Modelling Oceans, Climate, and the Future of El Niño

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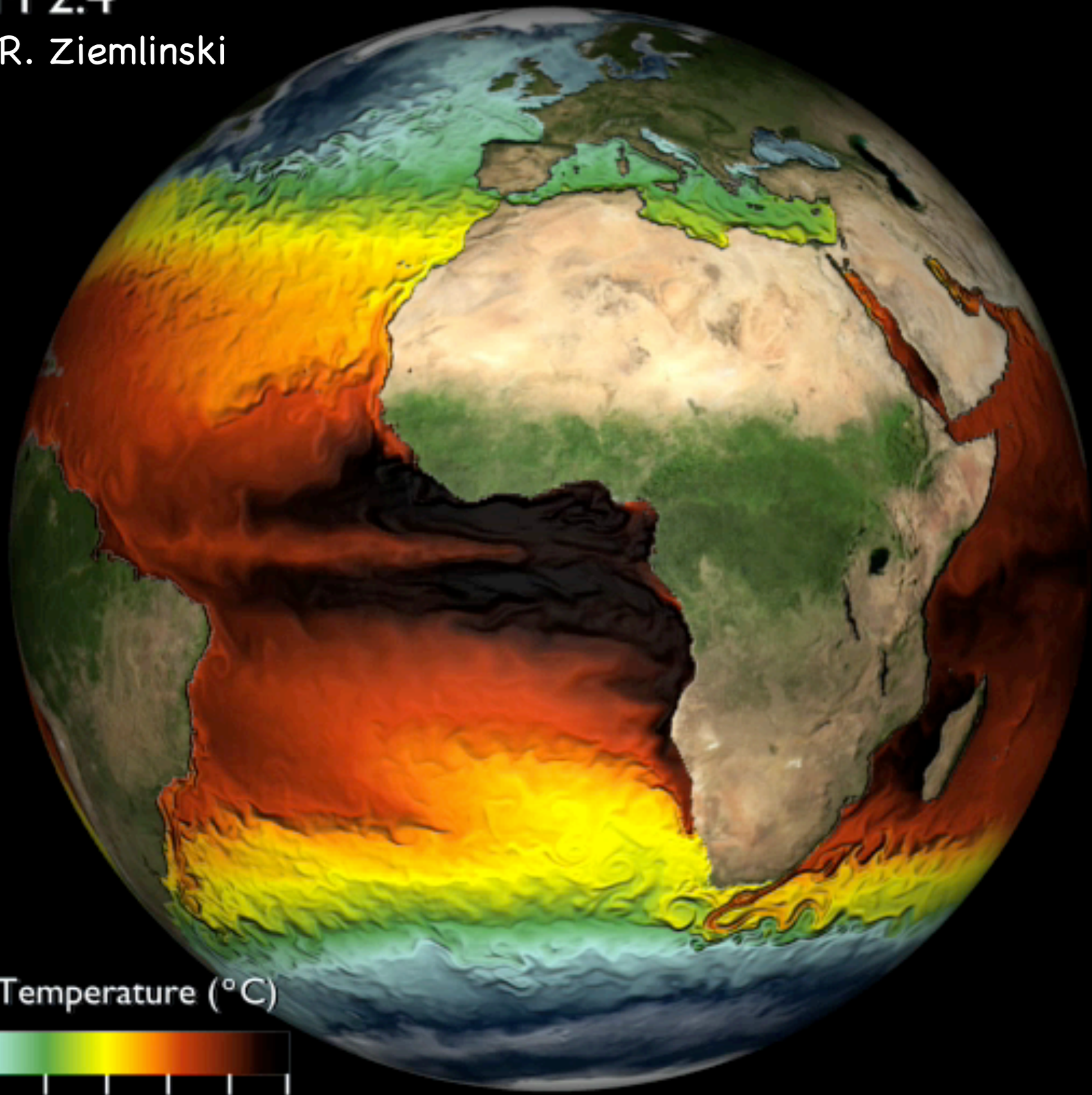
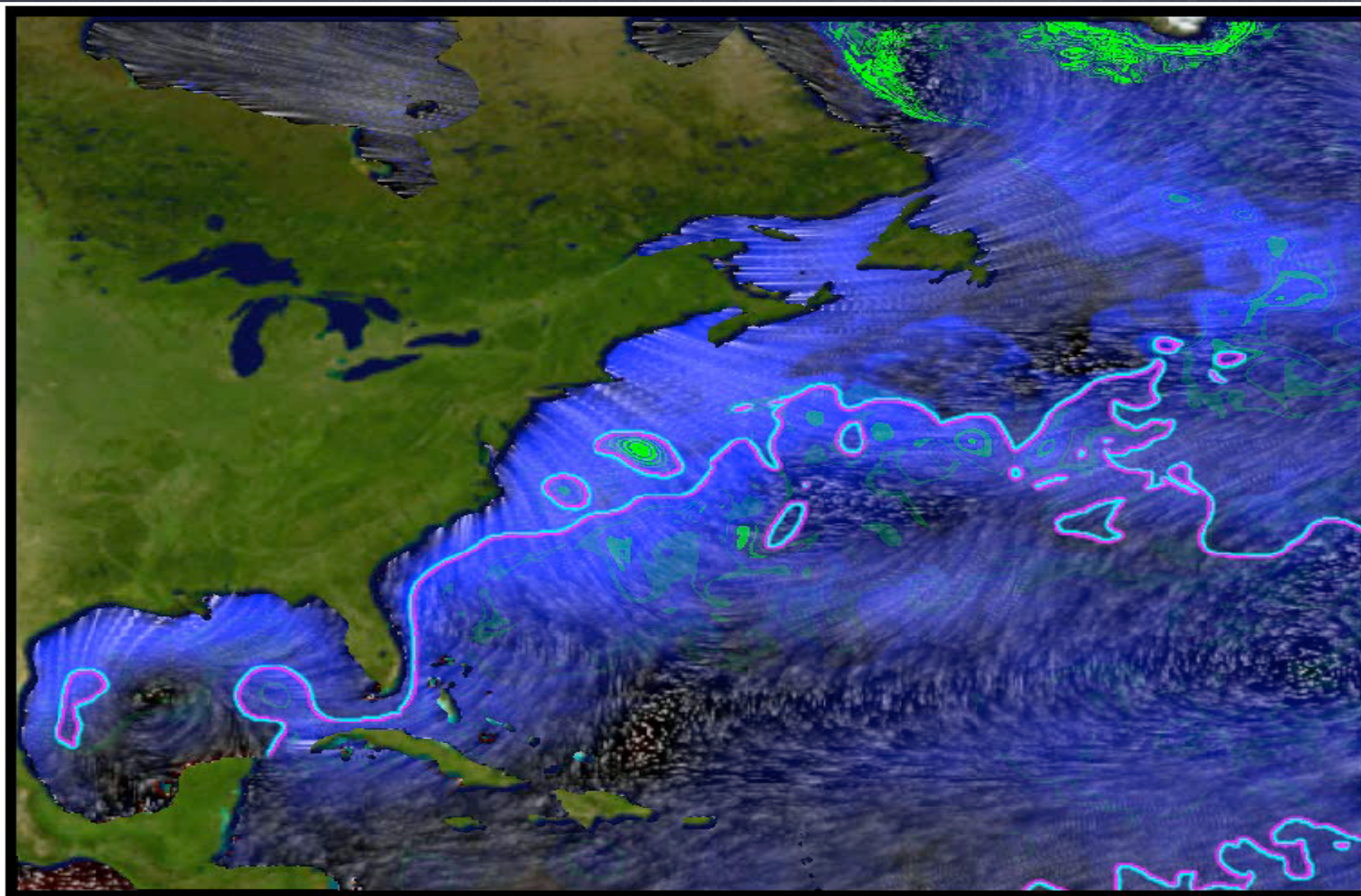
GFDL CM 2.4

Movie Credit: R. Ziemlinski



Sea Surface Temperature (°C)

-1.0 3.1 7.2 11.4 15.5 19.6 23.8 27.9 32.0



Movie Credit: Chris Henze, NASA Ames

Big Questions

- Why El Niño?
- What and who is El Niño and ENSO, anyway?
- What is a model?
- What is a good model?
- How do we know if we have a good one?

Why El Niño?
97-98, Biggest El Niño: Impact on Ecuador

Table 1: Impact of El Niño[2] (millions of US $)

Sector & Subsector	Direct Damages	Indirect Damages	External Effects	Total Damages
Social (a)	63.1	129.1	29.2	192.2
Infrastructure (b)	123.3	707.0	80.2	830.3
Economic (c)	582.9	709.0	545.4	1291.9
Expenses on mitigation, prevention and emergency		333.1		333.1
Total	769.3	1878.2	654.8	2647.5

(a) Social sector includes housing, health and education.
(b) Infrastructure sector includes water and sewage, energy and electricity, transportation and telecommunications, urban infrastructure.
(c) Economic sector includes agriculture, livestock and fisheries, industry, commerce and tourism.

Table of the economic impact of the 1997-1998 El Nino on Ecuador ALONE.
http://www.ccb.ucar.edu/un/ecuador.html

OVER 10% of GDP!

ENSO IS #1 SST
Variability slower than
the annual cycle

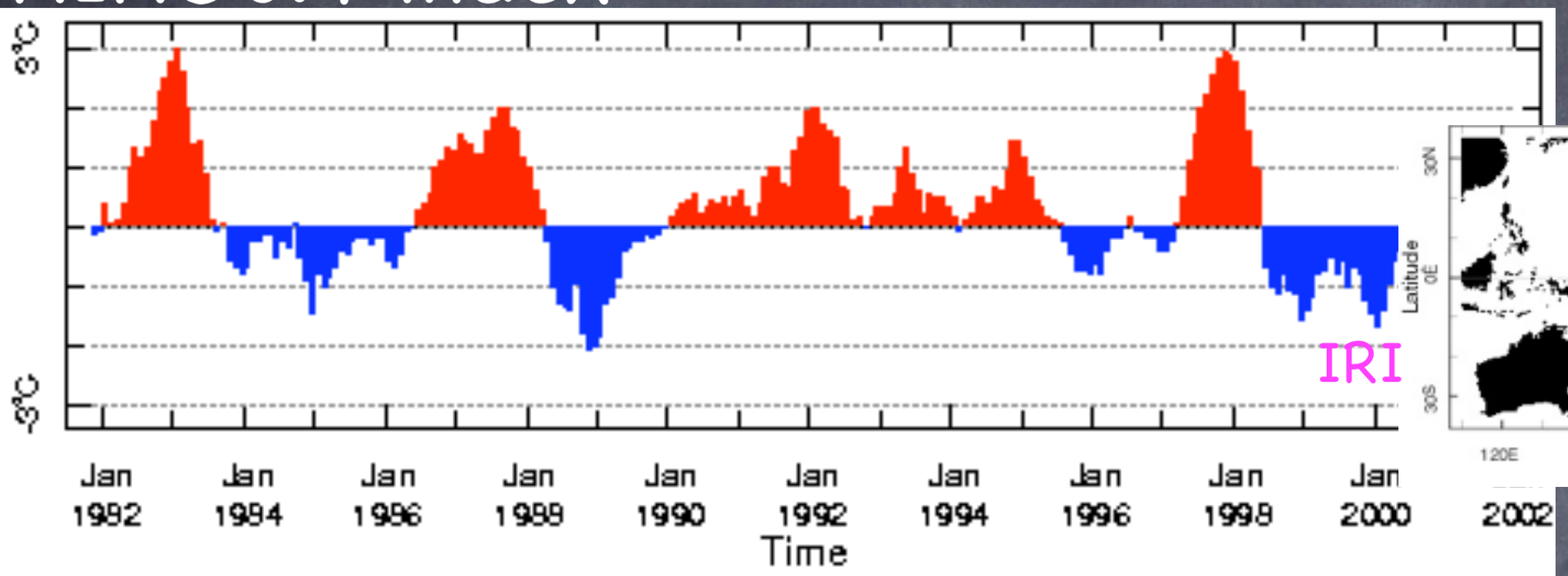
Nov 1997

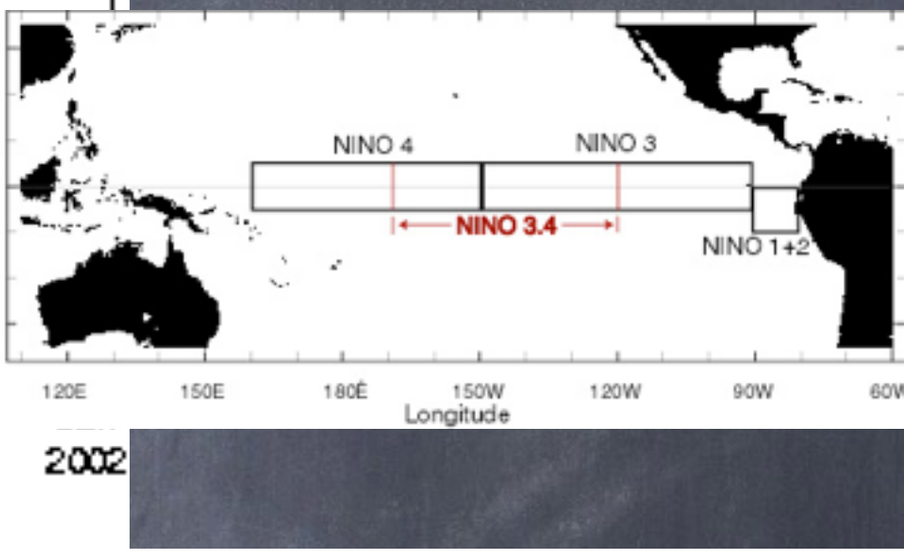
Image: NASA

EN and SO=ENSO

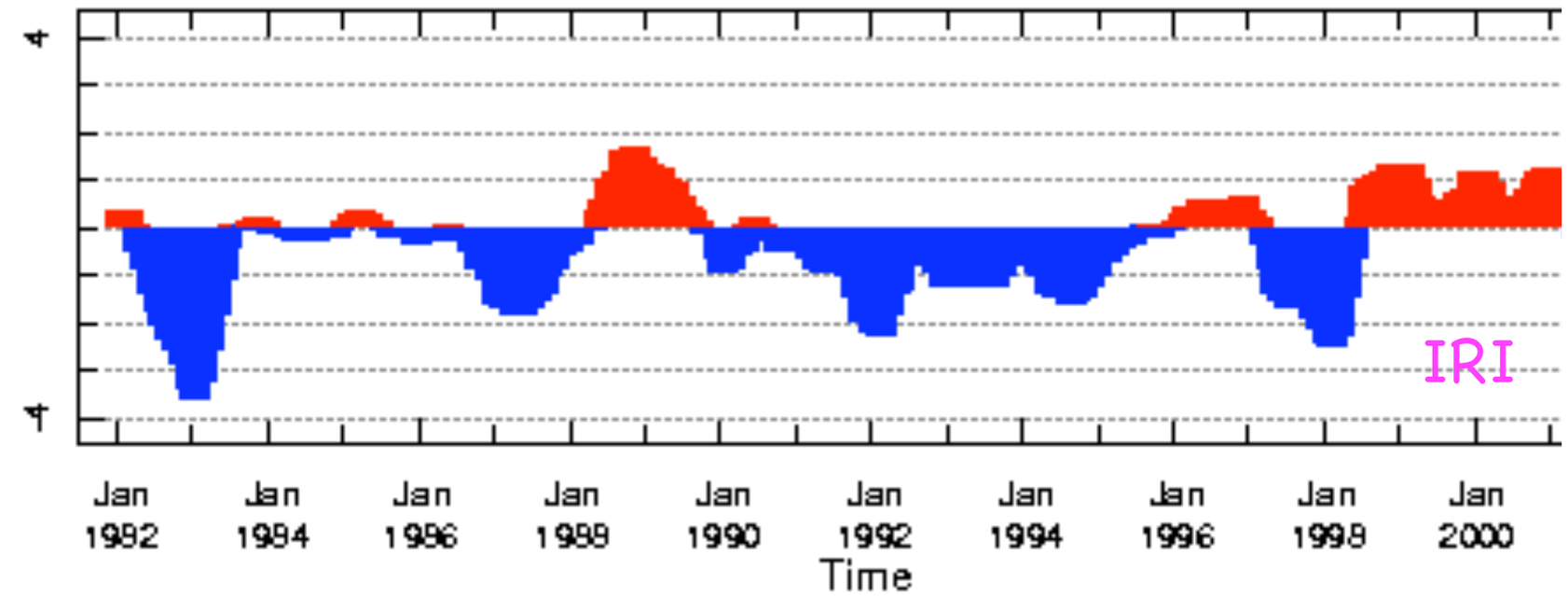
El Niño/Southern Oscillation

NINO3.4 index

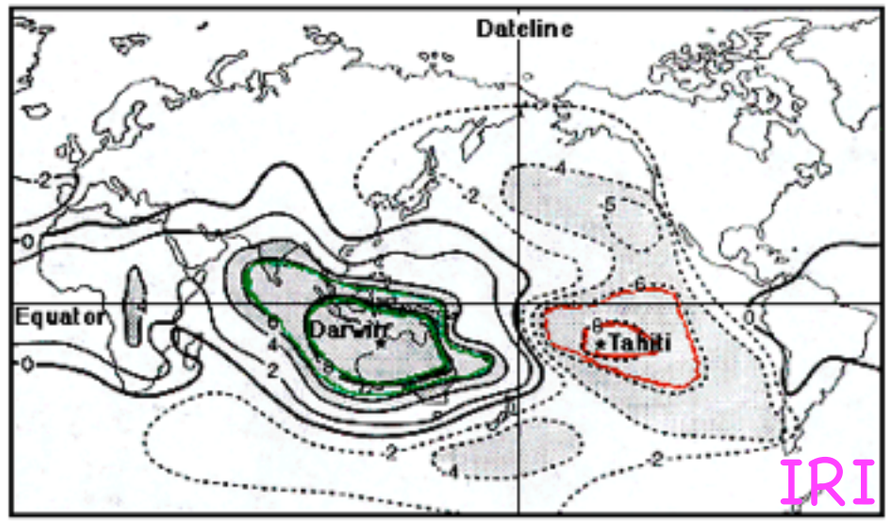




SO index: Tahiti-Darwin



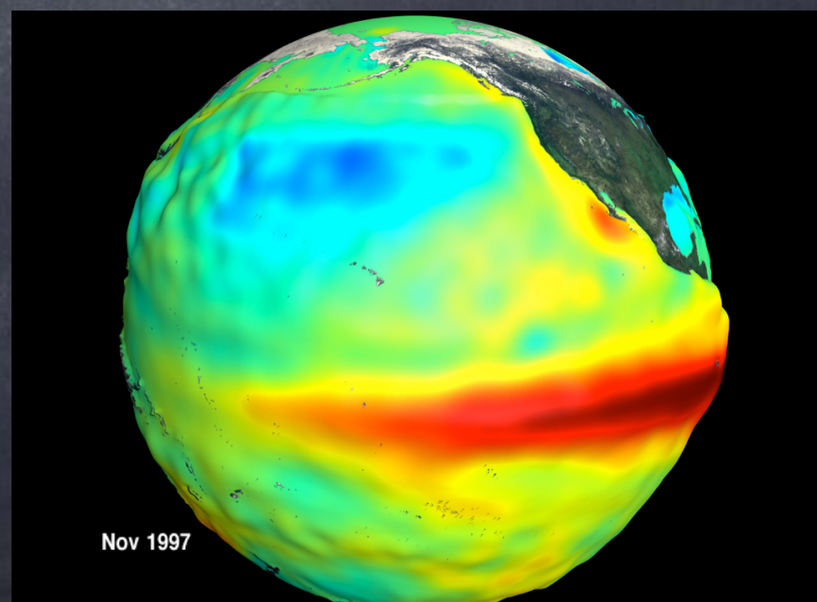
SOI: Tahiti and Darwin as "centers of action", mslp correlations between two locations



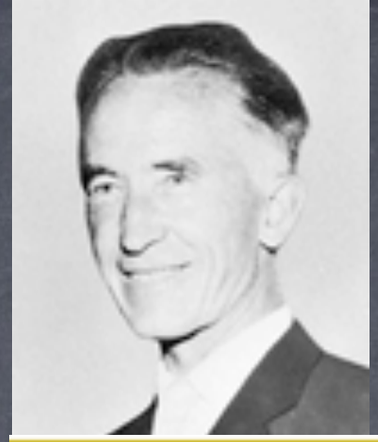
Tahiti and Darwin are at opposite ends of the Southern Oscillation's seesaw, and so the difference in pressure between them is used to measure the Southern Oscillation. The numbers represent a statistical measure called the correlation coefficient. The figure shows that the pressure variation at Tahiti is as closely related to Darwin as are locations near to Darwin, but with the opposite sign (i.e., if the Pressure is high at Darwin, it is low at Tahiti and vice versa). (After Rasmusson, 1984.)

