The Role of Vegetation Acclimation in Eco-Hydrologic Response to Global Change

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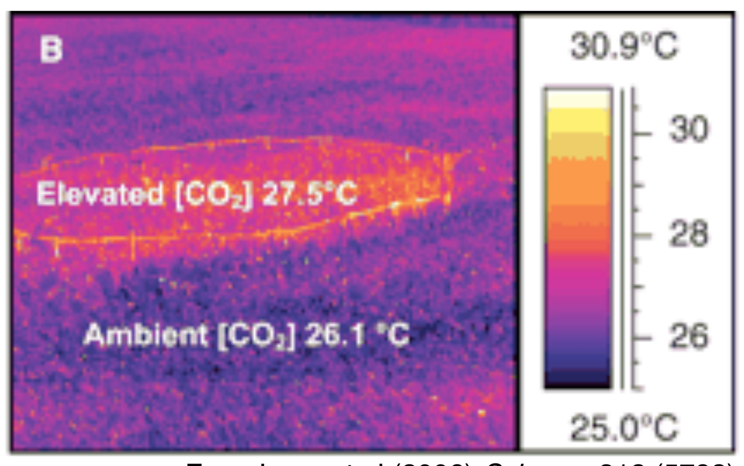
ILLINOIS

Overview



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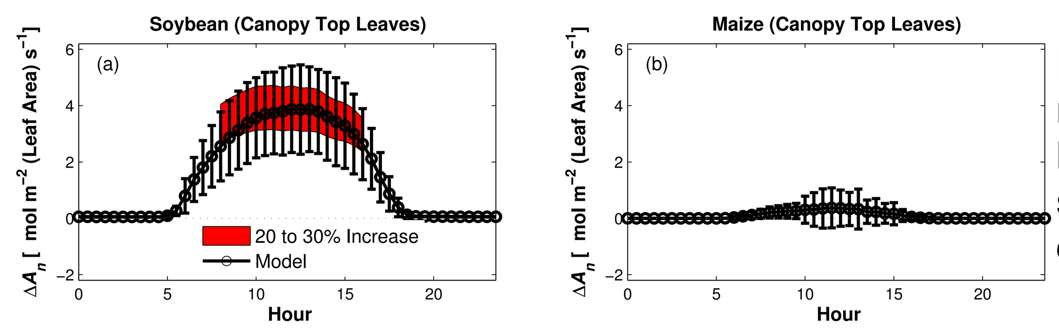
Amongst the most important environmental changes experienced by terrestrial vegetation over the last century has been the increase in ambient carbon dioxide (CO_2) concentrations, with a projected doubling in CO_2 from pre-industrial levels by the middle of this century. Accurate prediction of land-atmosphere exchange of mass, energy, and momentum requires the consideration of plant biochemical, ecophysiological and structural acclimation to modifications of the ambient environment. Here we present work that utilizes a detailed, vertically resolved canopy-atmosphere exchange model (MLCan) to examine the responses of central US soybean and maize canopies to elevated CO_2.

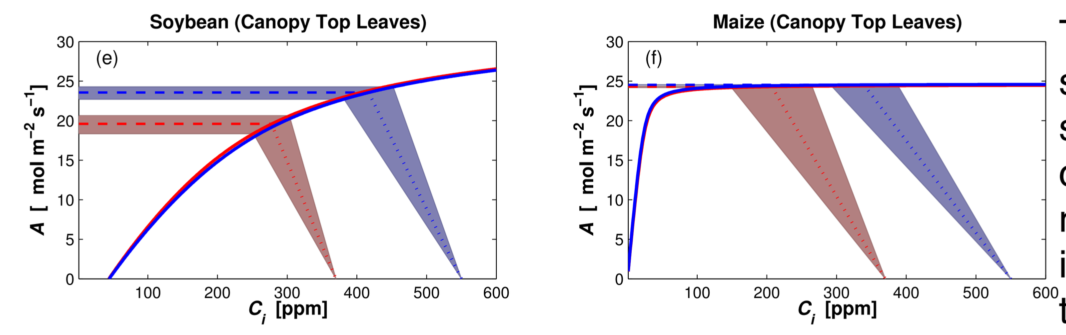
Free Air Carbon Enrichment (FACE) technology has provided significant insight into the functioning of vegetation in natural conditions under elevated CO_2. Observations from the SoyFACE experimental facility (Savoy, Illinois, USA) guide this work by providing estimates of changes in leaf states and fluxes under elevated CO_2 (550 [ppm]) for both soybean and maize. SoyFACE observations are routinely made for canopy-top foliage, leaving open the question of how vegetation responses scale to the canopy. We address this question here.

