Modeling Vegetation-Atmosphere CO_2 Exchange by a Coupled Eulerian-Lagrangian Approach

by

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Abstract

A Eulerian-Lagrangian canopy microclimate model was developed with the aim to discern physical from biophysical controls on CO_2 and H_2O fluxes. The model couples radiation attenuation with mass, energy, and momentum exchange at different levels within the canopy. Explicit accounting for within canopy CO_2, H_2O, and heat storage is resolved by considering non-steadiness in mean scalar concentration. A seven-day experiment was conducted in August of 1998 to investigate whether the proposed model can reproduce temporal evolution of scalar fluxes, sources and sinks, and concentration profiles within and above a uniform 15-year old pine forest. The model well reproduced measured depth-averaged canopy surface temperature, CO_2 and H_2O concentration profiles within the canopy volume, CO_2 storage flux, net radiation above the canopy, and heat and mass fluxes above the canopy, as well as the velocity statistics near the canopy-atmosphere interface.

Introduction

Quantifying the exchange of matter, energy, and momentum between the biosphere and the atmosphere requires detailed understanding of the interactions between canopy structure and local canopy microclimate. The vertical structure of vegetation affects canopy microclimate by intercepting radiation, extracting momentum from the air flow aloft, and acting as a source or sink of mass and energy. In return, the microclimate surrounding vegetation directly impacts physiological and biophysical processes controlling carbon dioxide, heat, and water vapor exchange with the atmosphere.

We propose to model such interactions by coupling a higher-order Eulerian closure approach to compute velocity statistics for use in Lagrangian scalar transport with the *CANVEG* radiation/energy balance/ biophysical framework of Baldocchi (1992, 1998). The combined Lagrangian-Eulerian approach is then used to estimate mean CO_2 concentration, sources and sinks, and fluxes within the canopy and compared to measurements.

Theory

The canopy is divided into layers, each of thickness dz, and all the below equations are solved at each layer.

→*Scalar Balance for Temperature, Water Vapor and* CO_2.

→*Lagrangian Dispersion Transport Approaches to couple Sources with Concentration.*

→*Leaf-Atmosphere Exchange to relate Sources to Concentration and physiological functions*

→*Collatz et al. (1991) biochemical model for linking physiological parameters to environmental and other modeled parameters*

→*Radiation/Energy balance for light/surface temperature*

→*Higher Order Closure Models for Computing Velocity Statistics needed to drive the Lagrangian models*

Model Operation

Input:

At a reference height above canopy:

- Atmospheric concentrations of CO_2, water vapor (H_2O), air temperature (T), mean wind speed, and PAR.

- Leaf area density, physiological functions, canopy radiative properties and drag properties.

Model Output:

- CO_2/H_2O/Heat sources and sinks
- CO_2/H_2O/Heat vertical fluxes
- CO_2/H_2O/Heat mean profiles

- Velocity statistics (first and second moments) inside the canopy.
- Radiation absorption by the foliage, and net radiation.
- Intercellular (C_i) profile within canopy.
- Surface temperature (T_s) profile within canopy.

