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Estimation of potential evapotranspiration with minimal data dependence

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1. Abstract

We develop a parametric expression which approximates the Penman-Monteith equation thus providing easy estimation of the potential evapotranspiration with minimal data requirements. Namely, the method requires as inputs the mean temperature and the extraterrestrial radiation, from which only the temperature needs to be measured. The model was applied on a monthly step in 37 meteorological stations of Greece for the period 1968-1983 (calibration period) and 1984-1989 (validation period). The results are satisfactory as the efficiency is greater than 0.97 for all stations and for both calibration and validation periods. Initially, the parametric expression involves three parameters but regional analysis indicates that reduction to one or two parameters is possible and does not increase the error substantially. Using optimization and geographic interpolation through a geographical information system, the parameters were mapped for the entire territory of Greece, which makes the method directly applicable to any site in the country, the only requirement being that mean temperature data be available.

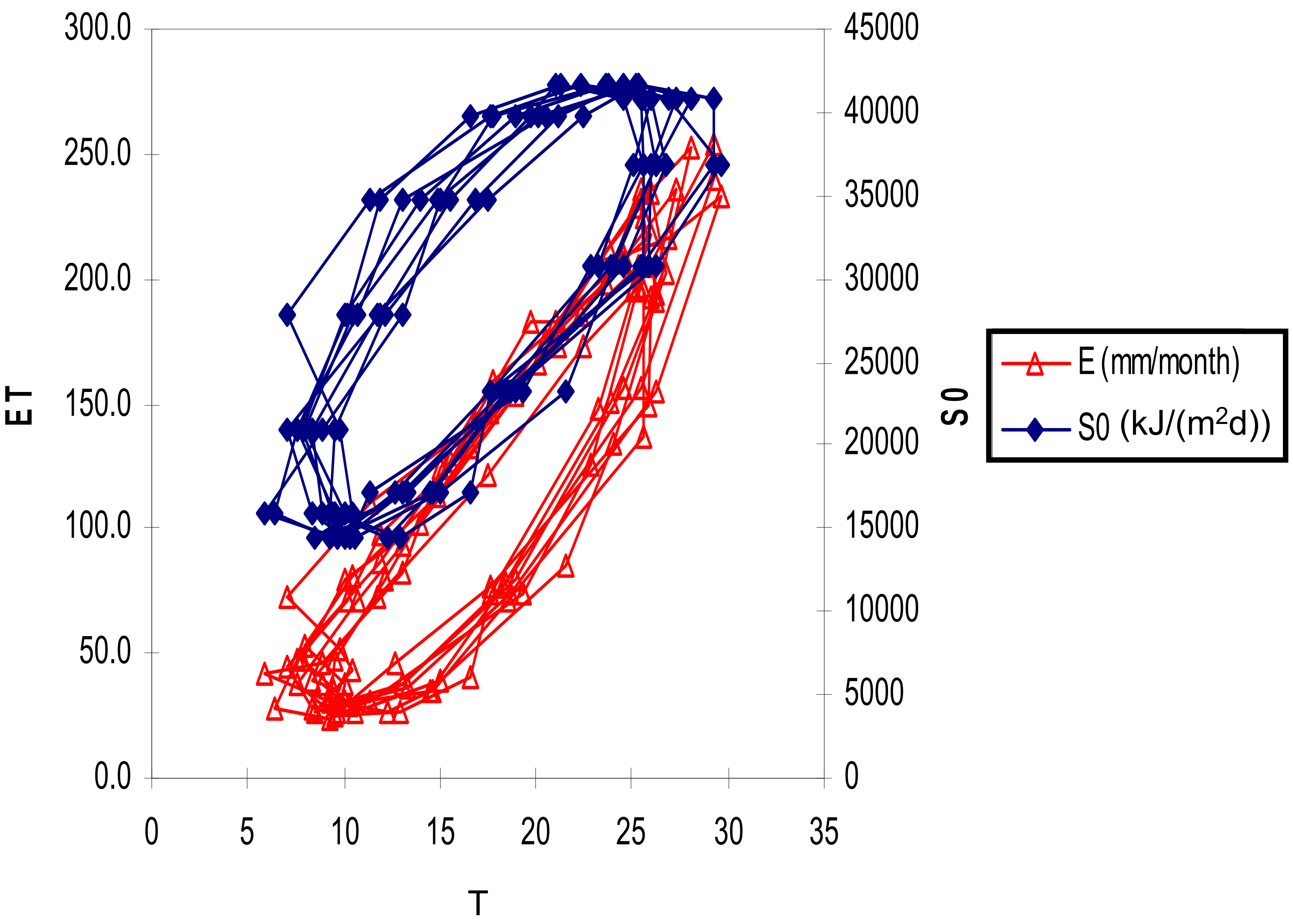
2. Quantification of evapotranspiration

- The estimation of evaporation is necessary for water budget estimation, hydrologic modelling, climatic studies, assessment of environmental impacts, reservoir modelling and management, crop water requirements.
- It is the major component of water losses. According to Sheckler et al. (1998) about 60% of the precipitation on the earth's surface returns back into the atmosphere.
- Despite of its importance in water resources engineering and management, evapotranspiration is one of the most difficult parameters to measure in field, unlike the other components of hydrological cycle (rainfall, streamflow).
- The first study to determine the water requirements for irrigation started at 1890 in Colorado, Utah and Wyoming (Jensen and Haise,1963).
