Is ENSO a cycle or a series of events?

NOAA

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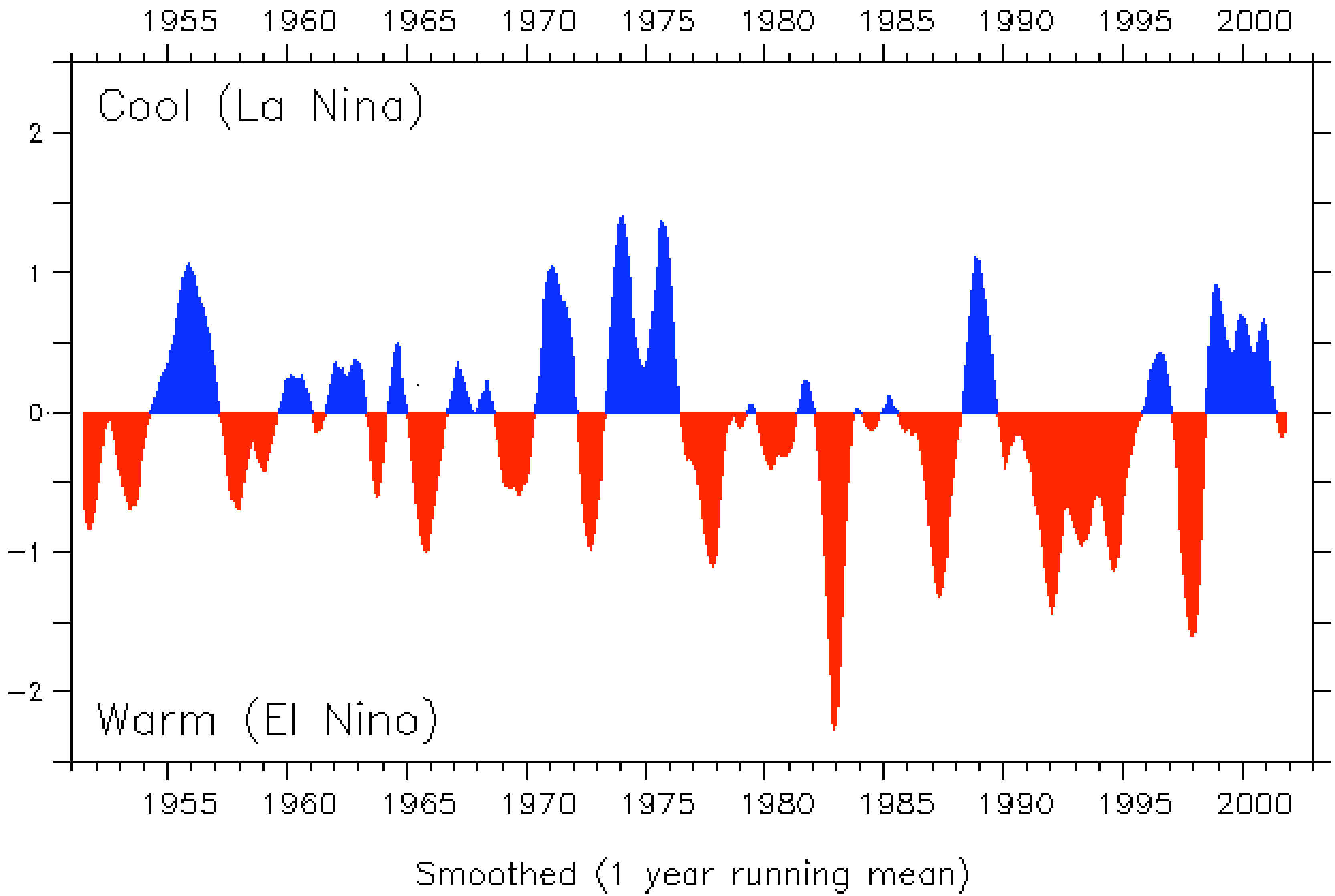
Is El Niño predictable?

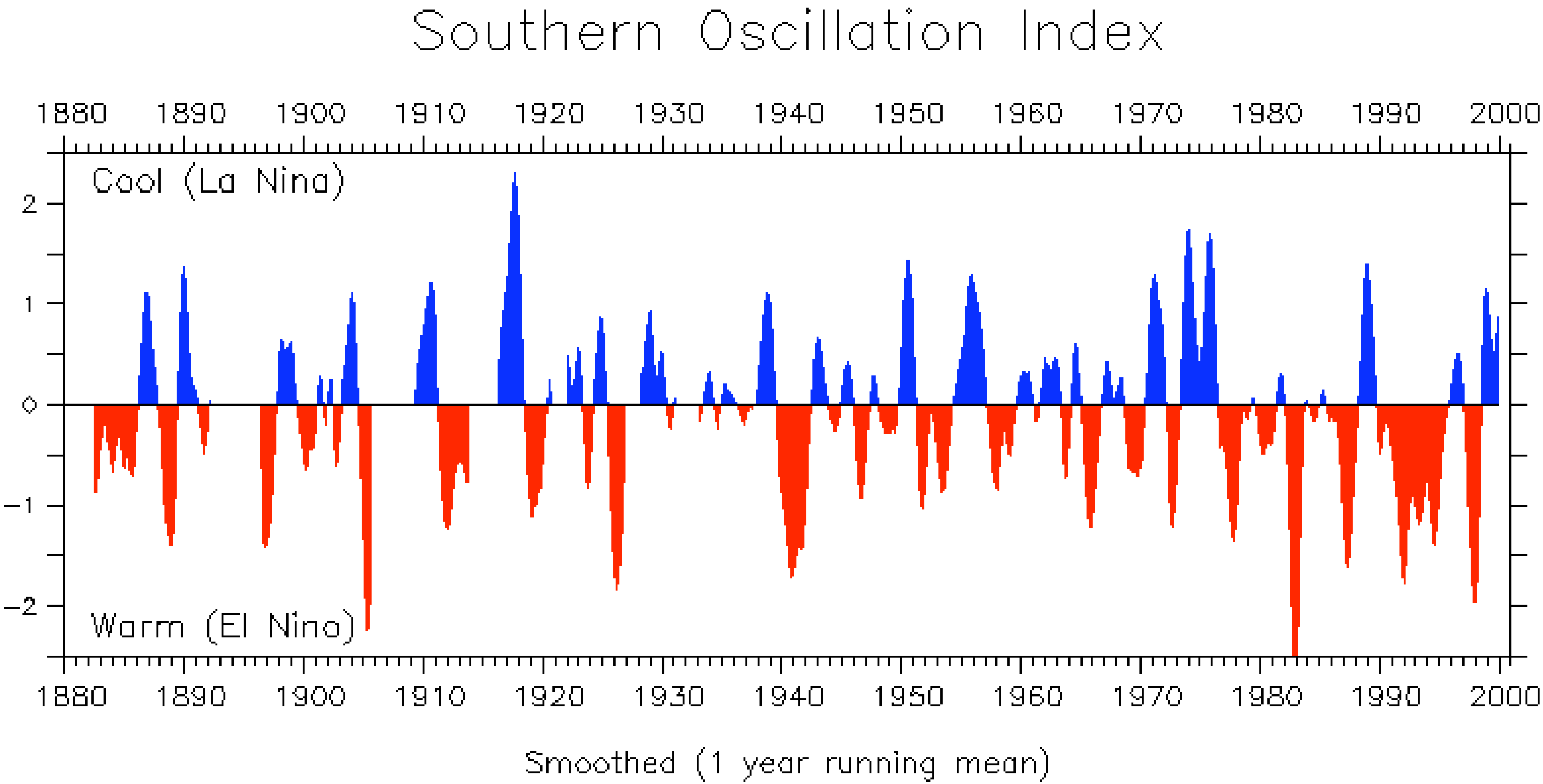
Could rephrase the title question:

- Does the memory of one El Niño event persist to the next event?
- Is ENSO a self-contained oscillation? Or does it need an external trigger?

Every event to date has come as a surprise. We have learned to recognize the onset early, and thus make an early forecast, but no one has successfully forecast an event before it has started.

