Mapping evapotranspiration over complex surface using modified Shuttleworth-Wallace model

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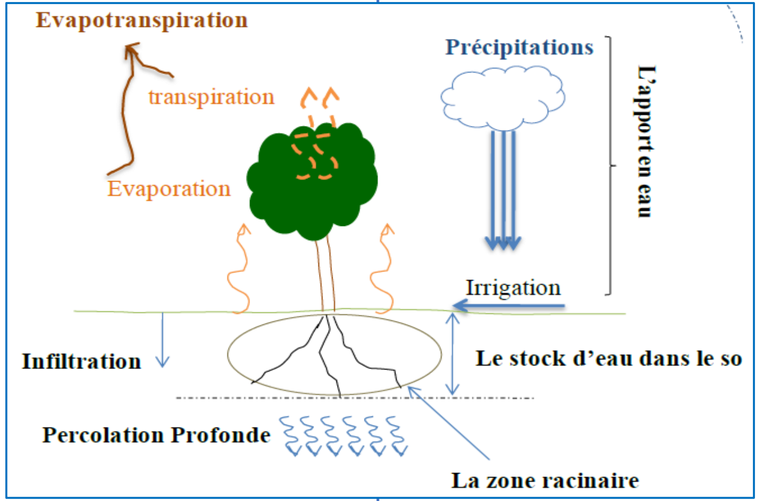
General context

Deterioration and depletion of water resources

The weight of agriculture

Insufficient resources and global warming

integrated management of water resources



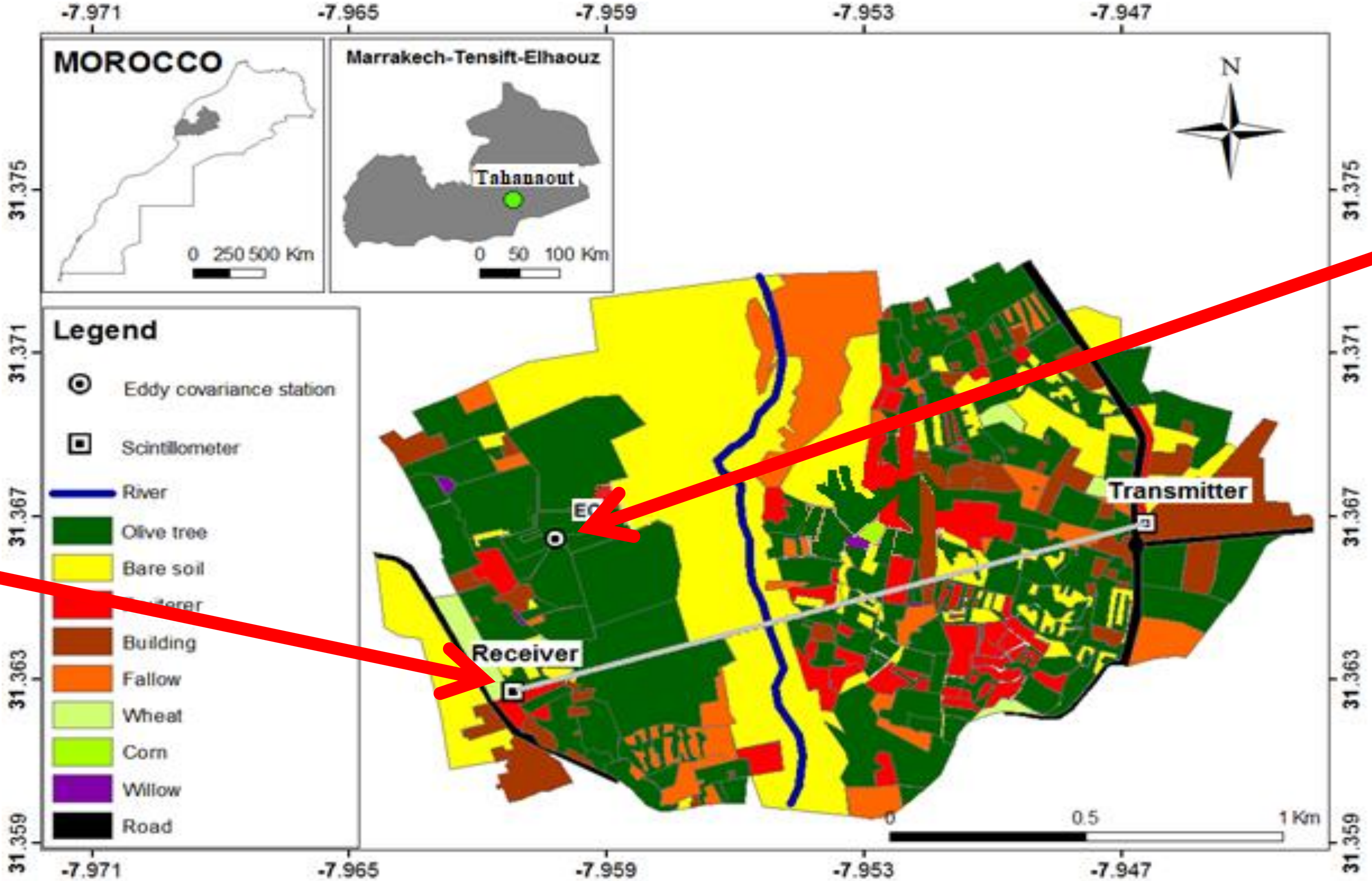
understanding the mechanism of the water cycle