Observations at SoyFACE indicate a 10% increase in leaf area (*structural acclimation*, SA), a 5% reduction in Rubisco carboxylation capacity (*biochemical acclimation*, BA), and a variable reduction of stomatal conductance for soybean (C3) due to elevated CO_2 (*ecophysiological acclimation*, EA). Maize (C4) has been shown to only experience ecophysiological acclimation.

A set of simulations are conducted to untangle the influences of observed levels of biochemical, structural and ecophysiological acclimation

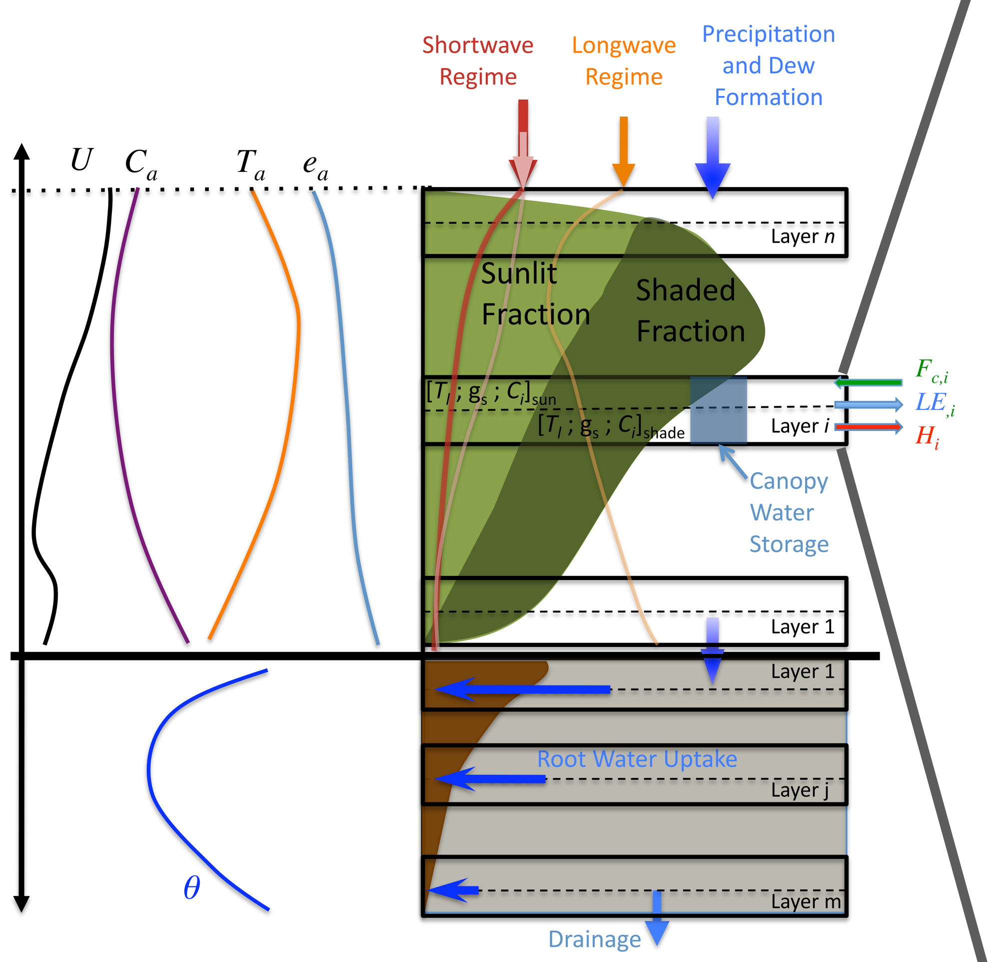


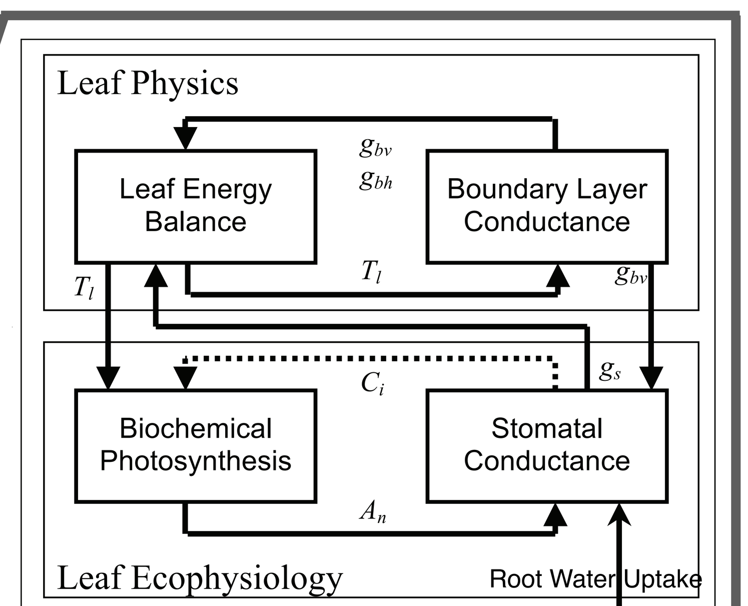
Direct stimulation of C3 photosynthesis results in a 20-30% increase in leaf-level (canopy top) photosynthesis for soybean, relative to a negligible increase for maize.



These synthetic A-C_i curves demonstrate photosynthetic sensitivity of C3 soybean leaves to ambient CO_2 concentration. The CO_2 saturating mechanism of C4 maize leaves makes them insensitive to ambient CO_2 concentrations.

