Strong Modulation of the Pacific Meridional Mode on the Occurrence of Intense Tropical Cyclones over the Western North Pacific

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ABSTRACT

This study finds a significant positive correlation between the Pacific meridional mode (PMM) index and the frequency of intense tropical cyclones (TCs) over the western North Pacific (WNP) during the peak TC season (June–November). The PMM influences the occurrence of intense TCs mainly by modulating large-scale dynamical conditions over the main development region. During the positive PMM phase, anomalous off-equatorial heating in the eastern Pacific induces anomalous low-level westerlies (and cyclonic flow) and upper-level easterlies (and anticyclonic flow) over a large portion of the main development region through a Matsuno–Gill-type Rossby wave response. The resulting weaker vertical wind shear and larger low-level relative vorticity favor the genesis of intense TCs over the southeastern part of the WNP and their subsequent intensification over the main development region. The PMM index would therefore be a valuable predictor for the frequency of intense TCs over the WNP.

1. Introduction

Tropical cyclones (TCs) are one of the most destructive natural disasters and cause huge economic losses and casualties. The western North Pacific (WNP) is the most active ocean basin, having approximately one-third of global TCs (Neumann 1993). Intense typhoons have posed a growing threat to the high density of population in the coastal regions of Southeast and East Asia (Park et al. 2014; Wu et al. 2005). One of the most extreme examples was (super) Typhoon Haiyan in 2013. The associated high wind, strong storm surge, and heavy rain caused catastrophic destruction when it made landfall in the Philippines (Lander et al. 2014). Climate models have generally projected higher frequency of

intense TCs over the WNP under global warming (e.g., Knutson et al. 2010, 2015; Sugi et al. 2017). As a result, a better understanding of the variations of intense typhoons over the WNP is of great significance to mitigate TC-related hazards.

Observed trends of intense typhoons have been extensively studied over the years. An overview of the trends was provided by Walsh et al. (2016). Webster et al. (2005) reported a pronounced upward trend in the number and fraction of intense typhoons during 1970–2004. This trend was questioned by a few studies. Chan (2006) claimed that this trend was likely a portion of interdecadal variations. Kamahori et al. (2006) and Wu et al. (2006) instead showed a downward trend in the number of intense typhoons using different TC best track datasets. The trend discrepancies of intense typhoons among different best track datasets were also

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reported by [Song et al. \(2010\)](#). Using a quantile method, [Kang and Elsner \(2012\)](#) obtained consensus on a decreasing trend in the number of intense typhoons and an increasing trend in the strength of intense typhoons during 1984–2010 between two best track datasets. [Kossin et al. \(2013\)](#), as an update of [Kossin et al. \(2007\)](#), found a negative trend in lifetime maximum intensity of TCs over the WNP using a reanalyzed TC intensity record during 1982–2009. The increasing trend in intense typhoon frequency during 1970–2004 ([Webster et al. 2005](#)) was attributed to observational improvements and no significant trend was found during the more recent periods when TC data were the most reliable and homogeneous ([Klotzbach 2006](#); [Klotzbach and Landsea 2015](#); [Landsea et al. 2006](#)). The possible overestimation of trend in frequency of intense typhoons was also noted by [Wu and Zhao \(2012\)](#) and [Barcikowska et al. \(2017\)](#) using different dynamical downscaling approaches. In addition, there were increases in frequency of intense typhoons in May over the WNP after 2000 ([Tu et al. 2011](#)) and in September over the Philippine Sea after the mid-2000s ([He et al. 2017](#)). The ratio of intense typhoons to all landfalling TCs was found to double or even triple over the past four decades ([Mei and Xie 2016](#)).

