Study on the Predictability of Climate Variations and Their Mechanisms

Project Representative

Swadhin K. Behera Application Laboratory, Japan Agency for Marine-Earth Science and Technology

Authors

Takeshi Doi[*1], Yushi Morioka[*1], Ratnam Venkata Jayanthi[*1], Chaoxia Yuan[*1], Hirofumi Sakuma[*1], Wataru Sasaki[*2], Sebastien Masson[*4], Antonio Navarra[*3], Silvio Gualdi[*3], Simona Masina[*3], Alessio Bellucci[*3], Annalisa Cherchi[*3], Pascal Delecluse[*5], Gurvan Madec[*4], Claire Levy[*4], Marie-Alice Foujols[*4], Arnaud Caubel[*4], Eric Maisonnave[*5], Guy Brasseur[*6], Erich Roeckner[*6], Marco Giorgetta[*6], Luis Kornblueh[*6], Monika Esch[*6], Yukio Masumoto[*1, 7] and Toshio Yamagata[*1]

*1 Application Laboratory, Japan Agency for Marine-Earth Science and Technology

*2 Center for Earth Information Science and Technology, Japan Agency for Marine-Earth Science and Technology

*3 Centro Euro-Mediterraneo per i Cambiamenti Climatici, INGV

*4 Laboratoire D'oceanographie et du Climat (LOCEAN)

*5 Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique

*6 Max Planck Institute for Meteorology

*7 Graduate School of Science, University of Tokyo, Tokyo

The SINTEX-Frontier coupled general circulation model version 1 (SINTEX-F1 GCM) has been developed under the EU-Japan collaborative framework to study the global climate variability and its predictability. The seasonal prediction system on a basis of the SINTEX-F1 GCM has so far demonstrated high performance of predicting the occurrences of El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole Mode (IOD) events in the tropics. However, it is still very challenging to predict their teleconnections to the mid-latitude, and the occurrences of coastal Niño phenomena like Ningaloo Niño/Niña and California Niño/Niña, subtropical climate variations such as the Indian Ocean Subtropical Dipole (IOSD), and the South Atlantic Subtropical Dipole (SASD) by the SINTEX-F1 seasonal prediction system.

In order to improve those difficulties, we successfully developed a new high-resolution SINTEX-F2 model with sea ice processes, which was implemented on the Earth Simulator. Using the long simulation results of the new model, we focused on the process studies in this last year. Those outcomes contribute to deep understanding and improving prediction skill of the teleconnection patterns and the occurrence of the subtropical climate variations.

In this fiscal year, we developed a proto-type of the real-time seasonal prediction system with the new SINTEX-F2 GCM. Preliminary analysis showed that this new seasonal prediction system improves the prediction skill of the IOSD and the austral rainfall in Southern Africa relative to the SINTEX-F1 seasonal prediction system.

In addition, we installed a suitable three-dimensional ocean data assimilation method (3DVAR) to improve on the SST-nudging coupled initialization scheme. In this fiscal year, we conducted test experiments for the 2012 Indian Ocean Dipole event. We can confirm that the new initialization scheme with 3DVAR correction can improve its prediction. Next fiscal year, we will conduct the reforecast experiments with this new scheme.

Using the SINTEX-F1 reforecast experiments in 1982-2014, we found an interdecadal regime shift in rainfall predictability related to the Ningaloo Niño in the late 1990s.

Keywords: SINTEX-F2 GCM, Seasonal Prediction, Indian Ocean Subtropical Dipole Mode, Ningaloo Niño

1. Introduction

We have been conducting seasonal predictions every month using the SINTEX-F1 seasonal prediction system on the Earth Simulator and providing a real-time outlook of seasonal to interannual climate variation on our website (http://www.jamstec.go.jp/frcgc/research/d1/iod/e/seasonal/outlook.html). From last fiscal year, those real-time seasonal prediction experiments were conducted by another project (Project representative: Swadhin K. Behera, APL/JAMSTEC; "Study on the real-time ensemble seasonal prediction system and its application"). Therefore, we focused on the process and predictability studies with model development in this project.

