Article

Potential evapotranspiration of managed grasslands - a climate change lysimeter study

Matevž LVremec [1,†,‡], Veronika Forstner [1,,†‡] and Steffen Birk [2,†,*]

[1] Affiliation 1; matevz.vremec@uni-graz.at
[2] Affiliation 2; e-mail@e-mail.com
* Correspondence: matevz.vremec@uni-graz.at
† Current address: Heinrich Strasse 26, Instutue for Earth Sciences, University of Graz
‡ These authors contributed equally to this work.

Version December 6, 2019 submitted to Hydrology

Abstract:
1. Evaluate default PET models
2. Evaluate calibrated PET models
3. Sensitivity analysis and model uncertainty of calibrated PET models
4. Implication of elevated CO_2 in PET models
5. Implication of warming in PET models
6. Combined effect of warming and elevated CO_2 in PET models
7. Evaluation, Sensitivity analysis and model uncertainty of calibrated PET models
[1], [2], [3], [4], [5], [6], [7]
8. Conclusion

Keywords: keyword 1; keyword 2; keyword 3 (list three to ten pertinent keywords specific to the article, yet reasonably common within the subject discipline.)

0. How to Use this Template

The template details the sections that can be used in a manuscript. Note that the order and names of article sections may differ from the requirements of the journal (e.g., the positioning of the Materials and Methods section). Please check the instructions for authors page of the journal to verify the correct order and names. For any questions, please contact the editorial office of the journal or support@mdpi.com. For LaTeX related questions please contact latex@mdpi.com.

1. Introduction

[8] - higher PET with managed grasslands and [9]

2. Evaluation of PET models(Materials and methos)

2.1. Previous research

Sensitivity to erros in potential evapotranspiration input [10] [11] and [12](z0 = 1 for meadow grass)(details of computation)(Blaney-Criddle-only mean T, Jensen-Hasie [13]-solar radiation with T) compared 9 PET methods using onsite meteo data (PEnman with empirical wind function applicable to a short grass with rougness coef of 1cm): [14]-sensitivty of PEnman

$$f(u) = 0.35 + 0.0035 * u_2 \quad (1)$$

23 Search for best PE formula [15], [16]

24 *2.2. Used PET models*

[16]

Priestley-Taylor [17]

$$E = \frac{\alpha}{\lambda}\frac{\Delta}{\Delta+\gamma}R_n \tag{2}$$

α = 1.26

Makink (default) [17] [18]

$$ET = \frac{1}{\lambda\rho}\left(\frac{0.63R_s\Delta}{\Delta+\gamma} - 14\right) \tag{3}$$

Blaney-Criddle [17]

$$ET = kp(0.46T_a + 8.13) \tag{4}$$

where p = percentage of total daytime hours for the used period (daily or monthly) out of total daytime hours of the year (365x12);k = monthly consumptive use coefficient, depending on vegetation type, location and season and for the growing season (May to October), k varies from 0.5 for orange tree to 1.2 for dense natural vegetation. Following the recommendation of Blaney and Criddle (1950)[19], in the first stage of the comparative study, values of 0.85 and 0.45 were used for the growing season (April to September) and the non-growing season (October toMarch), respectively.

Hargreaves [20][21][22]

$$ET = a(T_{max} - T_{min})^{0.5}(T_{mean} + 17.8)\frac{R_a}{\lambda\rho_w} \tag{5}$$

a=0.0023

Ra is average daily exoatmospheric radiation(extra terrestrial)

FAO PM for reference(potential) evapotranspiration [23]

$$ET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T_a+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{6}$$

Penman

$$E = \frac{1}{\lambda\rho_w}\frac{\Delta(R_n - G) + K_u\gamma(a_w + b_w u_2)(e_s - e_a)}{\Delta+\gamma} \tag{7}$$

where a_w and b_w are wind function coefficients that are usually receive a local or regional calibration. Parameter K_u =6.43 for ET in mmd^{-1} and K_u =0.268 for ET in mmhour^{-1}. Penman [24] used for clipped grass [17] a_w = 1.0 and b_w = 0.537, respectively,for wind speed in ms $^{-1}$, $es - ea$ in kPa and grass ETo in mmd^{-1}. The equations were intended for use with daily computations. In application of the 1963 Penman, saturation vapor pressure is traditionally based on mean daily air temperature rather than on Tmax and Tmin" [15].