ENSO: Variance and Mean

- Because O in ENSO="Oscillation", I use ENSO as a shorthand for,
- ENSO=Variability between El Niño and La Niña
  - Measured with "ENSO Variance"
- You can also have changes to the average, or mean Tropical Pacific conditions, sometimes I might say "Mean SST conditions are El Niño-like", by which I mean steady warm Eastern Pacific condition



What Causes El Niño?
The Bjerknes Feedback



Jacob Bjerknes

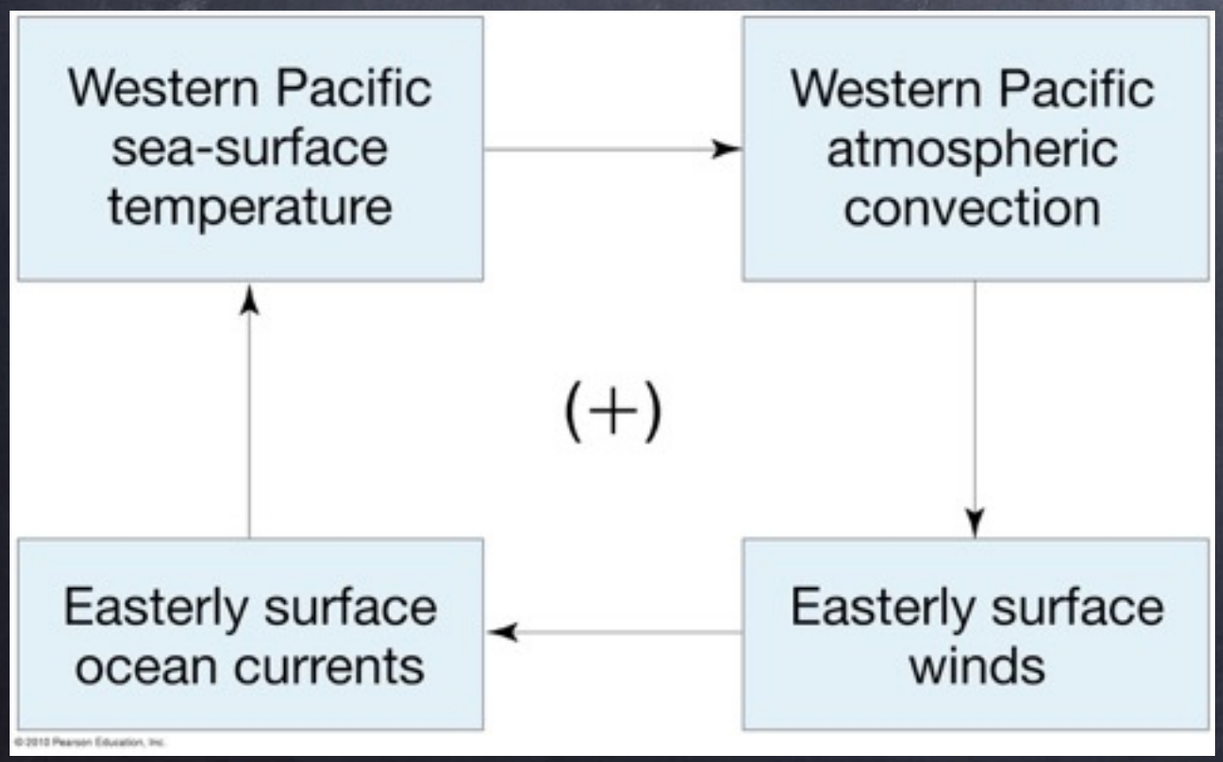
Main

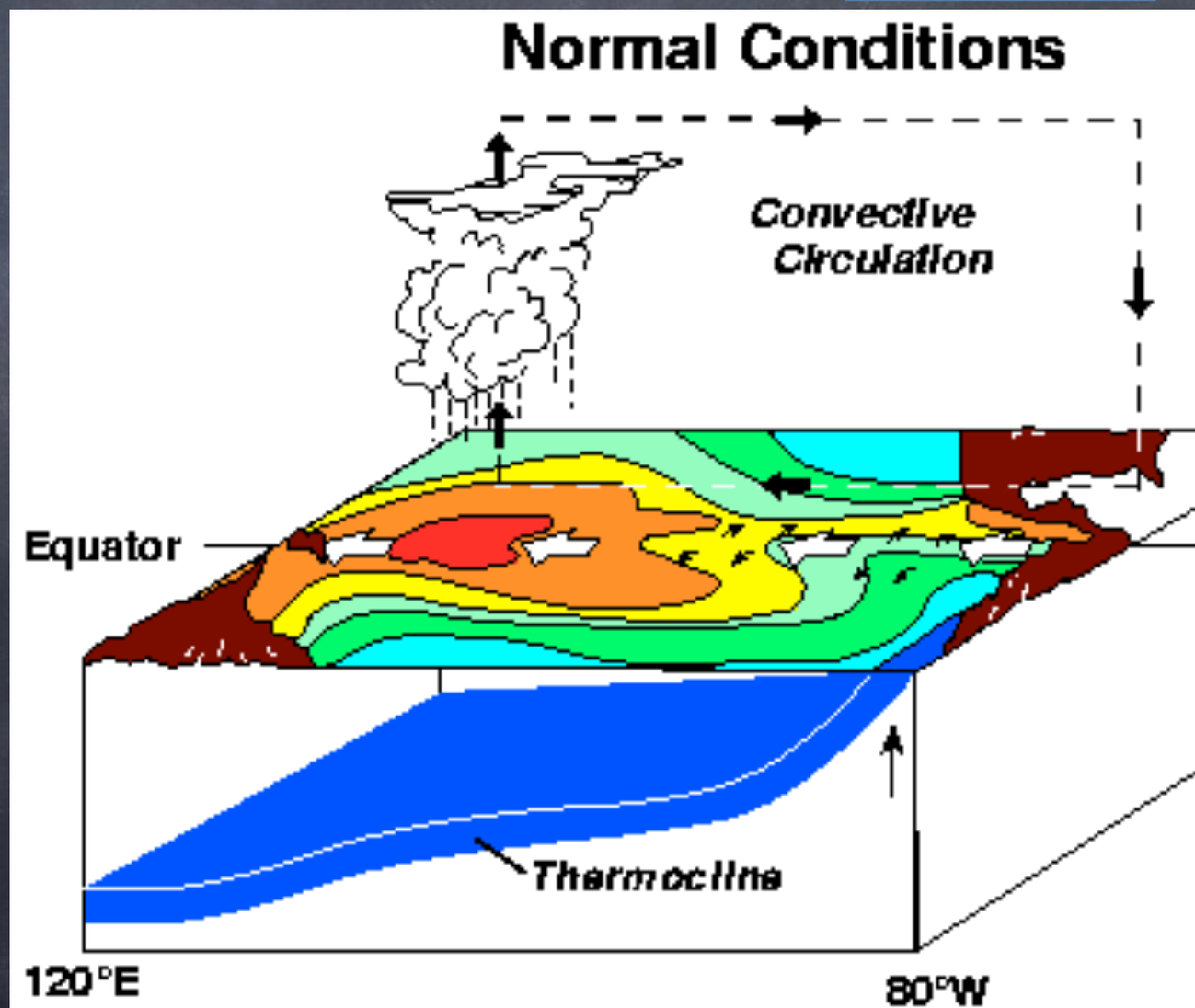
Norwegian-American meteorologist

born November 2, 1897, Stockholm, Swed.
died July 7, 1975, Los Angeles, Calif., U.S.

ENCYCLOPÆDIA Britannica

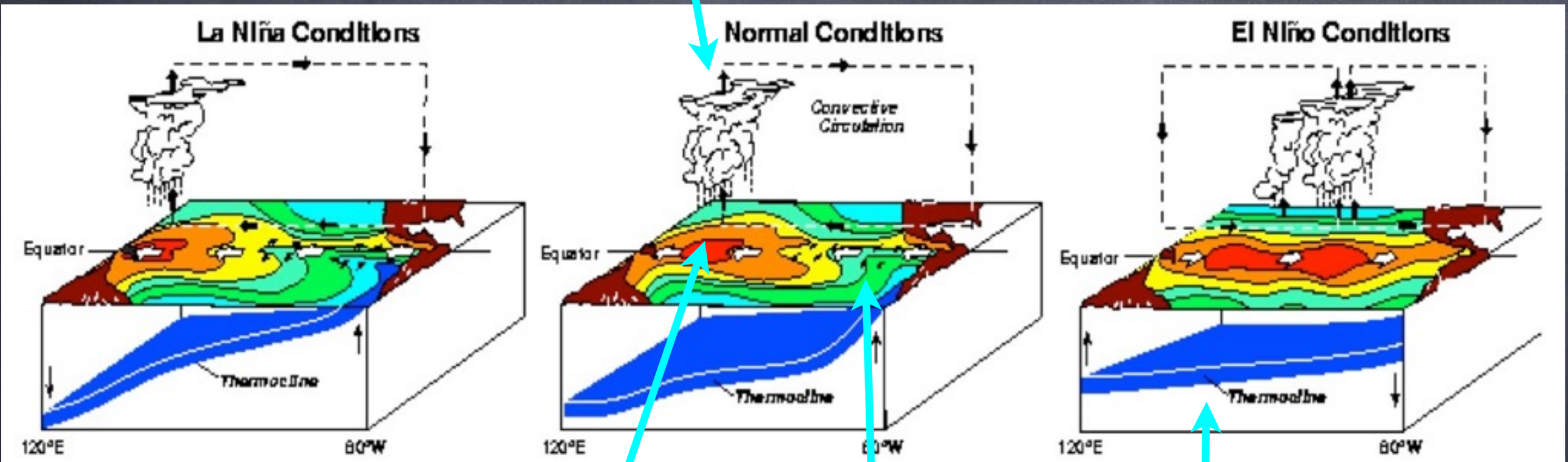
- Warm western water causes moist warm air to rise above western "Warm Pool"
- Cold, dry air sinks over eastern "Cold Tongue"
- Wind pushes down the thermocline in the west, which strengthens E-W SST difference





ENSO Phases

Warm Pool energizes convection



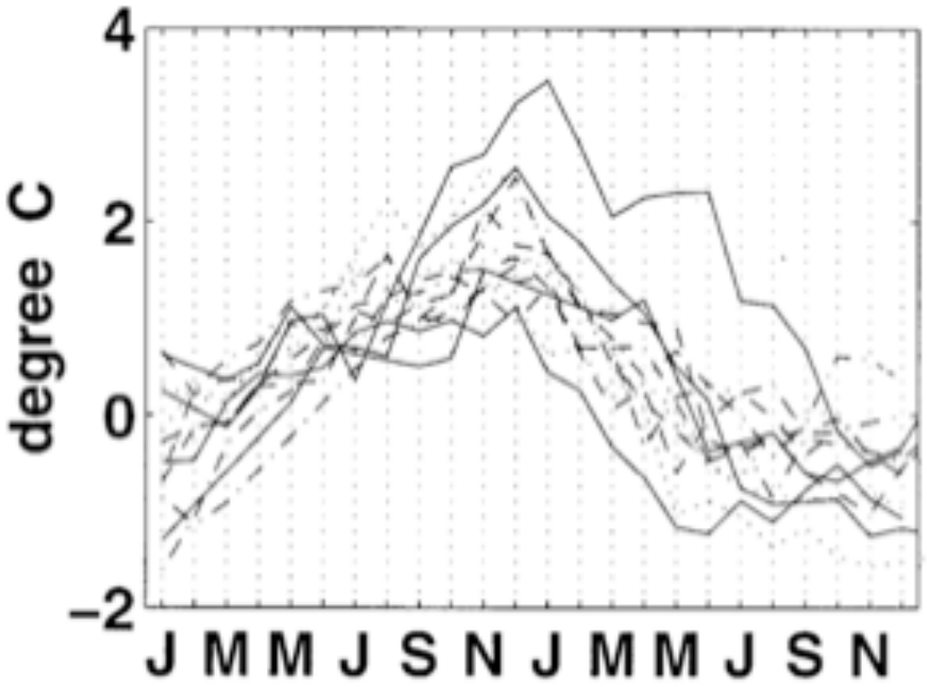
NOAA/PMEL

Warm Pool

Cold Tongue

Bjerknes Feedback: Wind->Tilt, Tilt->Wind

Why is it called 'El Nino'?



http://www.seas.harvard.edu/climate/eli

Two-year segments of the observed NINO3 index (SST averaged over the eastern equatorial Pacific) during several El Nino events, showing that El Niño tends to peak at the end of the calendar year.

at all. Originally the term El Nino referred to a warm coastal current that appears along the shores of Ecuador and Peru around Christmastime, when it brings welcome relief from the cold waters that otherwise bathe those shores.[1] The transformation of a regional curiosity, which we used to welcome as a blessing, into a global climate hazard happened recently, during the second half of the twentieth century.

G. Philander, Our Affair with El Nino

Flooding in Queensland, Dec. 2010

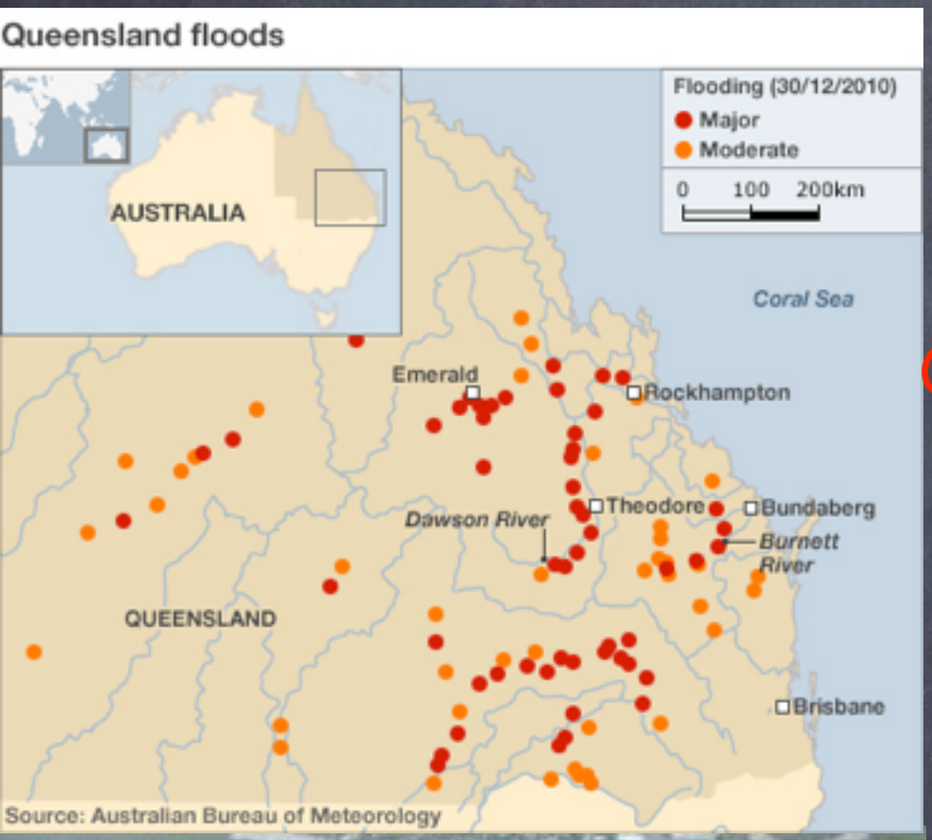
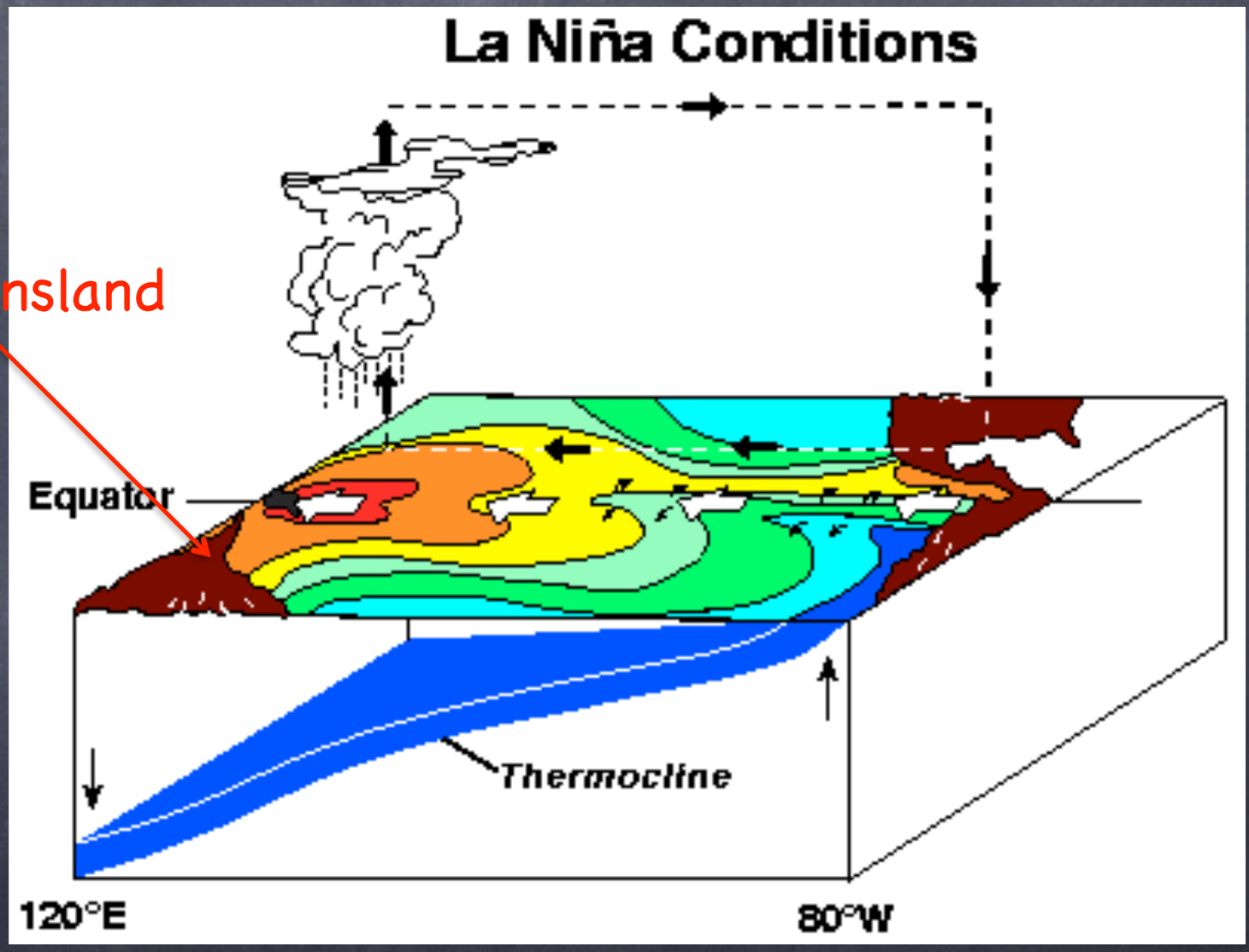
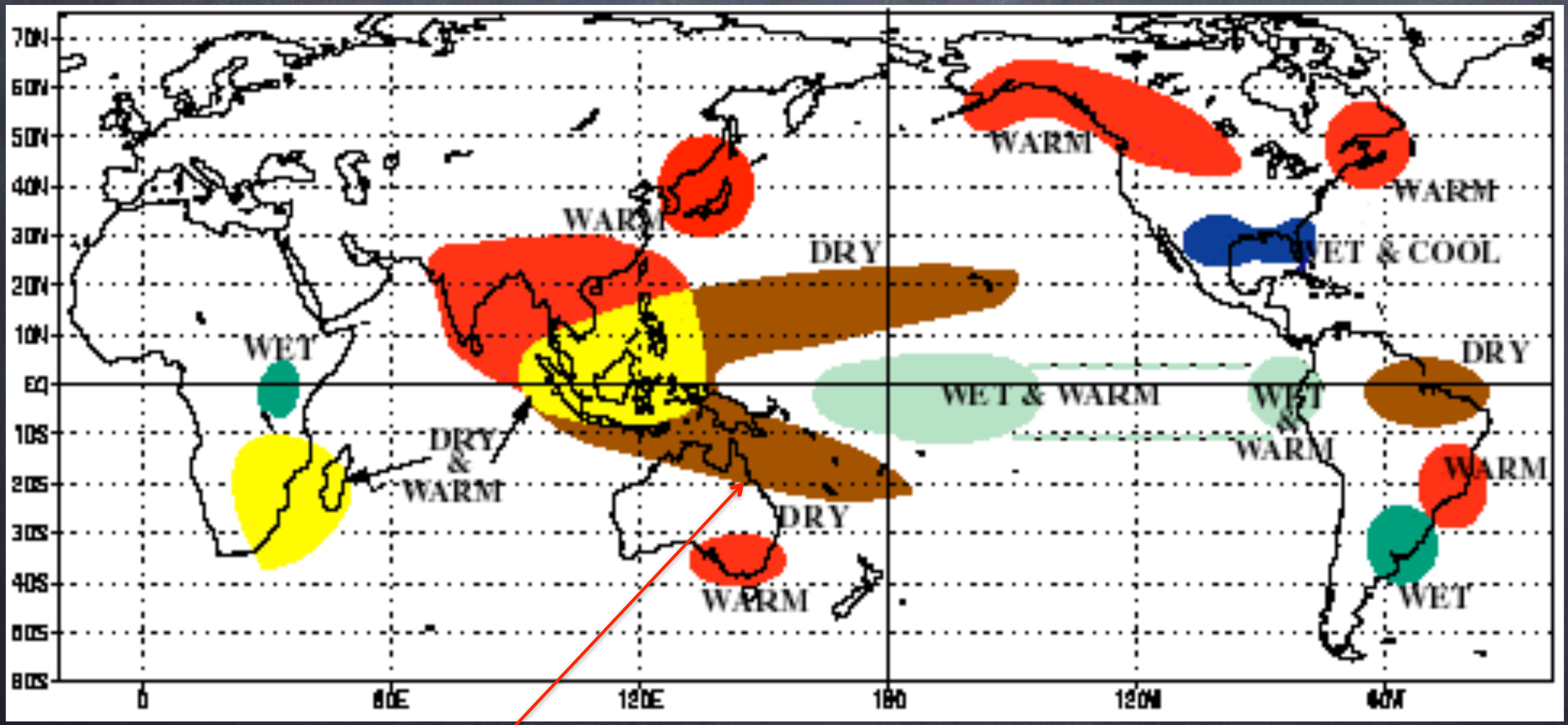


