Climate Scale Interactions in the Indo-Pacific Tropical basins

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Summary

The present work is actually a synthesis of three different studies investigating : (i) the role of a late 1994 strong Madden-Julian Oscillation (MJO) event in the early termination of the 1994-1995 Indian Zonal Mode, (ii) the impact of the March 1997 westerly wind event on the onset of the 1997-1998 El Niño/Southern Oscillation (ENSO) warm event, and (iii) a reflection on the sensitivity of ENSO dynamics on the warm-pool mean state and its impact on intraseasonal activity.

Our major results based on observations and models (Ocean, Atmosphere or Coupled General Circulation Models; respectively denoted OGCM, AGCM and CGCM) led us to conclude the following. (i) The November 1994 MJO event prematurely terminated the developing Indian Zonal Mode mainly by stopping the equatorial zonal advection of the warmest sea surface temperatures (SSTs) toward the western Indian Ocean (often leading to strong precipitation over East Africa). (ii) The March 1997 westerly wind event may have strongly contributed to the extreme El Niño events observed in 1997-1998 through two positive feedbacks (reduction of the trade winds in the central-eastern Pacific via the wind-forced Kelvin wave, and onset of stronger intraseasonal activity associated with the eastward displacement of the eastern edge of the warm-pool), although it is important to note that the Pacific state (oceanic and atmospheric) is crucial for these feedbacks to develop. (iii) The recent change in ENSO dynamics (mostly eastward propagating and more intense) since the 1982-1983 is concomitant with the 1976 warm shift in the Indo-Pacific warm-pool, leading us to question whether (a) intraseasonal activity (ISA) has increased or extended further west, or (b) the Pacific mean state has changed and is more sensitive to ISA. All these studies will require further investigation and multi-model examination of the suggested mechanisms to asses the robustness of the presented results.

Due to the shortness of the present report, reference is made to figures which are found in the associated presentation available on the ECMWF web site. These figures can also be made available upon request to any of the authors.

1. The November 1994 MJO event in the Indian Ocean

The two major differences between the 1994/1995 and 1997/1998 Indian Zonal Modes are the amplitude of the cooling along the Indonesian coasts (warmer in 1997/1998) and the absence of a warming along the African coast in early 1995. A close examination of the evolution of these interannual events shows that strong westerly wind anomalies linked to an MJO in November 1994 crossed the Indian basin, leaving a strong signature at the equator.

In order to assess the impact of that strong westerly wind event, we performed two OGCM simulations using the IPSL OPA model (Madec et al., 1998), where the only difference between the two simulations is that we removed the westerly wind spatio-temporal pattern. The results of our simulations (Fig. 1) show two major results: (1) a wind-forced downwelling Kelvin wave propagated eastward and favored the warming of the coastal cold anomalies by about 1°C; (2) a wind-forced upwelling Rossby wave propagated westward and led to a cooling of the western Indian Ocean by about 1.5°C. The Rossby wave impact was in fact mainly a reversal of the surface westward zonal currents which were advecting the warm SSTs (greater than 28°C). In order to investigate whether these simulated SSTAs may have generated a positive feedback with the atmosphere, leading to the early termination of the IZM, we performed two 10-member AGCM ensembles using the IPSL LMDZOR model forced by the two simulated SST fields. The mean evolution of the two 12-member ensembles (Fig. 2) clearly show that, in the absence of the MJO event, easterly wind anomalies over the equatorial Indian Ocean in December-January would have persisted, contributing to a subsequent warming of the western Indian Ocean. However, the members of the second ensemble (without the MJO impact on SST) show a large dispersion, highlighting a limit in the predictability of the IZM termination in the absence of the MJO event.

