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Ocean Science Discussions

Interactive comment on "Joint effect of the western and eastern Pacific warm pools on ENSO cycle" *by* Q. Qi et al.

Q. Qi et al.

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We really appreciate referees for their rational and constructive suggestions, and thank editor for providing us this opportunity for the final response. Here we would like to address those primary points that the reviewers mostly concerned:

1 On the innovative points of our manuscript (Anonymous referee 3)

The study of ENSO is the science of groping for the causes of the anomalous fluctuations of the SST in eastern Pacific (Nino3 region). Although, on the mechanism of ENSO cycle, researchers have proposed negative feedback theories as proposed by Delayed Oscillator;Suarez et al;1988;Western Pacific Oscillator (Weisberg et al, 1997); Recharge-Discharge Oscillator (Jin, 1997) Advective-Reflective Oscillator (Picaut et al; 1997), and so on, and also for a long time scientists have realized that ENSO is the

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result of air-sea interaction, and the ENSO cycle is virtually the process of the redistribution of mass and heat in the upper tropical Pacific Ocean (Wyrtki, 1975;1979;1985; Zebiak et al, 1987; Jin, 1997; Sun, 2003); however, the dynamics of formation and evolution of ENSO have not been completely figured out yet.

Warm pools are the warmest water mass of the sea. Therefore, in the process of air-sea interaction, they are the most dominant part that confirms the tightly coupled nature of the ocean-atmosphere system. The movement and variation of the warm pools can impact mostly by all means on ENSO through the air-sea interaction and the transportation of warm pool water. It will provide the base of theory and to virtually increase our understanding of the ENSO formation and evolution by studying the warm pool movement and variation. That is the most important significance to study the warm pools, and also the origin intention of our manuscript.

In previous studies on the relationship between warm pool and ENSO, researchers pointed out the importance of western Pacific warm pool (WPWP) and zonal wind anomaly (Fu et al, 1986; Deser et al, 1990; Lukas et al, 1992; Ho et al, 1995; Picaut et al, 1996; Delcroix et al, 1998, 2000; Machphden et al, 1998; Matsuura et al, 2000; Maes et al, 2004; Zhang et al,2004). The dynamics of the eastern Pacific warm pool (EPWP) are likely to have similar elements as those of the western Pacific warm pool (WPWP).

The ultimate goal of our manuscript focuses on the joint effect of the WPWP and EPWP on ENSO, and also to reflect the important role of meridional wind anomaly in ENSO cycle, which will certainly make an important contribution towards a better understanding of the ENSO. The point we presented in our article is the first time that attempts to analyze the possible relationship between the two warm pools and ENSO.

2 What does it mean that the displacement of warm pool denoted by 28C isotherm? (raised by both referees)

Regarding to the causes of anomalous variation of the SST in eastern Pacific, re-

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searches in the past emphasized mostly on the thermodynamic process (just like warming/cooling of the equatorial water or Nino3 SST mentioned by referee3, or like less upwelling water or remote causes that Dr. Webb talked about). Here we do not agree with the anonymous referee3 that the shift of isotherm results from warming/cooling of equatorial water or the SST in Nino3 region, because the direction of heat transportation (including zonal and meridional heat advection) during El Nino is from warm to cold, that means the warm pools- the heat engine of the tropics- are the source and the cause for the warming in eastern equatorial Pacific, but does not reverse. As to the remote causes that Dr. Webb talked about, they should certainly include the warm pools. In addition, both referees considered that the wind anomaly could result in the anomalous variation of the Nion3 SST. However, the intrusion and retreat of the warm pools can lead to changing gradients in SST between warm pools and cold tongue that contribute to wind variability. As we know, it is mostly thermodynamic that the response of air to sea, while dynamic that the response of sea to air. Based on the Bjerknes-Wyrtki theory (Bjerknes, 1969; Wyrtki, 1975, 1979), such dynamic process is stressed in our manuscript. Also, as we know, the anomalous variation of the SST in the eastern Pacific Ocean during ENSO goes with low-frequency variation of sea level; (Wyrtki, 1975, 1979, 1985). And at the same time, in El Nino events, the eastward current-North Equatorial Counter Current (NECC) strengthens (Wang et al, 1987; Zhang et al, 2001), which could have transported very warm pool of water (especially the north tongue of the WPWP) from west-central Pacific to eastern Pacific. So the movement of warm pool is associated with the variation of dynamic height. Otherwise, in one and half model, the dynamic height anomaly can come about without any thermodynamic processes. The high sea level and the eastward velocity during El Nino lead us to believe that the displacement (pileup and drain) of warm pool is dynamic. Therefore dynamic process of the warm pool is stressed in our manuscript.

