Relationships between tropical cyclone motion and surrounding flow with reference to the maximum sustained wind and longest radius

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1. Introduction

Tropical cyclones develop over tropical or subtropical oceans with warm sea surface temperatures. The Western North Pacific (WNP) basin (Fig. 1) is one of the most active areas for cyclone formation. The present study statistically examines how the β-drift is influenced by the maximum sustained wind (MSW) and longest radius (LR) of tropical cyclones, by comparing its actual track with ambient winds, considering the effects of MSW and LR.

2. Data and methodology

The present study uses a best track dataset over the WNP basin (Fig. 1), compiled by the JMA. The dataset includes the position of the typhoon center, its central pressure, MSW, LR, size grade, and symmetricity measured every six hours, covering the period from 1951 to the present.

Actual typhoon propagation speed is calculated from sequential positions of a typhoon in the zonal and meridional directions. The steering flow of a typhoon is calculated from reanalysis data (JCDAS; Japan Climate Data Assimilation System) provided by the JMA. JCDAS covers a period of 35 years, from 1979 to 2013, and has a grid spacing of 1.25° × 1.25° in the east-west and north-south directions. Further details of the JCDAS are provided by Onogi et al. (2007). The calculation of the steering flow of a typhoon is follows.

Firstly, horizontal winds are integrated between 1000 hPa to 300 hPa, and normalized by the mass between these two levels. Thus, the mass-weighted winds are expressed as:

$$\bar{u} = \frac{\int_{1000}^{300} u\, dp}{\int_{1000}^{300} dp} \quad \text{and} \quad \bar{v} = \frac{\int_{1000}^{300} v\, dp}{\int_{1000}^{300} dp},$$

where u and v are the zonal and meridional components of the horizontal winds, respectively. Secondly, the vertically-integrated wind is averaged over grids within a radius of 300 km, 400 km, or 500 km from the center of the typhoon. These vertically-integrated and horizontally-averaged winds are thus defined as the steering flow for a typhoon in the present study.

The relationships between typhoon propagation speed and steering flow are examined by scatter diagram, which are explained schematically in Fig. 2. Those typhoons falling in the upper-left (black-shaded) domain of Figs. 2a and 2b propagate towards the north and east, relative to the steering flow, respectively. In contrast, the lower-right (gray-shaded) domains correspond to the southward and westward propagation of typhoons, relative to the steering flow. In addition, the diagonal area in Fig. 2 represents the area in which the steering flow and typhoon propagation speed are strongly correlated with one another; typhoon propagation can be mostly accounted for by steering flow alone in this diagonal region.

Figure 3 shows the relationships between propagation speed and steering flow for all measured typhoons in the north-south (Fig. 3a) and east-west (Fig. 3b) directions. About half of the points fall within the diagonal (blue-shaded) area enclosed by the two dashed lines in Fig. 3. Figure 3 shows a greater number of points fall within the red-shaded areas in Figs. 3a and 3b compared with other areas, with the exception of the diagonal blue-shaded area. This indicates that the majority of typhoons propagate to the north and west under northward and westward steering flows, respectively. Therefore, it can be considered that this feature of Fig. 3 reflects the hypothesized β-drift of typhoons (e.g., DeMaria, 1985).

3. Results and discussion

A) Drift in the northward and southward directions

In this section, we focus on the relationship between the steering flow and typhoon propagation in the north-south direction. Figure 4 shows the proportions of typhoons that propagate towards the north and south relative to the steering flow, and grouped according to MSW. These figures are constructed by counting the number of dots within the upper-left and lower-right domains in Fig. 2a, in accordance with their MSW. Those typhoons falling within the diagonal domain in Fig. 2a are excluded from this analysis, because typhoon propagation can be accounted for by the steering flow in this region. The proportion of typhoons propagating northward relative to the steering flow increases with increasing MSW, regardless of the average steering flow radius (300 km, 400 km, or 500 km). These features are more clearly seen in asymmetric typhoons than symmetric ones (Figs. 4b and Fig. 4c).

Figure 5 shows a scatter diagram comparing steering flow and propagation speed for asymmetric typhoons in the north and south directions, with reference to the MSW. With the exception of the grey-shaded areas, the number of points decreases more pronouncedly with increasing MSW, which reflects the increasing fractions of typhoons that propagate towards the north relative to the steering flow in Fig. 4c.

