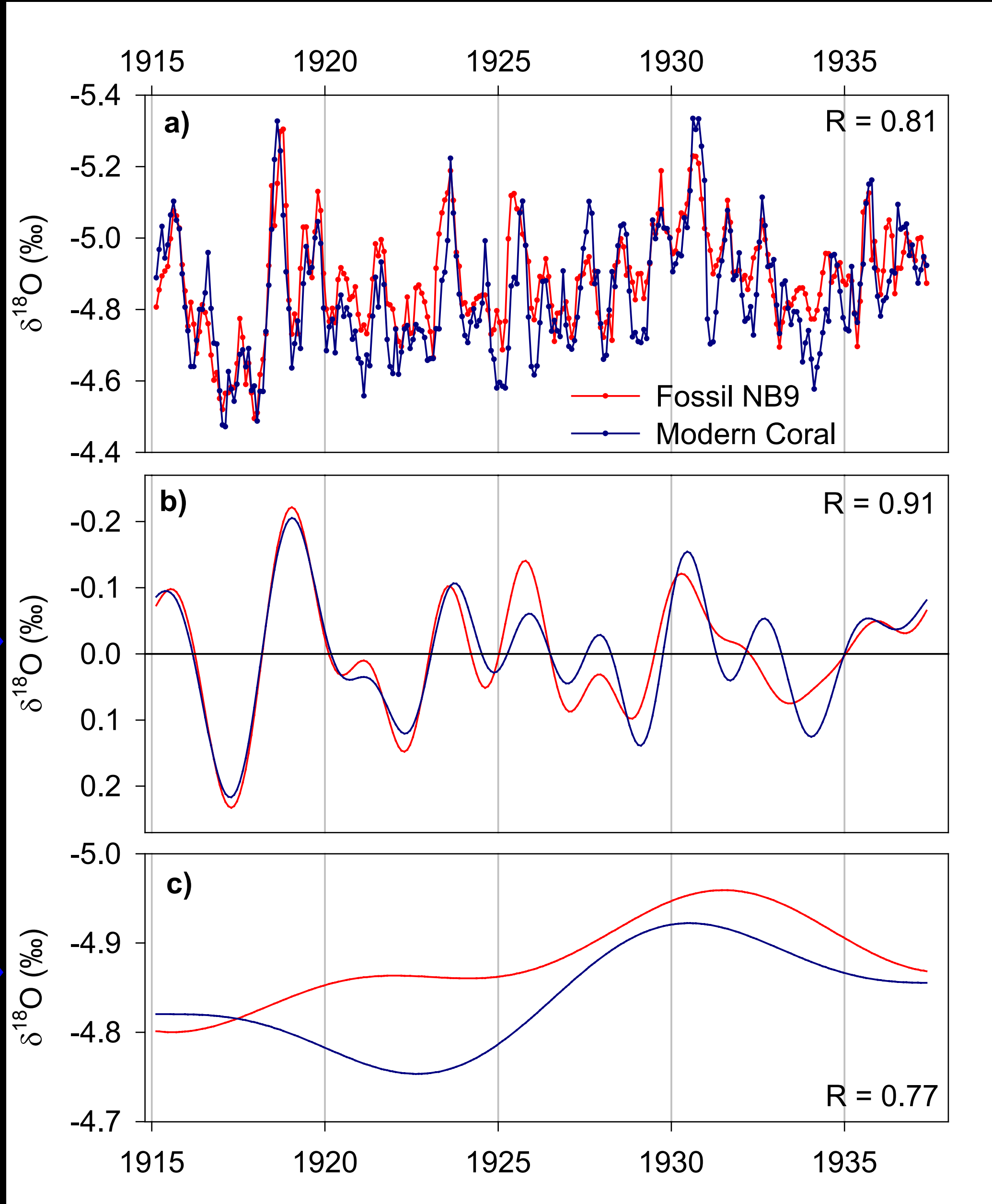
Cobb et al, EPSL, 2003

Modern Coral – Fossil Coral Overlap (cont.)

