Response of Boreal Forest Ecosystem to Climate Variations

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Earth Sciences Sector

Reducing Canada's vulnerability to climate change

Introduction

The boreal forest biome covers approximately 14% of the earth's land surface. It has been slowly accumulating organic carbon in its soils and living biomass since the last glaciation. This carbon sequestration has played an important role in the global carbon budget and climate system. Recent climate model simulations show that climate change is very likely to happen most rapidly in the northern high latitudes. How climate change and extreme events will impact the boreal forest ecosystem has become one the key areas in climate change studies.

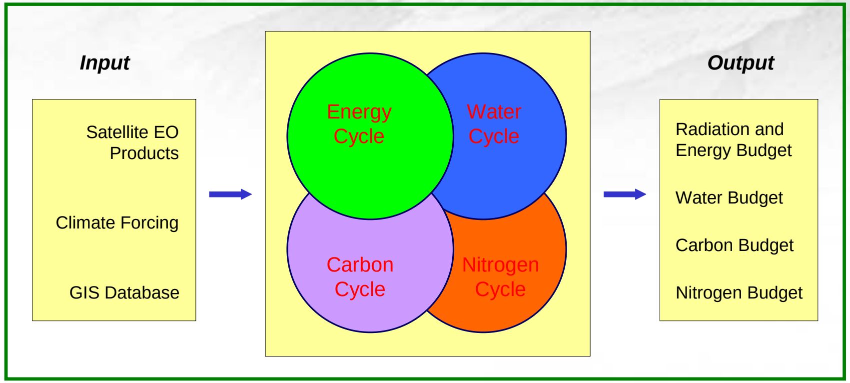
We investigated the detailed ecosystem response of a boreal deciduous forest (old aspen) to the recent climate variations. Specifically, the Canada's southern boreal forest experienced very dry climate conditions in 2001 and 2002, following the close-to-normal precipitation year of 2000. The 2001 and 2002 drought is an anomalous event occurred extensively across Canada. By using the EALCO model, we studied the detailed response of the ecosystem physical, physiological, and biogeochemical processes to this extreme climate event. Results provide us insight on both climate change studies and climate change impact and adaptation assessment.

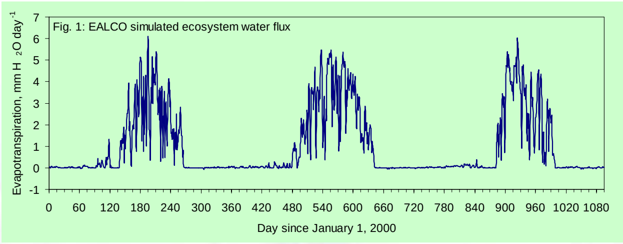
Site Description

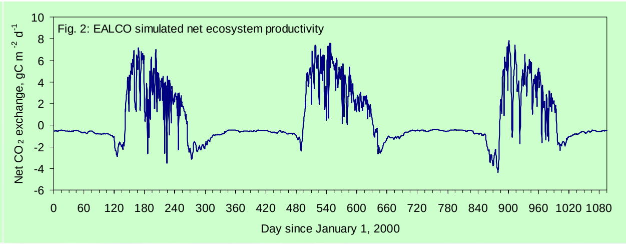
Aspen is the main deciduous species in Canada's boreal forest. This study selected the southern old aspen (SOA) ecosystem where one of the Fluxnet Canada measurement site is located (53.6°N, 106.2°W, Prince Albert National Park, Sask.). It is a mature forest regenerated after a natural fire more than 70 year ago. The total canopy leaf area index is about 5.0, with ecosystem closure of 90% and stem density of 830 ha^{-1}. Orthic gray luvisols with a loam to clay-loam texture have developed on Pleistocene deposits of glacial till. The ecosystem is near the southern limit of the boreal forest. Comparable aspen stands occupy 10-20% of the southern boreal forest.

Model Description

The EALCO model (Ecological Assimilation of Land and Climate Observations) was developed to study the climate-ecosystem interactions at regional scale through assimilating satellite and climate observations. The "point" version of model can be validated by using site data such as tower flux measurement. EALCO includes the coupled ecosystem energy, water, carbon, and nitrogen cycles as illustrated below. It simulates the climate change impacts and ecosystem feedbacks represented by the changes in ecosystem physical, physiological, and biogeochemical cycles. The model code and user manual will be made available at the CCP website shortly.