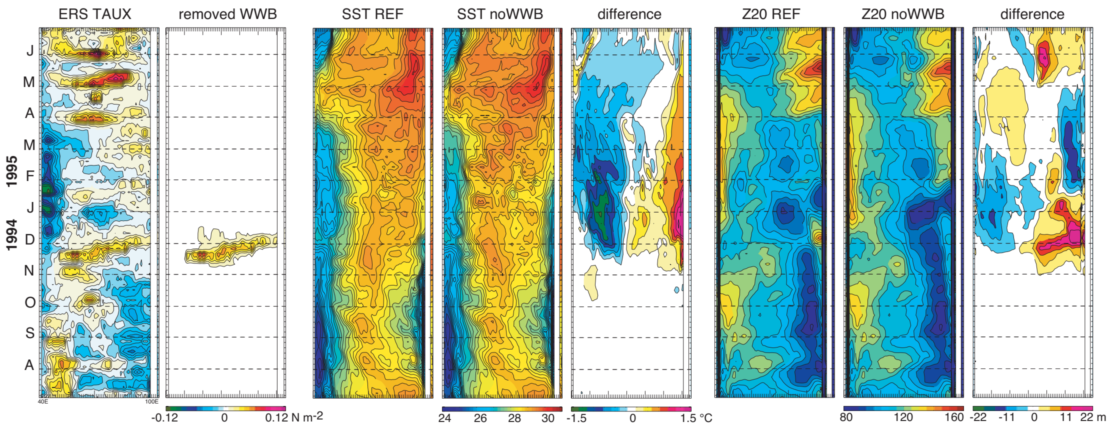

Figure 1: From left to right, 2°N-2°S mean: zonal wind stress from ERS data, westerly wind stress pattern from ERS data, SST simulated by OPA, SST simulated by OPA when forcing without the westerly wind stress pattern, SST difference between the two simulations, simulated 20°C isotherm depth, simulated 20°C isotherm depth when forcing without the westerly wind stress pattern, 20°C isotherm depth difference.

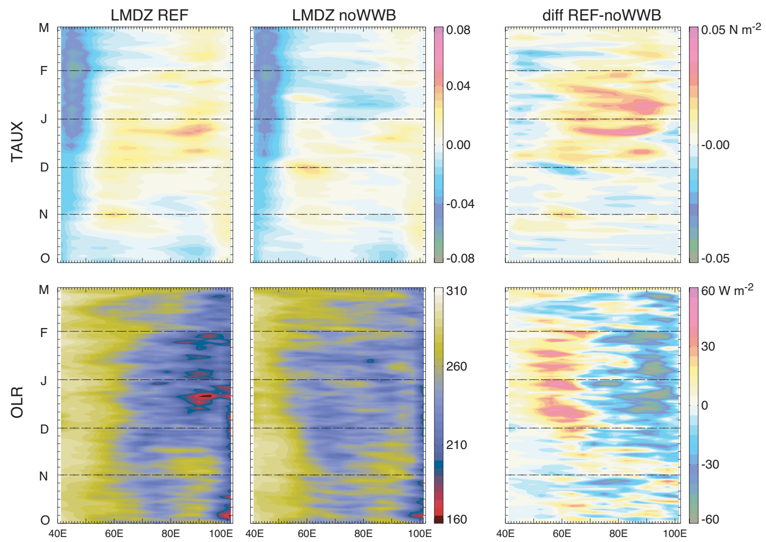

Figure 2: Simulated mean zonal wind stress (upper panels) and OLR (lower panels) when forced by SSTref (left panels), by SSTnoWWB (middle panel). Differences are plotted in right panels)

In any case, the impact of the MJO event may have also lead to an impact on the displacement of the convection regions and on the precipitation over Eastern Africa. It is therefore of importance in the future to assess whether such MJO events as that which occurred in 1994, but not in 1997, are purely stochastic (and therefore unpredictable) or whether they can be related to large scale conditions allowing for a certain level of predictability.

2. The March 1997 WWE in the western Pacific Ocean

Various studies based on observations or simple models (McPhaden, 1999; McPhaden and Yu, 1999; Boulanger and Menkes, 1999; Boulanger et al., 2001; Boulanger et al. 2003) have suggested the potential role of the March 1997 WWE in the onset of the largest El Niño on record. This question has been addressed through a three-fold investigation summarized in various papers (Lengaigne et al., 2002; Lengaigne et al., 2003; Lengaigne et al., 2004a,b). (i) The WWE impact on the ocean is investigating using the IPSL OPA model by simply running two simulations, one with and one without the WWE. (ii) Two 10-member ensembles using the Hadam3 AGCM (Ref) are forced by the two simulated SST fields. (iii) Coupled simulations are performed introducing the WWE, and sensitivity tests are conducted to pinpoint the largest coupled feedbacks important in the growth of extreme El Niño conditions.

(i) The oceanic impact of the March 1997 WWE is three-fold (Fig. 3): (1) a weak warming (0.5°C) along the Kelvin wave path as it propagates in the central-eastern Pacific; (2) a large warming (over 2°C) on the eastern edge of the warm-fresh pool (EEWFP) occurring due to the rapid displacement of the EEWFP under the development of a non-linear interaction between the wind forcing, the thermohaline and dynamical gradients present at that time (Boulanger et al., 2001; Lengaigne et al., 2002); (3) a strong cooling in the western Pacific due to the advection of cooler waters from the extra-equatorial northwest region.

