Evaporative fraction based on weather data for a cloud-topped boundary layer at diurnal equilibrium

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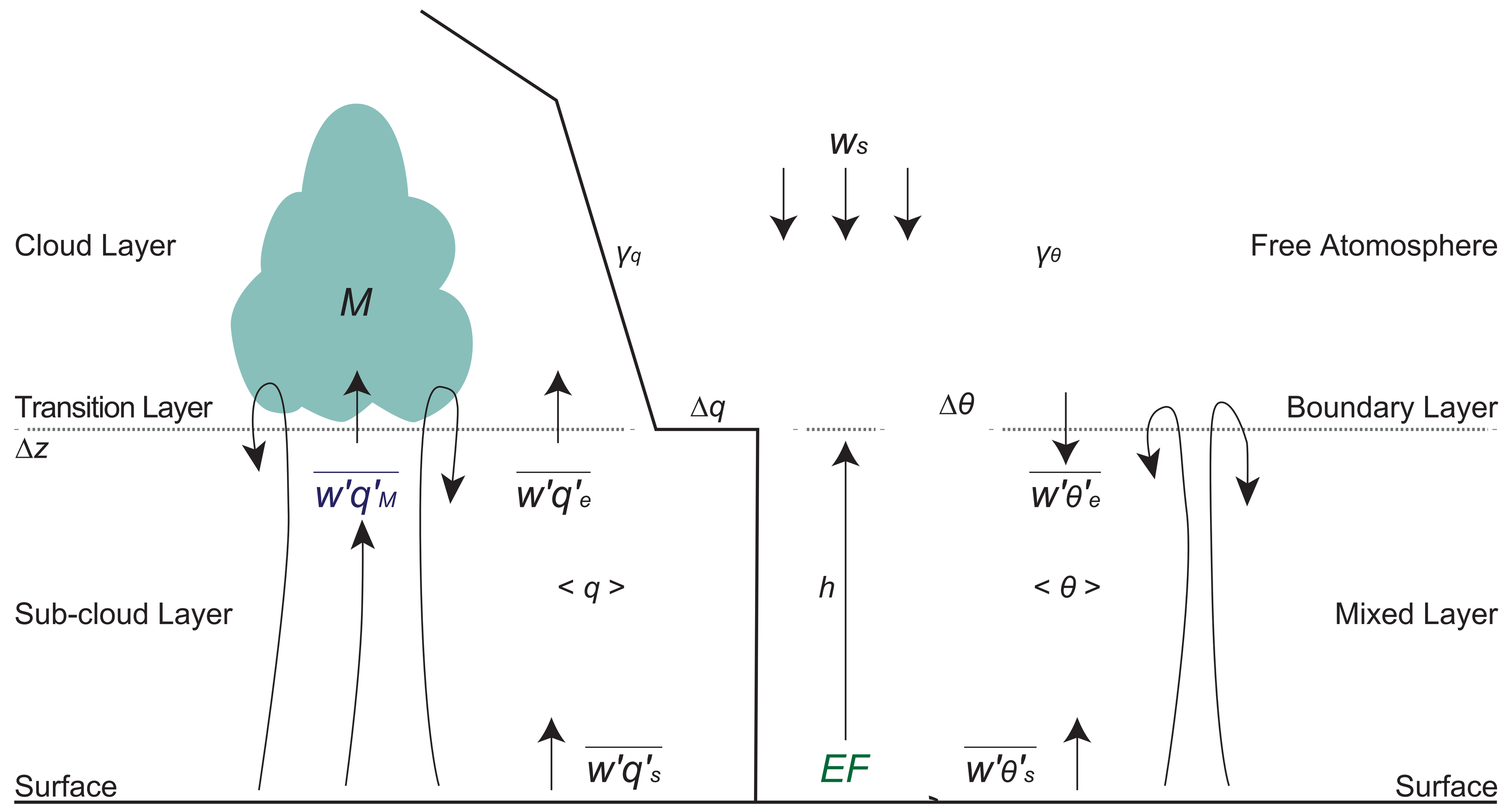
Abstract

