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Supporting Information for

Large ensemble simulation for investigating predictability of precursor vortex of Typhoon Faxai in 2019 with a 14-km mesh global nonhydrostatic atmospheric model

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Contents of this file

Introduction

This file includes additional details on vortex tracking (Text S1) and the classification of Faxai-like vortices into type-AB and type-B vortices (Text S2). Figure S1 shows a sample of the classification. Figure S2 shows strike probability densities for type-B vortex. Figure S3 shows the horizontal distribution of 100-member ensemble mean relative vorticity at 850 hPa and the position of Faxai-like vortices 24 h after starting the simulation. Figure S4 shows the ensemble mean central pressures of Faxai-like vortices around the genesis position of Faxai and Tokyo

Bay. Figure S5 shows the ensemble mean time difference between Faxai and Faxai-like vortices around the genesis position of Faxai and Tokyo Bay. Table S1 lists the names of vortices used in this study. Table S2 shows the position information of Pre-Faxai in the EDA.

Text S1. Vortex tracking.

We regarded a local maximum of relative vorticity at an 850-hPa altitude as a candidate for TCs. To find the local maximum, the vorticity field at the 850-hPa altitude was calculated every 6 h using a 1.25° mesh data that was regridded from the original 14-km mesh data for NICAM simulations and the original 25-km mesh data for ERA5. In this study, we ignored the local maxima of which the relative vorticity was less than 1.0×10^{-6} s^{-1}. The local maxima locations were modified using the vorticity field with the 14-km mesh data for NICAM 1600-member ensemble simulation and 25-km mesh data for ERA5. The location of vortex for NICAM climatology ensemble simulation was modified using the sea level pressure field with 14-km mesh data because of a limitation of data storage. We searched for the local minimum sea level pressure in 14-km mesh data around the local maximum relative vorticity in 1.25° mesh data. Next, to create a path, these locations were connected in a time direction by taking a nearest-neighbor approach considering the surrounding flow at 850- and 200-hPa altitudes. We assume the path had to last at least 96 h because the real Faxai took 96 h between genesis and approaching Tokyo Bay. Among the determined paths, those which satisfy the following three conditions for 36 h or longer once or more along the track were defined as the “TC” tracks.

1. The wind speed at 10 m with the original data exceeds 17.5 m s^{-1}.
2. The vorticity at 850 hPa with the 1.25° mesh data exceeds 3.5×10^{-5} s^{-1}.
3. The sum of temperature anomalies at 700, 500, and 300 hPa with the 1.25° mesh data exceeds 2 K.

Those which do not satisfy the above criteria are called “tropical depression” tracks.

Text S2. Faxai-like vortex

We selected Faxai-like vortices from the tracking data described in Text S1. First, we searched for a Faxai-like vortex using a method similar to that of Nakano et al. (2015) applied to the tracking data. The real Faxai was recorded as upgrading to tropical storm intensity at 18 UTC on September 4, 2019, on a location (18.5°N, 156.7°E). We regarded the time as the genesis time of Faxai and the location as the genesis location. Following the method of Nakano et al. (2015), we imposed a criterion for the genesis, which requires passage within a 1000-km radius of the genesis location within 5 days before and after the genesis time, to detect a Faxai-like vortex from the tracking data for each ensemble member. The criterion was called criterion B. We regarded the vortex that satisfied criterion B as a Faxai-like vortex. The minimum distance between the genesis location of the real Faxai and simulated vortex track is defined as DR_B [km], and the time difference at the minimum distance is defined as DT_B [h]. The score for criterion B (S_B) is calculated as follows:

$$S_B = 1 - \frac{DR_B}{1000}\frac{DT_B}{120}. \quad (1)$$

In this study, we discuss not only the genesis but also the subsequent track of Faxai. Because the real Faxai passed over Tokyo Bay (35.3°N, 139.7°E) at 18 UTC on September 8, 2019, we defined the time as the approaching time of Faxai, and the location as the approaching location. For this reason, we also defined criterion A, in which a passage within a 1,000-km radius of the approaching location within 5 days before and after the approaching time is required in addition to criterion B. As with criterion A, a score for criterion A (S_A) was defined as follows:

