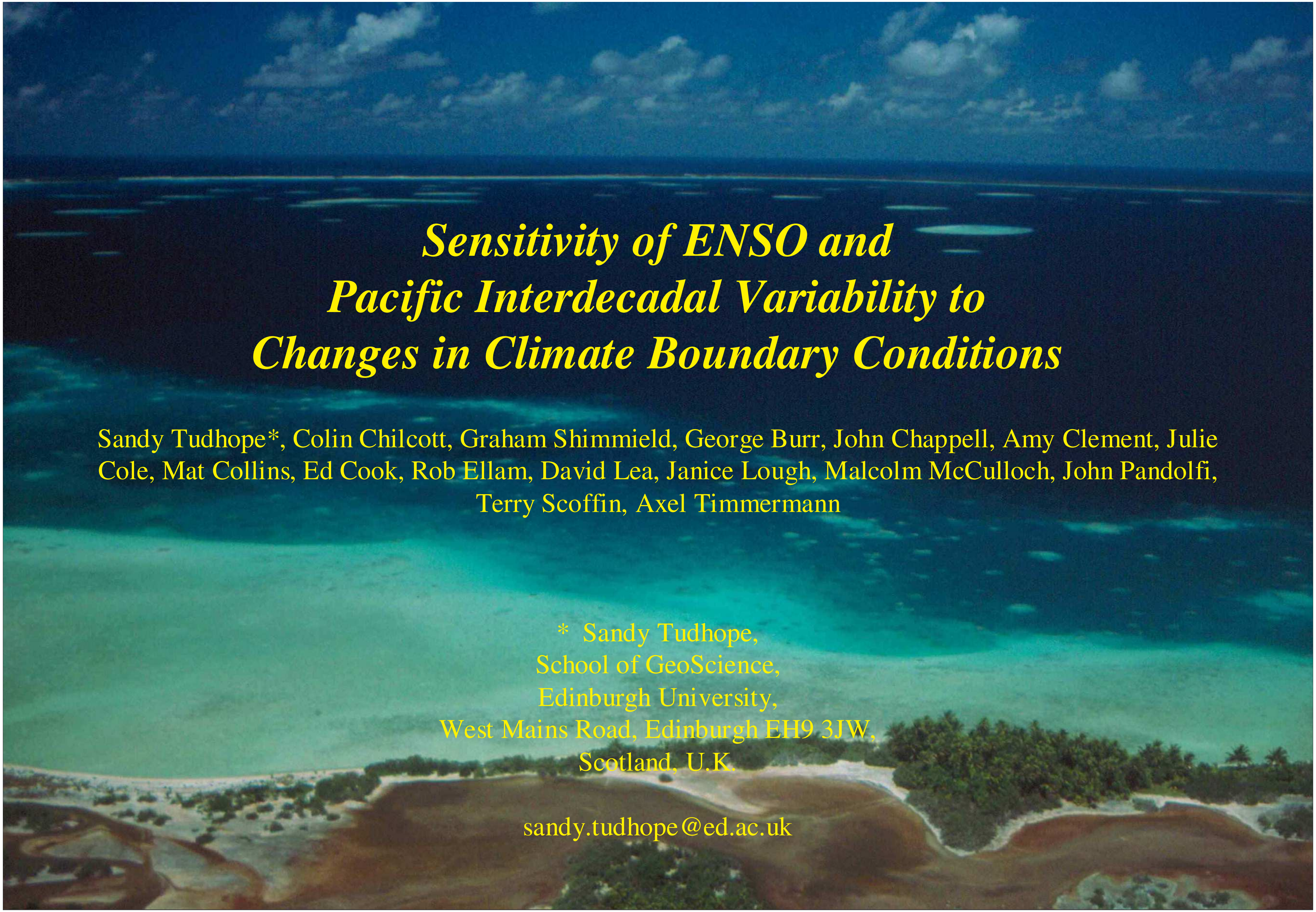


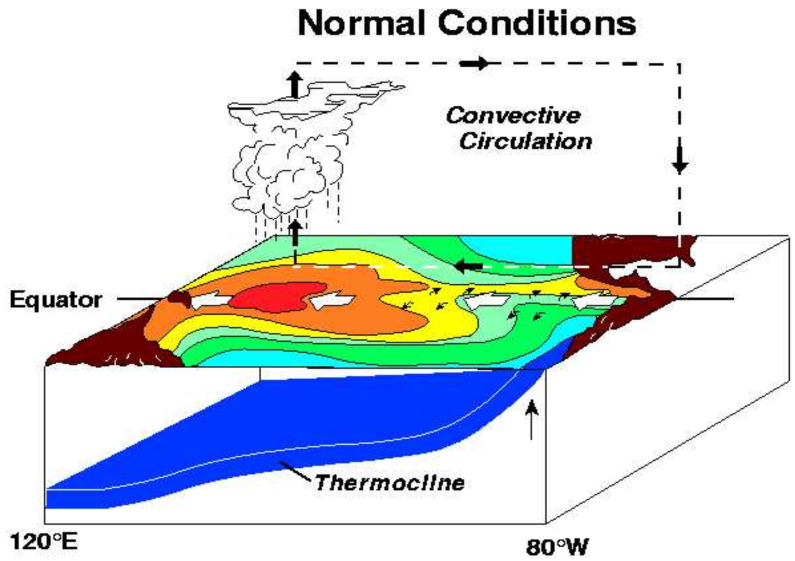
Sensitivity of ENSO and Pacific Interdecadal Variability to Changes in Climate Boundary Conditions

Sandy Tudhope*, Colin Chilcott, Graham Shimmield, George Burr, John Chappell, Amy Clement, Julie Cole, Mat Collins, Ed Cook, Rob Ellam, David Lea, Janice Lough, Malcolm McCulloch, John Pandolfi, Terry Scoffin, Axel Timmermann

* Sandy Tudhope,
School of GeoScience,
Edinburgh University,
West Mains Road, Edinburgh EH9 3JW,
Scotland, U.K.

sandy.tudhope@ed.ac.uk

The ENSO cycle …..



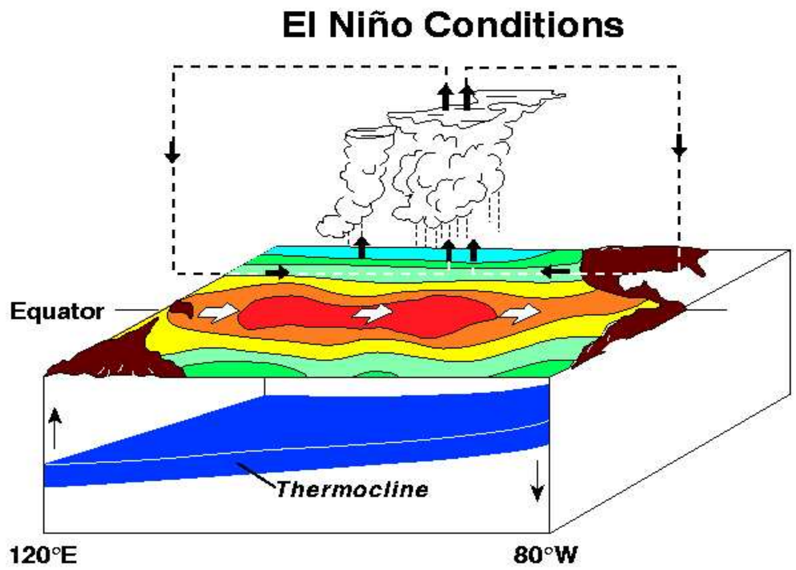
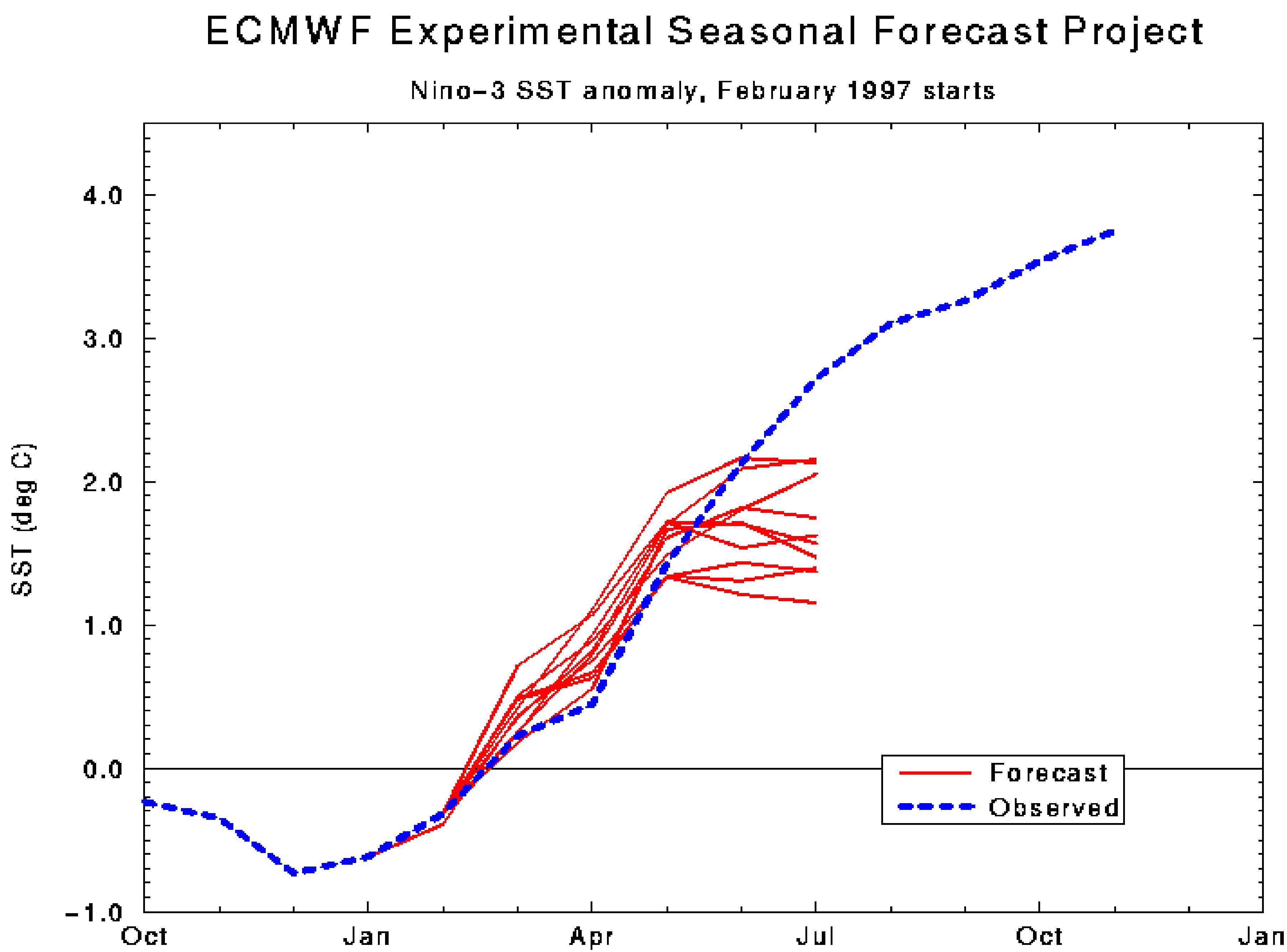
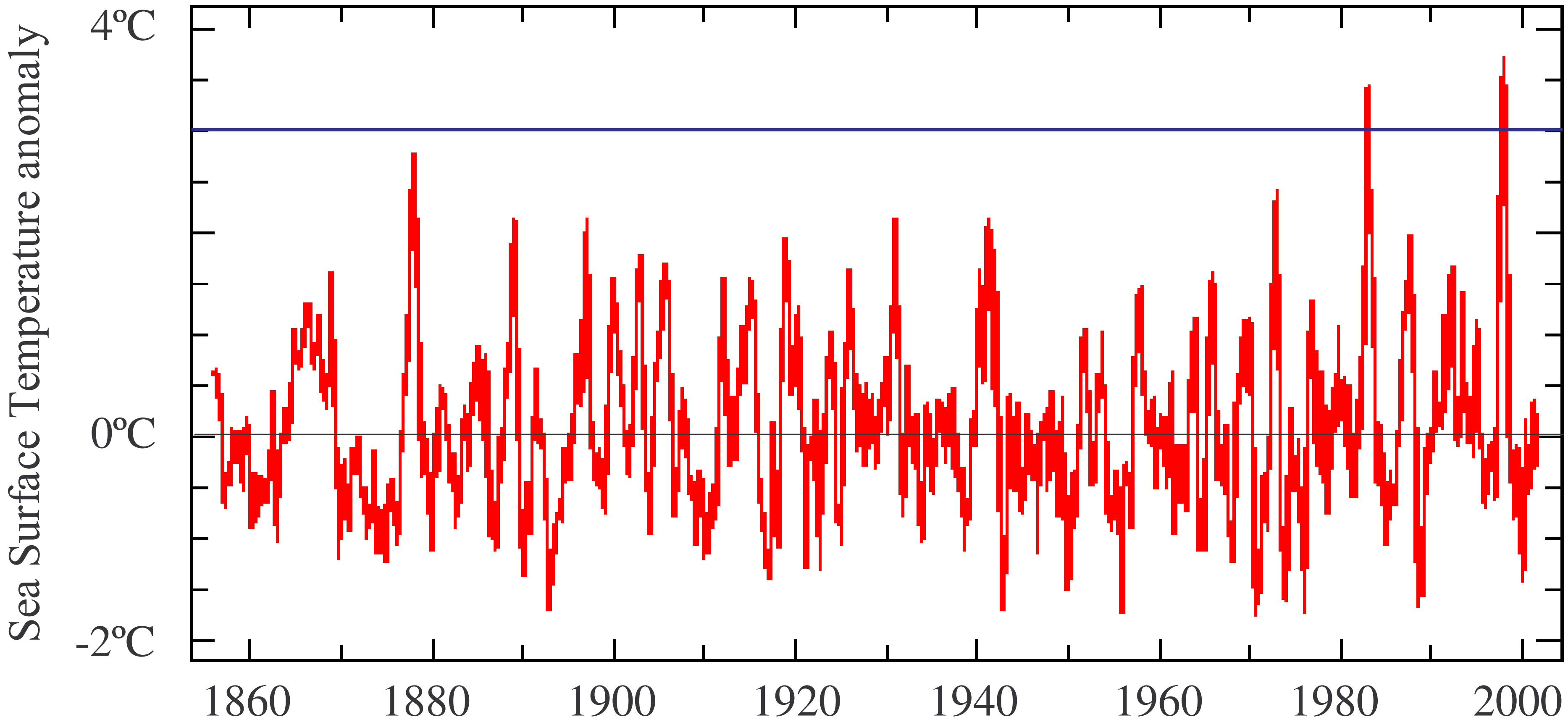


