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An observational study of a long-lived monsoon depression over the South China Sea

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Abstract— In general, there would be one monsoon depression affecting the South China Sea every summer. Such depressions are relatively short-lived and mostly last for a few days. In early June 2023, there was a relatively long-lived monsoon depression over the South China Sea with a lifespan of around 10 days. The paper documents the life of this monsoon depression, including the meteorological observations. This depression is found to have the typical structure of a monsoon depression, namely, very weak winds near the center and higher wind speed with intense convection associated with a burst of southwest monsoon in its periphery. The strong southwest monsoon was also observed as a boundary layer jet in the upper air observations. The study is unique from the perspective that there are more meteorological observations over the northern part of the South China Sea, including the weather buoys and oil platforms, which provide unprecedented meteorological observations of the depression. It is hoped that this paper could stimulate further studies of monsoon depressions in this region in the future.

Key-words: monsoon depression, meteorological observations, numerical weather prediction models, China

1. Introduction

The coast of southern China is often affected by tropical cyclones. For instance, for Hong Kong which is situated at the Pearl River Estuary, there are on average around 4 to 7 tropical cyclones affecting the place in every year. Timely monitoring of low pressure areas which may develop into a tropical cyclone is of utmost importance for ensuring the safety of the city.

Apart from tropical cyclones, Hong Kong may also be affected by monsoon depressions in the summer. This kind of depression has not yet developed into a tropical cyclone. It normally has a rather large center with very weak winds (say 2.5 to 5 m/s), whereas the outer region has intense convective developments and much strong winds (which are mostly related to the southwest monsoon over the South China Sea). Monsoon depressions may also bring about unsettled weather to the south China coastal areas.

According to *Hurley* and *Boos* (2014), there are on average about 0.5 to 1.0 monsoon depressions affecting the coast of southern China every summer. In general, they are relatively short-lived, with a lifespan in the order of a few days only. They may develop over the South China Sea, or enter this ocean from the northwest Pacific.

The Hong Kong Observatory has published a number of articles in its website to educate the public about the difference between monsoon depression and tropical cyclone (including https://www.hko.gov.hk/en/blog/00000142.htm and https://www.hko.gov.hk/en/blog/00000149.htm). In the scientific literature, the term monsoon depression is mainly used for cyclones over the Bay of Bengal and Indian subcontinent (such as https://glossary.ametsoc.org/wiki/Monsoon_depression). There have been a number of scientific papers, though limited, to study the monsoon depression in that region. The climatology of Indian monsoon depressions has been discussed in *Pottapinjara et al.* (2014), *Rastogi et al.* (2018), *Karmakar et al.* (2021), and *Ray* and *Sil* (2023), and the long-term trends in the number of them have been statistically analyzed in *Krishnamurti et al.* (2013), *Cohen* and *Boos* (2014), and *Vishnu et al.* (2016). Several important aspects related to Indian monsoon depressions, such as barotropic growth (*Diaz* and *Boos*, 2019a, 2019b; *Suhas* and *Boos*, 2023), westward drift (*Boos et al*., 2015; *Hunt* and *Parker*, 2016), and precipitation (*Hunt et al.,* 2016; *Murthy* and *Boos*, 2019), have been investigated. The influence of horizontal resolution (*Hunt* and *Turner*, 2017), cloud microphysics (*Hazra* and *Pattnaik*, 2021), and data assimilation (*Lodh et al*., 2022; *Vinodkumar et al*., 2009) on the mesoscale simulations of them have also been assessed.

2. *A case study of a monsoon depression*

In the first half of June 2023, there was a relatively long-lived monsoon depression over the South China Sea and southern China. It had a life of around 10 days, and the numerical weather prediction (NWP) models once forecasted that it might develop into a stronger system (possibly a tropical cyclone) affecting the Pearl River Estuary. As such, the weather services in the region conducted very close monitoring of its movement and development. Eventually, it remained as a rather weak system throughout its whole life and dissipated over the seas near Taiwan. With the availability of more weather observations nowadays, such as the buoys and oil platforms over the South China Sea, global lightning location system, etc., there are unprecedented observations of this system throughout its whole life. Though its impact on the coastal areas is not significant, its long life and the available weather observations worth to be documented for reference by weather forecasters in this part of the world in the future. This is the novelty of this observational study, and it is hoped that the study could stimulate similar analysis, especially statistical analysis, of tropical depressions in the South China Sea in the future.

2.1. Overview of the monsoon depression

The locations of the monsoon depression at various stages of its life are given in *Fig. 1*. Please note that, as shown in the later figures of this paper, the location of the depression is rather hard to pinpoint as it remains as a relatively weak system, and as such the locations are indicative only. However, the general trend of the movement of the depression is still rather clearly shown in this figure.

