A novel model uncovers the importance of dew deposition for canopy epiphytes in a tropical montane cloud forest

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Motivation

Tropical montane cloud forests (TMCFs) are hotspots of biodiversity that are threatened by deforestation, human activities, and climate change. Epiphytes are vascular and non-vascular plants that live in tree canopies, creating arboreal microecosystems. Predicted changes in cloudiness and land conversion threaten the abundance of epiphytes, and thus their capacity to contribute to ecosystem functions. Yet, it is unclear how losses in epiphyte abundance will affect microclimate and host tree water status, motivating the need for the ability to simulate the role of epiphytes in canopy water storage dynamics.

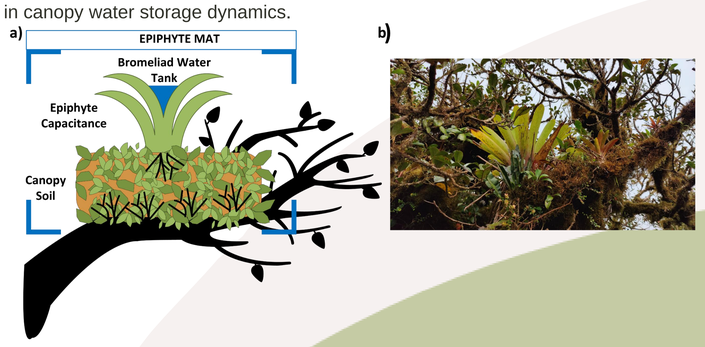
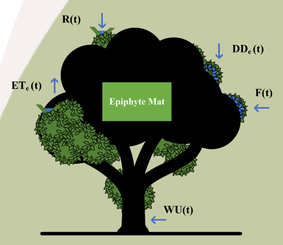


Figure 1. (a) The epiphyte water balance (EWB) model conceptualizes epiphyte mats in TMCF canopies as a water store suspended in the canopy which includes vascular and non-vascular vegetation, mosses, and canopy soils. The host tree branch and leaves shown in black are not considered in the EWB model. (b) Photo of an epiphyte mat on a branch in a TMCF near Monteverde, Costa Rica.

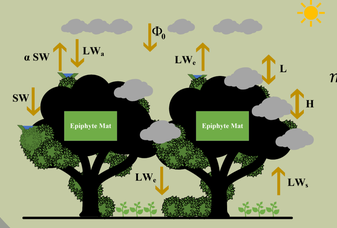
EWB Model Water and Energy Balances



Water Balance

$$\frac{dS_e(t)}{dt} = I_e(t) + DD_e(t) - ET_e(t) - WU(t)$$

Figure 2. Water storage (S_e) is estimated with a mass balance in the EWB model. Water enters the epiphyte mat via rainfall (R) and fog (F) interception and dew deposition (DD_e). Water leaves the epiphyte mat through evapotranspiration (ET_e) and water uptake by the host tree roots (WU).



Energy Balance

$$m_e(t)\, c_{p,e}(t) \frac{d\,T_e(t)}{dt} = f_e \Phi_{net}(t) + H(t) - L(t)$$

m_e	– Mass of epiphyte mat (dry biomass and water)
$c_{p,e}$	– Specific heat capacity of epiphyte mat
T_e	– Epiphyte mat temperature
f_e	– Fraction of the canopy covered by epiphytes
Φ_{net}	– Net radiation
H	– Sensible heat
L	– Latent heat

Figure 3. Energy balance for the EWB model. The epiphyte mat warms by absorbing shortwave radiation (SW) from the above canopy incoming solar radiation (Φ_0), long wave radiation emitted from the atmosphere (LW_a) and soil (LW_s), latent heat (L) when the water vapor concentration is greater in the air than in the epiphyte mat, and sensible heat (H) when the air is warmer than the epiphyte mat. The epiphyte mat cools when energy leaves through the reflection of shortwave radiation (αSW), long wave radiation emitted from the epiphyte mat (LW_e), and latent, and sensible heat when the epiphyte mat temperature is warmer than the air.

Results: EWB model simulations of TMCF sites in Monteverde, Costa

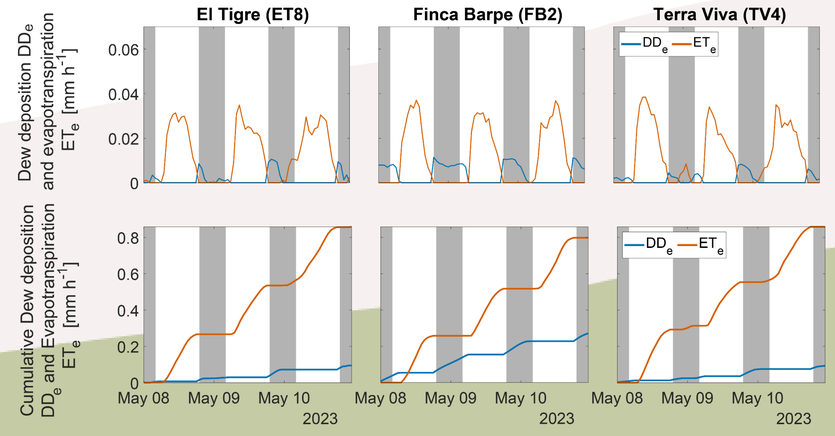


Figure 4. Simulated evapotranspiration (ET_e) and dew deposition (DD_e) from the EWB model for a 3-day dry-down event (i.e., no precipitation occurred) from May 8-10, 2023, at three study sites located near Monteverde, Costa Rica. Top row: ET_e is consistently higher than DD_e during the simulation, which leads to water losses from the epiphyte mat during the three-day dry down event. Bottom row: Cumulative water losses from evapotranspiration were mitigated by dew deposition which accounted for 11%, 34%, and 11% of the total evapotranspiration during the simulation at ET8, FB2, and TV4, respectively. The vertical grey lines mark nighttime hours.

