Study on the Mechanism of Climate and Ocean Variability and Their Predictability

Project Representative

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In this project, a relatively high resolution coupled ocean-atmosphere GCM SINTEX-FRCGC (SINTEX-F1: ECHAM4.6 AGCM + OPA8.2 OGCM + OASIS2.4 Coupler) has been developed under the EU-Japan collaborative framework. The ensemble seasonal prediction experiments using SINTEX-F have demonstrated high prediction skills for both ENSO and IOD. The model realistically predicted the 1994 IOD event at 3 seasons lead. This is first such an instance when an IOD event is predicted three seasons ahead in spite of the influences of active intraseasonal oscillations and monsoon variability. The SINTEX-F model showed high skills to predict ENSO at extended lead times of up to 2 years. The ACC skill scores are found to be above 0.6 up to 18 months ahead. All El Niño and La Niña events over the past two decades are predicted successfully. This demonstrates beyond doubt that the SINTEX-F has essential dynamics and physics to capture climate variations.

It has been consistently shown by our group that IOD, which has an influence as big as ENSO for a regional climate change of parts of the world, can be generated independently from ENSO. This finding based on observations is confirmed by a model experiment in which the Pacific ENSO variability is suppressed by decoupling the atmosphere from the tropical Pacific Ocean. The model could simulate IOD in absence of ENSO. It is also found that the IOD variability becomes increasingly biennial in absence of ENSO. The ENSO variability becomes quasi-pentadal in another experiment in which IOD was suppressed by decoupling the tropical Indian Ocean from the atmosphere.

Keywords: SINTEX-F, IOD, ENSO, PREDICTION

1. INTRODUCTION

The tropical ocean-atmosphere interactions give rise to coupled climate variations affecting the global climate on several time scales. The El Niño/Southern Oscillation (ENSO) coupled phenomenon of the tropical Pacific was already recognized as one such climate mode. Recent discovery of the Indian Ocean Dipole (IOD) mode (Saji et al. 1999; Yamagata et al. 2004) opened the door for ocean-atmosphere coupled studies in the Indian Ocean. The coupled mechanism related to the IOD is predominantly dynamical in nature; the equatorial ocean waves play an important role in introducing feedbacks between winds and SSTs through upper ocean dynamics (Rao et al. 2002, 2005; Yamagata et al. 2004; Behera et al. 2005, 2006). It is observed that significant IODs evolve in absence of ENSOs (Rao et al. 2002; Behera et al. 2006).

To verify the independent nature of the IOD from ENSO and to investigate their predictabilities, we carried out several ocean-atmosphere coupled global model (CGCM) experiments. The CGCM known as SINTEX-F is developed under the EU-Japan collaborative framework (Luo et al. 2003, 2005a; Masson et al. 2005). Some of these CGCM studies initiated by CVRP/FRCGC in collaboration with ESC and EU centers are accepted in a worldwide community of climate variability research, and have been followed by a lot of related researches. The research regarding the Indian Ocean variability in particular the IOD has now reached a stage to help to assess the predictability of the coupled system in the Indian Ocean. The modeling study also helps in the identification of individual underlying physical processes important for IOD evolution.

2. PHYSICAL ENTITY OF IOD

In the first model experiment ocean and atmosphere were fully coupled everywhere which is named as the control experiment. In the second model experiment the tropical Pacific Ocean was not coupled to the atmosphere which is named as the non-ENSO experiment. In this decoupling strategy, the atmosphere is forced by the climatological SST derived from the control experiment. Therefore, in the non-ENSO experiment the atmosphere did not recognize the interannual SST variability in the tropical Pacific Ocean. It is interesting to observe that the IOD evolved in the non-ENSO experiment as is in the control experiment (Behera et al. 2006). In fact in the non-ENSO experiment IOD became a dominant mode of climate variability with strong biennial signal. Therefore, it is concluded that the IOD formation in the Indian Ocean is not necessarily related to the ENSO in the tropical Pacific.

3. IMPACT OF IOD ON REGIONAL CLIMATE

Through changes in the Walker circulation and water vapor transport, a positive IOD event causes drought in Indonesia and flood in eastern Africa. This finding from an observation of relatively shorter period is well supported by 200-yr SINTEX-F coupled model results. The IOD impact on the East African region overwhelms that of ENSO during the short rains season that coincides the peak season of IOD (Behera et al. 2003, 2005). The IOD also influences the storm tracks of the southern hemisphere by modulating the subtropical jet stream during austral winter.