A method for estimating evaporation (ET) from net radiation and early morning temperature, humidity, and pressure is proposed. The method is demonstrated with approximately 150,000 site-days of fluxnet data (with one set of parameters) over a range of land cover and climate conditions. The method rests on two approximations: 1) Mixed layer humidity (q) is on average the same at the start and end of boundary layer growth; and 2) The morning humidity lapse rate is exponential and proportional to early morning humidity. The approximations are based on the absence of moisture sinks below the LCL, negligible convergence aloft, and equilibrating tendencies wherein increases in ET above equilibrium moisten the mixed layer (relative to the equilibrium q) and, with less sensible heating, cool it (relative to equilibrium temperature). These changes to humidity and temperature lower the LCL and increasing cloud fraction and propensity for cloud-mass flux, thus counter-acting the moistening from below. Depending on the values of the morning initial conditions, dis-equilibrating tendencies can occur as well, mainly through a decrease in the convective velocity scale with less sensible heating, which in turn reduces the cloud-mass flux. With these approximations, a unique value of daily-constant evaporative fraction (EF) yields an equilibrium diurnal cycle of predicted q, for which entrainment of dry air and cloud mass fluxes of humidity out of the mixed layer balance the flux of humidity from surface ET. Enforcing equilibrium with budget terms calculated from weather data and a cloud-topped mixed layer model estimates EF. In a related presentation (Ryu and Salvucci), the positive and negative sensitivity of the cloud mass flux to perturbations in EF are shown to be consistent with spatial patterns of soil moisture-precipitation feedbacks statistically estimated from satellite measured soil moisture. Performance of the estimation method at daily and seasonal scales are presented.

Boundary Layer Interactions: the CLASS model (Arellano et al., 2015)



The CLASS model
Vilà-Guerau de Arellano et al. (2015)

Methods

Data

- 206 Fluxnet Sites from a range of climate and land cover conditions.
- Morning potential temprature lapse rate from regression on morning state variables (q, theta, pressure) trained on North American Regional Reanalysis lapse rates.
- Morning humidity lapse rate from exponential model fit to climate data (q(z)=qo*exp(-z/2500))

Modifications

- Gaussian PDF of humidity at mixed layer based on Neggars variance budget modified as a mixture of two gaussians, once centered on the surface layer humidity to crudely represent plumes. Bimodal mixed pdf confirmed with LES simulations.
- Humidity lapse rate non-uniform in height, parameterized by exponential height dependence.

Diurnal Equilibrium Method

- Find the EF for which the predicted humidity integrated to the ML top at the end of the day matches the morning humidity integrated to the same height.
- Equivalent to the condition that the cloud mass flux averaged over the day equals the humidity flux at the surface. Note that entrainment only redistributes humidity in ML.

Equilibrium Illustration

Demonstration of diurnal humidity values from CLASS model with varying Evaporative Fraction

