FINAL REPORT

DOE Award: **DE-SC0001470**
Title: **Modeling Diurnal Variations of California Land Biosphere CO_2 Fluxes**
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Abstract

In Mediterranean climates, the season of water availability (winter) is out of phase with the season of light availability and atmospheric demand for moisture (summer). Multi-year half-hourly observations of sap flow velocities in 26 evergreen trees in a small watershed in Northern California show that different species of evergreen trees have different seasonalities of transpiration: Douglas-firs respond immediately to the first winter rain, while Pacific madrones have peak transpiration in the dry summer. Using these observations, we have derived species-specific parameterization of normalized sap flow velocities in terms of insolation, vapor pressure deficit and near-surface soil moisture. A simple 1-D boundary layer model showed that afternoon temperatures may be higher by 1°C in an area with Douglas-firs than with Pacific madrones.

The results point to the need to develop a new representation of subsurface moisture, in particular pools beneath the organic soil mantle and the vadose zone. Our ongoing and future work includes coupling our new parameterization of transpiration with new representation of sub-surface moisture in saprolite and weathered bedrock. The results will be implemented in a regional climate model to explore vegetation-climate feedbacks, especially in the dry season.

Final Report: Modeling Diurnal Variations of California Land Biosphere CO_2 Fluxes

Estimation of carbon-climate feedbacks in Earth System Models depends on the modeled soil moisture status and the response of ecosystems when soil moisture is low (e.g. Fung et al. 2005; Friedlingstein et al. 2006). Current parameterizations of photosynthesis and evapotranspiration (ET) use a simple sigmoid function dependence on soil moisture, loosely defined as the degree of saturation in the rooting zone. The same dependence is used for all plant function types. The goal of the work is to improve the parameterization of photosynthesis and transpiration, especially their dependence on soil moisture, in regional and global climate model.

1. New Parameterization

The work took advantage of unprecedented high-frequency (30 minutes) observations of sapflow velocities in 26 evergreen trees, temperature, humidity, insolation and soil moisture in a steep (~32°) very small watershed (~4,000 m^2) 16 km east of the Pacific coast in northern California (39.729°N 123.644°W). The observations span three years, from 2009 to 2011. The observations show that sap-flow of evergreen needle-leaved trees (Douglas-firs) responded to the first rains of the winter rainy season, and shut down in the dry summer season; while sapflow of evergreen broadleaved trees (oak, Pacific madrones) ramped up slowly in the winter. Madrones, in particular, have maximum sapflow in the dry summer season.

We applied a Jarvis model (Jarvis 1976) parameterization for normalized sapflow velocity (v_n) as:

$$v_n = \kappa \cdot \frac{VPD}{1+\frac{VPD}{D_0}} \cdot \frac{1}{1+exp(-\beta(\vartheta-\vartheta_0))} \cdot \left(\gamma(I-1000)+1\right) \tag{1}$$

where *VPD* is vapor pressure deficit, θ is volumetric soil moisture (m^3 water/m^3 total), and I is insolation. κ, D_0, β, θ_0 and γ are constants we determined for each tree species by the Markov Chain Monte Carlo method (Table 1). The radiation function is modeled after Waring and Landsberg (2011). The soil moisture function is a sigmoid function that represents threshold limitation of transpiration by θ in very dry soils; it approximates the piecewise linear Feddes model (Feddes et al. 1978, Chen et al. 2008). The VPD function is an asymptotic function (Lohammar et al. 1980; Lindroth and Halldin 1986; Dang et al. 1997). The results are shown in Table 1 and Figure 1.

Table 1. Median values of estimated Jarvis parameter distributions for each tree species.

	κ (kPa^{-1})	D_0 (kPa)	β (unitless)	θ_0 (unitless)	γ (W/m^2)$^{-1}$
Douglas-Fir	7.23	0.14	30	0.263	5.44e-4
Pacific Madrone	1.02	1.23	42	0.173	7.20e-4
Live Oak	1.57	0.81	28	0.208	8.25e-4
Bay	1.16	1.04	87	0.218	7.46e-4
Tanoak	0.95	1.55	35	0.250	8.45e-4

