A method of calibration and variance analysis with respect to the Penman-Monteith equation for the Turc, Hargreaves and Abtew potential evapotranspiration models

Authors: Martin Goodchild, Tony Peloe, Karl Kühn

Introduction: The full ASCE/FAO-56 Penman-Monteith evapotranspiration (PM-ET) equation and crop coefficients are often employed for irrigation scheduling of open-field crops. To obtain PM-ET derived water-use figures requires access to full weather station datasets, which includes radiation, air temperature, wind-speed, and relative humidity measurements.

Over the years there have been many studies aiming to create (and evaluate) simpler models with fewer measurements that are easier to use and less costly to implement than a full weather station facility. In this paper we have focussed on the Turc, Hargreaves and Abtew models which employ daily averages of: solar radiation, air temperature and relative humid to determine daily ET.

Daily PM-ET values were obtained from a WS-GP2 weather station located at the Quinta de São Pedro study centre on the Setúbal peninsula in Portugal. The WS-GP2 is based around the programmable GP2 Data Logger and Controller, whose software (controlled by a script editor) can create step by step operations to control complex processes or recording requirements.

The Turc, Hargreaves and Abtew models were integrated into the WS-GP2 (using the GP2's script editor) enabling direct daily comparisons with PM-ET values. Daily average values of: solar radiation, air temperature and relative humidity were recorded for model recalibration purposes. Data was collected over 12-months from May 2018. Dataset comparisons between the Turc, Hargreaves and Abtew models and the PM-ET equation indicated that all three potential ET models overestimated ET and benefitted from recalibration. In each case the Bland-Altman method of variance analysis was applied, resulting in the following 2-sigma confidence level accuracies against PM-ET of: Turc ± 0.43 mm/day, Hargreaves ± 0.46 mm/day, and Abtew ± 0.88 mm/day.

For the Abtew and Turc models, recalibration consisted of the application of an offset whilst retaining the originally published coefficients, the Hargreaves model required adjustment to one of the two published coefficients. Following recalibration, the comparison of ET from the Turc and Hargreaves models follows a 1:1 relationship.
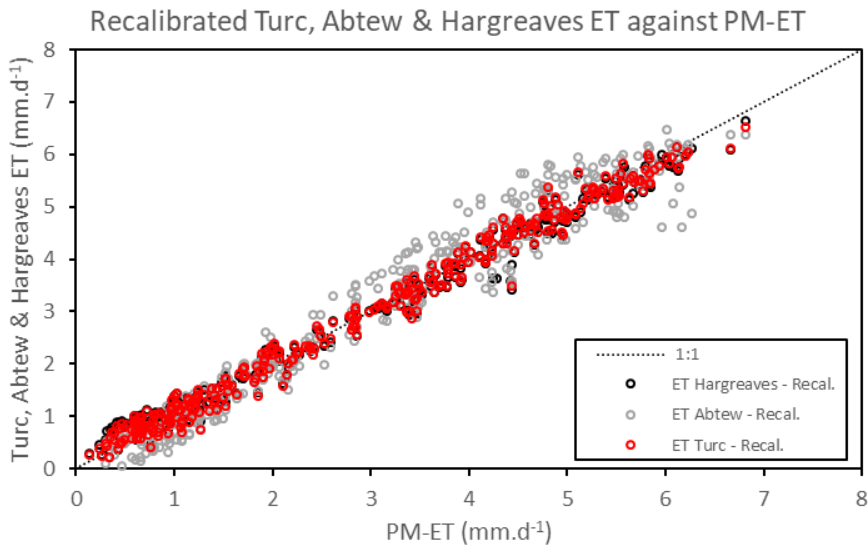
The Portugal Site
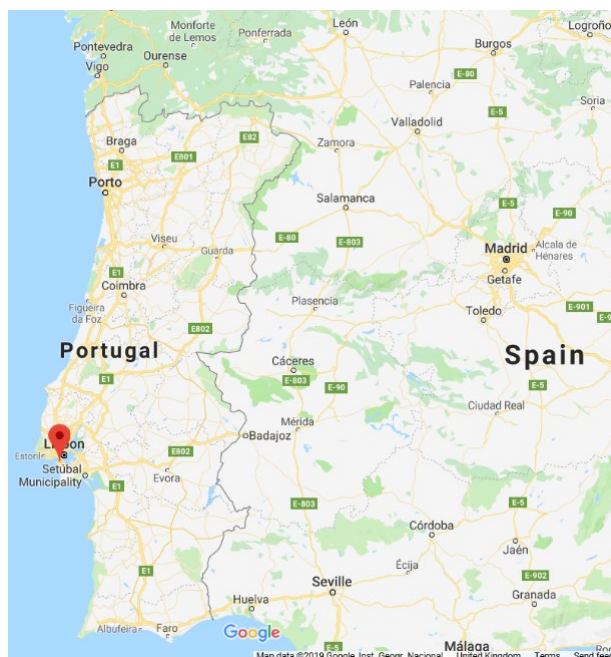
Key Data and Results

