Environmental Flow Characteristics of Slowly-Moving Typhoons near Taiwan

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Introduction

Motivation

Taiwan lies in the heart of the Northwest Pacific, the most active typhoon basin worldwide. Slow-moving typhoons are especially hazardous: they linger over the island, bringing intense and prolonged rainfall. Yet, these storms are notoriously difficult to predict because their steering flows are weak or poorly defined.

Objectives

- Identify large-scale circulation patterns associated with slow-moving typhoons.
- Evaluate the influence of the subtropical high and mid-latitude troughs.
- Provide conceptual implications for forecasting slow-moving typhoons.

Data and Methodology

Sources

- JTWC Best Track (storm position & intensity)
- ERA5 reanalysis (0.25°, 6-hourly Geopotential height(H) & winds)

Selections

Segments were defined as continuous portions of track within the study region (21–26°N, 119–124°E) that lasted ≥12 hours at ≥35 knots.
Translation speed(V_T) was calculated for each segment and averaged per storm. The fastest and slowest 25% of storms (≈30 each) were compared.
To evaluate differences between fast and slow groups, three complementary analyses were conducted:

- Correlation analysis between typhoon V_T and H.
- Composite analysis of H fields during segment periods, with statistical tests of fast–slow differences.
- Steering flow analysis was conducted by comparing the mean steering flow, averaged from 200–850 hPa within 400 km of the storm center, with the actual motion. The steering vector was then decomposed into two parts: the speed contribution, defined as the projection along the motion vector that quantifies how much of the translation speed is explained by steering, and the directional contribution, defined as the projection perpendicular to the motion vector that measures angular deviation and systematic bias. This decomposition clarifies both the magnitude and the direction of steering's influence and highlights the differences between the fast and slow groups.

Correlation Analysis

- **over central–southern China(200–500 hPa):** weak negative correlations suggest that relatively lower heights may favor faster typhoon motion.
- **Over the subtropical Pacific (500–850 hPa)** weak positive correlations indicate a tendency for higher heights to be linked with faster motion.
- **East of Japan (500–850 hPa):** weak negative correlations suggest that higher heights may be associated with slower motion.

