Proceedings of the 4th International Conference on Applied Physics and Mathematical Modeling
DOI: 10.54254/2753-8818/2026.37848

The Formation Process of Typhoons and the Air-Sea Energy Transfer Mechanism in Rapid Intensification

Leshan Sun

Xiaoshan High School, Hangzhou, China
leshansun08@gmail.com

Abstract. The rapid intensification of tropical cyclones significantly increases their potential for causing disasters, and both their formation and intensification are influenced by a variety of physical conditions such as the ocean and the atmosphere. This article focuses on the analysis of the energy transfer mechanism between the ocean and the atmosphere during the formation and rapid intensification of typhoons, with a particular emphasis on the influence of ocean thermal conditions, energy exchange between the ocean and atmosphere, and the atmospheric environment on the rapid intensification of typhoons. Studies have shown that higher sea surface temperatures and the heat content of the upper ocean layer provide favourable thermal conditions for the formation of typhoons. Latent heat flux, sensible heat flux, water vapour condensation and release are important pathways for the transfer of ocean energy into the interior of typhoons. Meanwhile, factors such as environmental humidity and vertical wind shear further regulate the intensity of deep convection and circulation. Take Typhoon Bavi in 2026 as an example. During its rapid intensification phase, it had high SST and OHC, abundant water vapour and weak vertical wind shear, and significantly intensified within a short period of time. Studies have shown that the rapid intensification of typhoons is the result of the combined effects of ocean energy supply, sea-air energy exchange, and the atmospheric environment. Therefore, the prediction of rapid typhoon intensification requires careful consideration of multiple factors.

Keywords: Tropical Cyclone, Rapid Intensification, Air-Sea Energy Transfer, Ocean Heat Content, Atmospheric Environment

1. Introduction

In today's society, typhoons, as a kind of unpredictable natural disaster, have significant consequences and losses. Even a slightly weaker typhoon may cause local heavy rain and strong winds that make it difficult to travel, resulting in some economic losses. For large typhoons, they can even cause floods and the collapse of buildings. Moreover, in coastal areas, they may trigger coastal erosion, posing a significant potential safety hazard to the residents in those areas. For instance, the typhoon Haiyan that struck the Philippines in 2013 caused floods and the collapse of numerous houses in the region, resulting in approximately 6,000 deaths and billions of dollars in losses. From ancient times to the present, with the advancement of technology, the methods for predicting typhoons have gradually evolved from the initial observations on ships and land to

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2753-8818/2026.37848

internal analysis, prediction of paths, and now to the use of AI models for observation, enabling more precise predictions of typhoons and thus reducing economic losses. Therefore, an understanding of the causes of typhoons and the application of the necessary forecasting techniques is a prerequisite for preventing economic losses and reducing human resource shortages. However, the formation of typhoons is inseparable from the formation of oceanic cyclones, as well as the interaction of ocean energy exchange and the appropriate atmospheric environment. This article will focus on the formation of oceanic cyclones, how the ocean exchanges energy, what constitutes an appropriate atmospheric environment for the formation of typhoons, and ultimately how this leads to the rapid intensification of typhoons.

2. Fundamental principles of typhoon formation and intensification & key factors influencing rapid typhoon intensification

2.1. The formation process of a typhoon

Based on the statistical distribution of the 24-hour intensity changes of tropical cyclones in the North Atlantic during 1989-2000 as reported by Kaplan & DeMaria, this paper defines rapid intensification of typhoons as an increase of at least 30 kt in the maximum sustained wind speed of the tropical cyclone within 24 hours. The entire process of a typhoon's formation involves a relatively long sequence of stages: initial cyclonic disturbance - low-level convergence and deep convection organisation - water vapour condensation and latent heat release - pressure drop and strengthening of the lower-level circulation - establishment of the warm core structure. Based on the data and research analysis in the paper "Formation of Tropical Cyclones" published by Michio Yanai in 1964, the main formation process of typhoons is caused by atmospheric disturbances, such as eastward waves, and the low-level air converges towards the centre of the typhoon to form internal deep convection, which satisfies the conditions for the formation of a typhoon. Then, due to the latent heat energy released by the ascending airflow in the atmosphere to the cloud layer, the temperature at the centre of the typhoon increases, the air pressure decreases, resulting in an increase in the air pressure gradient, and the low-level air converges towards the centre to accelerate and strengthen the circulation, ultimately establishing a warm core structure, which enables the initial vortex to develop into a mature typhoon vortex.