4. PREDICTABILITY OF IOD AND ENSO

The SINTEX-F model is found to be very successful for seasonal to interannual predictions of IOD and ENSO and associated global climate variations. Based on three models with different coupling physics and three different initial conditions for each model (Luo et al. 2005a, b), 9-member ensemble retrospective forecasts up to 24 months lead were carried out. The results showed for the first time that several ENSO events over the past two decades, particularly the long-lasting 1984-85 and 1999-2000 La Niña and the mild 2002/03 El Niño, and their related seasonal climate anomalies over vast parts of the globe can be predicted at lead times of up to two years (Luo et al. 2006a). The strongest 1997/98 El Niño event is predicted 21-month ahead despite the influence of active stochastic wind bursts.

The model also predicts IOD events in the Indian Ocean (Luo et al. 2006b). For example, the model is able to predict the strong positive IOD event of 1994 at 3 seasons ahead (Fig. 1). However, the skill scores of the IOD prediction are reduced by seasonal predictability barriers. For example, results from retrospective ensemble forecast experiments for the past two decades reveal a winter prediction barrier associated with the intrinsic strong phase-locking of IOD, and a false spring barrier due to remote impacts of ENSO. Encouragingly, increasing ensembles may improve IOD predictions. Our experimental real time forecasts with 18 members successfully predicted the weak negative IOD in 2005 fall and La Niña in 2005/06 winter at two or three seasons lead (Luo et al. 2006b).

Besides seasonal predictability barrier, the intra-seasonal oscillations play a significant role in the termination of IOD

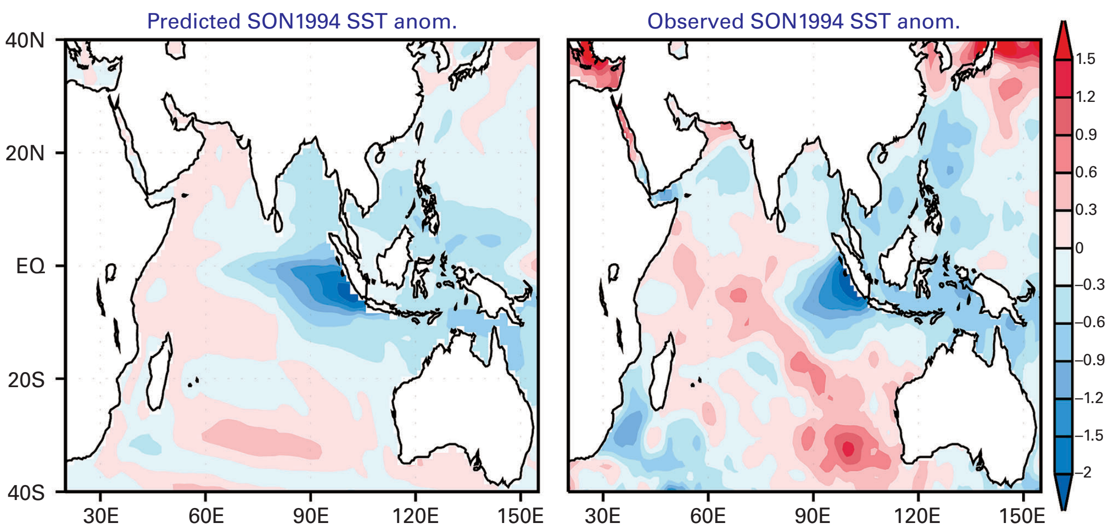

Fig. 1 The Sep-Nov SST anomalies predicted by SINTEX-F (left panel) from 1 June 1994 and its comparison with the observed SST anomalies (right panel).

