Process Studies and Seasonal Prediction Experiment Using Coupled General Circulation Model

Project Representative

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In this project, a high resolution coupled GCM SINTEX-FRCGC (SINTEX-F1.0: ECHAM4.0/5 AGCM + OPA 8.2 OGCM + OASIS Coupler) has been developed under the EU-Japan collaborative framework. The model could reproduce the correct phase of the IOD, its influence on the rainfall variabilities over East Africa and La Plata during boreal fall and decadal variability in the Indian Ocean. In a processes study, it is found that the barrier layer plays a role in the spring warming of the southeast Arabian Sea and associated onset of Indian summer monsoon. The predictability experiments using the SINTEX-F showed high skills in predicting the ENSO signal at 12 month lead time with ACC skill scores above 0.7. All past El Niño and La Niña events, including the strongest 1997/98 warm episode, are predicted successfully with the 12-month lead time. Various model resolutions are also tested.

Keywords: SINTEX-F, IOD, ENSO, BIAS, PREDICTION, 2004FY

IOD and ENSO Analyses:

The first version of the SINTEX-F coupled model showed remarkable skill in simulating realistic ocean-atmosphere conditions in the tropical Indo-Pacific sector (Yamagata et al. 2004). Based on the model results several research articles are on various stages of publication. Model simulated results were used to investigate the regional climate variabilities in response to IOD and ENSO. It is found that the model reproduced the double peaks observed in annual rainfall of the Eastern Africa (Behera et al. 2005). Those peaks are often referred to as long and short rains. Although the averaged rainfall amount is larger during the long rains than during the short rains, the latter show more interannual variability and have larger impact on the society through changes of the regional hydrological cycle.

The short rains link to large scale ocean-atmosphere variability in the Indian Ocean is seen from the correlation between the short rains index and the rainfall anomalies over the Indian Ocean from the SINTEX-F1 results (Fig. 1a). Those correlation coefficients depict a dipole pattern with peak correlation coefficients of 0.7 over East Africa and -0.5 over eastern Indian Ocean. The east-west inverse correlation in the rainfall anomalies is further supported by the associated changes in the atmospheric conditions. A dipole pattern is observed in the correlation between the short rains index and the SST anomalies in the tropical Indian Ocean (Fig. 1b). This dipole pattern concurrent with a high correlation between the short rains index and the zonal wind anomalies (Fig. 1b) of the equatorial Indian Ocean supports the role of IOD on short rains variability. The model results are corroborated with 41 years data from the observation. The analysis of observed data and model results reveals that the influence of the IOD on short rains is overwhelming as compared to that of the ENSO; the correlation between ENSO and short