Results

In year 2000, precipitation at the SOA site was 484 mm (30 years normal 463mm*). Annual evapotranspiration (ET) simulated by EALCO was 316 mm, which was 65% of its total precipitation, indicating water surplus conditions of the ecosystem. Ecosystem gross primary production (GPP) was simulated to be 1060 g C m^{-2}, of which 617 g C m^{-2} was consumed by plant autotrophic respiration R_a. As a result, the ecosystem net primary production (NPP) was 443 g C m^{-2}. Annual heterotrophic respiration R_h was simulated to be 311 g C m^{-2}. These carbon transfers finally made the ecosystem as a carbon sink of 132 g C m^{-2}.

In the dry year 2001, annual precipitation was less than half of year 2000 (Table 1). However, the ecosystem physical and physiological processes were simulated to be much more active. Total ET in 2001 was simulated at 443 mm, 40% higher than year 2000. Higher ET indicates more active plant physiological reactions because ET is mainly controlled by the canopy stomatal resistance which is an indicator of plant carbon fixation rates. This can be reflected by the high annual GPP of 1305 g C m^{-2} in 2001, 23% higher than that in 2000. Though R_a was also simulated higher in 2001, NPP in the dry year 2001 was 40% higher than that of 2000. Microbial activity was slightly constrained by the dry soil conditions in 2001 and the annual R_h was simulated 5% lower than year 2000. Together with the higher NPP, the ecosystem in 2001 was simulated as a strong carbon sink of 319 g C m^{-2}, 140% higher than that in year 2000.

The year 2002 is the second consecutive dry year following 2001. Even though, ET was still simulated higher than the wet year of 2000. The annual GPP, R_a, and R_h were all modeled lower due to water stress. However, the ecosystem still had a net carbon sequestration of 155 g C m^{-2}, which was 23 g C m^{-2} more than that of the wet year 2000.

(* 1951-1980, from Griffis, T.J. et al., Agr. For. Meteorol., 117, 53-71)

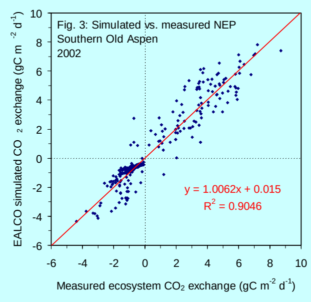


Table 1: Annual summaries of carbon and water fluxes for the boreal old aspen ecosystem during 2000 – 2002.

Year	Precipitation (mm)	ET* (mm)	G. ET* (mm)	Runoff (mm)	Drainage (mm)	GPP* (g C m^{-2})	R_a* (g C m^{-2})	NPP* (g C m^{-2})	R_h* (g C m^{-2})	NEP* (g C m^{-2})	Measured NEP (g C m^{-2})
2000	484	316	306	13	141	1060	617	443	311	132	135
2001	235	443	430	4	4	1305	691	614	295	319	382
2002	287	338	330	0	0.1	954	537	417	262	155	148

* ET – Evapotranspiration; G. ET – Growing-season Evapotranspiration; GPP – Gross Primary Production; R_a – Autotrophic Respiration; NPP – Net Primary Production; R_h – Heterotrophic Respiration; NEP – Net Ecosystem Productivity.

Discussion

Extreme climate events such as drought can have very different impacts on different ecosystems. While the 2001 and 2002 drought occurred in Canada induced severe reduction in the grassland and cropland ecosystem production in the Canadian prairies, we found it significantly benefited the southern boreal aspen ecosystem in terms of plant productivity and net ecosystem carbon sequestration. This ecosystem response to climate variations and extreme events will have significant impact on the global carbon and water budgets. Our model results were supported by the tower flux measurement as shown in Tab. 1 and Fig. 3. More detailed analyses are required to identify the mechanisms of these changes to the climate variations, such as the impact due to different temperature and radiation conditions among the three years. The findings will not only improve our understandings on the boreal forest ecosystem feedbacks on the local as well as global physical climate system, they also provide us more solid scientific information for the climate change impact assessment and adaptation studies.

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