MedGU Mediterranean Geosciences Union
Annual Meeting | Marrakech, 27–30 November 2022
Springer | Publishing Partner

Topography-based estimation of evapotranspiration at high altitudes in semi-arid regions

Badreddine Sebbar[1,2], Olivier Merlin[2], Saïd Khabba[1,3], Vincent Simonneaux[2], Marine Bouchet[2], and Abdelghani Chehbouni[1,2, 4]
[1] Center for Remote Sensing Applications, Mohammed VI Polytechnic University, Benguerir, Morocco
[2]Centre d'Etudes Spatiales de la Biosphère (CESBIO), Université de Toulouse, CNES, CNRS, IRD, UPS, Toulouse, France
[3]LMFE, Physics department, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakech, Morocco
[4] International Water Research Institute (IWRI), Mohammed VI Polytechnic University (UM6P), Benguerir, Morocco
`Badreddine.SEBBAR@um6p.ma`

Abstract. Assessing the surface water balance of mountains is a real challenge given notably the extreme variability of meteorological conditions and the sparsity of in situ monitoring. While mountains are recognized as water towers feeding the surrounding plains, there is only unconsolidated knowledge about the individual water balance components especially the evapotranspiration (ET). Satellites Land Surface Temperature (LST) along with air temperature (Ta) and global solar radiation (Rg) can be used to assess the energy budget and provide a reasonable estimation of instantaneous ET. Nevertheless, over mountains the Ta and Rg respectively undergo strong topographical changes due to elevation and sun exposure effects. Moreover, upscaling the instantaneous ET to its daily value is expected to be uncertain in mountains as the evaporative fraction (EF, defined as the ratio of ET to available energy ratio) of a given pixel can no longer be considered constant during daytime until proven otherwise. In this context, this contribution focuses on a topography-based estimation of ET using the Two Source Energy Balance (TSEB) model. We also examine the variability of hourly and daily EF estimates through both satellite and in situ monitoring. An eddy covariance tower was installed at 3850 m.a.s.l over the High Atlas Mountains in central Morocco and has been operating since September 2020 to present. 30 m resolution LST is derived from thermal data collected by Landsat-7, 8 and 9 on clear sky days. Rg is estimated at the Landsat (30 m) resolution from the SRTM's Digital Elevation Model (DEM) and two different topography-based approaches: a physically based model (DART) and a simplified semi-empirical model. The 9 km resolution ERA5-Land's air temperature product is spatialized at the same (30 m) resolution by applying the environmental lapse rate (ELR) retrieved at the Landsat overpass time over a 9 Km² area including the eddy covariance tower. Satellite-derived estimates of ET and EF are compared to instantaneous station measurements for three and nine dates in 2020 and 2021 respectively. The variability during daytime of the in-situ EF is also assessed to evaluate the potential for upscaling instantaneous remotely sensed ET to a daily scale.

Keywords: Evapotranspiration, Topography, Evaporative Fraction, Remote Sensing, Energy-balance.

1 Introduction

The estimation of evapotranspiration (ET) in mountainous areas using temperature-based models that rely on remotely sensed Land Surface Temperature (LST) is challenging due to the influence of topographical effects. The elevation-dependent temperature (Ta) and incoming radiation (Rg) from adjacent surfaces make it difficult to spatially distribute the necessary inputs. To overcome this challenge, a new methodological approach is proposed in this study. This approach considers these effects prior to estimating ET in mountainous regions.

2 Materials and Methods

The study area is the Rheraya sub-basin located in the High Atlas Mountains in central Morocco. The area has a semi-arid climate, and its elevation varies from about 1000 to 4127 meters. The high-altitude regions are characterized by low temperatures, rugged terrain, and sparse vegetation cover.

Malbeteau et al. [1] normalized LST for topographical effects. Dynamic environmental lapse rate (ELR) was physically inverted through an energy balance model, whereas Rg was spatialized based on the DART model [2]. Ta is then spatialized following the expression:

$$T_{pixel} = T_{station} + ELR(E_{pixel} - E_{station}) \qquad (1)$$

We adapted a similar methodological approach through replacing in-situ measurements with ERA5-Land meteorological data. Rg was estimated using an alternative approach based on direct radiation [3] instead of DART (which is potentially very precise but difficult to apply over large areas).

ET is estimated as a residual of the two-source energy balance (TSEB) model. The latter calculates the energy balance of the soil-canopy-atmosphere continuum, where transpiration is initially determined by the Priestley-Taylor equation [4]. In our case the model is triggered by the aforementioned meteorological forcing and the LST.