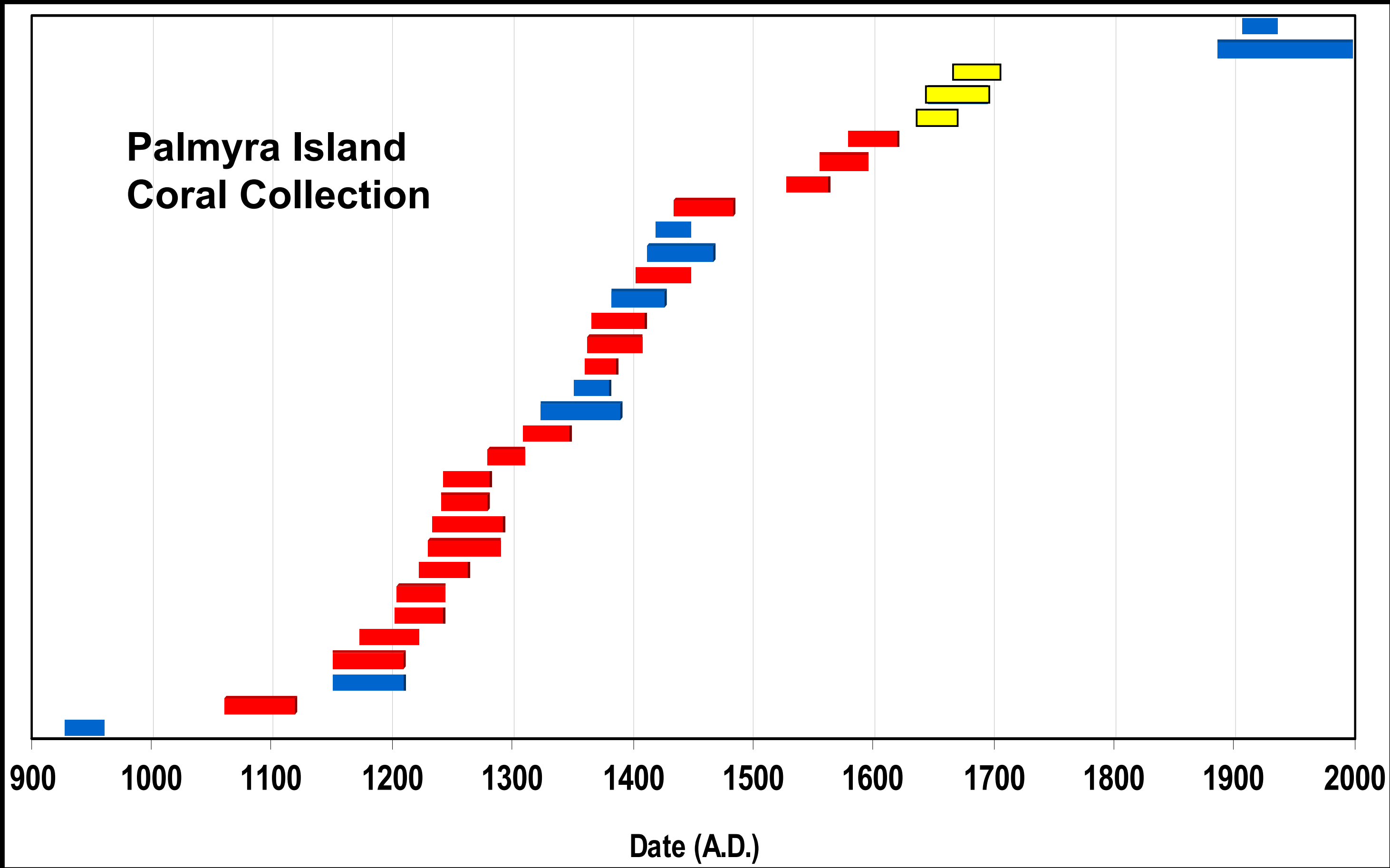
B. Assessing the reproducibility of coral $\delta^{18}O$ records

