Coral Records of Decadal and Interannual Variability in the South Pacific: New Results from the Expanding Coral Network

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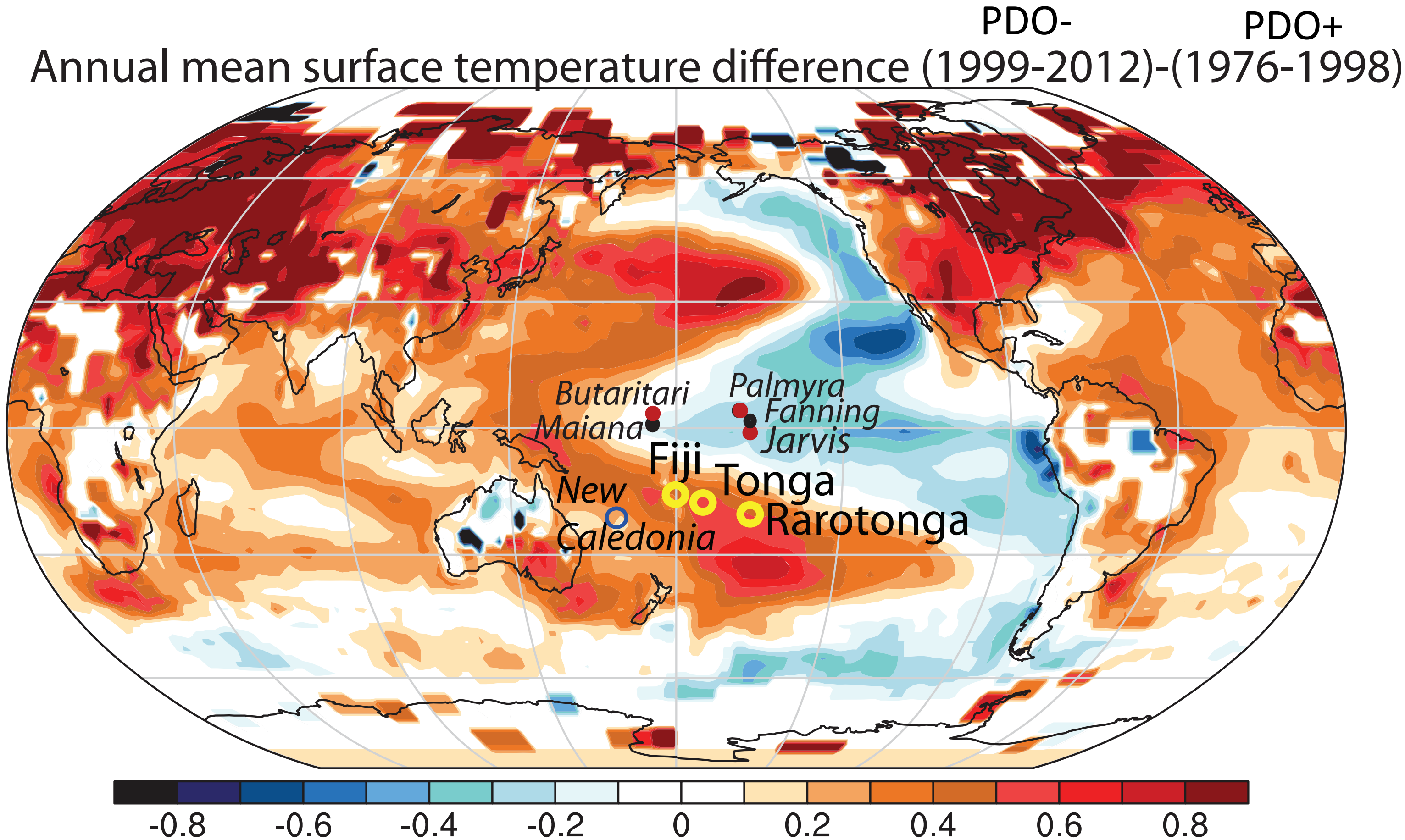
Part 1: Fiji, Tonga Rarotonga: Decadal SST and Ocean Heat

Collaborators: Henry Wu, Emilie Dassié, Dan Schrag
Jerry Wellington (*deceased*)

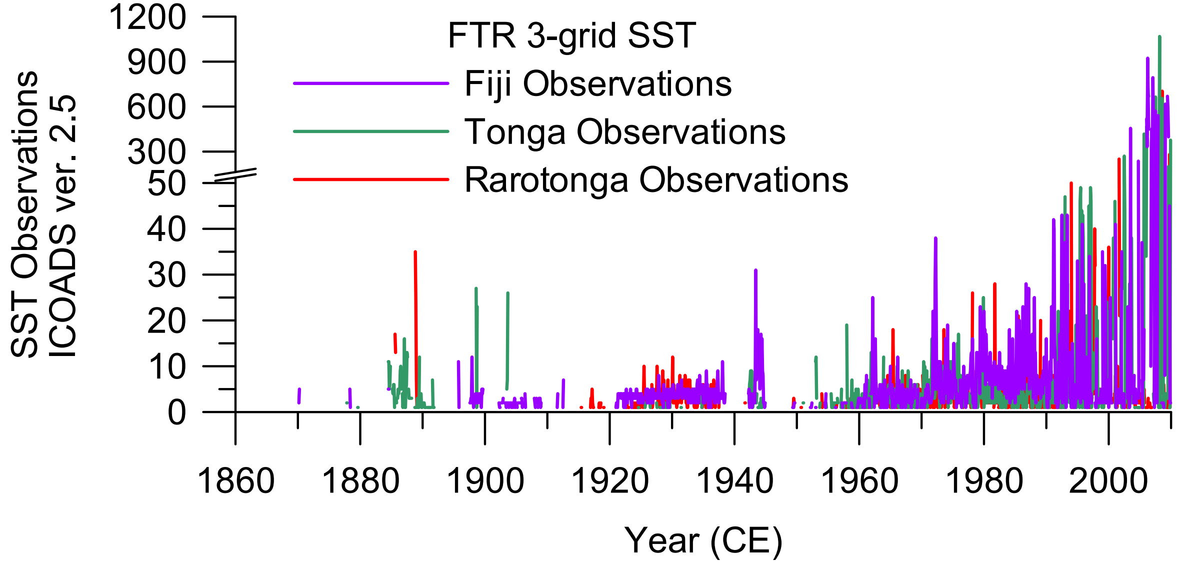
Part 2: Ta'u, American Samoa; South Pacific Convergence Zone and ENSO

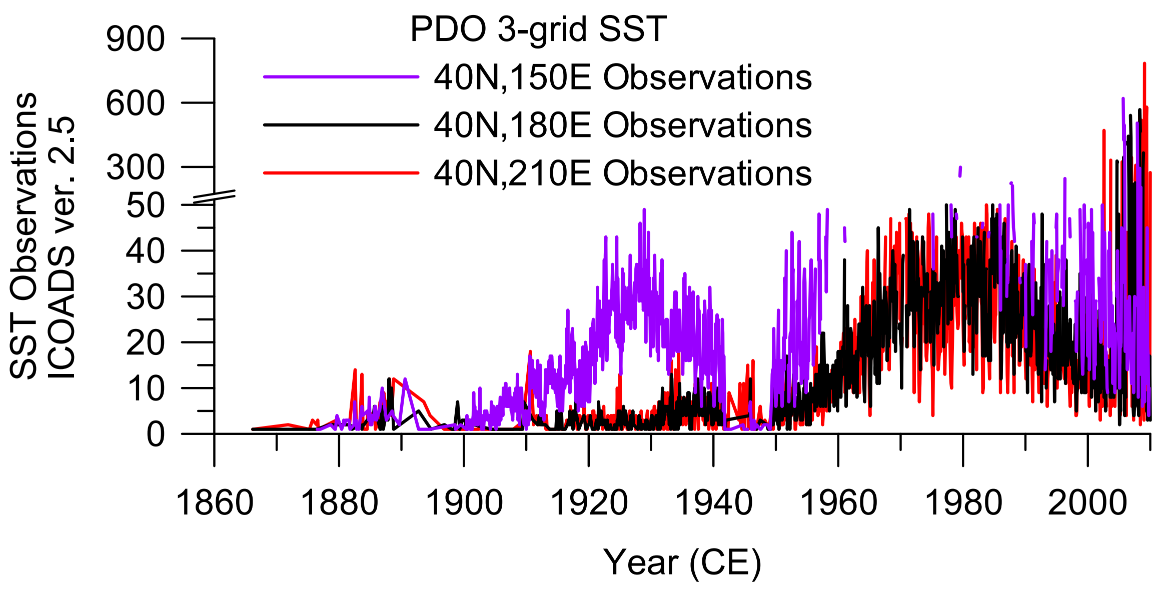
Collaborators: Robert Dunbar, Emilie Dassié



Mean annual surface temperature differences between the periods from 1999 to 2012 and 1976 to 1998 in °C. *(Figure modified from Trenberth and Fasullo [2013]).* In the Pacific the spatial pattern strongly resembles the negative phase of the Pacific Decadal Oscillation (PDO) [see Trenberth and Fasullo, 2013]. The location of our coral Sr/Ca records at Fiji, Tonga, and Rarotonga (FTR) are indicated as our other coral records from along the equator.

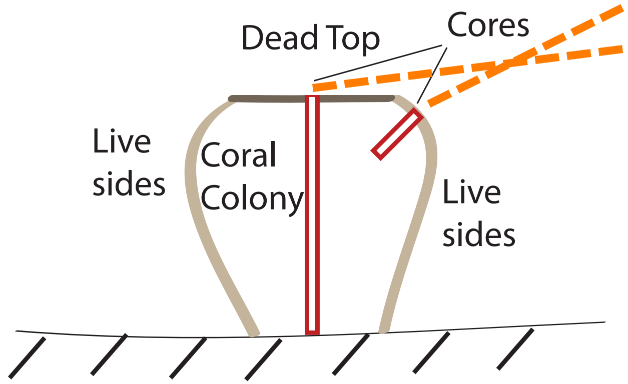
Lack of SST observations in South Pacific before ~ 1960

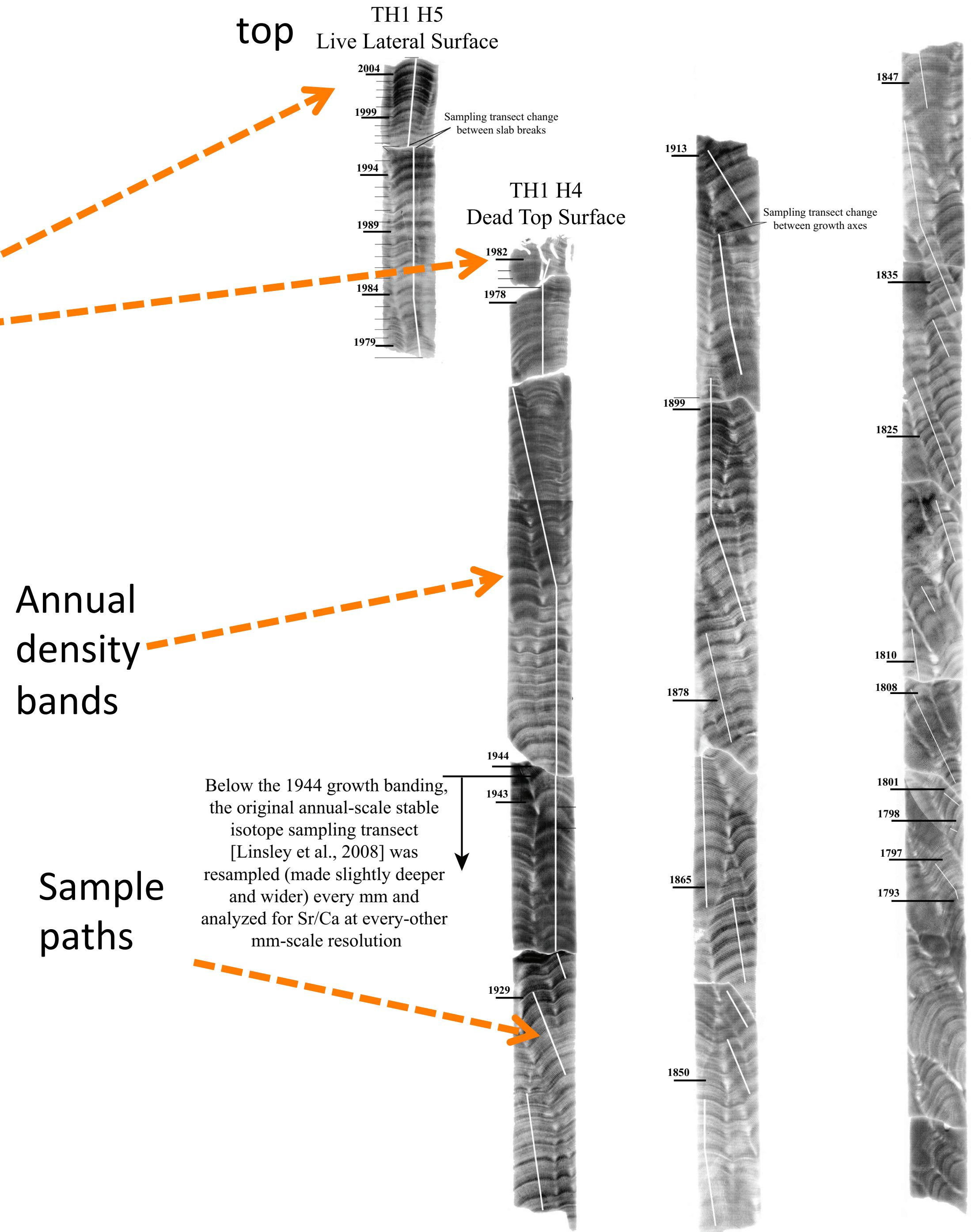





Coral colony of *Porites lutea*
at Ta'u, American Samoa.

X-ray collage of Tonga coral cores collected in December 2004 at Ha'afera Island. The time-series from this coral extends back 1791.





Decadal changes in South Pacific sea surface temperatures and the relationship to the Pacific decadal oscillation and upper ocean heat content

Braddock K. Linsley[1], Henry C. Wu[2], Emilie P. Dassié[1], and Daniel P. Schrag[3]

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Abstract Decadal changes in Pacific sea surface temperatures (SSTs) and upper ocean heat content (OHC) remain poorly understood. We present an annual average composite coral Sr/Ca-derived SST time series extending back to 1791 from Fiji, Tonga, and Rarotonga (FTR) in the Pacific Decadal Oscillation (PDO) sensitive region of the southwest Pacific. Decadal SST maxima between 1805 and 1830 Common Era (C.E.) indicate unexplained elevated SSTs near the end of the Little Ice Age. The mean period of decadal SST variability in this region has a period near 25 years. Decades of warmer (cooler) FTR SST co-occur with PDO negative (positive) phases since at least ~1930 C.E. and positively correlate with South Pacific OHC (0–700 m). FTR SST is also inversely correlated with decadal changes in equatorial Pacific SST as measured by coral Sr/Ca. Collectively, these results support the fluctuating trade wind-shallow meridional overturning cell mechanism for decadal modulation of Pacific SSTs and OHC.

