Seasonal Prediction Experiment and Process Studies Using Coupled General Circulation Model

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The SINTEX-Frontier coupled general circulation model version 1 (SINTEX-F1) is developed under the EU-Japan collaborative framework to study the variability in global climate and its predictability. The seasonal prediction system based on the SINTEX-F1 has so far demonstrated good performance of prediction on El Niño-Southern Oscillation (ENSO), ENSO-Modoki, and the Indian Ocean Dipole Mode (IOD) events. However, the system failed to predict the 2012 positive IOD event one season ahead for the first time since we started the climate prediction experiments. A major reason for this problem is found to be related to the ocean subsurface temperature in the equatorial western Indian Ocean in April 2012. Besides tropical climate variations, the seasonal to interannual predictability of subtropical dipoles in southern Indian and Atlantic Oceans are also investigated using results from the SINTEX-F1 retrospective predictions, showing predictability of one to two seasons. In addition to basin-scale climate variations, the predictability of regional climate over southern Africa is evaluated by dynamical downscaling of SINTEX-F1 seasonal prediction using the Advanced Research Weather Research and Forecasting (WRF) model.

In addition to conduct process studies and real-time prediction experiments with the SINTEX-F1, a new high-resolution SINTEX-F2 model with sea ice processes is implemented into the Earth Simulator. Using the long simulation results of the new model, it is corroborated that the ocean mixed-layer plays an important role in the formation of South Pacific Subtropical Dipole.

Keywords: SINTEX-F GCM, 2012 positive Indian Ocean Dipole Mode, Subtropical Dipole Modes, Downscaling

1. Introduction

The SINTEX-F1 coupled general circulation model (CGCM) has emerged as the leading CGCM in the world to provide real-time predictions of seasonal to interannual climate variations. We have been conducting every month experimental seasonal predictions in real time using the SINTEX-F1, taking advantage of its outstanding performance of prediction of El Niño-Southern Oscillation (ENSO), ENSO-Modoki, and the Indian Ocean Dipole Mode (IOD) events. Using the SINTEX-F1 prediction outputs, we are investigating recent tropical climate variations and their predictability, climate variations in the sub-tropical regions, and regional impacts of tropical/sub-tropical climate variations with dynamical downscaling method.

In addition, we have been developing a new seasonal prediction system on a basis of a high-resolution version of SINTEX-F with sea-ice processes, the SINTEX-F2. It has shown that the SINTEX-F2 is good in reproducing realistic mean atmosphere/ocean conditions and extreme events, such as tropical cyclones, compared to those in the SINTEX-F1. We are hence expecting significant contributions of the SINTEX-F2 for better understanding of finer scale climate processes, mid-latitude climate variations, and interactions among climate

modes in tropics and mid-latitude regions.

In the following sections, we introduce several important results obtained from our research activities in the fiscal year of 2012.

2. SINTEX-F1 climate prediction

2.1 Why was the prediction of 2012 positive IOD difficult?

The seasonal prediction system based on the SINTEX-F1 has failed to predict the 2012 positive IOD event one season ahead for the first time since we started operational prediction experiments (Doi et al. 2013[1]; Figs. 1a, b). We explored possible reasons of unexpected generation of a negative IOD in the model and found that the ocean subsurface temperature initialization in April, 2012 was the key (Figs. 1c, d). For ocean initialization, the SINTEX-F prediction system uses a simple and until now a successful method of the sea surface temperature (SST)-nudging, which failed to capture the observed warm subsurface temperature anomaly over the western equatorial Indian Ocean in April 2012. The warm SST anomaly in the western equatorial Indian Ocean disappeared quickly in our prediction system in May, generating zonal SST gradient opposite to the observed one along the equator. This evolved into the negative IOD in the prediction system through

a positive feedback between the atmosphere and ocean, resulting in the warm SST anomaly off Sumatra. Considering the importance of subsurface temperature anomaly in the western tropical Indian Ocean, we are now in cooperating subsurface data assimilation scheme to improve the prediction skills of short term climate variations.