2.2. Impact of the marine environment on rapid typhoon intensification

After the formation of a typhoon, its further rapid intensification requires continuous energy supply. Therefore, it is necessary to further analyse the role of the ocean heat state. According to research by Chih & Wu, they studied the SST and OHC during the period of rapid intensification of typhoons in the western North Pacific from 1998 to 2016 [1]. Analysis reveals that during the period of rapid intensification of the typhoon, higher ocean temperatures mainly provide favourable thermal conditions for the formation of the typhoon. However, although there is a significant correlation between high ocean temperatures and the rapid intensification of the typhoon, they are not sensitive to it; they are merely important environmental conditions. Even so, Vincent et al. pointed out that during the rapid intensification stage of a typhoon, based on statistical results, the vertical mixing of the upper ocean caused by the typhoon usually brings the colder subsurface seawater to the surface, forming a cold wake. This, instead, leads to a decrease in SST, resulting in a decrease in the sea-air heat flux, thereby forming a negative feedback that inhibits the intensification of the typhoon, creating a cold wake. This leads to a balanced conclusion: The ocean is not only the source of

DOI: 10.54254/2753-8818/2026.37848

typhoon energy but also an important source of negative feedback during the enhancement process of typhoons. OHC refers to a favourable ocean thermal condition. In areas with a higher OHC, the warm water layer is deeper, and the ocean cooling is relatively weak. As a result, the sea surface can maintain a relatively high temperature during the influence of typhoons and is less likely to rapidly cool due to mixing and cooling, thereby facilitating the continuous maintenance of strong sea-air energy exchange and facilitating the sustained development and intensification of typhoons [2, 3].

2.3. Mechanism of air-sea energy transfer

The thermal state of the ocean provides a complete source of available energy for typhoons, and this energy needs to be transferred into the atmospheric system through the exchange at the sea-air interface. Therefore, regarding the mechanism of heat transfer between the ocean and the atmosphere, one of the main factors is the latent heat flux of seawater and the enhanced intensity of typhoons due to the release of latent heat during cloud condensation. The main process is that after seawater evaporates, it inputs water vapour and enthalpy into the atmosphere, which is beneficial for the formation of deep convection on the sea surface. After the water vapour enters the boundary layer of the typhoon, it condenses and releases energy during convection, causing internal energy conversion, heating the interior of the typhoon and creating a pressure difference that accelerates the rotational speed of the air within the typhoon, leading to the gradual strengthening of moist convection, which is conducive to maintaining the warm core structure of the typhoon and further strengthening its circulation. Kerry A. Emanuel pointed out that the latent heat exchange between the ocean and the atmosphere is the primary source of energy for the intensification of typhoons. David S. Nolan et al. have explained that the moisture enthalpy transported by the ocean to the atmosphere is the fundamental energy source for the formation of typhoons. The energy released by the latent heat is the key factor that drives the transfer of ocean thermal energy into the kinetic and potential energy of typhoons. Meanwhile, sensible heat flux is also a factor that enhances typhoons, but its impact is usually relatively low. It also simultaneously increases the size of the typhoon and the outer rain belt. However, it also simultaneously takes up a portion of the energy source at the centre of the typhoon. Zhanhong Ma, Jianfang Fei, Xiaogang Huang, and Xiaoping Cheng, based on specific numerical simulation experiments, studied a specific simulated tropical cyclone and, through sensitivity tests, concluded that if the effect of the sensible heat flux of the typhoon is removed, the scale of the typhoon may decrease by approximately 20%.