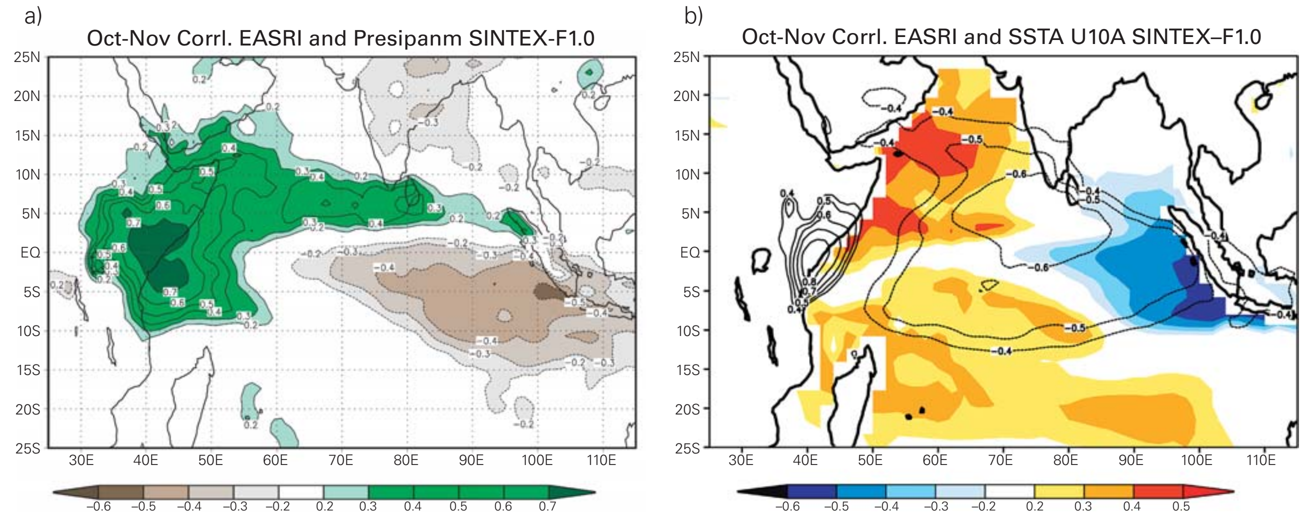

Fig. 1 a) Correlation of the short rains index with the rainfall anomalies over the Indian Ocean region during October-November season derived from the SINTEX-F simulation results. b) Same as (a) but for correlation of the short rains index with the anomalies of SST and surface zonal wind.

rains is insignificant when IOD influence is excluded. The IOD-short rains relationship dose not change significantly in a model experiment in which the ENSO influence is removed by decoupling ocean and atmosphere in the tropical Pacific. It is also found that the IOD periodicity is strongly biennial in the absence of air-sea coupling in the tropical Pacific. In another study it is found that the SINTEX-F simulation results capture the IOD influence in the La Plata region of the Southern America (Chan et al. 2004).

The SINTEX-F model results also resolve the low frequency decadal variation in the tropical Indian Ocean. The first EOF mode that explains 37% of variance in the band-pass (9-35 years) filtered SSTA represents a basin-wide warming (or cooling) mode which is correlated well with the decadal Niño3 index. The second EOF mode explains 14% of the variance in the decadal band and shows a clear east-west SSTA dipole pattern. Based on the examination of dipole mode index and its wavelet analysis, Tozuka et al. (2005) suggest that the decadal IOD-like variability is an artifact of the linear statistical analysis. It should be interpreted more precisely as *decadal modulation of interannual IOD events* (i.e. asymmetric or skewed occurrence of positive and negative events).

Process Studies

The role of the barrier layer (BL) in the development of the Indian summer monsoon onset is investigated in a process study using the SINTEX-F model (Masson et al. 2005). From February to May, before the Indian summer monsoon, the temperature in the south-eastern Arabian Sea warms up to temperatures exceeding 30°C; the so called mini-warm pool. Recent observationbal studies suggest that the physics of the ocean mixed layer must be involved to explain the rapid warming of sea surface temperature (SST) in the Lakshadweep Sea as compared to other regions in the Arabian Sea.

In order to assess the role of BL in SST warming, two experiments are conducted using SINTEX-F; the reference experiment (REF) and the sensitivity experiment (PERTURB) in which we suppressed, only in the southeast Arabian Sea, the impact of the salinity stratification on the vertical mixing. Figure 2a displays the April climatological SST difference (REF minus PERTURB). Significant differences are observed from March to May. As expected, the

