Testing a theory of El Niño with altimetry data: recharge/discharge of the upper layer of the Tropical Pacific Ocean

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With the progress in space-based and in-situ observations and in modeling, several theories of the El Niño-Southern Oscillation (ENSO) coupled system have emerged over the last 15 years. The recharge/discharge paradigm relies on the accumulation of warm water in the upper layer of the equatorial Pacific basin for the onset of El Niño and the discharge of this water for the transition to La Niña. One of the goals of our Jason-1 team is to test this theory with a combination of TOPEX/POSEIDON and Jason-1 sea level data, in-situ data and model outputs.

The 1982-83 El Niño, considered at that time as the El Niño of the century, caught the scientific community by surprise. Because of a lack of observations, this El Niño was already well developed when it was first detected. Over the next 15 years, major progress was made in understanding this coupled ocean-atmosphere phenomenon (now known as ENSO for El Niño-Southern Oscillation), to the point where it can now be predicted six months to one year in advance. This was feasible because the thermal inertia of the coupled climate system lies within the upper tropical ocean and has a slow time-scale compared to the atmosphere. Such progress was made possible by the 1985-94 TOGA (Tropical Ocean-Global Atmosphere) international program. TOGA successfully set up a routine in-situ observing system and initiated experimental prediction of ENSO. However, this observing system was mostly concentrated in the equatorial Pacific Ocean (e.g., the TAO moored array), and research satellites were very useful in complementing the in-situ data. In particular, the TOPEX/POSEIDON satellite was found to be one of the best instruments to monitor and analyze ENSO events. The description and understanding of ENSO was greatly improved during TOGA, and several theories or paradigms of ENSO were proposed. At the same time, various dynamical and statistical models were conceived for ENSO prediction. Despite the prediction by some of these models of a warm event as early as September 1996, the failure to predict the enormous intensity of the 1997-98 El Niño was a reminder to the scientific community that many gaps remain in our understanding of ENSO mechanisms.

One of the goals of our Jason-1 team is to develop a better understanding of the processes involved in the build-up of ENSO events. Wyrtki [1985] suggested that an accumulation of warm water in the upper layer of the equatorial basin, and in particular in the west, is a necessary precondition for the onset of El Niño. According to Wyrtki, a warm event appears first through the spreading of the warm water toward the east, then the upper layer of the equatorial basin is slowly depleted of its water by equatorial and coastal Kelvin waves. The end result is the uplifting of the thermocline in the east, which sets up favorable conditions for the development of the cold phase of ENSO, i.e., a La Niña event. Based on Wyrtki's idea and the positive feedback of the tropical ocean-atmosphere interaction, Jin [1997] designed a conceptual model for El Niño-Southern Oscillation (ENSO). His ocean recharge/discharge paradigm is based on the imbalance between the zonal mean equatorial thermocline and wind stress. Discharge (recharge) of the water in the upper layer occurs during El Niño (La Niña) in the open ocean away from the equator and through meridional Sverdrup transports. The duration of a complete ENSO cycle is determined by the time it takes for the upper equatorial ocean to be discharged of its warm water and then recharged.

Because of the two-layer approximation of the tropical ocean, sea level is a good indicator of the heat content of the upper layer. Hence, altimetry measurements are appropriate for studying the exchange of warm water in the tropical Pacific Ocean.
A fundamental feature of ENSO is the coupling between SST and wind stress. In order to extract the ENSO signal from sea level, a multivariate empirical orthogonal function analysis (MVEOF) analysis between sea level, SST and wind stress has been attempted over the tropical Pacific Ocean [Picaut et al., 2001]. The data are predominantly space-based, with TOPEX/POSEIDON sea level, Reynolds' SST and SSM/I wind

