Climatology of wintertime long-distance transport of surface layer air masses arriving urban Beijing in 2001-2012

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Outline

- Background and motivation
- Model and methodology
- Preliminary results
- Summary and Conclusions

Background

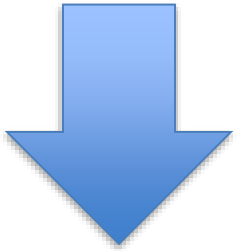
- The alleviation of air-quality problems in Beijing has become a important issue of concern for the public and the government.

Background

- The trans-boundary transport of air pollutants is being recognized as a main mechanism that affects air quality over Beijing [e.g., Guo et al., 2014; Sun et al., 2014; Zheng et al., 2014; Yang et al., 2015; Zheng et al., 2015]. (Wang et al. 2014; Zheng et al ,2014].
- To alleviate severe haze pollution, Beijing must further strengthen its emission-reduction measures, and a similar control should be extended to other regions of eastern China [Sun et al., 2014; Tao et al., 2014b; Yang et al., 2015; Zheng et al., 2015].

Background

The quantification of 'Airshed' of Beijing urban and the transport conditions associated with air quality evolution are important for developing optimized emission-control strategies.



Details regarding the transport properties over Beijing and their association with regional air quality, particularly from a climatological perspective, remain unclear.

Motivation

The goals of this study are to explore:

- From which geographical region does the air masses reaching Beijing originate? - 'Airshed',
  —from a perspective of climatology.

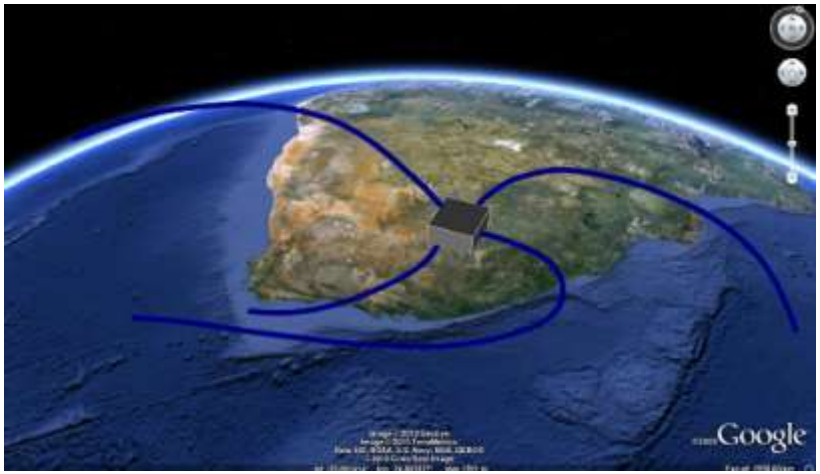
- Are the variability of transport conditions and the corresponding occurrence of air pollution events over Beijing closely related?
  — focusing on synoptic scales.

- What are the regional and long-trending variations of the geographic sources and ventilation conditions
  — particularly for the last decade.

Model and methodology

A. Model: **Mesoscale meteorological model (WRF) + Lagrangian dispersion model (FLEXPART)**

B. Lagrangian analysis: **Backward trajectories**



Model and methodology

Time-consuming, memory-intensive simulations were performed using WRF Model version 3.3.

■ **WRF：http://www.wrf-model.org/index.php**
The Weather Research & Forecasting Model

■ **Model setup**

- Grid dimensions: 211×221, 199×211, and 175×118.
- Horizontal grid spacing: 18 km (30 s), 6 km (10 s), and 2 km (3 s).
- Vertical levels: 61 unevenly spaced terrain following sigma levels
- ERA-Interim data served as initial and boundary conditions
- The frequent re-initialization method [Zhang et al., 2012; Jiménez et al., 2013; Chen et al., 2014]: Thirty-six-hour simulations were conducted from 00:00 (local time) each day during the winters of 2001 to 2013, and each 12–36-hours period (from 08:00 to 08:00 the next day) was collected to build the datasets at intervals of 1 hours.

Model and methodology

The 3D-Lagrangian transport and dispersion model: FLEXPART

■ **FLEXPART：** http://flexpart.eu

- a comprehensive tool for atmospheric transport modeling and analysis at multiple timescales.

■ **Model setup**

- Driven by the meteorological fields produced by WRF modeling.
- The backward trajectories arriving at the target region were initialized once each day at 0000 UT (8:00 a.m. local time).
- For each FLEXPART model running, ten thousand particles (air parcels) were released from the target region at heights of 0 to 1800 m above the ground level.
- Approximately 11,960,000 air parcels were released during the winters of 2001-2012.
- The air parcel trajectories were tracked backward for 10 days, and the model output information are recorded every 6 h.

Model and methodology

Geographic source identification: Backward-tracking

PBL-trajectories selection

- Only trajectories departing from the surface layer of Beijing and then visiting (below) the PBL along their 10-daysbackward journey.

PBL source identification

- The “climatology” of the geographic sources are defined in terms of the locations of the backward trajectories within the PBL.

Potential grid-cell source contribution

- A well-resolved density field of backward PBL trajectories could be represented as $\text{Contribution}_{ij} = n_{ij} / m_{ij}$
- here, n_{ij} is the total number of trajectory endpoints in the ij-th grid cell within the PBL, and m_{ij} is the total number of trajectories released in the target region.

Model and methodology

Backward ventilation diagnosis: BV index

■ The definition of BV index

- A simple BV index was defined as the vectorial mean of the particle velocities, i.e., the distance between the starting and end points of a particle divided by the length of the time interval.
- The distribution of daily BV index could be derived directly from the averaged of all backward-trajectories.

■ High values indicate strong ventilation, and low values denote strong stagnation.