B) Drift in the eastward and westward directions

In this section, we focus on the relationship between the steering flow and typhoon propagation in the east-west direction. Figure 6 shows the proportions of typhoons that propagate towards the east and west relative to the steering flow, and grouped according to MSW. In contrast to the results found for the north-south propagation, no significant relationships are seen between the typhoon motion and steering flow (Fig. 6a). Focusing only on symmetric typhoons, however, it is possible to see an increase in the numbers of eastward propagating typhoons relative to steering flow (Fig. 6b). In contrast, such variations are not seen in the distribution of asymmetric typhoons (Fig. 6c).

Figure 7 is a scatter diagram representing the relationship between steering flow and propagation speed of symmetric typhoons in the east and west direction, with reference to the MSW. From this, it can be seen that the number of points in the gray-shaded areas decreases as the MSW in the typhoon intensifies. This reduction corresponds to the increasing fraction of typhoons that propagate eastward relative to the steering flow, as shown in Fig. 6b.

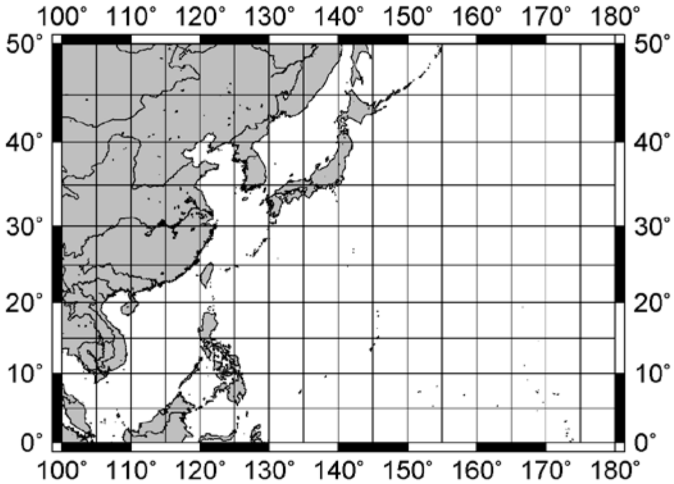

Fig. 1: The Western North Pacific (WNP) basin, which is the target area of the present analysis.

