Variability of winter haze over the Beijing-Tianjin-Hebei region tied to wind speed in the lower troposphere and particulate sources

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ABSTRACT: This study analyzes the variability of winter haze days and visibility in the Beijing-Tianjin-Hebei (BTH) region in relation to wind speed changes in the lower troposphere and emissions for 1961–2014. Daily surface meteorological data, NCEP/NCAR atmospheric reanalysis data, and fossil fuel emission data are used in this research. The results reveal a significant increase in winter haze days of +0.8 days decade^{-1} (p<0.01), and a subsequent decline in visibility of -1.56 km decade^{-1} (p<0.01). Most interestingly, an accelerated increase in haze days was observed for the last 11-year period (+8.3 days decade^{-1}) of the study (2004–2014). The increase of winter haze occurrence and decrease in visibility are partly attributed to: the significant (p<0.01) declining trend of mean wind speed at the near-surface (-0.19 m s^{-1} decade^{-1}), 925hPa (-0.23 m s^{-1} decade^{-1}), and 850hPa (-0.21 m s^{-1} decade^{-1}); the vertical shear of wind between 1000hPa and 850hPa (-0.07 m s^{-1} decade^{-1}); and, the declining (dust storm frequency as a proxy, -0.41 days dec^{-1}) surrounding particulate sources and increasing fossil fuel emissions (total carbon emission as a proxy, +4820.6 metric tons dec^{-1}). Specifically, wind speed changes in the lower troposphere explain 41.3% of winter haze days and 71.2% of the visibility variance. These are extended to 51.7% and 81.6% respectively when combined with natural (dust storm frequency) and anthropogenic (fossil fuel emissions) particulate sources. Therefore, the analyses show that wind speed changes in the lower troposphere, together with the varied natural and anthropogenic sources of particulates, play a key role in modulating winter haze and visibility conditions in the BTH area.

1. Homogenization of meteorological data

- **Location:** 23 stations from Beijing-Tianjing-Hebei (here after BTH).
- **Meteorological data:** Daily mean of wind speed, air temperature, visibility and relative humidity since 1961.
- **Homogenization method:** R package CLIMATOL version 3.0 (http://www.climatol.eu/) .

