University of Virginia Forest Model Enhanced

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How to Run UVAFME

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Contents

UVAFME is written in Fortran(90), and can be run on a Linux platform and easily compiled on a Linux system with the ifort compiler. Each site simulated in UVAFME is independent from other sites. Thus, when simulating multiple sites, UVAFME runs them in succession. This setup means that UVAFME simulations may be run 'interactively' (i.e. from an active command line session), or distributed across several linux nodes via a job manager such as SLURM.

1 Model Inputs

1.1 Files Needed for UVAFME

In order to successfully run UVAFME, all the necessary files must be present in the correct directories and with the correct naming system. These files/folders must be present (though they need not be named as below):

1. *UVAFME.exe*: the UVAFME executable file for the model
2. *file_list.txt*: the text file that tells the model where the input/output directories are located
3. **input_data**: the input directory
4. **output_data**: the output directory

1.1.1 File list file

The file list text file is a Fortran namelist file, which produces format-free inputs of groups of variables, or a selection of a group of variables. This file specifies the path and directories for the input and output folders (Fig. 1). As a namelist file, the parameters **must** match those inside the model. The values on the right side (i.e. those in quotes in Fig. 1) can be changed to match the path/name of the input and output directories. If these files cannot be found, an I/O error will be thrown and the model will not run. If there is a problem with the file list file (e.g. the model cannot find it or read it), default folder names ('input_data' and 'output_data') will be used, and a message will be printed to the screen as such.

The directories within the file list should contain the input/output files as follows (see below for description of each file):

- **input_directory**
  - *UVAFME2018_runtime.txt*

```
&filenames
input_directory='input_data'
output_directory='output_data'
climate_directory='input_data'
site_directory='input_data'
sitelist_directory='input_data'
GCM_directory='input_data'
/

```

Figure 1: Example of a *file_list.txt* file. As with all Fortran namelist files, the filelist file **must** start with "&filenames" (the name of the namelist in the model) and end with "/". The parameters for the input/output directories (left side) should **not** be in quotes, whereas the path/name of the folder (right side) should be in quotes.

  - *UVAFME2018_rangelist.csv*
  - *UVAFME2018_specieslist.csv*
  - *UVAFME2018_litterpars.csv*

- **output_directory**
  - All output files
- **climate_directory**
  - *UVAFME2018_climate.csv*
  - *UVAFME2018_climate_stddev.csv*
  - *UVAFME2018_climate_ex.csv*
  - *UVAFME2018_climate_ex_stddev.csv*
- **site_directory**
  - *UVAFME2018_site.csv*
- **sitelist_directory**
  - *UVAFME2018_sitelist.csv*
- **GCM_directory** (optional)
  - *UVAFME2018_climate_GCM.csv*

As in Fig. 1, all input files may be in the same input directory, and thus all input directory parameters would be set to the same path/folder. However, these input files need not be in the same directory. The ability to break the input files up into separate directories allows for easier batch runs of multiple sites (see Section 2).

1.1.2 Input files needed

For a basic run, these ten files must be present in the appropriate input directory:

1. *UVAFME2018_runtime.txt*
2. *UVAFME2018_sitelist.csv*
3. *UVAFME2018_site.csv*
4. *UVAFME2018_rangelist.csv*
5. *UVAFME2018_specieslist.csv*
6. *UVAFME2018_climate.csv*
7. *UVAFME2018_climate_stddev.csv*
8. *UVAFME2018_climate_ex.csv*
9. *UVAFME2018_climate_ex_stddev.csv*
10. *UVAFME2018_litterpars.csv*

An optional *UVAFME2018_climate_GCM.csv* file can be used for a non-linear climate change application (i.e. from a GCM file) (Section 1.3). These files **must** have this exact naming convention or UVAFME will not recognize them and an I/O runtime error will occur.

1.2 Description of Input Files

1.2.1 Runtime File

The *UVAFME2018_runtime.txt* file sets up runtime parameters which are the same across all sites run. Such parameters include how many plots to simulate per site and their size, the number of years to run the simulations, as well as parameters for implementing climate change. The runtime file is a Fortran namelist file (Fig. 2; see above description of filelist file). Thus,

```
&uvafme
! variables that can be changed
!incr/decr variables are total change, and both should be positive
!incr_tmin_by=3
!incr_tmax_by=3
!incr_precip_by=0
!decr_tmin_by
!decr_tmax_by
!decr_prec_by
!incr_or_decr_prcp=incr
!incr_or_decr_temp=incr

year_print_interval=5
fixed_seed=.true.
debug=.false.

numyears=100
numplots=200
plotsize=500
growth_thresh=0.03
maxtrees=1000
maxcells=30

with_clim_change=.false.
use_gcm=.true.
linear_cc=.false.
gcm_duration=96
start_gcm=0
end_gcm=96
tree_level_data=.false.
plot_level_data=.false.
daily_soil_data = .false.
/
```

Figure 2: Example of a *UVAFME2018_runtime.txt* file. Lines that are commented out with a "!" will not be read and those variables will take on the default parameters. As with all Fortran namelist files, the runtime file **must** start with "&uvafme" and end with "/".

the parameter names in the input runtime file **must** match the parameter names set up inside the model or an I/O error will occur, and the default values for all subsequent parameters will be used.

Runtime parameters that can be changed via the runtime file can be seen in Table 1. The climate change-related parameters have checks intended to prevent unintended errors:

1. If using a climate change application (i.e. **with_clim_change** = TRUE) an error is thrown if the duration (i.e. **gcm_duration**) is 0.0.

2. If a linear climate change application is being used, an error is thrown if all of the **incr_** or **decr_tmin/tmax/precip_by** values are 0.0.