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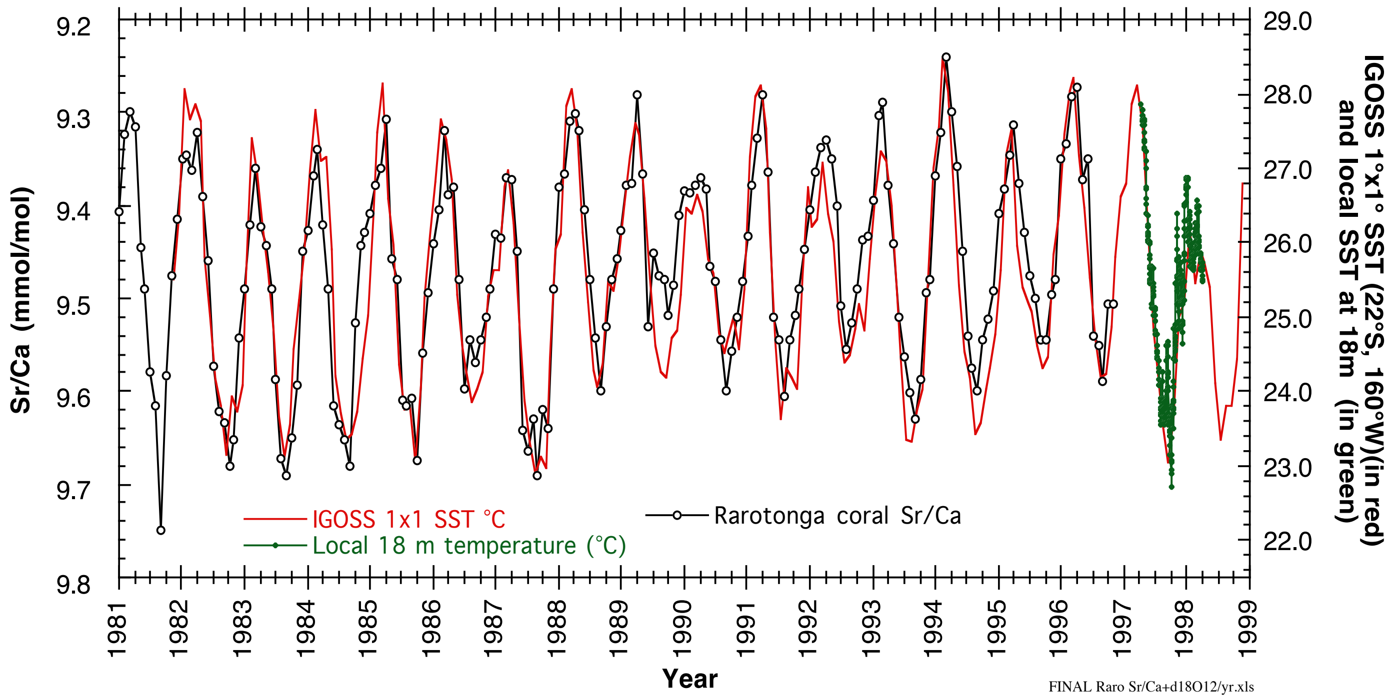
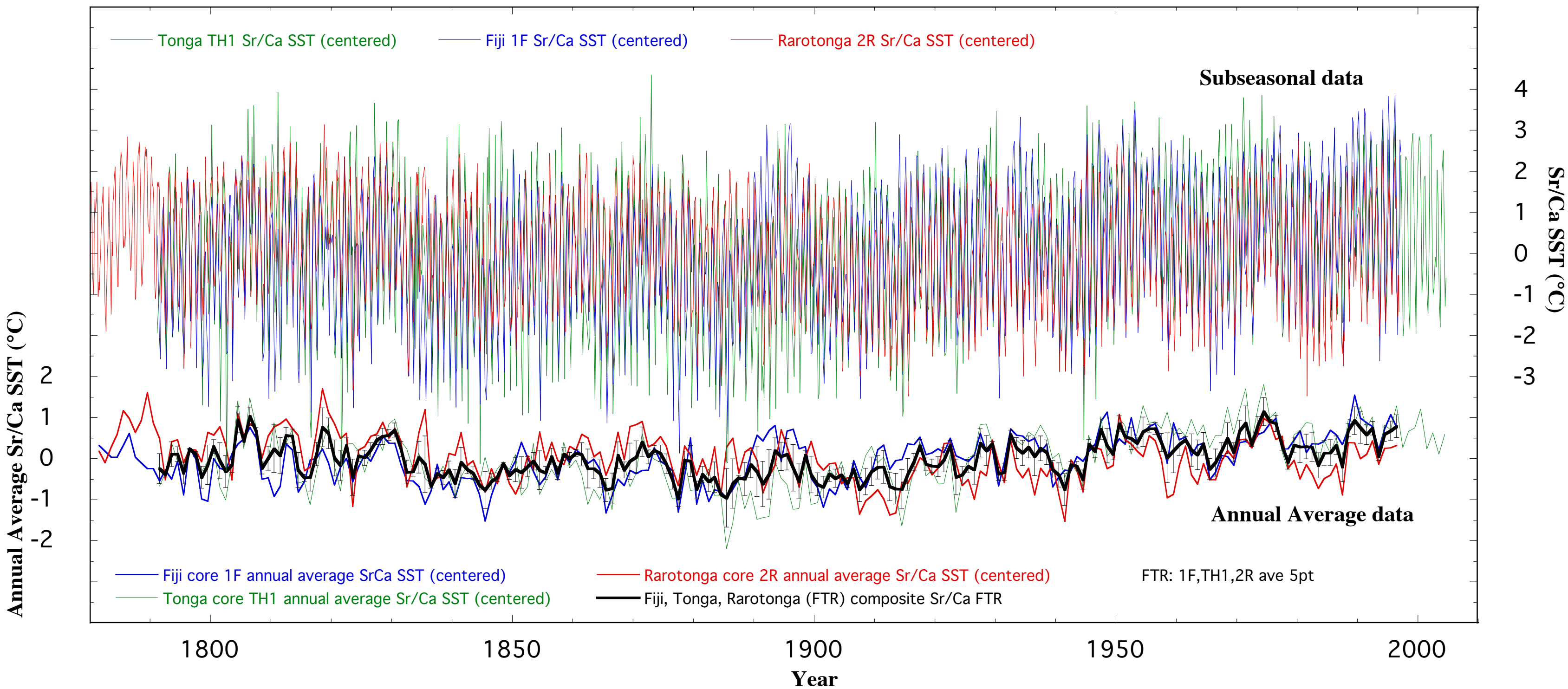
Coral Skeletal Strontium/Calcium (Sr/Ca) and Sea Surface Temperature (SST)



Example of Sr/Ca – SST calibration from Rarotonga also showing a strong correlation between in-situ temperature at a coral site to IGOSS gridded SST. Downcore Rarotonga *Porites* Sr/Ca (**black**) vs. IGOSS SST (*Reynolds and Smith, 1994*)(**red**). Coral was collected at 18m off the western side of Rarotonga in an exposed setting. In-situ daily water temperature data at the coral site is shown in **green** (from Linsley and Wellington and presented in *Wu et al., 2013*).

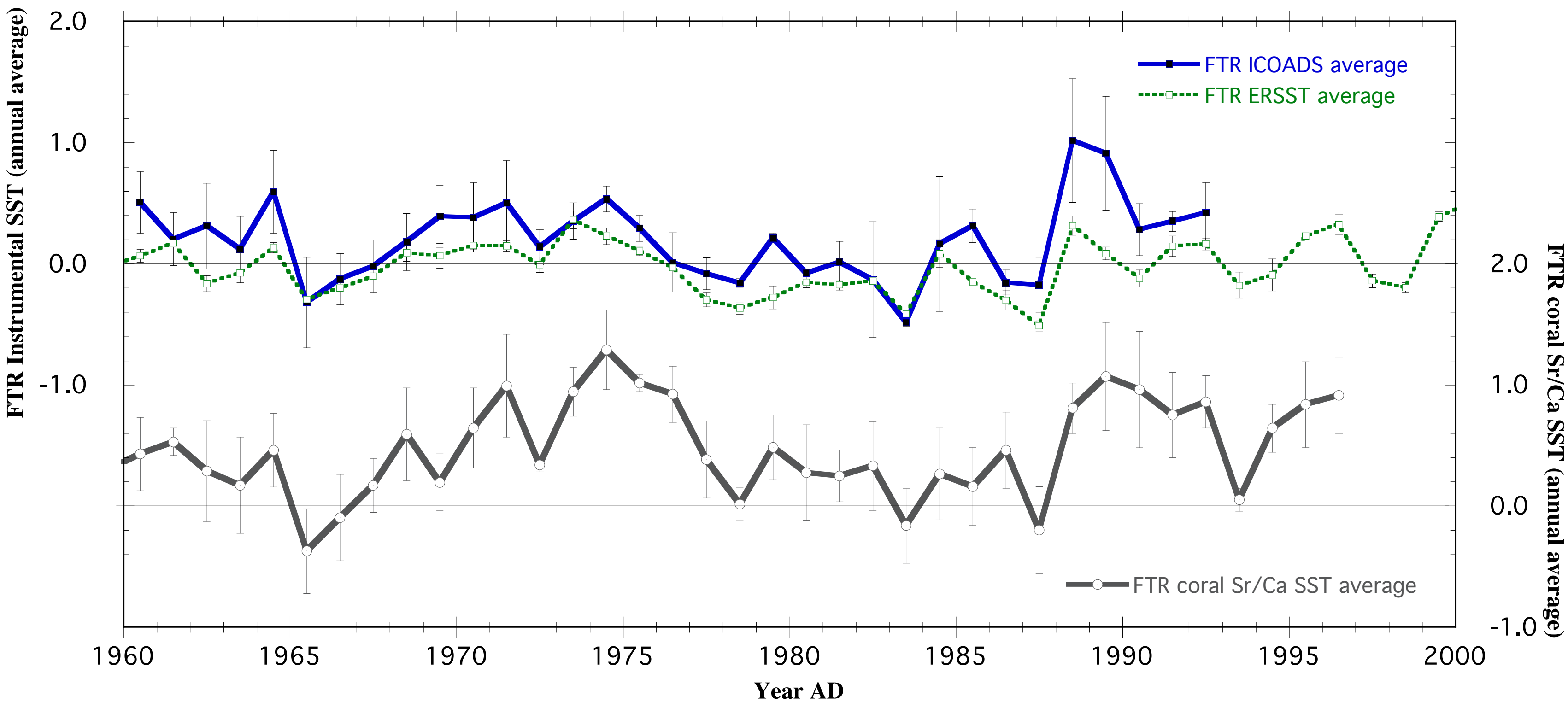
Tonga, Fiji Rarotonga



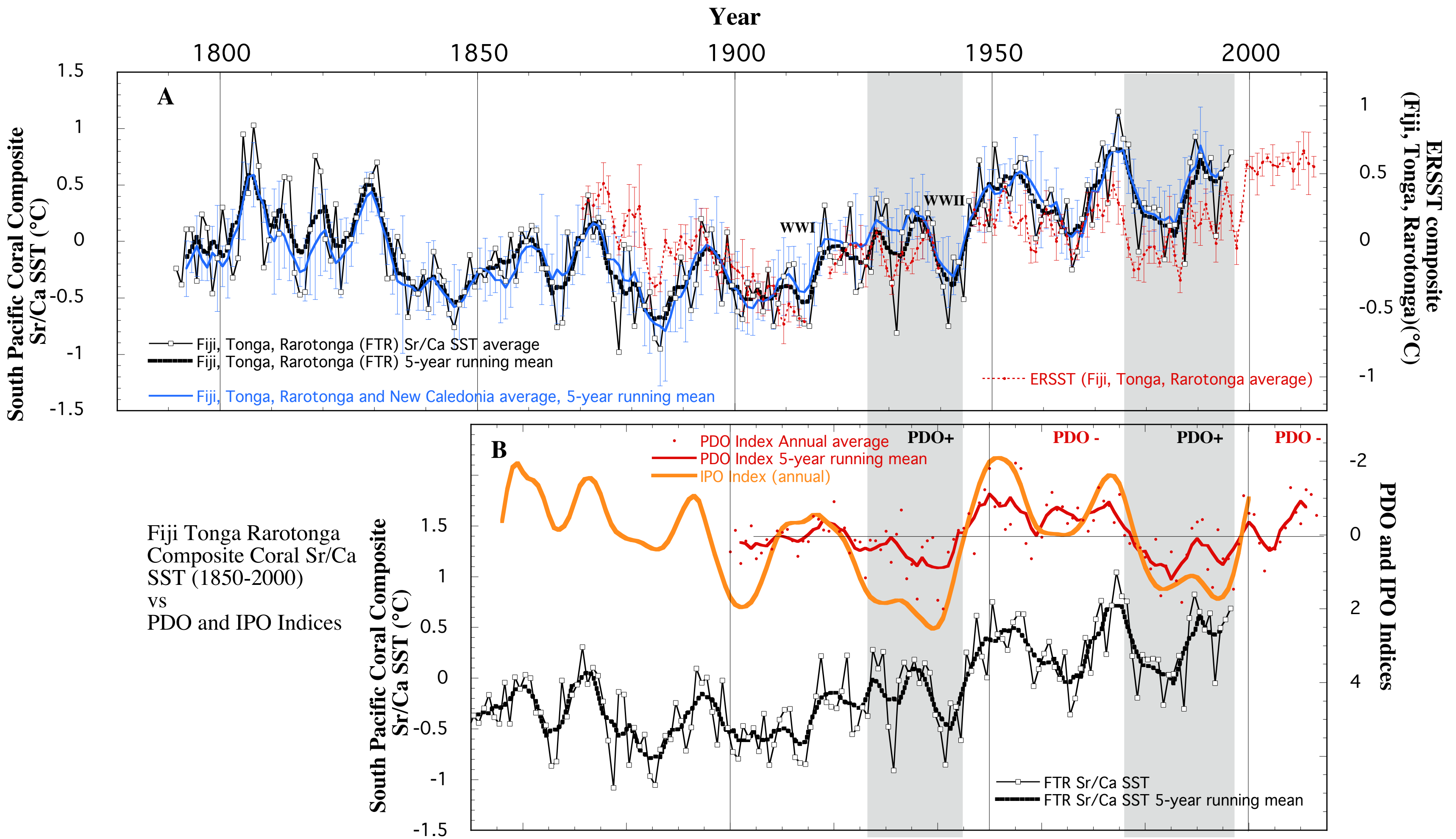
Fiji-Tonga-Rarotonga (FTR) composite coral Sr/Ca SST (1997-1791).
(top) Subseasonal Sr/Ca SST data from Fiji (blue), Tonga (green) and Rarotonga (red) based on sub-seasonal calibrations to SST. Data has been centered by removing the 1800-1997 C.E. average. (Bottom) Annually average Sr/Ca SST from the same three sites. Bold black line is the average with standard error (SE); where SE = (standard deviation of annual average / square root of n); where n = the number of cores in the FTR average for each year.

In general the error on coral Sr/Ca SST estimates is ~0.3°C based on single core calibration studies. The error is less than this for composite-average reconstructions.

FTR Sr/Ca SST and ICOADS SST and ERSST

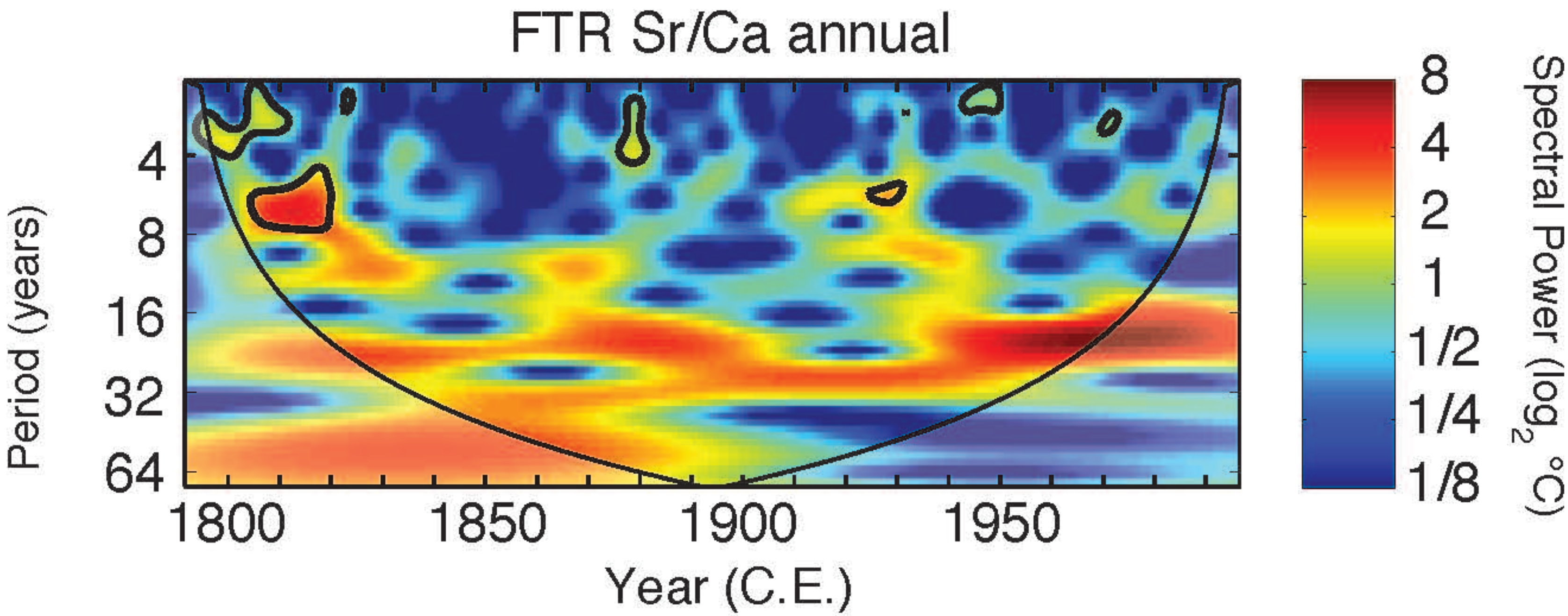


Correlations between annual FTR coral Sr/Ca SST and annual ICOADS and ERSST SST from the FTR grids back to 1960 are 0.71 ($p \leq 0.01$) and 0.75 ($p \leq 0.01$), respectively. Correlations of individual Sr/Ca records to local Fiji, Tonga and Rarotonga SST range from 0.5 to 0.58 ($p \leq 0.01$). This indicates that the composite average approach has increased the climatic signal to noise ratio.



(A) Three-coral Sr/Ca SST average from Fiji, Tonga, and Rarotonga (in black) along with a 5 year running mean (dashed black line). The centered instrumental ERSST (version 3) (red) is from the grids that include these same FTR sites. Blue curve is the average of Fiji, Tonga, Rarotonga, and New Caledonia [from Delong et al., 2012] Sr/Ca SST along with the standard error (SE).

