Process Studies and Seasonal Prediction Experiment Using Coupled General Circulation Model

Project Representative

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In this project, the coupled ocean-atmosphere GCM SINTEX-F1 developed under EU-Japan collaborative framework is used to simulate climate processes and to predict the tropical climate variabilities. During last several years of real time prediction experiments, it is demonstrated that the model has high level of skill for ENSO and IOD predictions. Recently, the SINTEX-F1 predicted well in advance the evolution of El Niño and La Niña events together with consecutive occurrences of positive IODs. The occurrences of positive IOD events in 2006 and 2007 were predicted several seasons ahead. The two positive IOD events co-occurred with an El Niño and a La Niña, respectively. The latter case clearly demonstrated that the evolution of positive IOD is not necessarily dependent on the El Niño.

The retrospective forecast results also suggest good predictive skill of SINTEX-F1 in the Kuroshio extension region. Process studies using the model simulated results suggest importance of horizontal advection in determining the surface cooling off Somalia. The El Niño Modoki signal is identified in the SINTEX-F1 simulation results using a new statistical method known as the self-organizing maps.

Keywords: SINTEX-F1 coupled model, IOD, ENSO, predictability

1. INTRODUCTION

The tropical climate modes such as the El Niño/Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are shown to influence the climate variabilities in several parts of the world. The IOD, which is an inherent air-sea coupled climate mode in the tropical Indian Ocean, has been extensively studied during the recent decade (e.g. Saji et al. 1999; Yamagata et al. 2004). Because of its large impact on the Indian Ocean rim for societal benefits it is important to have accurate prediction of the evolution of IOD in addition to ENSO.

The prediction system using the SINTEX-F1 model is found to be very successful in the prediction of IOD and ENSO and the associated global climate variations. Based on 9-member ensemble predictions, Luo et al. (2005, 2008a) showed good forecast skills for ENSO up to two years ahead of their occurrences. The model was also able to predict IOD events in the Indian Ocean (Luo et al. 2007) several seasons ahead. For example, the model is able to predict the strong positive IOD event of 1994 at 3 seasons lead time. 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. Nevertheless, SINTEX-F1 prediction system has been successful in predicting recent IOD events that consecutively occurred in 2006 and 2007.

The SINTEX-F1 retrospective hindcast experiment results

also showed good skill in the predictions of decadal extrat-ropical SST anomalies of the Kuroshio Extension region. Decadal scale oceanic variations in this region are important for climate variations in the North Pacific domain, and also Japanese fisheries.

2. SUCCESSFUL PREDICTIONS

The positive IOD event of 2007 was very unusual. It has evolved consecutively after the demise of the positive IOD of 2006 and also it has co-occurred with a La Niña. Either of those cases is very rare in the observational records of sea surface temperature (SST) and rainfall (Behera et al. 2008). Co-occurrence of positive IOD and La Niña in 1967 is the only other occasion that could be detected in the last 50 years. So, it was interesting to find that such a rare event could be predicted at least 2 seasons ahead (Luo et al. 2008b) by the SINTEX-F1 prediction system (Fig. 1).

The 2006 positive IOD event, which occurred before the 2007 event, had caused huge societal impacts, including the severe haze problem in Indonesia due to forest-fires, exceptionally long-lasting drought in Australia (e.g. Yamagata and Behera 2007), and many deaths and financial losses in East Africa due to excessive rainfall and flooding. Usually a negative IOD event develops after the demise of a positive IOD event when the warm SST anomalies from the western Indian Ocean moves back to the eastern Indian Ocean. However, in 2007 summer a weak signal for positive IOD developed with sudden cooling of SST off Java and Sumatra. Strong easterly wind anomalies appeared in the central Indian Ocean in May 2007 driving eastward propagating upwelling Kelvin waves to arrive Sumatra and Java coasts. This caused shoaling of the thermocline and SST cooling, which was helped further by the generation of southeasterlies along the coasts. Observational findings are supported by 4 consecutive IOD events found in the SINTEX-F1 model simulations.

The weak cooling in the east, warming in the west, and the easterly anomaly in the central tropical Indian Ocean were well predicted from April of 2007. However, the model predictions of IOD index showed large uncertainties in 2007 as compared to that in 2006 because of large spreads in IOD signals as found among the ensemble members (Luo et al. 2008b). The IOD impacts were also predicted reasonably well up to 1–2 seasons ahead for 2007 fall despite that this IOD signal was weak and La Niña might have large influence. In particular, the dry and warm anomalies in Australia and Arabian continent, and the floods in East Africa and South India are predicted well by the model.

The ensemble members for the real-time prediction experiments are increased to 27 from 9. The new results show some improvement in the predictability of ENSO and IOD. A series of predictability experiments were also carried out using SINTEX-F1 by decoupling Indian and Pacific Oceans respectively. Comparison of results from these experiments with the results from the real-time predictability experiment suggests that the ocean-atmosphere coupling in the Indian Ocean plays an important role in the ENSO predictability. The hindcast experiment results of SINTEX-F1 are used in an international study under CliPas to improve model predictions using multi model ensemble (MME) approach (Wang et al. 2008a, 2008b). The MME forecast based on 10 coupled models has shown improved skill compared to any one model in the prediction of Asian monsoon rainfall and most importantly the Indian Ocean variability (Jin et al., 2008).