image from Geelong

Queensland



Global Teleconnections of El Niño

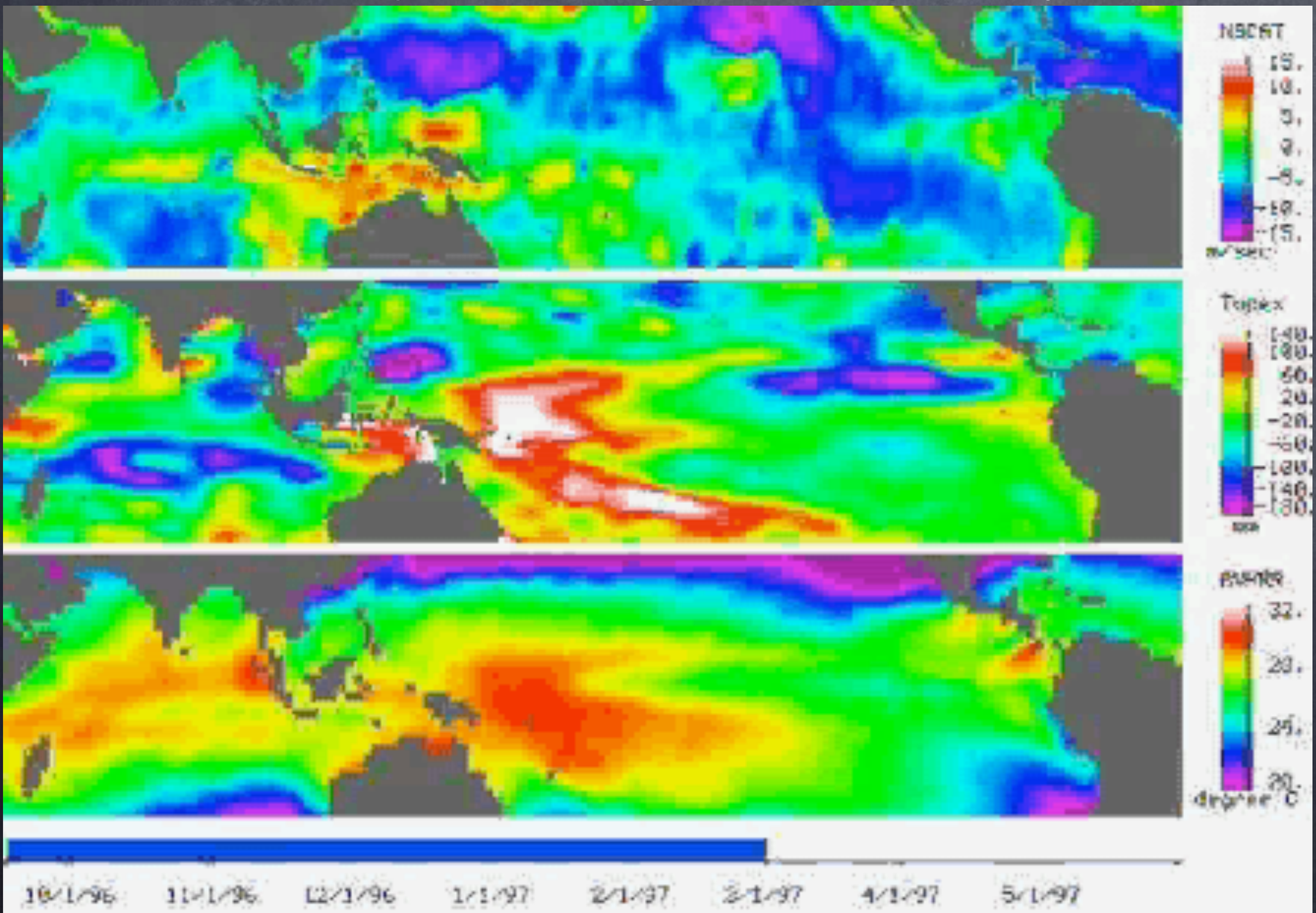


Queensland

http://www.seas.harvard.edu/climate/eli

Credit: NASA/JPL Air-Sea Connections

Satellites: the 1997-1998 El Niño. COMPLEX!

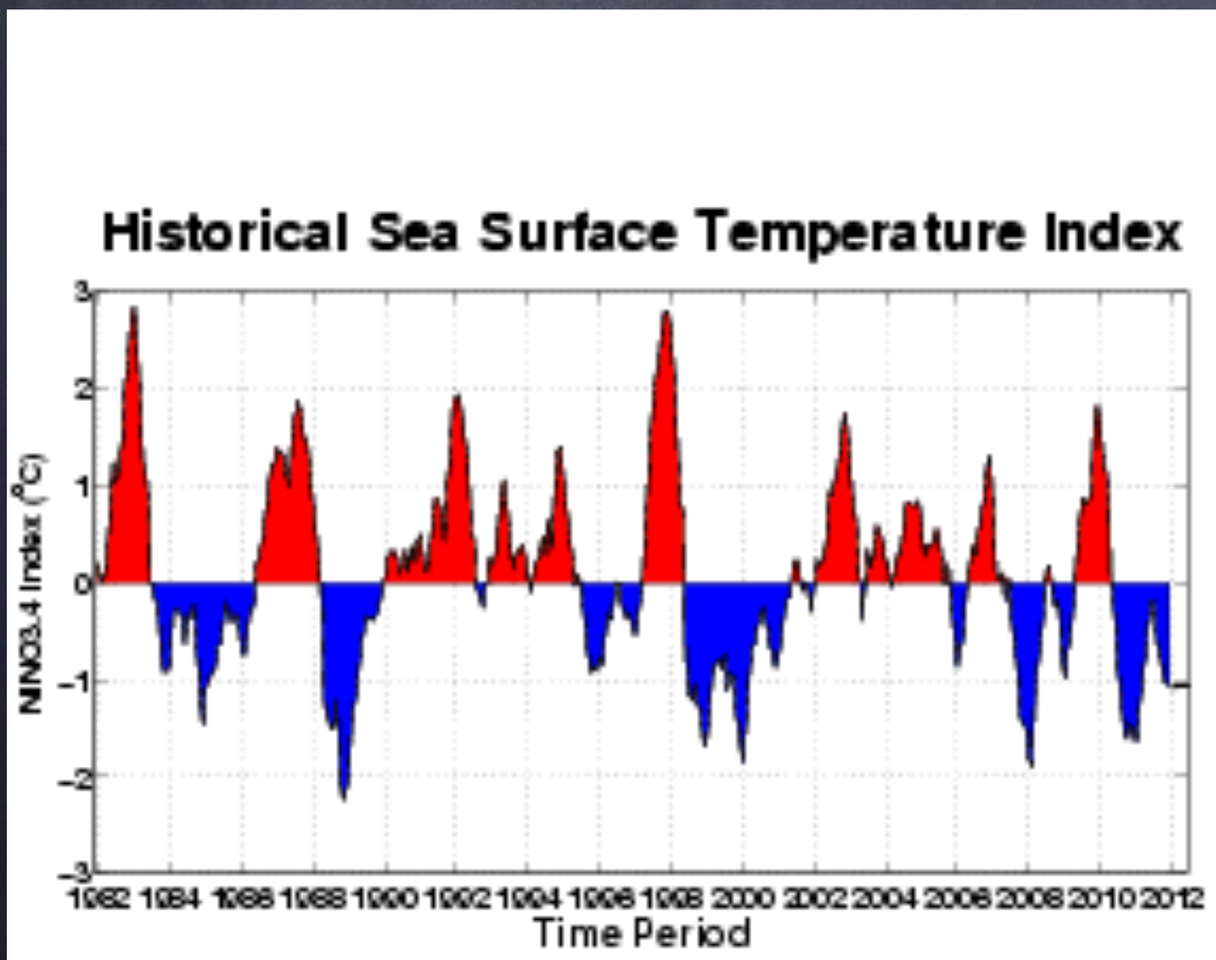


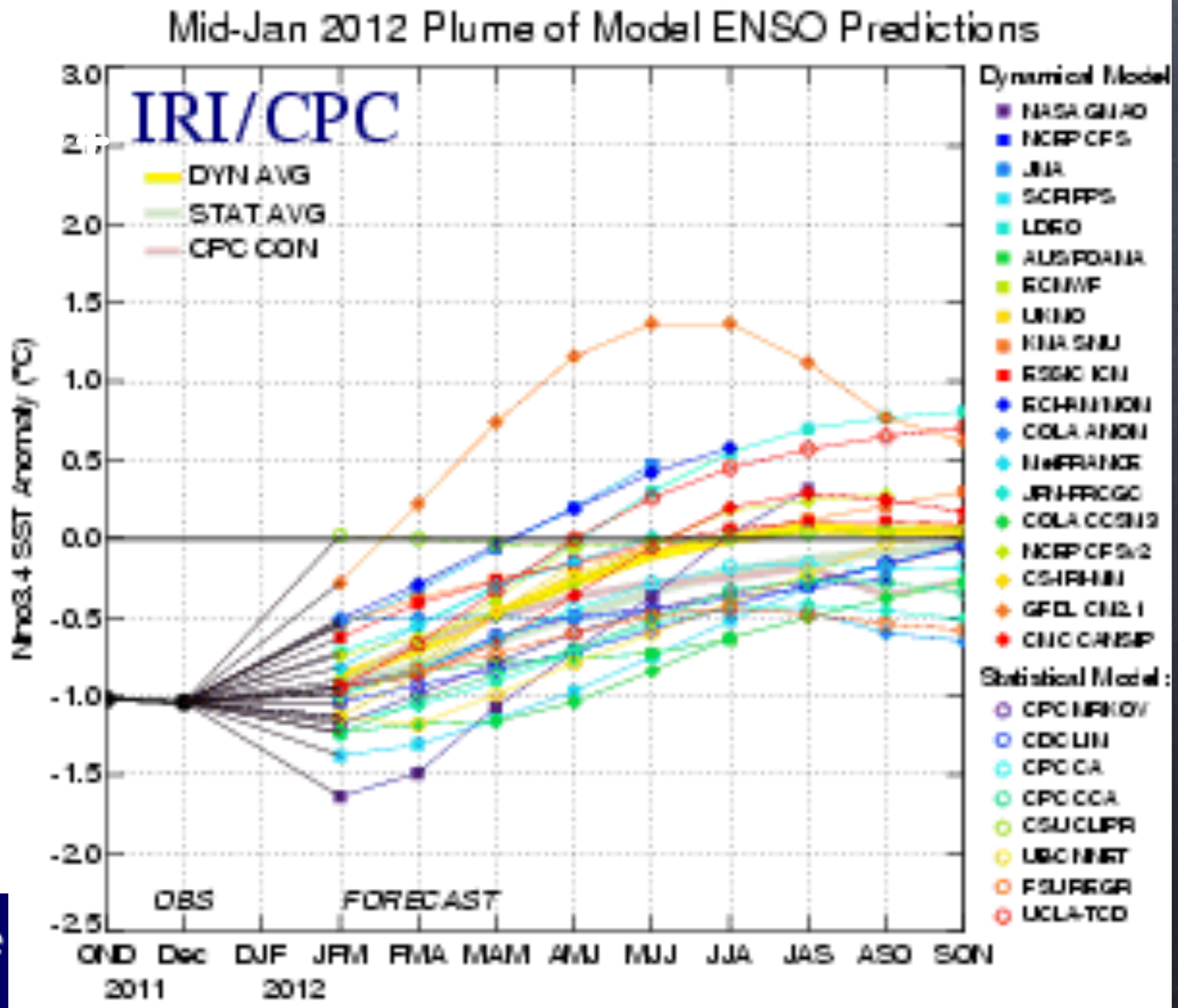
Winds

SSH

SST

What's ENSO doing now? and soon?





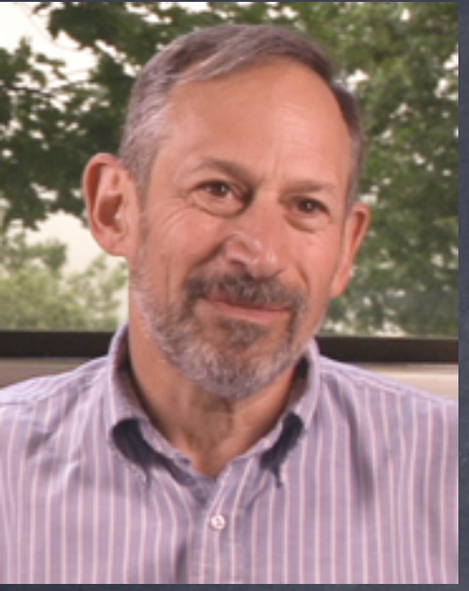
Source: The International Research Institute for Climate and Society

So, a few Big Questions are answered:

- Why ENSO?
  - It's globally and economically important
- What and who is El Niño?
  - Tropical Pacific Anomalies: Bjerknes feedback crucial
  - Near Christmas: Locked to the seasonal cycle
- ENSO is my shorthand for the variations, which are what costs money (it's hard to adapt to variability).

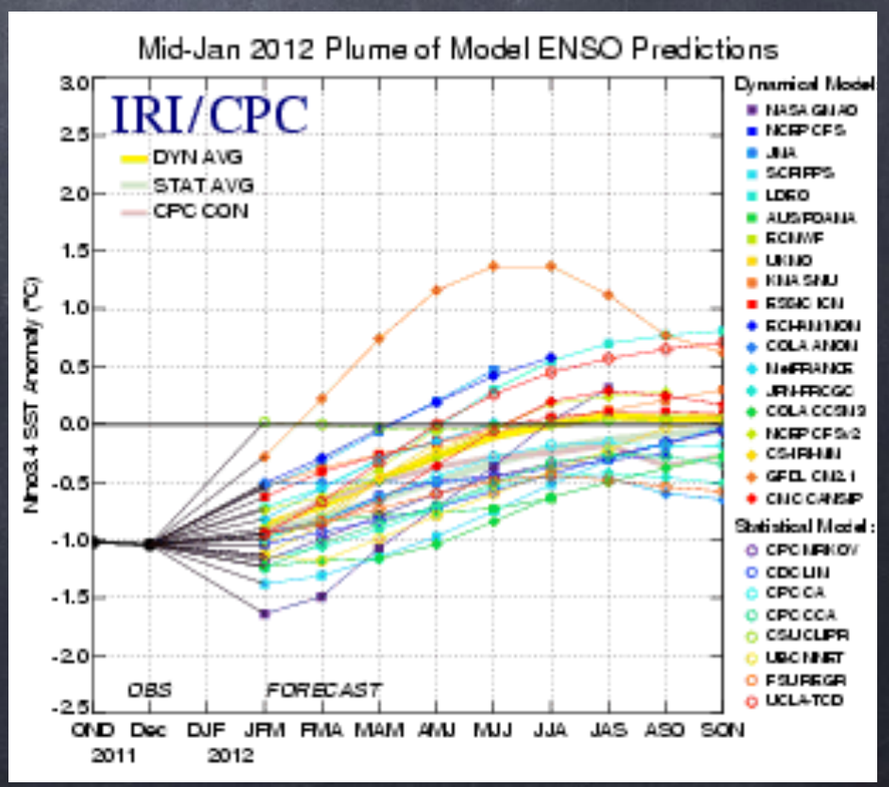
On to models...

- What is a model? Many different types:
  - Conceptual framework
  - Set of equations, maybe solvable
    - Analytic model, usually 'reduced'
  - Set of equations, not solvable
    - Idealized Numerical Model
  - Large collection of equations, algorithms, parameterizations, etc.
    - Kitchen Sink, General Circulation, Global Climate, or Earth System Model



Cane-Zebiak

- The first successful (skillful predictions) ENSO numerical model.
- IDEALIZED numerical model
- No atmosphere, just parameterized
- 1 active layer in ocean
- Not global: Tropical Pacific only

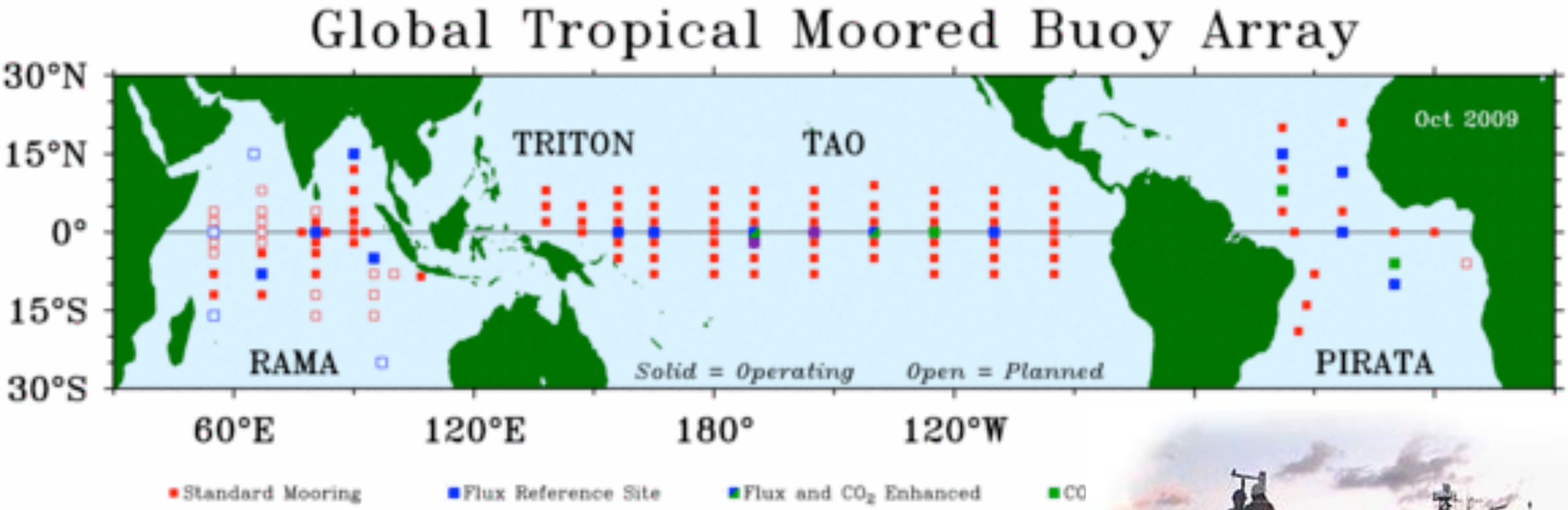


Is Cane-Zebiak a "good" model?

- Yes! It is skilled at 1 yr forecasts
- No! There are many things it can't do

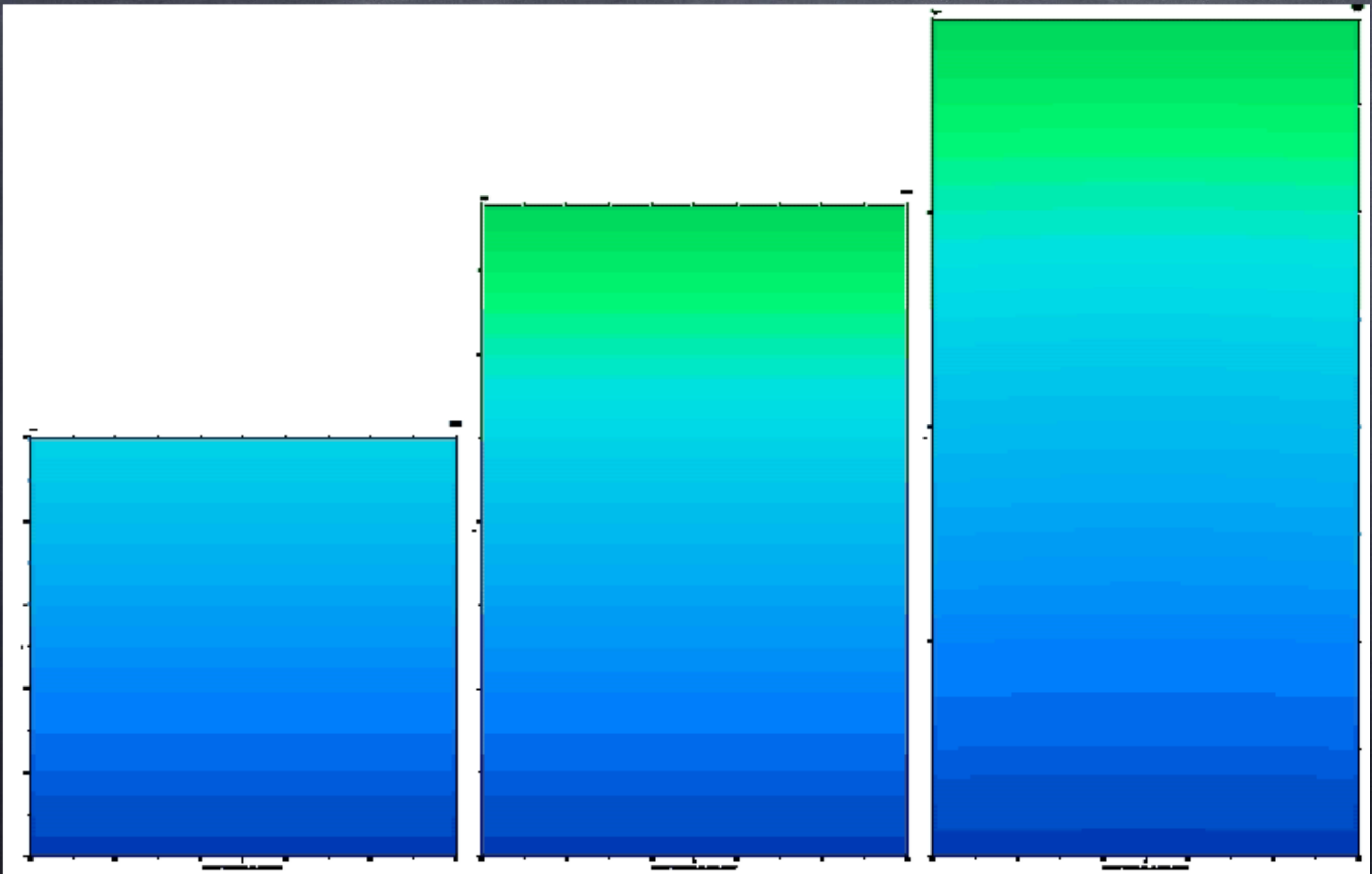
- What about other models that are more trustworthy?
  - Are they "good"?