Model and methodology

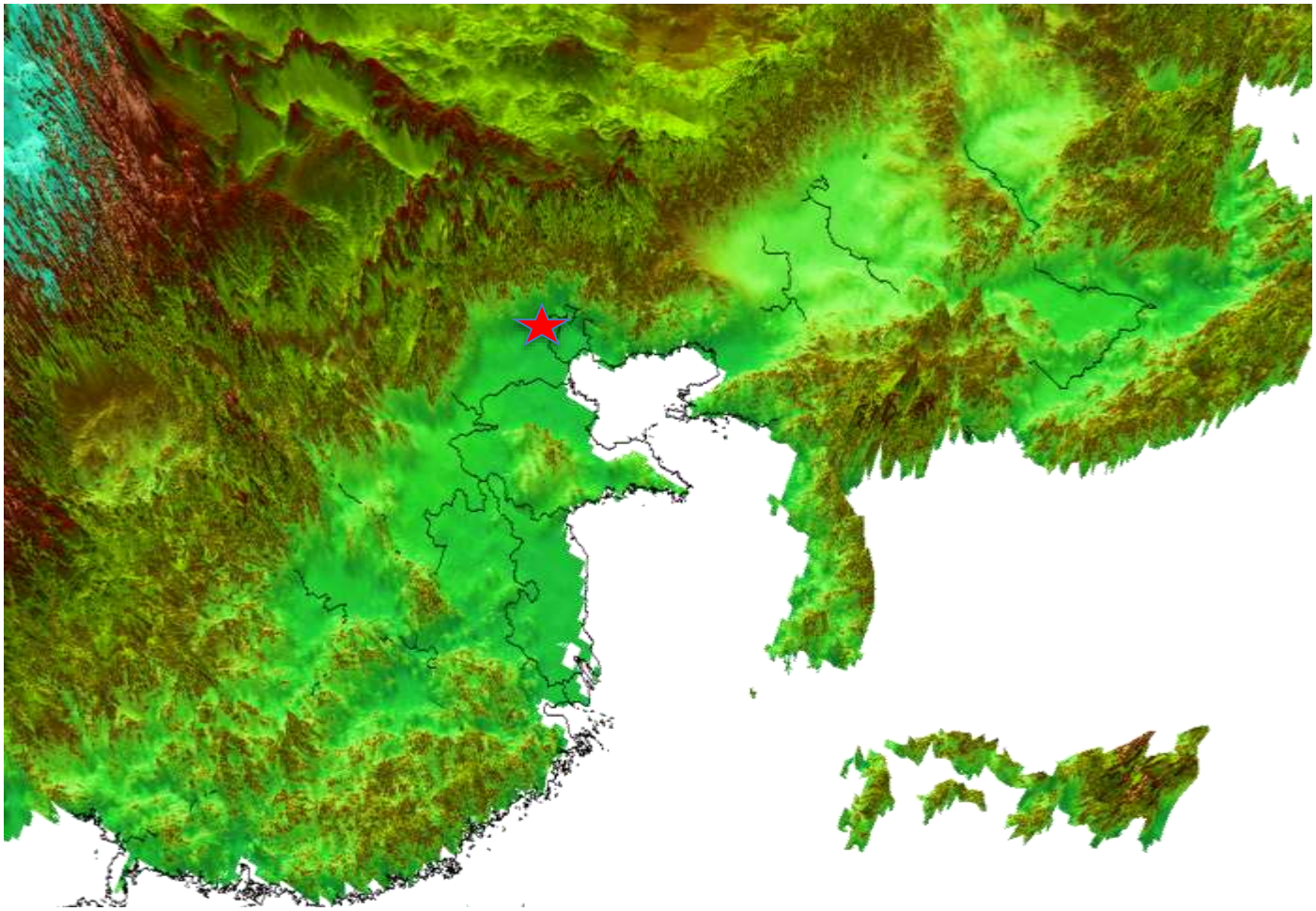
■ Atmospheric visibility data

- The daily visibility data were obtained from experienced observers that made observations every 6 hours at fixed-site monitoring stations in Beijing.
- The average station observations from Beijing (hereafter referred to as the “target region”, 115.45-117.50° E, 39.43-41.05° N) were used to establish the atmospheric visibility indices.