Kimberley-Penman [17]

$$E = \frac{1}{\lambda\rho_w}\frac{\Delta(R_n - G) + K_u\gamma(a_w + b_w u_2)(e_s - e_a)}{\Delta+\gamma} \tag{8}$$

where:

$$a_w = 0.4 + 1.4exp - \left[\left(\frac{J - 173}{58} \right)^2 \right] \quad (9)$$

$$b_w = 0.605 + 0.345exp - \left[\left(\frac{J - 243}{80} \right)^2 \right] \quad (10)$$

Reference ET FAO with kc for grass

Jensen-Haise [17] - ET_r is alfalfa reference ET

$$ET_r = \frac{1}{\lambda} C_r (T - Tx) R_s \quad (11)$$

C_r and T_x should be constant for a given area... Later Jensen defined:

$$C_r = \frac{1}{C_1 + C_2 C_H} \quad (12)$$

$$C_H = \frac{5}{e_2 + e_1} \quad (13)$$

e2 and e1 are the saturation vapor pressures in kPa at the mean daily maximum and mean daily minimum temperatures, respectively, for the average warmest month of the year in an area, and C1 and C2 are constants (C2 = 13 degress F or 7.3 degrees C).

$$C_1 = 38 - (2Elev/305) \quad (14)$$

$$T_x = -2.5 - 1.4(e_2 - e_1) - Elev/550 \quad (15)$$

Penman-Monteith [17]

$$E = \frac{1}{\lambda} \frac{\Delta(R_n - G) + \rho_a c_p (e_s - e_a)/r_{ah}}{\left[\Delta + \gamma(1 + \frac{r_s}{r_{ah}}) \right]} \quad (16)$$

Oudin [25]

$$ET = \frac{R_e}{\lambda \rho} \frac{T_a + 5}{100}, if T_a + 5 > 0, else ET = 0 \quad (17)$$

Hamon [25]

$$ET = \left(\frac{DL}{12} \right)^2 exp \left(\frac{T_a}{16} \right) \quad (18)$$

3. Evaluation of PET models with original constant values

Priestley-Taylor Makkink Blaney-Criddle Hargreaves FAO-pm-reference Kimberley-Penman Jensen-Haise Penman-Monteith Penman Oudin Hamon FAO-pm-reference + crop coefficient

4. Evaluation of PET models with calibrated constant values

Priestley-Taylor

α

Makink to calibrate [17]

$$ET = f * \frac{1}{\lambda \rho} \left(\frac{0.63 R_s \Delta}{\Delta + \gamma} - 14 \right) \quad (19)$$

Blaney-Criddle
1. k
2. a, b Hargreaves
a
Kimberley-Penman = Penman
a, b
Jensen-Haise
Cr, tx
Penman-Monteith
rs, ra
Oudin
k1, k2
FAO-pm-reference + crop coefficient
crop coefficient(k_max)

5. Evaluation of PET models with original constant values/results

6. Evaluation of PET models with calibrated constant values/results

6.0.1. Inputs

R_n net longwave radiation

$$R_nl = f_{cd}(a_1 + b_1\sqrt{e_a})\sigma T^4 \tag{20}$$

if 24-hour or longer time steps...T^4 transforms to $(T^4_{max} - T^4_{min})/2$.
σ is for daily values 4.901 x 10^{-9} $\mathrm{MJm^{-2}d^{-1}K^{-4}}$ with Rnl in $\mathrm{MJm^{-2}d^{-1}}$
for hourly calculations σ = 2.042 x 10^{-10} MJm2 $\mathrm{h^{-1}K^{-4}}$, Rnl is in $\mathrm{MJm^{-2}\ h^{-1}}$.