Comparison of the three models against PM-ET, using published co-efficients, following recalibration
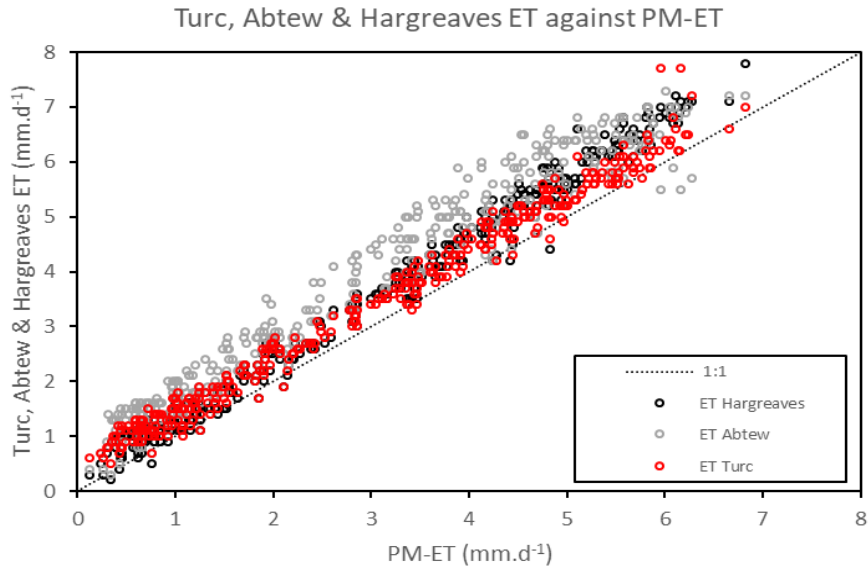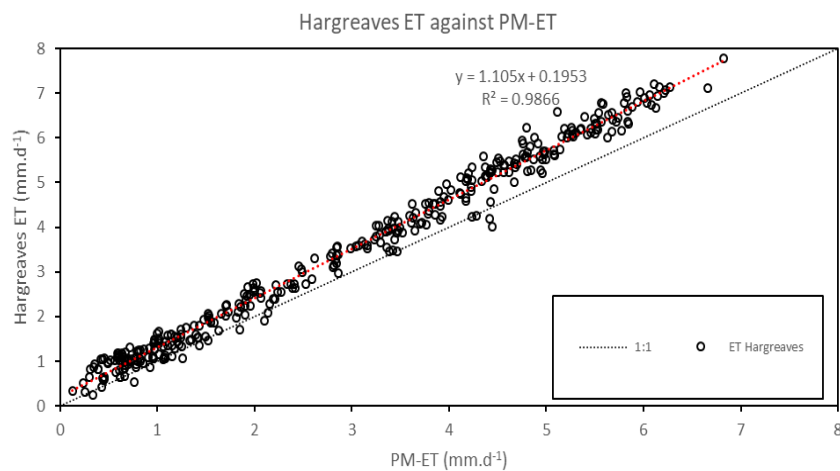

