THE CANADIAN TERRESTRIAL ECOSYSTEM MODEL (CTEM) – THE TERRESTRIAL CARBON CYCLE COMPONENT OF THE CANADIAN GLOBAL COUPLED CARBON CYCLE MODEL (CGC^3M)

Vivek Arora

Canadian Centre for Climate Modelling and Analysis (CCCma), Meteorological Service of Canada, Univ. of Victoria, PO Box 1700, STN CSC, Victoria, B.C., V8W2Y2, Canada, Vivek.Arora@ec.gc.ca

ABSTRACT

The Canadian Centre for Climate Modelling and Analysis (CCCma) is currently working towards development of a coupled carbon climate model in which the time-evolving atmospheric concentrations of greenhouse gases, and in particular CO_2, are computed prognostically on the basis of scenario-specific emissions. The Canadian Model for Ocean Carbon (CMOC) and the Canadian Terrestrial Ecosystem Model (CTEM) are the oceanic and terrestrial carbon cycle models implemented in this coupled framework. This presentation will focus on the terrestrial carbon cycle component CTEM that is able to grow vegetation from bare ground and includes processes of photosynthesis, autotrophic and heterotrophic respiration, phenology, allocation, mortality, land use change, fire, and competition between plant functional types (PFTs). In the coupled model CTEM provides a dynamic land surface interface to the climate model by simulating time-varying vegetation structural attributes as a function of model climate and provides net fluxes of CO_2 between the land surface and the atmosphere. This presentation provides an overview of how the primary terrestrial ecosystem processes are modeled in CTEM. It also discusses in some detail the parameterizations of fire and competition among plant functional types (PFTs). These two processes have not received adequate attention in the current generation of dynamic global vegetation models. The fire module of CTEM takes into account all three aspects of the fire triangle: fuel availability, readiness of fuel to burn depending on weather conditions, and the presence of an ignition source. The approach also takes into account the anthropogenic effect on natural fire regimes. Competition between PFTs is modeled on the basis of a modified form of Lotka-Volterra equations that, unlike existing applications, allows coexisting PFTs. Model results at selected locations show that CTEM estimates of vegetation biomass, leaf area index, fire return interval, biomass burning CO_2 emissions and fractional coverages of coexisting PFTs compare reasonably well with observation-based estimates.

AN OVERVIEW OF CTEM

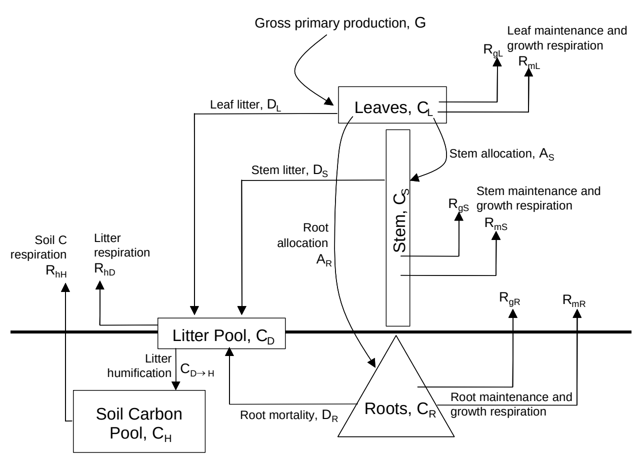

Fig. 1: The structure of the Canadian Terrestrial Ecosystem Model (CTEM)