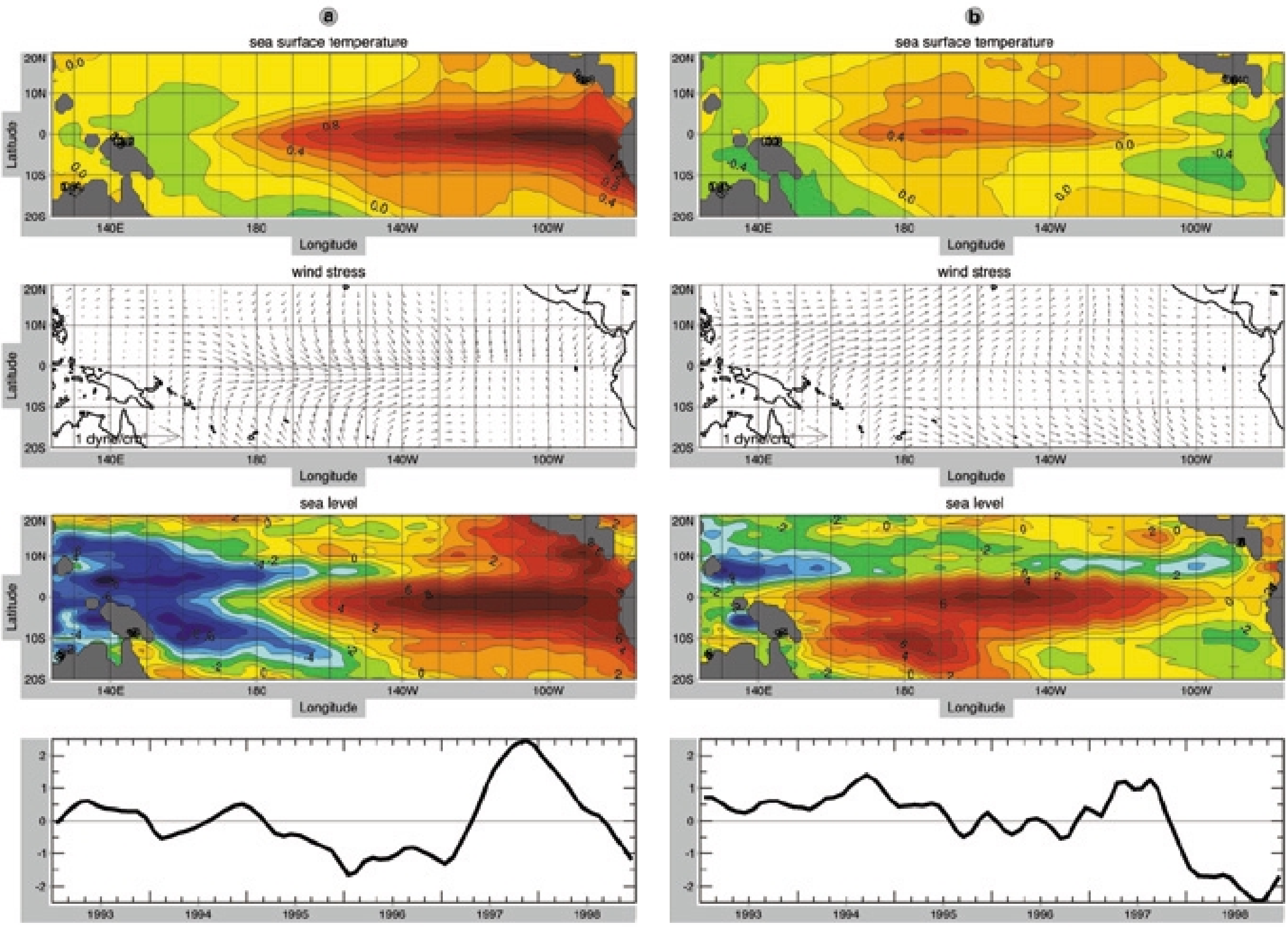

Figure 1: Spatial and temporal patterns of the first (a) and second (b) multivariate EOF analysis of sea surface temperature, SSM/I wind stress vector and TOPEX/POSEIDON sea level anomaly fields over the 1993-1998 period.

stress over the common period 1993-98. The spatial patterns of the first MVEOF (figure 1a), which accounts for 24% of the total joint variance, correspond to the well-known pattern of the mature phase of ENSO. The SST maximum is trapped near the equator in the east, and westerly winds converge into the SST anomaly during the warm phase. Sea level exhibits the characteristic signatures of equatorial Kelvin waves in the east and equatorial Rossby waves in the west, and the nodal point around the dateline underlines the exchanges of water in the upper layer between the two sides of the equatorial basin. The time series of the first MVEOF resembles the inverse of the Southern Oscillation Index and highlights the 1995-1996 weak La Niña and the drastic changes due to the 1997 El Niño and the 1998 La Niña. The second MVEOF (figure 1b) accounts for 16% of the total joint variance. With its time series resembling those of the first MVEOF, with a lead of about seven months, it partly describes the onset of El Niño and most of all the transition into La Niña. A strong sea level gradient and pivot line along the North Equatorial Counter Current separates the northern region from the southern equatorial region, which are recharged or discharged out of phase with their upper waters. This analysis is one of the first attempts to separate the basic exchange of warm water in the upper layer of the tropical Pacific Ocean during the onset and mature phases of El Niño and La Niña.

A preliminary test of the recharge/discharge theory of ENSO has recently been done by Meinen and McPhaden [2000] using subsurface data. That study will be expanded upon with a combination of TOPEX/POSEIDON and Jason-1 sea level data, in-situ data and model outputs.

References

Jin F.F., 1997: An equatorial ocean recharge paradigm for ENSO. Part I: conceptual model, *J. Atmosph. Sci.*, 54, 811-829.

Meinen C.S., and M.J. McPhaden, 2000: Observations of warm water volume changes in the equatorial Pacific and their relationship to El Niño and La Niña, *J. Climate*, 13, 3551-3559.

Picaut J., E. Hackert, A.J. Busalacchi, and R. Murtugudde, 2001: Mechanisms of the 1997-1998 El Niño-La Niña, as inferred from space-based observation, *J. Geophys. Res.* (submitted).

Wyrtki K., 1985: Water displacements in the Pacific and the genesis of El Niño cycles, *J. Geophys. Res.*, 90, 7129-7132.

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