Development of Seasonal/Weather Prediction System for Predicting Extreme Events

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1. Introduction

Global warming increases global mean temperature and it is causing climate change thus climate risks all over the world. In Japan, heavy rainfall amount and frequency are increasing due to the influence of global warming. Not only in Japan, but also in other countries, extreme weather events such as heavy rainfall occurs, and the features are becoming different from the past. To accurately predict the extreme events, numerical weather (seasonal) prediction models should be updated in terms of assimilation and physical parameterization. In this research project, we worked on evaluation and the update of several prediction models. Results of this project are summarized as follows. (1) Evaluation of heavy rainfall prediction during Baiu season using a regional coupled model, (2) implementation of atmospheric initialization in a seasonal prediction system, and (3) implementation of a new spectral cumulus parameterization in operational weather forecast model.

2. Heavy rainfall prediction during Baiu using a regional coupled model

Japanese operational numerical weather prediction has been conducted using atmosphere-only model so far, but recent study pointed out that atmosphere-ocean coupled model can predict heavy rainfall earlier than the atmosphere-only (atmospheric) model. Baba (2022) presented heavy rainfall which was caused by atmospheric river (AR) was better predicted by a regional coupled model [1]. In Japan, heavy rainfall frequently occurs during summertime, due to not only AR but also Baiu front tends to cause heavy rainfall. To evaluate the superiority of coupled model in predicting heavy rainfall during Biau season, we performed hindcast experiments for three past summer heavy rainfall events (2010, 2016, and 2020) that lasted at least from one to two weeks.

The results show that the coupled model outperformed the atmospheric model in predicting heavy rainfall, especially in the accumulated rainfall in Kyushu area (Fig. 1). This is because the coupled model could predict pressure patterns of Baiu front and so better predict incoming low-level moisture from southwest toward Japan. In particular, the pressure gradient of Pacific high formed by atmospheric feedback was well predicted by the coupled model, since atmospheric feedback on sea surface temperature (SST) can be predicted only by a coupled model [2]. Through the better prediction for the pressure pattern around Japan, the coupled model improved prediction skill for heavy rainfall. Further investigation on the ocean heat budget revealed that not only air-sea coupling but also ocean dynamics is important for the formation of summertime SST around Japan. In this feature, Kuroshio extension has an influence on the formation of SST at the region of Pacific high [3]. These facts suggest that a slab ocean model which only considers the surface heat exchange between the atmosphere and the ocean surface is insufficient to realize a better prediction for heavy rainfall, especially for predicting its pressure pattern.

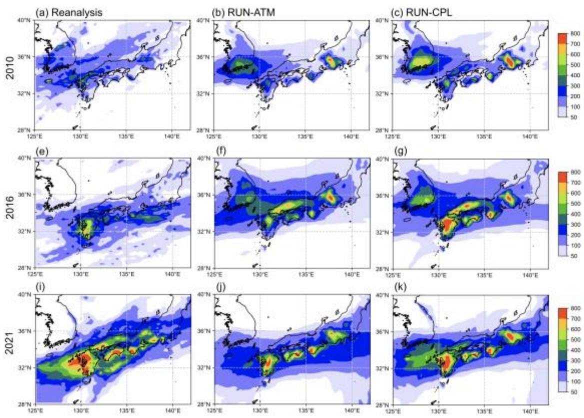

Fig.1: Comparison of accumulated rainfall for three summer heavy rainfall events. (a) left column: Reanalysis based on JMA's mesoscaole model (MSM), (b) center column: hindcast by an atmospheric model, and (c) right column: hindcast by a coupled model.

3. Atmospheric initialization in a seasonal prediction system

Seasonal prediction is useful to estimate the climate risk due to the extreme events which are caused by seasonal to interannual timescale climate variability. To provide accurate seasonal forecast to public, we are conducting operational forecast using the seasonal prediction system, named Scale Interaction Experiment for Frontier version 2 (SINTEX-F2) [4]. This seasonal prediction system initializes the atmosphere and the ocean only with a simple SST nudging scheme, however, climate variability such as interannual variability (e.g., El Nino Southern Oscillation: ENSO) normally involves atmospheric variability. Therefore, the atmospheric condition also should be initialized before prediction. Based on these backgrounds, an atmospheric initialization using atmospheric nudging scheme was implemented in SINTEX-F2.

To evaluate merits of the atmospheric initialization in seasonal prediction, hindcast experiments were performed using SINTEX-F2 with and without the atmospheric initialization during 1990-2006. The prediction skill is evaluated for 9 climate indices against the observed indices. Statistical analysis for the prediction skill revealed that the atmospheric initialization improved prediction skill for some climate indices in tropics and many indices in other than tropics (i.e., subtropics and midlatitude). The key factor that improved the prediction skill was found to be sea level pressure (SLP). When the atmospheric nudging was applied, better atmospheric forcing was correctly given to the ocean, then the prediction skill for interannual variability was improved.