Assessing evapotranspiration

Good control of the use of water resources

Study area

Scintillometer
(receiver)



Station
Eddy covariance

Shuttleworth-Wallace model

Evapotranspiration

Evaporation

Transpiration

$$ET = E + T = C_s PM_s + C_v PM_v$$

Penman-Monteith combination equation

$$PM_s = \frac{\Delta A + \left[\left(\rho C_p D - \Delta r_a^s (A - A_s)\right)/(r_a + r_a^s)\right]}{\Delta + \gamma[1 + r_s^s/(r_a + r_a^s)]}$$

$$PM_v = \frac{\Delta A + \left[\left(\rho C_p D - \Delta r_a^v A_s\right)/(r_a + r_a^v)\right]}{\Delta + \gamma[1 + r_s^v/(r_a + r_a^v)]}$$

$$C_s = \frac{1}{1 + [R_s R_a / R_v (R_s + R_a)]}$$

$$C_v = \frac{1}{1 + [R_v R_a / R_s (R_v + R_a)]}$$

$$R_s = (\Delta + \gamma) r_a^s + \gamma r_s^s \qquad R_v = (\Delta + \gamma) r_a^v + \gamma r_s^v \qquad R_a = (\Delta + \gamma) r_a$$

soil surface resistance

$$r_S^S = r_{Smin}^S f(\theta_S) \qquad f(\theta_S) = 2.5\left(\frac{\theta_F}{\theta_S}\right) - 1.5$$

