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PyEt: A Python package for the estimation of reference and potential evaporation

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Summary

The evaporation (ET) of water from land surfaces to the atmosphere is a major component of the water cycle and accurate estimates of the flux are essential to the water and agricultural sector. As direct measurement of ET is difficult, the evaporation flux is often estimated from available meteorological data using empirical formulas. There exist a variety of such formulas, where most tend to estimate the potential evaporation (PET), which is the maximum amount of water that would be evaporated if enough water were available. Consistently implementing these methods is difficult due to the significant diversity in the level of input data, process representation, assumptions and data requirements. The goal of `PyEt` is to provide a Python package that includes a wide range of methods for the estimation of PET, is fully documented and easy to use. Currently, `PyEt` includes eighteen different methods to estimate daily PET and various methods to estimate surface and aerodynamic resistance (see Table below). The package allows users to compute and compare potential evaporation estimates using different approaches with minimum effort. The structure of the package allows the implementation of the methods in other hydrological models or sensitivity analysis.

Statement of Need

In the Python community, there are already several Python packages that compute evaporation but only allow the user to choose between one or a maximum of three evaporation methods, e.g. `evaporation` (https://github.com/openmeteo/evaporation),`PyETo` (https://github.com/woodcrafty/PyETo), `RefET` (https://github.com/WSWUP/RefET). A package that includes a number of evaporation methods is already available in the R community by Guo et al. (2016). `PyEt` therefore aims to provide similar contributions to the Python community. `PyEt` also includes simple evaporation methods that require fewer input data than the commonly used Penman-Monteith method (see table below). Thus, `PyEt` can be of great importance in regions with sparsely distributed networks of measurement stations or climate change studies, where observations/predictions of wind velocity and humidity are often not available. The importance of simple evaporation models and their efficiency in rainfall-runoff models is thoroughly discussed in Oudin et al. (2005). In this paper, the term `evaporation` refers to the total evaporation from land, comprising of transpiration (evaporation of water from inside the leaves), evaporation from bare soils and interception loss (evaporation of intercepted precipitation) (Miralles et al., 2020).

Table 1: PET, surface and aerodynamic resistance methods included in `PyEt`. T, Temperature; U, Wind Speed; D, Radiation; RH, Relative Humidity; h_{crop}, crop height; LAI, Leaf area index; $[CO_2]$ - atmospheric CO_2 concentration. Adapted from Oudin et al. (2005).

Method	Data needed	PyEt Method	Reference
Penman	RH, T, U, D	`penman`	Penman (1948)
Penman-Monteith	RH, T, U, D	`pm`	Monteith (1965) Schymanski & Or (2017)
FAO-56	RH, T, U, D	`pm_fao56`	Allen et al. (1998)
Priestley-Taylor	T, D	`priestley_taylor`	Priestley & Taylor (1972)
Kimberly-Penman	RH, T, U, D	`kimberly_penman`	Wright (1982)
Thom-Oliver	RH, T, U, D	`thom_oliver`	Thom & Oliver (1977)
Blaney–Criddle	T, D	`blaney_criddle`	Blaney & others (1952)
Hamon	T	`hamon`	Hamon (1963)
Romanenko	RH, T	`romanenko`	Xu & Singh (2001)
Linacre	T	`linacre`	Linacre (1977)
Turc	T, D	`turc`	Xu & Singh (2001)
Jensen–Haise	T, D	`jensen_haise`	Jensen & Haise (1963)
McGuinness–Bordne	T, D	`mcguinness_bordne`	McGuinness & Bordne (1972)
Hargreaves	T	`hargreaves`	Hargreaves & Samani (1982)
Doorenbos–Pruitt (FAO-24)	RH, T, U, D	`fao_24`	Jensen et al. (1990)
Abtew	T, D	`abtew`	Abtew (1996)
Makkink	T, D	`makkink`	Makkink (1957)
Oudin	T	`oudin`	Oudin et al. (2005)
Aerodynamic resistance	U,(h_{crop})	`calc_res_aero`	Allen et al. (1998)
Surface resistance	(LAI),($[CO_2]$)	`calc_res_surf`	Allen et al. (1998) Yang et al. (2018)

