EFFECTS OF DISTURBANCE AND CLIMATE CHANGE ON CARBON BALANCE IN CANADA'S FORESTS AND WETLANDS

W. Ju, and J. M. Chen

Department of Geography, University of Toronto, 100 St. George Street, Toronto, ON, Canada, M5S 3G3
juw@geog.utornto.ca; chenj@geog.utronto.ca

ABSTRACT
Model simulations indicated that Canada's forests and wetlands acted as a carbon (C) sink of 112 Tg C yr^{-1} averaged during 1901-1998. Wetlands was a crucial contributor to this sink (50 Tg C yr^{-1}). Disturbance history determined the decadal temporal pattern of C balance. Nondisturbance factors enhanced C accumulations in Canada's forests and wetlands in the last century. The enhancement of each nondisturbance factor on C uptake changed temporally.

INTRODUCTION
In recent years, eddy covariance measurements and model simulations have shown that carbon (C) balance in forests and wetlands is determined by disturbance history, climate, atmospheric CO_2 concentration, nitrogen (N) availability, and water conditions. Wetlands cover 127 million hectares or 14% of the landscapes of Canada. In spite of their low productivity, these ecosystems have been acting as small C sinks of 20 to 30 g C m^{-2} yr^{-1} over the past 5,000 to 10,000 years. Wetlands are often ignored in regional- and global-scale terrestrial C budget models that do not resolve small surface futures. The lumped representation of wetlands and forests possibly diminishes our confidence on the estimate of regional terrestrial C balance. The present study explicitly simulates C dynamics in Canada's forests and wetlands by adapting different parameterization and initialization schemes for these different ecosystems and using topographic, drainage, soil and remote-sensed vegetation datasets for reliable simulations of the hydrological cycle which tightly interacts with the C cycle.

MODEL DESCRIPTION AND SIMULATIONS PERFORMED
The model used is the Integrated Terrestrial Ecosystem Carbon Cycle (InTEC) model, which was originally developed for simulating C balance in Canada's forests by integrating effects of disturbance (stand age) and nondisturbance (climate, CO_2 concentration and N deposition) factors on C assimilation and release [*Chen et al*., 2000]. After recent improvements, this model now consists on three components, i.e., a canopy level photosynthesis module for simulating historical annual net primary productivity (NPP), a soil C and N dynamics module adopted from the CENTURY model for simulating soil C and N dynamics, and a three dimensional hydrological module for the simulation of soil moisture and temperature [*Ju and Chen*, 2005]. The hydrological module includes the effects of surface hydrology and drainage on the redistribution of saturated subsurface soil water, which are crucial for simulating water table depth in wetlands. To consider the influences of disturbance history and stand age on C balance, a map of forest stand age in 1998 was constructed based on GIS-based large fire polygons, forest inventory and remote sensing data [*Chen at al*., 2003].

Table 1. Description of five simulation experiments

Simulation	Climate	CO_2	N deposition
I	Baseline	Baseline	Baseline
II	Historical	Baseline	Baseline
III	Baseline	Historical	Baseline
IV	Baseline	Baseline	Historical
V	Historical	Historical	Historical

Five numerical experiments were conducted to investigate the responses of C balance in Canada's forests and wetlands to historical changes in disturbance frequency, climate, atmospheric CO_2 concentration, and

N deposition from 1901 to 1998 (Table 1). All experiments used the same initialization scheme to determine the initial sizes of C pools and same spatial datasets of vegetation, soil, DEM and drainage class to drive the model.

RESULTS

Model validation showed that simulated spatial patterns of soil C mirrored those compiled from the soil landscape of Canada database well. The discrepancies between model outputs and SLC values are less than 10 kg C m^{-2} and 15 kg C m^{-2} for more than 52% and 66% of total forests and wetlands. Large departures are mainly in poorly drained areas. This model was able to capture 84% of interannual variability of NEP measured at five tower flux sites. Simulated growing-season soil moisture content was also in good agreement with measurements made at four forested tower sites.

The mean of annual net uptake of C by all Canada's forests and wetlands was 112 Tg C during 1901-1998. The spatial distribution patterns of C sources and sinks were related to disturbance history, climate variability, and drainage class. On average, wetlands in Canada was a C sink of about 50 Tg C yr^{-1} in the same period, and is of importance to the national C budget. Climate had not only direct effects on plant growth, but also indirect effects on N net mineralization and fixation, and was the largest contributor to the net C uptake among non-disturbance factors, followed by N deposition and CO_2 fertilization (Table 2). However, the enhancement of climate on C uptake was smaller than those of N deposition and CO_2 fertilization after 1980 due to the acceleration of heterotrophic respiration by the warming and dry climate. N deposition had the biggest effect on the maintenance of the C sink in these years. The distinct decadal temporal pattern of C balance in Canada's forests and wetlands was mainly determined by the disturbance factor, which increased NPP from 153 to 158 g C m^{-2} yr^{-1} during 98 simulation years and caused Canada's forests and wetlands to act as an average C sink of 49.8 Tg C yr^{-1} during 1901-1998. Disturbance rates increased dramatically after 1970, inducing a small C source of 20.1Tg C yr^{-1}, averaged over 1980-1998.

Table 2. Effects of nondisturbance factors on total NPP and NEP of Canada's forests and wetlands

	1901-1998		1980-1998	
	ΔNPP g C m^{-2} yr^{-1}	C Balance Tg C yr^{-1}	ΔNPP g C m^{-2} yr^{-1}	C Balance Tg C yr^{-1}
Climate change	7.8	25.8	7.9	20.7
N deposition	5.8	16.0	12.4	33.0
CO_2 fertilization	3.5	13.1	6.9	27.7
All nondisturbance factors	17.9	57.8	29.9	94.9

SUMMARY

Canada's forests and wetlands have been acting as a C sink since the beginning of the last century. Wetlands as a whole assimilate a considerable amount of C and should be explicitly represented in regional and global C models. Disturbance history determines the past, current and future C balances. For reliable estimates of C balance, it is necessary to compile stand age information from relevant datasets. N deposition was simulated as the biggest contributor to the recent C sink. If this factor is not considered terrestrial C models, the size of C sinks would be underestimated.

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