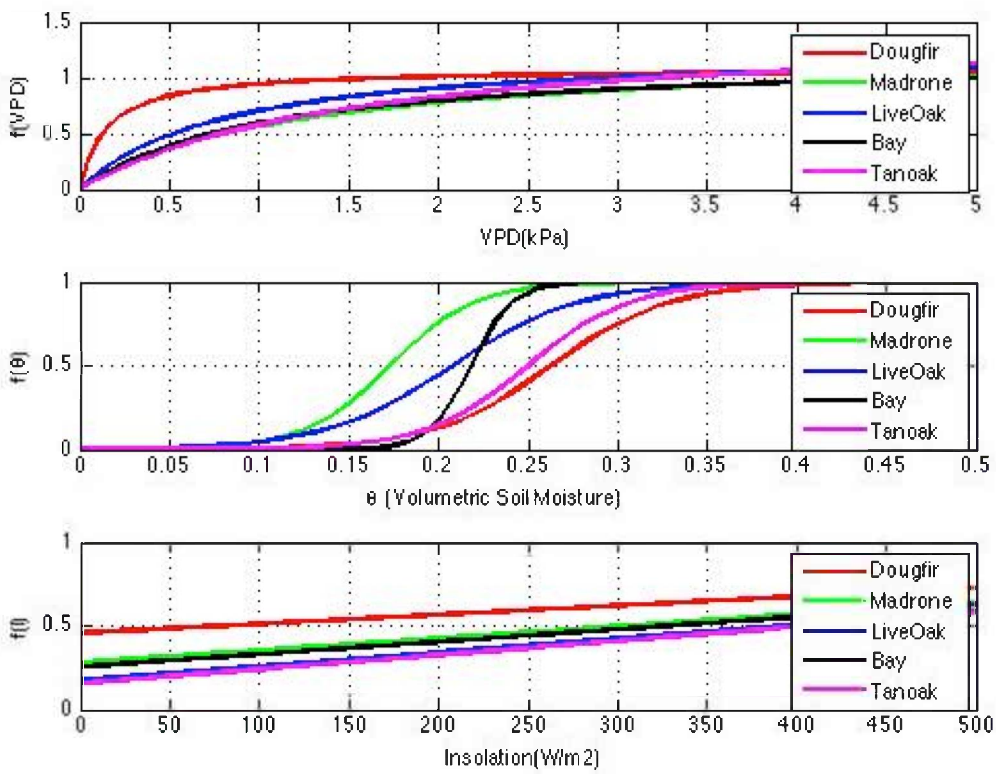

Figure 1. Functional dependence of normalized sap flow velocities (Equation 1) on VPD (top panel), soil moisture (middle panel), and insolation (lower panel) for five evergreen tree species (Douglas-fir, Pacific madrone, live oak, bay and tanoak) in a small Northern California watershed (Link et al. 2014).

Douglas-fir has a low γ, meaning its sap flow remains high at low insolation and increases only slightly with increasing insolation. Also Douglas-fir sapflow increases more quickly at low VPD and is not very sensitive to VPD variations. Pacific madrone, on the other hand, has a higher γ, showing a strong dependence on insolation. Similarly, madrone sap flow increases more gradually with VPD (higher D_0).

The moisture response is captured by the two parameters β and θ_0. Douglas-flr's higher θ_0 shows that its sapflow begins to decline at higher values of θ. The lower value of θ_0 for Pacific madrone reflects that its sapflow can remain high at low values of θ.

These results demonstrate the different ET responses to the demand for moisture. Douglas-firs appear to be limited by moisture in the shallow soils and respond immediately to the first rains. Madrone sapflow appears to be driven by energy supply and atmospheric demand for water in the summer; as the shallow soils are dry, these trees must access a different moisture pool.

2. Climate Feedback

The ability of Pacific madrones and other evergreen broadleaved trees to transpire in the dry summer season has implications for energy balance and temperature.

To illustrate the species difference on climate feedback, we used a simple slab model to calculate the climate response in a uniform Douglas-fir plantation with a uniform plantation of Pacific madrones. Because advective effects (especially cooling effects from the ocean) are left out, temperatures are expected to be higher than observed. In August, soil evaporation is the same ~15 W/m^2 in both cases. However, peak afternoon latent flux plateaued around 130 W/m^2 in the Douglas-fir case, much lower than the 210 W/m^2 in the Pacific madrone case. Despite the slightly lower radiation, the afternoon sensible heat flux at the Douglas-fir plantation was higher by ~70 W/m^2 to compensate for the much lower latent heat flux. As a result, surface air temperature was ~1°C higher at the Douglas-fir case (Figure 2) .

