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Processes and boreal summer impacts of the 2004 El Niño Modoki: An AGCM study

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[1] The sea surface temperature anomalies (SSTA) of tropical Pacific in the boreal summer of 2004 show a distinct tripolar pattern with warm SSTA in the central tropical Pacific, flanked on both sides by cold SSTA. The distinct conditions during the boreal summer of 2004 and the following winter were catalogued as a new coupled phenomenon named El Niño Modoki in a recent generalized study. The 2004 event is unique in the sense that it occurred without any co-occurring IOD, thereby without any possibility of external modulation of its processes and impacts in the tropics. Using observed data since 1979, we show that the 2004 event indeed involves the distinct equatorial coupled ocean-atmosphere dynamics different from the conventional El Niño. Further, using an AGCM, we confirm that during boreal summer anomalous twin Walker circulation cells associated with the El Niño Modoki SSTA give rise to observed rainfall anomalies in the tropics.
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1. Introduction

[2] Several parts of the globe experienced anomalous climate conditions during the summer (June–September; JJAS) of 2004 (see auxiliary material, Figure S1).[1] Many areas of Japan and the Far East region experienced severe drought and heat waves whereas Philippine Islands received surplus rainfall due to active cumulus activities. The Maritime Continent, and southern Mexico and Ecuador suffered from drought whereas central tropical Pacific received surplus rainfall. Peninsular India experienced weaker than normal monsoon conditions and Queensland in Australia also received less than normal austral winter rainfall. *Ashok et al.* [2007] attribute these anomalous summer conditions in 2004 to an unusual distribution of sea surface temperature anomalies (SSTA), which is composed of anomalous warming in the tropical central Pacific flanked by colder than normal SST to the east and west [see *Ashok et al.*, 2007, Figure 1b] (Figure 1). Interestingly, the maximum warming did not migrate to the eastern tropical Pacific as in case of El Niño events. In fact, the central warming maximum persisted through the following winter. The distinctness of similar SSTA evolution in some other years has been recorded earlier in studies such as *Donguy and Dessier* [1983] and *McPhaden* [2004].

[3] Because of the unique behavior of this phenomenon that is to be discussed further in section 3, the tropical Pacific tripolar SSTA pattern during 2004 was classified, as a newly identified phenomenon named the El Niño Modoki, or, Pseudo-El Niño (see *Ashok et al.* [2007] for further details of canonical El Niño Modoki). The 2004, among all the El Niño Modoki cases, is distinct from the point that it is a pure event; that is, there is no accompanying IOD event in the tropical Indian Ocean, from whose influence it would be difficult to distinguish that of the Modoki events when they co-occur, as in years such as 1994.

[4] In this article, we demonstrate for the first time, using an atmospheric General Circulation Model (AGCM), that the attributed impacts of the El Niño Modoki events in the tropics and the suggested mechanisms of teleconnection during boreal summer [*Ashok et al.*, 2007; *Weng et al.*, 2007] are plausible. While doing so, we also describe some unique and salient features of the ocean-atmosphere conditions in tropical Pacific during 2004 to exemplify the pure El Niño Modoki.

2. Datasets and Model Used and Methodology

[5] Datasets used in this study are, the Hadley Centre Global Sea Ice and Sea Surface Temperature [*Rayner et al.*, 2003] datasets, the Climate Prediction Center Merged Analysis of Precipitation (CMAP) data [*Xie and Arkin*, 1996], NCEP/NCAR reanalysis products [*Kalnay et al.*, 1996], and subsurface temperature data from the Simple Ocean Data Assimilation (SODA) [*Carton and Giese*, 2008] all from January 1979 to April 2005, Merged sea surface height (SSH) data from Aviso and satellite derived winds from Quikscat, both from 2000–2005. Anomalies are based on monthly deviations from climatology from the respective base periods mentioned above. The AGCM used in this study is based on the Japan Meteorological Agency global spectral model (JMA-GSM8911).The model, with standard physics packages such as Relaxed Arakawa-Schubert convection scheme [*Moorthi and Suarez*, 1992], uses triangular truncation at wave number 42, and has 21 levels in the vertical from the surface to about 10 hPa. Further detailed description, is provided by *Iizuka et al.* [2003, and references therein]. We have carried out two sets of experiments, each with 20 ensembles with different initial conditions, starting from January 1 and lasting through 9 months. In the first experiment, henceforth referred to as the control experiment, the lower boundary

