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Software Update

"Version 1.3.0 pyfao56: FAO-56 evapotranspiration in Python"☆

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ABSTRACT

The pyfao56 software package is a Python-based implementation of the standardized evapotranspiration (ET) methodologies described in Irrigation and Drainage paper No. 56 of the Food and Agriculture Organization of the United Nations, commonly known as FAO-56. This update improved pyfao56 by 1) adding an optional surface runoff methodology, 2) adding an extensive algorithm for automating the computation of irrigation schedules, 3) considering irrigation losses due to irrigation system inefficiencies, 4) adding an optional method to compute the transpiration reduction coefficient (K_s) based on the curvilinear approach from AquaCrop, 5) incorporating a module for computing 15 goodness-of-fit statistics between simulated and measured data, and 6) computing a cumulative seasonal water balance summary. Most of these updates arose from user requests to add new features or options, and the collaborations demonstrated the value of community-based development for rapid improvement and generalization of scientific software.

Metadata

Nr	Code metadata description	*Please fill in this column*
C1	Current code version	*v1.3.0*
C2	Permanent link to code/repository used for this code version	https://github.com/kthorp/pyfao56 https://pypi.org/project/pyfao56/1.3.0/ https://github.com/conda-forge/pyfao56-feedstock
C3	Permanent link to reproducible capsule	N/A
C4	Legal code license	Creative Commons Zero (CC0)
C5	Code versioning system used	Git
C6	Software code languages, tools and services used	python
C7	Compilation requirements, operating environments and dependencies	Python: charset-normalizer-2.0.12, idna-3.3, matplotlib-3.5.2, numpy-1.21.6, pandas-1.3.5, python-3.7.13, python-dateutil-2.8.2, pytz2022.1, requests-2.28.0, six-1.16.0, urllib3–1.26. 9
C8	If available, link to developer documentation/manual	https://github.com/kthorp/pyfao56/blob/main/README.md
C9	Support email for questions	kelly.thorp@usda.gov

1. Introduction

The pyfao56 software package [1,2,3] is a Python-based

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implementation of the ASCE Standardized Reference Evapotranspiration (ET) Equation [4] and the FAO-56 dual crop coefficient methodology [5]. As interest in the package has grown, users commonly identified several opportunities for improvement and expansion. In particular, the model lacked a surface runoff methodology, did not consider irrigation system efficiency, and lacked algorithms to compute irrigation schedules automatically. With input from the user community, these issues were addressed in the present update.

2. New features

Since the previous software update paper [3], two software releases have been made, including one minor [ver. 1.2.1] and one major [ver. 1.3.0] release. Six new primary features were added in these releases: 1) a surface runoff method, 2) an automatic irrigation scheduling algorithm, 3) inputs for irrigation system efficiency, 4) a curvilinear approach to compute the transpiration reduction factor (K_s), 5) a goodness-of-fit statistics module, and 6) a seasonal water balance summary. Other minor edits to the functionality of core modules and additional test cases were also included.

2.1. Consideration of surface runoff

FAO-56 [5, pp. 153, 171] assumes that surface runoff can be ignored or can be accounted for by reducing precipitation depth using standard procedures from hydrological texts. In most arid and semi-arid environments, assuming zero runoff and making an occasional adjustment to large precipitation events is an appropriate simplification. However, applications of FAO-56 methods in humid environments or for fields with varying surface characteristics necessitate a more robust consideration of surface runoff. Furthermore, global projections of increasing precipitation intensity [6] with concomitant projected increases in surface runoff strengthen the need. The ASCE Manual of Practice #70 [7], pp. 451–454] describes a straightforward surface runoff algorithm that integrates well with the FAO-56 dual crop coefficient method. Based on the USDA-NRCS curve number (CN) approach, the method uses the readily evaporable water (REW), total evaporable water (TEW), and cumulative depth of evaporation (D_e) variables from the FAO-56 water balance to compute CN for surface runoff estimation. The method requires an additional input parameter, the curve number for antecedent water condition 2 (CN2), which was added to the Parameters class of pyfao56. The runoff approach in pyfao56 is optional and, by default, is not considered. Users can activate runoff calculations by setting the "roff" argument to "True" in the constructor for the Model class. Effective precipitation, defined as precipitation minus surface runoff, is then used in the pyfao56 water balance calculations.

