



# Contribution distinguish between emission reduction and meteorological conditions to “Blue Sky”

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## ABSTRACT

Emissions and meteorological conditions are two important factors on aerosol accumulation or dilution. Identifying the contributions of both emission reduction (ER) and meteorological conditions (MC) on aerosol pollution abatement is a hot topic recently. An objective assessment of ER measures' contribution on improving air quality is also of great significance. This study focuses on objective assessment for the air quality improvements (known as “Blue Sky”) due to ER measures. A quantitative algorithm on identifying the contribution of ER measures was proposed. The emission-reducing contributions to the “Beijing blue” (August 20 to September 3, 2015, Beijing, International Association of Athletics Federations World Athletics Championships), the “Asia Pacific Economic Cooperation (APEC) blue” (November 10–11, 2014, Beijing, APEC meeting), and the “Games blue” (November 12–27, 2010, Guangzhou, 16th Asian Games) were studied based on pollutant MC of Parameters Linking Air-quality to Meteorological Conditions index. Two individual evaluation algorithms of an average change rate algorithm and a parameter fitting method were developed in this study. Results showed that the special comprehensive emission-reducing measures contributions were up to 26%–30% for “Beijing blue.” By analyzing the circulation anomaly during the “Beijing blue” with 30-year average historical atmospheric circulation and the real-time information in 3rd September 2015, we concluded that the “North China Cold Vortex,” as unusual stable circulation system stagnation, provides favorable weather conditions for the “Beijing blue.” This finding indicates that approximately 70%–74% of the “Beijing blue” came from long terms of favorable weather conditions. This algorithm for evaluating the contributions of ER and MC was also applied for the “APEC blue” and the “Games blue.” The contribution of emission-reducing measures on the “APEC blue” and the “Games blue” accounted for 36% and 25%, respectively. In summary, the favorable MC would contribute 65%–75% to the “Blue Sky” in China and acts as a remarkable role on the improvement of air quality.

## 1. Introduction

Emissions and variations of meteorological conditions (MC) have significant influences on the concentration and distribution of regional atmospheric aerosol in China. To eventually distinguish the relative contributions of emission reduction (ER) measures and atmospheric conditions (MC) to the influence on regional change of aerosol pollution is extremely important. The forecast of assurance of air quality plays remarkable roles on important public events significantly. For instance, during the Beijing Olympic Games in 2008, the planned regional ER measures based on air-quality monitoring and warning made actual

contributions to the reduction of air pollution (Zhang et al., 2009). The planned ER is a special issue for all the governmental departments, scholars, and the public in connection with pollution control. Given that emission factors are not the only one in tight relation with the level of atmospheric aerosol pollution, the contribution of regional MC cannot be underestimated. In general, only a single element or a conventional multiple-element combination was discussed, and to achieve the desired effect is difficult (McKee, 2007).

Some research works mentioned that certain correlations sometimes exist between the common meteorological parameters (such as atmospheric pressure, air temperature, and relative humidity) and aerosol

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pollution. However, they would interact in mutual contradiction and even offset each other, causing uncertainty in real application purpose (Li et al., 2011a, 2015b). Thus, how to explore an objective identification method for the contribution of the improvement of air quality from the reduction of emission and the changes of MC and the comprehensive influences of ER and MC becomes a challenge (Honoré, 2008; Yu et al., 2012). To evaluate quantitatively the contribution of “emission reduction” measures to the improvement of air quality, to distinguish the proportions of contribution from ER and from the good MC is necessary. Especially, the influence of atmospheric circulation and weather conditions cannot be ignored. In certain situations, although the emission is under certain control, the unfavorable MC may also cause particulate matters to accumulate and aggravate in local or regional area. Contrarily, a kind of favorable MCs may blow the pollution away and result in overestimating the contribution from emission control strategy. Thus, to study the objective resolution to identify the influences of ER on air quality and that of MC changes is of great significance. Parameters Linking Air-quality to Meteorological Conditions (PLAM) index is designed to describe the influential characteristics of aerosol pollution. Through analyzing the large dataset of meteorological and atmospheric components, the sensitive elements, including condensation function, moist potential temperature, wind field, boundary layer height, and stability characteristics, were obtained first (Niu et al., 2017; Wang et al., 2012, 2013; Zhang et al., 2015) to connect with air quality. Based on these data, the roles in physical process of relevant atmosphere could be analyzed, and the physical correlation between key meteorological factors affecting air pollution could be established (Wang et al., 2017; Yang et al., 2016). As PLAM index was designed by the parameter-based method, comprehensive consideration is given to the expression of influence on multi-element and multi-dimension process of MC, including large-dimension MCs with significant quantitative difference and small-dimension change characteristics. According to the studies based on the index in terms of multiyear aerosol distribution, the index is of the capacity to describe the inter-annual variation features (Wang et al., 2012, 2013; Zhang et al., 2012, 2015).