Figure 5. Simulated specific heat capacity ($c_{p,e}$) and water storage (S_e) from the EWB model for the 3-day dry down event at each site: ET8, FB2, and TV4. The energy balance is coupled to the water balance as water has a large specific heat capacity and influences how epiphyte mat temperatures change throughout the day (**Eq. 2**). The vertical grey lines mark nighttime hours.

Key Takeaways

- A mechanistic model for the water and energy fluxes of epiphyte mats was developed
- Simulated epiphyte mat temperatures were within 1°C of field observations
- Nighttime epiphyte mat temperatures consistently fall to air dew point temperatures
- Nighttime dew deposition refilled up to 34% of water lost through evapotranspiration

Future Work

- Investigate how water storage in epiphytes differs across topographic and climate gradients
- Evaluate interactions between epiphyte mats and host trees by coupling the EWB model to a soil-plant-atmosphere continuum (SPAC) model for host trees
- Upscale EWB model results to regional scales by developing a high spatial resolution Leaf Area Index (LAI) dataset for tropical forests

Low epiphyte mat temperatures promote dew deposition at night

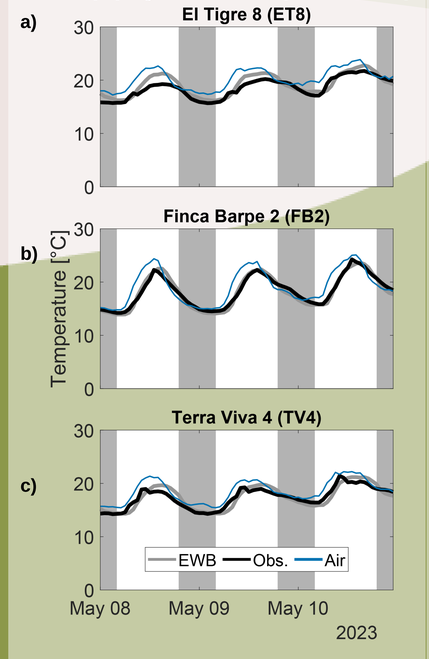


Figure 6. Observed (black) and simulated (gray) epiphyte mat temperatures versus observed air temperature (blue) during a one-month simulation event at the three study sites. The gray shared area marks nighttime hours.

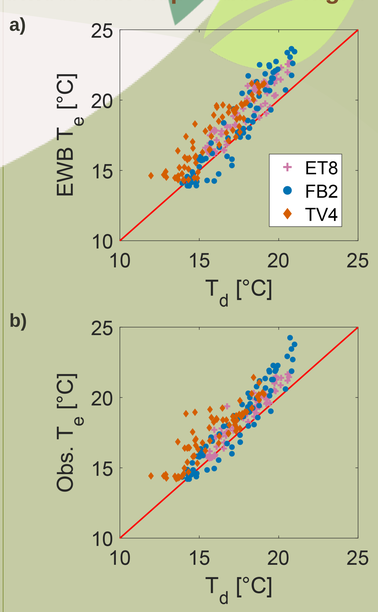
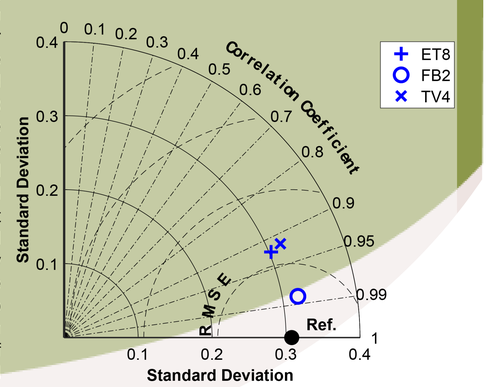


Figure 7. Hourly dew point air temperature versus epiphyte mat temperature estimated by (a) the EWB model, and (b) from observations at the three study sites: ET8 (purple cross), FB2 (blue circles), and TV4 (orange diamonds). The 1:1 line is shown in red.

Model Validation

Figure 8. Taylor diagram illustrating standard deviation, Pearson correlation coefficient, and root mean square error (RMSE) of EWB model-simulated epiphyte mat temperatures (blue markers) compared to normalized field observations (black dot) during a three-day dry down simulation. The epiphyte mat temperatures estimated by the EWB model were consistent with field observations in terms of magnitude and timing. The RMSE for epiphyte mat temperatures estimated by the EWB model were less than 1°C throughout the 3-day dry-down simulations for all three sites. The EWB model results are highly correlated to field observations, with correlation coefficients above 0.9. The distributions of all simulated epiphyte mat temperatures had a similar standard deviation to the distributions of the observed epiphyte mat temperatures for all three sites.



Standard deviation is shown along the x- and y-axis and is provided by the radial distance (solid lines) from the origin of the figure. The correlation coefficient is shown as rays (dashed-dot lines) extending from the origin and is provided by the azimuthal position of each model simulation. RMSE is displayed as arced isolines (dashed lines) increasing away from the reference data in increments of 0.1. The field observations were normalized by their minimum and maximum temperatures to provide a single reference point for the Taylor Diagram. The reference point is located where the standard deviation and RMSE are zero and the correlation coefficient is one on the Taylor diagram.

Contact

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