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SINTEX-F seasonal prediction system and its application
A brief review of my recent activities

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ABSTRACT

Skillful seasonal climate prediction is crucial to sustainable well-being of humankind. Successful seasonal prediction, together with an early warning system using the product, could be useful to all stakeholders involved in management of water resources. Identifying potential sources of predictability for seasonal climate is a key not only for climate research, but also for benefit to society.

The SINTEX-F climate model was developed within the EU-Japan collaborative framework to study global climate variations and predictions by use of the supercomputer “Earth Simulator” at JAMSTEC. We have been conducting seasonal predictions every month using the system and providing a real-time outlook of seasonal to interannual climate prediction on our website. It has demonstrated its outstanding performance of predicting El Niño/Southern Oscillation and the Indian Ocean Dipole. For recent example, the system successfully predicted a positive super Indian Ocean Dipole event in 2019 and the following warm winter in East Asia.

In addition, as application studies of the seasonal climate prediction, we have developed a Malaria prediction system in South Africa and a worldwide crop predication system based on SINTEX-F seasonal prediction system.

Keywords—Sesonal prediction, Indian Ocean Dipole, Malaria Prediction, Crop Prediction

1. INTRODUCTION

Almost 15 years ago, we have developed the SINTEX-F1 ocean-atmosphere coupled general circulation model under the EU-Japan research collaboration. Based on this seasonal prediction system ("F1", Luo et al. 2005). We have performed climate predictions 2 year ahead and distributed the Prediction information on JAMSTEC website since 2005 (http://www.jamstec.go.jp/aplinfo/sintexf/e/seasonal/outlook.html). As predictability is the ultimate test of scientific theory, routinely using these quasi-real time climate-forecast informed frameworks can also improve understanding of climate dynamics (e.g. Tommasi et al. 2017). Actually, the JAMSTEC/APL have achieved great successes in these years and the SINTEX-F1 has become one of the leading models of the world for predicting the tropical climate variations in particular the Indian Ocean Dipole, the El Niño/Southern Oscillation (ENSO) and the ENSO Modoki. Since a 2 year-lead time retrospective forecast is beyond most of current operational capabilities, a skill assessment of the model results could be conducted as a first attempt for some studies. For example, Doi et al. (2020a) found a new skillful prediction region of sea level anomaly in the North Pacific about 2 years lead.

To improve prediction of extratropical climate, an upgraded CGCM called SINTEX-F2 has been developed; the new system is a high-resolution version of the previous model added with a dynamical sea-ice model ("F2", Doi et al. 2016). For the tropical climate variations in the Pacific and the Indian Ocean, the SINTEX-F2 preserves the high-prediction skill, and sometimes even shows higher skill especially for strong events, as compared to the SINTEX-F1. In addition, it has turned out that the new system is more skillful in predicting the subtropics, particularly, the Indian Ocean Subtropical Dipole and the Ningaloo Niño.

The SINTEX-F1/F2 seasonal prediction systems adopt a relatively simple initialization scheme based on nudging only the sea surface temperature (SST). However, it is to be expected that the system is not sufficient to capture in detail the subsurface oceanic preconditions. Therefore, we have introduced a new three-dimensional variational ocean data assimilation (3DVAR) method that takes three-dimensional observed ocean temperature and salinity into account. This system ("F2-3DVAR", Doi et al. 2017) has successfully improved seasonal predictions in the tropical Indian and Atlantic Oceans. We have started to provide a real time seasonal prediction based on those three systems "SINTEX-F Family" (Doi et al. 2020b). The 12-member system of "F2-3DVAR" has recently been upgraded to a bigger ensemble system of 108 members using the Lagged Average Forecasting (LAF) method (Doi et al., 2019a). Observing System Experiments (OSEs); a certain observation-type is withheld from, or added to, the regularly assimilated data to evaluate existing ocean observations for seasonal prediction, are also possible at the "F2-3DVAR" system (Doi et al. 2019b).

Here, I present a brief review of my recent works with the SINTEX-F systems.

2. Methodology

We have conducted the reforecasting experiments with a 12-month lead-time with the "SINTEX-F Family", starting from the first day of each month from January 1983 to the present. The prediction anomalies were determined by removing the model mean climatology a posteriori at each lead-time using the reforecast outputs over the period 1983-2015. The outputs were used for Section 3.1. In addition, we conducted the prediction runs with a four-month lead-time from the nine initialized dates (1st–9th) in Octobers of 1983–2019 based on the 108-members prediction system. The outputs were used for Section 3.2. We note that the large ensemble may capture seasonal predictable signals, particularly in the mid-latitudes where the signal-to-noise ratio is relatively low.

