Impact of atmospheric quasi-biweekly oscillation on the persistent heavy $PM_{2.5}$ pollution over Beijing-Tianjin-Hebei region, China during winter

Libo Gao, Tijian Wang, Xuejuan Ren, Bingliang Zhuang, Shu Li, Ruan Yao and Xiu-Qun Yang

School of Atmospheric Sciences, Nanjing University, Nanjing 210023, China

Introduction

During the past decades, persistent heavy $PM_{2.5}$ pollution (PHP) events occurred frequently over the Beijing-Tianjin-Hebei (BTH) region in China, which posed a great threat to human life. The PHP events are generally characterized by large value of $PM_{2.5}$ concentration ($\geqslant$150 μg·m^{3}) and long duration (3–7 days). Before or after one PHP event, there exists a relatively clean break. Therefore, the air quality exhibits a feature of quasi-biweekly (10–30-day) variation over the BTH region, and the PHP event occupies the heavy pollution stage.

The atmospheric quasi-biweekly variation over the mid-latitude Eurasian continent can cause fluctuation of meteorological factors over East Asia on 10–30-day time scale (Guo et al., 2019;Ren et al., 2017).We speculate that the PHP event over the BTH region is closely related to the atmospheric quasi-biweekly variation over the mid-latitude Eurasian continent.

Methodology

- **Data.** Surface $PM_{2.5}$ observation in winters of 2013-2017 & NCEP FNL reanalysis data
- **Methods.**
  - Persistent heavy pollution index (PHPI): averaged $PM_{2.5}$ concentration over the BTH region
  - Time scale decomposition: Fast Fourier Transform (FFT) filter
  - Phase composition

Results

BTH suffered from the most serious persistent heavy $PM_{2.5}$ pollution (PHP)

- More than 14 single-city PHP events occurred in the cities of BTH during the 5 winters (Fig. 1b).
- Averaged $PM_{2.5}$ in events > 240 μg·m^{-3} (Fig. 1c).
- 12 regional PHP events are identified in 5 winters.

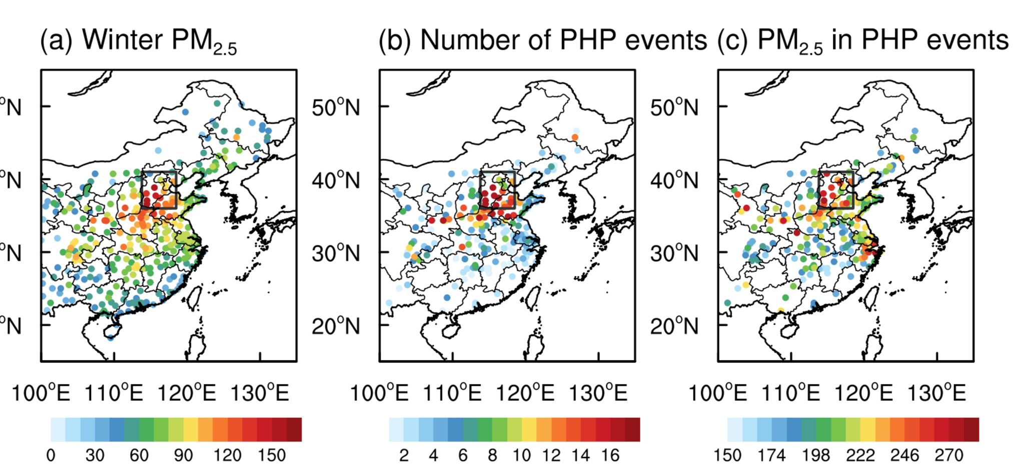


Figure 1. Distribution of $PM_{2.5}$ concentration and single-city PHP events over eastern China in winters of 2013–2017. (a) Averaged daily $PM_{2.5}$ concentration (units: μg·m^{-3}). (b) Total number of single-city PHP events (c) Averaged $PM_{2.5}$ concentration (units: μg·m^{-3}) in single-station PHP events. Black boxes denote the BTH region.