Timing and amplitude of ENSO signals agree

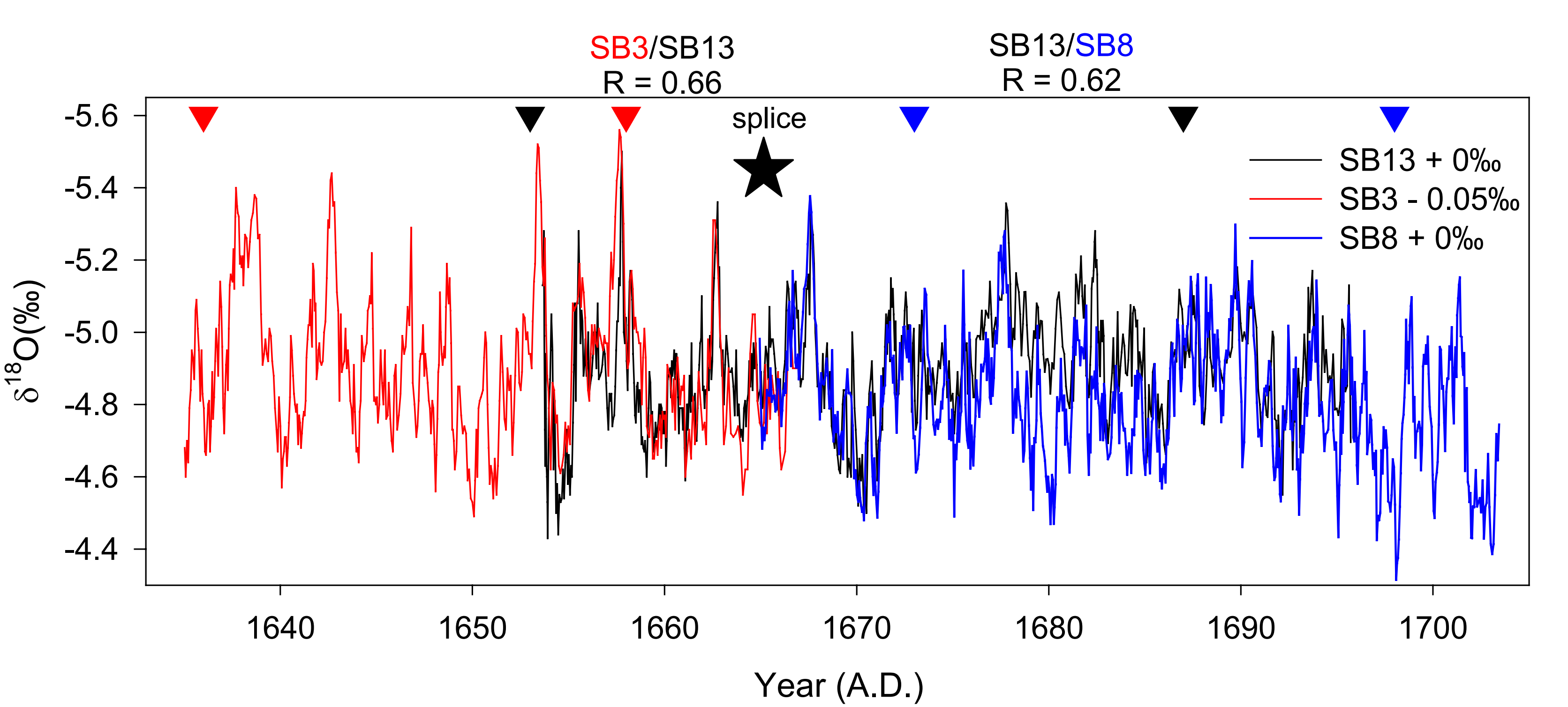
Decadal reproducibility lower



Test #2: Fossil coral vs. Fossil coral



17th Century Splice



<u>As the number of overlapping corals increases:</u>

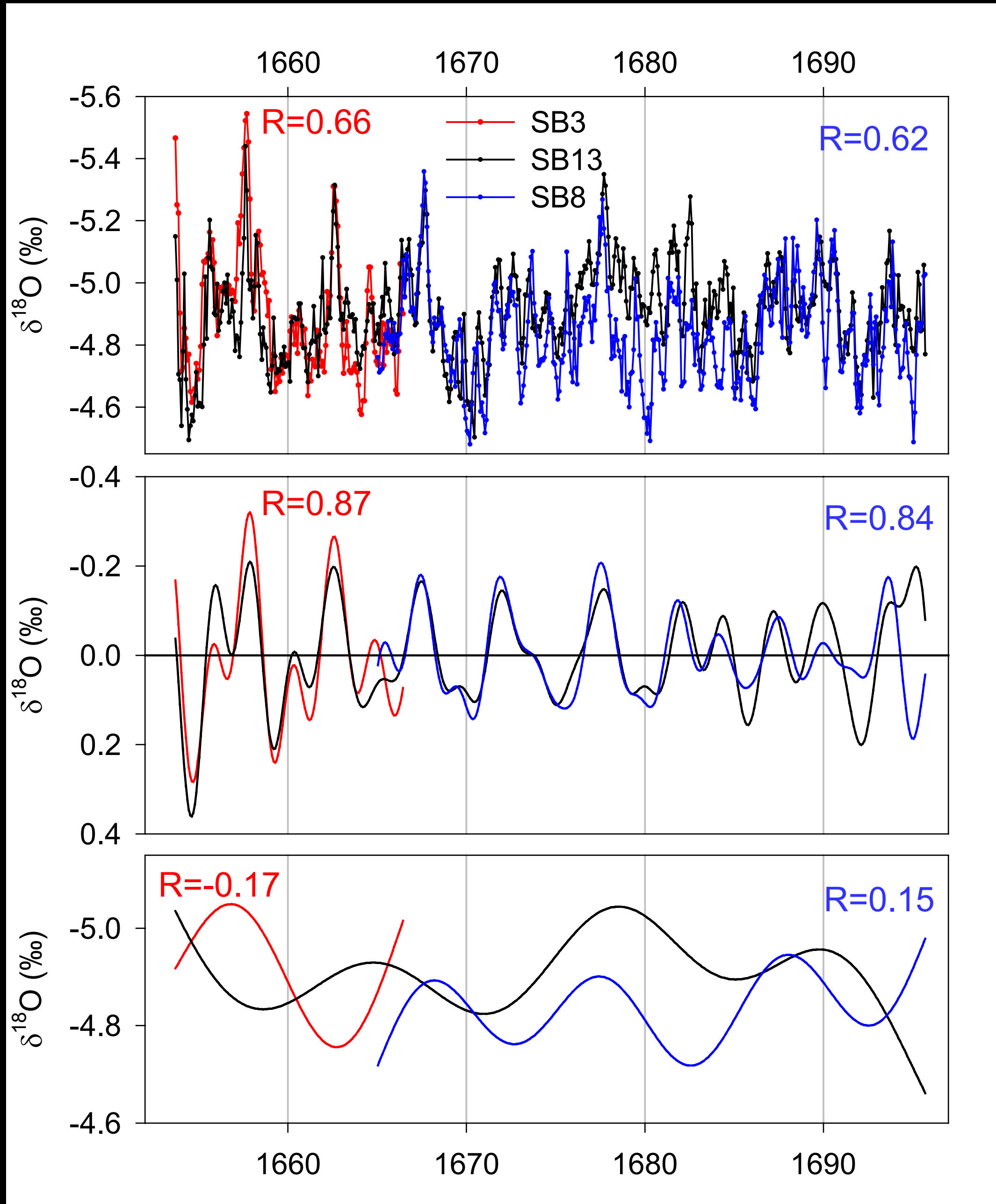
- confidence in shared $\delta^{18}O$ variability increases

