A Case Study on Observed and Simulated CO_2 Concentration Profiles in Hefei based on Raman Lidar and GEOS-Chem Model

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ABSTRACT

Observations of atmospheric CO_2 concentration profiles provide significative constraints on the global/regional inversions of carbon sources and sinks. Anhui Institute of Optics and Fine Mechanics of Chinese Academy of Sciences developed a Raman Lidar system to detect the vertical distribution of atmospheric CO_2. This paper compared the observations with the modeled results from a three-dimensional global chemistry transport model-GEOS-Chem, which showed a good agreement in the trend of change with lidar measurements. The case study indicated a potential for better simulating vertical distribution of atmospheric CO_2 by combining with lidar measurements.

1. INTRODUCTION

Observations of atmospheric CO_2 concentration profiles provide significative constraints on the global/regional inversion of carbon sources and sinks. Raman Lidar has possessed the capability of conducting high temporal and vertical resolution measurements of CO_2 concentration profiles [**1-3**]. By assimilating those informations of vertical distribution of CO_2 concentration in atmosphere under synthetic inversion framework, the uncertainty of the regional carbon budget prediction will be reduced. In this paper, we proceeded a case study on CO_2 concentration profiles observed by a complicated Raman lidar system, developed by Anhui Institute of Optics and Fine Mechanics of Chinese Academy of Sciences, and compared observations with simulated results from a global three-dimensional chemistry transport model-GEOS-Chem, which could provide a valuable basis for better using lidar data to improve the simulation of atmospheric CO_2 concentration.

2. DATA AND METHOD

2.1 GEOS-CHEM MODEL

GEOS-Chem is a global 3-D chemical transport model of atmospheric composition driven by assimilated meteorological observations from the Goddard Earth Observing System (GEOS) of the National Aeronautics and Space Administration (NASA) Global Modeling and Assimilation Office (GMAO). We used the model (v9-01-02) to simulate the atmospheric CO_2 concentrations on a horizontal resolution of 2° latitude × 2.5° longitude and on a vertical resolution of 47 layers from the surface to 0.01 hPa. The model was integrated with GEOS-5 meteorology for eight years (2004–2011) from an initial condition of uniform CO_2 (375.0 ppmv) as a "spin up" period [**4**]. The sources (or sinks) for the simulations in

this study included emissions from fossil-fuel burning and cement production, biomass burning, biofuel burning, balanced biosphere (net ecosystem production), ocean, net terrestrial exchange, aircraft, and marine.

2.2 RAMAN LIDAR SYSTEM

The Raman lidar system applied 354.7nm third harmonic of Nd:YAG laser, which was transmitted with 350 mJ pulse energy and repetition rate of 20 Hz. The receiver employed a photomultiplier tube with quantum efficiency of 25% and 200 MHz photon counter, and detected Raman backscattering 371.66 nm (shift 1285cm(-1)) signal [detailed lidar description can be found in **5**, **6**]. The principle of the system is based on the Raman scattering by CO_2 molecules in the atmosphere. The laser beam simultaneously motivated Raman scattering of atmospheric CO_2 and N_2, and the number of received photons is in proportion to the molecular density of the two gases. By detecting the backscattering Raman signal ratio of CO_2 to N_2 at different altitude, we can obtain the relative concentration of atmospheric CO_2 as the following formula:

$$\frac{n_1(z)}{n_2(z)} = \frac{\beta_{CO2}}{\beta_{N2}} \frac{\eta_1}{\eta_2} \frac{N_1(z)}{N_2(z)} \exp\left[\int_0^z [\alpha(\lambda_1, z) - \alpha(\lambda_2, z)] dz\right]$$

Where $N_1(z)$ and $N_2(z)$ represent backscattering Raman signal ratio of CO_2 and N_2 received by lidar system, η_1 and η_2 denote the instrument efficiency constants of the two channels, β indicates the scattering cross section.