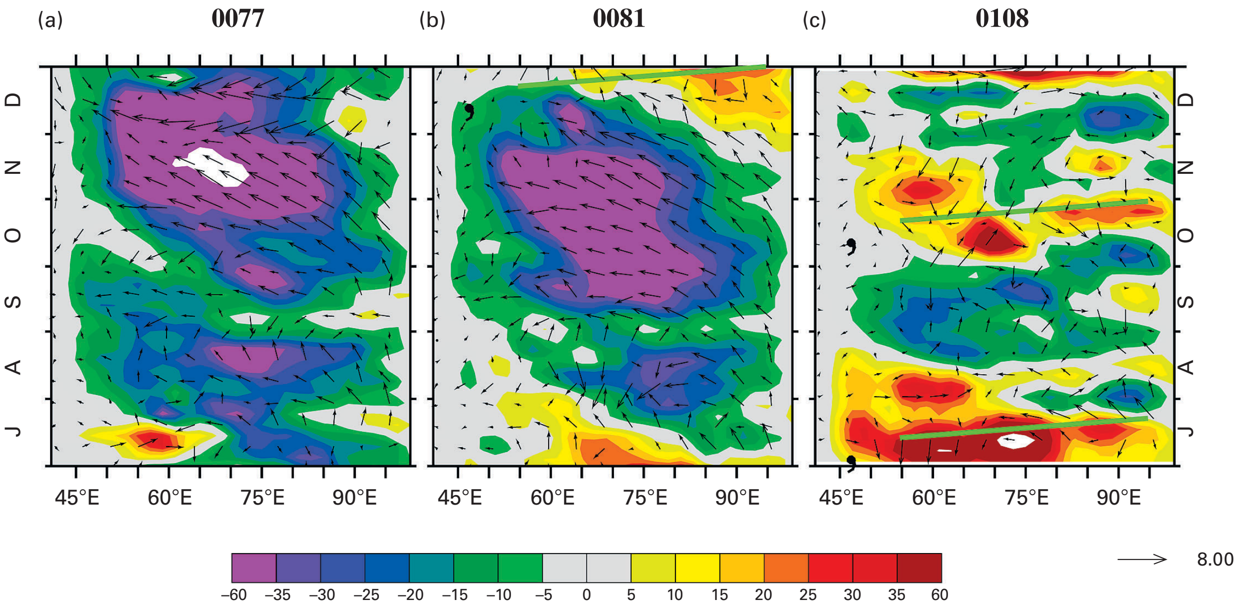

Fig. 2 The time-longitude plots of model zonal equatorial current anomalies (shading) in the upper 50m and equatorial wind anomalies (vectors), to show the eastward propagating warm Kelvin waves in the model years of 0081 and 0108 (suggested by light green lines). Those Kelvin waves were initiated by model 20-40 day intraseasonal disturbances. In contrast, the model IOD event in 0077 year was terminated by the reversal of seasonal cycle.

and thereby introducing additional uncertainties in the predictability. In normal IOD years, winds over the equatorial Indian Ocean are easterlies and intra-seasonal disturbances are also weak or absent for the duration of IOD event. However, just (about one month) prior to the IOD termination it is observed that strong intra-seasonal disturbances at 30-60 day period evolve. These unusual disturbances produce westerly wind bursts which drive oceanic Kelvin waves that travel eastward. These waves take about one month to travel from west to east in the equatorial Indian Ocean. After reaching the east coast these waves weaken the cold eastern pole of the IOD, leading to the termination of the IOD (Rao and Yamagata 2004). These observed features are simulated by the model. For example, the model IOD events in year 0081 and 0108 are terminated by downwelling Kelvin waves (Fig. 2). In other cases, such as the 0077 IOD event, an event is terminated by the reversal of seasonal cycle (Rao et al. 2006).

International collaborations based on the SINTEX-F model have been expanded in 2005. These include the collaborations of seasonal climate prediction with USA and South Korea, Asian summer monsoon with IPRC (Kug et al. 2006; Zheng et al. 2006) and with INGV (Cherchi et al. 2006), decadal IOD with the University of Tokyo (Tozuka et al. 2006), tropical climate variations with INGV (Navarra et al. 2006) and institutions in Qingdao, etc.

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気候・海洋変動のメカニズムの解明およびその予測可能性の研究

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本プロジェクトでは、欧州—日本共同研究の枠組で開発中の結合モデル SINTEX-FRCGC を比較的高い分解能で用いてアンサンブル実験を行い、エルニーニョ/南方振動(ENSO)やインド洋ダイポールモード現象(IOD)に対する極めて高い予測可能性を示した。例えば1994年に発生したIODについては3シーズン前からの予測が可能であった。季節内振動やモンスーンの変動に左右されるIODを3シーズン前から予測できたことは世界でも初めてのことであり、特筆すべき成果である。ENSOの予測可能性は昨年度の12ヶ月から18ヶ月と延び、偏差相関係数による予測スキルが0.6以上であった。

IODやENSOのような気候変動現象を力学的及び物理的に適切に表現できるこのモデルを用い、IODがENSOとは独立の大気海洋結合現象であることを示した。具体的には、太平洋の海面水温を気候学的状態にして人工的にENSOが生じない状況で結合モデルを動かしてもIODが発生することを確認した。その周期は現実よりも更に準二年的である。同様に、インド洋の海面水温を気候学的状態にして人工的にIODが生じない状況で結合モデルを動かしたところ、ENSOが準五年周期で生じることが判った。

キーワード：SINTEX-Fモデル，インド洋ダイポールモード現象，エルニーニョ/南方振動，予測研究