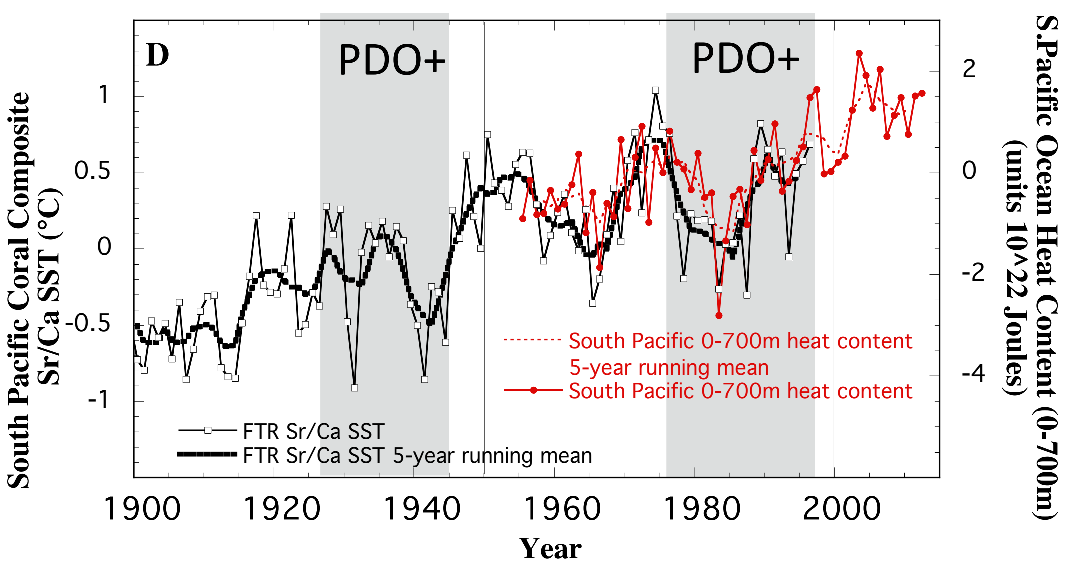
(B) The FTR Sr/Ca SST reconstruction compared to the PDO and IPO indices. Periods of positive PDO phases are demarcated in gray.



Evolutionary spectra of FTR Sr/Ca SST indicates a mean period near 20-25 years after ~ 1940 with slightly more complex bandwidth in the 1800s.

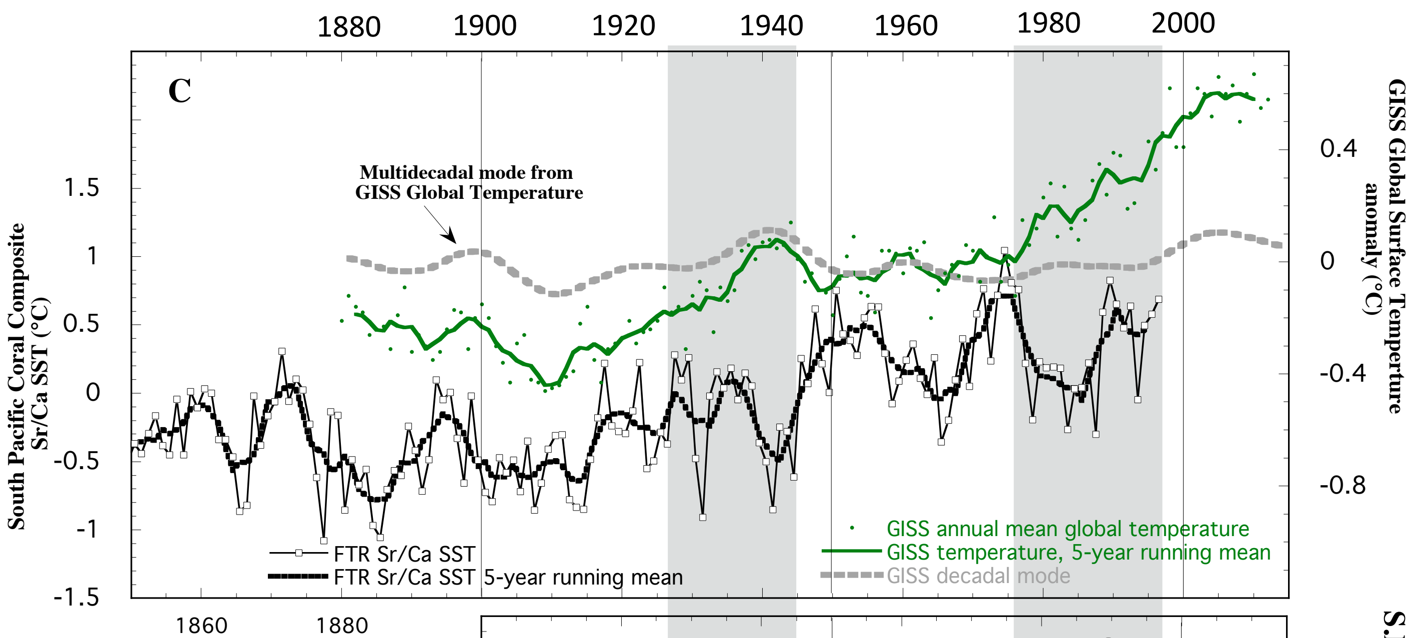
FTR and 0-700m South Pacific Ocean Heat content

Fiji Tonga Rarotonga Composite Coral Sr/Ca SST (1900-2000) vs. South Pacific Ocean Heat Content (0-700m)



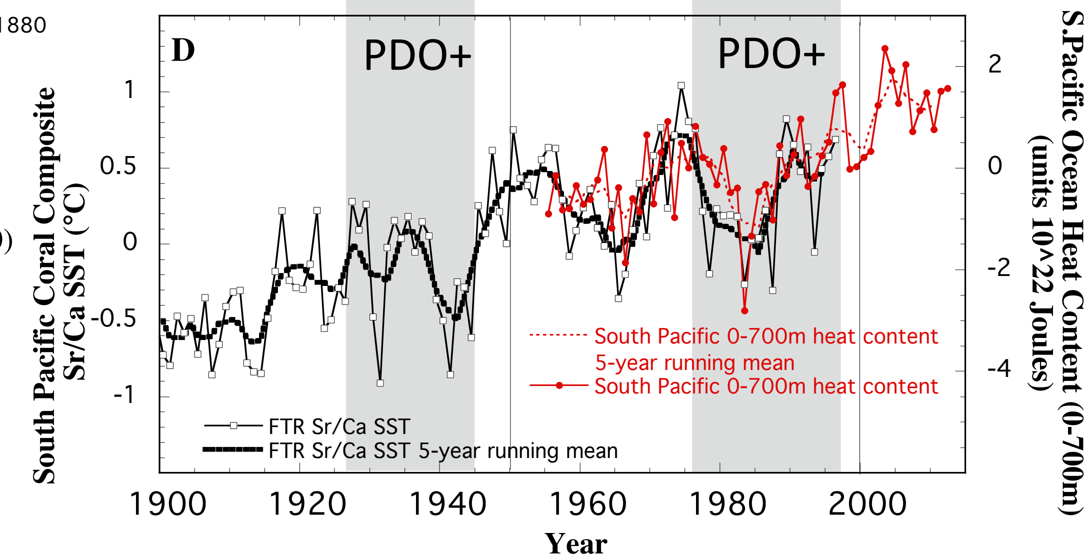
(D) 0-700m heat content anomaly **(red)** relative to the 1955-2006 base period *(Levitus et al., 2012),* compared the FTR Sr/Ca SST reconstruction. FTR Sr/Ca SST are significantly correlated with oceanic heat storage ($R = 0.45$, $p<0.01$ for annual averages and $R = 0.82$, $p<0.001$ for 5 year running means).

Fiji Tonga Rarotonga
Composite Coral
Sr/Ca SST (1850-2000)
vs
GISS Global
Surface Temperatures

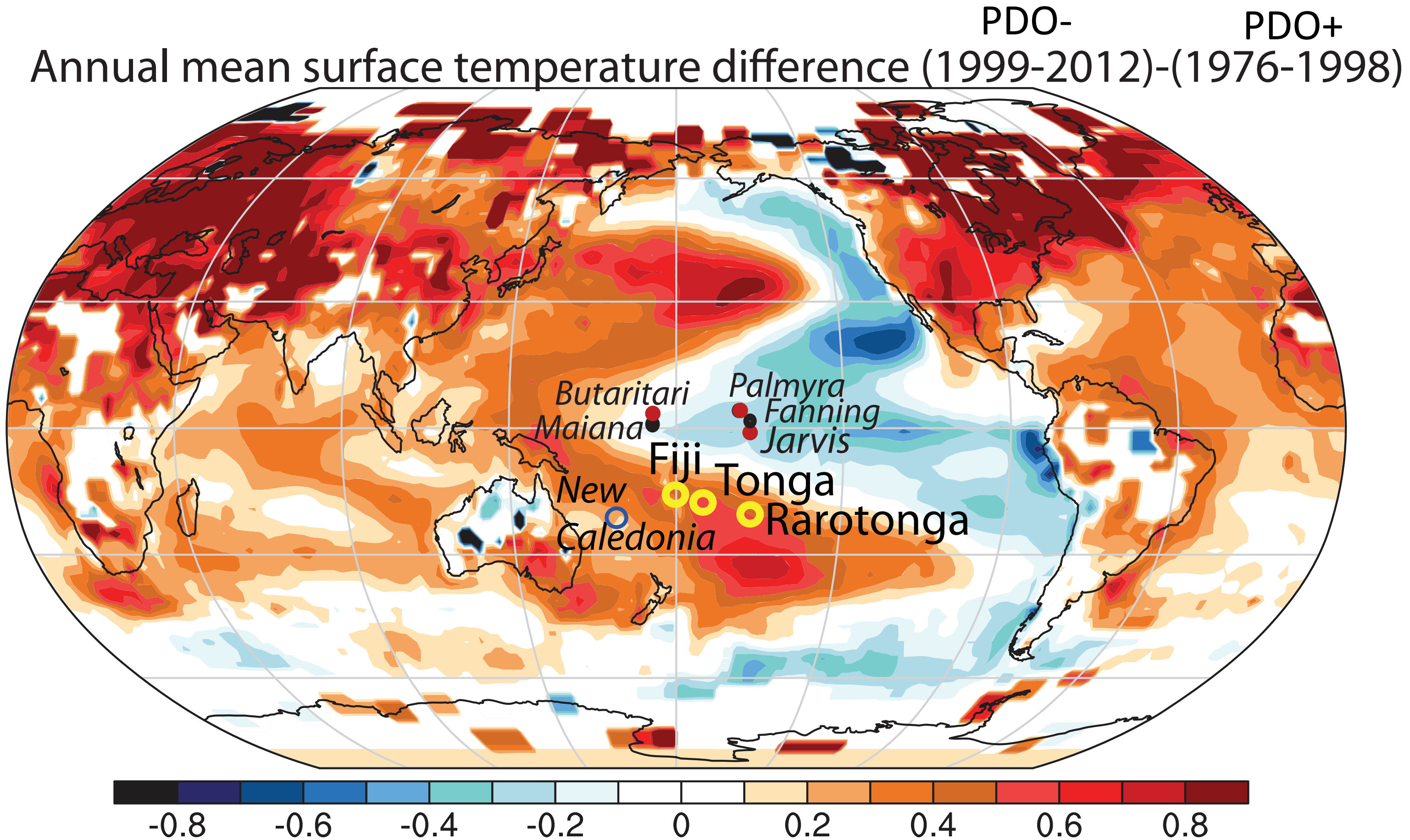


FTR and 0-700m South Pacific Ocean Heat content

Fiji Tonga Rarotonga
Composite Coral
Sr/Ca SST (1900-2000)
vs. South Pacific
Ocean Heat Content
(0-700m)

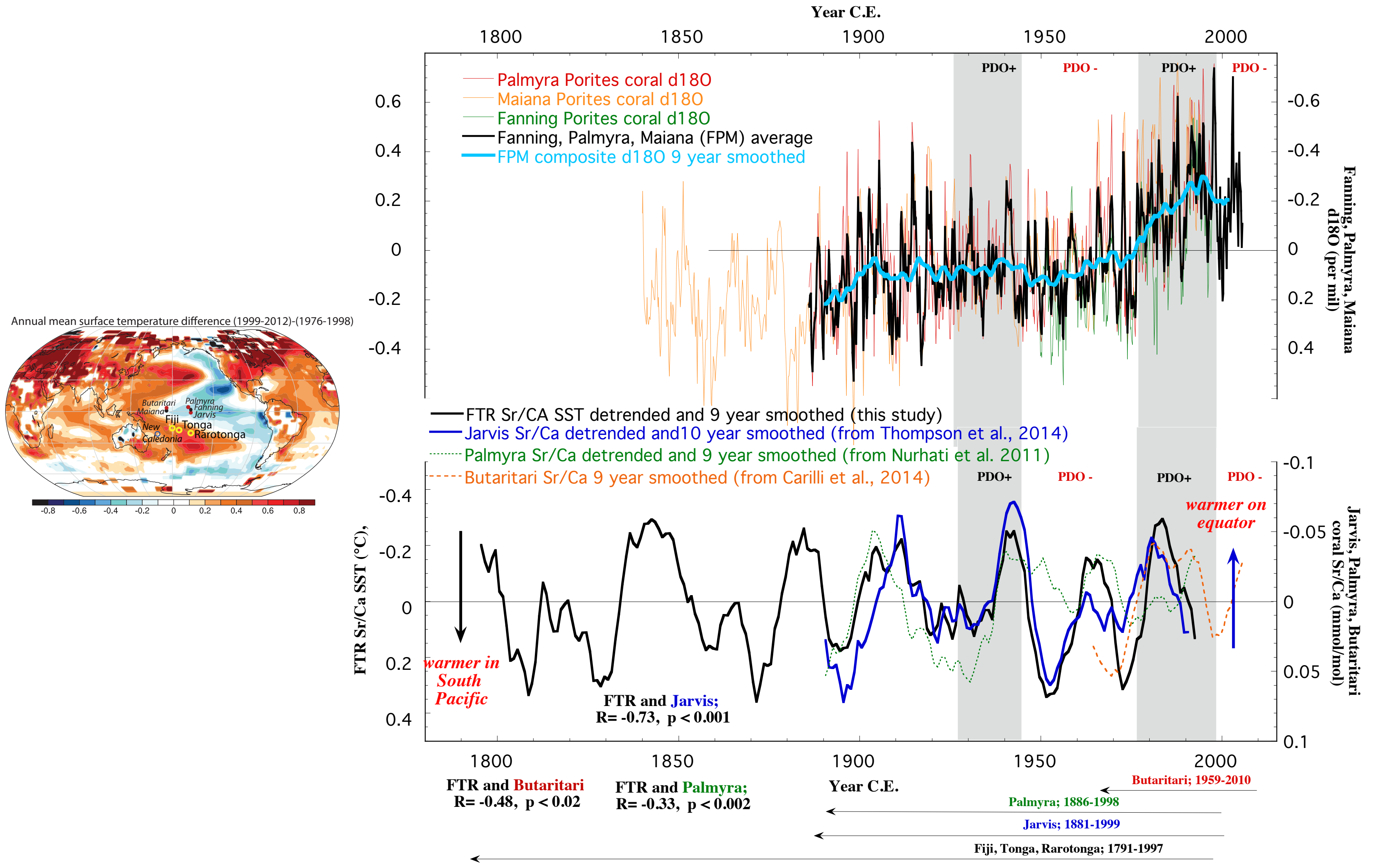


(C) The FTR Sr/Ca SST reconstruction compared to the GISS Earth surface temperature record (**green**). Also shown is the SSA extracted decadal-scale mode from the GISS record with the amplitude doubled to highlight the subtle, but significant decadal variability. **(D)** 0-700m heat content anomaly **(red)** relative to the 1955-2006 base period *(Levitus et al., 2012),* compared the FTR Sr/Ca SST reconstruction. FTR Sr/Ca SST are significantly correlated with oceanic heat storage (R = 0.45, p<0.01 for annual averages and R = 0.82, p<0.001 for 5 year running means).