(ii) The atmospheric response to these three patterns are the following (Fig. 4). (1) the weak warming in the central-eastern Pacific favors a weakening of the trades, suggesting a potential positive coupled feedback (Bjerknes-type); (2) the large SSTAs along the EEWFP favored the displacement of the convection near 160°E and the onset of westerly wind events potentially able to reinforce the displacement of the EEWFP as observed in 1997; (3) the cooling in the far western Pacific created a positive zonal SST gradient which (in the model) reinforced the subsequent intraseasonal activity.

(iii) The coupled response to the introduction of the March 1997 WWE shows a mean warm impact (Fig. 5) with patterns similar to the 1997-1998 El Niño. However among the 10 members of each ensemble, we found that the actual impact of the WWE was diverse: about 4 members developed very strong El Niño events, 4 developed moderate conditions while 2 remained in neutral conditions (see Fig. 6). Various sensitivity experiments have then been conducted zeroing the westerly wind pulses following the WWE introduction, imposing only the Kelvin wave induced warming rather than the WWE, or introducing two WWE, one in December, another one in March. Basically, the sensitivity of the distribution of the coupled model responses lead us to conclude that one single event may not be enough to develop a strong El Niño, and that a succession of various events is crucial to set up such an extreme growth. In particular, the succession of an event in December and then in March strongly increased the probability of developing an extreme El Niño. Overall, we also found that the location of the WWE with respect to the EEWFP was important in the following coupled response, as well as in the intensity of the trades at or after the moment of WWE introduction.

The robustness of our results need to be tested by performing similar simulations with other coupled models and by evaluating the sensitivity to the seasonal cycle and the interannual "mean" conditions (e.g. heat content in the western Pacific). We hope other groups will be interested in developing collaborations leading to intercomparison of coupled models in such specific case studies.

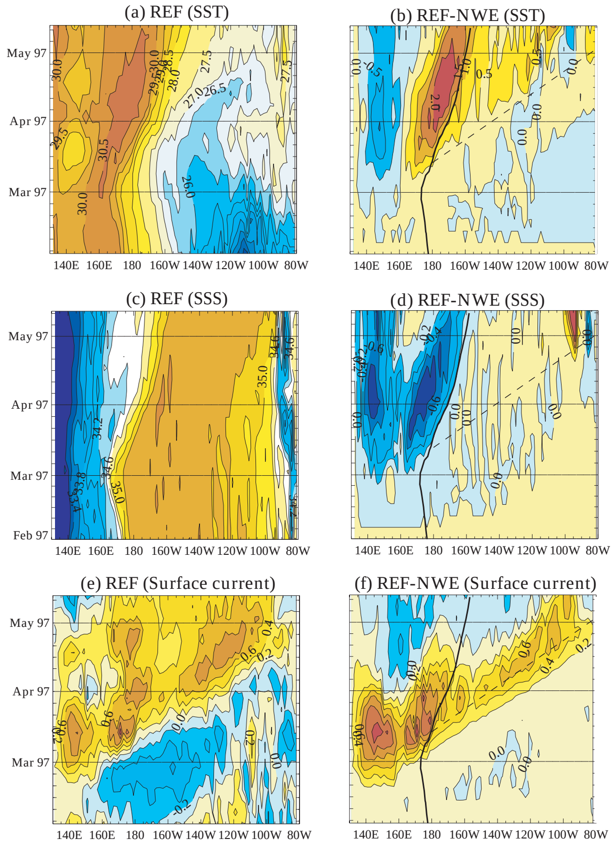

Figure 3: Equatorial sections of the REF simulations and the REF-NEW simulations in terms of SST, SSS and surface zonal current.

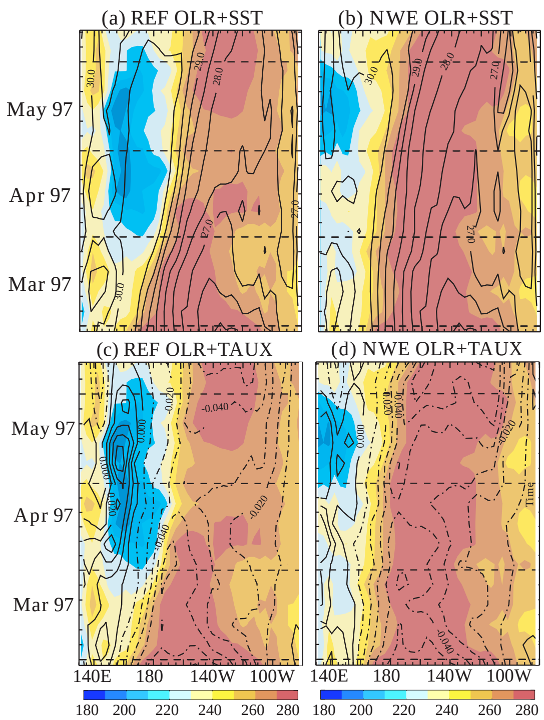

Figure 4: Equatorial sections of zonal wind stress (upper panels) and OLR (lower panels) when the model is forced by the simulated SST REF (left panels) and SST NEW (no westerly wind event; right panels).

