Atmospheric Environment 122 (2015) 154–162

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Interannual increase of regional haze-fog in North China Plain in summer by intensified easterly winds and orographic forcing

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HIGHLIGHTS

- Characteristics of regional haze-fog over the North China Plain are described.
- Physical mechanism of the effect of atmospheric circulation on haze-fog is discussed.
- Atmospheric circulation change and orographic forcing led to haze-fog variation.
- A possible relationship between haze-fog and ENSO is reported.

ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form
14 September 2015
Accepted 15 September 2015
Available online 16 September 2015

Keywords:
Haze-fog
Interannual variation
Orographic forcing
Summer monsoon
ENSO

ABSTRACT

Regional haze-fog events over the North China Plain (NCP) have attracted much attention in recent years. Their increase has been attributed to anthropogenic emissions of air pollutants and synoptic weather conditions. We investigated the influence of local meteorological conditions and large-scale circulation on the haze-fog events over the NCP during 2001–2012, and found a significant interannual increase in the number of summer regional haze-fog days. Analysis indicated that local meteorological conditions could partly explain the increase but failed to explain the spatial variation; meanwhile, regional circulation change induced by large-scale circulation and orographic forcing unveiled a possible spatiotemporal variation mechanism. In summer, the prevalent southerly winds over the NCP were obstructed by the Taihang and Yanshan mountains, steadying the outflow direction to the southeast, while different inflow direction controlled by large-scale circulation had different effects on regional circulation. In weak (strong) East Asian summer monsoon years, an intensified eastward (westward) zonal inflow wind component reinforced (weakened) the negative vorticity and formed an anomalous anticyclone (cyclone), which strengthened (weakened) the downward motion, so the dissipation capability was weakened (strengthened) and the wind speed decreased (increased), ultimately resulting in the increased (decreased) occurrence of haze-fog. We also found that the circulation anomaly had a good relationship with strong El Niño and La Niña events. There was more haze-fog over the NCP in the summers that followed a La Niña event, and less in summers that followed an El Niño event. This suggested the possibility that summer haze-fog phenomena could be predicted based on the phase of ENSO.

1. Introduction

Haze and fog are reductions in horizontal visibility caused by suspension in the air (WMO, 2014). Although the composition of the suspended material is different, fog and haze often co-exist, and interchangeably, under certain conditions (Ding and Liu, 2014; Mu and Zhang, 2014). When studied together, they are referred to as the ‘haze-fog’ phenomena. The conditions of low visibility during a haze-fog event adversely affect human activities such as transportation and aviation (Bobrowsky, 2013; Li and Zhou, 2013). The associated pollutants accumulated in the air also pose great threats

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http://dx.doi.org/10.1016/j.atmosenv.2015.09.042
1352-2310/

to human health (Tie et al., 2009).

The North China Plain (NCP) – home to the megacities of Beijing and Tianjin – is a political, economic and cultural center of China. As one of the three most populous and economically developed regions in the country, the economy of the NCP region has soared in recent years. However, associated with this economic success, the NCP suffers from some of the most severe air pollution in China, related to the heavy aerosol loading generated by industry (Zhang et al., 2013; Wang et al., 2014a). According to the air quality status report released by the Ministry of Environmental Protection of China (2014), eight out of ten of the most polluted cities were situated in this region. As a result of air pollution, haze events over the NCP have increased since the 1990s (Zhao et al., 2011), and have occurred more frequently post-2000. Moreover, the haze-fog has begun to show a number of new characteristics; for instance, a more regional tendency (Wang et al., 2013) and greater persistence. In January 2013, a severe haze-fog event of strong intensity, long duration and extensive coverage occurred over eastern China, leading to heavy air pollution for 27 days around the NCP region (Zhang et al., 2014). Thus regional haze-fog events, which triggered both public anxiety and official concern, have been one of the most disastrous weather phenomena in China in recent years (Li and Zhang, 2014), and has become a hot topic for researchers. In this vein, the present work is focused on the characteristics of regional haze-fog and its variation.

It is known that the number of haze-fog days in the NCP shows obvious seasonal variation. For example, the number was fewer in summer than in winter based on the long-term records from 1981 to 2010 (Fu et al., 2013). This is in agreement with the results of the present study as depicted in Fig. 2a for each season after 2001. However, it is found that the number of regional haze-fog days in summer had a more significant interannual increase than the other three seasons, and it could reach the high values experienced during the winter. Rapid increase of summer haze-fog days over the NCP has also attracted the attention of researchers (Fu et al., 2014; Wu et al., 2014b; Xu et al., 2015). Fu et al. (2014) found that haze-fog events in summer have been increasing continually over the past three decades, probably due to the variation in aerosol composition and high relative humidity which favors the hygroscopic growth of particles. However, the reason for the interannual increase of summer haze-fog and the detail of the physical processes involved have yet to be explored.

