APPLICABILITY OF ATMOSPHERIC REANALYSIS DATA FOR THE REPRODUCTION OF TYPHOON-INDUCED STORM SURGE IN JAPAN

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INTRODUCTION

The accurate estimation of a typhoon is a key to improving the reproducibility of typhoon-induced storm surges. The grid point value (GPV) data of Local Forecasting Model (LFM), which are provided by the Japan Meteorological Agency (JMA), are shown to be the most accurate data to simulate typhoons in and around Japan. However, due to the limitations of LFM data (limited spatial and temporal coverage), the atmospheric reanalysis data, which are available for the global domain covering a long period, are commonly used in practical applications. According to previous researchers, it is expected to give a better representation of typhoons in terms of structure and intensity with reanalysis datasets although they are in too coarse resolutions to capture the internal dynamics (Malakar et al., 2020), and the reproducibility of typhoons with different reanalysis datasets varies over different oceanic basins (Schenkel and Hart, 2012). Hence, this paper analyses the two major atmospheric reanalysis datasets together with LFM dataset, and confirms their applicability to reproduce typhoon-induced storm surges in Japan.

METHODOLOGY

As shown in Table 1, three different datasets: LFM, JRA-55 (Japanese 55-year Reanalysis), and ERA5 (the fifth generation ECMWF atmospheric reanalysis of the global climate) are used during this study. Five destructive typhoons that stroke three major bays in Japan (Osaka Bay: Cimaron-T1820 and Jebi-T1821, Ise Bay: Trami-T1824, and Tokyo Bay: Faxai-T1915 and Hagibis-T1919) are selected for the analysis (Figure 1). The Weather Research and Forecasting (WRF) model (Skamarock et al., 2008) with the fixed-nest is forced by three GPV datasets (Hereafter referred to as WLFM: WRF forced by LFM data, WJRA55: WRF forced by JRA-55 data, and WERA5: WRF forced by ERA5 data) to reproduce the five typhoons. Characteristics of GPV data for these five typhoons are compared with those of the typhoons reproduced by WRF. The Coupled Ocean Atmosphere Wave Sediment Transport (COAWST) modeling system (Kumar et al., 2012) is used to simulate typhoon-induced storm surges. The COAWST model is forced by a set of forcing (mean sea level (MSL) pressure (Pair), and wind at 10m above MSL (magnitude: W10, direction: W10_Dir)) which is created from WRF output. The applicability of reanalysis data to reproduce the typhoon-induced storm surges in Japan is confirmed by verifying the change of sea surface elevation (ζ).

Table 1 - Specifications of datasets

Description	Dataset		
	LFM	JRA-55	ERA5
Spatial coverage	Japan and surroundings	Global	Global
Temporal coverage	2014 to present	1958 to present	1950 to present
Resolution: Horizontal	2 km	~55 km	31 km
Temporal	Hourly	6-Hourly	Hourly
Vertical levels/ Top	76/21.8 km	61/0.1 hPa	137/1.0 hPa
Initial condition/Data assimilation	3D-Var	4D-Var	4D-Var

APPLICABILITY OF REANALYSIS DATA

The simulated five typhoons in WRF are analyzed with JMA hourly meteorological observational data at three locations in each bay. Similarly, the simulated storm surge results in COAWST are analyzed with JMA hourly tidal observational data at three locations in each bay. Figure 2 shows temporal variations of ζ, Pair, W10 and W10_dir at one selected location from each bay (Osaka in Osaka Bay, Nagoya in Ise Bay, and Tokyo in Tokyo Bay) as the other two locations showed similar variations. Spatial variations of the above four variables are also analyzed and Figure 3 shows how Pair varies with three different datasets.

As shown in Figure 2, the temporal variations of typhoons reproduced by WERA5 are in the best agreement with the observation for T1820 and T1821 in Osaka Bay and, for T1824 in Ise Bay. In contrast, the temporal variations of typhoons reproduced by WLFM are in the best agreement with the observations for T1915 and T1919 in Tokyo Bay.