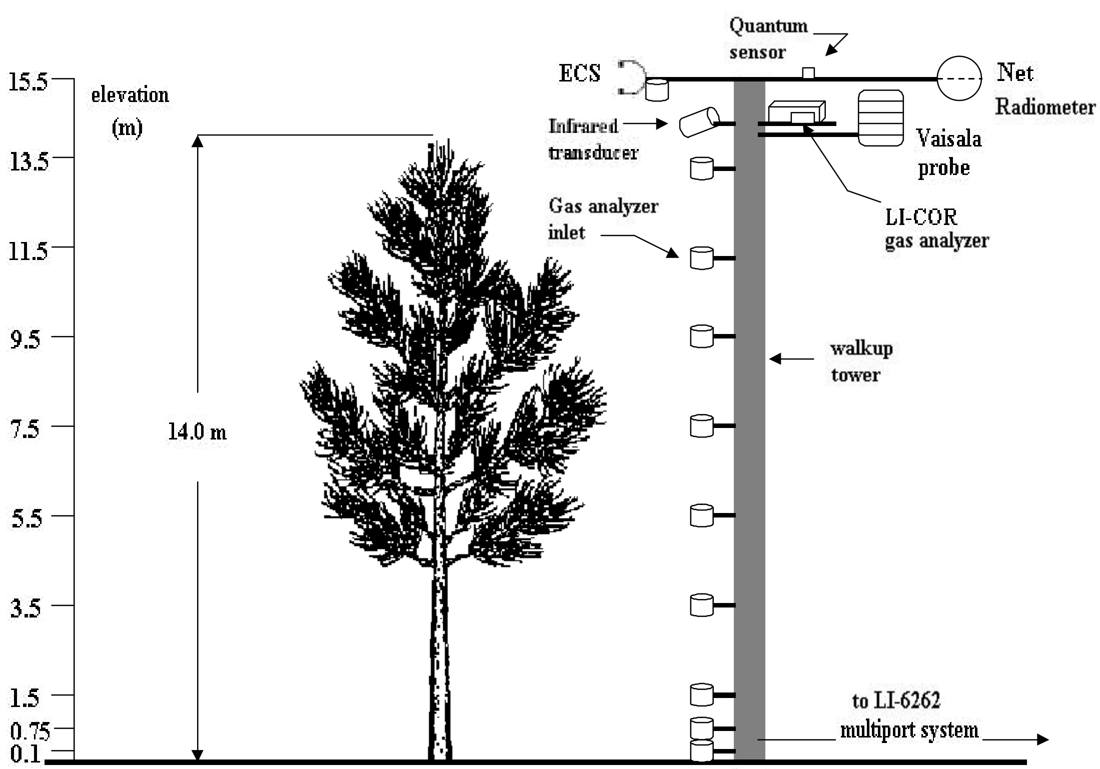
Experiment - Duke Forest AmeriFlux Site

Site:

The data set was collected from August 24 – 31, 1998 at the Blackwood Division of the Duke Forest near Durham, North Carolina (35^{o}98'N, 79^{o}8'W, elevation=163 m). The site is a uniformly planted loblolly pine (*Pinus* taeda *L.)* forest that extends 300 – 600 m in the east-west direction and 1000 m in the north-south direction. The mean canopy height was 14.0 m ($\pm$0.5 m) at the time of the experiment.

Setup:

Eddy-Covariance System (ECS)



Results and Discussion

- The model well reproduced the measured net radiation and remotely sensed skin temperature (*Figure 1*).
- The modeled sources and sinks for CO_2 and H_2O are strongly coupled to the leaf area density but are very different from the heat sources (*Figure 2*) in terms of maximum source strength location.
- The model also reproduced eddy-covariance measured CO_2 (F_{co2}), latent (LE), and sensible heat (H) fluxes above the canopy (*Figure 3*).
- While explicit testing of the source strength is not possible, the model calculations agree well with the measured CO_2 concentration within the canopy volume (*Figure 4*).
- The storage flux for CO_2 was also well reproduced by the model (*Figure 5*). Notice that the storage flux is significant between 08:00 - 09:00 and 18:00 - 20:00 when compared to the eddy covariance flux (*Figure 5*).