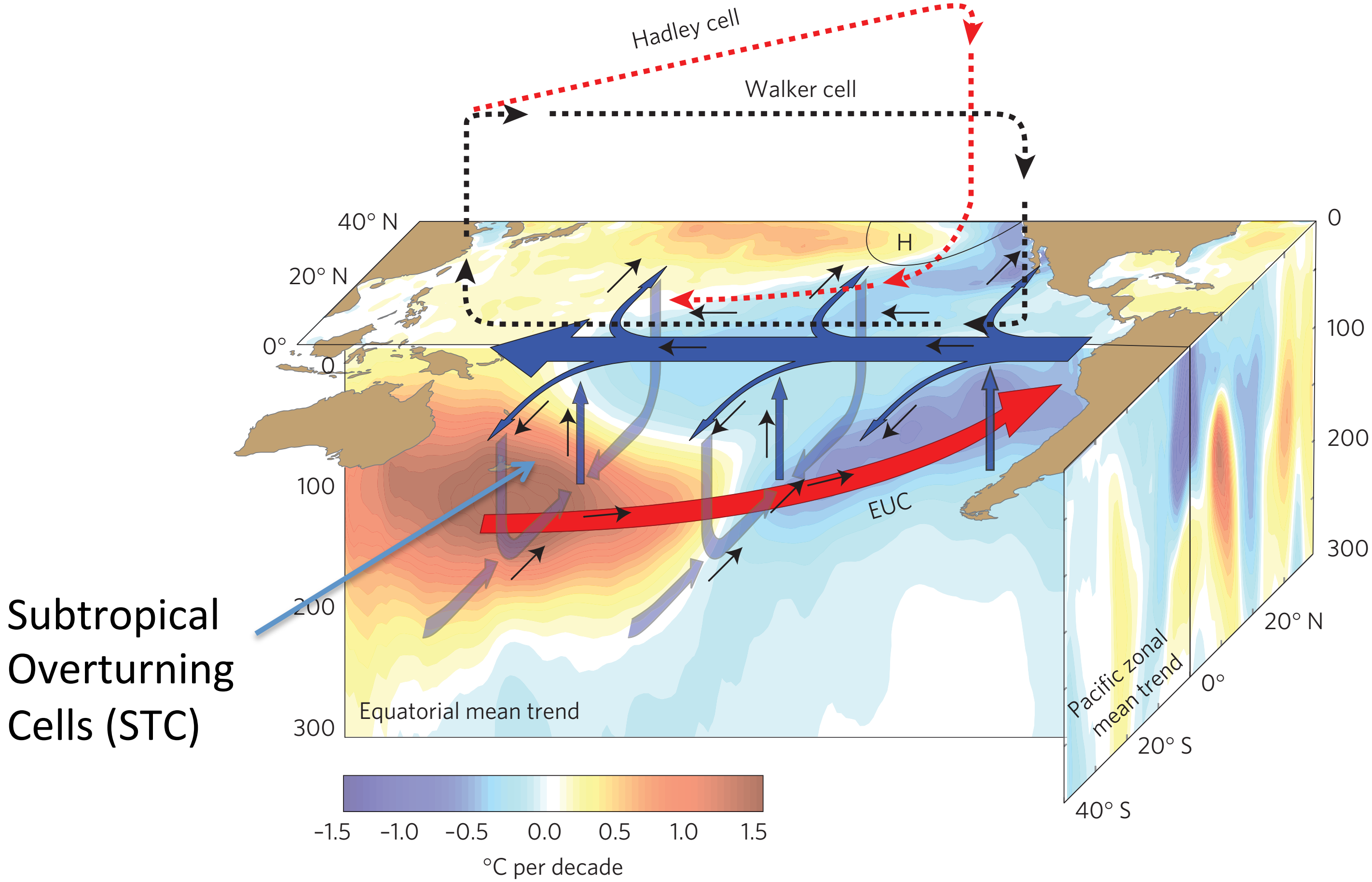


Mean annual surface temperature differences between the periods from 1999 to 2012 and 1976 to 1998 in °C. [Figure modified from Trenberth and Fasullo [2013].

The next slide compares our FTR Sr/Ca composite record from the South Pacific to equatorial coral Sr/Ca records from Jarvis, Palmyra and Butaritari.



(top) : (top) Coral $\delta^{18}O$ records from the equatorial Pacific sites at Fanning (Cobb et al., 2013), Palmyra (Cobb et al., 2013 and Maiana (Urban et al., 2000) along with the three coral core $\delta^{18}O$ average (dark gray line) and the 9 year running average (blue line). (bottom) Fiji-Tonga-Rarotonga (FTR) coral Sr/Ca SST detrended and 9 year smoothed (black line)(note y axis is inverted) compared to decadal changes in coral Sr/Ca from Jarvis Atoll (in blue), Palmyra Atoll (in green) and Butaritari Atoll (in red). Jarvis coral Sr/Ca data (detrended and 10 year smoothed) from Thompson et al. (2014)(blue line). Palmyra coral Sr/Ca (detrended and 9 year smoothed) from Nurhati et al. (2011). Butaritari coral Sr/Ca (detrended and 9 year smoothed) from Carilli et al. (2014).



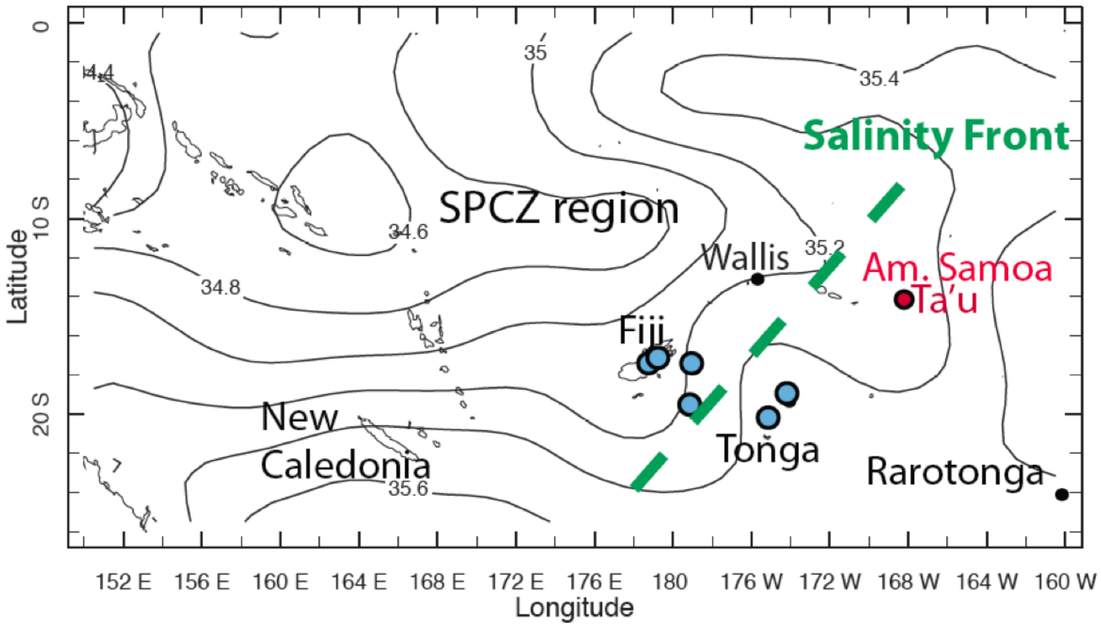
Schematic of the trends in temperature and ocean–atmosphere circulation in the Pacific over the past two decades (from England et al., 2014). Color shading shows observed temperature trends (◦C per decade) during 1992–2011 at the sea surface (Northern Hemisphere only), zonally averaged in the latitude-depth sense and along the equatorial Pacific in the longitude-depth plane (averaged between 5°N–5°S). Peak warming in the western Pacific thermocline is 2.0°C per decade in the reanalysis data and 2.2°C per decade in the model. The mean and anomalous circulation in the Pacific Ocean is shown by bold and thin arrows, respectively, indicating an overall acceleration of the Pacific Ocean shallow overturning cells, the equatorial surface currents and the Equatorial Undercurrent (EUC)