Southern Oscillation Index




Southern Oscillation Index
Cool (La Nina)
Warm (El Nino)
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2
1
0
−1
−2
Smoothed (1 year running mean)

History of ideas about the progression of ENSO

Bjerknes (1969)	Positive feedbacks maintain each state.
Wyrtki (1975, 86)	Buildup in the west Pacific precedes events. Other than that, events are independent.
McCreary (1983)	Oscillation can occur via western boundary reflection delay. Time-lagged negative feedback
Schopf/Suarez (88) Battisti/Hirst (89)	Delayed Oscillator paradigm. More realistic delay via coupled growth on the equator.
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Jin (1997)	Recharge/Discharge Oscillator.

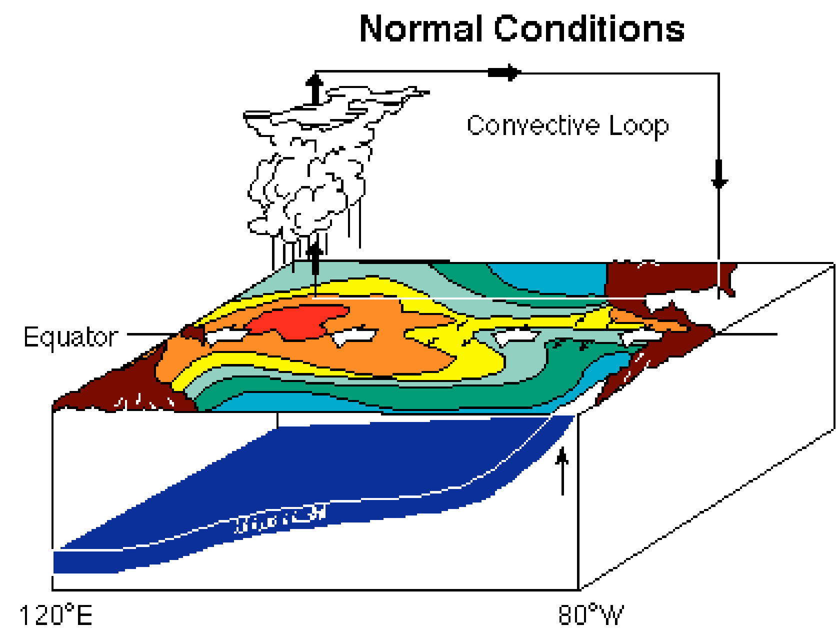
Bjerknes: positive feedbacks

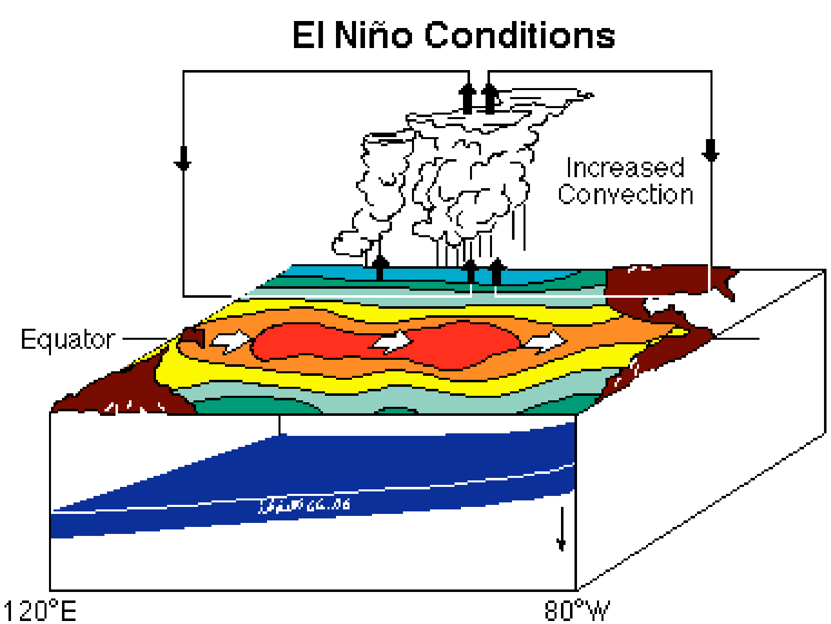
Convection occurs over warm SST
→ Winds blow towards warm SST

During normal conditions,
SST is warm in the west:
→ produces convection there
→ strengthens the trade winds
→ strong upwelling in the east
→ cools the surface there.

During El Niño conditions,
SST is warm across the basin:
→ produces generalized convection
→ weakens the trade winds
→ suppresses upwelling

But, Bjerknes did not know how
the phase could reverse.





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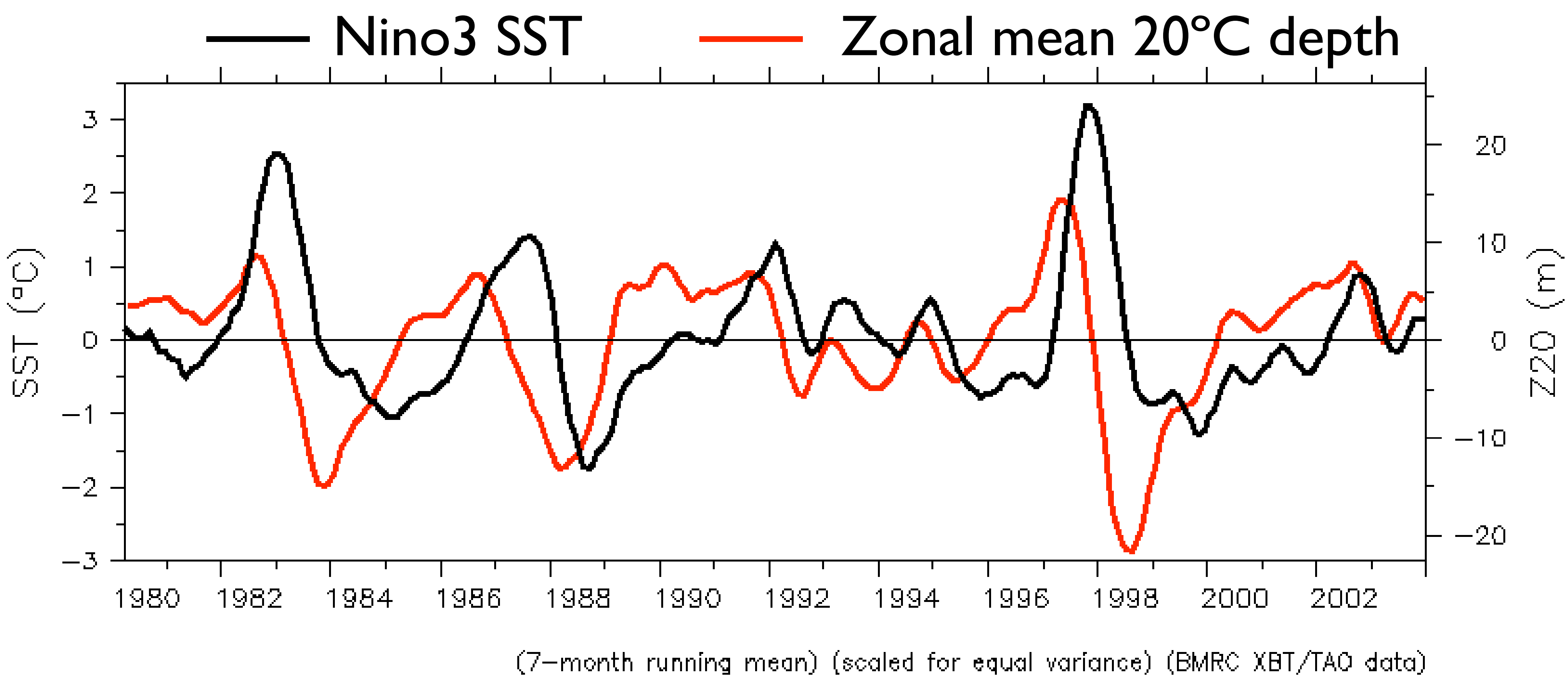
Warm water volume increases before each event



Trade winds pile up warm water in the west Pacific.
El Niño serves the climate "purpose" of episodically draining the warm pool.