The SINTEX-F1 seasonal prediction system has demonstrated its outstanding performance of predicting El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole Mode (IOD). In addition, it is recently shown that the SINTEX-F1 prediction system is highly skillful in predicting not only basin-scale tropical climate phenomena like ENSO and IOD, but also the regional climate phenomenon like the Ningaloo Niño/Niña off the west coast of Australia.

However, it is still very challenging to predict ENSO and IOD teleconnection patterns and subtropical climate variations such as the Indian Ocean Subtropical Dipole (IOSD) and the South Atlantic Subtropical Dipole (SASD) by the SINTEX-F1 seasonal prediction system. To tackle those difficulties, we successfully had developed a new high-resolution version of SINTEX-F with sea-ice processes, the SINTEX-F2. Some previous works showed that the SINTEX-F2 GCM is better in reproducing realistic mean atmosphere/ocean conditions, tropical/subtropical climate variations and extreme events, such as tropical cyclones, relative to 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 2014. In Section 2, we show that preliminary results with a proto-type of new SINTEX-F2 seasonal prediction system. In Section 3, we show our discovery of an interdecadal regime shift in rainfall predictability related to the Ningaloo Niño in the late 1990s using SINTEX-F1 hindcast experiments.

2. A proto-type of new seasonal prediction system by SINTEX-F2 GCM

We developed the SINTEX-F2 GCM for better representation of several physical processes and to resolve relatively small-scale phenomena in the ocean. Table 1 briefly summarizes major differences between the SINTEX-F1 and the new SINTEX-F2 GCMs (there are also some differences in numerical schemes and parameterizations). 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. As a next step, we have been trying to develop a new seasonal prediction system on the basis of SINTEX-F2. In this fiscal year, we successfully developed a proto-type of the new SINTEX-F2 seasonal prediction system.

Similar to the SINTEX-F1 system, we adopted the SST-nudging coupled initialization scheme in SINTEX-F2; model SSTs are strongly nudged toward daily observations by applying three large negative feedback values (-2400, -1200, and -800 W m-2 K-1) to the surface heat flux since 1st January 1982. These negative feedback values correspond to 1-, 2-, and 3-day restoring time for temperature in a 50-m surface mixed layer, respectively. We used two kinds of daily SST observational data; one is interpolated from weekly NCEP analysis with 1.0 degree latitude x 1.0 degree longitude global grid (Reynolds et al. 2002), and the other is the high-resolution daily SST with 0.25 degree latitude x 0.25 degree longitude global grid (Reynolds et al. 2007). The coupled SST-nudging initialization scheme can capture well the interannual variations of the equatorial Pacific thermocline due to its high model performance.

Concerning large uncertainties in ocean vertical mixing estimations, ocean physics is perturbed in two different

Table 1 Main differences between SINTEX-F1 and SINTEX-F2

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

Table 2 A proto-type of seasonal prediction system with SINTEX-F1 and SINTEX-F2

	Initialization	Ensemble size	Lead time	Reforecast Period
SINTEX-F1	SST-nudging, every month	9	2yr	1982 ~
SINTEX-F2	SST-nudging, every month	12	6mo	2000 ~