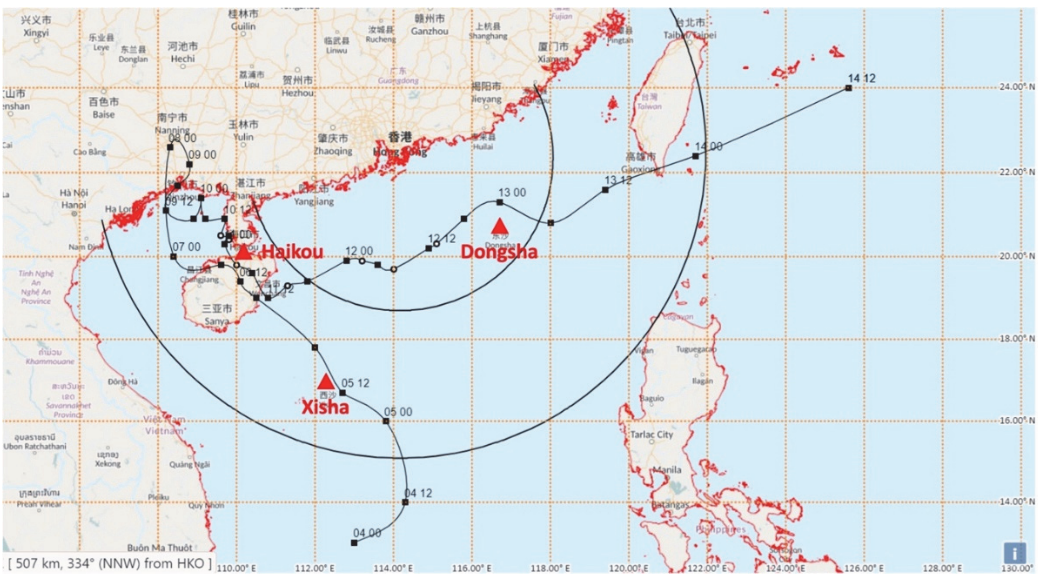


Fig. 1. The track and location of the monsoon depression under study in this paper for its whole lifespan. The locations of the radiosonde stations which have been included in the study are marked by red triangles.

The monsoon depression first appeared in the central part of the South China Sea. It then generally moved in the direction of the Hainan Island and entered the Beibu Wan. It further moved north and made landfall over the southwestern part of China, and lingered over that area for a couple of days. Afterwards it moved into the Hainan Island again.

The threat of the monsoon depression over south China coastal areas was closely monitored and assessed when this depression moved into and across the northern part of the South China Sea in an east-northeast direction. The depression remained at a distance of more than 200 km from Hong Kong, and thus turned out to have rather limited impact on the Pearl River Estuary. Finally, it touched upon the southern tip of Taiwan, moved into the northwest Pacific and dissipated.

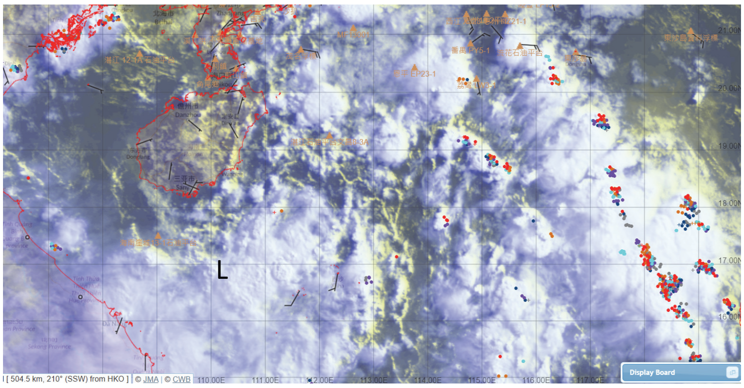
2.2. Surface, satellite, and lightning observations

The observations at four stages of the life of the monsoon depression are documented here using surface wind observations, weather satellite imageries, and lightning location area. *Fig. 2(a)* refers to the time when the depression was about to make landfall over Hainan Island. The convective clouds associated with the depression were rather loosely organized. The surface winds were generally rather weak, only about 2.5 to 5 m/ss from the available observation. The most significant convective development appeared at the northeastern part of the South China Sea, where the southwest monsoon over the southern flank of the monsoon depression converged with the western flank of the subtropical ridge. There was north-northwest to south-southeast oriented cloud band over there with frequent lightning.

