SIDEBAR 4.2: **TAIWAN IN THE BULLSEYE OF SEVERAL MAJOR TYPHOONS**—I-I LIN, M.-M. LU, AND M.-D. CHENG

During summer 2016, Taiwan was hit by a series of three major typhoons (Supertyphoons Nepartak and Meranti, and Typhoon Megi), with a fourth typhoon (Malakas) nearly making landfall (Fig. SB4.3). It was one of the most severe seasons for a single region in the global record. Fortunately, with advances in disaster mitigation, prediction of landfall locations, and relatively fast typhoon translation speeds, the damage was not as severe as anticipated. The estimated total death toll in Taiwan from the direct impact of these typhoons was eight, according to the Taiwan government's Central Emergency Operation Center (www.emic.gov.tw), with other socioeconomic impacts (e.g., agricultural loss and power shortages) also reported.

The 2016 typhoon season started very late, with the first named storm, Nepartak, identified in early July. This late start likely resulted from the strong subsidence/weak cyclonic vorticity over the South China Sea and western North Pacific Ocean, possibly caused by the lingering influence of the strong El Niño conditions there (Wang and Chan 2002). On the other hand, oceanic conditions were becoming increasingly favorable with above-normal SSTs and tropical cyclone heat potential (TCHP) conditions (Goni et al. 2016; see also Section 4g) that readily supported Nepartak's intensification. After a few days of development, Nepartak reached category 1 on 5 July, and within 30 hours it rapidly intensified to its category-5 lifetime peak intensity of 150 kt (77 m s^{-1}) on 6 July, making Nepartak one of the world's most intense tropical cyclones on record.

Nepartak maintained a peak intensity of 150 kt (77 m s^{-1}) over favorable ocean conditions (with an SST of about 30°C and a TCHP value of about 120 KJ cm^{-2}) for another day. At around 0000 UTC on 7 July, Nepartak encountered a pre-existing cold eddy at the western Pacific southern eddy zone (Lin et al. 2008), with the TCHP values having dropped to 50–60 KJ cm^{-2} (Shay et al. 2000; Lin et al. 2008). After passing over this cold ocean feature, it also passed over a small patch of warm water for a short while and soon after made landfall in southern Taiwan. Just prior to landfall, Nepartak's intensity was at 130 kt (67 m s^{-1}) at 1800 UTC on 7 July and after landfall, at 0000 UTC on 8 July, it was reduced to 90 kt (46 m s^{-1}; Fig. SB4.3). It is worth noting that two deep-ocean buoys from National Taiwan University's Institute of Oceanography were directly in the path of Nepartak as it approached Taiwan, with the storm's center passing close to or directly over the buoys. Post-calibration efforts are ongoing to analyze these rarely-captured data (see http://po.oc.ntu.edu.tw/buoy/typhoons.php).

The 2016 season then went into a rather quiet period with little activity near Taiwan. The lack of typhoon activity around Taiwan, specifically in August, was due to an unusually strong low pressure system over the subtropical western North Pacific which caused more-than-usual northward recurving of typhoon tracks toward Japan. The abnormal low pressure could be an intraseasonal wave excited from high latitudes (Bin Wang and Tim Li, University of Hawaii, personal communications).

At the beginning of September, western North Pacific typhoon activity ramped up considerably with four major typhoons developing (category 3 Typhoons Namtheun and Megi, category 4 Typhoon Malakas, and category 5 Typhoon Meranti). The increase in activity was likely related to the developing La Niña which enhances large-scale convergence over the western north Pacific Ocean east of the Philippines, the South China Sea, and the Maritime Continent (Chan 2000; Chia and Ropelewski 2002; Wang and Chan 2002). For example, reduced vertical wind shear over the western

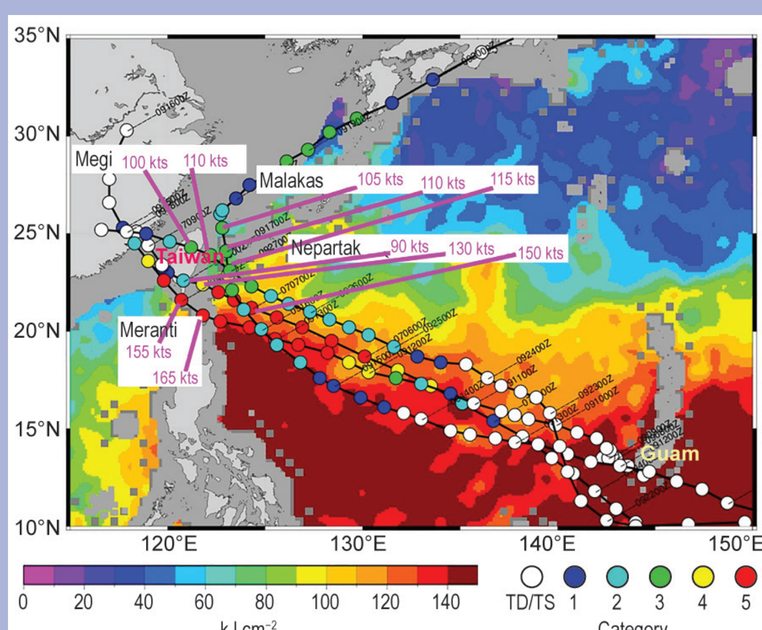

Fig. SB4.3. The tracks of four typhoons (Supertyphoons Nepartak and Meranti, category-4 Typhoon Malakas, and category-3 Typhoon Megi) approaching Taiwan. Typhoon's peak intensity and intensity closest to Taiwan are depicted. The background map is based on daily composite of the four pre-typhoon TCHP (i.e., integrated heat content from SST down to the 26°C isotherm depth) maps from 3 Jul, and 9, 12, and 22 Sep.