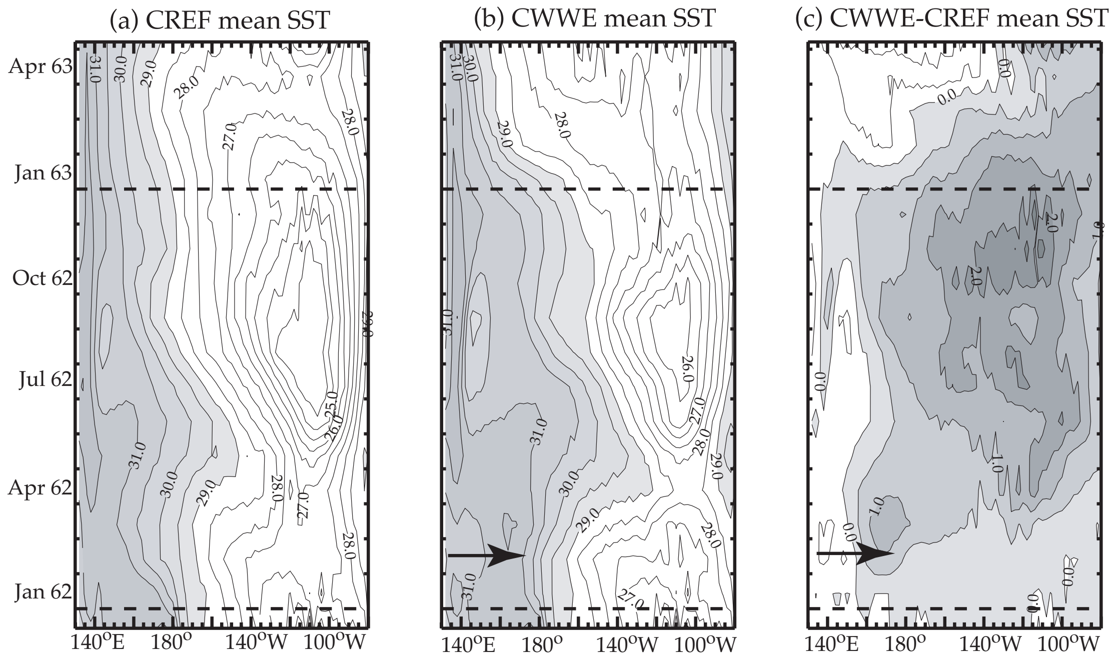

Figure 6: Equatorial sections of ensemble-mean SST simulated by the coupled model (CREF) and when inserting the March 1997 westerly wind event (indicated by the arrow, CWWE), and their difference.

3. ENSO dynamics

Interdecadal variability of ENSO has been a recent subject of intense research, focusing on the oceanic or atmospheric teleconnections with the midlatitudes as well as on the possibility of the tropics creating their own variability through non-linear processes.

In a first attempt to document the ENSO variability with respect to the decadal-to-interdecadal tropical Pacific variability, we compared various historical reconstructed SST datasets between themselves and with the Southern Oscillation pressure Index (SOI). Our conclusions (partially documented by Figure 7) were that the differences between the datasets and with the SOI was too large before the 1950's, for either interannual or decadal variability, to have any confidence in results based on that period. Thus, focusing on the last 50 years, we found that the timing of El Niño peaks changed from being first at the coast in boreal summer-fall followed by the central Pacific in boreal winter, to the opposite, with the 1982-1983 El Niño. It is worth noting that such a shift in ENSO dynamics (westward propagating to eastward propagating) and amplitude (Fig. 8) seems to be concomitant to the 1976 warm shift observed in the Indo-Pacific warm-pool. We believe that it is important that more interest be put on studying whether (1) the ISA in the western Pacific has increased (either because MJO activity is larger or because warmer SSTs favor stronger westerly wind events of various origins: MJO, cyclones, midlatitude cold air surges,...) or (2) the Pacific mean state (weakened trade winds, different thermocline slope leading to different surface regions being sensitive to subsurface anomalies) is more sensitive to ISA. Such topics have strong implications in the context of climate change impacts on ENSO characteristics (amplitude, frequency, duration).