surface vegetation resistance

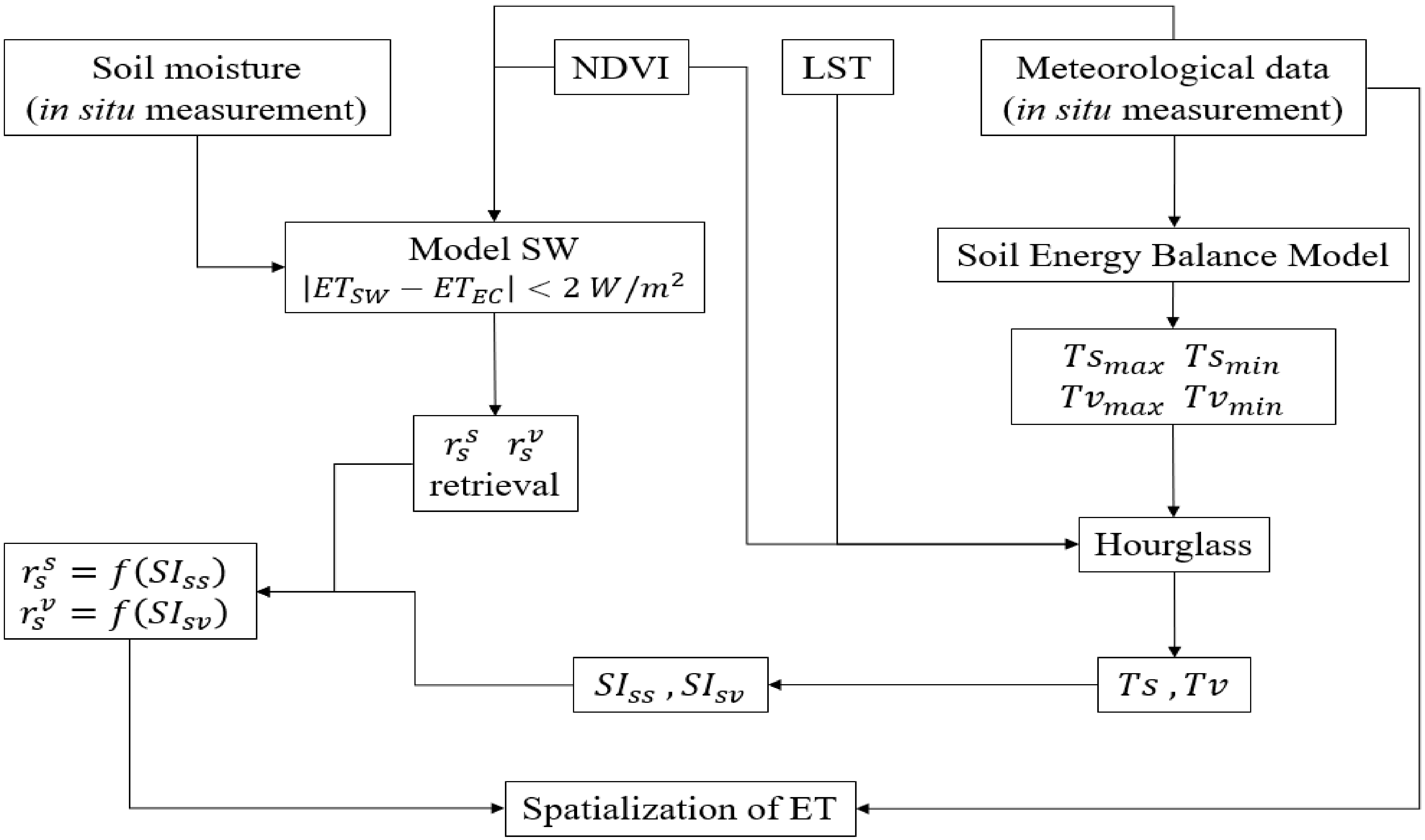
$$r_S^v = \frac{r_{ST\,min}}{LAI \prod_i F_i(X_i)}$$

stress functions

$$F_1(S) = \left(\frac{S}{1100}\right)\left(\frac{1100 + a_1}{S + a_1}\right) \qquad F_2(T) = \frac{(T - T_L)(T_H - T)^{\frac{(T_H - a_2)}{(a_2 - T_L)}}}{(a_2 - T_L)(T_H - a_2)^{\frac{(T_H - a_2)}{(a_2 - T_L)}}}$$

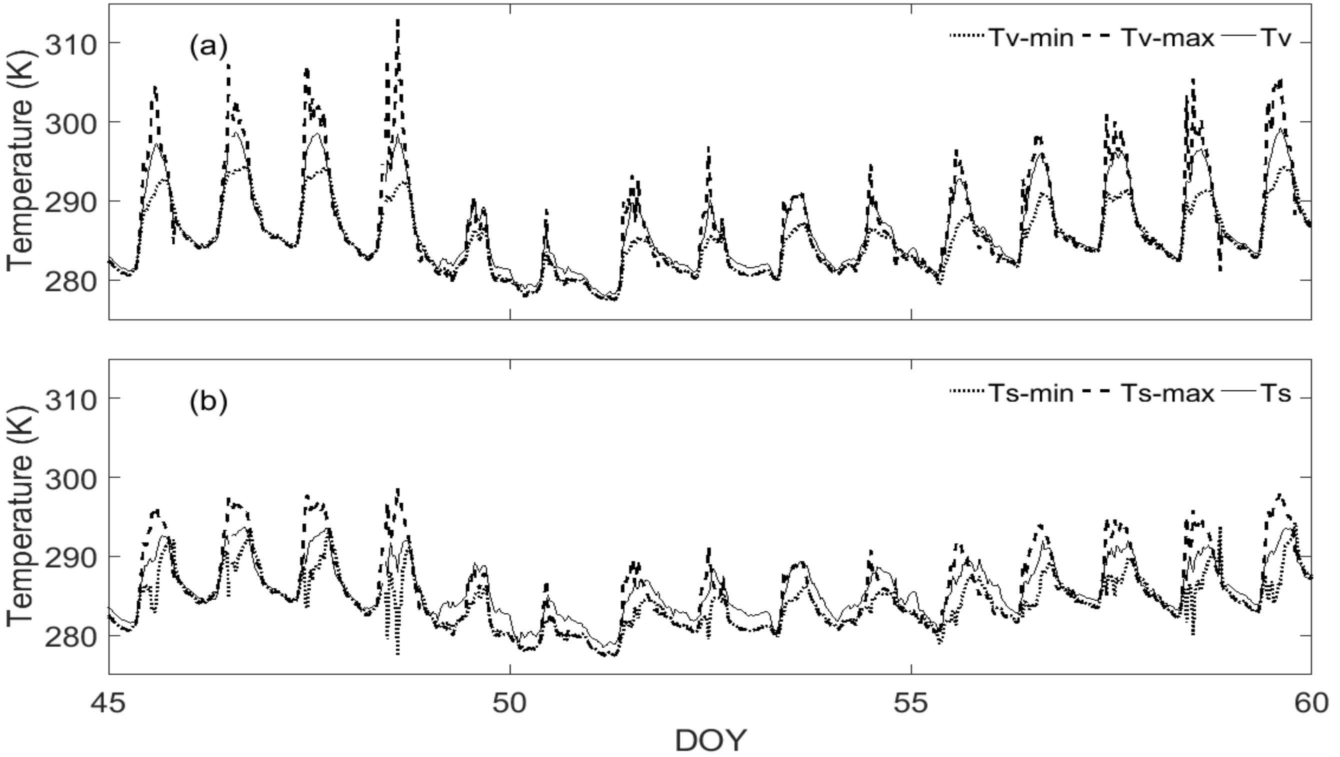
$$F_3(\theta) = \begin{cases} 1, & \theta \geq \theta_F \\ \dfrac{\theta - \theta_W}{\theta_F - \theta_W}, & \theta_F < \theta < \theta_W \\ 0, & \theta \leq \theta_W \end{cases}$$

