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Software update

Version 1.1.0—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) fixing a major bug related to testing for availability of weather data, (2) expanding options for reference ET calculations including hourly estimates, (3) adding functionality to specify variable soil characteristics with profile depth, (4) including optional water balance enhancements that consider soil water depletion for both the dynamic and maximum root zones, and (5) enabling the use of either constant or variable depletion fraction (p). The updates increase software versatility and expand options for use, while also maintaining the core functionality of the original software design.

Code metadata

Current code version	*v1.1.0*
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-23-00060
Permanent link to reproducible capsule	*N/A*
Legal code license	*Creative Commons Zero (CC0)*
Code versioning system used	*git*
Software code languages, tools and services used	*python*
Compilation requirements, operating environments and dependencies	*Python: charset-normalizer-2.0.12, idna-3.3, numpy-1.21.6, pandas-1.3.5, python-dateutil-2.8.2, pytz2022.1, requests-2.28.0, six-1.16.0, urllib3-1.26. 9*
If available, link to developer documentation/manual	https://github.com/kthorp/pyfao56/blob/main/README.md
Support email for questions	kelly.thorp@usda.gov

1. Introduction

The pyfao56 software package [1] is a Python-based implementation of the ASCE Standardized Reference Evapotranspiration (ET) Equation [2] and the FAO-56 dual crop coefficient methodology [3]. As discussed in the original software publication [1], pyfao56 was initially conceived as an ET estimation and irrigation scheduling tool for field studies conducted by USDA-ARS scientists at the Maricopa Agricultural Center (MAC) in Maricopa, Arizona. The original formulation of pyfao56 was based on a fairly strict interpretation of the methods described in prominent ET texts [2,3], and the implementation favored the specific manner in which scientists at Maricopa typically used these methods.

Since the original release, scientists conducting field studies at the USDA-ARS Limited Irrigation Research Farm (LIRF) in Greeley, Colorado sought to incorporate similar but nuanced approaches for using ASCE [2] and FAO-56 [3] methods into pyfao56. The resulting updates fostered a more robust and versatile implementation of the software, including several novel and optional features that are not explicitly described in FAO-56 [3]. This article describes these new features, now available in pyfao56 version 1.1.0.

2. New features

2.1. NaN bug fix

The pyfao56 source code performs conditional checks to determine if certain weather input variables are not a number

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(NaN), meaning data for that variable is unavailable. However, the conditional checks were not syntactically correct in pyfao56 version 1.0.9 and earlier, which can cause runtime errors when users fail to provide certain input variables (e.g., ETref). To fix this bug, pyfao56 now utilizes the "isnan()" function of the Python "math" package to correctly perform conditional checks for NaN.

2.2. Expansion of reference ET algorithms

Recent software updates include three changes related to reference ET (ETref) computations. First, the upper limit crop coefficient (Kcmax) calculation was expanded to consider both the short-crop (i.e., grass or ETo) and tall-crop (i.e., alfalfa or ETr) reference surfaces, as described in FAO-56 [3]. Second, measured vapor pressure was added as a Weather input variable, which increases flexibility for computing ETref as described in the ASCE method [2]. Third, an algorithm was added for calculating hourly ETref, following the methods described in the ASCE method [2]. As an alternative to calculating daily ETref directly, hourly ETref can be summed to provide daily ETref values as required by the model. Comparisons of hourly ETref from pyfao56 and Ref-ET software [4] demonstrated root mean squared deviations (RMSD) of 0.007 and 0.011 mm h^{-1} for ETo and ETr, respectively, while the corresponding comparisons of daily ETref sums from the hourly data showed RMSD of 0.05 and 0.08 mm d^{-1} for ETo and ETr, respectively. These comparisons were based on five years of LIRF weather data from 2 January 2017 to 31 December 2021.

2.3. Consideration of stratified soil layers

FAO-56 [3] unrealistically represents the soil profile with homogeneous soil properties throughout the root zone. To address this limitation, pyfao56 now includes the "SoilProfile" data class, which defines soil properties for unique soil layers. The primary attribute ("sdata") of SoilProfile is a Pandas DataFrame object with three columns ("thetaFC", "thetaWP", "theta0"), and the bottom depth of each soil layer (cm) is used for the row indices. When a SoilProfile class object is passed to a pyfao56 Model class object, the pyfao56 model simulates a layered soil profile; otherwise, it simulates a homogeneous, single-layer soil based on the thetaFC, thetaWP, and theta0 data in the Parameters class.

2.4. Enhanced soil water depletion calculations

FAO-56 [3] methodology does not account for water below the dynamic root zone. Consequently, any water leached below the root zone is unrecoverable, even with subsequent increases in root depth. To address this limitation, pyfao56 can now optionally compute soil water depletion for three different segments of soil: (1) depletion within the crop's active root zone (D_r), (2) depletion from the surface to the maximum assumed rooting depth (D_{rmax}), and subsequently (3) depletion between the active rooting depth and the maximum rooting depth. When crop roots reach their maximum depth, the depletion in the crop's active root zone converges to the depletion in the crop's maximum root zone, i.e. D_{rmax} - $D_r = 0$. This novel water balance methodology expands FAO-56 [3] by considering future root growth potential when assessing soil water depletion and making irrigation decisions. It also permits water percolated below the active root zone to become available to the plant later as roots expand. Because the enhanced water balance method is linked to the use of stratified soil layers (Section 2.3), both approaches are enabled by initializing the Model class with layered soil profile information in a SoilProfile class. Otherwise, the original FAO-56 [3] water balance methodology is implemented.

2.5. Constant depletion fraction

Equation 83 in FAO-56 [3] demonstrates the multiplication of total available water (TAW) by a depletion fraction (p) to compute readily available water (RAW). FAO-56 states that p is a function of the evaporative power of the atmosphere and provides an equation for its adjustment based on simulated daily crop evapotranspiration (ETc), yet FAO-56 also states that a constant p is often assumed. Furthermore, Annex 8 of FAO-56 suggests the use of a constant p that is equivalent to management allowed depletion (MAD). While prior versions of pyfao56 assumed a variable p based on ETc, pyfao56 now allows simulations with a constant p via an optional "cons_p" boolean argument given at Model class initialization. By setting the "cons_p" argument to "True", p is fixed to the value specified by the "pbase" attribute of the Parameters class. By default, "cons_p" is "False", which enables variable p computations.

3. Conclusion

The purpose of pyfao56 is to make standardized ET and water balance methodologies [2,3,5] available to a wider audience using the modern Python programming language and git/Github version control methodologies. The pyfao56 version 1.1.0 updates provide an example of collaborative software development to incorporate the nuanced approaches of another irrigation research group while also retaining the original software functionality, making the software more robust and versatile overall. As such, the developers welcome additional collaborations and contributions to further develop and test the software for broad agricultural applications.

CRediT authorship contribution statement

Josh Brekel: Led the programming and troubleshooting of new modules, Writing of the manuscript. **Kelly R. Thorp:** Originator of the software, Led the integration of the new functionality with previous code, Writing of the manuscript. **Kendall C. DeJonge:** Led and coordinated efforts to conceptualize and integrate new functionality into pyfao56, Writing of the manuscript. **Thomas J. Trout:** initially conceived many of the new adaptations of FAO-56 described herein and served as a consultant on the effort, Writing of the manuscript.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kelly Thorp reports financial support was provided by National Institute of Food and Agriculture. Kelly Thorp reports financial support was provided by Cotton Inc.

Data availability

Data will be made available on request.

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