AquaCrop coupled to NASA's Land Information System (LIS-AC)

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1 Source code

This document provides the steps to run the AquaCrop model within NASA's Land Information System (LIS). The user should note that AquaCrop is plugged into LIS for the first time in 2024, and may be subject to changes before the official acceptance within the NASA-LISF/master. Other code developments from ongoing research (ensemble runs, DA, crop specific maps, ...) developed at KU Leuven will be submitted to NASA-LISF as separate Pull Requests. This document assumes that the user is able to run LDT and LIS with another land surface model (e.g. Noah) using the NASA test cases.

The current working source code can be found under a LISF branch of the KUL-RSDA on GitHub (version on November 4th 2024). The LISF code with inclusion of the AquaCrop model can be downloaded to your local working directory using git commands:

```
$ git clone git@github.com:KUL-RSDA/LISF.git
$ cd LISF
$ git checkout ac.7.2_integration
```

The AquaCrop source code is available at (`https://github.com/KUL-RSDA/AquaCrop`). The specific source code used and included in the LIS source code (under `./lis/surfacemodels/land/ac.7.2/ac_modules`) is stored under an LIS-AC branch. The AquaCrop source code embedded into LIS differs from the official AquaCrop source code in two ways: (1) it includes minor fixes which will be included in the next AquaCrop source code release, (2) the precision of floating values was changed from double precision (Fortran real64) to single precision (Fortran real32) to allow for a better compatibility with the LISF procedures. To compile the LDT and LIS executables, you can refer to the NASA LISF documentation.

2 Running LDT

The Land Data Toolkit (LDT) prepares the input files and parameters that are used in the LIS run using the "LSM parameter processing" run mode. All options are set in the ldt.config file to generate a netcdf file (hereafter `lis_input.d01.nc` file) that contains parameters and other ancillary information (terrain information, grid, landmask, crop type, soil and climatological information). In the current version, AquaCrop runs over all land pixels, independent of the land cover class. This means that the user needs to mask the results to croplands in postprocessing, if so desired. Specific LDT options for AquaCrop are shown in the following box.

```
#AquaCrop
##AquaCrop crop file directories
AquaCrop crop type data source:         "CONSTANT"
AquaCrop crop library directory:        ./INPUT/AC_INPUT/crop_params/
AquaCrop crop type:                     "GDD_grain_crop"

##AquaCrop soil layers
AquaCrop number of soil layers: 2
AquaCrop soil layer thickness:  0.3 0.9

##AquaCrop tmin/tmax climatology
AquaCrop temperature climatology directory: ./INPUT/Tmin_max_2000-2022/
AquaCrop reference year for climatology: 2011
AquaCrop temperature climatology spatial transform: "bilinear"
```

2.1 Crop types

Currently, only a constant (spatially uniform) crop type can be chosen in LIS. This is defined in the ldt.config file (here set to `GDD_grain_crop`). The crop library directory (`crop_params`) contains (1) the `AC_Crop.Inventory` (numbered list of the crop types, example in box) and (2) the `AC_Crop.List` directory, containing the corresponding AquaCrop crop files (*.CRO). These files contain the crop parameters. An example crop file inventory is given.

```
2
Number  File name               Crop name
 1      Wheat                   'Wheat crop calendar AquaCrop GUI'
 2      GDD_grain_crop          'test GDD grain crop'
```

The `lis_input.d01.nc` contains a `AC_CROPT` layer containing the number corresponding to the chosen crop type. By editing the `AC_CROPT` layer, it is possible to run simulations with spatially variable crop types.

2.2 Soil layers and compartments

Currently, in LIS, every land surface model runs with a single soil texture for the whole soil profile, i.e. the same texture is used for all layers. This same paradigm is currently kept for AquaCrop. However, the user can define different numbers of layers for the various models (up to 5 in AquaCrop) of different thicknesses to then attribute an initial soil moisture content to each layer in the LIS run (`lis.config` file). This is important for realistic initial conditions in drier areas, where the soil is not refilled to field capacity in winter.

To model the soil water balance, AquaCrop relies on (computational) compartments (different from soil layers). The number and size of compartments depend on (1) the soil profile depth, and (2) the maximum root-zone depth of the crop. Since the size of the compartments can vary, this information is computed via LDT and included in the `lis_input.d01.nc` file (`AC_comp_size`).

