Characterization of urban NO_2 transport with a Coherent Doppler Lidar and WRF-Chem model

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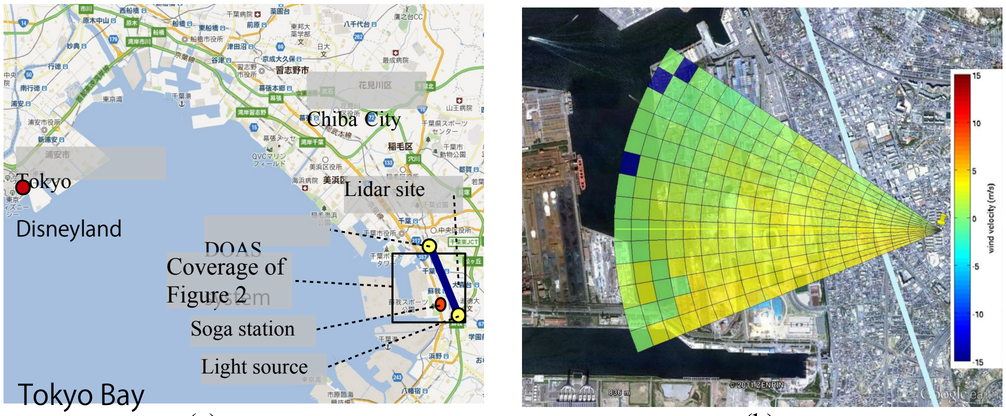
ABSTRACT

The temporal and spatial distribution of NO_2 within parts of Kanto region in central Japan was characterized with differential optical absorption spectroscopy (DOAS) and a regional air-quality model WRF-Chem initialized by a coherent Doppler lidar. The DOAS system utilizes existing aviation obstruction xenon flashlamps to measure horizontally averaged column NO_2 concentration. Simulation of NO_2 emission, transport and dispersion using WRF-Chem reproduced the observations well. Physical initialization of initial and boundary wind conditions was applied using wind velocity data from a high resolution coherent Doppler lidar, with the initialized simulation case having qualitatively better correspondence to DOAS and ground measurements. The Doppler wind data proves suitable as input in a chemical transport model. Moreover, the result reiterates the importance of accurate meteorological data in air quality modeling to properly characterize urban pollutants.

1. Introduction

Atmospheric NO_2, half of which can usually be attributed to combustion of fossil fuel (Lee et al., 1997), appears to have a decreasing emission trend especially in developed countries. Nonetheless, it remains to be an important pollutant due to its key role in the atmospheric radical chemistry that leads to the oxidation of reactive gases and to the (photochemical) formation of ozone (Monks et al., 2009). In this study, we compare tropospheric NO_2 measurements from differential optical absorption spectroscopy (DOAS) and WRF-Chem air quality model to characterize the transport of NO_2 in the area. The DOAS technique measures horizontally integrated column of such gases as NO_2, SO_2 and O_3 based on the measurement of the difference between the maxima and minima in the absorption spectrum of the probed gas (Platt 1979). In the conventional long-path DOAS method, a continuously emitting light source is employed and the source is placed at a certain distance from the observation site where the spectrum of the transmitted light is analyzed with a spectrometer. Our group utilizes aviation flashlamps as the DOAS light source, and this novel setup has been proven to be effective in some previous studies (Yoshii, 2003; Si, 2005; Kuriyama, 2011). We have shown that the NO_2 detection limit is approximately 1 part per billion and that the DOAS measurements were in agreement with other concurrent observations (i.e. ground stations). In addition, we used wind data from a

Coherent Doppler lidar to assimilate model wind pattern by physical initialization. Figure 1 (a) shows the observation location which is on the eastern side of Tokyo Bay, and (b) the range of the coherent Doppler lidar.



(a) (b)

Figure 1 (a) Location of observation site East of Tokyo Bay and (b) Coherent Doppler Lidar area coverage and DOAS light path (blue line).