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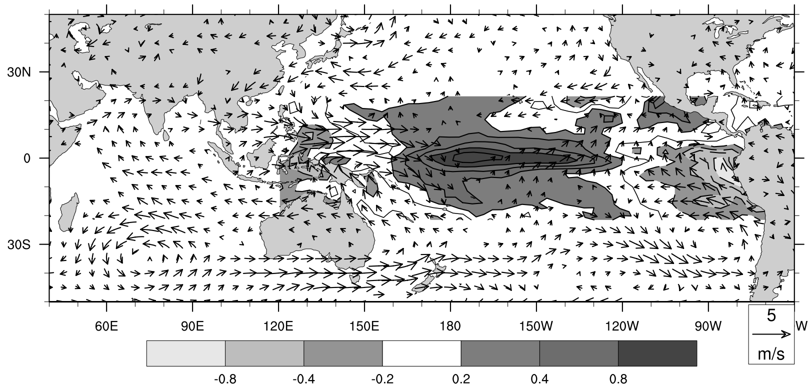

Figure 1. The JJAS composite (over 1994, 2002 and 2004) canonical El Niño Modoki SSTA forcing (°C) in the Modoki experiments. The vectors represent the corresponding composite observed surface wind anomalies (m/s).

SST are climatological. In the second experiment, henceforth referred to as the Modoki experiment, we impose the canonical monthly El Niño Modoki SSTA (Figure 1) on the climatological SSTA *only in the tropical Pacific region* to obtain the lower boundary SST forcing; the imposed SSTA are obtained by compositing the SSTA in three strongest El Niño Modoki years during 1994, 2002 and 2004. The seasonal ensemble mean differences in climate variables between these two experiments can be interpreted as the El Niño Modoki SSTA-induced responses.

3. Anomalous Evolution of the Tropical Pacific in 2004

[6] The anomalous SST warming (Figure 2a) in central tropical Pacific during boreal summer of 2004 was caused by a series of intraseasonal downwelling Kelvin waves from April in response to anomalous westerlies over the western tropical Pacific (Figure 2b). In response to anomalous westerlies in the western Pacific, warm waters in the western Pacific were transported eastward, causing colder-than-normal SST in that region. Due to the excited Kelvin waves, the SSH in the central tropical Pacific was anomalously high along with subsurface warming (Figure 2b). However, the maximum in the Kelvin wave-induced downwelling was rarely seen in the eastern tropical Pacific in most of the period despite some weak and intermittent eastward propagation of Kelvin waves beyond the central tropical Pacific, probably due to prevalence of strong easterly winds in the eastern equatorial Pacific. More importantly, the central warming was sustained by the presence of anomalous tropical easterlies over the tropical eastern Pacific and westerlies west of the 150°W. The anomalous easterlies in the eastern Pacific enhanced upwelling in the eastern equatorial Pacific. Further, maximum temperature anomalies up to $1.5 \sim 2.5$°C along the equator in summer and fall of 2004 are also observed at thermocline depth (for example, 110 m in September; figure not shown) in the central tropical Pacific. It is interesting to note that the warmest SSTA is located between 155°W and 160°E until February 2005. This is despite the weak intermittent propagation of positive SSTA to the east between September and December, also along with some spreading of the anomalous warm waters to the west during the late boreal winter; also peculiar is that the SSTA did not amplify during the eastward propagation. By the end of January 2005, anomalously cooler SSTA is again seen in both the eastern and western equatorial Pacific flanking the warmer central equatorial Pacific SSTA. All this is different from the post-1977 El Niños that are characterized by propagation of the warmest SSTA from the central tropical Pacific to the coast of Peru.

[7] The interesting patterns of SSTA (Figure 2a) in the tropical Pacific are associated with unusual patterns of wind and rainfall anomalies during boreal summer of 2004. The anomalous summer SST cooling in the east and west that flank the anomalously warm central tropical Pacific are overlaid with anomalous low level easterlies and westerlies (Figure 2b). This is apparently associated with an above normal rainfall in the central equatorial Pacific around 160°E flanked on both sides by the negative rainfall anomalies (Figure 2a). The SSTA is associated with a pair of anomalous Walker cells (Figure S2) with a common ascending limb overlying the warmer central Pacific, markedly different from the single-cell Walker circulation in the tropical Pacific during a typical El Niño case. The surface easterlies and westerlies associated with the Walker cells then reinforce the tripolar SSTA as evidenced from the persistence of SSTA and subsurface temperature anomalies (figure not shown).

