Effect of Fine-scale Canopy Heterogeneity on Energy and Soil Water Fluxes in a Northern Temperate Deciduous Forest

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Introduction

- Trees influence the coupling between soil moisture and atmosphere at different scales.
- Canopy-scale structure of vegetation may strongly impact spatial heterogeneity of soil moisture and atmospheric boundary layer.
- Current land surface parameterizations use simplified representation of interactions between vegetation and soil moisture.
- Our study uses a high-resolution, physically-based eco-hydrological model (**tRIBS+VEGGIE**) as a data integration tool to upscale heterogeneity of canopy structure resolved at few meters (5m) to the watershed and larger scales (>1000 m).

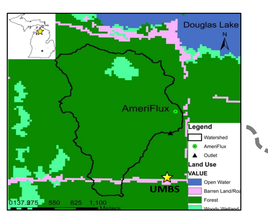
Questions

This study aims to improve the understanding of scale in atmosphere-biosphere-hydrosphere interactions during growing seasons by using different scenarios representing heterogeneous canopy and different initializations of soil moisture.

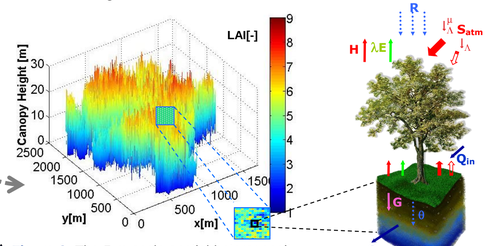
1. **Do spatially averaged dynamics differ among the scenarios using different spatial representations of canopy and initializations of soil moisture?**
2. **How does small-scale heterogeneous soil moisture initialization influence spatio-temporal distribution of state variables and fluxes?**
3. **How does fine-scale canopy heterogeneity affect spatio-temporal dynamics?**

Methods

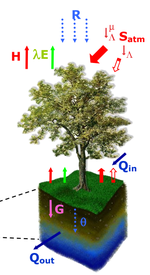
The modeling work was conducted in a deciduous forest environment of Northern Michigan, near the AmeriFlux tower at the University of Michigan Biological Station (**UMBS**, **Figure 1**). Canopy height and Leaf Index Area (**LAI**) were observed to be heterogeneous over the domain (**Figure 2**). Fine-resolution (5 m x 5 m) DEM and canopy properties, meteorological data from the **AmeriFlux** tower, soil moisture (SM) data during 2010 growing season (06/07/2010~8/23/2010) were used in modeling.



▲ **Figure 1**. The location of the studied forest system at the UMBS and the AmeriFlux tower. The domain area is ~2 km². The area is relatively flat, the maximum change of elevation within the domain is ~20 m.



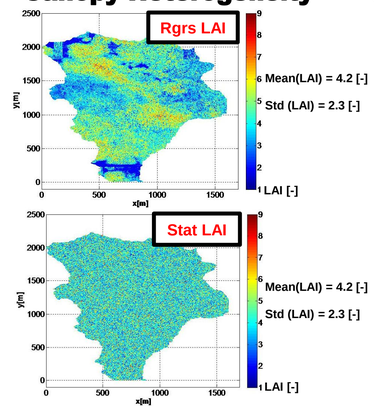
▲ **Figure 2**. The 5 m scale spatial heterogeneity of canopy over the simulation domain: canopy height (z-values) and LAI (color). Canopy heights were measured by remotely sensed data (airborne lidar), LAI was inferred from the height data using empirical relationships determined from ground measurements (leaf litter traps, and portable canopy lidar).



▲ **Figure 3**. A conceptual diagram of tRIBS+VEGGIE. At the element scale, the energy and water budgets of a vegetated layer is simulated.

