

An aerial photograph of a tropical atoll. The water transitions from a deep blue in the open ocean to a vibrant turquoise near the shore, indicating a shallow reef flat. A small, lush green island with a dense forest of palm trees is visible in the foreground. The sky is a clear, bright blue with scattered white cumulus clouds.

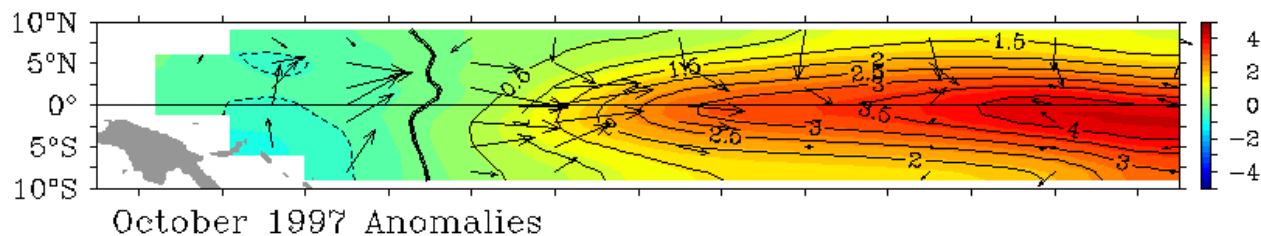
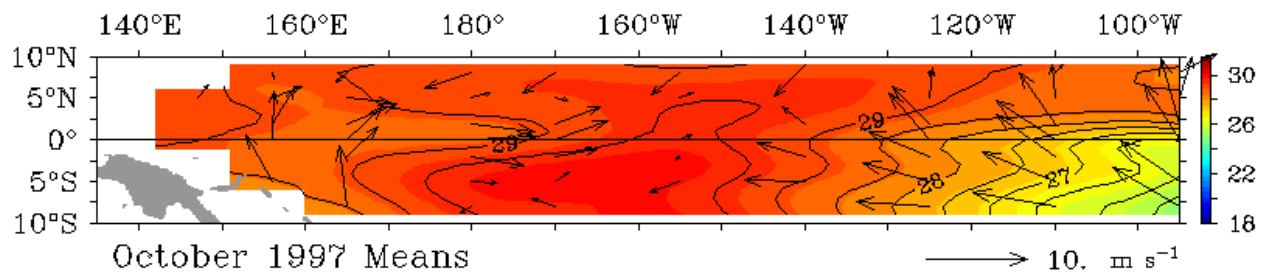
El Niño's Beauty and Wrath

Fei-Fei Jin

University of Hawaii

Nov 19, 2015, APCC

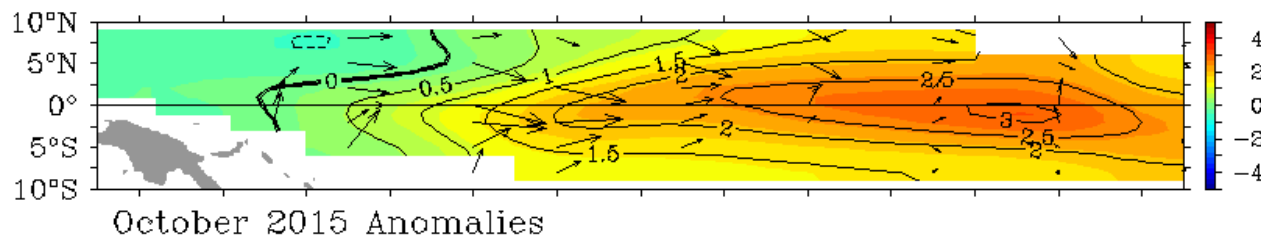
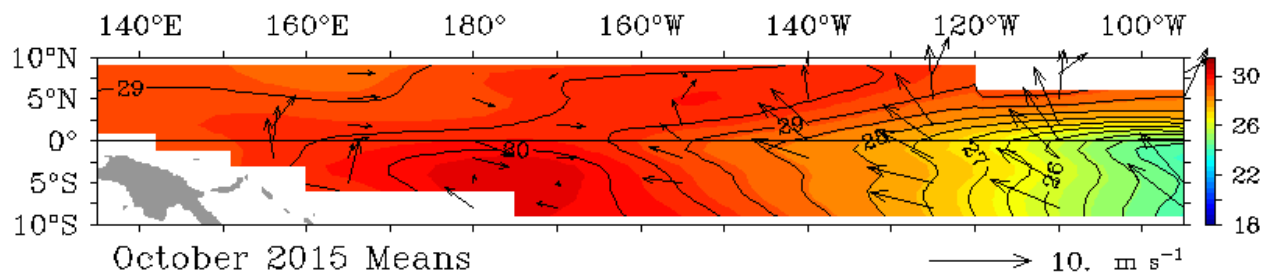
TAO/TRITON Monthly SST ($^{\circ}\text{C}$) and Winds (m s^{-1})



TAO Project Office/PMEL/NOAA

Nov 10 2015

TAO/TRITON Monthly SST ($^{\circ}\text{C}$) and Winds (m s^{-1})



80%

TAO Project Office/PMEL/NOAA

Nov 10 2015

1998 Summer Flood in China

Death toll 3,656



world > asia-pac

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More rain pounds South

Korea; death toll now 234

August 10, 1998

Web posted at: 10:56 a.m. EDT (1456 GMT)

[SEOUL, South Korea](#) (CNN) -- Heavy rains returned to South Korea on Monday, hampering search and recovery work after some of the worst flooding on record had left 234 people dead and 91 missing nationwide.

Mathematics
is a language plus reasoning,
a language plus logic;
a tool for reasoning, ...
**a way of going from one set of statements
to another.**

Richard Feynman



RICHARD FEYNMAN ON THE BEAUTY OF A FLOWER

I have a friend who's an artist and has sometimes taken a view which I don't agree with very well. He'll hold up a flower and say...

LOOK HOW
BEAUTIFUL
IT IS!



And I'll agree.
Then he says...



I AS AN
ARTIST CAN SEE
HOW BEAUTIFUL
THIS IS...



... BUT YOU AS A
SCIENTIST TAKE THIS ALL
APART AND IT BECOMES
A DULL THING.

AND I THINK THAT HE'S KIND OF NUTTY.

First of all...

...the beauty that he sees is available to other people and to me too, I believe.



Although I may not be quite as refined aesthetically as he is...



...I can appreciate the beauty of a flower.

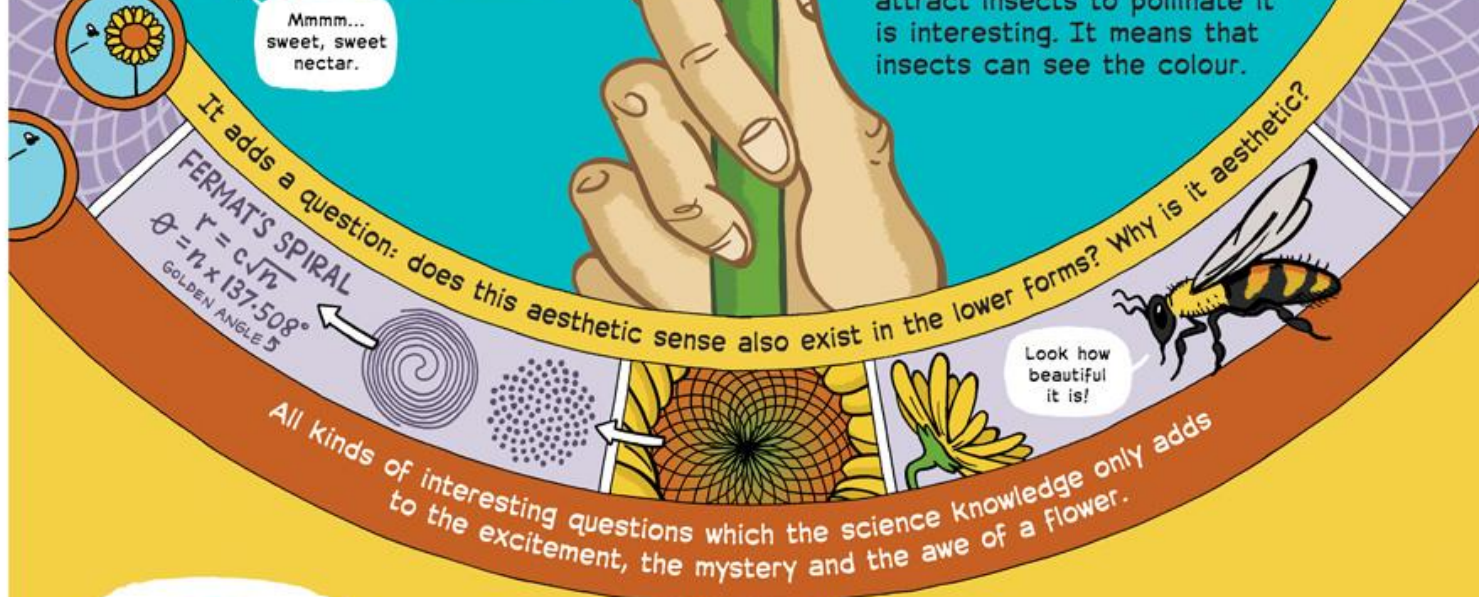
AT THE SAME TIME, I SEE MUCH MORE ABOUT THE FLOWER THAN HE SEES.



PHOTOSYNTHESIS
H₂O MOLECULE → ENERGY
OXYGEN



...could imagine the cells in there, the complicated actions inside, which also have a beautiful



IT ONLY ADDS.

I DON'T UNDERSTAND HOW IT SUBTRACTS.
 - RICHARD FEYNMAN



Amethman

zenpencils.com

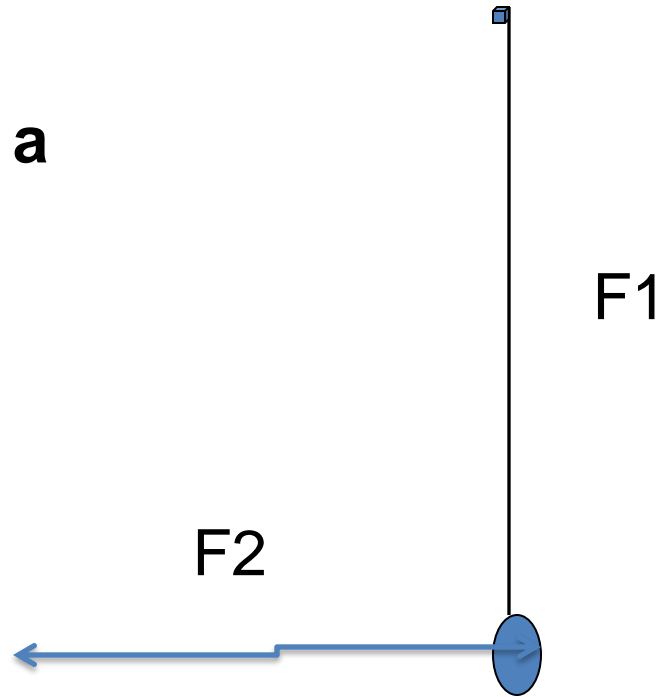


'The swing,' a painting by Nicholas Lancret, 1690–1743. The swing and attendant illustrate phase locking in systems containing two competing frequencies. Figure 1