Figure source: NOAA PMEL

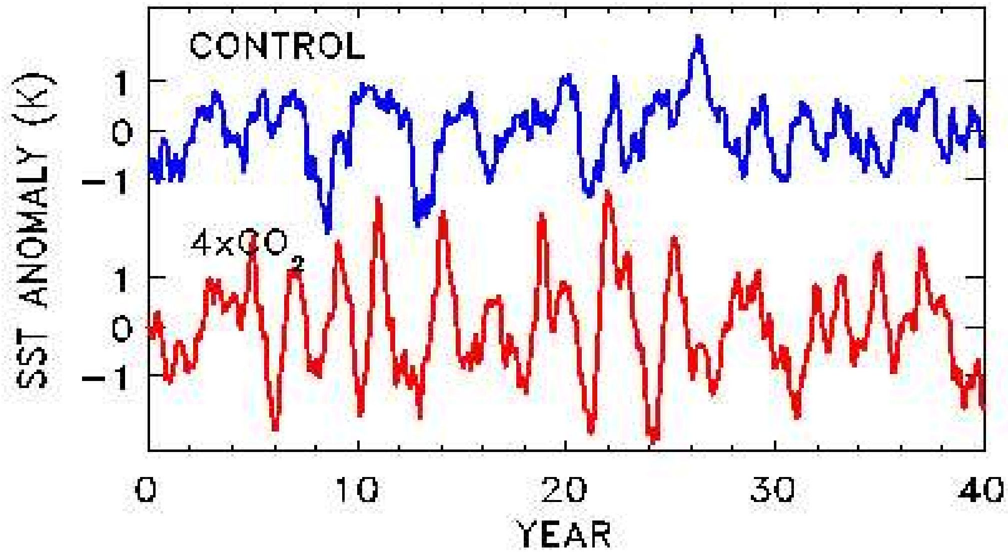

ECMWF Experimental Seasonal Forecast Project
Nino-3 SST anomaly, February 1997 starts
SST (deg C)
4.0
3.0
2.0
1.0
0.0
-1.0
Oct
Jan
Apr
Jul
Oct
Jan
Forecast
Observed



NINO3 Index of ENSO

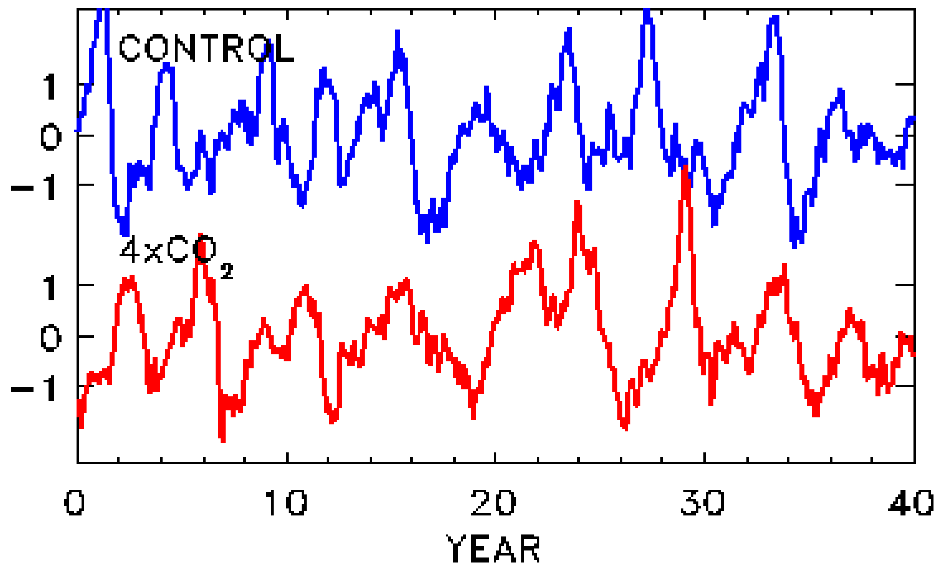
ENSO in the Future – Large Uncertainties

Model 1 – HadCM2



Collins, 2000, J. Clim., Vol 13, No. 7, pp1299-1312.

Model 2 – HadCM3



Collins, 2000, GRL, Vol. 27, No. 21, pp3509-3513.

WHAT WE WOULD LIKE TO RECONSTRUCT:

- **VARIANCE** …. interannual-interdecadal
- **BACKGROUND STATE** of the tropical Pacific
- **TELECONNECTION PATTERNS** ….. extra-tropical and extra-Pacific

a) **Within ‘climate regime’** … little or no change in external forcing, e.g., late Holocene

b) **Between ‘climate regimes’** ….. significant changes in climatic boundary conditions, e.g., glacial vs. interglacial

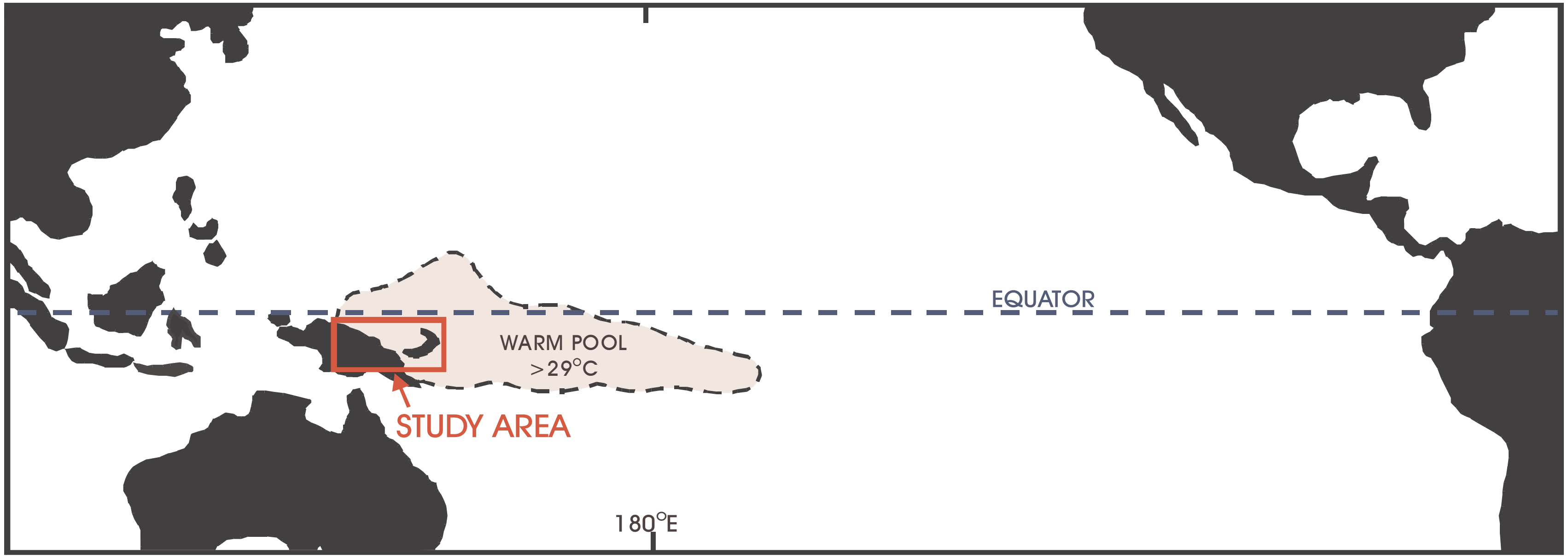
ENSO ARCHIVES:

Ideal attributes:

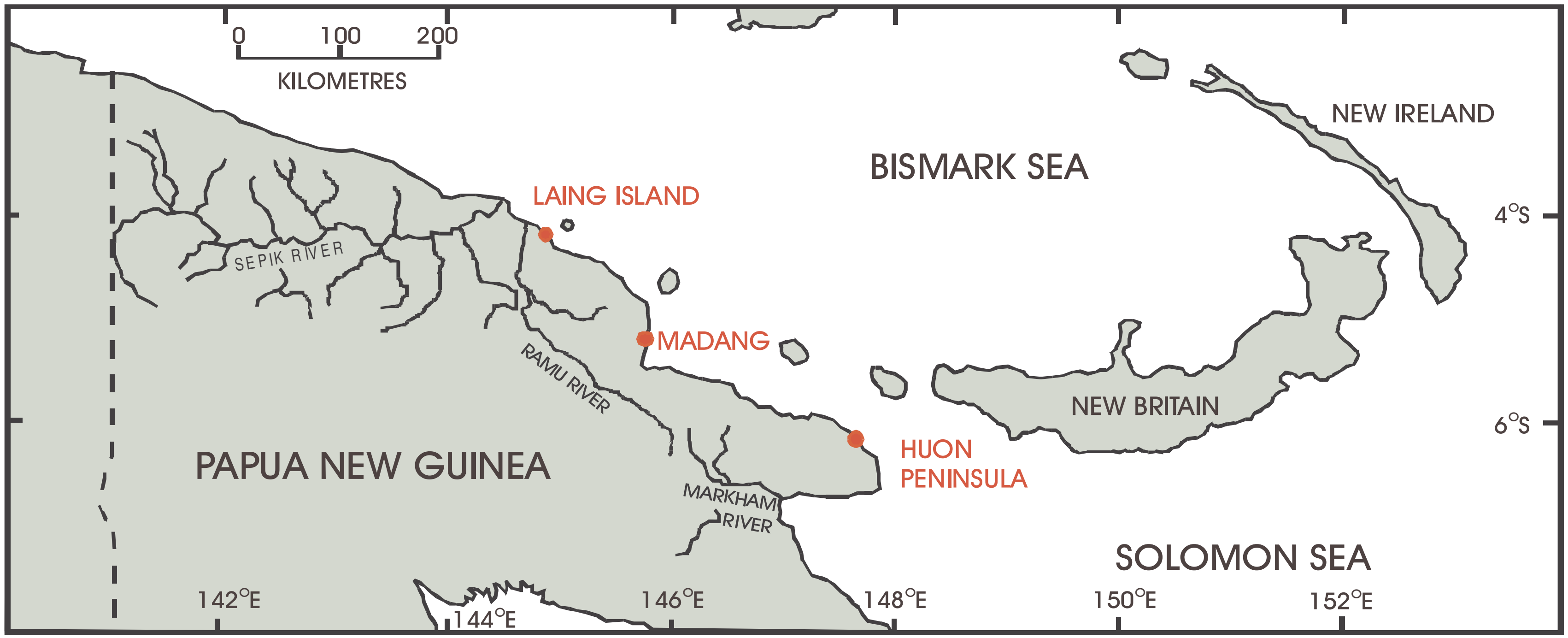
- seasonal resolution
- from core regions of ENSO dynamics

Potential Archives:

- laminated sediments
- tropical ice cores
- trees
- corals
- calcareous sponges?
- speleothems?
- (faunal/floral assemblages)

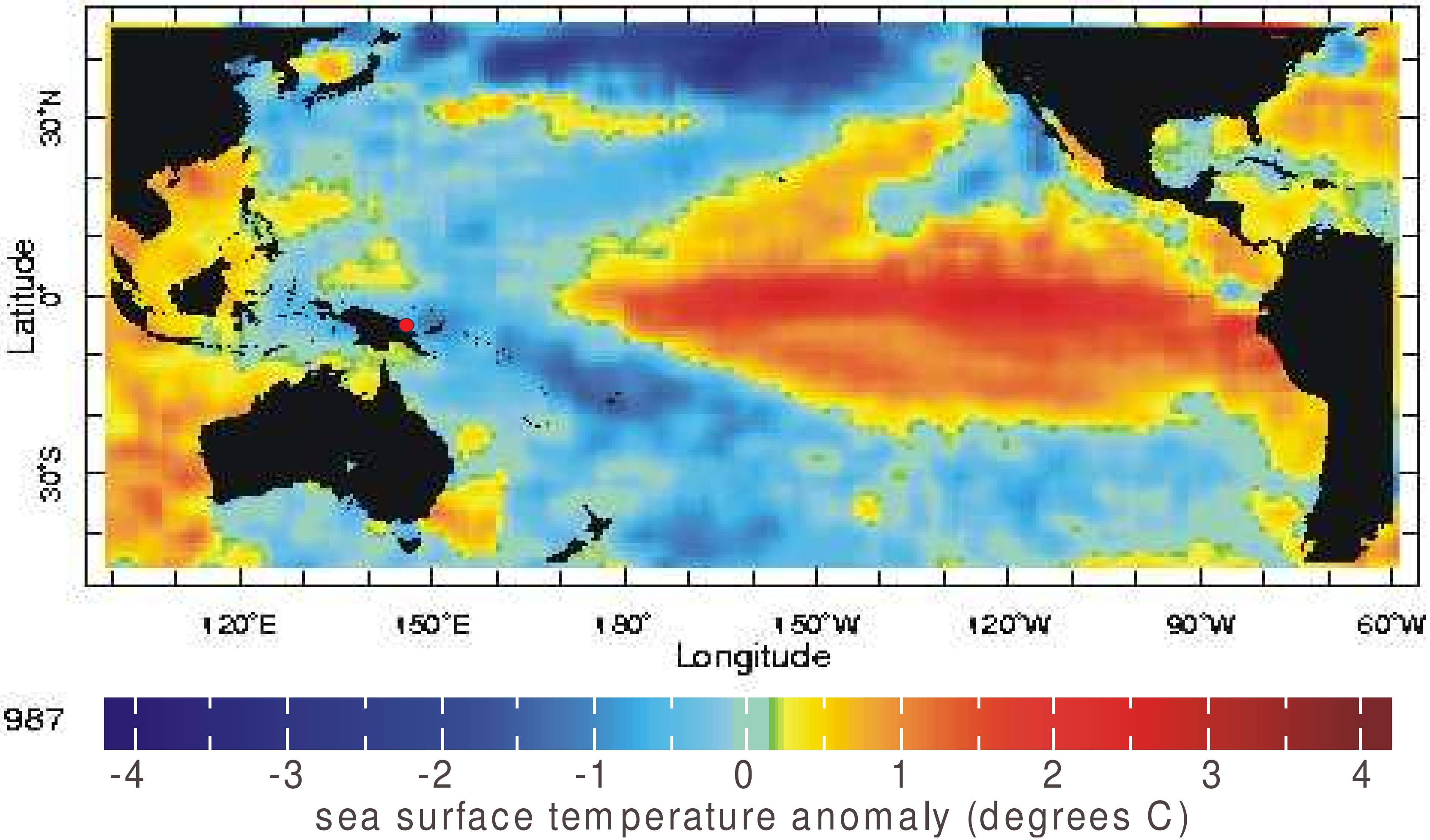


EQUATOR
WARM POOL
>29°C
STUDY AREA
180°E



0
100
200
KILOMETRES
BISMARK SEA
NEW IRELAND
LAING ISLAND
SEPIK RIVER
MADANG
RAMU RIVER
NEW BRITAIN
HUON
PENINSULA
PAPUA NEW GUINEA
MARKHAM
RIVER
SOLOMON SEA
4°S
6°S
142°E
144°E
146°E
148°E
150°E
152°E