MLCan Overview





Coupled leaf-level processes include:
- Biochemical Photosynthesis (Farquhar-based)
  - $A_n = f(T_l, C_i, Q_{abs})$ for C3 Soybean
  - $A_n = f(T_l, Q_{abs})$ for C4 Maize
  - (CO_2 saturating mechanism of C4 pathway)
- Stomatal Conductance (Ball-Berry)
  - $g_s = f(A_n, RH_s, C_s)$
- Leaf Energy Balance
  - $T_l = f(g_s, g_{bh}, T_a, e_a)$
- Leaf Boundary Layer Conductance
  - $g_{b,h} = f(U_s$, leaf dimensions)

MLCan, a multi-layer canopy-root-soil system model, resolves the radiative, scalar and foliage micro-environment through a closed plant canopy, including:

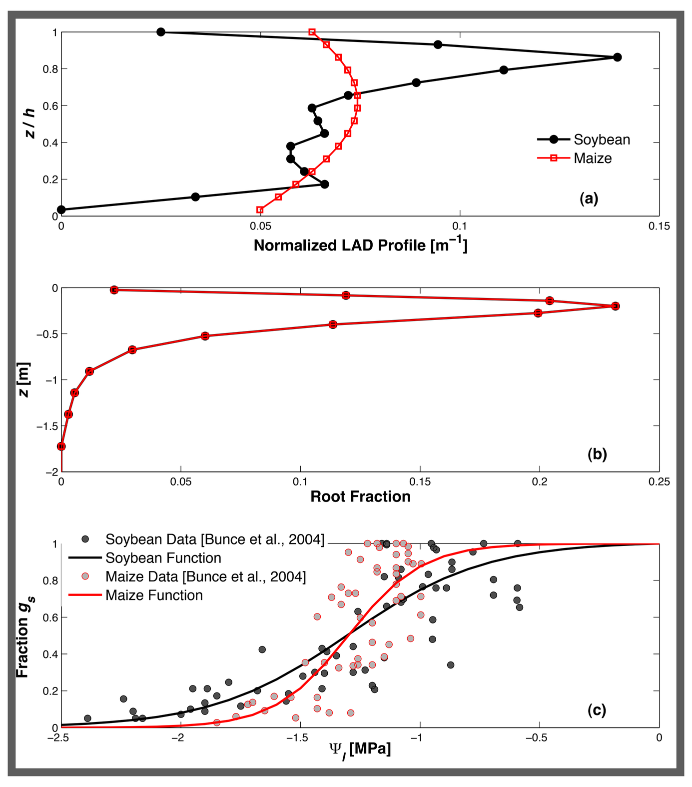
✦ Shortwave and longwave radiation attenuation and emission
- Direct (sunlit foliage) and diffuse (sunlit and shaded foliage) radiation considered separately
- Longwave sources from sky, soil and through canopy (foliage; sunlit and shaded at different temperatures)

