The “pyfao56” Package for Python: Codifying FAO-56 Evapotranspiration in a Modern Programming Language

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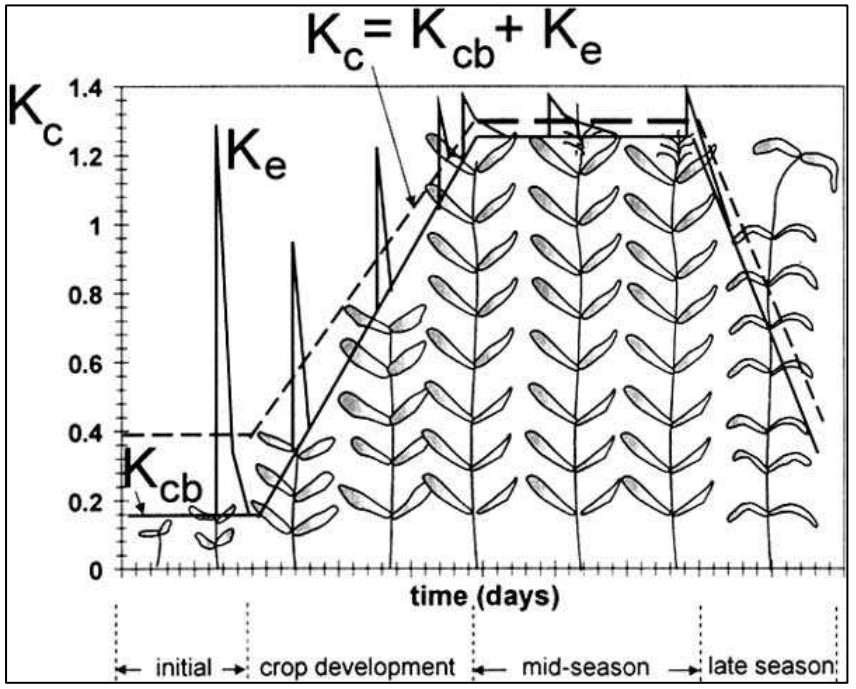
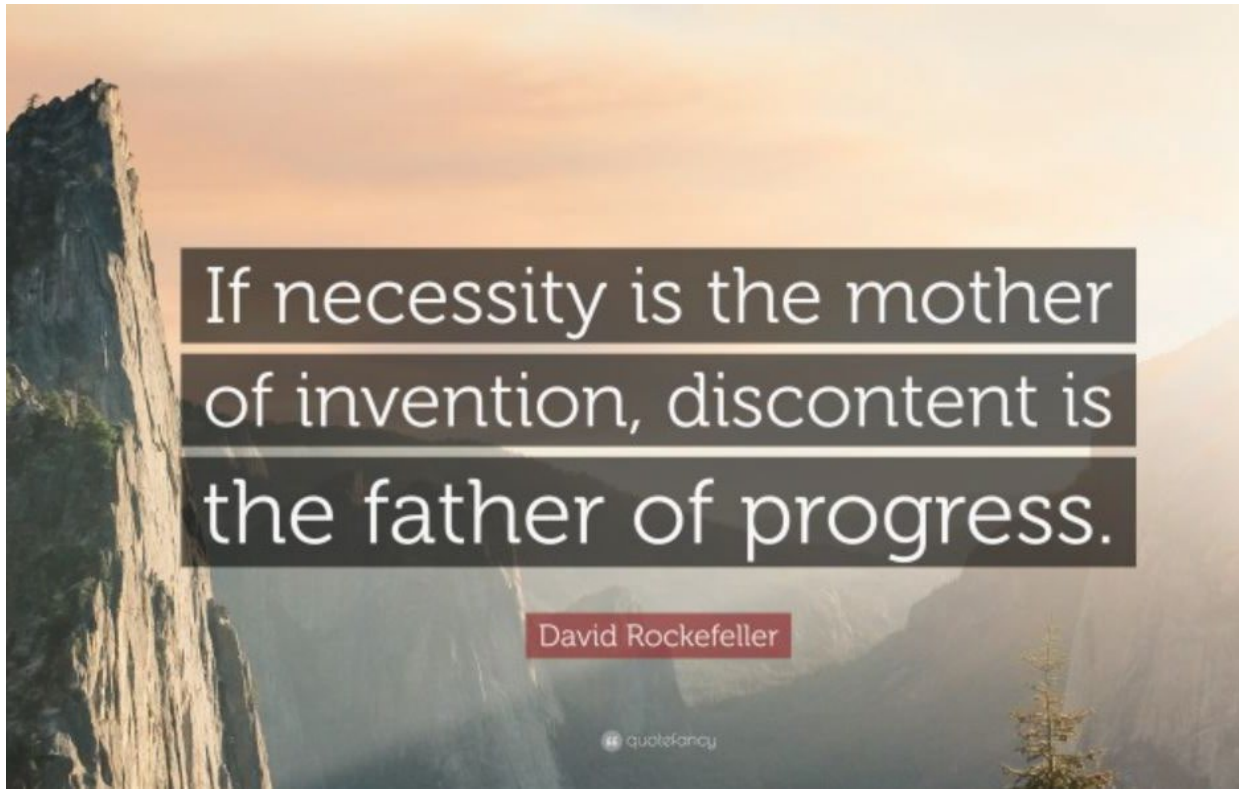
Introduction