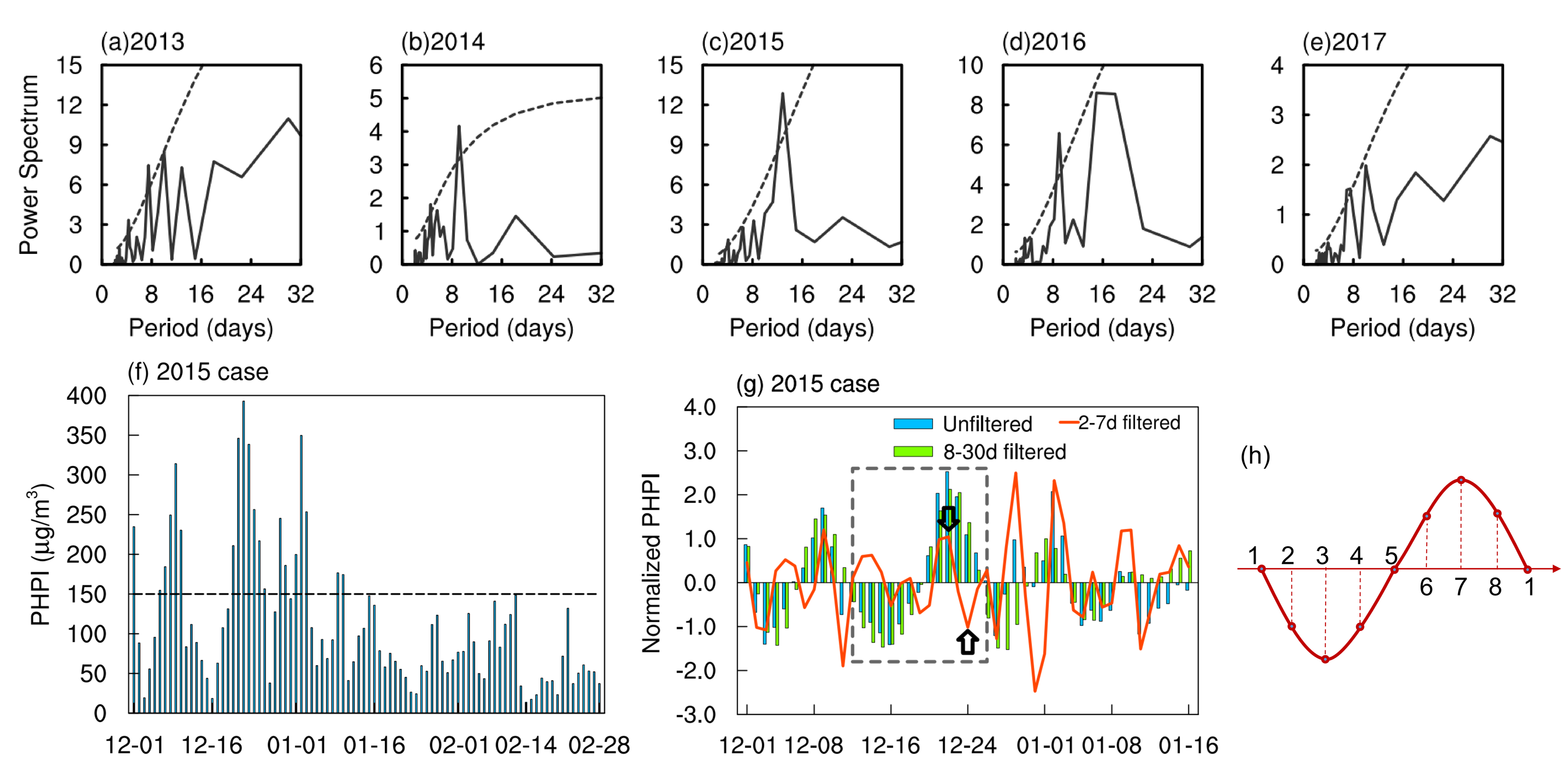