2.4. Impact of the atmospheric environment on the rapid intensification of typhoons

However, whether the energy input from the ocean and atmosphere can effectively be converted into deep convection and enhanced circulation is also subject to the regulation of atmospheric environmental conditions. The atmospheric environment is also a crucial influencing factor during the rapid intensification process of typhoons. Firstly, atmospheric humidity is an important thermodynamic condition influencing the intensification of typhoons. According to the AIRS satellite humidity data utilised by Longtao Wu et al., under the systematic reference of the ocean basin, the atmospheric humidity around rapidly intensifying typhoons is significantly higher than that of weak typhoons. Moreover, the humidity distribution is uneven, showing obvious asymmetry. The wet air can reduce the entry of dry air, resulting in a decrease in the intensity of the typhoon. This is beneficial for maintaining a high-temperature core, convection, and the release of thermal potential energy of the typhoon. Vertical wind shear affects the strengthening or weakening of a typhoon, depending on its intensity, direction, and the structure of the typhoon itself. If the vortex is

DOI: 10.54254/2753-8818/2026.37848

tilted, it may cause the convection to be out of alignment with the low-level circulation centre, ultimately leading to the disruption of the core structure of the typhoon and a reduction in its strength. The research conducted by Zhihua Zeng et al. revealed that the rapid intensification of typhoons often occurs in environments with relatively weak vertical wind shear, and it is concentrated within a relatively narrow range of environmental conditions [4]. The lower-level relative vorticity plays a significant role in the formation and early development of tropical cyclones. The enhanced lower-level vorticity mainly maintains the rotational circulation of the typhoon, while the lower-level convergence and upward movement promote deep convection, leading to the rapid intensification of the typhoon. At the same time, for a formed tropical cyclone, its rapid intensification also requires the joint action of sea-air heat flux, environmental humidity, vertical wind shear, and the core convection structure. Wu Yusi et al. studied multiple factors in the tropical cyclone environment of the Northwest Pacific and concluded that, in different environments, the intensification of the atmospheric cyclone is caused by the relative vorticity of the environment and multiple environmental conditions [5]. Therefore, the rapid intensification of typhoons is the result of the combined effects of ocean energy supply, sea-air energy exchange, and atmospheric environmental conditions.

3. Analysis of the rapid intensification process and environmental conditions of typhoon BAVI

3.1. Changes in the marine environment during the rapid intensification of BAVI

Regarding the study of Typhoon BAVI (2026), NASA stated that BAVI was formed on the warm ocean surface with a temperature ranging from 29°C to 30°C [6]. On July 2nd, BAVI entered a clearly rapid intensification stage. During this period, the sea areas it passed through had relatively high SST values. According to satellite observations, the SST at that time was approximately 30 degrees Celsius. Although NASA did not explicitly state the OHC of the sea area at that time, the Pacific Disaster Centre (PDC) mentioned in its environmental analysis on July 5th that the path area of the ocean at that time had a relatively high marine heat content (OHC) of approximately 150 kJ/cm^2. Therefore, the higher SST and OHC increase the latent heat and sensible heat fluxes in the ocean, providing sufficient heat energy for the sea-air interaction to the BAVI. This is conducive to maintaining deep convection and the warm core structure, and provides important oceanic thermal conditions for rapid intensification.

3.2. Changes in the atmospheric environment during the rapid intensification of BAVI

As mentioned earlier, the corresponding water vapour energy enters the atmospheric exchange system. Therefore, NASA also clearly pointed out that at the early stage of the rapid development of BAVI, it was in a low vertical wind shear environment. Thus, its vertical structure was not easily disrupted, and the deep convection could continue to develop around the centre, which was conducive to the rapid intensification of Typhoon BAVI. The tropical cyclone professional analysis report of the Pacific Disaster Centre (PDC) states that BAVI is located in an environment rich in deep moisture and with strong upper-level radiation, all of which are conducive to the rapid intensification of BAVI. Furthermore, NASA data also indicates that there is a high-pressure ridge to the north of BAVI, which guides BAVI to move in a northwest-to-southwest direction, heading towards the northern Mariana Islands and eventually causing it to land in Zhejiang Taizhou, China.