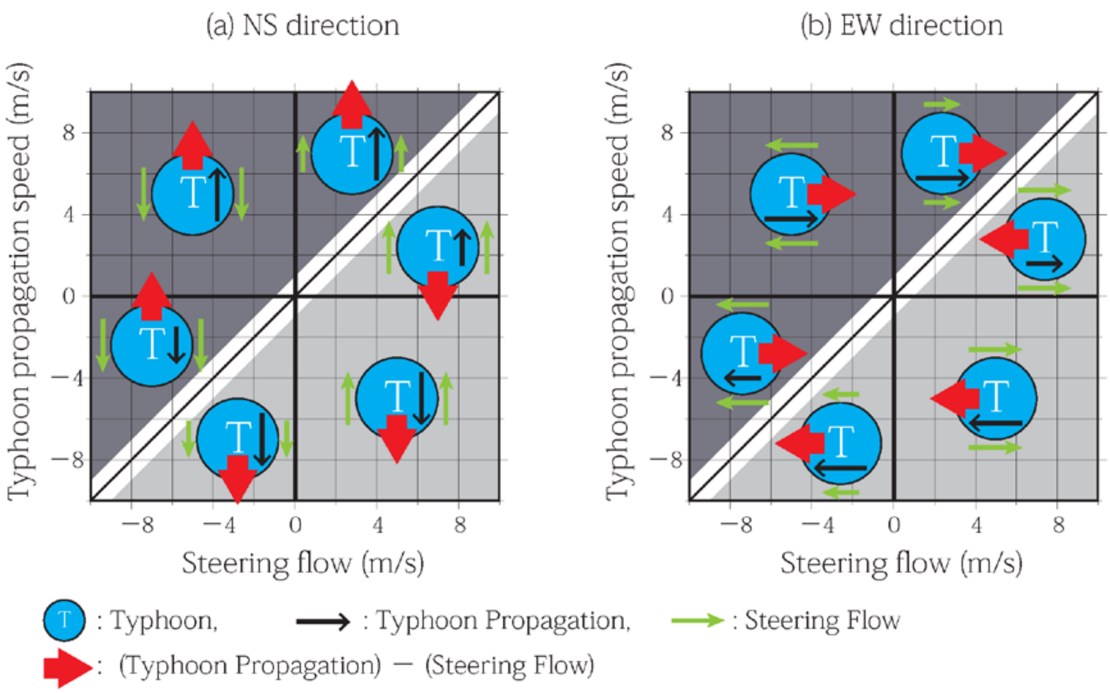

Fig. 2: Schematic showing the relationships between steering flow (x-axis) and typhoon propagation speed (y-axis). Green and black arrows in the panel indicate the directions of steering wind and typhoon propagation, respectively. The large red arrow shows the difference between the two (propagation speed minus ambient flow), and indicates the direction of typhoon propagation relative to the ambient flow.

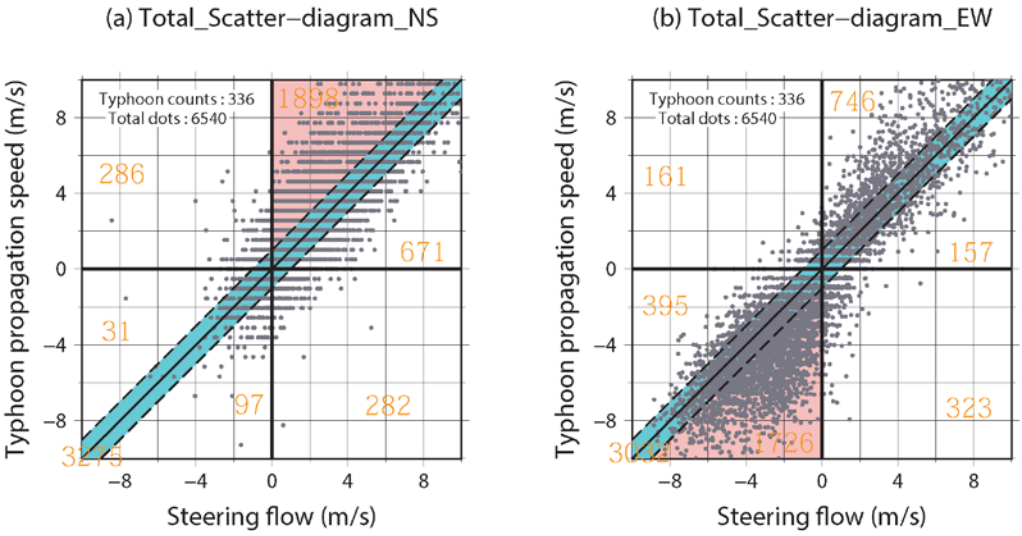

Fig. 3: Scatter diagram of steering flow (x-axis) and propagation speed (y-axis) of typhoons in the (a) north-south, and (b) east-west directions. Steering flow is defined as the ambient wind averaged between 1000 hPa to 300 hPa over areas within a 400 km radius of the typhoon center. The orange-colored numbers in the panel indicate the number of points in each domain. The total number of points and the typhoon counts are shown in the upper left corner of each panel.