Sea Surface Temperature anomalies during 1987 El Niño

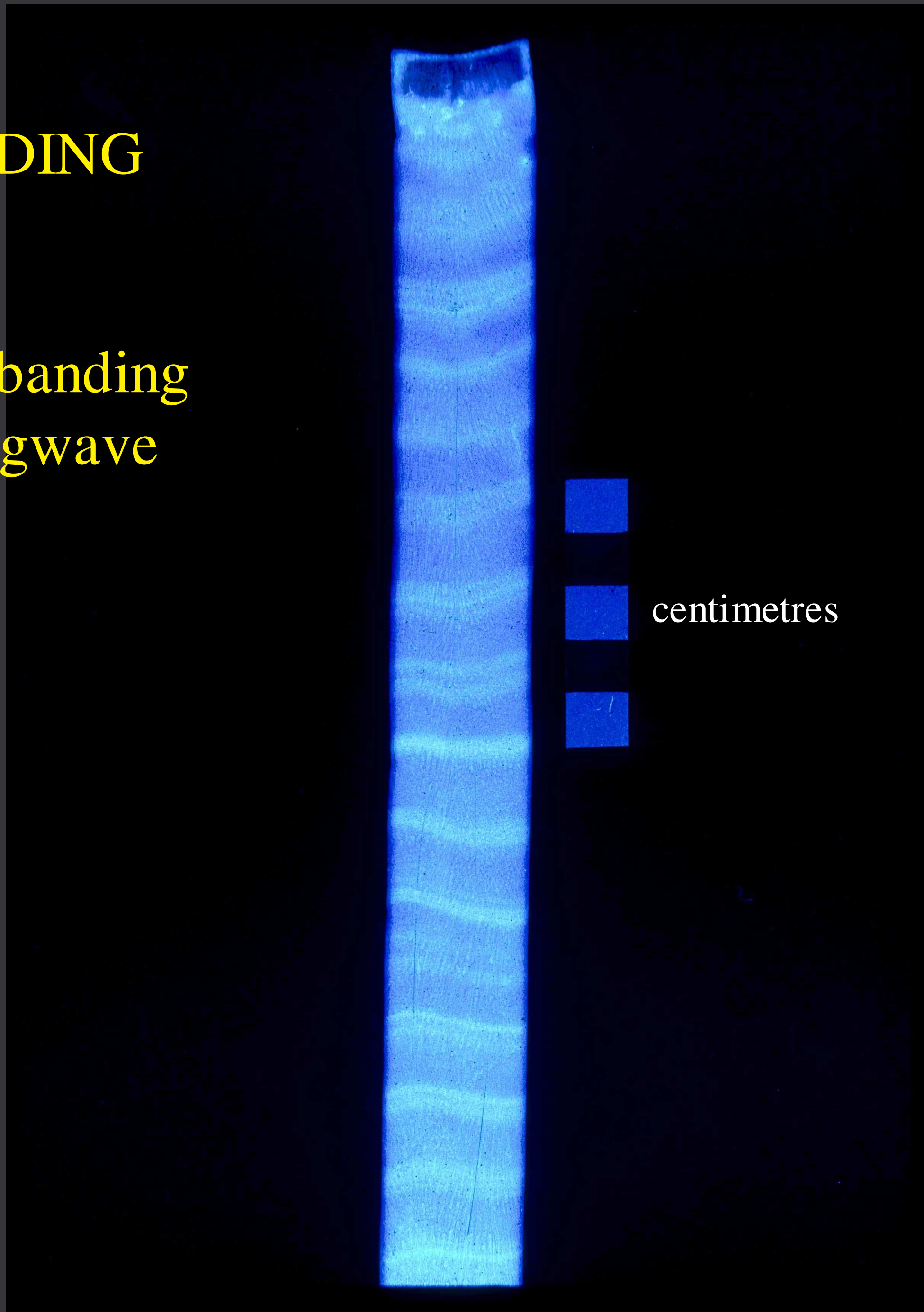


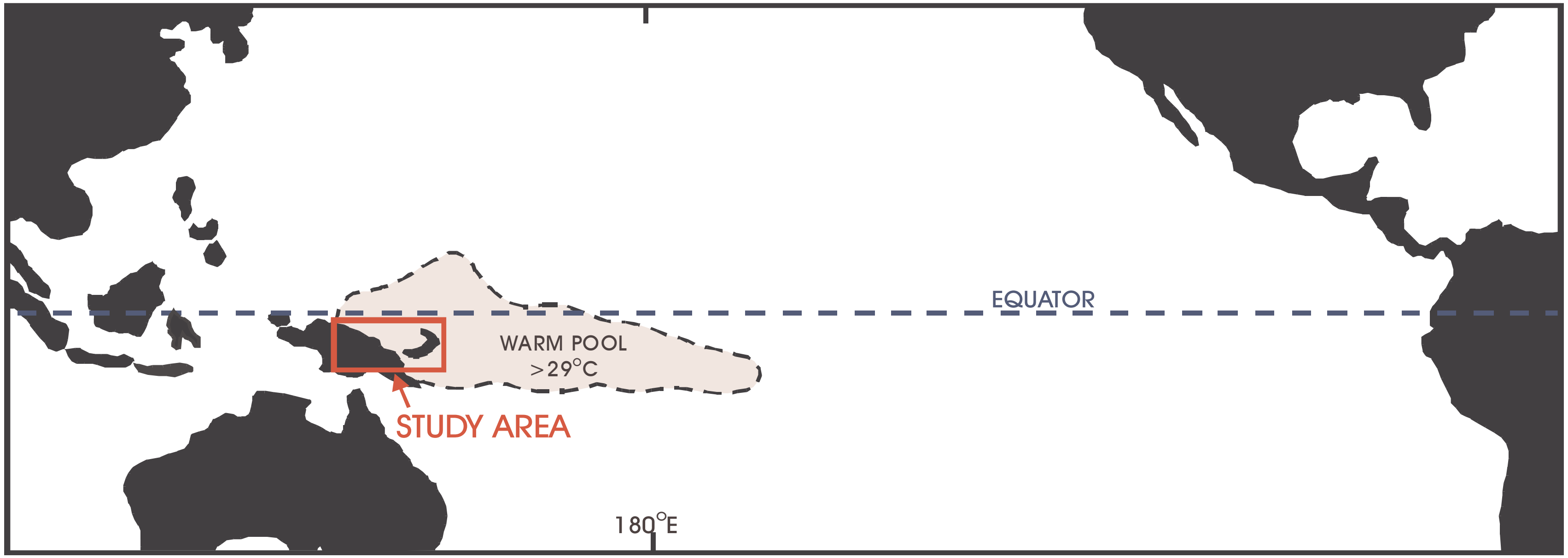
(SOURCE: IGOSS nmc ship, buoy & satellite data; http://ingrid.ldgo.columbia.edu/)

ENVIRONMENTAL RECORDS FROM MASSIVE CORALS:

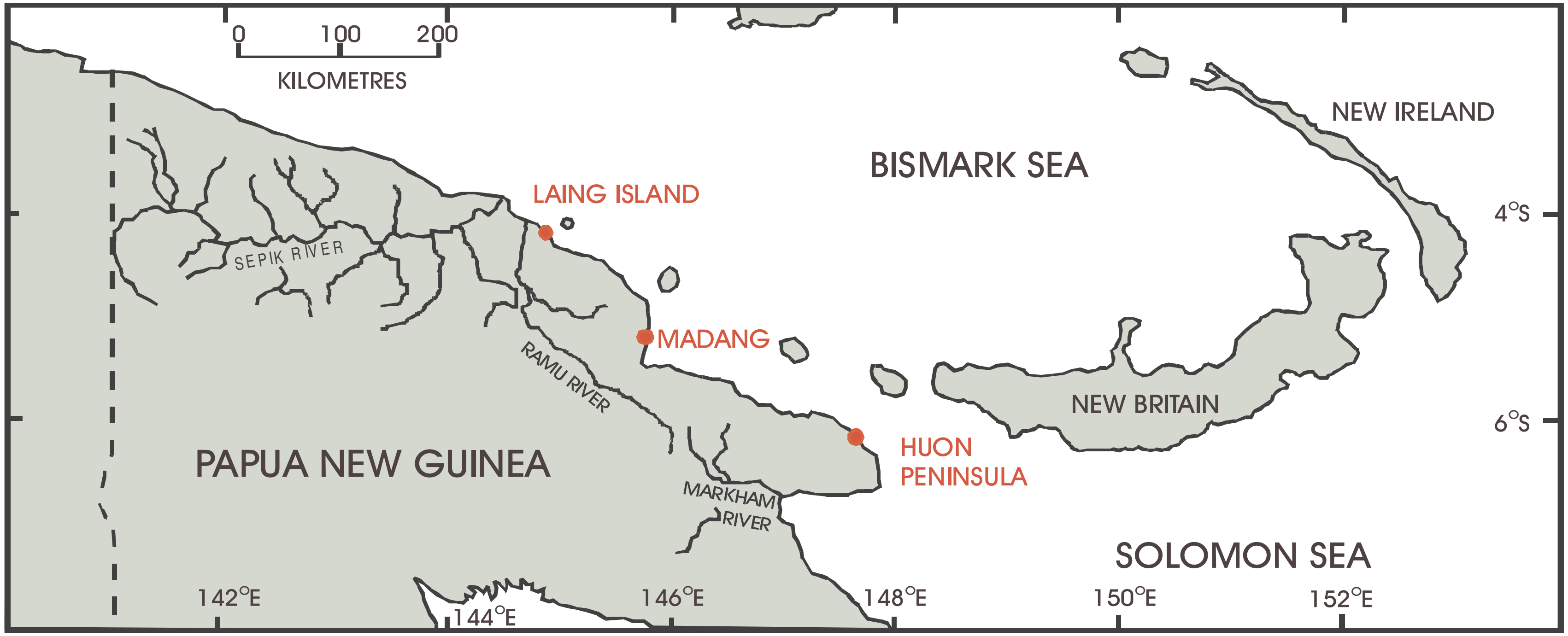
ANNUAL BANDING IN CORALS

e.g., fluorescent banding visible under longwave ultraviolet light:



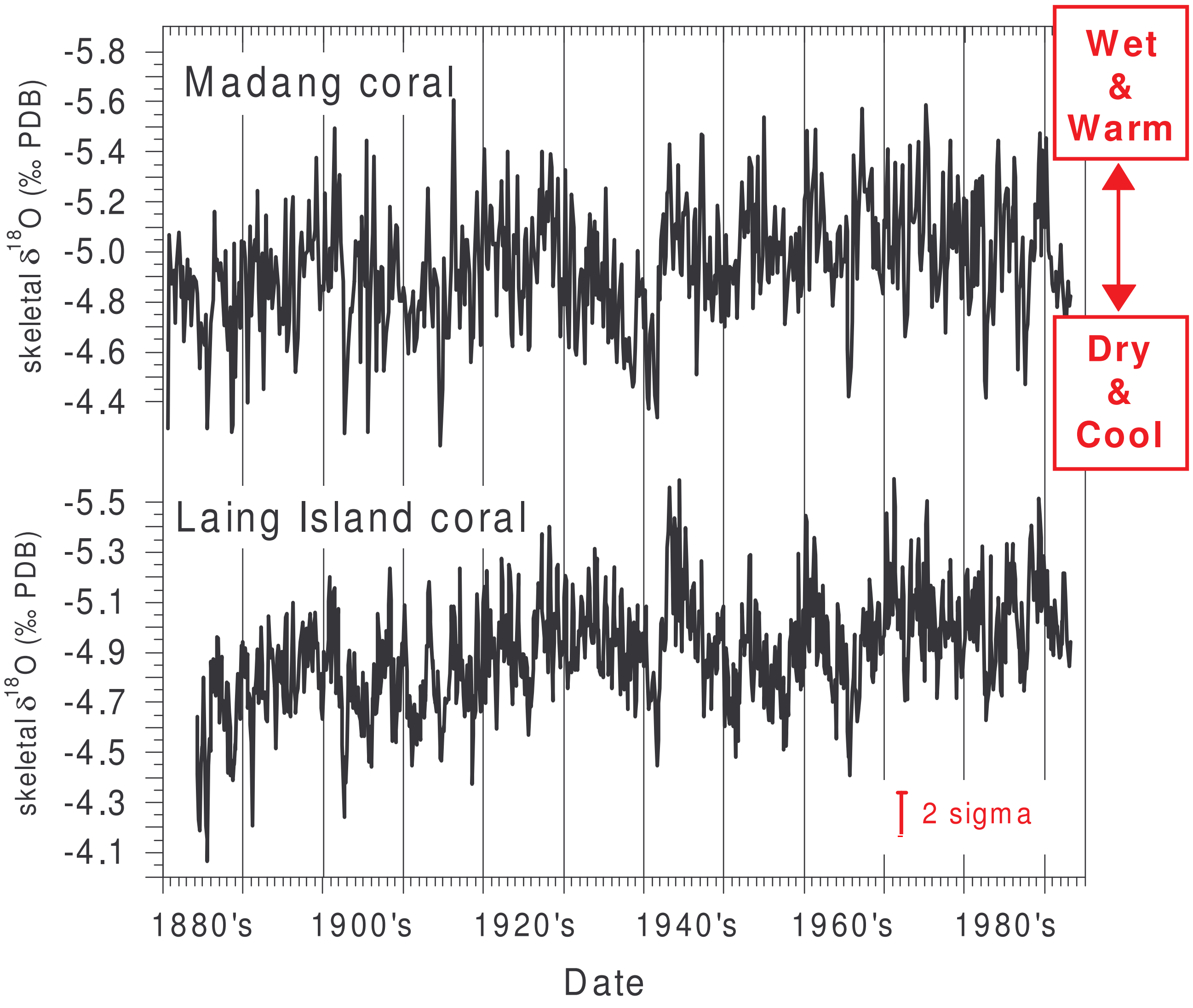


EQUATOR
WARM POOL
>29°C
STUDY AREA
180°E



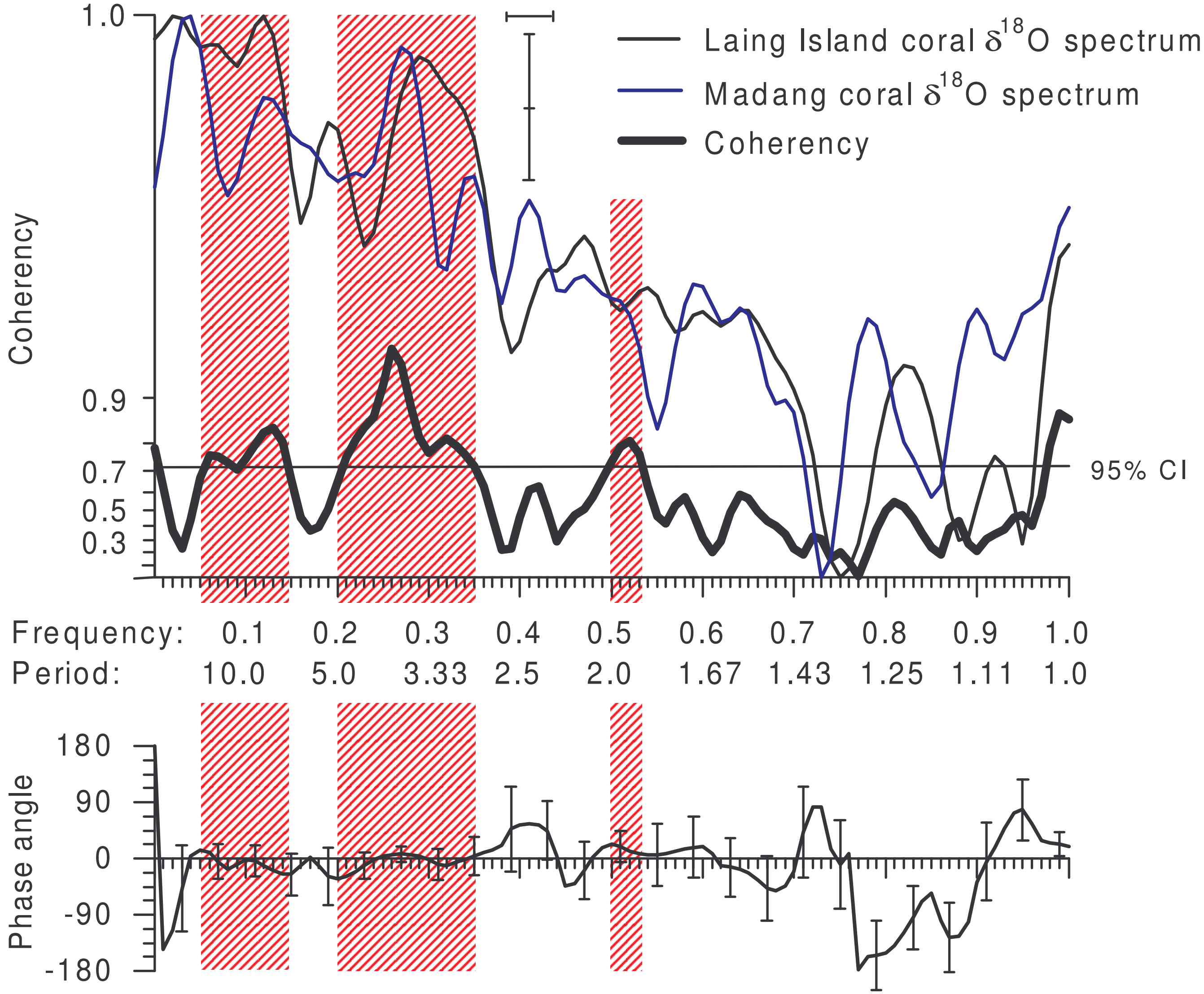
0
100
200
KILOMETRES
BISMARK SEA
NEW IRELAND
LAING ISLAND
SEPIK RIVER
4°S
MADANG
RAMU RIVER
NEW BRITAIN
6°S
HUON
PENINSULA
PAPUA NEW GUINEA
MARKHAM
RIVER
SOLOMON SEA
142°E
144°E
146°E
148°E
150°E
152°E

Porites coral $\delta^{18}O$ records from Papua New Guinea: sample data



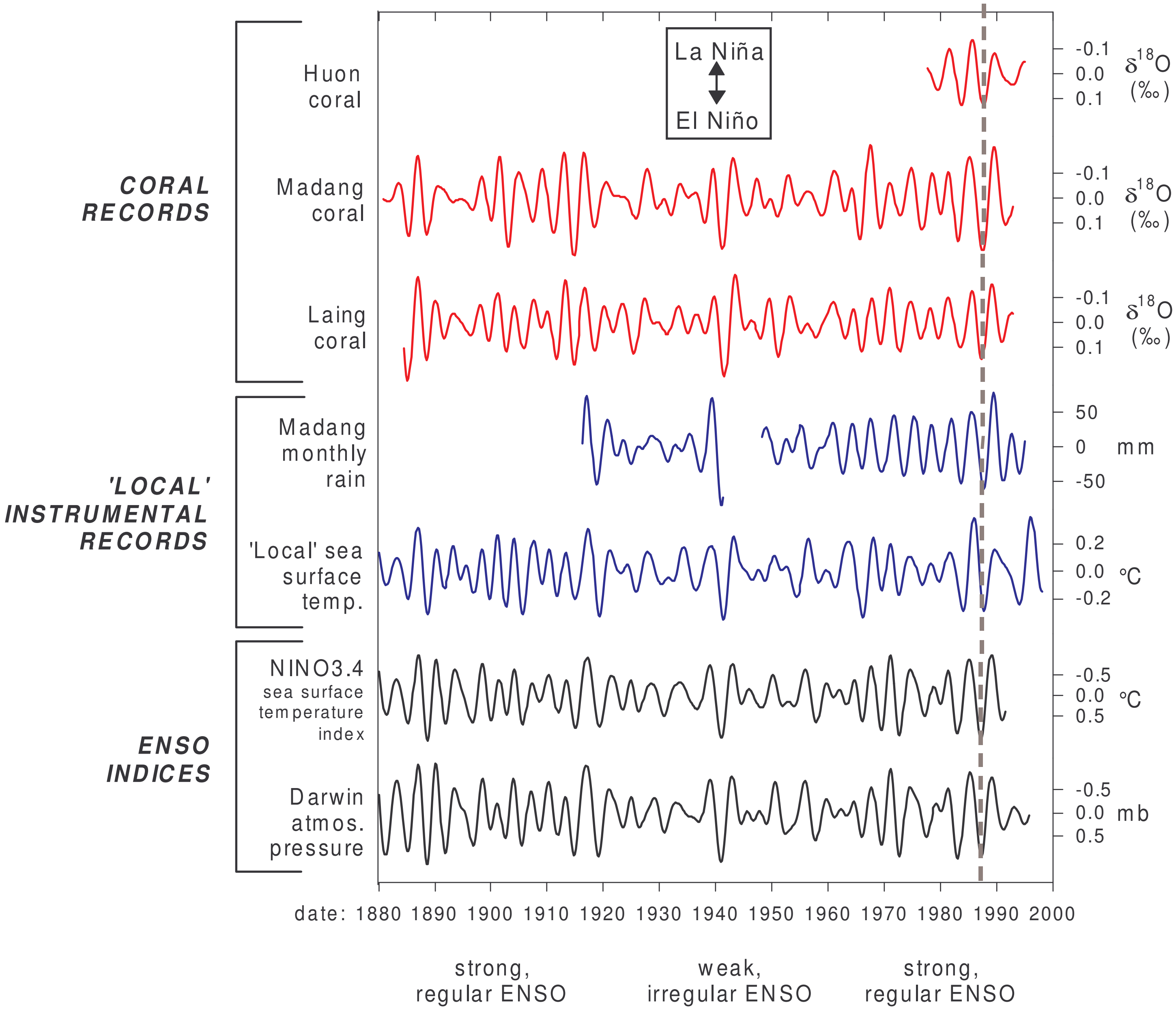
(Tudhope et al., 2001, *Science*, 291, 1511-1517)

Cross spectral analysis of coral $\delta^{18}O$ records 1885-1991
(ARAND software courtesy of Phil Howell)



CORAL AND INSTRUMENTAL RECORDS OF ENSO SINCE 1880

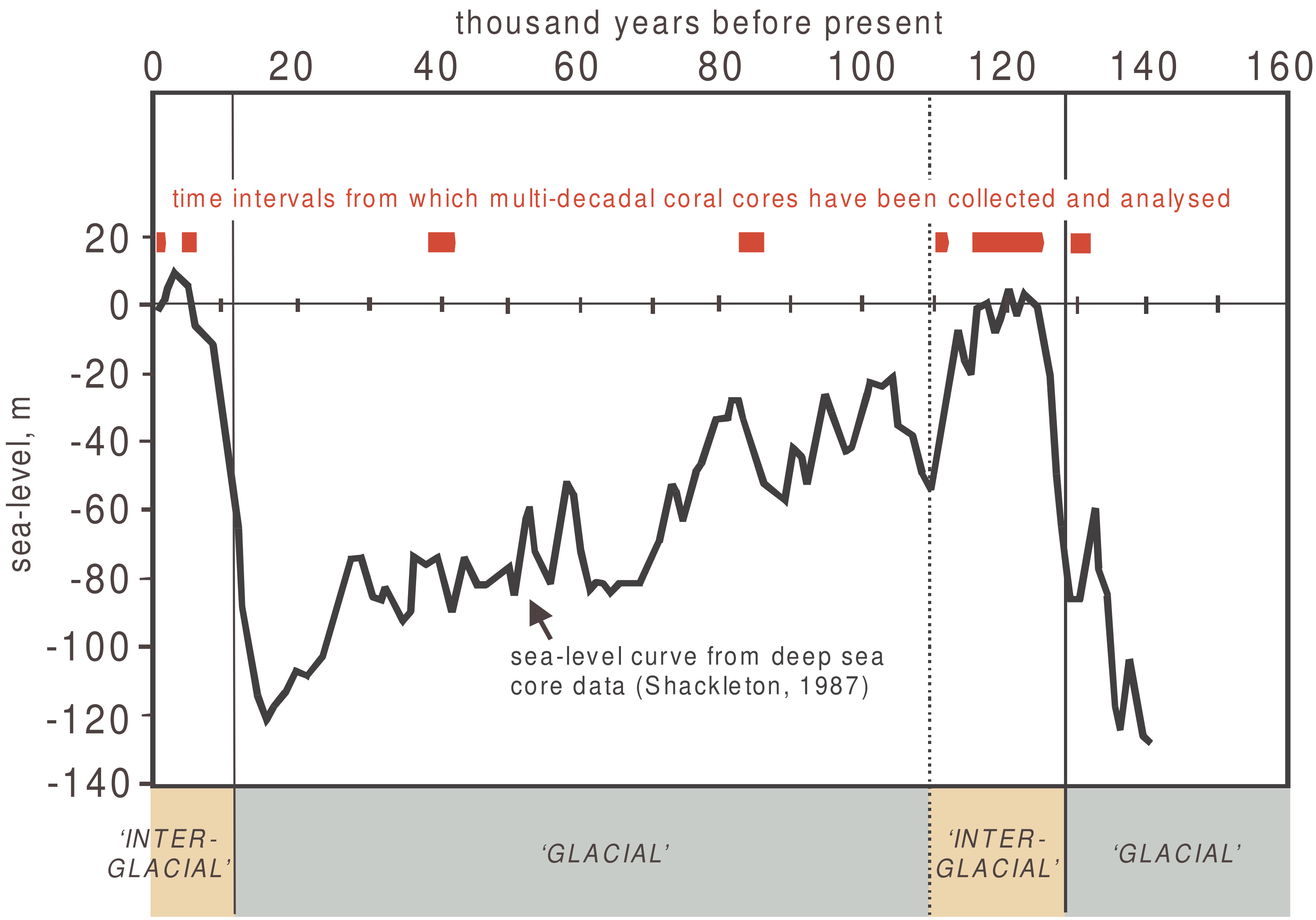
all records treated with a 2.5-7 year bandpass filter to reveal ENSO variability

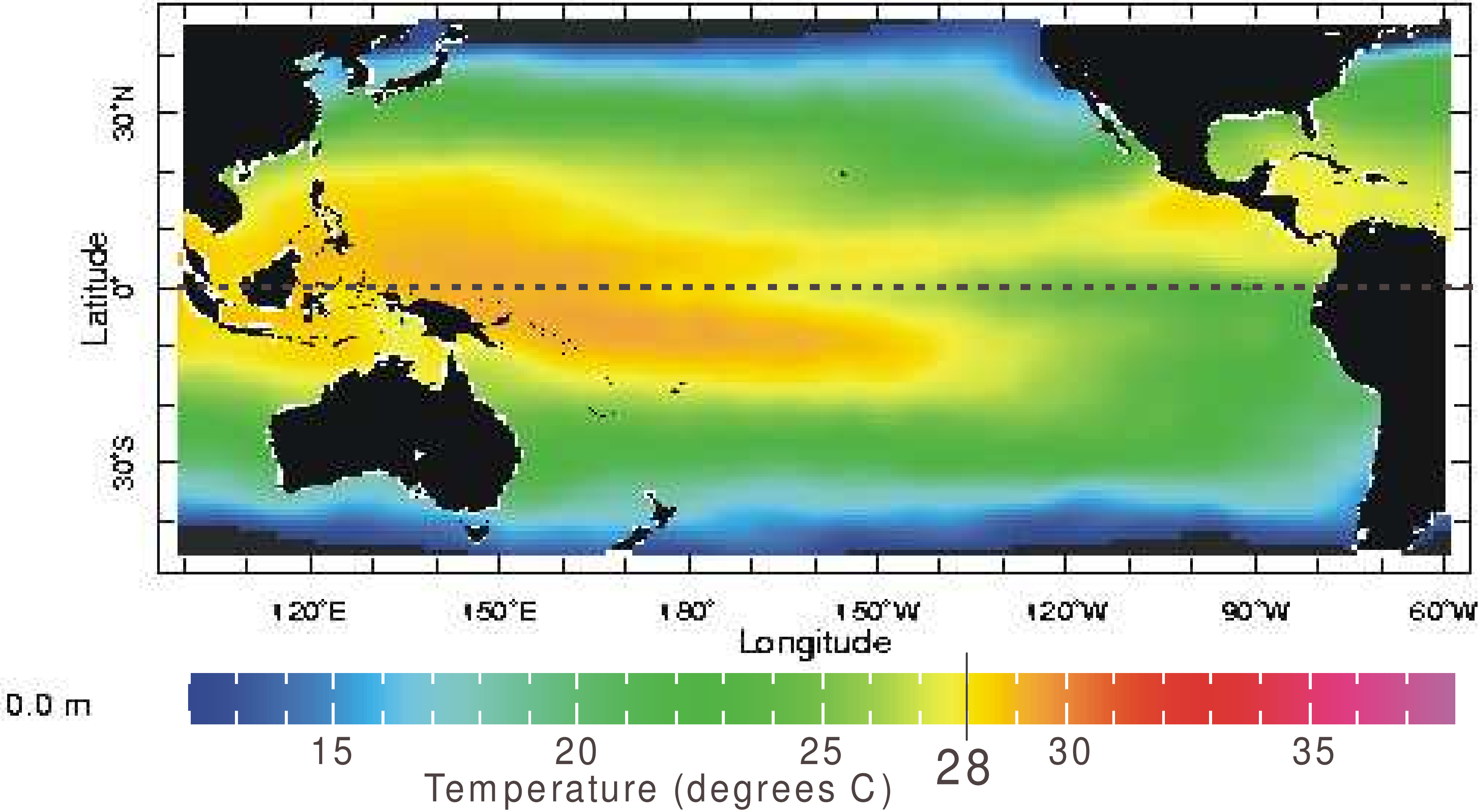


(Tudhope et al., 2001, *Science*, 291, 1511-1517)