Example application

This example shows how PyEt can be used to compute potential evaporation using different evaporation methods. The potential evaporation is estimated for the city of Maribor (Slovenia), using online available data from the Slovenian Environmental Agency (ARSO). The potential evaporation is computed using four different methods (Penman, Priestley-Taylor, Makking, Hammon) and plotted for comparison.

```
import pandas as pd
import pyet

# Import meteorological data
meteo = pd.read_csv("data/meteo_maribor_2017.csv", parse_dates=True,
                    index_col="Date")
tmax, tmin, rh, wind, rs = [meteo[col] for col in meteo.columns]

et_penman = pyet.pm(wind, rs=rs, elevation=279, lat=0.813, tmax=tmax,
                    tmin=tmin, rh=rh)
et_pt = pyet.priestley_taylor(wind, rs=rs, elevation=279, lat=0.813,
                              tmax=tmax, tmin=tmin, rh=rh)
et_mak = pyet.makkink(rs, tmax=tmax, tmin=tmin, elevation=279)
et_hamon = pyet.hamon(tmean.index, tmean, 0.813)
```

In the code above `R_s` is the incoming solar radiation [MJ m-2 d-1], `elevation` the site

elevation [m], `lat` the the site latitude [rad], `tmax` and `tmin` the maximum and minimum temperature [°C] and `rh` the mean relative humidity [%].

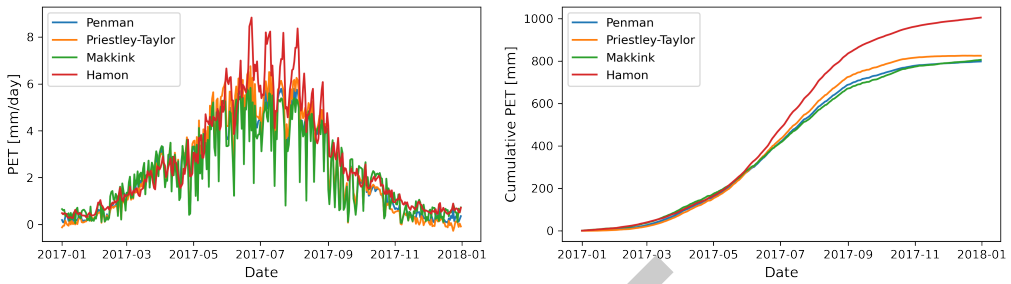

Figure 1: Daily potential evaporation for Maribor (Slovenia) estimated according to (Monteith, 1965), (Priestley & Taylor, 1972), (Makkink, 1957) and (Hamon, 1963).

Concluding remarks

This paper presents `PyEt`, a Python package to estimate daily potential evaporation from available meteorological data. Using `PyEt`, users can estimate PET using 18 different methods with only a few lines of Python-code. At this stage (PyEt v1.0), the methods are implemented for 1D data (e.g. time series data). Further developments will focus on enabling 2D and 3D data input (Numpy Arrays, Array, and NetCDF files). The authors believe that `PyEt` is a valuable contribution to the hydrology, meteorology and agricultural communities, enabling a simple PET estimation and comparison between different PET estimates. `PyEt` methods and estimates can be further used in hydrological models and sensitivity analyses. The `PyEt` design enables simple extension of the software with new capabilities and new model options. The authors warmly welcome code contributions, bug reports, and feedback from the community to further improve the package. `PyEt` is free and open-source software under the LGPL-3.0 license and is available at http://www.github.com/phydrus/PyEt. Full documentation is available on ReadTheDocs (https://pyet.readthedocs.io). The notebook and data necessary to reproduce the Figure in this manuscript are available through PyEt GitHub page.

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