Part 2: Ta'u, American Samoa;
South Pacific Convergence Zone and ENSO

- Collaborators: Robert Dunbar, Emilie Dassié

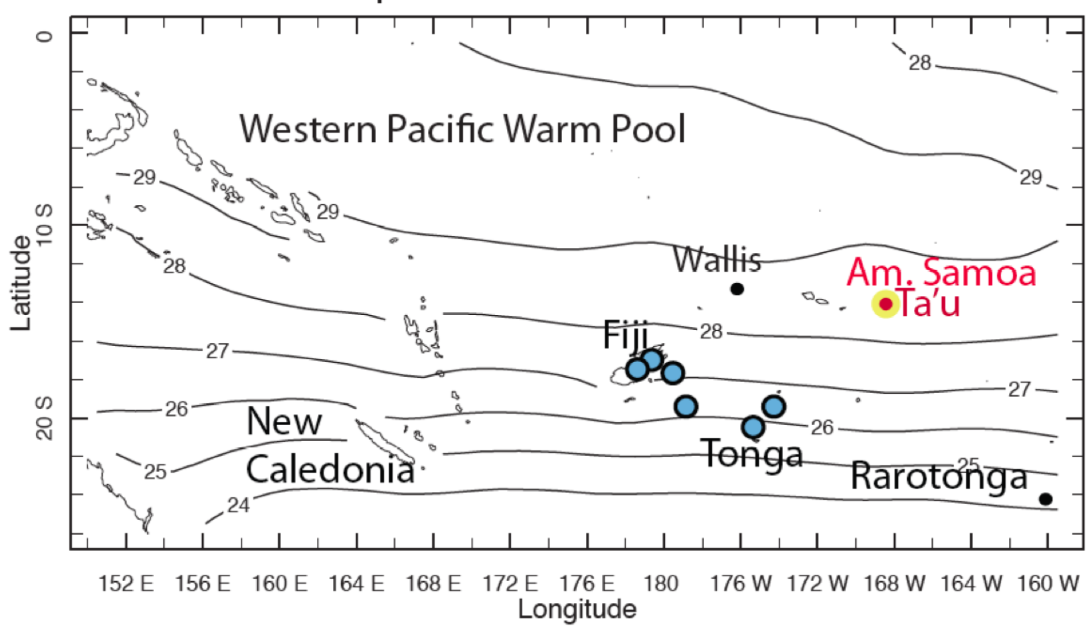
Surface Salinity

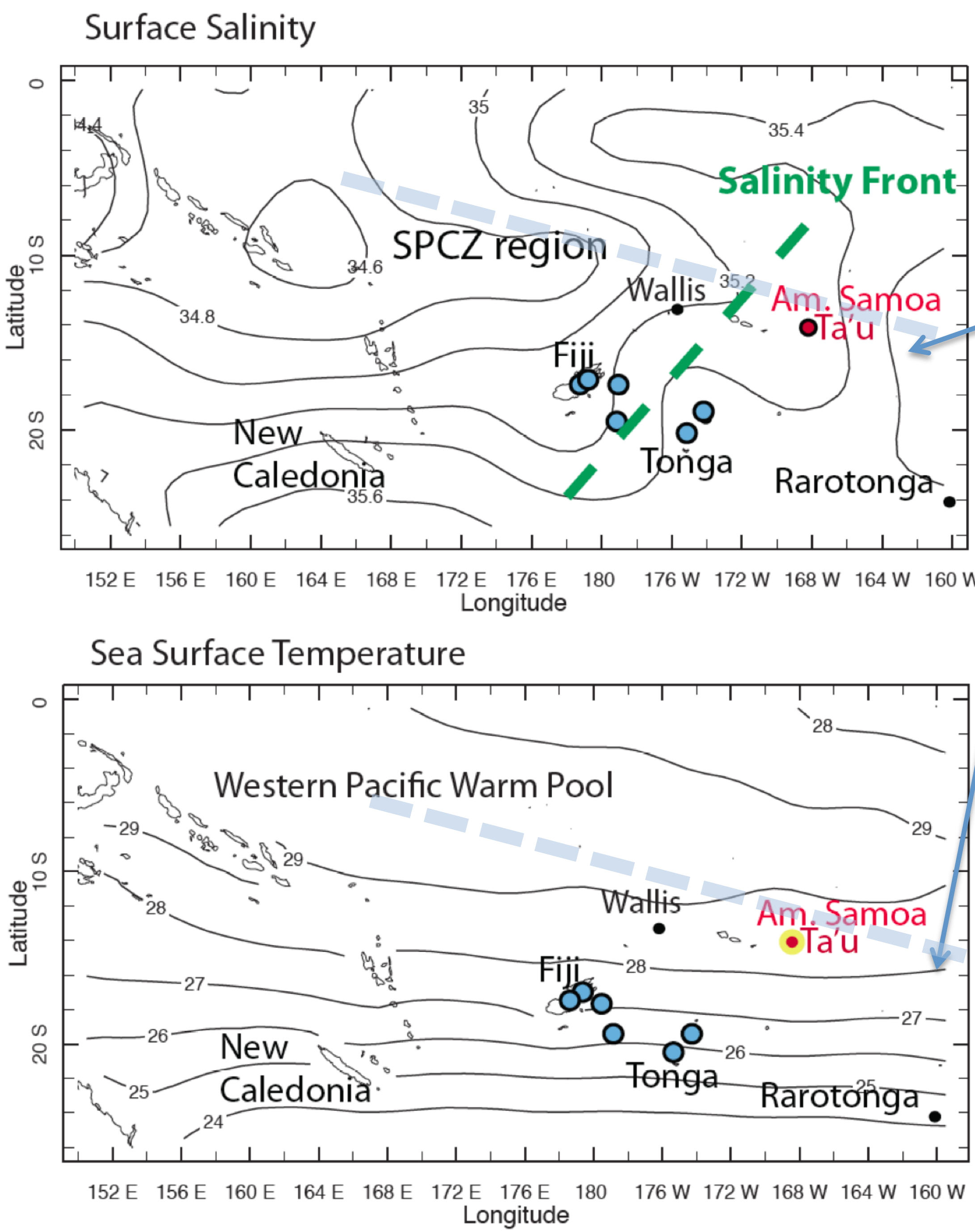
Surface Salinity



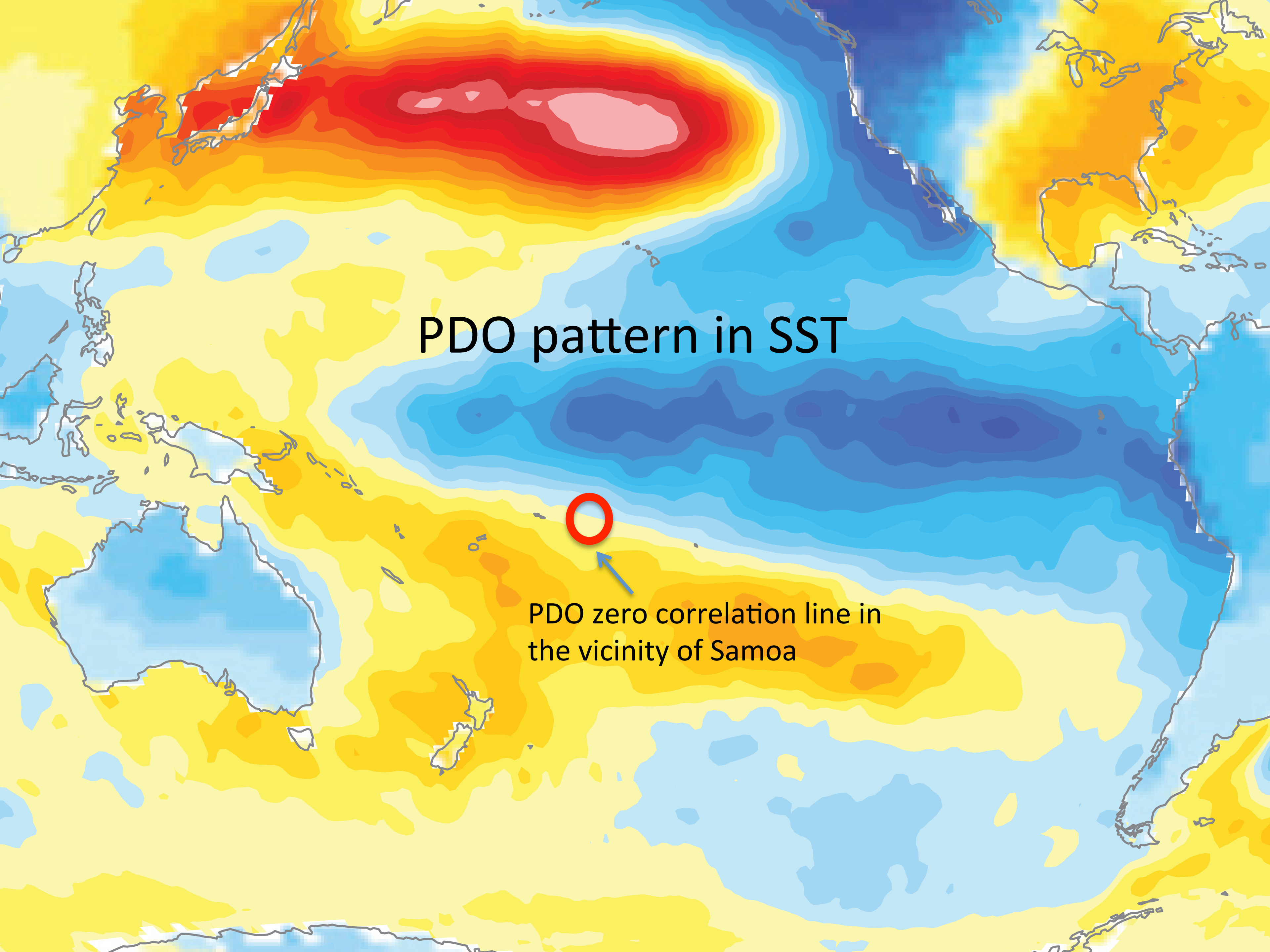
Sea Surface Temperature

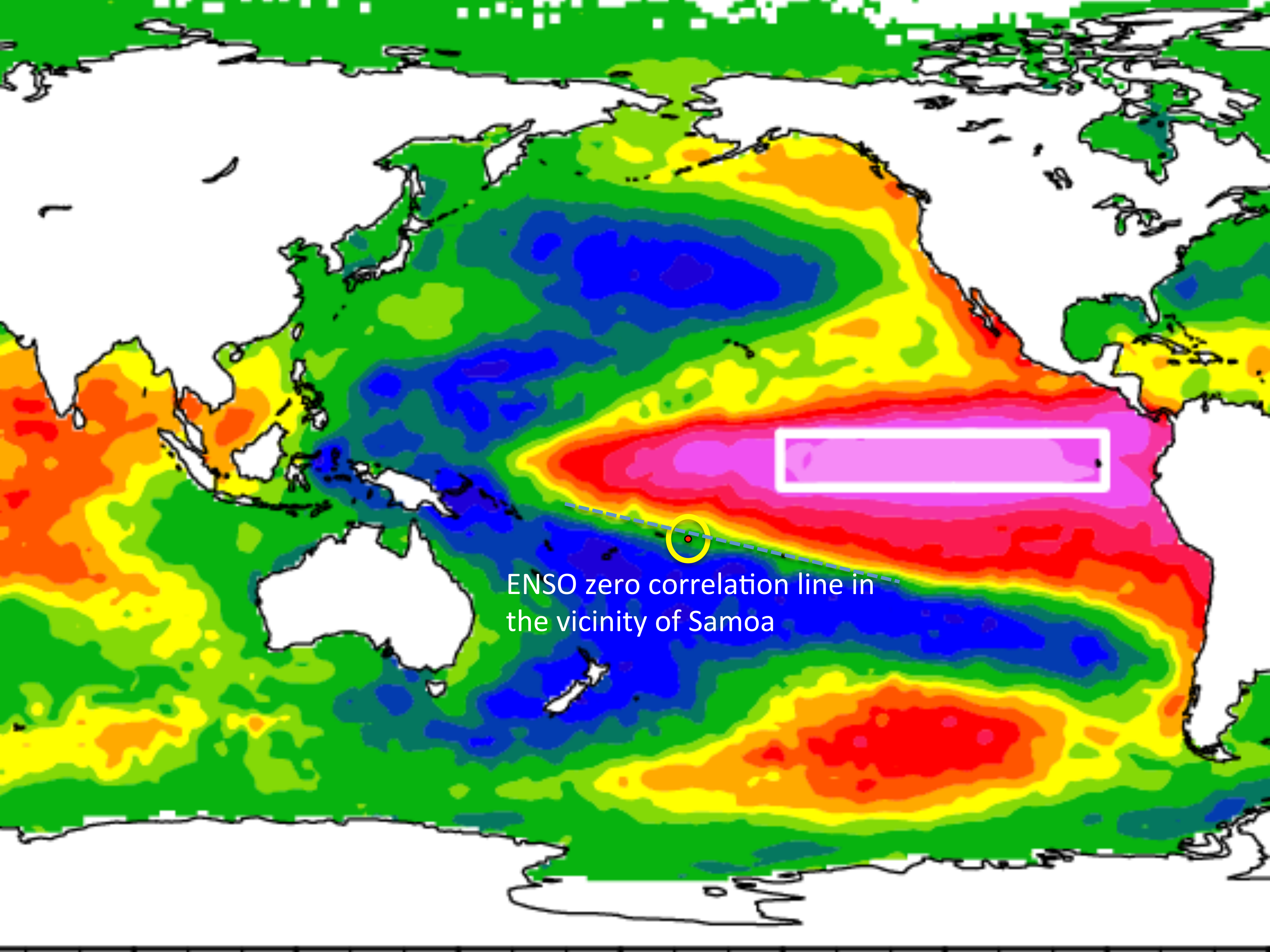
Sea Surface Temperature





Approximate location of nodal line (zero correlation contour) for ENSO and the IPO-PDO


PDO pattern in SST
PDO zero correlation line in
the vicinity of Samoa


ENSO zero correlation line in
the vicinity of Samoa

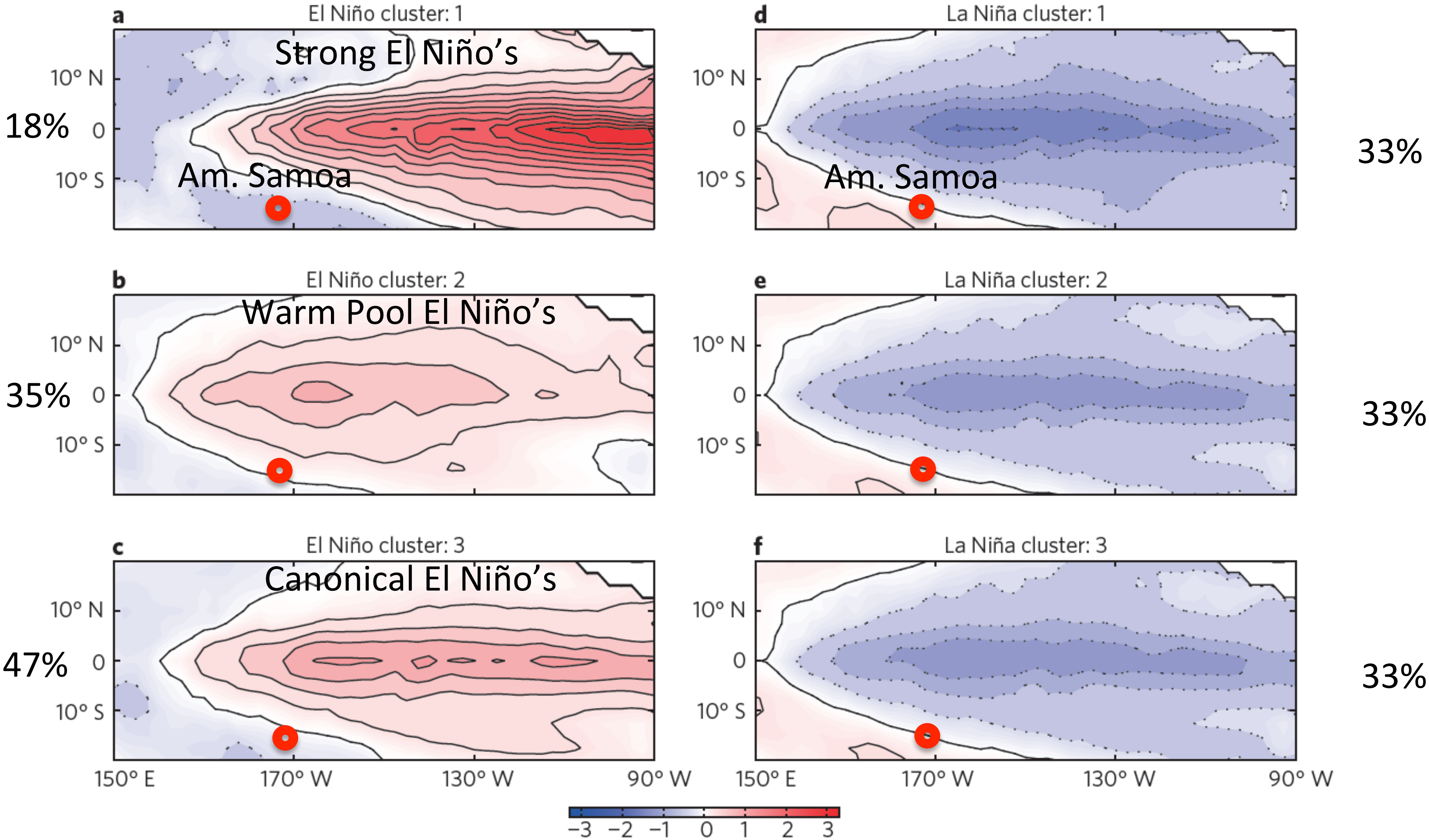
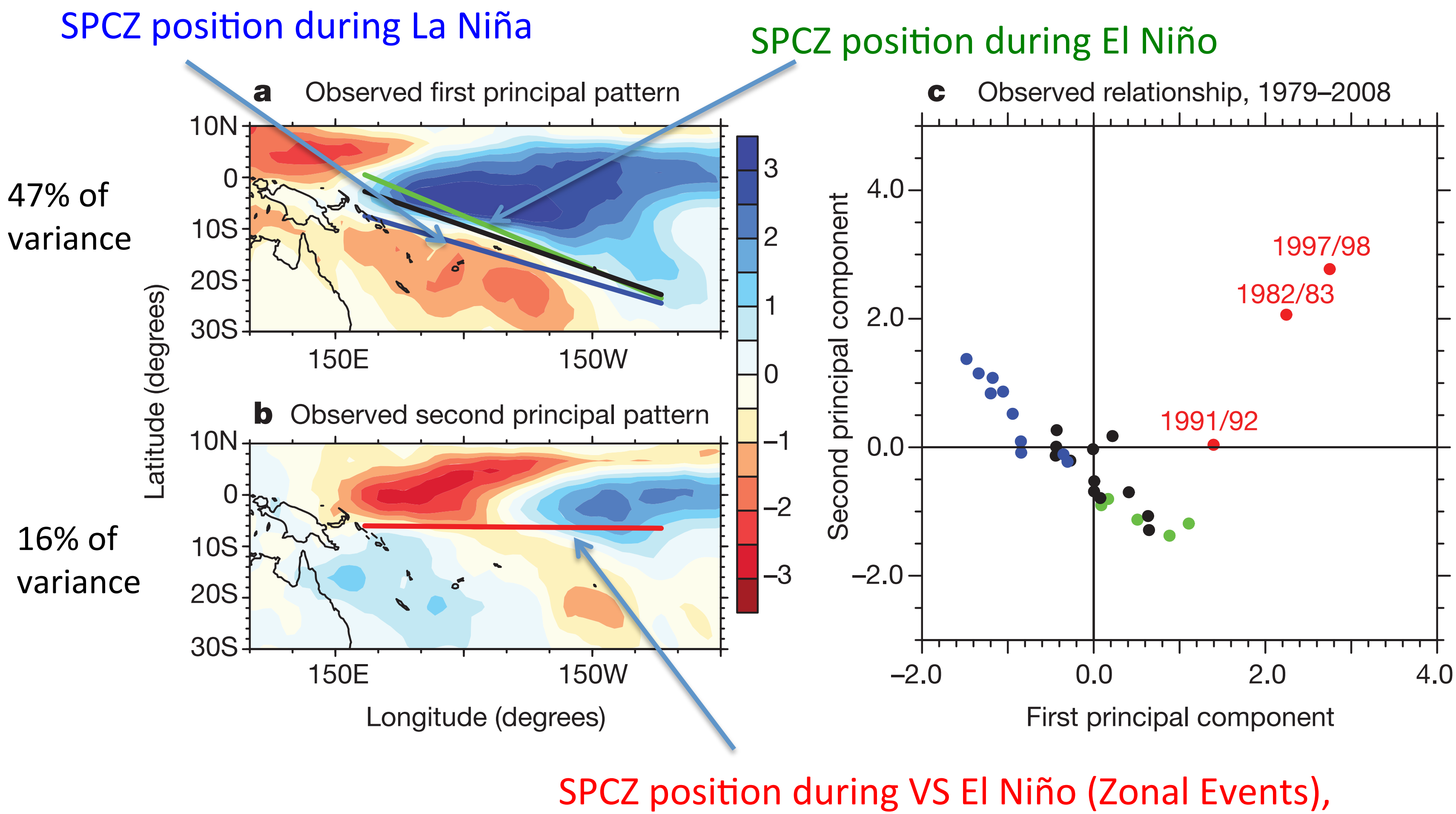
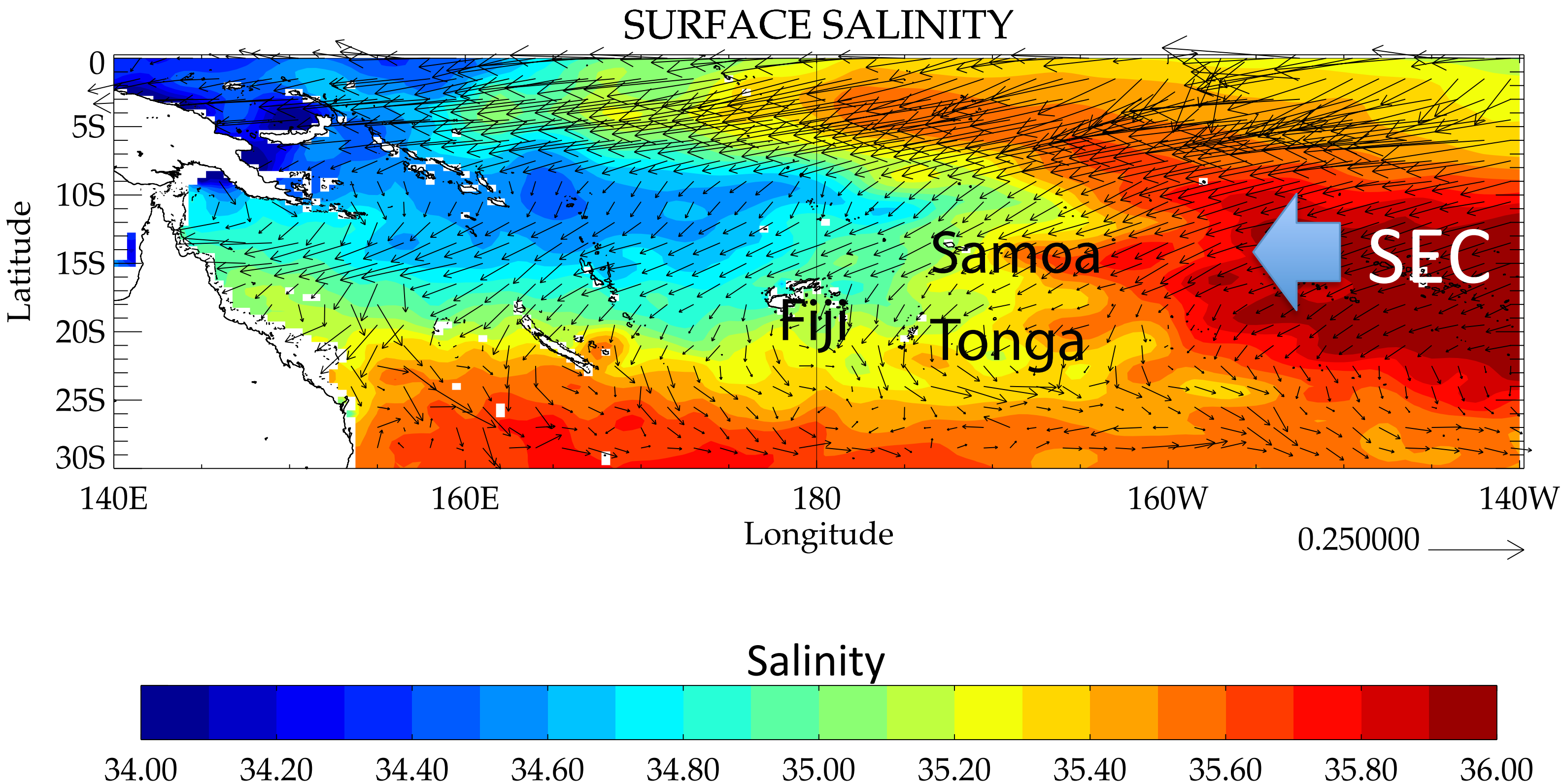


Figure modified from Chen et al.; Nat Geo., vol 8. 13 April 2015: **a**–**f**, Warm (**a**–**c**) and cold (**d**–**f**) clusters of the tropical Pacific SST variability based on 1961–2010 HadISST data. The contour interval is 0.3 °C, and negative contours are dotted. The three El Niño patterns are distinctively different, whereas the three La Niña patterns are essentially identical. The numbers of El Niño events dominated by patterns **a**,**b**,**c** are 3, 6, 8, respectively, while La Niña events are equally shared by patterns **d**,**e**,**f**.

Rainfall and SPCZ Position in relationship to ENSO



Principal variability patterns in observed December-February rainfall in the South Pacific **from Cai et al. (2012)**. The SPCZ position for El Niño (green line), La Niña (blue line) and neutral (**black line**) states is shown.

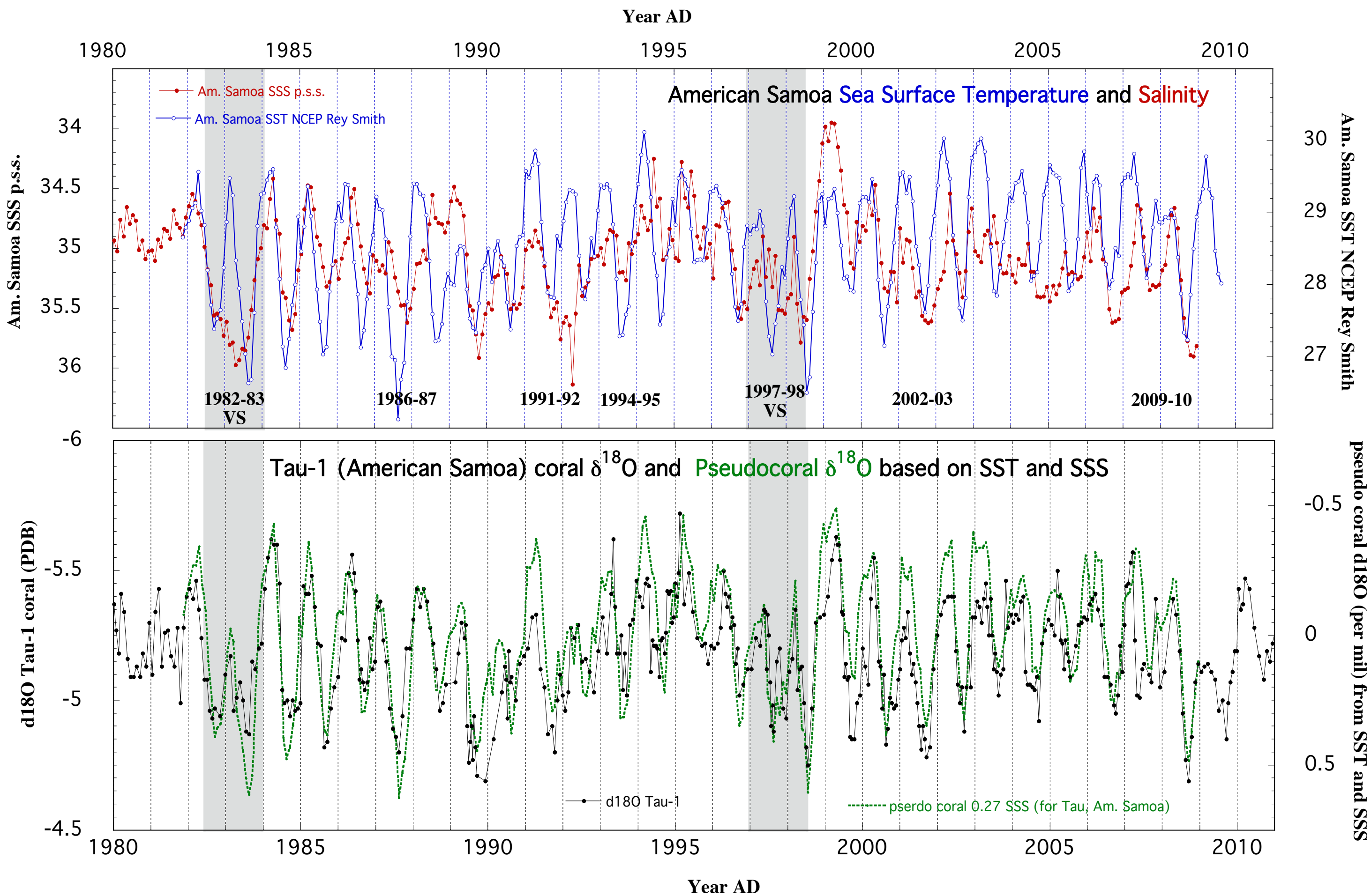


Today the South Equatorial Current (SEC) advects salty water into the SPCZ region during El Niño.

