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Assimilation of wind profiler observations and its impact on three-dimensional transport of ozone over the Southeast Korean Peninsula

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HIGHLIGHTS

- Wind profiler data assimilation was carried out in the south-east coast of Korea.
- Different distribution of ozone concentration due to assimilation is clarified.
- Transported ozone can be estimated precisely through wind profiler data assimilation.
- Its impact on ozone concentration is more effective in upper levels at inland area.

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ABSTRACT

In order to investigate the impact of data assimilation on the assessment of ozone concentration in inland regions in the eastern area of the Korean Peninsula, several numerical experiments have been carried out using the Weather Research and Forecasting (WRF) model to estimate atmospheric circulations and the Community Multiscale Air Quality (CMAQ) model to assess air quality. Observations of wind that are assimilated into the modeling system are obtained from a wind profiler located at Changwon (CW), which is an urbanized coastal region in the Korean Peninsula.

The simulated wind and temperature that is related to a well-developed sea breeze circulation are more consistent with observations in the experiment with dada assimilation than that without the assimilation. The ozone concentrations at both the coastal area of CW and the inland region of DG are well reproduced in the simulation with application of profiler data assimilation. Results from experiments without data assimilation are less realistic than that from the experiment with data assimilation.

However, the improvement in simulation of meteorological variables and ozone concentration due to data assimilation is greater in the inland area than in the coastal area, where the wind profiler is located. The ozone concentration in CW changes only over a limited area and below the altitude of 1 km with a maximum change of 25 ppb. In contrast, the simulated ozone concentration in DG has been improved from the ground to upper levels of the planetary boundary layer (PBL), despite the fact that the observations are collected and assimilated into the model at the coastal region. Based on the results of process analysis, we find that the horizontal and vertical transportation of ozone related to the sea-breeze is more important than the local contribution of chemical production in determining the ozone concentration over the inland area. Therefore, observations of wind profiles in the coastal area and assimilation of these observations into the modeling system are important in our modeling study to assess the ozone concentration in inland areas. The assimilation of observations can greatly improve the model performance in both circulation simulation and ozone concentration simulation.

1. Introduction

Atmospheric circulation is closely related with the transportation and dispersion of air pollutants and under strong influence of surface forcing. Due to topography and the large thermal-dynamic contrast between land and sea, three-dimensional atmospheric circulations tend to be complicated at the complex terrain

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area along the coastal region of the Korean Peninsula. This makes it a challenging issue to understand the characteristics of air pollution solely based on analyses of meteorological and air quality observational data in the Korean peninsula.

Numerical models provide a useful tool to study interaction between atmospheric circulation and air quality. Despite the large uncertainties in numerical model simulations caused by various physical parameterization schemes, such as the planetary boundary layer (PBL) scheme etc., many numerical modeling studies have been conducted to investigate the behavior of air pollutants and their impact. These studies overcome the problem of limited and/or lack of air pollutant observations and give us a relatively complete picture of spatial-temporal variation of air pollutants within the PBL.

Talbot et al. (2007) implemented ground-based remote sensing observations to identify the sea-breeze system and its impact on the atmospheric stratification in the lower troposphere. Based on vertical observations, they investigated the complex structure of the sea-breeze system, such as the thermal internal boundary layer, the sea-breeze-induced front, and the recirculation during the cycle of a sea-breeze development. They also conducted several numerical simulations with hypothetical emission sources of a passive tracer and found that the transport and diffusion of air pollutants were significantly affected by different vertical flows that are related to the sea-breeze structure. Their study clearly indicated that vertical motions that are related to the sea-breeze circulation are essential for understanding the three-dimensional pollutants transport from coastal to inland areas.

Among the observational data used in data assimilation, the wind profiler (hereafter, profiler) measures wind speed and direction every 10 min throughout the PBL. This is a type of Doppler radar that can continuously measure vertical wind structures and therefore produce datasets with high temporal and vertical resolution within the PBL. These two major features ensure that it can provide observations with necessary details, especially when the speed and direction of the local circulation are constantly varying. In addition, observations from the profilers located at the shore or near-shore area compensates for the lack of vertical observations over the sea. Because this observational system is based on a remote sensing technique, errors in radar echoes may be larger than those provided by a direct sensing system. The mathematical algorithm used to produce data from the profiler observations, however, includes several quality control methods such as Gaussian-function fitting, homogeneity check, and quadratic surface check (Ishihara et al., 2006). These methods can efficiently remove the observational errors and provide high-quality products. Benjamin et al. (2004) showed how the profiler observations are assimilated in numerical weather prediction over the USA and concluded that the predictability, especially the short-range forecasts, can be improved for severe weather cases. Observations from the densely distributed profilers in Japan, which has a spatial resolution of 130 km, also contribute to the forecasting accuracy of a mesoscale weather system (Ishihara et al., 2006).