[8] *Ashok et al.* [2007] attribute the drought over the Maritime Continent during the boreal summers in El Niño Modoki years to the anomalous descending branch of the western Walker cell associated with the tropical Pacific tripolar SSTA; the apparent influence in 2004, just as suggested in that study, extends northwest till Bangladesh, south India and Sri Lanka (figure not shown). The deficit rainfall in the western Pacific region also extended southward to southeastern Australia in the Southern Hemisphere [e.g., *Wang and Hendon*, 2007; *Taschetto and England*, 2009]. Negative rainfall anomalies over the equatorial eastern Pacific in response to the descending branch of the eastern Walker cell extend to Mexico. The El Niño Modoki events apparently have their own distinct signature impacts in mid-latitudes also [e.g., *Ashok et al.*, 2007; *Weng et al.*, 2007].

[9] The simulated JJAS rainfall anomalies (Figure 3a) present a tripolar pattern in the tropical Pacific, with surplus

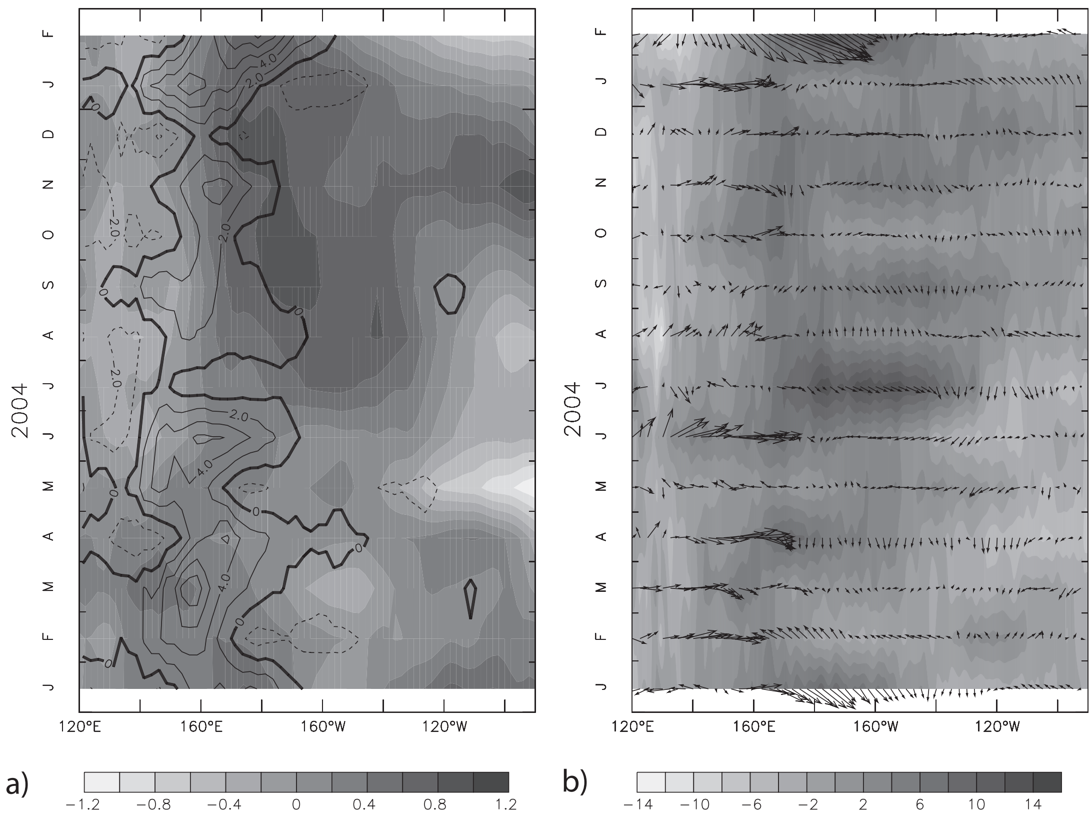

Figure 2. Evolution of (a) SSTA (shaded; in °C) and rainfall (contours; in mm.day^{-1}) averaged between 5°S–5° N and (b) Aviso SSHA in cm (shaded) and Quikscat wind anomalies (m.s^{-1}; vectors) averaged between 2°S–2°N.