The skill improvements are also related to different regimes of air-sea coupling (Fig. 2). In tropics, SST feedback on atmosphere is significant, so the SST nudging works well to initialize the atmosphere and ocean. However, in midlatitude, atmospheric feedback on SST is significant [1, 2], so the atmospheric initialization (i.e., atmospheric nudging) is more important than SST nudging. In this regime, SST nudging or fixed observed SST does not work because it neglects the atmospheric feedback on SST, and assumes a strong SST forcing, then the air-sea coupling tends to be that in tropics. Therefore, it can be concluded that the atmospheric initialization is necessary to realize more accurate seasonal prediction for tropics and midlatitude where the SST variability is affected by atmospheric variability [5].

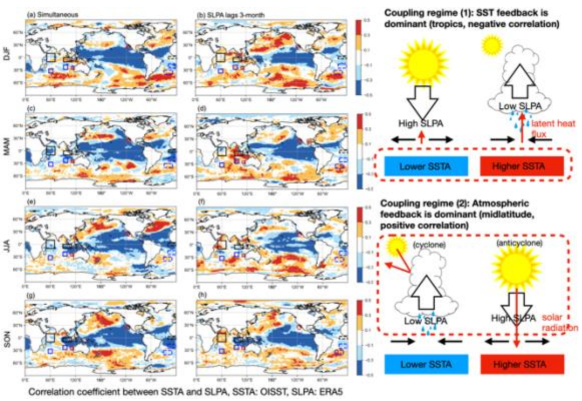

Fig. 2: Seasonally averaged correlation coefficient between SST and SLP anomalies (left), and schematics of air-sea coupling regimes (right). The negative (positive) correlation indicates the regime of significant SST (atmospheric) feedback.

4. Implementation of a spectral cumulus parameterization in JMA-GSM

Japanese operational weather forecast has been conducted by Japan Meteorological Agency (JMA) using atmosphere-only model, such as global spectral model (GSM). GSM is used to provide typhoon forecast, but its skill improvement is known to be difficult. Even though various assimilation techniques have been adopted, recent degree of prediction skill improvements remain relatively smaller than the past. To further improve the prediction skill, update of convection scheme is necessary, since the convection scheme has significant impact on convective cloud properties of tropical cyclone (TC). Indeed, Baba (2021) presented that spectral cumulus parameterization based on cloud-resolving model (spectral scheme) [6] can improve statistical properties of TC as well as their variability responding to interannual and intraseasonal variability [7].

Considering these backgrounds, we started an official collaboration with JMA to implement the new convection scheme into JMA-GSM. Since the replacement of convection scheme greatly changes the mean state and variability of the model, climatological error analysis [8] was first conducted. In the error analysis, tuning and modification of internal parameterization were also performed to suppress further error increase. The error increase due to the replacement of convection scheme was found to be within the range of 11-19%, which is relatively small when the convection scheme is replaced. Further error decrease needs parameter tuning of other physical schemes. Tropical variability regarding to Madden-Julian oscillation (MJO) which was difficult for GSM to simulate was evaluated using MJO diagnostics. It was found that GSM with the new scheme can simulate MJO much better than the original model (Fig. 3). Therefore, the updated GSM is expected to simulate large scale convective cloud activity better than the past version. Further evaluations regarding TC statistics and predictability are now being conducted, and the results will be presented in our near future results.

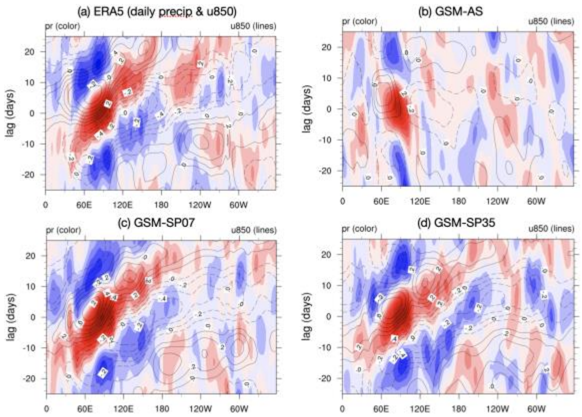

Fig. 3: Lag-cross correlation of zonal wind at 850 hPa (contour line) and precipitation (shading) anomalies in tropics for 5-yr integration results of GSM (TL63L100 resolution). (a) ERA5 reanalysis, (b) original GSM, (c) GSM with new scheme, and (d) GSM with tuned new scheme. Eastward propagating anomalies from Indian Ocean to western Pacific represents MJO activity. The tuned case shows slightly weaker signal, but indicated smaller climatological error.

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