2.2. Automatic irrigation scheduling

The original design of pyfao56 required users to input the irrigation schedule explicitly. However, many pyfao56 applications can be envisioned where the specific irrigation schedule is unknown, and capability to estimate an irrigation management schedule from model state variables would be useful. The new "autoirrigate" module provides the "AutoIrrigate" class, which provides 25 parameters that can control the model's determination of irrigation timing and amount. The Model class can now be instantiated with either an explicit irrigation schedule using the Irrigation class or sets of autoirrigation parameters via the AutoIrrigate class or both or neither. Implementing both approaches is useful for in-season irrigation management decisions requiring a historical irrigation record in combination with future predictions of irrigation requirements. Parameters for controlling autoirrigation timing include the start and end dates for an autoirrigation time period, day(s) of week that irrigation is permitted, consideration of forecasted precipitation events, management allowed depletion, K_s below a critical value, and days since last irrigation or watering event. When autoirrigation is triggered, the default irrigation amount is the root-zone soil water depletion (D_r, mm). Parameters to alter this amount include a constant application depth, a targeted depletion (i.e. deficit irrigation), a variety of options based on replacement of ET computed for the past number of days or since the last irrigation, an adjustment of the default rate by a fixed percentage, an adjustment for irrigation inefficiency, and limits for minimum and maximum irrigation application amount. Given the range of options, the automatic irrigation scheduling algorithm provides a flexible method for determination of realistic irrigation management strategies that consider both the crop water requirement and practical constraints for irrigation scheduling. Thus, the recommended irrigation rates should have improved potential for practical field implementation.

2.3. Losses due to irrigation system inefficiency

In earlier versions of pyfao56, no irrigation losses were considered, and inputted irrigation amounts were considered 100 % effective. To allow the simulation of different irrigation methods with varying efficiency, pyfao56 now incorporates an irrigation efficiency parameter in both the Irrigation and AutoIrrigate classes. For explicit specification of irrigation amounts in the Irrigation class, an irrigation efficiency (%) can be specified for each irrigation event, and the inputted irrigation amount will be deducted accordingly. For autoirrigation, specification of an irrigation efficiency will increase the recommended irrigation amount to account for irrigation system inefficiencies. Irrigation amounts in pyfao56 are considered as applied irrigation, and the irrigation efficiency parameter is used to consider losses from the applied amount, which are ineffective. Effective irrigation, defined as applied irrigation minus irrigation loss, is then used in the pyfao56 water balance calculations.

2.4. Curvilinear K_s method

FAO-56 [5, pp. 167–169] documents an equation in which the transpiration reduction coefficient (K_s) varies linearly with changes in root zone soil water depletion (D_r) when D_r is greater than readily available water (RAW). Maize field data in Colorado [8] suggested that a curvilinear relationship between K_s and D_r, as used in the AquaCrop model [9], was better than the linear relationship from FAO-56. Thus, while the default approach in pyfao56 remains as the linear computation from FAO-56, an optional boolean argument ("aq_ks") was added to the constructor of the Model class to replace the linear computation with curvilinear computation of K_s.

2.5. Statistics module

The new "statistics" module in the "tools" subpackage provides the "Statistics" class, which can compute 15 goodness-of-fit statistics commonly used in model evaluation. Computed statistics include bias, relative bias, percent bias, maximum error, mean error, mean absolute error, sum of squared error, Pearson's correlation coefficient, coefficient of determination, root mean squared error, relative root mean squared error, percent root mean squared error, coefficient of residual mass, the Nash and Sutcliffe model efficiency [10], and the Willmott index of agreement [11]. Given inputs of two Python lists containing measured and simulated data, each of the goodness-of-fit statistics will be computed and preserved as a class attribute.

2.6. Seasonal summary

A new method was added to the Model class, which computes cumulative values for pyfao56 water balance components from the simulation start date to end date. The cumulative data are saved to a summary file. The data are useful for evaluating water balance variables over the entire simulation period.

3. Conclusion

Growing interest in the pyfao56 Python package led to many common user requests to add useful features and options. This update addressed many of those requests through an effort of collaborative discussion and software development. Further improvements to pyfao56 are likely possible through continued collaborative efforts among the global ET community.

CRediT authorship contribution statement

Kelly R. Thorp: Conceptualization, Data curation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **Kendall C. DeJonge:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. **Tyler Pokoski:** Software, Data curation, Validation. **Dinesh Gulati:** Conceptualization, Methodology, Software, Data curation. **Meetpal Kukal:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Fared Farag:** Conceptualization, Methodology, Software. **Ahmed Hashem:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Gabrial Erismann:** Validation. **Tamara Baumgartner:** Validation. **Annelie Holzkaemper:** Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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