UPLIFTED CORAL REEFS AT HUON PENINSULA:

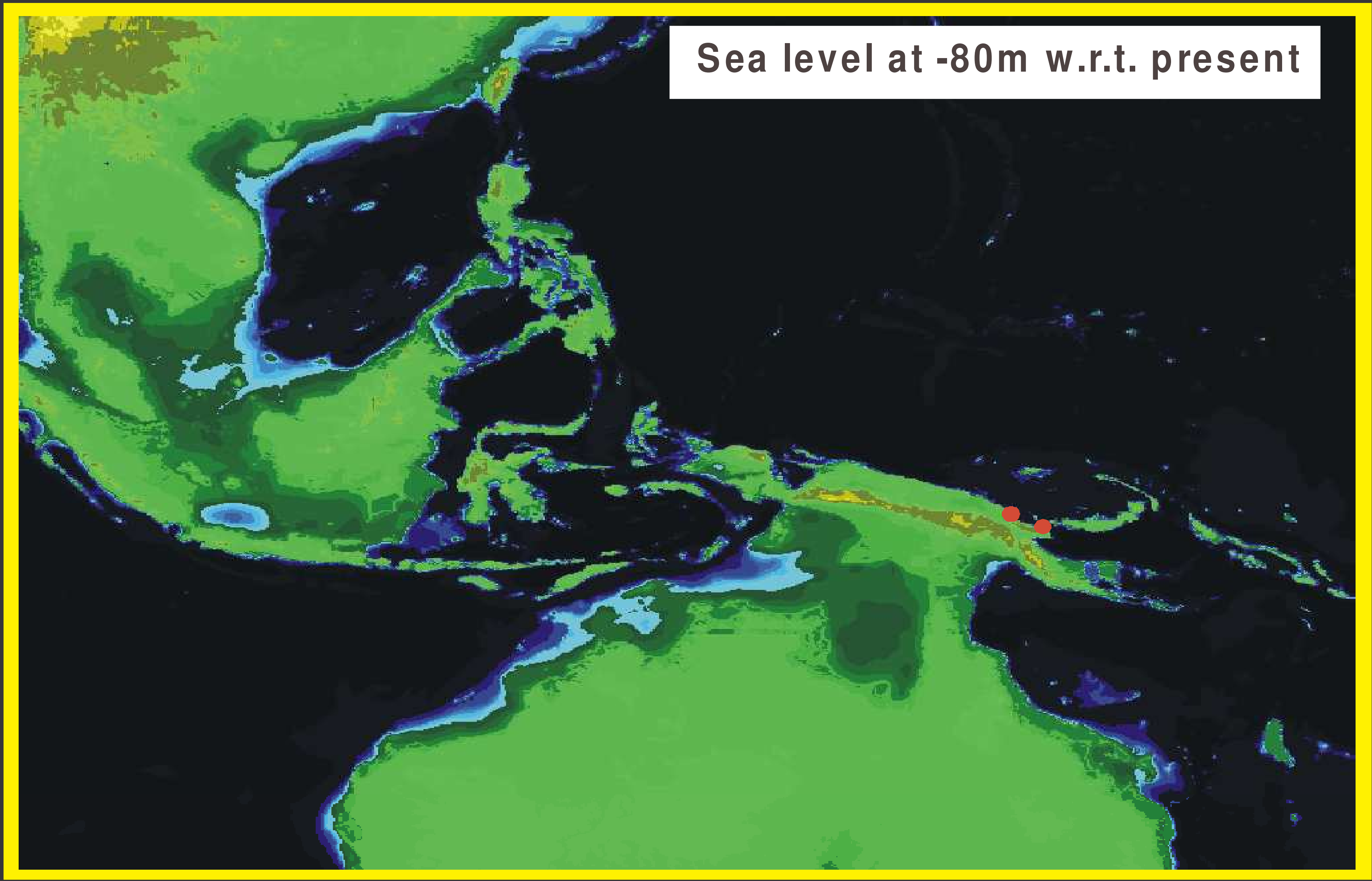
GLOBAL SEA-LEVEL AND FOSSIL CORAL SAMPLES



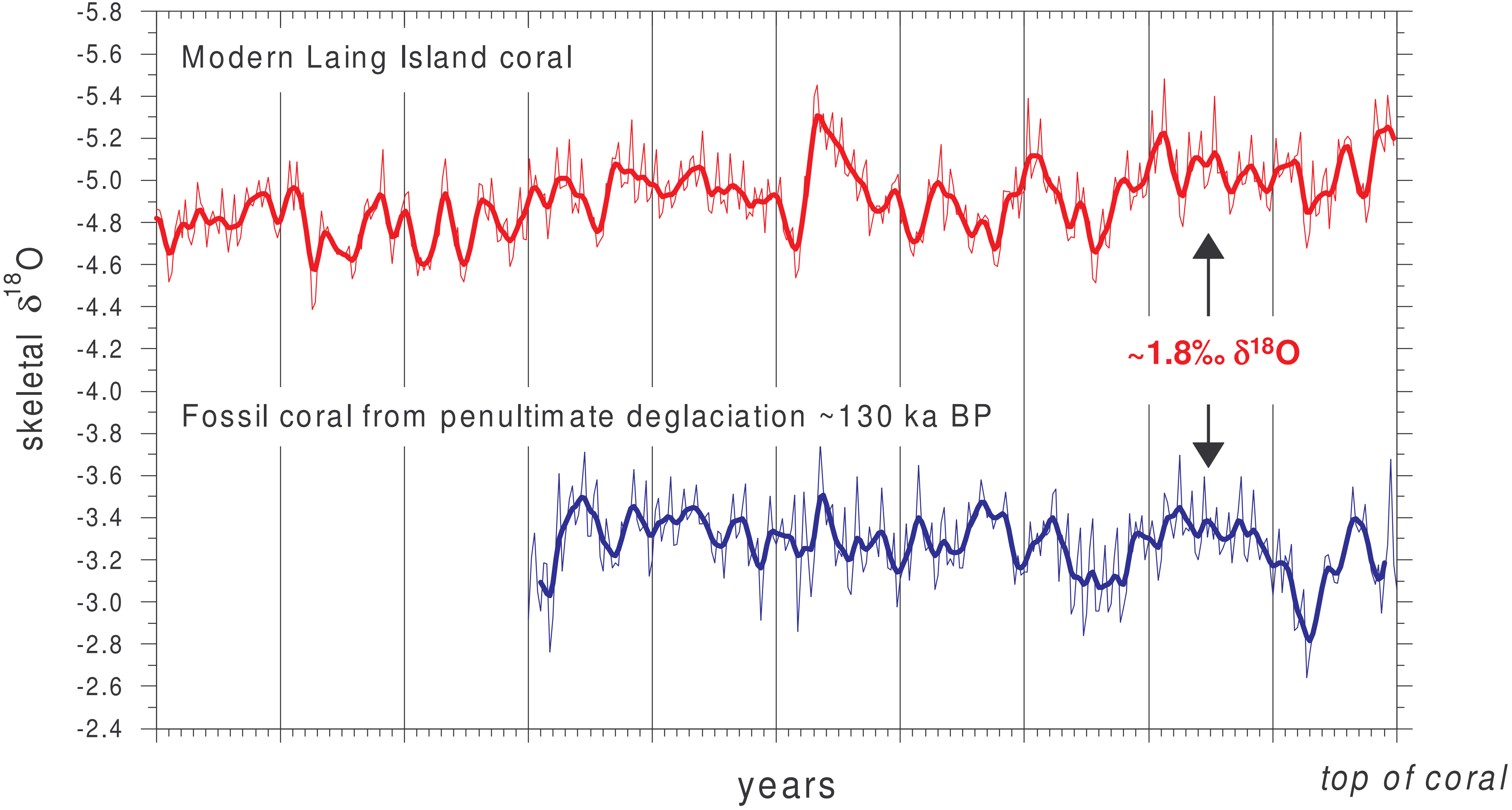


Mean annual sea surface temperature.

(SOURCE: LEVITUS94 Ocean Climatology; http://ingrid.ldgo.columbia.edu/)

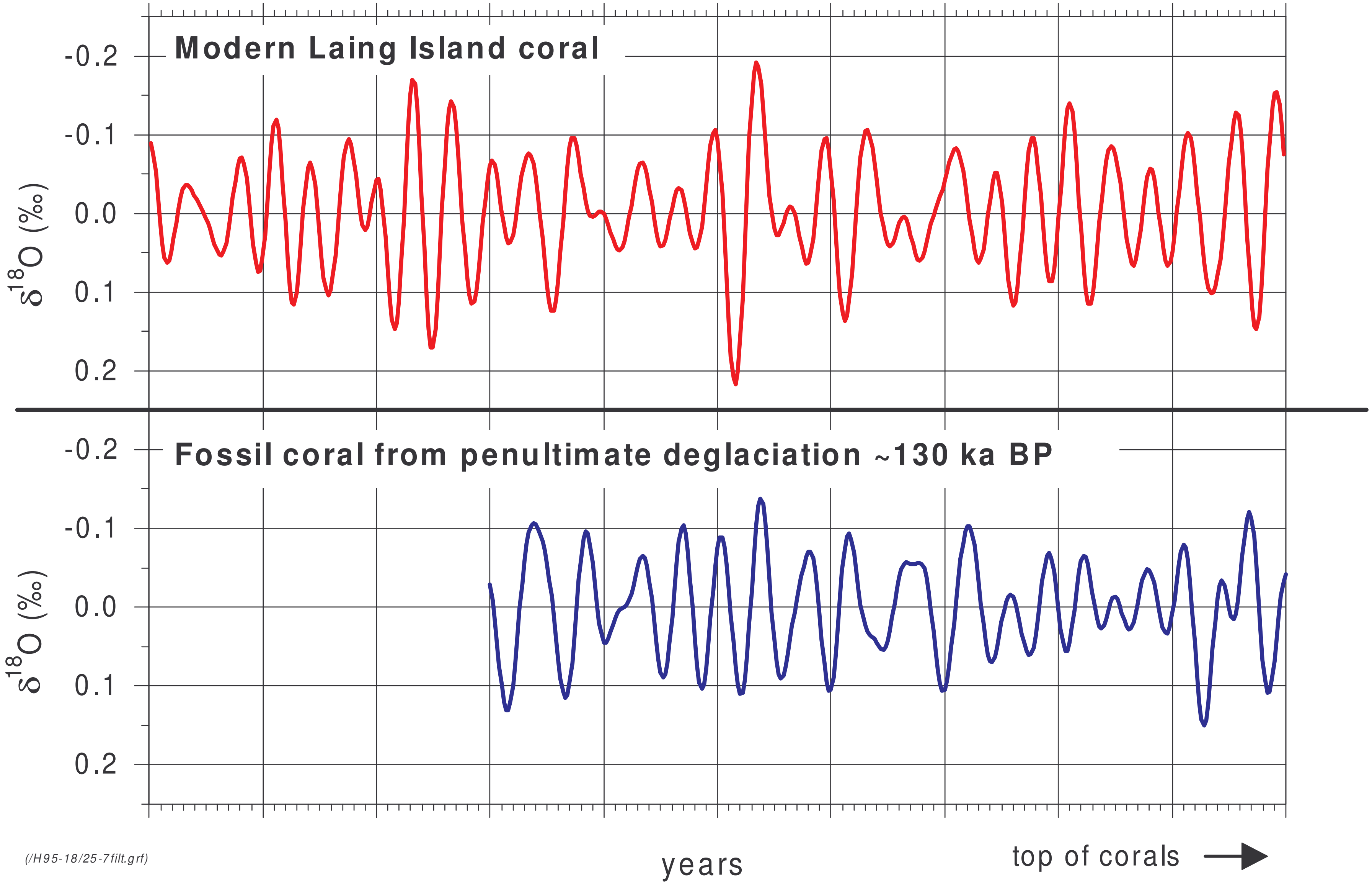

Sea level at -80m w.r.t. present

Comparison of living and 'glacial' coral δ18O records; seasonal data and 9pt binomial filter