- FAO-56 evapotranspiration
  - Allen et al. (1998) and ASCE (2005)
  - Standardized reference evapotranspiration (ET_o)
    - Defines atmospheric demand for water
    - Computed from weather station variables
    - air temp, dew point, solar radiation, and wind speed
  - Crop coefficients (K_c) adjust ET_o to crop ET (ET_c)
    - Single method: $ET_c = K_c \times ET_o$
    - Dual method: $ET_c = (K_{cb} \times K_s + K_e) \times ET_o$
- Python (www.python.org)
  - Highly popular modern programming language
  - Large development and user community
  - Open-source, easy syntax, lots of packages, etc.
- Goal: Codify FAO-56 algorithms in Python



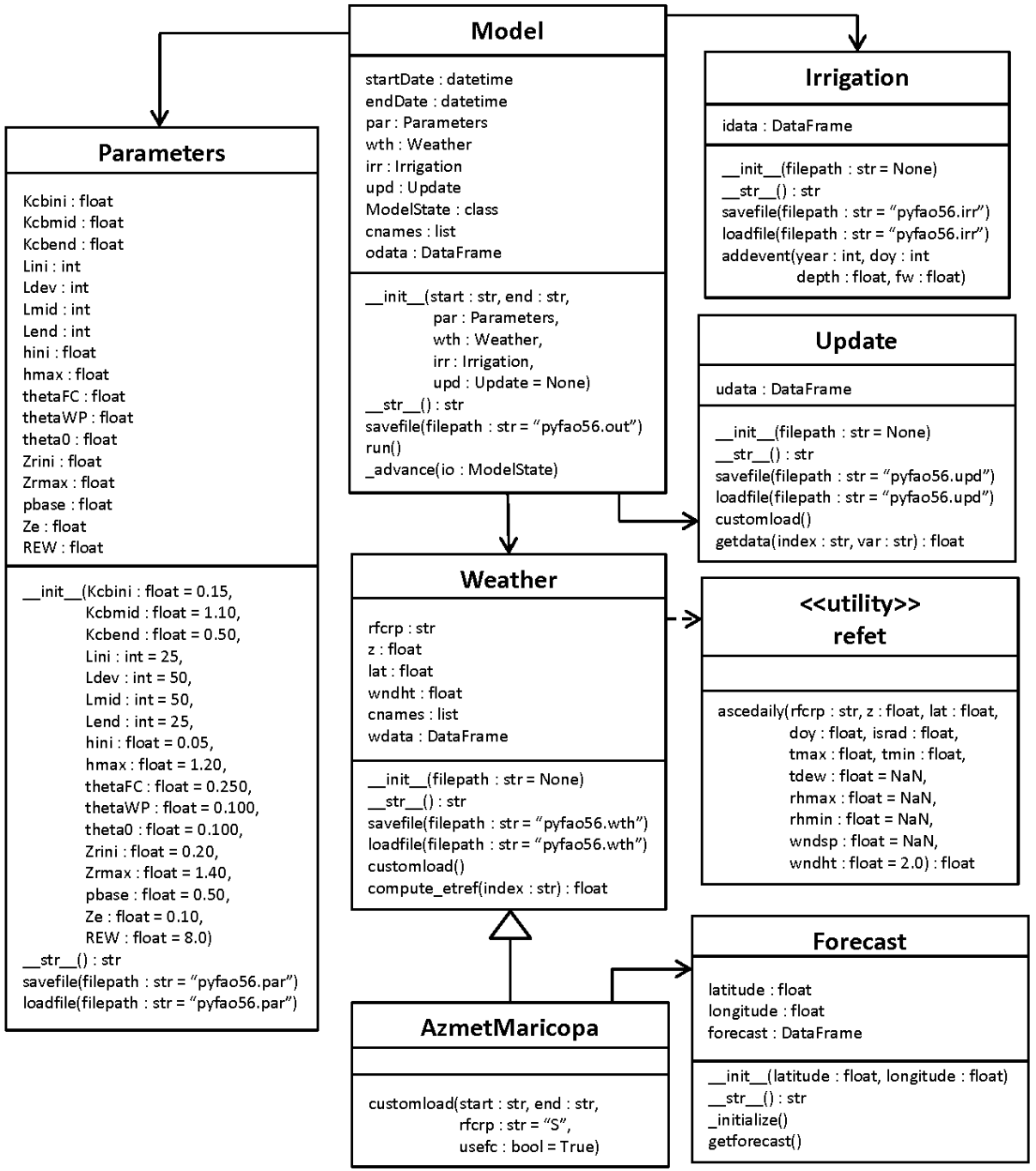
Software Design Goals

- Develop a Python tool for ET estimation and irrigation scheduling
  - Started as a script to support field studies
  - Then organized as a formal Python package
    - Importable to any Python module
    - Usable within other Python workflows
  - Eventually named it “pyfao56”
- Promote FAO-56 interpretation
  - Accurately represent FAO-56 methods
  - Clean, simple, readable, organized code
  - Well-documented and commented code
  - Serve as an extension of ET texts
  - Serve as a resource for learning FAO-56
- Promote accessibility of code
  - Open-source code
  - Distributed via Github, PyPI, conda-forge
  - Encourage collaborative development



Software Architecture

- Object-oriented modular design
  - Parameters
  - Irrigation
  - Autoirrigate (new in ver. 1.3.0)
  - Weather
  - SoilProfile (new in ver. 1.1.0)
  - Model
  - Update
  - Standardized reference ET module
- "pandas" DataFrames for data handling
- Multiple ways to inject data
  - Reading formatted text files
  - "customload" functions
    - Users can develop customized wrappers
    - Based on class inheritance
- Test suite and documented examples



