Process Studies and Seasonal Prediction Experiment using Coupled General Circulation Model

Project Representative

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In this project, a relatively high resolution coupled ocean-atmosphere GCM SINTEX-FRCGC (SINTEX-F1: ECHAM4.6 T106L19 AGCM + OPA 8.2 ORCA2 OGCM + OASIS2.4 Coupler) has been developed at FRCGC under the EU-Japan collaborative framework. The model has shown excellent skill in reproducing tropical climate variabilities including the variabilities of Indian Ocean Dipole (IOD) and El Niño/Southern Oscillation (ENSO). Using sensitivity experiments it is found that the ENSO variability is affected by the IOD variability. ENSO events last longer and are intense in absence of IOD events. The predictability experiments using the SINTEX-F showed high skills in predicting the ENSO and IOD. ENSO can be predicted up to 24 months ahead with ACC skill scores above 0.5. All past El Niño and La Niña events, including the strongest 1997/98 warm episode, are predicted successfully. The 2006 IOD event was successfully forecast up to one year lead in a real time manner. The IOD predictability is affected by the spring and winter barriers in addition to the barriers raised by process with different scales such as monsoon, ISO and synoptic disturbances in the Indian Ocean.

Keywords: SINTEX-F, IOD, ENSO, BIAS, PREDICTION

1. Tropical climate modes and their interactions:

The SINTEX-F coupled model showed remarkable skill in simulating realistic ocean-atmosphere conditions in the tropical Indo-Pacific sector ([1], [2]). The model results also corroborated observational findings that the IOD is an intrinsic coupled mode of the Indian Ocean ([3]). To verify this observed independent nature of the IOD we carried out several atmosphere-ocean coupled global model (CGCM) experiments using SINTEX-F. In addition to a globally coupled run is named as the control experiment, a couple of sensitivity experiments are carried out by decoupling the tropical Pacific (no-ENSO) and the tropical Indian Oceans (no-IOD). 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. Similarly in the no-IOD experiment the tropical Indian Ocean was decoupled from the atmosphere.

It is interesting to observe that the IOD evolved in the non-ENSO experiment as is in the control experiment. 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. Moreover, the IOD impact on the East African region overwhelms that of the ENSO during the short rains season that coincides the peak season of IOD. However, it is found that the western pole of a positive IOD event is warmer when concurrent with an El Niño event.

This link to El Niño is associated with both the atmospheric bridge and oceanic connection. The western pole is seen to be affected by changes in the Walker Circulation and Indonesian Throughflow during concurrent IOD and El Niño events.

Further, from a comparison between the no-IOD experiment and the control experiment results, it is found that the periodicity of the ENSO variability is affected by the IOD variability. In the no-IOD case, ENSO variability was predominantly pentadal as compare to a variability of 3–4 years periodicity in case of the control experiment. It is also found that the concurrent evolution of the IOD shortens the average lifespan of ENSO; ENSO events are seen to prolong until the summer of the following years in no-IOD case. This indicates that the future variations in IOD evolutions, which are expected to be more frequent under the stress of climate change, can change the ENSO variability in the Pacific.

In another set of sensitivity experiments, the model is used to assess the role of the Somali upwelling on the monsoon variability of the Indian region. It is found that a decrease in the upwelling strengthens monsoon precipitations along the west coast of India by increasing SST along Somalia-Oman coasts and thus local evaporation and water vapor transport towards the Indian Western Ghats (mountains).

2. Predictability Experiments:

A forecast system is developed using SINTEX-F with only sea surface temperature (SST) information assimilated in the model prediction experiments. The coupling physics is perturbed for each member through varying interaction between ocean surface current and surface wind stress ([4]). This accounts for the uncertainties not only in the initial conditions but also partly in the model physics. Compatible initial conditions between the atmosphere and ocean are generated using the simple coupled SST-nudging scheme with a strong restoring coefficient to the observations. From an earlier predictability experiment, it is found that the model has a high predictability score for ENSO: All past El Niño and La Niña events, including the strongest 1997/98 warm episode, are predicted successfully at 12-month lead time. The model ACC skill scores reach above 0.7 at 12-month lead time with the RMSEs much smaller than one standard deviation of the Nino3.4 SST index. Recent hindcast experiments for extended ENSO prediction show that several ENSO events over the past two decades can be predicted even up to 24 months lead (Fig. 1, [5]).