Wyrtki (1975)

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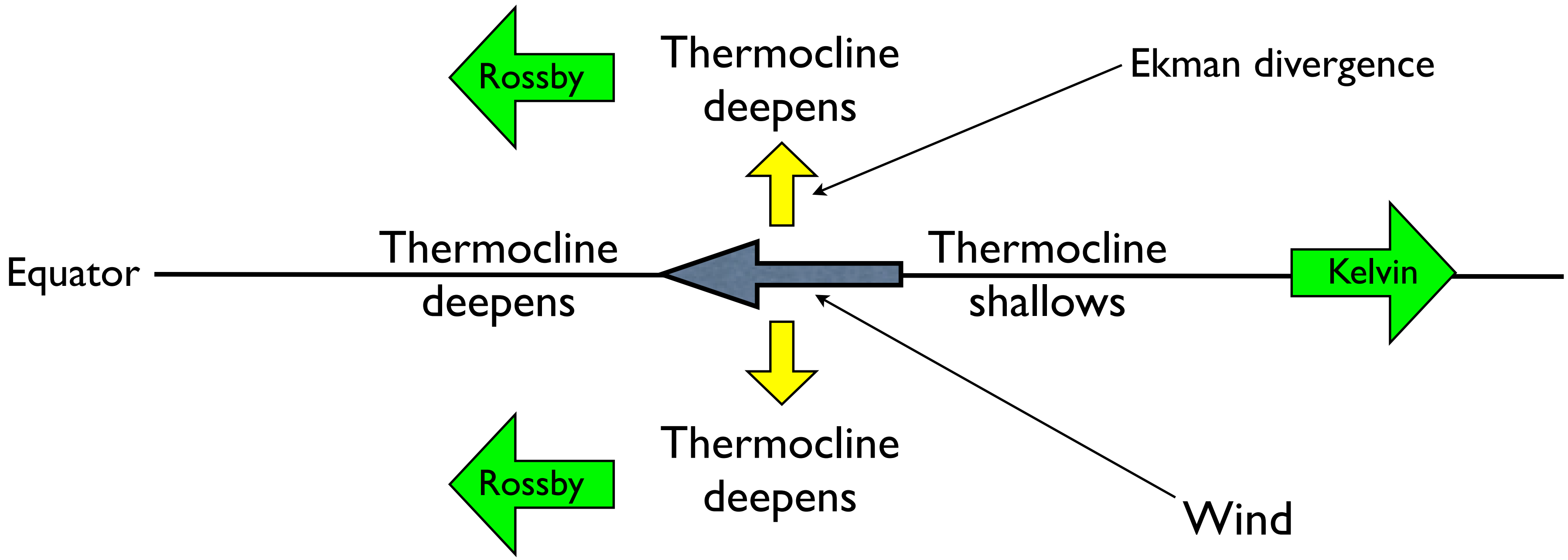
Equatorial winds generate both Kelvin and Rossby waves

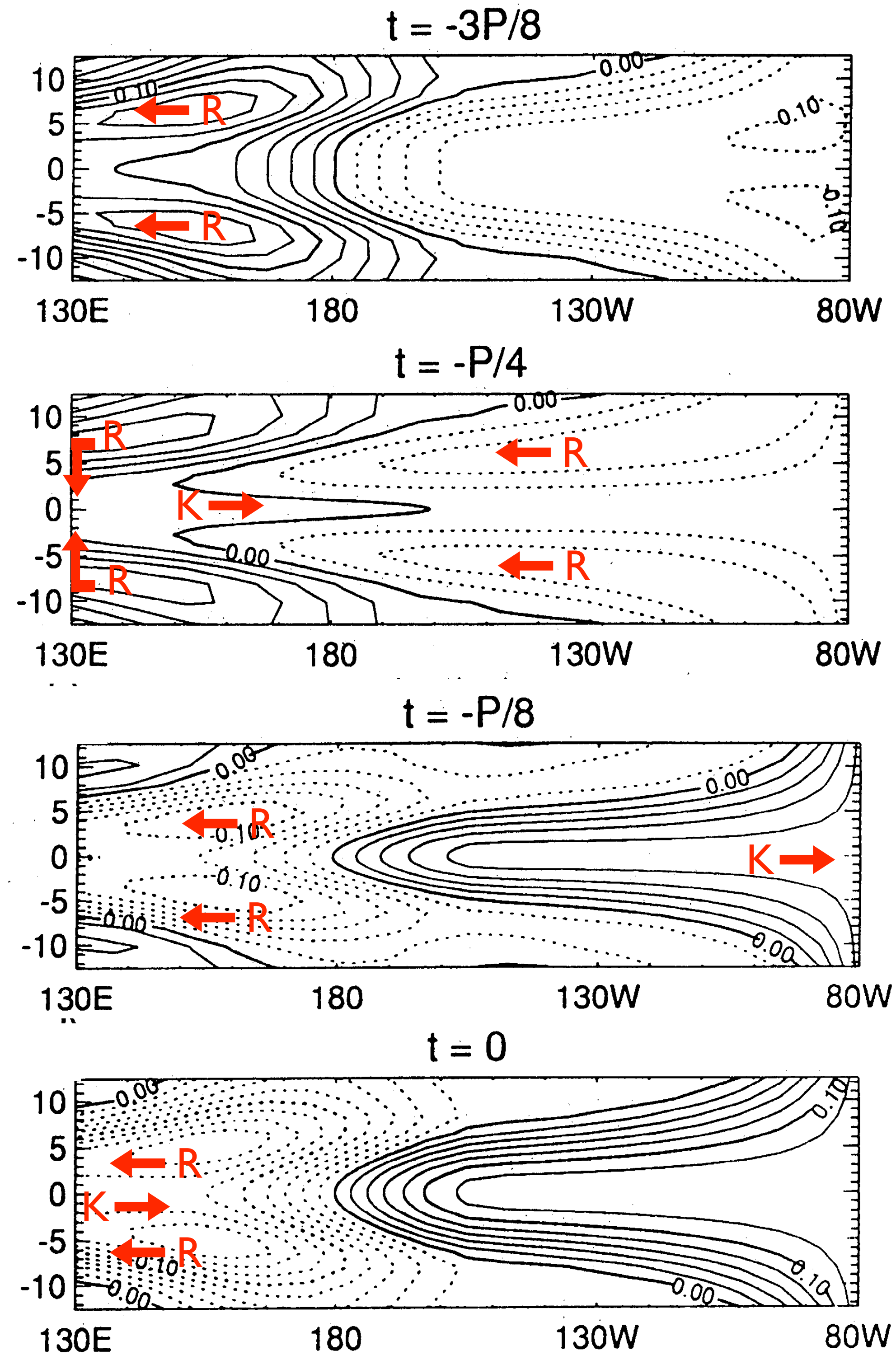


Kelvin waves: ~2.5 m/s (6500 km/month)
Rossby waves: ~0.8 m/s (2000 km/month)

Wave reflection allows an oscillation

- Kelvin waves carry the wind signal rapidly to the eastern Pacific.
- Rossby waves (with opposite sign) propagate slowly west, then reflect from the boundary to return on the equator and change the sign of the anomaly.

- Thermocline depths change SST and thus change the winds (by Bjerknes' feedbacks). Thus, an oscillation. But a cycle is only ~1 year.