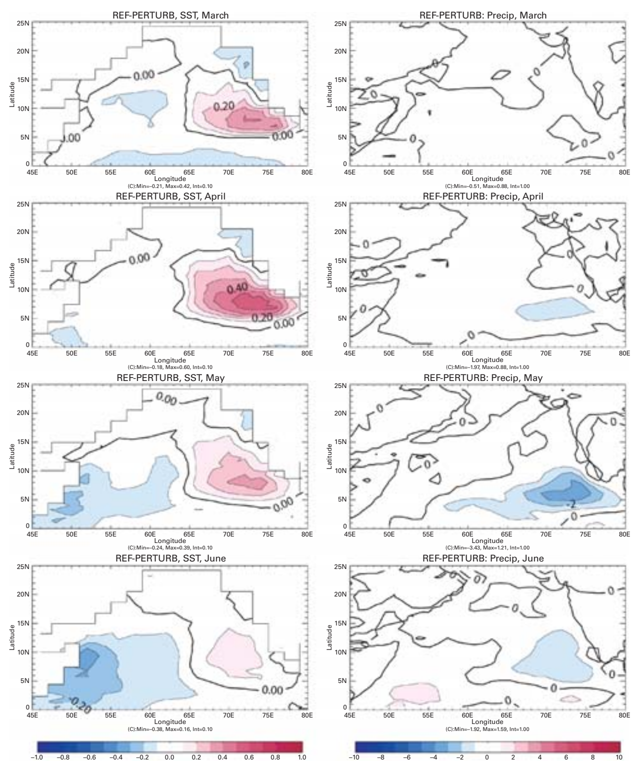

Fig. 2 Maps of monthly climatological differences (REF)-(PERTURB). a: SST (°C) from March to June, CI=0.1°C. b: Precipitation (mm/day), CI=1mm/day, significant areas (95% using a Student's T-test) are shaded.

presence of the BL favors the spring SST warming in the southeast Arabian Sea. REF experiment is warmer in that area with peak SST differences of 0.5°C in April, two months after the maximum of BL extension. The atmospheric response to this positive SST difference peaks in May (Fig. 2b). Because of additional moisture transport precipitation anomaly for the REF experiment is 3 mm/day higher than the PERTURB experiment. The monsoon onset is delayed by 10 to 15 days in the latter case.

Predictability Experiments:

The SINTEX-F model is used to investigate the seasonal climate/ENSO predictability for the period 1982-2001. Prior to the predictability experiments, several model experiments are carried out to reduce the model biases; particularly the problem related to the east Pacific cold tongue and the westward spread of SST anomalies during ENSO. Considerable improvements are observed when the surface currents are used in the calculation of the surface wind stresses (Luo et al. 2005a).

In the predictability experiment, five ensemble forecast members are generated by perturbing the model coupling physics. The coupling physics is perturbed for each member through varying interaction between ocean surface current and surface wind stress (Luo et al. 2005b). 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. The model hindcast results show a high predictability of 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 (Fig. 3) with the RMSEs much smaller than one standard deviation of the Nino3.4 SST index.

The global drought/flood associated with the three ENSO phases is predicted successfully over 9 months lead. This implies potential societal impacts of the long-lead ENSO forecasts. The model results show considerable predictabilities in the tropical north Atlantic and western south Indian Ocean, where the SST changes are largely affected by ENSO. In the

