TESTING APPROACH TO ESTIMATE HOURLY REFERENCE EVAPOTRANSPIRATION WITH SCINTILLOMETER MEASUREMENTS UNDER MEDITERRANEAN CLIMATE

Agnese Carmelo[1], Cammalleri Carmelo[2], Minacapilli Mario[1], Provenzano Giuseppe[1], Rallo Giovanni[1*]

[1] Department of Agro-Environmental Systems (SAgA), Università degli Studi di Palermo, Viale delle Scienze Ed. 4 - 90128, Palermo, Italy.
[2] USDA-ARS Hydrology & Remote Sensing Lab, 10300 Baltimore Avenue, Beltsville, MD, USA.
* rallo.giovanni@gmail.com

Abstract
In the paper a comparison between radiation-aerodynamic and radiation based evapotranspiration models with an independent dataset of Alfalfa reference evapotranspiration acquired by means a scintillometer is carried out. The satisfactory performance of the selected models is comparable to that showed in earlier investigations. This study also shows that using values of model parameters locally determined, is possible to improve hourly estimation of potential evapotranspiration, as obtained with the scintillometer.

Keywords: Reference Evapotranspiration, Scintillometry, Alfalfa, Hourly timescale.

Introduction
Reference evapotranspiration, *ET0*, can be considered a climatic parameter that objectively defines the magnitude of atmospheric demand, regardless of the use of the underlying soil. Numerous approaches have been developed to estimate hourly *ET0* (Ventura *et al.*, 1999), mostly requiring several meteorological records. Unfortunately, it is common a lack of some of the required data to estimate *ET0*; for this reason, empirical functions are often considered, even if they require a local calibration. Moreover, it is desirable to use *ET0* models giving accurate results with a minimum request of input data, in order to dispose of useful tools for irrigation assistance. The modified 24-h Penman-Monteith equation (Allen *et al.*, 1998) has received widespread acceptance for estimating *ET0*. This equation is currently recommended and proposed by the ASCE-EWRI Association for the standard reference crop, as described in the guideline for *ET0* computation (Allen *et al.*, 2005). A simplification of the Penman-Monteith equation is possible by using radiation-based models, as proposed by Priestley-Taylor (1972) and Makkink (1957). The first model neglect the aerodynamic part of Penman-Monteith equation, whereas the second adopts a simplified relationship between solar and net radiation fluxes. The latter relationship has the huge advantage to require only solar radiation measurements and not all the four components of net radiation. In contrast to their simplicity, empirical models take into account any dimensionless correction factor closely linked to the environment. Furthermore, a unique physics-based functional form for the modified Priestley–Taylor has not been defined and must be determined empirically.
The accuracy of the evapotranspiration models can be assessed by using micrometeorological or lysimeter data. In particular, micrometeorological systems include the scintillometry, allowing to measure the sensible heat fluxes by means of a laser beam scattered by the turbulence between a light source (transmitter) and a detector (receiver), measuring the intensity fluctuations of the atmospheric turbulence due to both heat and momentum fluxes (De Bruin, 2002). Field scale evapotranspiration can be obtained as a residual term of the surface energy balance.

The main objective of this paper is evaluate the reliability of Priestley–Taylor ($ET0_{P\&T}$), Makkink ($ET0_{MAK}$), FAO modified 24-h Penman-Monteith equation ($ET0_{P\&M}$) and ASCE-EWRI's standardized Penman Monteith ($ET0_s$) models, through the comparison with hourly latent heat fluxes derived from scintillometric measurements (ET_{SAS}).

Materials and Methods
The research was carried out in an agricultural area near Castelvetrano (TP), in Sicily (Lat. 37.645977° Long. 12.852929°) placed 120 m above sea level and characterized by the typical Mediterranean climate. The soil is a sandy-clay-loam (USDA classification) with field capacity and wilting point equal to 0.33 [cm^3 cm^{-3}] and 0.13 [cm^3 cm^{-3}], respectively (Rallo *et al.*, 2009).
The four evapotranspiration models were applied in the period May 17 to August 24, using hourly weather data recorded by Servizio Informativo Agrometeorologico Siciliano (SIAS); the results were then compared with hourly actual evapotranspiration data acquired by means of a scintillometer (Scintec SL 20), on an Alfalfa (*Medicago sativa* L.) field, located nearby the SIAS meteorological station.
The crop was maintained under optimal water conditions with a sprinkler system. This result was achieved by monitoring continuously the soil water content in the layer 0-120 cm with a Frequency Domain Reflectometry (FDR) probe. Additionally, Alfalfa was frequently cut (every 7–10 days) in order to maintain approximately uniform and constant its height, that resulted always lower than 15 cm.

Tab.1 - Summary of statistics parameters obtained by comparing ET0 models with scintillometer data. The slope of the regression equations is obtained imposing the intercept equal to zero.