- **EAR-interim analysis (Nov- Jan, 2001-2012)**

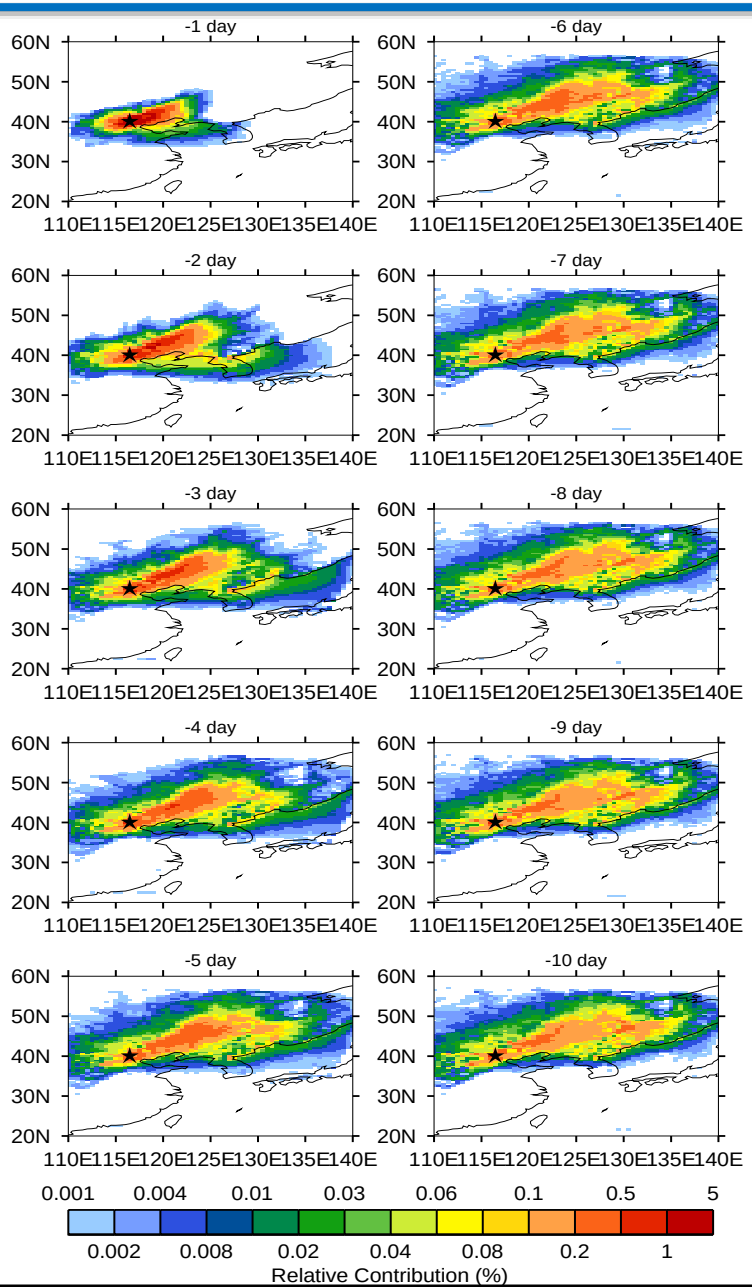
- **An integrated EAWM (Eastern Asian Winter Monsoon) index deduced by He and Wang [2012]**

Preliminary results



Topographical trends in Beijing and in the surrounding provinces (in meters above sea level).

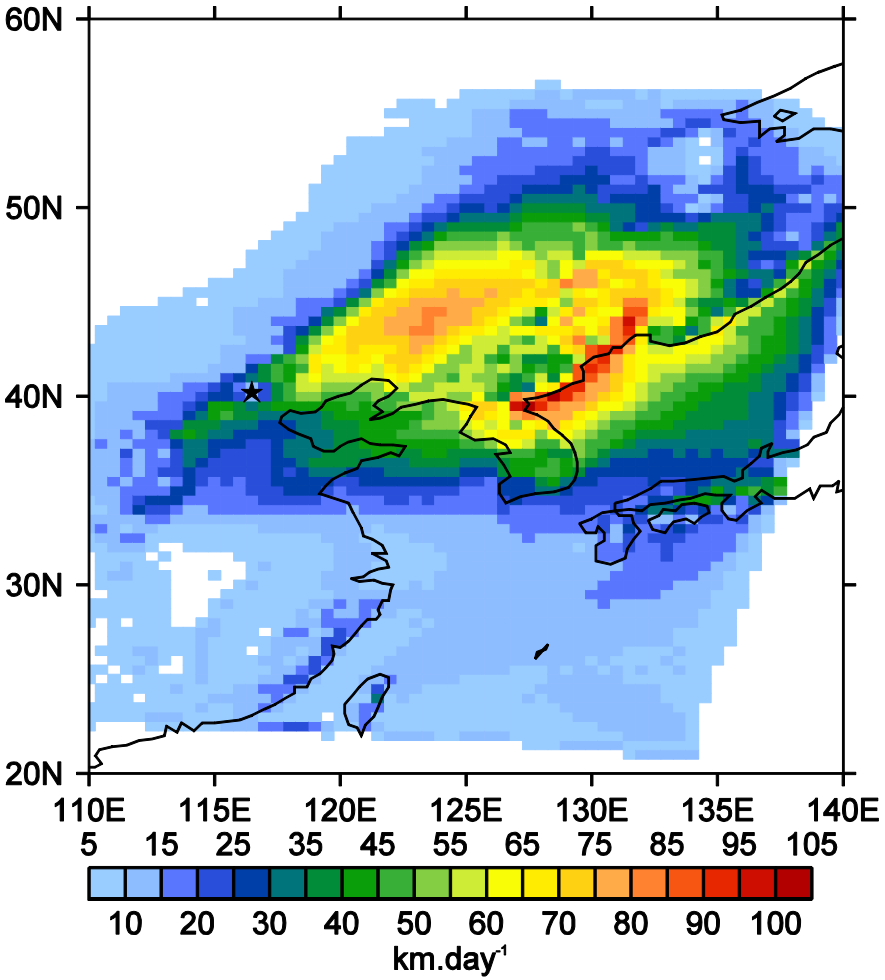
Geographic source regions (PBL air mass origin)



The 2001-2012 boreal winter seasonal (Nov-Dec-Jan) distribution density for 1- 10 days backward trajectories within the boundary later, respectively. The distribution density are binned on 0.5×0.5 latitudinal-longitudinal grid.