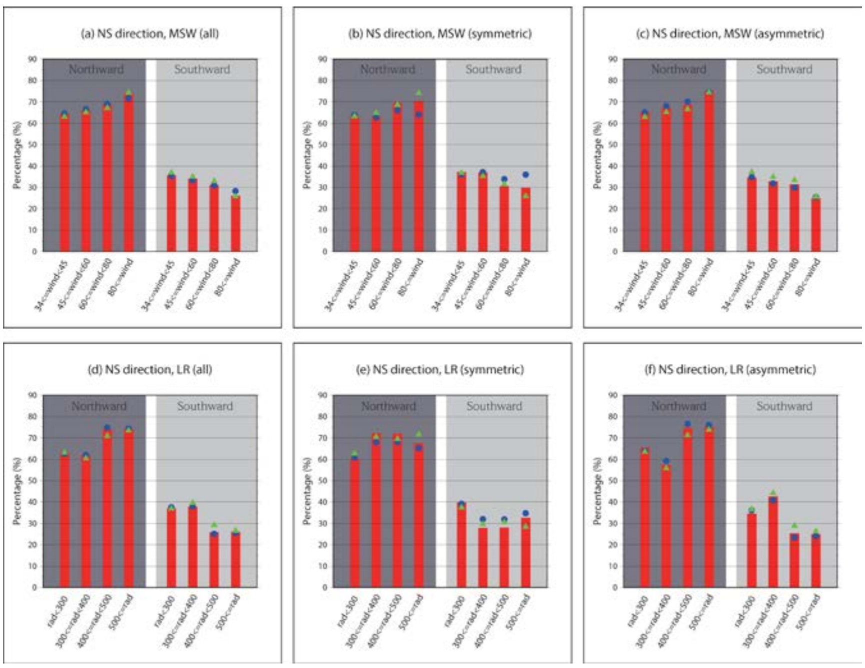

Fig. 4: Proportions of typhoons that propagate towards the north and south relative to the steering flow. In the upper panels, the typhoons are sorted by MSW, and in the lower panels, typhoons are sorted by LR. The left panels include all typhoons, while middle and right panels count only symmetric and asymmetric typhoons, respectively. The circle, bar and triangle in the panel corresponds to the results in which the ambient winds are averaged between 1000 hPa to 300 hPa over areas within 300 km, 400 km, and 500 km radius around the typhoon, respectively.