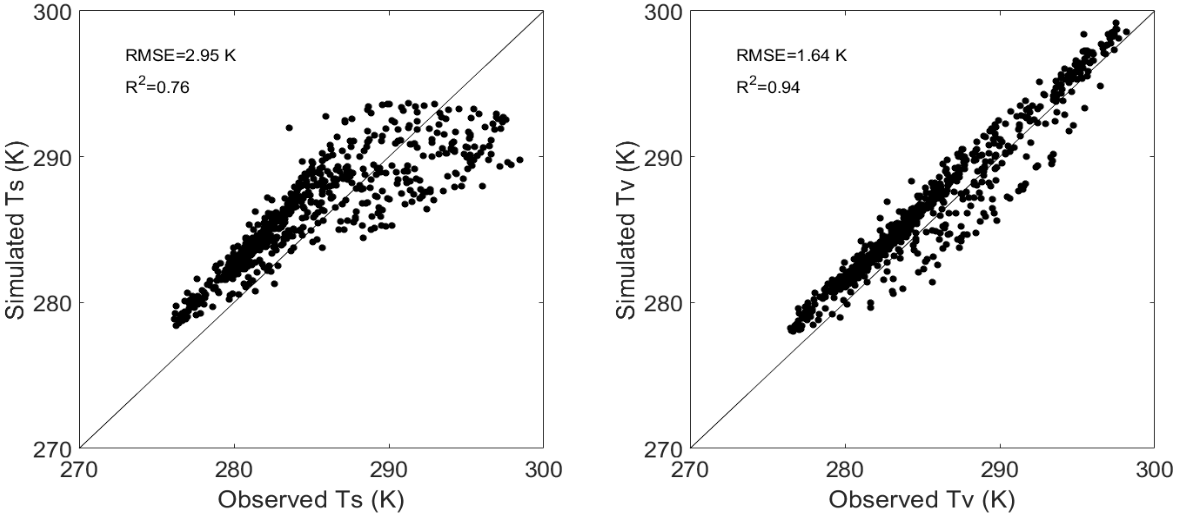
The proposed approach



Validation of the soil and vegetation temperatures component

Variation of soil (a) and vegetation (b) temperatures derived from Hourglass method, and their maximum and minimum computed from soil surface energy balance model, from DOY 45 to DOY 60.