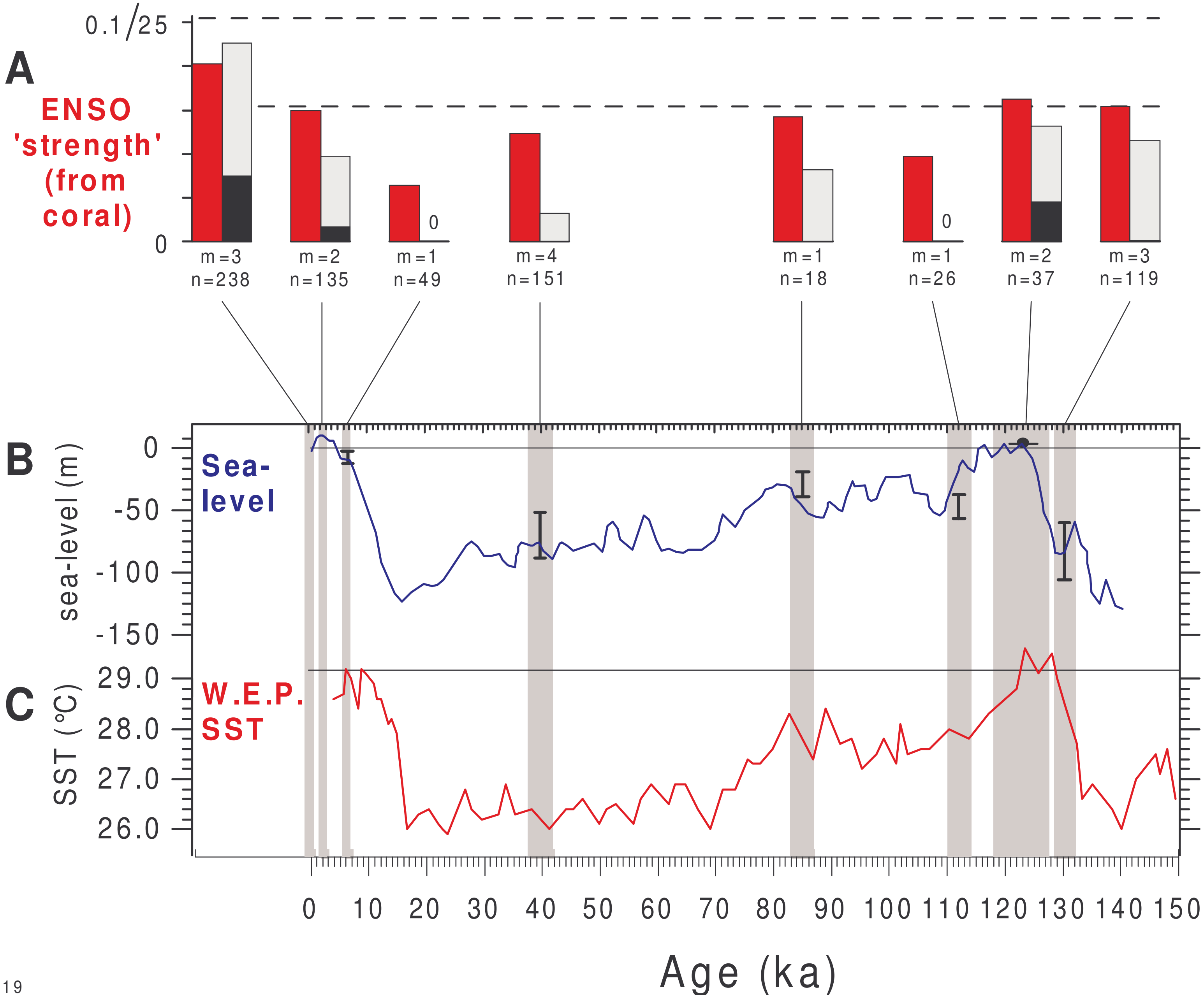
(....../H95-18/seasvsdu.grf)

Comparison of living and 'glacial' coral $\delta^{18}O$ records
2.5-7 year bandpass filtered to reveal ENSO-style climate variability



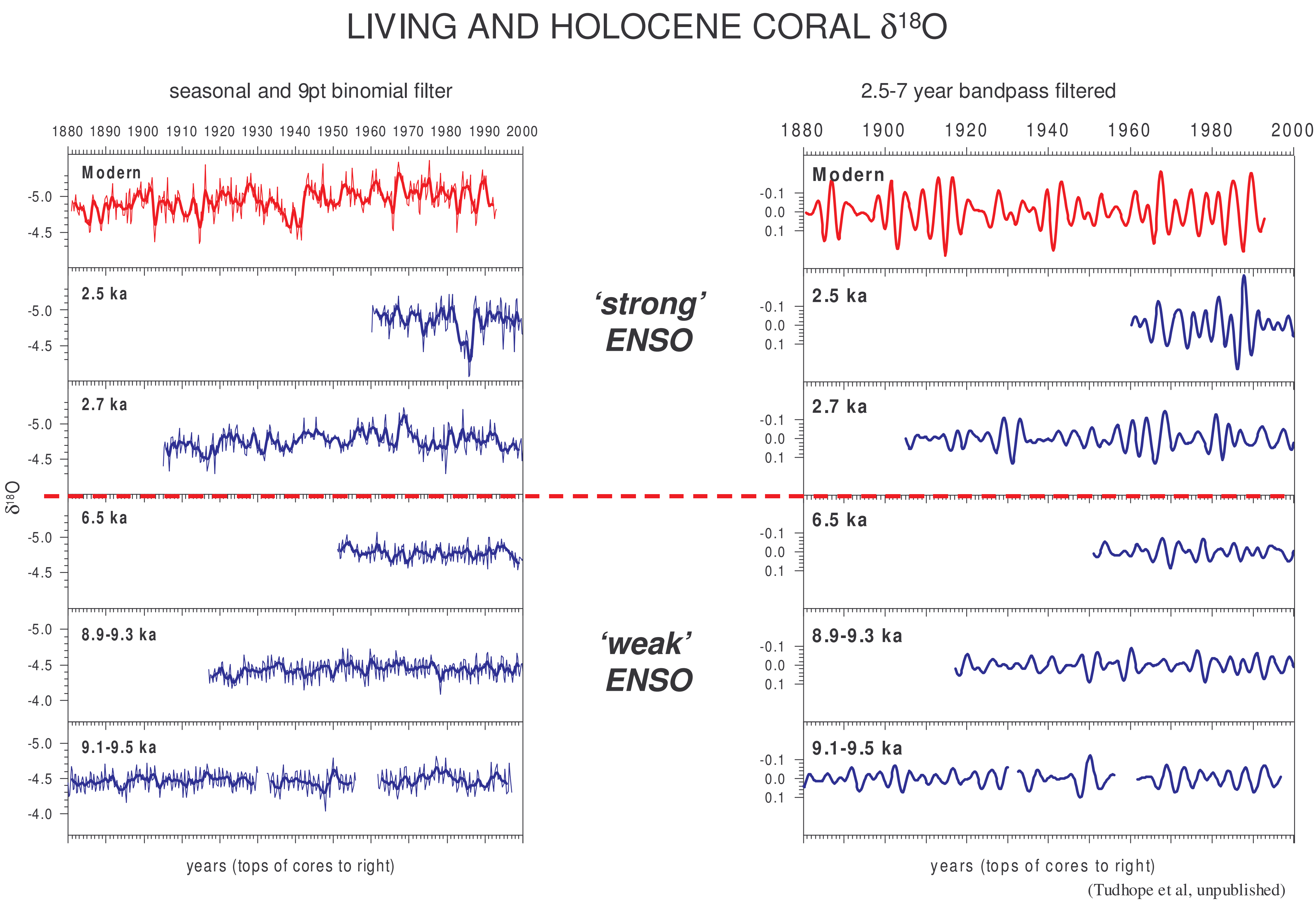
(/H95-18/25-7filt.grf)

ENSO variability through a glacial-interglacial cycle

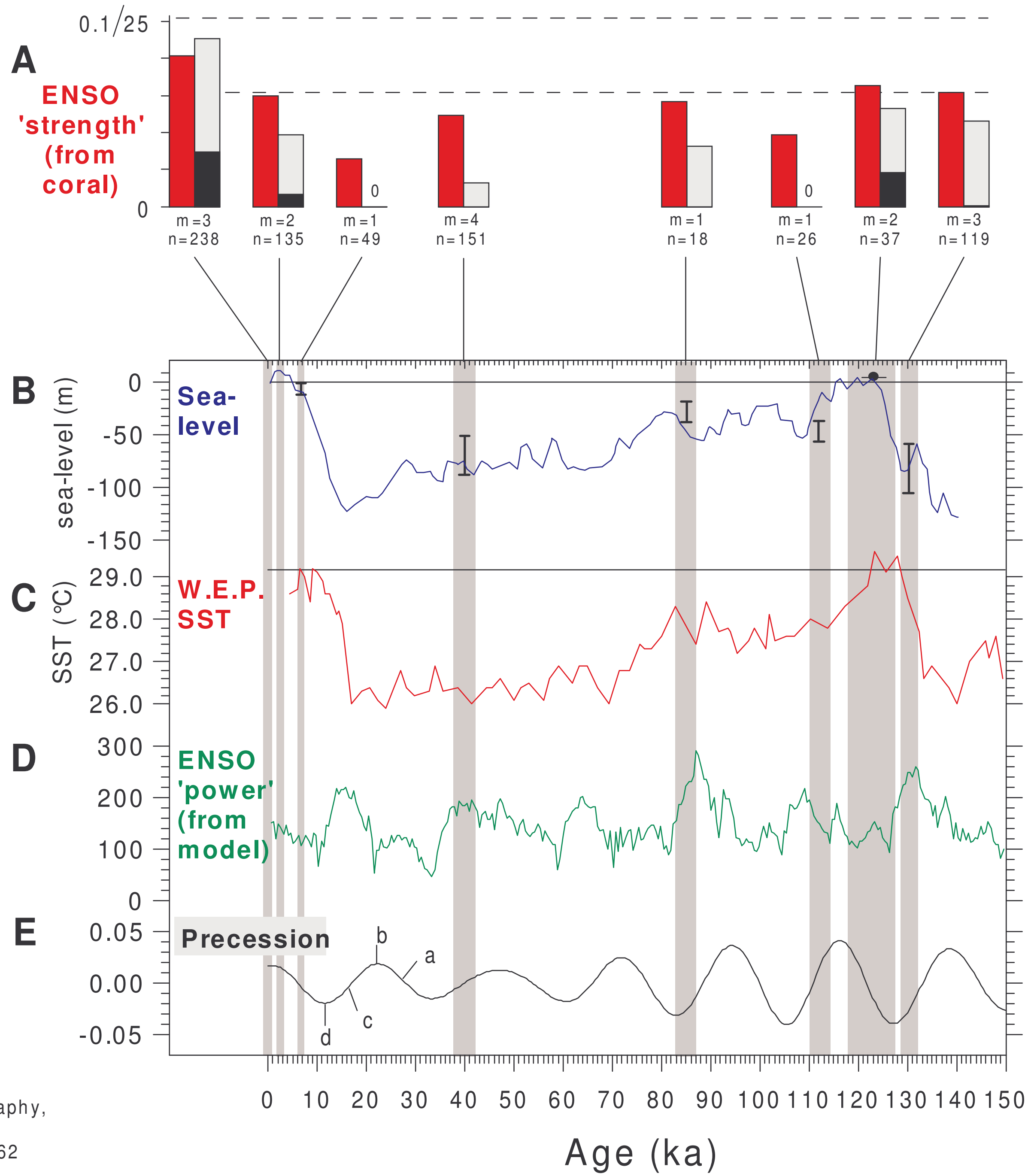


DATA SOURCES:
'B': Shackleton, 1987
'C': Lea et al., 2000, Science, 289, 1719
'D': Clement et al., 1999, Paleoceanography, 14, 441 & pers. com.
'E': Berger, 1978, J. Atmos. Sci., 35, 2362

(Tudhope et al., 2001, *Science*, 291, 1511-1517)


LIVING AND HOLOCENE CORAL δ18O
seasonal and 9pt binomial filter
2.5-7 year bandpass filtered
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
1880 1900 1920 1940 1960 1980 2000
Modern
2.5 ka
2.7 ka
6.5 ka
8.9-9.3 ka
9.1-9.5 ka
-5.0
-4.5
-4.0
-0.1
0.0
0.1
δ18O
'strong' ENSO
'weak' ENSO
years (tops of cores to right)
years (tops of cores to right)
(Tudhope et al, unpublished)

ENSO variability through a glacial-interglacial cycle



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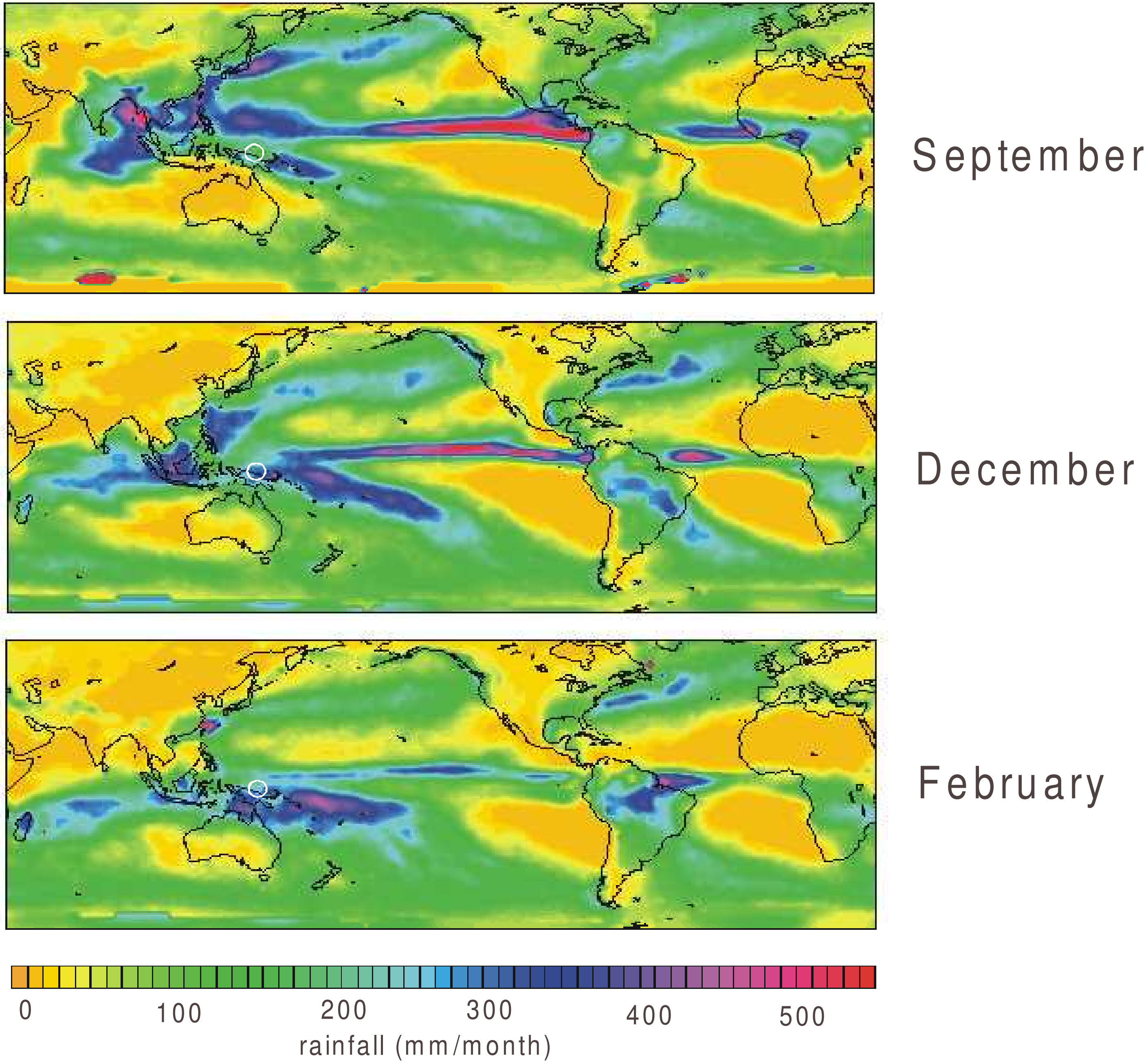
'E': Berger, 1978, J. Atmos. Sci., 35, 2362

