Seasonal to Decadal Prediction and Its Application

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In this year, we have published four papers under the project.
East Africa suffered from an extreme drought during the short rains season of October–December 2021. Using our dynamical prediction system based on an ocean-atmosphere coupled model (SINTEX-F2), we showed that the 2021 negative Indian Ocean Dipole was responsible for the devastating drought and played a key role in its seasonal predictability. We also proposed a hybrid statistical-dynamical prediction of drought in East Africa on longer lead time, which may help people to take mitigation measures.

Skillful prediction of decadal sea ice variability in the west Antarctic Seas was demonstrated using the SINTEX-F2 in which the ocean and sea ice are initialized with the observation data. Initialization of ocean temperature and salinity in the model leads to improved accuracy in sea ice prediction over the Amundsen-Bellingshausen Sea, while initialization of sea ice concentration improves the prediction accuracy over the Weddell Sea.

Using selected members of a large ensemble re-forecast outputs by the SINTEX-F2, we successfully improved prediction of surface air temperature anomalies over Japan in the winter months from mid-Autumn. The improvement in the skill scores in the method is found to be due to improved representation of 200 hPa geopotential height anomalies.

We proposed a statistical El Niño-Southern Oscillation (ENSO) prediction system based on a convolutional neural network (CNN) based with the heterogeneous parameters for each season. It is highly skillful in predicting ENSO at long-lead times of 18-24 months with high skills compared to the SINTEX-F2 dynamical system and several other statistical prediction systems.

Keywords: Seasonal prediction, Decadal prediction, Drought in East Africa, Antarctic sea ice, Selected members, Convolutional neural network, El Niño-Southern Oscillation

1. On the predictability of the extreme drought in East Africa during the short rains season ~Key roles of the negative Indian Ocean Dipole~

Many parts of East Africa experienced extremely dry conditions during the short rains season (October–December) of 2021. Such a devastating drought in East Africa leads to unsafe drinking water, food insecurity, and other socio-economic issues. We showed that the extreme drought in East Africa was predicted a few months earlier by the large-ensemble seasonal prediction system based on the SINTEX-F climate model. We also found the 2021 negative Indian Ocean Dipole (IOD) was responsible for these unusually dry conditions over East Africa. The IOD, an intrinsic ocean–atmosphere coupled climate phenomenon in the tropical Indian Ocean, is characterized by cold (warm) sea surface temperature anomalies and reduced (enhanced) rainfall in the western (eastern) tropical Indian Ocean during its negative phase. Some of the devastating droughts (severe floods) in East Africa are observed during negative (positive) IOD years, respectively. In addition, they demonstrated that a hybrid statistical-dynamical framework is more skillful than the SINTEX-F model at predicting drought in East Africa over a longer lead time. This skillful prediction will help people to take necessary mitigation measures to reduce the devastating impact of a drought in future.

Based on this research, we have recently begun to provide a more detailed forecast for East African rainfall during the upcoming short rains season on the SINTEX-F website (see https://www.jamstec.go.jp/aplinfo/sintexf/e/seasonal/outlook.html). Going forward, we have noted that East Africa may experience drier than normal conditions again during the short rains season of 2022, owing to the negative IOD, as similar to the 2021 drought (Figure 1).

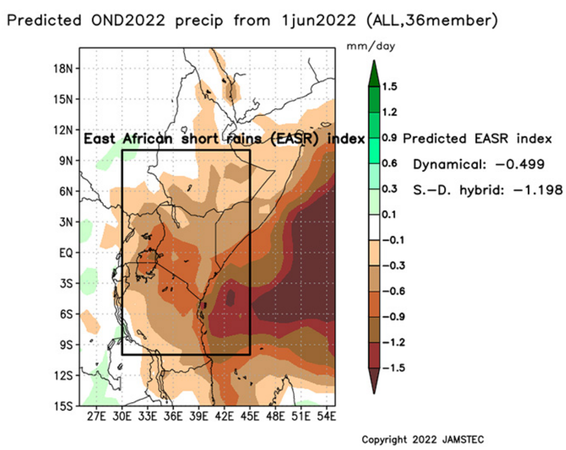

Figure 1: Prediction issued on June 1st 2022 of precipitation anomaly averaged in October–December (OND) 2022 (mm day-1). The East African short rains (EASR) index region is shown by a black box. A dynamical prediction by the SINTEX-F system and a hybrid statistical-dynamical (S.-D.) prediction of the EASR index are also shown in the right respectively.

This paper is published in Geophysical Research Letters on November 22, 2022 [1]. *Nature* published a research highlight about the work [2].