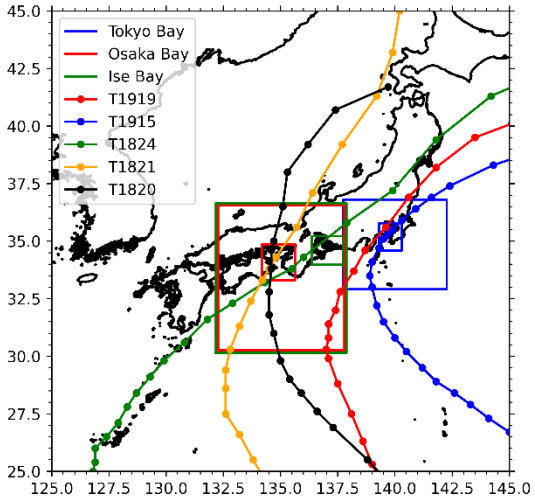

Figure 1 - Computational domains (2nd & 3rd) for COAWST model with typhoon best tracks

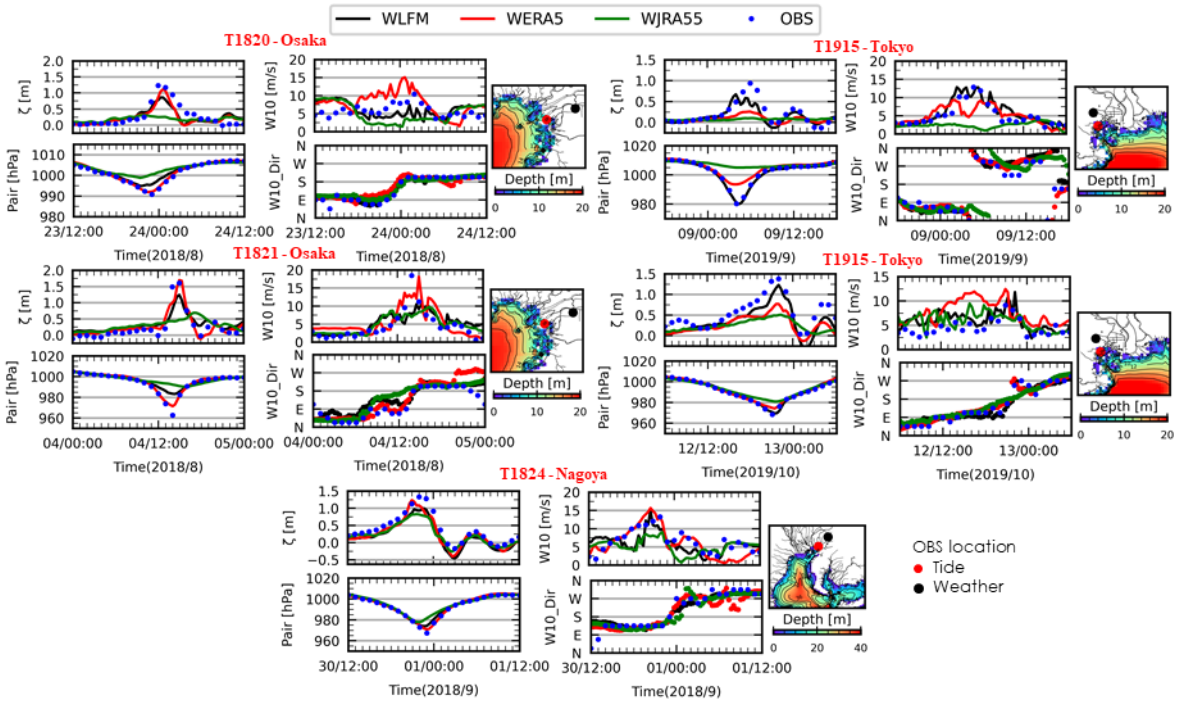

Figure 2 - Temporal variations of sea surface elevation (ζ), MSL pressure (Pair), and wind at 10m above MSL (W10, W10_Dir) at JMA observational locations