✦ Scalar concentrations (CO_2 and vapor), air temperature and wind speed profiles

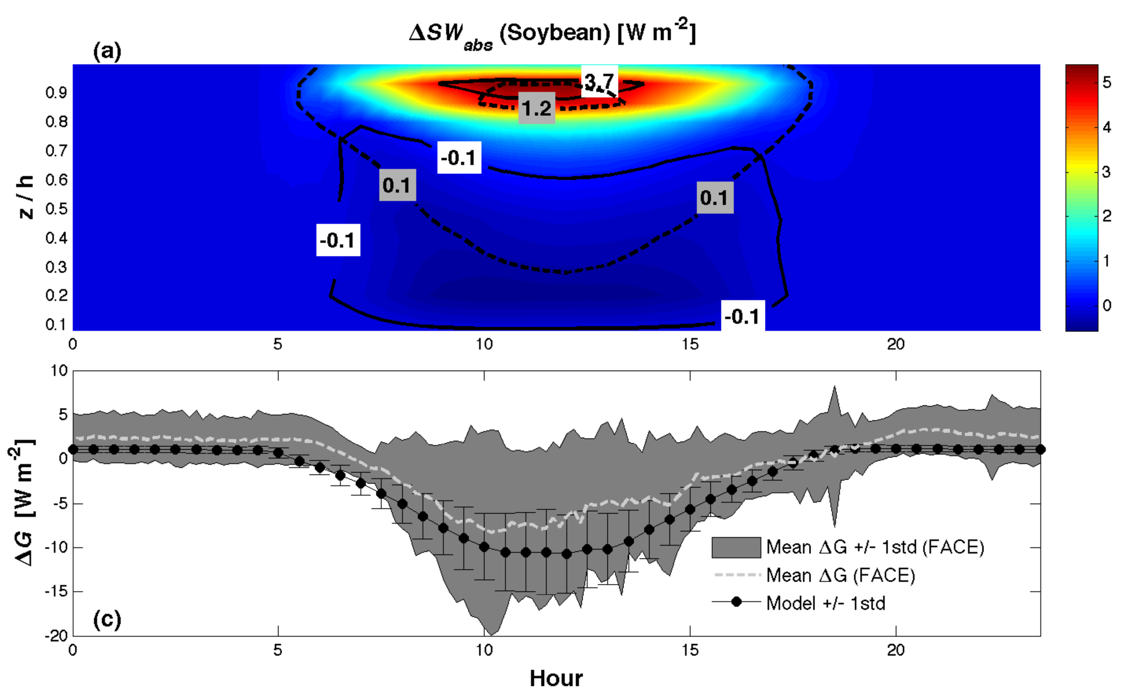
✦ Canopy interception of precipitation, dew formation

✦ Soil hydrology, root water uptake and stomatal sensitivity to root pressure potential (Figure to right, panel c)

Requires specification of vertical distributions of canopy leaf area and root biomass (Figure to right, panels a and b)