- The PBL sources are strongly localized geographically (northeast, west, and southwest of Beijing)
- Reflecting the combined effects of the topographical and dominant airflows
- Source regions cover a larger area over a greater backward tracking time, and the regions around Beijing act as persistent contributors
- year-to-year variability is significant

Large-scale ventilation conditions (BV index)



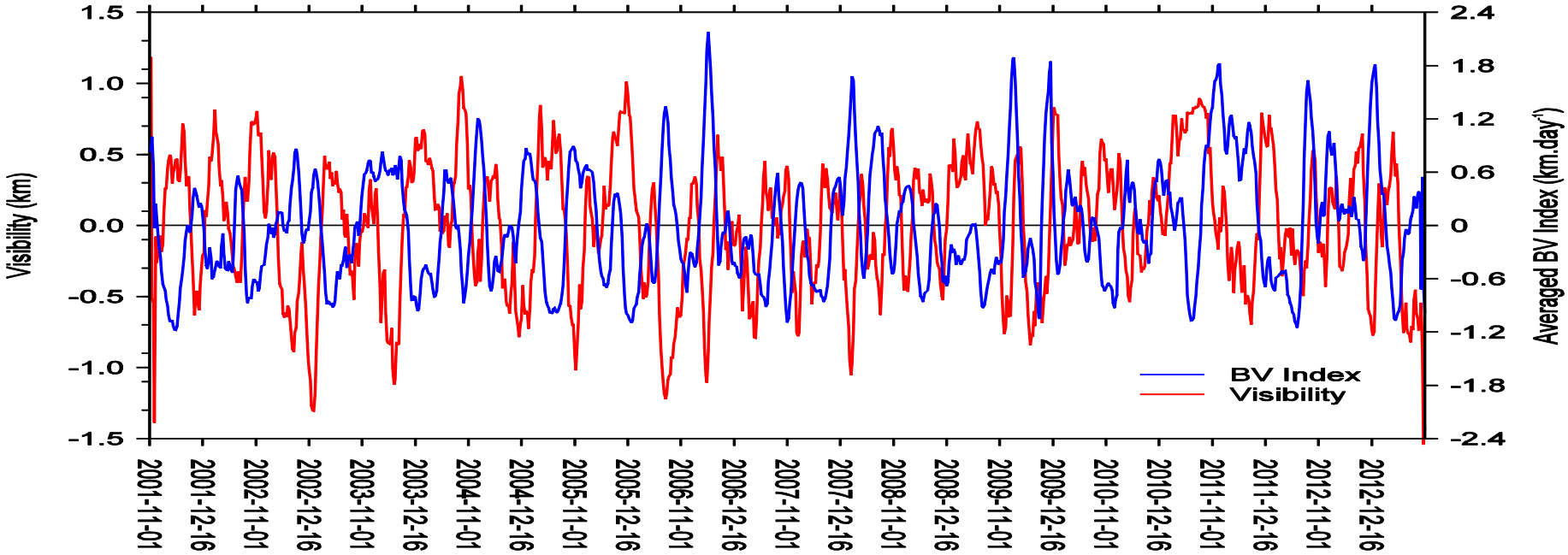
The averaged 10-days integrated of 2001-2012 winter seasonal (Nov-Jan) of the backward ventilation (BV) index over the Beijing urban. High values indicate the strong ventilation, versus low values strong stagnation. (km.day^{-1}).

- Regions with a higher velocity transported to the Beijing are primarily located in the northeastern region of Beijing.
- Two regions with the highest values are apparent: the Northeast Plain of China and the east coast of China.
- The nearby source regions with a high BV index should be considered with high priority.

Association of large-scale ventilation with air quality

Synoptic scale relationship

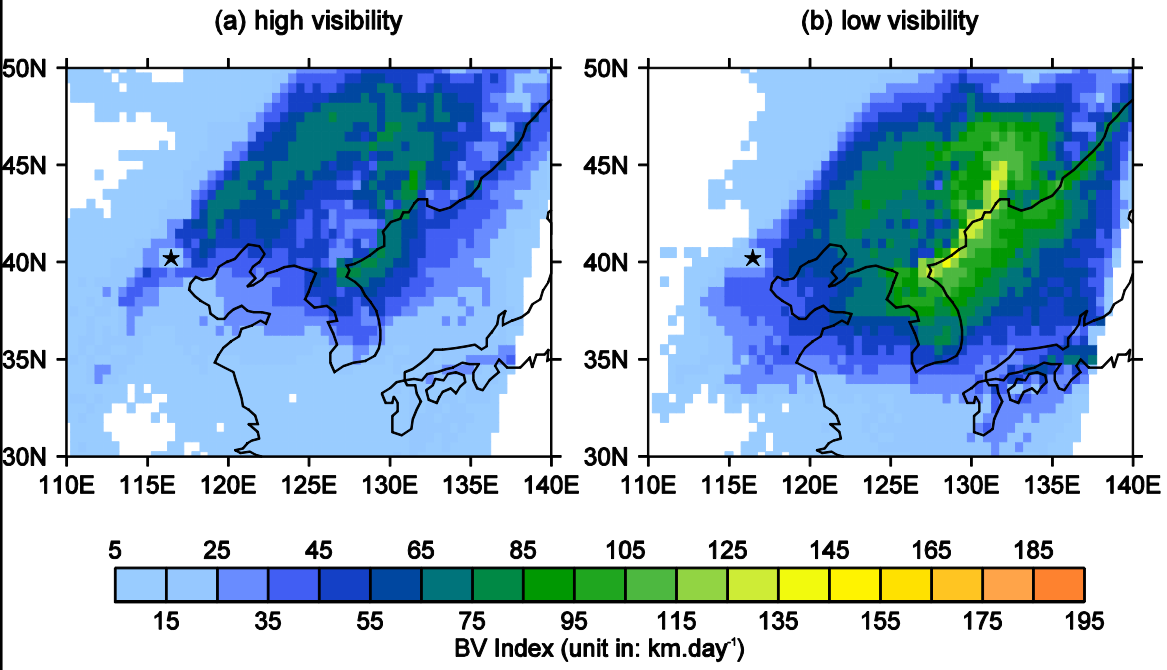
The anomalies of daily variation of visibility of Beijing (red line) and the averaged BV index (blue line), both with a nine-point moving average, with a correlation coefficient of -0.58 (exceeding the 95% confidence level)