- Today, around 50 methods for the quantitative estimation of evapotranspiration have been developed (Jianbiao *et al.*, 2005).

3. Review of principles and models for evapotranspiration estimation

- Classical combination method (Penman, Penman-Monteith), which combines the energy balance and aerodynamic approaches.
- Simplification of combination method (Priestley- Taylor, Linacre).
- Empirical methods which rely on observations and correlation with temperature data such as the methods by Blaney-Criddle, Hargreaves, Thornthwaite.
- Models which use the temperature and extraterrestrial radiation as entry data such as the models by Oudin *et al.* (2004), McGuiness and Bordne (1972), and Jensen and Haise (1963).
- Models that make use of hydrological models calibration results (e.g. Oudin *et al.*, 2004).
- Models based on remotely sensed data, including satellite-derived feedbacks, biophysical processes and energy balance techniques (e.g. Tsouni *et al.*, 2008).

4. Correlation between temperature, extraterrestrial radiation and evapotranspiration



Monthly extraterrestrial radiation (S_0) and potential evapotranspiration (ET) vs. temperature (*T*) for two years at the Agrinio station.

Observations from figure:

- The loops S_0-T and ET-T have a similar shape.
- Thermal inertia has an important influence on evapotranspiration.
- The estimation of potential evapotranspiration requires at least two separate variables: the temperature and the extraterrestrial radiation.

5. The parametric expression of the new model

- Main idea: fitting of a new parametric form to a calculated Penman – Monteith time series and derivation of a new simplified expression.
- Replacement of the energy term of the Penman – Monteith formula with a term expressing the extraterrestrial radiation.
- Denominator of Penman – Monteith equation: a decreasing function of temperature almost linearly.
- Result: a first parametric expression with three independent parameters.
- Parameter estimation: least squares.
- Sensitivity analysis of parameters and optimization techniques to reduce the number of parameters.

