Impacts of air pollution on the global biosphere and climate

Christopher D. Holmes,
Jason A. Ducker
Florida State University
(cdholmes@fsu.edu)

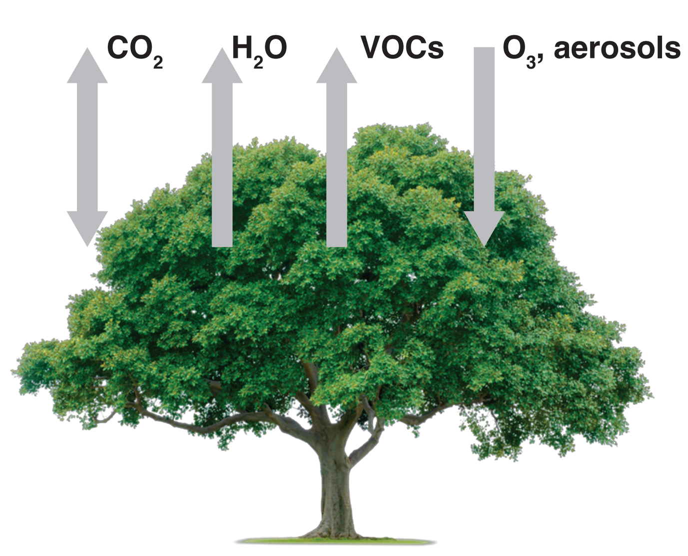
Trevor Keenan
Lawrence Berkeley National Lab

Silvano Fares, Allen Goldstein
University of California, Berkeley

Ivan Mammarella
University of Helsinki

Overview

Human life depends intimately on interactions between Earth's atmosphere and biosphere. Plants emit life-sustaining oxygen and water vapor while taking up carbon dioxide and removing air pollutants. Air pollutants also harm the biosphere in turn. Surface ozone (O_3) is toxic to plants, as well as people, and it suppresses their growth and carbon dioxide (CO_2) uptake. In the face of climatic and industrial change in the 21st century, society needs solid understanding of the atmosphere-biosphere interactions that support our well being and knowledge of how susceptible or resilient these interactions are to global change. This project aims: (1) to quantify the effects of ozone air pollution on biosphere-atmosphere fluxes of water, carbon dioxide and heat through analysis of long- term measurements at experimental forests and (2) to evaluate and better represent those coupling processes in a state-of-the-art climate model.



Water-use efficiency:
$WUE = F_{in}(CO_2) / F_{out}(H_2O)$

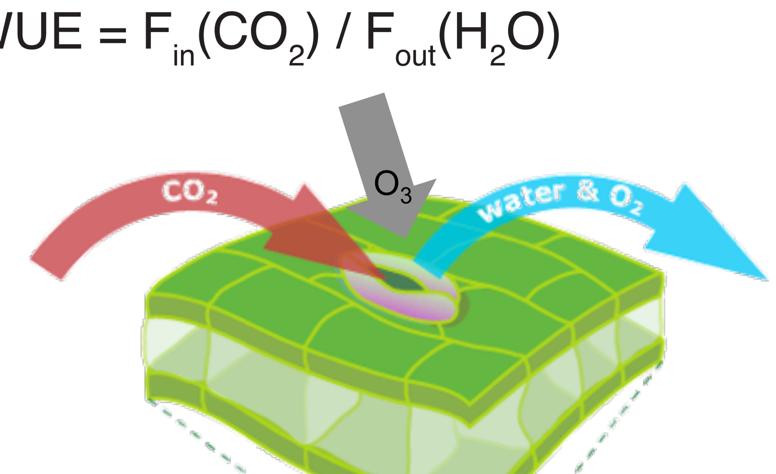


Figure 2. Plants control the stomata (pores) on leaves to optimize their CO_2 intake for photosynthesis and minimize H_2O loss (transpiration). O_3 enters the stomata when stomata are open and can then damage cellular membranes and proteins.