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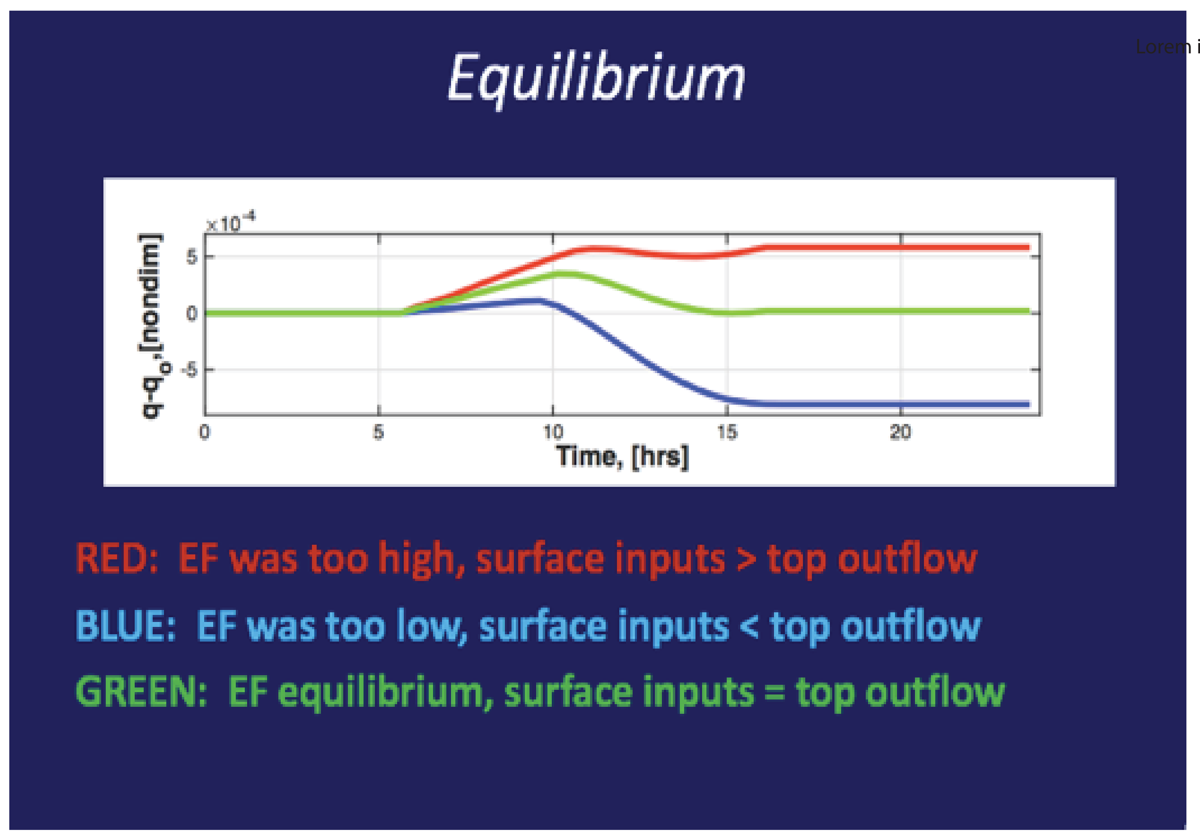