In Korea, Lee et al. (2007) compared two data assimilation results using surface meteorological observations with different spatial resolutions. They found that using densely distributed observations could provide higher accuracy in the prediction of the ozone concentration than that using the less densely observations. Park et al. (2010) proposed that the profiler data should be assimilated as frequently as possible to enable the atmospheric model to capture the varying local wind. On the other hand, they also found low sensitivity to data assimilation interval under the condition of strong synoptic wind.

Most of the previous studies only focused on improving the accuracy of weather forecast by assimilating routinely observed data. So far, few attempts have been made to explore the impact of data assimilation in PBL simulation, including not only the simulation of meteorological variables but also the assessment of air quality within the PBL in the Korean peninsula, where complex terrain and coastal lines add extra difficulties for realistic modeling studies.

In this study, a case of simultaneous occurrence of sea-breeze and high ozone concentration at the southeastern area of the Korean Peninsula is simulated. The profiler data collected near the coast are assimilated for the numerical simulation. Improvements in the simulation of circulation and ozone concentration due to the data assimilation are assessed.

2. High ozone concentrations and the sea-breeze occurrence

Many industrialized and densely populated cities such as Busan (BS), Ulsan (US), Pohang (PH), Changwon (CW), and Jinju (JJ) are located at the coastal area of the southeastern Korean Peninsula (Fig. 1). These cities naturally emit large amounts of pollutants, which influence other areas through dispersion and transportation. For example, Daegu (DG), which is a representative inland city, is under strong influence of various pollutants that are emitted from these coastal urban areas (Lee et al., 2008).

An episode of high ozone concentration occurred over the southeastern area of the Korean Peninsula in early August, 2008. Table 1 shows the counts per site for the 8-h average ozone concentration larger than 60 ppb, which is the maximum allowable ozone concentration recommended by the Korean Environmental Ministry. The table also shows the number of sites at each city and the daily maximum ozone concentration in parentheses. In DG, the episode of high-ozone concentration lasted for 4 days and the maximum ozone concentration occurred on 5 Aug, 2008. Although the episode lasted for only 1 dayat cites located in the eastern coast of this area such as PH and US, high ozone concentration continued at CW and JJ, which are located in the southern coast of this area. The situation in CW and JJ is quite similar to that in DG. Since high concentration of air pollutants usually occurs under the condition of weak synoptic forcing, air quality is largely affected by local circulation. Under the calm weather with low wind speed and cloud fraction, local circulation patterns are dominant in chemical reaction rate and transportation of pollutants (Choi et al., 2009).

The synoptic pattern of surface pressure (not shown here) is favorable for the development of local circulation during the period of this episode. The North Pacific anticyclone extended eastward and covered most of the East Asia, resulting in a separated high pressure system that was located in the central Korean Peninsula.

The local circulation induced by the land-sea contrast was well observed by the profiler installed in CW during the first two days of this high ozone episode (Fig. 2). Changes in the synoptic scale high pressure system resulted in changes in wind direction in the upper layer at an altitude above 1 km. Diurnal variations in wind speed and direction were detected near the ground, which actually reflected the land-sea breeze circulation. The northerly and easterly winds in the morning of 4 August changed to southeasterly in the afternoon due to the penetration of the fully developed sea-breeze, and the wind speed increased simultaneously. The sea-breeze further developed until night time and reached the altitude of 1 km, as judged by the vertically extended southerly wind with time. A similar diurnal variation of surface winds was observed on 5 August. However, the vertical extension of the sea-breeze was relatively suppressed on 5 August since the northerly synoptic wind above 1 km was stronger than that on 4 August. Note that the wind speed and direction in this area frequently change due to the complicated interaction between the synoptic and local circulations. Therefore, assimilation of the observations at this area is