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Modelling of CO_2 exchange between grassland ecosystems and the atmospheric boundary layer

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Abstract

To calculate and analyse diurnal and seasonal patterns of CO_2 exchange between grassland ecosystems and the atmospheric boundary layer, a dynamic simulation model was developed. It distinguishes between a vegetational component, based on crop growth model SUCROS, and a soil component, based on soil organic matter model MOSOM, and calculates CO_2 exchange as a function of half-hourly values of air and soil temperature, shortwave irradiance and atmospheric [CO_2]. As compared to measured CO_2 fluxes in a grassland ecosystem in Cabauw, The Netherlands, measurements and preliminary model calculations agreed better for nighttime fluxes than for daytime fluxes. This discrepancy suggests incorrect model assumptions. The CO_2 emission from cattle and manure, not yet included in the simulation model, is estimated to be approximately one tenth of the maximum daytime CO_2 flux in July.

1. INTRODUCTION

It has been widely suggested that atmospheric CO_2 could serve as a climatic factor [1,2]. Apart from a general trend of increasing atmospheric [CO_2] [3], spatially fluctuating cycles in atmospheric [CO_2] have been observed [4,5,6]. The vertical dimensions of the cycles very much depend on the time scale [4]. The biosphere is thought to exert a major influence on these cycles [4,5,7,8,9]. A decrease in atmospheric [CO_2] is observed during spring and summer and an increase during autumn and winter [5]. In the southern hemisphere the cycle's amplitudo is considerably less than in the northern hemisphere [4].

Within the global biosphere grasslands have an important position, in surface area, long term soil C storage and net primary productivity [7,10]. Therefore, grasslands could be a significant factor in cycles in atmospheric [CO_2]. Despite having substantially different characteristics when compared with most of the world's grasslands, pasture land in The Netherlands also displays a high productivity and C storage [11]. This study aims at model development for the diurnal and seasonal cycles of total CO_2 exchange and their components between grassland ecosystems and the atmospheric boundary layer in The Netherlands, using CO_2 flux measurements for validation.

2. METHODOLOGY

In pasture land near Cabauw, The Netherlands, situated on a 1 m thick layer of alluvial clay on peat, the Netherlands Energy Research Foundation (ECN) and the Royal Netherlands Meteorological Institute (KNMI) measured CO_2 fluxes between the vegetated surface and the atmospheric boundary layer [12], and environmental variables. Measurements used here were taken at the meteorological site of KNMI, from March 1993 up to February 1994. CO_2 flux measurements were done using the CO_2 gradient method, covering a fetch of approximately 1.5 km length. To avoid, as much as possible, disturbance of the measurements as a result of nearby orchards and built-up area, only measurements taken at wind angles ranging from 195 up to 250° were used for analysis.

A preliminary dynamic simulation model for CO_2 exchange and its components between a grassland ecosystem and the atmospheric boundary layer was developed (figure 1). The model distinguishes between a vegetational component, based on SUCROS, a model for crop growth [13], and a soil component, based on MOSOM, a model for soil organic matter dynamics [14]. The dynamics of the vegetational and soil component are a function of species characteristics and half-hourly values of shortwave irradiance, air temperature and atmospheric [CO_2], and of soil characteristics and half-hourly values of soil temperature, respectively.

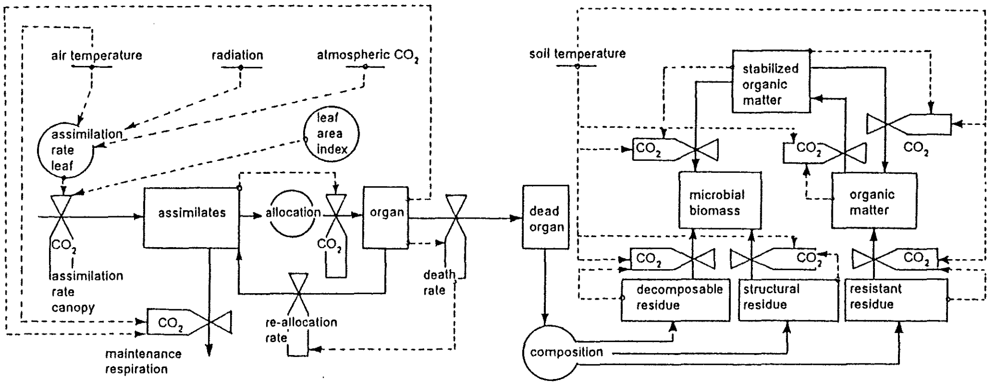

Figure 1. Schematic representation of a dynamic simulation model for CO_2 exchange between a homogeneous grassland ecosystem and the atmosphere. Boxes represent state variables, valves rate variables, closed lines mass flows and dashed lines information flows.