A two- frequency system

**An oscillator with its own
intrinsic frequency**

**An external driver with a
forcing frequency**



Cantor Set

1, $1/2$, $1/3$, $2/3$, $p/q, \dots 0$

between any two rational number,
there are infinite rational numbers

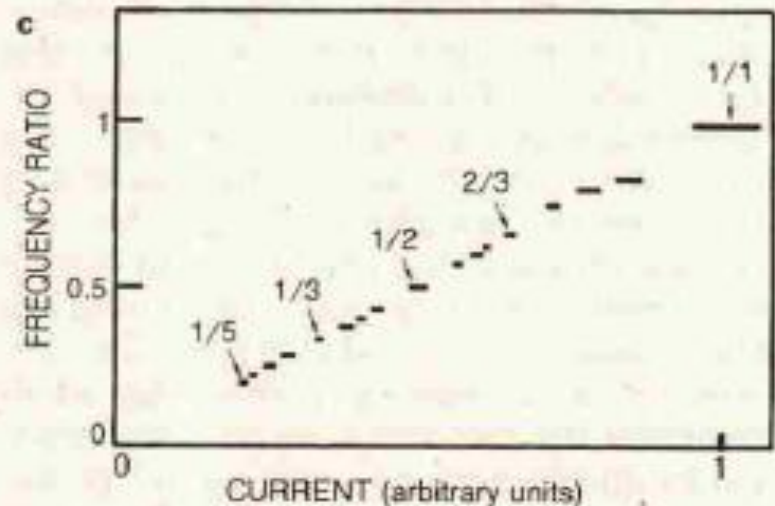
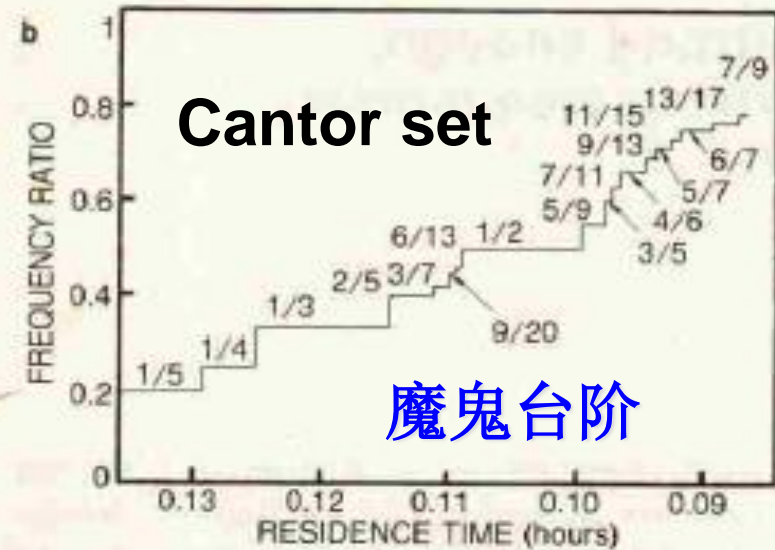
When the interaction between an oscillator and its driver is strong enough, the oscillator will resonate at, or “lock” onto, an infinity of driving frequencies, giving rise to steps with a fractal dimension between 0 and 1.

P. Bak, 1986. Physics Today

The Devil's staircase



'The swing,' a painting by Nicholas Lancret, 1690–1743. The swing and attendant illustrate phase locking in systems containing two competing frequencies. Figure 1



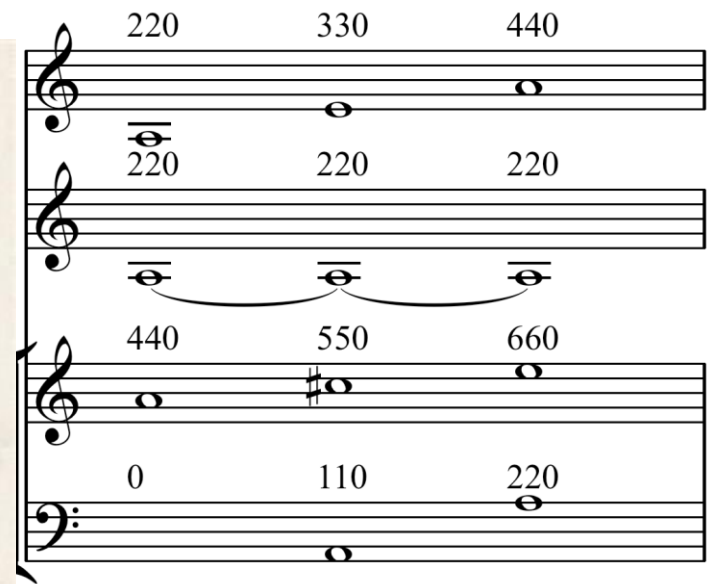
A Music Phenomena : Tartini Tones (1754)

When two tones(F_1 , F_2) are played simultaneously, a listener can sometimes perceive an additional tone whose frequency is a sum (F_1+F_2) or difference (F_1-F_2) of the two frequencies caused by the non-linearity of the inner ear. This new tune is called a combination tone, also known as Tartini tones



The Devil's Trill

惡魔的顫音



$$A = \cos(F_1 t), \quad B = \cos(F_2 t)$$

$$C = A \times B = \frac{\cos((F_1 + F_2)t) + \cos((F_1 - F_2)t)}{2}$$



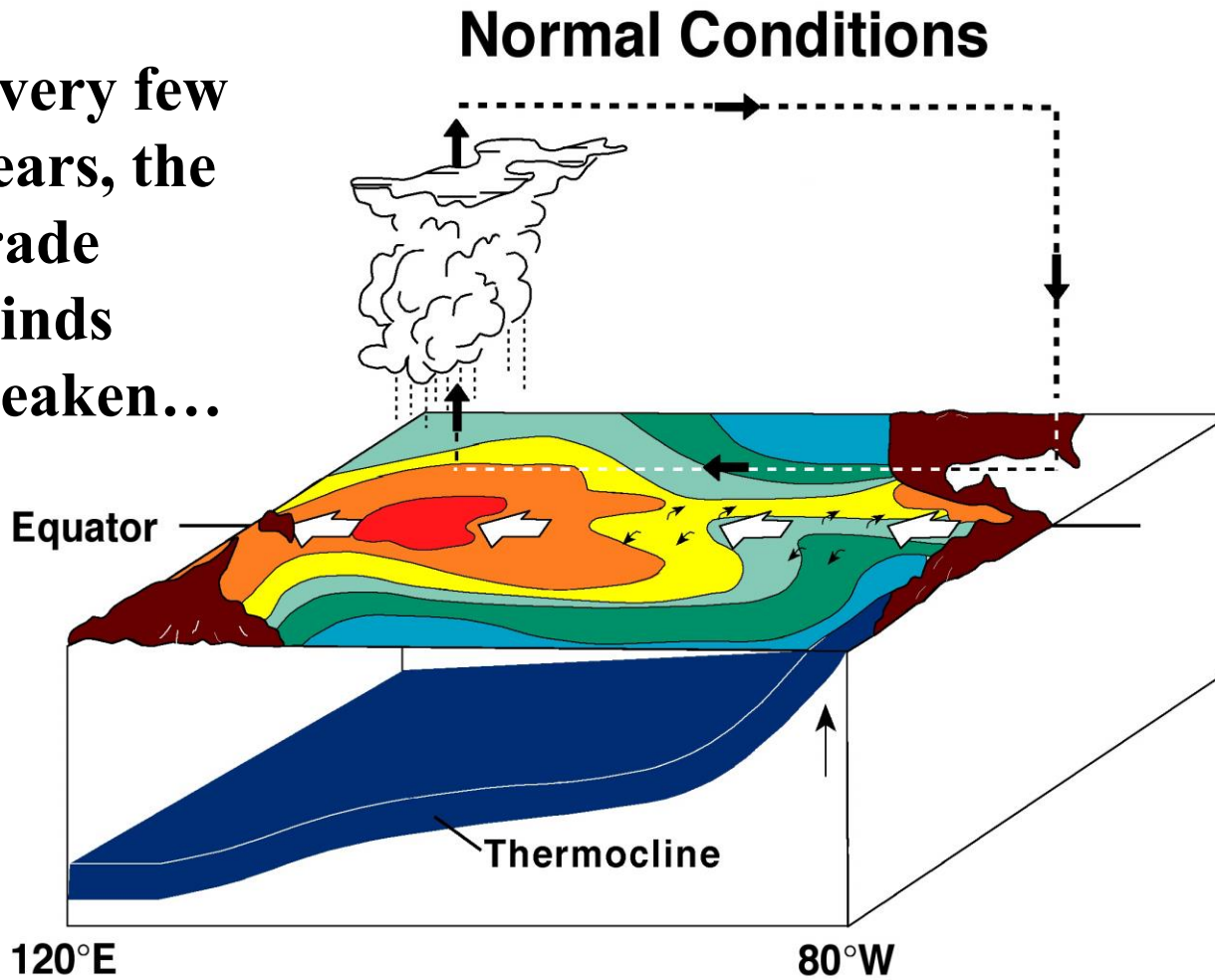
In summary

two frequencies + NL →

Devil staircase & combination tones

But, how all these have anything to do with El Niño?

Every few years, the trade winds weaken...



Recharge Oscillator Model for ENSO

Jin 1996, (Science) 1997(JAS)

$$\frac{dT}{dt} = \lambda T + wh$$

$$\frac{dh}{dt} = -WT,$$

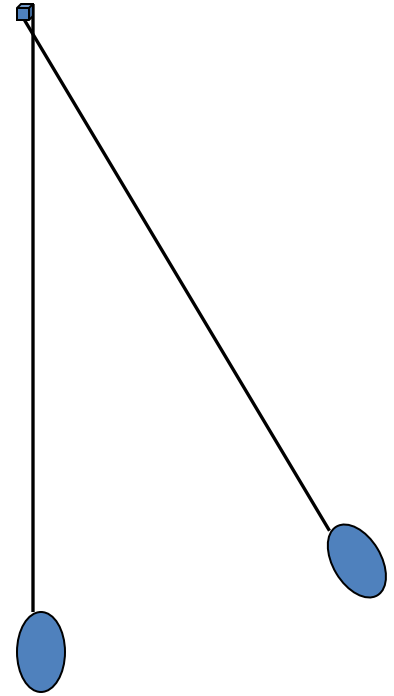
Two numbers:

Growth rate

(Bjerknes index)

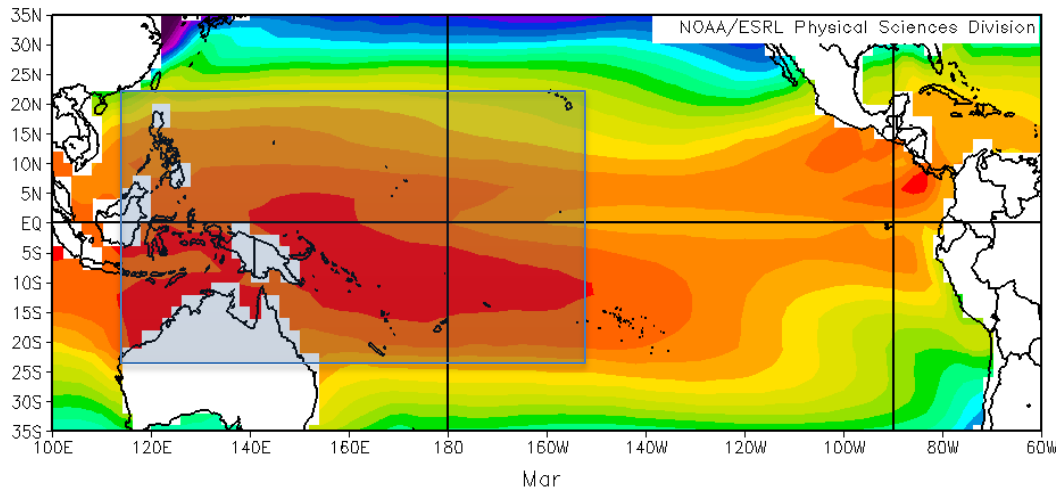
Frequency

(Wyrтки index?)