2.2 Predictability of the Subtropical Dipole Modes

Despite the known difficulty in predicting subtropical climate due to large internal variability of the atmosphere and weak ocean–atmosphere coupling, the SINTEX-F1 can successfully predict the South Atlantic and Indian Ocean Subtropical Dipoles (SASD and IOSD, respectively) one season ahead, and the prediction skill is better than the persistence up to 12-month lead hindcast experiments (Yuan et al. 2013[2]; Fig. 2). A prediction barrier is identified in austral winter associated with the seasonal phase locking of the SASD to austral summer. The prediction skill is lower for the IOSD than for the SASD, and only slightly better than the persistence till 6-month lead because of the low predictability of the sea surface temperature anomaly in its southwestern pole. Owing to the overall good performances of the SINTEX-F model in predicting not only ENSO and IOD, but also SASD and some strong IOSD, the prediction skill of the southern African summer precipitation is high in the SINTEX-F
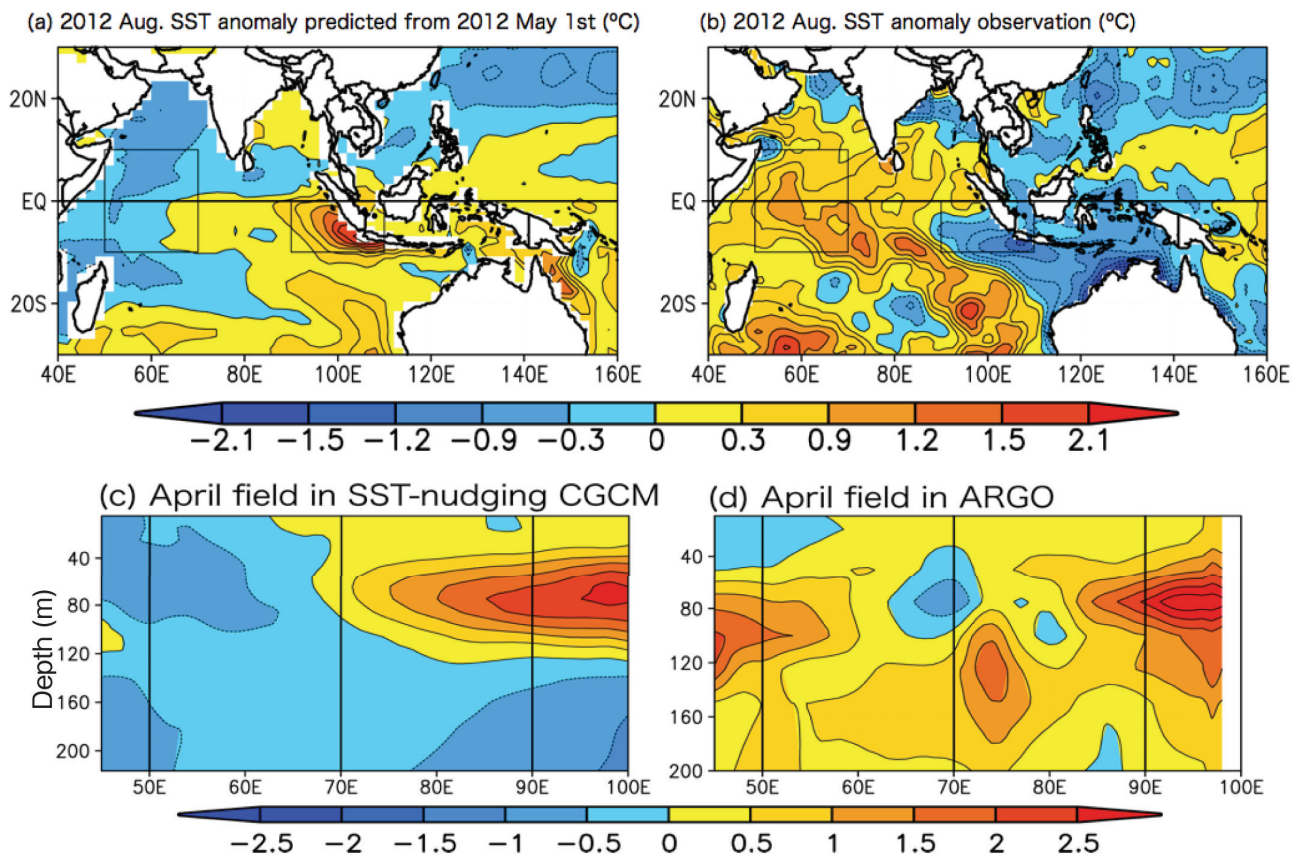

Fig. 1 (a) 2012 August SST anomalies (a) predicted from May 1st 2012 initialization and (b) in the NOAA/OISSTv2 (ºC). Contour interval is 0.3ºC. The eastern pole of DMI and the western pole of DMI are shown by black box. (c) Vertical profile of ocean temperature anomaly along the equator (averaged in 2ºS-2ºN) in 2012 April from the SST-nudging coupled GCM results (ºC). Contour interval is 0.5ºC. (d) Same as (c), but for the ARGO gridded data. Solid lines show the boundaries of the western and eastern poles of DMI.

model.