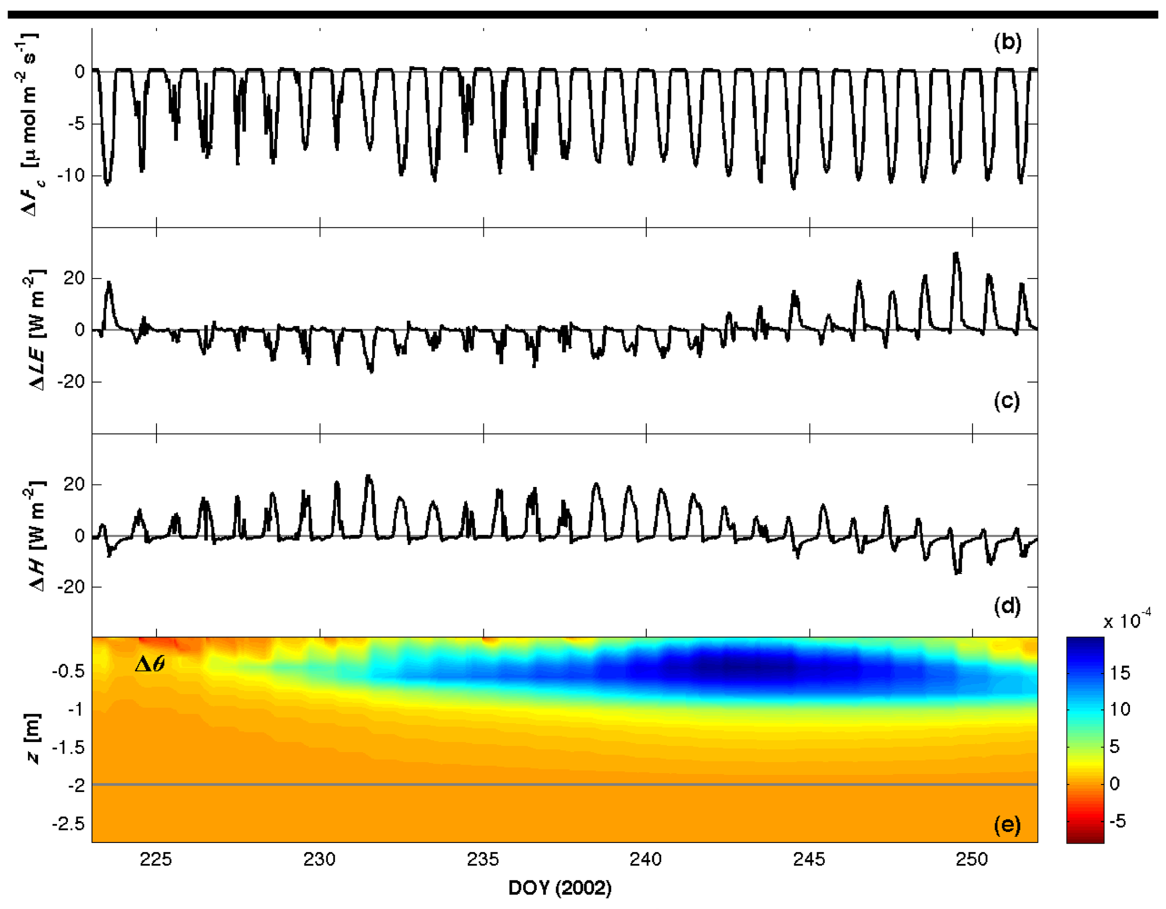


Impacts of Structural and Ecophysiological Acclimation



Top Panel: Soybean LAI augmentation results in mean noon-time increases in shortwave absorption of 15 [W m^{-2}] concentrated in the upper canopy. This results in shading of lower canopy, where foliage can more efficiently utilize radiation.