In Section 3.1 and 3.2, we used analysis of inter-member co-variability. Anomalies among the ensemble members (defined as deviations from the ensemble mean) may provide useful insights into possible precursors and teleconnection patterns related to a climate event. We calculated the inter-ensemble correlation: correlation coefficient in the ensemble space between a target index and a horizontal map of a variable for each grid point among the individual members of ensemble prediction in a particular month. In this analysis, the conventional time dimension was replaced by the ensemble dimension. For the present purpose, the ensemble prediction system with 108-member has an advantage in finding possible teleconnection patterns influencing the mid-latitude climate with the large stochastic internal variability.

3. RESULTS

3.1 El Niño Modoki in the tropical Pacific Ocean was key to successfully predicting the 2019 Super Indian Ocean Dipole phenomenon

We showed that the El Niño Modoki phenomenon in the tropical Pacific Ocean played a critical role in successfully predicting the extremely strong positive Indian Ocean Dipole (IOD) that occurred in 2019.

IOD is a climate variation phenomenon that is observed in the tropical Indian Ocean once every several years from summer to autumn. This phenomenon has both positive and negative phases. When a positive Indian Ocean Dipole occurs, sea surface temperatures become cooler than in an average year on the southeastern side of the tropical Indian Ocean and warmer than in an average year on the western side. These variations in ocean temperatures cause vigorous convection that usually occurs in the eastern Indian Ocean to move westward; east Africa receives more rain, while Indonesia receives less. These variations also tend to result in less rain and higher temperatures in Japan. Conversely, when a negative Indian Ocean Dipole occurs, sea surface temperatures are warmer than in an average year in the southeastern tropical Indian Ocean and colder than in an average year in the west, causing convection in the eastern Indian Ocean to be more intense than usual, and more rain falls in Indonesia and Australia, and there is generally more rain and temperatures are lower in Japan. For these reasons, accurately predicting the occurrence of such phenomena is important not only from a scientific perspective, but from a socioeconomic one as well. However, it is extremely difficult to predict IOD phenomena, which occur from the summer to autumn, from as early as the previous autumn and across the winter season.

We distributed monthly quasi-real-time IOD prediction data up to 12 months in advance, based on the numerical prediction system "SINTEX-F", which uses the "Earth Simulator" supercomputer (URL: http://www.jamstec.go.jp/aplinfo/sintexf/e/seasonal/outlook.html). While the current predictive accuracy of simulations conducted from the previous autumn remain low, the 2019 prediction of the strong IOD was accurate (Figure 1). Upon further investigation, it was found that the occurrence of the El Niño Modoki phenomenon in the tropical Pacific Ocean was a key factor that controlled the accuracy in this prediction. The results of this study are expected to advance our understanding of the mutual relationships between the IOD and El Niño Modoki phenomena, as well as the development of agricultural and infectious disease research based on related predictive data.

This study was published as Doi et al (2020b).

