Incorporating energy advection by the tide into the energy balance for a mangrove ecosystem

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Introduction

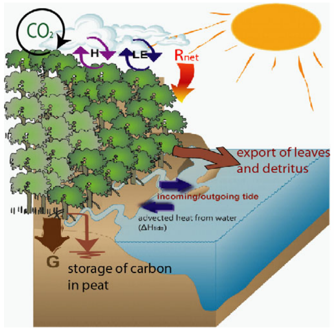
Tidal energy advection was quantified during a 10 day period in August 2005 at FCE LTER site Shark River Slough (SRS) – 6.

Tidal energy advection was partitioned into:

- Total enthalpy transferred from the soil and the atmosphere into the water column within the forest
- Lateral energy advection at the mangrove forest-estuary interface

Research Objectives:

- To improve the understanding of the local climate within the forest, which in turn improves the physiological modeling of carbon dioxide and water vapor exchange across the mangrove forest – atmosphere interface.
- To quantify a realistic heat flux into the forest water that will improve energy closure on the half-hourly and daily time scales.

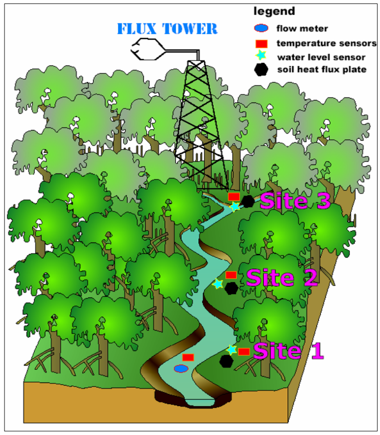


Left: The difference between net radiation (Rnet) and soil heat flux (G) (i.e., the available energy) may be balanced by sensible (H) and latent (LE) heating and net energy advection by the tide (ΔHtide). Carbon dioxide is exchanged at the forest-atmosphere interface, while carbon is both exported by the tide and stored in the soil.

The goals of ascertaining the individual energy components include to:

- Learn dynamics of energy flows within this coastal ecosystem
- Develop predictive capabilities for water vapor and carbon dioxide cycling with an emphasis on vertical transport

Site Setup



Above: Site setup at FCE LTER site SRS-6.

At sites 1-3:

- Thermocouples were deployed at 0.051, 0.13, and 0.31 m to obtain vertically averaged temperature profiles
- Soil heat flux plates were used to measure the net flux of sensible heat from the soil
- A water level sensor provided water depth

Within the tidal creek:

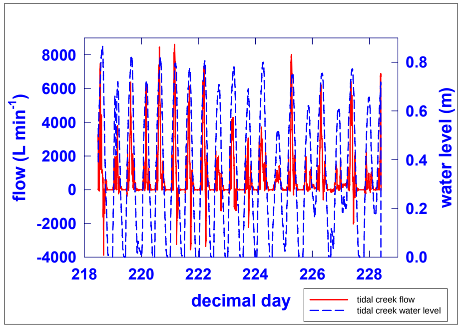
- A flow meter provided magnitude and direction of flow
- Thermocouples provided a vertically averaged creek temperature

The flux tower:

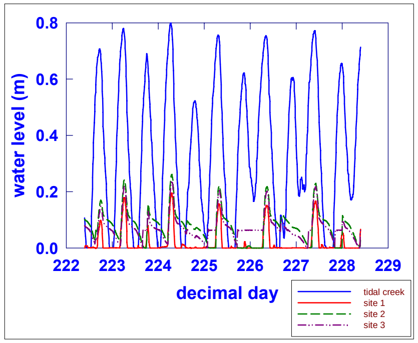
- Provides fluxes of H and LE at the forest – atmosphere interface
- Provides measurements of Rnet

Left: Picture of Site 1. Thermocouples, soil heat flux plates, and water level sensors were deployed at each site.

Flow Dynamics

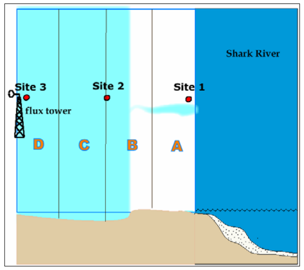


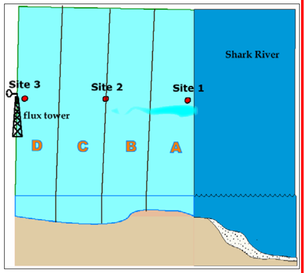
Right: A time series of flow and water level within the tidal creek shows that flow is almost always positive into the forest as the tide floods and ebbs. This indicates that, while tidal waters enter the forest through the tidal creek, they exit the forest via soil percolation.