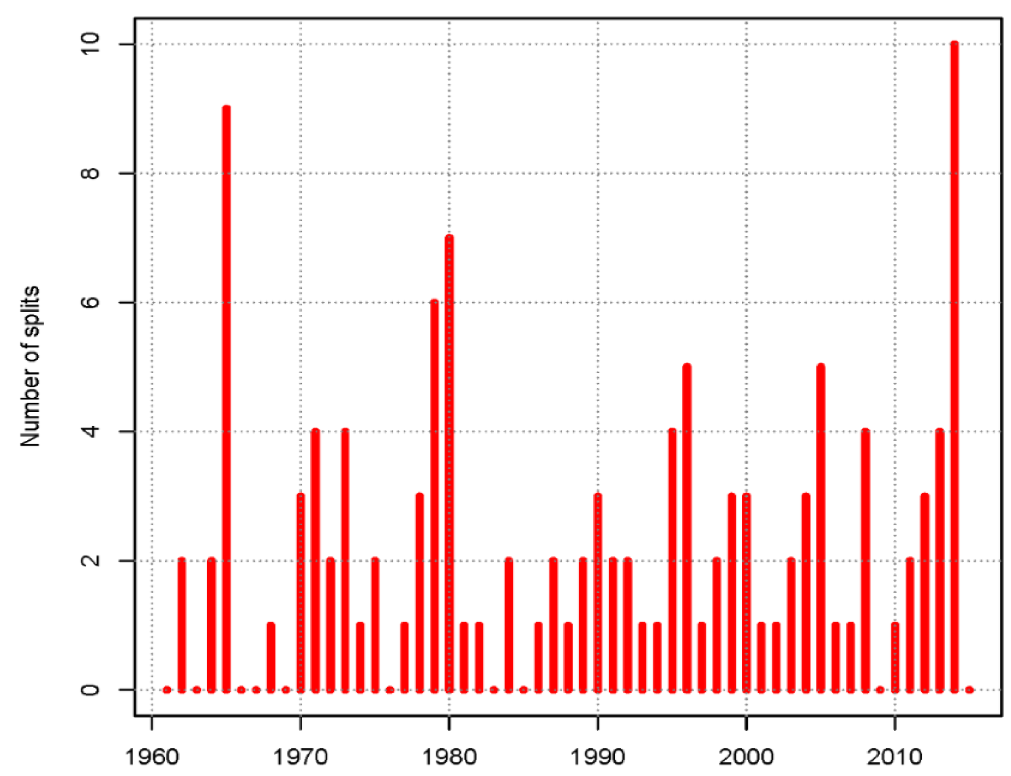


Figure 1. Number of splits per year for visibility over the BTH region for 1961–2014

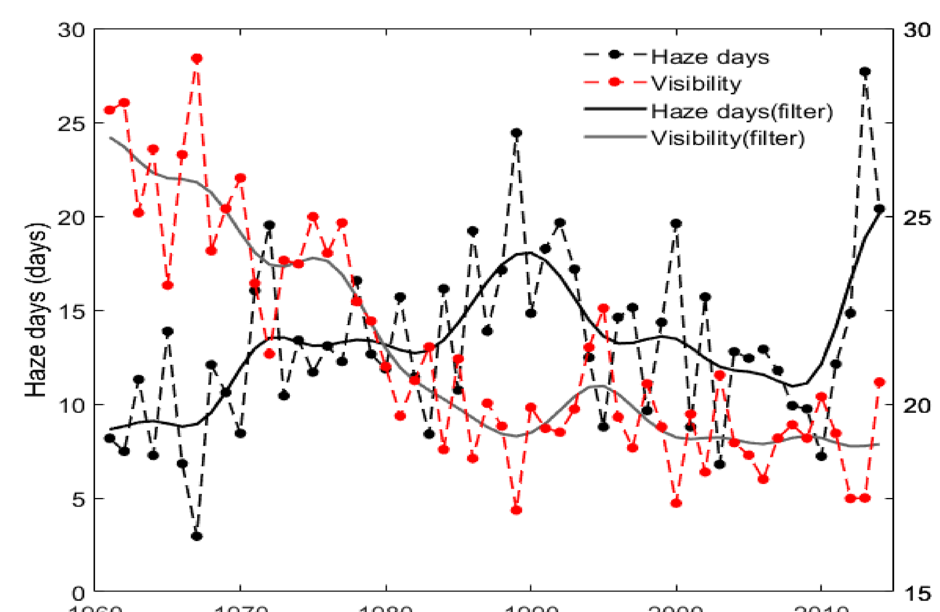
2. Temporal and spatial trends of winter haze

Definition of haze days:

(i) Horizontal visibility ≤10 km at 14:00 (Beijing local time),

(ii) Relative humidity ≤ 90%. Meanwhile, rain, hail, and other weather phenomena (i.e., snow) are excluded .

Figure 2. (right) Mean winter haze days and visibility in the BTH region for 1961–2014. A 15-year low-pass Gaussian filter is drawn.