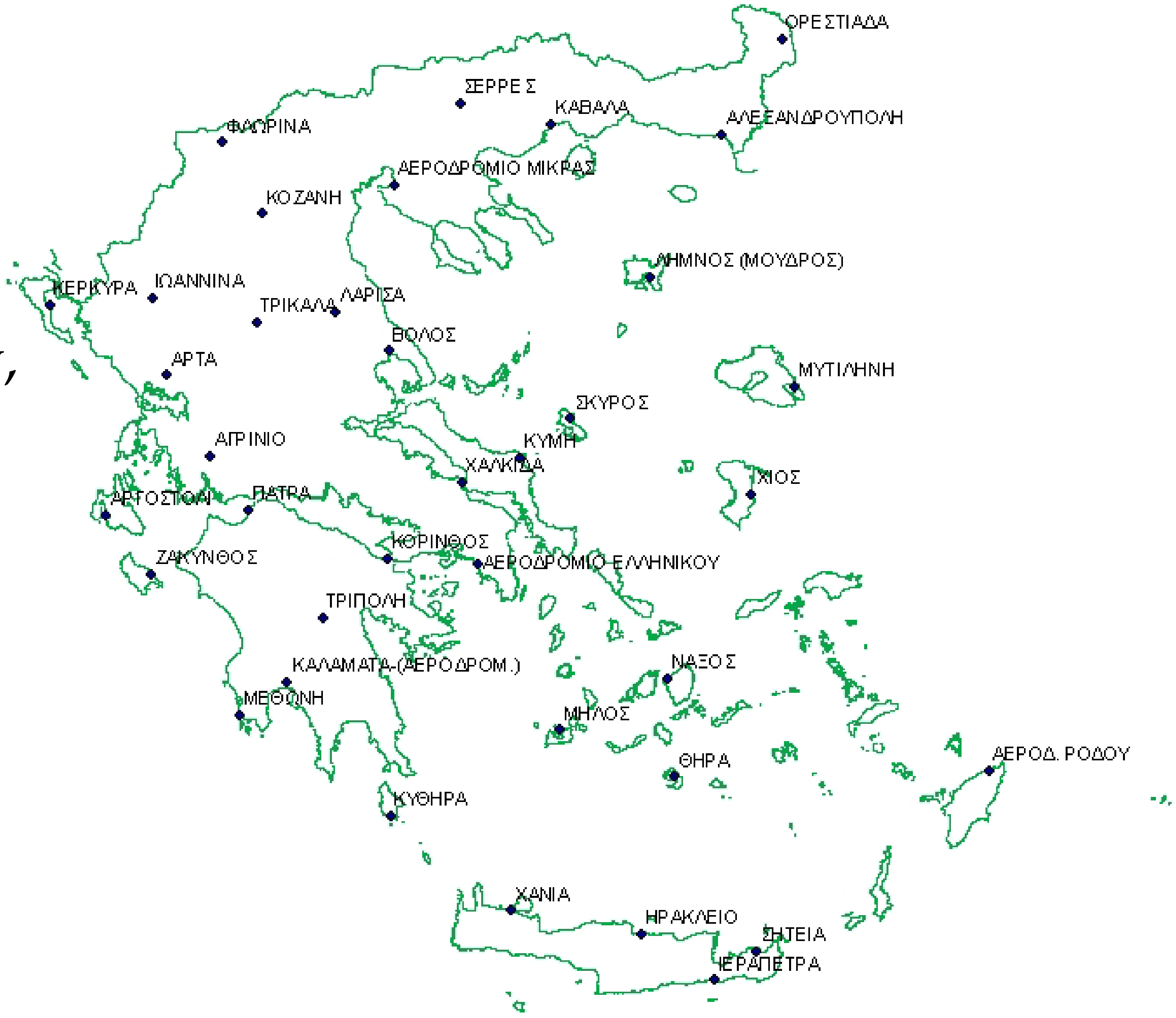
$$PE = \frac{R_n + \gamma F(u) D}{1 + \frac{\gamma}{\Delta}}$$