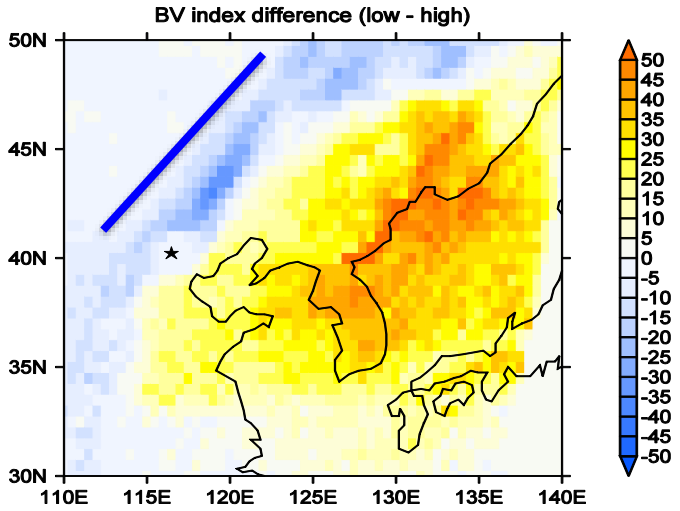


- Extreme air pollution levels over Beijing largely closely relate to large-scale ventilation of the long-range transport on a synoptic time scale.
- BV index defined here could be used to facilitate operational forecasting and warnings for air pollution events.

Comparison between the higher and lower visibility events

Only days with an averaged visibility lower than 5.0 km and higher than 30.0 km based on the gauging observations were selected and compared.

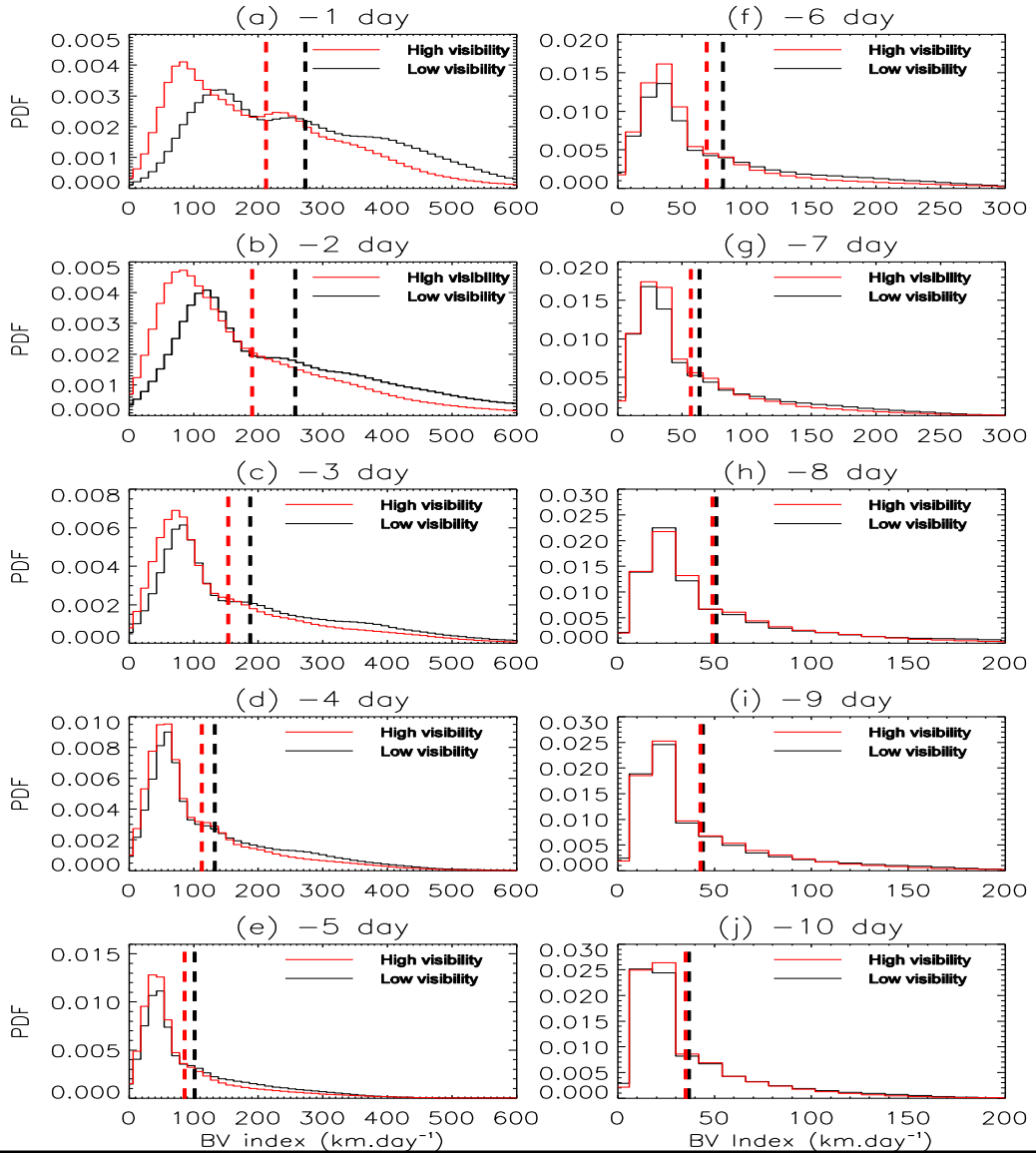




- Generally, the areas with higher ventilation efficiencies are likely to transport more air mass to Beijing during the lower visibility event episodes.
- The dominant transport timescale responsible for these differences remains unclear.