$$S_A = 1 - \frac{DR_A}{1000}\frac{DT_A}{120}. \quad (2)$$

In the main text, Faxai-like vortices can be classified into two-type vortices: type-AB vortex (satisfying both criteria A and B) and type-B vortex (satisfying only criteria B). We select only one Faxai-like vortex from each ensemble member. When two or more type-AB vortices were detected in an ensemble member, we selected the type-AB vortex with the highest product of the scores for criteria A and B ($S_A \times S_B$). When there is no type-AB vortex in an ensemble member, we selected a type-B vortex as a Faxai-like vortex. When two or more type-B vortices exist, the vortex with the greatest S_B is selected as the Faxai-like vortex. Fig. S1 shows samples of type-AB and type-B vortices.

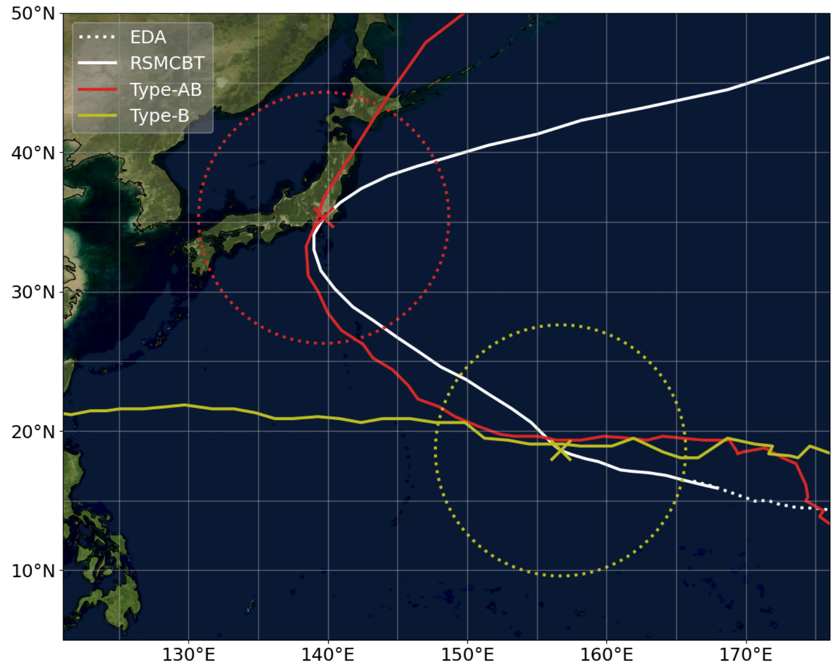

Figure S1. Samples of type-AB and type-B vortex tracks. The red and yellow lines indicate samples of type-AB and type-B vortex tracks respectively. The red and yellow crosses indicate the locations of Faxai genesis (18.5°N, 156.7°E) and Tokyo Bay (35.3°N, 139.7°E), respectively. The red and yellow dotted lines indicate areas within a 1000-km radius of the genesis location and Tokyo Bay, respectively. The white solid and dashed lines represent the RSMCBT and EDA, respectively. Topography and bathymetry are Blue Marble: Next generation (September) which was produced by Reto Stöckli, NASA Earth Observatory.