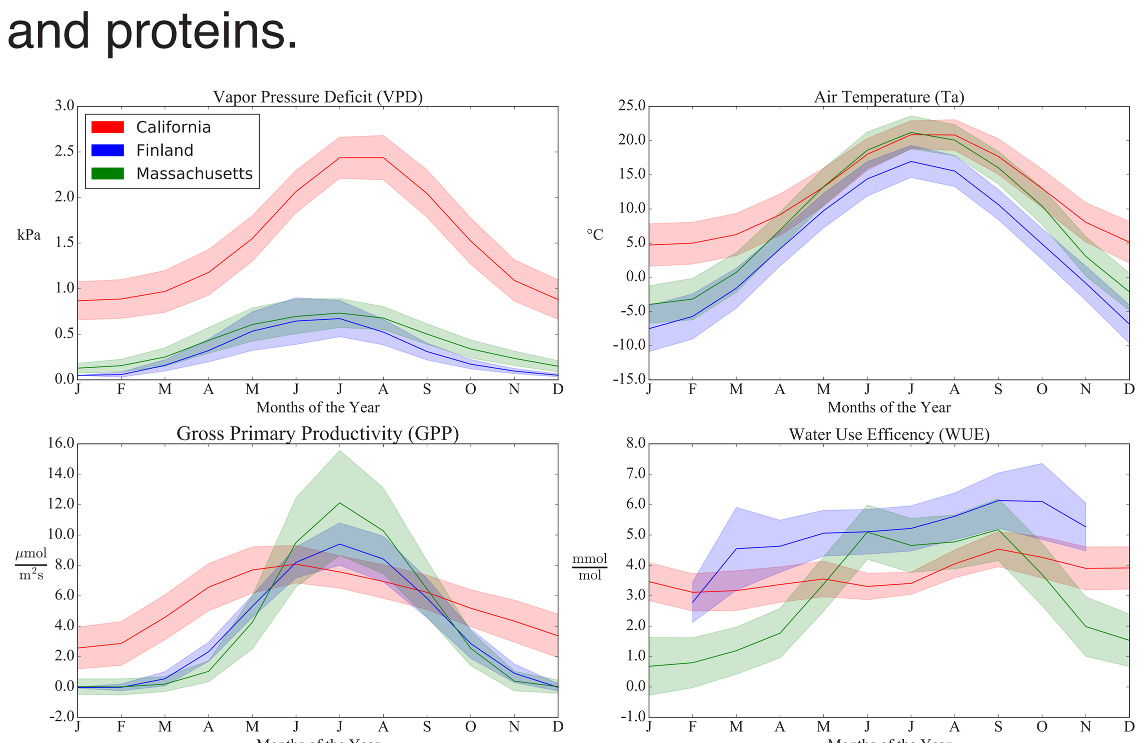
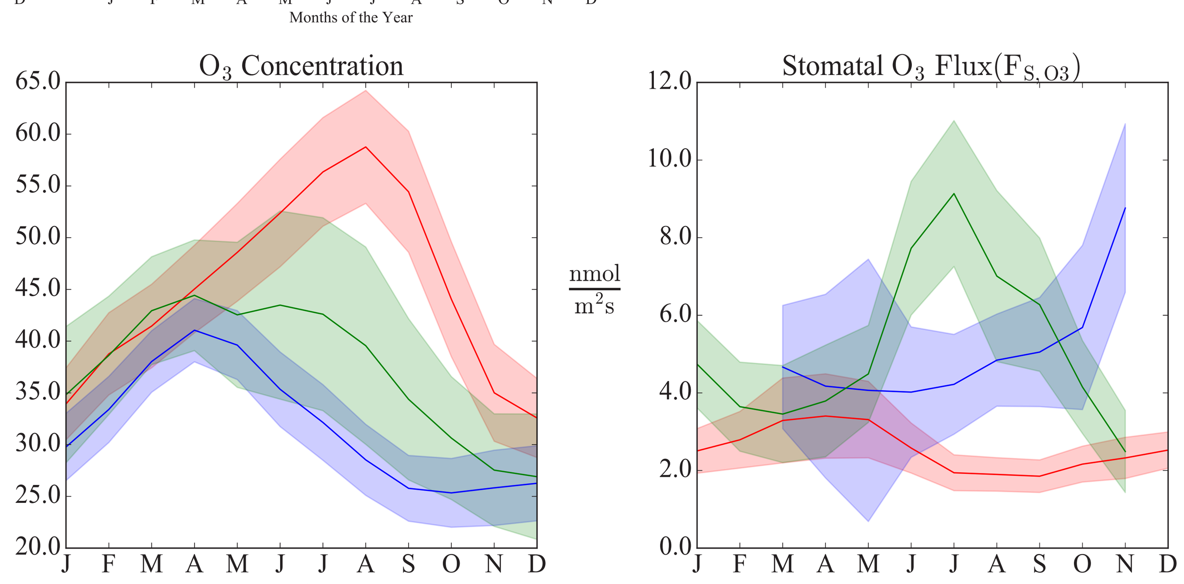


