# MODELING DAILY AND SEASONAL DYNAMICS OF $CO_2$ STABLE CARBON ISOTOPIC EXCHANGE BETWEEN BOREAL ECOSYSTEMS AND PLANETARY BOUNDARY LAYER

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## ABSTRACT

In this study, we developed an integrated modeling system to simulate dynamics of a stable carbon isotope of $CO_2$, moisture, energy, and momentum between boreal ecosystems and the atmosphere as well as their diffusion processes through the whole convective boundary layer (CBL), using remotely sensed surface parameters to characterize the surface heterogeneity, and the marine boundary layer matrix data to represent the CBL top condition. Model validation and primary results in boreal ecosystems were presented in this paper.

## INTRODUCTION

Stable isotopes of $CO_2$ contain unique information on the biological and physical processes that exchange $CO_2$ between terrestrial ecosystems and the atmosphere [*Tans et al*., 1993].Mechanistic biophysical models that couple micrometeorological and eco-physiological process simulations have the potential to provide additional information on the global carbon budget [*Baldocchi and Bowling*, 2003]. The influence of the CBL cannot be ignored when using isotope composition of $CO_2$ to investigate biological processes [*Bowling et al*., 1999] because the effect of atmospheric stability on turbulent diffusion has an important impact on scalar fluxes and concentration fields.

## METHODOLOGY

In order to account for the influences of the CBL turbulent mixing and entrainment of the air aloft on $^{13}CO_2$ discrimination and diffusion, we designed a one-dimensional vertical diffusion scheme (VDS) for $^{13}CO_2$ based on conservation of mass and energy, which involves the interaction between plant canopies and the atmosphere in the surface layer (i.e., $^{13}C$ discrimination) and $^{13}CO_2$ diffusion within the mixed layer. We extend previous work on $CO_2$ [*Chen et al*., 2004] to a stable carbon isotope. We also made some expansions in the BEPS2.0 model to simulate flux densities of $^{13}CO_2$ at the canopy level. The photosynthetic discrimination against $^{13}CO_2$ at the leaf level (Δ, in per mil, ‰) was computed according to previous methods [*Farquhar et al*., 1989]. The $\Delta_{canopy}$ is calculated as the flux-weighted average of net carbon assimilation for sunlit leaves and shaded leaves.

## RESULTS AND DISCUSSION

Modeled and measured hourly averaged $\delta^{13}C$ mixing ratios for the three campaign periods in 1999 at Fraserdale tower (Ontario, Canada) is plotted in Fig.1 and the regressions against these data are list in Table 1. These results show that the diurnal variations in both $CO_2$ and $\delta^{13}C$ in the surface layer were simulated well in the growing season (e.g., Fig.2). During the growing season in 1999, the mean $\Delta_{canopy}$ against $^{13}CO_2$, by boreal ecosystems in the vicinity of the Fraserdale tower was computed to be 18.38‰. The monthly averages of $\Delta_{canopy}$ varied betwen14.98‰ and 20.74‰ and peaked in the middle growing season. While on a diurnal basis, the greatest discrimination occurred during the early morning and late afternoon with a varying range of 10‰ to 26‰.The strong opposing influences of respired and photosynthetic fluxes on forest air (both $CO_2$ and $^{13}CO_2$) were apparent on both the diurnal and seasonal time scales. $CO_2$ was consistently enriched with the heavier $^{13}C$ isotope (less negative $\delta^{13}C$) from July to October and depleted during the remaining months, while on a diurnal basis, $CO_2$ was enriched with the heavier $^{13}C$ in the late afternoon and depleted in early morning. The boreal ecosystems in the vicinity of the Fraserdale tower sequestered around 1.90 mol $m^{-2}$ of carbon and -20 mol $m^{-2}$ ‰ of $\delta^{13}C$ in 1999.

