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Software update

Version 1.2.0 — pyfao56: FAO-56 evapotranspiration in Python

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ARTICLE INFO

Article history:
Received 1 September 2023
Accepted 3 September 2023

Keywords:
Crop coefficient
Evapotranspiration
Irrigation
Precision agriculture
Soil
Water management

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) enhancing the "forecast" module which obtains seven-day weather forecasts from the National Weather Service (NWS), (2) incorporating measured soil water content profiles to estimate soil water depletion in the dynamic and maximum root zones, (3) adding visualization tools that plot measured and simulated soil water depletion and ET versus time, (4) updating the format of standard file headers to include timestamps, simulation options, and user defined metadata, and (5) incorporating minor improvements to the functionality of the core pyfao56 modules. These updates arose from efforts to incorporate pyfao56 into a computational workflow for maize irrigation scheduling research at the Limited Irrigation Research Farm (LIRF) in Greeley, Colorado during the 2023 growing season.

Published by Elsevier B.V.

Code metadata

Current code version	*v1.2.0*
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-23-00583
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, 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*
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 [1,2] is a Python-based implementation of the ASCE Standardized Reference Evapotranspiration (ET) Equation [3] and the FAO-56 dual crop coefficient methodology [4]. During the 2023 growing season, pyfao56 was incorporated into a computational workflow for maize irrigation scheduling research at the Limited Irrigation Research Farm (LIRF) in Greeley, Colorado. The updates in pyfao56 version 1.2.0 arose mainly from this effort to use the model for in-season irrigation decisions at a new field site.

2. New features

A primary new feature is the "tools" subpackage, which provides three modules to enhance model use. These modules provide functionality to obtain seven-day weather forecasts from the National Weather Service (NWS), assess root zone soil water depletion from measured soil water content data, and visualize comparisons of measured and simulated soil water depletion and ET time series. Other minor edits to the functionality of core modules were also included.

2.1. Improved weather forecast retrieval

Originally included in the "custom" subpackage, the "forecast" module was relocated to the new "tools" subpackage, and methods for retrieval of solar radiation and wind speed forecasts

DOI of original article: https://doi.org/10.1016/j.softx.2022.101208.
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https://doi.org/10.1016/j.softx.2023.101518
2352-7110/Published by Elsevier B.V.

were improved. The "Forecast" class issues REpresentational State Transfer (REST) commands to request weather forecast data from the NWS National Digital Forecast Database (NDFD). With input of field site geocoordinates, data are retrieved to compute forecasts of ASCE Standardized Reference ET, including wind speed and minimum, maximum, and dew point air temperature. Though solar radiation forecasts are not directly provided by NDFD, cloud cover forecasts are available. With input of the field site elevation, solar radiation forecasts are computed from cloud cover and clear-sky solar radiation. Liquid precipitation forecasts are also available. Because the NDFD provides wind speed forecasts at a 10 m height, the "Forecast" class provides methods to convert wind speed forecasts to the same height as wind speed measurements from the local weather station. This adjustment ensures consistent measured and predicted wind speed data are contained in the "Weather" class and provided to the model.

2.2. Measured soil water content data

Two classes ("SoilWaterSeries" and "SoilWaterProfile") are provided in the new "soil_water" module in the "tools" subpackage. These classes provide a framework for representing and analyzing measured volumetric soil water content data, as collected at one field location over time (e.g., neutron probe measurements at one access tube over the growing season). The "SoilWaterSeries" class represents a time series of soil water content measurements, while the "SoilWaterProfile" class represents and analyzes soil water content profiles from a single measurement date. With an estimate of root depth on the measurement date (e.g., from a pyfao56 model simulation) and inputs of soil properties (e.g., from pyfao56 "Parameters" or "SoilProfile" classes), the "SoilWaterProfile" class computes root zone water status metrics from the measured data, including the soil water depletion for both the dynamic and maximum root depths. Additionally, an estimate of the transpiration reduction factor due to water stress (K_s) is computed from the measured depletion and the total and readily available water (TAW and RAW, respectively). A new test case ("test6") demonstrates the methodology for a series of soil water content data collected by neutron probe during a 2022 cotton field study at Maricopa, Arizona. The new "soil_water" module is useful for evaluations of pyfao56 model simulations and for incorporating measured soil water content data into irrigation scheduling decisions.

2.3. Visualization of measured and simulated data

The new "visualization" module provides the "Visualization" class, which formats two figures for visualizing pyfao56 model output using Python's "matplotlib" library. By default, the first figure demonstrates simulation output for soil water depletion for the dynamic root zone over time. Optionally, the figure can be enhanced by adding the following plots: RAW, simulated soil water depletion for the maximum root zone, measured soil water depletion for the dynamic and maximum root zones, water inputs from precipitation and irrigation, K_s estimated from both measurements and simulations, and deep percolation. Taken together, the figure provides a comprehensive look at measured and simulated soil water balance data for a single scenario. The second figure demonstrates simulated ET time series, including the reference ET (ET_{ref}), the non-stressed crop ET (ET_c), and the adjusted crop ET under water limitations (ET_{cadj}). A new test case ("test7") demonstrates both the calculation of measured soil water depletion (Section 2.2) and visualization of soil water balance data for a 2023 maize study at Greeley, Colorado.

2.4. Updated file headers

The standard file header was updated to include a timestamp for file creation and a designated section for user defined comments and metadata. Furthermore, output files from pyfao56 model simulations were updated to contain information about simulation options, including the simulation start and end dates and the selected soil profile characterization method. A character string of 72 asterisks is used to demarcate sections of the file header in pyfao56. The new file header is demarcated into top and bottom sections, where the top section reports fixed information that should not be edited by the user, and the bottom section is completely editable by the user. The model retains ability to read input files from previous pyfao56 versions.

2.5. Changes to core modules

Several minor changes in functionality of the core pyfao56 modules were also introduced in version 1.2.0. First, the stress-adjusted crop coefficient (K_{cadj}), which is the ratio of ET_{cadj} and the ET_{ref}, was computed and added to the model output. Second, the "loadfile" method of the "Parameters" class was made flexible to handle different orderings of parameters in the input file. Third, the "Irrigation" class was made an optional input to the "Model" class to allow the model to run without inputs of irrigation data. Fourth, a "customload" method was added to the "Irrigation" class to allow users to develop custom methods for loading irrigation data and to make the "Irrigation" class consistent with other customizable classes (i.e., "Weather", "Update", and "SoilProfile"). Fifth, the "__str__" methods of pyfao56 classes were updated to prevent printing DataFrame information when the DataFrame is empty. Taken together, these changes improved the core functionality of pyfao56 without impacting model calculations.

3. Conclusion

In 2023, the pyfao56 software was implemented for in-season irrigation scheduling at a new field site in Greeley, Colorado. Incorporating pyfao56 into the workflow of another research group led to many improvements to the model and its supporting tools. Further improvements to pyfao56 are likely possible through continued collaborative efforts with ET researchers and practitioners who find the tool useful and worthwhile.

CRediT authorship contribution statement

Kelly R. Thorp: Conceptualization of software design, Integration of new functionality with previous code. **Josh Brekel:** Initial programming of new functionality, Troubleshooting of new modules. **Kendall C. DeJonge:** Coordinated efforts to conceptualize and integrate new functionality into pyfao56, including testing with 2023 maize field data at Greeley.

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.

Acknowledgments

The authors acknowledge the many scientists who have devoted their careers to development and demonstration of the FAO-56 methodology and its subsequent standardization, which continues to advance technology for ET estimation and irrigation

scheduling worldwide. USDA is an equal opportunity provider and employer.

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