Comparison between the higher and lower visibility events

Dominant transport timescale responsible for the differences

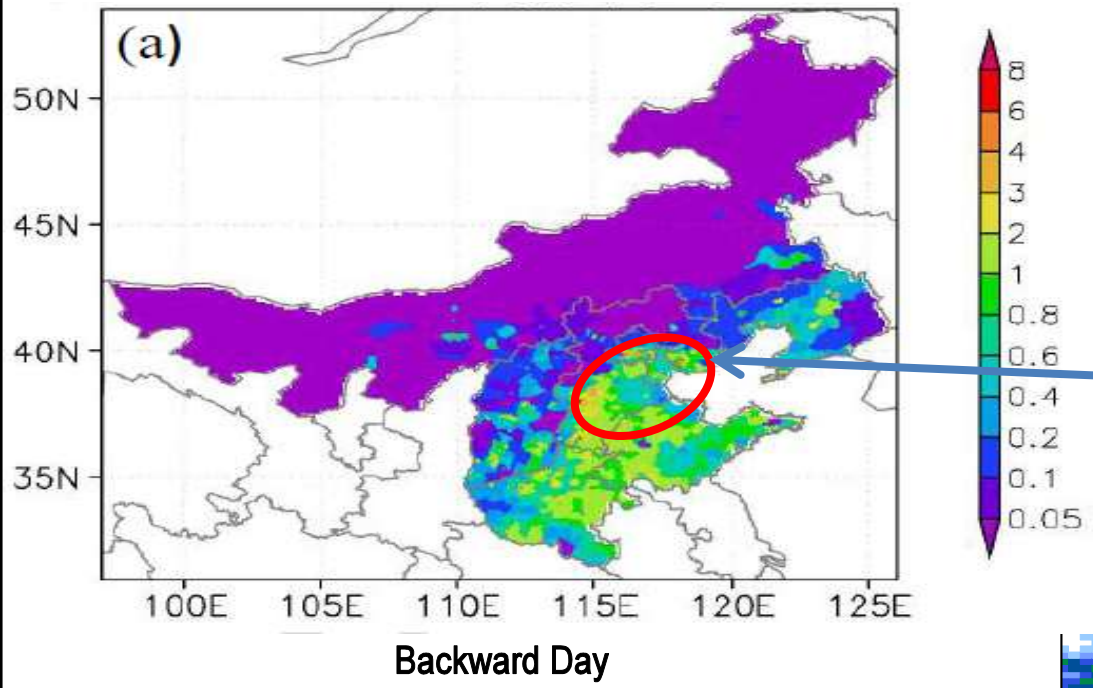


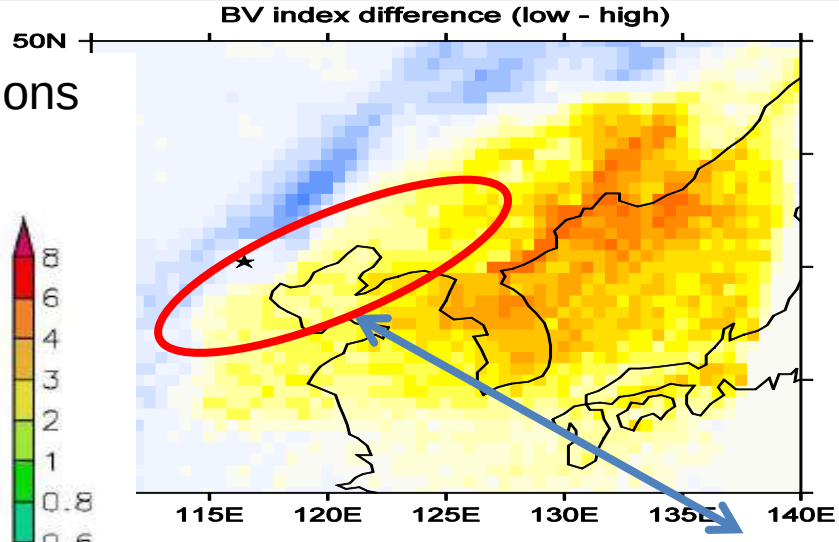
The probability distribution function (PDF) of BV index both for the days of higher visibility (read lines) and those of lower visibility(black lines), both averaging for 2001–2013 boreal winter (Nov-Jan). Solid lines indicate the mean values, respectively.

- The greatest difference occurring at approximately 1-3 days, nearly negligible for more than 6 days.
- Daily variations of air pollution levels (including severe events) are primarily modulated by transport with a timescale less than 3 days

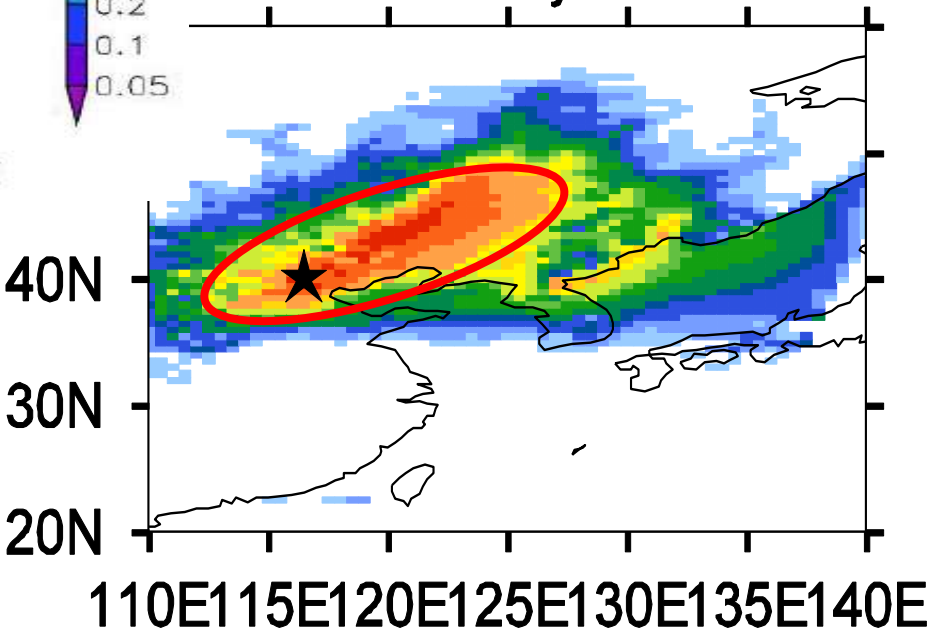
Identification of regions for the mitigation of air pollution

