Links between the large-scale circulation and daily air quality variations over central–eastern China during winter

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We evaluate relationships between daily variations in the large-scale atmospheric circulation and the categorical occurrence, intensity, and duration of haze in Beijing during four recent winters. Composite analysis based on direct measurements of fine particulates ($PM_{2.5}$) indicates that severe air pollution preferentially occurred when the East Asian Winter Monsoon (EAWM; based on potential vorticity, or PV) and Siberian High (SH; based on sea level pressure) were weak. This preferential occurrence was even more pronounced for extended haze events, which persisted for up to two weeks. Severe pollution rarely occurred when the EAWM or SH were strong but a wide range of conditions occurred when the EAWM or SH were weak. Thus, linear correlations, while significant, are relatively small (approximately –0.3). Daily variations in the EAWM and SH are also cross-correlated, but with substantial independent variability and multiple indications that these indices influence $PM_{2.5}$ in Beijing via different mechanisms. Whereas relationships between air quality and the SH are best understood through ventilation and dispersion of boundary-layer pollution, the EAWM is more strongly correlated with relative humidity, and thereby particulate formation. As such, the SH index is a more effective metric for distinguishing clean days ($PM_{2.5} < 75 \mu g\ m^{-3}$) from polluted days ($PM_{2.5} \geq 75 \mu g\ m^{-3}$), while the PV-based EAWM index is more effective for distinguishing between moderate ($75\ \mu g\ m^{-3} \leq PM_{2.5} < 150\ \mu g\ m^{-3}$) and heavy ($PM_{2.5} \geq 150\ \mu g\ m^{-3}$) boundary-layer pollution.

A simple large-scale circulation index that combines weighted EAWM and SH indices is proposed, which outperforms the atmospheric stagnation index (ASI) even after tuning conditional ASI thresholds for air quality in Beijing. Extension of this approach to other cities in China reveals that similar combined EAWM–SH indices, optimized and cross-validated for each location, are effective over a broad swath of central–eastern China extending from Liaoning Province in the northeast, west to Shanxi Province, and south to the Yangtze River Valley. This region contains most of the cities in China with mean $PM_{2.5}$ concentrations larger than $100\ \mu g\ m^{-3}$ during the winters of 2015 and 2016. Among the two indices, the PV-based EAWM index plays the dominant role, with more explanatory power over a larger geographical domain than the SH index.

Examination of circulation patterns from the 2017–2018 winter, when air quality in Beijing was greatly improved, shows that the PV-based EAWM index was substantially enhanced, with average values almost a full standard deviation above the climatological mean. Although the SH index was indistinguishable from its climatology, this result confirms that the dramatic improvement in air quality in Beijing during this winter occurred under favorable climate conditions, and argues for caution in extrapolating the potential long-term effectiveness of policy changes to date.

Key words: winter monsoon, Siberian high, atmospheric pollution, China