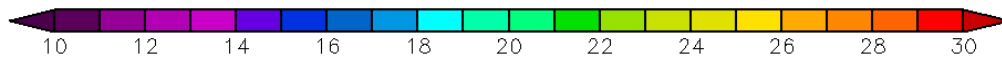
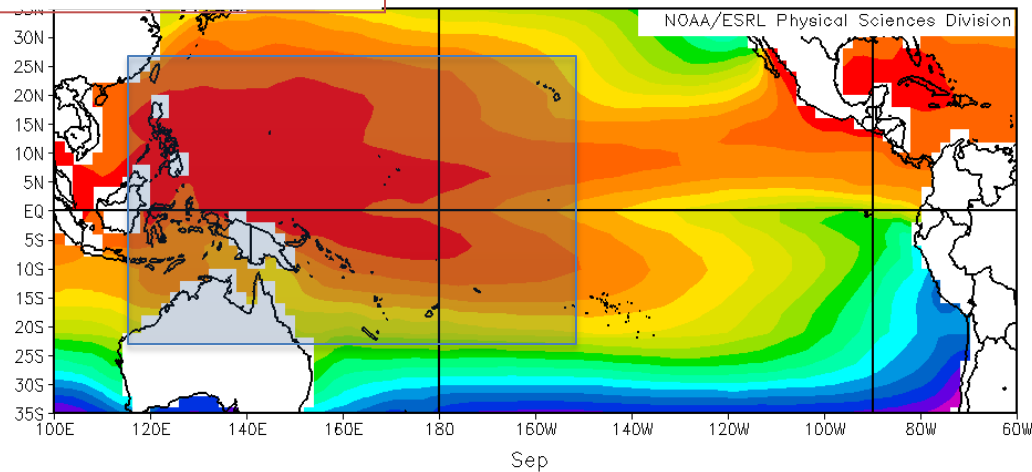
Like a swing!

NOAA Extended SST
Surface SST (C) Climatology 1971–200 climo



Seasonal Cycle: SST Over the WP/CT

NOAA Extended SST
Surface SST (C) Climatology 1971–200 climo



El Niño on the Devil's Staircase: Annual Subharmonic Steps to Chaos

聖嬰走在魔鬼台阶

Fei-Fei Jin, J. David Neelin,* Michael Ghil

Science, 1994

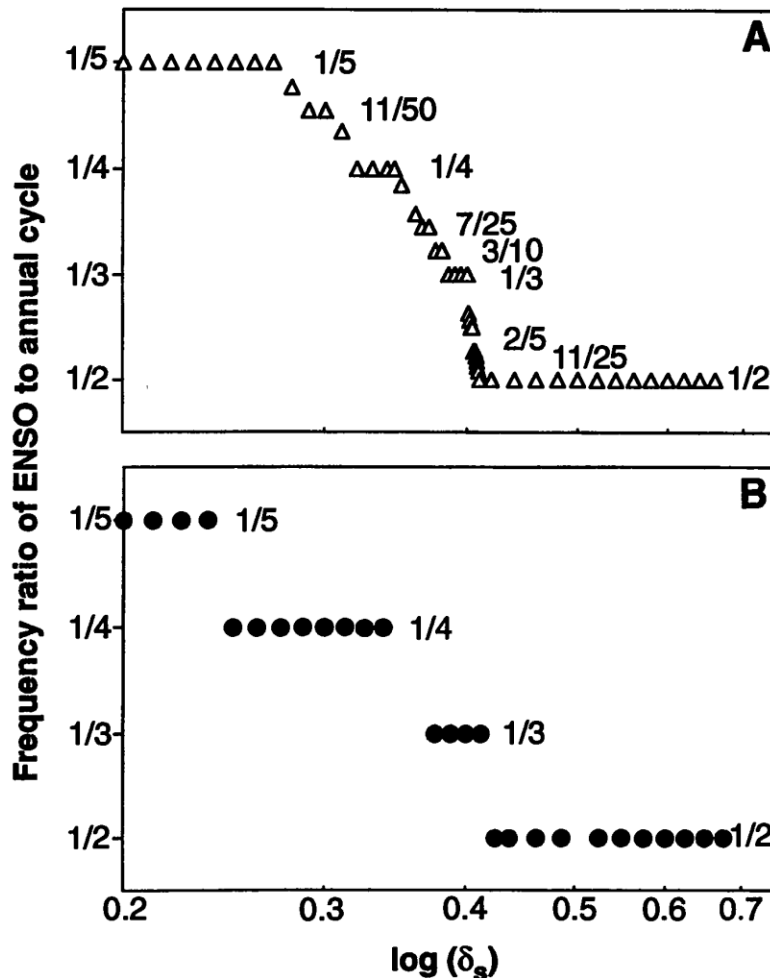
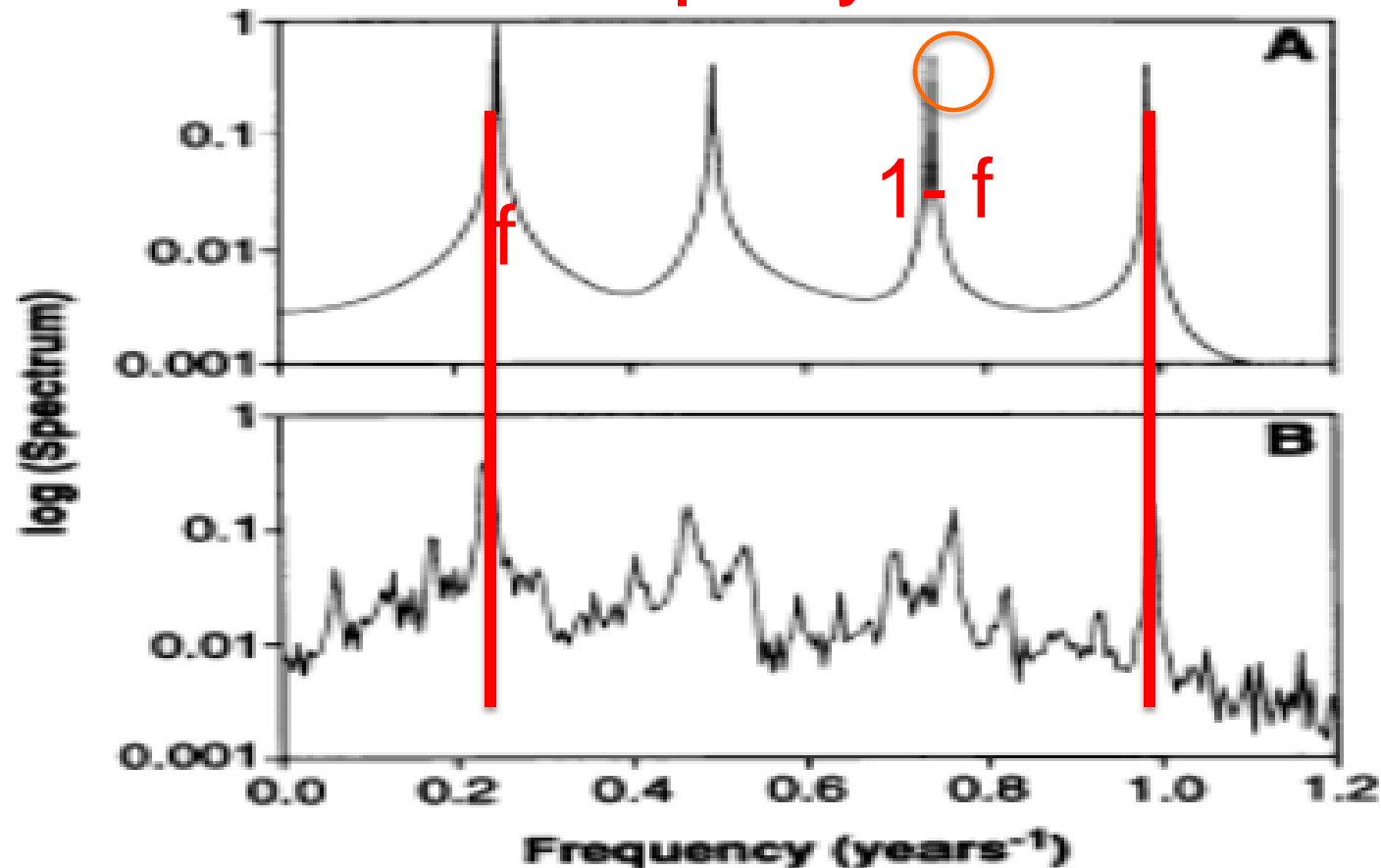


Fig. 1. Frequency ratio of the model El Niño oscillation to the annual cycle, as a function of a parameter, δ_s , that affects the inherent ENSO period. Another parameter, the coupling coefficient, μ , is changed to keep the El Niño cycle below its transition to chaos. Nonlinear frequency locking to the annual cycle creates a staircase of discrete steps at rational values of the frequency ratio. For instance, for a frequency ratio 1/4, the ENSO period is exactly 4 years, while for 3/10, a sequence of three El Niño cycles repeats every 10 years. **(A)** The approximate devil's staircase, slightly above the primary Hopf bifurcation where the ENSO mode goes unstable. All points shown correspond to rational frequency ratios (some labeled). **(B)** Frequency-locked solutions for slightly larger (by about 10%) values of μ , showing the rapid widening of the integer-period steps.

El Niño on the Devil's Staircase: Annual Subharmonic Steps to Chaos

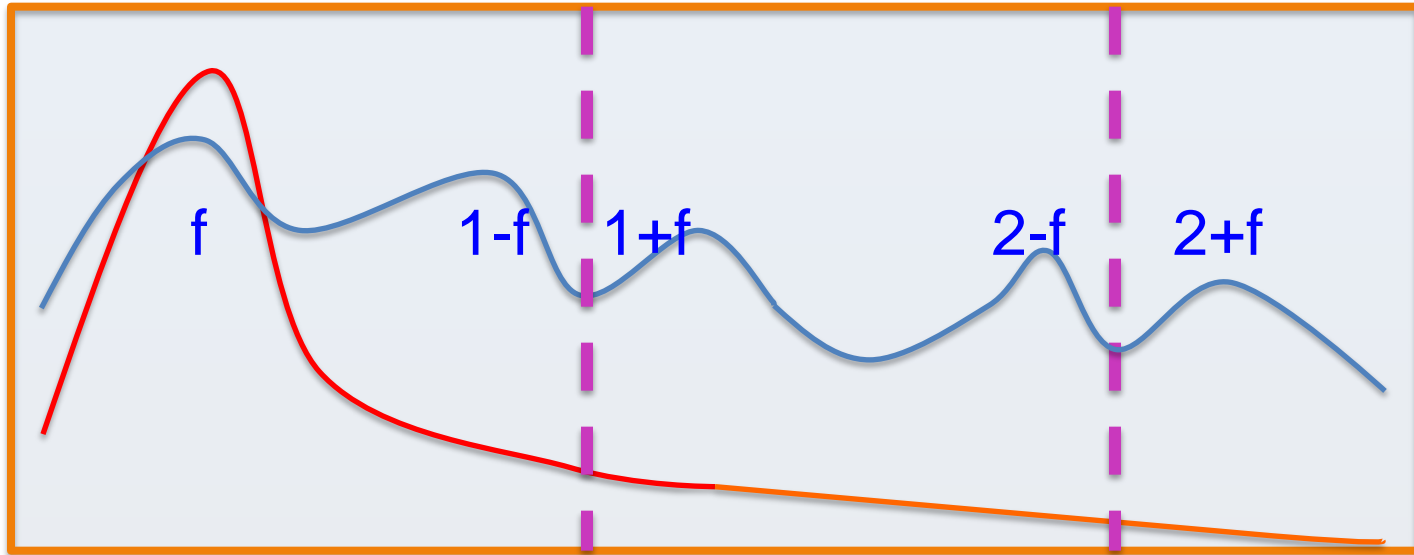
Fei-Fei Jin, J. David Neelin,* Michael Ghil (1994, Science)