2.3 Dynamical Downscaling of austral summer climate forecasts over southern Africa

Prediction skill of dynamical downscaling is evaluated for climate forecasts over southern Africa using the Advanced Research Weather Research and Forecasting (WRF) model (Ratnam et al. 2013[3]). As a case study, forecasts for the December-January-February (DJF) season of 2011/12 are evaluated. Initial and Boundary conditions for the WRF model are taken from seasonal prediction experiments of the SINTEX-F1. In addition to predicted SST fields generated by 9-member ensemble predictions, the WRF model is also coupled to configured to a simple mixed layer Price-Weller-

Pinkel (PWP) ocean model to incorporate influences of local air-sea interactions. It turns out that, when coupled to a simple mixed layer ocean model, the WRF model improves the spatial distribution of precipitation over southern Africa due to better representation of the moisture fluxes that are modified through the local air-sea interactions (Fig. 3).

3. SINTEX-F2 development
3.1 Differences between SINTEX-F1 and SINTEX-F2

For better representation of several physical processes in the model and to resolve relatively small scale phenomena in the ocean, we have been trying to develop a new version of the SINTEX-F model, SINTEX-F2, which will be used for the seasonal prediction experiments in the near future together
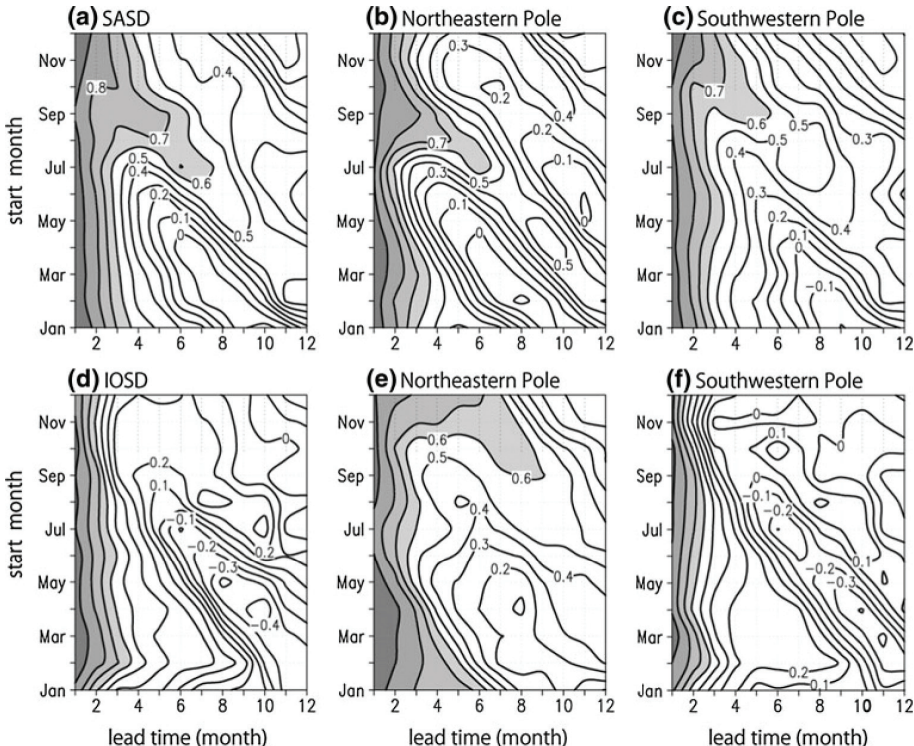