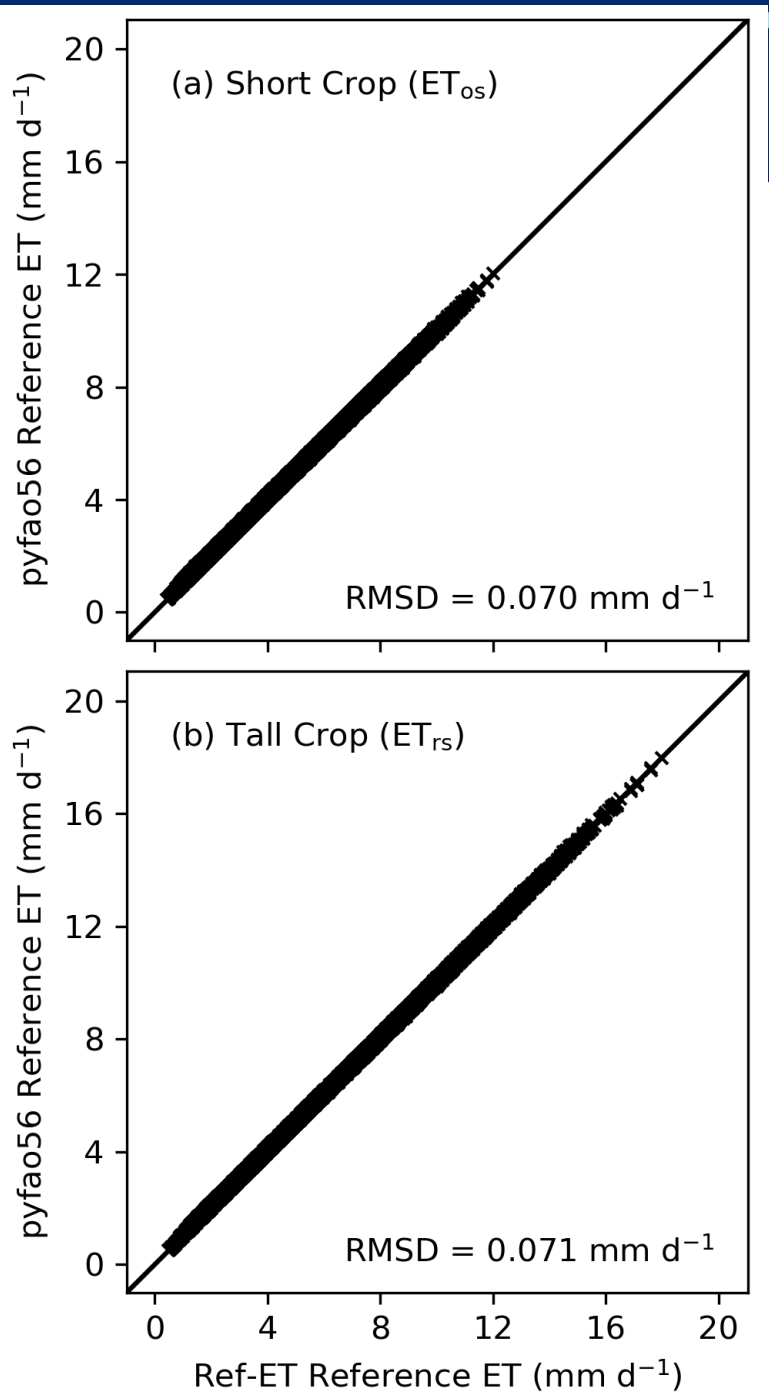
Quickstart

- Import pyfao56
- Specify model parameters
- Specify weather data
- Specify irrigation data
- Run the model
- More examples available

```
par.Kcbend = 0.15
par.Lini = 20
par.Ldev = 50
par.Lmid = 60
par.Lend = 30
par.hmax = 0.7
par.thetaFC = 0.2050
par.thetaWP = 0.0980
par.theta0  = 0.1919
par.Zrini = 0.20
par.Zrmax = 1.20
par.savefile(os.path.join(module_dir,'barley2023.par'))

#Specify the weather data
wth = custom.AzmetMaricopa()
wth.customload('2023-024','2023-121')
wth.savefile(os.path.join(module_dir,'barley2023.wth'))

#Specify the irrigation schedule
irr = fao.Irrigation()
irr.addevent(2023,  25, 20.4, 1.0)
irr.addevent(2023,  32, 20.4, 1.0)
irr.addevent(2023,  39, 20.4, 1.0)
irr.addevent(2023,  46, 10.2, 1.0)
irr.addevent(2023,  55, 20.4, 1.0)
irr.addevent(2023,  66, 20.4, 1.0)

#Run the model
mdl = fao.Model('2023-024','2023-121', par, wth, irr)
mdl.run()
print(mdl)
mdl.savefile(os.path.join(module_dir,'barley2023.out'))
```