Spatial distributions of anthropogenic emissions of PM2.5 (Wang et al., 2015)





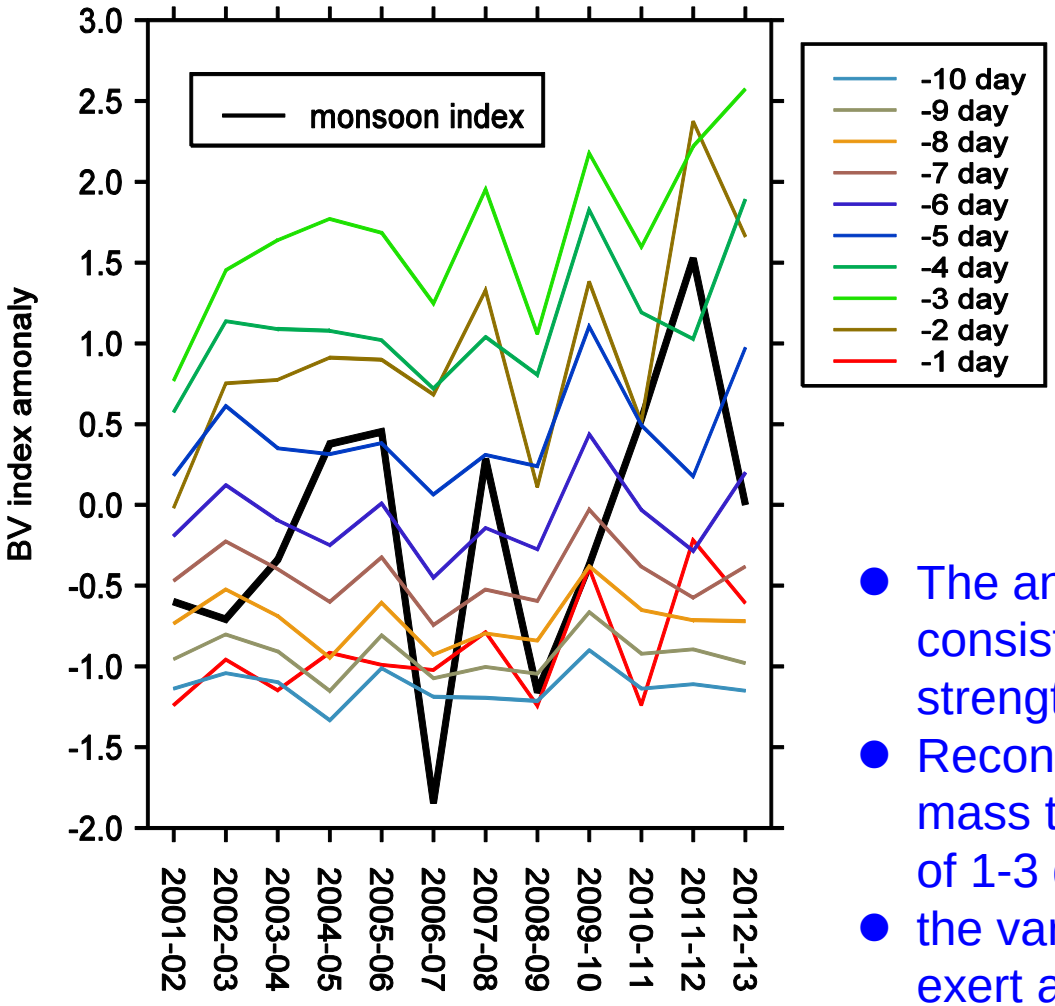
Key regions



Temporal evolution of the difference in the averaged BV index between the high and low visibility conditions. A greater difference primarily occurred when the timescale was less than three days.