Recently, the IOD is shown to have profound socio-economic impacts on various parts of the world. A predictability experiment is carried out to access the model's skill in predicting the IOD. Prior to that retrospective ensemble forecasts of IOD index for the past two decades show skillful IOD predictions up to a season ahead. Skill scores are seen to remain above 0.5 until 3–4 months lead time. The shorter lead time for IOD predictability as compared to that of ENSO is caused by a winter prediction barrier associated with its intrinsic strong seasonal phase-locking. The predictability of IOD is also marred by various modes of climate variability found in the Indian Ocean such as the monsoon, ISO and synoptic weather disturbances. However, prediction skills of the SST anomalies in both the eastern and western Indian Ocean are higher than those of the IOD index; this is due to the influences of ENSO which is highly predictable by the model. Nevertheless, the model predicts the extreme positive IOD event in 1994 at 2–3 seasons lead. The strong 1997 cold signal in the eastern pole, however, is not well predicted owing to errors in model initial subsurface conditions. Interestingly, the model could successfully predict the IOD event of 2006 one year ahead (Fig. 2, [6]). This was the first time that a real-time forecast system predicted

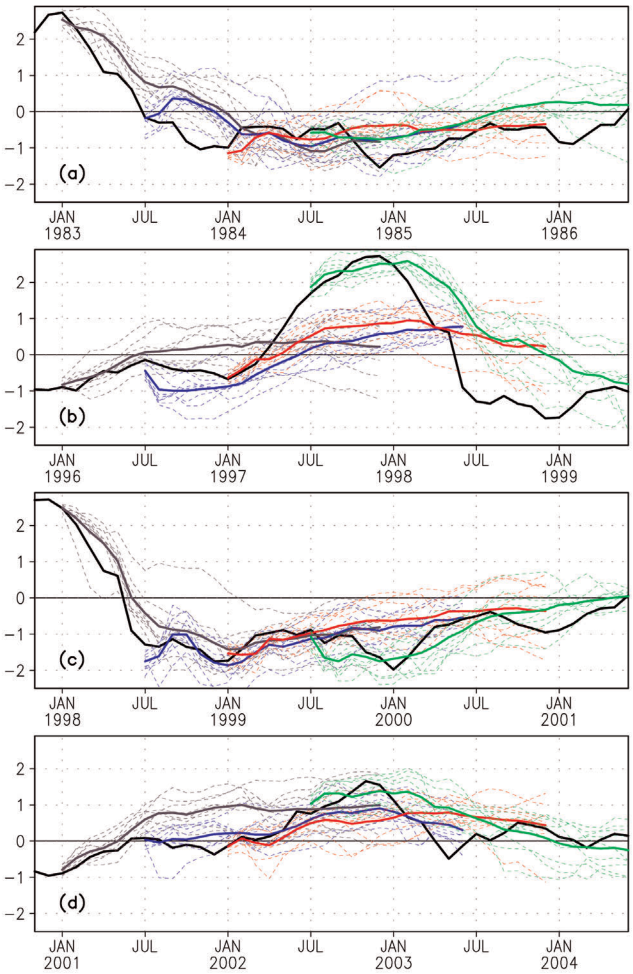

Fig. 1 a) Prediction plumes of the monthly Niño3.4 SST anomalies initiated from 1 January 1983 and 1984, and 1 July 1983 and 1984 (grey, yellow, blue, and green lines) for the 1984/85 La Niña event. b-d) Same as in a), but for the predictions of the 1997/98, 1999/2000, and 2002/03 ENSO events, respectively. The thick solid (thin dashed) colored lines show 9-member ensemble mean (each member) predictions for 24 target months. The thick black curves denote the NCEP monthly analysis.

