Ecological Assimilation of Land and Climate Observations - The EALCO model

Shusen Wang, Yinsuo Zhang

Earth Sciences Sector

Reducing Canada's vulnerability to climate change

Introduction

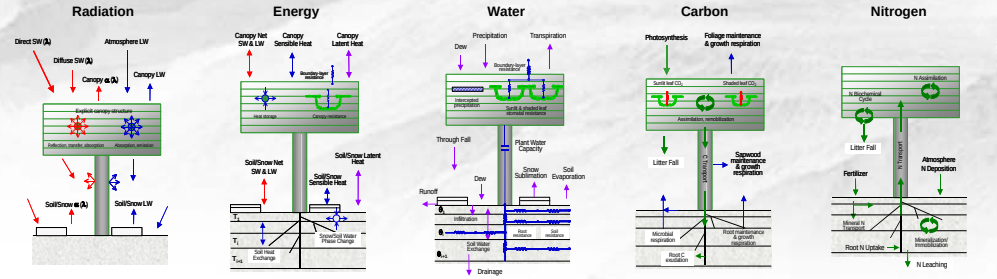
Ecosystems are intrinsically dynamic and interact with climate at a highly integrated level. Climate variables are the main driving factors in controlling the ecosystem physical, physiological, and biogeochemical processes including energy balance, evapotranspiration, photosynthesis, respiration, and nutrient cycling. On the other hand, ecosystems function as an integrity and influence climate conditions through their control on surface radiation balance, energy partitioning, and greenhouse gases exchange. Impacts and feedbacks between climate change and ecosystems have become one of the key areas in both climate change science and climate change impact and adaptation studies.

Ecosystem processes are closely coupled with each other. Any process that is altered by climate change could strongly influence others and ultimately the ecosystem services. For example, ecosystem water conditions strongly influence plant carbon fixation and ecosystem nitrogen recycling (Wang et al., 2001, 2002a, 2002b, 2002c, 2004c). Changes in plant carbon dynamics determine the canopy conditions which could change the land surface conditions such as albedo (Wang et al., 2002d, 2004a, 2004b;, Davidson and Wang, 2004). Albedo change alters the radiation absorption of the surface and in turn affects ecosystem evapotranspiration and water conditions. To improve our capability in climate change impact assessment, a comprehensive ecosystem model is required to address the many interactions between climate change and ecosystems. On the other hand, different ecosystems can have very different responses to the climate change and its variation. For example, while decrease of precipitation could severely damage the ecosystem function of grassland and cropland and decrease their productivity in the Canada's prairies, it was found that it could significantly increase the ecosystem carbon sequestration in the Canada's boreal forest (Wang, 2004c). To better evaluate the ecosystem vulnerabilities to climate change at national scale and provide more scientific support for policy making, it is imperative that ecosystem models have the capability of assimilating the large scale geospatial information including satellite observations, GIS datasets, and climate model outputs or reanalysis.

The EALCO model (Ecological Assimilation of Land and Climate Observations) is developed for such purposes at the Earth Science Sector of Natural Resources Canada. EALCO includes the comprehensive interactions among ecosystem processes and assimilates a variety of remote sensing products and GIS database. It provides both national and local scale model outputs for ecosystem responses to climate change including radiation and energy balances, water conditions and hydrological cycles, carbon sequestration and greenhouse gas exchange, and nutrient recycling. These results form the foundation for the assessment of climate change impact on ecosystems, their services, and adaptation options.

Modelling Domain and Diagrams

EALCO includes five main modules for ecosystem radiation, energy, water, carbon, and nitrogen simulations. Their main processes and coupling relationships are illustrated below. Detailed algorithms and user manual will be available at CCP website.



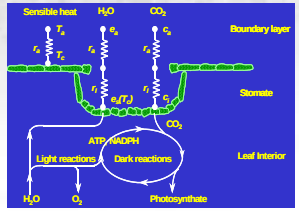
Ray tracing based on gap probability approach. Multi-canopy layers and multi-wavelength for solar radiation. Separation of direct vs. diffuse components. Long wave radiation calculated from canopy and ground surface temperatures obtained through their energy balance solutions.