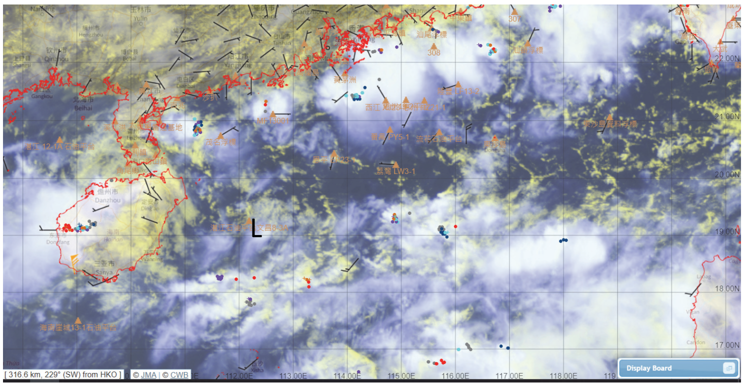
Fig. 2(b) refers to the time when the depression entered the Hainan Island the second time and was about leave the Island to enter the northern part of the South China Sea. Since the depression was over the land, the associated convective development was very weak, and it was once thought that the depression was about to dissipate. The winds near the center of the depression were extremely weak, generally less than 2.5 m/s.

In *Fig. 2(c),* the monsoon depression was crossing the northern part of the South China Sea, and it was closest to Hong Kong. The surface wind observations, though rather weak, clearly depicted that there was a close circulation, and the convective development (west-east oriented cloud band with frequent lightning activity) appeared in the southern part of the system. The southwest monsoon remained rather weak, as shown in the surface observations, and this is consistent with the NWP analysis and forecast (not shown).

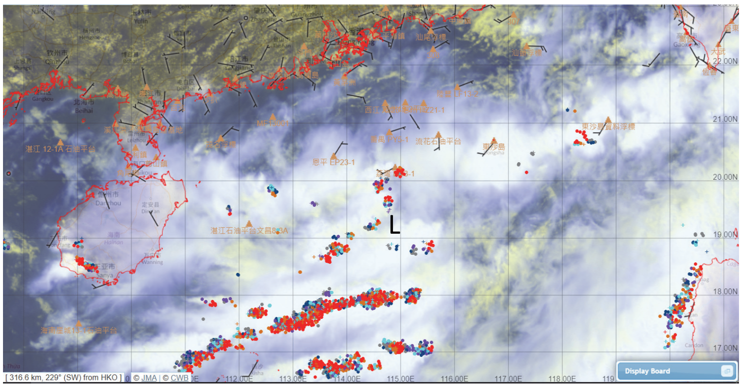
The monsoon depression continued to track east-northeastwards towards Taiwan, as shown in *Fig. 2(d)*. Consistent with NWP model forecast (not shown), there was a burst of southwest monsoonal flow at that time, and a ship observation recorded southwesterly winds of around 18 m/s (red wind barb in *Fig. 2(d)*).