↓

$$PE = \frac{aS_0 - b}{1 - cT_a}$$

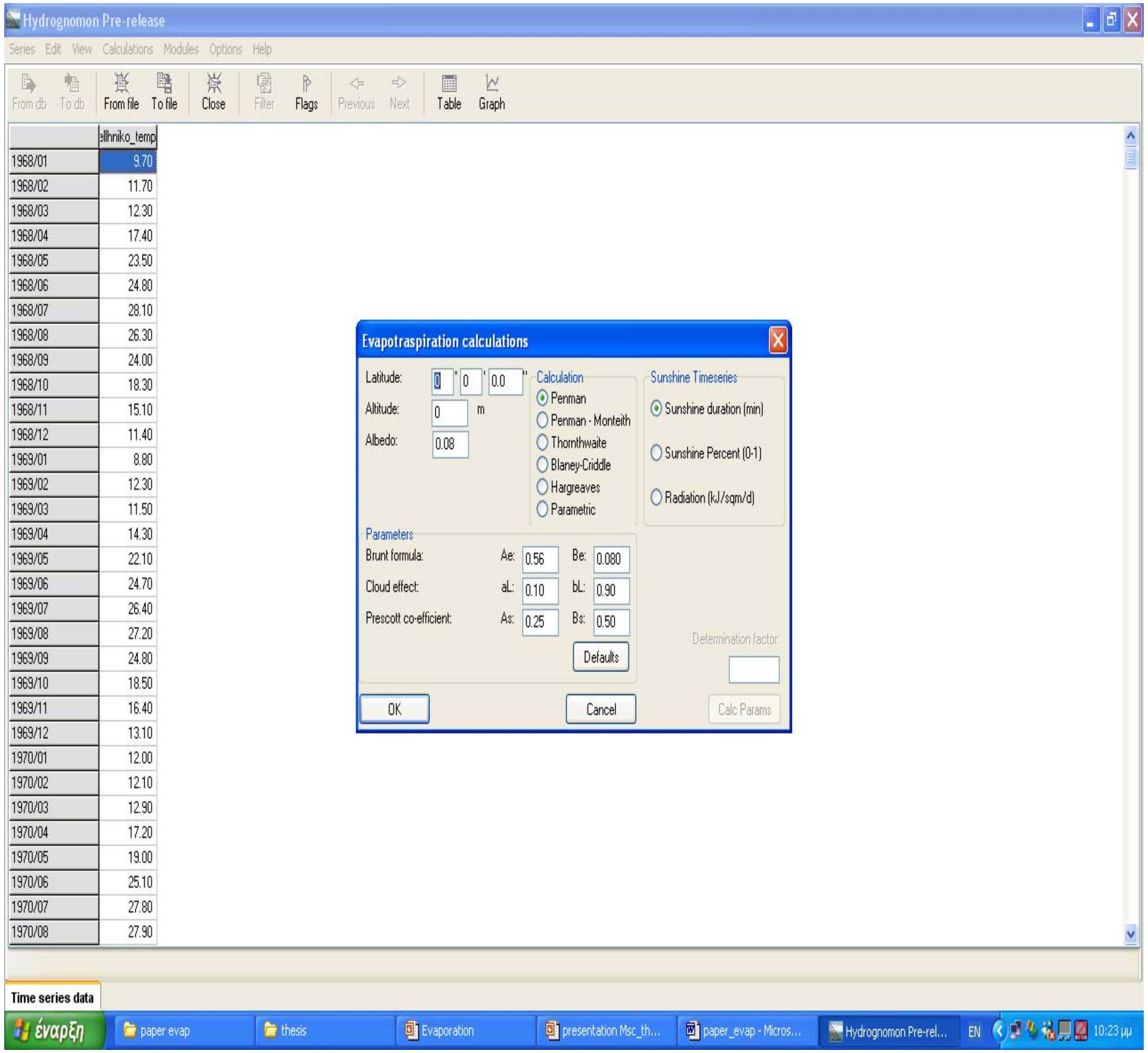
6. Study area and data

- Collection of monthly data of 37 stations around Greece (Hellenic National Meteorological Service)
- Use of monthly time series of temperature, relative humidity, sunshine duration and wind velocity.
- Two working periods, calibration (1968-1973) and validation (1984-1989) where the prediction skill of the new parametric model was tested.
- Use of «HYDROGNOMON» software for automated calculation and processing (Kozanis *et al.*, 2005).



7. Procedures

- Creation of a local data base with monthly hydrometeorological time series.
- Automated calculation of each station's potential evapotranspiration (Penman-Monteith) and of the parametric estimate for the first period.
- Estimation of the three parameters by optimizing the coefficient of efficiency for the calibration period.
- Calculation of the coefficient of efficiency for the validation period and testing of the model forecast skill.



- Use of nonlinear optimization techniques to reduce the parameters of the initial form.
- Production of another two more simplified forms with two or one parameters—but with small reduction of efficiency (2%).