El Niño Frequency Cascade



El Niño Frequency Cascade

El Niño and WNP
Circulation spectra



Nonlinear interaction between El Niño
And annual cycle → frequency cascade

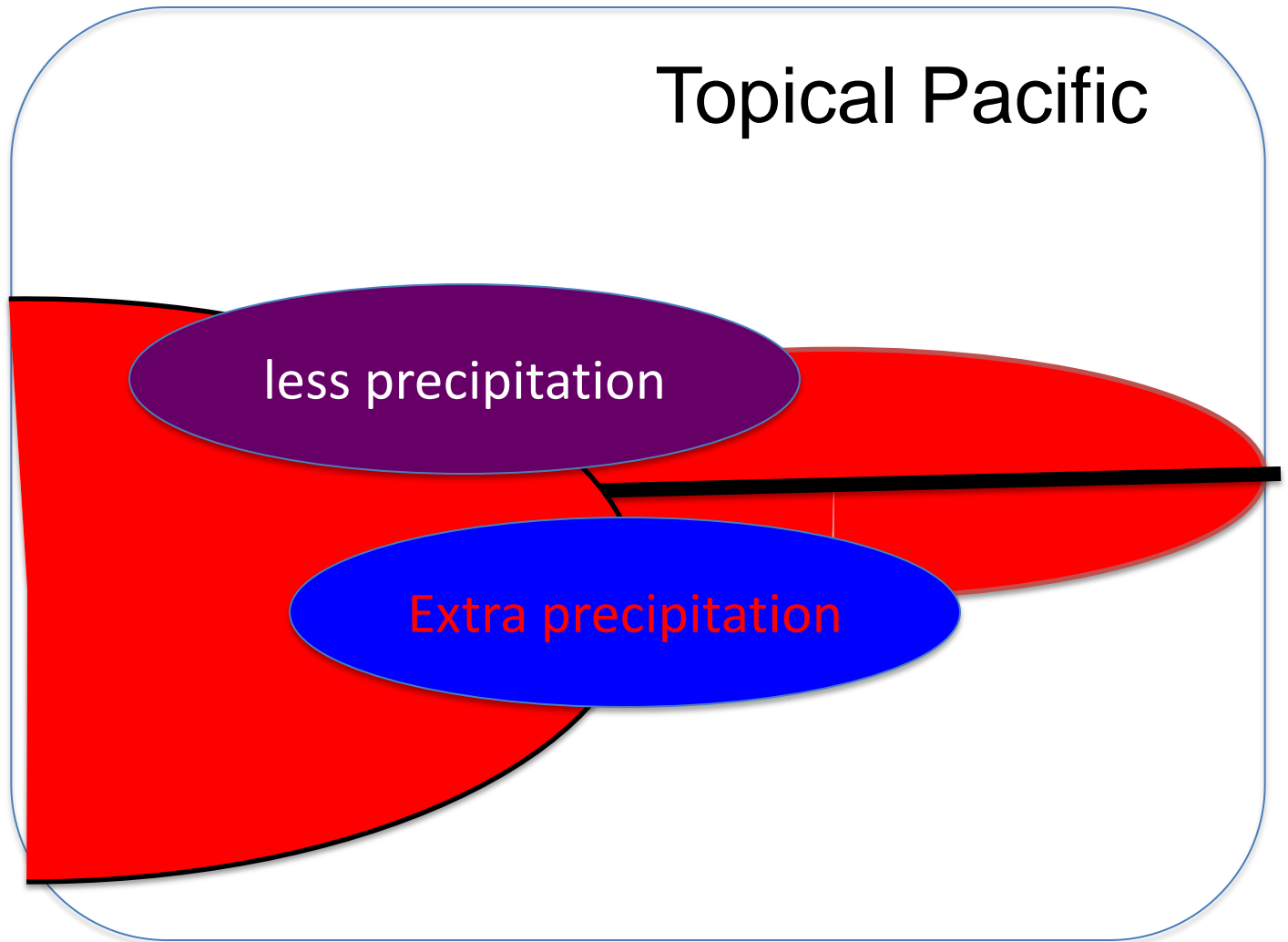
$$nF_1 \pm mF_2$$

M. Stuecker, F-F Jin, A Timmermann (2015, PNAS)

**Mathematically and physically,
El Niño certainly has its share
of inner beauty !**

So what?

Topical Pacific

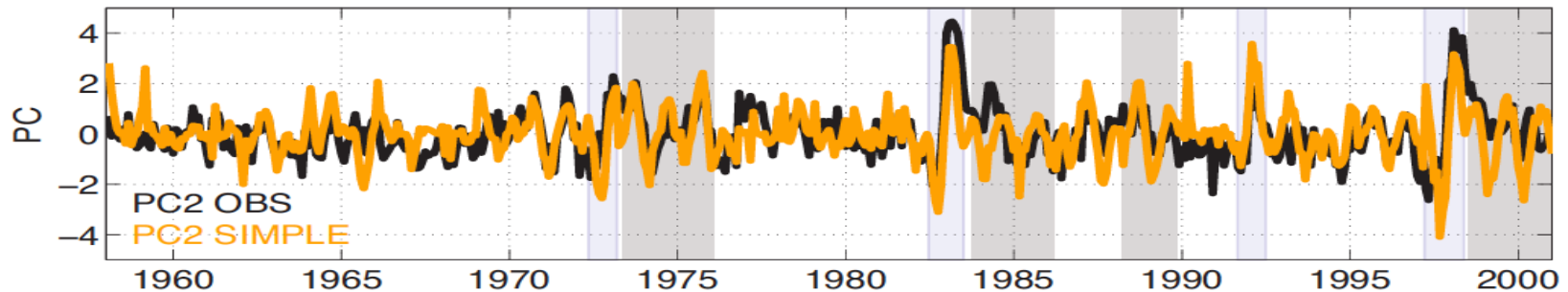
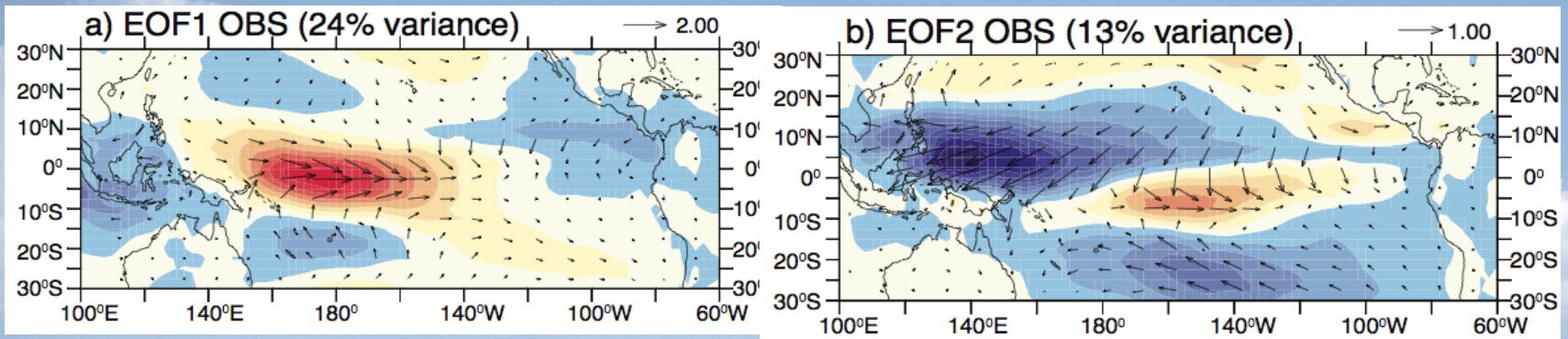


less precipitation

Extra precipitation

ENSO & AC nonlinear interaction over Pacific warm pool

EOF decomposition of the Surface Wind field



$$\text{PC2 SIMPLE} = \text{PC1}(t) * \cos(w_A t)$$

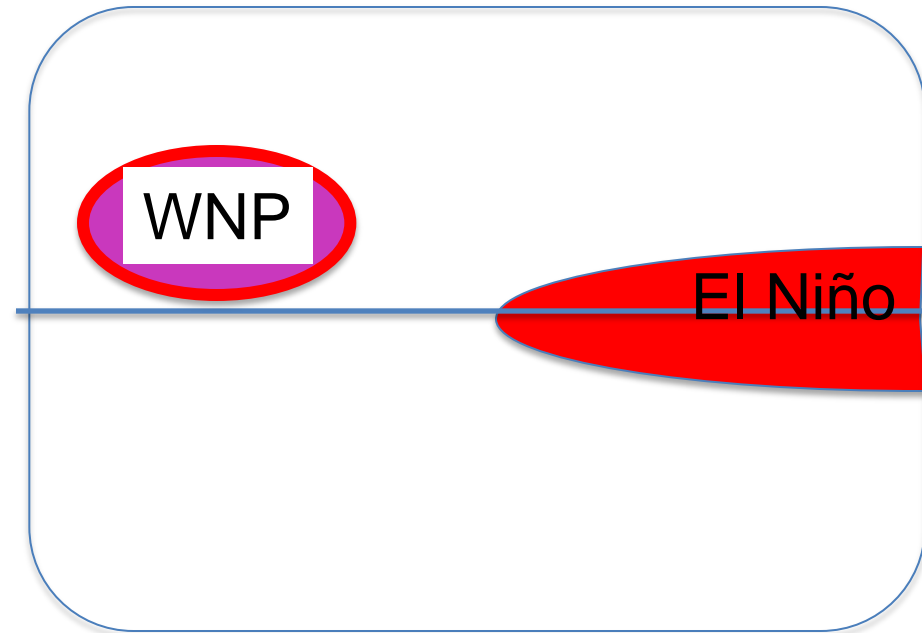
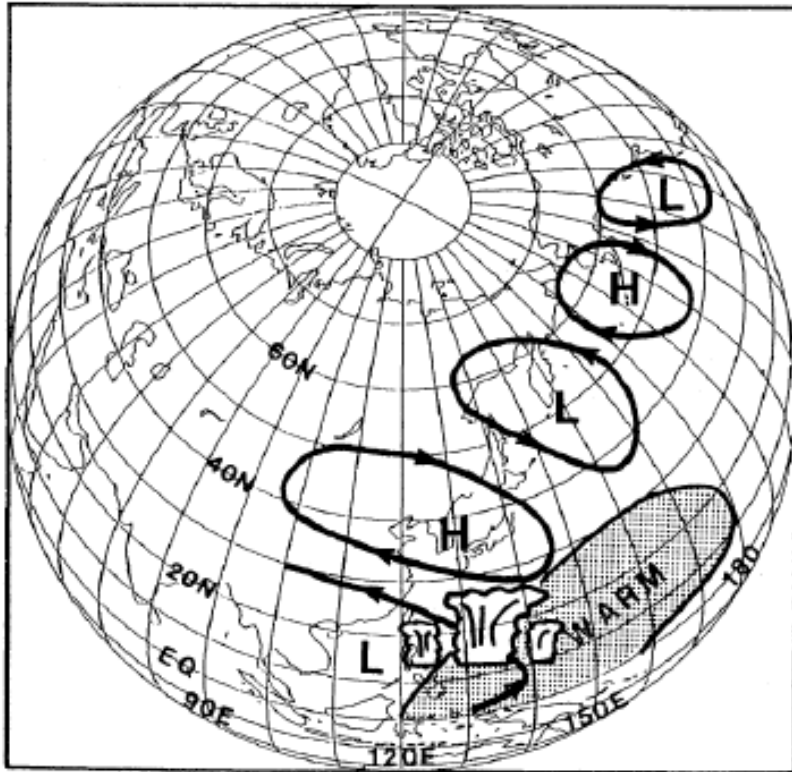
PC2 emerges from the nonlinear interaction of ENSO and the Annual Cycle!