Figure 5. Seasonal cycle of ecosystem fluxes and meteorological conditions at 3 forest sites with O_3 flux measurements. These include evergreen needleleaf forests (California, Finland) and a deciduous broadleaf forest (Massachusetts).

Figure 6. Concentration of O_3 in the atmosphere (left) is not a good predictor of O_3 into leaves (right) and associated injury. Rather, fluxes are high when stomatal pores are most open.



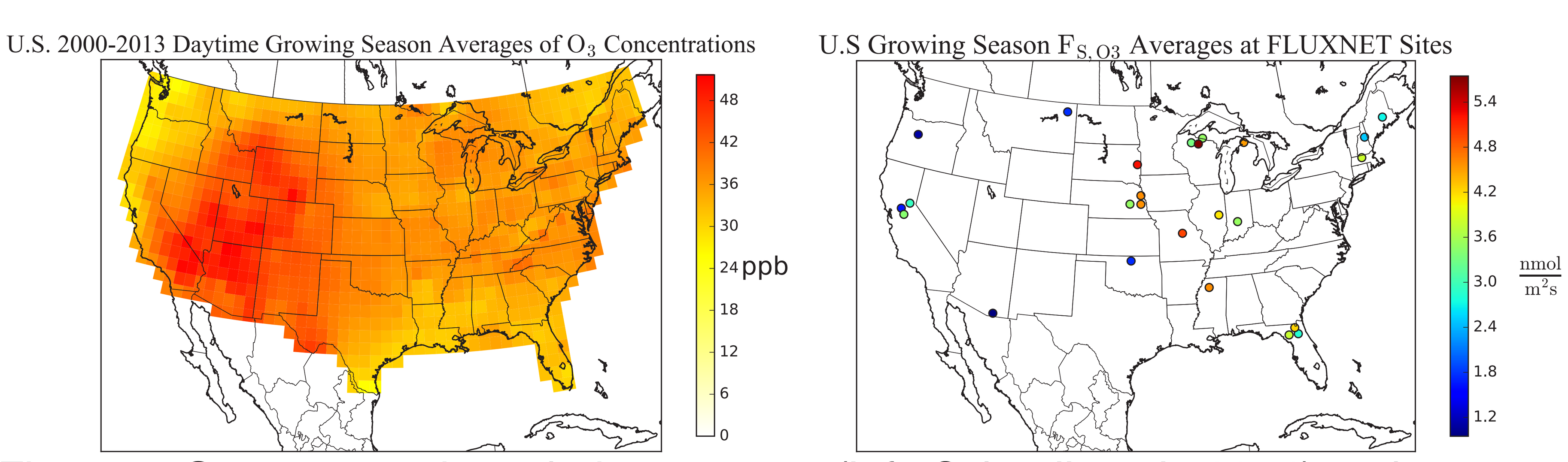
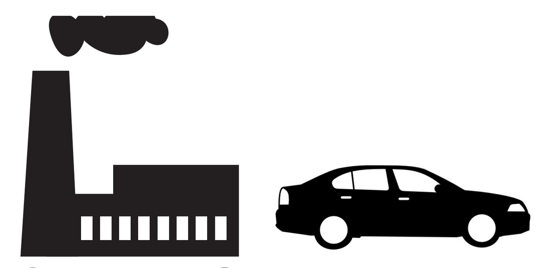


Figure 7. O_3 concentrations during summer (left, Schnell et al., 2014) and fluxes at FLUXNET sites where WUE is measured (right).