8. Results and comparisons

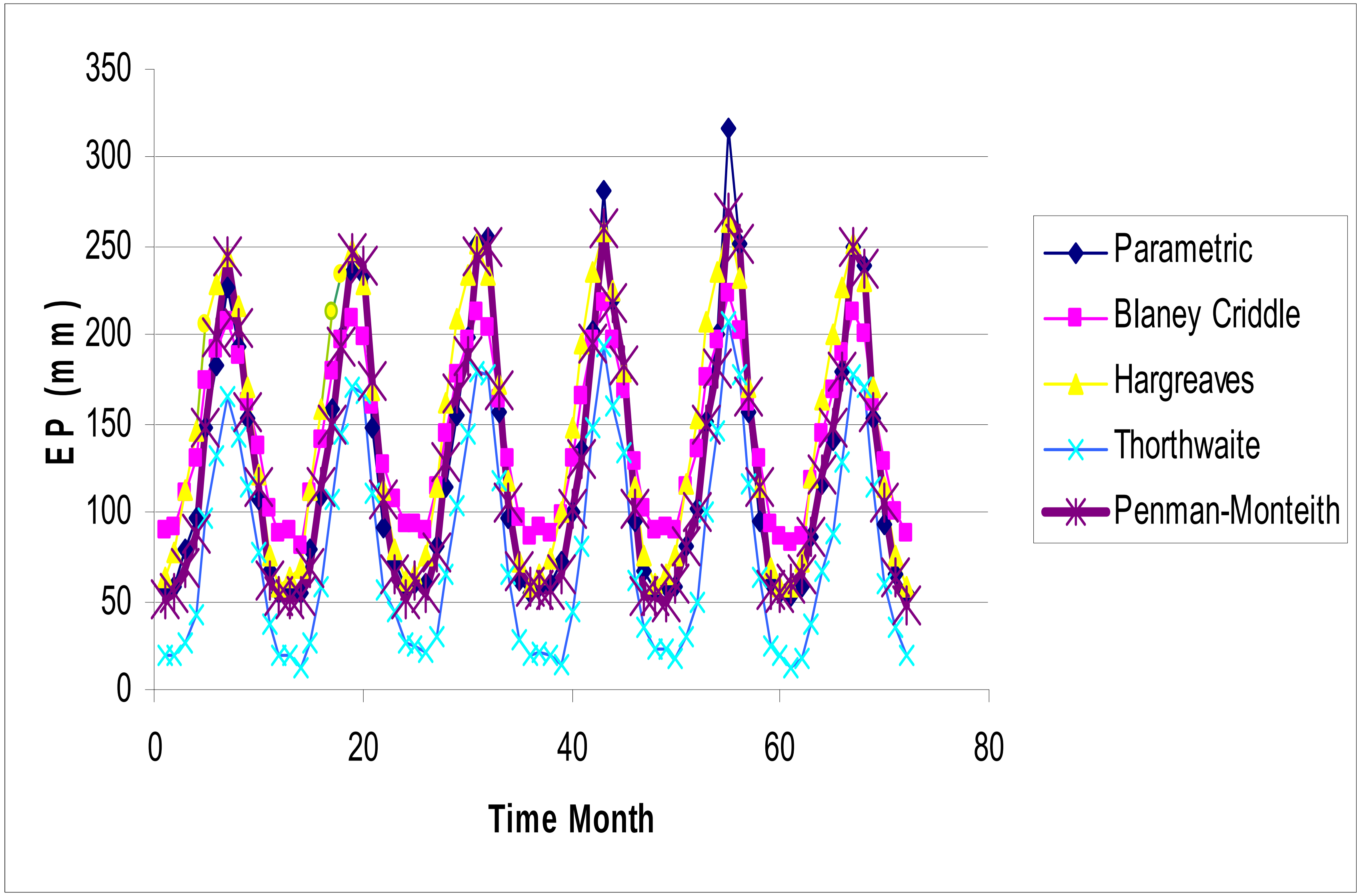
- The parametric method is compared with Oudin *et al.*, and McGuinness and Bordne equations, which are both based on extraterrestrial radiation.
- The Penman- Monteith time series is taken as reference series and the coefficient of efficiency (CE) is taken as a performance index.
- The parametric expression yields excellent CE for all stations for and for both periods.
- There are substantial differences with the other two methods.