(McCreary 1983)

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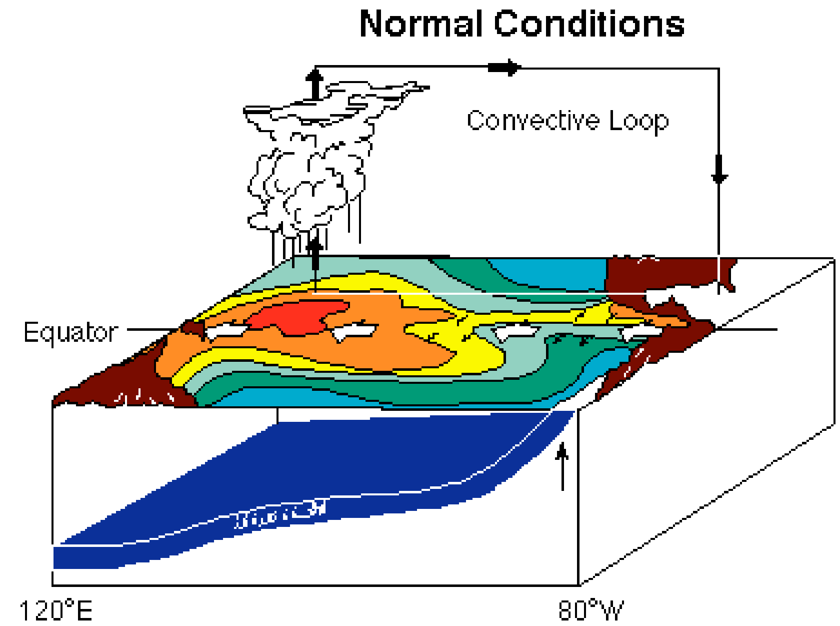
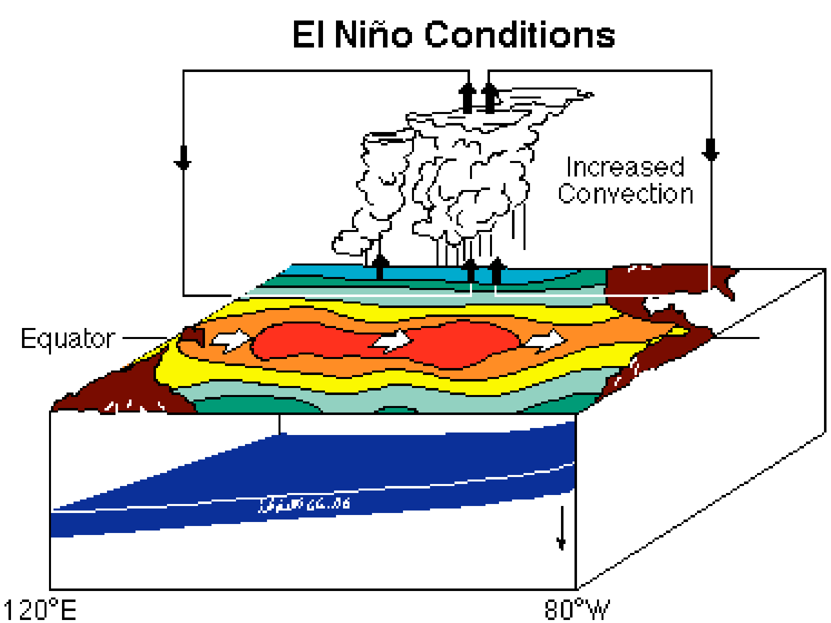
Delayed Oscillator Models incorporate both western boundary reflection and Bjerknes positive feedbacks

During normal conditions, easterly winds give Ekman divergence from the equator

→ shallow the equatorial thermocline
→ deepen the off-equatorial thermocline
→ produce downwelling Rossby waves that propagate west
→ reflect to deepen the equatorial thermocline
→ begin to warm equatorial SST
→ Bjerknes positive feedbacks increase the warming (slowly)
→ system moves *gradually* towards El Niño: 3-4 year timescale





Delayed Oscillator models

- Fundamental mechanism is the reflection of Rossby waves at the western boundary, returning to initiate the reversal of phase on the equator.
- Have forecast skill comparable to advanced GCMs. (Which is to say, not so much).
- Allow exploration of the parameter space of tropical climate: very popular, and they have become the dominant paradigm for thinking about ENSO.
- Produce nearly symmetric and regular El Niños and La Niñas (not very realistic). Observational studies have shown that the D.O. mechanism works for the termination of an El Niño but not for its initiation.

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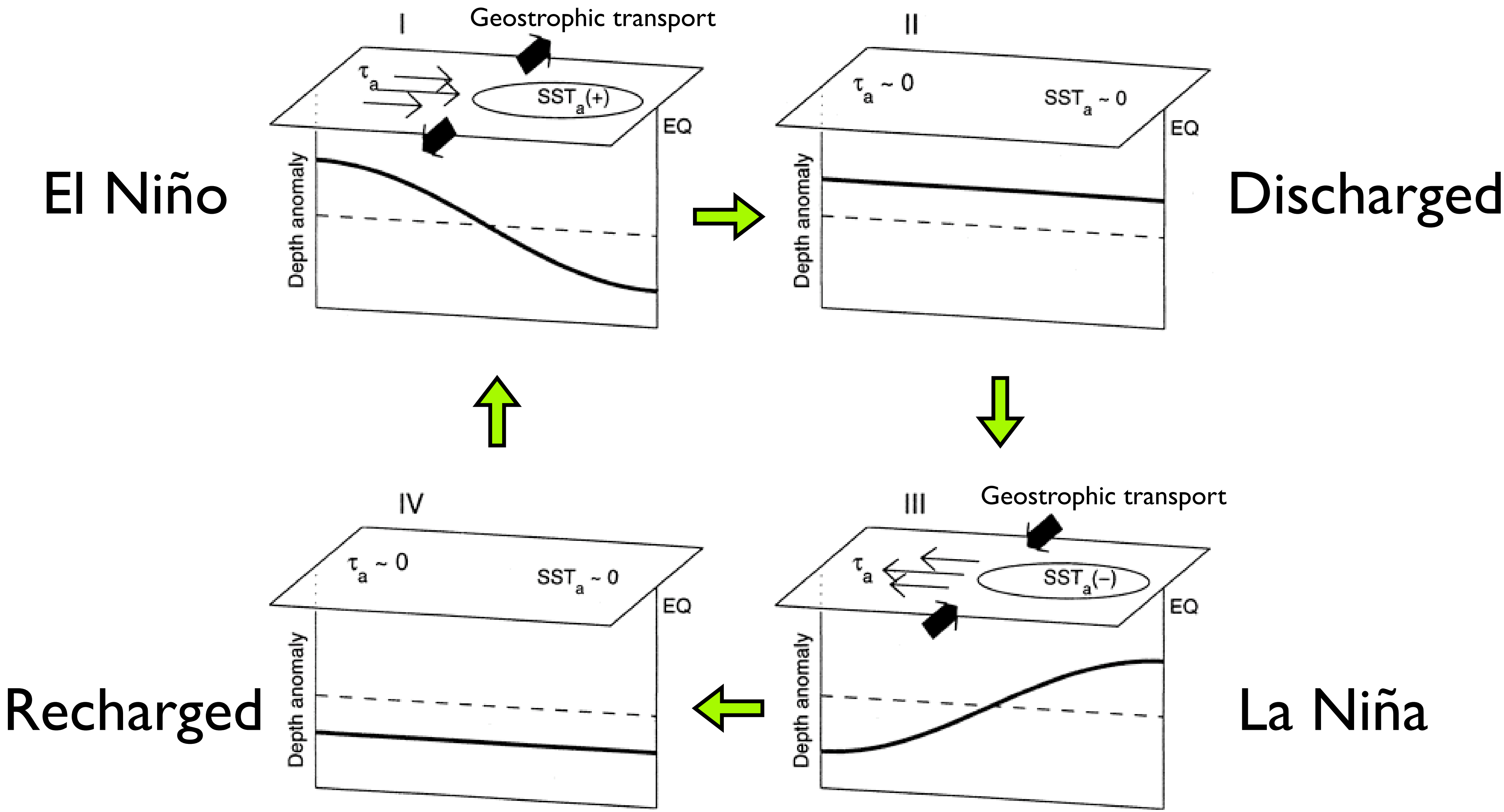
Schematic of the Jin (1997) Recharge-Discharge mode:



(After Meinen and McPhaden (2000))

The Recharge-Discharge Oscillator

- More general than the delayed oscillator since it does not depend on wave reflection times.
- Similar to Wyrtki's "buildup", but each event leads explicitly to the opposite phase.
- Memory of the system contained in the zonal mean thermocline depth.
- Points to a convenient set of variables that can be evaluated from observations.

Two over-arching hypotheses

- Cyclic ENSO (McCreary ➙ Cane/Zebiak ➙ Jin)

⇨ ENSO is a self-sustained oscillation.

⇨ Predictability!