M. Stuecker, A Timmermann, F-F Jin, S. McGregor, H-L Ren (2013)

El Niño's Wrath on Monsoon

ENSO directly alters the pace of the monsoon via its interaction with warm-pool annual cycle.

Two existing hypotheses for ENSO's Impact on Monsoon through WNP



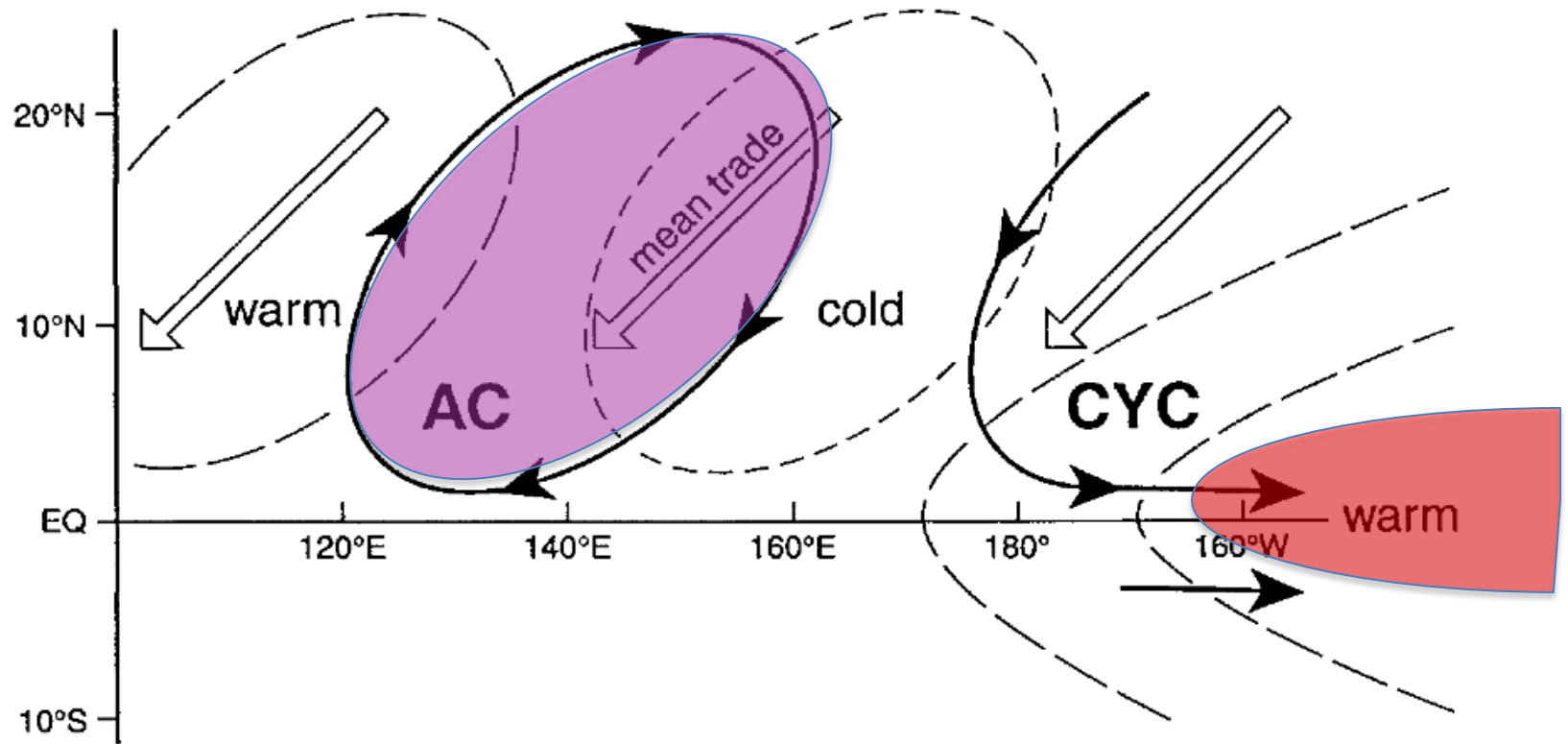
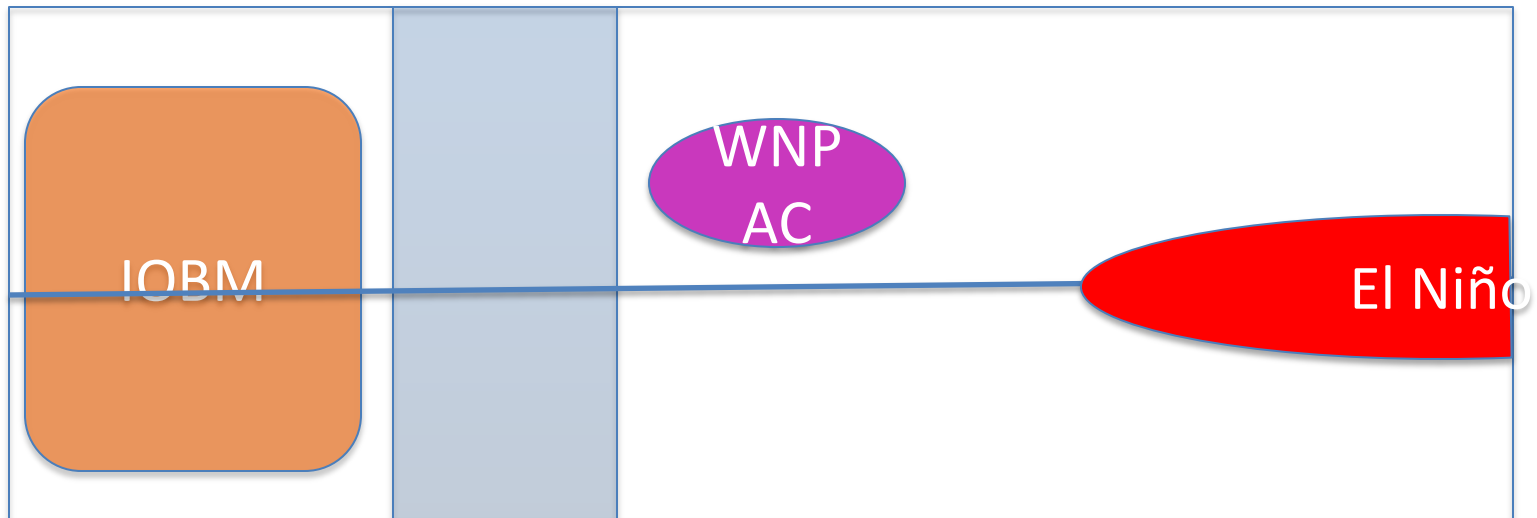
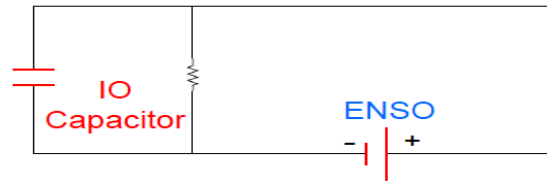
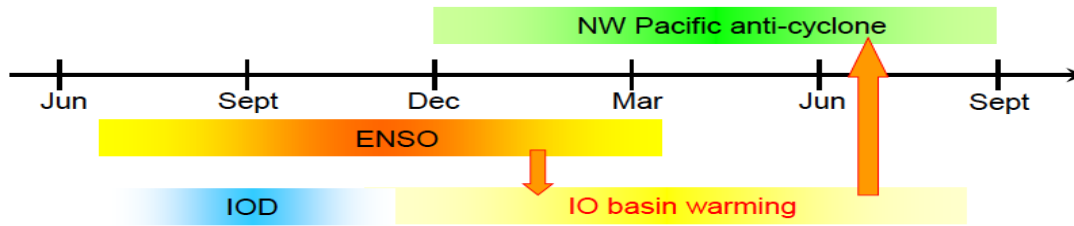
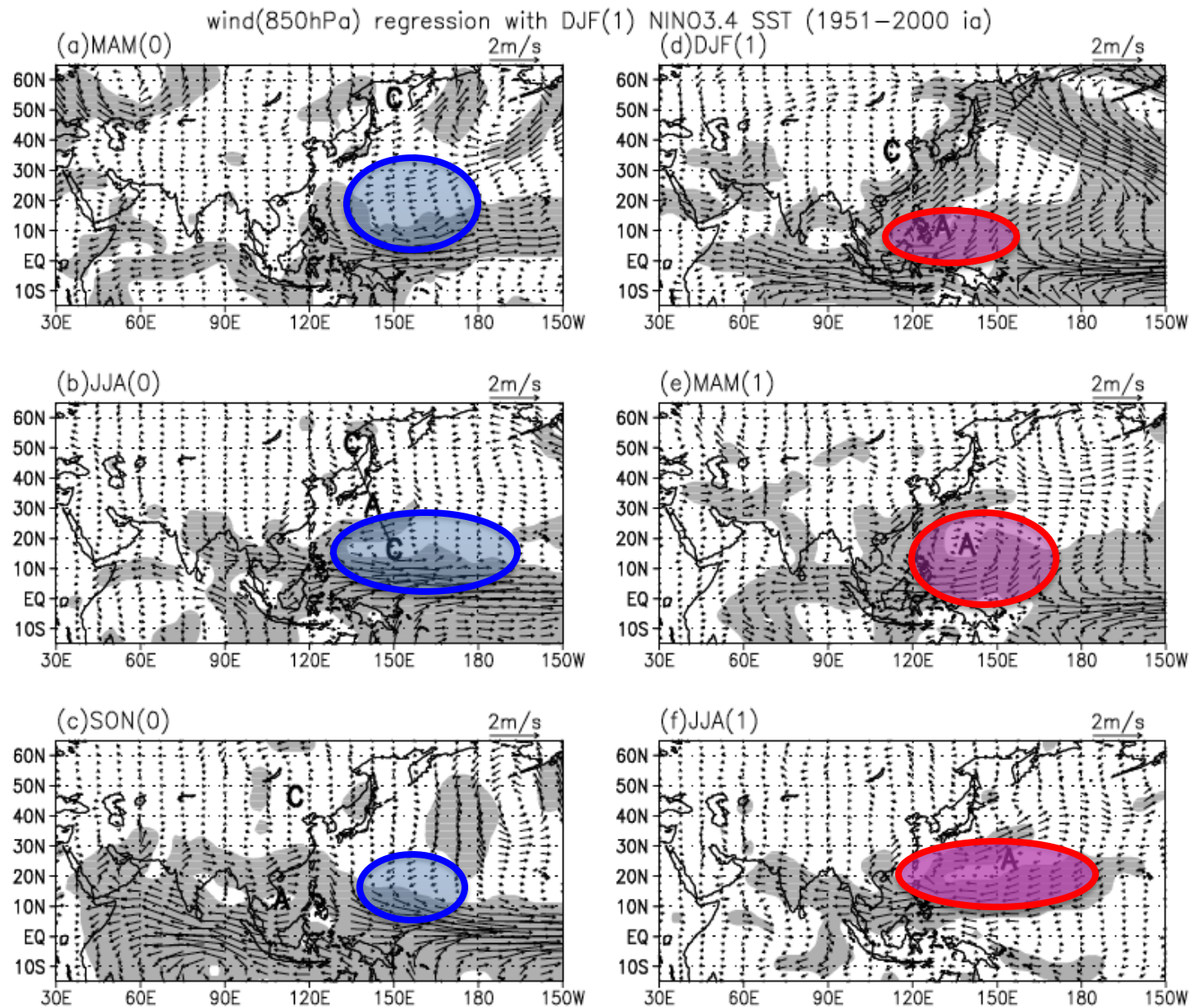


FIG. 16. Schematic diagram showing the air–sea interaction in the western North Pacific that maintains the Philippine Sea anticyclonic anomalies and associated negative SST anomalies in the western North Pacific. The double arrows denote the mean trade winds. The heavy lines with black arrows represent the anomalous winds. The long (short) dashed lines indicate contours of positive (negative) SST anomalies.