3. Future Plans

Direct observations of ET at our site and at several AmeriFlux sites show sustained dry-season ET despite declining soil moisture. The seasonality of ET at these sites is not captured by current parameterizations that depend on soil moisture in the upper 0.5-1 m. Here we point to species-specific behavior. We present three hypotheses:

(1) Pacific madrones have deeper roots and can access deeper water. In SW Oregon, Douglas-fir roots were confined to the upper 1.5m of the subsurface, with no roots below 2.5 m, while madrones in the same area had roots extending to 2-3.5 m below the surface (Wang et al. 1995);

(2) Madrones can access water tightly bound in the soil-rock matrix by maintaining hydraulic function at lower tissue water potentials. Madrones have minimum leaf water potentials of about -3.0 MPa (Morrow and Mooney 1974; Wang et al. 1995) vs. -2.0 MPa in Douglas-firs (Running 1976; Wang et al. 1995);

(3) Madrones may have maximum LAI in the summer. LAI lifespan is ~14 months (Ackerly 2004) and Madrones are observed to drop their leaves in late summer.

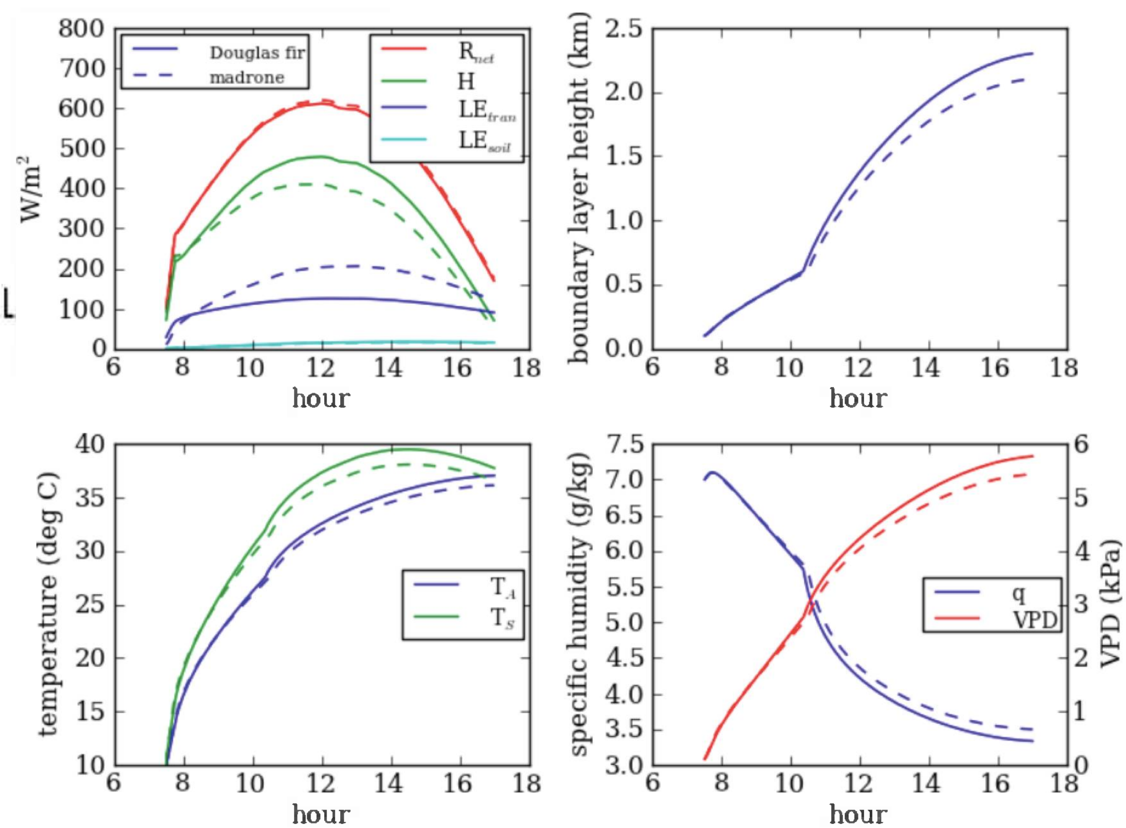

Figure 2. Diurnal variation of the atmospheric boundary layer for August as modeled by a simple 1D slab model, with soil moisture of 0.07 m^3/m^3. Solid and dashed lines show results for an all-Douglas-fir surface and an all madrone surface, respectively. Top left: net radiation, sensible heat (H), and latent heat flux (LE). Top Right: height of the boundary layer. Bottom left: Air temperature (T_A) and ground temperature (T_S). Bottom right: specific humidity and VPD. From Link 2014 (in preparation).

Thompson et al. (2011) also found that current models can capture ET seasonality at AmeriFlux sites with shallow-rooted vegetation. Their model was improved when the model soil depth was increased at some time or at other times when deeper water was made available for ET.

With DOE support, we are developing a new parameterization of subsurface moisture that includes moisture in saprolite and weathered bedrock below the organic soil mantle. This will be coupled with our species-specific sensitivity of ET, and implemented in WRF to test our ability to simulate ET seasonality at all AmeriFlux sites.

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