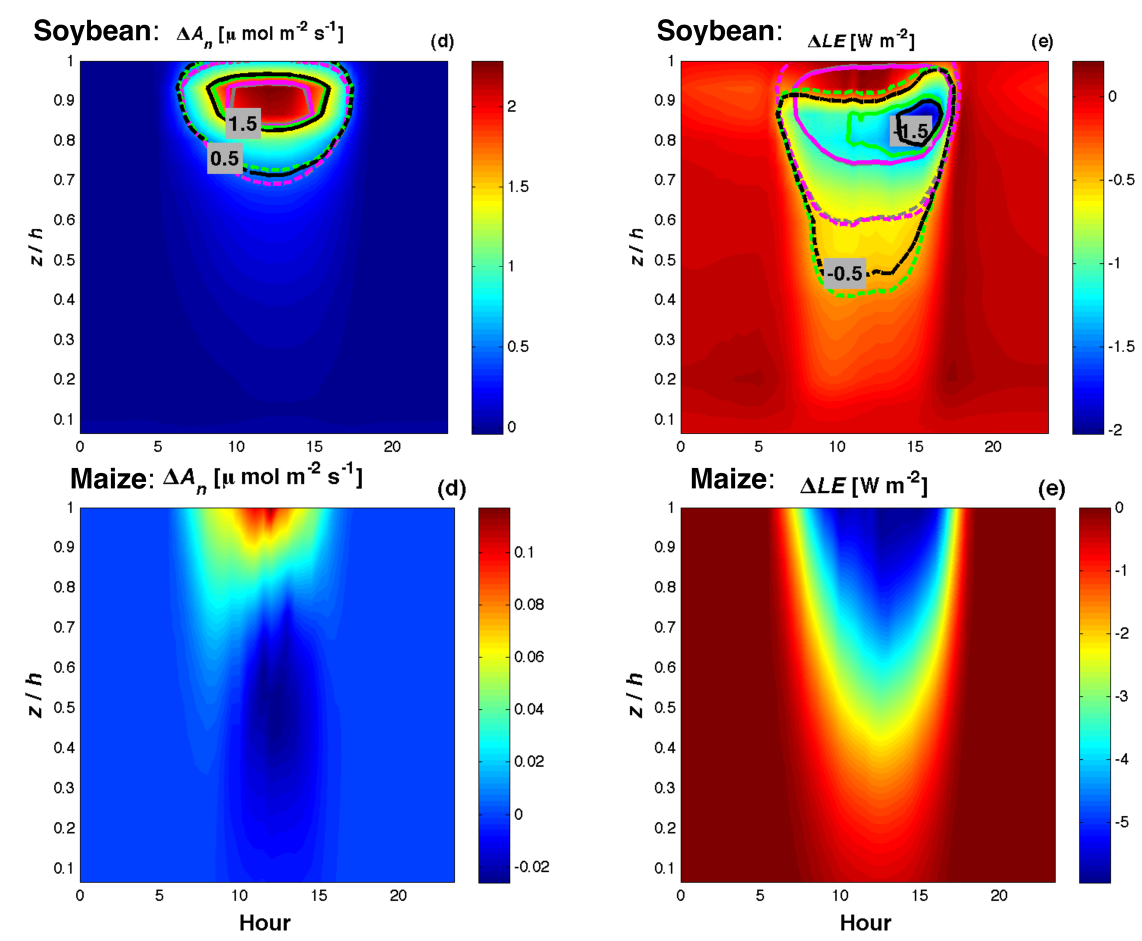
Bottom Panel: Structural acclimation also results in a reduced energy flux into the soil, with implications for soil biogeochemical reactions.



