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Seasonal variation in carbon dioxide exchange over a 200-year-old Chinese broad-leaved Korean pine mixed forest

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Abstract

Long-term measurement of carbon metabolism of old-growth forests is critical to predict their behaviors and to reduce the uncertainties of carbon accounting under changing climate. Eddy-covariance technology was applied to investigate the long-term carbon exchange over a 200-year-old Chinese broad-leaved Korean pine mixed forest of Forest Ecosystem Open Research Station of Changbai Mountains (128°28′E and 42°24′N, Jilin Province, PR China), Chinese Academy of Sciences, since August 2002. This paper reports the result on (1) phase and amplitude of ecosystem CO_2 uptake and release and (2) sink/source status on the data obtained with open-path eddy-covariance system and CO_2 profile measurement system from August 2002 to August 2003. Corrections due to storage and friction velocity were applied to the eddy carbon flux. Behavior of pressure flux, neglected in common WPL correction, was analyzed to develop acceptable u_* range in dormant periods.

The ecosystem was a net sink of atmospheric CO_2 and sequestered -308 ± 116 g C m^{-2} during the study period. The estimates of gross carbon gain and loss at this forest were -1432 ± 216 and -1124 ± 181 g C m^{-2} separately. The seasonal trend of gross primary productivity (F_{GPP}) and respiration (R_E) followed closely the change in vegetation absorption index (V_{AI}) and temperature. The summer is the most significant season as far as ecosystem carbon balance is concerned. The net ecosystem exchange (F_{NEE}) during this period was about -298.0 ± 65.2 g C m^{-2}. The 90 days of summer contributed 67.0% of F_{GPP}, 58.9% of R_E of whole year. This study shows that old-growth forest can be strong net carbon sink of atmospheric CO_2.

There are uncertainties in estimate of annual carbon fluxes with eddy-covariance method. More work on advection and pressure fluxes is warranted.

Keywords: Net ecosystem exchange; Gross primary production; Ecosystem respiration; Old-growth forest; Eddy-covariance; Friction velocity

1. Introduction

Forests have been proposed as possible sinks of the 'missing' atmospheric carbon that is not accounted for by global carbon cycle models (Tans et al., 1990; Francey et al., 1995; Keeling et al., 1996; Fan et al., 1998). While young and recovering forest have obvious potential as carbon sinks, forests older than approximately 100 years are thought to be in equilibrium between carbon uptake and total ecosystem respiration (TER), sequestering little and are generally considered to be insignificant carbon sinks (Jarvis, 1989; Melillo et al., 1996).

In contrast research by Carey et al. (2001) emphasized the need to account for multiple-aged, species-diverse, mature forests in models of terrestrial carbon dynamics to approximate the global carbon budget. Several recent process studies have indicated that some old forest ecosystems do not reach a steady

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Nomenclature

Meteorological variables

L MO length scale (m)
P_a barometric pressure (kPa)
Q_{PPFD} photosynthetic photon flux density (μmol m^{-2} s^{-1})
T_a air temperature (°C)
T_s soil temperature (°C)
u wind speed (m s^{-1})
u_* friction velocity (m s^{-1})
V_{PD} vapor pressure deficit (kPa)

Flux variables

F_{GPP} gross primary production (g C m^{-2})
F_{NEE} net ecosystem exchange of CO_2, calculated as the sum of the CO_2 flux determined by eddy-covariance and the CO_2 storage change in the canopy air layer (the sign convention of F_{NEE} is from the perspective of the atmosphere, i.e. a negative sign means the atmosphere is losing carbon) (mg CO_2 m^{-2} s^{-1} or g C m^{-2} yr^{-1})
F_{NPP} net primary production (g C m^{-2} yr^{-1})
F_{RE} ecosystem respiration (mg CO_2 m^{-2} s^{-1} or g C m^{-2} yr^{-1})
$F_{RE,day}$ ecosystem respiration during daytime (mg CO_2 m^{-2} s^{-1})
$F_{RE,night}$ ecosystem respiration during nighttime (mg CO_2 m^{-2} s^{-1})
$F_{RE,T_{ref}}$ F_{RE} at reference temperature T_{ref} (mg CO_2 m^{-2} s^{-1})
$F_{WPL,M\&L}$ WPL correction term including pressure contribution (Massman and Lee, 2002) (mg CO_2 m^{-2} s^{-1})
R_s soil respiration (mg CO_2 m^{-2} s^{-1} or g C m^{-2})
γ_s the contribution of soil surface efflux to ecosystem respiration

Other variables

a_1 parameter of Eq. (6) and may be interpreted as the maximum photosynthetic uptake (mg CO_2 m^{-2} s^{-1})
a_2 parameter of Eq. (6) and may be interpreted as the light level (Q_{PPFD}) corresponding to half the maximum photosynthesis rate
D_{WG} annual biomass dry weight growth (g m^{-2} yr^{-1})
E_a parameter of Eq. (7) and can be interpreted as the activation energy (J mol^{-1})
I_C carbon content (%)
k the extinction coefficient for diffuse light
R the gas constant (8.314 J K^{-1} mol^{-1})
R_D parameter of Eq. (6) and may be interpreted as the mean of daytime respiration
V_{AI} vegetation absorption index, deduced from Q_{PPFD} measurements above and below canopy
z_r the height where eddy-covariance systems installed (m)
γ_{wc} ratio of pressure flux to eddy CO_2 flux
μ_v the ratio of the molecular mass of dry air to the molecular mass of water vapor
$\bar{\rho}_c$ the mean ambient CO_2 density (mg m^{-3})
τ_c the canopy transmittance, estimated as the ratio of the averaged flux density measured below the canopy to the flux density measured above canopy
$\bar{\chi}_v$ the volumetric mixing ratio for water vapor
$\bar{\varpi}_c$ the mean mass mixing ratio for CO_2

state carbon flux and can continue to act as a net sink for atmospheric carbon dioxide over several decades or longer (Buchmann and Schulze, 1999; Hollinger et al., 1999; Janssens et al., 2001; Chen et al., 2002). Long-term measurements of whole ecosystem carbon exchange are needed to determine the sink/source and budget status of ecosystems, and to analyze how carbon exchange varies with seasonal and interannual variation in environmental conditions. However, very few actual measurements of F_{NEE} in old forest have been conducted, and results varied depending on conditions (Hollinger et al., 1999; Anthoni et al., 2002; Chen et al., 2002; Knohl et al., 2003; Kurpius et al., 2003; Law et al., 2003; Paw and Falk, 2003). More actual measurements are needed to clarify the role of old-growth forests. Given the importance of the world's old-growth forests as a major terrestrial carbon store, the study on the dynamics of carbon stock capacity and carbon sink strength of old-growth forests will help to reduce the uncertainties in carbon accounting.

The Changbai mountain mixed broad-leaved and Korean pine forest, which is the dominant vegetation type of north-east of China (Institute of Applied Ecology, Chinese Academy of Sciences, 1980), is about 200 years old (Yang et al., 1985). In this paper, we