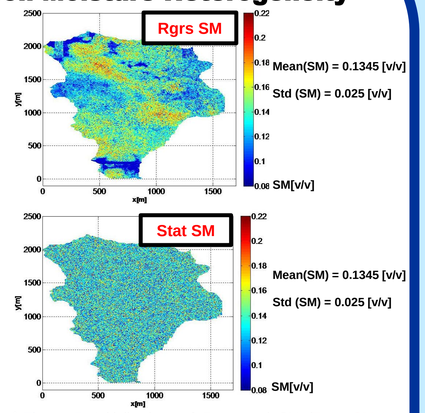
tRIBS+VEGGIE (Ivanov et al., 2008 a, b) is a dynamic eco-hydrological model that represents the essential water and energy processes over a basin and links them to the basic plant life regulatory processes. In the studied domain, the dynamics of each computational element (**5 m x 5 m** for this case) are simulated separately (**Figure 3**). Spatial dependencies are introduced by considering the surface and subsurface moisture transfers among the elements, affecting the local dynamics via the coupled energy-water interactions. **In this study, no lateral canopy shading effects are simulated.**

Scenarios of Canopy Heterogeneity



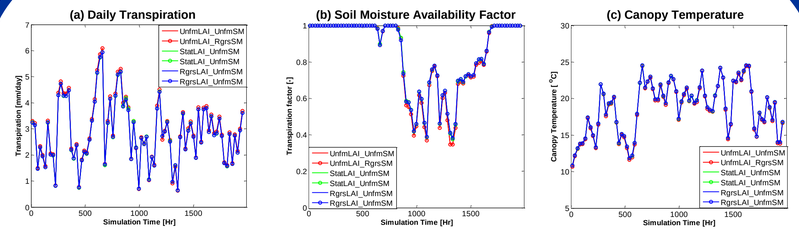
▲ **Figure 4.** Scenarios of Regressed LAI (**Rgrs LAI**, upper plot) and Statistical LAI (**Stat LAI**, lower plot). Rgrs LAI was regressed from canopy heights. Stat LAI was generated with a virtual canopy generator (V-CaGe, Bohrer et al., 2007). An additional scenario of spatially uniform LAI (**Unfm LAI**, not shown) with LAI = 4.2 [-] was constructed as a control case.

Initializations of Soil Moisture Heterogeneity

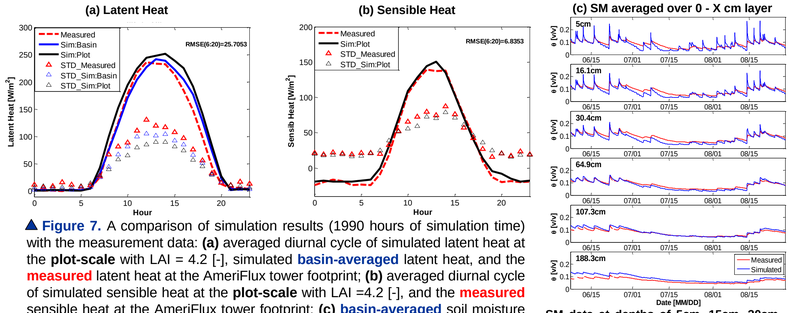


▲ **Figure 5.** Initializations of Regressed SM (**Rgrs SM**, upper plot) and Statistical SM (**Stat SM**, lower plot). An additional initialization of uniform SM (**Unfm SM**) with SM = 0.1345 [v/v] was constructed as a control case. SM in the vertical direction (0 - 188.3 cm) was assigned to be uniform.

1. Spatially Averaged Dynamics



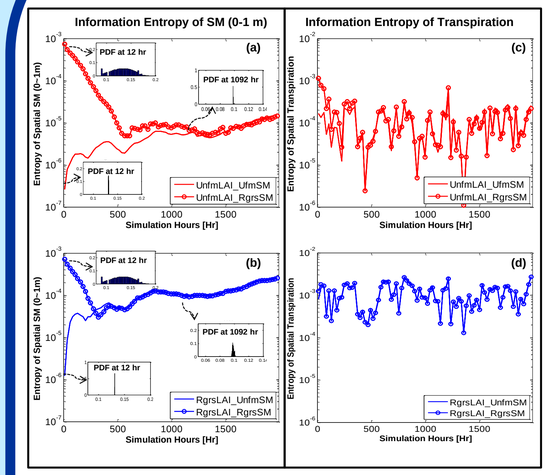
▲ **Figure 6. Spatially averaged** simulation results, by using different LAI and SM scenarios: **(a)** daily transpiration; **(b)** soil moisture availability factor; **(c)** canopy temperature.