Comparison of Turc, Abtew & Hargreaves model against PM-ET (using the published coefficients).
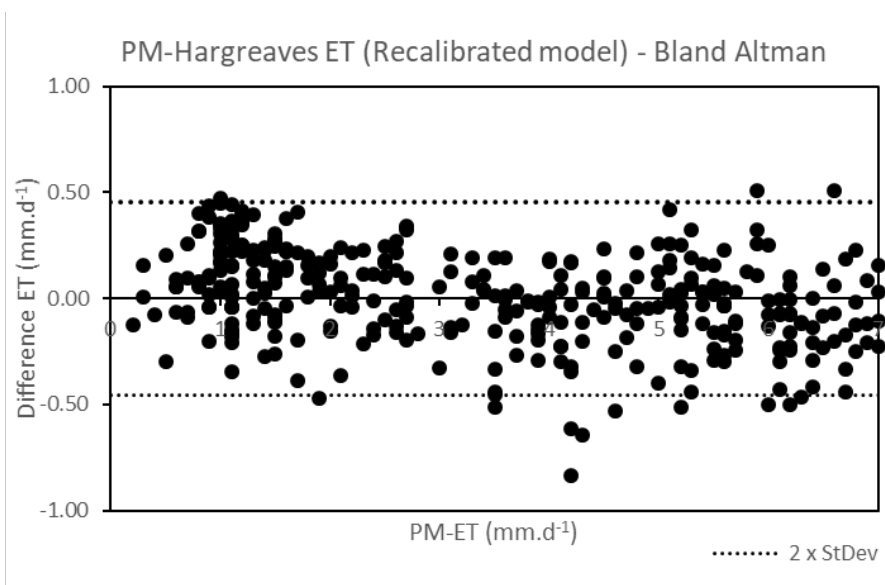

Comparison of Turc, Abtew & Hargreaves models against PM-ET following model recalibration.
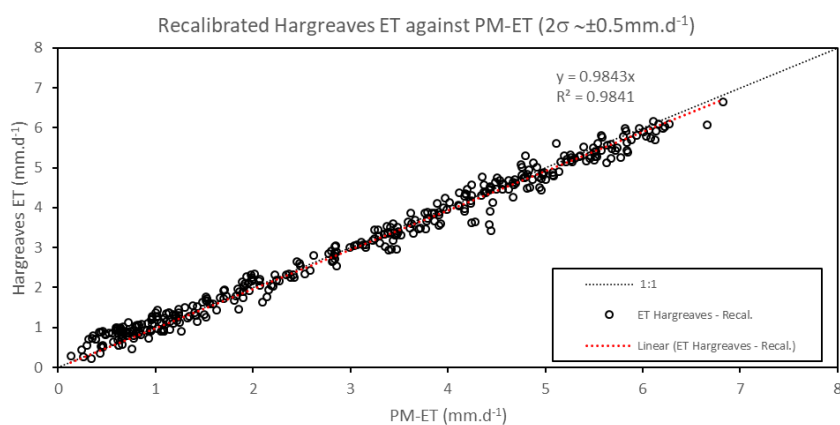
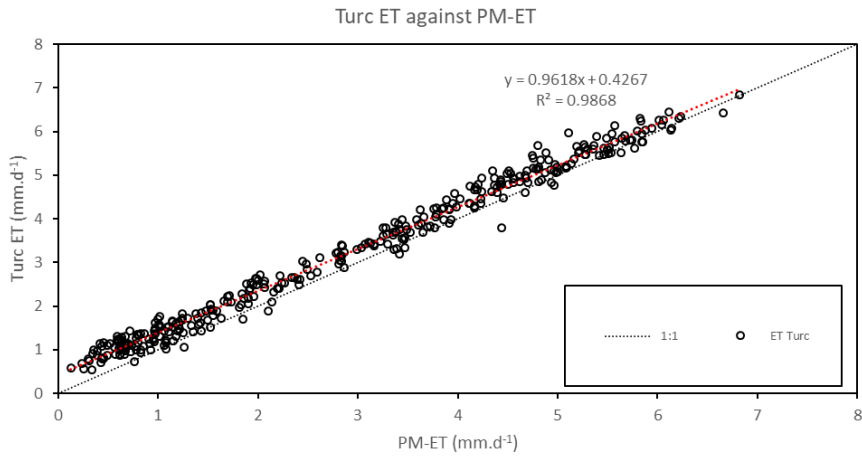# Recalibration & variance analysis of the Turc, Abtew & Hargreaves models

