#### Air masses affecting Beijing in November and December

Fast north-westerly air masses had higher relative frequency in November 2017 (73% by MC2, 3, 4, 6, 7, 9) than in November climatology (35% by MC4, 5, 6, 7) (Table 10). Accordingly, north-westerly slow air masses In November climatology occurred more frequently (65% by MC1, 2, 3) than in November 2017 (22% by MC1 and 5). In November 2017, an additional type of air mass was identified (northerly slow recirculated, MC8), which had minimal relative frequency (6%) (Table 10). In December, north-westerly fast air masses were dominant in both periods, but occurred less frequently in climatology (42% MC1, 2, 4, 6) than in 2017 (76% by MC1, 2, 4, 5, 6) (Table 10) North-westerly slow were more frequent in December climatology (34% by MC3 and MC5) than in 2017 (10% MC3)(Table 10), but the latter, was recirculated (MC3). Northerly fast was identified in both periods of December and had similar relative frequency (MC7 in 2017, 14% and MC7 in climatology, 13%). In December climatology, a newly identified air mass type occurred (MC8, north-easterly slow) which accounted for 10% of the total air mass arriving in Beijing during that time (Table 10).

Climatology results are consistent with previous similar studies, <http://dx.doi.org/10.1016/j.jes.2016.06.03>, which found a greater occurrence of fast north-westerly air masses during winter in Beijing, with minor occurrence of slow recirculated north-westerly air masses.

Residence time, travel path and mean PM2.5 MC concentrations

November

In climatology, MC2 (17% relative frequency) was associated with the highest mean PM2.5 concentrations (extreme). Air masses associated with MC2 travelled through some of the most industrialised areas surrounding Beijing, where PM 2.5 emissions are intense (Shanxi, Shaanxi and Hebei) (Figure 11-12). The long permanence time and travel path of this cluster over these areas might justify its association with extreme mean PM2.5 concentration (Figure 11). This result is consistent with <http://dx.doi.org/10.1016/j.jes.2016.06.03>, which found that MCs associated with higher mean PM 2.5 concentrations arriving in Beijing, travel through the surrounding industrialised areas. In 2017, MC1 and MC8 have similar travel paths than MC2 in climatology and are associated with air masses with the highest concentration observed during the period (Figure 11-12). However, the mean PM2.5 concentrations associated with MC1 and MC8 (high) are lower than those associated with MC2 (extreme). Having similar path, similar residence time but lower concentrations in 2017 than in climatology might indicate that a reduction in the emissions in local and surrounding regions in 2017 is likely. Cheng et al (doi:10.5194/acp-19-6125-2019) which conducted studies on the reduction emissions in China using model-based composition analysis, estimated that 65.4% and 22.5% of PM 2.5 local emission abatements between 2013 and 2017 were due to local air pollution control policies and reduction in emissions from Beijing’s surroundings respectively). He also stated that favourable meteorological conditions were also accountable for this reduction, especially In November 2017. However, these contributed in substantially lower measures (12.1%). Therefore, it is likely that PM2.5 concentrations recorded for MC1, MC9 for 2017 were lower than MC1 due to a reduction of PM2.5 emissions in Beijing and surroundings.

In climatology, MC4 (13%) and MC5 (11%) are associated with high mean PM2.5 concentrations and have similar paths (Figure 11-12 D). These originate in south-western Russia and southern Russia respectively, travelling through Mongolia (and Kazakhstan for MC4), inner Mongolia and the Hebei province before reaching Beijing. MC2 and MC3 (nearly average) in 2017 are analogous to MC4 and MC5 in climatology but are associated with approximately half mean PM2.5 concentrations than MC4 and MC5 (high) in climatology (Figure 12 A-B). (DOI: 10.3103/S1068373913020039) Dement et al, studying annual variations of PM 25 in the Eastern Gobi desert found that the highest monthly mean PM 2.5 concentrations occur in spring and winter). Furthermore, (http://dx.doi.org/10.1016/j.jes.2016.06.03) hypothesized that MCs with travel path similar to the MCs mentioned above, were responsible for transporting PM 2.5 to Beijing. As the travel paths for these MCs in 2017 and climatology, do not differ substantially, but they are associated with different concentrations in 2017 and climatology, it is likely that a reduction in the emission in 2017 in their final section of their travel path is the cause of this difference, rather than higher proportion of PM 2.5 transported from eastern Gobi desert. However, this should be confirmed by further analysis using tools to identify the relative contribution of PM 2.5 pollution sources, such as PSCF (http://dx.doi.org/10.1016/j.jes.2016.06.03).

MC5 and MC9 in 2017 and MC6 and MC7 in climatology are associated with the lowest mean concentrations of PM2.5 (nearly average). These are associated air masses from Siberia, which brings unpolluted air to Beijing during the winter. In both periods, they have similar contributions towards total air masses (11% and 1% for MC5 and MC9 in 2017 and 8% and 3% for MC6 and MC7 in climatology).

MC3 in climatology (20%) originated in Kazakhstan , travelling through Mongolia and inner Mongolia prior to arrival in Beijing. It had a similar travel path than MC4 in 2017 (9%), however, MC3 in climatology was associated with high mean PM2.5 concentrations, while MC4 in 2017 was associated with nearly average concentrations. The difference could be explained by reduced emissions of PM2.5 pollution in the areas travelled in the MCs final section in 2017.

MC1 in climatology and MC6 in 2017 also had similar characteristics to MC4 in 2017 (travel paths and residence time). However, these MCs had different mean PM2.5 concentrations (high for MC1 and nearly average for MC6). Furthermore, MC1 in climatology had higher relative frequency in the climatology (28%) than MC4 in 2017 (9%).

