

A Study on the Reconstruction of the Horizontal Wind Speed Field of Deep-Sea Typhoons Based on Global Reanalysis Data

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Abstract: The mesoscale processes of typhoons in the deep sea are an important way for mesoscale kinetic energy to be dissipated into small-scale turbulence. The wind field of these typhoons is also the main initial field and real-time assimilation data source for current mesoscale meteorological models. Traditional ground-based and sea-based observation methods are difficult to provide complete information on the horizontal wind speed field of typhoons in the deep sea. This study proposes a method for reconstructing the horizontal wind speed field of typhoons in the deep sea based on ERA5 global reanalysis data, and establishes a temporal and spatial matching database for the horizontal wind speed field of typhoons in the Northwest Pacific deep sea. The study shows that this database can effectively reconstruct the gradient change characteristics of the horizontal wind speed along the radial direction of typhoons.

1. Introduction

Deep-sea typhoon near-surface mesoscale turbulence^[1] at the sea-air interface determines the efficiency of heat and water vapor exchange between the sea and atmosphere, and is an important factor affecting typhoon formation and intensity development. Its wind field is also the main initial field and real-time assimilation data source for current mesoscale meteorological models^[2] for typhoon simulation. Conventional land and near-sea observation methods (such as meteorological stations, sounding balloons, buoys, etc.) cannot effectively obtain the complete information of the mesoscale wind speed field of deep-sea typhoons. Therefore, global reanalysis data has become a potential important data source. However, existing global reanalysis data rarely focus on the movement and development process of typhoons in the deep-sea area^[3,4]. Therefore, it is urgent to propose a method for reconstructing the horizontal wind speed field of deep-sea typhoons based on global reanalysis data.

This study based on ERA5 global reanalysis data proposes a method for reconstructing the horizontal wind speed field of deep-sea typhoons and establishes a temporal and spatial matching database of the horizontal wind speed field of typhoons in the Northwest Pacific deep-sea area, providing a reference for the application of meteorological reanalysis data in the typhoon field.

2. Dynamic grid adaptation method for deep-sea typhoon wind speed field

2.1 ERA5 global reanalysis data wind field data

ERA5 is a fifth-generation global atmospheric reanalysis data set released by the European Centre for Medium-Range Weather Forecasts (ECMWF). It reconstructs a three-dimensional dynamic database covering the global atmosphere, ocean, and land by integrating multi-source data such as satellites, ground observations, radiosondes, and ocean buoys, combined with numerical weather prediction models and four-dimensional variational assimilation techniques. The spatial resolution is $0.25^{\circ} \times 0.25^{\circ}$, the time resolution is 1 hour, and the data extends from 1950 to the present and is continuously updated. It is a cornerstone data set for research in meteorology, oceanography, and environmental science^[5,6]. The wind field data is one of the core data of ERA5 reanalysis data, providing three-dimensional wind speed and wind direction information from the surface to 80 km above the ground. In the typhoon research field, it is often used to trace the three-dimensional dynamic evolution process of typhoons, specifically including describing the typhoon's dynamic structure, analyzing the typhoon field's vorticity, divergence, and secondary circulation, revealing the changes in the strong convective activities in the typhoon eye wall and predicting the typhoon's movement path, etc. (as shown in Figure 1). It can also be used as the initial field for typhoon simulations in numerical weather prediction models such as WRF. Relevant studies^[7,8] have shown that the typhoon field data of ERA5 reanalysis data can accurately verify typhoon intensity and structural parameters. Therefore, this study selects it as the reference data for reconstructing the horizontal wind speed field of deep-sea typhoons.