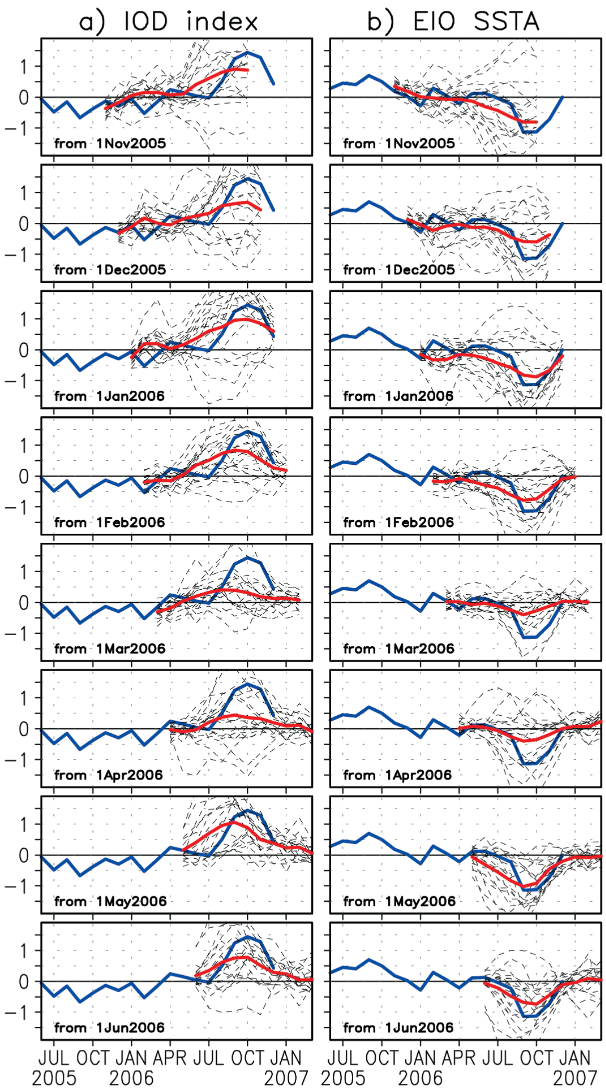

Fig. 2 Prediction plumes of the IOD index and eastern Indian Ocean (EIO, 90˚–110˚E, 10˚S–0˚) SST anomalies initiated at 1-month intervals from 1 November 2005 to 1 June 2006. The blue curves denote NCEP monthly SST analysis and the red curves the 18-member ensemble mean forecasts for 12 target months. The dashed lines denote individual member forecasts. The IOD index is defined as the SST anomaly difference between the western (50˚–70˚E, 10˚S–10˚N) and eastern Indian Ocean.

the IOD at such a long lead time anywhere in the world. The predictability is owing to the negative heat content anomalies in the southwestern Indian Ocean associated with the negative IOD event of 2005 and La Niña event in 2005/06 boreal winter.

Real time seasonal forecasts at one-month intervals with increased ensemble members have been started since 2005. Climate forecasts out to 12 months has been made available and continuously updated every month on http://www.jamstec.go.jp/frcgc/research/d1/iod/index.html.

3. Development of higher resolution SINTEX-F model:

A new version of SINTEX-F model with high resolution ocean and atmosphere components has been under development. The atmosphere model is ECHAM5 with many improved physical processes compared to ECHAM4. The horizontal resolution varies from T106 to T319 with 31 (or 60) vertical levels. The ocean model is OPA9 with and without sea ice model. Compared to OPA8, many physical processes have been improved including the partial steps for bottom bathymetry. The horizontal resolution is 0.5˚ globally with 31 or 300 vertical layers. The coupler is OASIS3 with better parallelization efficiency. Preliminary results based on the new coupled model are encouraging.

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References:

[1] Yamagata, T., S. K. Behera, J.-J. Luo, S. Masson, M. Jury, and S. A. Rao, Coupled ocean-atmosphere variability in the tropical Indian Ocean. In Earth Climate: The Ocean-Atmosphere Interaction, C. Wang, S.-P. Xie and J.A. Carton (eds.), Geophys. Monogr., 147, AGU, Washington D.C., 189–212, 2004.

[2] Luo, J.-J., S. Masson, E. Roeckner, G. Madec, and T. Yamagata, Reducing climatology bias in an ocean-atmosphere CGCM with improved coupling physics. *J. Climate*, **18**, 2344–2360, 2005a.

[3] Behera, S. K., J.J. Luo, S. Masson, S. A. Rao, H. Sakuma and T. Yamagata, A CGCM study on the interaction between IOD and ENSO, *J. Climate*, **19**, 1608–1705, 2006.

[4] Luo, J.-J., S. Masson, S. Behera, S. Shingu, and T. Yamagata, Seasonal climate predictability in a coupled OAGCM using a different approach for ensemble forecasts. *J. Climate*, **18**, 4474–4497, 2005b.

[5] Luo, J.-J., S. Masson, S. Behera, and T. Yamagata, Extended ENSO predictions using a fully coupled ocean-atmosphere model. *J. Climate*, accepted, 2007a.

[6] Luo, J.-J., S. Masson, S. Behera, and T. Yamagata, Experimental forecasts of Indian Ocean Dipole using a coupled OAGCM. *J. Climate*, **20**, 2178–2190, 2007b.

大気海洋結合大循環モデルを用いたプロセス研究と季節予報実験

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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、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)といった熱帯域に顕著な気候変動現象を極めて高いスキルで再現することに成功した。このモデルを用いて感度実験を行ったところ、ENSOの変動がIODの変動に影響を受けていることがわかった。例えばIODが発生しない年に生じたENSOは持続期間が長く、またその振幅も大きい。このように現実の世界を非常によく模擬できる結合モデルを用いて過去に発生したENSOの予測可能性を調べたところ、24ヵ月前からENSOを予測することができ、しかもその際の自己相関係数による予測スコアが0.5以上であった。一方、IODの予測可能性は、ちょうどENSOのそれにいわゆる「春の障壁」があるように、「冬ないし春の障壁」に影響を受け、またモンスーン、季節内振動、インド洋の総観規模擾乱といった様々な時空間スケールを持つ現象によっても影響を受けることがわかった。

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, モデルバイアス