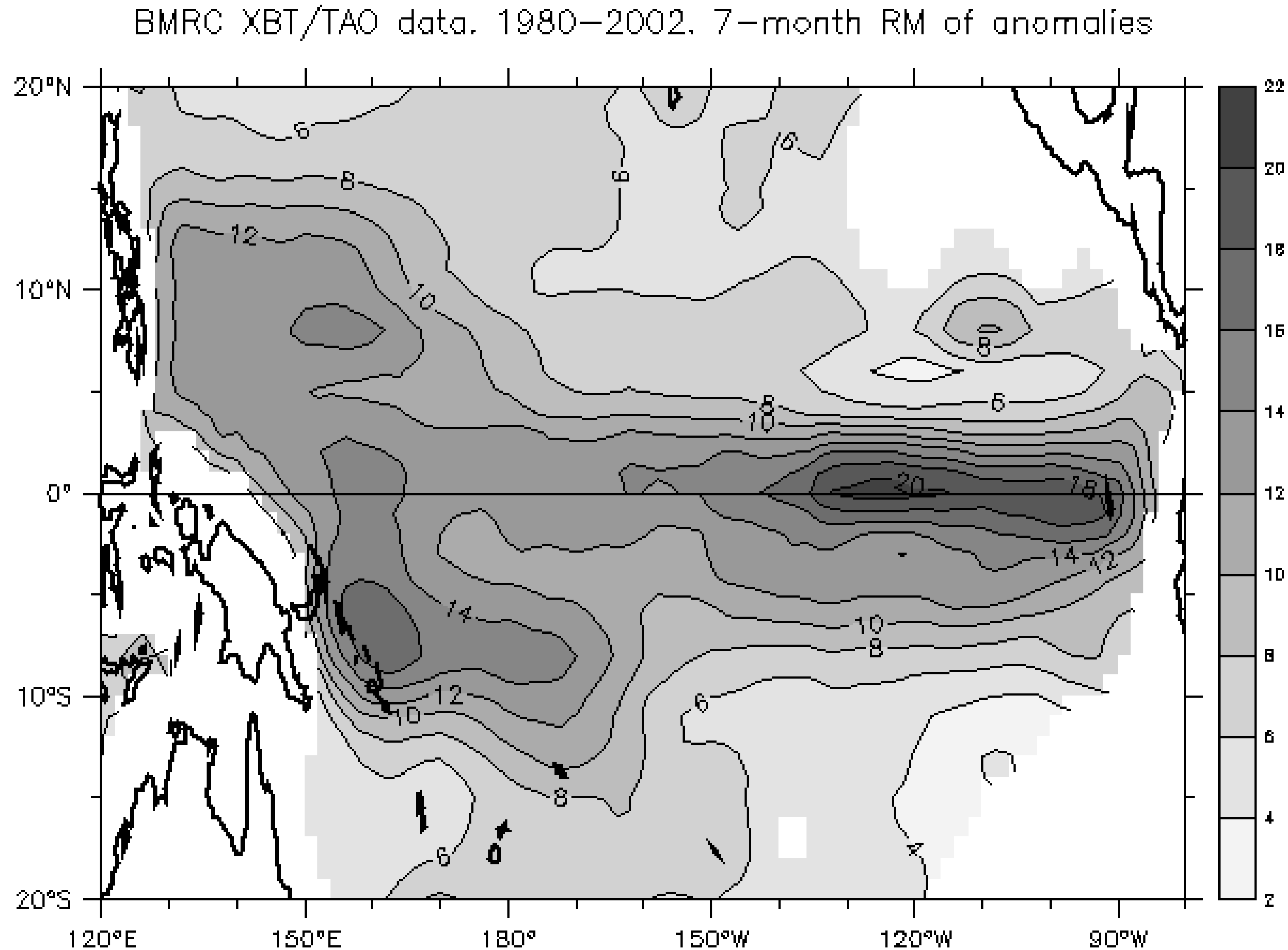
- Event-like ENSO (Wyrtki ➙ Kessler?)

⇨ The basic state is stable, thus each event requires an external trigger.

⇨ Implies that there is limited predictability.

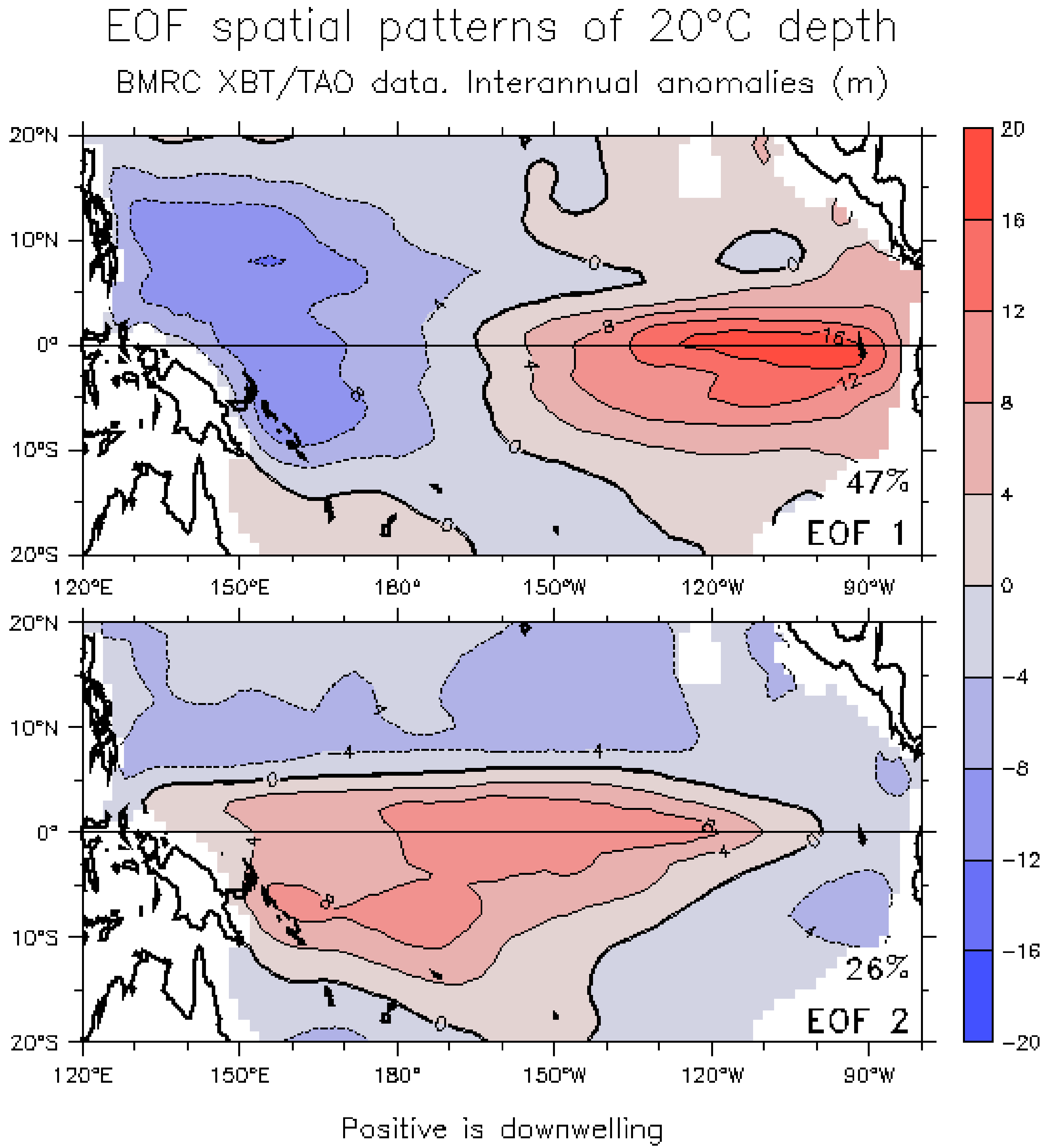
What does the data say?

