"Global Land Carbon Cycle: Data, Theory, and Future Projections"

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Terrestrial ecosystems play a crucial role in the global carbon cycle and in the regulation of climate change. They absorbed nearly 30% of anthropogenic CO_2 emissions in the past six decades. If that absorption capacity were to change, in either direction, it would have a large impact on atmospheric CO_2 concentrations, resulting in a strong feedback effect on climate.

To date, the magnitude of the terrestrial carbon sink has been deduced indirectly: combining analyses of atmospheric carbon dioxide concentrations with ocean observations to infer the net terrestrial carbon flux. In contrast, when knowledge about the terrestrial carbon cycle is integrated into different terrestrial carbon models they make widely different predictions and fit observations poorly. These problems have been known for more than a decade and obstruct our ability to adequately inform policy and decision makers about the probable consequences of anthropogenic emissions and land use change scenarios.

The modeling community has adopted a variety of different approaches to improve the terrestrial carbon models in ESMs, none of which, unfortunately, has led to significant reductions in the variation between model predictions. A common approach has been to incorporate an increasing number of processes known to influence the carbon cycle, to make the models as realistic as possible. However, the more processes the models incorporate, the more complex and less tractable the models are, making it practically impossible to understand why different models make different predictions. Model intercomparisons have been effective at revealing the extent of the differences between model predictions but have typically provided limited insights into its origins. Benchmark analyses have provided assessments of model performance against standard datasets, but so far been restricted to processes occurring over short time-scales (e.g. days to years). Data assimilation methods have been applied to directly constrain simple models or model components with observations yet less extensively to global models.

Many research programs, involving observations and experiments, are underway to improve understanding of the terrestrial carbon cycle. Observations to characterize carbon cycle components over all continents on Earth are usually carried out by satellites or research networks. These have generated various regional and global data products, such as global maps of gross and net primary production (GPP and NPP), and regional and global distributions of soil carbon content and soil respiration. These data products have been extremely useful for improving of our understanding of the processes and properties underpinning patterns in terrestrial carbon cycle components. Experimental studies are also implemented to manipulate factors that are expected to vary as a consequence of climate change, such as elevating CO_2 concentrations, increasing ambient temperature, and altering precipitation rates. This enables direct insights into how ecosystems respond to such perturbations and have revealed some important new mechanisms, such as acclimation and adaptation of the carbon cycle to climate change. Nevertheless, they have yet to lead to better-constrained predictions of the terrestrial carbon cycle.

In this talk, I will carefully use available data to examine the internal properties of the terrestrial carbon cycle. Those properties largely determine and constrain its dynamics everywhere on the Earth, and thus form the basis upon which general theory can be formed for the terrestrial carbon cycle. I then discuss how five classes of external forcing each influence the predictability of the terrestrial carbon cycle. Together, these classes encompass almost all possible scenarios that terrestrial ecosystems experience. Finally, I highlight key areas for empirical research to improve predictive understanding and outline strategies to realize the predictability in terrestrial carbon models.