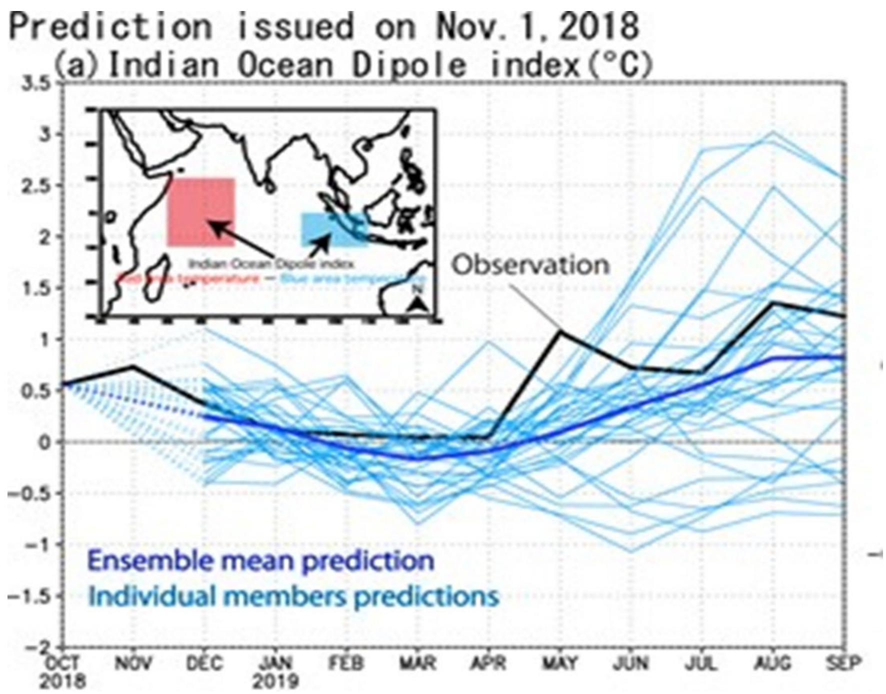

Figure 1: Indian Ocean Dipole index. The black line is the observed value and colored lines are the predictions made on November 1, 2018 (light blue lines: predicted values of each ensemble member; dark blue lines: averaged value of the ensemble members). The trajectories of the dark blue line and the black line are very similar, and the prediction is thought to have been broadly successful. From the light blue lines, it can be seen that there is variation between the ensemble members, with some overestimating and others underestimating the occurrence of a dipole event.

3.2 Wintertime impacts of the 2019 super IOD on East Asia

Many parts of East Asia, including Japan, experienced extremely warm conditions during the 2019–2020 winter. Warm SST anomalies associated with the super Indian Ocean Dipole in 2019 persisted even through the winter. Prolonged active convection over the western pole of the Indian Ocean Dipole may explain the unusual winter.

Doi et al. (2020c) showed that the 2019–2020 East Asian warm winter was successfully predicted in October of 2019 by the 108-member ensemble seasonal prediction system based on the SINTEX-F climate model (Figure 2). By analyzing co-variability of inter-member anomalies defined as deviations from the ensemble mean, we have found that the active convection over the western pole of the Indian Ocean Dipole caused these unusual conditions over East Asia by generating the meander of the subtropical jet. The ensemble prediction system with 108-member may have an advantage in finding such kind of the teleconnection influencing the mid-latitude climate with the large stochastic internal variability. Successful prediction of the teleconnection of such a super event may contribute to reducing the risks of socio-economic losses under suitable measures for adaptation and mitigation.