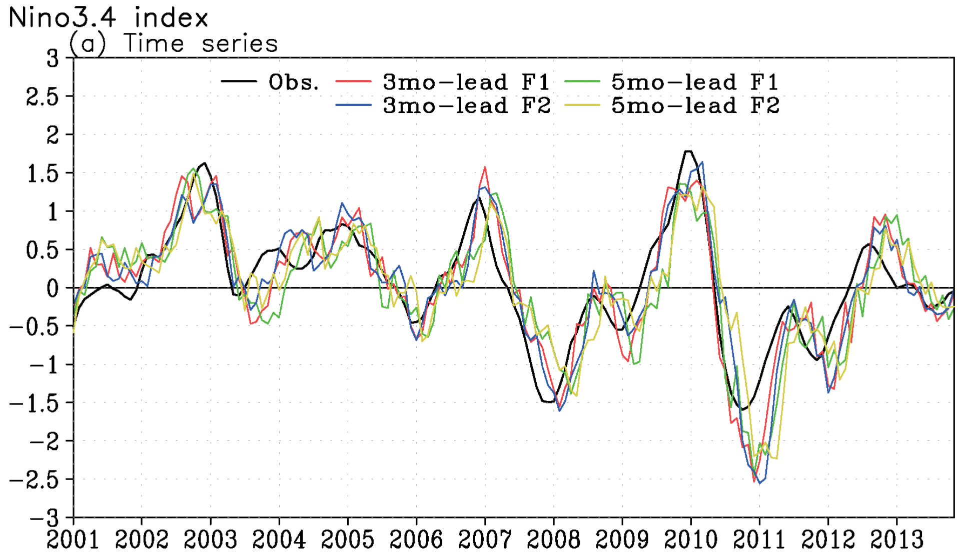

Fig. 1 Three-month averaged time series of the El Niño Index (Nino3.4: SST anomalies averaged over 150º-90ºW and 5ºS-5ºN, ºC) from the observational data of NOAA OISSTv2 (black). 3 (red/blue) and 5(green/yellow) - month lead predictions from a fixed start time by the SINTEX-F1/F2 seasonal prediction system.

ways by considering or neglecting ocean vertical mixing induced by small vertical scale structures (SVSs) within and above the equatorial thermocline. Therefore, our ensemble prediction system attempts to measure uncertainties of both initial conditions and model physics for forecasts. Based on this semimultimodel ensemble prediction system, we have performed 12-member retrospective forecasts with 6-month lead from the first day of each month from January 2000 to December 2014 by SINTEX-F2 (Table 2).

As shown in Fig. 1, ENSO prediction skill is almost same between the SINTEX-F1 system and the new SINTEX-F2 system. This is not bad news at all, because the SINTEX-F1 system already shown to be highly skillful in predicting ENSO. In addition, we found that the SINTEX-F2 system is much better skillful to predict IOSD. This might be due to the better simulation skill of the mean state in the mid-latitude and interactions between the tropics and subtropics in the SINTEX-F2 GCM. Also, we found that it causes improvement of seasonal prediction of summer rainfall over South Africa (Fig. 2). The previous works showed that La Niña, the positive IOSD event, and the positive SASD are highly correlated with the wetter-than-normal condition over Southern Africa in austral summer, which can be its potential source of seasonal predictability. In particular, December 2012 is very interesting, when La Niña and positive IOSD, and positive SASD events occurred together. The SINTEX-F1 system nicely predicted La Niña and positive SASD occurrence from the Oct. 1st 2010 initialization, but failed to predict positive IOSD occurrence. Therefore, the SINTEX-F1 system underestimated to predict the wetter-than-normal condition over Southern Africa. On the other hand, the SINTEX-F2 system nicely predicted La Niña, positive SASD, and positive IOSD events occurrences from the Oct. 1st 2010 initialization. Therefore, the SINTEX-F2 system successfully captured more-than-normal rainfall over Southern Africa. Those results may encourage development of an early warning system for anomalous rainfall events and their impacts to agriculture, water management, and infectious disease around South Africa, using climate prediction information by the SINTEX-F2 system.