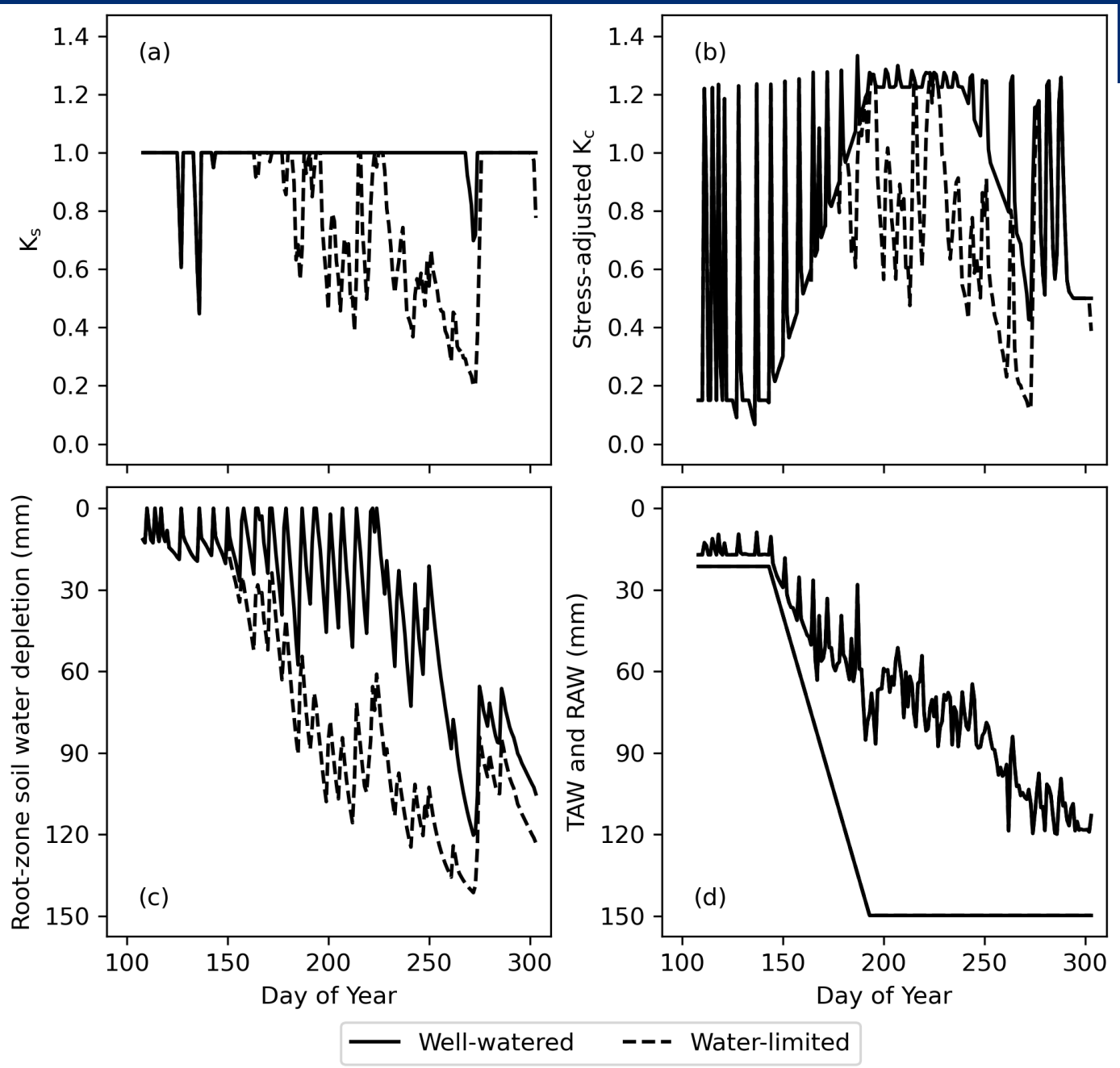
Reference Evapotranspiration

- How accurate are pyfao56 ET_{ref} computations?
  - No known open-source ET_{ref} algorithms
  - Can't borrow syntax from other sources
  - Can only follow the text in ASCE (2005)
- Compare ET_{ref} output from pyfao56 and Ref-ET software
  - Ref-ET software (Allen, 2012)
  - Known authority on ET_{ref} computation, but closed source
- Daily ET_{ref} comparison (pyfao56 vs. Ref-ET)
  - 18 years of AZMET weather data (2003 to 2020) at Maricopa, AZ
  - Short Crop ET_{ref} : RMSD = 0.070 mm d^{-1}
  - Tall Crop ET_{ref} : RMSD = 0.071 mm d^{-1}
- Hourly ET_{ref} comparison (pyfao56 vs. Ref-ET)
  - 5 years of weather data (2017 to 2021) at Greeley, CO
  - Short Crop ET_{ref}
    - RMSD (hourly data) = 0.007 mm h^{-1}
    - RMSD (daily sums) = 0.05 mm d^{-1}
  - Tall Crop ET_{ref}
    - RMSD (hourly data) = 0.011 mm h^{-1}
    - RMSD (daily sums) = 0.08 mm d^{-1}