Standard deviation of interannual 20°C depth

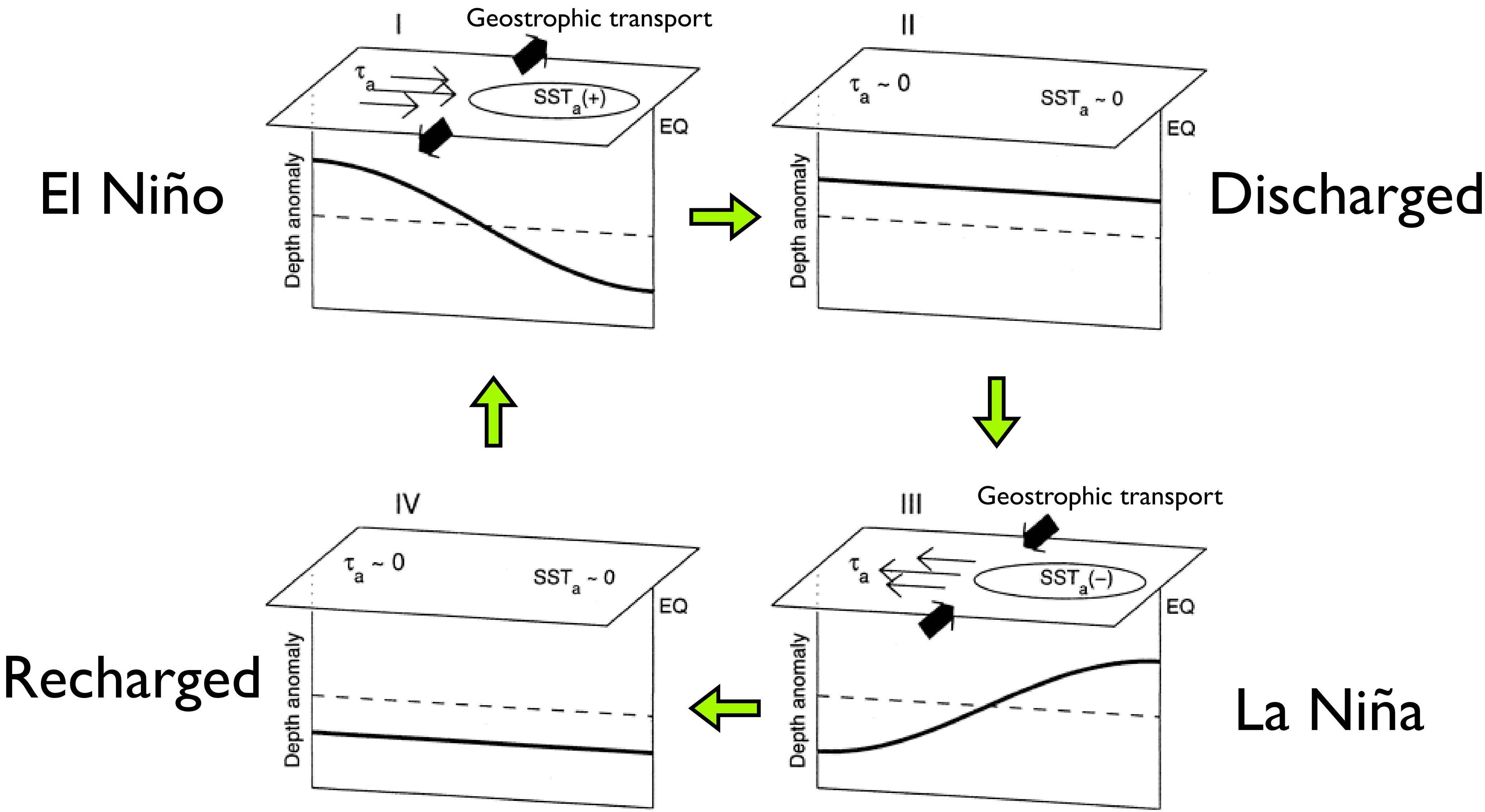


Thermocline depth variability is large on the eastern equator and in the western off-equatorial Pacific.

Spatial pattern of thermocline variability is consistent with a tilting mode (EOF 1) and zonal mean mode (EOF 2).



Evaluate the Recharge-Discharge mode using time series of eastern Pacific SST and zonal mean thermocline depth



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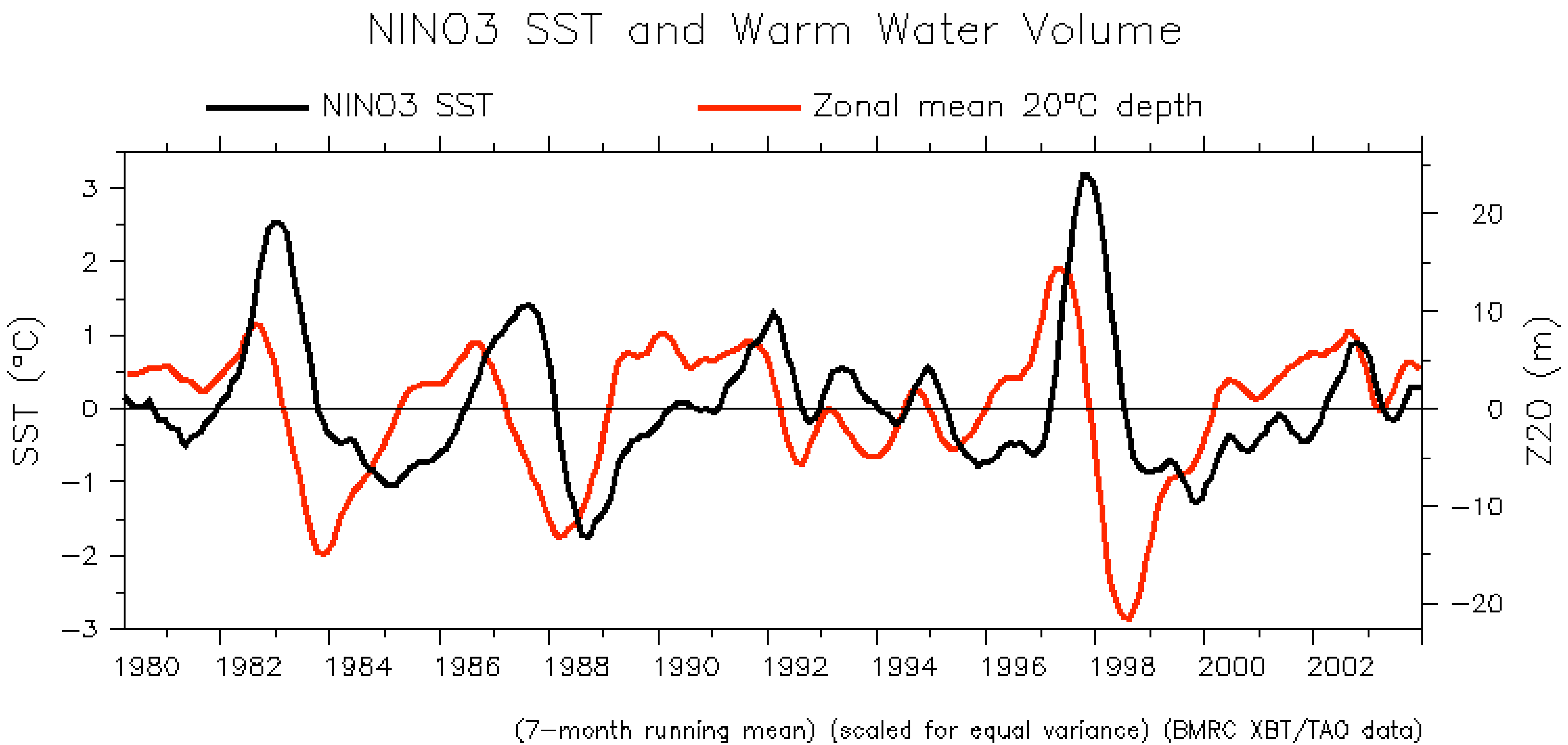
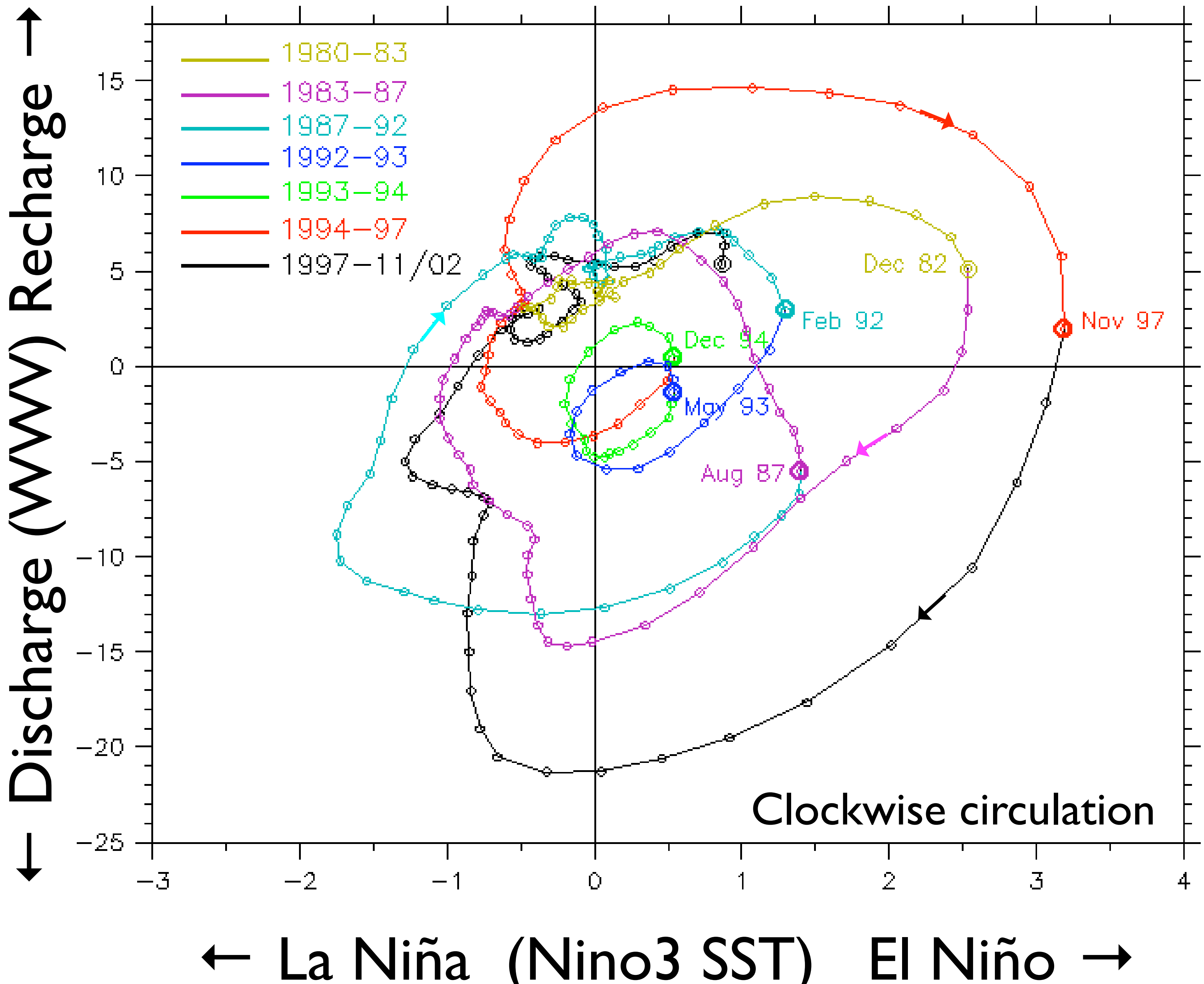
Time series to evaluate the cyclic hypotheses