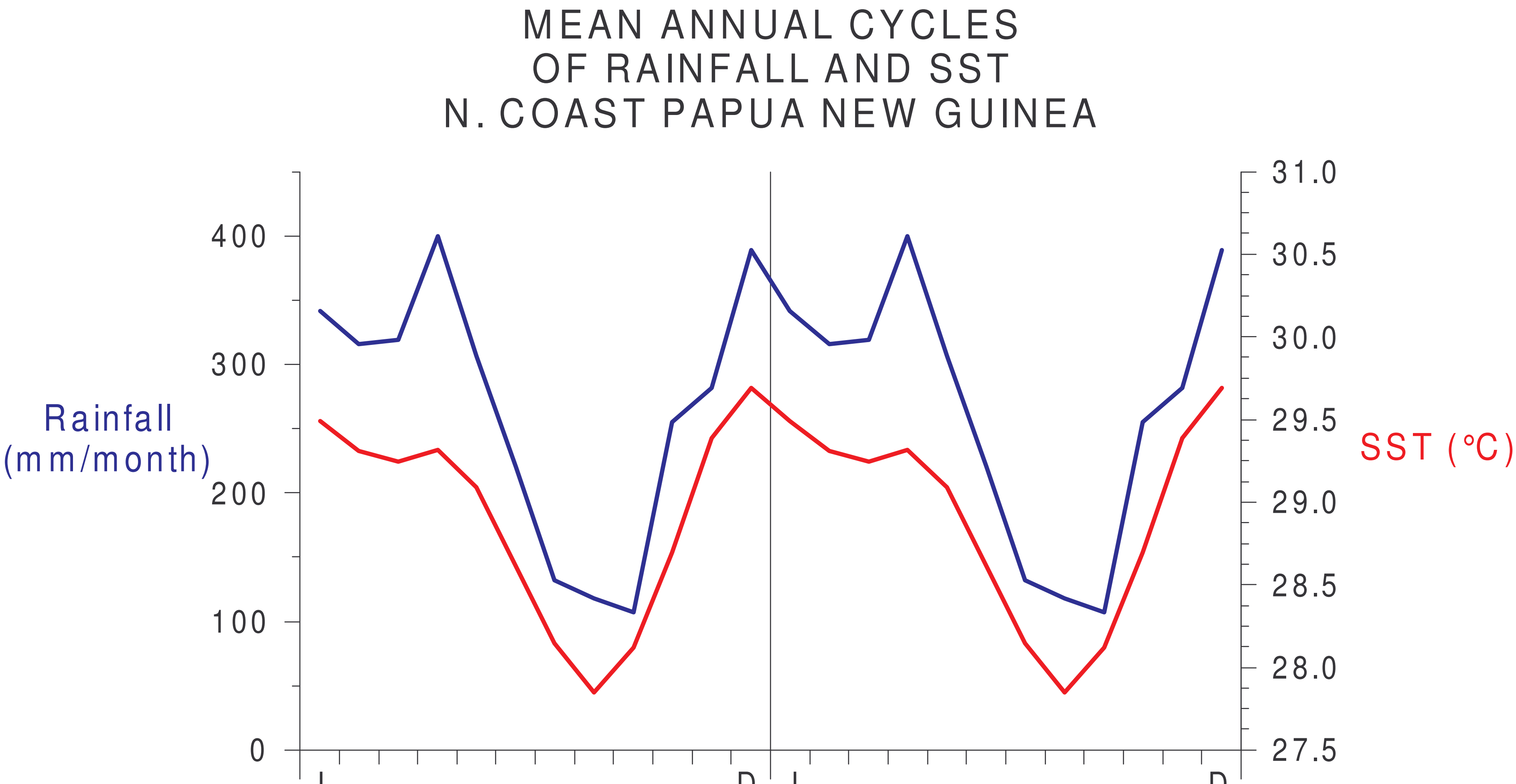
(Tudhope et al., 2001)

Summary:

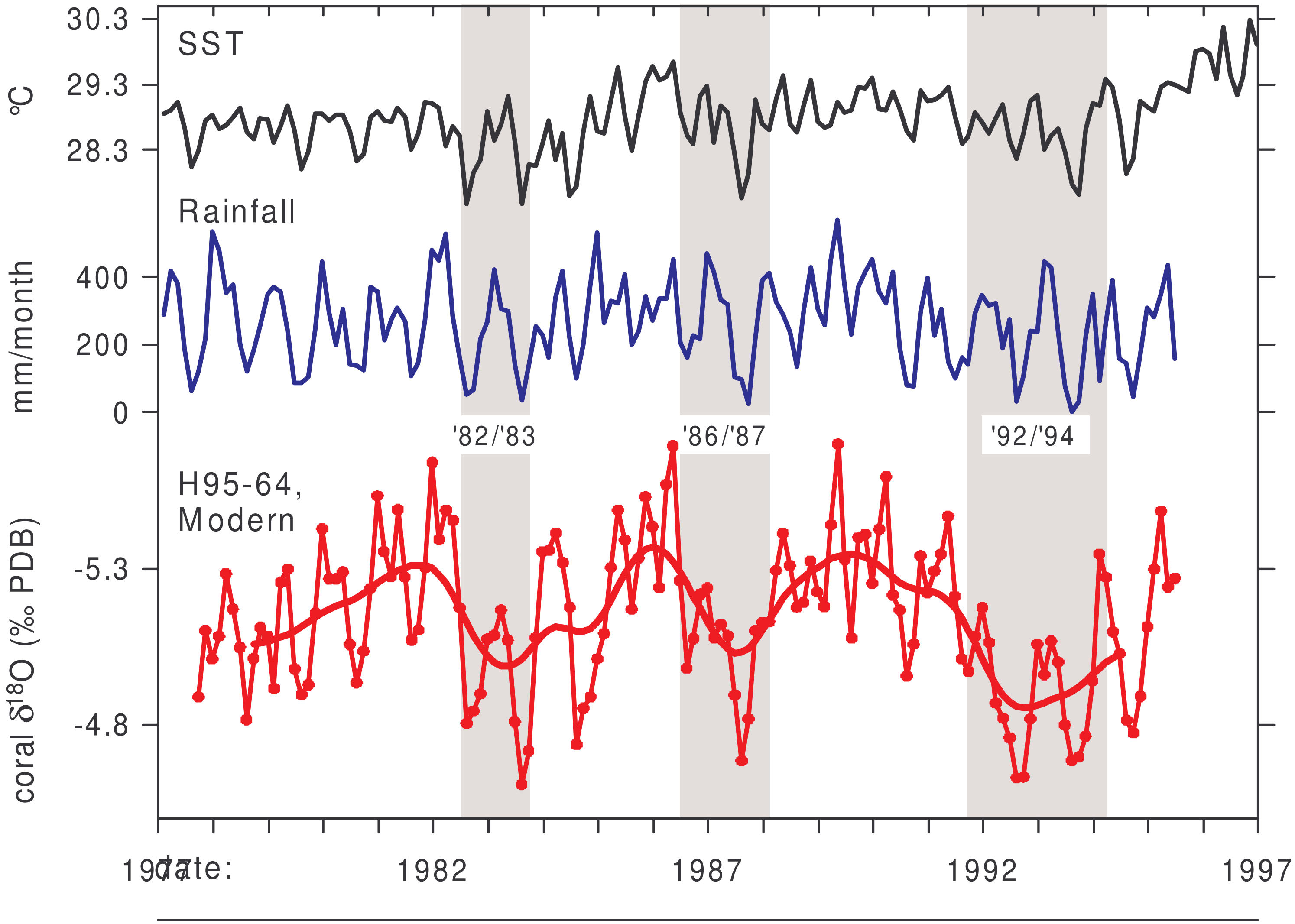
- ENSO has existed for at least 130,000 years, operating even during ‘glacial’ times
- HOWEVER, ENSO has varied in strength, with modern ENSO strong relative to previous ‘glacial’ and interglacial times
- On these timescales, ENSO strength may be controlled by the combined effects of:
  - Variations in the Earth’s orbit (precessional forcing)
  - ‘dampening’ of ENSO variability during cool ‘glacial’ periods

Legate's MSU precipitation climatology

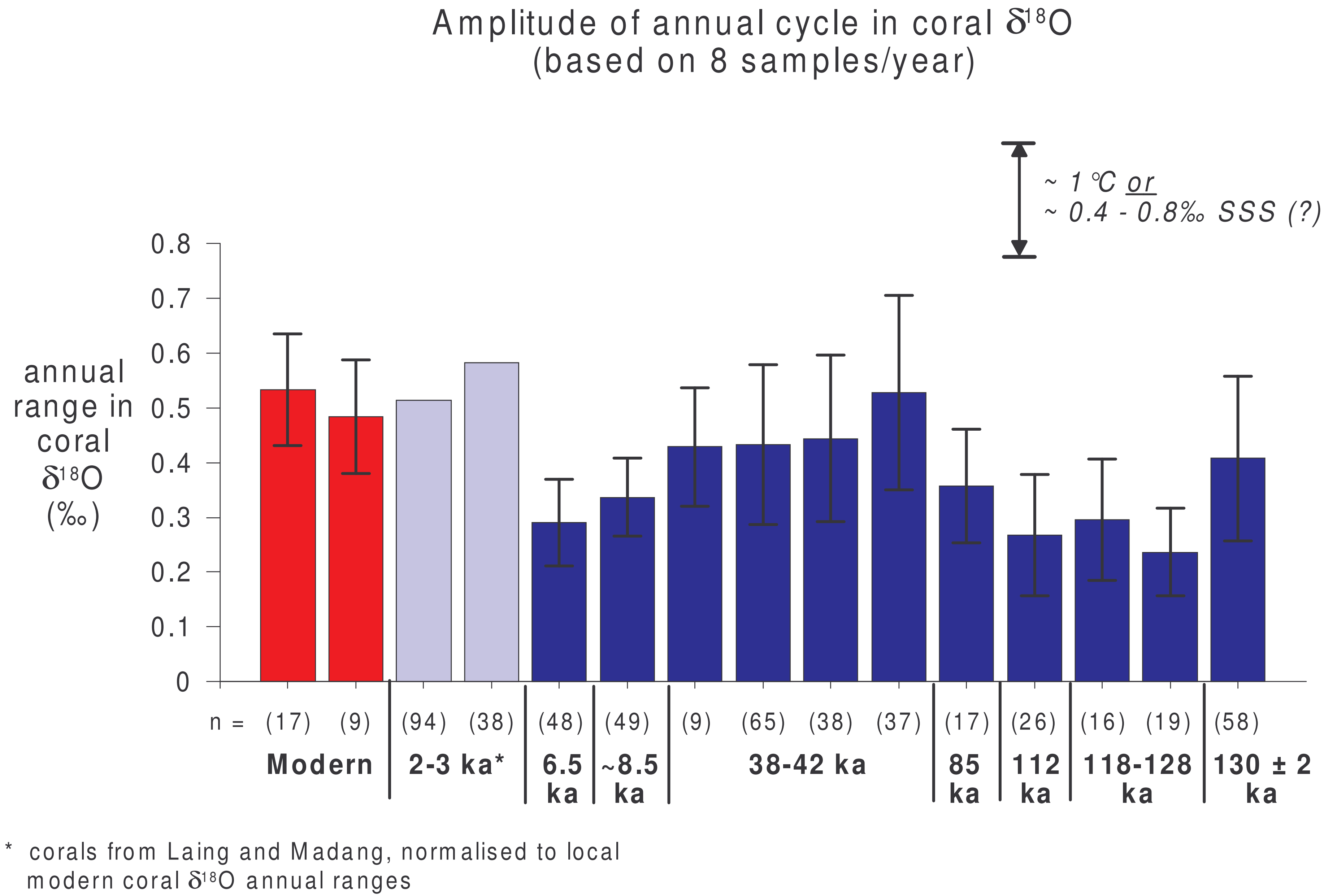


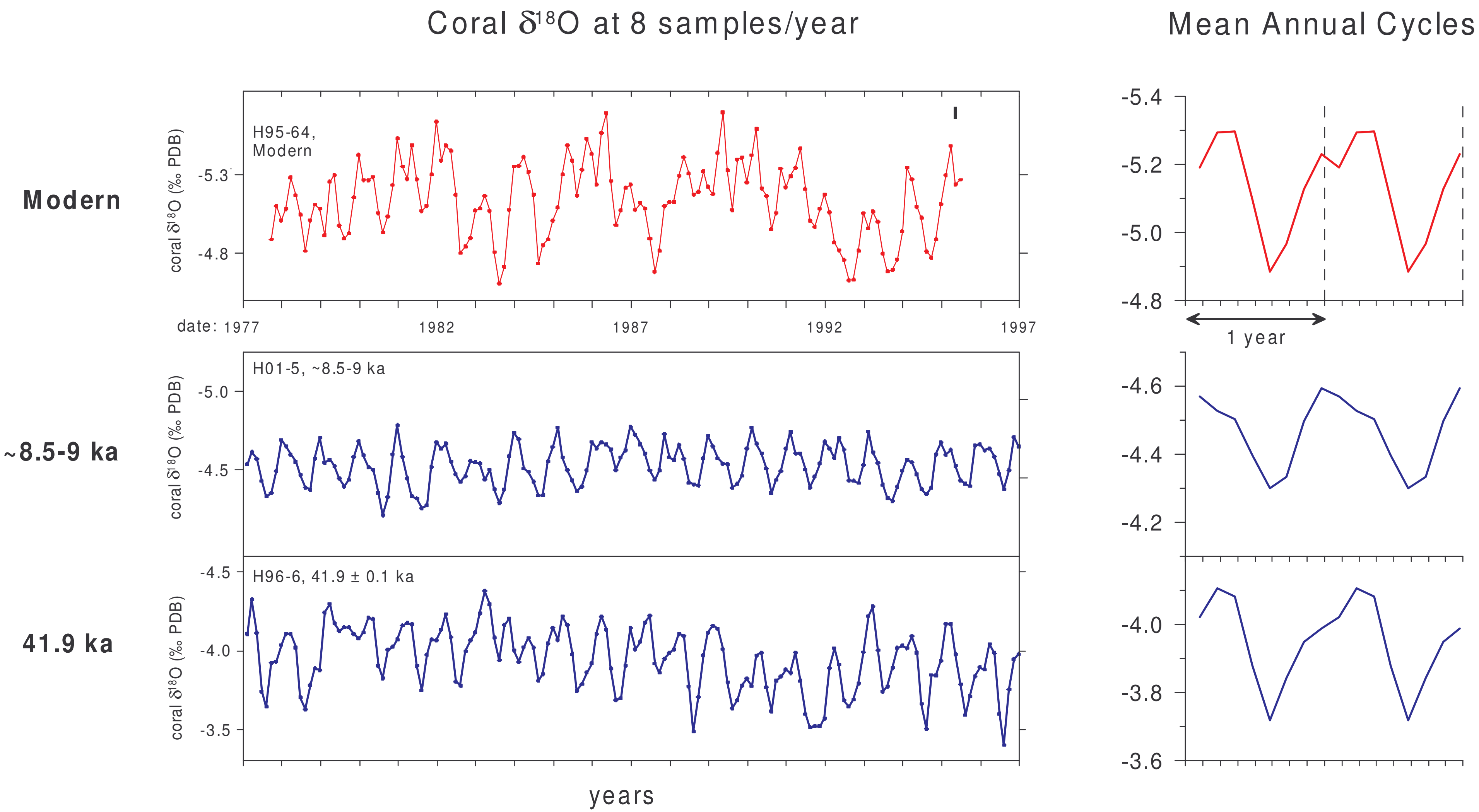

MEAN ANNUAL CYCLES
OF RAINFALL AND SST
N. COAST PAPUA NEW GUINEA
Rainfall
(mm/month)
SST (°C)
400
300
200
100
0
31.0
30.5
30.0
29.5
29.0
28.5
28.0
27.5
J
D
J
D