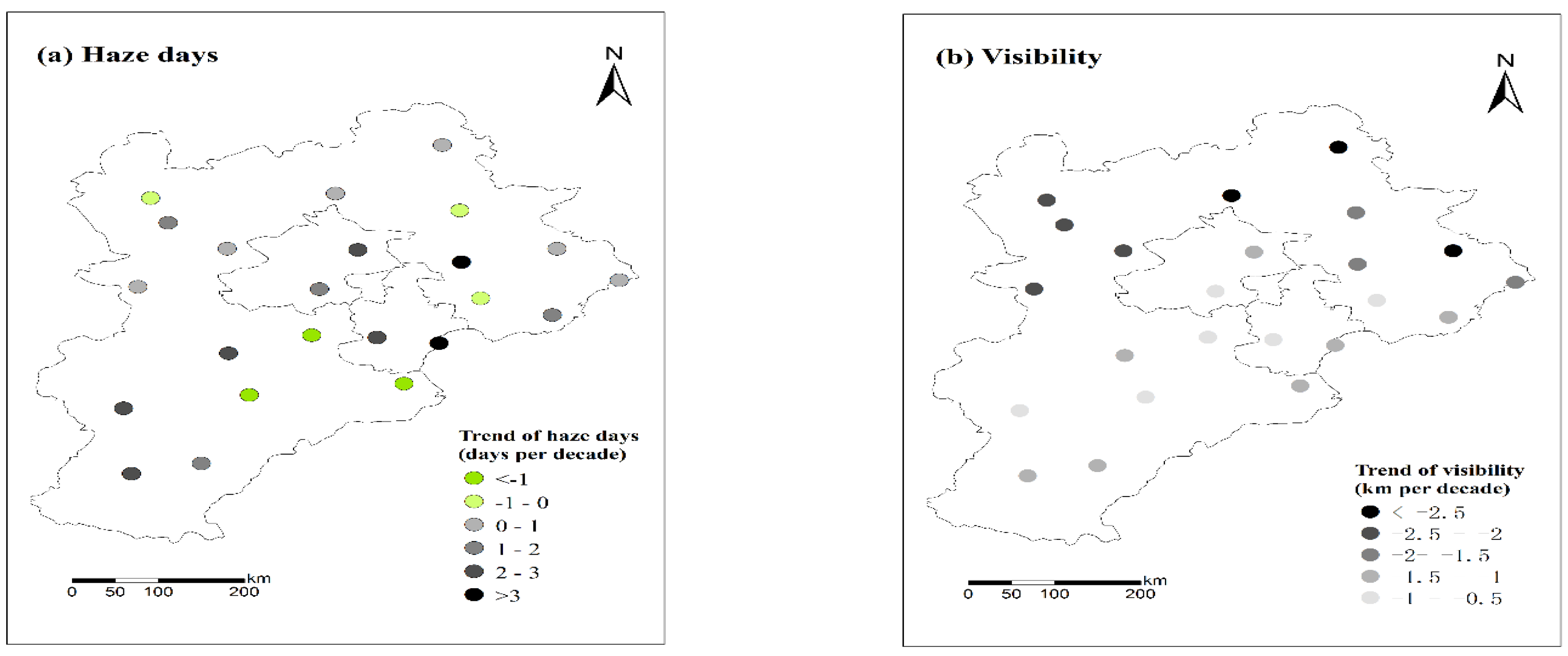


Figure 3. Spatial distribution of (a) winter haze days and (b) visibility trend in the BTH for 1961-2014.

3. Variability of wind speed in the lower troposphere and relation with haze days

- Wind speed in the lower troposphere declined significantly for 1961-2014.
- Change of wind speed can explain 41.3% of the interannual varation of the winter haze days and 71.2% of the visibility variance.