Pacific main development region (east of the Philippines), as compared to both August and the long-term climatology, likely favored more TC activity.

With a peak intensity of 165 kt (85 m s^{-1}), Supertyphoon Meranti was the most intense tropical cyclone on Earth in 2016. At a peak intensity only 5 kt (3 m s^{-1}) below Supertyphoon Haiyan in 2013, Meranti was also the second most intense western North Pacific typhoon on record. It was first identified on 7 September near Guam and developed into a category 1 typhoon on 11 September over the Philippine Sea (Fig. SB4.3). Within 30 hours, it rapidly intensified to category 5 intensity of 155 kt (80 m s^{-1}) and, in another day, reached an impressive intensity (I-I Lin et al. 2014) of 165 kt (85 m s^{-1}). These intensity values were similar to those of Hurricane Patricia in 2015 at 185 kt (95 m s^{-1}) (Foltz and Balaguru 2016); and Supertyphoon Haiyan in 2013 at 170 kt (87 m s^{-1}). The peak intensities of these three storms were far above (30–50 kt; 15–26 m s^{-1}) the existing category 5 threshold of 135 kt (69 m s^{-1}) on the Saffir–Simpson scale.

Due to the strengthening of the subtropical high pressure system in September, Supertyphoon Meranti followed a westward track toward Taiwan (Figs. SB4.3, SB4.4). Throughout its intensification, Meranti was mostly over favorable ocean conditions with SSTs at about 30°C and TCHPs of about 130 kJ cm^{-2}. After reaching its peak intensity of 165 kt (85 m s^{-1}) at 1200 UTC on 13 September, its northern sector encountered a pre-existing cold feature, which may have slightly weakened its intensity to 155 kt (80 m s^{-1}). Meranti's center then passed over the waters close to the southern tip of Taiwan (Lu et al. 2013), with the northern half of the storm making landfall (Fig. SB4.4). Due to its large circulation, the entire Taiwan island was impacted by Meranti for another day following landfall.

Three days after Meranti's genesis, Typhoon Malakas formed in association with monsoon trough activity (Lia Wu et al. 2012; Fig. SB4.3). During its intensification phase, Malakas followed a track similar to that of Meranti. However, its intensification was not as drastic as it traveled over the weak cold wake region caused by the previous storm (e.g., Price 1981), with reduced SSTs and TCHP values. At 1800 UTC on 16 September, it reached its category 4 peak of 115 kt (59 m s^{-1}) over the waters near eastern Taiwan. Due to the steering effect from a deep, shortwave trough to the west of Taiwan, Malakas traveled northward along the front of the trough. It did not make landfall in Taiwan but did eventually strike southern Japan where it caused substantial damage.

Shortly after the passages of Meranti and Malakas, Typhoon Megi formed on 21 September near Guam (Fig. SB4.3). As noted earlier, the strengthened subtropical high pressure in September guided the track of these typhoons, and all followed a similar westward track towards Taiwan. However, as Megi followed both Meranti and Malakas, ocean conditions along its track were not as favorable for development due to reduced SSTs (e.g., Price 1981). It took Megi three days to intensify from a category 1 to a category 3 typhoon, and it made landfall in central Taiwan on 27 September (Fig. SB4.3). Megi caused considerable damage, which included three deaths and the loss of electrical power to nearly 4 million households.

In retrospect, the 2016 typhoon season was an eventful and particularly intense one for Taiwan. Given the landfall of three major typhoons, including the most powerful tropical cyclone in 2016 (Meranti), the total number of deaths was fortunately limited to eight. It is interesting to note that while Supertyphoon Nepartak had a smaller outer circulation, it had very tight and intense winds near the center. Supertyphoon Meranti had a broad outer circulation, as well as very intense central winds. Typhoon Megi had a broad outer circulation with weaker winds around its center.

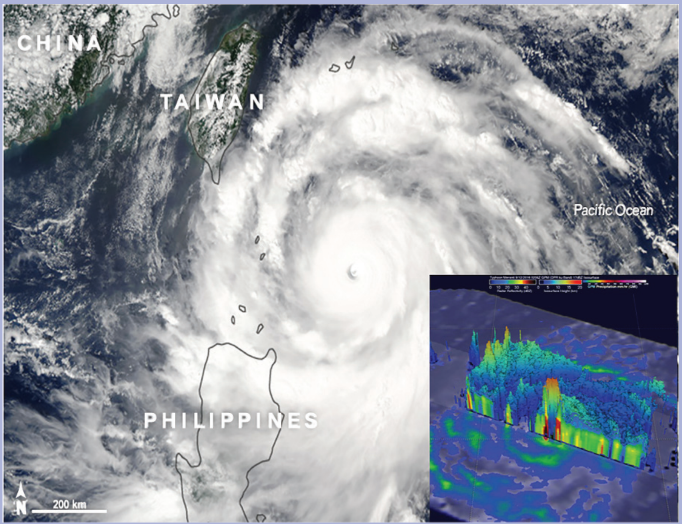

Fig. SB4.4. At an extraordinary intensity of ~155–165 kts (80–85 m s^{-1}), Supertyphoon Meranti approached Taiwan, as observed by NASA's MODIS on 13 Sep. The smaller figure at lower right was observed by NASA's GPM on 12 Sep, showing the extreme rainfall of ~ 300 mm hr^{-1} from Meranti, during its rapid intensification phase before reaching peak intensity. The "hot towers" (deep convective activities) of Meranti were observed to reach >17 km in height by GPM's Ku band radar (Image courtesy: NASA Earth Observatory, www.nasa.gov/feature/goddard/2016/meranti-northwestern-pacific-ocean.)