Cane-Zebiak: Good enough to warrant permanent array of coordinated global observational moorings for forecasting!



http://www.pmel.noaa.gov/tao

Before Global...my PhD code



Is my PhD code a "good" model?

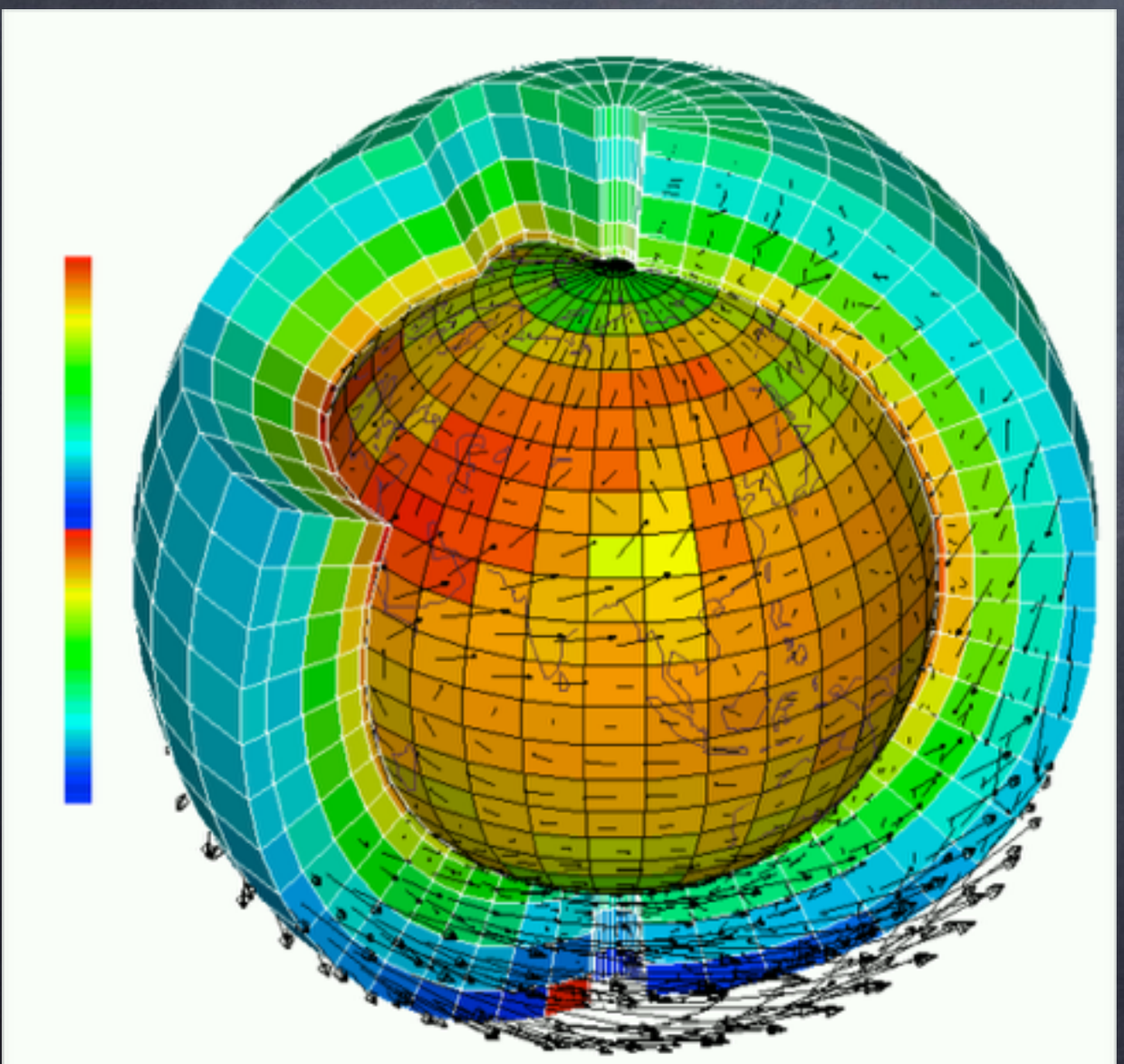
- Yes! It is capable of resolving all 2d flows of interest to the global budget of potential vorticity

- No! It can only handle rectangular oceans!

- What about other models that can do more?

CMIP5: promoting a balance between prediction, evaluating models using observations, and understanding

The Intergovernmental Panel on Climate Change (IPCC)-class models.



Max-Planck-Institut für Meteorologie

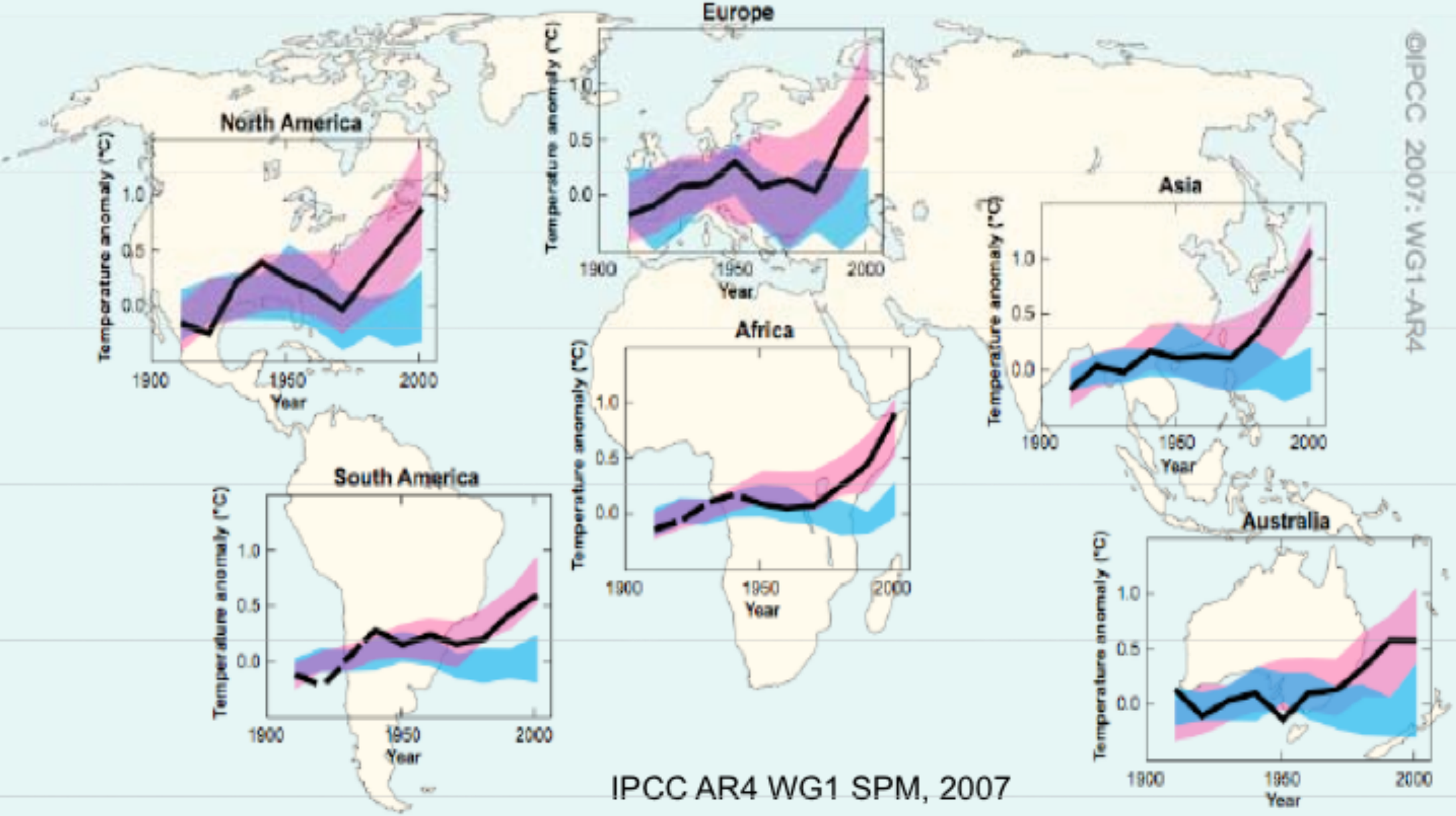
CSIRO

GFDL Geophysical Fluid Dynamics Laboratory

NCAR

Computer models match observed ΔT on all continents -

Africa and Asia at high end of projections….

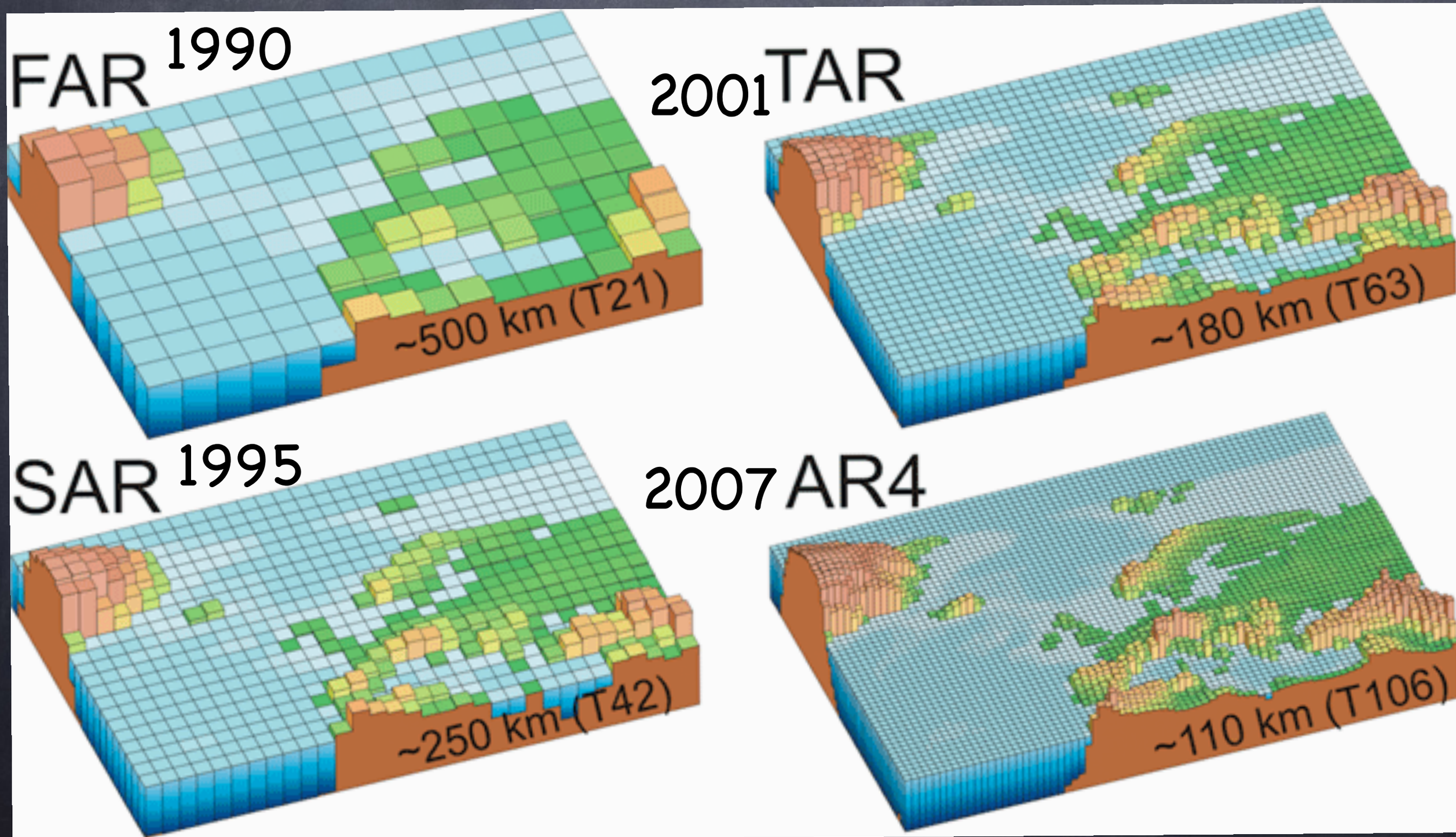


IPCC AR4 WG1 SPM, 2007

Black lines are decadally averaged observations. Blue bands are computer models with natural forcings only. Pink bands are computer models with human + natural forcings.

IPCC Models are global, good for climate change scenarios, but resolution & physics limits accuracy

Image: ipcc.ch



Before the IPCC

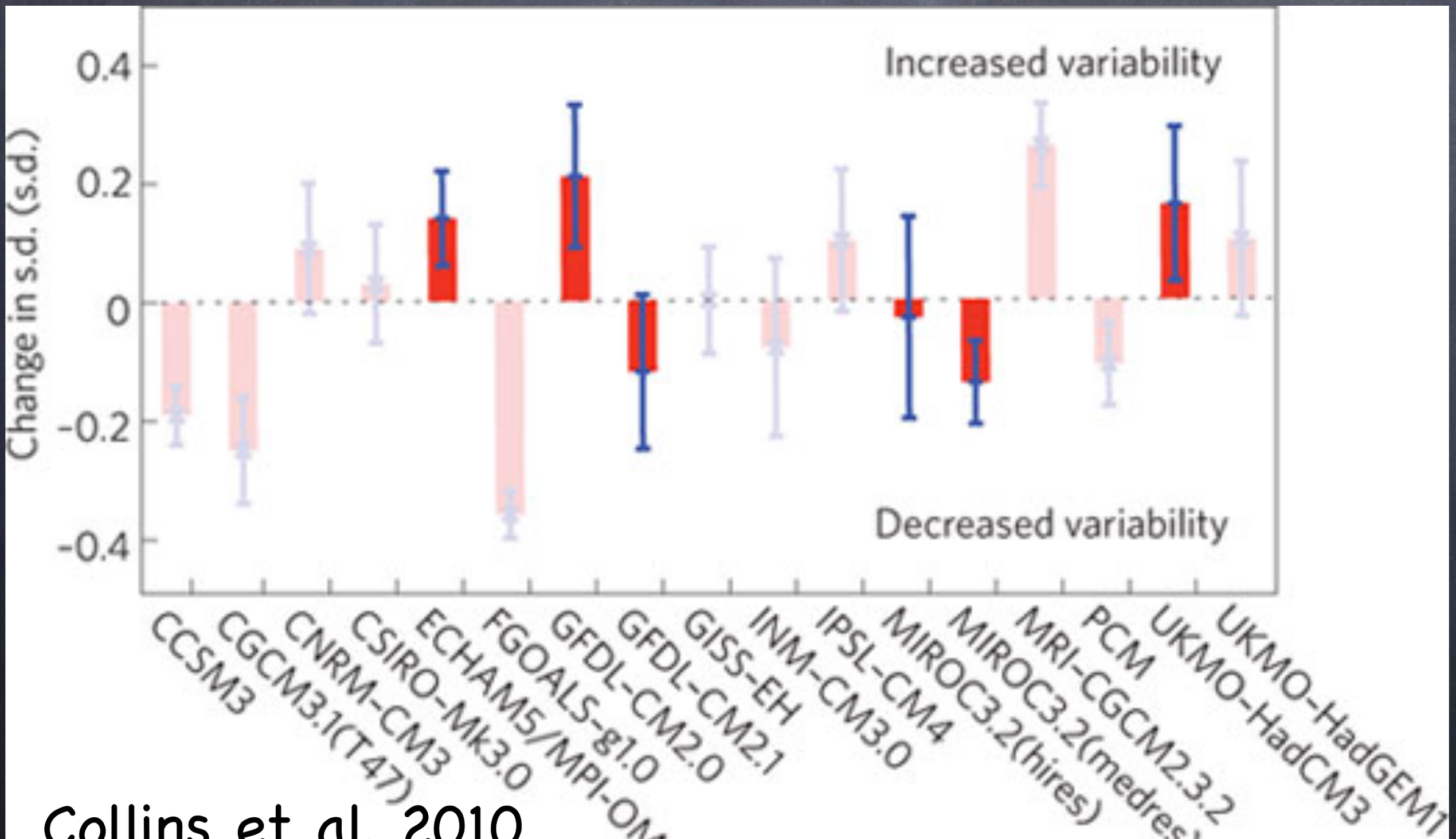
- The Charney et al. 1979 National Academy Assessment warned of a 1.5K to 4.5K warming with doubled CO_2
- This range came from two modeling groups
  - Jim Hansen's group at NASA Goddard
  - Suki Manabe's group at Princeton
- 1.5K to 4.5K
- Charney worked on the first numerical weather models (1952)

- In 1906, Svante Arrhenius estimated that doubling CO_2 would raise temps by 5-6K, and halving would decrease by 4-5K

- Similar to IPCC estimates!
  - But more is known about uncertainties and consequences—like maybe ENSO!

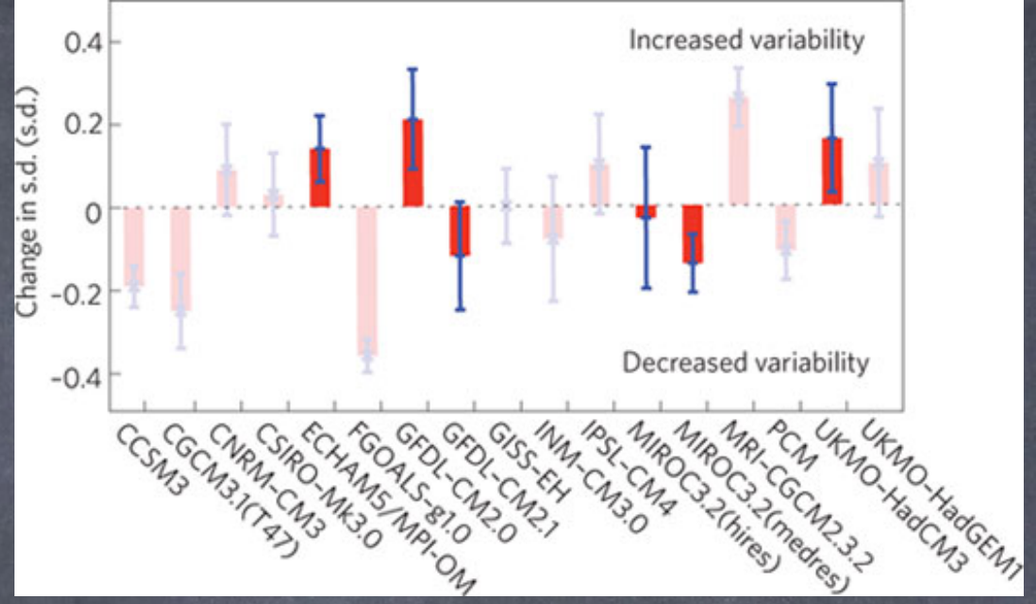
Images from Wikipedia, unescso.org,

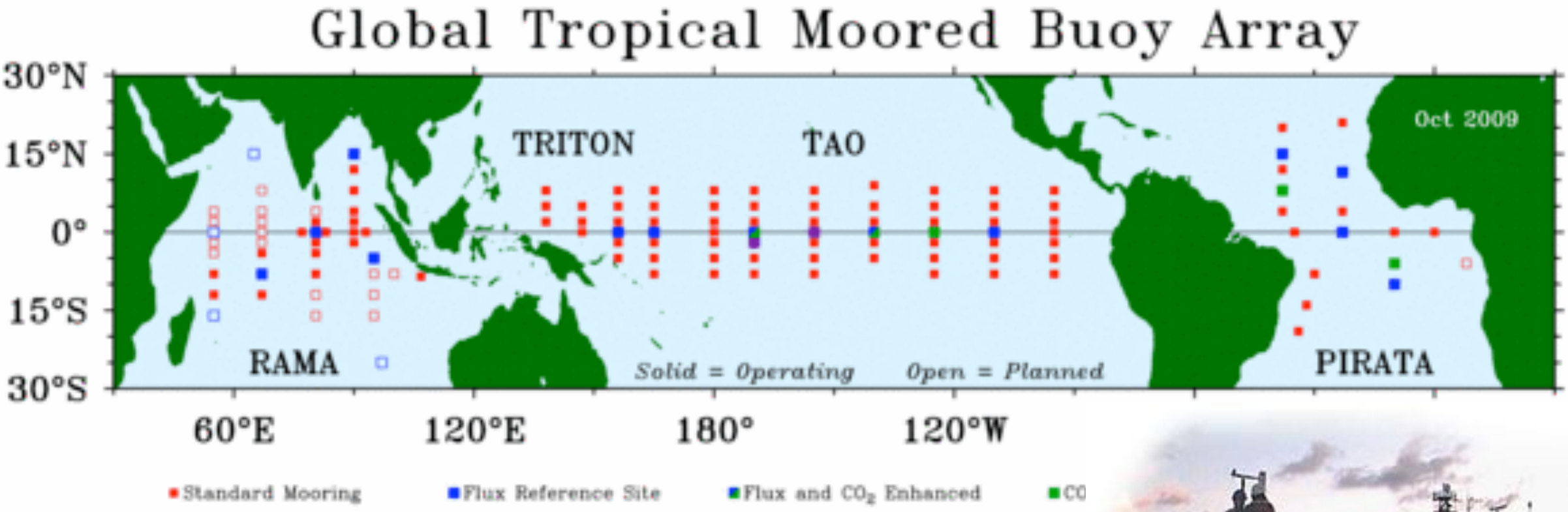
Question: Can we use IPCC models to predict future ENSO variability?