In addition, we installed a suitable three-dimensional ocean data assimilation method (3DVAR) to improve the SST-nudging coupled initialization scheme. In this fiscal year, we conducted test experiments for 2012 Indian Ocean Dipole prediction. We

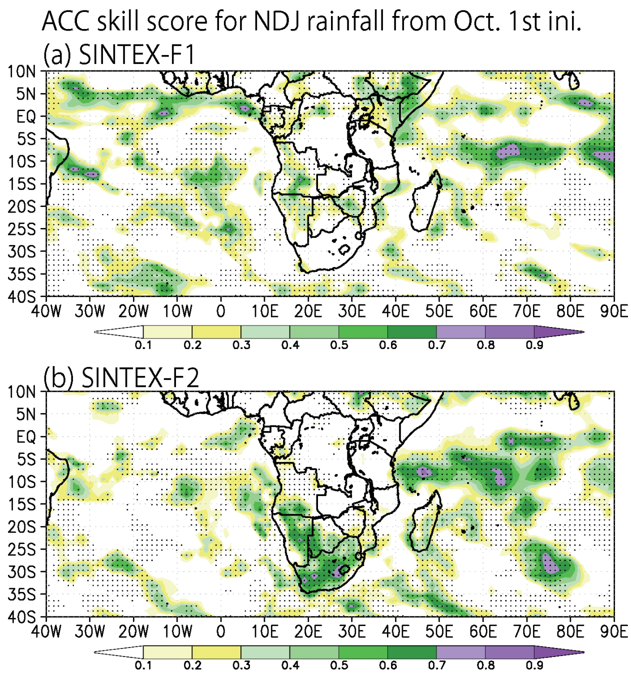

Fig. 2 Anomaly correlation coefficient (ACC) for the austral summer (NDJ) rainfall in 2001-2013 between the observation and the prediction by the (a) SINTEX-F1 and (b) SINTEX-F2 seasonal prediction system initialized on every 1st October of each year.

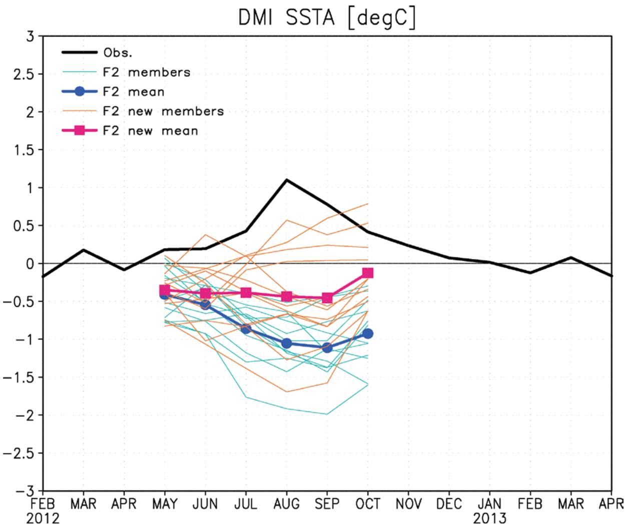

Fig. 3 (a) Monthly time series of the Indian Ocean Dipole Index, DMI: SSTA difference between the western pole (50º-70ºE, 10ºS-10ºN) and the eastern pole (90º-110ºE, 10ºS-Eq), by observational data of NOAA OISSTv2 (black), the SINTEX-F2 prediction initialized on May 1st, 2012 by the SST-nudging scheme (ºC, blue: ensemble mean, thin sky blue: each member), and the SINTEX-F2 prediction initialized on May 1st, 2012 with 3DVAR correction (ºC, pink: ensemble mean, thin orange: each member).

confirmed that the new initialization scheme with 3DVAR correction could partly improve 2012 Indian Ocean Dipole prediction (Fig. 3). In the next fiscal year, we will conduct reforecast using the new initialization scheme.

