# Development of Seasonal/Weather Prediction System for Predicting Extreme Events

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**Keywords :** Numerical weather prediction, Seasonal prediction, Convection scheme, Atmospheric river, Typhoon

## 1. Introduction

Intensity and frequency of extreme events such as typhoon and heavy rainfall are increasing along with the progress of global warming. To mitigate the risks originating from the extreme events for society, more accurate seasonal and weather prediction systems have been required. Based on this demand, we continued some developments for newer prediction systems using dynamical models which started several years ago. In this fiscal year, we worked on three major topics related to the developments. They are (1) evaluation of a prediction system for seasonal prediction of atmospheric rivers, (2) evaluation of updated operational numerical weather prediction (NWP) model for typhoon forecast, and (3) miscellaneous developments for future research.

## 2. Seasonal prediction of atmospheric rivers

The atmospheric river (AR) is known to be rich water vapor extending from the tropics toward midlatitude and causing heavy rainfall there. The influence has been mainly recognized in the western north US, as it causes heavy rainfall in the west coast during wintertime. The AR also has influences in the western north Pacific, as it sometimes causes heavy rainfall over Japan. The impact is significant, but the AR originally has shorter timescale compared with the interannual variability such as El Nino Southern oscillation (ENSO), it has been considered that it is not easy to predict its seasonal variability.

However, recently, an American research group has shown that the seasonal prediction of AR is possible with up to 9-month lead time in the west coast of north US [1]. The reason has not been clarified yet, but it was suggested that tropical variability can be a source of the seasonal AR predictability. Considering this preceding study, seasonal prediction of AR may be also possible for the western north Pacific especially over Japan. Based on this idea, we conducted hindcast experiments using our seasonal prediction system named SINTEX-F2, targeting the term during 2001-2020.

The hindcast experiments were conducted without and with atmospheric initialization to analyze the impact of initialized atmosphere and ocean by the nudging scheme. Figure 1 indicate the seasonally stratified anomaly correlation (ACC) map for seasonal AR frequency over Japan area. The AR over Japan is active during spring to fall, and peaks during the summer. The ACC maps indicate that the model successfully predicted the seasonal AR frequency especially during the peak season with over 7 months lead time. It also indicates that the nudging scheme increases the seasonal AR predictability. Further analyses on the prediction skill revealed that the seasonal prediction system has higher seasonal AR predictability than other models in the western coast of US.

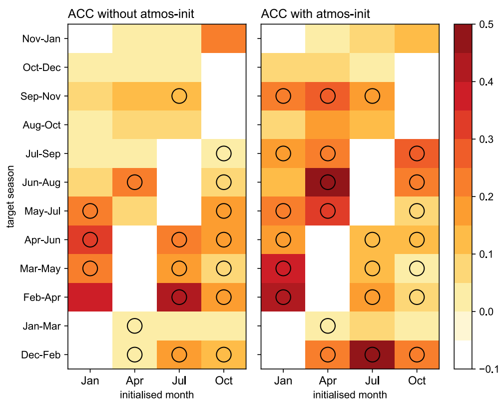


Figure 1: Seasonally stratified ACC maps for seasonal AR frequency averaged over Japan area. The horizontal and vertical axes indicate initialized month and target month. Left and right panels correspond to with and without atmospheric nudging. The black colored circle indicates that the ACC exceeds the seasonal AR persistent, i.e., the model indicates the predictability at the initialized and target months.

The source of potential predictability which enabled the seasonal AR prediction is investigated based on the findings of the preceding studies. Wang et al. (2013) noted that Pacific high has large impact on the extreme events in the western north Pacific, and it is controlled by Indo-Pacific and central Pacific variability [2]. This implies that tropical interannual variability can be a source of potential predictability of seasonal AR through the variability of Pacific high. To confirm this hypothesis, regression analysis is performed for sea surface temperature (SST) and sea level pressure (SLP) onto the seasonal AR over Japan area (Figure 2). It was found that when the seasonal AR increased over Japan, the high-pressure pattern appears over the region of Pacific high. Meantime, negative SLP pattern and warmer SST variability appears over the Maritime continent, thus there is Pacific-Japan (PJ) pattern type teleconnection. Indeed, when the tropical variability was well predicted, the seasonal AR prediction was also better.

In conclusion, the seasonal prediction of AR is possible in western north Pacific, and the possible lead time can be over 7 months using the present system. This lead time is extraordinary longer than normally expected for mid-latitude prediction. The source of predictability stems from the tropical variability, thus increasing the prediction skill for tropics may contribute to further accurate seasonal prediction of AR [3].

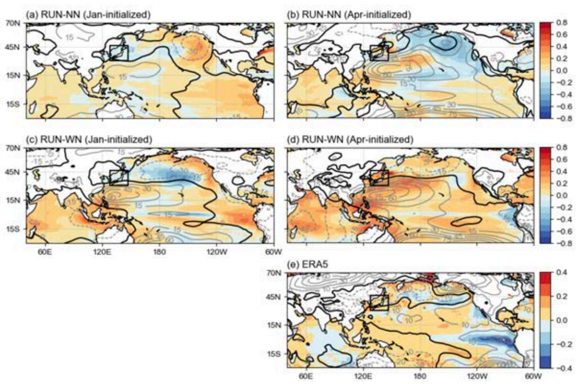


Figure 2: Regressed SST (shading, K) and SLP (gray colored contour lines, Pa) onto seasonal AR frequency averaged over Japan area (black colored box) during summer season. RUN-NN and RUN-WN indicate the cases without and with atmospheric nudging (initialization). ERA5 (OISST) is used as the reference.