Collins et al. 2010

Dark red agree with modern data: Does that make them "good"?

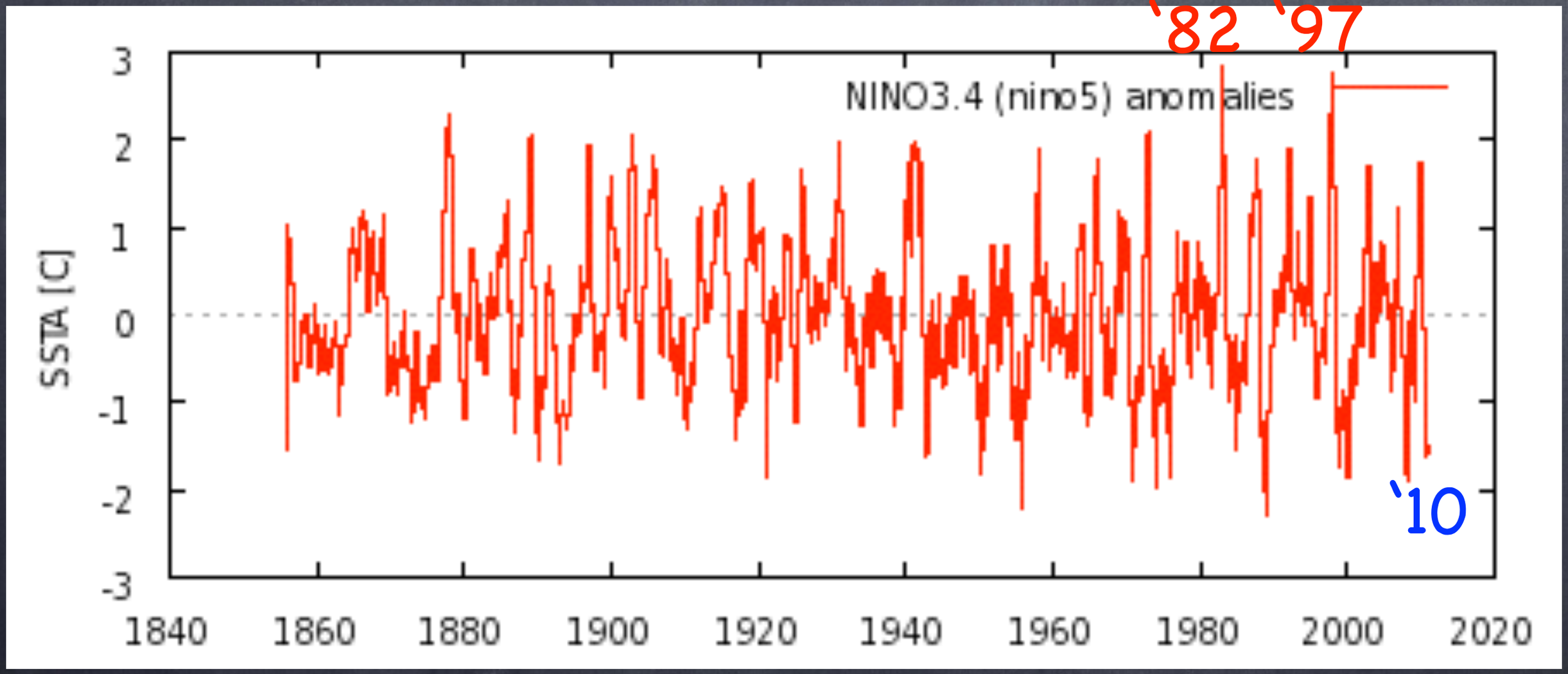




http://www.pmel.noaa.gov/tao

They don't agree with each other!

"Modern" Obs. of ENSO



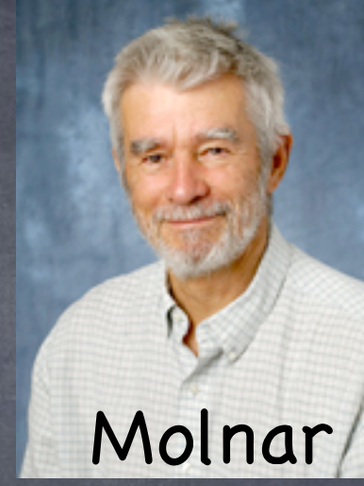
NINO3.4 index, SST anomalies in 5S-5N, 120W-170W, 1856-1949: Kaplan reconstruction, 1950-now: CPC (Reynolds OI SST), last updated: 2011-02-14, SSTA [C]

Credit http://climexp.knmi.nl/

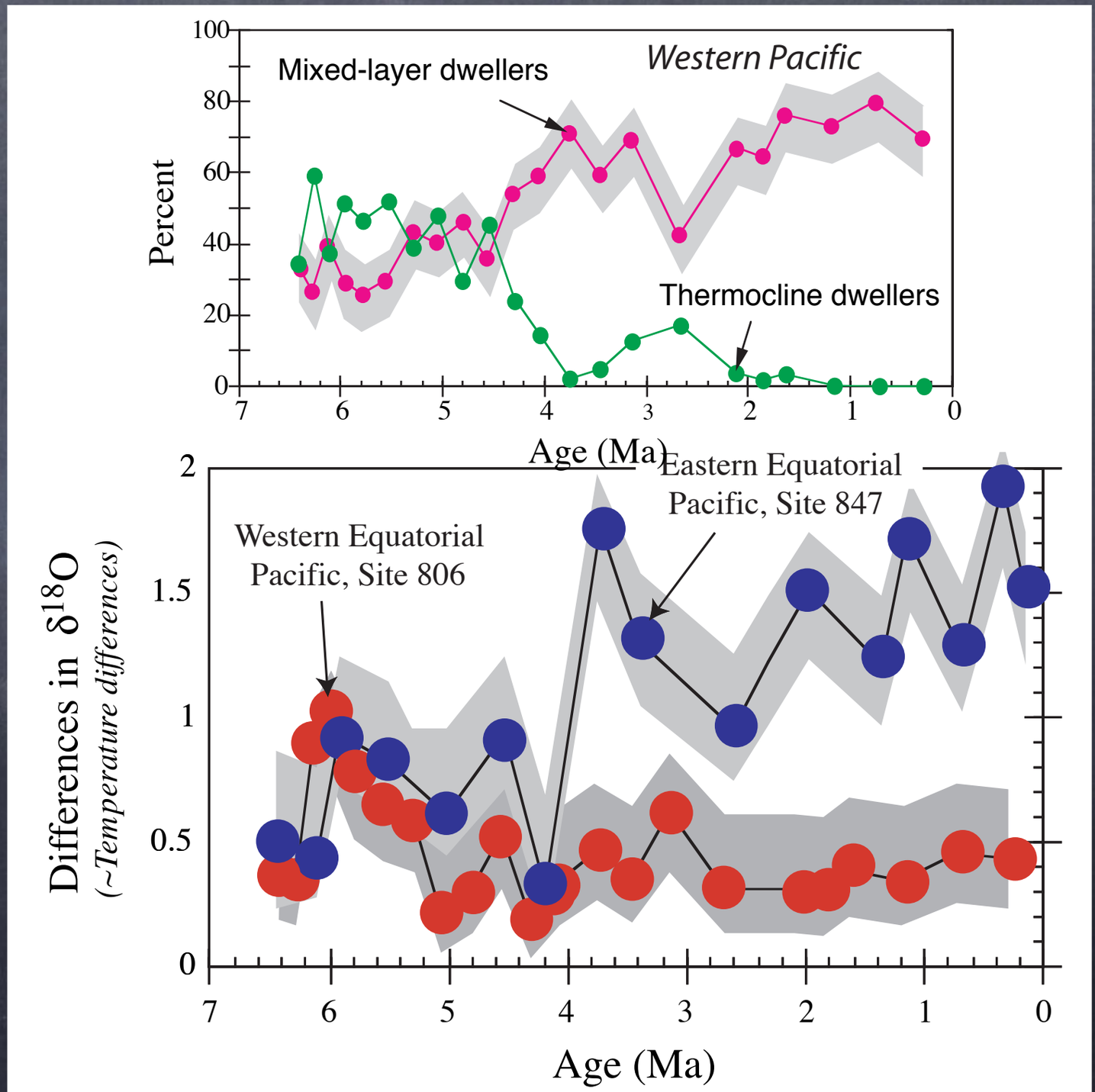
3-7 year period

About 33 El Niños in 150 years.

El Niño in the Pliocene—"Permanent" El Niño?



- 3-5 Ma ago, the Earth was much warmer overall (no ice ages)
- The E-W temp diff. in the Pacific was less
- The western warm pool was much shallower
- Sediment cores (Chaisson & Ravelo, 2000) are one example on right.
- Cane & Molnar (2001)

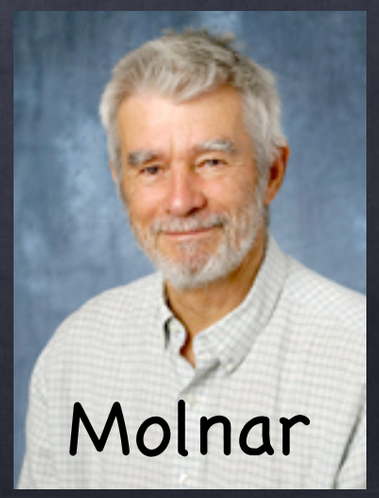


My Work:
El Niño in the Future—
Permanent El Niño?
Stronger or weaker ENSO?

With:

My Student
Sam Stevenson

Jochum, NCAR

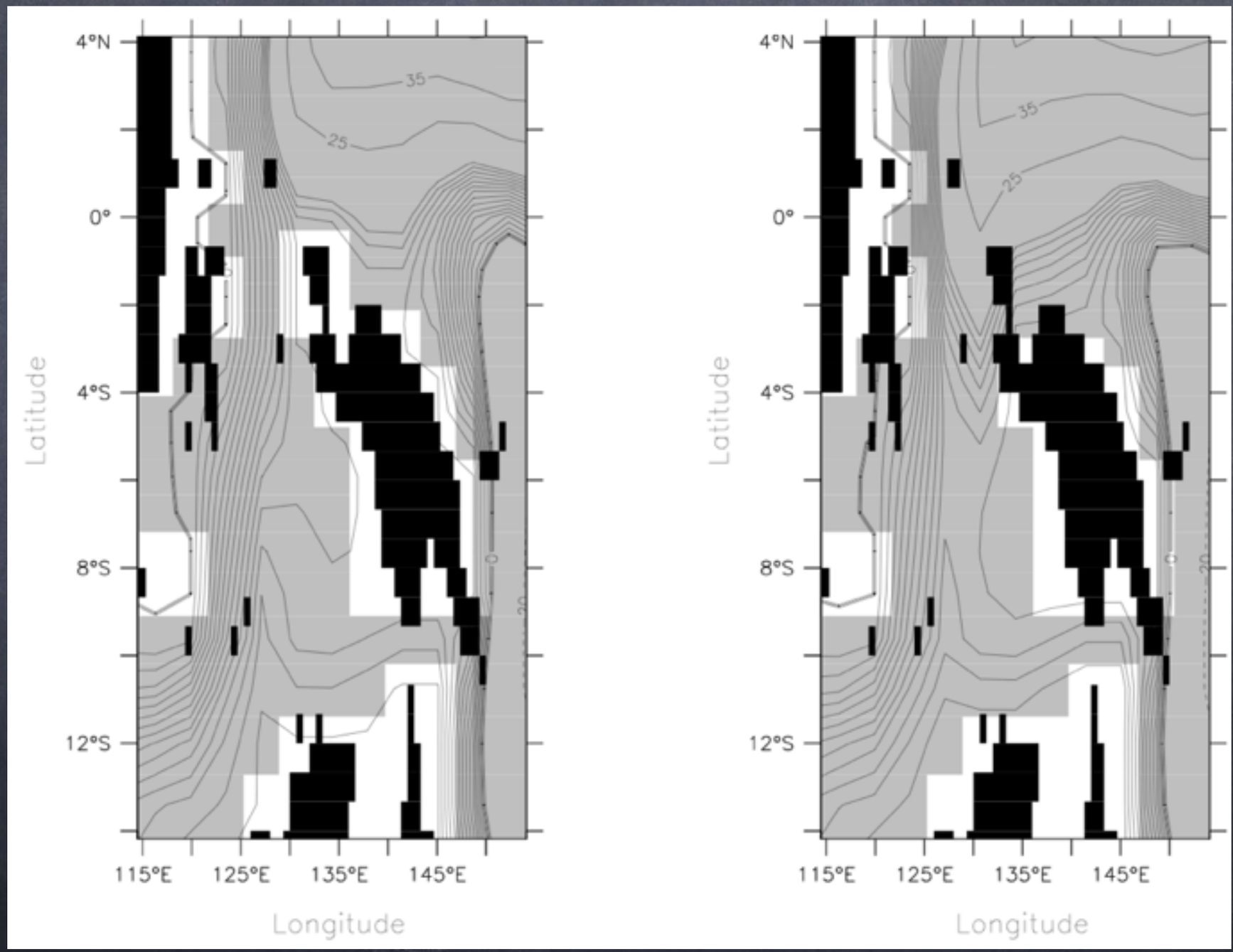


Molnar

Indonesian Throughflow Passage Effect?

Contemporary

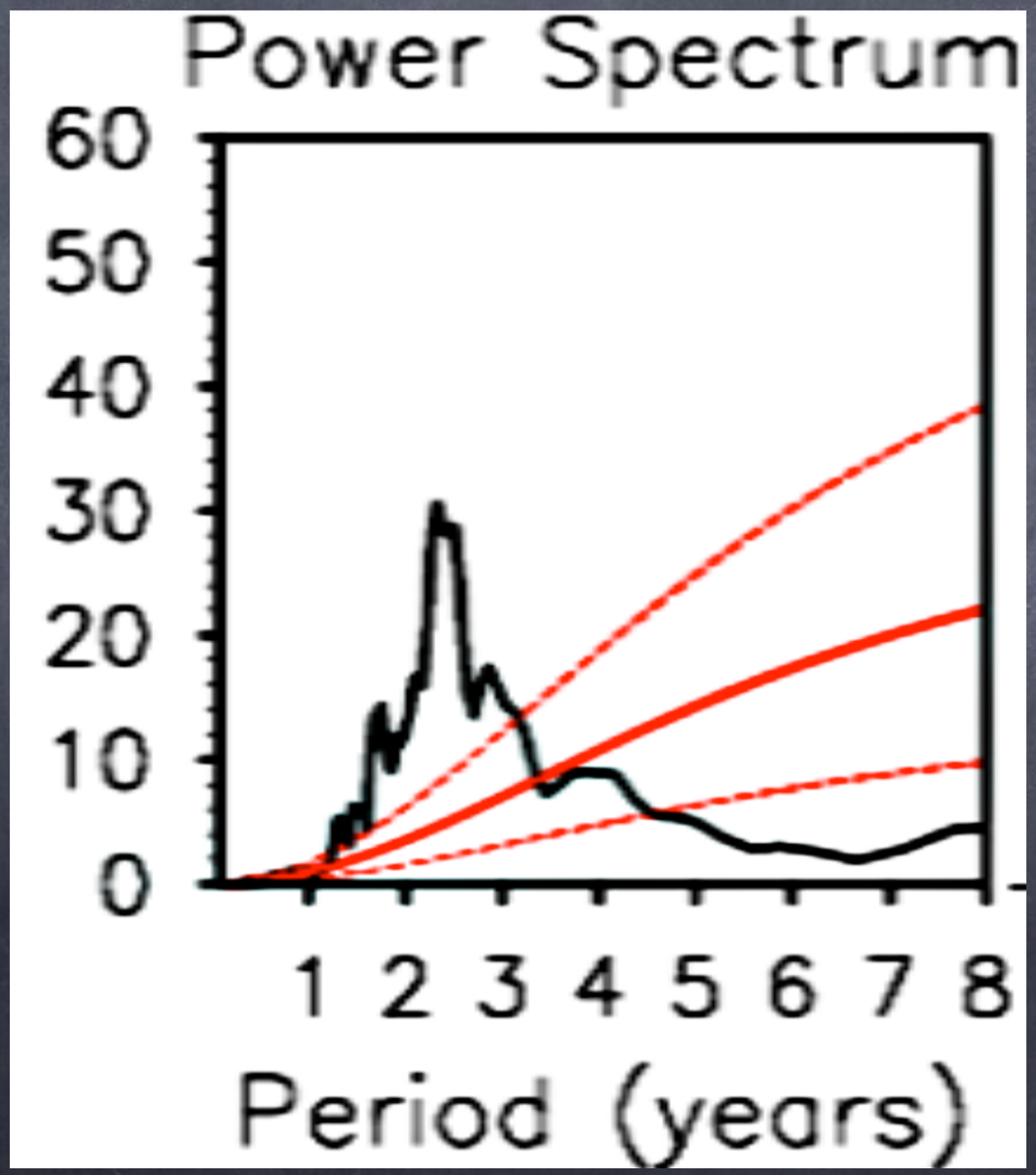
Pliocene



M. Jochum, B. Fox-Kemper, P. Molnar, and C. Shields. Differences in the Indonesian Seaway in a coupled climate model and their relevance to Pliocene climate and El Nino. Paleoceanography, 24:PA1212, 2009

Our metric of ENSO: Wavelet Power Spectrum

Power (funny units, but added up, it's proportional to ENSO variance)



S. Stevenson, B. Fox-Kemper, M. Jochum, B. Rajagopalan, and S. G. Yeager. ENSO model validation using wavelet probability analysis. Journal of Climate, 23:5540-5547, 2010

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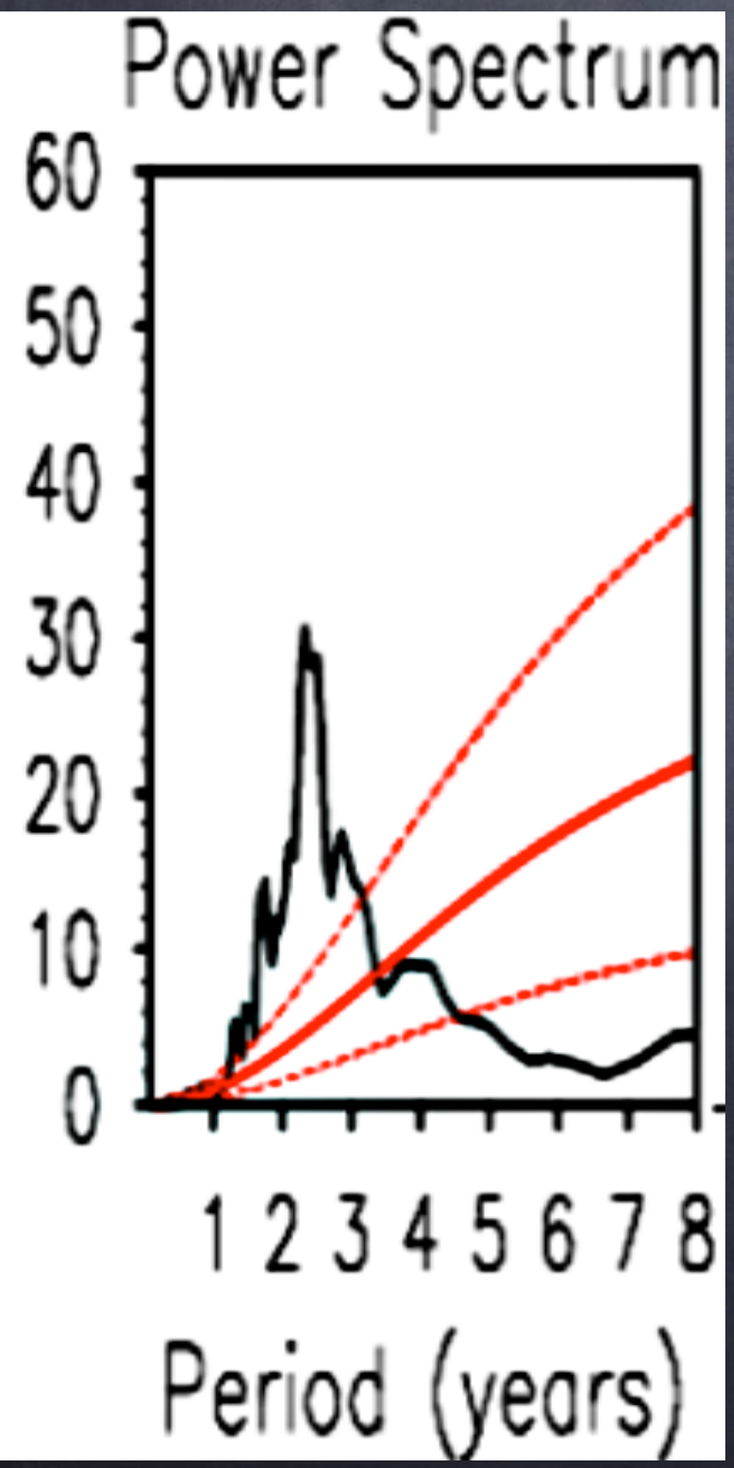
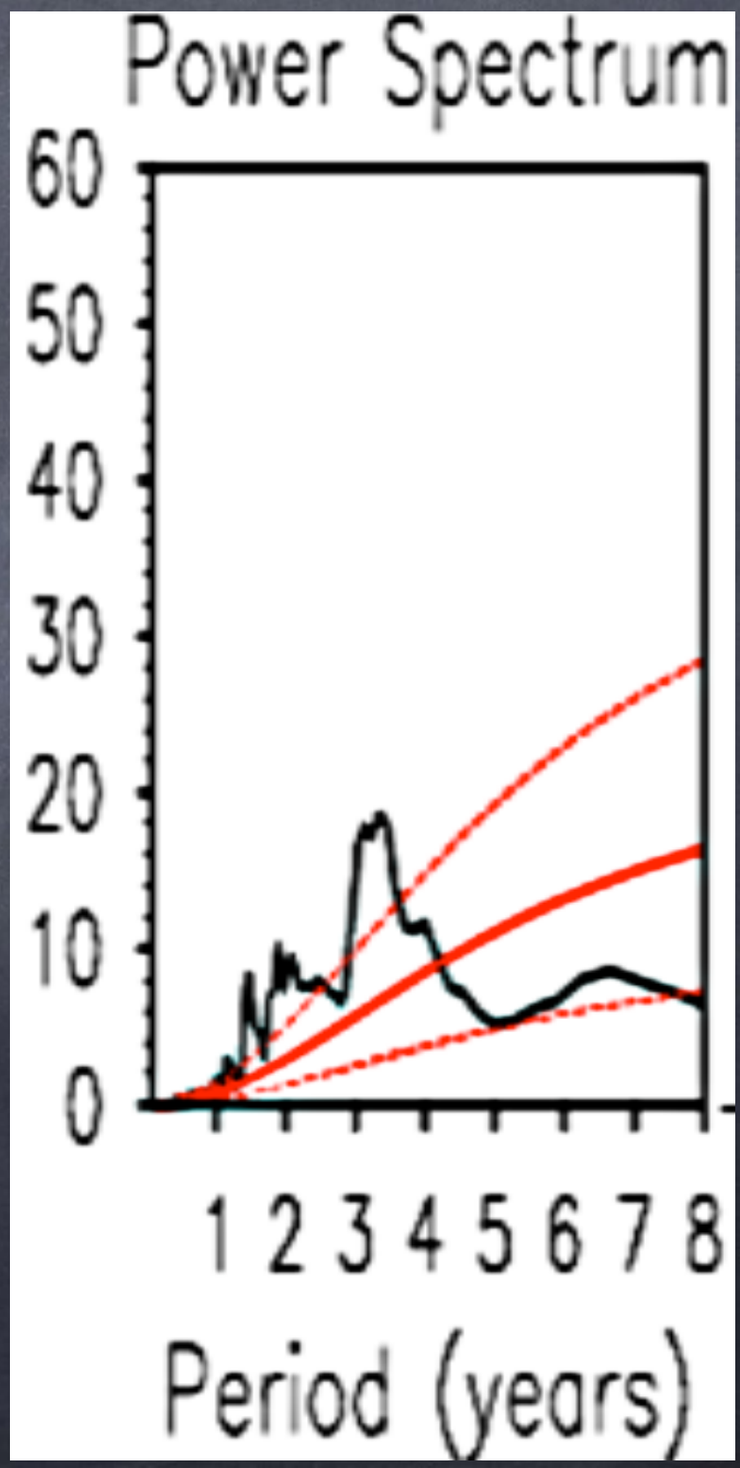


So, great!