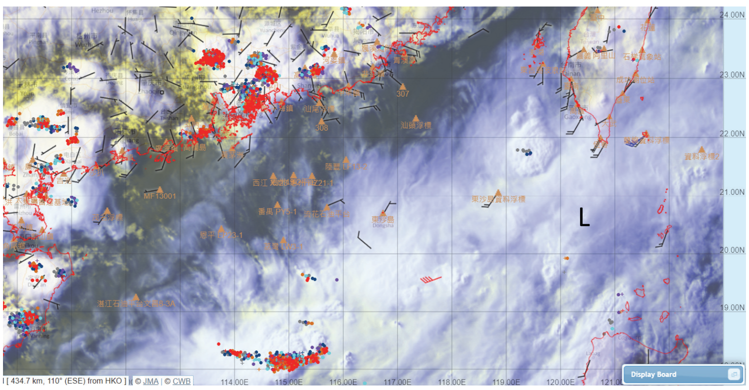
(a) 07:30 UTC, June 6, 2023



(b) 10:40 UTC, June 11, 2023



(c) 13:30 UTC, June 12, 2023

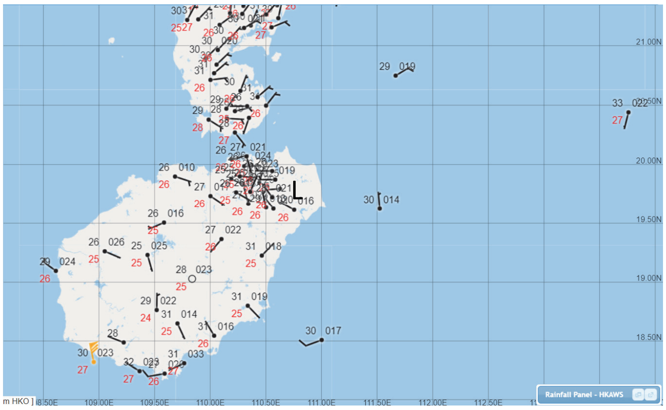


(d) 16:30 UTC, June 13, 2023

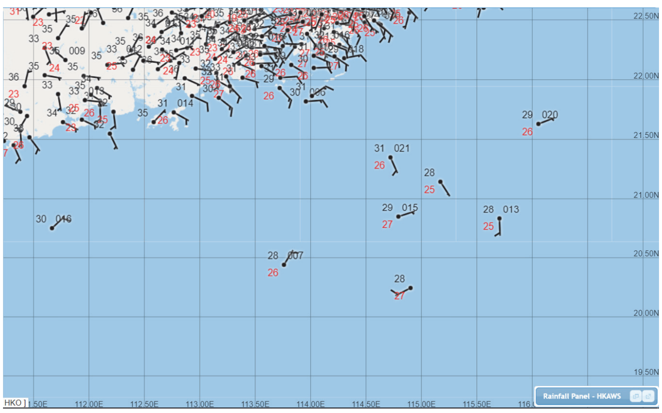
Fig. 2. Meteorological observations of the monsoon depression at four instances of its life, including surface wind observations (wind barbs), satellite imageries, and lightning location information (colored dots). Indicative location of the depression is marked as “L”.

There were rather significant convective cloud bands to the southwest of the system with frequent lightning activity. There were frequent discussions among the weather forecasters on the need to upgrade the system into a tropical depression by that time. However, as the system was about to make landfall over Taiwan, the upgrade was withheld, and eventually the monsoon depression, when located to the east of Taiwan, was submerged into a surface trough of low pressure and could no longer to be identified independently. This is taken to be the end of the life of the monsoon depression. On the whole, the monsoon depression lasted for 10 days.

Apart from surface wind observations, there are additional measurements of the surface pressure. Two instances of the surface pressure distributions are given in *Fig. 3*. *Fig.3(a)* refers to the time when the monsoon depression was located at the northeastern corner of Hainan Island and was about to enter the northern part of the South China Sea. The surface pressure near the center of the depression was found to be around 1001.5 hPa. When the depression was rather close to Hong Kong, as shown in *Fig. 3(b),* it was found to have a pressure of around 1000.7 hPa near the center. It appears that, throughout the whole life, the monsoon depression had a lowest pressure of around 1000 hPa near its centre.



(a) 10:40 UTC, June 11, 2023



(b) 13:30 UTC, June 12, 2023

Fig. 3. Surface observations at two time instances of the lifespan of the monsoon depression. They include wind barbs, temperature (black), dew point (red), and pressure (013 refers to 1001.3 hPa, etc.). The indicative location of the monsoon depression is given by "L".

2.3. Radar observations

As the convective developments near the center of the monsoon depression were rather weak, the weather radar imageries of the system did not show the typical radar echoes in association with the spiral rain bands. Two instances of the radar pictures are shown in *Fig. 4*.

In *Fig. 4(a),* when the monsoon depression just left the Hainan Island, there were only isolated radar echoes near the center of the system. The echoes did not take a band shape, and they did not appear to be circulating from the radar picture animations (not shown).

When located at around 200 km to the south-southwest of Hong Kong, the monsoon depression had rather weak and isolated radar echoes near its center (*Fig.4(b)*). On the other hand, the convective developments associated with the southwest monsoon, the south and east of the system appeared to be much more intense, consistently with satellite imagery and lightning location information.

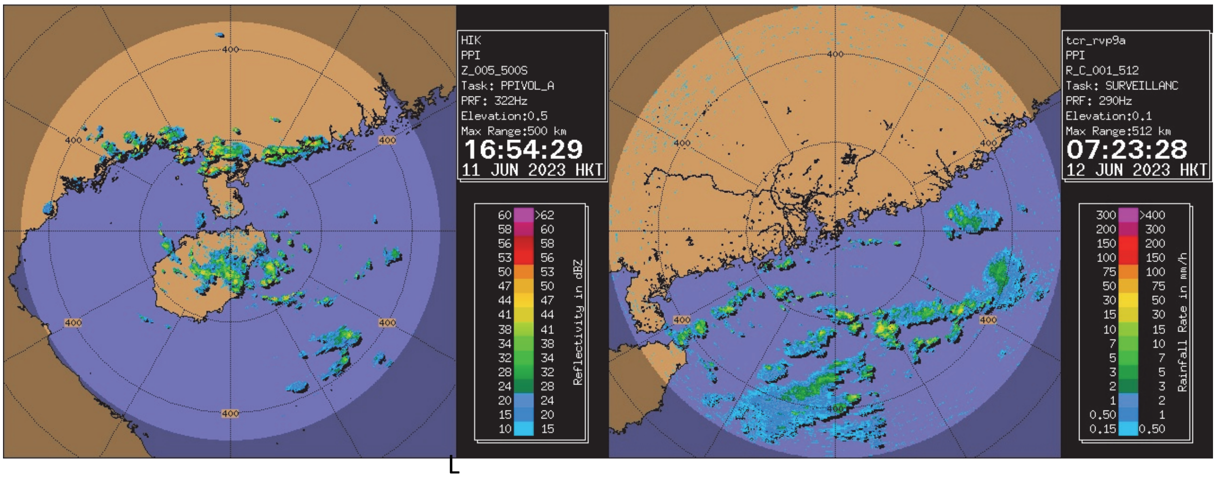


Fig. 4. Weather radar imageries of the monsoon depression with indicative location "L".
(a) 16:54 UTC, June 11, 2023, for Haikou radar (b) 07:23 UTC, June 12, 2023, for Hong Kong radar

2.4. Upper air observations

Regular radiosonde data are available from a number of stations within 300 km from the center of the monsoon depression, and they provide some information, though rather limited, about the upper air situation in association with the depression. The stations include Xisha, Haikou, and Dongsha, and their locations are given in *Fig. 1*.