Association of large-scale ventilation with EAWM

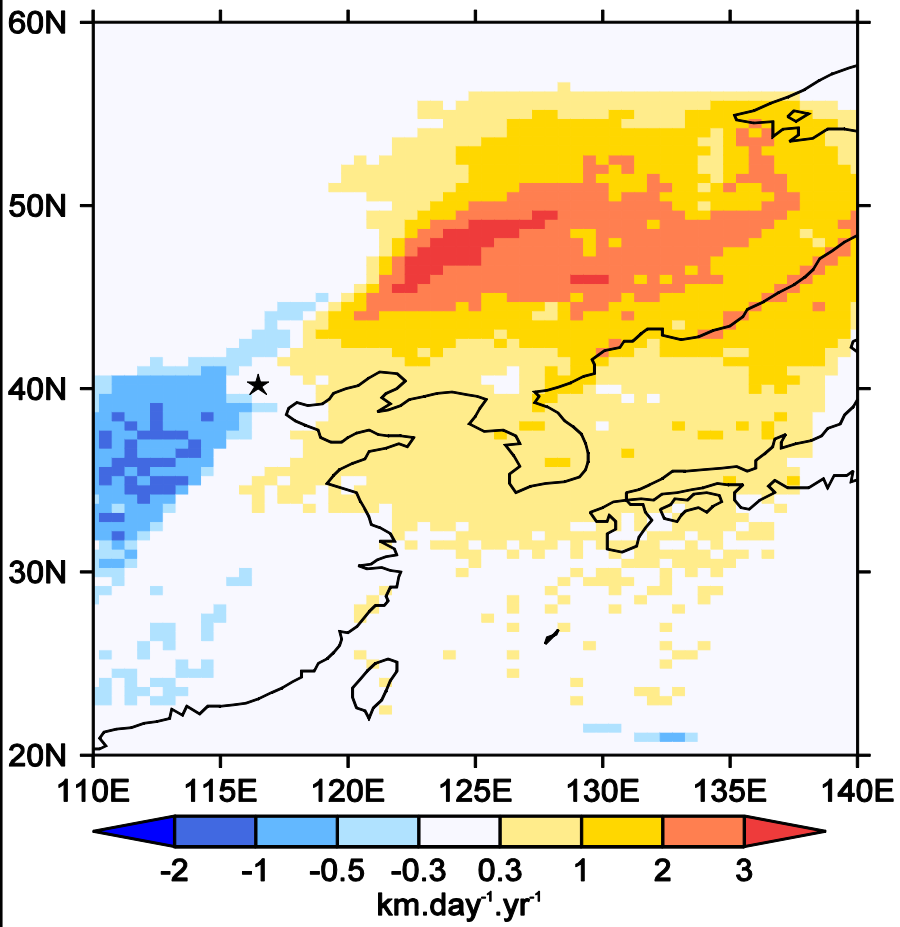
The relationships between large-scale ventilation and the Eastern Asian winter monsoon (EAWM) on an interannual time scale



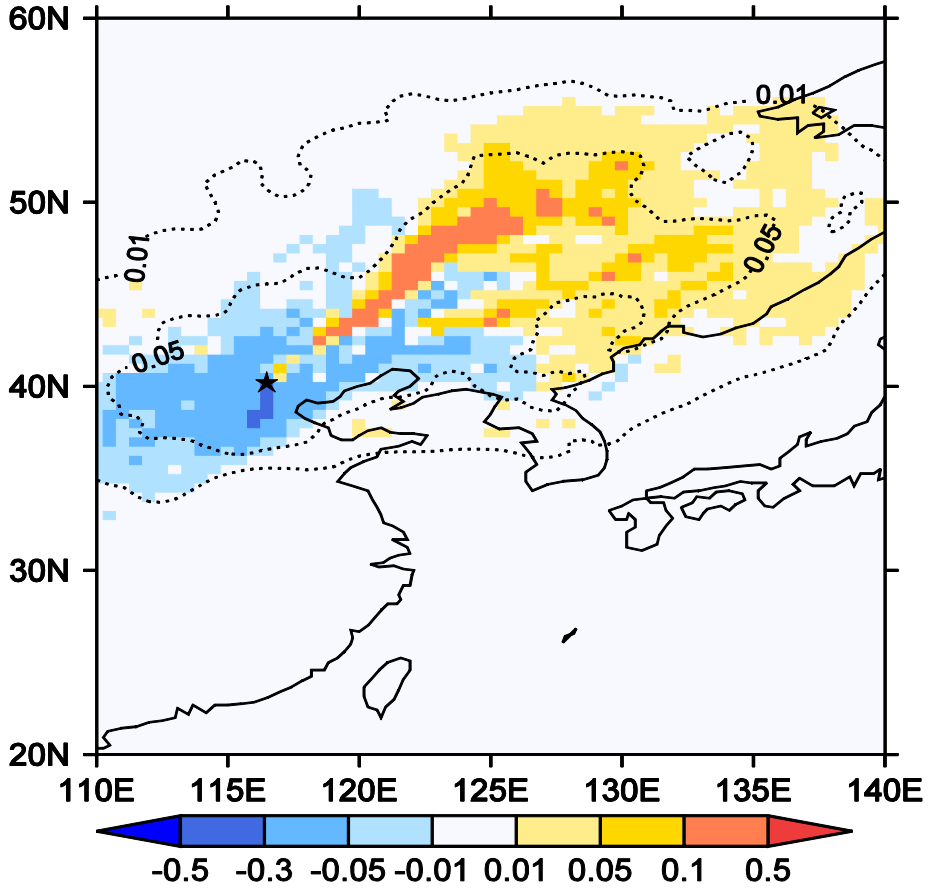
The annual variations of 1-10 days BV index anomalies and corresponding monsoon index for the boreal winter seasonal (Nov-Jan). From 1 to 5 days, the correlation coefficients reached 0.49, 0.64, 0.60, 0.25, and 0.078, respectively

- The annual variations of the BV index are consistent with the evolution of the EAWM strength.
- Reconfirming the importance of the air mass transport to Beijing with a timescale of 1-3 days .
- the variability of Asian summer monsoon exert an influence of air quality level

Long-term trends



The distribution of BV index trends for the 2001-2013 boreal winter season.



The trend of air mass contribution trend (Nov-Jan).

Summary and conclusions

- The long-term Lagrangian modeling of air masses arriving at the Beijing city were implemented. The first climatology analysis on the boundary layer sources regions and its associated ventilation conditions for Beijing urban is carried out.
- The defined Backward ventilation (BV) index is significantly negative correlated to the air pollution levels, and thereby can potentially server as a useful factor in operational forecasting and early warning system.
- Geographically, the regional transport with a transport timescale of less than 3 days can contribute to the transport of air pollutants and local accumulation over Beijing City. Those regions that needs to to be given highest priority for the mitigation of regional pollution of Beijing are identified.
- The relationships between the large-scale ventilations and the EAWM on an annual scale are significant, implying that the changing climate or large-scale atmospheric circulation would potentially affect the air pollution levels over Beijing.


Thanks for your attention!