Figure from Christophe Menkes

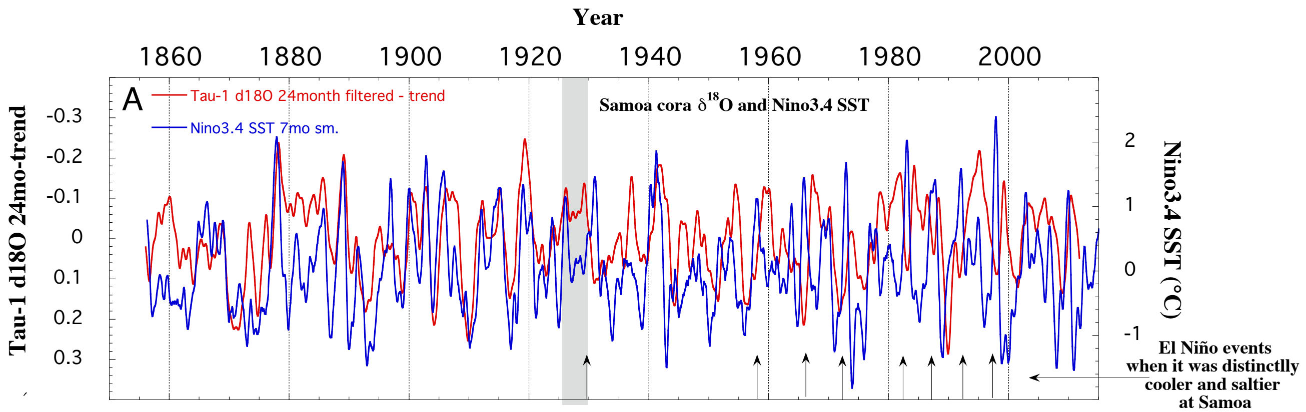
Am. Samoa
SST and
Salinity

Am. Samoa
Coral $\delta^{18}O$
and
Modeled
Coral d18O



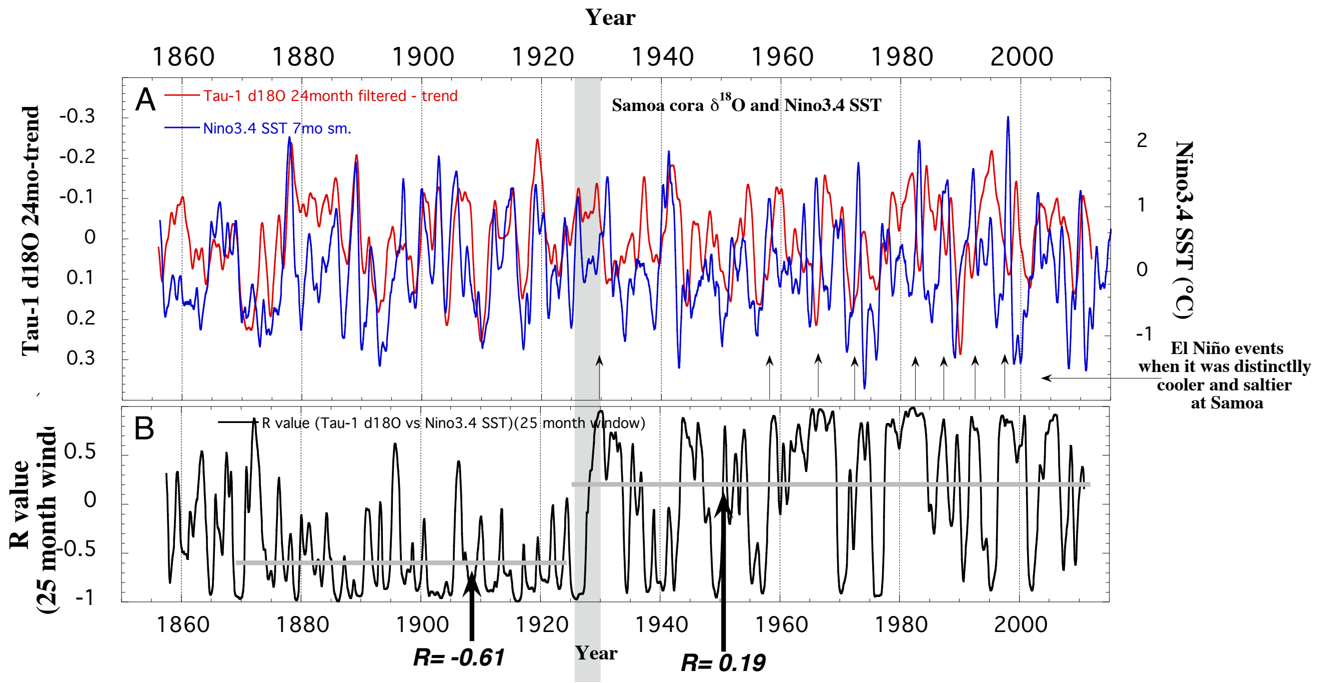
Annual average Ta'u coral $\delta^{18}O$ variability is predominantly driven by salinity ($R=0.64$, $p<0.001$) with a lesser influence of temperature ($R=-0.58$, $p<0.01$). Annual average $\delta^{18}O$ and pseudocoral $\delta^{18}O$ $R = 0.61$ ($p<0.01$)**. This demonstrates that coral $\delta^{18}O$ at Samoa is accurately recording surface ocean temperature and salinity.**

Tau-1 $\delta^{18}O$ and Nino3.4 SST



Tau-1 $\delta^{18}O$ and Nino3.4 SST

Running R

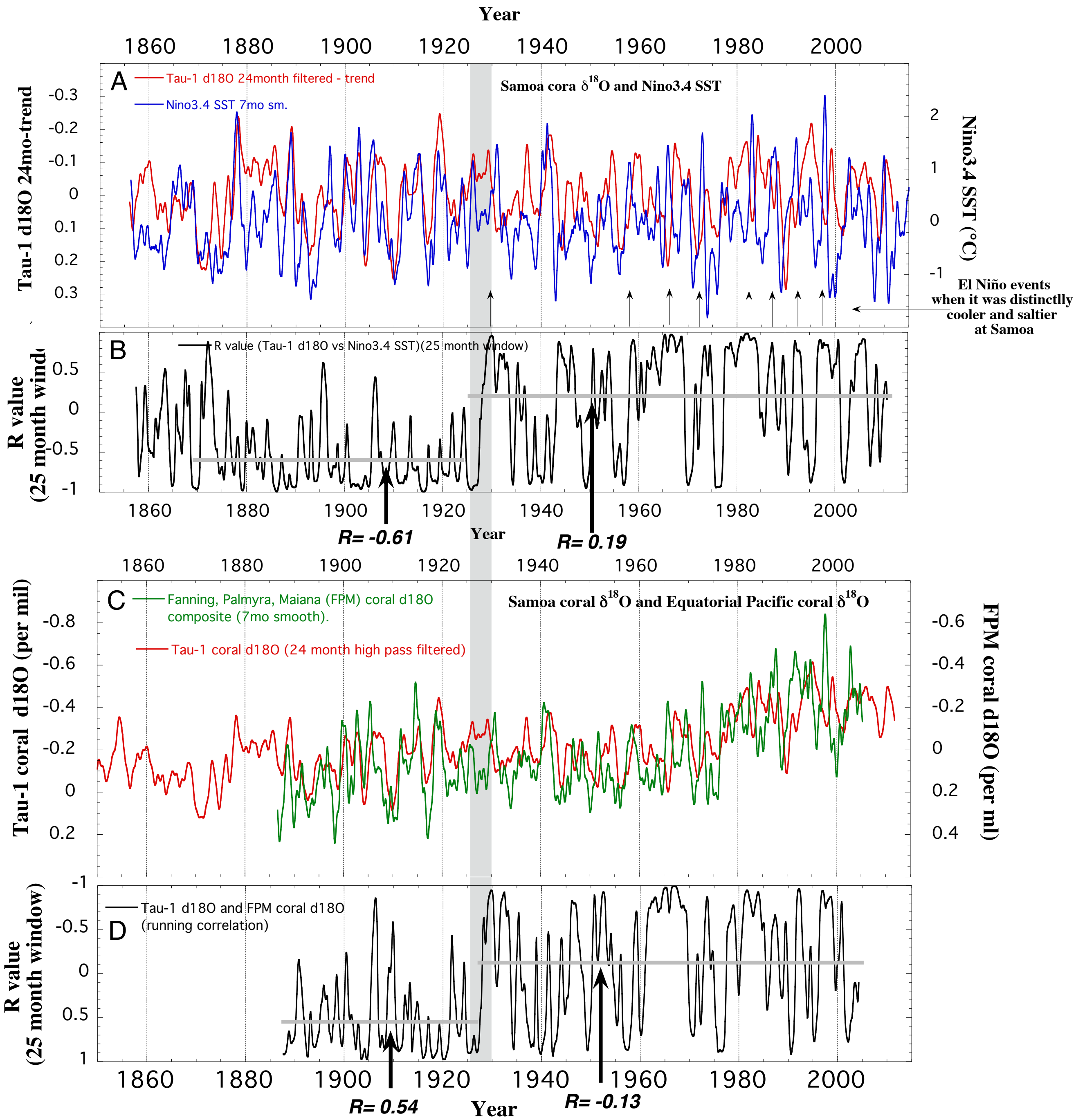


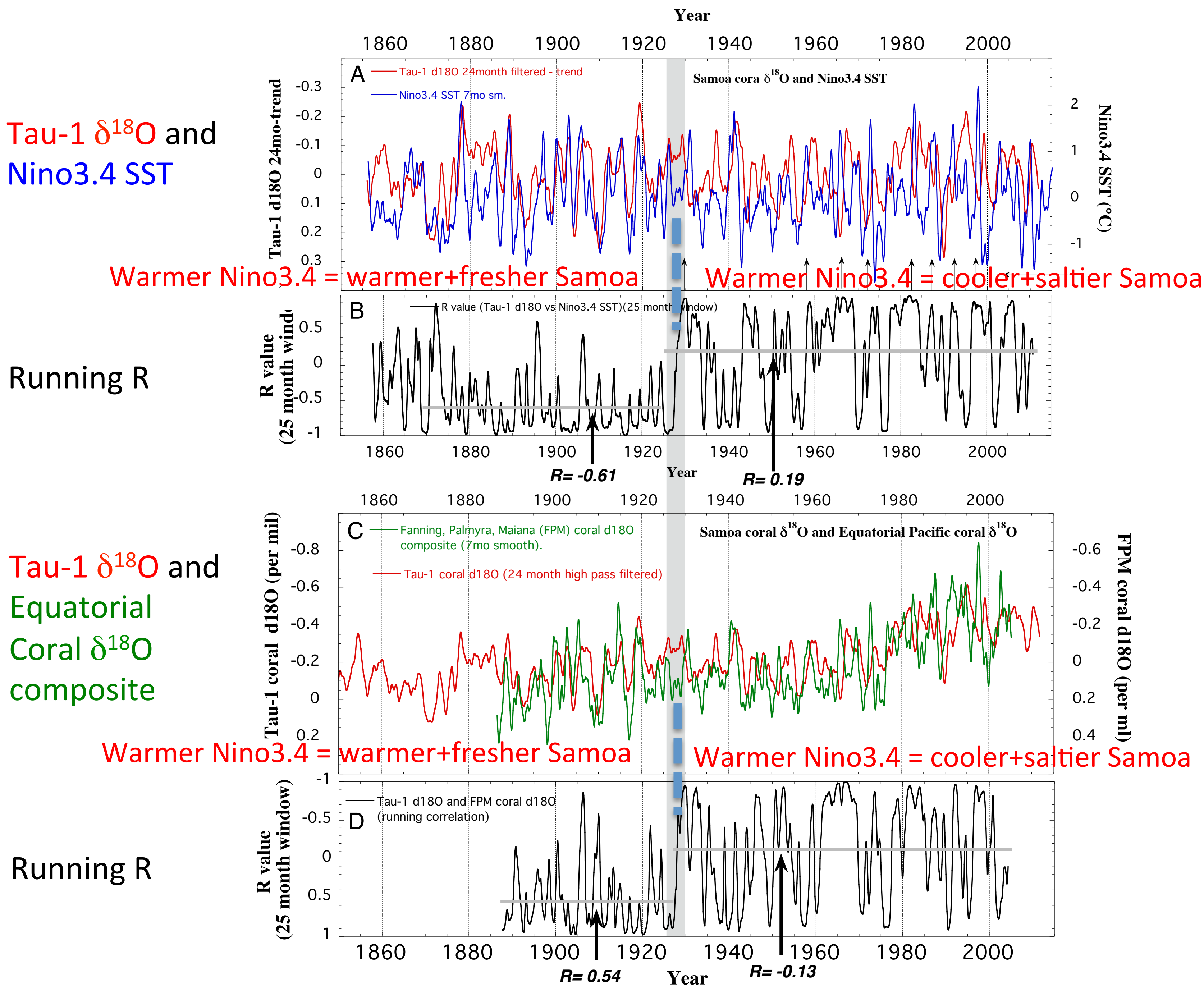
Tau-1 $\delta^{18}O$ and Nino3.4 SST

Running R

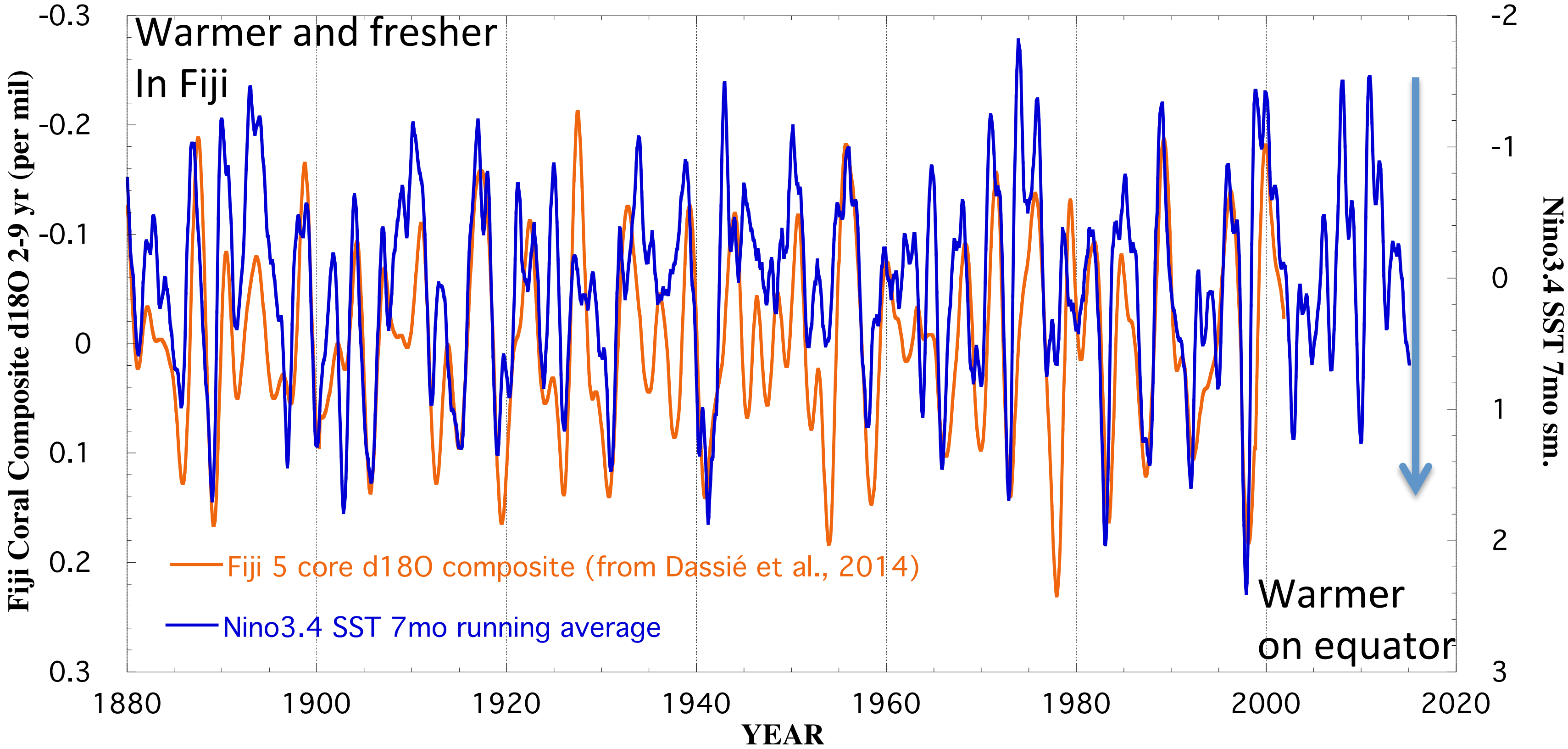
Tau-1 $\delta^{18}O$ and Equatorial Coral $\delta^{18}O$ composite

Running R




Tau-1 δ18O and
Nino3.4 SST
Running R
Tau-1 δ18O and
Equatorial
Coral δ18O
composite
Running R
Year
A
Tau-1 d18O 24month filtered - trend
Nino3.4 SST 7mo sm.
Samoa cora δ18O and Nino3.4 SST
Tau-1 d18O 24mo-trend
Nino3.4 SST (°C)
Warmer Nino3.4 = warmer+fresher Samoa
Warmer Nino3.4 = cooler+saltier Samoa
B
R value (Tau-1 d18O vs Nino3.4 SST)(25 month window)
R value (25 month window)
R= -0.61
R= 0.19
Year
C
Fanning, Palmyra, Maiana (FPM) coral d18O composite (7mo smooth).
Tau-1 coral d18O (24 month high pass filtered)
Samoa coral δ18O and Equatorial Pacific coral δ18O
Tau-1 coral d18O (per mil)
FPM coral d18O (per ml)
Warmer Nino3.4 = warmer+fresher Samoa
Warmer Nino3.4 = cooler+saltier Samoa
D
Tau-1 d18O and FPM coral d18O (running correlation)
R value (25 month window)
R= 0.54
R= -0.13
Year

Fiji 5 coral composite δ^{18}O 2-9 yr band from Dassié et al. (2014) and Nino3.4 SST.
….. NO phase change in mid 1920s in Fiji !



