Supplementary Information

Synoptic Weather Patterns and Associated Air Pollution in Taiwan

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1. Statistical test in each cluster

The statistical test is conducted to determine the statistical significance. The Welch's t-test (Welch 1947) are applied to test the differences in each cluster's mean wind speed and $PM_{2.5}$, PM_{10} and O_3 concentrations. Tables S1 to S4 summarize the p-value of each pair of clusters.

For the mean wind speed (Table S1), the p-value of each cluster pair is less than 0.05 (significance level) except for the C2, C4 pair. Although C2 and C4 do not pass the significance test, the composite plot of the SLP and surface wind field still reveal different weather patterns. The significance test is not passed because both C2 and C4 are under the influence of northeasterly monsoonal (NEM) flow; however, these results do not negatively influence our classification result because the two clusters present completely different weather types. The C2 cluster primarily occurs in the winter season, whereas the C4 cluster mostly occurs in seasonally transitional months (April, May, September and October). The two clusters exhibit distinctive $PM_{2.5}$, PM_{10} and O_3 level characteristics.

For the mean $PM_{2.5}$ concentration (Table S2), the p-value of each cluster pair is less than 0.05 (significance level) except for the C1, C2 and C5, C6 pairs. Although some clusters do not pass the significance test, the composite plot of the SLP and surface wind field still reveals distinctive weather patterns and exhibits different air pollutant behaviors. In the C1 and C2 clusters, the synoptic weather condition is dominated by the continental high-pressure system. The C1 cluster occurs first, when the continental high-pressure system brings strong NEM winds. After the system migrates eastward, the weather pattern transits to the C2 cluster. Under the influence of the NEM wind, the northern Taiwan (NT and CM) region can be affected by the long-range transport of air pollutants from East Asia. From the central to southern parts of western Taiwan (CT, YCN and KP area), $PM_{2.5}$ can be composed of a mixture of local, upwind and long-range transported pollutants in the C1 cluster, whereas it is primarily composed of locally produced emissions in the C2 cluster.

The C5 and C6 clusters both present summer-related weather patterns. During the summer season, the $PM_{2.5}$ concentrations are generally very low; therefore, the difference is not significant in both clusters. However, the composite plot of the SLP and surface wind field still reveal distinctive weather patterns and different synoptic wind fields that can affect the source relationship. Although the $PM_{2.5}$ level is not significantly different in the C5 and C6 clusters, the O_3 concentration passed the significance test.

For the mean PM_{10} concentrations (Table S3), although the p-value fails the significance test in the C1, C2 and C5, C6 clusters, differences are observed in terms of the regional distribution. In the C1 cluster, due to the strong NEM wind, the YCN and KP show higher PM_{10} due to the impact of river sand dust. In the C2 cluster, NT and CM can be affected by the long-range transported air pollutants; however, in CT, YCN and KP areas, the distributions of the PM_{10} is more affected by the locally released emissions. Additionally, the PM_{10} concentrations generally stays at a low level in the C5 and C6 clusters.

For the mean O_3 concentration (Table S4), the p-value of each cluster pair is less than 0.05 (significance level) except the C1 to C3 clusters. Although the mean O_3 concentrations are very close in C1 to C3, the sources and spatial distributions of O_3 in each cluster are very different. In C1, the mean O_3 concentration is higher in northern Taiwan (NT and CM) due to the long-range transported pollutants. In C2 and C3, the mean O_3 concentration is higher in central to southern Taiwan, and it is mainly contributed from the locally produced emissions.

Table S1. Wind speed p-value of each pair of clusters.

WS	C1	C2	C3	C4	C5	C6
C1	–	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
C2	–	–	< 0.01	0.066	< 0.01	< 0.01
C3	–	–	–	< 0.01	< 0.01	< 0.01
C4	–	–	–	–	< 0.01	< 0.01
C5	–	–	–	–	–	0.017
C6	–	–	–	–	–	–

Table S2. $PM_{2.5}$ p-value of each pair of clusters.

PM_{25}	C1	C2	C3	C4	C5	C6
C1	–	0.053	< 0.01	< 0.01	< 0.01	< 0.01
C2	–	–	< 0.01	< 0.01	< 0.01	< 0.01
C3	–	–	–	< 0.01	< 0.01	< 0.01
C4	–	–	–	–	< 0.01	< 0.01
C5	–	–	–	–	–	0.291
C6	–	–	–	–	–	–

Table S3. PM_{10} p-value of each pair of clusters.

PM_{10}	C1	C2	C3	C4	C5	C6
C1	–	0.709	< 0.01	< 0.01	< 0.01	< 0.01

C2	–	–	< 0.01	< 0.01	< 0.01	< 0.01
C3	–	–	–	< 0.01	< 0.01	< 0.01
C4	–	–	–	–	< 0.01	< 0.01
C5	–	–	–	–	–	0.808
C6	–	–	–	–	–	–

Table S4. O_3 p-value of each pair of clusters.

O_3	C1	C2	C3	C4	C5	C6
C1	–	0.457	0.292	< 0.01	< 0.01	< 0.01
C2	–	–	0.070	< 0.01	< 0.01	< 0.01
C3	–	–	–	< 0.01	< 0.01	< 0.01
C4	–	–	–	–	< 0.01	< 0.01
C5	–	–	–	–	–	< 0.01
C6	–	–	–	–	–	–

2. Analysis on the days that are affected by the typhoons

To avoid discussions on the tropical depression and typhoon related weather types, the two-stage cluster analysis was applied twice. The first application of the cluster analysis identified a cluster that is associated with the tropical depression and typhoon system (due to the inclusion of the SLP) and includes 35 days. The composite map shows that the SLP is lower and accompanied by a strong cyclonic wind flow structure in the Taiwan region (Fig. S1). This weather condition occurs from June to September (typhoon season in Taiwan) (Fig. S2).

