Seasonal Controls on Energy Partitioning Patterns of a Mangrove Forest

Dane Barr[1], Jordan G. Barr[1], José D. Fuentes[1], Jay C. Zieman[1], Tim Grahl[2], and Dan Childers[2]
[1]Department of Environmental Sciences, University of Virginia
[2]Department of Biological Sciences, Florida International University

Introduction

The FCE-LTER SRS-6 site is inundated by the lunar tide twice daily, and observed trends in sensible (H) and and latent heat flux (LE), as well as the degree of energy closure, are strongly governed by whether or not the tide is acting as a source of or sink for energy. During the summer months (June to September), warm air masses, intermittent cloudiness, and afternoon thunderstorms predominate. The temperature gradient between the air and the soil-water column is positive, and energy is advected with the cooler tide. Energy closure during the winter and spring months, however, is better, when clear skies and cooler air masses predominate, and the amount tidal energy advection is smaller.

The mangrove ecosystem is extremely water conservative. When irradiance levels and evaporative demand are high during the middle of the day, the mangrove leaves will close their stomata to reduce water loss and photosynthesis will deactivate. Consequently, evapotranspiration (ET) rates are suppressed and LE is equal to or lower than H.

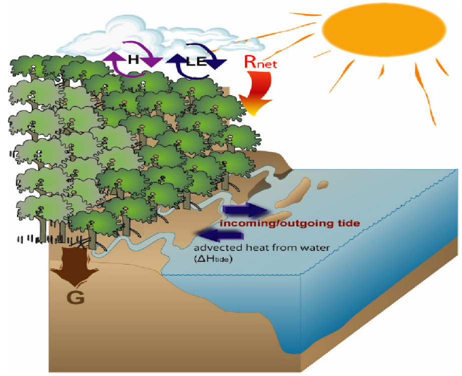

Figure 1. Energy balance within a coastal ecosystem. The difference between net radiation (Rnet) and soil heat flux (G) (i.e., the available energy) is balanced by sensible (H) and latent (LE) heating and net energy advection by the tide (ΔHtide).

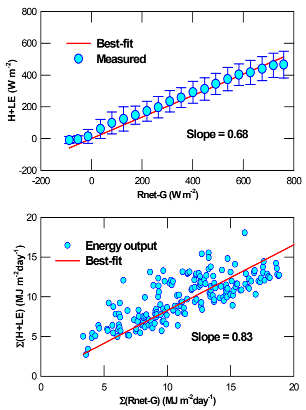

Figure 2. Half-hourly (top panel) and daily-integrated surface energy balance closure over the Shark River mangrove forest during day of year 7 through 240, 2004. Slopes are from best-fit lines forced through the origin.

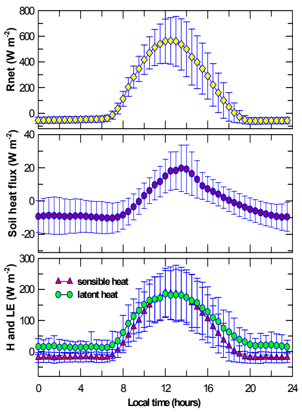

Figure 3. Ensemble half-hourly mean and one standard deviation in components of the surface energy balance over the Shark River mangrove forest during day of year 7 through 240, 2004.

Results

Diurnal Energy Partitioning Patterns

On days when available energy and water levels are simultaneously high, LE approximately equals H due to surface evaporation (Figure 4). Spikes in LE may also be observed due to this phenomenon (Figure 6). On 28 February 2004, winds blowing out toward the Gulf of Mexico prevented high tide from reaching inland mangrove zones. Low water levels, in conjunction with the passage of a cold front, resulted in a warmer soil-water column compared to the atmosphere. Consequently, the soil-water column acted as a source of energy, which was partitioned as sensible heat (Figure 5). A local stable layer inside the forest canopy, which develops during the daytime as the canopy absorbs large radiational loads, may suppress surface evaporation and LE (Figure 7).

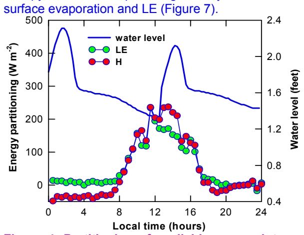

Figure 4. Partitioning of available energy into sensible and latent heating during high water events and daytime high tides on 07 March 2004.

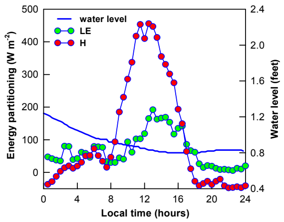

Figure 5. Partitioning of available energy into sensible and latent heating during low water events when high tides were suppressed on 28 February 2004.

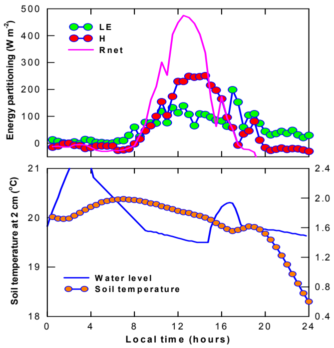

Figure 6. Partitioning of available energy into sensible and latent heating (top panel) during an afternoon high tide on 10 January 2004. Soil temperature reached a local minimum (bottom panel) as a result of surface evaporation.

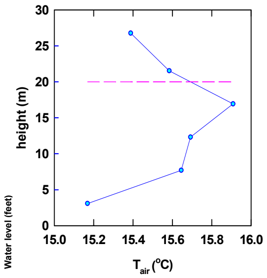

Figure 7. Formation of a statically stable layer inside the forest canopy at 12:00 hours on 28 February 2004. The canopy height is 20 meters.