3 Results

3.1 Ta and Rg spatialization

Figure 1 depicts scatterplots of simulated Rg and Ta compared to in-situ observations using the Samani [3] and ELR methods, respectively. In addition, it compares measured and simulated Rn based on the resulting Rg and Ta, as well as LST. Rg, Ta, and Rn each have RMSE values of 49.80 W/m2, 1.9 °C, and 43.30 W/m2 correspondingly. 0.80, 0.85, and 0.76 are the R2 values for the same variables in the same sequence.

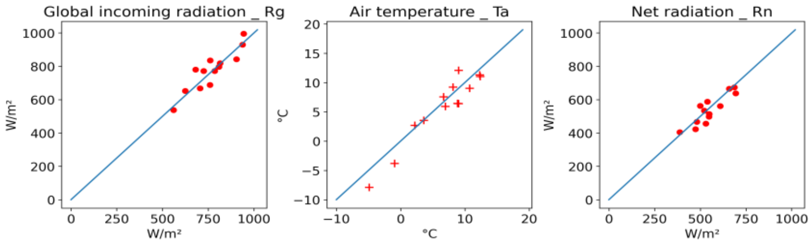

Fig. 1. Scatterplots of measured vs modeled Rg, Ta and Rn at the top-left corner, top-right corner, and the bottom respectively.

3.2 EF daily variation

Figure 2 compares the model-based instantaneous EF estimate at the satellite overpass to hourly and daily measurements. The satellite's midday overpass gives an interesting configuration; the projected instantaneous EF values are fairly close to the daily observed EF. The highest recorded bias is approximately 5%, which corresponds to the 7th of August 2021, when the observed EF around sunset rises abruptly due to instrumentation faults.

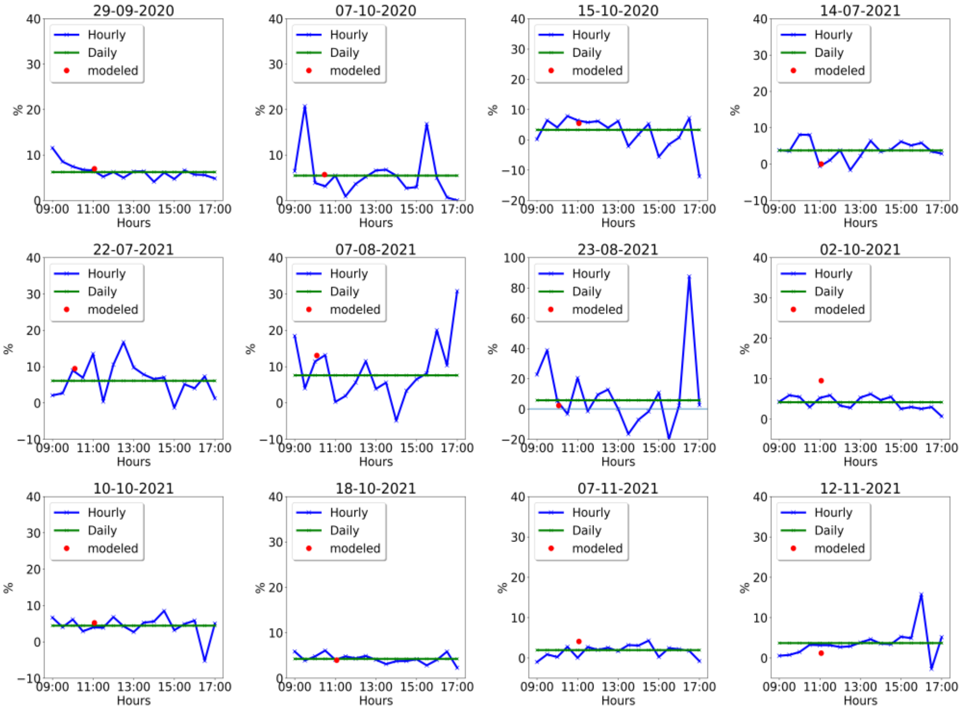

Fig. 2. Instantaneous remotely sensed (red dot) vs daily/hourly (green line/blue line) in-situ measured EF.

3.3 ET estimation

Taking topographic effects into account in Figure 3 results in an RMSE of 27.08 W/m2 and an R2 of 0.81 for the simulated ET; for Rn, these values are 42.73 W/m2 and 0.67; and for the sensible heat flux (H), they are 56.43 W/m2 and 0.79. When topography is considered, the findings mostly agree with the observations, except for the conductive flux (G), which was approximated as a percentage of Rn (RMSE = 73.26 W/m2, R2 = 0.12).