Fig. 2 Seasonally stratified anomaly correlation coefficients of (a) SASD index, (b) SST in the northeastern pole, and (c) SST in the southwestern pole of the SASD as a function of start month and lead time. (d), (e), and (f) are the same as (a), (b), and (c), respectively, but for the IOSD. Values larger than 0.6 are shaded. All the time series have been smoothed by the 3-month running mean before the calculation.
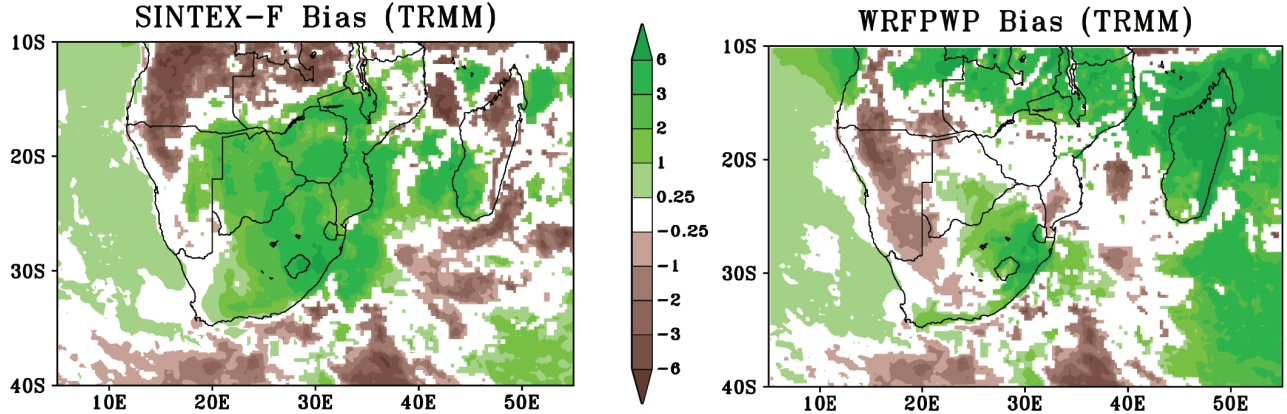

Fig. 3 Southern Africa rainfall bias from TRMM data in 2011/12 DJF for SINTEX-F1 3-month lead forecast (left) and its dynamical downscaling with the WRF-PWP coupled model (right) in mm day⁻¹.

with the SINTEX-F1. Table 1 briefly summarizes differences between the SINTEX-F1 and the new SINTEX-F2 GCMs (Sasaki et al. 2012[4]). Owing to these differences, model biases in climatological fields are much reduced in SINTEX-F2 compared with those in SINTEX-F1, particularly in mid-latitude. The SINTEX-F2 model is now available for the seasonal prediction experiment, with three-member ensemble integrations.

Table 1

	AGCM	OGCM	Coupling	Sea Ice
SINTEX-F1	ECHAM4.6 T106L19	OPA8.2 2×2 L31	Every 2 hour No flux correction	No
SINTEX-F2	ECHAM5 T106L31	OPA9 0.5×0.5 L31	Same as F1	Yes

3.2 The South Pacific Subtropical Dipole simulated by SINTEX-F2

Using results from the SINTEX-F2 experiments, the generation mechanism of the South Pacific Subtropical Dipole (SPSD) is investigated in detail for the first time (Morioka et al. 2013[5]). The SPSD is detected as the second EOF mode of SST anomalies in the South Pacific, and it has a northeast-southwest oriented dipole structure of positive and negative SST anomalies in the central basin (Fig. 4). Close examination of mixed-layer heat balance in the SPSD region yields that the positive and negative SST anomaly poles develop during austral spring and reach their peak during austral summer, mainly due to contribution of anomalous shortwave radiation. Within the positive (negative) pole, the mixed layer becomes

thinner (thicker) than normal, therefore enhancing (reducing) the warming tendency of the mixed layer temperature by the climatological shortwave radiation. This thinner (thicker) mixed layer is considered to have a link with the suppressed evaporation and reduced wind (enhanced evaporation) associated with the overlying positive (negative) sea level pressure anomaly. The analysis of wave activity flux in the upper troposphere suggests a remote influence from the upstream geopotential height anomalies southeast of Australia through the southeastward penetration of the stationary Rossby wave pattern. The mean state of the westerly jet in the mid-latitudes may be responsible for the direction of this Rossby wave response.