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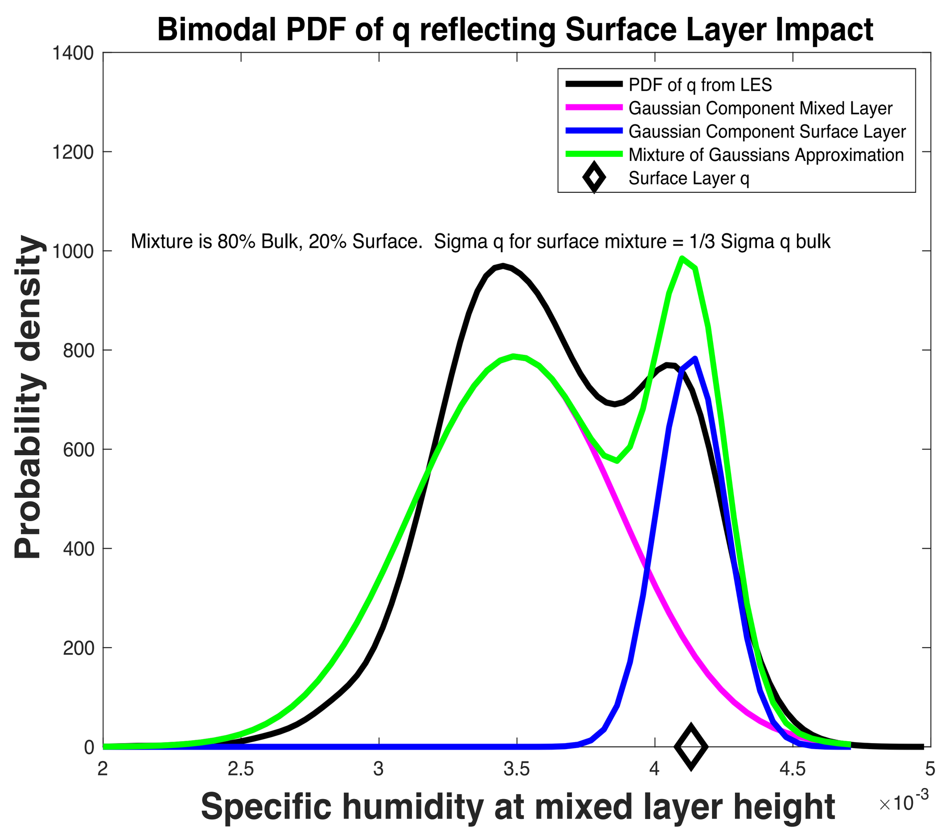
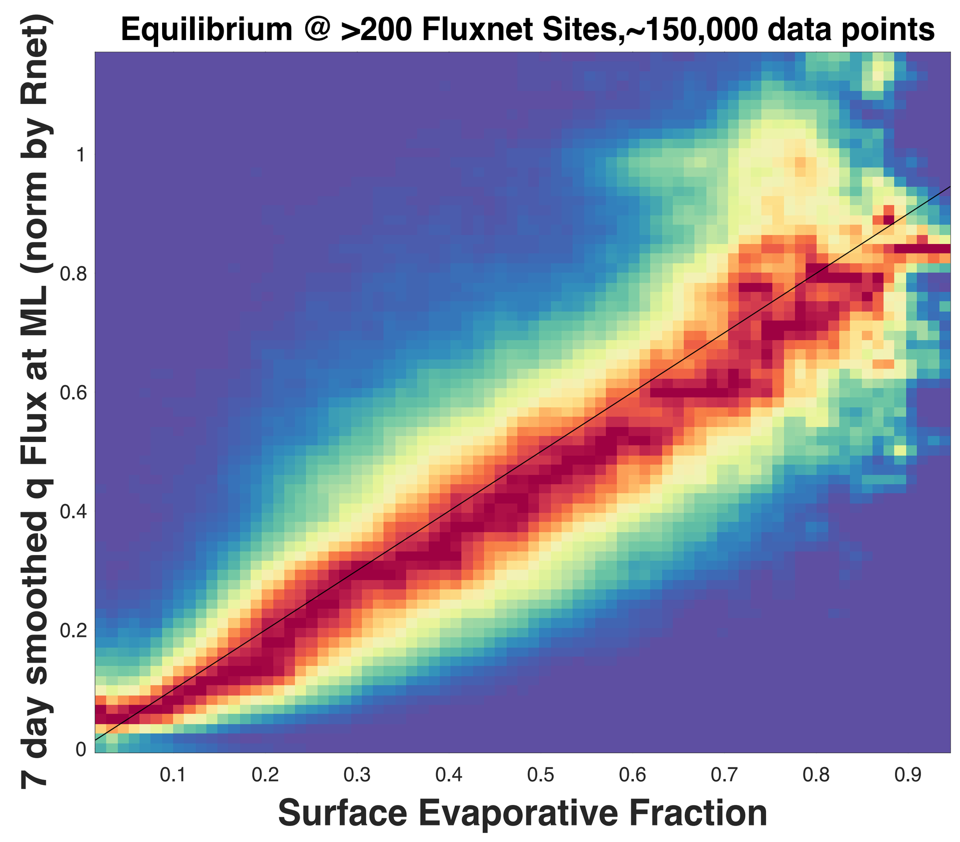
Modification to Class based on LES

Bimodal/mixed PDF of q. Critical impact on estimation of cloud fraction (”ac”)