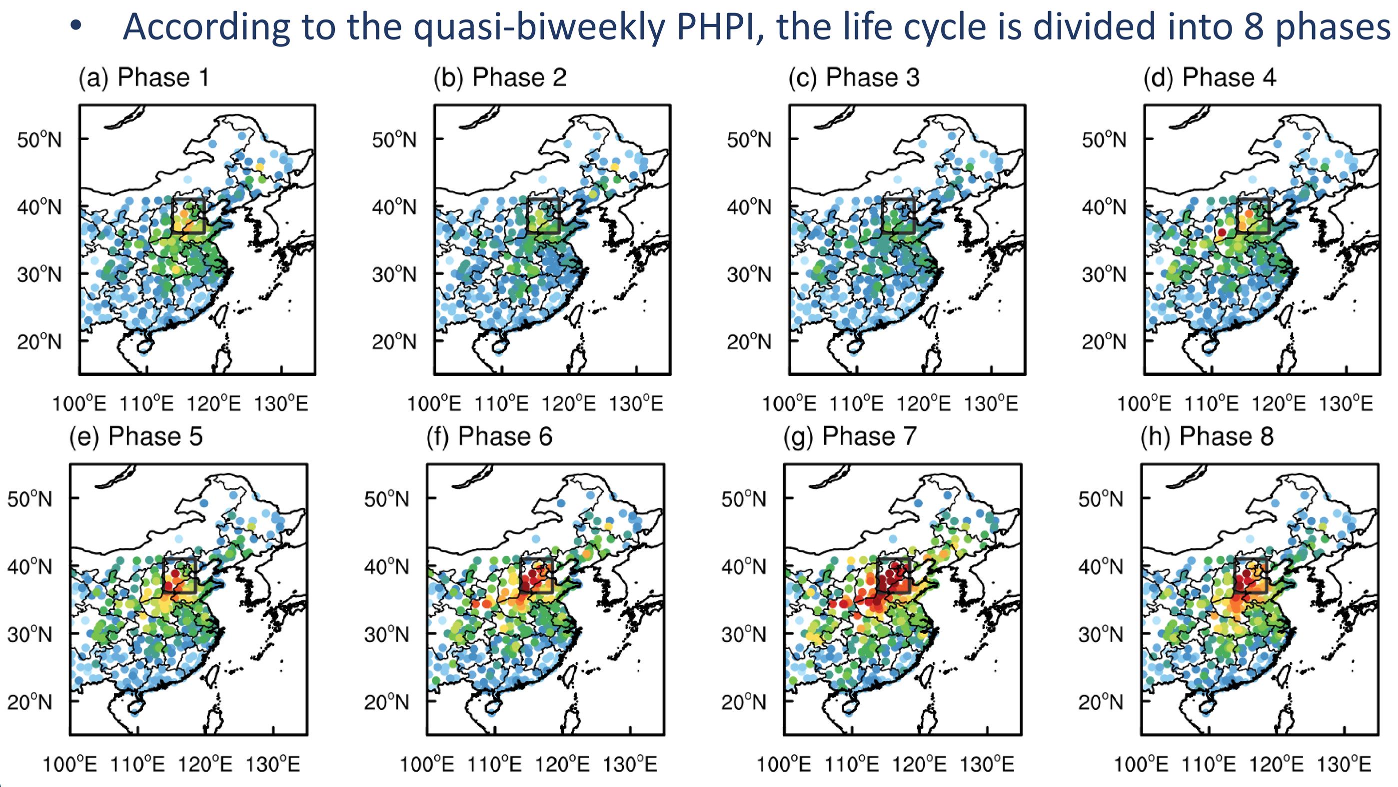