	Parametric		Oudin et al.		Mcguiness & Bordne	
Station	**CE(cal)**	**CE(val)**	**CE(cal)**	**CE(val)**	**CE(cal)**	**CE(val)**
Limnos	96.40%	97.10%	53%	62.70%	73.80%	94.30%
Chania	97.30%	96.30%	81.90%	82.40%	59.70%	76.60%
Chalkis	95%	95.30%	91%	81.90%	59.90%	84.10%
Florina	96.70%	96.00%	95.30%	94.10%	64.30%	71.70%
Tripoli	94.20%	95.00%	84.80%	80.60%	85.70%	91.50%
Trikala	97.30%	97.00%	94.30%	92.30%	66.80%	76.40%
Skiros	92.60%	91.00%	72.50%	70.20%	76.30%	77.60%
Sitia	98.50%	99.00%	61.10%	66.80%	92.30%	89.40%
Serres	98.20%	97.00%	97.20%	93.40%	50.10%	74%
Rhodes	97.20%	97.00%	55.20%	53.80%	93.50%	95%
Patra	98.70%	96.00%	90.40%	90.70%	60.80%	59.50%
Orestiada	98.10%	97.00%	93.60%	90.40%	68.30%	72.40%
Naxos	97.50%	98%	45.50%	43.90%	80.30%	85.70%
Mitilini	98.80%	97.00%	52.50%	73.80%	94.90%	81.50%
Milos	97.20%	98%	53.60%	48.40%	92.60%	94.10%
Methoni	96.20%	97.00%	76.70%	74.20%	59.40%	62.58%
Larisa	98.70%	98.00%	95.20%	94%	62.30%	71.00%
Kimi	97.50%	91.00%	69.80%	60.90%	92.20%	95.60%
Kithira	95.70%	97.00%	41.70%	50.40%	92.30%	93.50%

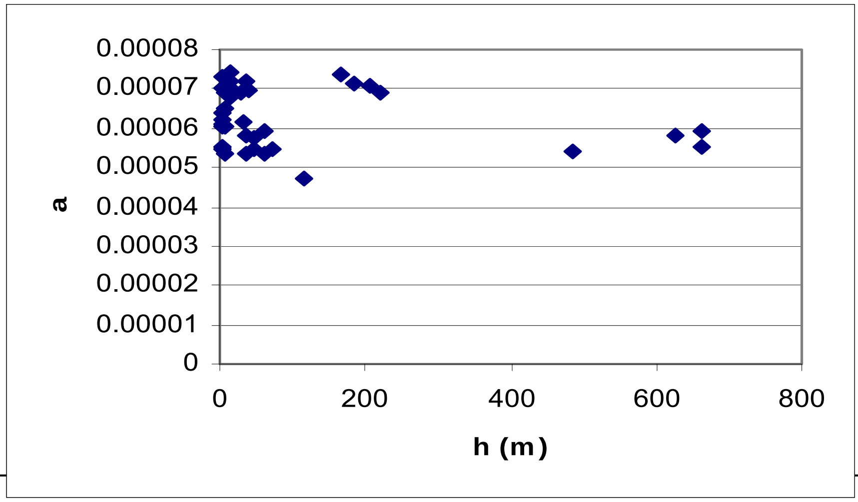
9. Results and comparison with temperature- based and empirical methods

Comparison of potential evapotranspiration for the meteorological station Elliniko (near Athens) produced by the parametric method as well as by the Hargreaves, Thornthwaite, and Blaney-Criddle methods (for the first period) indicates that:

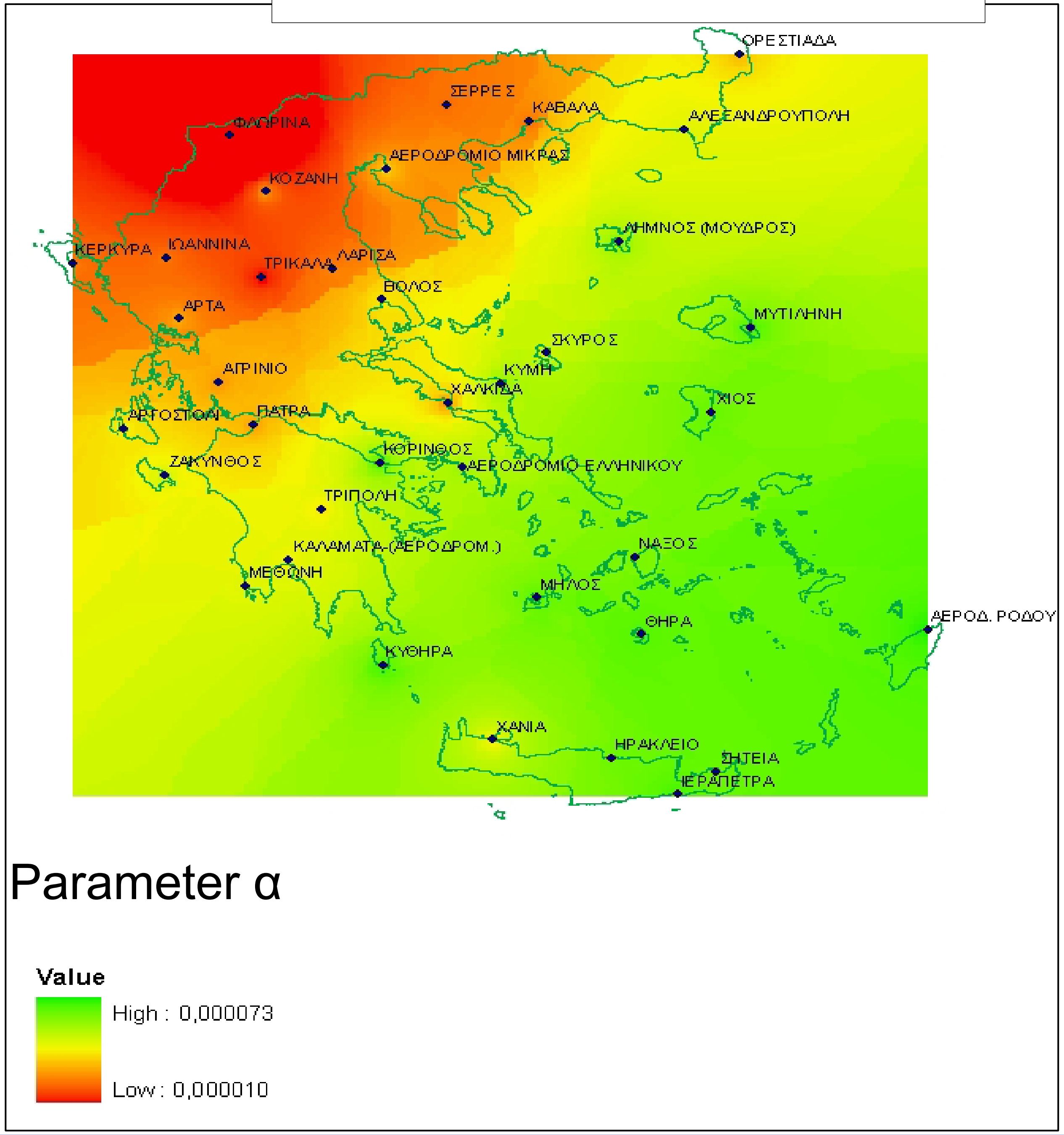
- There are substantial differences among the four methods.
- The three simplified models substantially underestimate the monthly PE.
- The worst results are given by the Thornthwaite (CE = 47.9%) and Blaney – Criddle (CE = 79.6%) methods, which are often used in Greece.
- The Hargreaves method, which uses the extraterrestrial radiation as entry data, gives better results (CE = 84.4%).



10. Mapping of the parameters



- We examined the influence of the elevation of each station on the value of the parameters. We concluded that:
  - There is no correlation between the parameters and the elevation.
  - There is no need for complex geographical interpolation methods (e.g. co-Kriging).
- We used the Inverse Distance Weight (IDW) method for the geographical interpolation of parameters.
- The map shows the variation of the single parameter version of the parametric relationship, where $b = 0$ and c has a constant value over the entire Greece.
- We observe that the results are physically meaningful: The values of the parameter α increase from northwest to southeast (insular Greece, where considerable wind velocities appear).



11. Conclusions

- A new parsimonious model for simple estimation of potential evapotranspiration has been developed.
- This simple method keeps the advantages of combination methods (Penman-Monteith) while reduces the hydrometeorological data requirements for its application.
- The method provides an excellent approximation of the Penman- Monteith time series and has better performance than other similar models, as well as than empirical, temperature-based methods.
- The method parameters seem to be physically meaningful.
- A minimalist model with only one parameter that varies geographically was developed for Greece, which is applicable to all sites in the country. The only data requirement is a temperature time series.
- The method might be useful for countries without an advanced infrastructure of hydrometeorological networks.

12. References

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