Comparison of the Hargreaves model against PM-ET (using the published coefficients).
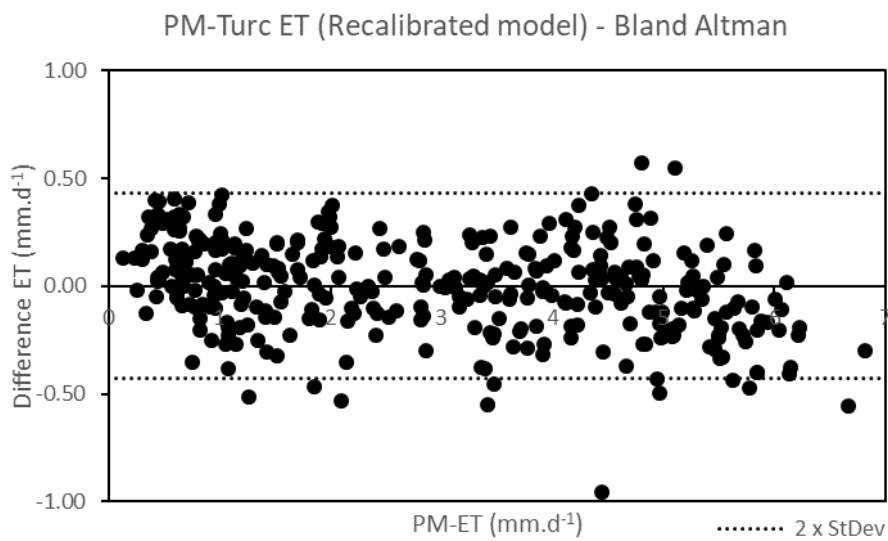

Variance analysis of the recalibrated Hargreaves model with respect to PM-ET, using the Bland-Altman method and a 2-sigma confidence level.

Comparison of the recalibrated Hargreaves model against PM-ET.

Turc ET against PM-ET

$$y = 0.9618x + 0.4267$$
$$R^2 = 0.9868$$

Comparison of the Turc model against PM-ET (using the published coefficients).

.

PM-Turc ET (Recalibrated model) - Bland Altman

Variance analysis of the recalibrated Turc model with respect to PM-ET, using the Bland-Altman method and a 2-sigma confidence level.

Turc ET against PM-ET - with offset (2σ ~±0.5mm.d^{-1})

$$y = 0.9618x + 0.1117$$
$$R^2 = 0.9868$$

Comparison of the recalibrated Turc model against PM-ET.

Abtew against PM-ET

$y = 1.0369x + 0.7279$
$R^2 = 0.9514$
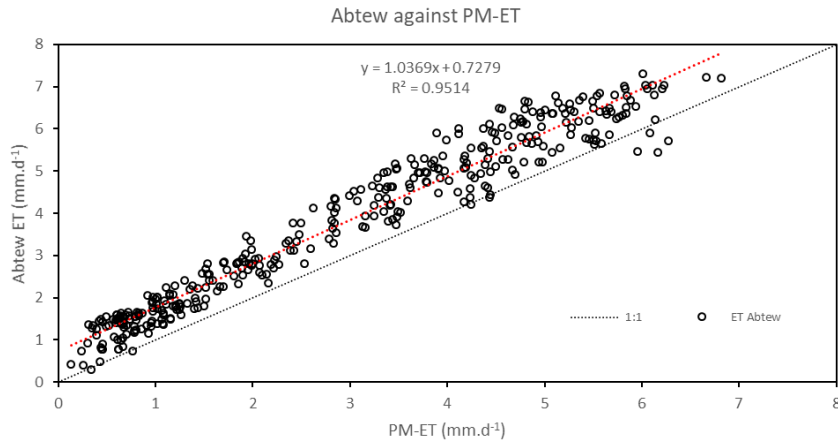
Comparison of the Abtew model against PM-ET (using the published coefficients).

.

