Deriving Biophysical Constraints from MODIS and SEVIRI to Estimate Daily Evapotranspiration in Semiarid Regions

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INTRODUCTION

There is a need to estimate **evapotranspiration** spatially **over semiarid ecosystems** and to capture the quick vegetation responses to rainfall pulses. The model proposed by **Fisher *et al.*, (2008)** estimates evapotranspiration at monthly scales based on the Priestley-Taylor equation adjusted to down regulate for multiple constraints. It has proven to be successful over 16 Fluxnet sites, none included semiarid vegetation.

We evaluated the model in the **Sahelian semiarid savanna** at a daily time scales in Agoufou (**Mali**) using a micrometeorological dataset from the African Monsoon Multidisciplinary Analyses (AMMA) and MODIS (Terra and Aqua) and SEVIRI (Meteosat Second Generation) products during the 2007 growing season.

A **global sensitivity analysis** was performed using Extended Fourier Amplitude Sensitivity Test (EFAST) (Saltelli *et al.*, 1999) to identify the relative importance, in terms of contribution to the output variance, of each input variable required by the model. Then, we ran the model using different climatic and satellite based estimates for some of the more critical parameters found with EFAST.

RESEARCH QUESTIONS

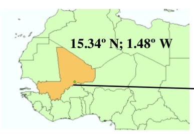
- Which variables contribute the most to the annual variability of evapotranspiration?
- What is the evapotranspiration model sensitivity to input parameter uncertainties?
- What is the performance of the Fisher model at daily time scale using a combination of field and remotely-sensed data as inputs to estimate the biophysical constraints?

CONCLUSIONS

- **Annual dynamics of evapotranspiration** were mostly driven by the *Rn*, followed by moisture and vegetation phenology.
- **Uncertainty analyses** showed that the most critical parameters were the soil moisture constraint (f_{SM}), those related with net radiation (*Rn*) partition and f_{IPAR}.
- Fisher´s model at **daily-time scale** provided satisfactory results (R^2=0.86; MAE=14.81 Wm^{-2}) using field data for soil moisture and MODIS *NDVI*.
- We also obtained promising results when using only **satellite products:** MODIS for f_{IPAR} and *LAI* and **SEVIRI** for **surface temperature** as a proxy for soil moisture.

STUDY SITE

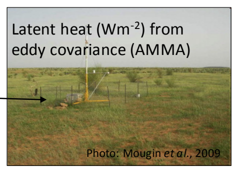
West Africa
Agoufou, Mali.



Land use in Agoufou: open woody savanna

DATA

1. For model evaluation



2. For model input

Used in all algorithm versions	*Rn*	Net radiation (Wm^{-2}) (AMMA)
	G	Soil heat flux(Wm^{-2}) (AMMA)
	T_{air}	Air temperature (C) (AMMA)
	NDVI	MODIS (MOD13Q1)
Used only in some Algorithm versions	*SWC*	Soil Water Content (%)(AMMA)
	VPD	Vapor pressure deficit (kPa) (AMMA)
	RH	Relative humidity (AMMA)
	Ts	Surface temperature (C) (AMMA)/MSG-SEVIRI
	LAI	MODIS (MOD15A2, MYD15A2)
	f_{PAR}	MODIS (MOD15A2, MYD15A2)

METHODOLOGY

1. Global sensitivity analyses (EFAST)

EFAST provides the contribution to the variance of modeled outputs of each input factor alone (main effect) or with interactions (total effect).

- **Simulations:** evaluate the contribution of each input factor to the annual variability in evapotranspiration. Annual ranges for input variables (*Rn, G, Tair*) and uncertainty values (literature) for parameters.
- **Uncertainty analysis:** *Rn, G, Tair* were affected by a 10% perturbation around their monthly mean and the total growth season value. For the parameters *m1, b1, m2, b2*, k_{Rn}, and k_{PAR} the uncertainty level was set based on ranges found in literature. For the biophysical constraints f_{SM} and f_T uncertainties of 25% were considered (see Table 1 for model description).

Table 1: Description of the evapotranspiration model

λE	Evapotranspiration	$\lambda E_c + \lambda E_s$
λE_c	Canopy transpiration	$\lambda Ec = fg \cdot fT \cdot fM \cdot \alpha \frac{\Delta}{\Delta+\gamma}(Rn - Rn_s)$
λE_s	Soil evaporation	$\lambda Es = fSM \cdot \alpha \frac{\Delta}{\Delta+\gamma}(Rn \cdot exp(-k_{Rn} \cdot LAI)) - G$