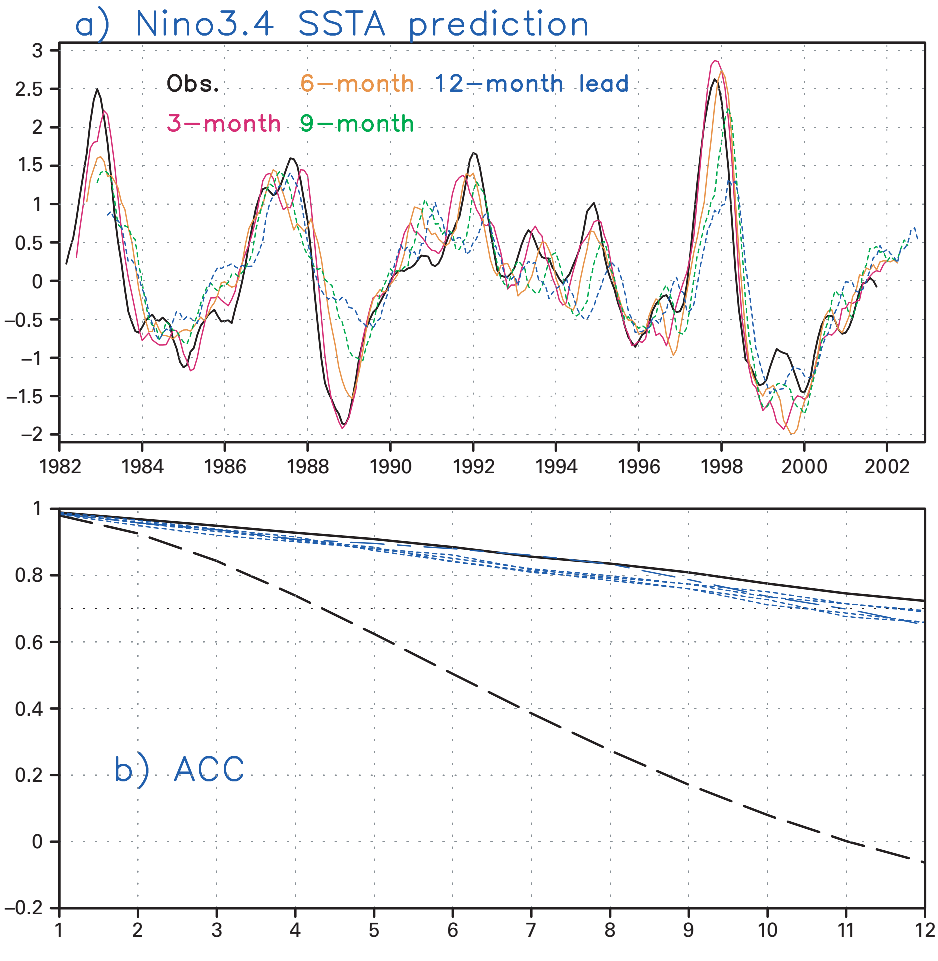

Fig. 3 (a) Nino3.4 SST anomalies (5°S-5°N, 170°-120°W) based on the NCEP Reynolds observations (solid line) and model predictions at 3-month (red line), 6-month (green line), 9-month (blue line), and 12-month (yellow line) lead time. Results have been smoothed with 5-month running mean. (b) ACC scores of the persistence (long-dashed lines), ensemble mean (solid lines), and individual member forecasts (short-dashed lines).

eastern equatorial Indian Ocean, where the local air-sea interactions are active and the signals are variable, the model shows skillful predictions only at about one season lead. However, the extreme IOD event in 1994 is successfully predicted at 6months lead. Away from the equatorial region, where mechanisms for generating subsurface variations are rather complicated, errors of the initial oceanic conditions found to be more severe. This tends to affect the ENSO prediction at long lead time. Assimilation of subsurface observations into the model in a coupled mode is currently being tested to further improve the predictability. Besides implementing the data assimilation in the SINTEX-F, a high resolution SINTEX-F2 model is also under development. The first version of the new coupled model (ECHAM5 T159L31 + OPA 0.5x0.5L31 + OASIS3) is successfully tested. The new version of the SINTEX-F model is expected to scale well while utilizing 80 nodes of the Earth Simulator.

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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を中程度の分解能で用いて様々な気候変動研究を行った。まず再現実験を行ったところ、近年その重要性が世界的に認知されてきたインド洋ダイポール現象、そしてそれが齎す影響、殊更北半球の秋のアフリカ東部及び南米ラプラタ川流域の降水変動やインド洋上の十年規模変動に及ぼす影響を発生時期と共に正確に再現することに成功した。プロセス研究からは、バリアレイヤーがアラビア海南東域における春季昇温とそれに関連した夏季インドモンスーンの発生に果たす役割について明らかにすることができた。また予測可能性実験を行ったところ、1997/1998に発生した前世紀最大級のエルニーニョ・イベントを含む過去20年間のエルニーニョ及びラニーニャ現象を12ヶ月前から予測することに成功し、しかもその予報スキルが偏差相関係数(ACC: Anomaly Correlation Coefficient)で 0.7 以上と非常に高いことが分かった。

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，モデルバイアス，予測研究