DOI: 10.54254/2753-8818/2026.37848

3.3. Rapid intensification process and intensity changes of BAVI

As for the formation process of BAVI, in the initial formation stage, according to the system data recorded by IBTrACS for BAVI, at 00 UTC on July 1, 2026, BAVI began to form at 8.7°N, 163.3°E. Its initial maximum wind speed was approximately 25 kt, and the central pressure was 1003 hPa. After 12 UTC on July 2nd, BAVI began to enter a clearly rapid intensification stage. At this time, its maximum wind speed was 52 kt (60 mph). Within one day and a half, its maximum sustained wind speed rapidly increased to 139 kt (160 mph), increasing by 87 kt (100 mph) in a short period of time, and approximately 70 kt (80 mph) within 24 hours. This far exceeded the 30 kt/24hr definition for rapid intensification; thus, this is the process by which BAVI rapidly intensified from a tropical storm to a super typhoon [7]. On July 4th, the barometric pressure of BAVI reached its first peak: 143 kt. Subsequently, due to the cycle of eyewall replacement, its intensity briefly dropped to approximately 135 kt; the strengthening of BAVI was not a linear and rapid increase, and was also affected by changes in its internal structure. Finally, at 12 UTC on July 5th, the IBTrACS data showed that its second maximum peak reached an astonishing 156 kt. After landing in China, it gradually weakened and showed a significant weakening after entering Chinese territory [8-10].

3.4. The damage caused by BAVI to the local area

The impact of BAVI was significant. It successively affected the Northern Mariana Islands, the southern islands of Japan, Taiwan, eastern China, and many areas in northern China subsequently. Among them, after landing near Taizhou, Zhejiang Province, on July 11th, Reuters reported that many areas in China had evacuated their populations in advance, with nearly 2 million people being evacuated [11, 12]. After that, Ba Wei moved northward and caused severe floods in Liaoning Province, with over 260,000 people evacuated. AP News also reported that during the landing period, many people were evacuated in Zhejiang, Wenzhou, Shanghai and other places; many trees fell over, flights were cancelled, and the impact of strong winds and heavy rain was significant [13, 14].

4. Rapidly enhanced prediction methods and their applications

During the rapid intensification of BAVI, the higher SST and OHC provided sufficient energy sources for the typhoon. Meanwhile, the weaker vertical wind shear and higher environmental humidity were conducive to the organisation of convection and the development of the vortex, resulting in a stable warm core structure. Therefore, in the process of rapid enhancement of predictions, it is necessary to comprehensively consider the marine thermal conditions - marine heat content, sea-air fluxes - as well as environmental field parameters, rather than relying solely on a single meteorological parameter. This enables appropriate, effective predictions and timely defences, thereby minimising economic losses to the greatest extent possible.

5. Conclusion

This article focuses on the analysis of the energy transfer mechanism between the sea and the atmosphere during the formation and rapid intensification of typhoons. The research indicates that the rapid intensification of typhoons is not determined by a single factor, but rather by the combined effects of ocean thermal conditions, sea-air energy exchange, and the atmospheric environment. Higher SST and OHC can provide favourable marine energy conditions. The latent heat flux and

DOI: 10.54254/2753-8818/2026.37848

water vapour condensation release are important processes for energy entering the typhoon system. Meanwhile, higher environmental humidity and weaker vertical wind shear are conducive to maintaining deep convection and warm core structures. For instance, BAVI, during its rapid intensification phase, exhibited high SST, OHC, abundant water vapour, and weak vertical wind shear, and showed a significant increase in intensity within a short period of time. This was the result of the combined effect of multiple favourable environmental conditions. However, it also had certain limitations. Since the data used in this article come from various sources and existing studies, there is no unified standard or quantitative comparison yet; moreover, this article only uses the case of Baewi, and the applicability to other typhoons still needs to be further verified. Based on this conclusion, future satellite observations combined with AI numerical inkblots will conduct unified quantitative observations and analyses of factors such as ocean surface temperature (SST), ocean heat content (OHC), sea-air fluxes, humidity, and vertical wind shear, providing a reference for current organisational predictions, thereby being more conducive to future typhoon prediction, defence, and reasonable and effective control.