For upper-air winds, only Xisha and Haikou are considered as the vertical resolution of the available radiosonde, data from Dongsha are rather coarse. For Xisha (*Fig. 5(a)*), the wind direction changed from northeasterly to southeasterly and then southerly, with the passage of the monsoon depression over this station. The boundary layer winds remained rather weak, consistently with the surface observations. When turning to southerly, the mid-tropospheric flow (around 4 km) showed a jet, reaching around 15 m/s. This might be related to the mid-level southwest monsoon.

For Haikou (*Fig.5(b)*, one notable feature was the low-level jet (below 2 km) on June 11-13, 2023, though the wind speed was not particularly high (around 6 to 13 m/s). The jet feature was rather apparent. More specifically, for southwest monsoon at 00 UTC, June 13, 2023, the jet feature was the most significant, and the boundary layer wind speed reached the maximum of around 13 m/s.

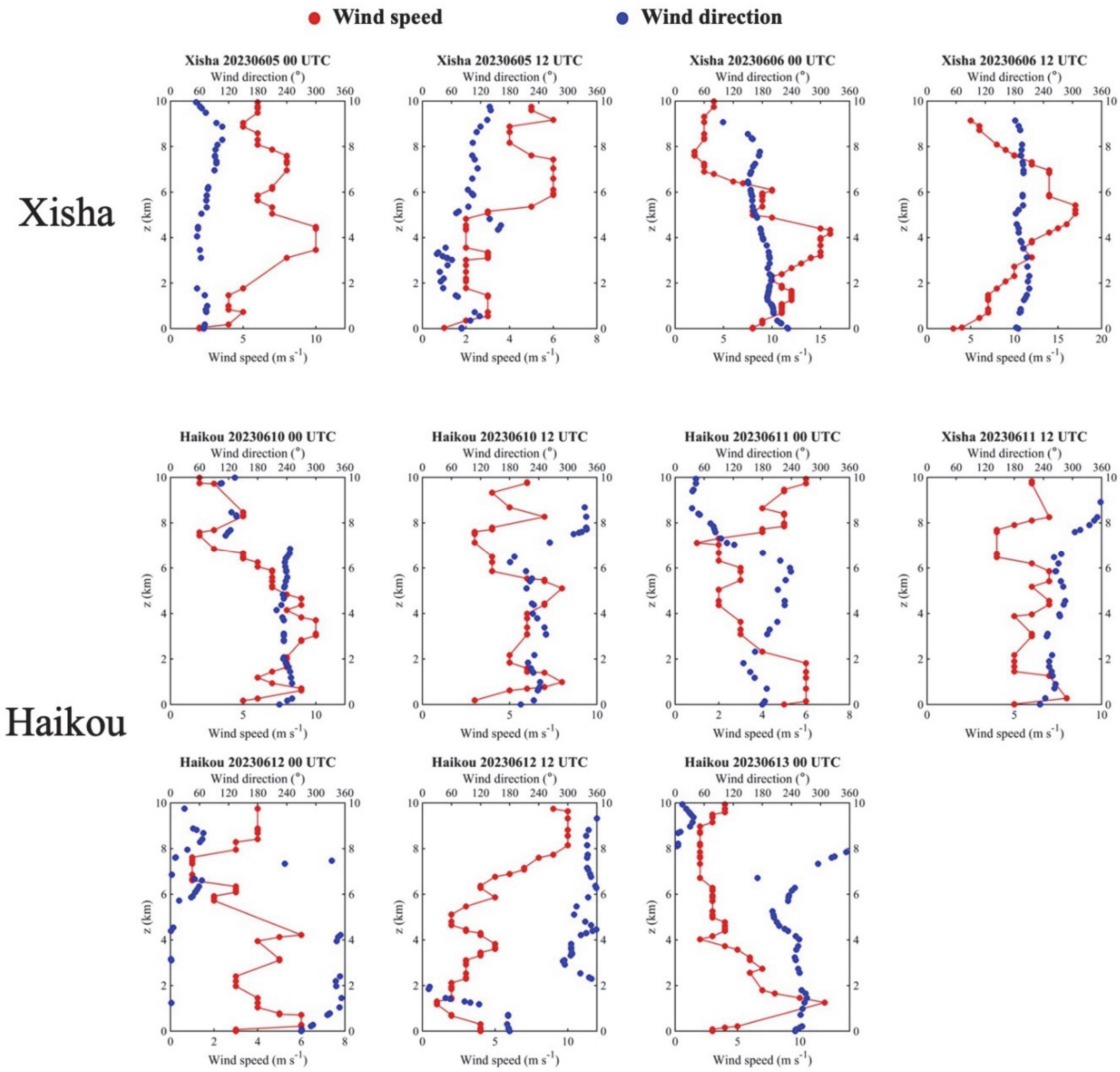


Fig. 5. Radiosonde observations of Xisha and Haikou for wind speed and wind direction.

The thermodynamic features of the upper-air soundings from the three stations are shown in *Fig. 6*. In general, the boundary layers of the three stations (below 2 km) were rather unstable, shown in the relatively sharp decrease of equivalent potential temperature with height. A previous study of dropsonde data of tropical cyclones (*He et al.*, 2022) suggests that, in such conditions, there could be chance of intensification of the cyclonic system. As such, from the available observations, the thermodynamic conditions of the atmosphere did favor the further development of the system.

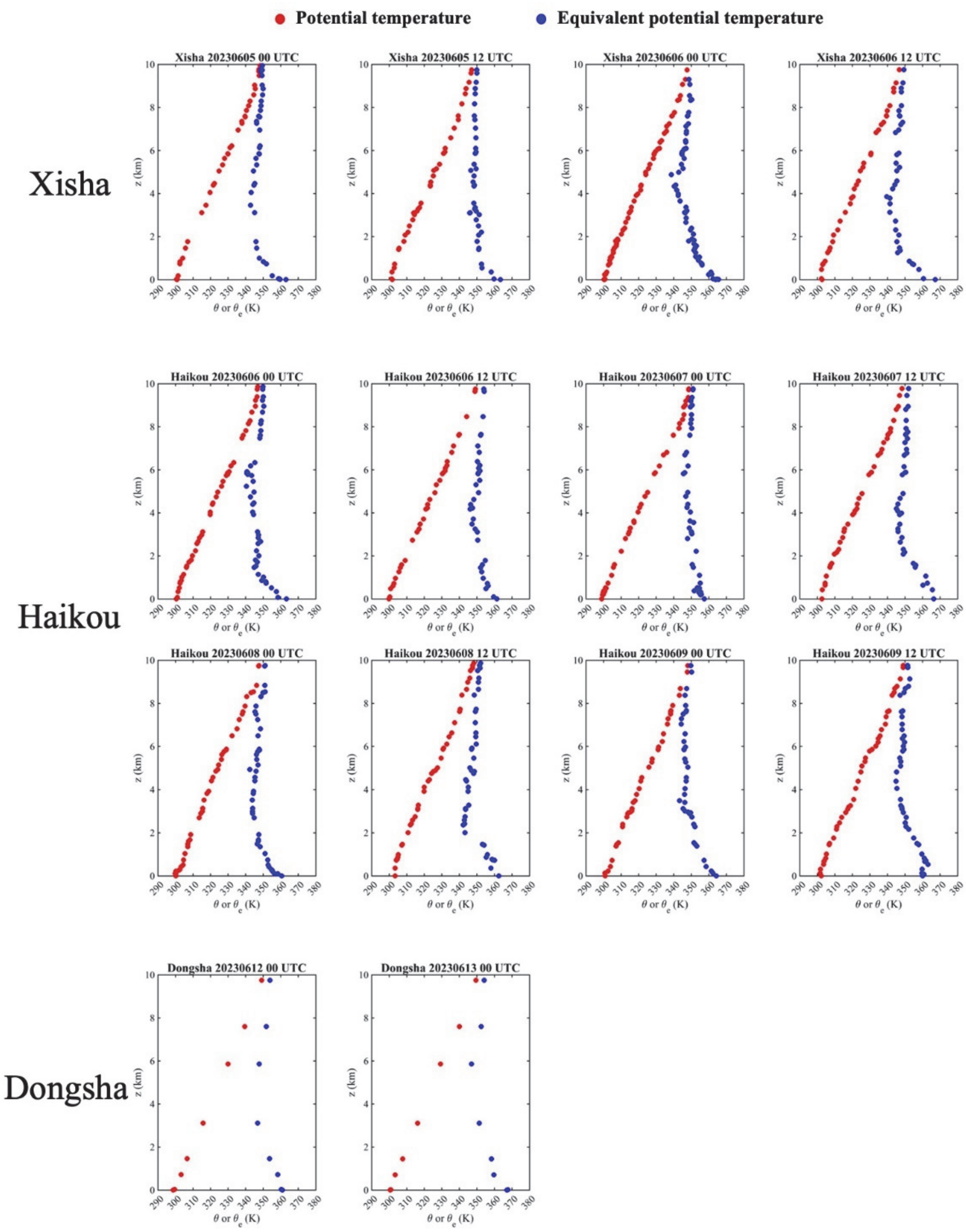


Fig. 6. Radiosonde observations of Xisha, Haikou, and Dongsha for potential temperature and equivalent potential temperature.

