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From "missing sink" to process understanding: The expanding role of top-down studies in carbon cycle science

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The development of the first approaches for using atmospheric observations to understand the global carbon cycle was driven largely by the search for the "missing carbon sink." This focus set the stage for later advances in atmospheric inverse modeling and data assimilation (a.k.a. "top down") approaches, with research questions centering on quantifying biospheric and oceanic carbon fluxes for various regions and at various spatiotemporal scales.

Although these questions remain relevant, a shift is under way, driven by three primary factors. The first is that the quantification of the net carbon balance of large regions has proven more elusive than anticipated. The carbon budget and its uncertainties have remained largely unchanged for over a decade for even the most heavily monitoring regions of the world, i.e. Europe and the United States. The second is the more explicit acknowledgment that the search for a net flux is only a steppingstone towards the process-based understanding that is critical to constraining projections of carbon balance and feedbacks under changing climate conditions. Given the increasing awareness of challenges posed by equifinality in mechanistic modeling, getting the right "number" for a snapshot in time is not sufficient to anticipate responses to changing conditions. The third is the need to develop approaches for monitoring anthropogenic emissions and tracking emission reduction targets, which moves the focus from the biosphere to anthropogenic sources. This change presents a challenge, because top-down approaches were largely built on the assumption that anthropogenic emissions are known, and because observational networks were specifically designed to minimize influence from anthropogenic emissions.

After examining each of these three drivers, this talk will discuss the fundamental shifts in observational and modeling strategies that are needed to respond to this changing landscape. Observational networks that were designed to monitor large-scale atmospheric gradients need to be augmented with long-term sustained observations (both in situ and satellite) in highly heterogeneous regions. Inverse modeling approaches that leverage process-based understanding need to be sufficiently flexible to test competing hypotheses about driving processes. Statistical frameworks that were designed to describe biospheric fluxes need to be adapted to the (even) more heterogeneous patterns of anthropogenic emissions.

The talk will present examples of recent progress in the development of approaches that are responsive to the expanding scope of questions addressed by top-down studies. The presentation will close with open questions and remaining challenges which the modeling and observational communities need to address in order to complete the transition from asking "Where is the carbon sink?" to examining "What will the carbon sink be in the future?" and "Are we reaching our emissions targets?"