# Carbon cycling in extratropical terrestrial ecosystems of the Northern Hemisphere during the 20th Century: A modeling analysis of the influences of soil thermal dynamics

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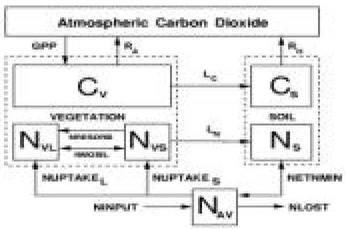
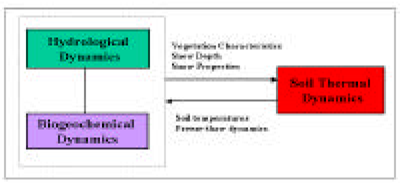
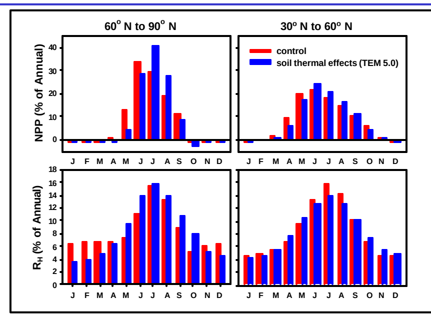
***BACKGROUND and OBJECTIVE:*** There is substantial evidence that soil thermal dynamics are changing in terrestrial ecosystems of the Northern Hemisphere and that these dynamics have implications for the exchange of carbon between terrestrial ecosystems and the atmosphere. To date, large-scale biogeochemical models have been slow to incorporate the effects of soil thermal dynamics on processes that affect carbon exchange with the atmosphere. In this study, we incorporated a soil thermal module (STM), appropriate to both permafrost and non-permafrost soils, into a large-scale ecosystem model, version 5.0 of the Terrestrial Ecosystem Model (TEM). We then compared observed regional and seasonal patterns of atmospheric $CO_2$ to simulations of carbon dynamics for terrestrial ecosystems north of 30º N between TEM 5.0 and an earlier version of TEM (version 4.2, referred to Control) that lacked a STM. We also evaluate the simulated carbon sequestration by comparisons to remote sensing data, inventory data, inversing modeling, and other studies.



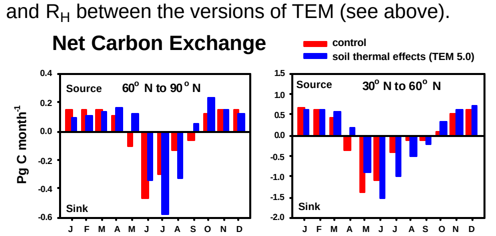

## *Model Modifications:*

- The TEM (top figure) was modified by adding a freeze-thaw index which affects the timing of GPP: GPP = Cmax * f(FT) * other scalars
- The Soil Thermal Model (STM, bottom figure) was modified by implementing a new snow cover classification system associated with vegetation type, snow density, and snow thermal conductivity for ecosystems (Sturm & Holgren, J of Climate, 1995, 8:1261-1283).
- Soil temperatures at organic layer are used for driving soil decomposition and nitrogen processes. f(FT), which is calculated by the STM is used for influencing carbon uptake by vegetation.

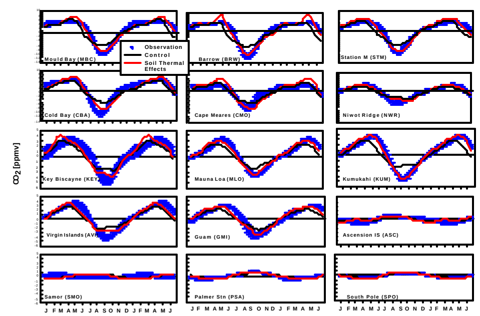



The seasonal distribution of monthly net primary production (NPP) and heterotrophic respiration ($R_H$) are altered in simulations with TEM 5.0 (soil thermal effects). At high latitudes, the peak in NPP has shifted to July, while at northern temperate latitudes, the peak has shifted to June.

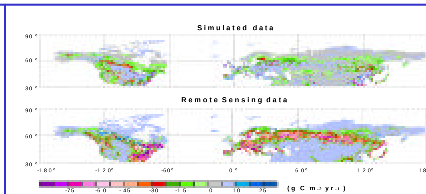
At both northern temperate and high latitudes, TEM 5.0 caused the month of peak NEP to shift (see below). This was a result of the change in distribution of NPP and $R_H$ between the versions of TEM (see above).




The figure below compares the observed seasonal cycle of $CO_2$ and the simulated seasonal cycle produced by coupling the monthly estimates of NCE (by TEM) and fossil fuel emissions with the MATCH atmospheric transport model for 15 monitoring stations of NOAA/CMDL network. The first 6 months are displayed twice to reveal the annual variation more clearly. Mean and standard deviation are shown for the observed data.

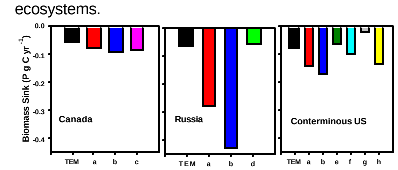



When coupled to MATCH, the simulated magnitude and timing of draw down of $CO_2$ in the growing season (northern hemisphere) is improved in many stations in TEM 5.0 in comparison to the control version of TEM.




The spatial patterns of simulated annual changes in vegetation carbon storage during the 1980s and 1990s between the TEM 5.0 simulation and the analysis of Myneni et al. (2001).

Positive values represent sources of $CO_2$ to the atmosphere, while negative values represent sinks of $CO_2$ into terrestrial ecosystems.




[a] Myneni et al., 2001; for mid 1980s to early 1990s
[b] TBFRA-2000 (Liski and Kauppi 2000); for early to mid-1990
[c] Canadian Forest Service, 1993; for 1982-1991
[d] Nilsson et al., 2000 ; for 1990
[e] Turner et al., 1995; for the 1980s
[f] Birdsey and Heath, 1995; for the 1980s
[g] Houghton et al., 1999; for the 1980s
[h] Pacala et al., 2001; for 1980-1990

The carbon sinks simulated by TEM 5.0 in the 1980s and 1990s are generally lower in comparison to estimates from inventory analyses (see above) and atmospheric inversion models (not shown). This suggests that other issues besides the role of soil thermal dynamics may be responsible, in part, for the temporal and spatial dynamics of carbon storage of extratropical terrestrial ecosystems.

***CONCLUSIONS:*** The consideration of soil thermal dynamics and terrestrial cryospheric processes in modeling the global carbon cycle has helped to reduce biases in the simulation of the seasonality of carbon dynamics of extratropical terrestrial ecosystems. This progress should lead to an enhanced ability to clarify the role of other issues that influence carbon dynamics in terrestrial regions that experience seasonal freezing and thawing of soil.