Interannual and decadal to multidecadal variations of intense typhoons have also been examined. A few studies showed higher frequency of intense typhoons associated with eastward shift of genesis location, weak vertical wind shear, and large relative vorticity and moist static energy in canonical El Niño years ([Camargo and Sobel 2005](#); [Chan 2007](#); [Huang and Xu 2010](#); [Li and Zhou 2012](#)). Compared to canonical El Niño, El Niño Modoki (e.g., [Ashok et al. 2007](#)) was found to exert different impacts on WNP TC frequency and intensity (e.g., [Chen 2011](#); [Chen and Tam 2010](#); [Ha et al. 2013](#); [Kim et al. 2011](#); [Wang et al. 2013](#); [Zhao 2016](#)). [Zhang et al. \(2015\)](#) further reported more intense typhoons in the autumns of El Niño Modoki years than canonical El Niño years. [Tao and Lan \(2017\)](#) identified an interdecadal variation of the interannual relationship between El Niño–Southern Oscillation (ENSO) and the frequency of intense typhoons. [Chan \(2008\)](#) and [Zhao et al. \(2014\)](#) showed that multidecadal and decadal variations of intense typhoons arose from environmental conditions at similar time scales governing TC genesis, intensification, and motion. Given significant impacts of ENSO on variations of intense typhoons spanning various time scales, one might speculate about possible impacts of other climate modes in the Pacific.

The Pacific meridional mode (PMM) refers to an ocean–atmosphere coupled variability characterized by an anomalous meridional sea surface temperature (SST) gradient across the mean intertropical convergence zone

(ITCZ) latitude coupled with a cross-gradient boundary layer airflow toward the anomalously warmer hemisphere ([Chiang and Vimont 2004](#)). The PMM spatial pattern is defined as the leading maximum covariance analysis (MCA) mode of SST and 10-m wind vector, after removing the seasonal cycle and linear trend and subtracting the linear fit to the cold tongue index (an ENSO index similar to Niño-3.4) for each grid point. The PMM SST or wind index is then calculated by projecting SST or 10-m wind field onto the spatial pattern ([Chiang and Vimont 2004](#)). The PMM has strong signals at the interannual time scale, similar to ENSO. PMM matures in boreal spring while ENSO peaks in boreal winter. The positive PMM phase, which means positive SST anomalies in the northwestern portion from the North American coast toward Hawaii and negative SST anomalies in the southeastern portion in the eastern tropical Pacific ([Chiang and Vimont 2004](#)), is proven to be a precursor and trigger of ENSO events and could thus be used to predict ENSO ([Chang et al. 2007](#); [Larson and Kirtman 2013, 2014](#)). The PMM, however, is largely independent of ENSO because the ENSO signal as well as the trend in SST are linearly removed when calculating the PMM index ([Chiang and Vimont 2004](#)). The positive PMM phase has recently been found to favor TC occurrence over the WNP by weakening vertical wind shear ([Zhan et al. 2017](#); [Zhang et al. 2016](#)). [Vimont and Kossin \(2007\)](#) have showed a very similar relationship between Atlantic TC activity and the Atlantic meridional mode (AMM), and vertical wind shear associated with the AMM is one of the key climatic conditions responsible for changes in Atlantic TC activity. [Kossin and Vimont \(2007\)](#) have emphasized the important role of vertical wind shear in the strong relationship between major hurricanes and the AMM. [Zhang et al. \(2016, 2017\)](#) have reported a significant association between the PMM and frequency of WNP TCs in observations and climate model simulations and have used the PMM index to improve the statistical–dynamical prediction of TC frequency and landfalling TC frequency over the WNP. However, roles of the PMM in the occurrence of intense typhoons over the WNP remain elusive. Because of the potential of intense typhoons for massive destruction, it is desirable to investigate whether the PMM modulates the frequency of intense typhoons and to unravel possible underlying physical mechanisms.

2. Data and methods

The Joint Typhoon Warning Center (JTWC) best track dataset is used to derive the frequency of intense typhoons during the peak TC season [June–November

(JJASON)] of each year in the period 1990–2016, during which the historical intense typhoon records are considered to be the most reliable and homogeneous (Klotzbach 2006; Klotzbach and Landsea 2015; Landsea et al. 2006). This study period is also similar to that in He et al. (2017). An intense typhoon is defined as a category 4–5 TC (with the maximum 1-min sustained wind speed exceeding 58 m s^{-1}) at the Saffir–Simpson hurricane wind scale, following previous studies (e.g., Chan 2007, 2008; He et al. 2017; Klotzbach and Landsea 2015; Zhao et al. 2014).