Instrumental and coral oxygen isotope timeseries, Papua New Guinea

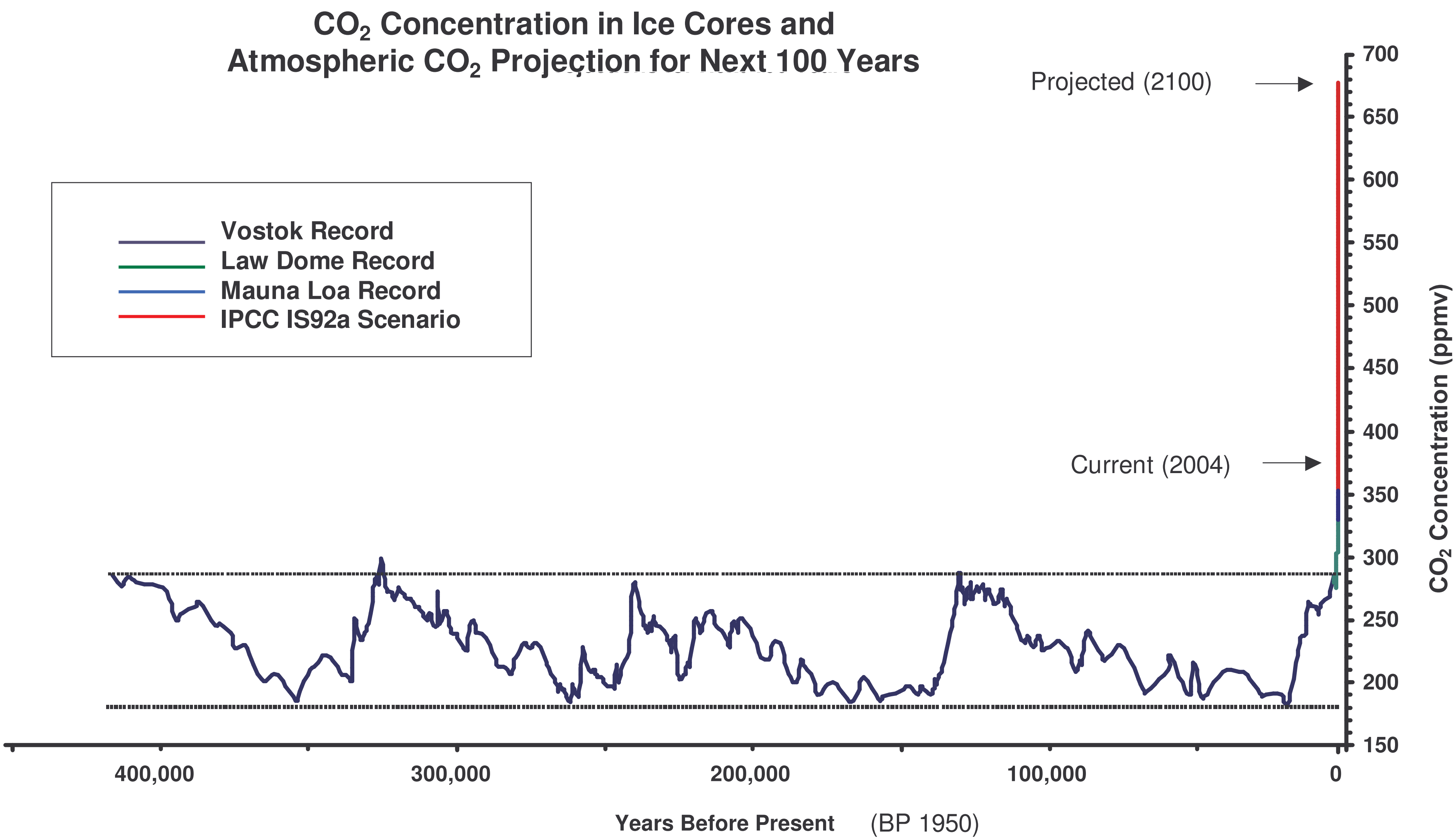


(Tudhope et al., 2001, *Science*, 291, 1511-1517)


Amplitude of annual cycle in coral δ18O
(based on 8 samples/year)
~ 1 °C or
~ 0.4 - 0.8‰ SSS (?)
annual range in coral δ18O (‰)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
n = (17) (9) (94) (38) (48) (49) (9) (65) (38) (37) (17) (26) (16) (19) (58)
Modern
2-3 ka*
6.5 ka
~8.5 ka
38-42 ka
85 ka
112 ka
118-128 ka
130 ± 2 ka
* corals from Laing and Madang, normalised to local modern coral δ18O annual ranges



Coral δ18O at 8 samples/year
Mean Annual Cycles
Modern
~8.5-9 ka
41.9 ka
coral δ18O (‰ PDB)
H95-64,
Modern
-5.3
-4.8
date: 1977
1982
1987
1992
1997
H01-5, ~8.5-9 ka
-5.0
-4.5
H96-6, 41.9 ± 0.1 ka
-4.5
-4.0
-3.5
years
-5.4
-5.2
-5.0
-4.8
1 year
-4.6
-4.4
-4.2
-4.0
-3.8
-3.6



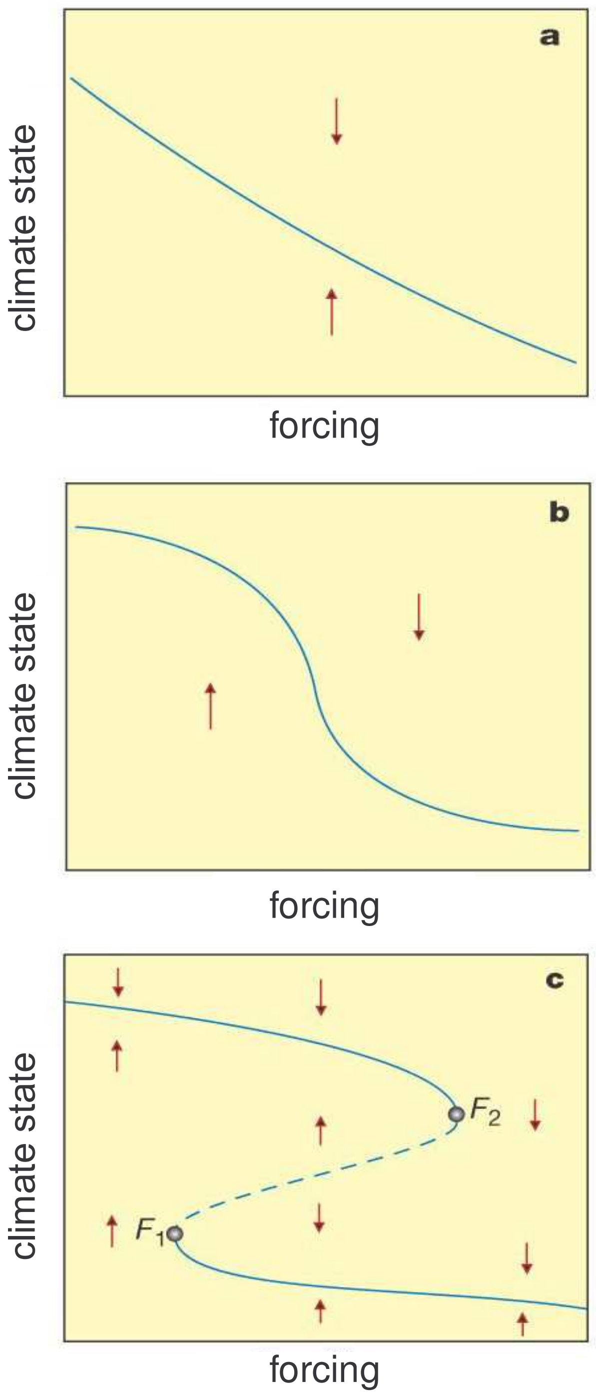
Source: C. D. Keeling and T. P. Whorf; Etheridge *et.al.;* Barnola *et.al.;* (*PAGES* / IGBP); IPCC

Future ENSO:

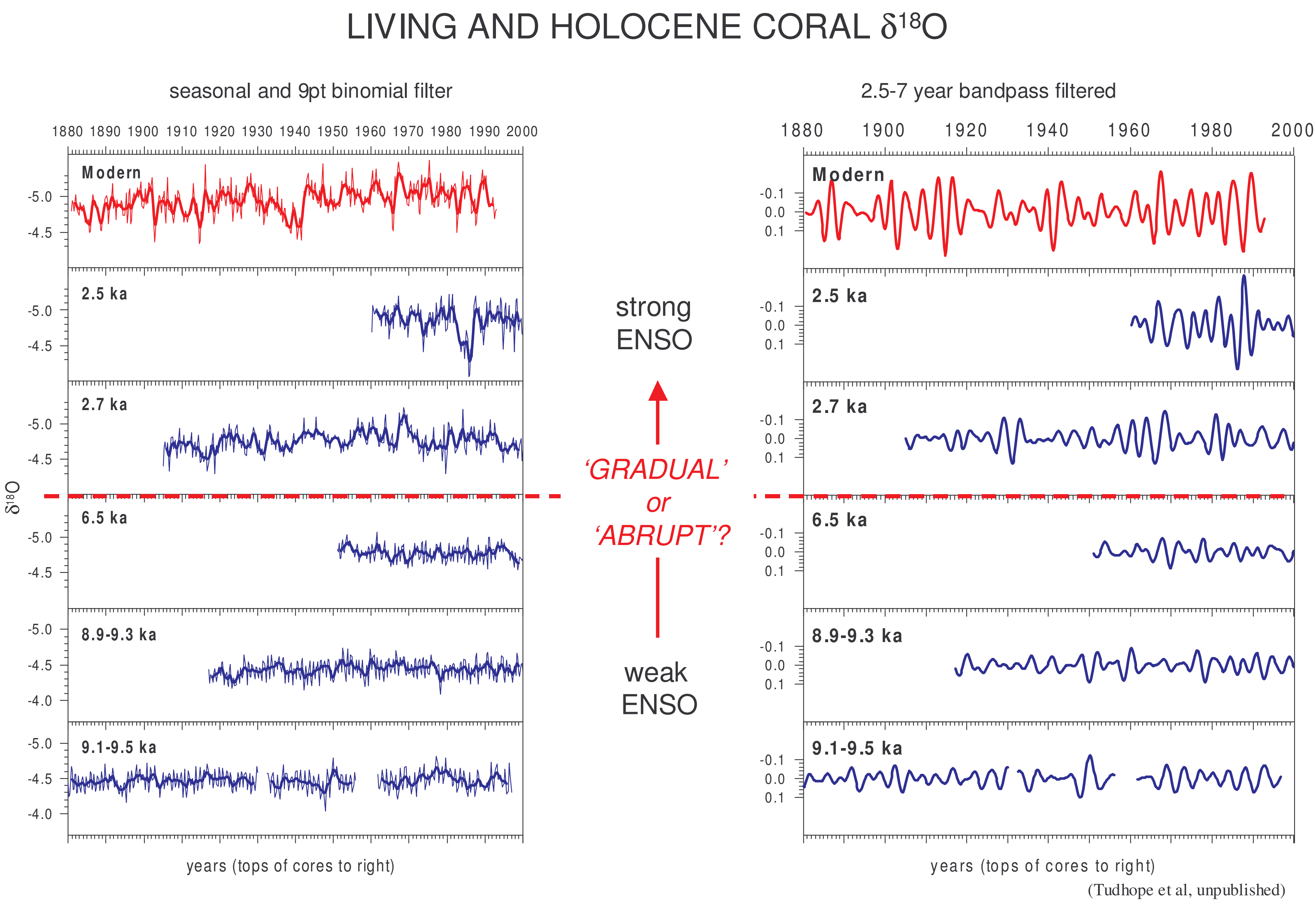
- ENSO appears to be sensitive to global climatic boundary conditions, THEREFORE, ENSO is likely to respond to future Greenhouse Warming. A strengthening of ENSO is possible/probable
- Likely role of the tropics in future global climate change
- Possibility for ABRUPT changes?

Abrupt changes in climate:

thresholds and alternate stable states



SOURCE: Modified from:
Scheffer et al., 2001, *Nature,* 413, 591-596



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seasonal and 9pt binomial filter
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2.7 ka
6.5 ka
8.9-9.3 ka
9.1-9.5 ka
-5.0
-4.5
-4.0
-0.1
0.0
0.1
δ18O
strong
ENSO
'GRADUAL'
or
'ABRUPT'?
weak
ENSO
years (tops of cores to right)
years (tops of cores to right)
(Tudhope et al, unpublished)