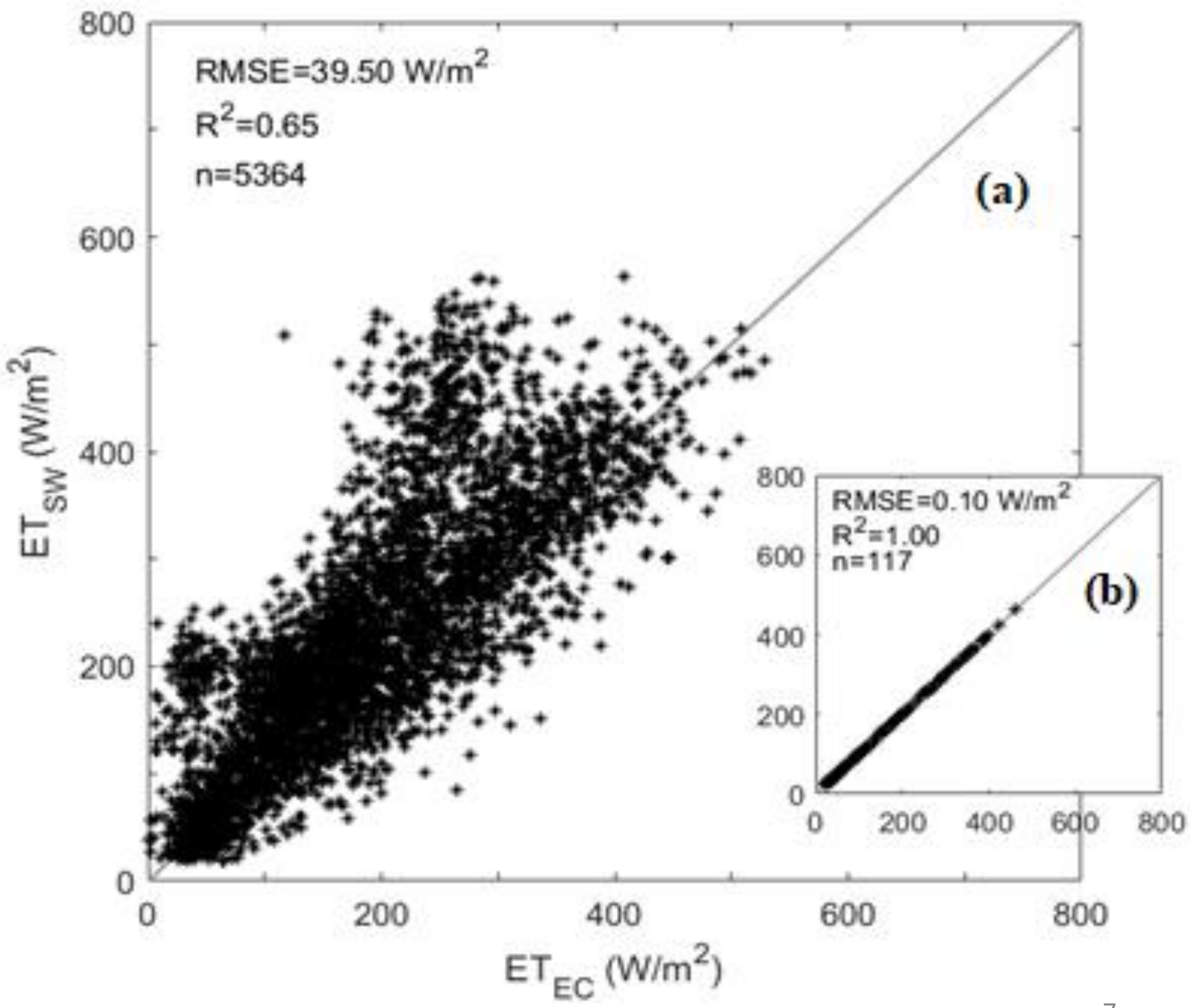


Simulated soil and vegetation temperatures versus in situ measurements

Comparison between the SW model estimation and the EC measurement

(a) Half-hourly comparison between evapotranspiration predicted by the Shuttleworth–Wallace model (ET_{SW}) and measured by the Eddy covariance system (ET_{EC}) during 2017.

(b) only the points selected based on a minimum error (smaller than 2 W/m2) between estimated and measured evapotranspiration are displayed.

