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Rasmusson & Carpenter 1982







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Dead Dolphins and Birds Are Causing Alarm in Peru

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LIMA, Peru — Late last year, fishermen began finding dead dolphins, hundreds of them, washed up on Peru's northern coast. Now, seabirds have begun dying, too, and the government has yet to conclusively pinpoint a cause.

We are comfused by El Niño and comfusing the others too,



SST Departures (°C) in the Tropical Pacific

SST Anomalies



The Dichotomy of Wave Delayed-Oscillator (WDO) and Recharge-Oscillator (RO) paradigms for ENSO

Wave Delayed Oscillator

(Schopf & Suarez, 1988; Battisti & Hirst, 1989)



Positive SSTA \rightarrow Winds weaken \rightarrow Downwelling Kelvin wave to the east, upwelling Rossby wave to the west

Reflections at east and western boundaries cools the eastern Pacific cold tongue, shutting down El Niño and triggering La Niña

The turning round critically depends on wave speed, at a weak coupling, its period is about 8 months, but a strong coupling slows it down !!

Recharge Oscillator Theory (Wyrtki, 1985; Cane et al, 1986; Jin, 1997)

Meinen & McPhaden, 2000



 $+SSTA \rightarrow$ weaken trade winds \rightarrow discharge due to meridional transport of mass/heat content \rightarrow cools the cold tongue \rightarrow turning an El Niño around into La Nina

The timescale for renewal of the equatorial heat content depends on it's the

meriodional extent, not the wave speed!

Two valid hypotheses:

I) The ENSO continuum hypothesis: ENSO is from one coupled mode (RO/WDO) with stochastic variations

II) ENSO Duality hypothesis : CT and WP El Niño originated from the two different coupled modes (RO and WDO) with stochastic variations

Evidences in support?

Evidences in support of ENSO Duality Hypothesis Observational evidences: not by SST pattern statistics.

Theoretical / simple model evidences **#1 Quantization**.



FIG. 1. The eigenvalue distribution with respect to the index $k_j = k + j/N$. The straight line is the dependence of the imaginary part (frequency) of the eigenvalue on k_j and the curve is the dependence of the real part (growth rate) of the eigenvalues on k_j . The real part is multiplied by 10 to display its variations more clearly. Heavy dots indicate the eigenvalues for the ocean basin modes ($k_j = 0, 1, 2, \ldots$).







Evidences in support of ENSO Duality Hypothesis

#2: WP- and CT- Types of ENSO like modes in ZC model.

Eigen-vector of CT mode at H140S95



Eigen-vector of WP mode at H140S95



Evidences in support of ENSO Duality Hypothesis

#3 Two leading conceptual ENSO models capture the dynamics of the two CT/WP ENSO-like modes.

RO is an destabilized slow ocean recharge mode whose period is proportional to spatial size of the mode and is independent of wave speed!



Dependence of CT and WP modes on g'
At H140S95, g' is varying from its 50% value to its 150% value.



ENSO Duality and its Sensitivity: **Dependence on Climate State**



Summary

There are supporting evidence for El Niño Duality.

There is a WP ENSO-like mode relaying mostly on largely zonal advective feedback and its period sensitively proportional to wave delay time, more like WDO.

There is a CT ENSO-like mode relaying mostly on thermocline feedback, its period is proportional to its meridional size, more like RO.

The CT/WP and RO/WDO ENSO Duality hypothesis is worthy further testing, because it provides an fundamental framework for ENSO diversity and sensitivity. It poses an challenge / opportunity for monitoring, diagnosing, modeling, and predicting ENSO as well assessing its change and impacts.

Wave delayed oscillator (SSBH, 1988,89) is a distorted/simplified wave oscillator (CMZ, 1991), its period is intrinsically and sensitively proportional to wave speed and normally short!



WDO paradigm exclude ocean recharge mode



τ (days)

FIG. 3. The growth rate $(yr^{-1})(a)$ and period (yr)(b) of the coupled system vs time lag τ , for b = 3.9 yr⁻¹ at $\tau = 180$ days. Each curve is for a difference reference value for c (in yr⁻¹) (for the Pacific c = 2.2 yr⁻¹).







Dependence of two leading modes on mean state in a ZC model



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The star indicates the mean state H140S95, where the two modes are coexistent with comparable growth rate.