2. Experimental Setup

2.1 Differential optical absorption spectroscopy

A commercial astronomical telescope (20 cm diameter/800 mm long) is used to focus the image of an aviation obstruction flashlamp (Sanken Electric) mounted on an electric transmission tower. A compact CCD spectrometer (Ocean Optics, USB2000) is placed in the eyepiece location of the telescope where the image of the flashlight forms. The DOAS system is placed on the top floor of a 4 story building (Samugawa High School, 35.60N, 140.12E) and the light source on an electric transmission tower, 74 m above the ground that is approximately 3.5 km away.

2.2 Coherent Doppler lidar

A coherent Doppler lidar (CDL) was used to measure wind velocity over the area of observation (Fig. 1 (b). The CDL system uses a 1.5 μm cw erbium-doped fiber laser with variable pulse width and automatic polarization control. A summary of the specification of the CDL system is enumerated in Table 1. The lidar is located on the 5th floor of the Miyako library in Chiba City (35.57N, 140.14E), facing west where a steel factory on the east coast of Tokyo Bay is located about 1.5 km away. The system scans from 242° to 298° (± 28° from 270° (west)) at a rate of 1°/sec, resulting in one complete scan per minute.

Table 1: Specification of Doppler lidar

Laser	Erbium-doped fiber laser (DFB EDFL)
Wavelength	1545 nm
Laser Pulse energy	3.2 μJ
Receiving bandwidth	2 MHz
Effective aperture diameter	50 mm
Max Range / resolution	2.75 km / 150 m

2.3 WRF-Chem Model

Weather Research and Forecast (WRF) (http://www.wrf-model.org) is a mesoscale numerical weather system designed for both operational forecasting and atmospheric research applications with horizontal resolutions ranging from meters to thousands of kilometers. Is is a non-hydrostatic model, with several dynamic cores including a fully mass and scalar conserving coordinate version that is widely used in air quality prediction applications. The chemistry component of the WRF-CHEM (Grell et. al., 2005) is a fully coupled regional air quality modeling system, which is being continually developed by NOAA (National Oceanic and Atmospheric Administration of USA) and several other research institutes (http://ruc.noaa.gov/wrf/WG11/). The meteorological initial and boundary conditions are from the National Center for Environmental Prediction (NCEP) Final Operational Model Global Tropospheric Analyses (FNL) data, available every 6 hours at 1°×1° grid spacing resolution (http://dss.ucar.edu/). Anthropogenic emissions for gaseous species were taken from the global emission inventory data for the year 2005 compiled and distributed by the Database for Global Atmospheric Research (EDGAR) system.

3. Results and discussion

In this study, we make use of the physical initialization method in assimilating data from the high resolution CDL wind data. Two simulation cases are conducted: one control run (WRF-Chem) using FNL reanalysis data and another (WRF-PI) with wind initial and boundary conditions modified by physical initialization. Observed and simulated diurnal variations in NO_2 concentration for 1 November 2011 are shown in Fig. 2. Observed values are from the DOAS system and AEROS (Soramame) ground sampling at a nearby (Soga) station, while simulated values are from the WRF-Chem model with and without physical initialization.