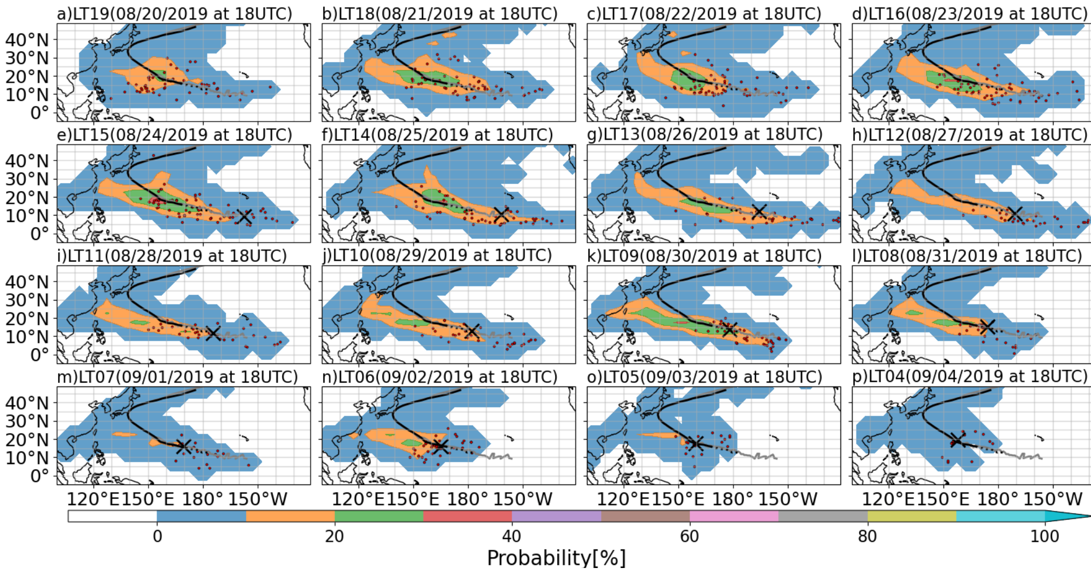

Figure S2. Plan views of strike probability densities for type-B vortex for each 100-member simulation starting from each LT. The density was defined by vortices per 5° cap. The black solid, black dotted, and solid gray lines represent the RSMCBT, the EDA, and ERA5, respectively. The figures in parentheses indicate the start time of each 100-member ensemble simulation. The cross symbol indicates the location of Pre-Faxai (e–o) or Faxai (p) at the start time for each LT. These locations were determined from ERA5. The red circles indicate the starting points of type-AB vortex tracks.

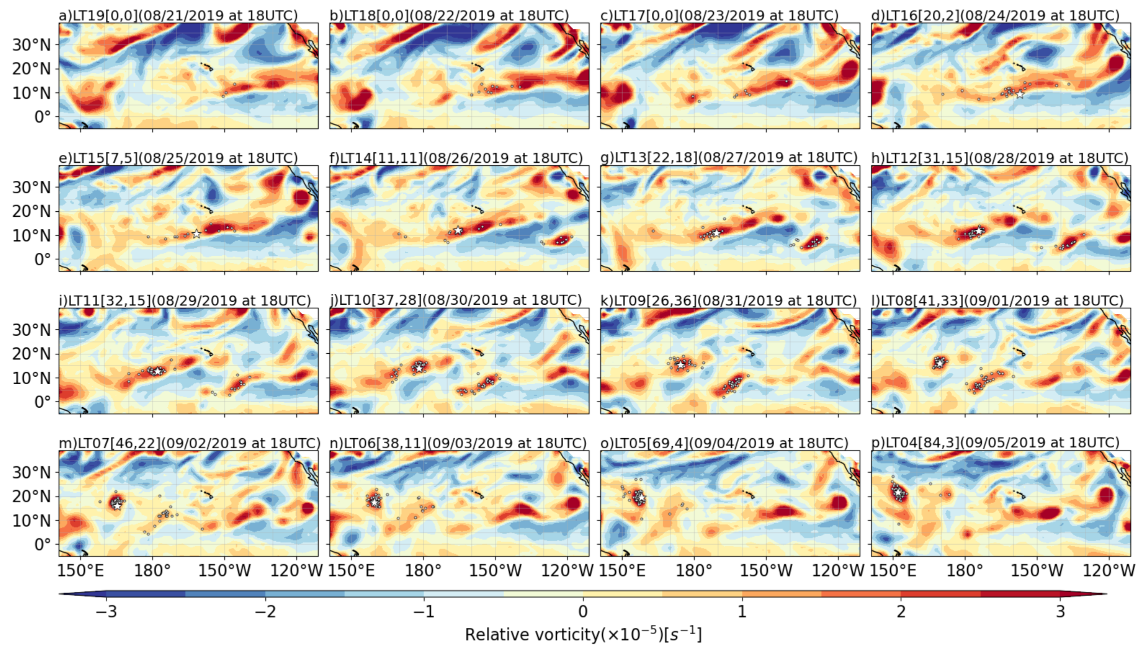

Figure S3. Plan views of the 100-member ensemble mean relative vorticity at 850 hPa at 24 h after the start of simulation for each LT. The figures in parentheses on the panels indicate forecast time. Numerals in square brackets denote the number of vortices originated from the correct vortex at the forecast time, and that originated from the possible vortex. Faxai-like vortices were classified into correct and possible vortices based on the relative position to the real Faxai at the forecast time. A vortex located more than 5° east far from the position of the real Faxai was regarded as a possible vortex. Positions of Faxai-like vortices at the forecast time are embedded on each panel with circles. The star-shaped symbol is the positions of Pre-Faxai (d–n) and Faxai (o and p) analyzed in the ERA5 at the same time as the forecast time.