2.5. Performance of numerical weather prediction models

The NWP models in general capture the weak system quite well, which may be related to the improved data assimilation system and higher spatial resolution of the model. Here we take the ensemble system ECEPS of the European Centre of Medium-Range Weather Forecasts as an example. Ensemble tracks of the three stages of the system are shown in *Fig.7*. The model ensemble forecasts are shown as black curves. They are in generally consistent with the actual locations of the monsoon depression in *Fig. 1*. The ECEPS forecasts are all 120-hour forecasts in the figure.

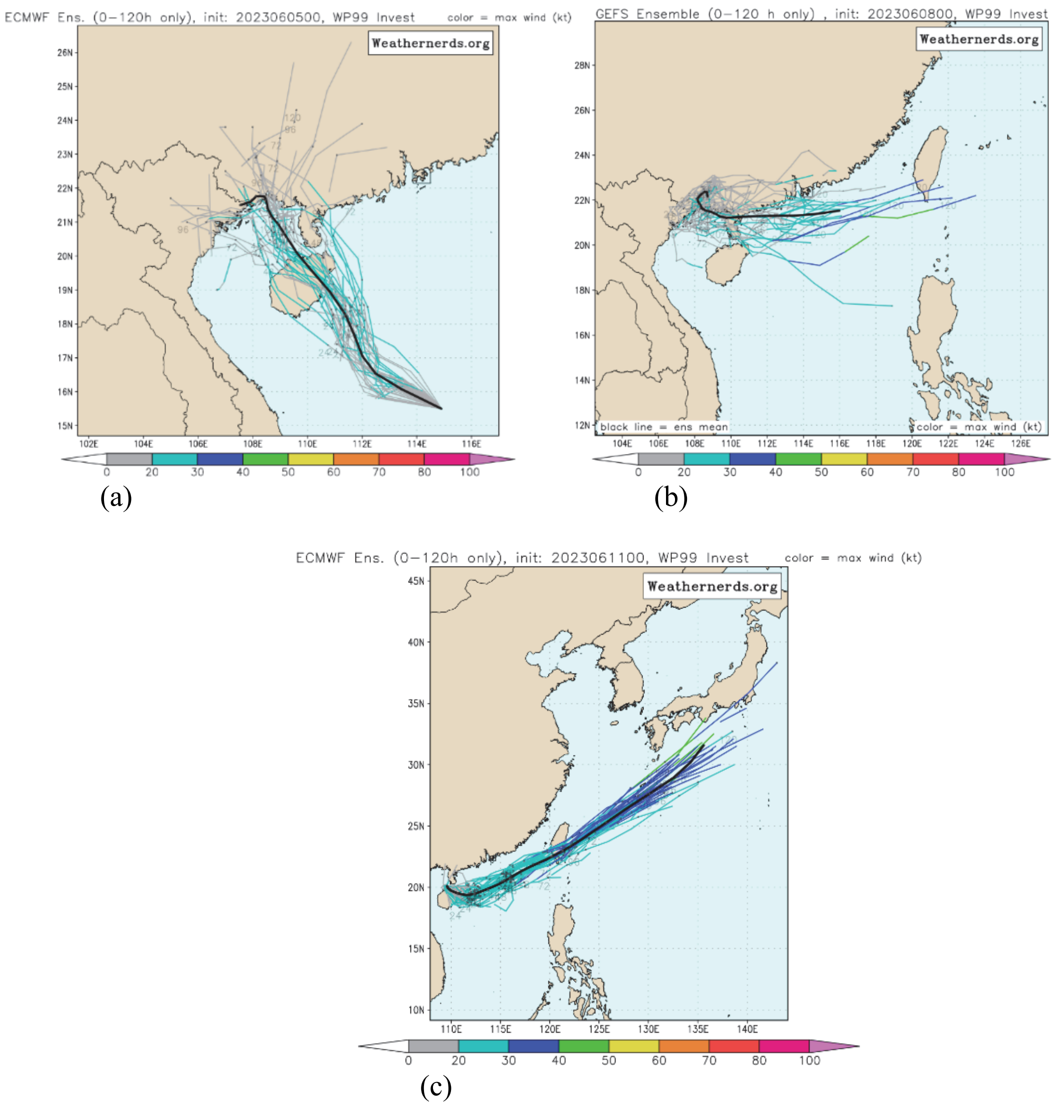
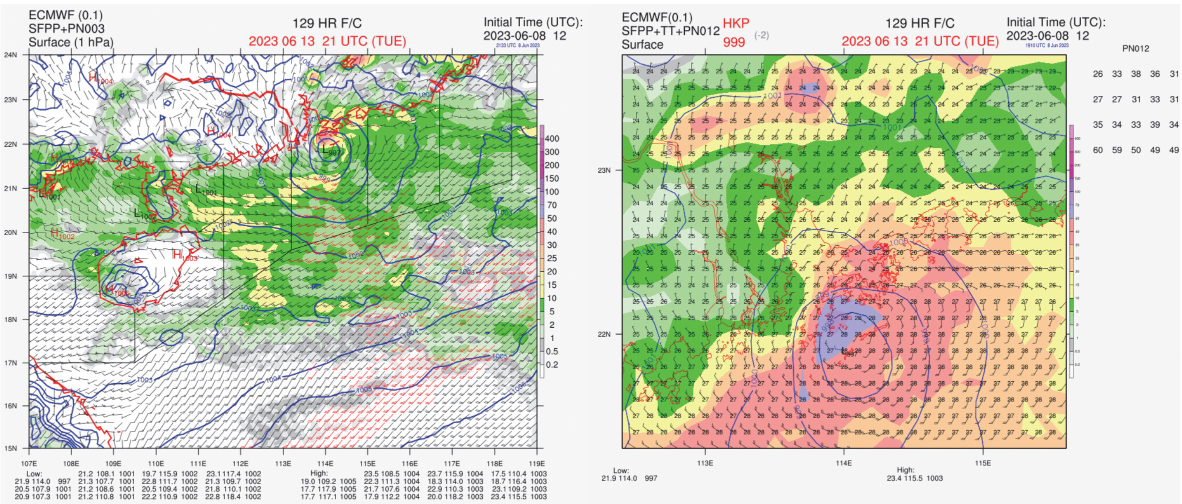