2.3 Monthly climatologies of minimum and maximum temperatures

From AquaCrop version 7.2 onwards, the fertility functions rely on an a priori parameterization based on a monthly climatology of the minimum and maximum temperatures, which should be stored in the `lis_input.d01.nc` file during the LDT run. The climatologies are given as text files for each month. The climatologies based on MERRA-2 can be found with the test cases input data (section 4). The scripts to prepare these data can be found on GitHub in the KUL-RSDA pylis repository (under `preprocessing/forcing/AquaCrop_T_climatology/`). The allowed spatial transformations are: "neighbor", "bilinear", "none". Note that for the "none" option, the climatology files should be on the same grid as the lis domain. Along with the directory, the user should specify the reference year that should be used for the CO_2 concentrations. This reference year for the CO_2 concentrations is stored in the `lis_input.d01.nc` file.

3 Running LIS

The Land Information System (LIS) runs AquaCrop in a spatially distributed way. The running options are defined in the `lis.config` file. For general information on the LIS running options, please refer to the LIS User Guide. Specific AquaCrop information is outlined in this document.

Unlike the other land surface models, it is important to note that AquaCrop can be run only at a daily time step. As opposed to the AquaCrop GUI or standalone executables, AquaCrop does not rely on input climate files (.CLI, .ETo, .Tnx, .PLU) or soil files (.SOL) when run within LIS. This information is provided via the coupling to LIS. However, it still requires the CO_2 file (.CO2), a crop file (.CRO, stored in the `AC_INPUT/crop_params`) and (optional) management (.MAN) and irrigation (.IRR) files.

```
#-----------------------LAND SURFACE MODELS-------------------------
#AquaCrop.7.2
AquaCrop.7.2 soil parameter table:          ./INPUT/SOILPARM_AC72.TBL
AquaCrop.7.2 model timestep:                "1da"
AquaCrop.7.2 restart output interval:       "1mo"
AquaCrop.7.2 restart file:                  none
AquaCrop.7.2 restart file format:           netcdf
AquaCrop.7.2 reference height of T and q:   2.0
AquaCrop.7.2 reference height of u and v:   10.0
AquaCrop.7.2 initial liquid soil moistures: 0.33 0.33
AquaCrop.7.2 input path:                    "./INPUT/AC_INPUT/"
AquaCrop.7.2 CO2_Filename:                  "MaunaLoa.CO2"
AquaCrop.7.2 crop library directory:        "./INPUT/AC_INPUT/crop_params/"
AquaCrop.7.2 Management_Filename:           "NearOpt.MAN"
AquaCrop.7.2 Irrigation_Filename:           "sprinkler.IRR"
##Simulation and crop period
AquaCrop.7.2 starting day of sim period:     1
AquaCrop.7.2 starting month of sim period:   1
AquaCrop.7.2 starting day of crop period:    22
AquaCrop.7.2 starting month of crop period:  3
```

3.1 Soil parameters

The parameter table is for now only available for the STATSGOFAO scheme. The soil hydraulic parameters correspond to the default values of AquaCrop for each textural class and are stored in the SOILPARM_AC72.TBL file. WP, SAT, FC are volumetric water contents $[m^3\ m^{-3}]$ and INFRATE is the saturated hydraulic conductivity (K_{sat}) expressed in mm/day. SD, CL, and SI are the percentages of sand, clay, and silt, as given by the default values in AquaCrop. The organic matter content (OC) is set to a constant value for all classes. Note that all non-cropland type texture classes (13 through 19) are set to default parameters, and these soil types should not be used.

```
Soil Parameters
19,1  WP    SAT    FC   INFRATE SD    CL    SI     OC '
1,    0.06, 0.36, 0.13, 1500, 0.92, 0.03, 0.05, 0.258,  'SAND'
2,    0.08, 0.38, 0.16, 800,  0.82, 0.06, 0.12, 0.258,  'LOAMY SAND'
3,    0.10, 0.41, 0.22, 500,  0.58, 0.10, 0.32, 0.258,  'SANDY LOAM'
4,    0.13, 0.46, 0.33, 150,  0.17, 0.13, 0.70, 0.258,  'SILT LOAM'
5,    0.09, 0.43, 0.33, 50,   0.10, 0.05, 0.85, 0.258,  'SILT'
6,    0.15, 0.46, 0.31, 250,  0.43, 0.18, 0.39, 0.258,  'LOAM'
7,    0.20, 0.47, 0.32, 125,  0.58, 0.27, 0.15, 0.258,  'SANDY CLAY LOAM'
8,    0.23, 0.52, 0.44, 120,  0.10, 0.34, 0.56, 0.258,  'SILTY CLAY LOAM'
9,    0.23, 0.50, 0.39, 100,  0.32, 0.34, 0.34, 0.258,  'CLAY LOAM'
10,   0.27, 0.50, 0.39, 75,   0.52, 0.42, 0.06, 0.258,  'SANDY CLAY'
11,   0.32, 0.54, 0.50, 15,   0.06, 0.47, 0.47, 0.258,  'SILTY CLAY'
12,   0.32, 0.54, 0.50, 15,   0.22, 0.58, 0.20, 0.258,  'CLAY'
13,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'ORGANIC MATERIAL'
14,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'WATER'
15,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'BEDROCK'
16,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'OTHER(land-ice)'
17,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'PLAYA'
18,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'LAVA'
19,   0.39, 0.55, 0.54, 15,   0.22, 0.58, 0.20, 0.258,  'WHITE SAND'
```