Conclusions

- Stomatal O_3 flux reduces forest water-use efficiency across a wide range of plant and ecosystem types that have not been studied previously. The effect is significant at 18 of 23 sites and consistently 1-3% of mean WUE.
- Past controlled experiments found a similar response in a small selection of species, indicating that the O_3 damages are regular across many species.
- At grassland and shrub sites, WUE does not respond to O_3 flux, indicating possible differences between C3 and C4 plants.
- O_3 pollution interferes with the terrestrial water cycle, causing plants to waste water without gains in biomass or crop yield. Effects on precipitation, runoff, and drought-tolerance are likely and focus of ongoing work.



$$NO_x + \begin{matrix} CO \\ VOCs \\ CH_4 \end{matrix} + \begin{matrix} (Sunlight) \\ h\nu \end{matrix} \rightarrow O_3$$

Figure 1. Surface O_3 pollution is produced in the atmosphere from natural and anthropogenic precursor gases in the presence of sunlight. Emission reductions since the 1970s have reduced surface O_3 pollution in much of the US and Europe, but O_3 continues to rise in many other regions.

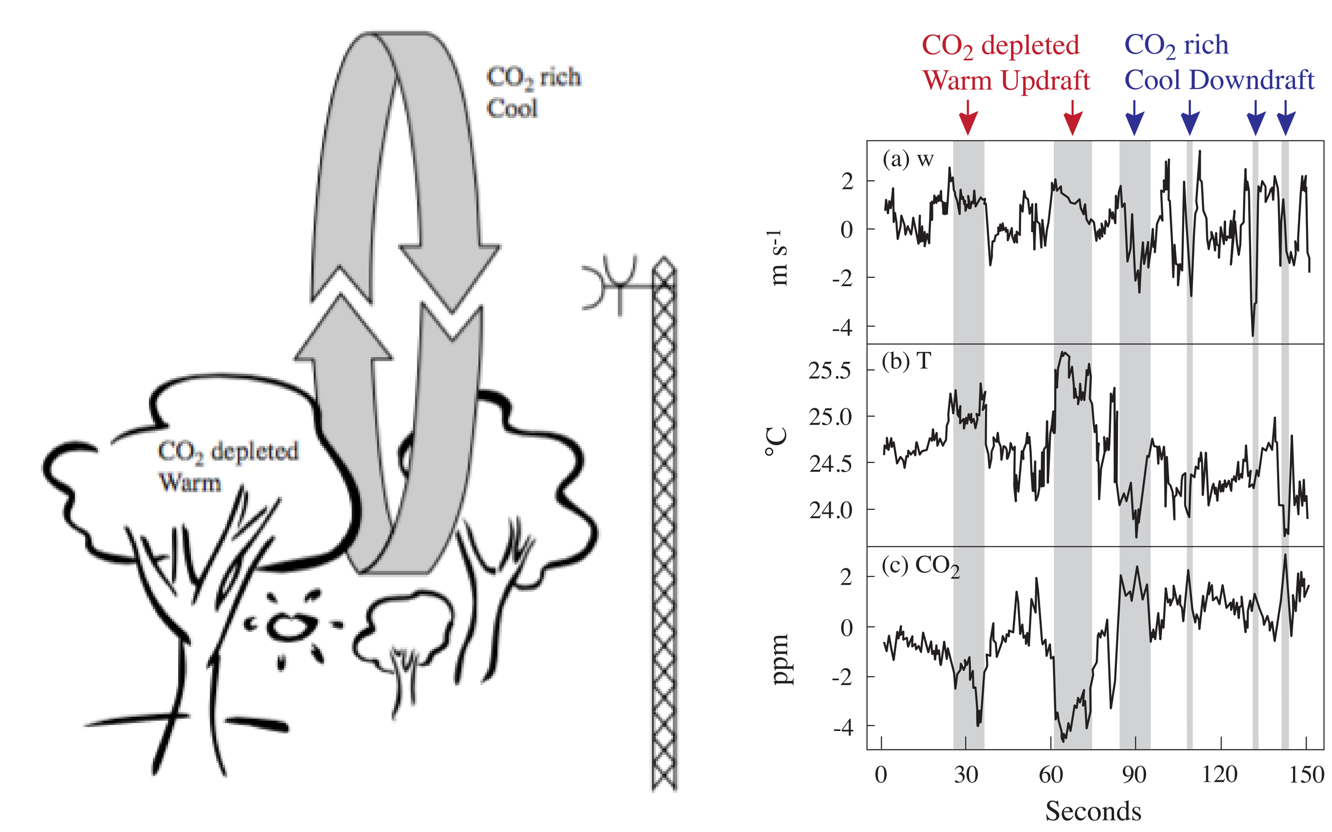
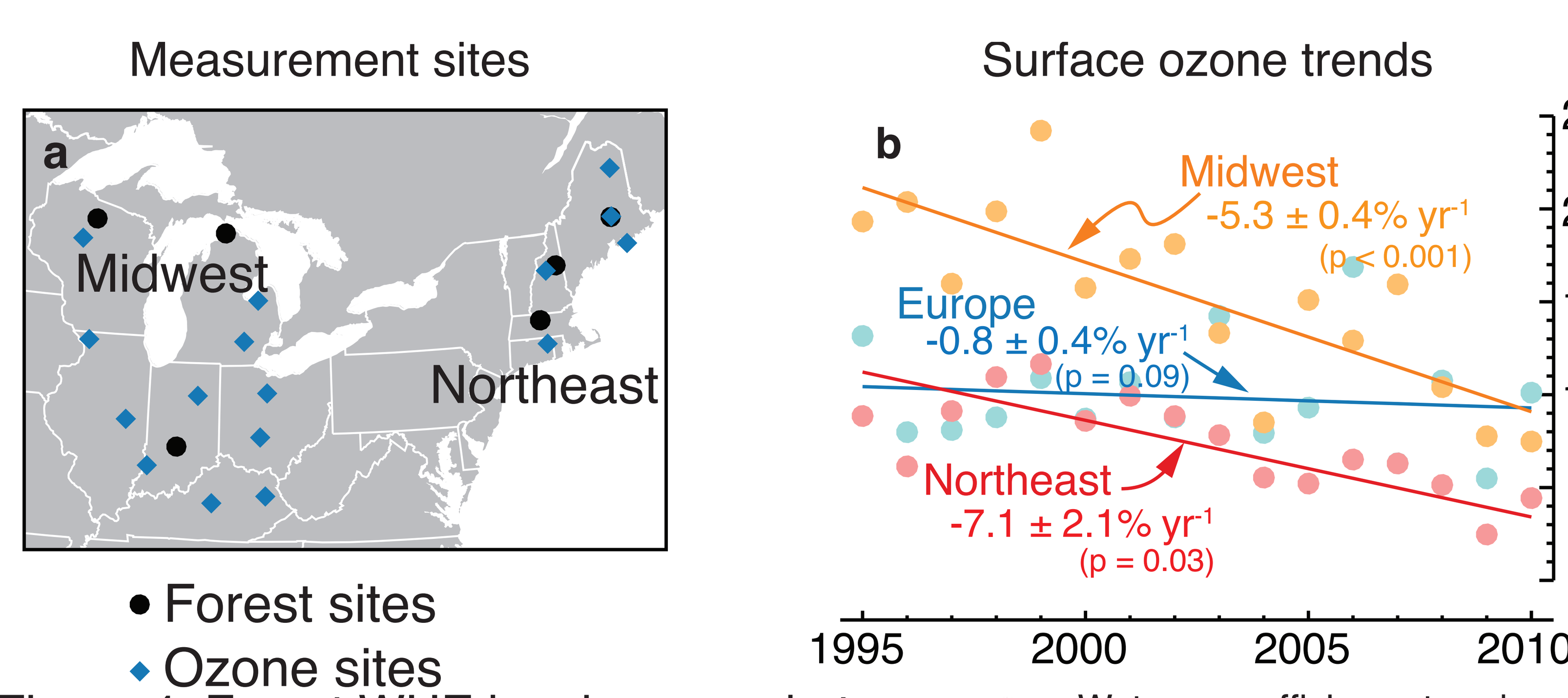