## CONCLUSIONS

The ecosystem model (BEPS2.0) and the 1-D atmosphere model (VDS) were expanded and coupled to simulate the dynamics of stable carbon isotope of $CO_2$ exchange between boreal ecosystems and the atmosphere as well as their diffusion processes through the whole CBL. The computed concentration of $^{13}CO_2$ at the surface layer during the growing season in 1999 at Fraserdale agreed well with intensive campaign data. Factors contributing to the satisfactory performance of the isotope BEPS-VDS model include its large vertical domain through the whole CBL, its dependence on coupled and constraining processes, such as leaf energy exchange, turbulent transfer, photosynthesis and stomata conductance, and its representation of these processes on separate sunlit and shaded leaf classes. This approach contrasts with that of simpler 'big leaf models' which do not properly consider non-linear biological combinations of the sunlit and shaded fractions of the canopy. This approach is also different from most existing isotopic biophysical models [e.g., *Baldocchi and Bowling*, 2003] that only focus on the land surface layer without involving the CBL turbulent mixing and entrainment of the air aloft.

**Table 1.** Linear regression statistics between modeled and tower observed hourly averaged $CO_2$ and campaign measured $\delta^{13}C$ in the surface layer (20m height) for the three campaign's periods in 1999, Fraserdale, Ontario, Canada

| | MBE ( ‰) | RMSE ( ‰) | RMSD(%) | $r^2$ | n |
|---|---|---|---|---|---|
| Campaign 1 (2-7, June) | 0.007 | 0.127 | 1.504 | 0.926 | 32 |
| Campaign 2 (21-23, July) | 0.112 | 0.343 | 4.298 | 0.757 | 40 |
| Campaign 3 (10-12, Sept.) | 0.078 | 0.393 | 4.773 | 0.705 | 35 |

**---MBE is the mean bias error; RMSE is the root mean square error, RMSD is the root mean square difference expressed in percentage of the average of observed $\delta^{13}C$, $r^2$ is the squared linear regression coefficient, and n is the sample number.*

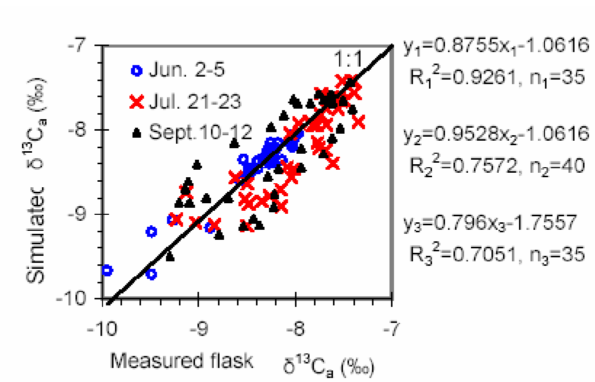


Fig. 1. Linear regression relationships between simulated and measured hourly $\delta^{13}CO_2$ at 20 m height during the growing season in 1999 at Fraserdale tower site, Ontario, Canada. Here *y* and *x* represent simulated and observed $\delta^{13}CO_2$ ratio, respectively; *R* and *n* denote the linear correlation coefficient and sample number, respectively; subscript 1-3 denotes the campaigns during June 2-7, July 21-23, and September 10-12, respectively.

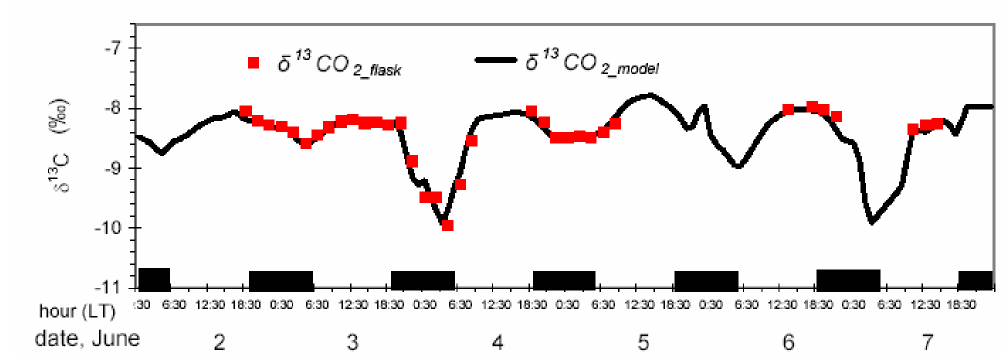


Fig. 2. Simulated and flask measured $\delta^{13}C$ of $CO_2$ at 20 m height during 2-7, June 1999 at Fraserdale tower site, Ontario, Canada. Dark bars on the horizontal axis denote nocturnal periods.

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