

Linkages among climate variability, terrestrial ecosystems and the global atmospheric CO₂ budget as determined from atmospheric observations

Kenneth J. Davis
Department of Meteorology
The Pennsylvania State University

Ecosystem responses to climate variability are evident on a global scale. The global CO₂ budget shows striking interannual variability that is most likely due to climate. The large degree of global-scale interannual variability argues that the terrestrial component of the atmospheric CO₂ budget has the potential to respond strongly to climate change. Terrestrial ecosystems currently store roughly 2 PgC yr⁻¹ of atmospheric CO₂, a substantial fraction of annual fossil fuel emissions. It is not clear whether this sink of atmospheric CO₂ will increase, decrease, or remain steady as climate changes. While global- to continental-scale “inverse studies” provide a very strong constraint to the globally integrated net ecosystem-atmosphere (NEE) of CO₂, the mechanisms responsible for this interannual variability are not evident.

A global network of roughly 130 micrometeorological towers have emerged in an effort to quantify NEE of CO₂ between the land surface and the atmosphere on time scales from hours to years. These towers employ eddy-covariance flux measurements that operate continuously and provide direct observations of the turbulent exchange of CO₂, sensible and latent heat, and momentum representative of spatial scales on the order of 1 km². Data from the towers are beginning to reveal the ways in which the ecosystems at these sites respond to climate variability in terms of both CO₂ fluxes and the surface energy budget. Examples from forests and grasslands will be presented, and suggest large potential sensitivity to climate change, especially at the beginning and end of the growing season. These towers also provide direct observations of the annual cumulative NEE of CO₂ at these sites, helping to quantify the sources of the global terrestrial sink of carbon.

Current research is attempting to generalize the results from single tower sites to whole biomes or geographic regions. If successful, this research, in combination with a proposed increased in the density of atmospheric CO₂ mixing ratio observations and improved transport models, will bridge the gap in spatial scales between the flux towers and atmospheric inverse studies. Challenges include a lack of data from the tropics, the need to determine universal responses of ecosystems to climate variability, uncertainty about systematic errors in the tower-based flux observations, and the gap in spatial scales between 1 km² flux footprints and continental to global scale inverse studies. There is also currently insufficient flux tower data to quantify the influence of forest age on carbon sequestration rates and sensitivity to climate. Forest inventory data provides a powerful complement to tower flux data and global inverse studies in this respect. Finally, these flux towers have not yet been widely applied to studying the response of ecosystem evapotranspiration and surface energy budget to climate change.

Micrometeorological observations can also be used to test mechanisms hypothesized to connect ecosystem fluxes to weather and climate. These ecosystem-atmosphere

interactions are mediated by the dynamics of the atmospheric boundary layer, the lowest 1-2 km of the atmosphere. In homogeneous terrain changes in the surface energy budget can be the difference between a day of deep convective clouds and precipitation and fair weather cumulus. In heterogeneous terrain the situation becomes more complex as mesoscale flows such as sea breezes can develop within the atmospheric boundary layer. At very small scales, surface heterogeneity is mixed out by atmospheric turbulence and the atmosphere responds to essentially homogeneous conditions. Micrometeorological theory and aircraft observations are being used to more clearly delineate the regimes of heterogeneous vs. essentially homogeneous surface conditions. It is well established that changes in land use lead to large changes in the surface energy balance. Land use change, therefore, creates a first-order feedback to the climate system. Studies of the coupling among the surface energy budget, boundary layer development and convective cloud formation reveal the mechanisms and magnitudes of this feedback.