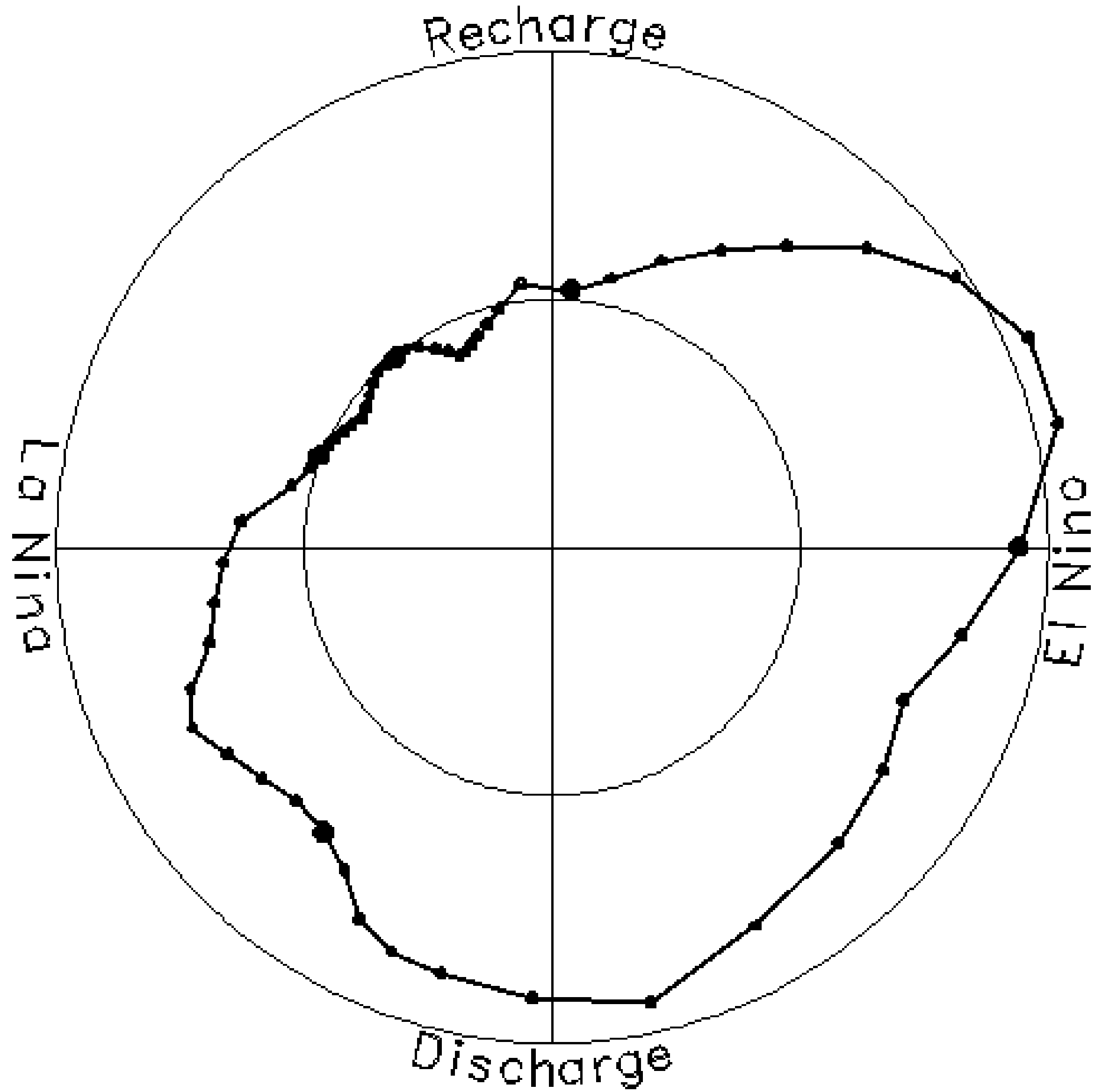


The Recharge-Discharge Oscillator predicts that mean thermocline depth should lead SST by 1/4 cycle