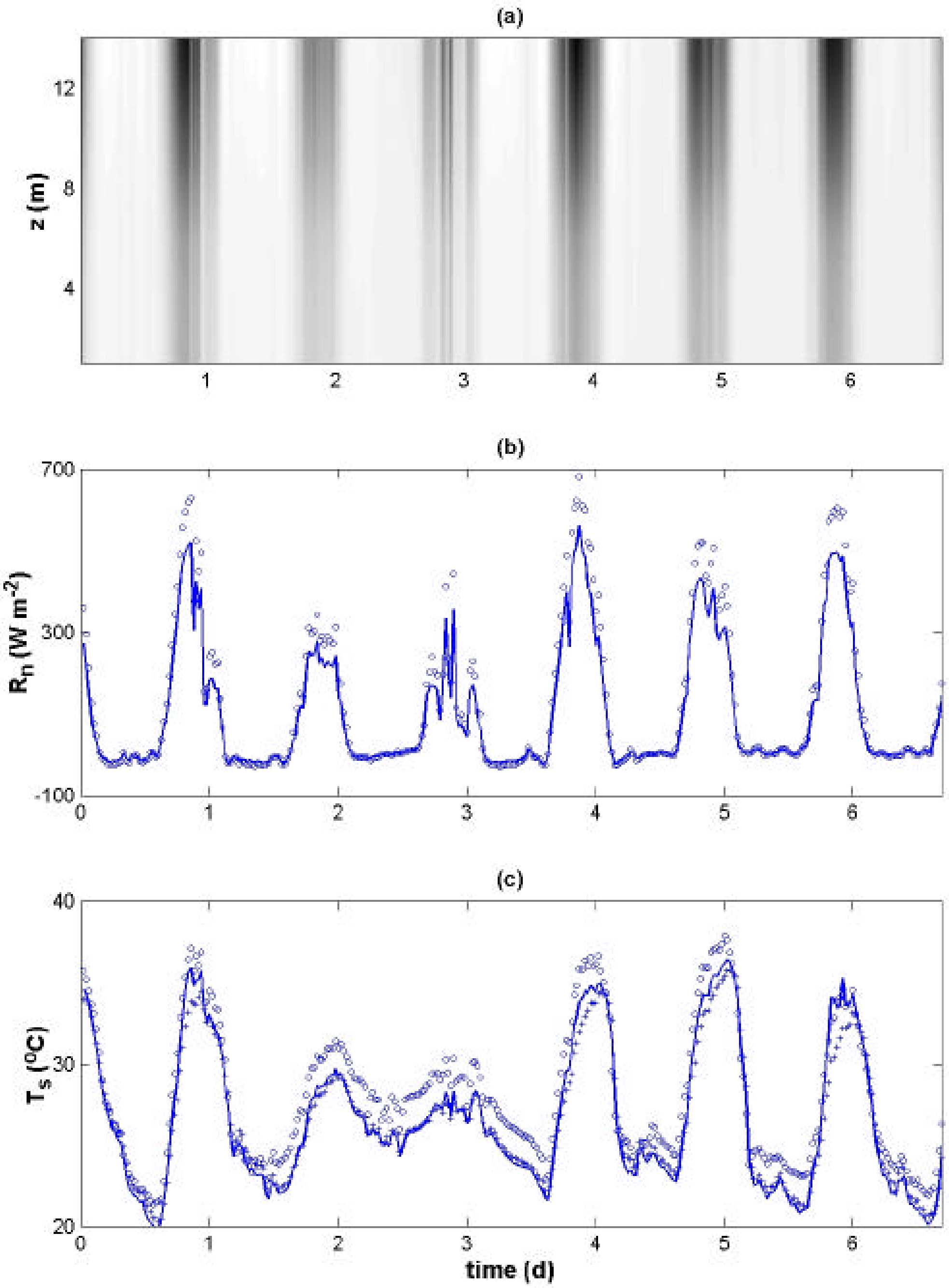


Figure 1: (a) Computed radiation absorption by the canopy; (b) Modeled net radiation R_n (solid) compared to measurement (circles) (c) Modeled over-all depth-averaged canopy surface temperature T_s (solid) with measured air (+) and remotely sensed surface (circle) temperatures.