3. An interdecadal regime shift in rainfall predictability related to the Ningaloo Niño in the late 1990s (Doi et al. 2015 [1])

Using the SINTEX-F1 reforecast experiments, we found an interdecadal regime shift in rainfall predictability related to the Ningaloo Niño in the late 1990s. The global warming and the Interdecadal Pacific Oscillation (IPO) started influencing the coastal ocean off Western Australia, leading to a dramatic change in the regional climate predictability (Fig. 4). The warmer ocean started driving rainfall variability regionally there, after the late 1990s. Because of this, rainfall predictability near the coastal region of Western Australia on a seasonal time scale was drastically enhanced in the late 1990s; it is significantly predictable 5 months ahead after the late 1990s. The high prediction skill of the rainfall in recent decades is very encouraging and would help to develop an early warning system of Ningaloo Niño/Niña events to mitigate possible societal as well as agricultural impacts in the granary of Western Australia. It is ironical that the warming SST may increase not only the extreme rainfall event and its societal impact but also predictability of the event by use of a climate model.

Acknowledgement

The SINTEX-F1/F2 seasonal climate prediction system was developed using the Earth Simulator at JAMSTEC. We are grateful to Jing-Jia Luo, Sebastien Masson, and our European colleagues of INGV/CMCC and L'OCEAN for their contribution to the development of the prototype of the prediction model. This research was supported by the Environment Research and Technology Development Fund (2– 1405) of the Ministry of the Environment, Japan and the Japan Science and Technology Agency/ Japan International Cooperation Agency through the Science and Technology Research Partnership for Sustainable Development (SATREPS).

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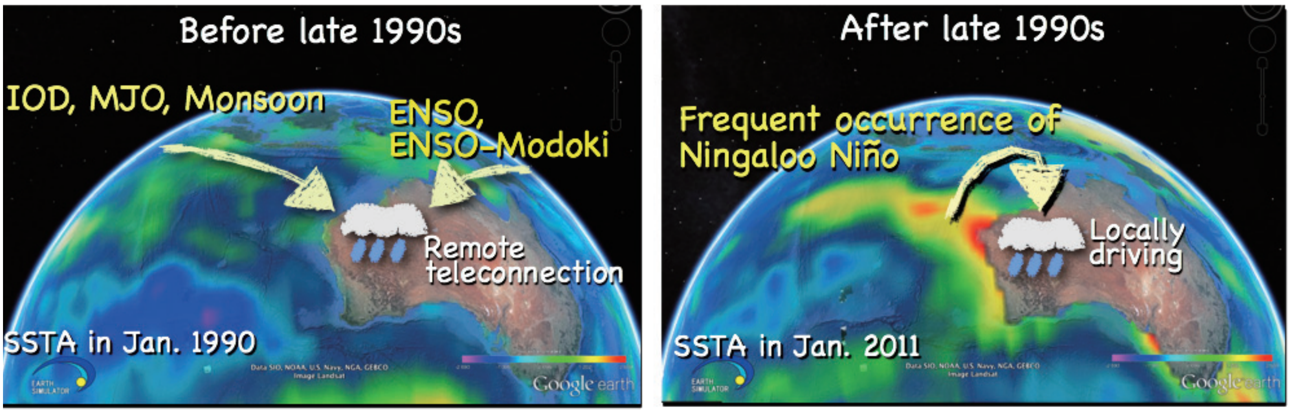

Fig. 4 Schematic figure for an interdecadal regime shift in rainfall predictability related to the Ningaloo Niño in the late 1990s. Austral summer rainfall predictability near the coastal region of Western Australia was drastically enhanced in the late 1990s due to the air-sea coupling process associated with the Ningaloo Niño.

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大気海洋結合モデルを用いた短期気候変動のプロセス研究とその季節予測可能性研究

課題責任者

スワディン ベヘラ　　海洋研究開発機構　アプリケーションラボ

著者

土井　威志 [*1]，森岡　優志 [*1]，Ratnam Venkata Jayanthi[*1]，Chaoxia Yuan[*1]，佐久間弘文 [*1]，
佐々木　亘 [*2]，Sebastien Masson[*4]，Antonio Navarra[*3]，Silvio Gualdi[*3]，Simona Masina[*3]，Alessio Bellucci[*3]，
Annalisa Cherchi[*3]，Pascal Delecluse[*5]，Gurvan Madec[*4]，Claire Levy[*4]，Marie-Alice Foujols[*4]，
Arnaud Caubel[*4]，Eric Maisonnave[*5]，Guy Brasseur[*6]，Erich Roeckner[*6]，Marco Giorgetta[*6]，Luis Kornblueh[*6]，
Monika Esch[*6]，升本　順夫 [*1, 7]，山形　俊男 [*1]