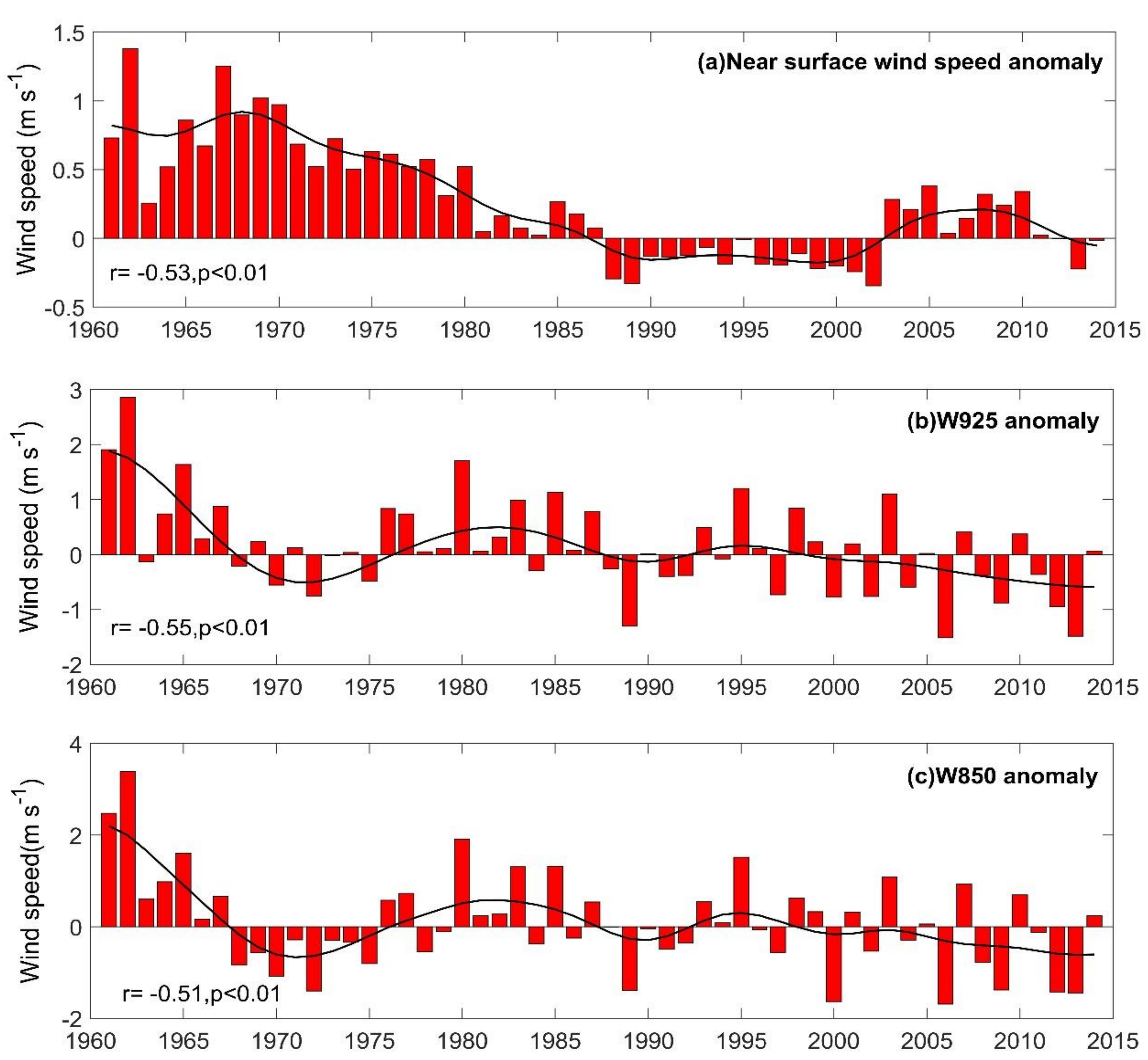


Figure 4. Regional mean winter mean wind speed anomalies over the BTH at (a) near surface, (b) 925 hPa and (c) 850 hPa for 1961–2014. A 15-year low-pass Gaussian filter is drawn. (r is the correlation coefficient between wind speed and number of haze days. Anomalies are drawn with respect to the 1981–2010 mean.),