Wright and Jensen [26] developed an expression for f_{cd}:

$$f_{cd} = a\frac{R_S}{R_{SO}} + b \tag{21}$$

a and b are empirical coefficients. General a= 1.3, b=0.3, a_1 = 0.39 and b_1=0.158

Bulleted lists look like this:

- First bullet
- Second bullet
- Third bullet

Numbered lists can be added as follows:

1. First item
2. Second item
3. Third item

The text continues here.

6.1. Figures, Tables and Schemes

All figures and tables should be cited in the main text as Figure 1, Table 1, etc.

Figure 1. This is a figure, Schemes follow the same formatting. If there are multiple panels, they should be listed as: (**a**) Description of what is contained in the first panel. (**b**) Description of what is contained in the second panel. Figures should be placed in the main text near to the first time they are cited. A caption on a single line should be centered.

Text

Text

Table 1. This is a table caption. Tables should be placed in the main text near to the first time they are cited.

Title 1	**Title 2**	**Title 3**
entry 1	data	data
entry 2	data	data

Text

Text

6.2. Formatting of Mathematical Components

This is an example of an equation:

$$a + b = c \tag{22}$$

Please punctuate equations as regular text. Theorem-type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

Theorem 1. *Example text of a theorem.*

The text continues here. Proofs must be formatted as follows:

Proof of Theorem 1. Text of the proof. Note that the phrase 'of Theorem 1' is optional if it is clear which theorem is being referred to. □

The text continues here.

7. Discussion

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

8. Materials and Methods

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

9. Conclusions

This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

10. Patents

This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing–original draft preparation, X.X.; writing–review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y.", please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

Funding: Please add: "This research received no external funding" or "This research was funded by NAME OF FUNDER grant number XXX." and and "The APC was funded by XXX". Check carefully that the details given are accurate and use the standard spelling of funding agency names at https://search.crossref.org/funding, any errors may affect your future funding.

Acknowledgments: In this section you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest." Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. Any role of the funders in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript, or in the decision to publish the results must be declared in this section. If there is no role, please state "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results".

Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	linear dichroism

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text. For example, explanations of experimental details that would disrupt the flow of the main text, but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data is shown in the main text can be added here if brief, or as Supplementary data. Mathematical proofs of results not central to the paper can be added as an appendix.

Appendix B

All appendix sections must be cited in the main text. In the appendixes, Figures, Tables, etc. should be labeled starting with 'A', e.g., Figure A1, Figure A2, etc.