The principle, method, and application of PLAM index are already cited by previous references (Bollasina et al., 2011; Wang et al., 2012, 2017; Yang et al., 2009, 2016; Zhang et al., 2009, 2015; Zhong et al., 2018). The said index was published by the China Meteorological Administration as the national industry standard in early 2016. Based on the analysis and diagnosis of PLAM index method of MC of pollution, this study strives to develop its algorithm further to distinguish the MC from ER measures influencing the air quality improvement, especially on the respective contributions of MC and ER for the “Blue Sky.”

Three typical cases, namely, the “Beijing blue” during the Beijing International Association of Athletics Federations (IAAF) World Athletics Championships held in Beijing from August 22 to early September 2015, the “Asia Pacific Economic Cooperation (APEC) blue” during the Beijing meeting of APEC 2014, and the “Games blue” during Guangzhou Asian Games of 2010 (November 12–27 in 2010) were investigated in the study to propose an objective and quantitative analytical method of distinguishing the individual contributions of ER and MC. Notably, the defined words “Beijing blue,” “APEC blue,” and “Games blue” are all referred to the events with good air quality. We named them as “Blue Sky” in this study similar to the meaning of the meteorological term “clear sky.”

## 2. Data and methodology

### 2.1. Data

The observed data for urban areas of Beijing and Guangzhou used in this study were supplied by the China Meteorological Information Center. Real-time and historical data including air temperature, dew temperature, air pressure, wind direction, wind speed, and visibility for

surrounding areas were obtained from corresponding Automatic Weather Station, and hourly re-analyzed meteorological parameter data were downloaded from the China Climate Center Figure Forecasting System. The atmospheric composition data in Beijing (during 2014–2015) and Guangzhou (during 2010) including PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, and PM<sub>10</sub> in this study were downloaded from the website of the Ministry of Ecology and Environment of PRC (<http://www.zhb.gov.cn/hjzl/>).

### 2.2. PLAM index

The air quality and MC have been expressed by several literature (Bindoff et al., 2013; Zhang et al., 2009, 2013). In general, the MC are significant factors influencing the aerosol concentrations. The expressional methods between MC and air quality have been studied by several previous works (Wang et al., 2012; Yang et al., 2009). These results demonstrated that the PLAM index is a comprehensive parameter to describe whether the MC is in favor to the pollution accumulation or not. Moreover, to identify the relationship between the MC and the variation of pollution concentration (VPC) is a fundamental proof. Notably, the PLAM index is a parameter to describe the relationships between the VPC and the combined MCs (including temperature, pressure, relative humidity, and wind). The PLAM index is not similar to the relationships between the VPC and single meteorological factors, e.g., temperature, pressure, relative humidity or wind, because these relationships between VPC and any single meteorological factor might be nonlinear, multivariable, and unstable. The quasilinear relationships between PLAM index and PM are based on the real-time observed particulate matter (PM) concentration and the on-line observed meteorological factors. In addition, this relationship is an objective relationship rather than a prior assuming. PLAM index method has been applied to the regional characteristics of major pollution, including the North China Plain, Yangtze River Delta, Pearl River Delta, and Si-Chuan Basin (Wang et al., 2017), where heavy air pollution occurs frequently. In these areas, to investigate the formation mechanisms of the haze–fog and heavy pollution events is a practical tool.

By analyzing the changes of the pollution MC index, PLAM mainly characterizes whether MC favor the regional accumulation and aggravation of atmospheric pollution or not (Yang et al., 2009; Zhang et al., 2013). High PLAM index indicates that the MC promote the accumulation of aerosol pollution and secondary aerosol transformation, known as “unfavorable pollution meteorological conditions.” On the contrary, the low PLAM index indicates that the MC favor the dilution and reduction of aerosol pollution. PLAM index was, for the first time, applied during the 2008 Beijing Olympic Games (Zhang et al., 2009), and it forecasted the air quality successfully. A good description and prediction for aerosol pollution situation have been announced using the PLAM index in the area of North China, Yangtze River Delta, Pearl River Delta, and Si-Chuan Basin. PLAM is defined as follows (Wang et al., 2012, 2017):

$$\left\{ \begin{array}{l} \text{PLAM} \propto \frac{d\theta_e}{dt} \propto \frac{\partial \theta_e}{\partial p} \frac{f_c}{C_p T} \\ \theta_e = \theta \exp \left[ \left( \frac{Lw_s}{C_p T} \right) \right] \\ \theta = T \left[ \left( \frac{1000}{p} \right)^{\frac{R_d}{C_p}} \right] \end{array} \right. \quad (1)$$

Expression (1) provides the basic equations to parameterize the “homogeneous” attribute ( $\theta_e$ ) of the air masses.  $T$ ,  $\theta_e$ ,  $f_c$ ,  $w_s$ , and  $C_p$  represent air temperature, equivalent wet potential temperature, condensation function, saturation mixing ratio, and specific heat at constant pressure, respectively.

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