values in the center flanked by less than normal rainfall in the tropical east and west. The model qualitatively reproduces most of the observed rainfall anomalies reasonably (compare with Figure S1). The deficit rainfall anomalies in the western tropical Pacific and maritime continent extend northwest into India. The simulated drought signals in the subtropical and tropical regions such as Japan, eastern Australia, Columbia etc. experience deficit rainfall and are similar to those observed in JJAS 2004, despite being just below the statistically significant levels.

[10] The simulated 850 hPa temperature anomalies (Figure 3b) in boreal summer also exhibit a tripolar pattern in the tropical Pacific in agreement with the signatures attributed to the El Niño Modoki [see *Ashok et al.*, 2007, Figure 10a]. In general the simulated features presented in Figures 3a and 3b confirm the impacts attributed to the tropical tripolar SSTA associated with the El Niño Modokis such as in 2004; the composited JJAS rainfall and 850 hPa temperature anomalies over the years 1994, 2004 and 2004 (Figure S3) also support this conclusion. To confirm the attribution of the impacts in the equatorial region and neighboring areas to the anomalous twin-Walker circulations during these events *Ashok et al.* [2007], we present the simulated Walker circulation differences between the Modoki and control experiments (Figure 4). Anomalous upward motion is simulated at the lower levels in the central tropical Pacific flanked by two anomalous subsidence zones in the eastern and western tropics, confirming the mechanism. The simulated sea level pressure distribution (Figure S4) also supports this. All these confirm the suggested mechanism for the transmission of the El Niño Modoki events during the boreal summer in the tropics.

4. Concluding Remarks

[11] In this paper, using different datasets, we examine the tropical pacific conditions in 2004 to study the evolution of a pure El Niño Modoki event in 2004. The study confirms that the 2004 phenomenon indeed involves equatorial coupled ocean-atmosphere dynamics distinctly different from the conventional El Niño; the maximum warming of the SSTA is confined to the central equatorial Pacific until boreal winter instead of propagating to the east and amplifying while doing so. We also discuss the associated rainfall anomalies during the boreal summer of 2004 as an example of the signature impacts. Using an AGCM, we further confirm that in such boreal summers, anomalous twin Walker circulation cells associated with the SSTA give rise to rainfall anomalies, which also form a tripole similar to the SSTA.

[12] Changes in characteristics of the tropical Pacific coupled system, including the location of the maximum SSTA, may have vast impact on global teleconnection patterns [cf. *Navarra et al.*, 1999; *McPhaden*, 2004; *Larkin and Harrison*, 2005; *Kumar et al.*, 2005, 2006; *Wang and Hendon*, 2007; *Weng et al.*, 2007]. We believe that the present study brings out the importance of the ENSO-