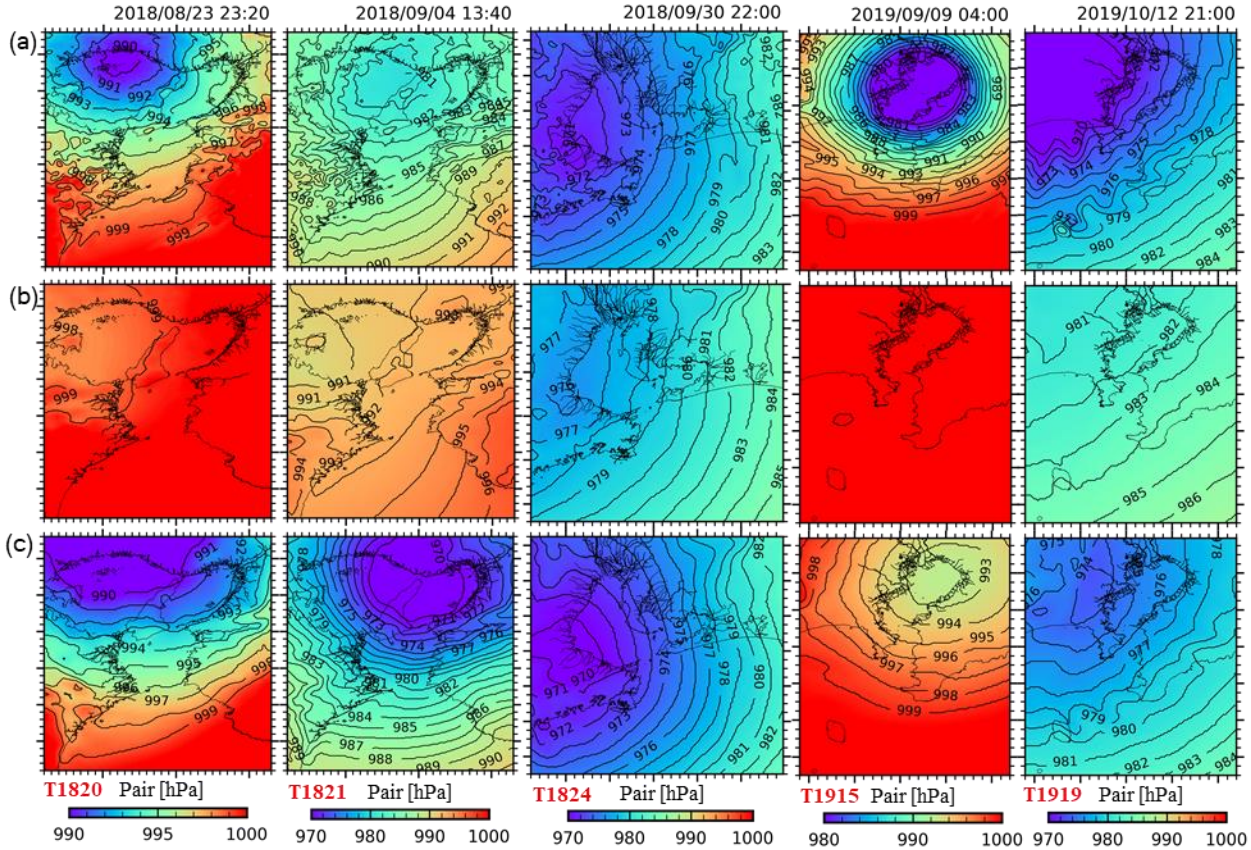

Figure 3 - Spatial variations of MSL pressure (Pair): (a) WLFM, (b) WJRA55, and (c) WERA5

Moreover, the temporal variations of typhoons reproduced by WJRA55 show the largest deviations with observations for all five typhoons.

The reproducibility of the temporal variations of typhoon-induced storm surges is consistent with that of typhoons. ζ reproduced by WERA5 forcing is in the best agreement with the observations for T1820 and T1821 in Osaka Bay, and for T1824 in Ise Bay. In contrast, ζ reproduced by WLFM forcing is in the best agreement with the observations for T1915 and T1919 in Tokyo Bay. ζ reproduced by WJRA55 forcing shows the largest deviations with observations for all five typhoons.

