ATMS/OCN/ESS 588 Global Carbon Cycle and Climate
Winter 2013
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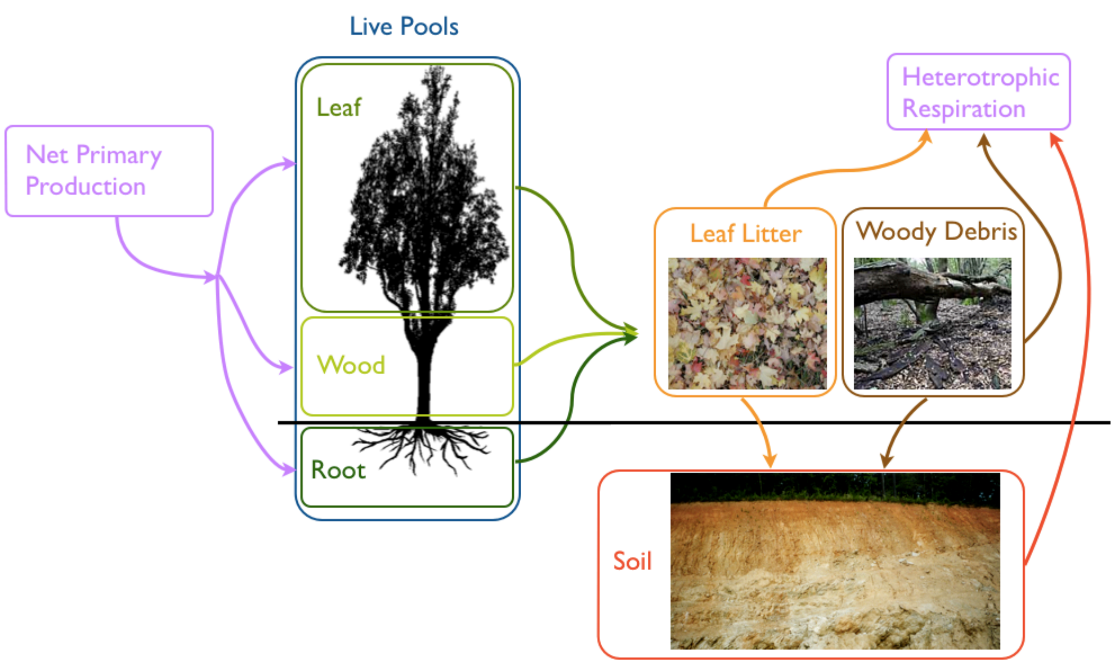
Assignment 4 – A Toy Ecosystem Carbon Model
You are welcome to work in small groups. You may choose to provide answers as numbers, tables, or graphs as needed but please give short written descriptions of your answers in addition to any numerical values and graphical representations.

Matlab codes:
```
EcoCarbonModel.m
Run_ToyEcoCarbonModel.m
fn_GetVegParams.m
fn_GetNPPScenario.m
```

The goal of this assignment is to investigate carbon balance of an ecosystem in response to climate variability, secular change (from warming or CO_2 fertilization), or disturbance.

The toy model consists of 6 carbon pools, with fluxes between them. Leaf, root and wood are the live pools. We represent the dead material with 3 pools - their different composition is captured by their turnover times – with litter decomposing faster than woody debris than soil. During decomposition, microbes respire, and the microbial respiration from the 3 dead pools sum to heterotrophic respiration. The (im)balance between NPP and heterotrophic is the net exchange with the atmosphere.



The governing equations are:

$$\frac{\partial M_i}{\partial t} = \alpha_i \cdot NPP - \frac{M_i}{\tau_i}; \quad \mathbf{i = L,R,W}$$

$$\frac{\partial M_{Litter}}{\partial t} = \left(\frac{M_L}{\tau_L} + \frac{M_R}{\tau_R}\right) - \gamma \frac{M_{Litter}}{\tau_{Litter}} - \underbrace{(1-\gamma)\frac{M_{Litter}}{\tau_{Litter}}}_{to\_atm}$$

$$\frac{\partial M_{CWD}}{\partial t} = \frac{M_W}{\tau_L} - \gamma \frac{M_{CWD}}{\tau_{CWD}} - (1-\gamma)\frac{M_{CWD}}{\tau_{CWD}}$$

$$\frac{\partial M_{Soil}}{\partial t} = \gamma \frac{M_{Litter}}{\tau_{Litter}} + \gamma \frac{M_{CWD}}{\tau_{CWD}} - \frac{M_{Soil}}{\tau_{Soil}}$$

$$R_h = (1-\gamma)\frac{M_{Litter}}{\tau_{Litter}} + (1-\gamma)\frac{M_{CWD}}{\tau_{CWD}} + \frac{M_{Soil}}{\tau_{Soil}}$$

where i can represent any of the live pools (leaves, wood, roots), leaves are indicated by L, live wood by W, roots by R, and coarse woody debris by CWD. Tau is the residence time of a given pool, and gamma is the fraction of mass lost from either litter or coarse woody debris that is sent to the soil with the remainder (1-gamma) sent to the atmosphere as respiration. "Dead" carbon will be considered as the sum of Litter + CWD+ Soil. "Live" carbon is the sum of Leaves, Wood and Roots.

Tour of the code:
Turnover time and allocation parameters are set in `fn_GetVegParams.m`
The timeseries for NPP is created in `fn_GetNPPScenario.m` for different patterns
Model integration occurs in `Run_ToyEcoCarbonModel.m`
You will do most of your modifications and execute the model from
`ToyEcoCarbonModel.m`

---Questions---

The code lists typical values turnover times and productivity values for four ecosystems. You can switch between them in `ToyEcoCarbonModel.m` under
`%% Step 1:  Specify VegetationType`

For **each** the 4 ecosystems:
(1) Explore how an oscillatory signal in NPP is propagated through the ecosystem.
NPP Period=

- 1 year (annual cycle)
- 5 years (El-Nino Southern Oscillation)
- 10 years (Northern Annular Mode)

Modify the period of NPP in ToyEcoCarbonModel.m at

`%% Step 3:  Specify NPP fluctuations`
and make sure `scenario = 'NatVar'`

(a) What are the amplitude and period of oscillation in the mass of the wood pool? the dead pool (Litter + CWD + Soil)? Which parameter is most important in setting the characteristics of the response of these pools?

(b) Vary the various turnover times (in `fn_GetVegParams.m`). What determines the equilibration time of the wood pool? the dead pool?

(2) Let NPP increase linearly with time. Explore rates of 0.01, 0.1, 1% per year. To do this you will change to `scenario = 'trend'` and modify the rates.

(a) What are the relative rates of increase in the wood and dead pools?

(b) Calculate the trend in total carbon in the ecosystem.

(c) In the real world we cannot measure the total carbon in the ecosystem, but we can measure some of the pools. Which pool or combination of pools best capture the trend?

(3) Experiment with the deforestation scenario in different ecosystems. `scenario = 'defor'` What is the time scale of carbon loss from the dead pools?

(4) Finally, consider a scenario that combines a trend with natural variability in NPP. Consider two cases of natural variability: (i) period = 5 years, amplitude=0.1; (ii) period = 10 years, amplitude=0.05. Vary the trend from 0.01 to 1% per year. The question here is given the natural variability, how large does the trend have to be before it is detectable? Use the detectable threshold of signal/noise = 3. In which pool is the trend first detectable? How does this vary across ecosystem types?