Figure 3. Ecosystem fluxes of CO_2, H_2O, and O_3 are measured from a tower above the canopy (left) which makes high-frequency measurements of vertical winds and concentrations (right). We analyze observations from the global FLUXNET monitoring network (www.fluxdata.org).



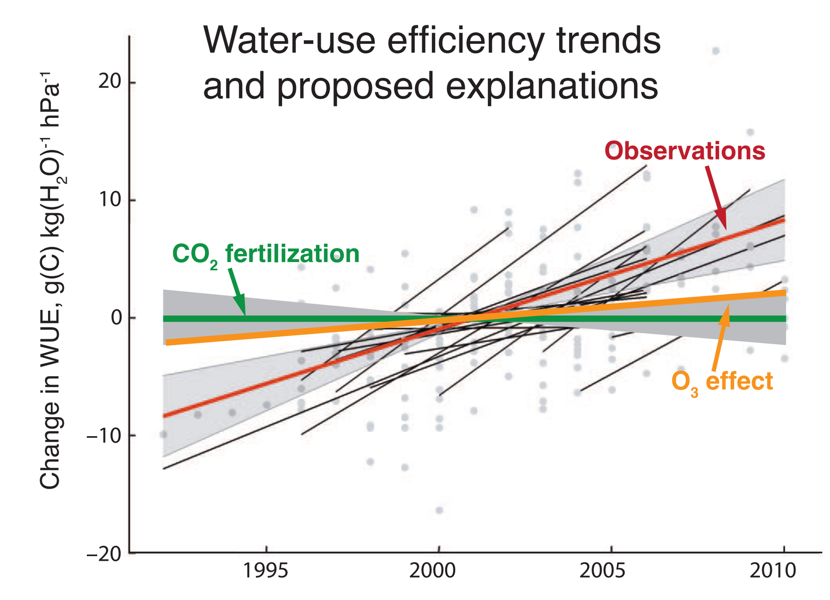


Figure 4. Forest WUE has increased at many sites in North America and Europe (Keenan et al., 2014). Improved O_3 air quality explains part of this trend (Holmes, 2014), but the O_3 effects have only been measured in a few species. Our FYAP work quantifies the O_3-WUE effect across multiple ecosystems and plant types.

	Effect on WUE (%)		
Variables	California	Massachusetts	Finland
$F_{S,O3}$	** -0.8%	*** -1.6%	*** -3.3%
VPD	* -1.3%	*** -3.8%	*** -3.0%
PAR	*** -1.4%	*** -2.0%	*** -3.4%
Ta	0.5%	*** 1.1%	* 0.1%
R^2	4.0%	8.5%	9.8%

Table 1. O_3 flux is a significant predictor of reduced WUE at 3 forest sites with the highest-quality data ($p<0.05$). WUE falls -0.8% to -3.3% in response to a 1 s.d. increase in stomatal O_3 flux, which is as important as major meteorological factors.

References

Holmes, C.D. (2014) Air pollution and forest water use, Nature, 507, E1-E2, doi:10.1038/nature13113.
Keenan, T. F. et al., (2013) Increase in forest water use efficiency as atmospheric carbon dioxide concentrations rise, Nature 499, 324-327.

Schnell, J. L., Holmes, C. D., et al. (2014) Skill in forecasting extreme ozone pollution episodes with a global atmospheric chemistry model, Atmos. Chem. Phys., 14, 7721–7739, doi:10.5194/acp-14-7721-2014.