3. RESULTS AND DISCUSSION

The absence of a distinct seasonal pattern of atmospheric [CO_2] (figure 2) corresponds to similar observations in industrialized and densely populated areas [3]. The average diurnal pattern (figure 3) displays a relative low during daytime and a concentration gradient inversion

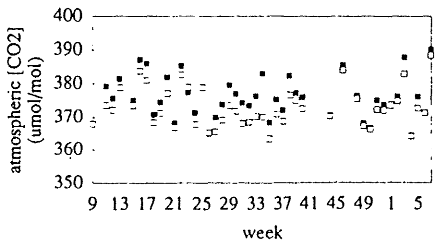

Figure 2. Seasonal pattern of atmospheric [CO_2] at 1 m (■) and 10 m (□), as weekly averages from half-hourly values, Cabauw, from March 1993 up to February 1994 (source data: ECN).

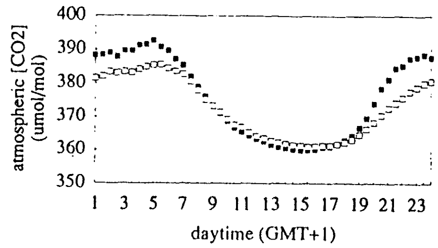

Figure 3. Diurnal pattern of atmospheric [CO_2] at 1 m (■) and 10 m (□), as a yearly average of half-hourly values, Cabauw, from March 1993 up to February 1994 (source data: ECN).

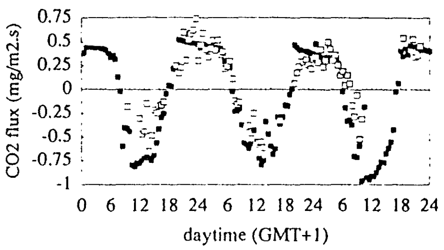

Figure 4. Calculated (■) and measured (□) half-hourly CO_2 exchange, from 16 up to 18 July 1993, Cabauw (source measurements: ECN).

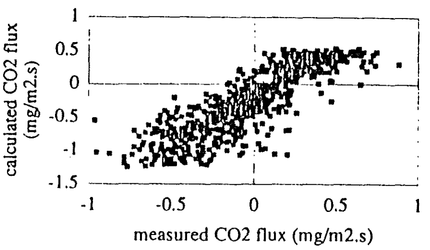

Figure 5. Comparison between measured and calculated half-hourly CO_2 exchange, in March, May, July and December, 1993, Cabauw (source measurements: ECN).

at transitions between daytime and nighttime, the latter reflecting transitions between upward and downward CO_2 fluxes. Depletion and replenishment of atmospheric CO_2 are thought to be governed by canopy CO_2 assimilation and respiratory processes, respectively.

Patterns of calculated and measured CO_2 exchange (figure 4) during a selected period in July 1993, show a better agreement for CO_2 fluxes during nighttime than during daytime. Comparison for several months (figure 5) indicated the consistency of this discrepancy. A reasonable description of the nighttime processes - plant maintenance and soil organic matter dynamics - is suggested, especially during the 2nd half of the nighttime time interval (figure 4). Further validation would be required, encompassing the determination of the significance of the degree of detail in the process descriptions, CO_2 flux measurements under more homogeneous conditions (i.e. at a smaller spatial scale) and measurements of the CO_2 flux components. In addition it needs to be established which fraction of the variation in the measurements is inherent in the method of measurement.

The different patterns of calculated and measured CO_2 fluxes during the 1st half of the nighttime time interval and the differences between calculated and measured daytime CO_2 fluxes (figure 4), seem to point to incorrect or incomplete model assumptions. CO_2 emission from cattle and manure was not yet included in the calculations, but can be estimated. An uptake of 20 kg dry matter per cow per day, a dry matter C content of 40%, a 2.5 cows per ha, an equal division between actual uptake and excretion, a steady state in manure supply and decomposition, and a relatively negligible C release through CH_4 [15] results in a CO_2 emission of 0.07 $mg.m^{-2}.s^{-1}$ - approximately one tenth of the maximum daytime CO_2 flux in July 1993. In this additional CO_2 emission the manure provides a continuous background source, whereas the cattle acts as point sources.

4. ACKNOWLEDGMENTS

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