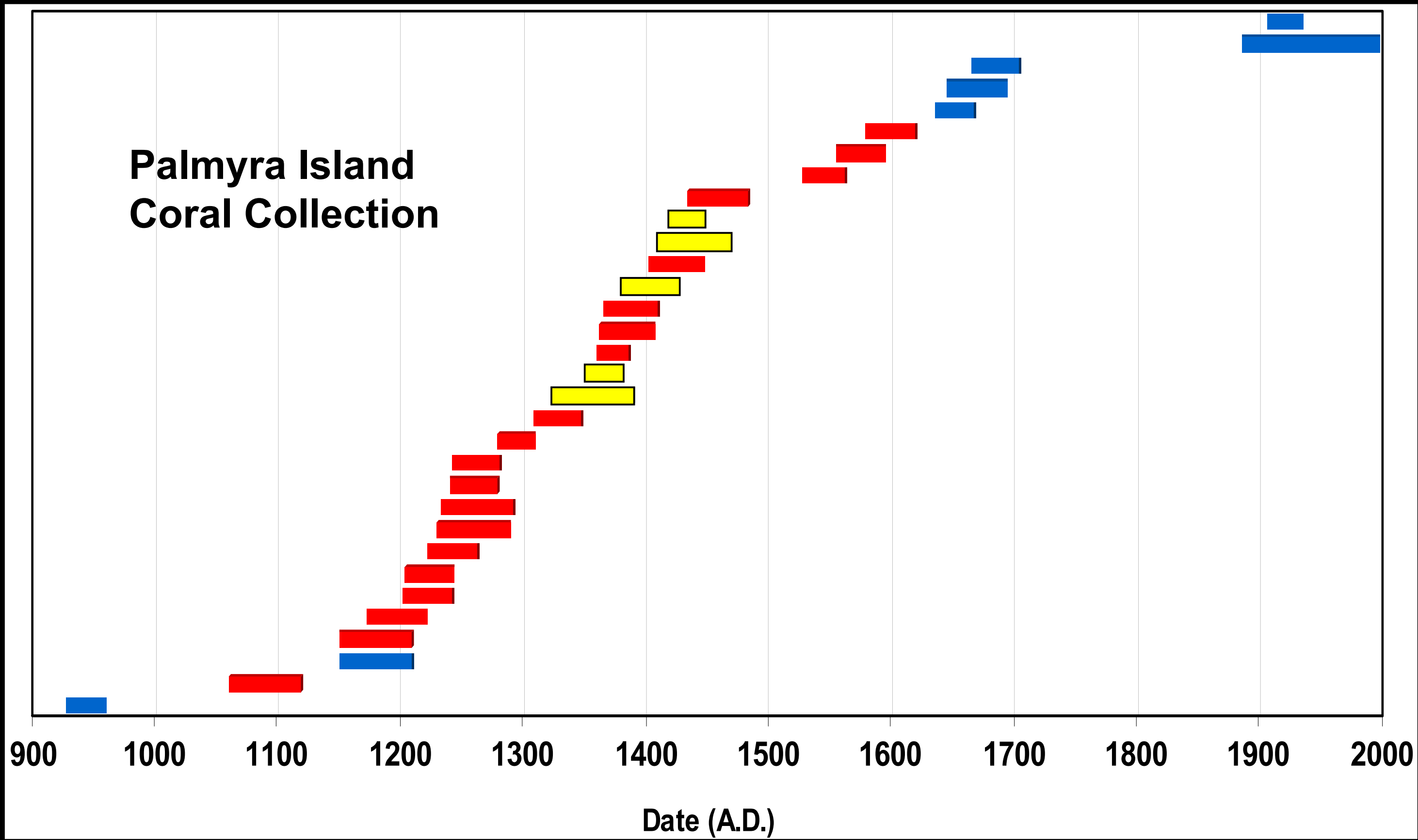
- dating accuracy increases

Reproducibility of 17th Century $\delta^{18}O$ records

ENSO high

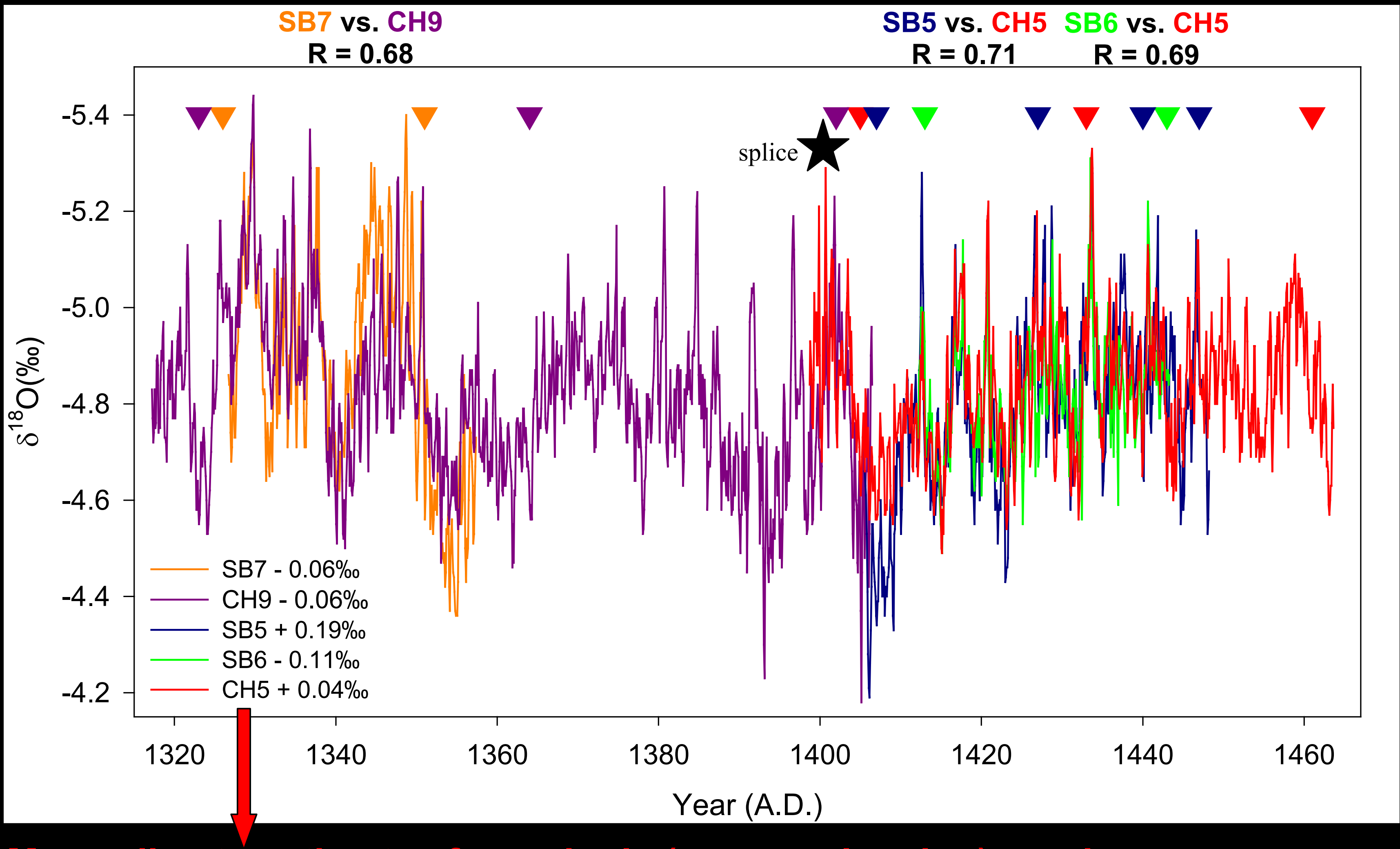
Decadal low





Palmyra Island
Coral Collection
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Date (A.D.)

14th-15th Century Splice



Mean climate estimates from single (non-overlapping) corals are associated with a ±0.12‰ (±0.5°C) error

Research Questions:

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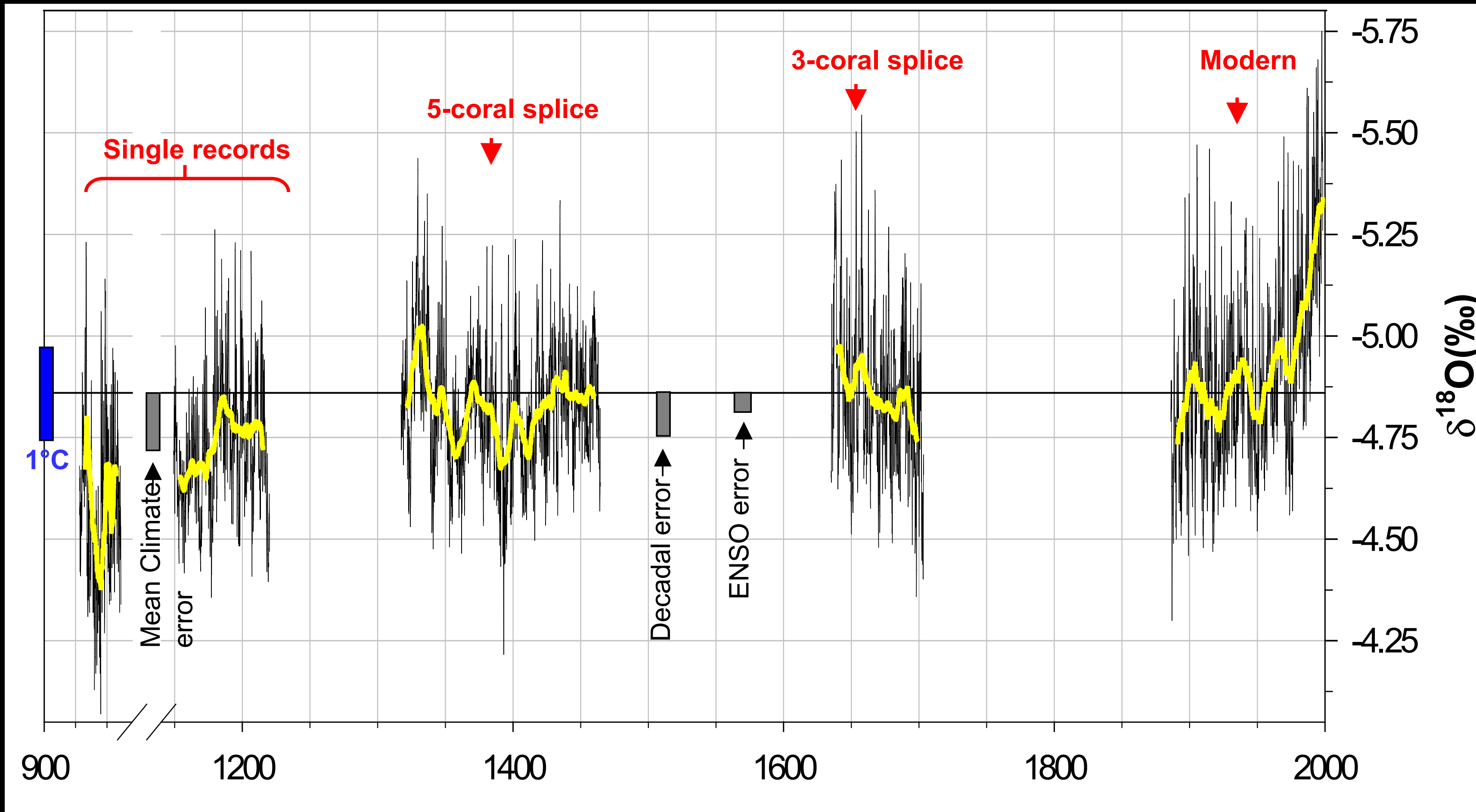
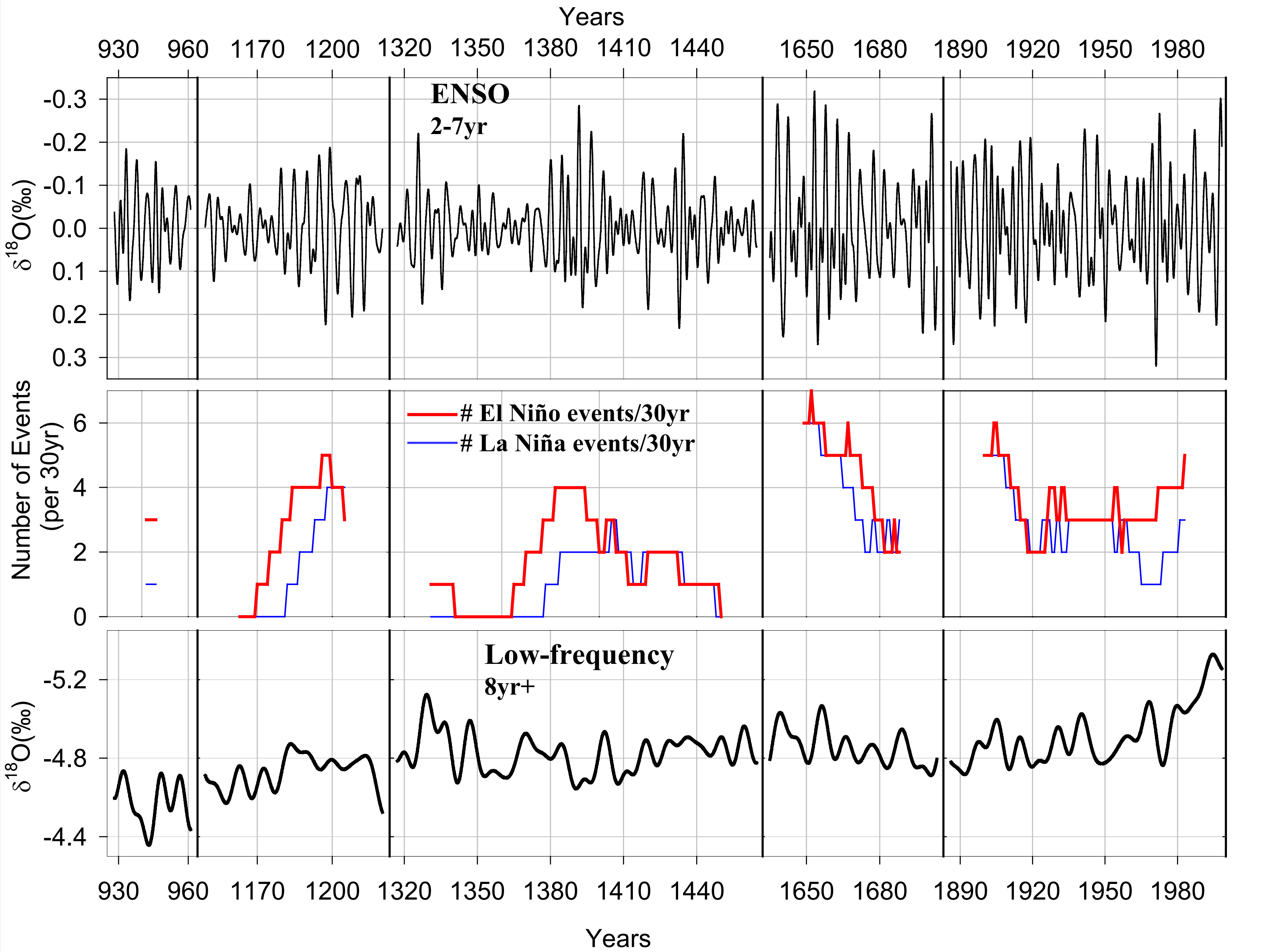
Palmyra Coral Sequences