PM-Abtew ET (Recalibrated model) - Bland Altman

Variance analysis of the recalibrated Abtew model with respect to PM-ET, using the Bland-Altman method and a 2-sigma confidence level.

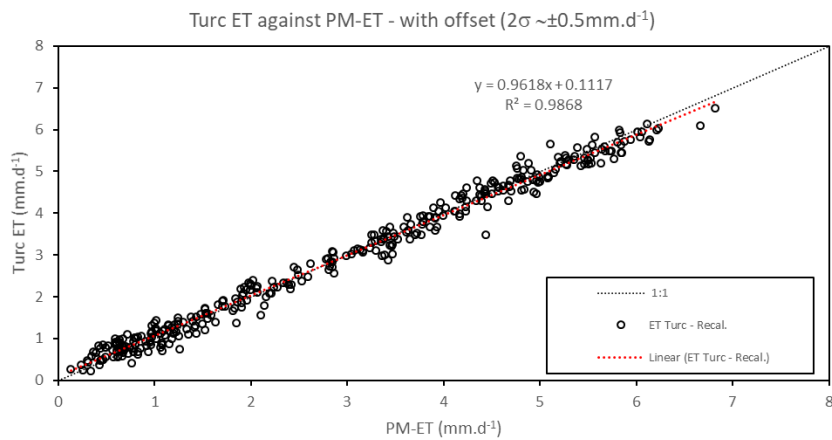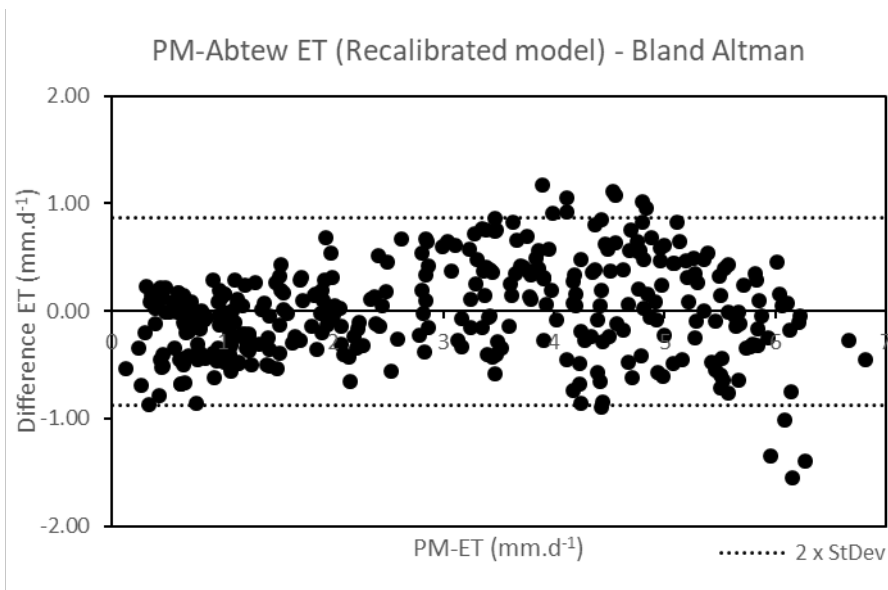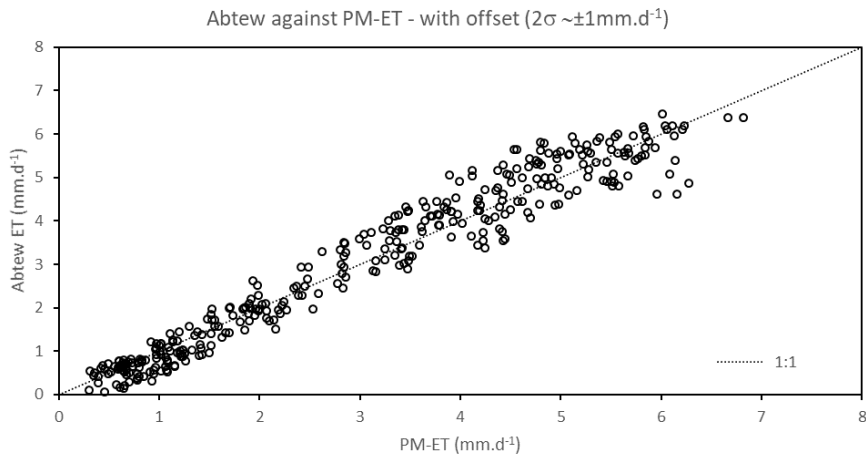Abtew against PM-ET - with offset (2σ ~±1mm.d⁻¹)

Comparison of the recalibrated Abtew model against PM-ET.