Seasonal Bowen Ratios

The Bowen ratio declines into the summer during the onset of the wet season. The total available energy decreases due to cloudiness, and LE, driven primarily by surface evaporation, consumes a greater proportion of the available energy. During the two peaks in Bowen ratio, skies were mostly clear, and radiation was partitioned primarily into the sensible heating of foliage and air masses within the forest canopy. Also, lower surface and air temperatures resulted in suppressed surface evaporation during the winter and spring, Thus, regional irradiance and temperature trends, as opposed to plant physiological controls, govern the observed seasonal trend in Bowen ratios.

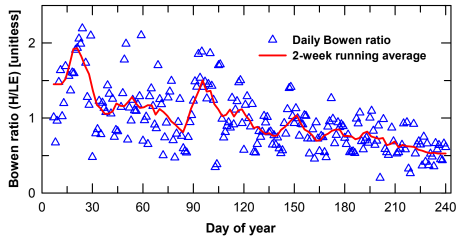

Figure 8. Daily weighted average Bowen ratios (H/LE) and two-week running average during January through August 2004.

Forest-Atmosphere Coupling/ De-coupling

Evaporation is controlled both by the amount of available energy and plant physiological activity (i.e. stomata opening and closing). Jarvis and McNaughton (1986) proposed the concept of the decoupling coefficient (Ω), which incorporates both equilibrium latent heating, LE_{eq}, controlled by available energy, and imposed latent heating, LE_{imp}, controlled by atmospheric VPD and stomata.

$$LE_{eq} = \frac{s}{s+\gamma}(Rnet - G) \qquad LE_{imp} = \frac{\rho C_p}{\gamma}\left(\frac{e_s - e_a}{R_{cv}}\right)$$

$$R_{cv} = \left(\frac{s R_{ah}(Rnet - G) + \rho C_p (e_s - e_a)}{\gamma LE} + \frac{s}{\gamma} R_{ah} - R_{av}\right)$$

$$LE = \Omega\, LE_{eq} + (1-\Omega) LE_{imp}$$

$$\Omega = \frac{LE - LE_{imp}}{LE_{eq} - LE_{imp}}$$

Where,
s - saturation vapor pressure slope defined at the air temperature within the canopy, T_{air}
γ - the psychrometric constant (66 Pa K^{-1})
ρ - the density of air (~1.2 kg m^{-3})
C_p - the heat capacity of air (1004 J kg^{-1} K^{-1})
e_s and e_a - saturation and atmospheric vapor pressure at air temperature, respectively
R_{cv} (in s m^{-1}) - forest canopy resistance to water vapor transport
R_{ah} and R_{av} (in s m^{-1}) - resistances to heat and water vapor, respectively

When $g_{sv} \ll g_{bv}$, the stomata are the dominant controller of ET rates. Evaporative demand governs transpiration, and the surface is well coupled to the environment (Ω = 0). When $g_{sv} \gg g_{bv}$, available energy dictates ET rates, heat and water vapor transport between the surface and the atmosphere is poor, and the surface is poorly coupled to the environment (Ω = 1). Forests are generally well coupled to the atmosphere, while grasses and crops are poorly coupled.

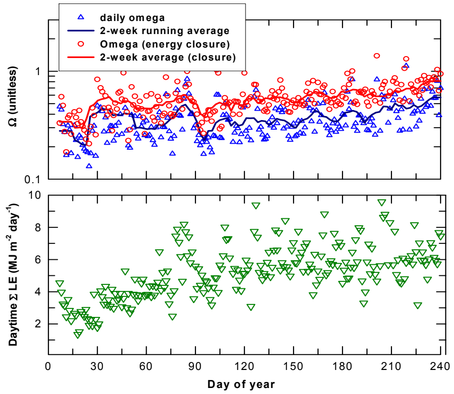

Figure 9. Daily weighted average decoupling coefficients (top panel) considering available energy is Rnet-G (blue) and forcing energy closure (red), so that available energy is H+LE. Two-week running averages of Ω are also provided. Measured daily-integrated latent heating (bottom panel) remained near its spring maximum through August.

Unique diurnal decoupling coefficient trends were observed (data not shown). When energy closure was forced so that available energy is H + LE, the decoupling coefficient was larger during the daytime and decreased from 0.7 to ~0.5 from the morning into the afternoon, indicating that plant physiology plays an increasingly important role on ET rates in the afternoon.

On a seasonal basis, stomata and VPD mostly controlled ET during the winter, but during the late spring and summer, control shifted to available energy (Figure 9). Also, the forest behaved more like a broad-leafed terrestrial forest, with Ω values of ~0.2, during January and early March cool periods. It is also notable that forcing energy closure resulted in daily average decoupling coefficients 0.2 greater than those computed in the traditional manner (available energy is Rnet-G).

Summary

The mangrove foliage within Shark River is water conservative, so the physiology limits transpiration. Also, the forest canopy can serve as a physical barrier to evaporation, so that there is low shear driven turbulence near the forest floor. The processes of atmospheric turbulence, the absorption of irradiance, and foliage biochemistry interact to provide the observed fluxes of water vapor. Consequently, a suite of quantities must be measured to estimate water vapor fluxes. At the very least, measurements must include zonal wind speed, solar irradiance, air temperature, and humidity measured above the canopy, and some measure of either water or soil temperature depending on the tide.

References

Jarvis, P.G., K.G. McNaughton. 1986. Stomatal control of transpiration: scaling up from leaf to region. Adv. Ecol. Res. 15, 1-49.

Acknowledgements

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