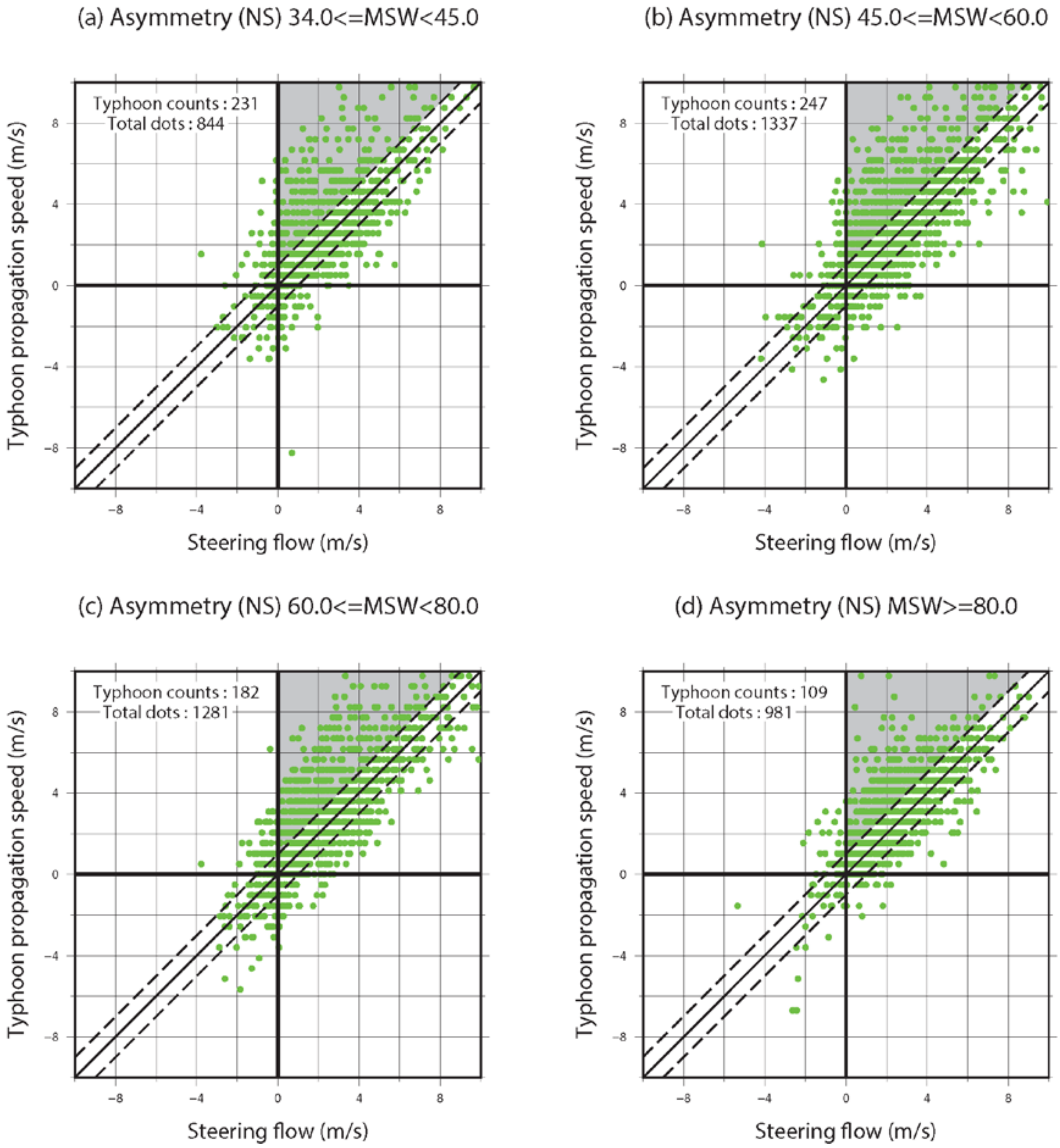

Fig. 5: Scatter diagram of the steering flow (x-axis) and propagation speed of asymmetric typhoons (y-axis) in the meridional direction. The steering flow is defined as the ambient wind averaged between 1000 hPa to 300 hPa over areas within a 400 km radius of the typhoon center. The typhoons are sorted by MSW: (a) MSW of 34–45 knots, (b) MSW of 45–60 knots, (c) MSW of 60–80 knots, and (d) MSW larger than 80 knots. The total number of points and typhoon counts are shown in the upper left corner of each panel.

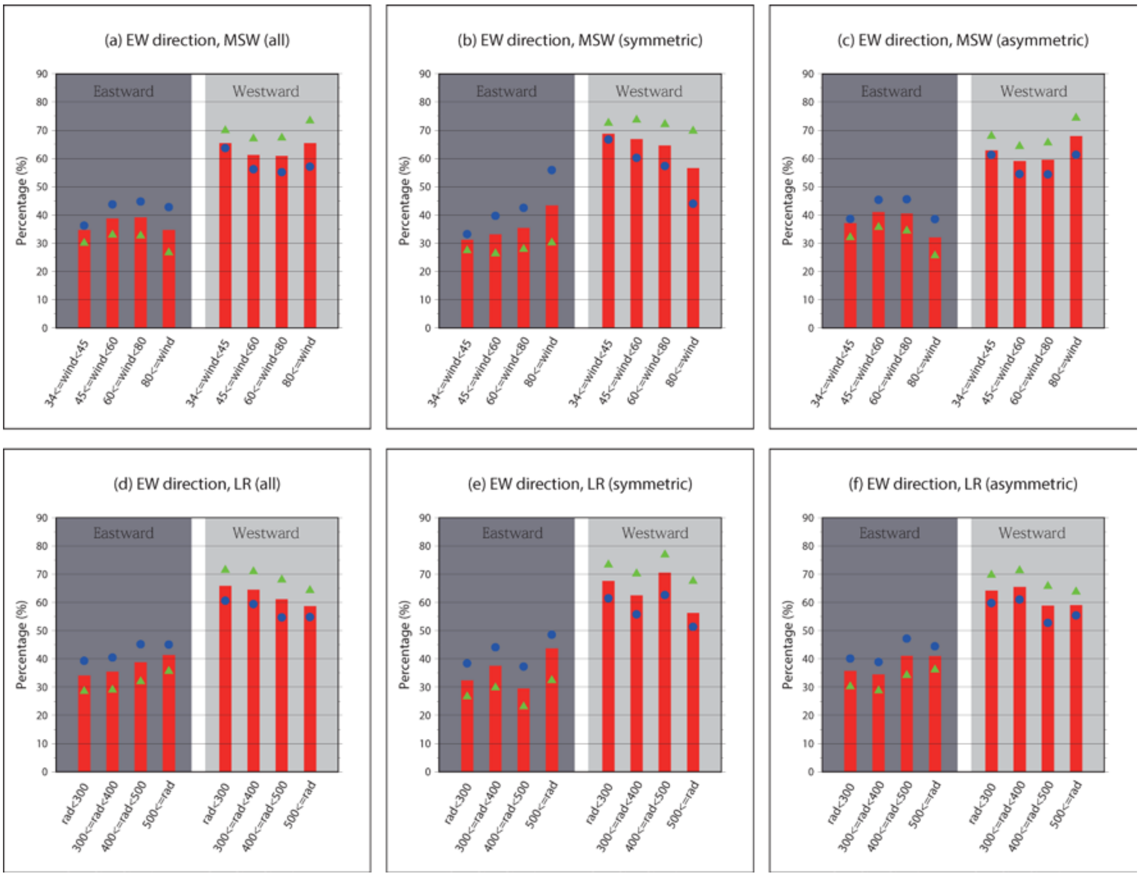

Fig. 6: As for Fig. 4, but in the zonal direction.