References

[1] Kaplan, J., & DeMaria, M. (2003). Large-scale characteristics of rapidly intensifying tropical cyclones in the North Atlantic Basin. *Weather and Forecasting, 18*(6), 1093–1108. doi:10.1175/1520-0434(2003)018<1093:LCORIT>2.0.CO;2

[2] Ma, Z., Fei, J., Huang, X., & Cheng, X. (2015). Contributions of surface sensible heat fluxes to tropical cyclones. Part I: Evolution of tropical cyclone intensity and structure. *Journal of the Atmospheric Sciences, 72*(1), 120–140. doi:10.1175/JAS-D-14-0199.1

[3] Quan, X., & Li, X. (2023). Kinetic energy budgets during the rapid intensification of Typhoon Rammasun (2014). *Advances in Atmospheric Sciences, 40*(1), 78–94. doi:10.1007/s00376-022-2060-z

[4] Yanai, M. (1964). Formation of tropical cyclones. *Reviews of Geophysics, 2*(2), 367–414. doi:10.1029/RG002i002p00367

[5] Chih, C.-H., & Wu, C.-C. (2020). Exploratory analysis of upper-ocean heat content and sea surface temperature underlying tropical cyclone rapid intensification in the western North Pacific. *Journal of Climate, 33*(3), 1031–1050. doi:10.1175/JCLI-D-19-0305.1

[6] Vincent, E. M., Lengaigne, M., Madec, G., Vialard, J., Samson, G., Jourdain, N. C., Menkes, C. E., & Jullien, S. (2012). Processes setting the characteristics of sea surface cooling induced by tropical cyclones. *Journal of Geophysical Research: Oceans, 117*(C2), C02020. doi:10.1029/2011JC007396

[7] Lin, I.-I., Wu, C.-C., Pun, I.-F., & Ko, D.-S. (2008). Upper-ocean thermal structure and the western North Pacific category 5 typhoons. Part I: Ocean features and the category 5 typhoons' intensification. *Monthly Weather Review, 136*(9), 3288–3306. doi:10.1175/2008MWR2277.1

[8] Huang, J., Ma, Z., Zhao, H., Fei, J., & Chen, L. (2024). Increase in western North Pacific tropical cyclone intensification rates and their northwestward shifts. *Atmospheric Research, 301*, 107292. doi:10.1016/j.atmosres.2024.107292

[9] Shimada, U. (2022). Variability of environmental conditions for tropical cyclone rapid intensification in the western North Pacific. *Journal of Climate, 35*(14), 4437–4454. doi:10.1175/JCLI-D-21-0751.1

[10] Song, K., Zhan, R., & Wang, Y. (2024). Unveiling the dominant factors controlling the long-term changes in Northwest Pacific tropical cyclone intensification rates. *Geophysical Research Letters, 51*(15), e2024GL108344. doi:10.1029/2024GL108344

[11] Wu, Y., Gao, T., Xiao, X., Zhang, W., Cao, F., Yu, Y., Liu, Y., & Zhang, Y. (2026). Characterizing the changes and regional drivers of tropical cyclone intensification over the western North Pacific. *Global and Planetary Change, 266*, 105641. https://doi.org/10.1016/j.gloplacha.2026.105641

[12] Kang, S. K., Kim, S.-H., Lin, I.-I., Park, Y.-H., Choi, Y., Ginis, I., Cione, J., Shin, J. Y., Kim, E. J., Kim, K. O., Kang, H. W., Park, J.-H., Bidlot, J.-R., & Ward, B. (2024). The North Equatorial Current and rapid intensification of super typhoons. *Nature Communications, 15*, 1742. https://doi.org/10.1038/s41467-024-45685-2

[13] Xu, J., Zhao, P., Chan, J. C. L., Shi, M., Yang, C., Zhao, S., Xu, Y., Chen, J., Du, L., Wu, J., Ye, J., Xing, R., Wang, H., & Liu, L. (2024). Increasing tropical cyclone intensity in the western North Pacific partly driven by warming Tibetan Plateau. *Nature Communications, 15*, 310. https://doi.org/10.1038/s41467-023-44403-8

DOI: 10.54254/2753-8818/2026.37848

[14] Kim, H.-K., Park, J.-Y., Park, D.-S. R., Kug, J.-S., Yeh, S.-W., & Son, J.-H. (2024). Western North Pacific tropical cyclone activity modulated by phytoplankton feedback under global warming. *Nature Climate Change, 14*, 504–510. https://doi.org/10.1038/s41558-024-01976-6