The retrospective hindcast experiment results showed that the low-frequency SST anomalies can be predicted at 12- to 22-month lead time (Fig. 2) in the Kuroshio Extension region. The accompanying anomalies in sea surface height (SSH) and surface heat flux fields are also predicted fairly well. It is found that the sea level pressure variations are well predicted although the amplitude over the North Pacific in the model is weaker than that in the observation.

3. PROCESS STUDIES

It is well-known that the SST off Somalia is strongly influenced by seasonal upwelling during the boreal summer (de Boyer Montegut et al.; manuscript under preparation). The cold upwelled waters are then advected to offshore regions by the offshore branch of the Great Whirl (Fig. 3). However,
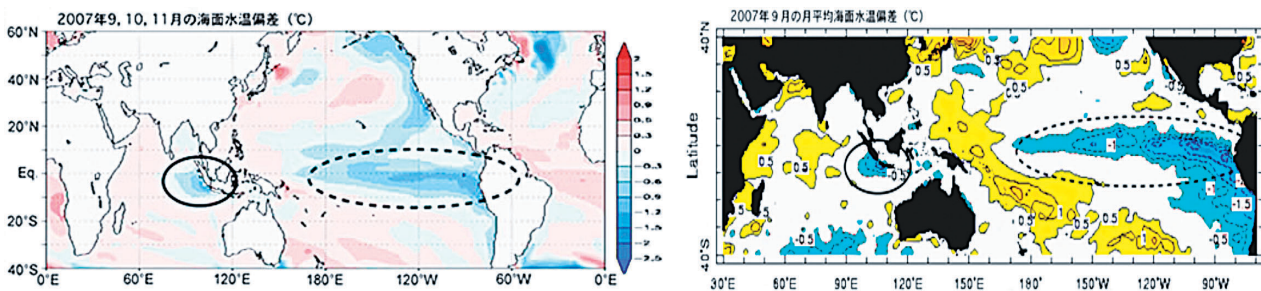

Fig. 1 The Sep-Nov SST anomalies predicted by SINTEX-F1 (left panel) from 1 April 2007 and its comparison with the observed SST anomalies (right panel) in September 2007.
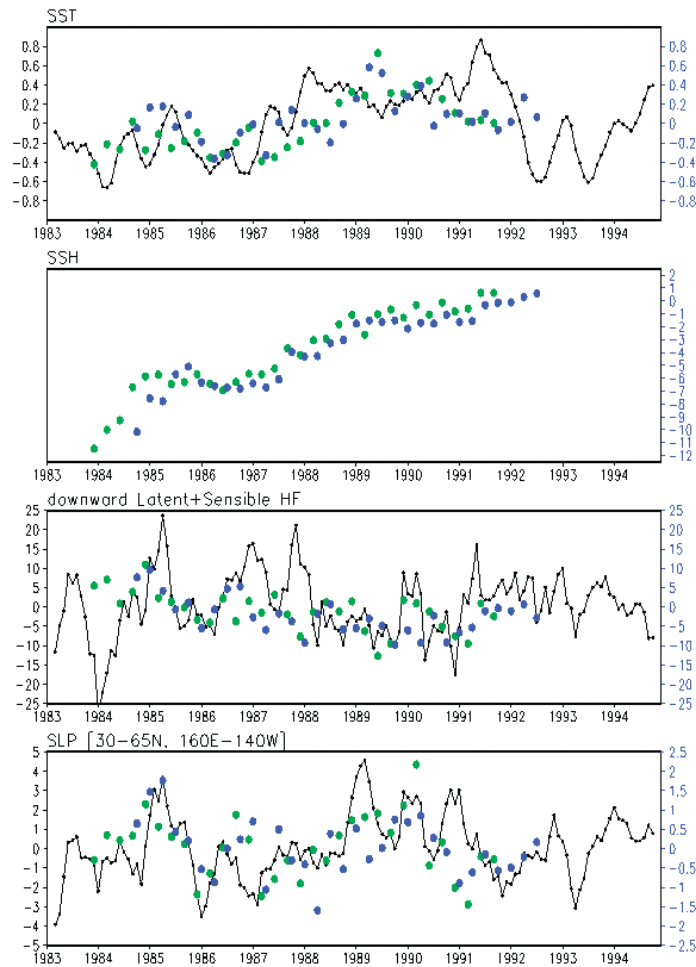
Fig. 2 Time series of area mean (top) SST, (second) SSH, (third) downward surface heat flux, in [30˚–35˚N, 140˚–180˚E] based on Japanese 25-year reanalysis (JRA25, black curve, omitted for SSH), and SINTEX-F1 12-month (green dots), and 22-month (blue dots) lead predictions (9-member mean). Bottom panel is for SLP averages in [30˚–65˚N, 160˚E–140˚W]. All variables are anomalies and a 5-month running mean is applied to filter high frequency variabilities.
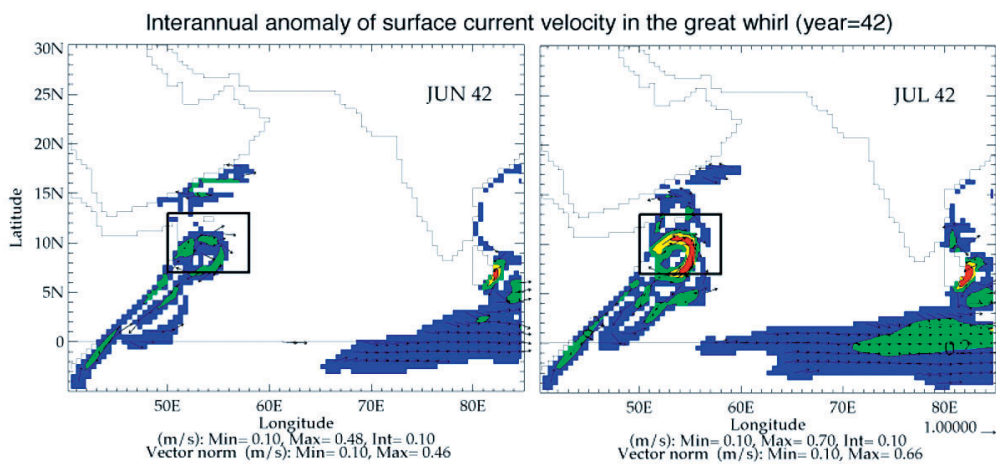