Plant Variables	f_{APAR}	Fraction of *PAR* absorbed by green vegetation	$f_{APAR} = m1 \cdot NDVI + b1$	Myneni & Williams, (1994)
	f_{IPAR}	Fraction of *PAR* intercepted by total vegetation	• $f_{IPAR-NDVI} = m2 \cdot NDVI + b2$	Fisher et al., (2008)
			• $f_{IPAR-MODIS}$	
	LAI	Leaf Area index	• $LAI_k = -Ln(1 - f_{IPAR})/k_{PAR}$	Norman et al., (1995)
			• LAI_{MODIS}	
Biophysical constraints	fg	Green canopy fraction	$f_g = f_{APAR}/f_{IPAR}$	
	f_T	Plant temperature constraint	f_T =function(T_{air}, T_{opt}) (CASA model)	Potter et al., (1993)
	f_M	Plant moisture constraint	$f_M = f_{APAR}/f_{APARmax}$	Fisher et al., (2008)
	f_{SM}	Soil moisture constraint	• $f_{SM} meas = 1 - \left(\frac{SWC - SWC_{min}}{SWC_{Max} - SWC_{min}}\right)$	Measured in situ
			• $f_{SM} Fisher = RH^{VPD/\beta}$	Fisher et al., (2008)
			• $f_{SM} Ts = \left(\frac{Ts - Ts_{min}}{Ts_{Max} - Ts_{min}}\right)$	This study

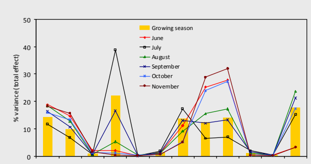
2. Model evaluation using eddy covariance data

- Evapotranspiration (λE) estimated with the Priestley-Taylor equation adjusted with soil moisture and plant constraints (Fisher *et al.*, 2008).
- Evaluation of 8 model versions based on different soil moisture constraint (f_{SM}), fraction of intercepted PAR (f_{IPAR}) and *LAI* estimates.

RESULTS

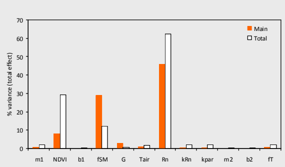
Global sensitivity Analyses using EFAST

Sensitivity of the evapotranspiration model to parameter uncertainty



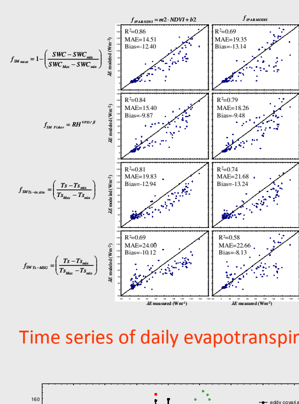
% of explained variance considering perturbations around the mean value of the growing season (yellow bars) and around mean monthly values (lines). Perturbations were of 10% for input variables *NDVI, Tair, Rn,* and *G* and of 25% for the soil moisture constraint (f_{SM}) and the plant temperature constraint (f_T). For the constant model parameters: *m1, b1, m2, b2*, k_{Rn}, and k_{PAR}, the range of uncertainty was based on values used in the literature.

Contribution of input variables to annual variability in evapotranspiration



% of explained variance of evapotranspiration considering the annual range of variability for input variables *NDVI*, f_{SM}, *Rn*, T_{mean}. For the fixed model parameters, uncertainty levels were established based on literature ranges. Main effect: without interactions. Total effect: with interactions.

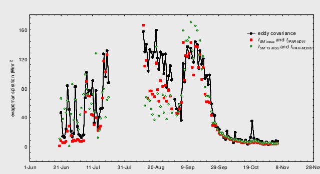
Modeled evapotranspiration vs. measured with eddy covariance



Daily evapotranspiration measured with eddy covariance system vs. modeled. Eight model outputs are shown: using f_{IPAR} (fraction of intercepted *PAR*) from *NDVI* ($f_{IPAR-NDVI}$) in the left column and from MODIS product ($f_{IPAR-MODIS}$) in the right column. The vertical axis shows results using four estimates of soil moisture constraint: measured soil moisture ($f_{SM-meas}$), Fisher´s approach ($f_{SM-Fisher}$), surface temperature (*Ts*) from in situ sensors-Apogee ($f_{SM\ Ts-in\ situ}$), and *Ts* from SEVIRI satellite data ($f_{SM-Ts\ MSG}$).

SWC is volumetric soil water content (%), *VPD* vapor pressure deficit (kPa), and *RH* relative humidity. MAE isMean Absolute Error. $_{Max}$ and $_{min}$ refer to the minimum and maximum value of the time series.

Time series of daily evapotranspiration



Time series of daily evapotranspiration for eddy covariance data, and modeled data using f_{IPAR} (fraction of intercepted PAR) from *NDVI* ($f_{SM-NDVI}$) and soil moisture constraint (f_{SM}) from in-situ measurements ($f_{SM-meas}$), using only satellite products ($f_{IPAR-MODIS}$) and f_{SM} from MSG-SEVIRI ($f_{SM-Ts\ MSG}$).

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