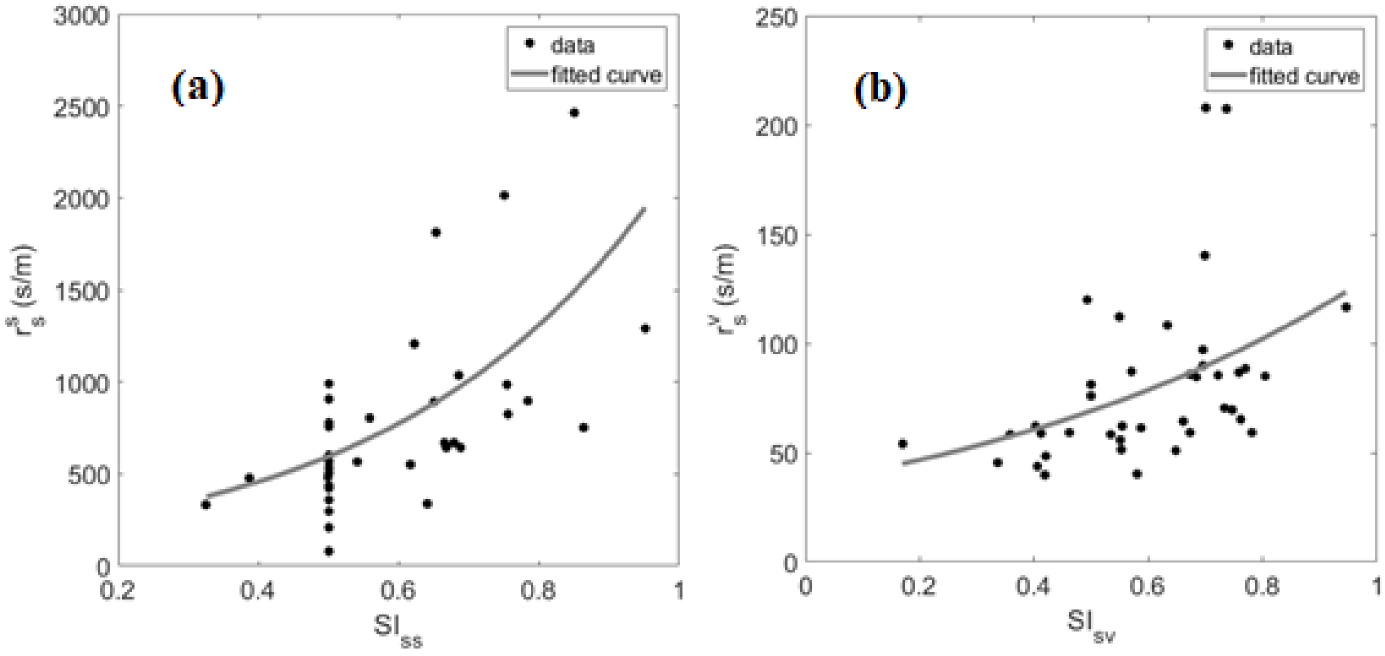


Soil and vegetation resistances

$$r_s^s = ae^{b*SI_{ss}}$$
$$r_s^v = ce^{d*SI_{sv}}$$

$$SI_{ss} = \frac{Ts - Ts_{min}}{Ts_{max} - Ts_{min}}$$

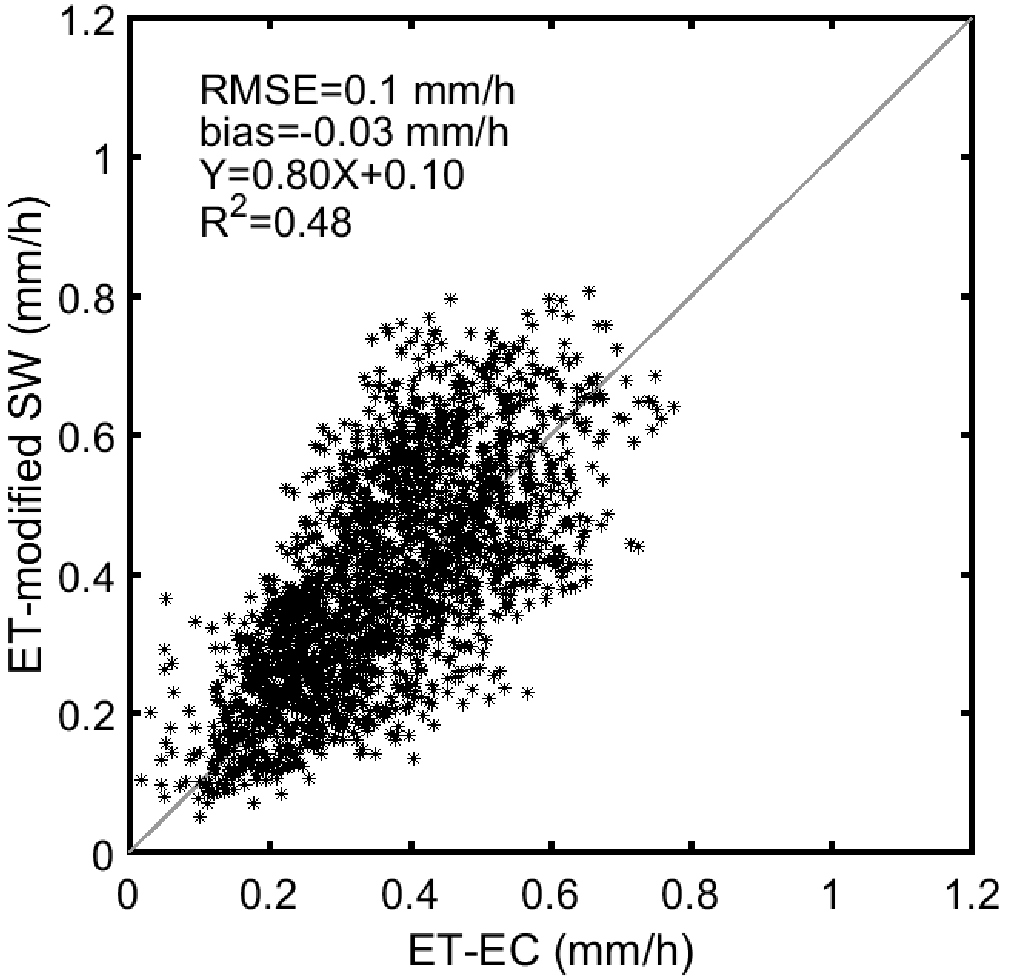
$$SI_{sv} = \frac{Tv - Tv_{min}}{Tv_{max} - Tv_{min}}$$