Fig. 3 Great Whirl velocity and associated upwelling intensification in a model year.

from a recent analysis of model results from the new version of SINTEX-F it is found that the SST cooling caused by the coastal upwelling is actually modulated by horizontal advec-tion. The net change in SST in that region is dependent on the relative influence of upwelling and the northward advec-tion of warmer waters from the equatorial region.

Detailed characteristics of simulated IOD events in the SINTEX-F1 results are analyzed to enhance our understanding of IOD mechanisms (Rao et al., 2007, 2008; Tozuka et al., 2007a, 2007b; Hong et al., 2008). In addition, process studies were carried out to understand the role of model resolution on simulated climate variability (Navarra et al. 2008), the role of tropical SST on monsoon variability (Cherchi et al. 2007; Izumo et al. 2008) and the changes in tropical cyclone frequencies in warmer climate (Bengtsson et al. 2007).

The SINTEX-F1 results are used to understand the low-frequency variability of the IOD and ENSO using new non-linear statistical technique called as self-organizing maps (SOM) (Tozuka et al., 2008). Composite diagrams constructed based on the SOM analyses of the SINTEX-F1 simulated SSTA have revealed interesting differences among the inter-annual SST modes of the Indo-Pacific sector. In these analyses, the basin-wide warming in the Indian Ocean is seen to be related to a strong positive SSTA in the eastern equatorial Pacific together with a negative Southern Oscillation. However, the positive IOD events in SOM classified composites are associated with a weak positive SSTA over the central equatorial Pacific. The warming in the central equatorial Pacific appears to correspond to El Niño Modoki discussed recently.

Several research papers are written/published based on the SINTEX-F1 results. These are listed in the reference list. A new version of the model named as SINTEX-F2 (which has ECHAM5 T159L31 + OPA 0.5x0.5L31 + OASIS3) is developed. Model results are intercompared to remove the biases in the new version of the model.

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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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　日欧協力のもとで開発されたSINTEX-F1大気海洋結合モデルを用い、インド洋・太平洋熱帯域を中心とした気候変動現象の再現実験および予測実験を行った。これまでの本プロジェクト研究の予測実験成果の積み重ねにより、エルニーニョ現象やインド洋ダイポールモード現象（IOD）の予測スキルは世界のトップクラスとなり、特にIOD予測では、現在最も予測スキルの高いモデルとなっている。2006年および2007年には、2年連続して正のIOD現象が発生するという過去に類を見ない状況となったが、SINTEX-F1モデルは両年のIODをそれぞれ半年程度前から予測することに成功した。また、中緯度域の変動に関しても、黒潮続流域の大気海洋場の予測スキルが非常に良いことが示された。

　SINTEX-F1モデル結果の詳細な解析から、インド洋熱帯域の気候変動に多大な影響を与えるソマリア沖の海面水温偏差の変動に対して、水平移流が非常に重要な役割を果たしていることが明らかとなった。また、自己組織化マップ法（self-organizing maps）という新たな統計解析手法を用い、SINTEX-F1シミュレーション結果にENSOやIODのみならず、「エルニーニョもどき」現象が有意に再現されていることも確認された。

キーワード：SINTEX-F1結合モデル, インド洋ダイポールモード現象（IOD）, ENSO, 予測可能性