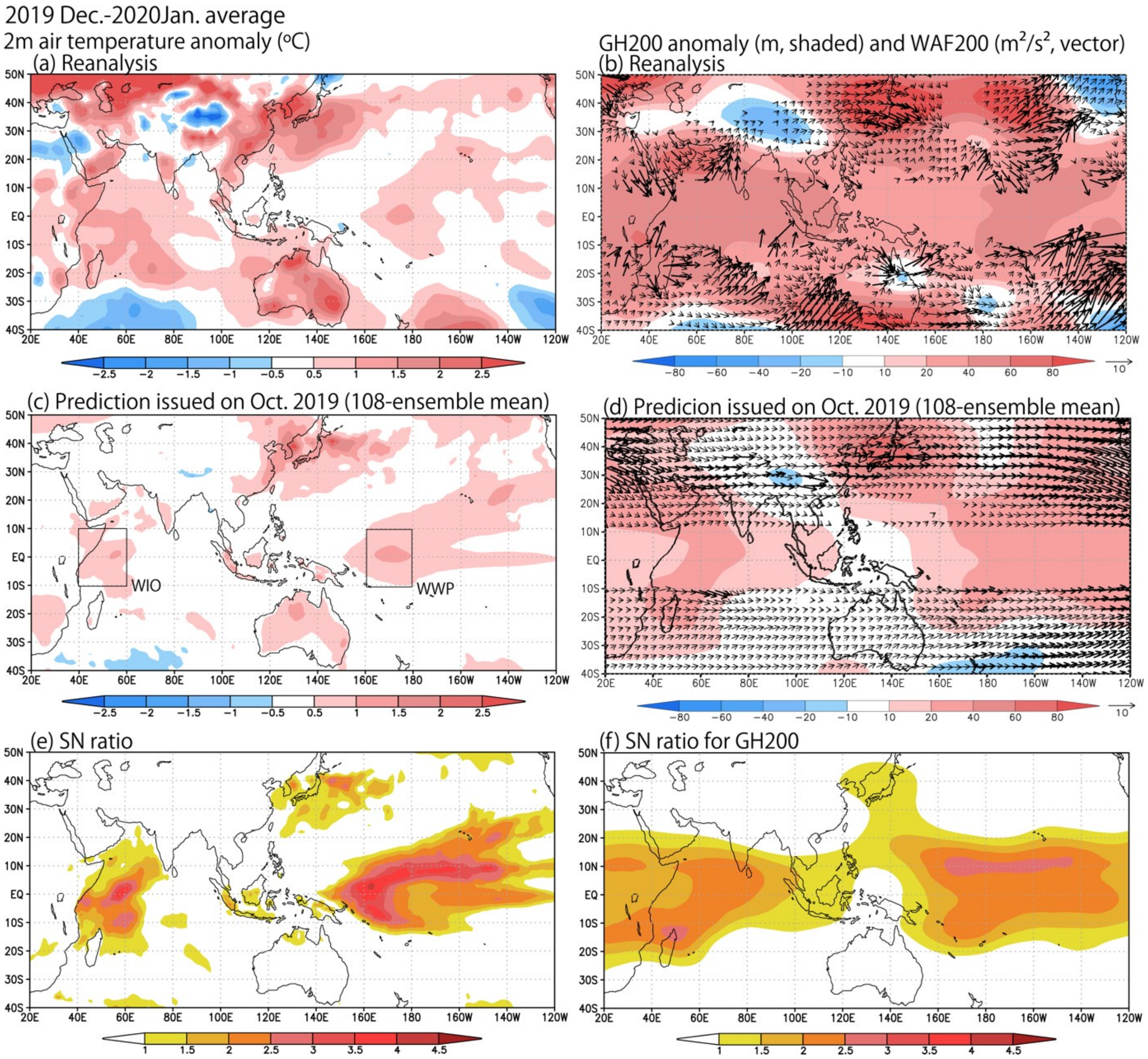

Figure 2. (a) 2m air temperature anomaly (ºC) from the NCEP/NCAR reanalysis data averaged in December 2019–January 2020. (b) Same as (a), but for the geopotential height anomaly (m; shaded) and the wave activity flux (m2s-2; vector) at 200hPa. For the wave activity flux, values above 5.0 (1.0) m2s-2 are shown by thick (thin) arrows, except for the tropics (10ºS-10ºN). (c) Same as (a), but for the prediction issued on early October 2019 (108-ensemble mean). Two regions are shown by boxes (WIO: 40ºE-60ºE, 10ºS-10ºN; WWP: 160ºE-180ºE, 10ºS-10ºN). (d) Same as (b), but for the prediction issued on early October 2019 (108-ensemble mean). (e) Signal-to-noise (SN) ratio for prediction of 2m air temperature anomaly in December 2019–January 2020 issued on early October: the ensemble mean values divided by the ensemble spread. (d) Same as (c), but for geopotential height at 200hPa.

3.3 Malaria predictions in South Africa based on our seasonal climate forecasts: A time series distributed lag nonlinear model

We developed a malaria prediction model taking into account nonlinear and delayed complexities of the malaria–climate dynamics (Kim et al. 2019). The prediction model showed good performance at the short-term lead time, and the prediction accuracy decreased as the lead time increased but retained fairly good performance. We also demonstrated the weekly-updated malaria prediction process based on seasonal climate forecasts and found that the malaria predictions for short-term lead time coincided closely with the observed malaria cases (Figure 3). The malaria prediction model we developed is promising because it is feasibly applicable in practice together with the skillful seasonal climate forecasts and existing malaria surveillance system in South Africa. Establishing an automated operating system based on real-time data inputs could potentially be beneficial for the malaria early warning system in Limpopo, South Africa, and can be an instructive example for other malaria-endemic areas.