3.2 Meteorological forcings

The current implementation has been tested with meteorological forcings extracted from MERRA-2, ERA5, and NLDAS2 (test case). The reference evapotranspiration (ET_o), required as input for AquaCrop, is derived within LIS and passed to the crop model using the Penman-Monteith equation (FAO Irrigation and drainage paper 56). Note that the options `AquaCrop.7.2 reference height of T and q:` (temperature and humidity) and `AquaCrop.7.2 reference height of u and v:` (wind speed fields) should be aligned with the forcings used for the simulation. In case of forcings at a height larger than 2 m, a correction is applied (lapse-rate for temperature and wind speed correction). Please note that a reference climatology is used for the parameterization of the fertility functions (see section 2.3).

3.3 AquaCrop simulation and crop period

The 'AquaCrop simulation period' is hard coded to correspond to the length of a calendar year (365 or 366 days). Within a 'LIS simulation period' (ranging from the defined start and end time in the `lis.config`) there can be several 'AquaCrop simulation periods'. Within an 'AquaCrop simulation period', only one crop cycle is possible (no double cropping allowed). The start of the 'AquaCrop simulation period' is defined in the `lis.config` file. This is useful in the case of simulations in the southern hemisphere or for the evaluation of a crop grown in winter. The start day of the cropping period then corresponds to the planting/sowing of the annual crop. The length of the cropping period is defined by the crop parameters stored in the crop file.

3.4 Optional AquaCrop files (management and irrigation)

The management (*.MAN) and irrigation files (*.IRR) are not essential to run AquaCrop. If they are not specified in the `lis.config`, AquaCrop will run considering that the .MAN and .IRR files are '(None)'. All irrigation options are available and tested. For the management file, only a simulation with soil fertility stress has been tested. For other options, the user should test the functionalities and assess if the output is as expected.

3.5 Restarting

The restart option was tested for several test cases, incl. crops calibrated in Growing Degree Days (GDD, thermal units) (flowering, irrigation, fertility stress) and in calendar days, and at several times (before planting, during early growth, mid season, late season, post-season). However, due to the complexity of AquaCrop's global variables, it is recommended to restart the model at the beginning of the 'AquaCrop simulation period', or to test if a restarted simulation aligns with a coldstart for the user's specific application.

3.6 Runtime

In version AquaCrop version 7.2, the full temperature record of the next 'AquaCrop simulation period' needs to be read-in beforehand to compute the length of the growing stages. This process takes about 15 min (for MERRA-2 forcings) and the time is relatively independent of the domain size/number of processors.

4 Test case

The LIS/LDT-AquaCrop test cases are based on the NASA test cases. The domain consists of 22 x 28 pixels at a 0.25° x 0.25° lat-lon resolution. Two runs are performed: (1) an "LSM parameter processing" LDT run, preparing the domain and parameters into a netcdf file (`lis_input.d01.nc`), and (2) a deterministic LIS run. The test cases are stored under the `/lis/testcases/` and `ldt/testcases/` folders in the source code, along with README files. The input data can be found in a Zenodo repository.

5 Future research

The current implementation of AquaCrop within LIS does not yet allow to use all the AquaCrop simulation options. We provide a non-exhaustive list of future developments.
Soil

- different soil texture classes, e.g. a topsoil and subsoil layer of different textural class
- the inclusion of a groundwater table to account for capillary rise
- the addition of an impermeable deeper layer for shallow soil profiles
- salinity

Crop

- crop maps read in LDT with corresponding calibrated crop files**
- perennial crops (grasslands)
- double cropping (summer and winter crops)
- flexible planting/sowing dates (based on temperature or rainfall criterion)

Management

- inclusion of irrigation practice maps
- fertility maps
- weeds

Ensemble runs and data assimilation

- coupling to SMAP DA*
- coupling to Sentinel-1 backscatter DA**
- ensemble runs* (perturb meteorological forcings, soil moisture state, irrigation threshold)

* currently being implemented and available shortly.
** in the research plans of the KU Leuven team, expected to be available in the coming years.