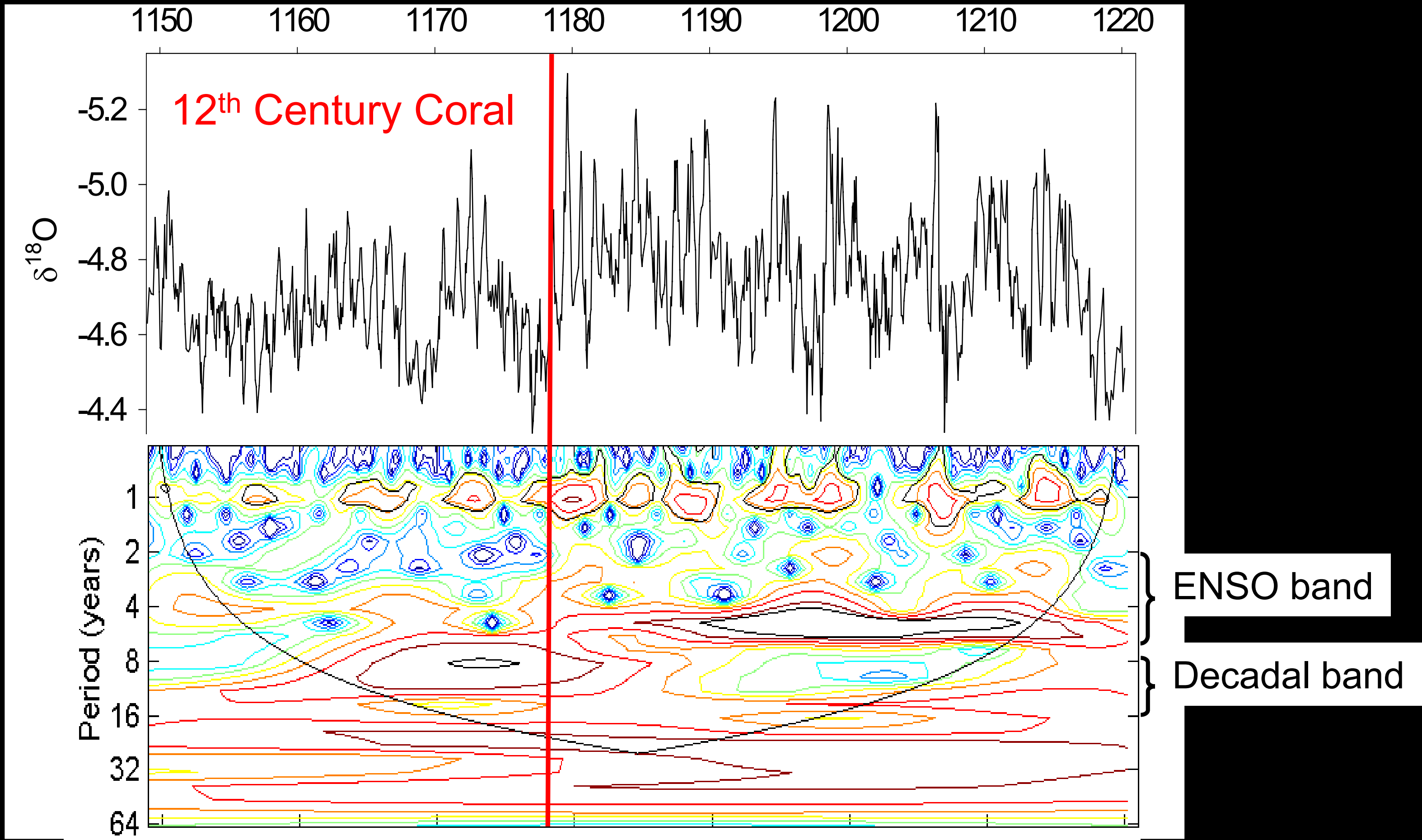


Cobb et al., Nature, 2003



Years
930 960 1170 1200 1320 1350 1380 1410 1440 1650 1680 1890 1920 1950 1980
ENSO
2-7yr
δ18O(‰)
-0.3 -0.2 -0.1 0.0 0.1 0.2 0.3
Number of Events (per 30yr)
El Niño events/30yr
La Niña events/30yr
0 2 4 6
Low-frequency
8yr+
δ18O(‰)
-5.2 -4.8 -4.4
930 960 1170 1200 1320 1350 1380 1410 1440 1650 1680 1890 1920 1950 1980
Years

An ENSO 'Regime Shift'?