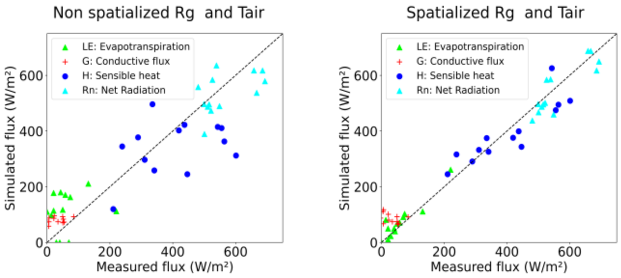

Fig. 3. Comparison of topographically-affected and non-topographically-affected modeled energy balance fluxes with Eddy-covariance observations.

4 Discussion

The results of our study indicate that the Rg, Ta, and Rn spatialization techniques used in the TSEB-PT model are highly effective in predicting instantaneous fluxes, with values that closely observations. Our analysis also revealed that the instantaneous EF could potentially be used to extrapolate instantaneous to daily ET values, particularly when the satellite overpass occurs around midday. This finding is consistent with previous studies that have demonstrated the utility of the EF in estimating daily energy fluxes over flat regions (e.g., Crago, R. D., 1996; Hoedjes et al., 2008). Furthermore, our study highlights the significant influence of topography on modeled fluxes, as evidenced by strong correlations between modeled and measured fluxes after daily extrapolation. These results are consistent with previous studies that have shown the importance of incorporating topographic information in energy flux estimation models (e.g., Rana et al., 2007; Hao et al., 2021). Overall, our study contributes to the growing body of literature on energy flux estimation in terrestrial ecosystems and supports the use of the TSEB-PT model in accurately predicting energy fluxes in various meteorological and topographic conditions.

5 Conclusions

The estimation of ET over mountainous terrain is the primary emphasis of this work. The removal of topographic influences is essential for achieving an accurate estimate of the spatial variation in ET values. When topographic effects are considered, the TSEB-PT model exhibits satisfactory performance. As a perspective, our aim is to estimate ET by applying a more straightforward contextual model, such as the LST-VI model while considering topographic normalization of LST.

References

1. Malbéteau, Y., Merlin, O., Gascoin, S., Gastellu, J. P., Mattar, C., Olivera-Guerra, L., Khabba, S. & Jarlan, L., 2017. Normalizing land surface temperature data for elevation and illumination effects in mountainous areas: A case study using ASTER data over a steep-sided valley in Morocco. Remote sensing of environment, 189, 25-39.

2. Gastellu-Etchegorry, J. P., Demarez, V., Pinel, V., & Zagolski, F. (1996). Modeling radiative transfer in heterogeneous 3-D vegetation canopies. Remote sensing of environment, 58(2), 131-156.
3. Samani, Z., Bawazir, A. S., Bleiweiss, M., Skaggs, R., & Tran, V. D. (2007). Estimating daily net radiation over vegetation canopy through remote sensing and climatic data. Journal of irrigation and drainage engineering, 133(4), 291-297.
4. Kustas, W. P., & Norman, J. M. (2000). A two-source energy balance approach using directional radiometric temperature observations for sparse canopy covered surfaces. Agronomy Journal, 92(5), 847-854.
5. Crago, R. D. (1996). Conservation and variability of the evaporative fraction during the day-time. Journal of Hydrology, 180(1-4), 173-194.
6. Hoedjes, J. C. B., Chehbouni, A., Jacob, F., Ezzahar, J., & Boulet, G. (2008). Deriving daily evapotranspiration from remotely sensed instantaneous evaporative fraction over olive or-chard in semi-arid Morocco. Journal of Hydrology, 354(1-4), 53-64.
7. Rana, G., Ferrara, R. M., Martinelli, N., Personnic, P., & Cellier, P. (2007). Estimating ener-gy fluxes from sloping crops using standard agrometeorological measurements and topog-raphy. Agricultural and forest meteorology, 146(3-4), 116-133.
8. Hao, D., Bisht, G., Gu, Y., Lee, W. L., Liou, K. N., & Leung, L. R. (2021). A parameterization of sub-grid topographical effects on solar radiation in the E3SM Land Model (version 1.0): implementation and evaluation over the Tibetan Plateau. Geoscientific Model Develop-ment, 14(10), 6273-6289.