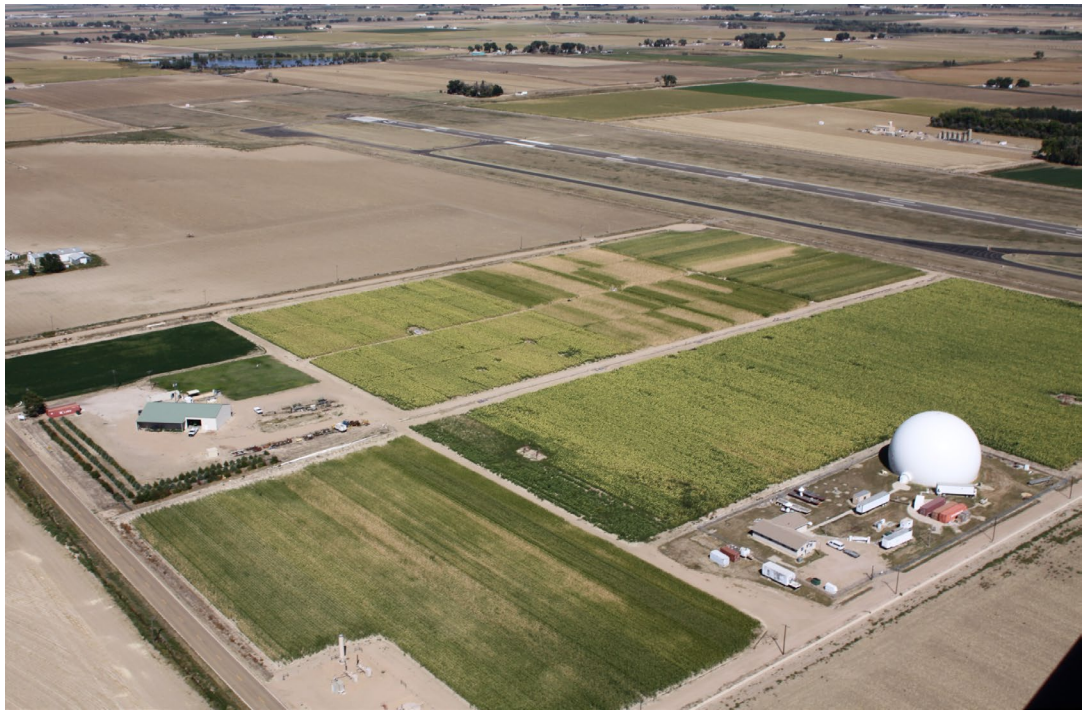
Model Response

- Model output
  - Fully represents all model states
  - Daily timestep data
  - Between start and end dates
- 2018 Maricopa cotton trial
  - Well-watered vs. water-limited
  - K_s responds to stress
  - D_r responds to stress
  - K_c spikes due to wetting events
  - TAW increases with root depth
  - Compare seasonal $ET_{c\ adj}$
    - pyfao56 vs. neutron water balance
    - Water-limited: +5.3% error
    - Well-watered: -5.6% error



Releases of pyfao56

- Initial development (ver. 1.0.9) by Thorp at Maricopa
  - Little input beyond the local research station
  - Favored specific FAO-56 methods used at Maricopa
- Later involvement with Fort Collins ARS
  - Incorporate their nuanced (better) FAO-56 implementations
  - But retain functionality of original software design
- Improvements from Fort Collins (ver. 1.1.0)
  - Inclusion of hourly ET_{ref} methodology
  - Consideration of stratified soil layers
    - FAO-56 uses only a single, homogeneous soil layer
    - Devised method for FAO-56 calculations with layered soil data
  - Enhanced soil water depletion calculations
    - FAO-56 does not account for water below dynamic root zone
    - Devised method to consider both dynamic and maximum root zones
  - Constant depletion fraction (p)
    - RAW = pTAW, but FAO-56 not clear on method for p computation
    - Devised method for considering p as constant or dynamic variable



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Releases of pyfao56

- Addition of “tools” subpackage (ver. 1.2.0)
  - New SoilWaterSeries and SoilWaterProfile classes
    - Integration of measured soil water content data