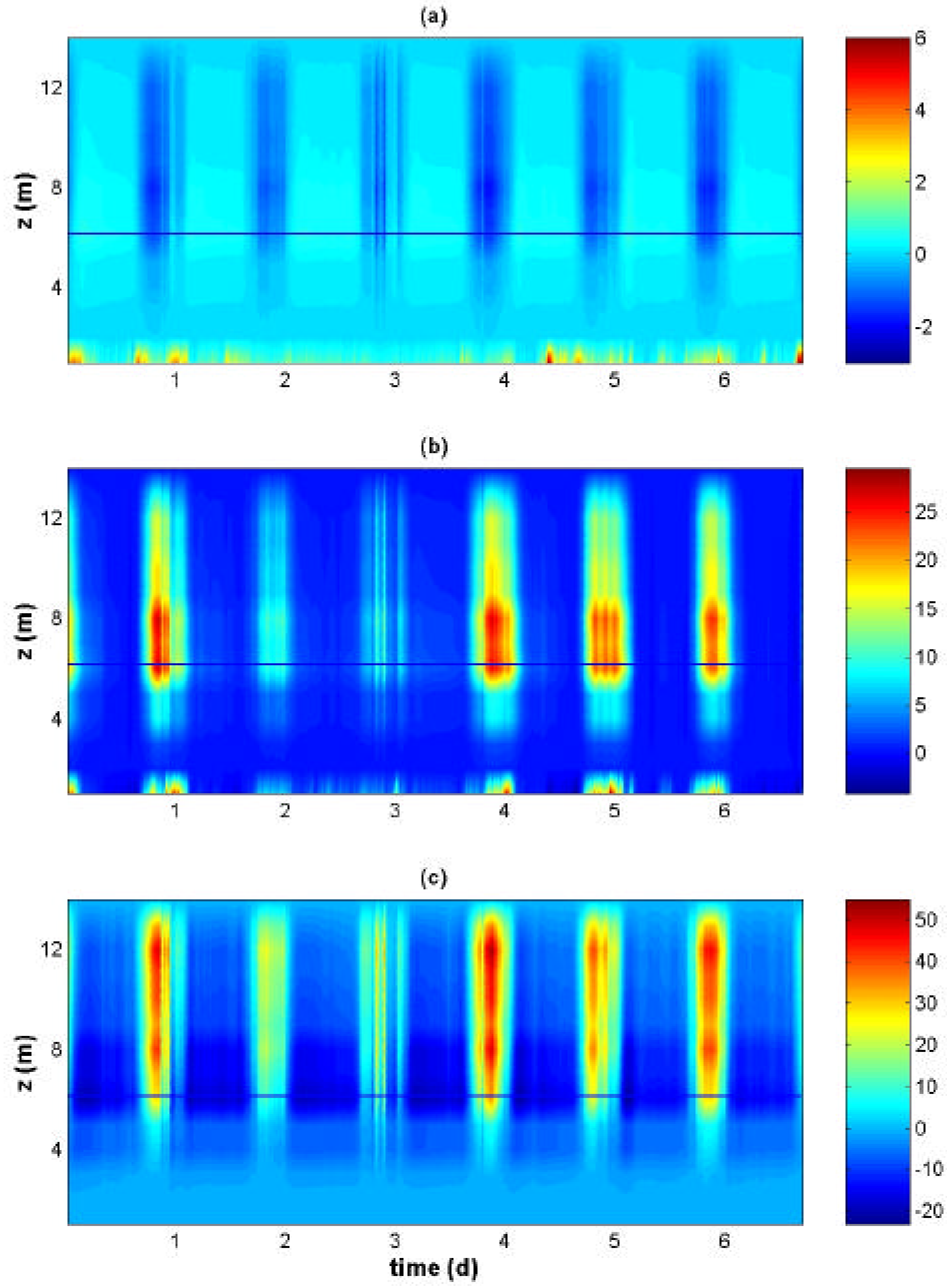


Figure 2: Computed sources and sinks for (a) CO_2, (b) water vapor, and (c) heat. The horizontal solid line is for the height corresponding to maximum leaf area density.