1. White, J.T.; Fienen, M.N.; Doherty, J.E. A python framework for environmental model uncertainty analysis. *Environmental Modelling & Software* **2016**, *85*, 217–228.
2. Tennøe, S.; Halnes, G.; Einevoll, G.T. Uncertainpy: A Python toolbox for uncertainty quantification and sensitivity analysis in computational neuroscience. *Frontiers in neuroinformatics* **2018**, *12*.
3. Van Daele, T.; Van Hoey, S.; Nopens, I. pyIDEAS: an open source Python package for model analysis. In *Computer Aided Chemical Engineering*; Elsevier, 2015; Vol. 37, pp. 569–574.
4. Herman, J.D.; Usher, W. SALib: An open-source Python library for Sensitivity Analysis. *J. Open Source Software* **2017**, *2*, 97.
5. Pianosi, F.; Beven, K.; Freer, J.; Hall, J.W.; Rougier, J.; Stephenson, D.B.; Wagener, T. Sensitivity analysis of environmental models: A systematic review with practical workflow. *Environmental Modelling & Software* **2016**, *79*, 214–232.
6. Wiecki, T.V.; Sofer, I.; Frank, M.J. HDDM: Hierarchical Bayesian estimation of the drift-diffusion model in Python. *Frontiers in neuroinformatics* **2013**, *7*, 14.
7. Miranda, L.J.V.; others. PySwarms: a research toolkit for Particle Swarm Optimization in Python. *J. Open Source Software* **2018**, *3*, 433.
8. Obojes, N.; Bahn, M.; Tasser, E.; Walde, J.; Inauen, N.; Hiltbrunner, E.; Saccone, P.; Lochet, J.; Clément, J.C.; Lavorel, S.; others. Vegetation effects on the water balance of mountain grasslands depend on climatic conditions. *Ecohydrology* **2015**, *8*, 552–569.
9. Leitinger, G.; Ruggenthaler, R.; Hammerle, A.; Lavorel, S.; Schirpke, U.; Clement, J.C.; Lamarque, P.; Obojes, N.; Tappeiner, U. Impact of droughts on water provision in managed alpine grasslands in two climatically different regions of the Alps. *Ecohydrology* **2015**, *8*, 1600–1613.
10. Parmele, L.H. Errors in output of hydrologic models due to errors in input potential evapotranspiration. *Water Resources Research* **1972**, *8*, 348–359.
11. Parmele, L.; McGuinness, J. Comparisons of measured and estimated daily potential evapotranspiration in a humid region. *Journal of Hydrology* **1974**, *22*, 239–251.
12. McGuinness, J.; Bordne, E. A comparison of lysimeter derived potential evapotranspiration with computed values, Tech. Bull., 1452. *Agric. Res. Serv., US Dep. of Agric., Washington, DC* **1972**.
13. Jensen, M.E.; Haise, H.R. Estimating evapotranspiration from solar radiation. *Proceedings of the American Society of Civil Engineers, Journal of the Irrigation and Drainage Division* **1963**, *89*, 15–41.
14. Andréassian, V.; Perrin, C.; Michel, C. Impact of imperfect potential evapotranspiration knowledge on the efficiency and parameters of watershed models. *Journal of Hydrology* **2004**, *286*, 19–35.
15. Jensen, M.E.; Burman, R.D.; Allen, R.G. Evapotranspiration and irrigation water requirements. ASCE, 1990.
16. Xu, C.Y.; Singh, V. Cross comparison of empirical equations for calculating potential evapotranspiration with data from Switzerland. *Water Resources Management* **2002**, *16*, 197–219.
17. ASCE-EWRI. The ASCE standardized reference evapotranspiration equation. *Technical Committee Rep. to the Environmental and Water Resources Institute of ASCE from the Task Committee on Standardization of Reference Evapotranspiration* **2005**.
18. Makkink, G. Testing the Penman formula by means of lysimeters. *Journal of the Institution of Water Engineerrs* **1957**, *11*, 277–288.
19. Blaney, H.; Criddle, W. Determining water needs from climatological data. *USDA Soil Conservation Service. SOS–TP, USA* **1950**, pp. 8–9.
20. Hargreaves, G.H. Moisture availability and crop production. *Transactions of the ASAE* **1975**, *18*, 980–0984.
21. Hargreaves, G.H.; Samani, Z.A. Reference crop evapotranspiration from temperature. *Applied engineering in agriculture* **1985**, *1*, 96–99.

22. Hargreaves, G.H.; Samani, Z.A. Estimating potential evapotranspiration. *Journal of the irrigation and Drainage Division* **1982**, *108*, 225–230.
23. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M.; others. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome* **1998**, *300*, D05109.
24. Penman, H.L. Vegetation and hydrology. *Soil Science* **1963**, *96*, 357.
25. Oudin, L.; Hervieu, F.; Michel, C.; Perrin, C.; Andréassian, V.; Anctil, F.; Loumagne, C. Which potential evapotranspiration input for a lumped rainfall–runoff model?: Part 2—Towards a simple and efficient potential evapotranspiration model for rainfall–runoff modelling. *Journal of hydrology* **2005**, *303*, 290–306.
26. Wright, J.L.; Jensen, M.E. Peak water requirements of crops in southern Idaho. *Proceedings of the American Society of Civil Engineers, Journal of the Irrigation and Drainage Division* **1972**, *98*, 193–201.

Sample Availability: Samples of the compounds ...... are available from the authors.