It should be pointed out that there has been no monolithic standard of warm pool definition yet. In our manuscript, the warm pool was defined as the warm water surrounded by 28C isotherm, so the 28C isotherm is the token of the front of warm pool water. The

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shift of the 28C isotherm is the indication of the movement of warm pools water. Expression in our text such as invasion into (raised by anonymous referee3), or flow into (raised by Dr. Webb) can be seen from other references (Mangum, et al,1986; Hayes, et al, 1991;Castro et al, 1994; Perry,1995; BoM, 2006a; Weier, 2001; Kessler,2000; Matsuura, 2000; Mehta et al, 2005b) in which the dynamic process is focused. Even though, we are not in the least to overlook the important thermodynamic processes (e.g. thermal advection, which is in fact dynamic if it is viewed from Lagrangian viewpoint) during ENSO (which is the emphases of previous studies), it is not particularly emphasized in our manuscript.

3 Is it a cause or an effect? (A question raised by both referees)

Given that warm pool holds the balance in the coupled air and sea system and its interannual movement is the essential attribute of ENSO, here the effect is essentially to be the cause. Take the famous theory of Advective-reflective oscillator for instance, the zonal displacement of the WPWP and the westerly wind have important effect on the burst of El Nino, and the effect is essential, so one mechanism of ENSO cycle, i.e. advective-reflective oscillator, comes about. ENSO is so complex that not only the WPWP, but also the EPWP need to be taken into account, because both of them can provide virtual warm water for El Nino breakout and both of them can affect the ENSO cycle through air-sea interaction. Similarly not only zonal wind anomaly but also the meridional wind anomaly (especially in northeast tropical Pacific) should be considered in order to have a fully understanding of the mechanism of ENSO.

Technical comments (raised by Dr. Webb)

We have followed those technical suggestions to improve the quality and clarity of the manuscript in the revised manuscript:

1 F-test was implemented to evaluate the quality to compare the joint model involving both warm pools and the model that just considers one of the warm pools.

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2 The Nino3 graph was added with the same horizontal scale as original. The mean positions of warm pool edges were given in the figure caption. The impractical expression was deleted. A set of plots revealing the displacements of the warm pools and the variation of Nino3 SSTA in 1976 El Nino was provided.

3 Explanation of the 5-month running mean methodology was given.

4 The term of NE Pacific was changed to NE tropical Pacific.

Additional comments from authors:

Warm pools are three dimensional warm water mass, occupied with vast territory and deep warmest seawater, which plays a key role in the Pacific air-sea coupling system. For instance, northern tongue of the WPWP connected with the EPWP during strong El Nino event, forms a warmest water zone in the whole equatorial Pacific (Fig.1 in revised manuscript). It therefore results in the meridional wind anomaly. However, the effect of meridinonal wind anomaly on ENSO was ignored in previous studies. The movement of the warm pool associated with the zone of atmosphere deep convection, precipitation, and the convergence of wind becomes the essential attributes of ENSO (Fu et al; Deser et al, 1990; Picaut et al, 1996; Delcroix et al, 1998; Matsuura et al, 2000; Raymond et al, 2003; Maes et al, 2004). It is believed that, in the unborn theory and model of ENSO, only when the variation of the warm pool is reproduced successfully could it make good predication of ENSO. Our manuscript is very primary analysis, which focuses merely on the sea surface level and the primary correlations. The relation of the movements and oscillations of the full three-dimensional warm pool with wind stress (through air-sea interaction), currents, sea level, thermocline depth, and etc. will be addressed in another paper. This manuscript provides a new clue to ENSO research. As the study is not an end to itself, we hope our endeavor will be continued. Thanks again for helps from the editor and referees.

Interactive comment on Ocean Sci. Discuss., 5, 163, 2008.