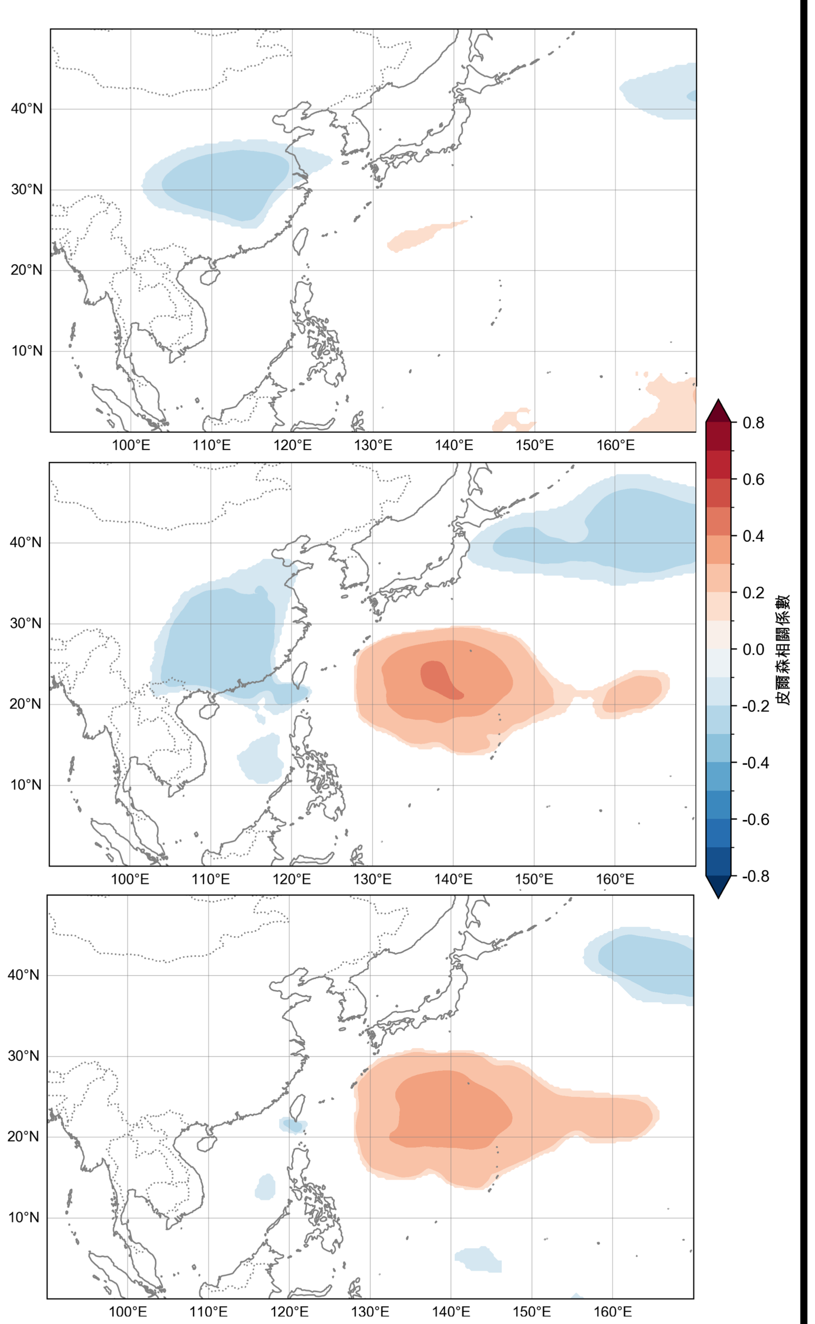

Figure 1. Correlation between typhoon V_T and H at (a) 200 hPa, (b) 500 hPa, and (c) 850 hPa. Shaded areas indicate regions where correlations are statistically significant at the 95% confidence level. Warm colors (red) denote positive correlations, while cool colors (blue) denote negative correlations.

Conclusions

- Slow storms → weaker China trough, weaker/eastward subtropical high, eastward ridge near Japan.
- Steering explains **speed well** (median ~100% contribution).
- Steering does **not explain direction**, with systematic leftward bias.
- Leftward deviation consistent with **beta drift**, more evident in slow cases.

Composite Analysis

- **Over China:** the slow group has a **weaker trough**, consistent with correlation results linking lower heights to faster motion.
- **In the subtropical Pacific:** the **high is weaker** and shifted eastward, reducing steering on its western flank.
- **Around Taiwan**, the weaker trough–ridge contrast leads to weaker southerly flow, favoring stalling.
- Overall, the combination of a weak China trough and an eastward-shifted (or weak) subtropical high creates a weak steering flow near Taiwan and slowing typhoons.