Widen ITF
Change Flow
(Not quite Cane & Molnar 2001)

Wider Warm Pool
(perm. El Nino?)
Weaker ENSO

Pliocene

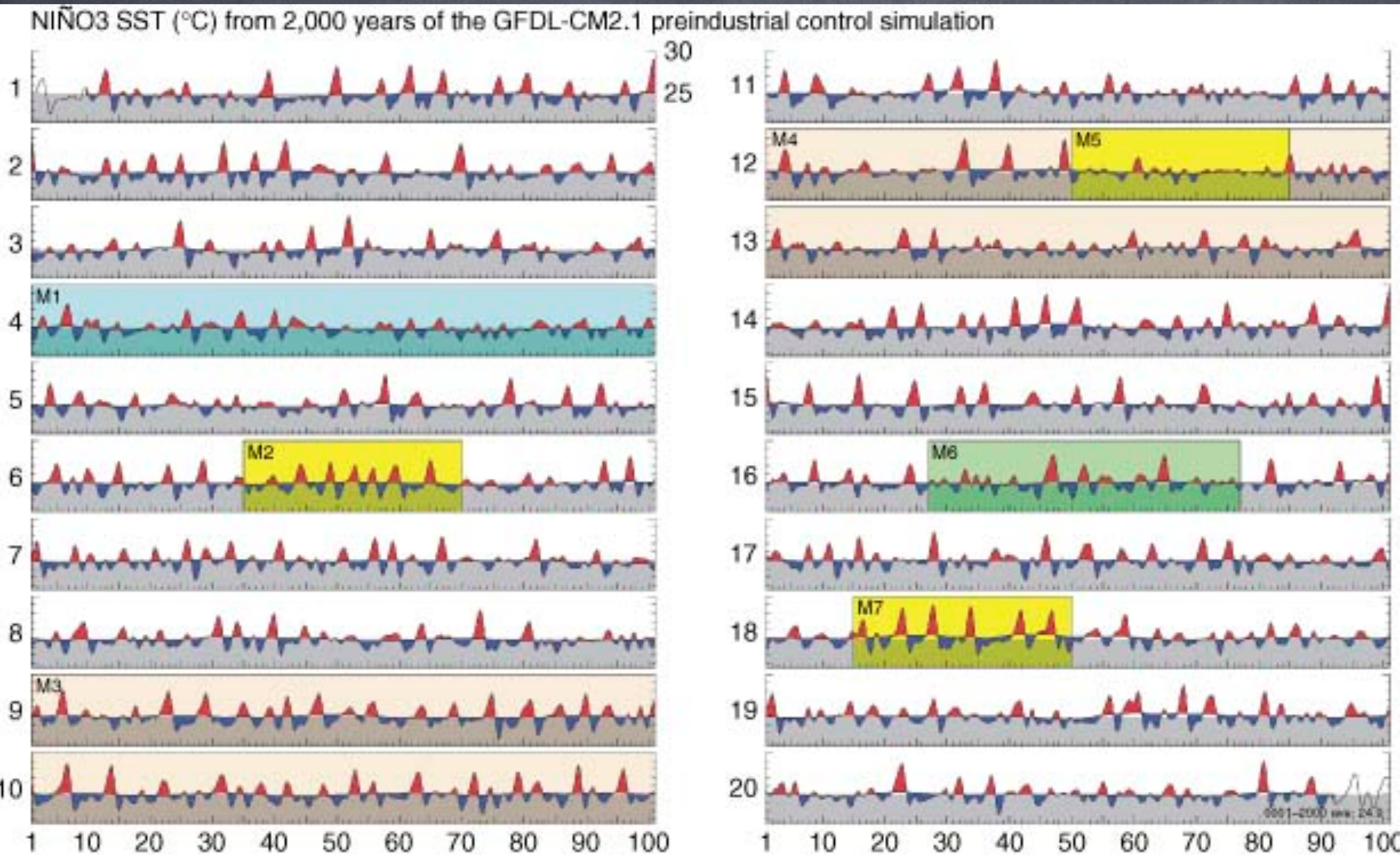


Why not model future El Niño?

- Well, certainly a warmer mean state
  - Sort of perm. El Niño, but...
- Already adapting to warming.

- But what about future ENSO? That's what damages and costs

There is variability ENSO on 100yr timescales, even when forcing is steady (Wittenberg, 2009)



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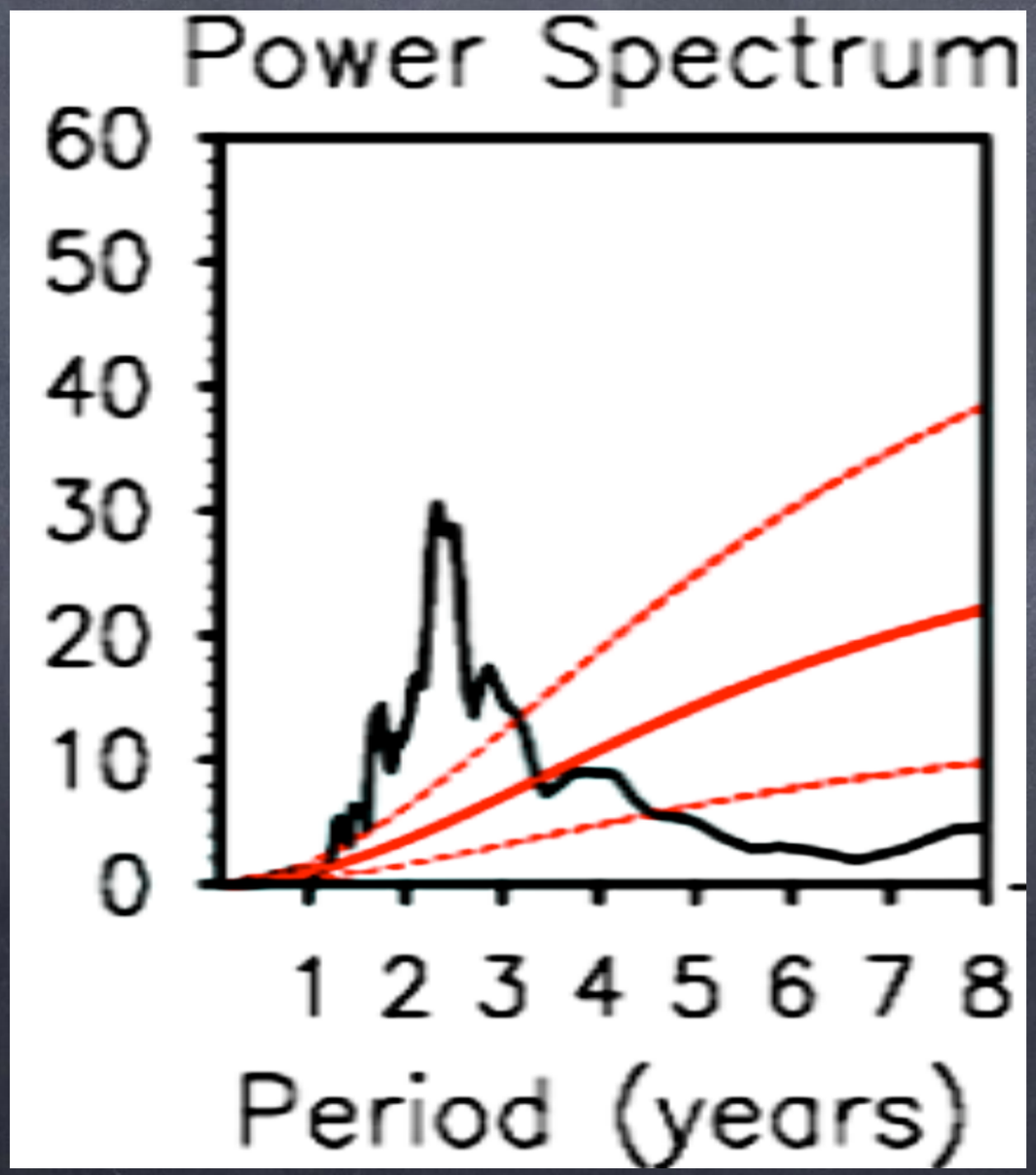


S. Stevenson, B. Fox-Kemper, M. Jochum, B. Rajagopalan, and S. G. Yeager. ENSO model validation using wavelet probability analysis. Journal of Climate, 23:5540-5547, 2010

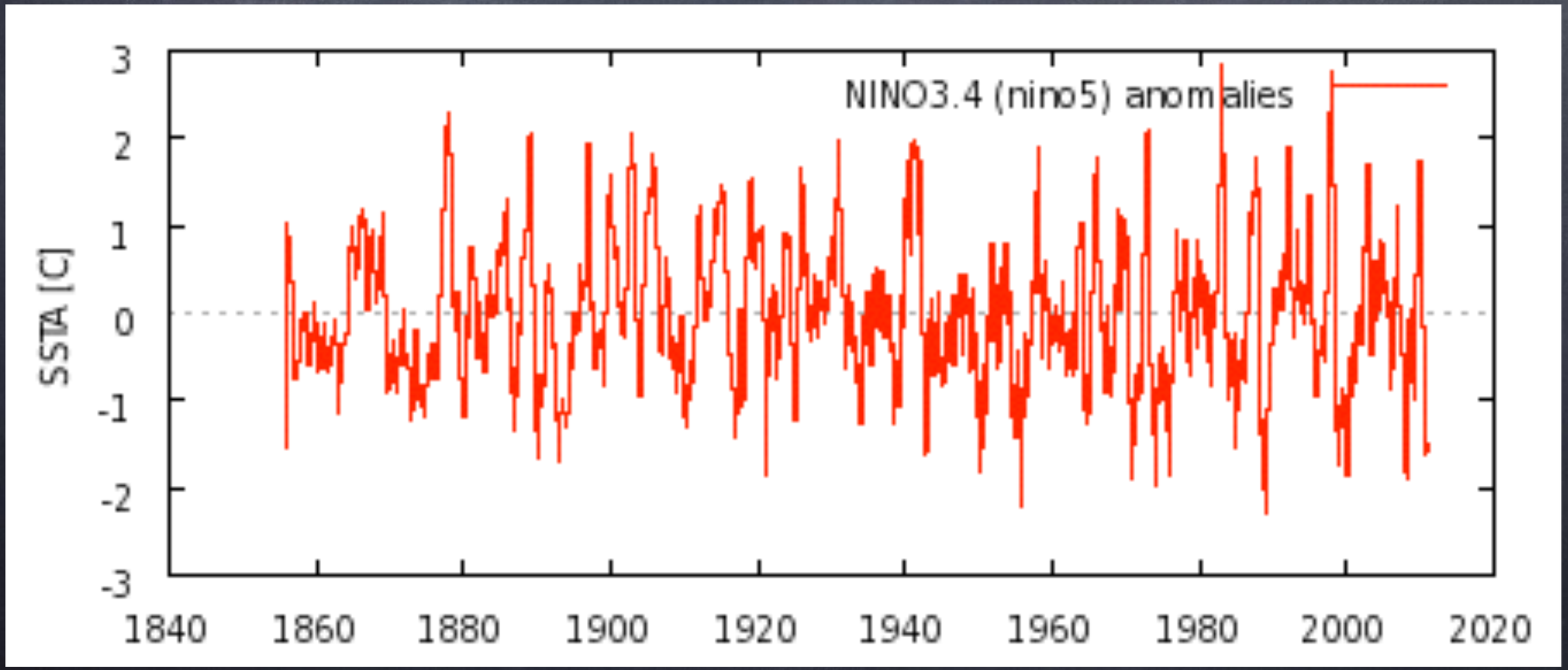
Our metric of ENSO: Wavelet Power Spectrum

How LONG does it take for the Wavelet power spectrum of ENSO to settle down, so that we have 90% confidence on ENSO (2-7 year) variability?

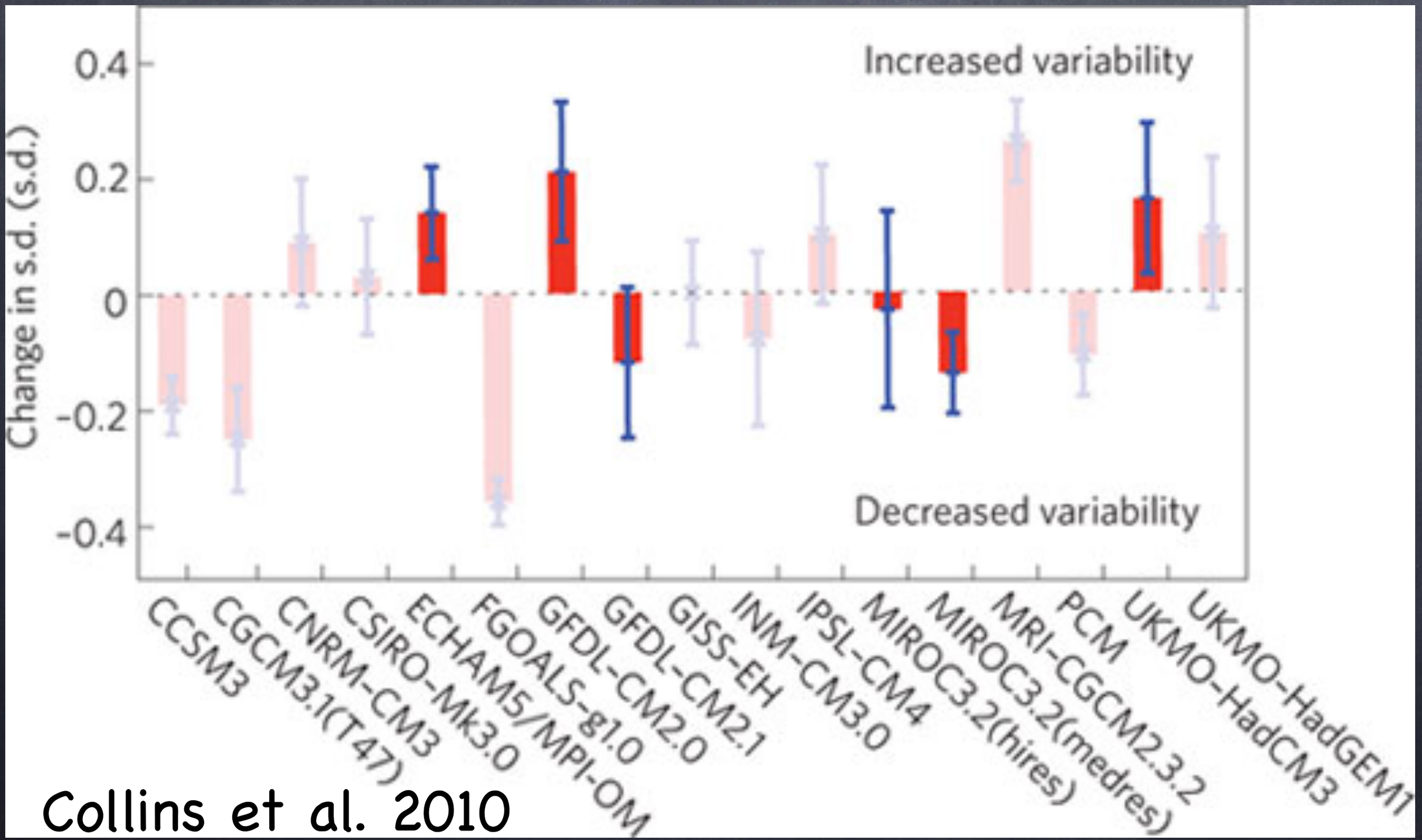
About 240 years!!!!

S. Stevenson, B. Fox-Kemper, M. Jochum, B. Rajagopalan, and S. G. Yeager. ENSO model validation using wavelet probability analysis. Journal of Climate, 23:5540-5547, 2010

Recalibrate my expectations:
Not enough modern observations to constrain the model!



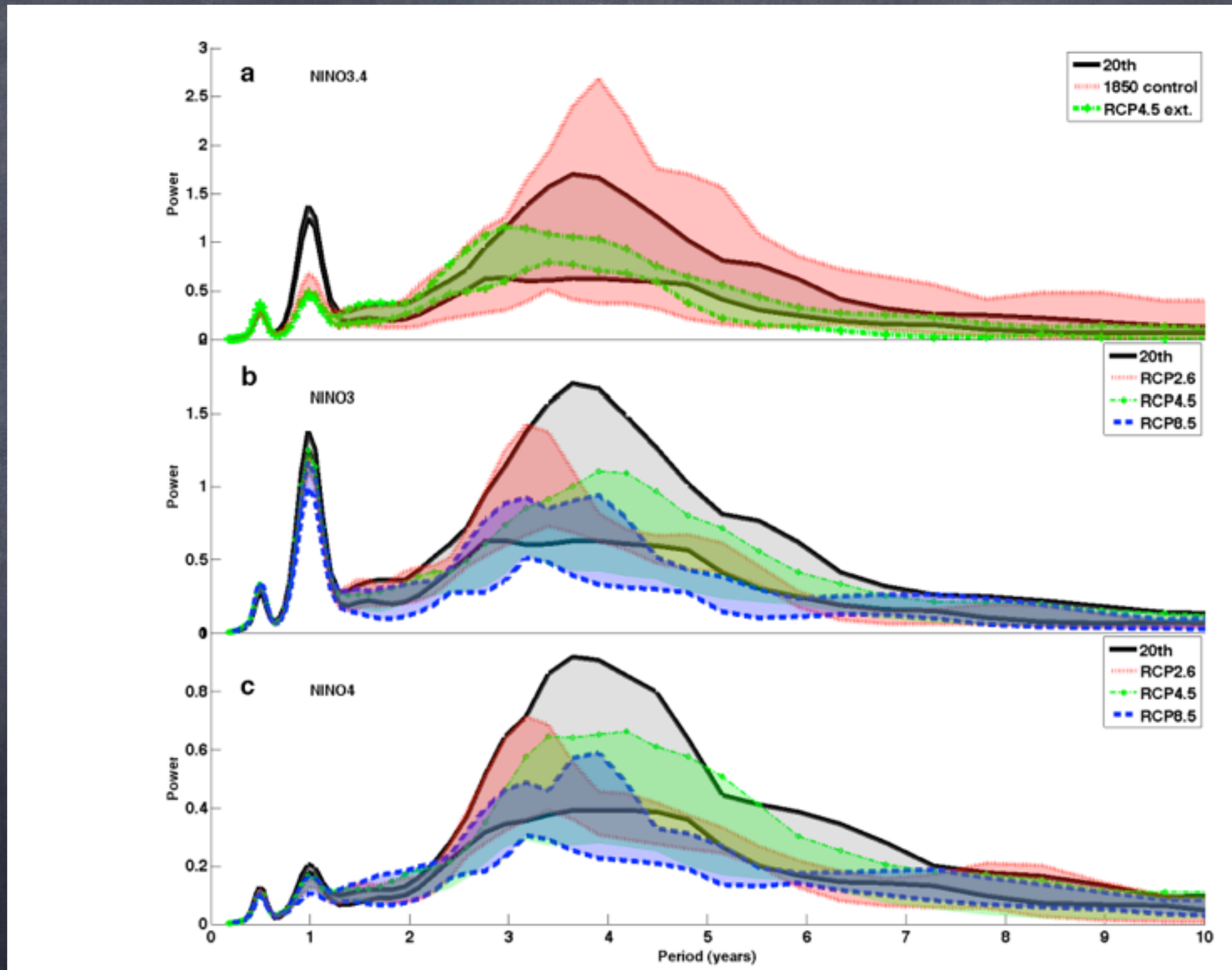
Maybe these results are not really statistically significant?