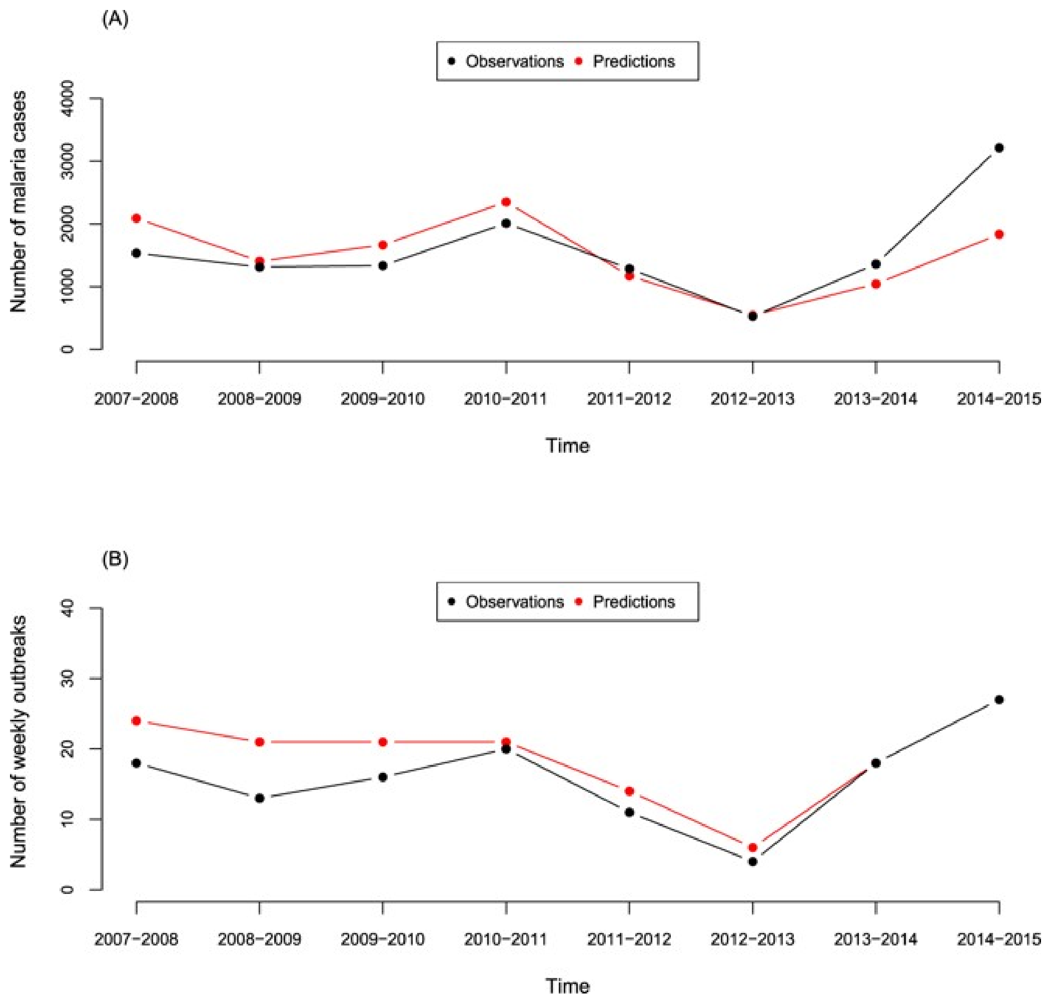

Figure 3: Cumulative annual number of malaria incidence and malaria outbreaks, defined by the 40th percentile of the past moving 5-years malaria cases during the endemic season (September–May), for the 2-weeks-ahead lead time (red, predictions; black, observations) in the demonstration of the weekly-updated malaria prediction process based on SINTEX-F seasonal climate forecasts.

3.4 Seasonal predictability of four major crop yields worldwide by a hybrid system of dynamical climate prediction and eco-physiological crop-growth simulation

Doi et al. (2020d) evaluated the prediction accuracy of a newly developed crop yield prediction system, composed of SINTEX-F2 and an eco-physiological process-based crop growth model (PRYSBI2). We explored the 3-month lead prediction accuracy of year-to-year variations in yield of four major crops (maize, rice, wheat, and soybean) in global regions and evaluated for which crops and in which areas the system performs well. The results indicated the system is more accurate for wheat relative to the other crops (Figure 4). Also, we found that different strategies would be useful in improving the system, depending on the crop. For winter wheat and rice, we need to improve the temperature predictions, particularly over the mid-latitudes, whereas improving rainfall predictions was more important for maize. For spring wheat and soybeans, the crop growth simulation itself should be improved. Although this study is only a first step, we believe that additional efforts to improve the system by understanding and incorporating processes of climate and crop growth will potentially provide useful prediction information to big stakeholders like global agribusiness companies and countries for improving food security in regions where crop yield is vulnerable to extreme climate shocks and where food markets are isolated from international trade.