Figure 2. (a-e) Power spectra of PHPI in five winters from 2013 to 2017. The dash lines are the spectrum of 90% confidence level. (f) Time series of PHPI for the winter of 2015. (g) Normalized PHPI (blue bar) and its filtered components on 2 to 7-day (synoptic, red line) and 8 to 30-day (quasi-biweekly, green bar) time scales. The dashed box in (g) denotes a life cycle of one PHP event, and the pair of hollow arrows in (g) marks positive and negative peaks of the synoptic fluctuation during the polluted stage. (h) A diagram showing eight phase points of quasi-biweekly oscillation for composition.

Quasi-biweekly variation of $PM_{2.5}$ notably contributes to the occurrence of PHP events

- A significant periodicity of 10-16 days of the $PM_{2.5}$ concentration over the BTH region is detected (Fig. 2a-e).
- Quasi-biweekly PHPI (8-30 day filtered) varies consistently with the unfiltered one, especially in the PHP events.
- The life cycle of PHP includes a PHP event (polluted stage) and the preceding relatively clean stage (dashed box in Fig. 2g).
- According to the quasi-biweekly PHPI, the life cycle is divided into 8 phases (Fig. 2h).



- Life cycle of the PHP events

Figure 3. Composite of $PM_{2.5}$ concentration in eastern China based on the quasi-biweekly PHPI in eight phases (units: μg·m^{-3}). (a) to (h) corresponding to phases 1 to 8. Black boxes denote the BTH region.

The atmospheric quasi-biweekly oscillation provides favorable conditions to the PHP events

During the PHP events (phases 5-8),

- Anomalous high pressure occupies eastern Asia and its coastal waters (Fig. 4) → Weakened winter monsoon
- More moisture transported to the BTH region (Fig. 5) → Promoted formation of fine particulates
- Warming in the lower and cooling in the higher troposphere (Fig. 6) → Stable stratification & Potential inversion near surface

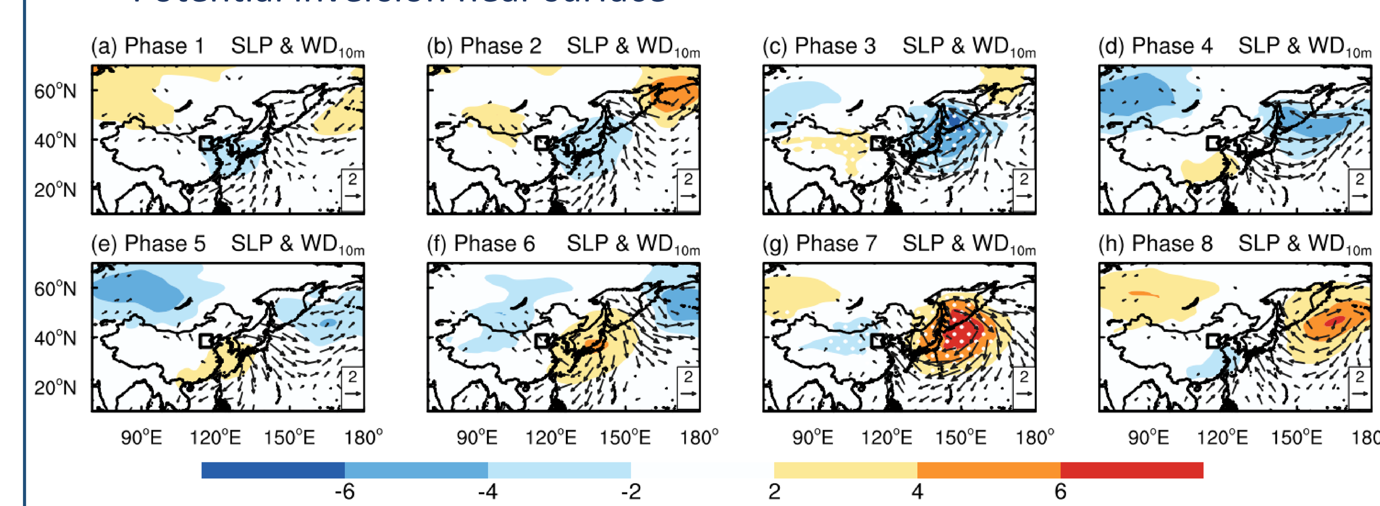


Figure 4. Composite of quasi-biweekly anomalies in SLP (shaded; units: hPa) and wind at V_{10m} (vector, only values above 0.2 are shown; units: m s^{-1}) for eight phases of the quasi-biweekly PHPI.