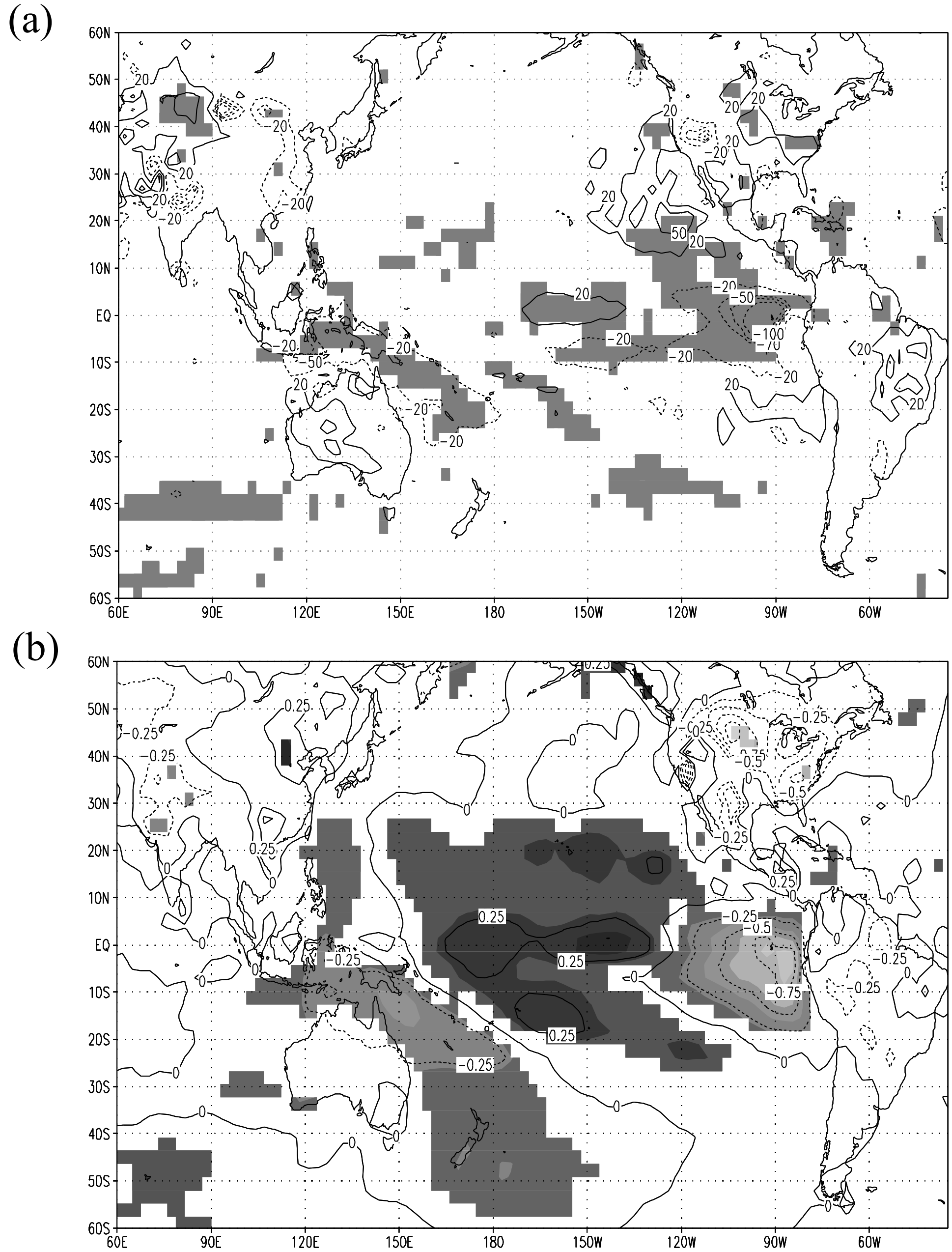

Figure 3. Simulated JJAS (a) rainfall differences (Modoki-Control) as a percentage of simulated seasonal rainfall climatology in control experiment and (b) temperature differences at 850 hPa (°C). Shaded regions indicate values above 90% confidence from a Student's 2-tailed t-test.

independent tropical Pacific coupled event from a societal viewpoint. We also plan to verify the proposed mechanisms for the Modoki impacts during boreal winter in our next study. *Ashok et al.* [2007] show that prior to late 1970s, the ENSO Modoki events are represented by the EOF2 of the tropical Pacific SST variability, and prior to that period, the EOF2 was just a representation of the ENSO phase changes [e.g., *Trenberth and Stepaniak*, 2001]; the Modoki events, however, have increased since late 1970s possibly due to background changes. The reason of the recent frequent occurrence of these events in the present climate needs further attention.

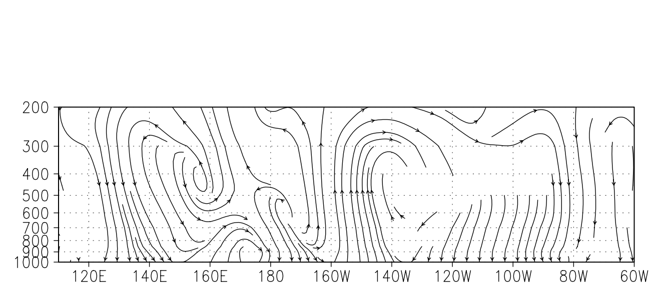

Figure 4. Simulated streamlines of summer Walker circulation difference (Modoki-Control) averaged over 10°S and 10°N.

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