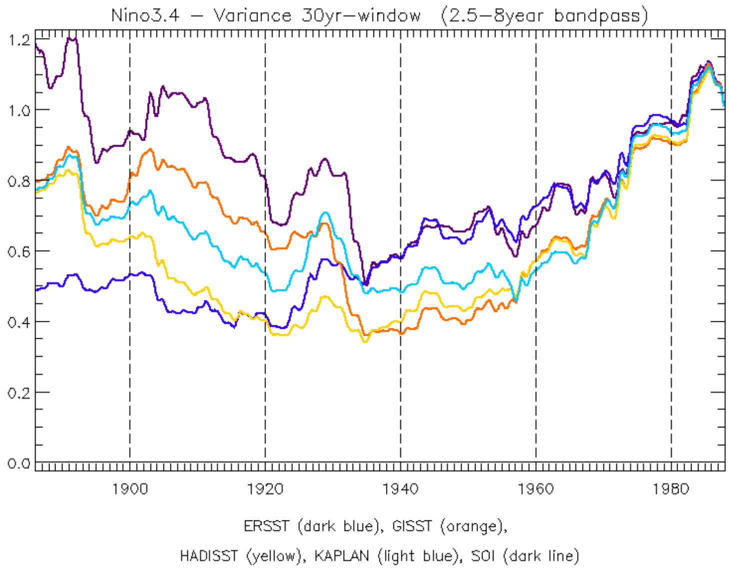

Figure 7: Niño3.4 and SOI (2.5-8 year band passed) variance computed over running 30-year windows

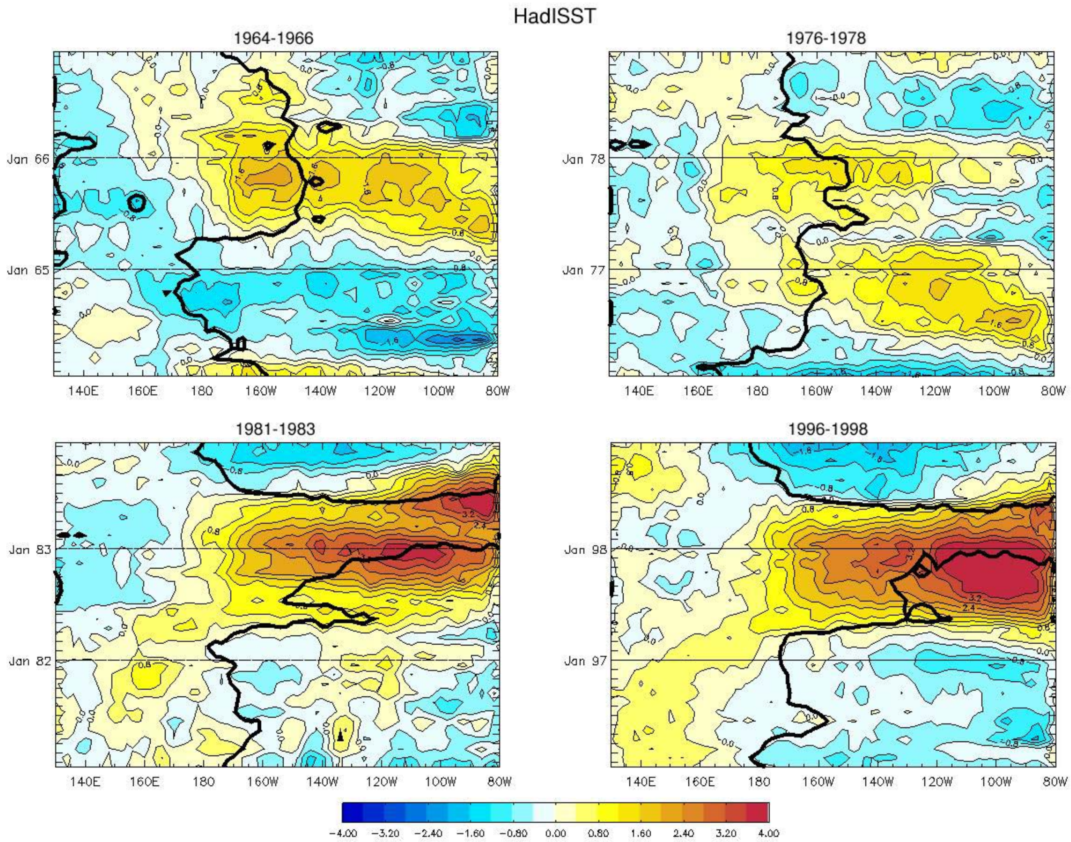

Figure 8: Equatorial sections of Hadisst SST anomalies for different El Niño events before and after the "1976 climate shift". The 28°C isotherm is overpotted in dark line.

Acknowledgments.

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