Figure 1 shows the structure of CTEM with its three live vegetation components (leaves, stem, and roots) and two dead carbon components (litter and soil carbon). Photosynthesis is modeled on the basis of the biochemical approach and designed to use both the big- and the two-leaf (sunlit/shaded) approaches either of which may be used for a given simulation [*Arora*, 2003]. The photosynthesis-stomatal conductance coupling is based on the *Leuning*'s [1995] vapor pressure deficit based formulation. Autotrophic respiration, R_a, is estimated as the sum of maintenance respiration, R_m, from the three live vegetation components (leaves, stem, and root) and growth respiration, R_g. Leaf respiration is calculated as a function of maximum Rubsico capacity (V_{max}). Stem and root respiration is function of specified PFT-dependent base respiration rates that are modified according to temperature using a temperature-dependent Q_{10} [*Arora*, 2003]. Allocation of carbon from leaf to stem and root components is based on root water, canopy light, and leaf phenological status [*Arora and Boer*, 2005]. Respiration from litter and soil carbon pools is calculated on the basis of specified PFT-dependent base decomposition rates that are modified according to temperature (using a temperature dependent Q_{10}) and soil moisture [*Arora*, 2003]. Both high and low soil moisture constrain respiration from the soil carbon pool. The changes in biomass of live vegetation components (leaves, stem, and root) is reflected in structural vegetation attributes used in the energy and water balance calculations of the Canadian Land Surface Scheme (CLASS) to which CTEM is coupled. The leaf biomass is converted to LAI via specific leaf area (SLA). The aboveground biomass is related to vegetation height that affects the roughness length and therefore the turbulent transfer of heat and moisture. Finally, time-varying root biomass is related to an evolving root distribution profile that in turn is used to calculate the fraction of roots present in each soil layer [*Arora and Boer*, 2003].

FIRE

The process-based fire parameterization of CTEM includes dependence on all three factors of the classic fire triangle that control combustion: availability of fuel, readiness of fuel to burn (depending on weather), and availability of an ignition source all of which determine the probability of fire. All these three factors must be present in a form conducive to combustion, or fire will not occur. The area burned is assumed to be elliptical in shape whose length-to-breadth ratio depends on wind speed. Higher wind speed yields more elongated fires. Fire spread rate is function of soil moisture and wind speed. Drier soil moisture conditions and higher wind speeds yield higher fire spread rate. The duration of the fire is estimated on the basis of a fire extinguishing probability. Rather than tracking individual fires that may be burning in a climate model grid cell the approach used in CTEM calculates the area burned by an average fire.

COMPETITION BETWEEN PFTs

CTEM uses a generalized version of competition-colonization equations to explicitly simulate competition between its PFTs. The colonization and mortality rates of PFTs, that determine competition, are function of their basic climate-dependent vegetation attributes (net primary productivity, NPP, and leaf area index, LAI). The colonization rates and the tree/grass distinction determine the order of dominance. The basic assumption is that within the broad functional groups of trees and grasses the PFT with higher NPP will dominate. Favourable climate for a PFT yields higher NPP, LAI, and vegetation biomass and thence a higher colonization and a lower mortality rate (and the reverse for unfavourable climate). Comparison with observation-based data shows that the approach successfully models the successional behavior of PFTs and their equilibrium fractional coverages that compare well with observations. The approach lies in between the inherently small-scale forest gap models and the large-scale vegetation climate quasi-equilibrium approach used in most DGVMs and offers a reasonable alternative for explicitly simulating inter-PFT competition and estimating time-varying fractional coverage of PFTs in dynamic vegetation models at large spatial scales.

See http://www.cccma.bc.ec.gc.ca/ctem/ for additional details about CTEM.

REFERENCES

Arora, V.K. (2003), Simulating energy and carbon fluxes over winter wheat using coupled land surface and terrestrial ecosystem models, *Agricultural and Forest Meteorology*, *118*(1-2), 21-47.

Arora, V.K., and G.J. Boer (2003), A representation of variable root distribution in dynamic vegetation models, *Earth Interactions*, Vol. *7*, Paper 6, 19 pp.

Arora, V.K., and G.J. Boer (2005), A parameterization of leaf phenology for the terrestrial ecosystem component of climate models, *Global Change Biology*, *11*(1), 39-59.

Leuning, R., (1995), A critical appraisal of a combined stomatal photosynthesis model for C_3 plants. *Plant Cell Environ.*, *18*, 339-355.