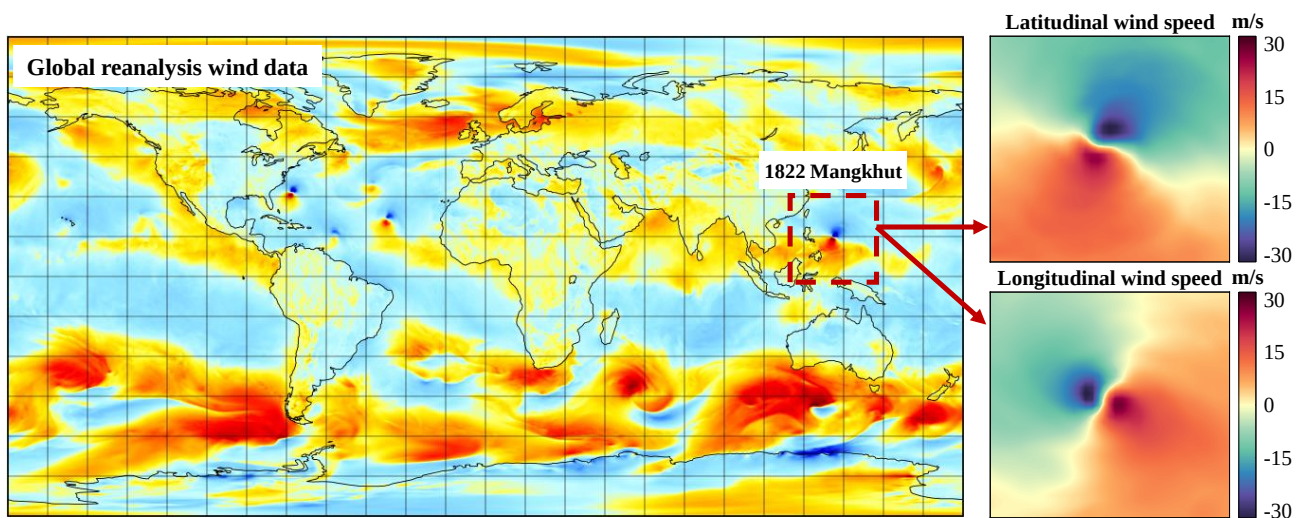


Fig. 1 Schematic diagram of typhoon wind field data from ERA5 global reanalysis data

2.2 Himawari-8 Satellite Meteorological Remote Sensing Data

The Himawari-8 satellite (hereinafter referred to as H-08) is an Earth-orbiting meteorological satellite operated by the Japan Meteorological Agency (JMA). It is positioned above the equator at 140°E . It is equipped with advanced multi-channel imagers and can provide comprehensive

observation data covering one-third of the Earth (including East Asia, the Western Pacific, and Australia). It is one of the core equipment for meteorological observation in the Asia-Pacific region. As shown in Table 1, the H-08 satellite meteorological observation has 16 spectral channels, including visible light, near-infrared, and infrared bands. In the field of typhoon monitoring and forecasting, its observation data is often used to continuously track the structure of the typhoon eye and identify strong convective cloud clusters, accurately determine the position, intensity, and path of the typhoon center. Further related research indicates^[9,10] that there is a strong nonlinear mapping relationship between the H-08 satellite remote sensing data and the typhoon intensity. Given that the spatial and temporal coverage of the H-08 satellite remote sensing precisely covers the entire process of typhoon formation, movement, development, landing on the southeastern coast of China, and extinction in the Northwest Pacific, and it has high spatial resolution and complete data, this study selects it as the matching data for reconstructing the horizontal wind speed field of deep-sea typhoons.

Table 1 Basic Information of H-08 Multispectral Channel Remote Sensing Data

Channel number	Channel type	Channel band	Spatial resolution	Temporal resolution	Observation range
01~03	Visible light	0.46 μ m~0.64 μ m	0.005 °	6h	60 °S-60 °N 80 °E-160 °W
04~06	Near-infrared	0.86 μ m~2.3 μ m			
07~16	Infrared	3.9 μ m~13.3 μ m	0.02 °		

2.3 Method for Spatial-Temporal Matching of Horizontal Wind Speed in Deep-Sea Typhoons

This study takes the wind fields of typhoons in the deep-sea area of the Northwest Pacific Ocean that are in the "super typhoon" stage (maximum average wind speed near the center ≥ 51.0 m/s) as the reconstruction target. A temporal-spatial matching database of H-08 satellite remote sensing data and ERA5 reanalysis wind fields is constructed. Firstly, based on the typhoon movement paths and intensity information released by the China Meteorological Administration (CMA), the position of the typhoon center (LatT, LonT) at each typical moment T of the "super typhoon" stage in the deep-sea area is determined. According to this information, the corresponding moments and typhoon center positions are matched from the H-08 satellite remote sensing data and the ERA5 reanalysis wind fields respectively. Then, with a wind field influence range of $1000 \text{ km} \times 1000 \text{ km}$ (approximately $10^\circ \times 10^\circ$), a 41×41 grid point range centered on (LatT, LonT) is selected in the ERA5 reanalysis wind fields data, which is approximately $10.25^\circ \times 10.25^\circ$. Finally, a 51×51 grid point range centered on each grid point coordinate is selected in the H-08 satellite remote sensing data to correspond with it, which is approximately $1.02^\circ \times 1.02^\circ$. Thus, a grid point temporal-spatial mapping from H-08 satellite remote sensing data to ERA5 reanalysis wind fields data (51×51) $\rightarrow$ (1×1) is constructed. The above matching method is shown in Figure 2.

Select 12 typical cases of extremely strong typhoons generated in the Northwest Pacific during the 10-year period from 2015 to 2024. The specific information is shown in Table 2. There are a total of 138 typical moments. According to the above method, a temporal and spatial matching database of typhoon horizontal wind speed is constructed. Considering the intermittent distortion of data caused by the alternation of day and night in the low-band channel of the H-08 satellite, 9 infrared channels of remote sensing data from 08 to 16 are selected as the input, and the horizontal wind speed data of the ERA5 reanalysis wind field (synthesized from two-dimensional wind speeds in latitude and longitude directions) is used as the output.