Fig. 7. ECEPS tracks of the monsoon depression for three model runs. Copyright: Weathernerds

However, there might be some limitations in the forecasts of the deterministic model of the ECMWF about the location and, especially, the intensity of the system. *Fig. 8* shows the deterministic forecast with the initial time of 12 UTC, June 8, 2023, with a forecast time of 129 hours. The ECEPS model once forecasted that the system could be extremely close to Hong Kong, with deepening of central pressure to around 997 hPa. As such, it was expected to bring about significant rain to Hong Kong (up to 60 mm of rain in 12 hours). Because of that, the Hong Kong Observatory once issued the message that the system would be closely monitored, and there might be a need of issuing tropical cyclone warning signal if the system further developed into a tropical cyclone and moved close to Hong Kong. This turned out to be a bust forecast. The performance of the NWP model is documented here for future reference by the model developers and weather forecasters.



(a) (b)

Fig. 8. 129-hour forecast of the ECMWF's deterministic model initialized at 12 UTC, June 8, 2023. (a) surface forecast for wind, pressure, and rainfall. (b) zoom in of (a) around Hong Kong.

The ECEPS and the deterministic model are considered this paper because they are considered to be operationally the most accurate systems for tropical cyclones. It is shown in the verification webpages of tropical cyclones of ECMWF, e.g., about the number of typhoons in each year over the last 20 years in the western North Pacific, the error in the annual number of typhoons is in the order of 3, and the correlation between the predicted and the actual number of typhoons are very high. At least in the Altantic Ocean (e.g., in the study https://iacweb.ethz.ch/doc/publications/TC_MasterThesis.pdf, which has been accessed on January 6, 2024), the track errors are verified to be rather small so that the model is considered to be skilful. However, the monsoon depression in the present study is rather weak. It could be difficult for global models to capture the intensity of tropical cyclones well due to a number of limitations, the major one being the cumulus parameterization (*Wang* and *Tan*, 2023). As such, it is not surprising that the present modeling systems are not satisfactory for a rather weak monsoon depression.

3. Conclusions

The life of a weak monsoon depression is documented in this paper. It has a lifespan of around 10 days and, to the knowledge of the author, it is a rather long lived monsoon depression in this part of the world. Thermodynamically speaking, there could be chance for the system to further intensify into a tropical cyclone. This is supported by ECMWF model forecasts. There is also a burst of southwest monsoon that could feed more energy and moisture into the system. The sea surface temperature was also favorable, which was measured to be around 28 to 29 °Celsius in Hong Kong. The monsoon depression failed to develop further at the end, probably because of the rather weak horizontal shear, particularly the northern frank of the system (very weak easterly winds).

There are more weather observations in the northern part of the South China Sea, which provide unprecedented observations of the weak systems for the first time. It is hoped that this documentation of the monsoon depression would stimulate more studies of this kind of system in this part of the world.

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