Left: The mangrove forest experiences two diurnal tidal cycles. Site 1, highest in elevation among the three sites, exhibits a symmetrical water level signature and is influenced very little by the smaller amplitude, diurnal tide. Sites 2 and 3 drain slowly after each tidal cycle as water percolates through the forest soil.

Below: Water enters the mangrove island from Shark River through the tidal channel and submerges the lower-lying sites 2 and 3. Water then backfills towards site 1, which is generally submerged by only one of the two diurnal tides.



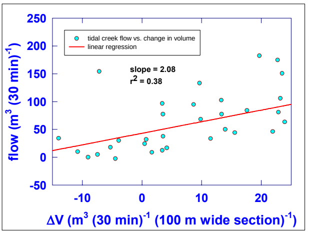


Above: Cross-section showing the partitioning of the study site into sectors A-D during the higher amplitude tide.

Mass Balance

A mass balance between flow and water levels:

- Was Required to compare the instantaneous rate of lateral energy advection occurring at the tidal creek to the vertical exchange of energy occurring at the water-atmosphere and water-soil interfaces over the entire study site
- Established a drainage area 208 m wide and the length from Shark River to the flux tower, approximately 148 m



Regression of flow vs. change in volume over a 100 m wide section during 30 minutes. Flow is derived from flow meter measurements within the tidal creek, while change in volume is determined from water levels at sites 1-3. The regression only includes data where the tide completely submerges the forest floor. The tidal creek contributes to an area 208 m wide by 148 m long.

Lateral Energy Advection

$$\Delta H_{adv} = \sum_{t=0}^{10\,\text{min}} H_{in}\,\Delta t - \sum_{t=0}^{10\,\text{min}} H_{out}\,\Delta t$$

instantaneous rates of enthalpy entering and exiting the mangrove forest via the tide

$$H_{in} = \rho C_w Q \overline{T}$$

depth-averaged water temperature

water density (kg m-3)

specific heat capacity of water (4186 J kg-1 K-1)

$$Q = UA$$

volumetric flow rate (m-3 s-1)

width and depth averaged velocity

cross-sectional area

Spatially Averaged Surface Heat Flux

$$\Delta H_f = H_{f2} - H_{f1}$$

change in enthalpy within the forest water

$$H_{fi} = \sum_{i=1}^{n} \rho C_w h_i A_i \overline{T}_i$$

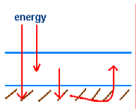
number of sectors

enthalpy within forest water at time i

water depth, total surface area, and depth-averaged temperature of sector i

$$\Delta H_{from\_soil/atmosphere\_to\_water} = \Delta H_f - \Delta H_{in}$$

total enthalpy transferred from the soil and the atmosphere into the water column within the forest



Energy transfer between the air-water and soil-water interfaces in the form of conduction, convection, and both shortwave and longwave radiation.

$$G_{total} = G_{soil} + \Delta H_{from\_soil/atmos.\_to\_water}$$

soil heat flux

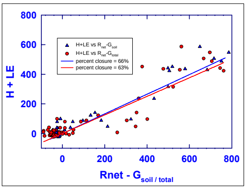
spatially averaged surface heat flux

Total Energy Advection

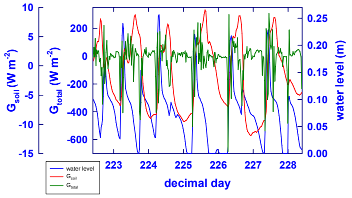
$$\sum_{t=0}^{t} G_{total} > 0 \Rightarrow$$ **ENERGY EXPORT**

$$\sum_{t=0}^{t} G_{total} < 0 \Rightarrow$$ **ENERGY IMPORT**

Results



Half-hourly energy closure over the 10 day study period with and without energy advection.



Time series of soil heat flux, spatially averaged surface heat flux, and water level. Spikes in energy import are observed during the morning of each day as high tide delivers energy to the cooler forest understory.

Conclusions

- Energy closure over the 10 day study period was not significantly affected by the incorporation of energy advection.
- More energy will be exported by tidal waters as the larger amplitude tide shifts towards the afternoon and energy is transferred from the heated understory to the forest water. This will result in less available energy and improved energy closure.

Acknowledgements

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