Validation of recalibrated Turc & Hargreaves models

Hargreaves against Turc ET (Published models)

$$y = 1.1506x - 0.2933$$
$$R^2 = 0.9989$$

1:1

Hargreaves ET (mm.d⁻¹) vs Turc (mm.d⁻¹)

Hargreaves against Turc ET (Recalibrated models)

$$y = 0.9826x + 0.059$$
$$R^2 = 0.9989$$

1:1

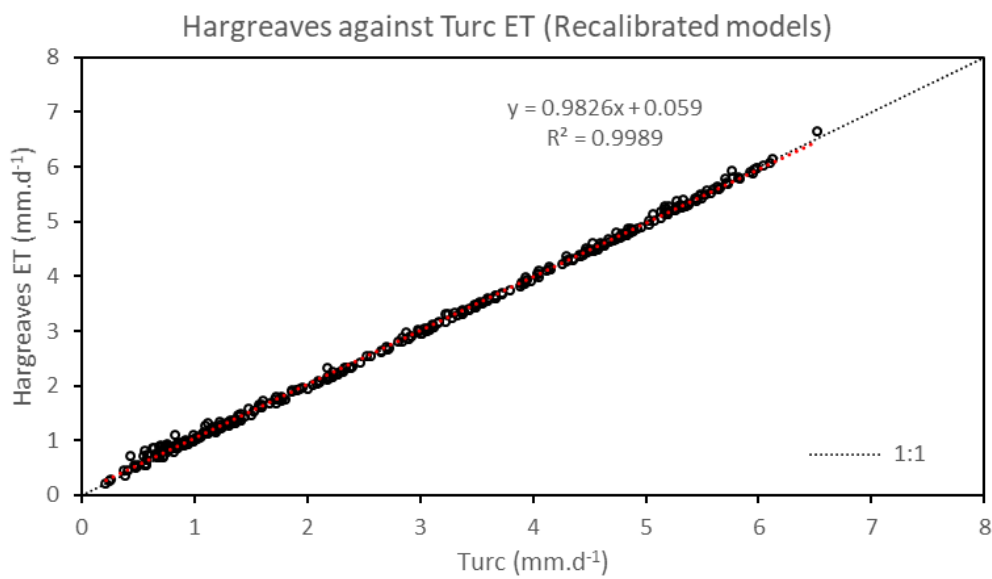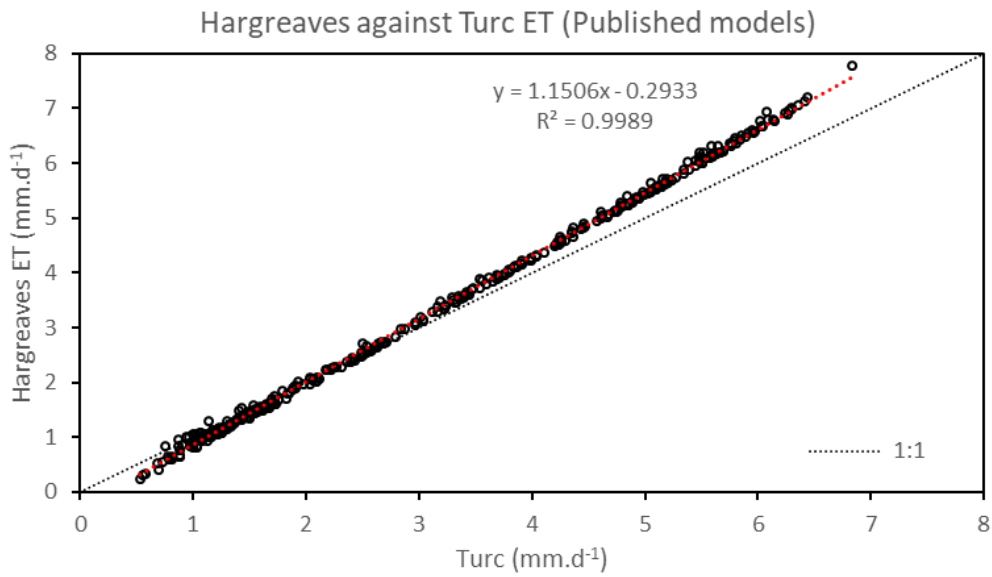Hargreaves ET (mm.d⁻¹) vs Turc (mm.d⁻¹)