Wang & Zhang 2000: Pacific–East Asian Teleconnection: How Does ENSO Affect East Asian Climate?



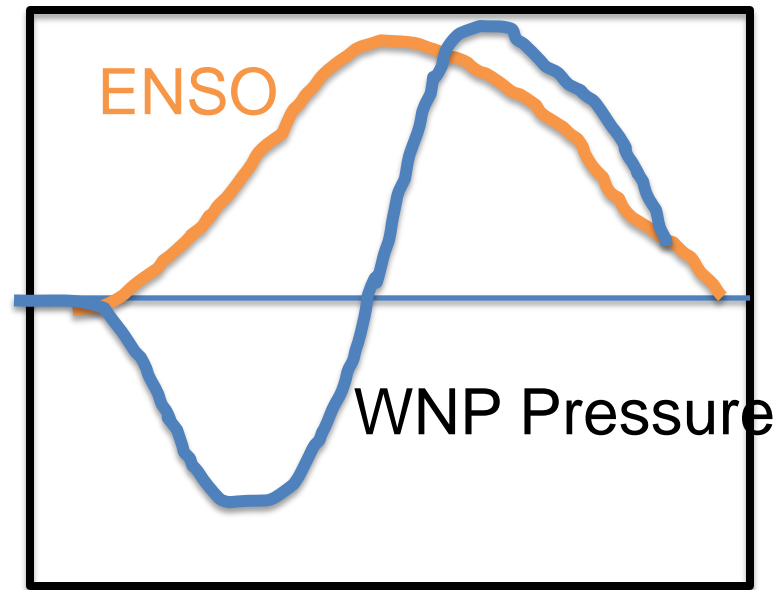
Xie et al. 2009: Indian Ocean Capacitor Effect on Indo–Western Pacific Climate during the Summer following El Niño



Wu et al
2003

Figure 7. Regression pattern of seasonal mean 850 hPa winds in MAM(0) (a), JJA(0) (b), SON(0) (c), DJF(1) (d), MAM(1) (e), and JJA(1) (f) with respect to DJF(1) Niño-3.4 SST for the period of 1951-2000. Shading indicates regions significant at 95% confidence level. Symbols “C” and “A” indicate anomalous cyclone and anticyclone, respectively. The lines connecting anomalous cyclones and anticyclone highlight the wave pattern. The wind scale is shown at the top-right of the panels. The regression is calculated using the interannual component only.

Both air-sea interaction mechanism and capacitor mechanism fails to explain different time scales of ENSO and WNP circulation anomalies and the opposite responses during ENSO developing and decaying years



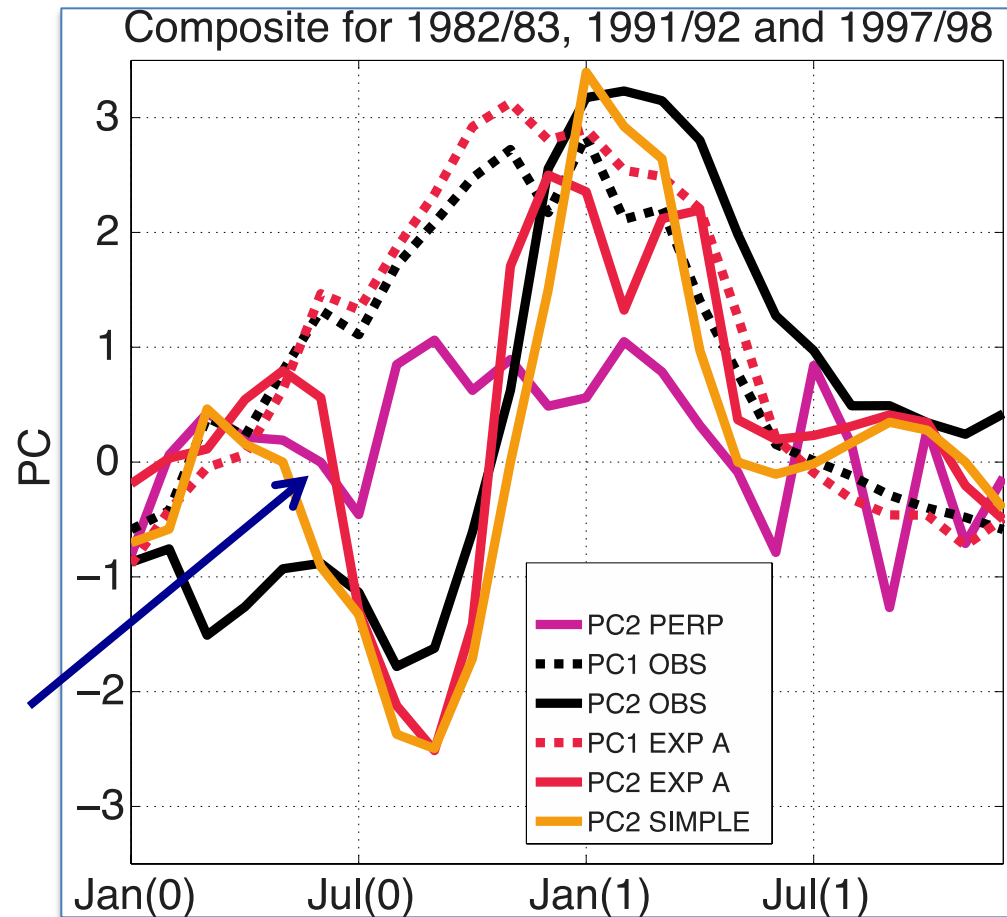
what is the missing link?

Which Nonlinearity?

Wind PC2 is an atmospheric combination mode of ENSO and the annual cycle!

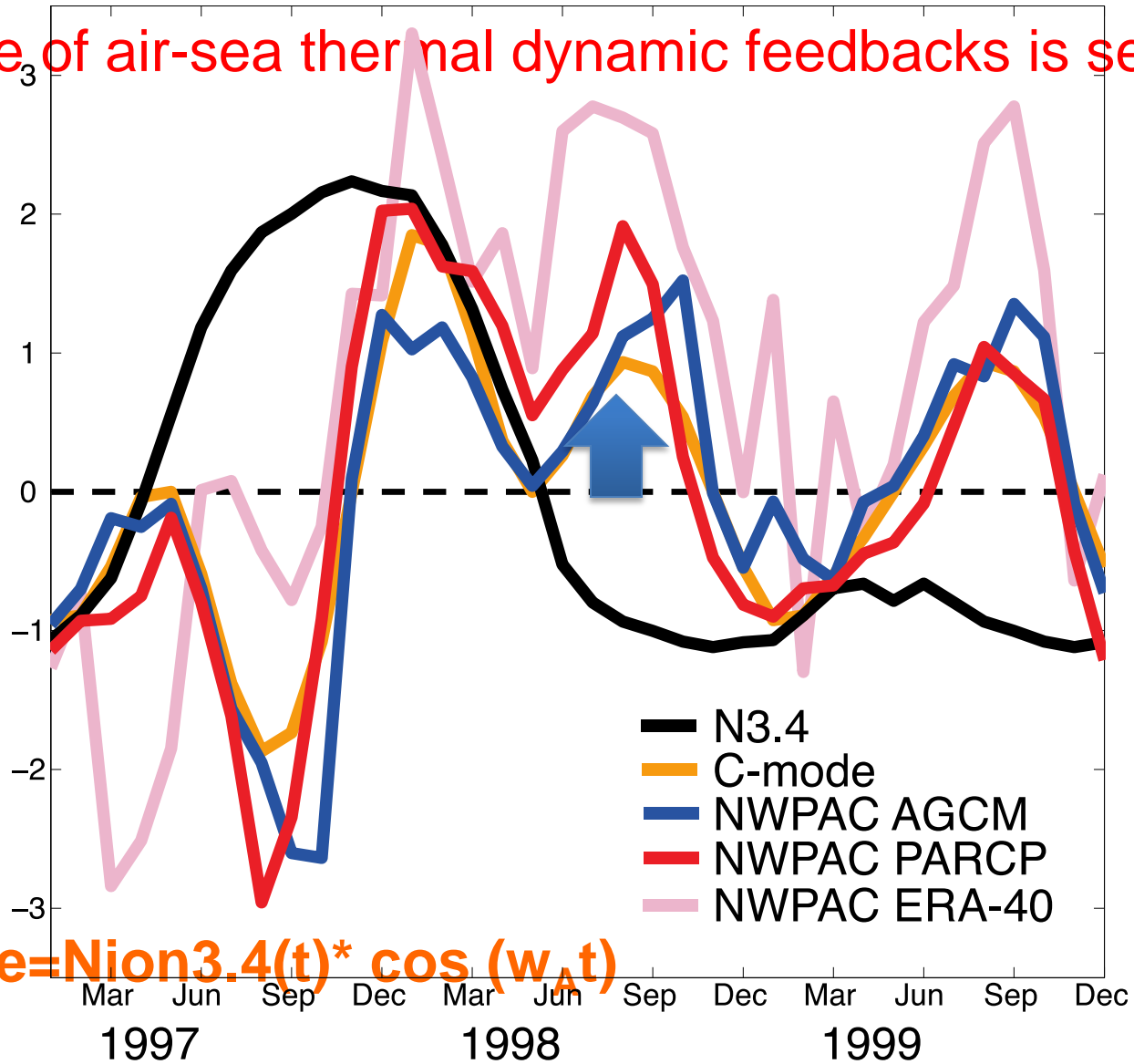
Perpetual Experiment (PERP):

Wind PC2 is not generated if the annual cycle is removed from the forcing!