The PMM SST index (hereafter PMM index) and Niño-3.4 index are acquired from the Physical Sciences Division (PSD) of the National Oceanic and Atmospheric Administration (NOAA)/Earth System Research Laboratory (ESRL). The Niño-3.4 index is used to represent canonical ENSO. The ENSO Modoki index is obtained from the Japan Agency for Marine–Earth Science and Technology (JAMSTEC). Consistent with previous studies (e.g., Camargo et al. 2007; Gao et al. 2018; Yu et al. 2016; Zhang et al. 2016), several atmospheric and oceanic variables are used to examine how the environmental conditions modulated by the PMM affect the occurrence of intense typhoons over the WNP. Monthly SST data are obtained from the Extended Reconstructed Sea Surface Temperature (ERSST) dataset version 4 (Huang et al. 2015). Monthly wind vector, relative humidity, air temperature, and sea level pressure data are attained from the National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) reanalysis data (Kalnay et al. 1996). Monthly interpolated outgoing longwave radiation (OLR) data (Liebmann and Smith 1996) are also acquired from the NOAA/ESRL PSD. Based on these variables, 850-hPa relative vorticity is derived, maximum potential intensity (MPI; Emanuel 1988) is calculated using the codes provided by K. Emanuel (<http://texmex.mit.edu/pub/emanuel/TCMAX/>), and vertical wind shear is computed as the difference of wind vectors between 200 and 850 hPa. Prior to regression analyses, all the environmental variables are detrended and their linear fits to the Niño-3.4 index are removed to minimize the ENSO effect.

To verify the physical mechanisms underlying the association between PMM and intense typhoons, we use the International Centre for Theoretical Physics atmospheric general circulation model (ICTP AGCM) (Kucharski et al. 2006, 2013; Molteni 2003) to perform perturbation experiments. We use the latest version (41) of this model, with 8 vertical levels, and the most commonly used horizontal spectral truncations are T30 (about $3.75^\circ \times 3.75^\circ$ horizontal resolution). This model is developed using physically based parameterizations of

FIG. 1. Time series of frequency of intense typhoons (red line) and normalized PMM index (black line), ENSO Modoki index (blue line), and Niño-3.4 index (gray bar) during JJASON 1990–2016.

large-scale condensation, shallow and deep convection, shortwave and longwave radiation, surface fluxes of momentum, heat, and moisture, and vertical diffusion (Kucharski et al. 2006, 2013; Molteni 2003).

To evaluate the impacts of SST associated with PMM, we prescribe the SST anomaly derived from the regression of SST onto the PMM index in this model. We performed two experiments: one is prescribed with the climatological seasonal cycle of SST (CTRL) and the other with the addition of the SST anomaly related to positive PMM and the climatological seasonal cycle of SST in the PMM region and the same as the CTRL experiment outside the PMM region (PPMM). Both experiments were integrated for 100 years and the subtraction of CTRL from PPMM represents the forced changes of PPMM. We compare the differences in the two experiments during JJASON.

3. Statistical relationships between the PMM and intense typhoons

Figure 1 shows the time series of frequency of intense typhoons and normalized PMM, Niño-3.4, and ENSO Modoki indices during JJASON. Correlation coefficients of the PMM, Niño-3.4, and ENSO Modoki indices with frequency of intense typhoons are 0.55, 0.54, and 0.57, respectively. All of them are significant above the 99% confidence level. The significant correlations between two types of ENSO events and frequency of intense typhoons are consistent with previous studies (Camargo and Sobel 2005; Chan 2007; Huang and Xu 2010; Li and Zhou 2012; Tao and Lan 2017; Zhang et al. 2015). However, there is very weak correlation (0.10)

TABLE 1. Total and average (in parentheses) frequency of intense typhoons and all TCs during JJASON in positive and negative PMM phases. Ratios of intense typhoons to all TCs in two phases are also shown. Boldface values indicate significance at the 0.1 level based on the Student's *t* test.

Parameter	Negative PMM phase (2 yr)	Positive PMM phase (6 yr)
Frequency of intense typhoons	9 (4.5)	50 (8.3)
Frequency of all TCs	43 (21.5)	158 (26.3)
Ratio of intense typhoons to all TCs	20.9%	31.6%

between the PMM and Niño-3.4 indices during JJASON (by design, ENSO is linearly removed from data prior to computing the PMM index; [Chiang and Vimont 2004](#)). Consistent with [Stuecker \(2018\)](#), the PMM index and ENSO Modoki index are significantly correlated ($r = 0.59$), indicating that they may not be strictly independent. However, the PMM and ENSO Modoki have different mature periods and spatial patterns of SST anomaly. Different patterns of SST anomaly have different impacts on the genesis location of TCs ([Hong et al. 2018](#)) and might therefore exert different influences on the frequency of intense typhoons.