Table of *as-published* and recalibrated co-efficients

Comparing Hargreaves with Turc ET data using published coefficients and following recalibration.

Model	Published 'a'	Published 'b'	Recalibrated 'a'	Recalibrated 'b'
Abtew	0.53	-	0.53	-0.835 mm/d Offset
Turc	0.013	-	0.013	-0.315 mm/d Offset
Hargreaves	0.0135	17.8	0.01153	17.8

Conclusions

- By employing the GP2 Data Logger's script editor (part of the WS-GP2 Weather Station) three models (Abtew, Hargreaves and Turc – RH% > 50% only) were evaluated using the published coefficients and each one was found to overestimate PM-ET at our test site on the Setúbal peninsula in Portugal during a 12-month period.
- Following recalibration, employing the Bland-Altman method:
    - the Abtew and Turc models required offsets,
    - the Hargreaves model required an adjustment to one of the coefficients.
- The recalibrated models achieved the following 2-sigma confidence level accuracies with respect to PM-ET of:
    - Turc ± 0.43 mm/day,
    - Hargreaves ± 0.46 mm/day, and,
    - Abtew ± 0.88 mm/day.
- The recalibrated Turc and Hargreaves models have a near 1:1 relationship.
- Given the relatively small accuracy difference between the recalibrated Turc and Hargreaves models, we recommend the Hargreaves as relative humidity data is not required.
- If model recalibration is not an option then the Turc model may be considered as the preferred option of the 3 models considered here, however, offset and variance error contributions should be considered as 0.315 mm/day & ± 0.43 mm/day respectively.
- The methodology described in this paper could be applied to other reduced measurement ET models, however, the accuracy figures derived for this site in Portugal could be indicative of the errors associated with reduced measurement ET models following recalibration.
- These relative accuracies should help with the selection of the most appropriate model and selection of measurement instrumentation required for a specific application.

References and further reading

- Abtew, W., (1996), Evapotranspiration measurement and modelling for three wetland systems in South Florida. Water Resources Bulletin, 32: 465-473
- Allen, R.G., Pereira, L.S., Raes, D., & Smith, M., (1998), Crop evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56
- Bland, J.M. & Altman, D.G., (1986), Statistical method for assessing agreement between two methods of clinical measurement. Lancet 1986; 327, 307-10 http://dx.doi.org/10.1016/S0140-6736(86)90837-8
- Hargreaves, G.H., (1975), Moisture availability and crop production. Transactions of the ASAE 18: 980-984.
- Irmak S., Allen R. G. & Whitty E.B., (2003), Daily grass and Alfalfa-reference evapotranspiration estimates and Alfalfa-to-grass evapotranspiration ratios in Florida. J. Irrg. Drain Eng., 129(5), 360-370
- Turc, L., (1961), Estimation of irrigation water requirements, potential evapotranspiration: a simple climatic formula evolved up to date. Annals of Agronomy 12: 13-49
- Xu C.-Y. & Singh V.P., (2000), Evaluation and generalization of radiation-based methods for calculating evaporation, Hydrol. Process. 14, 339-349
- Xystrakis F. & Matzarakis A., (2011), Evaluation of 13 Empirical Reference Potential Evapotranspiration Equations on the Island of Crete in Southern Greece. J. Irrg. Drain Eng., 137(4), 211-222

Quinta de São Pedro

Sobreda - Portugal

www.quintasaopedro.pt

AT

Delta-T Devices