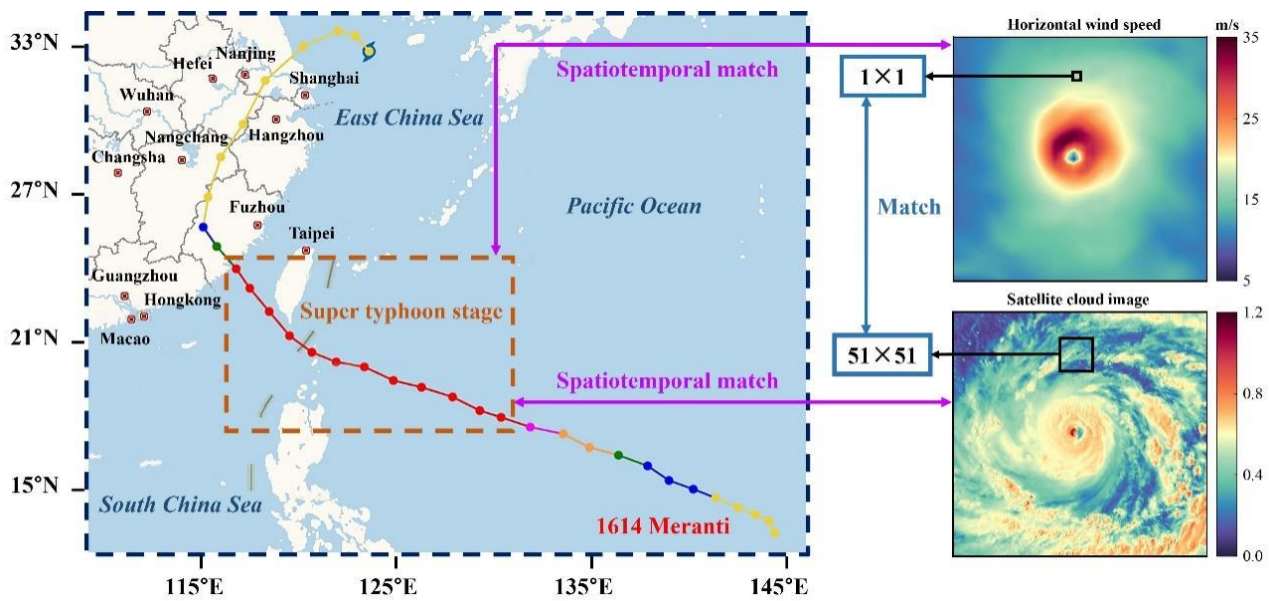


Fig. 2 Schematic diagram of the method for matching the temporal and spatial distribution of horizontal wind speeds of typhoons in the deep and distant sea areas

Table 2 Basic Information of the Case Study on Spatio-temporal Matching Database of Typhoon Horizontal Wind Speed

Serial Number	Typhoon name	Maximum wind speed	Typical event count	Serial Number	Typhoon name	Maximum wind speed	Typical event count
1513	Sudiro	68m/s	9	2019	Swan	70m/s	9
1614	Moranti	75m/s	12	2114	Chanda	68m/s	18
1618	Chaba	60m/s	10	2214	Nambudri	62m/s	7
1822	Typhoon Mangkhut	65m/s	17	2305	Dusu Re	62m/s	11
1909	Lihixma	62m/s	9	2309	Surra	62m/s	18
2010	The Sea God	60m/s	8	2411	Capricorn	68m/s	10

3. Verification of Reconstruction Effect of Horizontal Wind Speed Field of Typhoon in Remote Seas

Figure 3 presents the reconstruction result of the horizontal wind speed field of Typhoon "Shanchang" at a typical moment (18:00 on 2018.09.15). The relevant typhoon data indicate that due to the relatively small influence of topography in the remote sea area, at this moment, the horizontal wind speed field of the typhoon shows a relatively complete circular vortex distribution, with a clear low wind speed zone of the typhoon eye, a high wind speed zone of the eye wall, and a descending wind speed zone in the periphery from the center of the typhoon outward. From the reconstruction result, the ERA5 global reanalysis data not only accurately reconstructs the position of the typhoon center and the circular vortex distribution structure of the horizontal wind speed field, but also identifies the asymmetric distribution characteristics of the high wind speed zone of the eye

wall. The distribution intervals of the typhoon eye, eye wall, and periphery are highly consistent with the real wind field, and the wind speed reconstruction result has high accuracy in the high wind speed zone of the eye wall. Only on the southwest and southeast periphery of the typhoon center, the wind speed is slightly lower and higher, respectively, which indicates that the ERA5 global reanalysis data has the reconstruction ability for the horizontal wind speed field of the typhoon.