Nino3 SST and Warm Water Volume Phase Ellipses

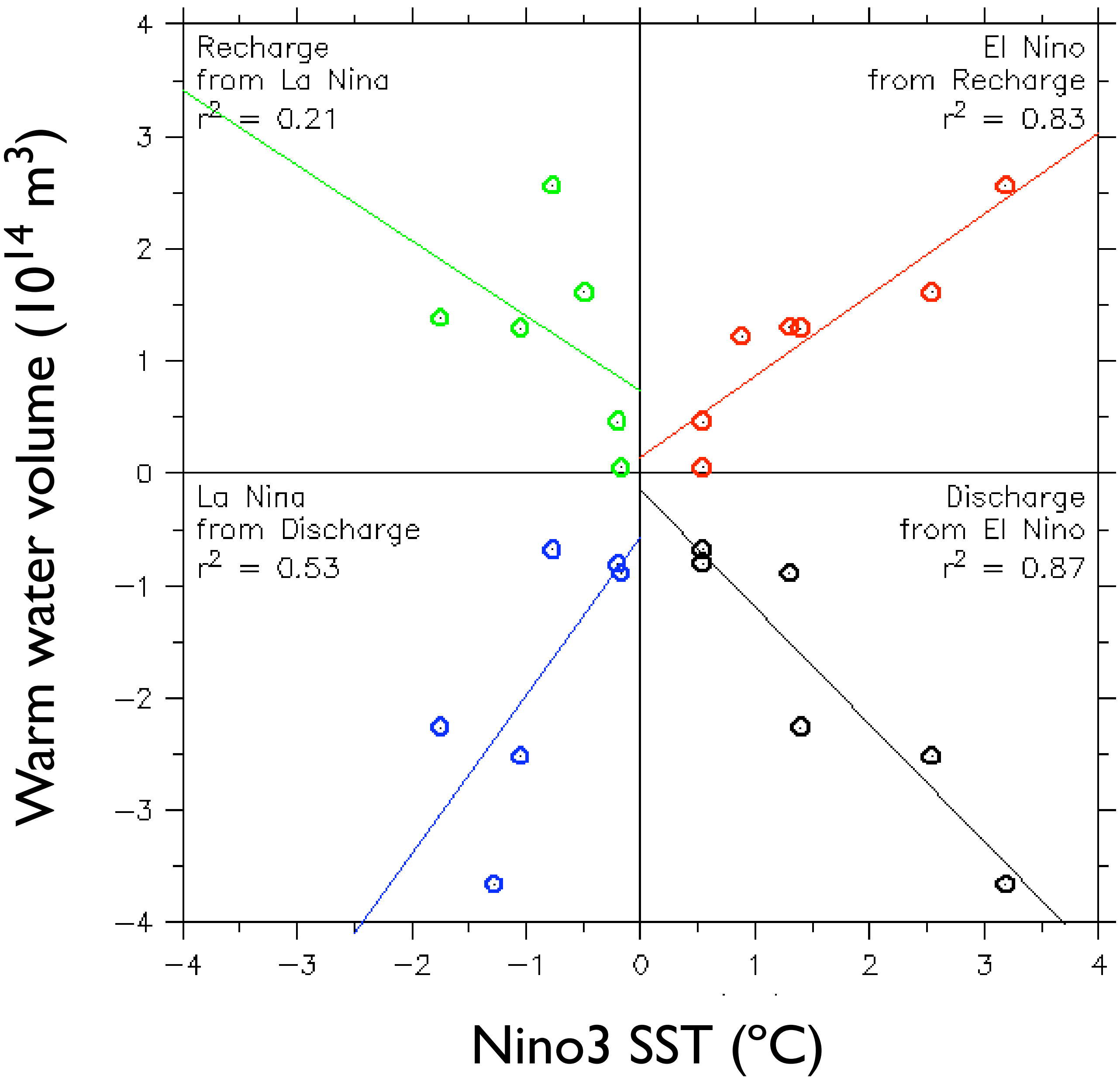


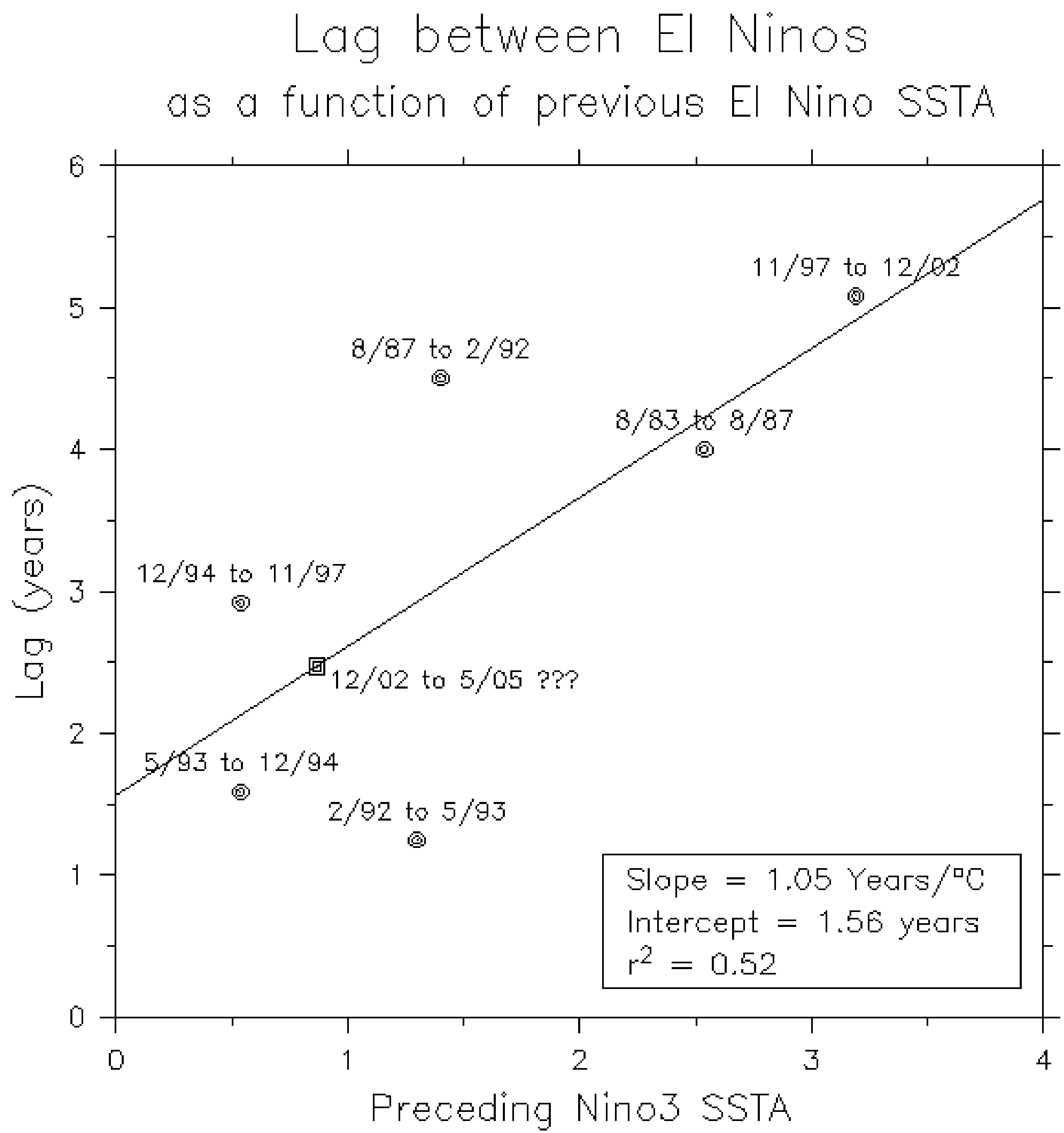
A mean ENSO cycle. Nino3 SST vs Upper Layer Volume



Observed mean amplitude and angular speed. Monthly and yearly tics
Mean cycle length is 4.75 years. Circles are 1 and 2 Std Dev

Memory of amplitude from phase to phase




Lag between El Ninos
as a function of previous El Nino SSTA
Lag (years)
Preceding Nino3 SSTA
0
1
2
3
4
5
6
0
1
2
3
4
11/97 to 12/02
8/87 to 2/92
8/83 to 8/87
12/94 to 11/97
12/02 to 5/05 ???
5/93 to 12/94
2/92 to 5/93
Slope = 1.05 Years/°C
Intercept = 1.56 years
r2 = 0.52

Conclude:

Wyrtki was right!

Observations suggest that an El Niño event leaves the system in a cool state with slightly increased warm water volume, and this state can persist for years, losing memory of previous conditions.

➙ ENSO is not a self-sustained oscillation.

The evolution of ENSO since 1980 appears consistent with the idea that the basic state is stable or nearly so, thus warm events must be triggered by (stochastic?) forcing external to the cycle itself.

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