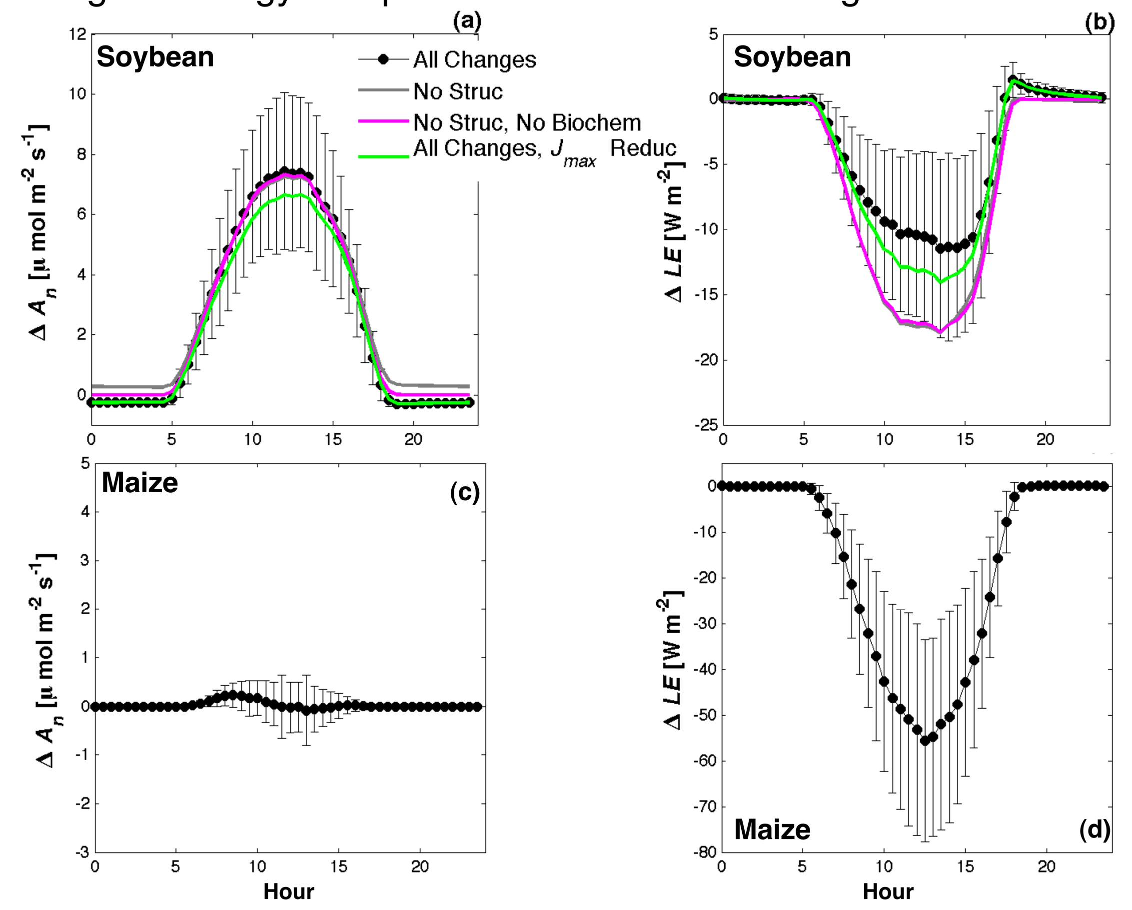
Immediately following a rain event (DOY 225) during the 2002 soybean growing season, greater CO_2 uptake (Δ = Elevated - Current CO_2 scenarios), a shift in energy partitioning from LE to H, and soil moisture conservation are apparent under elevated CO_2. As the current CO_2 crop experiences water stress (DOYs 242-251), the elevated CO_2 crop remains unstressed, using the moisture it has conserved (ecophysiological acclimation) for gas exchange.

Within-Canopy and Canopy-Integrated Flux Impacts

Increases in A_n and reductions in LE for soybean are localized around the LAI maximum under elevated CO_2. A_n increase through maize canopy is negligible (note difference in scales for soy and maize plots), with LE reduction under elevated CO_2 much larger and more uniformly distributed. Increase in A_n for soy due to CO_2 fertilization partially offsets reduction in LE due to stomatal closure.