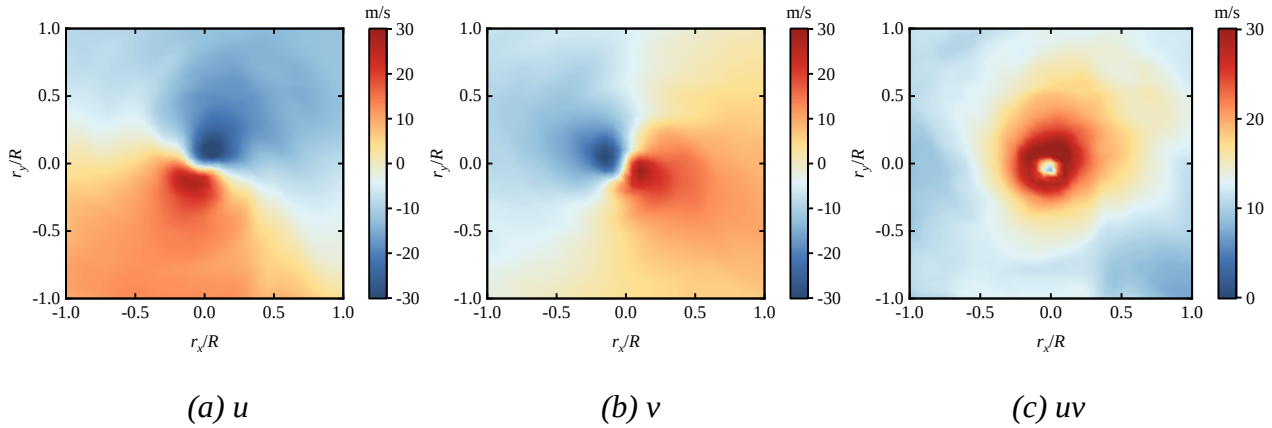


Fig. 3 Result of reconstructing the horizontal wind speed field of typhoons using ERA5 reanalysis data

Table 3 compares the reconstruction error of the deep-sea horizontal wind speed field based on ERA5 global reanalysis data and numerical simulation. As shown in the table, within the wind speed range of 20 m/s or less, the reconstruction effects of the two models are similar; when the wind speed is higher than 20 m/s, the reconstruction error of the numerical simulation significantly increases. Especially in the high wind speed area of the eye wall, the root mean square error and average deviation reach 9.00 m/s and -8.34 m/s respectively. This indicates that the model tends to underestimate the typhoon wind speed under extreme conditions. Meanwhile, the root mean square error of ERA5 global reanalysis data in this area is only 2.35 m/s, and the average deviation across the entire area is only -0.09 m. This shows that the model has high reconstruction accuracy and stability for extreme wind conditions.

Table 3 Statistical Table of Reconstruction Error of Horizontal Wind Speed Field of Typhoons in Remote Oceans (m/s)

Model	<10m/s		10~20m/s		20~30m/s		>30m/s		All	
	RMSE	BIAS	RMSE	BIAS	RMSE	BIAS	RMSE	BIAS	RMSE	BIAS
Numerical Simulation	4.11	3.15	1.81	-0.45	5.93	-4.00	9.00	-8.34	3.09	-0.38
ERA5	4.37	2.36	2.08	-0.51	2.56	-0.51	2.35	-0.91	2.60	-0.09

4. Conclusion

This study proposed a method for reconstructing the horizontal wind speed field of deep-sea typhoons based on ERA5 global reanalysis data, and established a spatio-temporal matching database for the horizontal wind speed field of typhoons in the Northwest Pacific Ocean. The main research conclusions are as follows:

(1) The sub-medium-scale horizontal wind speed database of typhoons in the Northwest Pacific Ocean constructed based on ERA5 global reanalysis wind field data can accurately reflect the counterclockwise vortex structure and asymmetric distribution characteristics of westward-moving typhoons in the Northern Hemisphere. The radial wind profile shows a trend of increasing first and then decreasing from the center to the periphery, and the dangerous semicircle is usually located to the east and north of the typhoon center.

(2) The numerical simulation method can only identify the position of the typhoon eye and the direction of the typhoon vortex in the reconstruction of the horizontal wind speed component of the typhoon, and seriously underestimates the high wind speed in the typhoon eye wall region. The root mean square error and average deviation reach 9.00 m/s and -8.34 m/s respectively; while the reconstruction model based on ERA5 global reanalysis data effectively identifies the gradient change characteristics of the horizontal wind speed of the typhoon along the radial direction. The root mean square error and average deviation of reconstructing the high wind speed in the typhoon eye wall are only 2.35 m/s and -0.91 m/s respectively.

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