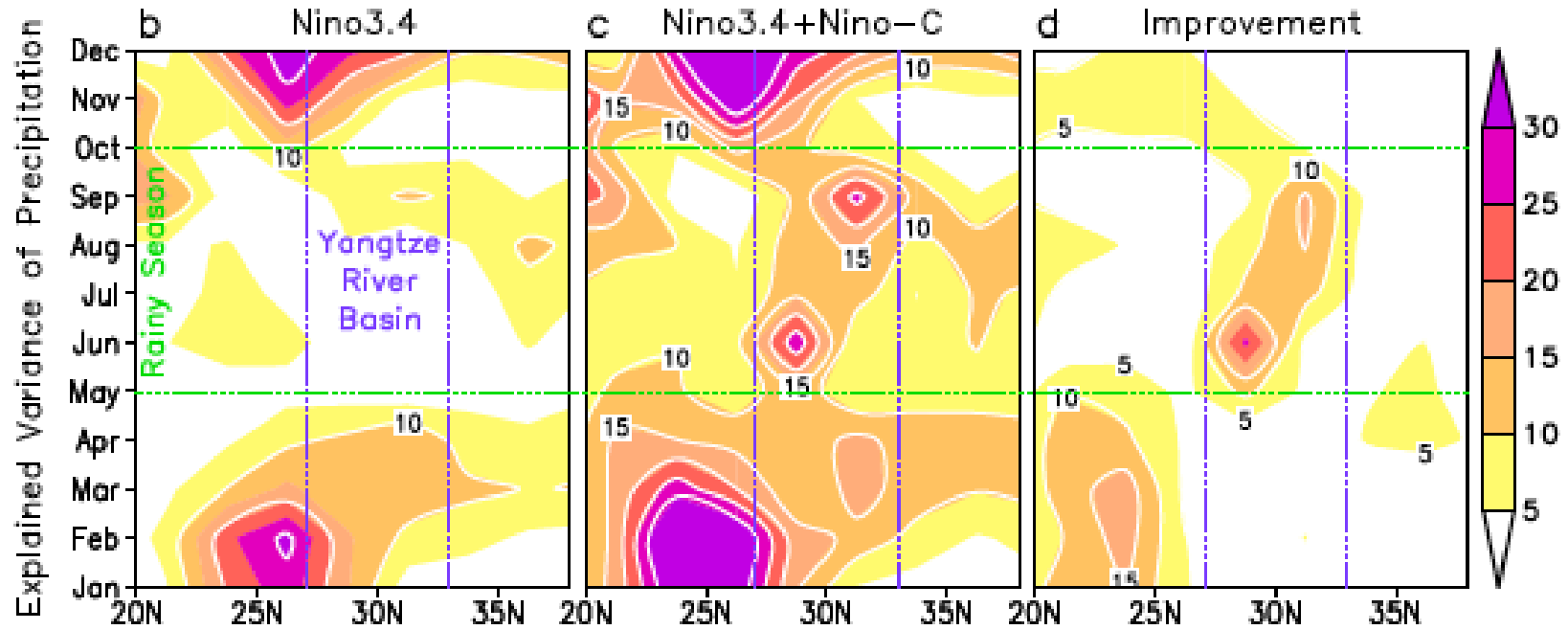
Repeated idealized 1997-99 ENSO cycle

The role of air-sea thermal dynamic feedbacks is secondary



$C\text{-mode} = N_{ion3.4}(t) * \cos(\omega_{at})$

Increased Explained Variance of Monsoon precipitation (China) due to El Nino-C

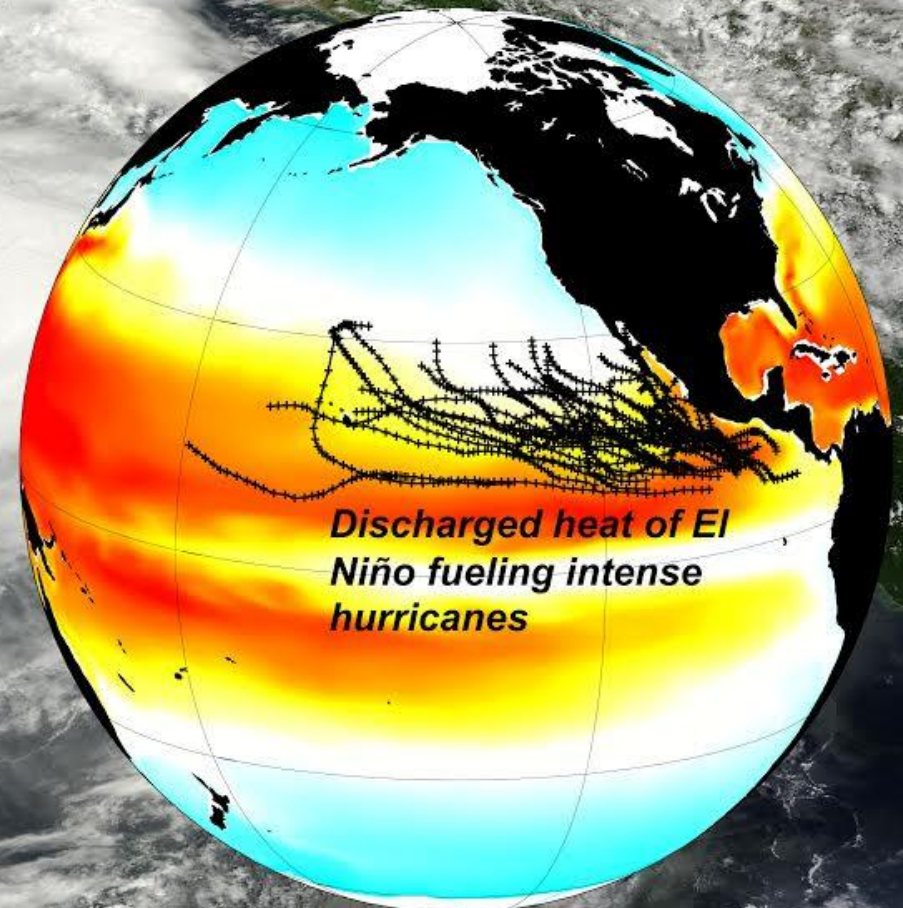
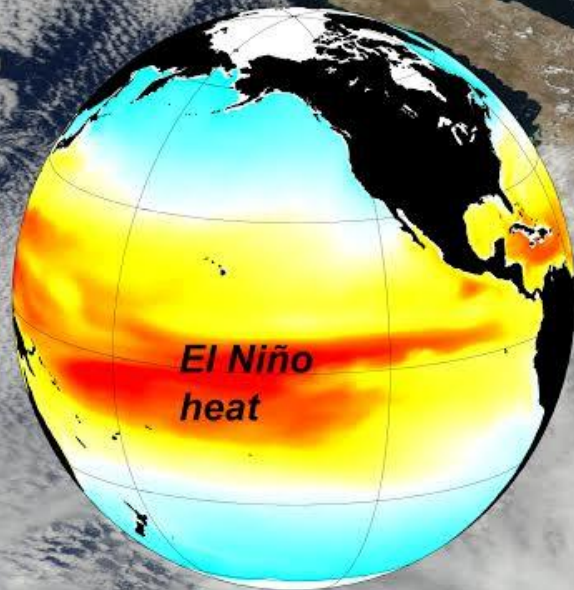


A photograph of a traditional Korean pavilion (Seogeomjae) partially submerged in water, with a city skyline in the background. The pavilion has a dark, curved roof and several pillars. The water is calm, and the sky is overcast. The text is overlaid on the left side of the image.

**2016 Summer Flooding of
Yangtze River and
Later Summer Flooding
in Korea ?!**

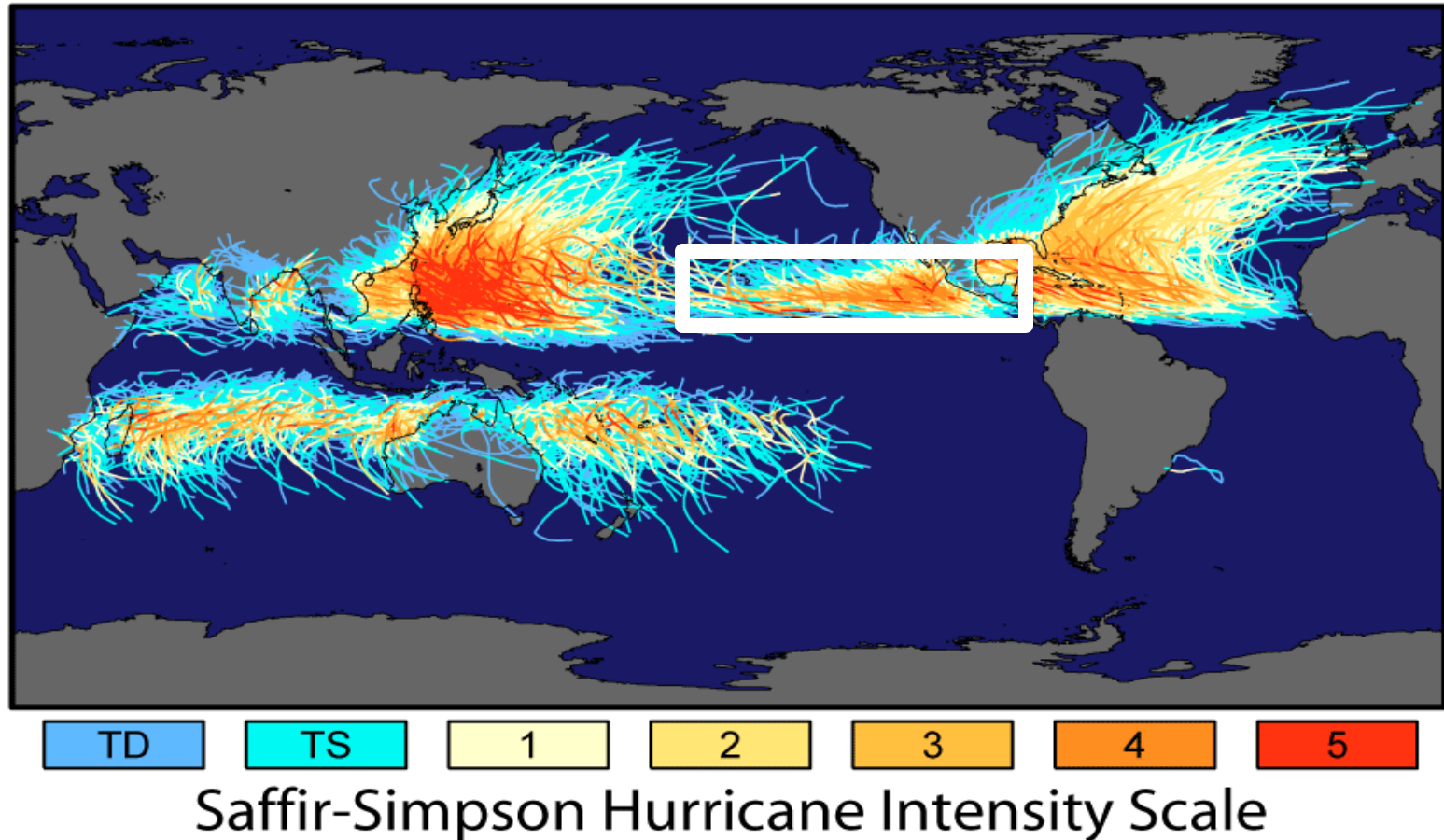
Good chance !

EL Nino's wrath revealed in hurricanes

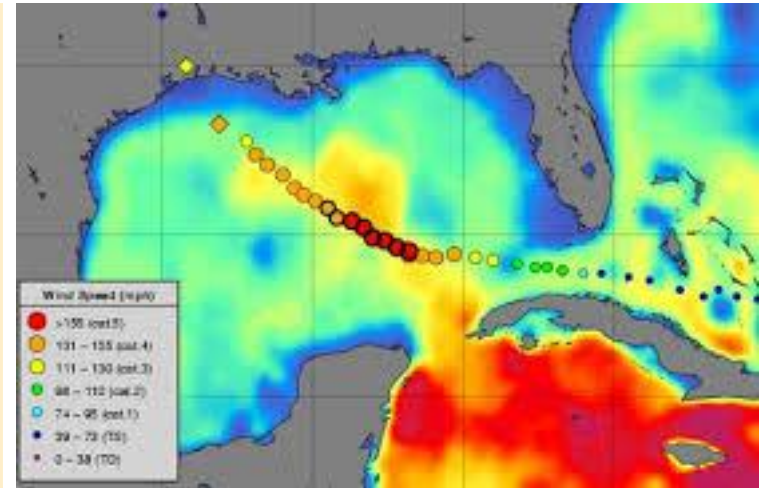
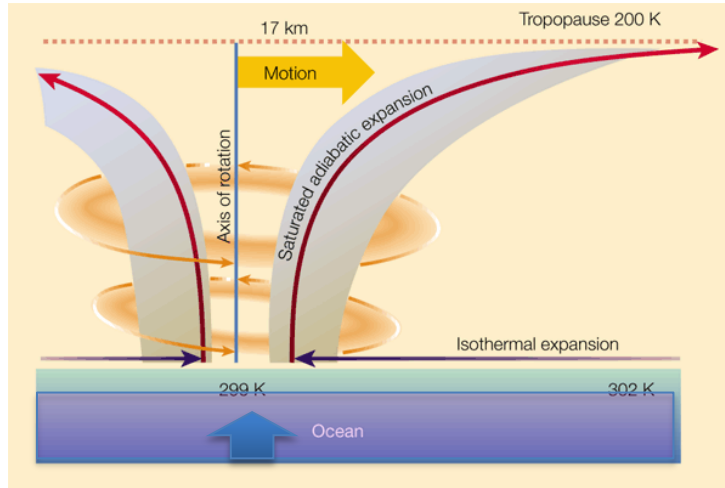