▲ **Figure 7.** A comparison of simulation results (1990 hours of simulation time) with the measurement data: **(a)** averaged diurnal cycle of simulated latent heat at the **plot-scale** with LAI = 4.2 [-], simulated **basin-averaged** latent heat, and the **measured** latent heat at the AmeriFlux tower footprint; **(b)** averaged diurnal cycle of simulated sensible heat at the **plot-scale** with LAI =4.2 [-], and the **measured** sensible heat at the AmeriFlux tower footprint; **(c) basin-averaged** soil moisture (averaged over 0 – X cm) and the continuously measured soil moisture data. STD is the temporal standard deviation for each hour for corresponding values. The shown simulated results are from the case using Rgrs LAI and Rgrs SM.

SM data at depths of 5cm, 15cm, 30cm, 60cm, 100cm, 200cm and 300cm are obtained as a part of our ongoing observational campaign (He et al., 2010).

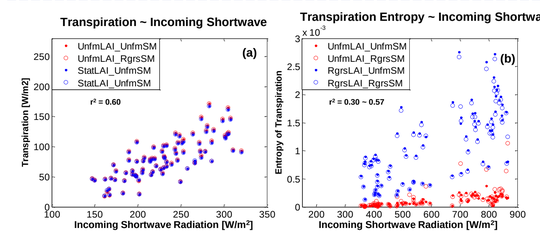
2. Effects of soil moisture and canopy heterogeneity on spatial distribution of state variables



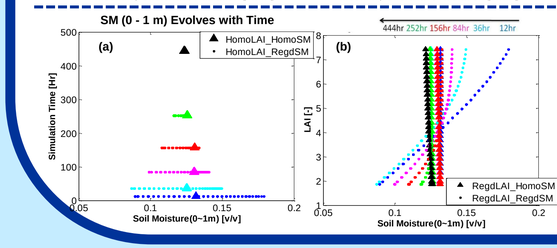
◀ **Figure 8**. The time series of Shannon Information Entropy for different LAI scenarios and SM initializations. **Shannon Information Entropy** was used to quantify the evolution of spatial distributions of SM (as average over 0-1 m depth) and transpiration.

(a) and (b): A comparison of information entropy of SM (0 – 1 m): the differences between the UnfmSM and RgrsSM cases disappear, i.e., the effects of SM initialization on SM spatial distribution becomes negligible. The soil moisture variability becomes dictated by the LAI distributions, which are either UnfmLAI (**a**) or RgrsLAI (**b**). Probability Distribution Functions (PDF) at hour 12 and 1092 are illustrated.

(c) and (d): A comparison of Information Entropy of daily transpiration. Cases using the same LAI scenario have similar pattern of entropy (**c** and **d**). Day-to-day fluctuations of transpiration entropy are believed to be driven by the day-to-day fluctuations of shortwave radiation (**Figure 9**).



◀ **Figure 9**. (**a**) A comparison of daily averaged transpiration with daily incoming shortwave radiation, linear relationships can be observed, with correlation coefficients (r^2) ~0.6. (**b**) A comparison of Information Entropy of transpiration with incoming shortwave radiation, at 12pm everyday. The smallest r^2 = 0.30 occurs for the case using RgrsLAI and RgrsSM. Other three cases have r^2 ~0.57.



◀ **Figure 10**. The spatial distribution of soil moisture evolves: (**a**) with respect to time; (**b**) with respect to both time and LAI. Canopy adjusts soil moisture field to LAI spatial distribution. Canopy 'homogenizes' soil moisture more rapidly at locations with higher LAI.

References

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Acknowledgements

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