ET model	RMSE		slope		R^2		e	
	orig.	recalib.	orig.	recalib.	orig.	recalib.	orig.	recalib.
$ET_{0P\&M}$	0.074		0.86		0.95		0.935	
ET_{0s}	0.070		0.88		0.95		0.942	
ET_{0MAK}	0.075	0.075	0.85	1.18	0.96	0.96	0.933	0.93
$ET_{0P\&T}$	0.072	0.057	1.13	0.96	0.96	0.96	0.937	0.96

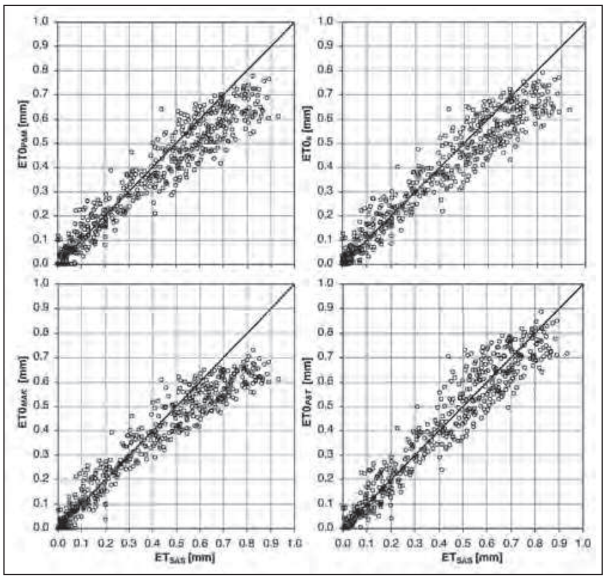

Fig. 1 - Comparisons of hourly measured, ET_{SAS}, with estimated using Priestley–Taylor ($ET0_{P\&T}$), Makkink ($ET0_{MAK}$), FAO modified 24-h Penman-Monteith equation ($ET0_{P\&M}$) and ASCE-EWRI's standardized Penman Monteith ($ET0_s$) models.

Thirty-five days of meteorological and scintillometer data were used for the study. These data refer to hourly information obtained in time periods uniformly distributed during the entire irrigation season.

A statistical analysis (Meek *et al.*, 2009), was performed in order to evaluate both the hourly and daily outputs for each model. Once established ET_{SAS} as the independent variable, statistical analysis included the computation of linear regression parameters (*slope* and *intercept*), coefficient of determination (R^2) and Root Mean Square Error (*RMSE*). For the radiation based *ET* models, the comparison was firstly carried out using the original coefficients and later with locally calibrated parameters obtained by minimizing the sum of square of the differences between estimated and measured ET data.

Results and Discussion

The statistical parameters of the four examined models are summarized in Table 1. Hourly comparisons show a satisfactory correlation between modelled *ET0* and measured data (ET_{SAS}), with R^2 of 0.96 for all the models. Moreover, the accuracy of the models is quite similar, with lower errors for the $ET0_s$ model (*RMSE* = 0.70 mm h^{-1}) compared with the others. The *RMSE* values obtained for all the models can be considered acceptable values for most practical purposes, and comparable with those observed in similar studies (Ventura *et al.*, 1999). The analysis of the radiation based models shows that the original parameter of $ET0_{MAK}$ worked quite well for the study area, whereas the value of α=1.26 proposed for the original Priestley-Taylor equation was found to be too high, so that a new value of α=1.09 was determined. Moreover, using locally determined parameter values, all the examined models give acceptable estimates of hourly potential.

Figure 1 shows the plots of $ET0_{P\&M}$, $ET0_s$, $ET0_{MAK}$, and recalibrated $ET0_{P\&T}$ versus ET_{SAS}. Except for a few outliers, observed for high *ET0* values model, a good distribution around the 1:1 line was observed.

Conclusions

Empirical models for calculating ET0 were evaluated in Sicily using micrometeorological data obtained with a Scintillometer. The Penman-Monteith method recommended by FAO (Allen *et al.*, 1998) and by ASCE-EWRI (Allen *et al.*, 2005) gave the best performance at both hourly and daily time scale. Priestley-Taylor model was calibrated with Scintillometer data to determine the best parameter (value of the constant) for the study area. Better performance of Priestley-Taylor model can be obtained when a value of α=1.09 is considered in place of the original α=1.26 proposed by the Authors.

Bibliografia

Allen, R.G., Periera, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration: Guidelines for Computing Crop Requirements, Irrigation and Drainage Paper No. 56. FAO, Rome, Italy, p. 300.

Allen R. G., Walter I., Elliot R., Howell T. 2005. The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers.

De Bruin, H.A.R., Meijninger, W.M.L., Smedman, A.-S., Magnusson. 2002. Displaced-beam small aperture scintillometer test. Part I: the WINTEX data-set. Boundary-Layer Meteorol. 105 (1), 129–148.

Makkink, G. F. 1957. Testing the Penman Formula by Means of Lysimeters. J. Instit. Water Engineers 11, 277–288.

Meek David W., Howell Terry A., and Phene Claude J.. 2009. Concordance Correlation for Model Performance Assessment: An Example with Reference Evapotranspiration Observations. Agronomy Journal 101:1012–1018.

Priestley, C. H. B. and Taylor, R. J. 1972. On the Assessment of the Surface heat Flux and Evaporation using Large-scale Parameters, Monthly Weather Review 100, 81–92.

Rallo G., Agnese C., Minacapilli M., Blanda F., Provenzano G. 2009. Capitolo 4. Applicazione, a scala aziendale, dei modelli di bilancio idrico FAO 56 e SWAP: validazione, confronto e possibilità applicative. In: Agnese *et al.*, 2009. *Sviluppi recenti e nuove tecnologie per la stima dei fabbisogni irrigui in ambiente mediterraneo.* Ed. Anteprima, ISBN 978-88-6305-002-8.

Ventura F., Spano D., Duce P., Snyder R. L. 1999. An evaluation of common evapotranspiration equations. Irrigation Science, 18: 163–170.