Atlantic Multidecadal Oscillation. (**a**) Regression pattern of monthly sea surface temperature (SST) anomalies (after removing the global mean SST anomaly) on the North Atlantic SST Index, based on the HadISST data set during 1870–2008.
(**b**) The North Atlantic SST Index, defined as the average monthly SST anomaly over the North Atlantic (0◦–70◦N) minus the global mean monthly SST anomaly (**red and blue bars**). The green line depicts an estimate of the natural (e.g., not due to forcing external to the ocean-atmosphere system) component of the 10-year low-pass-filtered North Atlantic SST index from Ting et al. (2009).

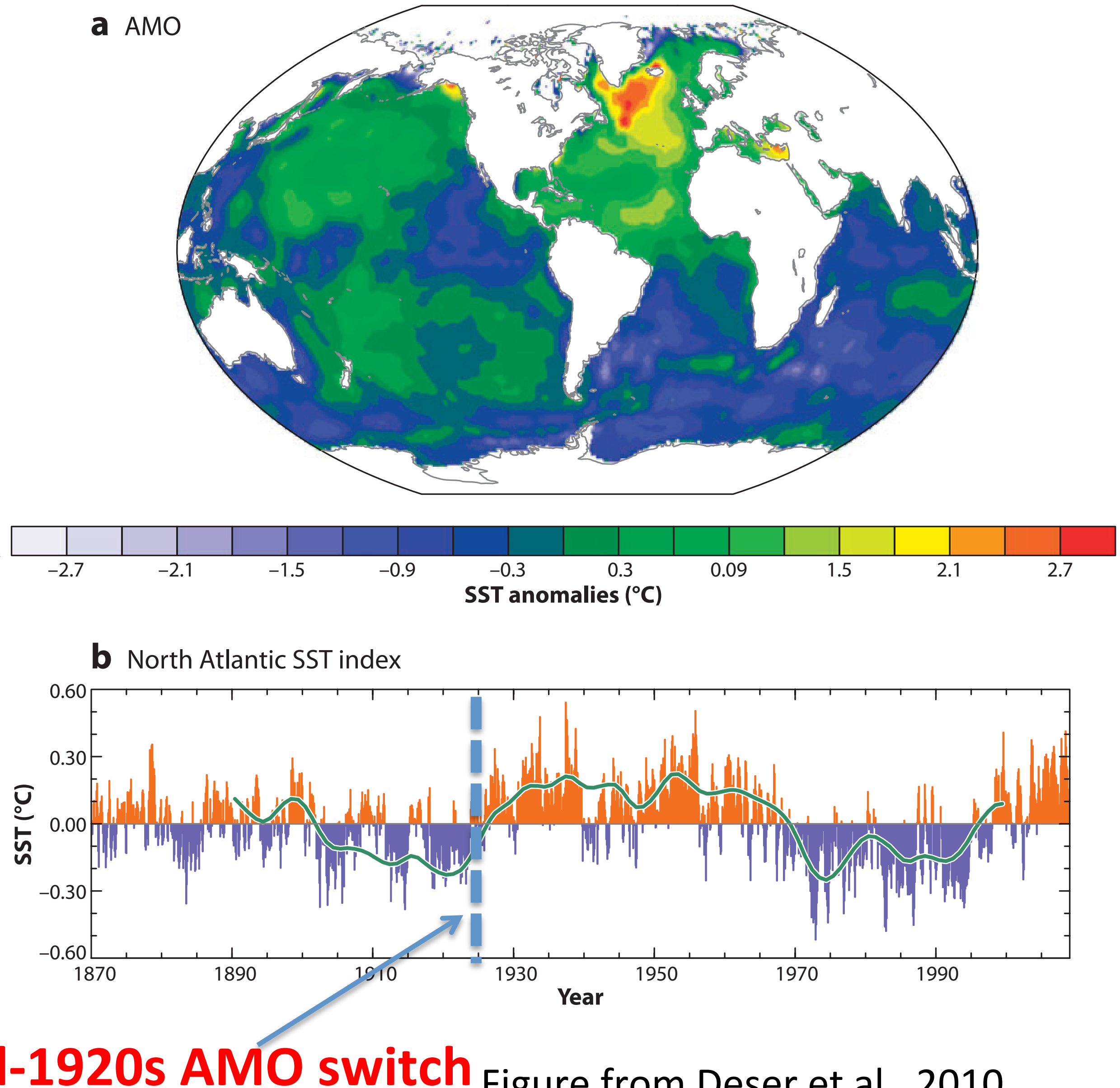


Figure from Deser et al., 2010

The **Great Mississippi Flood of 1927** was the most destructive river flood in the history of the United States with 27,000 square miles inundated up to a depth of 30 feet.

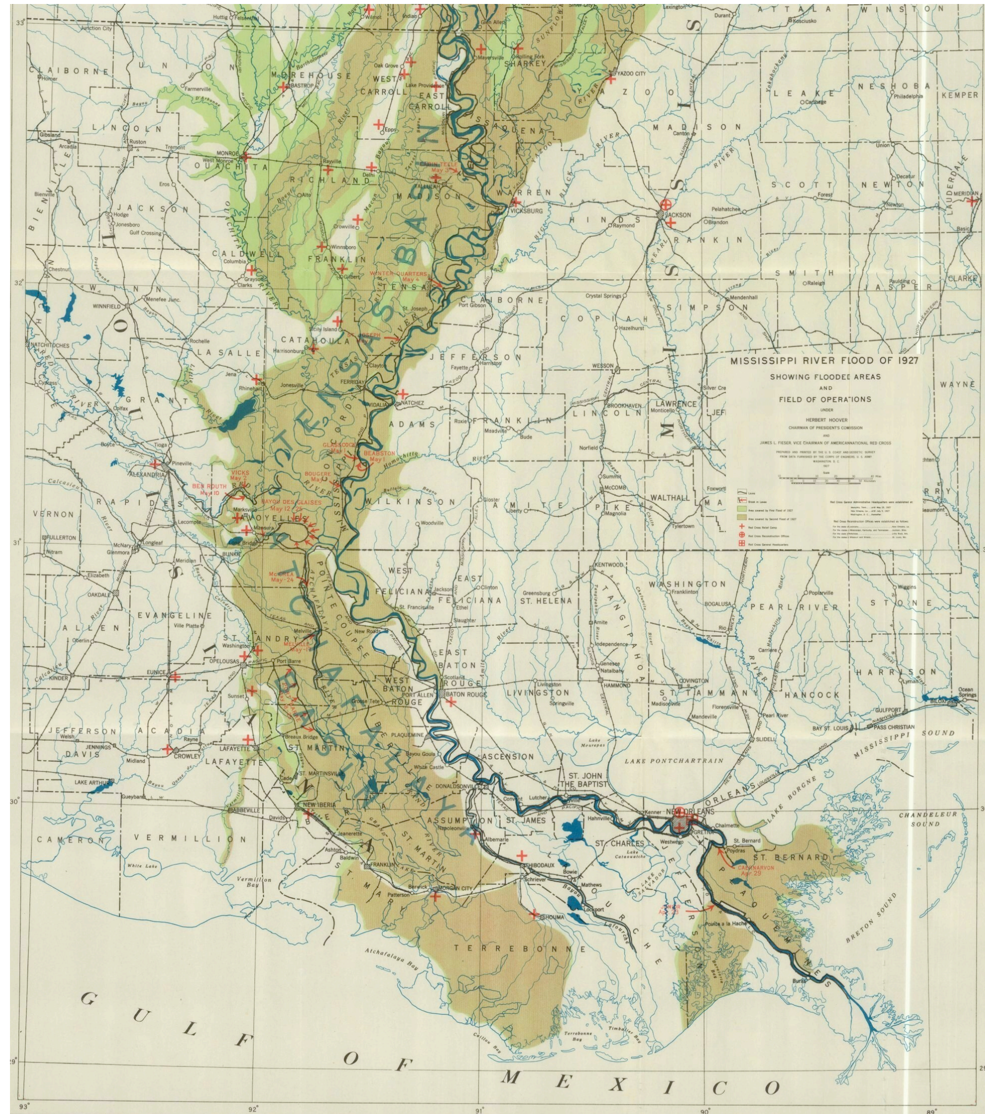
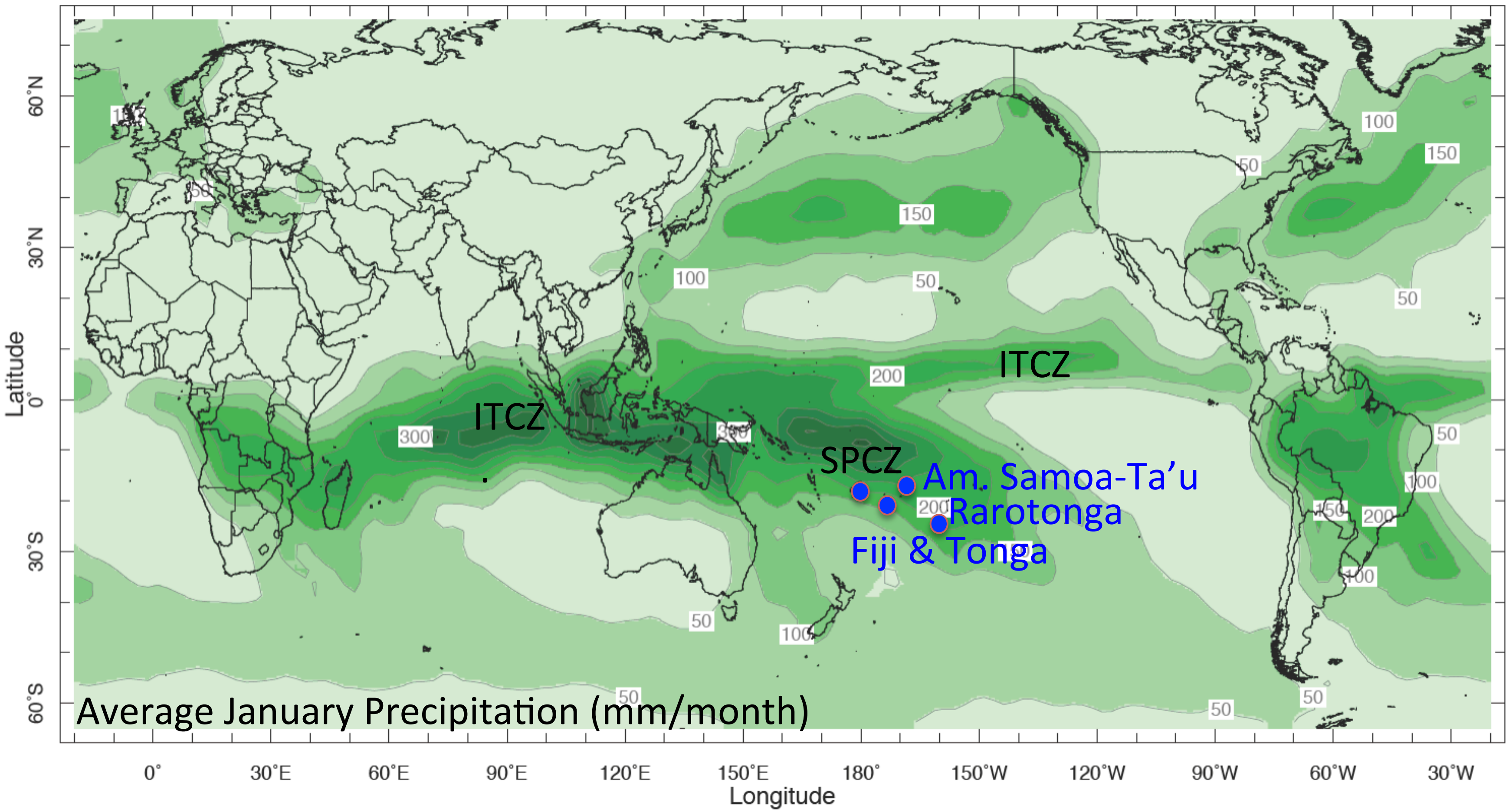


FIG. 2. MONTHLY WEATHER REVIEW, SUPPLEMENT NO. 29.

Mean ITCZ position in January

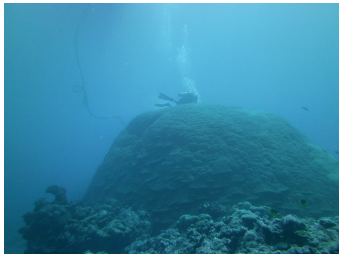


Summary

- **Decadal mode of Fiji-Tonga-Rarotonga (FTR) SST has a recurrence interval near 20-25 years**.
- The positive correlation between decadal SST and ocean heat content (OHC) in the South Pacific combined with the inverse correlation with decadal changes in equatorial Pacific SST **supports the fluctuating trade wind-shallow meridional overturning cell mechanism** for decadal modulation of Pacific SSTs and OHC

- **1926-1927 marks an ABRUPT interannual climate transition (shift?) in the SPCZ region where it appears that the SPCZ shifted north and northeast**.
- The timing of this abrupt mid-1920s change in the ENSO nodal line and SPCZ position coincided with a phase change in the Atlantic Multidecadal Oscillation (AMO) and a northward shift of the Atlantic ITCZ. **Was this a coordinated ITCZ change in both basins?**

- **Recommendation: need to closely evaluate climatic forcing at each paleo-site. Small scale variations in the oceans do matter at some (maybe all) sites.**



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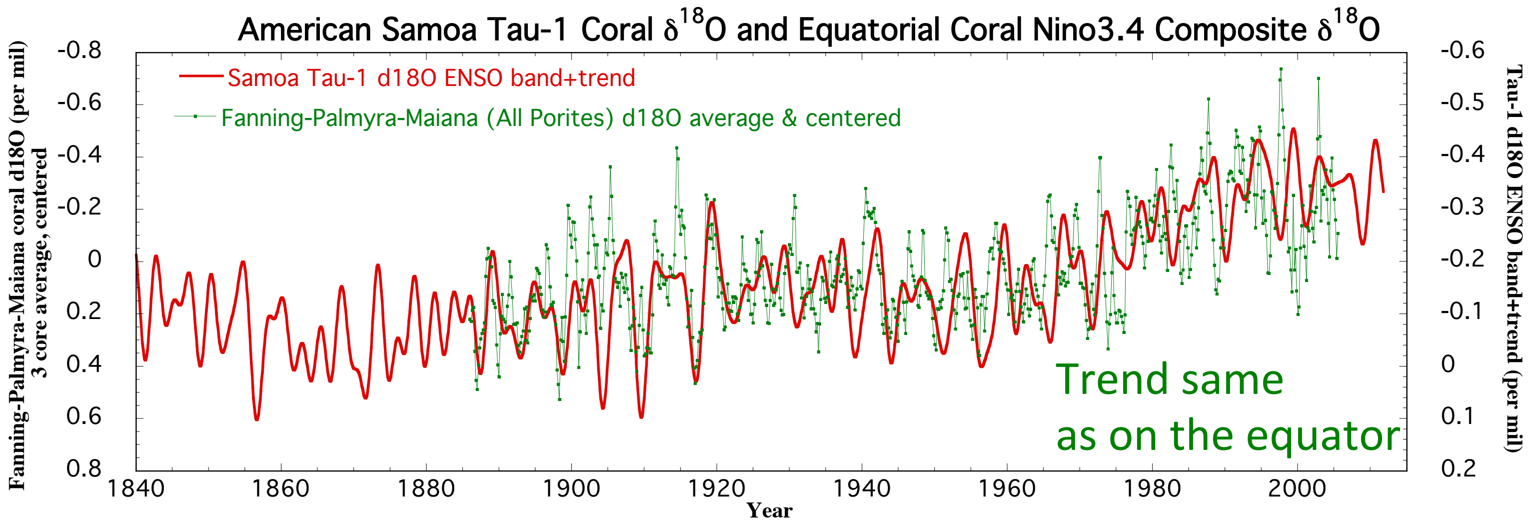
Thank You……