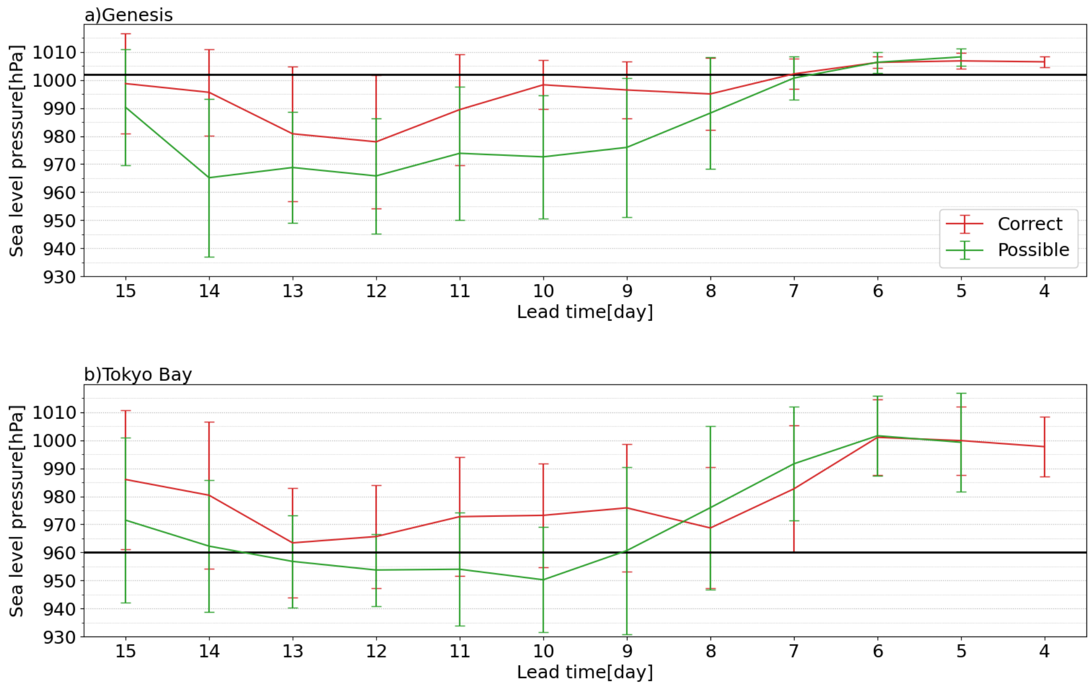

Figure S4. Ensemble mean central pressure of Faxai-like vortices for each LT. The error bars indicate the standard deviation (1− σ). (a) The central pressure of the vortex at the time when the vortex is closest to the genesis location of Faxai (18.5°N, 156.7°E). (b) The central pressure of the vortex at the time when the vortex is closest to the location of Faxai approaching Japan (Tokyo Bay; 35.3°N, 139.7°E). The red and green indicate vortices originated from the correct and possible vortices, respectively. We regarded a vortex whose starting location of the track was more than 5° east far from the location detected in ERA5 at the same time as a correct vortex. The other vortices were regarded as possible vortices.