2. Improved prediction of decadal sea ice variability in the west Antarctic Seas ~key roles of ocean and sea ice observation data~

We demonstrated improved prediction of decadal sea ice variability in the west Antarctic Seas by conducting reforecast experiments using the SINTEX-F2 in which ocean and sea ice variables are initialized with observation data using the Earth Simulator.

Antarctic sea ice has slightly increased over the past few decades, in contrast to rapidly decreasing Arctic sea ice under the influence of global warming. Several factors are reported to explain the increasing sea ice trend in the Antarctic Seas. Some studies have suggested that decadal sea ice variability with a frequency of more than 10 years contributes to the sea ice increase. However, accurate prediction of the decadal sea ice variability in the Antarctic Seas remains challenging for the climate modeling community.

One of the underlying causes is a difference in ocean and sea ice states between the observation data and coupled model simulations. Satellite observations have made sea surface temperature (SST) and sea ice concentration (SIC) data in the Antarctic Seas available since the 1980s. However, temperature and salinity data from subsurface ocean observations in the Antarctic Seas are few compared with other ocean basins. Most of the coupled models employ ocean reanalysis products (model output) to initialize the ocean model to compensate for the lack of subsurface ocean observations. Nevertheless, in recent years, subsurface ocean observations have significantly increased since the late 2000s, following implementation of Argo floats (autonomous descending/ascending drifting buoys). Incorporating these observation data into the coupled models may help improve the prediction accuracy of decadal sea ice variability in the Antarctic Seas.

In collaboration with researchers from CMCC, we developed a decadal prediction system using the SINTEX-F2 model, in which the model's SST, SIC, and subsurface ocean temperature and salinity are initialized with the observation data. Here, we demonstrate that decadal sea ice variability in the Amundsen-Bellingshausen Sea can be skillfully predicted (Figure 2). In the Amundsen-Bellingshausen Sea, the eastward Antarctic Circumpolar Current intensifies to increase zonal sea ice advection from the Ross Sea and induce anomalous cooling in the subsurface ocean, leading to an increase in sea ice since the late 2000s.

These results have implications for decadal sea ice prediction in the west Antarctic Seas, which requires accurate initialization of ocean and sea ice states in a coupled model. Further improvement of sea ice prediction accuracy needs a greater number of ocean and sea ice observations in the Antarctic Seas. It is highly anticipated that the results obtained from this study can be applied to other prediction studies on Arctic sea ice.

The paper is press-released and published in Communications Earth & Environment on Sep 12, 2022 [3]

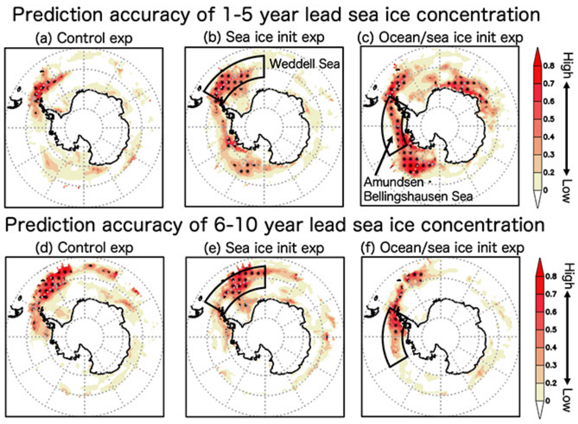

Figure 2: (a) Prediction accuracy of 1-5 year lead sea ice concentration (SIC) for the control experiment. The accuracy was measured with the correlation coefficient between the observed and predicted SIC anomalies during the analysis period of 1982-2019. Black dots indicate statistically significant correlation coefficients exceeding the 90% confidence level. (b) Same as in (a), but for the sea ice initialized experiment. The black box corresponds to the Weddell Sea. (c) Same as in (a), but for the ocean and sea ice initialized experiment. The black box corresponds to the Amundsen-Bellingshausen Sea. (d-f) Same as in (a-c), but for the prediction accuracy of 6-10 year lead SIC.