### 3. Evaluation of JMA-GSM typhoon forecast using a new convection scheme

Western north Pacific is the basin where the tropical cyclones (TCs) frequently pass during summer to fall. Because of the characteristics of the basin, Japan has suffered from the damage stem from the typhoon passage. Japan Meteorological Agency (JMA) has continued efforts to improve the typhoon forecast using Global Spectral Model (GSM or JMA-GSM), and indeed, typhoon track error has been decreased continuously in past decade. However, the forecast could not increase the accuracy for typhoon strength. They speculated that substantial updates for the convection scheme are necessary. Based on this ideal, JAMSTEC and JMA conducted a collaborative work to introduce a new convection scheme [4] into JMA-GSM. The updated model presented better climatological TC properties in the global scale simulation, and the result was out in a press release from JAMSTEC in the last fiscal year [5].

However, the improvements using a new scheme for practical typhoon forecast remained unknown, and we should confirm the actual benefit of the new scheme by conducting additional experiments. To confirm this, forecast experiments were conducted for recent two typhoon cases, i.e., Prapiroon (2018) and Hagibis (2019). To clarify the advantage of the new scheme, the forecast experiment using the original scheme was also conducted. The total 11 ensemble members are considered with shifting the initialization date with a 6-hour interval. The forecast experiments using the original scheme and new scheme are referred to as RUN-AS and RUN-SP, respectively.

Figure 3 compares the time evolution of typhoon track error and minimum pressure. RUN-SP predicted better typhoon track and minimum pressure in 2018, but it predicted worse track error and better minimum pressure in 2019. Because the comparison of minimum pressure in 2019 shows a minimum pressure gap between best track and the initial condition of both cases, thus the gap may be a reason why RUN-SP showed a larger track error.

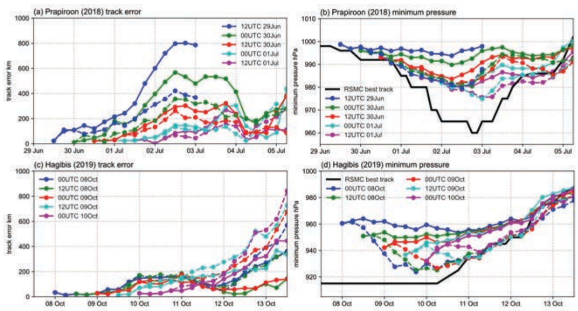


Figure 3: The time evolution of typhoon track error and minimum pressure predicted by the two forecast experiments. The black colored line, solid line, and dashed line indicate best track data, RUN-AS, and RUN-SP, respectively. Only 5 of 11 ensemble members are displayed.

To clarify the influence of pressure disturbance, which is induced by convection scheme after the initialization, ensemble singular vector sensitivity analysis (EnSVSA, Enomoto et al. 2015) [6] is performed. In the case of 2019, the low-pressure disturbance evolved behind the typhoon track, and the spread of RUN-SP is wider than that of RUN-AS (Figure 4). Along with the disturbance, horizontal winds appear to form the cyclonic circulation, meaning that the pressure disturbance acts to cause the westward movement of the typhoon. Further analysis revealed that the pressure disturbance induced by the difference of convection scheme also appeared in the mid and upper levels, leading to influence the typhoon track error.

These results indicate that the new convection scheme can improve the typhoon forecast, but it is dependent on the initial condition. The resulting convection reduces the typhoon track error when the initial condition is better, but it increases the track when the initial condition has a large difference from the observed field. To obtain further better results, the initial condition should be recreated suitable for the new convection scheme, e.g., the initial minimum pressure should match the best track [7].

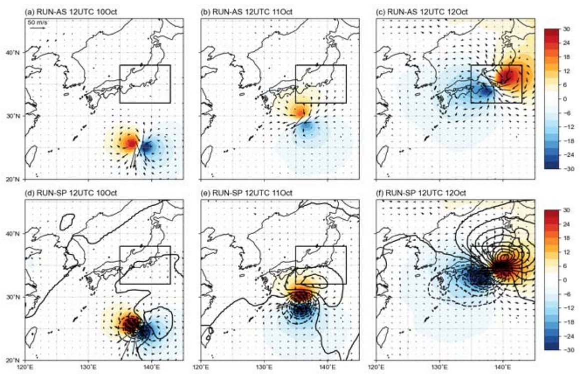


Figure 4: Ensemble singular vector sensitivity analysis for SLP and horizontal winds at 925 hPa in 2019. The time series are chosen so that the evolution can be seen from the 3 days before the landfall of Hagibis. The upper and lower panels correspond to RUN-AS and RUN-SP, respectively.

## 4. Miscellaneous developments for future research

To achieve the objectives of our future research, we conducted several developments for our general circulation models. They are (1) activation of biogeochemistry components and its IO arrangement for SINTEX-F2 seasonal prediction system, (2) high resolution version of SINTEX-F2 with introducing appropriate parameterizations, and (3) GPU tuning for several numerical models.

We have received support from the ES support desk regarding the MPI data transfer problem. If the resolution is increased, more theoretical cores in CPU are needed, i.e., number of processes increases. However, SINTEX-F2 CPU version) caused a deadlock in this case, so we had to solve this problem following the guidance from the ES support. After some investigation and modifications to the source code, the high resolution SINTEX-F2 became available with an increased number of CPUs (blocked data transfer was introduced).

For GPU tuning, we used ES4GPU on ES4 and Wisteria (Aquarius) of Univ. Tokyo. Some test models were tuned and the characteristics of OpenACC compiled with NVIDIA Fortran compiler were confirmed. These experiences will make the near future tuning to be more efficient and will realize a smooth migration of our codes from ES4CPU/ES4VE to a new architecture.

## Acknowledgement

The author thanks to ES support desk for their helps with trouble shooting regarding MPI data transfer and GPU tuning.

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