Relationships between the soil (a) and vegetation (b) resistances (r_s^s *and* r_s^v) and two stress indexes (SI_{ss}, SI_{sv}) derived from the temperatures (T_s and T_v) and their endmembers for the values between 12h and 15h. The best fit was also presented (solid line).

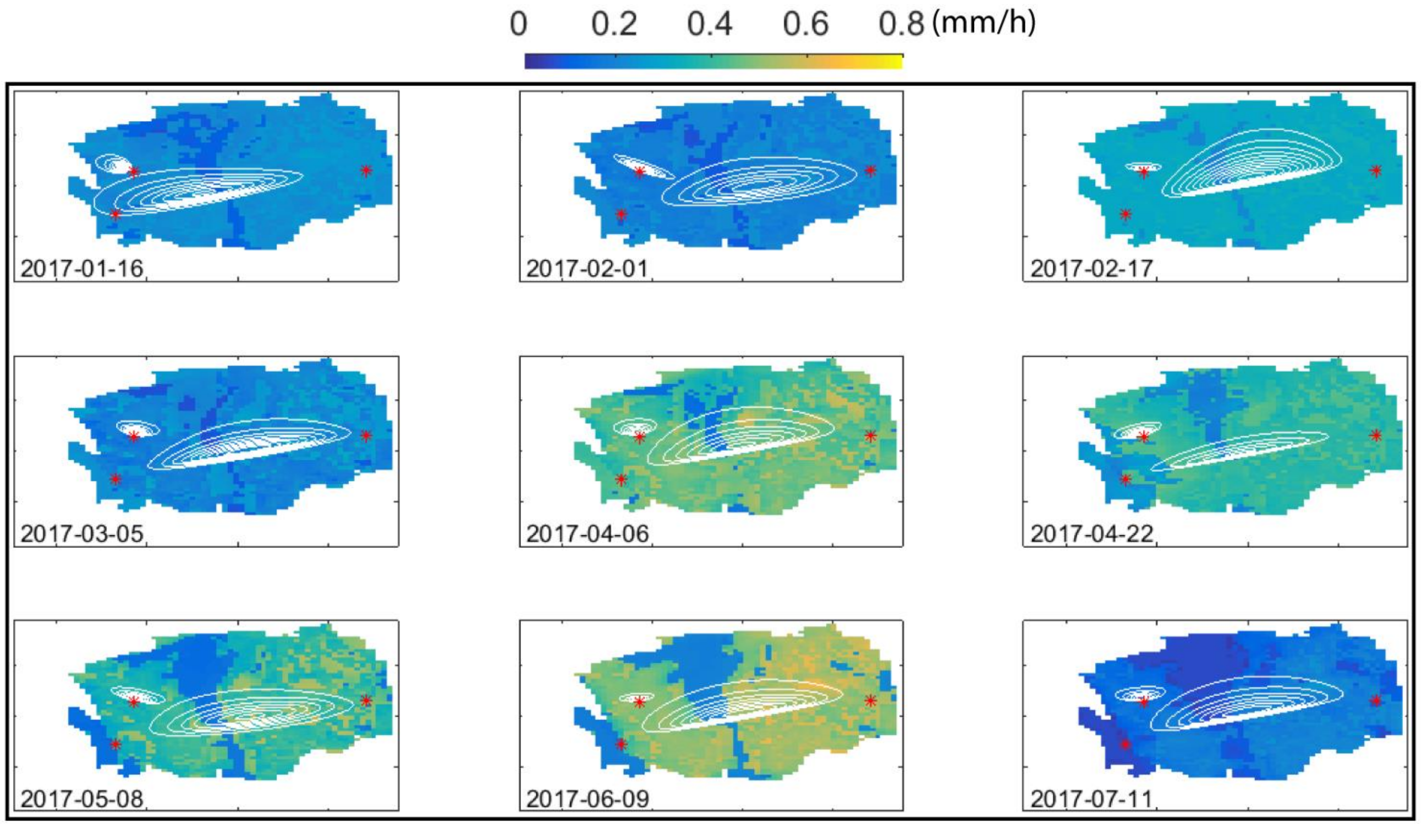
Validation of the proposed approach at the local scale