3. Using Selected Members of a Large Ensemble to Improve Prediction of Surface Air Temperature Anomalies Over Japan in the Winter Months From Mid-Autumn

A large ensemble of 120 predictions of the SINTEX-F2 was evaluated for their skill in predicting the surface air temperature (SAT) anomalies over Japan in the winter months December, January, and February. The predictions were initialized using November initial conditions. The members with skill scores based on anomaly correlation coefficient (ACC) were selected and an average of the selected predictions (SEM) was generated. Comparison of SAT anomaly predictions by the average of all the 120 members (ENS) to the SEM predictions shows SEM to outperform the ENS predictions in all the three winter months with higher ACC skill score (Figure 3), higher hit rate and low false alarm rate over the regions covering central Japan in

December and January and over the northern region of Hokkaido in February. The improvement in the skill scores in the SEM is found to be due to improved representation of 200 hPa geopotential height anomalies in SEM compared to ENS predictions. The results indicate SEM to be useful for improving skill in predicting SAT anomalies over parts of Japan in the winter months.

The content was published as Ratnam et al. 2022 [4].

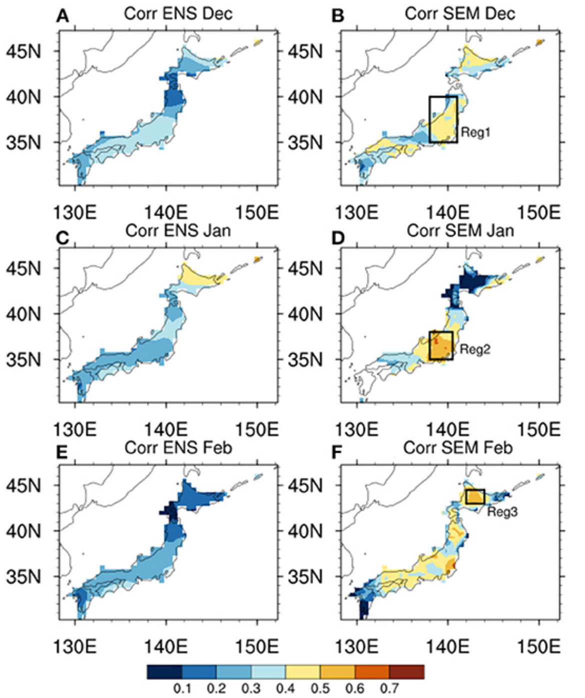

Figure 3: Spatial distribution of ACC between GHCN-CAMS and (A) ENS and (B) SEM in December. Panels (C, D) and (E,F) same as (A,B) but for January and February, respectively. Reg [1-3] correspond to the regions with higher ACC skill score in SEM compared to ENS.

4. Deep learning for skillful long lead ENSO forecasts

El Niño-Southern Oscillation (ENSO) is one of the fundamental drivers of the Earth's climate variability. Thus, its skillful prediction at least a few months to years ahead is of utmost importance to society. Using both dynamical and statistical methods, several studies reported skillful ENSO predictions at various lead times. Predictions with long lead times, on the other hand, remain difficult. In this study we propose a convolutional neural network (CNN) based statistical ENSO prediction system with heterogeneous CNN parameters for each season with a modified loss function to predict ENSO at least 18-24 months ahead. The developed prediction system indicates the CNN model to be highly skillful in predicting ENSO at long-lead times of 18-24 months with high skills in predicting extreme ENSO events compared to the SINTEX-F2 dynamical system and several other statistical prediction systems (Figure 4). The analysis indicates the CNN model to overcome the spring barrier, the major hindrance to dynamical prediction systems, in predicting ENSO at long-lead times. The improvement in the prediction skill can partly be attributed to the heterogeneous parameters of seasonal CNN models used in this study and also to the use of a modified loss function in the CNN model. In this study, we also attempted to identify various precursors to ENSO events using CNN heatmap analysis.

The content was published as Patil et al. 2022 [5].

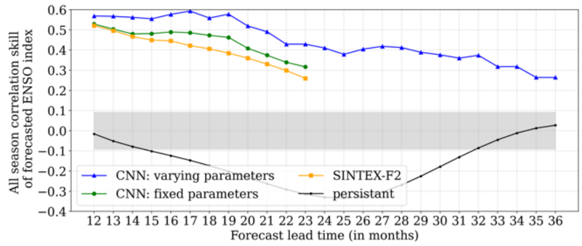

Figure 4: Multi-year CNN ensemble mean correlation skills as a function of lead time for all season forecasted ENSO index combined from each seasonal CNN model (blue) compared with fixed parameter CNN model (green), SINTEX-F2 (orange), and persistent predictions (black) (calculated from OISSTv2). Validation of CNN experiments is done using the observed ENSO index calculated from OISSTv2 data over a 38 years period from 1984 to 2021, whereas validation of SINTEX-F2 is done for 1984 to 2015 period (32 years). Correlations outside light gray shading are statistically significant at 95% level based on Student's 2-tailed t-test.

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