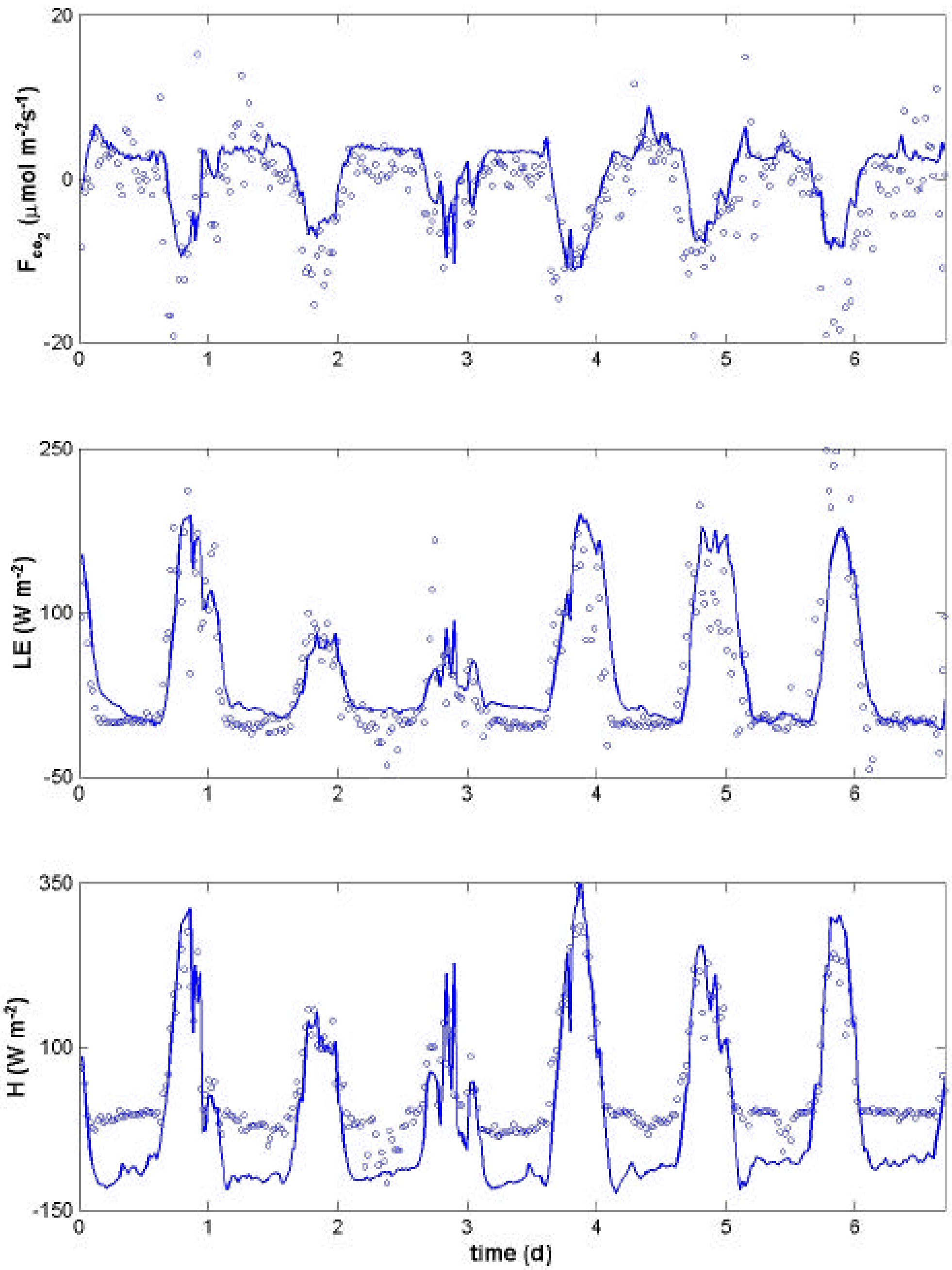


Figure 3: Comparison between measured (circle) and modeled (line) CO_2 F_{co2} (top), water vapor (LE) (middle), and sensible heat (H) fluxes for the 7-day experiment.