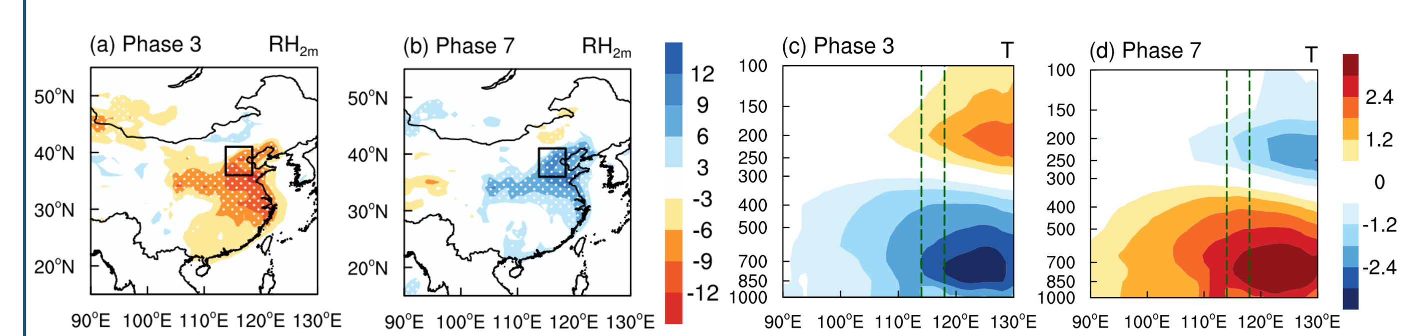
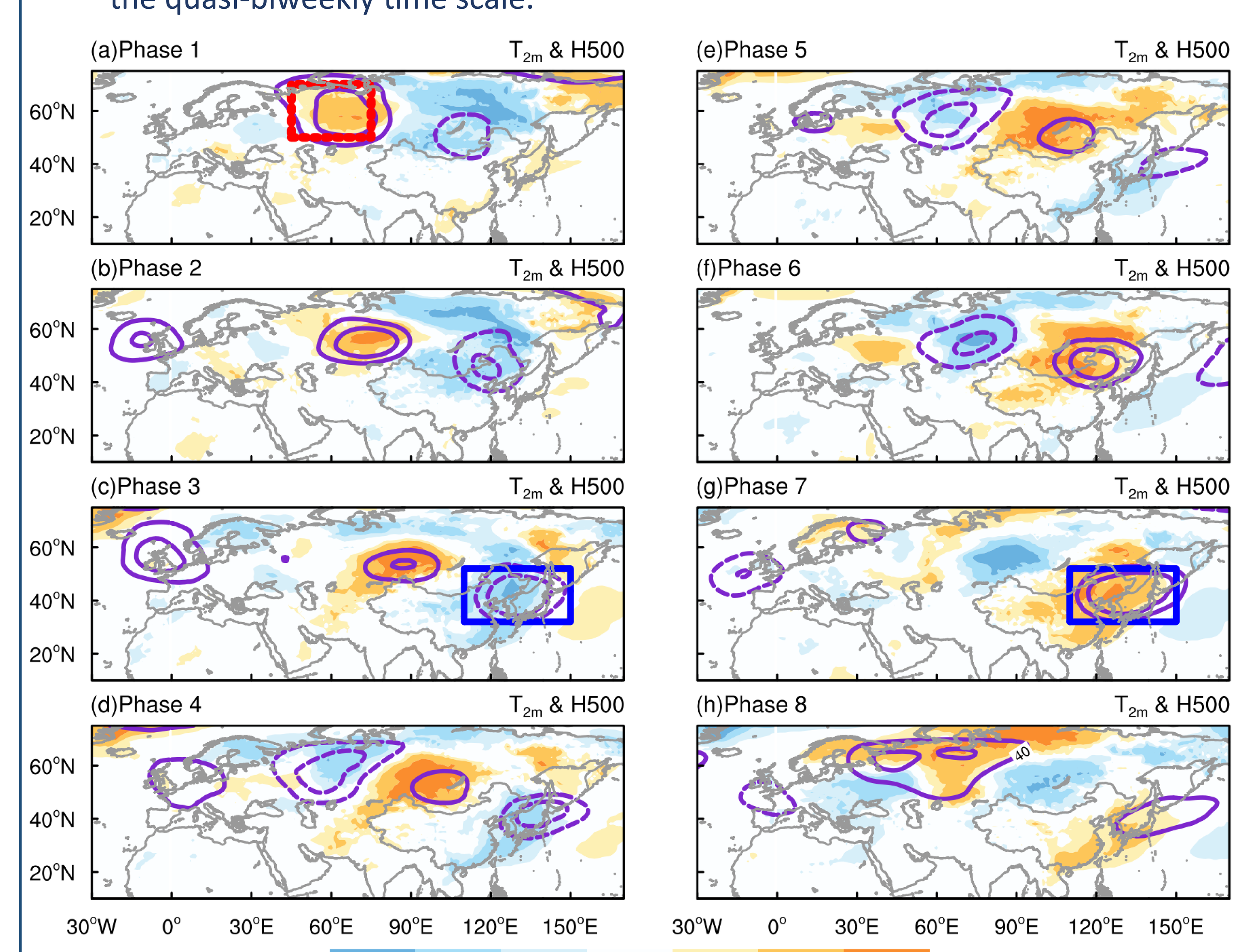