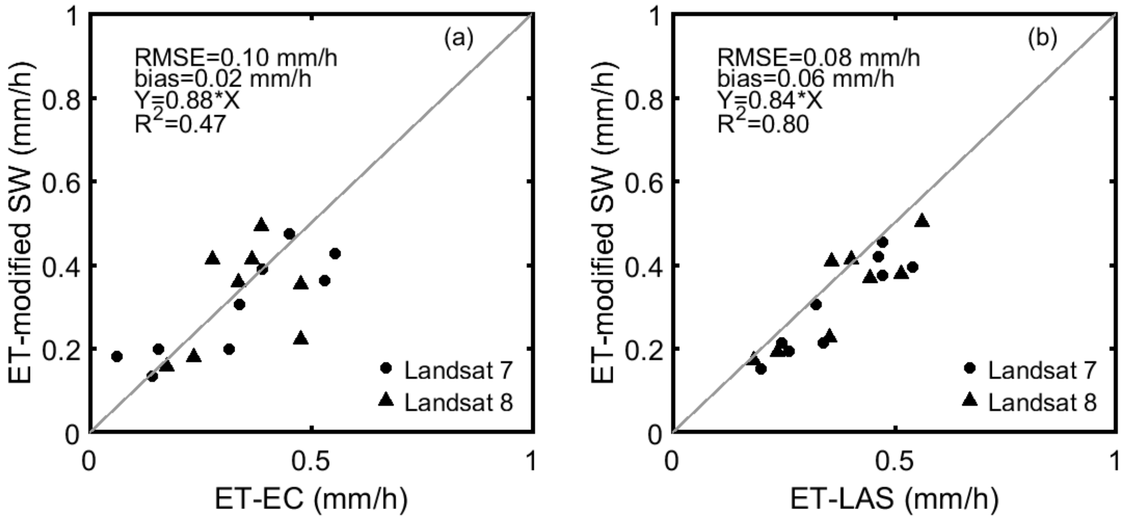
Half-hourly comparison between estimated ET using the proposed approach and measured one by the Eddy covariance system from January to June 2017.



Validation of the proposed approach at the regional scale

Evapotranspiration (mm/h) maps over the study area for the dates of the Landsat-7 overpass. The footprint of LAS and EC for the time of the satellite overpass is also represented.





Comparison of estimated evapotranspiration from the modified SW model driven by Landsat-7 and Landsat-8 and measured by the eddy covariance system (a) and the scintillometer (b).

Conclusion

- SW model was tested locally and acceptable results were obtained in estimating ET with a relative RMSE and bias equal to 0.38 and -0.1 mm/h, respectively.

- Soil and vegetation resistances values were inverted from the SW model and used to found the empirical relations based on the stress indexes.

- The proposed approach was validated at local scale by comparing the results with EC system and the statistical performance were encouraging with a relative RMSE and bias equal to 0.29 and -0.03 mm/h, respectively.

- The proposed approach was spatialized using Landsat 7 and 8 data and confirmed its accuracy by comparing the results with the LAS and EC measurements where the RMSE, bias and R^2 were equal to 0.08 mm/h, 0.06 mm/h and 0.80, respectively, compared to the LAS and equal to 0.1 mm/h, 0.02 mm/h and 0.47, respectively, compared to the EC.