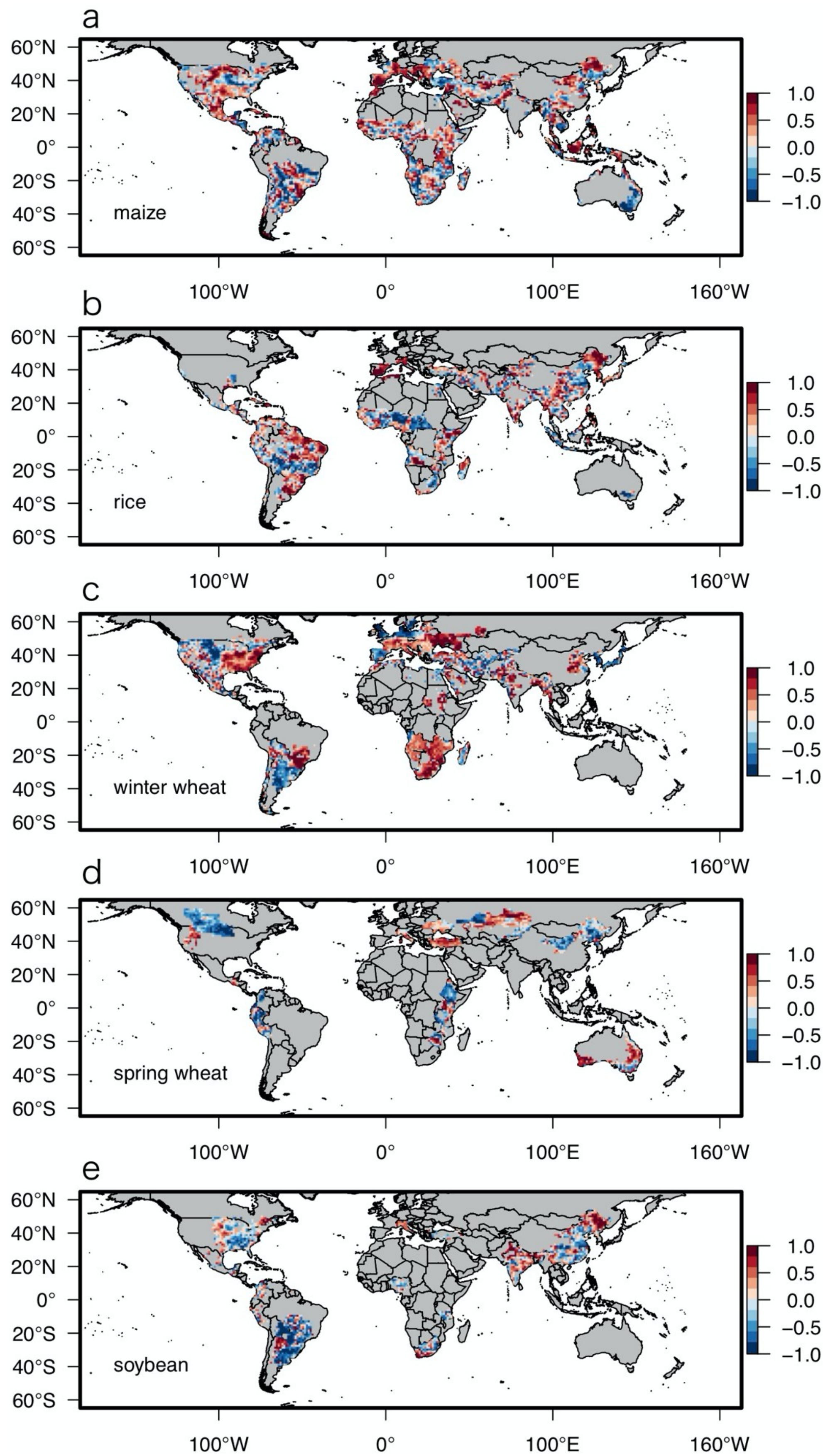

Figure 4. Horizontal distributions of ACC accuracy scores for a three-month lead prediction of year-to-year variations in yields of (a) maize, (b) rice, (c) winter wheat, (d) spring wheat, and (e) soybean. Gray indicates non-growing areas for the respective crops.

4. Conclusions

The SINTEX-F climate model was developed within the EU-Japan collaborative framework to study global climate variations and predictions. It has demonstrated its outstanding performance of predicting El Niño/Southern Oscillation and the Indian Ocean Dipole, which can work as main potential sources of seasonal climate predictability of precipitation as well as temperature over many parts of the tropical and subtropical regions. Recently, the system successfully predicted co-occurrence of a positive Indian Ocean Dipole event and an El Niño-Modoki event in 2019 and the following warm winter in East Asia. The successes are partly due to the large ensemble members with the SINTEX-F system. In addition, we have started application studies of the seasonal climate prediction, for example, a Malaria prediction system in South Africa and a worldwide crop predication system based on SINTEX- F seasonal prediction system. I hope that those studies will help stakeholders interpret limits as well as potential of seasonal climate predictions for possible societal applications.

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