Figure 5. Composite of quasi-biweekly RH_{2m} anomaly (units: %) for phases 3 (a) and 7 (b) of quasi-biweekly PHPI. Longitude-pressure section of composited quasi-biweekly T anomaly for phases 3 (c) and 7 (d), averaged over 36°–41°N (units: K).

A precursor signal of the atmospheric quasi-biweekly oscillation is suggested

- The quasi-biweekly oscillation of local circulation is modulated by the wave train propagation from high latitudes.
- The oscillation of the East Asian trough can be traced back to a precursor signal over northeastern Eurasia about 11 days earlier, through a southeastward wave train propagation.
- The meteorological conditions conducive to PHP events over the BTH region can be predicted on the quasi-biweekly time scale.



- The wave train propagation

Figure 6. As in Fig. 4, but for T_{2m} (shaded; units: K) and H_{500} (contours; units: gpm). The contours start at ±40 with interval of 20. Solid lines for positive values and dash lines for negative ones. The red dotted box in (a) marks the precursor region. The rectangles in (c) and (g) denotes the East Asian trough region.

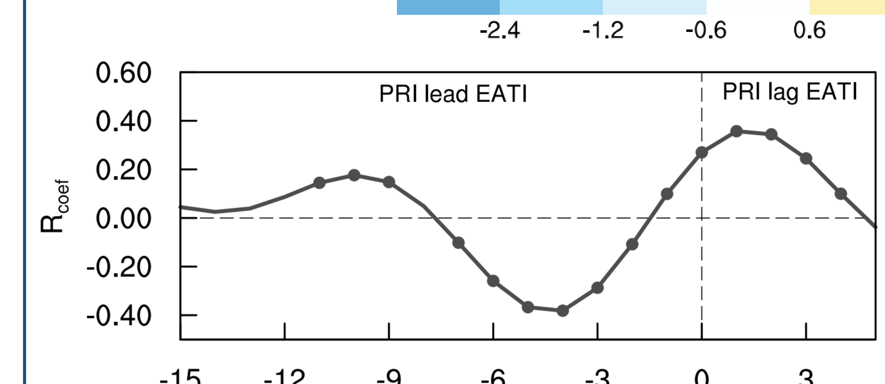


Figure 7. Lead-lag correlation between precursor index (PRI, averaged *H500* over the precursor region) and the East Asian Trough index (EATI, averaged *H500* over the East Asian trough region) on the quasi-biweekly time scale. Black dots denote values above 95% confidence level (t test).

Conclusions

a) The $PM_{2.5}$ concentration over the BTH region has a significant periodicity on the quasi-biweekly time scale, which notably accounts for the persistence of heavy pollution.
b) The long-lasting heavy pollution is closely related to the atmospheric quasi-biweekly circulation anomalies.
c) The quasi-biweekly oscillation of local circulation can be predicted by a precursor signal about 11 days in advance.

References

Guo, L., Zhu, C. W., and Liu, B. Q.: Possible causes of the flooding over south China during the 2015/2016 winter, International Journal of Climatology, 39, 3218-3230, https://doi.org/10.1002/joc.6013, 2019.

Ren, X. J., Yang, X. Q., and Hu, H. B.: Subseasonal Variations of Wintertime North Pacific Evaporation, Cold Air Surges, and Water Vapor Transport, Journal of Climate, 30, 9475-9491, https://doi.org/10.1175/Jcli-D-17-0140.1, 2017.

Acknowledgements

This work was jointly supported by the National Natural Science foundation of China [grant numbers 41621005, 41575145]; and the National Key R&D Program of China [grant numbers 2018YFC1505903, 2016YFC0203303].The PM2.5 observation is obtained from China National Environmental Monitoring Centre network (http://www.cnemc.cn/). The NCEP FNL hourly reanalysis data is available from the NCEP/NCAR data archive: https://rda.ucar.edu/data-sets/ds083.2/