*1　海洋研究開発機構　アプリケーションラボ

*2　海洋研究開発機構　地球情報基盤センター

*3　Centro Euro-Mediterraneo per i Cambiamenti Climatici, INGV

*4　Laboratoire D'oceanographie et du Climat (LOCEAN)

*5　Centre Européen Recherche et de Formation Avancée en Calcul Scientifique

*6　Max Planck Institute for Meteorology

*7　東京大学 理学系研究科

数ヶ月から数年スケールで発生する気候変動の理解ならびにその予測可能性研究のため、SINTEX-F 大気海洋結合大循環モデルを日欧研究協力に基づき開発および改良してきた。その第一版である SINTEX-F1 をベースにした季節予測システムのプロトタイプを 2005 年に完成させ、季節予測の分野において常に世界最先端の成果を上げてきた。1 週間程度の未来の気象を予測する天気予報と違って、季節予測においては、大きな熱容量を持つ海洋の存在が重要になる。海洋現象と大気現象が結合したエルニーニョ現象やインド洋ダイポールモード現象は世界各地に異常気象や極端現象を引き起こす気候変動現象であり、その発生予測に関して SINTEX-F1 季節予測システムは世界最先端の精度を誇っている。そのリアルタイムの季節･経年変動予測実験の計算は機構課題（課題責任者 : JAMSTEC/APL スワディヒン･ベヘラ）で行い、本課題では更なる気候予測可能性研究と、高度化させた第二版 SINTEX-F2 の開発を中心に実施した。

SINTEX-F2 では高解像度化や海氷モデルの導入により、中緯度域や海洋の比較的小さな現象の再現性が SINTEX-F1 より向上している。昨年度までは、SINTEX-F2 を使った季節予測実験は NOAA/OISST 1deg weekly SST データを初期化とした 6 アンサンブルメンバーで構成されていたが、時空間解像度の高い NOAA/OISST 0.25deg daily データを同化した 6 メンバーを追加し、12 アンサンブルメンバーを持つ SINTEX-F2 アンサンブル季節予測システムのプロトタイプを開発した。エルニーニョ現象の予測精度は、SINTEX-F1 と F2 で大きな違いは確認できなかったが、中緯度で発生するインド洋亜熱帯ダイポール現象の予測精度が SINTEX-F2 予測システムでは向上していることが確認できた。その結果として、アフリカ南部の夏季降水量の予測精度が向上していることも確認した。

更に、従来の SST ナッジング結合初期化スキームに加えて、海洋３次元の水温・塩分の観測データを初期値にとりこむ新しい初期化スキーム（3DVAR）を開発し、テスト実験を行った。従来の予測システムでは失敗していた 2012 年インド洋ダイポールモード現象の予測が改善することが確認できた。来年度からこの 3DVAR 初期化スキームを搭載した過去再予測実験を実施する準備が整った。

近年、オーストラリア西岸域の海水温が平年に比べて異常に暖まる現象が頻発するようになった。この現象はニンガルー・ニーニョと名付けられ、海洋学者や気候学者が活発に研究を進めている。SINTEX-F1 による過去再予測実験結果を解析したところ、1990 年代後半から、ニンガルー・ニーニョ現象の頻発に伴い西オーストラリアの夏季降水量の季節予測精度が劇的に向上していることを発見した。

これらの成果は国際学会や国際誌で発表され、世界の気候変動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。

キーワード : SINTEX-F2 季節予測システム , インド洋亜熱帯ダイポールモード , ニンガルー・ニーニョ