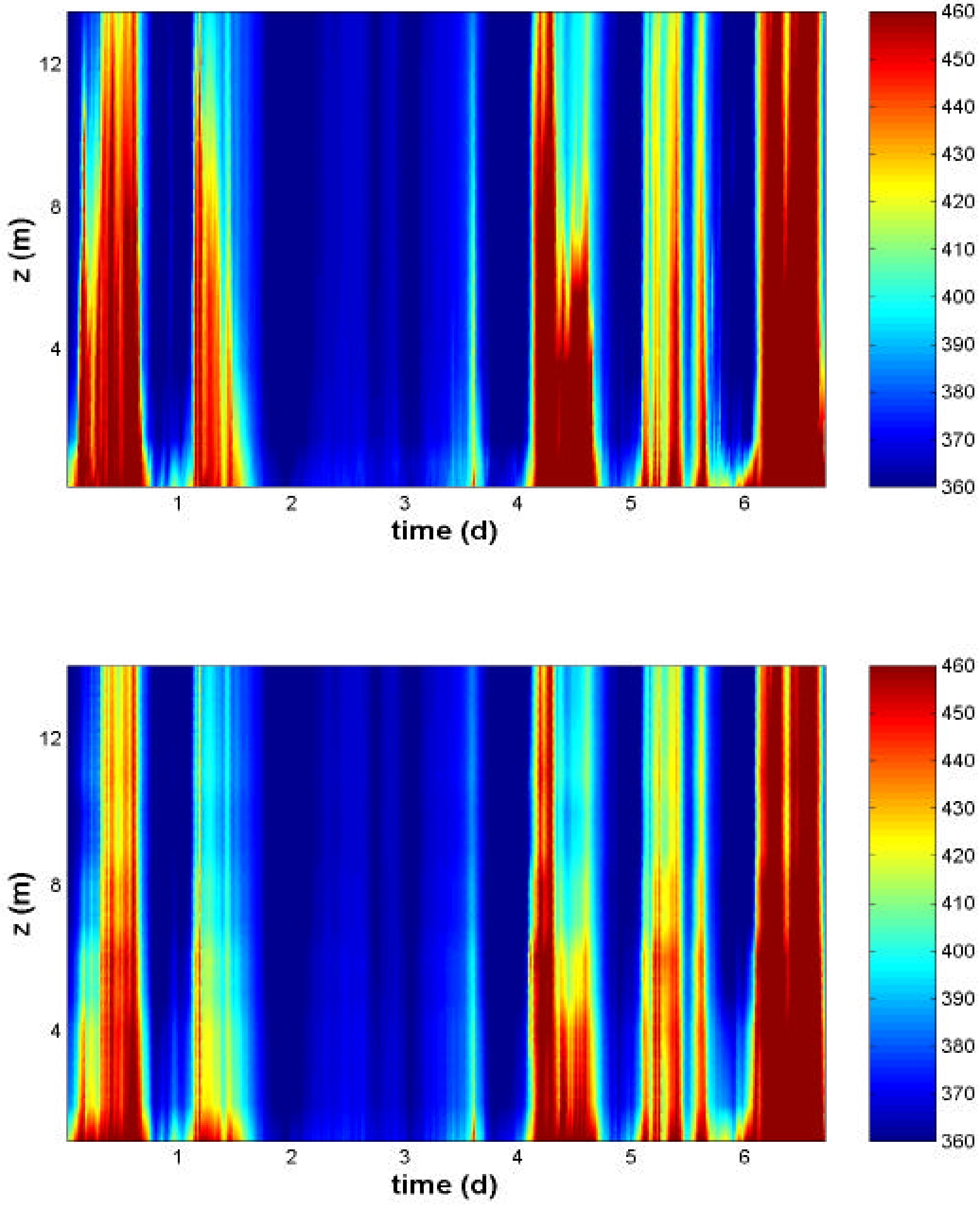


Figure 4: Computed (top) and measured (bottom) mean CO_2 concentration (ppm) evolution with time and depth within the canopy.