In climatology, MCs associated with high mean concentrations of PM2.5 had the highest relative frequency (72% given by MC1, MC3, MC4 and MC5)(Figure 12 and 12 B). Extreme mean PM2.5 concentrations were uncommon (17%, MC2), and the minority (11%) of the MCs were associated with nearly average PM2.5 concentrations (MC6 and MC7) (Figure 12 and 12 B).

Conversely, in 2017, most MCs were associated with nearly average mean PM2.5 concentrations (84% given by MC2, MC3, MC4, MC5, MC6, MC7 and MC9), while MCs with high concentrations (MC1, MC8) were uncommon (17%) (Figure 12 B, 12B). NO MC was associated with extreme PM2.5 concentrations.

It is likely that the lower PM 2.5 levels recorded in Beijing during November 2017 than the climatology are due to the higher proportion of MCs associated with nearly average mean PM2.5 concentrations in 2017 (84%) than in climatology (11%). The result is reflected in a higher proportion of MCs associated with high and extreme mean PM 2.5 concentrations in the climatology (72% and 17% respectively) than in 2017 (17% and 0% respectively) This was due to a reduction in local emissions in Beijing and surrounding regions in 2017, that caused air masses during that period to transport lower PM2.5 concentrations than in climatology due to the reasons described above.

December

In climatology, MC5 and MC4 are associated with the highest mean PM2.5 concentrations (extreme). This might be justified by the final section of their travel paths over the industrial areas on the west and south west of Beijing (Shaanxi, Hebei and Shanxi). The MCs associated with highest PM2.5 mean levels in 2017 is MC3 (high). This MC originated in southern Russia and recirculated over the polluted regions south of Beijing (Hebei and Shandong). However, MC3 in 2017 had lower mean PM2.5 concentrations than MC4 and MC5 in climatology, despite having similar path and residence time. This is likely due to a reduction in local emissions in Beijing, which contributed to the lowest mean PM 2.5 concentrations associated with the MC3 in 2017. This is also true for MC8 in climatology and MC7 in 2017, MC7 in climatology and MC6 in 2017, MC2 in both 2017 and climatology, MC6 in climatology and MC5 in 2017, MC1 in both 2017 and the climatology, MC4 in 2017 and MC3 in climatology.

In climatology, most MCs (44%) were associated with nearly average PM2.5 mean concentrations (MC1, MC2, MC7 and MC8). 32% MCs were associated with extreme concentrations (MC4, MC5), and a minority were associated with high (23% MC3 and MC6). In December 2017, most clusters were associated with nearly average PM2.5 concentrations (90% from MC1, MC2, MC4, MC5, MC6 and MC7). MCs with high concentrations occurred rarely (10% MC2).

It is likely that the lower PM 2.5 levels recorded in Beijing during December 2017 than during previous years are due to the higher proportion of MCs associated with nearly average mean PM2.5 concentrations in 2017 (90%) than in climatology (10%), similarly to November. This is reflected in the higher relative frequency of MCs with high and extreme mean PM2.5 levels in the climatology (23 and 32% respectively) than in 2017 (10% and 0%) It was found that a reduction in local emissions in Beijing in 2017, caused air masses that period to transport lower PM2.5 concentrations than in climatology due to the reasons explained above.

As found in this study, the interannual variation in air mass travel path can results in lower concentrations that can be misinterpreted as reductions in air pollutants emission due to effective policymaking. It is important that policy for reducing air pollutants emission account for air mass relative frequency and air pollution monitoring and forecast is informed with year-to-year variations in air masses contribution

Limitations

Cluster analysis interpretation is subjective and could lead to differences if the results are analysed by different individuals. Reanalysis by other researcher and comparison of this with the original interpretation might reduce error by providing an uncertainty estimate. HYSPLIT trajectory error was assumed to be 20% of the distance travelled by trajectories. Future studies with a detailed estimation of the uncertainty related to HYSPLIT trajectory generation for the specific case studies could provide a better basis for the interpretation of the results. Employing 5-day (120 h) BTs might have caused a considerable degree of error. Employing 4-day (96h) BTs in future studies could reduce the uncertainty associated with the analysis and provide a better balance between establishing long range transport pathways and reduced the induced error in trajectories

Further studies

Further studies adopting BT cluster analysis for the locations in this study would contribute to the current paucity of information in this area. This could provide a better understanding on the dynamics of air masses pollutants’ transport to London and their relative contributions to the area’s pollution levels. A deeper understanding of this topic could contribute to the development of effective policymaking for the amelioration of air pollution in London. Furthermore, investigation of pollutant’s source areas and relative contribution (using CWT and PSCF for example) could provide an understanding of the areas where these policies might be most needed. Future studies with higher resolution meteorological data should be considered to improve the accuracy of the results. This in turn could provide a better understanding of the relative contribution of air masses and the pollution transported at source location.

Conclusion

Pairing of BTs clusters generated with HYSPLIT were adopted to investigate whether better air quality in London and Beijing, were due to a difference in air masses relative contribution in 2017 and 2018 than in previous years. The uncertainty associated with HYSPLIT BTs was assumed to be 20% based on previous literature. It was found that air masses arriving in Beijing during November and December 2017 were associated with a lower concentration of PM25 than in November and December of the years between 2013 and 2016. This was explained by a reduction of local emissions in Beijing and surrounding industrialised regions. Air masses in London during January 2018 were associated with lower NO2 concentrations than during January of the years between 2014 and 2017. This was partly explained by a local reduction in NO2 emissions. Furthermore, it was determined that northerly air masses arriving in London transported a considerable amount of NO2 pollution from the West Midlands and southern regions of the North West of England during previous years. Air masses with similar origin arriving in London during January 2018 did not intercept these regions. This explained the lower NO2 concentrations observed during 2018 when compared to previous years.