Jin et al 2014 (Nature)

Tracks and Intensity of All Tropical Storms



Eastern Pacific is the 2nd most active region in terms of Tropical Cyclones activity, during boreal summer, June-November (*Neumann, 1993*)



New Formula for Potential Intensity of Hurricane

$$OCPI \propto (T_o - T_a)$$

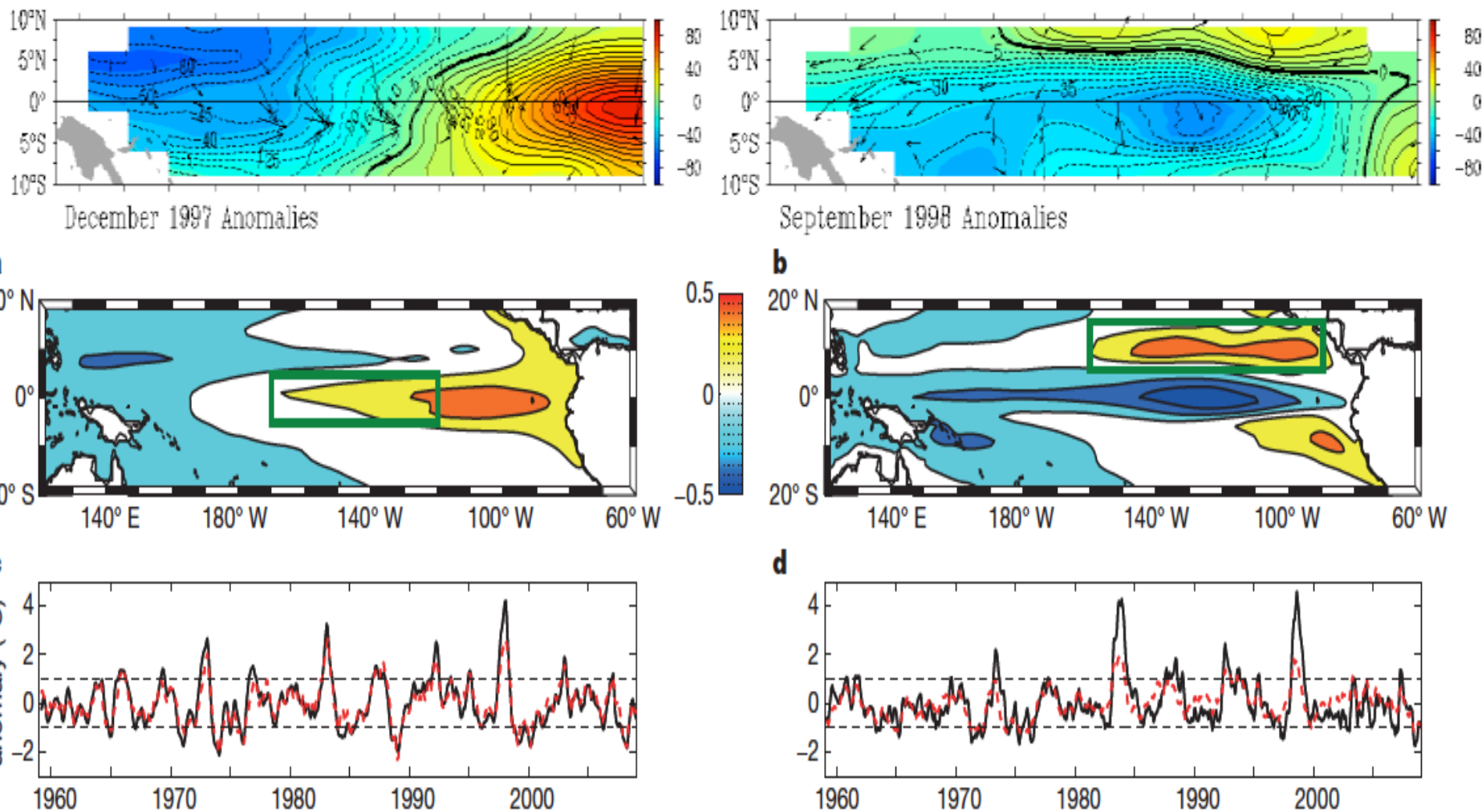


Figure 1 | EOF decomposition of T105 (temperatures averaged between 5 and 105 m) anomalies. a, b, The spatial patterns of the first (a) and second (b) EOF modes with explained variance at 46.8% and 11.7% respectively. c, The first PC (PC1, black) and the Niño3.4 time series (red) (SST anomalies averaged in the green box in a). d, The second PC (PC2, black) and time series

(red) of T105 anomalies averaged in region TC (160–90° W, 7–17° N) (green box in b). Horizontal dashed lines in c and d indicate ± 1 s.d. of the respective PCs. Correlation of PC1 and Niño3.4 = 0.92 ($P < 0.001$); correlation of PC2 and T105 = 0.75 ($P < 0.001$). PC time series are normalized, but units for Niño3.4 and T105 are temperature anomalies in degrees Celsius.

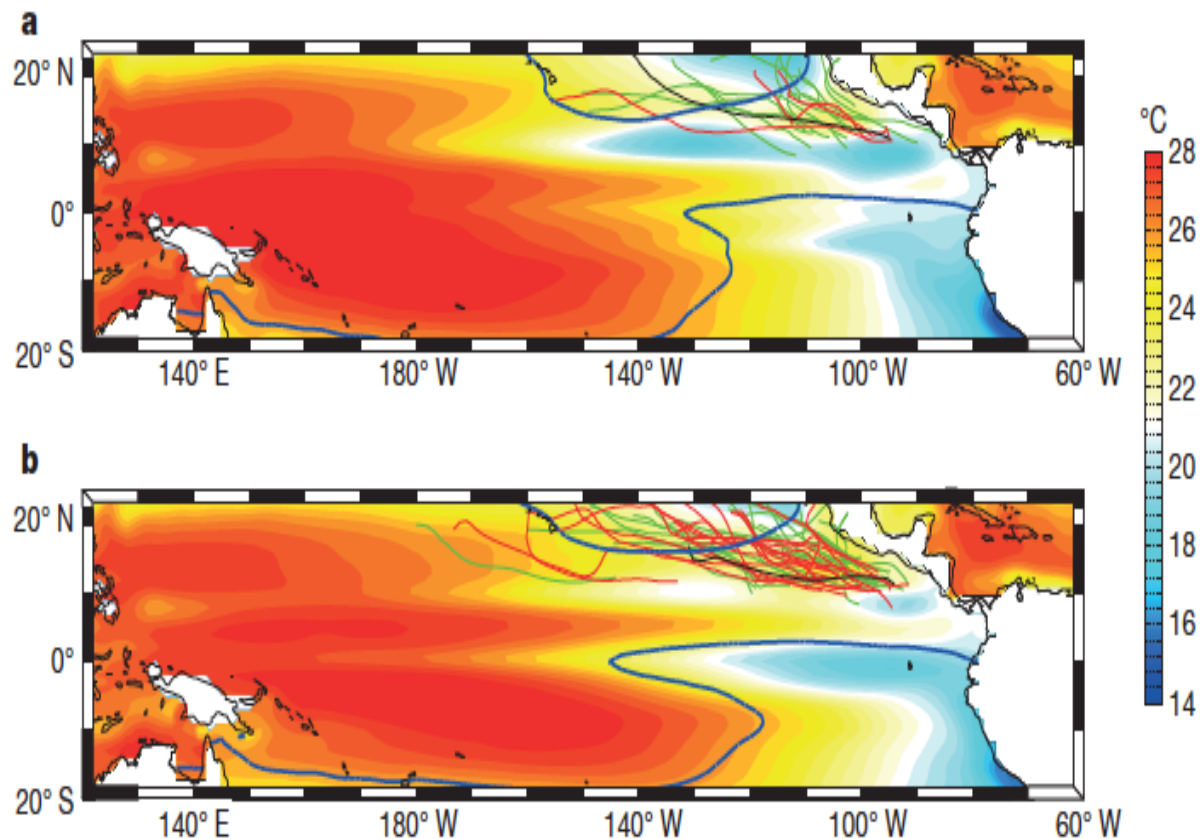


Figure 2 | Trajectories of intense TCs for periods of high and low subsurface temperature in the eastern North Pacific. The shading denotes the summer (June–November) subsurface temperature (T105) averaged over periods when $PC2 < -s.d.(PC2)$ (a) and when $PC2 > s.d.(PC2)$ (b). The thick blue line denotes the 26 °C isotherm of SST averaged over the periods of low (a) and high (b) PC2 activity. In each panel the coloured lines represent the trajectories of strong TCs that occurred during the corresponding periods: green, category 3; red, category 4; black, category 5.

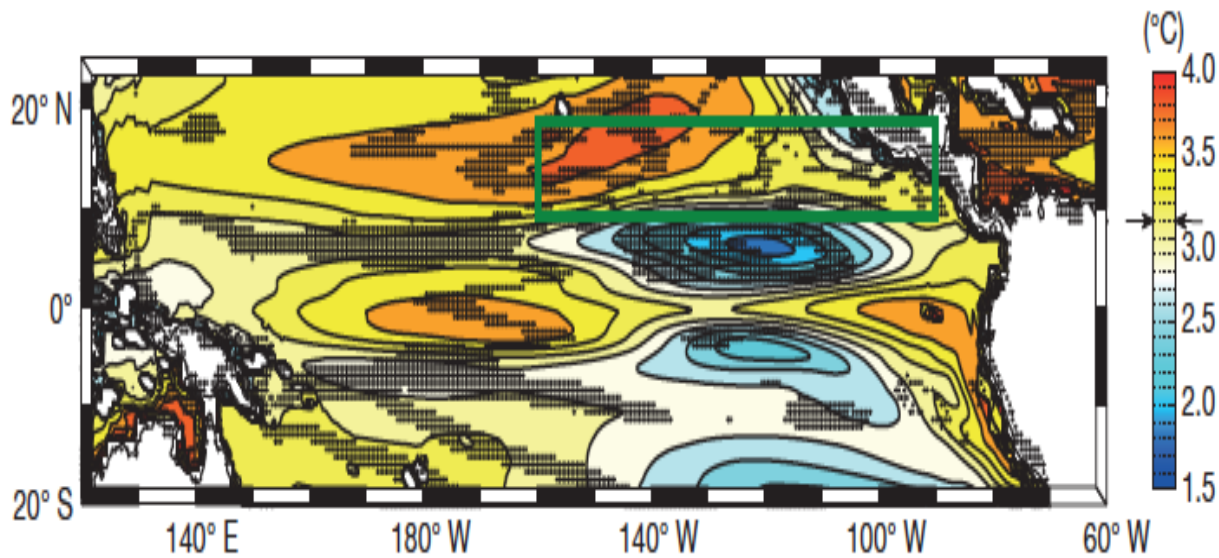


Figure 4 | Changes in subsurface T105 between the twentieth-century historical conditions and the rcp8.5 global warming scenario. Multi-model ensemble mean of mean T105 difference between the rcp8.5 scenario and historical simulations for models indicated in Supplementary Table 3. The two arrows on each side of the colour bar indicate the mean T105 difference for the basin. The green box represents region TC (160–90° W, 7–17° N). The cross-hatching denotes a statistical confidence level of 99% based on Student's *t*-test.

Intense Hurricanes coming to Hawaii & Mexico next year and in the future?!

Conclusions

- El Niño, as a natural created phenomenon, has its share of underlying beauty , once described in terms of math.
- ENSO delivers its impact on monsoon of Asia mainly through a unique path of frequency cascade, via its interaction with AC, which is a much simpler paradigm for ENSO-Monson relation. It delivers its heat to fuel hurricanes to Hawaii & Mexico as well.
- Korea may face flooding next in coming summer