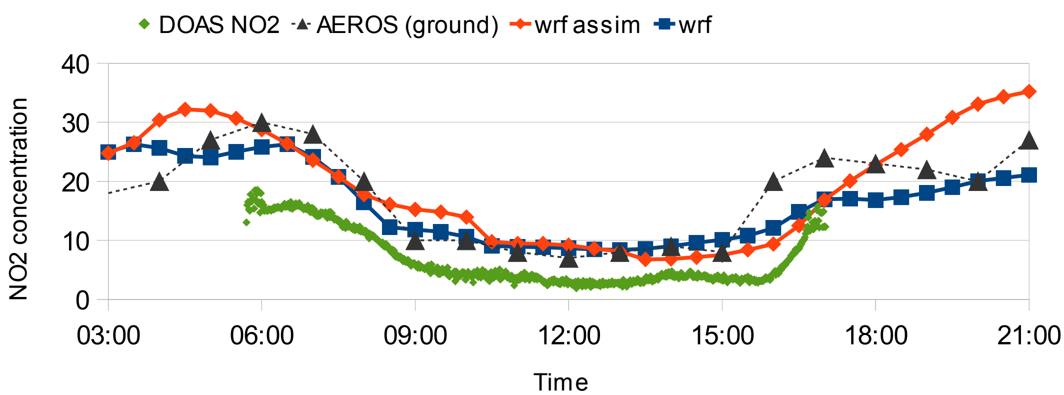
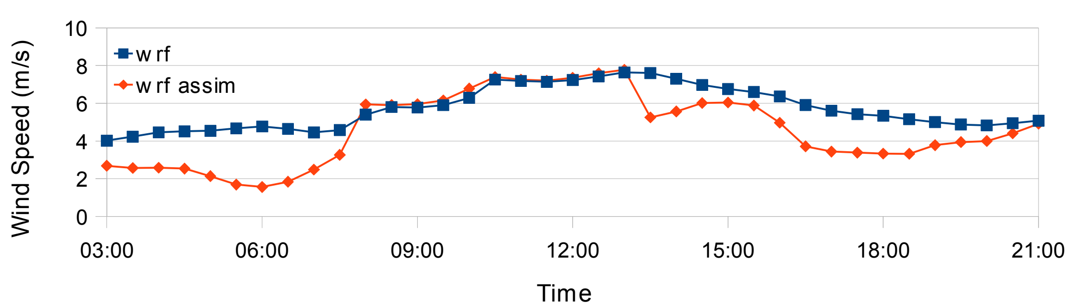
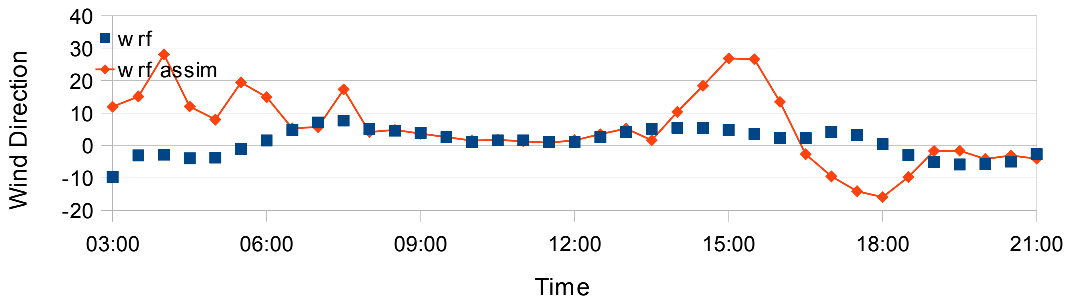


Figure 2. Observed and simulated NO_2 concentration by DOAS, Soramame ground sampling and WRF-Chem simulation with (wrf assim) and without (wrf) assimilation on 1 November 2011.



(a)



(b)

Figure 3. Simulated wind velocity with and without assimilation for 1 November 2011.

Ground sampling appears to have a positive bias compared to the DOAS observation. This is attributed to lower concentrations at relatively higher altitude observation of DOAS. Also, ground samplers may become sensitive to other gas species. Overall, there is a good qualitative fit between observed and simulated NO_2 concentration, with increased values seen during nighttime due to the development of the nocturnal boundary layer. Wind velocity plays a significant role in air pollution. Wind speed generally dictates the volume of air while direction affects the source of pollutants. There are subtle differences in the assimilated and non-assimilated winds, which resulted in differences in simulated NO_2 concentration.

4. Conclusion

Differential optical absorption spectroscopy is an effective tool in atmospheric gas measurement like NO_2, in addition to its capability of providing data on aerosol particles. In this work, comparison between DOAS and WRF-Chem model has shown good qualitative agreement, as well as ground sampling concentration. The use of coherent Doppler lidar yielded slight variations in the simulated wind speed and direction, and these changes translated to changes in simulated NO_2 concentration. More results will be presented in the conference presentation.

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