    - Computes measured root zone soil water depletion (D_r)
  - New Visualization class
    - Time series plots of depletion, crop coefficients, and ET
    - Comparisons of measured and modeled depletion
  - Updates to the Forecast class
- Growing community interest and user base (ver. 1.3.0)
  - Added runoff option to water balance (FAO-56 assumes runoff = 0)
  - Added comprehensive autoirrigation algorithm
  - Added considerations for irrigation efficiency
- Future plans
  - Soil water depletion data assimilation via direct insertion
  - Growth stage lengths based on growing degree days
  - Incorporate 2024 FAO56 revisions

More information

- Source code
  - Github: https://github.com/kthorp/pyfao56
  - Install to Python from Python Package Index (PyPI)
  - Install to conda from conda-forge
- SoftwareX articles
  - Thorp, K. R., 2022. pyfao56: FAO-56 evapotranspiration in Python. SoftwareX 19, 101208. doi:10.1016/softx.2022.101208
  - Brekel, J., Thorp, K. R., DeJonge, K. C., Trout, T. J., 2023. Version 1.1.0 – pyfao56: FAO-56 evapotranspiration in Python. SoftwareX 22, 101336. doi:10.1016/jsoftx.2023.101336
  - Thorp, K. R., Brekel, J., DeJonge, K. C., 2023. Version 1.2.0 – pyfao56: FAO-56 evapotranspiration in Python. SoftwareX 24, 101518. doi:10.1016/j.softx.2023.101518
  - Thorp, K. R., DeJonge, K. C., Pokoski, T., Gulati, D., Kukal, M., Farag, F., Hashem, A., Erismann, G., Baumgartner, T., Holzkaemper, A., 2024. Version 1.3.0 – pyfao56: FAO-56 evapotranspiration in Python. SoftwareX 26, 101724. doi:10.1016/j.softx.2024.101724

Thank you for your attention!

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