# Estimation of the Evaporative Fraction term of PET for Remote Sensing Applications of AET

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Actual evapotranspiration is the second largest term in the water balance equation and is therefore critical to eco-physiological modeling. The largest term in the water balance (precipitation) has been successfully estimated in data poor regions using remote sensing technology and ground-based meteorological data. Actual evapotranspiration, on the other hand, has been much more difficult to extrapolate at scales necessary for seasonal forecasting, given the lack of ground data and non-linearities in scaling parameters. Actual evapotranspiration is critical for effective crop modeling and forecasting in regions, such as Sub-Saharan Africa, where low purchasing power, combined with food shortages, requires preventative market based strategies to combat food insecurity.

The proposed work aims to develop a semi-empirical model for estimating actual evapotranspiration over Sub-Saharan Africa, using readily available remote sensing products (surface temperature, vegetation indices, and precipitation). The work will contribute to the pursuit of three strategic objectives:

1) Collection and characterization of baseline flux tower data in biomes that exist in Sub-Saharan Africa.

2) Coarse-scale model representation and extrapolation using remotely sensed and ground-based meteorology, and plant physiology.

3) Application and evaluation of the AET product in crop monitoring.

Actual evapotranspiration **AET** (1) is a function of maximum or potential evapotranspiration **PET**, constrained by two terms: the evaporative fraction of the canopy $\mathbf{f_M}$ and the soil $\mathbf{f_P}$. Potential evapotranspiration is typically calculated with the Priestly-Taylor formulation. The release of latent heat via transpiration lowers the temperature of the canopy relative to ambient air. Therefore, when canopy temperatures are low $\mathbf{T_{MIN}}$ (2), it is expected that **AET** is equal to **PET**. Similarly, when canopy temperatures are high $\mathbf{T_{MAX}}$, the plants are stressed and stomata are closed. Previous studies, involving the remote sensing of **AET**, have used the relationship between $\mathbf{T_{MAX}}$ and $\mathbf{T_{MIN}}$ to determine the evaporative fraction of the canopy. In these studies, $\mathbf{T_{MAX}}$ and $\mathbf{T_{MIN}}$ are determined from pixels within a single image. This approach tends to induce bias in heterogeneous canopies, as threshold temperatures tend to vary among species. In the formulation for **AET** outlined below, the threshold temperatures are determined over a times series of a single pixel. This significantly reduces the problems of interspecies variations.

The evaporative fraction for soil is important in sparse canopies or on bare soil. The thermal conductivity of soil, which controls evaporation, is several orders of magnitude lower when soil is dry, compared to when it is wet. Studies show that evaporation from soil can be described as a one week time decay of rainfall **P** following a storm event. Therefore, $\mathbf{f_P}$ (3) can be described using an autoregressive function of **AET** standardized residuals $\hat{\mathbf{e}}$ not explained by modeled canopy AET. The evaporative fraction of soil is the sum of precipitation lagged at time **t-p**, where **p** is the order of the autoregressive process. The coefficients **a** and $\mathbf{b_n}$ are determined empirically. The remaining terms, $\mathbf{f_G}$ (4) and $\mathbf{f_{1-G}}$ (5) are the fraction of the down-welling shortwave radiation $\mathbf{R_D}$ absorbed by the canopy **APAR**, and the soil respectively.

$$AET = (f_G f_M + f_{1-G} f_P) PET \qquad (1)$$

$$f_M = \frac{T_{MAX} - T}{T_{MAX} - T_{MIN}} \qquad (2)$$

$$f_P = \hat{\varepsilon} = a + \sum_1^p b_n P_{t-n} \qquad (3)$$

$$f_G = \frac{APAR}{R_D} \qquad (4)$$

$$f_{1-G} = 1 - f_G \qquad (5)$$

The flux tower datasets will include all of the major inputs for **AET** on a daily timestep: **PET** (net surface radiation, soil heat flux, vapor pressure flux, and temperature flux), $\mathbf{f_M}$ ($\mathbf{T_{MAX}}$, $\mathbf{T_{MIN}}$ and **T**), and $\mathbf{f_P}$ (**P**). The fraction of canopy cover will be determined using vegetation indices derived from MODIS 16-day 250m resolution blocks. The images will be corrected for data gaps, atmospheric contamination and clouds, using adjacent cells. A cross-validation and sensitivity analysis will be used to evaluate the robustness of the model and to identify potential sources of error. The model will be extrapolated to biomes in Sub-Saharan Africa using the daily 1km land surface temperature product from MODIS and 4km meteorology from METEOSAT. Meteorological station data will be used to remove bias. The model will be validated at seasonal and annual scales for major catchments in Africa using existing monthly runoff data. The model will also be compared to existing AET model estimates used in a standard crop monitoring index for Africa (Water Requirement Satisfaction Index).

Thirty flux towers (see data request) have been selected from across the globe that are in areas with similar landcover and climate as Sub-Saharan Africa: Evergreen Broadleaf (Tropical), Open Shrublands (Sub-Tropical/Arid/Semi-Arid), Woody Savannas (Sub-Tropical/Arid/Semi-Arid), Savannas (Sub-Tropical/Arid/Semi-Arid), Grasslands (Sub-Tropical/Arid/Semi-Arid), Croplands (C4: Maize, Sorghum, Sugarcane, Millet), and Closed Shrublands (Sub-Tropical/Arid/Semi-Arid). Datasets that do not include three or more years of 30-minute/daily data (for inter-annual and inter-seasonal comparison), and do not have years corresponding to MODIS acquisition, have been removed from the request.

The data providers will be invited to participate in the development and evaluation of the model, and the submission of papers to peer-review journals. Upon the approval of this proposal, communications will be established with individual data providers to determine site specific data handling and manipulation. Before the submission of a paper, the data handlers will be asked for their approval and to make contributions, comments, and suggestions. In the event that a consensus is not reached on the submission of an article, mediation from the Scientific Moderation Committee will be requested.