Constraining the simultaneous effects of elevated CO_2, temperature, and shifts in rainfall patterns on ecosystem carbon fluxes using multi-scale resource optimization theories

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Increases in atmospheric carbon dioxide concentrations (ca) leads to changes in the climate that alter mean air temperature (Ta) and precipitation (P) patterns. The ability of terrestrial ecosystems to absorb ca is sensitive to these climatic conditions, as well as to ca, thereby creating a feedback that has the potential to accelerate warming. To describe the feedback, the primary pathways by which elevated ca, Ta, and changing P patterns simultaneously impact ecosystem photosynthesis and respiration must be quantified. Our objective is to produce a synthesis that capitalizes on the strengths of different models and incorporates the important feedbacks of the soil-plant-atmosphere system at pertinent spatial and time scales. Our progress report to DOE will highlight the completed tasks. This presentation focuses on one completed task - a novel theoretical link between plant-water use strategies and parameters describing responses of stomata to their environment via stomatal optimizing theories. Optimization theories have been used to explain a variety of forms and functions in plants. At the leaf scale, it is often hypothesized that carbon gain is maximized, thus providing a quantifiable objective for a mathematical definition of optimality conditions. Eco-physiological trade-offs and limited resource availability introduces natural bounds to this optimization process. In particular, carbon uptake from the atmosphere is inherently linked to water losses from the soil as water is taken up by roots and evaporated. Hence, water availability in soils constrains the amount of carbon that can be taken up and assimilated into new biomass. The problem of maximizing photosynthesis at a given water availability by modifying stomatal conductance, the plant-controlled variable to be optimized, has been traditionally formulated for short time intervals over which soil moisture changes can be neglected. This simplification led to a mathematically open solution, where the undefined Lagrange multiplier (or marginal water use efficiency - MWUE) is heuristically determined via data fitting. A set of models based on different assumptions that account for soil moisture dynamics over an individual dry-down are proposed so as to provide closed analytical expressions for the carbon gain maximization problem. These novel solutions link the observed variability in MWUE over time, across soil moisture changes, and at ca concentrations to water use strategies ranging from intensive, in which all soil water is consumed by the end of the dry-down period, to more conservative, in which water stress is avoided by reducing transpiration.