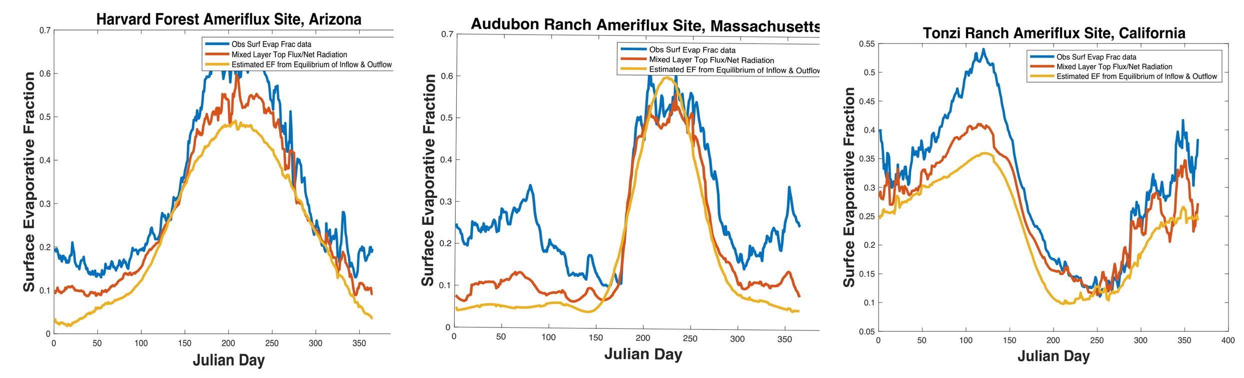


Equilibrium Demonstration from Fluxnet Data



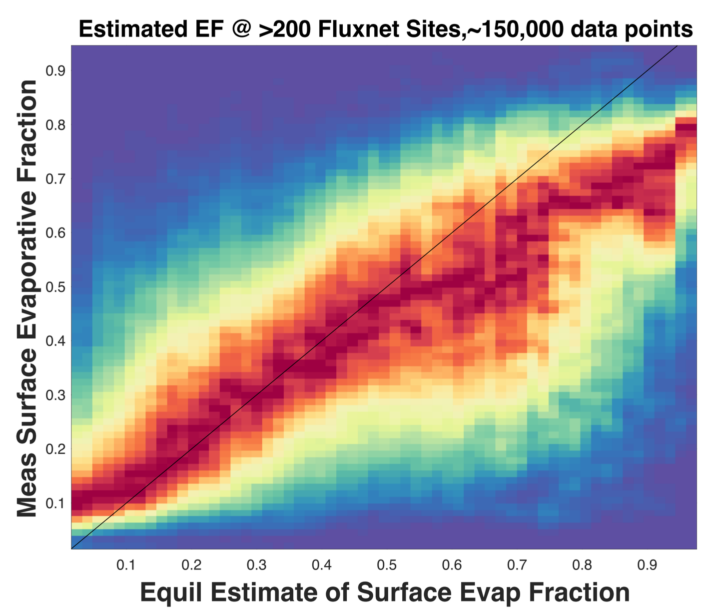
- Averaged over ~7 days, outflow = inflow
- One set of model parameters for all sites
- Demonstrates possibility of calibrating parameters of an atmospheric model from surface data

Equilibrium at individual sites



Blue lines are measured EF at surface. Red lines are “EF at Mixed Layer” (Cloud Mass Flux/Rnet) from CLASS model using measured EF as input. Orange lines are estimated EF found by choosing an EF at the surface for which EF at Mixed Layer = chosen EF (with smoothing). Solution of equilibrated system allows EF to be estimated from morning weather data (q, theta, pressure) and daily average net radiation.

Equilibrium Estimate at all sites



Relation between equilibrium estimated EF and measured EF (heat map to left) is not as strong as that between measured EF and EF at mixed layer (see above heat map). Reason is simply that lack of perfect equilibrium introduces error

Acknowledgment

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