TROPICAL DROUGHT AND THE CARBON CYCLE: C3/C4 PLANT FRACTIONS, ROOT-ZONE STRESS AND THE USE OF CARBON ISOTOPE DISCRIMINATION TO ESTIMATE TERRESTRIAL CO2 FLUXES

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ABSTRACT

Tropical drought can significantly impact inter-annual variations in the terrestrial CO_2 fluxes. Concentrations and carbon isotope ratios of atmospheric CO_2 can help to quantify this impact, however, their use requires a model estimation of the terrestrial isotope disequilibirum, i.e. the difference between the isotopic signature of photosynthesis and respiration, which can only be achieved by accurately accounting for changes in relative contributions of C3 and C4 plants (C4 fraction) and physiological effects of root-zone water stress.

We use a model of the terrestrial biosphere, SiB3, to simulate the magnitude and isotopic signature of CO_2 fluxes between the terrestrial biosphere and the atmosphere for the years 1982-2002. SiB3 is driven globally by 1°X1° NCEP2 assimilated meteorology. Time-varying phenological properties are constrained by processed normalized difference vegetation index (NDVI) calculated from AVHRR.

In the simulation, multiyear declines in re-analyzed precipitation in the tropics preceding the 1982, 1987, 1992 and 1998 El Niños result in spatially complex patterns of both soil water and relative humidity stresses. These, in turn, affect the relative contributions of C3 and C4 plants to total net assimilation, as well as the isotope effect associated with C3 photosynthesis. Variations in the magnitude of C3 discrimination are large; however, because of the lower carbon isotope discrimination associated with C4 plants (~4%) relative to that of C3 plants (~19%), relative rates of C3 and C4 photosynthesis are the most important control on discrimination of the terrestrial biosphere. The carbon isotopic signal of each ENSO is unique because each has a spatially unique impact on tropical areas of South America, Africa and Southeast Asia. Changes in tropical net discrimination during the 1998 el Niño (Fig. 1) are approximately 0.5‰ and are completely driven by changes in the C4 fraction. In contrast, changes in net discrimination during the 1992 el Niño are slightly larger, ~0.6‰, and are driven by variations in both the C4 fraction as well as changes in discrimination by C3 plants.

These results suggest that although temporal variations in carbon isotope discrimination of the terrestrial biosphere can be helpful in estimating the relative contribution of the biosphere and ocean to changes in atmospheric CO_2 concentrations, systematic relations between CO_2 fluxes and plant discrimination are complicated and controlled by temporal and spatial variations in precipitation, root-zone stress, and their impact on both C3/C4 plant growth, as well as the stomatal response of C3 plants to relative humidity.

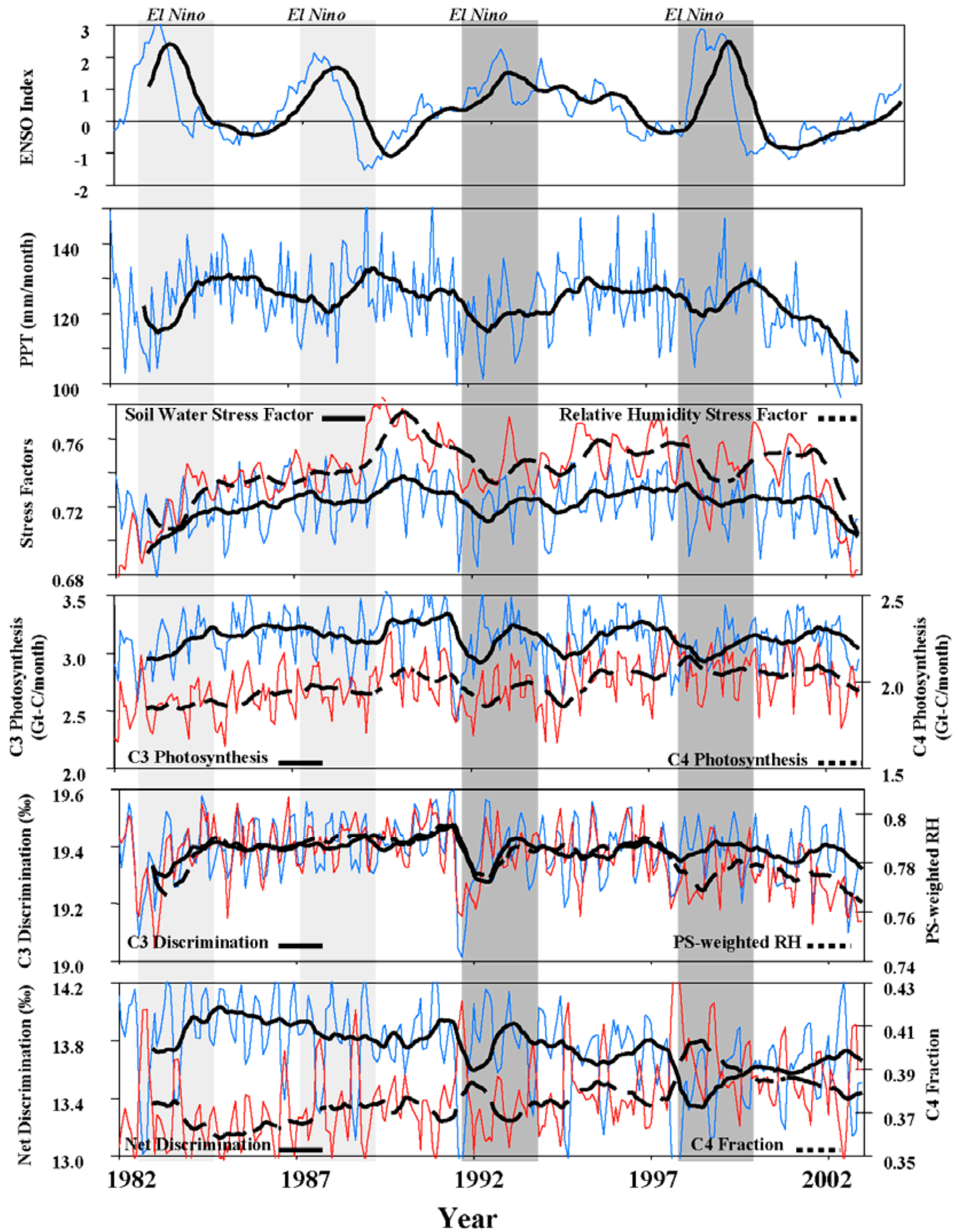

Fig. 1. Variations in the ENSO Index, precipitation, modeled plant growth stress factors, C3 and C4 plant photosynthetic rates, C3 discrimination and C3 assimilation-weighted relative humidity, net (combined C3 and C4) discrimination and C4 fraction of total net assimilation for the tropics during the years 1982-2002. El Niños are generally associated with declines in tropical rainfall. If the decreased rainfall lasts for extended periods it can result in increased root-zone and relative humidity stresses on plants that, in turn, impacts growth and carbon isotope discrimination by C3 plants. Depending on the spatial distribution of the drought stress, it can also result in variations in the relative contributions of C3 and C4 plants to total net assimilation, thus altering the isotopic ratios of atmospheric CO_2.