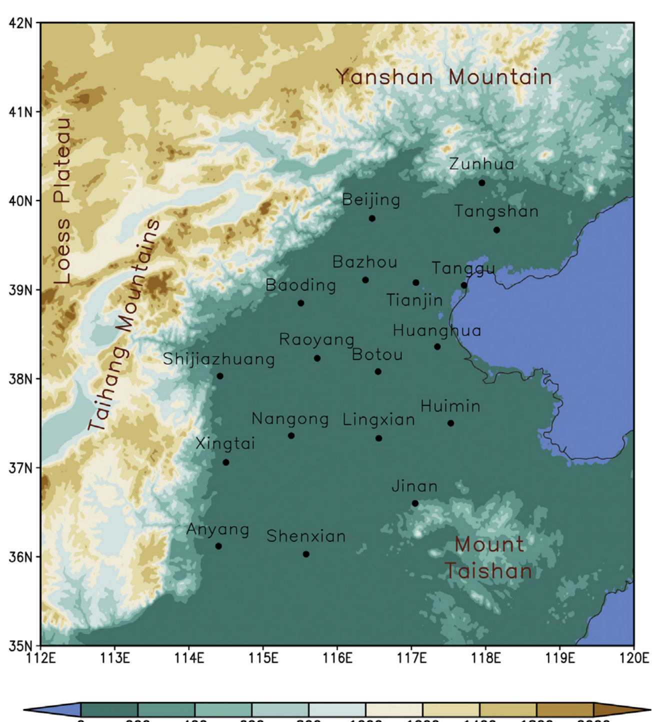

Fig. 1. Orography of the NCP and distribution of selected stations. The color scale represents the altitude (m, NOAA ETOPO1 data); black dots show the location of each station. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

A recent study concluded that the increase in haze-fog days in eastern China is associated with increasing atmospheric aerosols from anthropogenic emissions (Zhang et al., 2012). However, as we show in the present paper, the increasing trend of anthropogenic emissions (Reuter et al., 2014) does not completely match the interannual variation of regional haze-fog events, moreover, the trend in summer regional haze-fog over days and the Niño3.4 index are basically in opposite phase (Fig. 2b). Therefore, it can be hypothesized that the interannual variation in the summer regional haze-fog over the NCP is also affected by meteorological conditions, in addition to the variations in anthropogenic emissions. In this paper, we attempt to explain the relationship between meteorological conditions and regional haze-fog days by examining local meteorological variables and regional atmospheric circulation. We focus on the physical mechanism of how meteorological conditions affect haze-fog variability, and examine the possibility of a relationship between haze-fog and ENSO.

2. Data and methods

2.1. Data

The meteorological observation data in this study were obtained from the China Meteorological Administration (CMA). Observations including weather phenomena, visibility, temperature, relative humidity and wind speed were recorded four times daily (02:00, 08:00, 14:00, 20:00 LCT). The observation data for the period 2001–2012 from stations in the region (36°–41°N, 112°–120°E) were analyzed. Data from stations situated in mountain areas (e.g., Mount Taishan) and plateau areas (e.g., the Loess Plateau) were eliminated because of our focus on the plain. We considered that the 18 selected stations shown in Fig. 1 were capable of representing the regional characteristics of the NCP.

The NCEP FNL (Final) Operational Global Analysis data collected during 2001–2012 was obtained from UCAR/NCAR (http://rda.ucar.edu/datasets/ds083.2/) and used to analyze the atmospheric circulation. This product is calculated from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources (NECP, 2000). These gridded data are available every 6 h with a resolution of 1°, including geopotential height, components of wind and vertical velocity on 26 pressure levels. FNL uses the Global Forecast System (GFS) model but is delayed an hour or so after the GFS is initialized, so its analysis contains more observational information.

Monthly Niño3.4 data (OISST.v2, 1981–2010 base period) during 2001–2012 were obtained from CPC, NOAA (http://www.cpc.ncep.noaa.gov/data/indices/). The Niño3.4 index is the average sea surface temperature (SST) anomaly in the tropical Pacific (5°N–5°S, 170°–120°W). According to NOAA, this region encompasses the western half of the equatorial cold tongue region, and it provides a good measure of important changes in SST and SST gradients that result in changes in the pattern of deep tropical convection and atmospheric circulation (http://www.ncdc.noaa.gov/teleconnections/enso/indicators/sst.php). Positive (negative) anomalies of greater than or equal to 0.5 °C represent