Partial correlation between the PMM index and frequency of intense typhoons during JJASON by controlling simultaneous Niño-3.4 (ENSO Modoki) index are 0.60 (0.32), significant at the 99% (90%) confidence level. This demonstrates the robustness of the relationship between PMM index and frequency of intense typhoons. The results suggest that PMM and two types of ENSO are somewhat independent phenomena modulating the occurrence of intense typhoons. Two outstanding years illustrating the importance of the PMM in the frequency of intense typhoons are 1992 and 2016, during which two types of ENSO signals are either weak or negative. [Zhan et al. \(2017\)](#) found a dominate role of the PMM in the large number of TCs in 2016. The coexistence of canonical El Niño and positive PMM in 2015 and the coexistence of El Niño Modoki and positive PMM in 1994 and 2004 likely lead to the high frequency of intense typhoons. Although it is difficult to demonstrate which of the canonical ENSO, ENSO Modoki, and PMM events is dominant in regulating intense typhoon activity on interannual time scales, the PMM is a valuable new signal for the frequency of intense typhoons.

Following previous studies (e.g., [Kataoka et al. 2014](#); [Tao and Lan 2017](#)), the thresholds of ± 0.8 standard deviation are first applied to select typical years in the positive and negative PMM phases and typical canonical El Niño and La Niña years based on the time series of

TABLE 2. Total and average (in parentheses) RI number of intense typhoons and all TCs during JJASON in positive and negative PMM phases. Ratios of RI frequency of intense typhoons to that of all TCs in two phases are also shown. Boldface values indicate significance at the 0.1 level based on the Student's *t* test.

Parameter	Negative PMM phase (2 yr)	Positive PMM phase (6 yr)
RI number of intense typhoons	20 (10.0)	206 (34.3)
RI number of all TCs	30 (15.0)	252 (42.0)

normalized PMM and Niño-3.4 indices, respectively. To minimize the ENSO effect, the typical canonical El Niño and La Niña years are excluded. As a result, we use six neutral-ENSO years in the positive PMM phase (1990, 1992, 1994, 1995, 2004, and 2016) and two neutral-ENSO years in the negative PMM phase (2008 and 2012) to perform statistics of TC frequency, genesis location, and lifespan. We do not exclude the typical ENSO Modoki years because the PMM and ENSO Modoki are not strictly independent ([Stuecker 2018](#)).

Statistics for frequency of both intense typhoons and all TCs (i.e., those TCs reaching at least the tropical storm strength of 17 m s^{-1}) during two PMM phases are indicated in [Table 1](#). There are totally 52 (9) intense typhoons in 6 (2) peak TC seasons of positive (negative) PMM phase. The mean frequency of JJASON intense typhoons during the positive and negative PMM phases are 8.3 and 4.5, respectively, and their difference is significant at the 90% confidence level. There is also significant difference in average frequency of all JJASON TCs between the positive and negative PMM phases (26.3 vs 21.5). Moreover, the ratio of intense typhoons to all TCs is 31.6% (8.3/26.3) in the positive PMM phase, significantly larger than that of 20.9% (4.5/21.5) in the negative PMM phase at the 0.1 level.

Rapid intensification (RI), which is normally defined as an event with 24-h TC intensity change $\geq 30 \text{ kt}$ ([Kaplan and DeMaria 2003](#); [Gao et al. 2016, 2017](#)), can be used to measure the influence of the PMM on TC development. Note that there may be multiple RI events during the lifetime of a TC. [Table 2](#) shows statistics for the RI numbers of both intense typhoons and all TCs during two PMM phases. The average RI numbers of intense typhoons and all TCs (34.3 and 42, respectively) in the positive PMM phase are significantly larger than those (10 and 25, respectively) in the negative PMM phase. It is therefore suggested that the higher frequency of JJASON intense typhoons is not solely attributed to the higher frequency of all TCs in the positive PMM phase. Favorable environmental conditions in the positive PMM phase, as shown in [section 4](#), are also

FIG. 2. Tracks of all intense typhoons during JJASON 1990–2016. Blue plus signs denote genesis locations. Red and green curves represent the tracks in intensifying and decaying stages, respectively.

important for the development of intense typhoons from their initial stages.