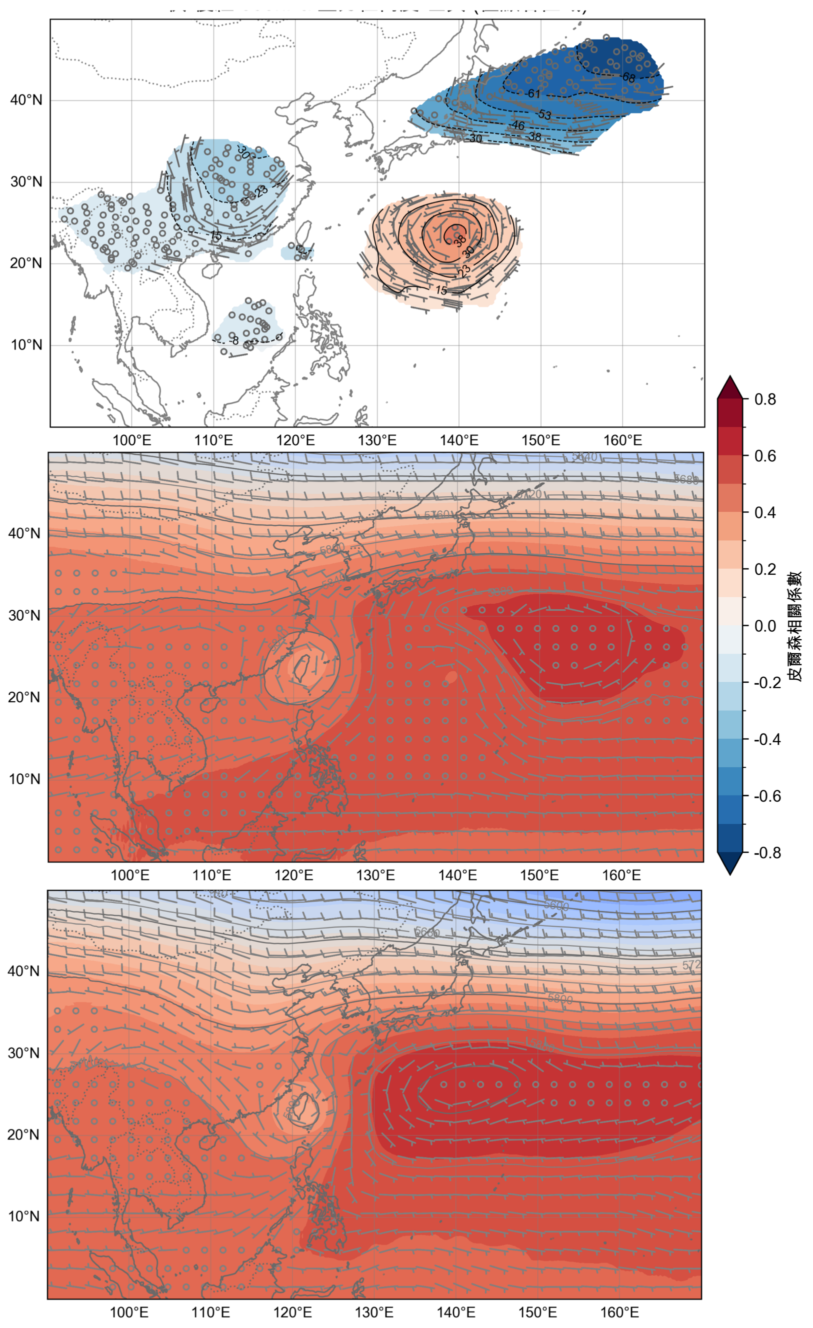

Figure 2. Composite differences of mean H and wind fields between fast and slow typhoon groups at 500 hPa. (a) Fast minus slow difference field, with shading denoting statistically significant regions at the 95% confidence level; red shading indicates higher values in the fast group, blue shading indicates higher values in the slow group. (b) Mean H field for the fast group. (c) Mean H field for the slow group. Contours show geopotential height, and vectors show horizontal winds.

Steering Flow Analysis

Sources

- Actual typhoon motion generally aligns with steering flow, confirming its dominant role. However, the match is not perfect — some cases show strong steering but slower motion.
- Speed contribution: projection along motion vector; explains nearly 100% of forward speed in all groups, strongest at mid-levels.
- Directional contribution: angular difference between steering and motion; reveals systematic biases.
- Slow group shows larger leftward deviation (~15°), while fast and overall cases show smaller bias (~5°).