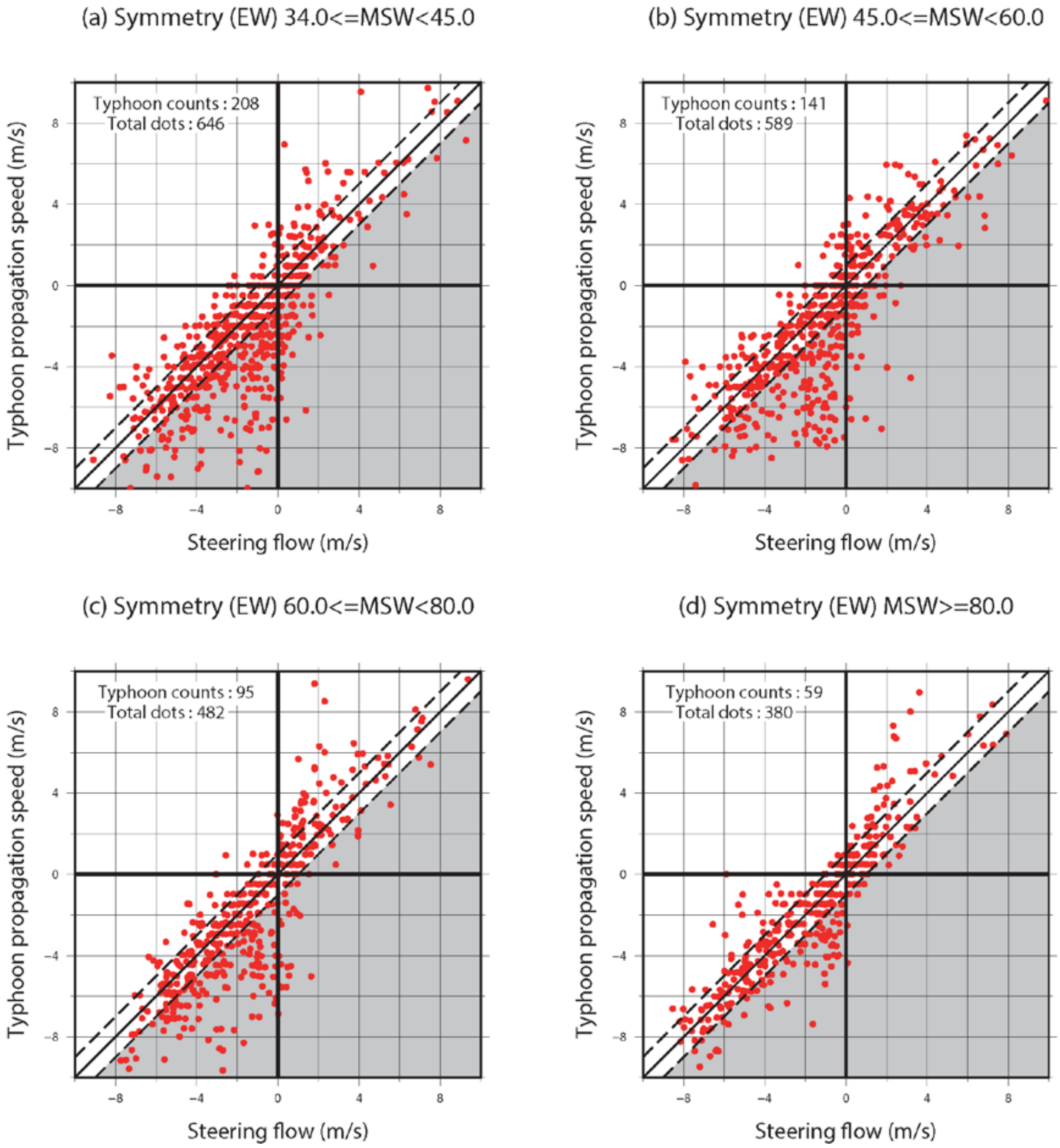

Fig. 7: As for Fig. 5, but for symmetric typhoons in the zonal direction.