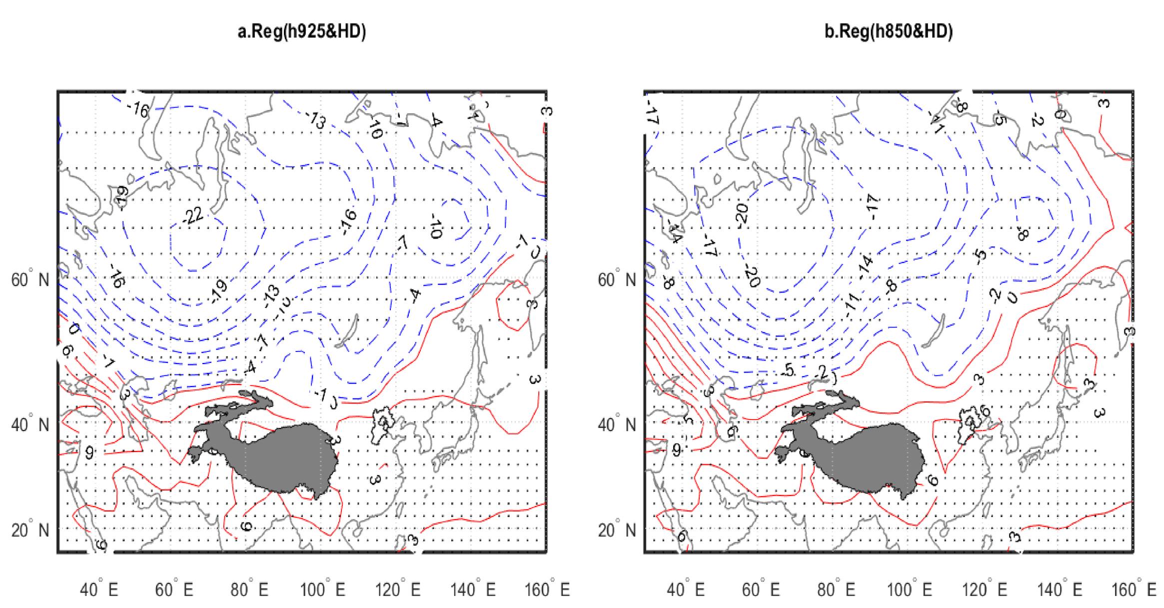


Figure 5. Distribution of the regression coefficients of (a) H925 and (b) H850 upon the regional mean haze days (H925 and H850 denote the geopotential height at 925 and 850 hPa); dots indicate regressions that are significant at the 95% confidence level.