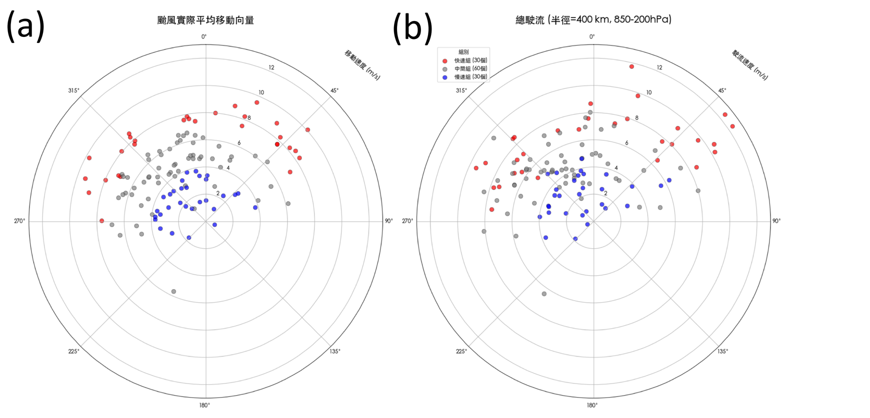

Figure 3. Comparison of actual typhoon motion vectors and environmental steering flow vector.(a) Scatter plot of actual typhoon motion vectors, where the radial distance from the origin represents speed and the azimuthal angle represents direction (0° = north, 90° = east). Red points denote the fast group, blue points the slow group, and gray points the intermediate group. (b) Same format as (a), but showing mean steering flow vectors.

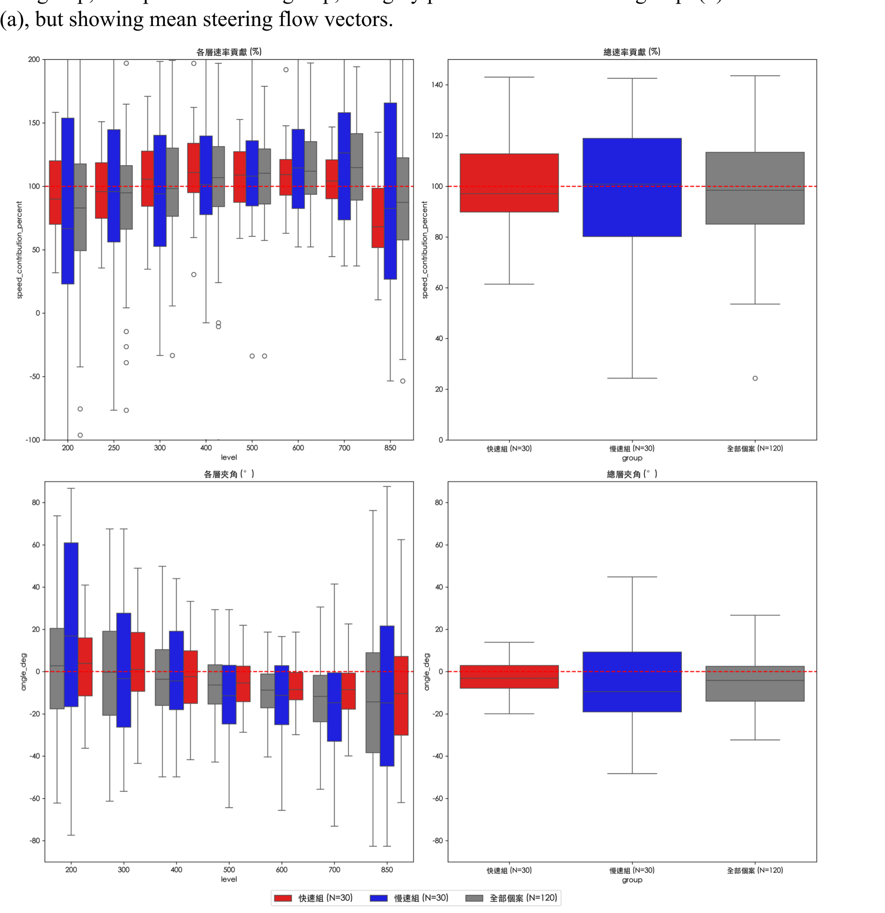

Figure 4. Boxplots showing the contribution of environmental steering flow to typhoon motion for the fast group (red), slow group (blue), and all cases (gray).(a) Speed contribution (%) at each pressure level, (b) Total-layer speed contribution (%) averaged from 200–850 hPa. (c) Directional deviation angle (°) at each pressure level.(d) Total-layer directional deviation angle (°) averaged from 200–850 hPa.

Conclusions

- Holland, G. J. (1983). Tropical cyclone motion: Environmental interaction plus a beta effect. *Journal of the Atmospheric Sciences, 40*(2), 328–342..