3. RESULTS

To deduce the atmospheric CO_2 concentration at different altitude, a Li-7500 H_2O/CO_2 analyzer installed on a tower at 30m height above the ground was employed to calibrate the observation results (as shown in Fig.1). The vertical resolution of the lidar system was 30m, and the signals were accumulated by 20000 pulses which generated a CO_2 concentration profile every 17 minutes. Fig.1 showed that the lidar observed CO_2 concentration (i.e. the backscattering Raman signal ratio of CO_2 to N_2 during the night of May 2, 2012 was in reasonable accordance with observations from Li-7500 except for the first measurement which was likely due to the instability of the lidar system at the beginning. The signals were then linear fitted with the CO_2 concentration observed by Li-7500 to obtain the profiles.

After the inversions of atmospheric CO_2 vertical

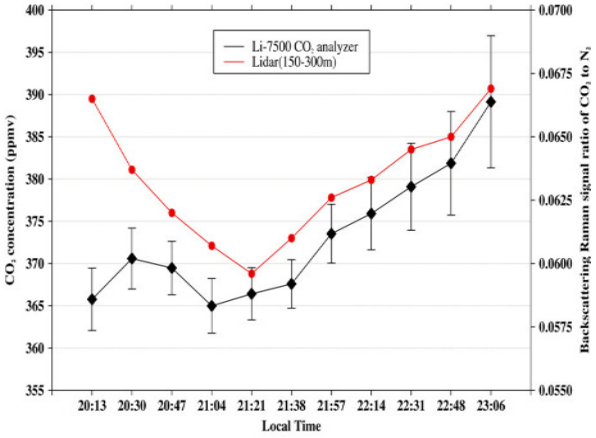

Fig.1. Comparisons between Li-7500 CO_2 analyzer and Raman lidar on May 2, 2012

profiles, we compared the average results with the model simulations (Fig.2). The nearest grid of GEOS-Chem was selected to represent the observed CO_2 concentrations in HeFei (39°58′N, 116°22′E), and the vertical layers under 1.05 km were chosen and linear interpolated to the resolution of the observations. The simulations mainly captured the observed vertical variations of CO_2 concentration with a lower changing amplitude (~15 ppmv). However, the observed CO_2 concentration decreased from ~430 ppmv at 0.03 km to ~385 ppmv at 0.09 km. This indicated that the modeled CO_2 concentration profile could not preferably reflect the coupling between the regional carbon sources/sinks and synoptic atmospheric transport, which could be

resolved by improving the resolution of the model and optimizing the subgrid parameterization scheme.

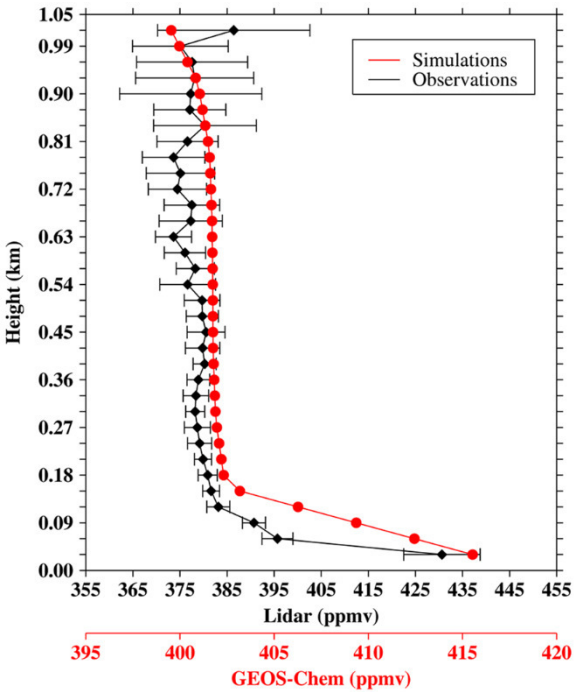

Fig.2. The mean lidar observed and simulated CO_2 concentration profiles on May 2, 2012. The error bars denote the spread of the observations.

4. CONCLUSIONS

The observations from Raman lidar system have shown a good agreement in the trend of change with the Li-7500 H_2O/CO_2 analyzer. Although the model simulations mainly captured the characteristics of atmospheric CO_2 vertical distribution, further in-depth studies need to be carried out to improve the capability of the model combining with lidar observations.

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