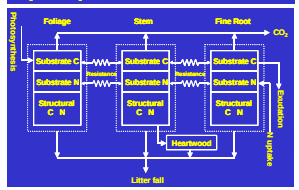
Energy balance solution for canopy and underlying soil and snow. Canopy energy balance coupled with plant carbon dynamics through photosynthesis-controlled stomatal resistance (Fig. 1). Multi-soil and snow layer identification for heat transfer and water/ice/snow phase change calculations.

Energy-coupled (Fig.1) dynamic canopy water balance solution (between transpiration, root water uptake, and plant water storage change) using leaf water potential as the prognostic variable. Identification of multi-soil layer hydraulic conductance for soil and root (radial and axial).

Identification of 4 plant compartments and 7 soil C pools (Fig.1). Farquhar model based C fixation. Impact of energy and water on C fixation through prognostic variables of canopy temperature and water potential. Identification of sunlit and shaded leaves. Multi-soil layer heterotrophic respiration.

Nitrogen balance among atmospheric deposition, fertilizer, and ecosystem leaching. Plant and soil N content balanced by root N uptake and litterfall. Dynamic root N uptake algorithms including both active and passive N transfers. Corresponding plant and soil N pools to carbon pools (Fig.1).





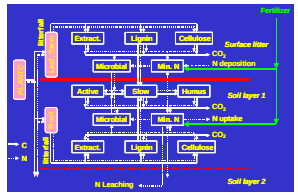
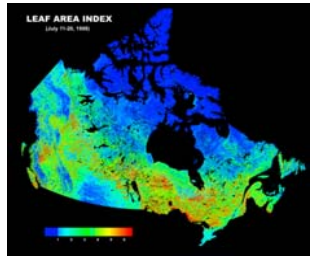
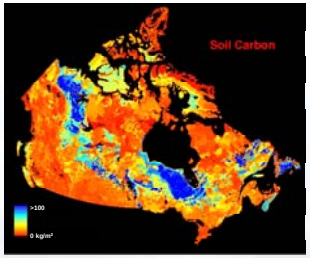


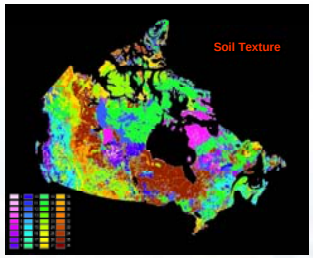
Figure 1

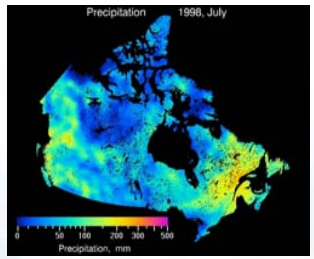
Model Inputs

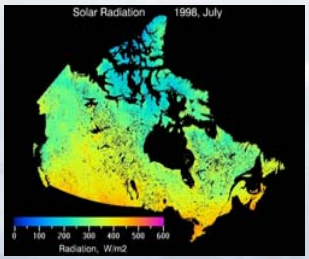
ELACO model can be used for both site and large spatial scale studies. For site applications, EALCO needs meteorological observations including air temperature, humidity, precipitation, wind speed, solar radiation, etc. EALCO runs at hourly time step and it includes a module to interpolate daily meteorological variables into hourly values. Site information including vegetation and soil parameters are required to initialize the model to the actual ecosystem conditions. For spatial applications, EALCO can be driven either by observations from meteorological station net, or by climate model output or climate reanalysed fields. EALCO includes a module for spatial interpolations of coarse resolution climate data to high resolution. Remote sensing products including land cover map and leaf area index series can be used during the model simulation. GIS datasets including soil texture map and soil carbon content are required to initialise the model. In the illustrations below, some sample input datasets for the model run at Canada national scale were given, which included the Canada land cover map and a sample leaf area index processed from SPOT VEGETATION sensor observations (Latifovic and Olthof, 2003; Fernandes, et al., 2003), the soil carbon content and soil texture maps produced by Agriculture and Agri-Food Canada, and the climate fields for the variables of precipitation, solar radiation, air temperature, and specific humidity obtained from model reanalysis by the U.S. National Center for Atmospheric Research (NCAR).