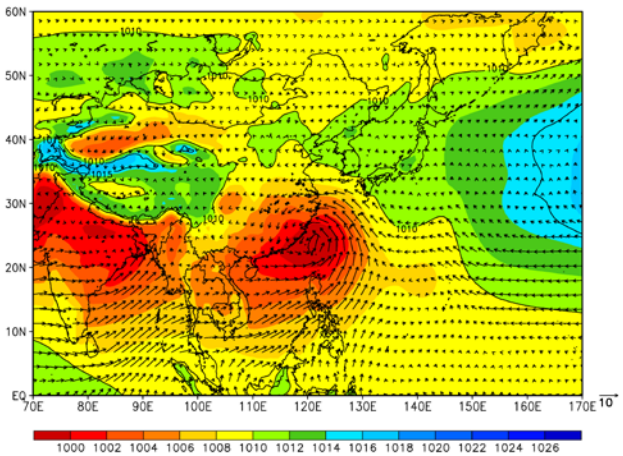

Fig. S1. Composite plot of the SLP (hPa) (shaded colors) and surface wind vectors (m s^{-1}) for the days affected by the typhoon and tropical low-pressure system.

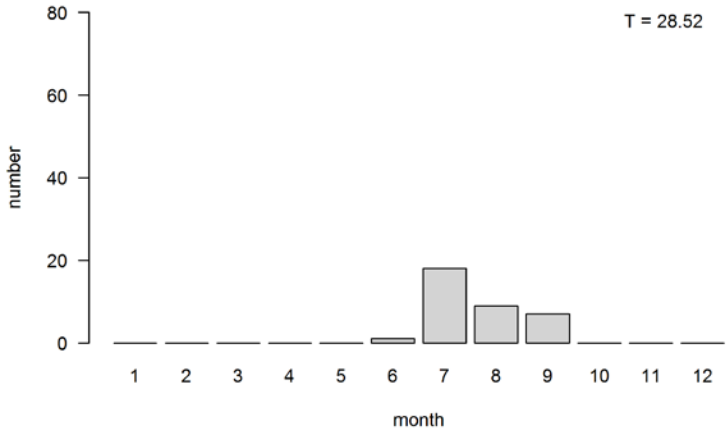

Fig. S2. Number of occurrences in each month for the typhoon event cluster. The upper-right corner shows the temperature (°C) averaged from the surface weather stations.

3. Analysis of the monthly O_3 variation

Fig. S3 shows the monthly O_3 concentration averaged from the air quality monitoring stations in five AQZs in western Taiwan. The analysis period is from January 2013 to March 2018. It can be seen that the high O_3 concentration is observed during the seasonal transition months particularly in the October and April.

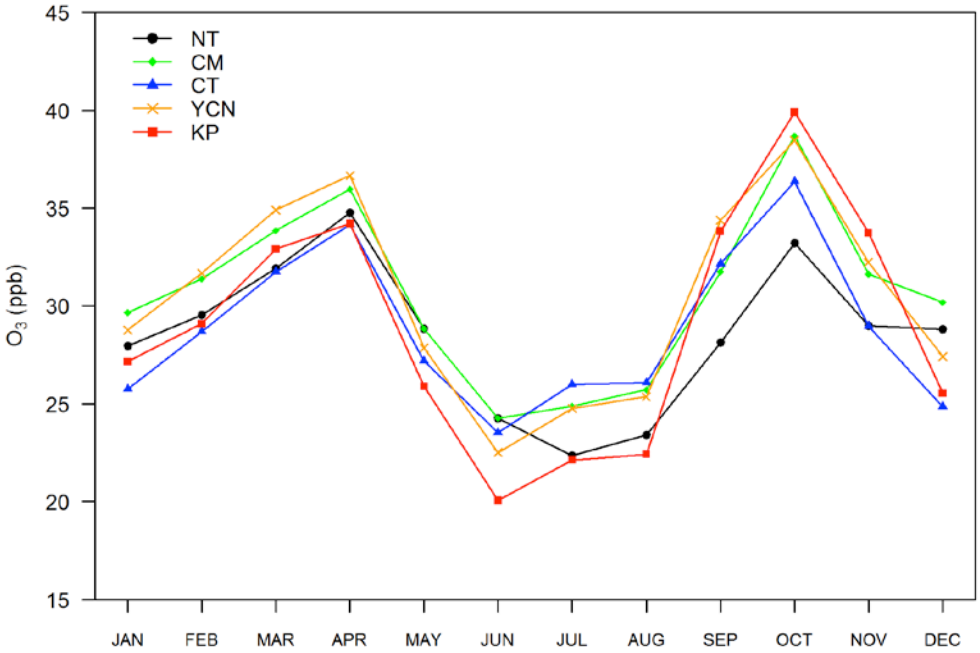

Fig. S3. Monthly O_3 concentration for five AQZs in western Taiwan.

References

Welch, B. L. (1947). The generalization of "Student's" problem when several different population variances are involved. *Biometrika*. 34 (1–2): 28–35. doi:10.1093/biomet/34.1-2.28. MR 0019277