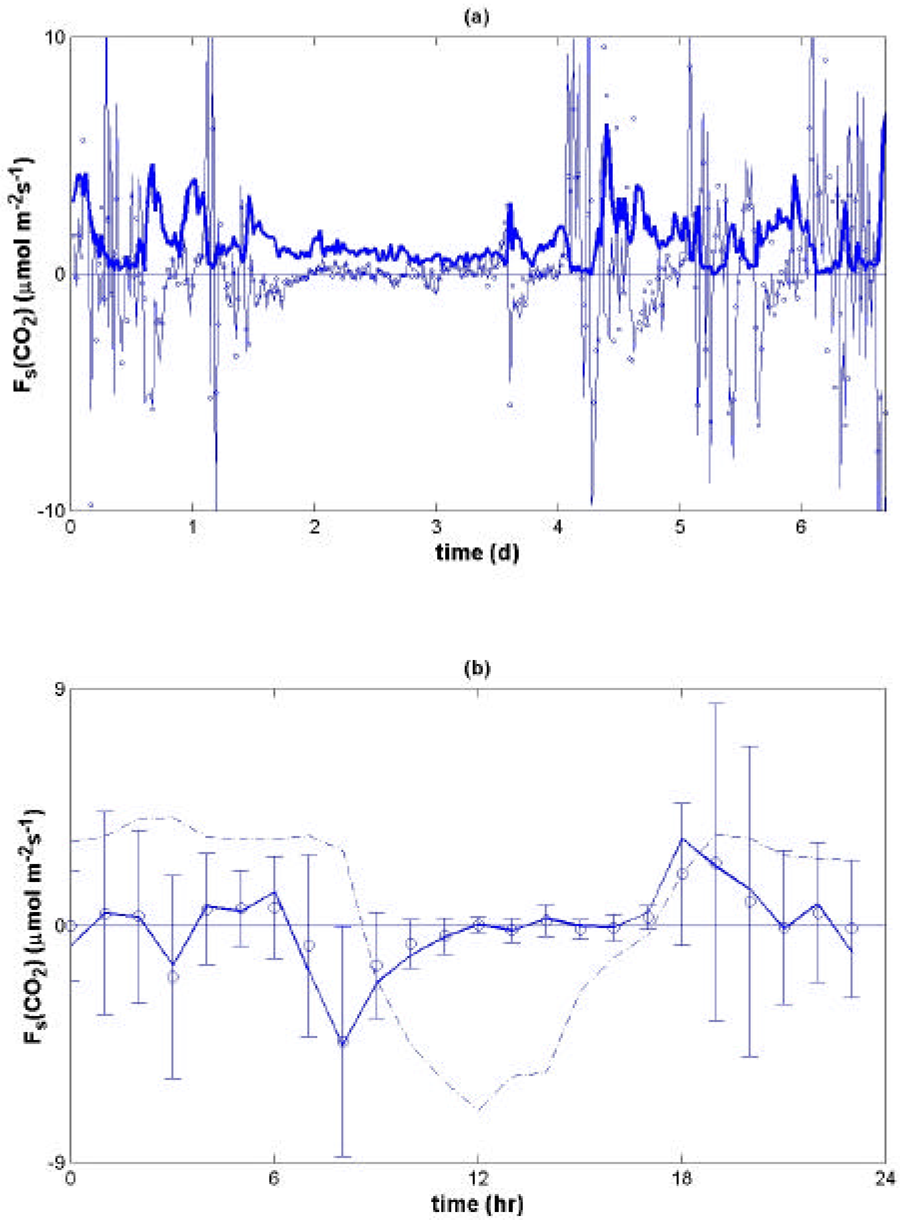


Figure 5 (a) comparison between modeled (thin line) and measured CO_2 storage flux (circles). The computed soil CO_2 respiration that reproduces measured CO_2 concentration at 10 cm is also shown (solid-thick).
(b) Relative importance of measured storage flux (circle-line) to measured CO_2 flux above the canopy (dot-dashed) as an hourly ensemble generated from the 7-day experiment.