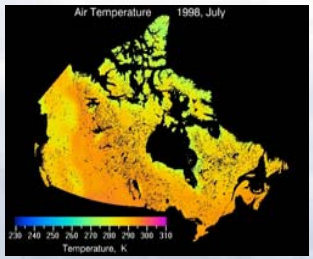


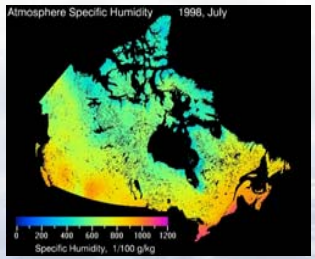








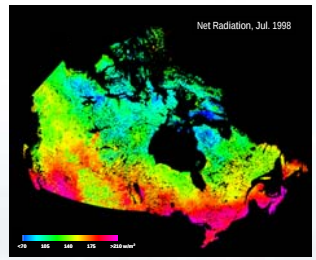


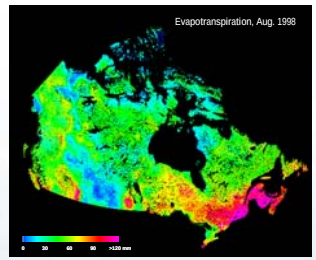


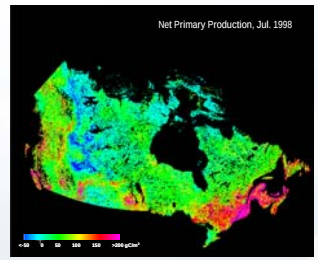
Model Outputs

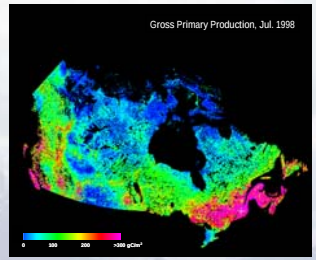
EALCO simulates the ecosystem response to climate change and variations, and provides impact assessment from multi-angles. The albedo outputs include the results of land surface reflectance at user selected wave length. The shortwave and long wave radiation simulation provides the surface net radiation which represents the radiative energy absorption of the ecosystem. Evapotranspiration output from water balance simulations provides the ecosystem water conditions and can be used in the water demands evaluation under changing climate conditions and ecosystem drought assessment. Drainage output has been used in the groundwater studies and it provides the link for the interdisciplinary studies of climate change and groundwater resources. Carbon simulations in EALCO provides the ecosystem gross primary production (GPP), net primary production (NPP), net ecosystem production (NEP), plant autotrophic respiration, and soil heterotrophic respiration. These carbon fluxes determine the ecosystem carbon sequestration and greenhouse gas (CO_2) exchange with the atmosphere. It provides one of the key indicators to evaluate the ecosystem service and the impact of climate change. The nitrogen cycling provides the availability of key nutrient for ecosystem carbon assimilation and it represents the dynamic status of the ecosystem. EALCO also provides the ecosystem conditions and climate change impacts including plant growth, soil temperature and moisture, and soil carbon and nitrogen contents. All these outputs represent the results of interactions between climate and the ecosystem physical, physiological, and biogeochemical processes, and it provides the key information for climate change impact and adaptation assessment.

Preliminary outputs from the model applications at the Canada national scale are illustrated below. These sample results including the spatial distributions of net radiation, evapotranspiration, gross primary production, net primary production, and net ecosystem production. These results were simulated by using the data inputs shown in the previous section. Detailed studies and effort to improve the input data quality are being conducted.









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Canada Centre for Remote Sensing, 588 Booth St., Ottawa, ON, K1A 0Y7, e-mail: Shusen.Wang@CCRS.NRCan.gc.ca

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