According to the spatial variations of Pair in Figure 3, the structure of typhoons with WERA5 is closer to WLFM while WJRA55 deviates considerably. Spatial variations of ζ are consistent with the spatial variations of Pair: WERA5 forcing has reproduced T1820, T1821, and T1824 with the largest intensities of ζ in inner Osaka Bay and in inner Ise Bay while WLFM forcing has reproduced T1915 and T1919 with the largest intensities of ζ in inner Tokyo Bay. Moreover, WJRA55 forcing has reproduced the smallest intensities of ζ in inner bays for all five typhoons.

In order to understand the behavior of typhoons further with different datasets, the minimum Pair locations, which represent the epicenters of typhoons are compared with JMA typhoon best track data. Typhoon best track data which are provided by JMA (with 3-hr or 6-hr time intervals depending on the speed of the typhoon) are used for the comparison when the typhoon is passing over each bay. As shown in Figure 4(a), LFM and ERA5 GPV data show good agreements with the best track while JRA-55 GPV data shows a significant deviation. Similarly, as shown in Figure 4(b), typhoon paths of WLFM and WERA5 show good agreements with the best track while typhoon path of WJRA55 shows a significant deviation. As a result, the intensity of the typhoon in WJRA55 has become too small at the time 'A' (Figure 4 (c)). In order to improve the reproducibility of typhoons in WJRA55, typhoon Bogus is applied (Suzuyama et al., 2012). Figure 5 shows how the reproducibility of WJRA55 can be improved with the inclusion of Bogus model data (Hereafter referred to as WJRA55-B). Applying typhoon Bogus data with the JRA-55 dataset in WRF improves the minimum Pair locations providing better forcing for COAWST, thereby improving the reproducibility of ζ.

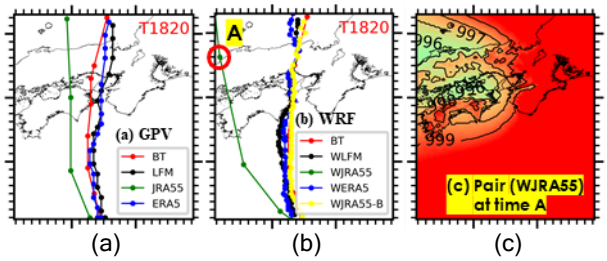

Figure 4 - Comparison of minimum Pair with the best track: (a) GPV data, (b) WRF output, and (c) spatial variation of Pair for WJRA55 at time A

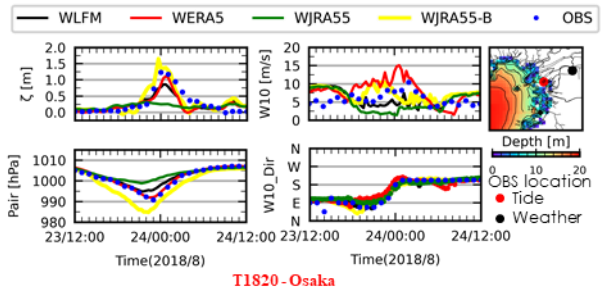

Figure 5 - Temporal variations of forcing for COAWST, and ζ at Osaka JMA observational location

Even though the ERA5 dataset has a coarser spatial resolution than that of the LFM dataset, WERA5 has reproduced typhoons nearly the same or with better accuracy than WLFM most of the time. Since JRA-55 and ERA5 are reanalysis datasets, the amount of data used for the analysis is larger than that of LFM. Moreover, JRA-55 and ERA5 use 4D-Var while LFM uses 3D-Var, and 4D-Var is shown to be globally superior to 3D-Var as it uses the time dimension within the assimilation window. However, these results of typhoon simulations show that the application of different reanalysis datasets in WRF with fixed-nest does not reproduce typhoons in similar accuracies.

CONCLUSION

WERA5 captures the evolution of typhoons in Japan with almost the same accuracy as WLFM most of the time, while WJRA55 shows large deviations. Typhoon-induced storm surge is consistent with the input forcing: WERA5 reproduces typhoon-induced storm surges in Japan with almost the same accuracy as WLFM most of the time, while WJRA55 shows large deviations. Hence, ERA5 data is more applicable than JAR-55 data to reproduce the typhoon-induced storm surges in Japan. Properly tuned WJRA55-B model data can also be applied as the same accuracy as WLFM to reproduce the typhoons and thereby typhoon-induced storm surges in Japan.

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