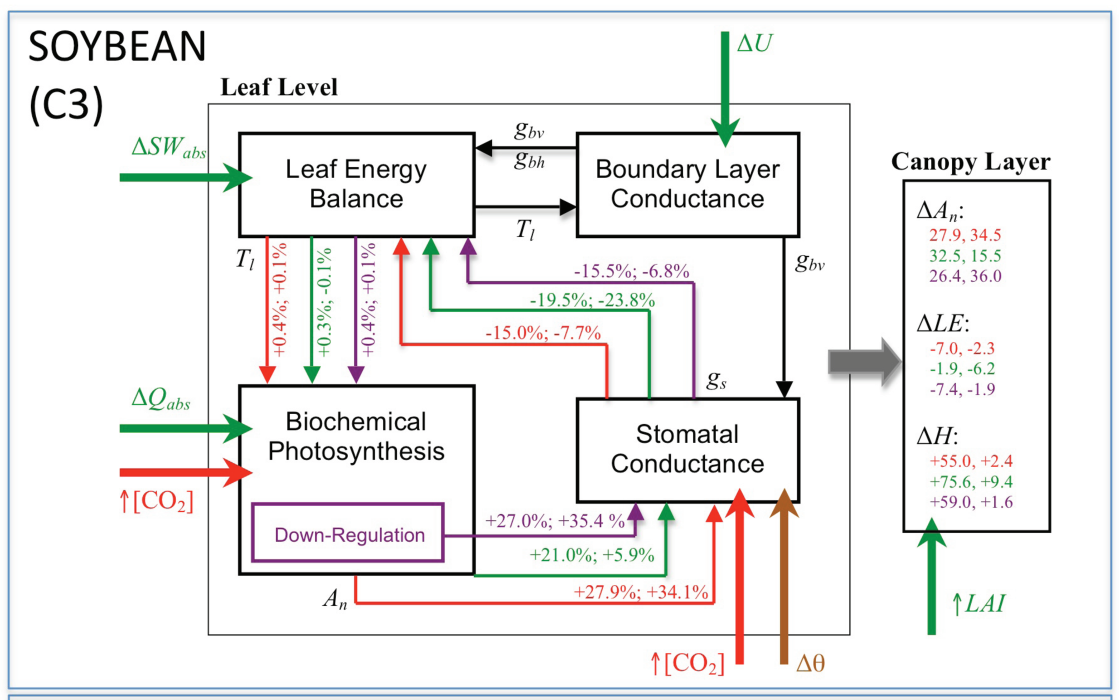


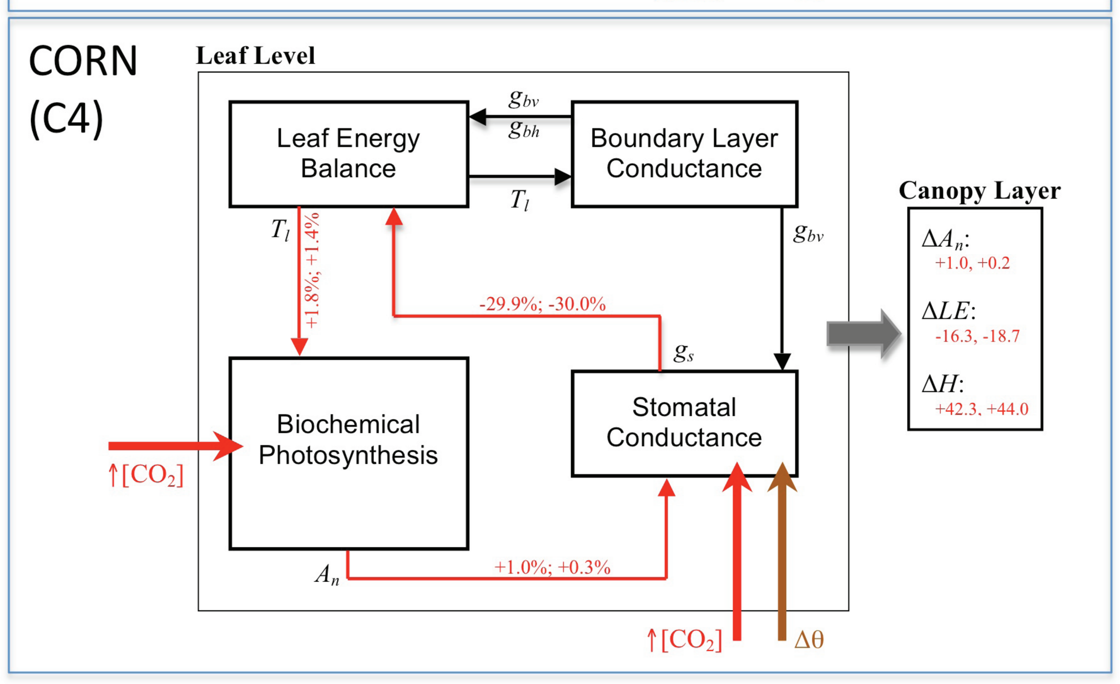
For soy canopy, BA had no effect as photosynthesis is RuBP-regeneration limited at high CO_2. SA partially offset EA to lessen reduction in LE. No CO_2 fertilization for C4 maize resulted in large net change in energy dissipation from LE to H and longwave emission.



Summary

For soy (C3), CO_2 fertilization and acclimations accounted for mean 30% increase in CO_2 uptake and 7% reduction in transpiration. Impact of greater LAI was to reduce net CO_2 uptake due to greater respiration losses. Maize (C4) had a negligible increase in CO_2 uptake, but a 19% net reduction in transpiration, with implications for interactions with daytime boundary layer and climate.





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