Collins et al. 2010

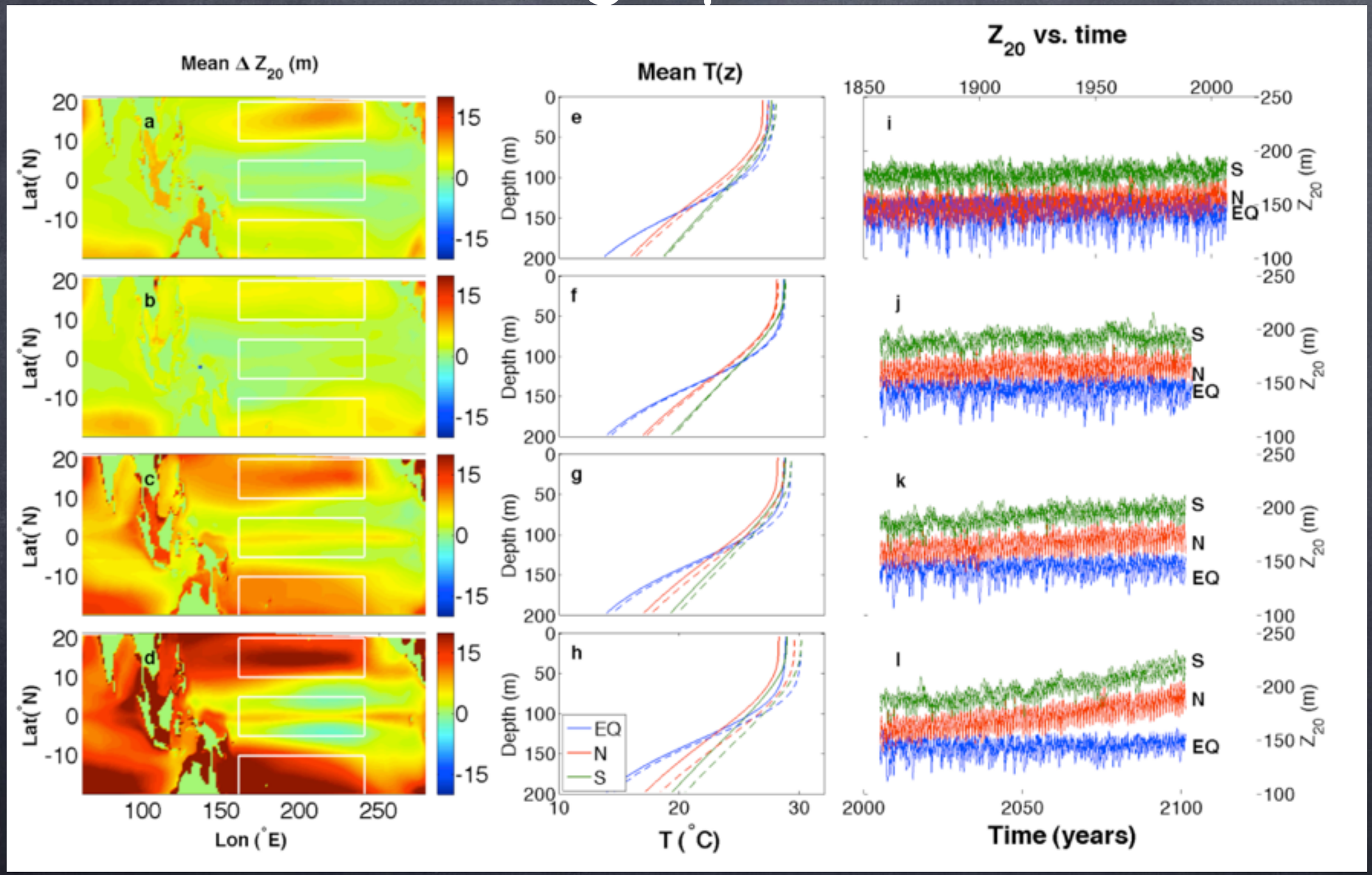
NCAR CMIP5/IPCC RUNS

NO SIGNAL OF SIGNIFICANT CHANGE IN 21st CENTURY!



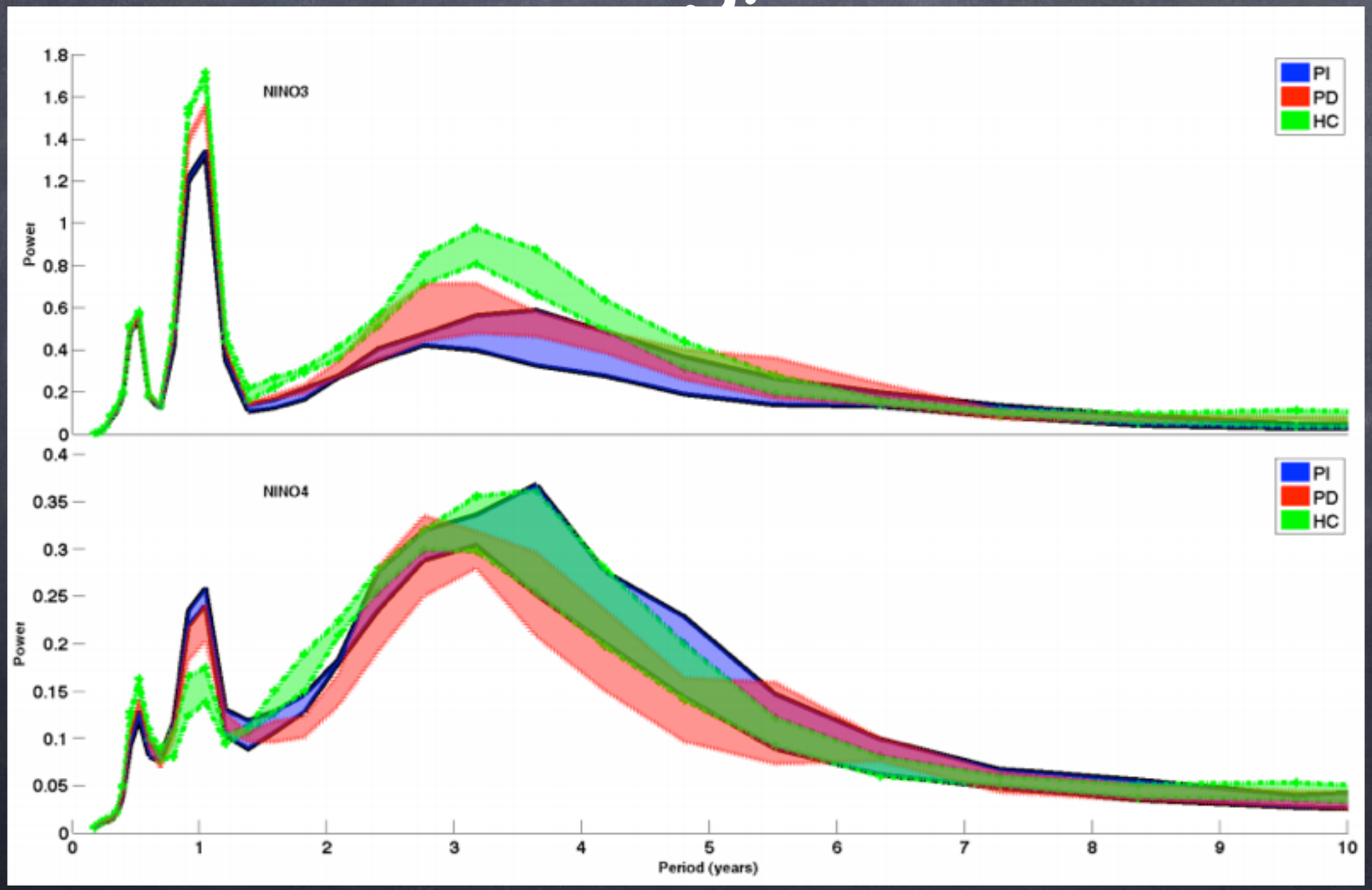
S. Stevenson, B. Fox-Kemper, M. Jochum, R. Neale, C. Deser, and G. Meehl. Will there be a significant change to El Nino in the 21st century? Journal of Climate, 2012. In press

Why? The tropical ocean is still warming up in 2100!



S. Stevenson, B. Fox-Kemper, M. Jochum, R. Neale, C. Deser, and G. Meehl. Will there be a significant change to El Nino in the 21st century? Journal of Climate, 2012. In press

In 1000yrs of persistent CO_2 warming, however...

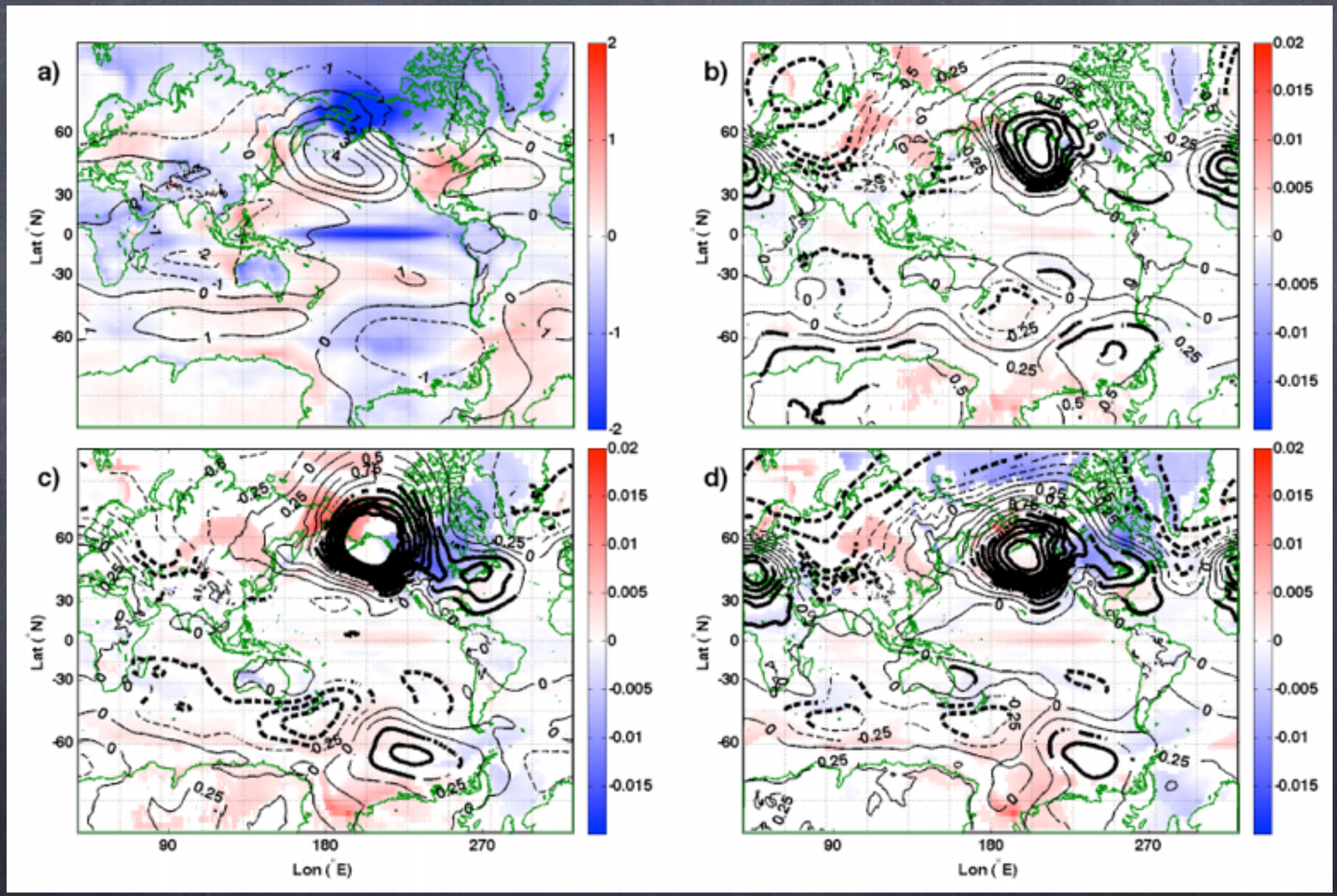


S. Stevenson, B. Fox-Kemper, and M. Jochum. Understanding the ENSO-CO2 link using stabilized climate simulations. Journal of Climate, 2011. Submitted.

Is anything going to change before then? Yes, teleconnections do change

DJF during La Niña

significance in colors/ bold



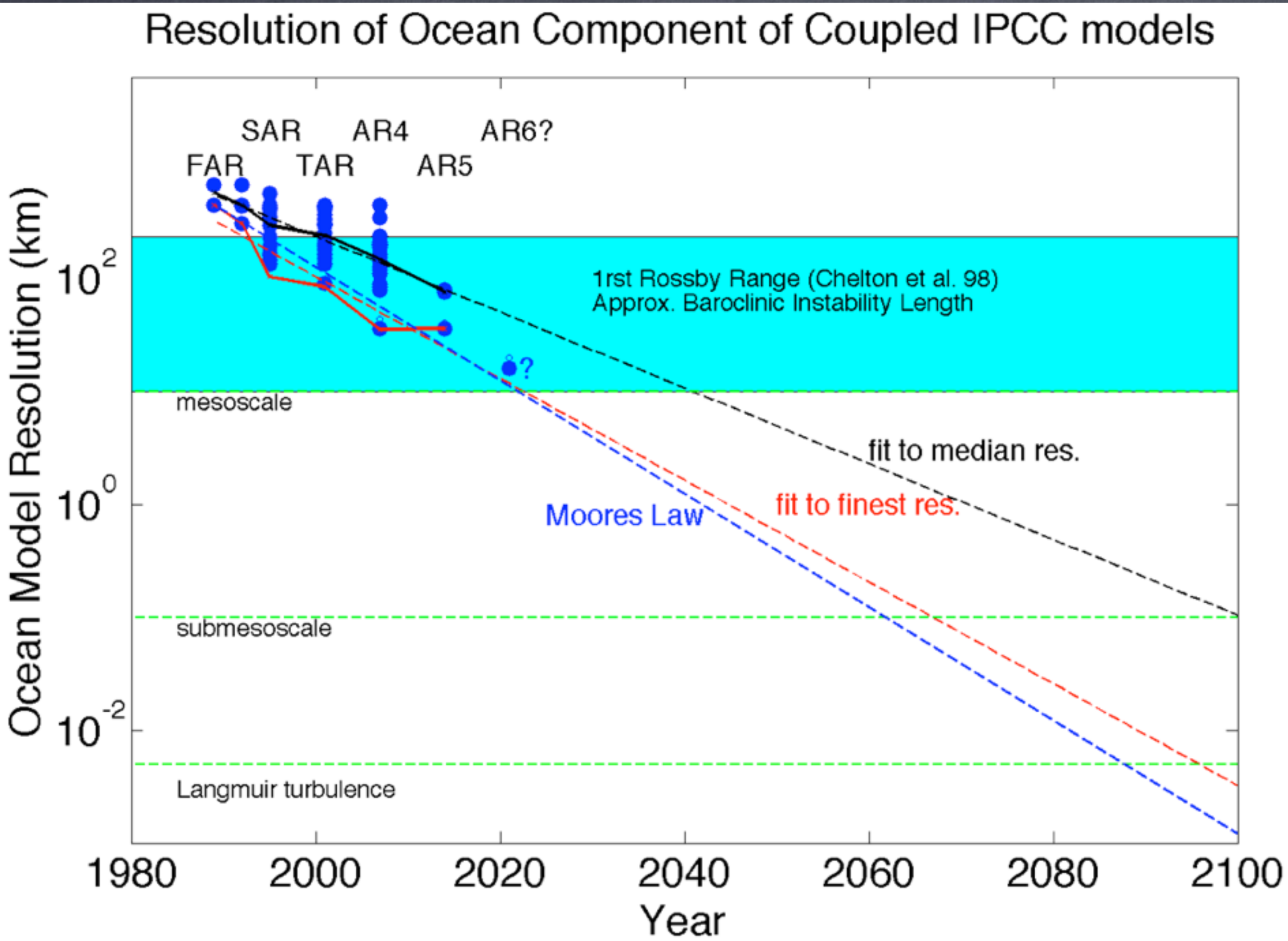
S. Stevenson, B. Fox-Kemper, M. Jochum, R. Neale, C. Deser, and G. Meehl. Will there be a significant change to El Nino in the 21st century? Journal of Climate, 2012. In press

Conclusions

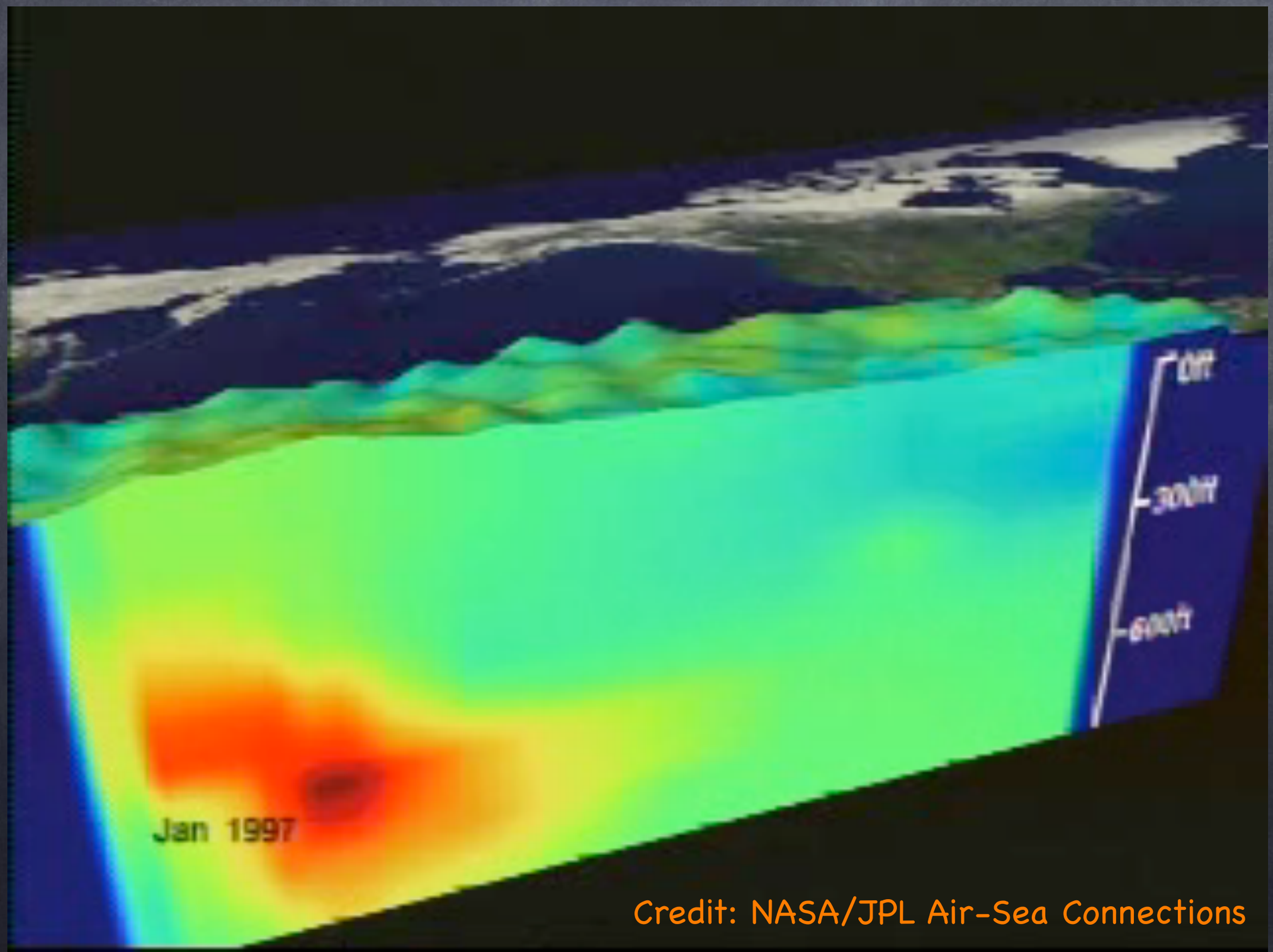
- El Niño because it's big and important
- Models can be good for some things and bad for others at the same time
- Bigger models are not always better!
- Models are not always statistically significant

- We can expect similar magnitude of ENSO events in the 21st century, but
- Some teleconnections impacts of ENSO may be different soon!