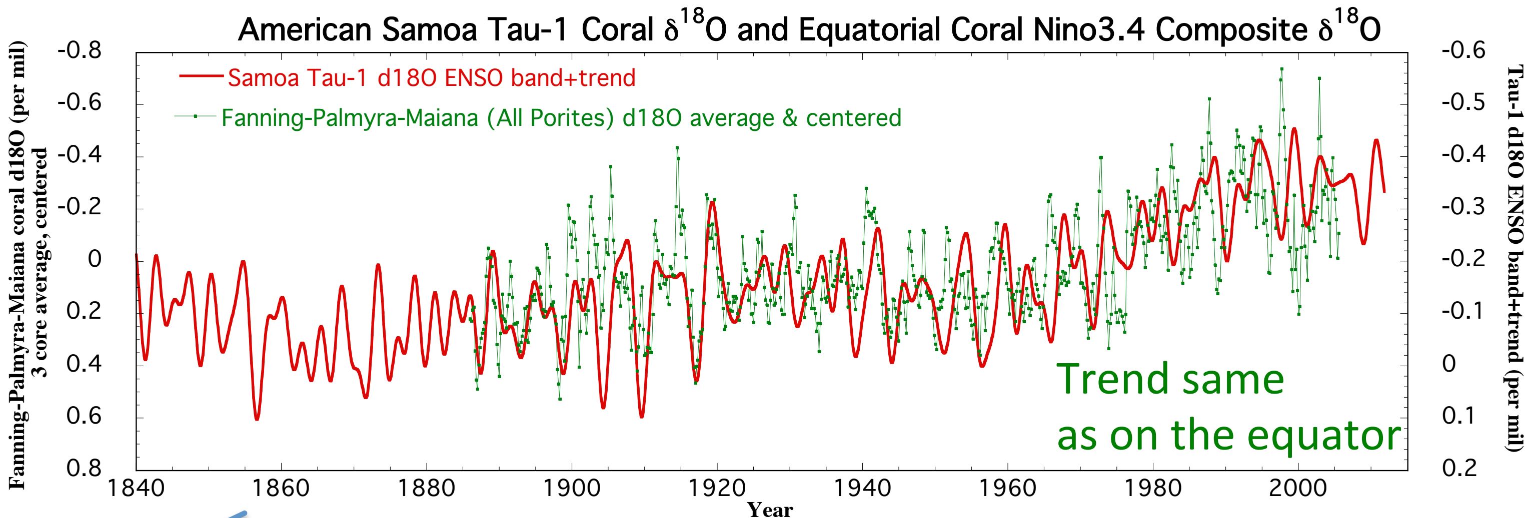
Secular Trend in Coral $\delta^{18}O$ in the SW Pacific

Samoa
vs.
Nino3.4
region

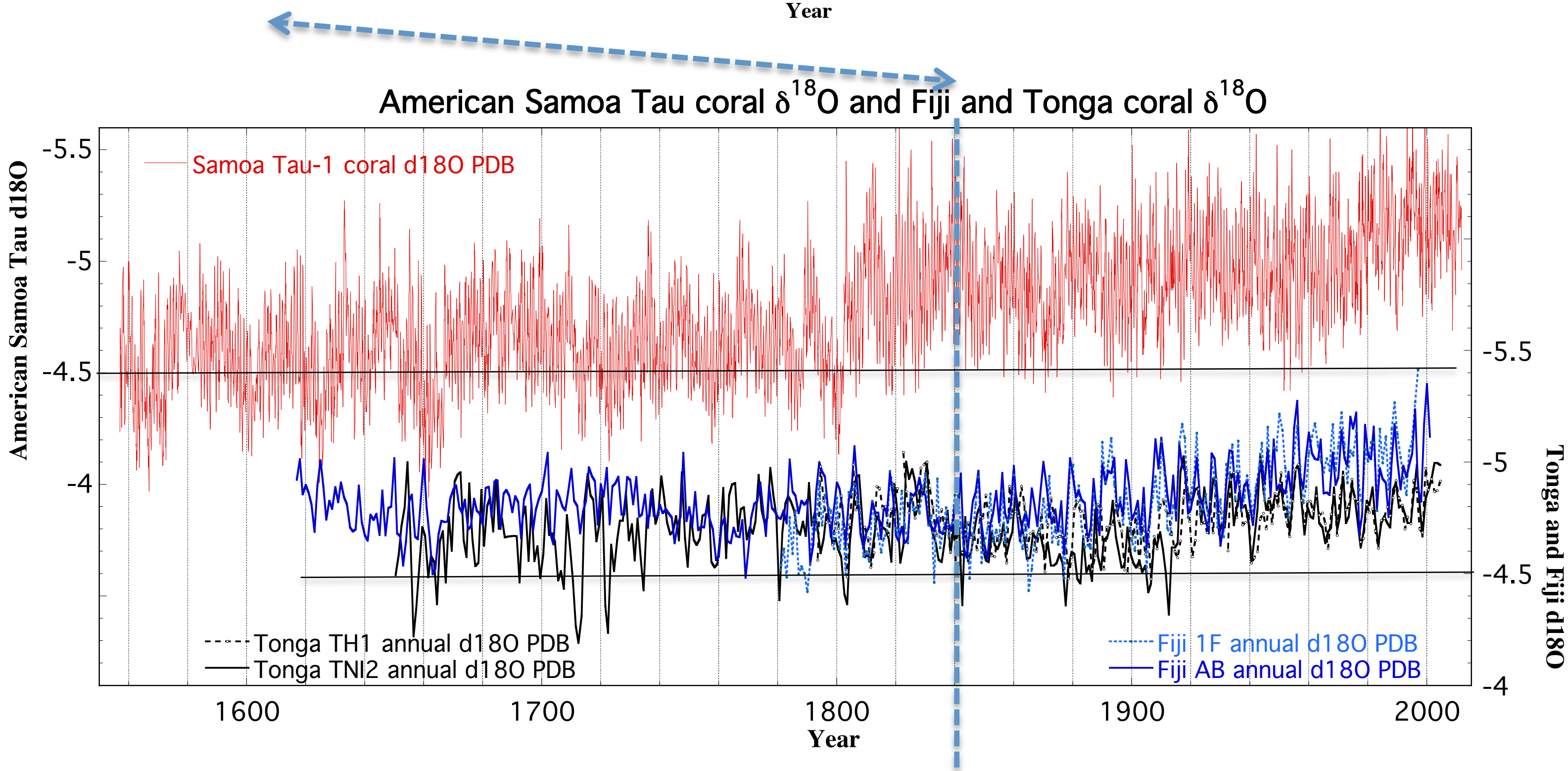


Secular Trend in Coral $\delta^{18}O$ in the SW Pacific

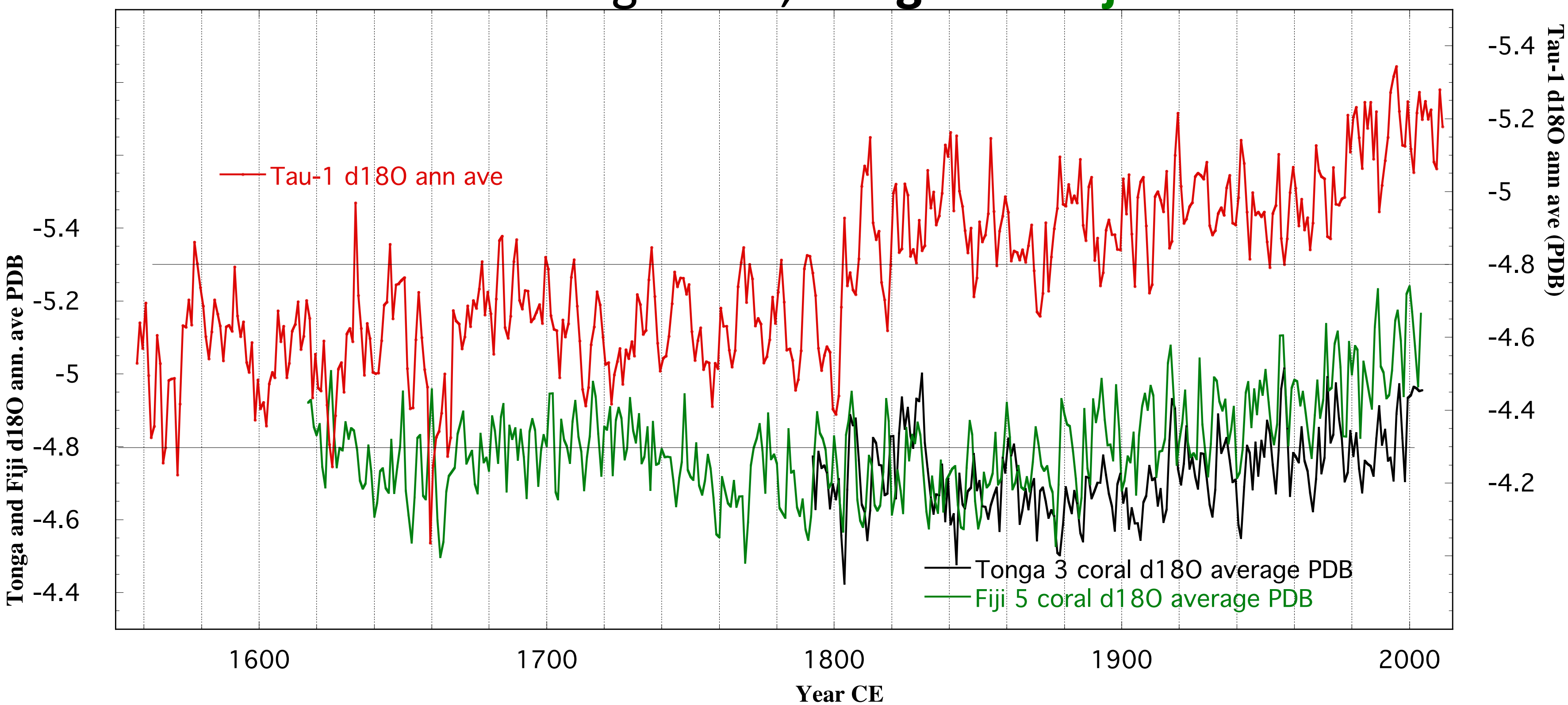
Samoa vs. Nino3.4 region

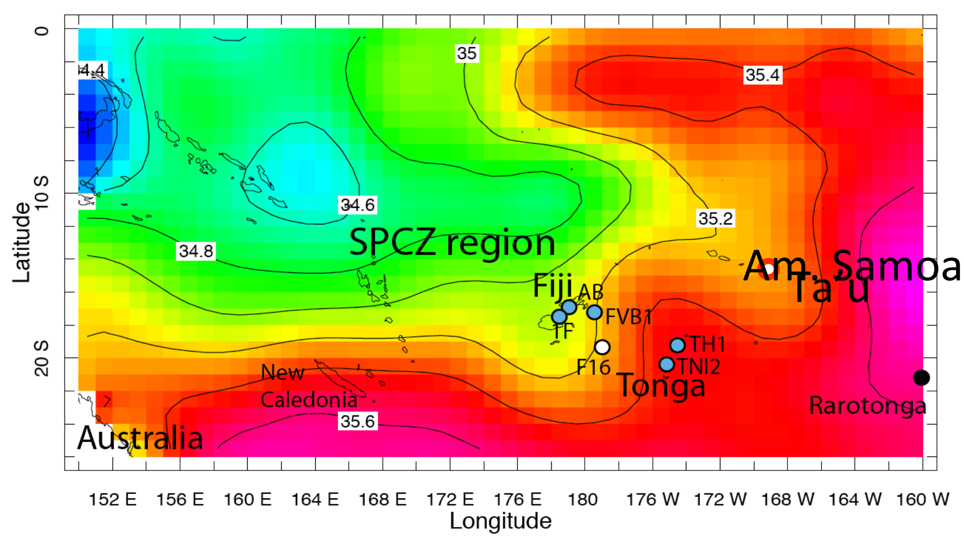


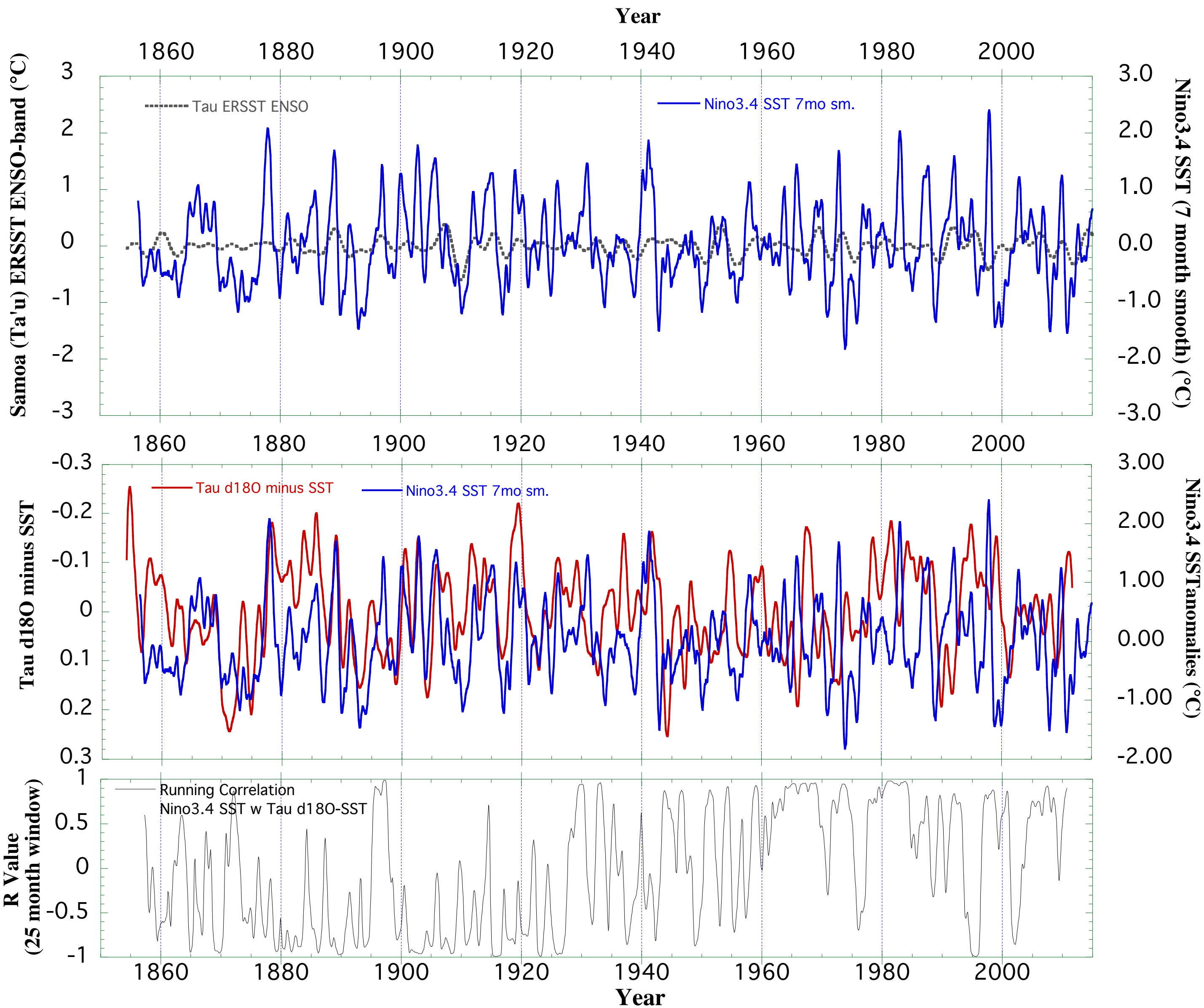
Samoa vs. Fiji & Tonga



Annual Average Ta'u, Tonga and Fiji $\delta^{18}O$







Year
Samoa (Ta'u) ERSST ENSO-band (°C)
Nino3.4 SST (7 month smooth) (°C)
Tau ERSST ENSO
Nino3.4 SST 7mo sm.
Tau d18O minus SST
Nino3.4 SSTanomalies (°C)
Tau d18O minus SST
Nino3.4 SST 7mo sm.
R Value
(25 month window)
Running Correlation
Nino3.4 SST w Tau d18O-SST
Year