4. Possible mechanisms

Owing to the statistically significant correlation between the PMM index and frequency of intense typhoons during JJASON, we focus on the possible mechanisms of how the PMM modulates genesis and intensification of intense typhoons in this section.

a. Genesis location and lifespan

Figure 2 shows tracks of all intense typhoons during JJASON of 1990–2016. Tracks in intensifying and decaying stages are distinguished by different colors. The genesis and intensification of intense typhoons are generally confined to a rectangular area of 5°–25°N, 125°–170°E, which is called the main development region hereafter. Figure 3 shows regressions of track density and genesis density of intense typhoons onto the PMM index during JJASON of 1990–2016. A larger number of intense typhoons form over the southeast portion of the WNP (5°–20°N, 130°–160°E) in the positive PMM phase than the negative PMM phase (Fig. 3b). Based on Fig. 3a and track maps of intense typhoons in

FIG. 3. Regressions of (a) track density and (b) genesis density onto the PMM index during JJASON 1990–2016. Numbers exceeding the 90% confidence level are stippled.

TABLE 3. Mean genesis location and lifespan of intense typhoons and all TCs during JJASON in positive and negative PMM phases. The boldface values indicate significance at the 0.1 level based on the Student's *t* test.

Parameter	Negative PMM phase	Positive PMM phase
Intense typhoons		
Mean longitude of geneses (°E)	132.2	144.9
Mean latitude of geneses (°N)	14.5	13.5
Mean lifespan (h)	194.7	210.5
All TCs		
Mean longitude of geneses (°E)	132.1	138.5
Mean latitude of geneses (°N)	18.3	16.8
Mean lifespan (h)	101.4	134.7

FIG. 4. Regressions of (a) 850-hPa relative vorticity (10^{-6} s^{-1}), (b) 600-hPa relative humidity (%), (c) MPI (m s^{-1}), and (d) vertical wind shear (m s^{-1}) onto the PMM index during JJASON 1990–2016. Numbers exceeding the 90% confidence level are stippled.

positive and negative PMM phases (not shown), one can identify that these extra intense typhoons mainly travel via two groups of northeastward recurving paths (one group mainly makes landfall in Japan and the other does not make landfall) and one group of northwestward

paths (making landfall in southeast China). The mean genesis location of intense typhoons and all TCs is more southeastward in the positive PMM phase compared to that in the negative PMM phase (Table 3). Only the longitude of genesis location is significantly different

FIG. 5. Regressions of (a) 850-hPa wind (m s^{-1} ; vector) and SST ($^{\circ}\text{C}$; shaded) and (b) 200-hPa wind (m s^{-1} ; vector) and OLR (W m^{-2} ; shaded) onto the PMM index during JJASON 1990–2016. Wind vectors exceeding the 90% confidence level are stippled.

FIG. 6. Regressions of (a) 850-hPa divergence (10^{-6} s^{-1}) and (b) 200-hPa divergence (10^{-6} s^{-1}) onto the PMM index during JJASON 1990–2016. Numbers exceeding the 90% confidence level are stippled.

between two PMM phases (Table 3), consistent with Hong et al. (2018). The southeastward shift of genesis location partially explains why a larger fraction of TCs develop into intense typhoons in the positive PMM phase, because TCs forming over the southeast portion of the WNP tend to have longer lifespan (Table 3) and gain more energy from the underlying warm tropical ocean before moving over land or over cold midlatitude water (Chan 2007; Tao and Lan 2017; Wang and Chan 2002; Zhang et al. 2015). The same argument was made in Kossin and Vimont (2007) for the link of the AMM with Atlantic major hurricanes.

b. Environmental conditions

To further examine large-scale environmental conditions responsible for intense typhoon activity modulated by the PMM, several dynamic and thermodynamic variables are regressed onto the PMM index during JJASON (Fig. 4). During the positive PMM phase, most of the main development region is characterized by significantly larger low-level relative vorticity (Fig. 4a) and weaker vertical wind shear (Fig. 4d), which are favorable for the genesis and intensification of intense typhoons. However, lower or insignificant midlevel relative humidity (Fig. 4b) and MPI (Fig. 4c) over the main development region suggests that the two thermodynamic variables are not that crucial for the higher occurrence of

intense typhoons during the positive PMM phase. The greater importance of local dynamic variables than local thermodynamic variables in TC genesis over the WNP is consistent with previous studies (e.g., Chan 2000; Chan and Liu 2004; Fu et al. 2012; Gao et al. 2018; Sharmila and Walsh 2017; Wang and Chan 2002; Zhang et al. 2016).