4. Variability of particulate sources

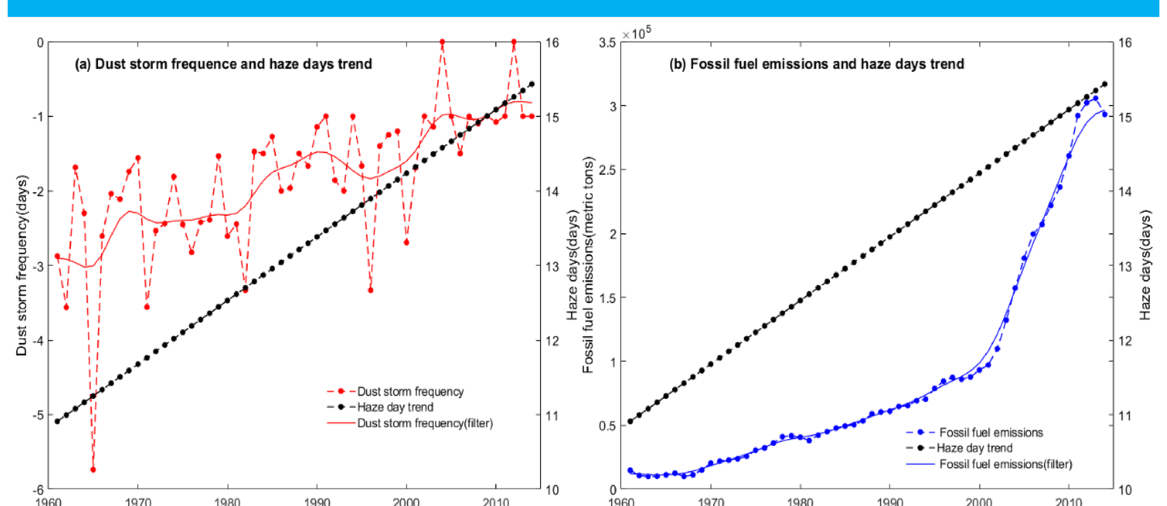


Figure 6. Temporal evolution of the regional mean winter haze day trend and dust storm frequency (*-1) (a) as well as the regional mean fossil fuel emission (b) in the BTH for 1961–2014..

5. Variance of haze days and visibility

- Wind speed in the lower troposphere combined with natural (dust storm frequency) and anthropogenic (fossil fuel emissions) particulate sources can explain 51.7% and 81.6%, respectively ,

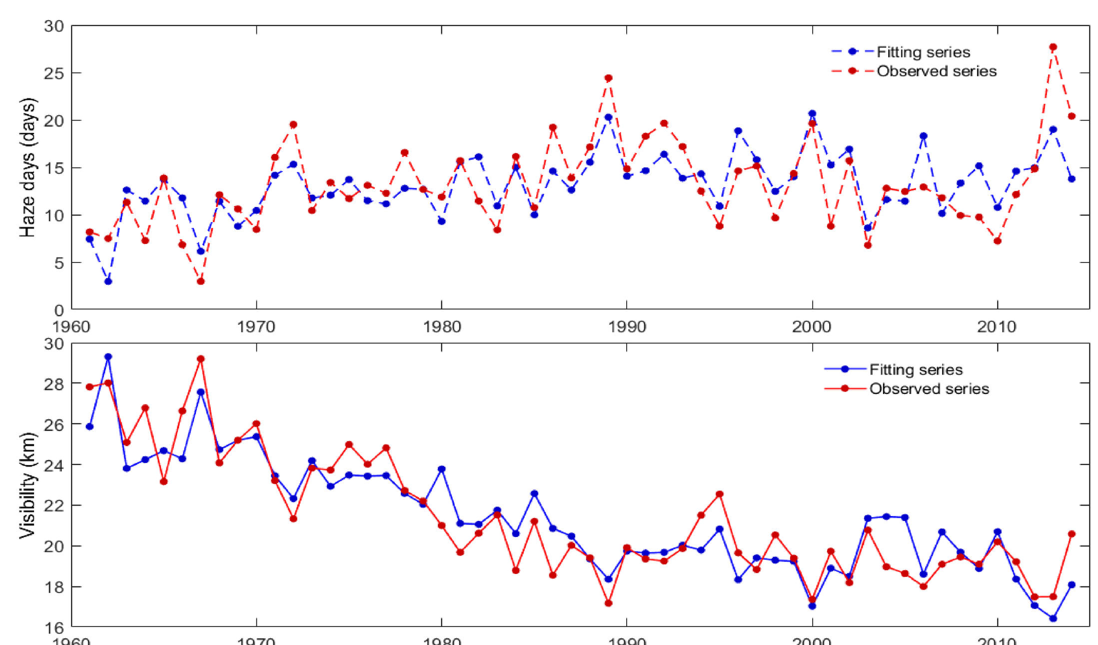


Figure 7. The observed and fitted winter (a) average haze days and (b) visibility in the BTH for 1961-2014.

6. Conclusions

- Number of winter haze days in the study region showed a distinct increasing trend whereas visibility showed a distinct declining trend for 1961-2014.
- Wind speed in the lower troposphere is the key factor driving the interannual variability of winter haze days and visibility, as well as natural and fossil fuel emissions of haze-inducing substances.
- Wind speed in the lower troposphere and particulate sources together can explain 51.7% of the interannual variability of haze days and 81.6% of visibility.

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