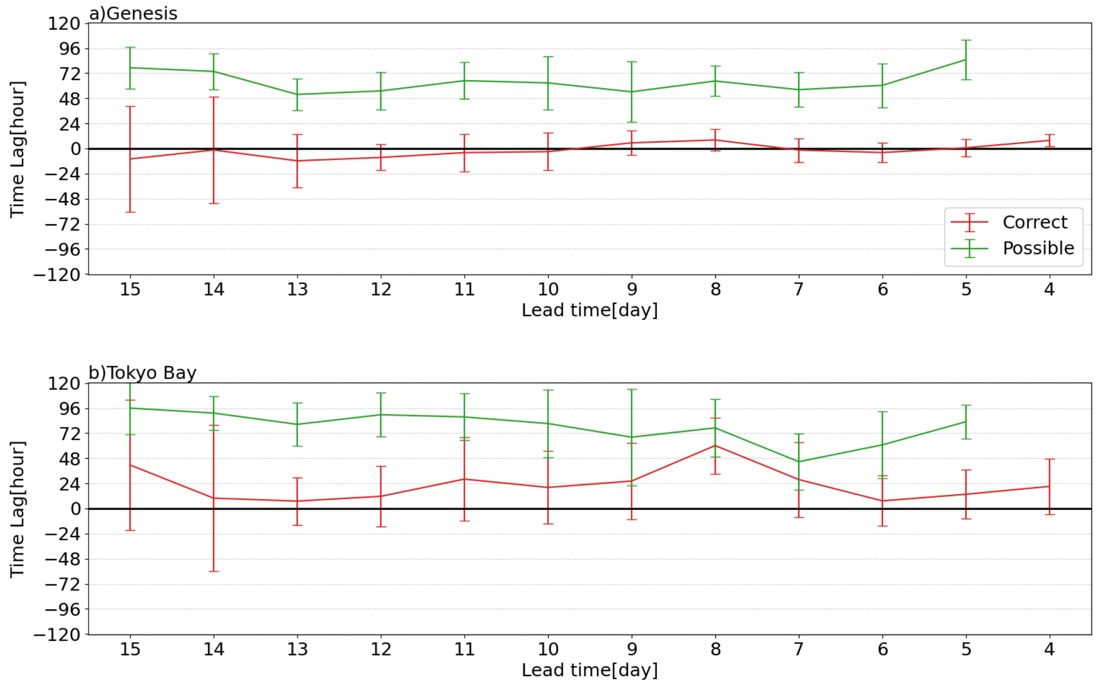

Figure S5. Ensemble mean time difference of Faxai-like vortices for each LT. The error bars indicate the standard deviation. (a) The difference between the genesis time of Faxai (18 UTC on September 4, 2019) and the time when the Faxai-like vortex is closest to the genesis location of Faxai (18.5°N, 156.7°E). (b) The difference between the time of Faxai approaching Tokyo Bay (18 UTC on September 8, 2019) and the time when the Faxai-like vortex is closest to Tokyo Bay (35.3°N, 139.7°E). The red and green indicate vortices originated from the correct and possible vortices, respectively. We regarded a vortex whose starting location of the track was more than 5° east far from the location detected in ERA5 at the same time as a correct vortex. The other vortices were regarded as possible vortices.

Table S1. Names of the vortices used in this study.

Name	Description
Faxai	Typhoon in 2019 caused severe hazards in the Tokyo metropolitan area.
Pre-Faxai	Vortex is the precursor vortex of Faxai, which was recorded in the RSMCBT between 12 UTC on September 4 and 00 UTC on September 2, 2019, the EDA between 6 UTC on September 2 and 12 UTC on August 29, 2019, and detected from ERA5 between 12 UTC on September 4 and 6 UCT on August 24, 2019.
type-AB vortex	Vortex in the ensemble simulation satisfying criteria A and B
type-B vortex	Vortex in the ensemble simulation satisfying only criteria B.
Faxai-like vortices	Vortices in the ensemble simulation, including type-AB and type-B vortices.
correct vortex	Faxai-like vortex originated from a precursor near Pre-Faxai.
Possible vortex	Faxai-like vortex originated from a precursor on the southeast side of Pre-Faxai.

Table S2. Positions of the Pre-Faxai based on the EDA.

Time [UTC]	Latitude [°]	Longitude [°]
2019-08-29T12	12.56	-177.36
2019-08-29T18	12.68	-178.84
2019-08-30T00	12.93	-179.55
2019-08-30T06	12.58	179.76
2019-08-30T12	12.94	179.00
2019-08-30T18	13.22	178.12
2019-08-31T00	13.82	177.52
2019-08-31T06	14.21	176.85
2019-08-31T12	14.44	175.14
2019-08-31T18	14.50	173.64
2019-09-01T00	14.76	172.30
2019-09-01T06	15.01	171.58
2019-09-01T12	14.96	170.64
2019-09-01T18	15.10	170.28
2019-09-02T00	16.03	167.63
2019-09-02T06	16.40	166.20