Regressions of SST, OLR (as an estimate of diabatic heating), and wind fields at 850 and 200 hPa onto the PMM index during JJASON are indicated in Fig. 5. Regressions of divergence at 850 and 200 hPa onto the PMM index during JJASON are shown in Fig. 6. During the positive PMM phase, an anomalous low-level cyclonic flow (Fig. 5a) and an anomalous upper-level anticyclonic flow (Fig. 5b) occur over a large portion of the WNP, both located to the northwest of anomalous off-equatorial heating (Fig. 5b). The associated anomalous low-level convergence (Fig. 6a) and upper-level divergence (Fig. 6b) offer favorable dynamic conditions for the development of intense typhoons. Provided the prevailing westerlies at 200 hPa and easterlies at 850 hPa occur over a large portion of the main development region, the weaker westerlies at 200 hPa (Fig. 5b) and weaker easterlies at 850 hPa (Fig. 5a) result in weaker vertical wind shear (Fig. 4d) in the main development region during the positive PMM phase. The anomalous flow patterns closely resemble Matsuno–Gill-type

FIG. 7. (a) The differences in 850-hPa wind fields (m s^{-1} ; vector) and OLR (W m^{-2} ; contour), and (b) SST (K) during JJASON between the PPMM and CTRL experiment with ICTP AGCM. The blue rectangle denotes the PMM region.

Rossby wave propagation (Gill 1980; Matsuno 1966) in response to anomalous heating in the northwestern portion of the PMM pattern during the positive PMM phase (Fig. 5b). The Matsuno–Gill-type responses to the positive PMM pattern were confirmed by Zhang et al. (2016) using perturbation experiments with a high-resolution Geophysical Fluid Dynamics Laboratory (GFDL) Forecast-Oriented Low Ocean Resolution (FLOR) coupled climate model (Vecchi et al. 2014).

c. Perturbation experiments

To further verify the modulation of PMM on large-scale circulation, we perform a suite of perturbation experiments using the ICTP AGCM (see section 2). We examine the differences in large-scale circulation between the CTRL and PPMM experiments. The differences in 850-hPa wind fields (PPMM minus CTRL) (Fig. 7a) bear a strong resemblance to the regressed pattern onto the PMM index in Fig. 5a, supporting the

forcing of warming related to PPMM. Moreover, the differences in the OLR pattern feature negative values in the northwestern part and positive ones in the southeastern part of the PMM region, respectively (Fig. 7a). Again, this is consistent with the regression of OLR onto the PMM index based on observations (Fig. 5b). The perturbation experiments reproduce reasonably well the Matsuno–Gill-type Rossby wave responses to deep convection related to SST warming (Fig. 7a), similar to what is shown in Fig. 5. The above discussion further supports the impacts of SST warming related to positive PMM (Fig. 7b) on large-scale circulation, probably leading to changes in intense typhoons.

5. Conclusions

Roles of the PMM in the occurrence of intense typhoons over the WNP have been examined. We have found a significant positive correlation between the

PMM index and the frequency of intense typhoons during JJASON. The PMM influences the occurrence of intense typhoons mainly by modulating large-scale dynamical conditions over the main development region. During the positive PMM phase, anomalous off-equatorial ocean warming in the eastern Pacific induces anomalous low-level westerlies and upper-level easterlies over a large portion of the main development region through Matsuno–Gill-type Rossby wave responses. The resultant weaker vertical wind shear and larger low-level relative vorticity associated with anomalous low-level cyclonic flow and upper-level anticyclonic flow are favorable for the genesis of intense typhoons over the southeastern part of the WNP and their subsequent intensification over the main development region. Overall, the physical mechanisms (e.g., Matsuno–Gill-type Rossby wave responses) underlying the association between PMM and intense typhoons based on observations have been reproduced well by ICTP AGCM. The PMM index, combined with other climate indices such as ENSO, may therefore be a crucial predictor for the frequency of JJASON intense typhoons over the WNP in statistical or statistical–dynamical forecast models.

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