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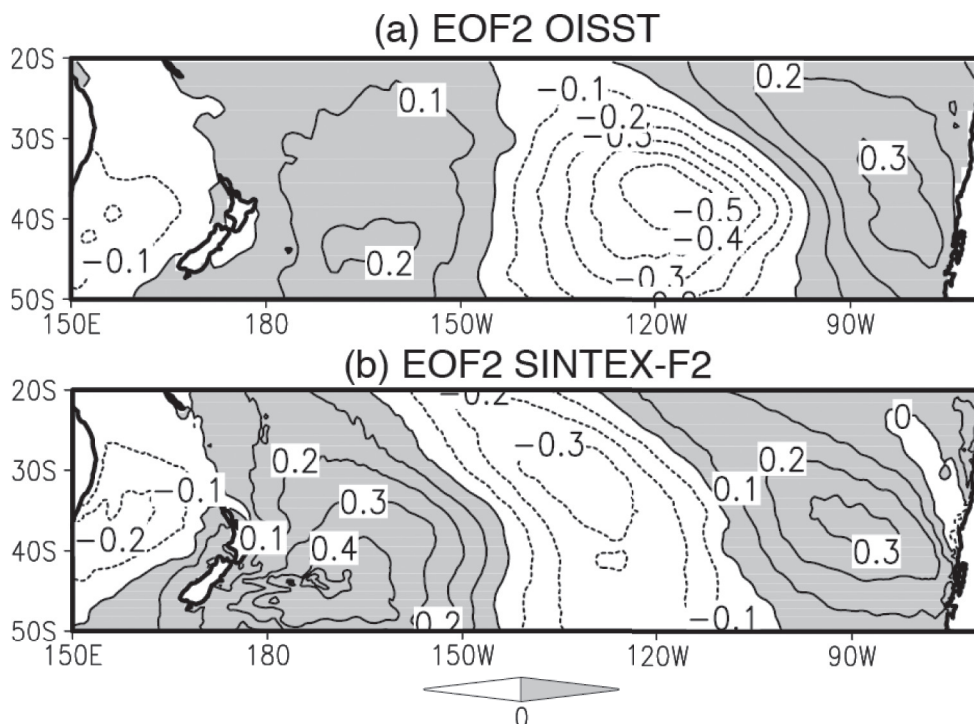

Fig. 4 (a) The second EOF mode of the observed SST anomalies (in ℃) in the South Pacific. (b) As in (a), but for the model. All months over the analysis period are used. Positive values are shaded.

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大気海洋結合モデルを用いたプロセス研究と季節予測実験

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　気候変動ならびにその予測可能性研究のための日欧研究協力に基づき、SINTEX-Frontier 大気海洋結合大循環モデルの開発および改良を推進し、これを用いた気候変動予測研究を行っている。その第一版である SINTEX-F1 は、リアルタイムの季節・経年変動予測実験に長く用いられており、近年発生したインド洋ダイポールモードやエルニーニョ現象のほとんどを現実的に予測している。しかし 2012 年に発生したインド洋ダイポールモード現象では、適切な予測結果を得られなかった。この原因を調べた結果、発達の前段階にあたる 2012 年 4 月において、赤道インド洋西部に存在していた正の亜表層水温偏差を、現行の SST-Nudging システムでは予測の初期値として充分に再現できなかったことが分かった。

　また熱帯域だけでなく、亜熱帯域にも予測研究を発展させた。特に、インド洋および大西洋の南半球亜熱帯域に発達する亜熱帯ダイポールモード現象について、それらの予測が半年程度前から可能であることを初めて示した。さらに、WRF モデルを用いた力学的ダウンスケーリング手法によって、アフリカ南部の降水量を高精度に予測することに成功した。これらの成果は国内外のメディア等で取り上げられると同時に、世界の気候変動予測研究を先導するモデルとして SINTEX-F の地位を確立する礎となっている。

　更に新しい高度化モデル SINTEX-F2 を開発し、アンサンブル気候予測実験やプロセス研究を行った。SINTEX-F2 では高解像度化や海氷モデルの導入により、中緯度域での再現性が SINTEX-F1 より向上している。この結果を用い、南太平洋に現れる亜熱帯ダイポールモードの形成メカニズムを世界で初めて解明することに成功した。

キーワード：SINTEX-F, 2012 インド洋ダイポールモード, 亜熱帯ダイポールモード, ダウンスケーリング