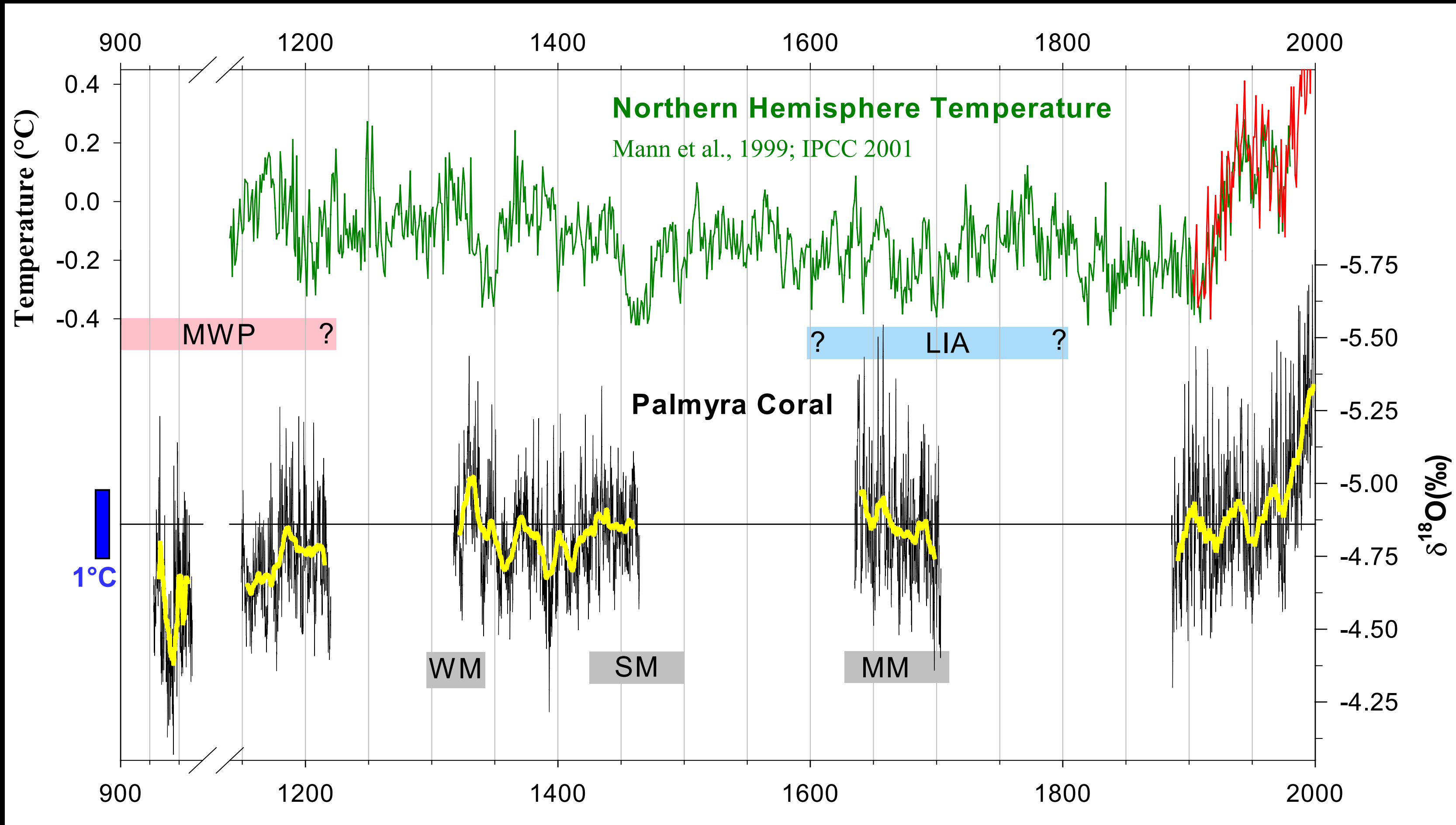


<u>What causes such an abrupt change in ENSO characteristics?</u>

Random noise in the climate system? *Unlikely (~2%).*

'Weak' chaos? *Perhaps.*

Proxy-proxy comparison for last millennium



- rate, magnitude of 20th century climate change unprecedented
- no evidence of CTP cooling during LIA, nor warming during the MWP
- changes in the meridional temperature gradients implied (inc. during LIA, dec. during MWP)

Clues from ENSO-sensitive proxy records…

La Niña-like?

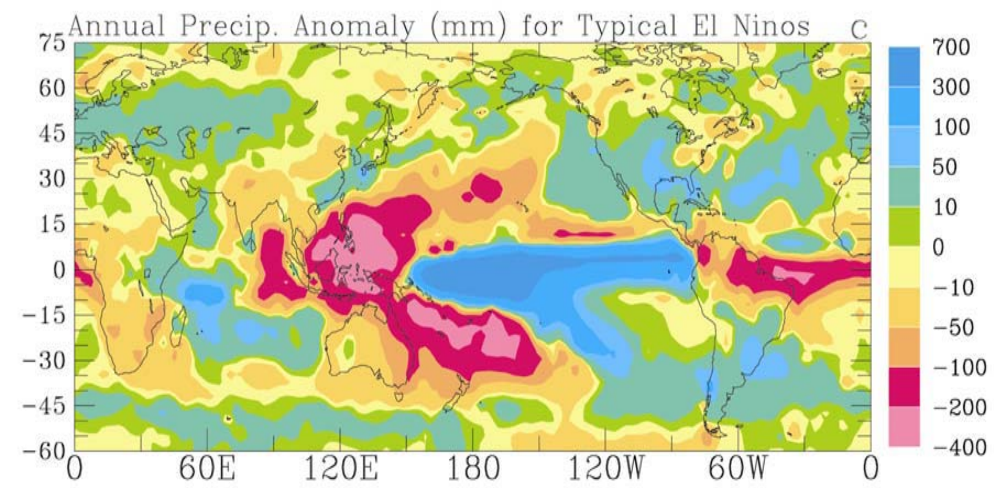
MWP – cooler, drier in CTP

-severe, prolonged drought in the Yucatan *(Hodell et al., 2001)*
-wetter in northern S. America *(Haug et al., 2001)*
-drier in Sierra Nevada (*Stine, 1994*)

El Niño-like?

LIA – no evidence of cooling in CTP, vigorous ENSO

-cooler (?), saltier Warm Pool *(Correge et al., 2001; Hendy et al., 2002)*
-drier in northern S. America *(Haug et al., 2001)*
-weaker Pacific trades (*Garcia et al., 2001*)



Dai and Wigley, 2000

Summary

Palmyra coral $\delta^{18}O$ is a sensitive, reliable proxy for interannual to interdecadal (to centennial?) climate change in the central tropical Pacific.

The coral-splicing approach: 1) enables the construction of longer records
2) increases confidence in climate reconstructions

Most intense ENSO activity occurred during 17^{th} century, no change in the CTP mean state. Cooler, drier conditions in the CTP implied during 10^{th} century.

ENSO characteristics can change dramatically from decade to decade.

No simple relationship emerges between ENSO character and NH or CTP temperature.

Changes in the tropical Pacific zonal SST gradient during the LIA (El Niño-like) and MWP (La Niña-like) are consistent with some key paleo-data, but will be more rigorously tested.

Data available at:
http://www.ngdc.noaa.gov/paleo/paleo.html