Worries


Resolution of Ocean Component of Coupled IPCC models
Ocean Model Resolution (km)
10^2
10^0
10^{-2}
FAR
SAR
TAR
AR4
AR5
AR6?
1rst Rossby Range (Chelton et al. 98)
Approx. Baroclinic Instability Length
mesoscale
submesoscale
Langmuir turbulence
fit to median res.
fit to finest res.
Moores Law
1980
2000
2020
2040
2060
2080
2100
Year

From the Side: Satellites & Moorings

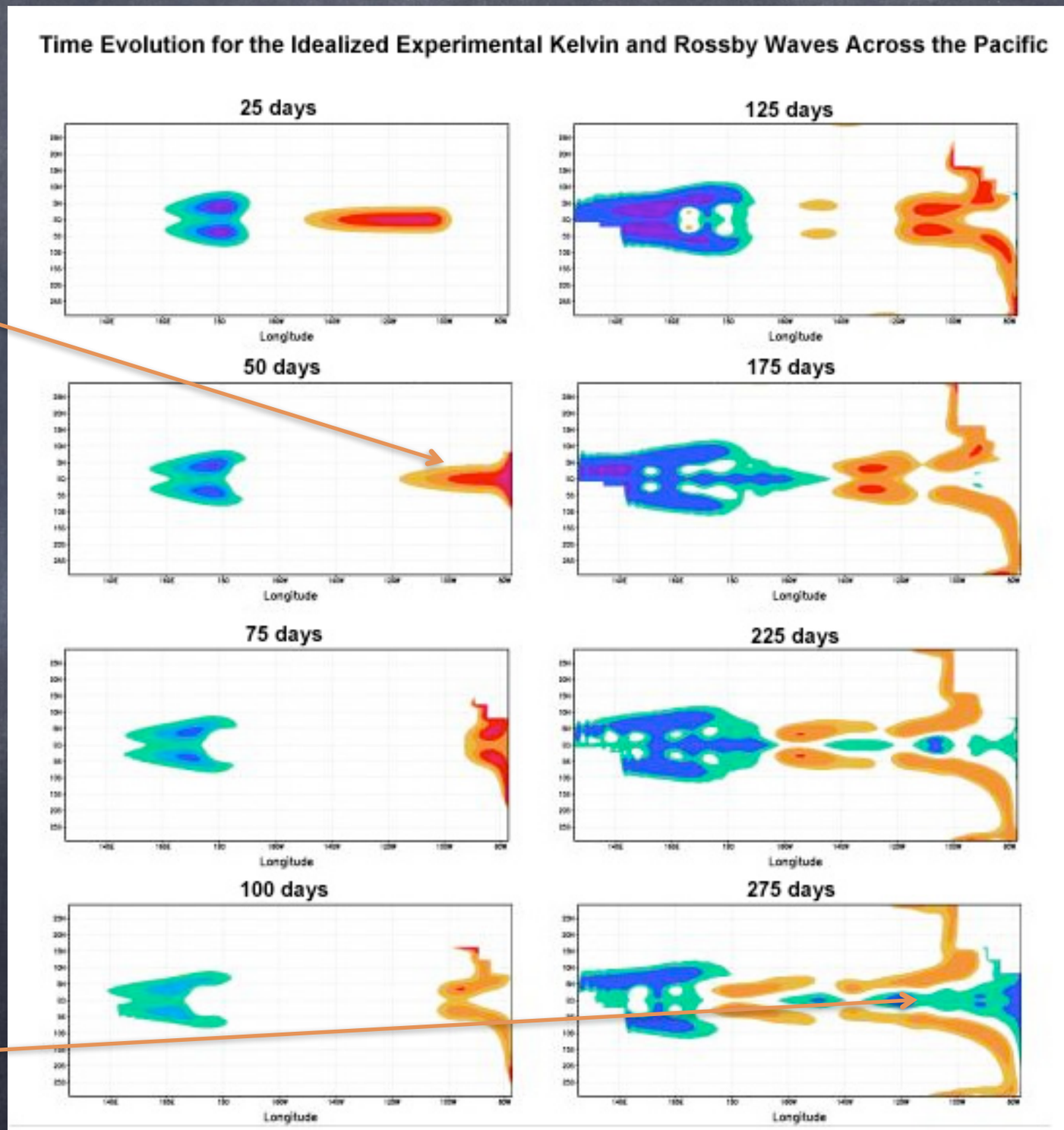


Credit: NASA/JPL Air-Sea Connections

So, with the Bjerknes Feedback, Anomalies will be self-enhancing.

- Type I: Delayed Oscillator (www.meted.ucar.edu)

El Nino



- Therefore the oscillatory cycle will reverse the initial SST warming about six months after its onset. The delayed-oscillator theory can explain the tendency for cold anomalies to follow warm anomalies and the typical time scale of an El Niño event. (www.meted.ucar.edu)

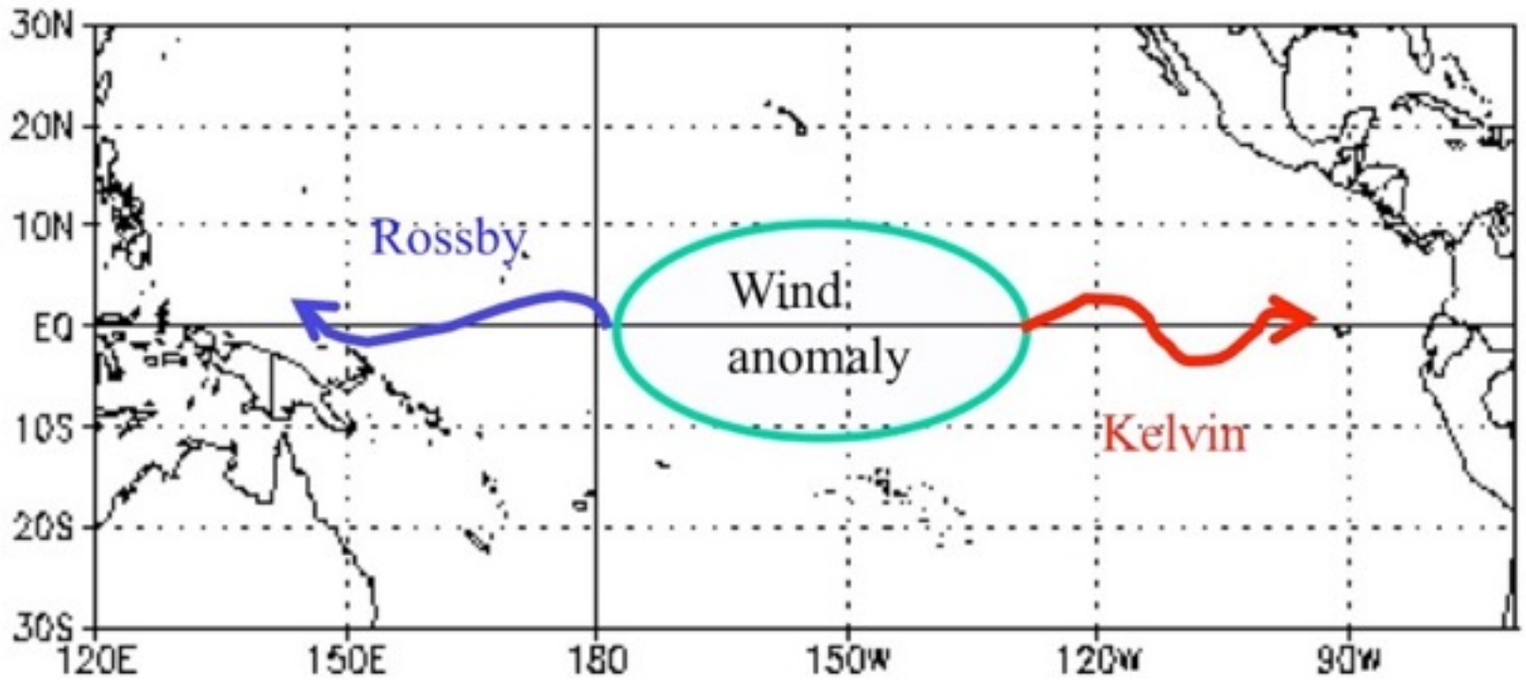
La Nina-like

Delayed Oscillator

Idea: Suarez & Schopf (88)

Math: Battisti & Hirst (89)

Ocean adjustment

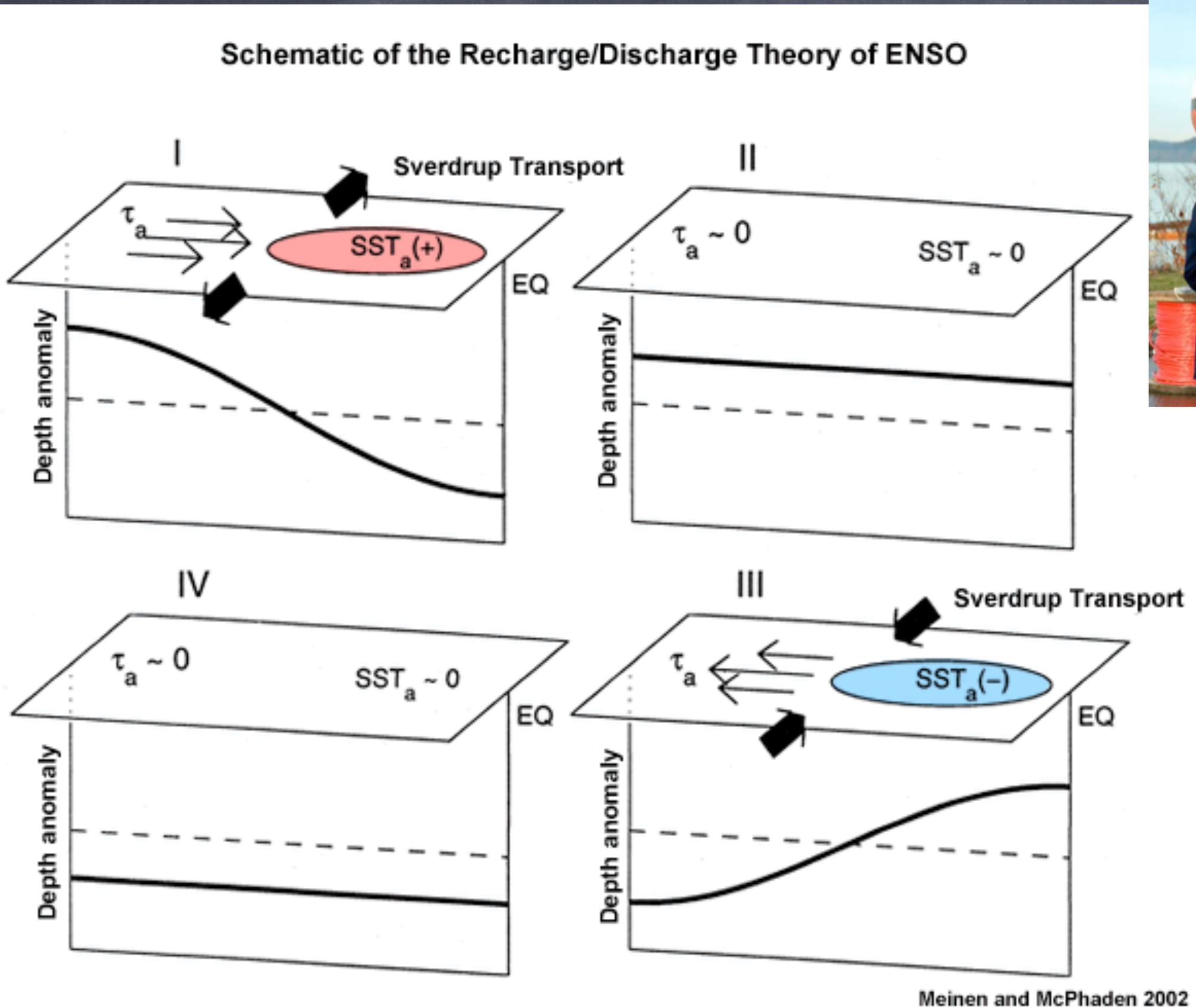


Kelvin waves propagate eastward from the area of wind anomalies and make the thermocline become deeper in the east. This is a positive feedback known as Bijerknes feedback.

Rossby waves propagate westward, and reflect at the coast as eastward propagating Kelvin waves, providing a negative feedback.

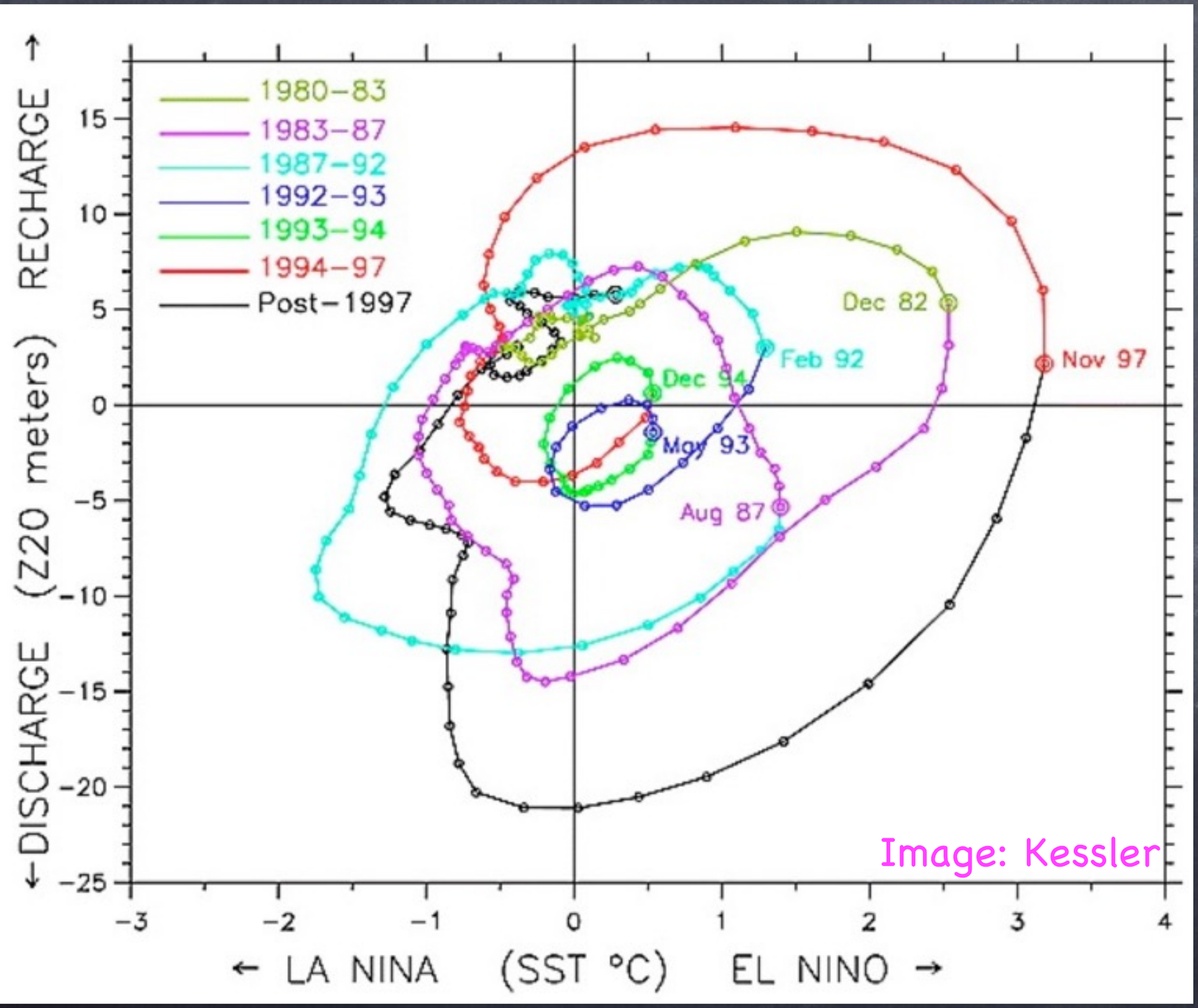
This Figure: Capotondi

Recharge-Discharge Oscillator



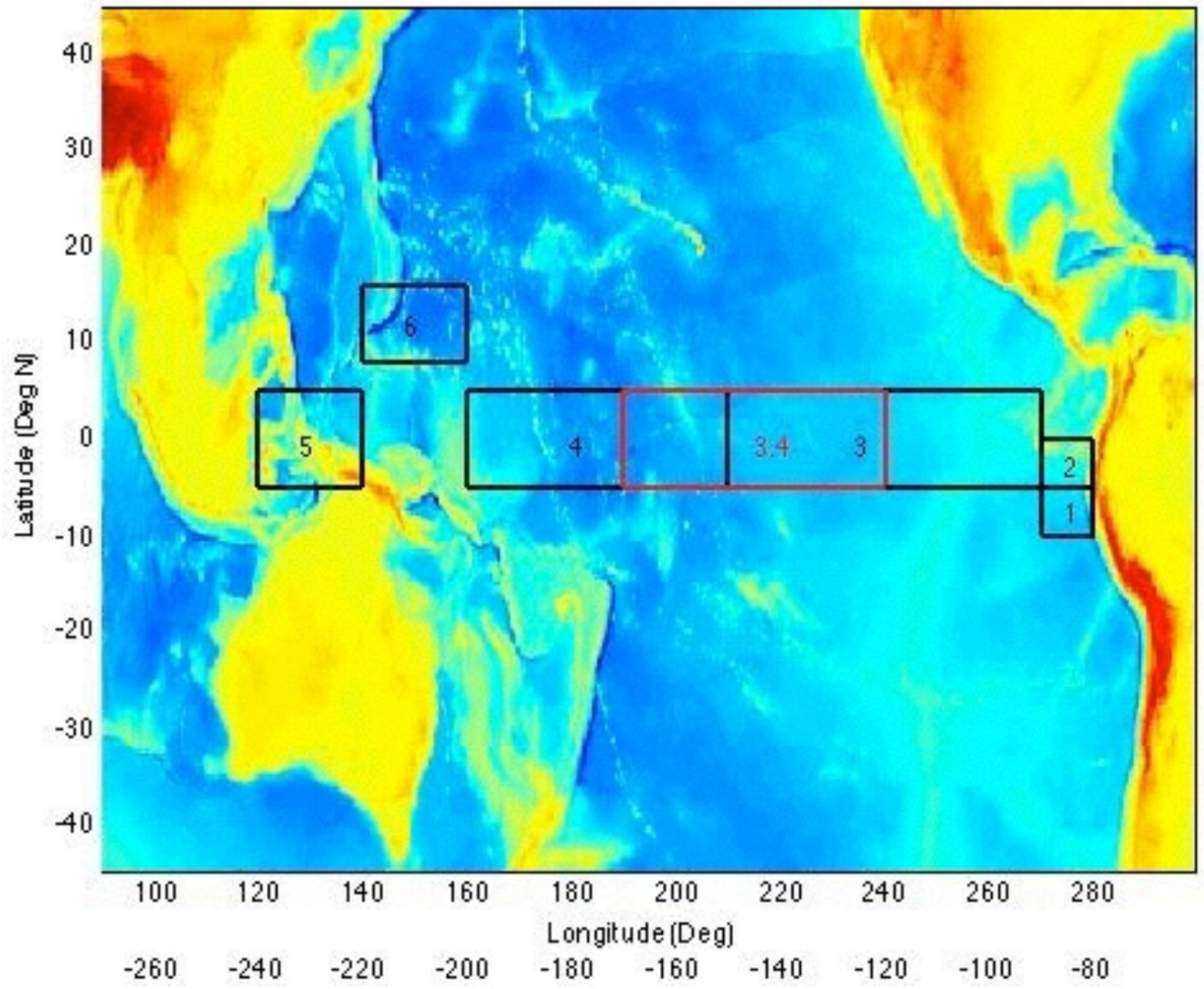
Nancy Soreide and Mike McPhaden

Recharge-Discharge



Foret des Koghis, New Caledonia

Nino Indices and Typical Obs.



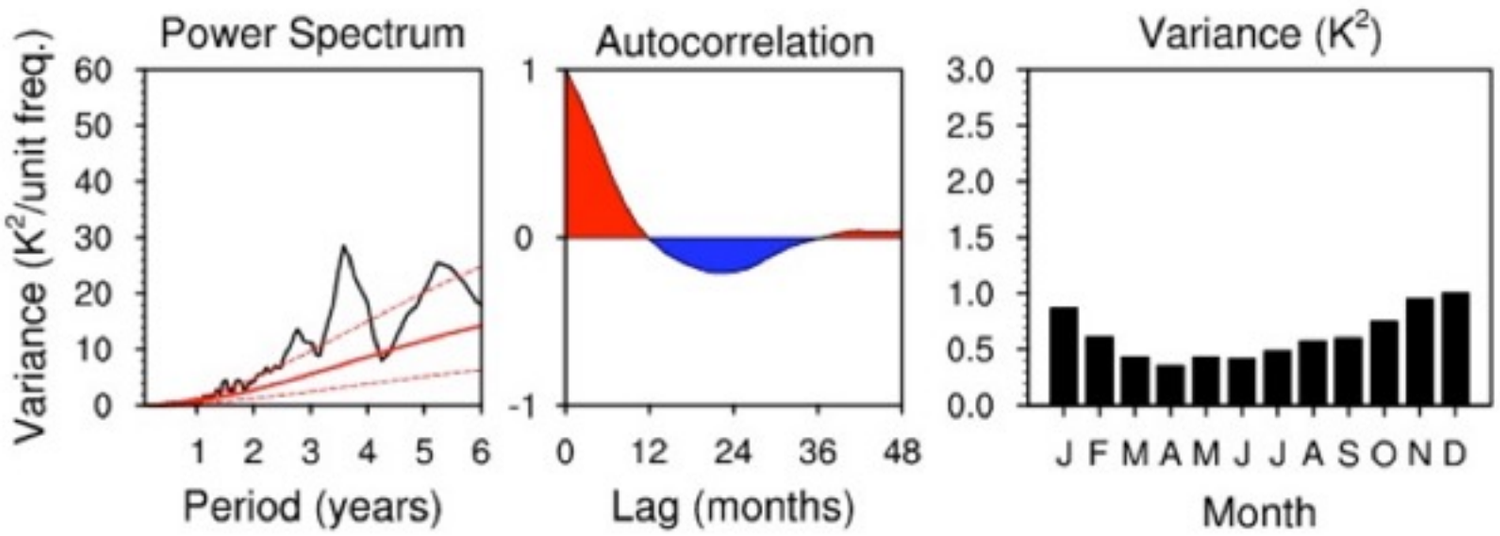
SST

anomaly

average

or

other



Nino-3 SST Anomalies

Observations

Jochum. 07