3. Errors are thrown if **incr_tmin_by** or **incr_tmax_by** are negative when **incr_or_decr_temp** is 'incr'.

4. Errors are thrown if **decr_tmin_by** or **decr_tmax_by** are 0.0 when **incr_or_decr_temp** is 'decr'.

5. Errors are thrown if **incr_precip_by** is negative when **incr_or_decr_precip** is 'incr'.

6. Errors are thrown if **decr_precip_by** is 0.0 when **incr_or_decr_precip** is 'decr'.
7. The decrease-by values are intended to be input as positive values so if any **decr_tmin/tmax/precip_by** values are negative when a decrease is intended, then the value is changed to positive.

Otherwise, for linear climate change applications, the annual temperature and precipitation change is calculated as:

$$t' = \begin{cases} \frac{incr\_t\_by}{gcm\_duration+1}, & incr\_or\_decr\_temp = \text{`incr'} \\ \frac{-decr\_t\_by}{gcm\_duration+1}, & incr\_or\_decr\_temp = \text{`decr'} \end{cases} \tag{1}$$

and

$$p' = \begin{cases} \frac{incr\_precip\_by}{gcm\_duration+1}, & incr\_or\_decr\_prcp = \text{`incr'} \\ \frac{-decr\_precip\_by}{gcm\_duration+1}, & incr\_or\_decr\_prcp = \text{`decr'} \end{cases} \tag{2}$$

where t' is the annual minimum or maximum temperature change (°C), p' is the annual precipitation change (proportional), and $incr\_t\_by$ and $decr\_t\_by$ are the overall linear **incr_tmin/tmax_by** or **decr_tmin/tmax_by** values.

1.2.2 Sitelist File

The *UVAFME2018_sitelist.csv* file sets up the sites to be run in a simulation, as well as site-specific parameters such as fire probability and intensity, windthrow probability, and elevation of a site. While each of these parameters is generally also present in the site file (*UVAFME2018_site.csv*) or is a default parameter in the model, the setup here allows for sites to be parameterized with "base" conditions in the Site file, and run with different parameters using the Sitelist file. This setup also allows the same site to be run multiple times with different parameters values (e.g. the same site run a multiple elevations). The Sitelist file must have the site IDs of each site to be run present in the **siteID** column, but all other columns may be left blank. Any other parameter left blank in the Sitelist file will take the values present in the Site file or default values in the model.

1.2.3 Specieslist File

The *UVAFME2018_specieslist.csv* file contains the species-level parameters for each species to be simulated. These parameters include average maximum age, DBH, and height, tolerance levels to shade, drought and nutrients, and seedling/seedbank parameters (Table 3). Unless otherwise noted, most

Table 1: Parameters set up in runtime file.

Parameter Name	Description	Default Value
incr_tmin_by	amount to increase $\bar{t}_{min}$ under linear climate change application	0.0 °C
incr_tmax_by	amount to increase $\bar{t}_{max}$ under linear climate change application	0.0 °C
incr_precip_by	proportion to increase $\bar{p}$ under linear climate change application	0.0
decr_tmin_by	amount to decrease $\bar{t}_{min}$ under linear climate change application	0.0 °C
decr_tmax_by	amount to decrease $\bar{t}_{max}$ under linear climate change application	0.0 °C
decr_precip_by	proportion to decrease $\bar{p}$ under linear climate change application	0.0
incr_or_decr_prcp	whether or increase or decrease $\bar{p}$ under linear climate change application	'decr'
incr_or_decr_temp	whether or increase or decrease $\bar{t}$ under linear climate change application	'incr'
year_print_interval	interval at which to print output data	10 years
fixed_seed	whether random seed is default (.true.) or generated (.false.)	.false.
debug	whether climate random seeds are default (.true.) or generated (.false.)	.false.
numyears	number of years to run model	1000
numplots	number of plots to run per site	200
plotsize	size of plot	500 m^2
growth_thresh	minimum growth threshold (δDBH_{min})	0.03
maxtrees	maximum possible trees per plot	900
maxcells	maximum possible rows/columns for plot grid	30
with_clim_change	whether or not to run with climate change application	.false.
use_gcm	whether or not to use an input GCM file for climate change application	.false.
linear_cc	whether or not to use a linear climate change application	.false.
gcm_duration	the length of the climate change application	0 years
start_gcm	the start year of the input GCM file	0
end_gcm	the end year of the input GCM file	100
tree_level_data	whether to print out tree-level output data	.false.
plot_level_data	whether to print out plot-level output data	.false.

Table 2: Sitelist file parameters.

Column Number	Column Name	Description	Units
1	**siteID**	site ID for site - must include for runs	integer
2	**runID**	run ID for site	integer
3	**altitude**	altitude for site	meters
4	**fire_level**	fires in 1000 years	1000/FRI
5	**wind_level**	windthrow events in 1000 years	1000/WRI

parameters are derived from a scientific literature review (e.g. Burns and Honkala (1990)).

To derive the parameters s and g, equation A4 from Botkin et al. (1972) is used. The parameter g is calculated using input parameters of H_{max}, DBH_{max}, and AGE_{max}:

$$g = \frac{4H_{max}}{AGE_{max}} \left[\ln\Big(2(2DBH_{max} - 1)\Big) + \frac{\alpha}{2\ln(e_1)} - f \ln\left(\frac{a \times c}{b \times d}\right) \right] \tag{3}$$

where:

$$\alpha = 1 - 1.37/H_{max} \tag{4}$$

$$e_1 = \frac{\frac{9}{4} + 0.5\alpha}{(4DBH_{max}^2 + 2\alpha DBH_{max} - \alpha)} \tag{5}$$

$$a = 3 + \alpha - \sqrt{\alpha^2 + 4\alpha} \tag{6}$$

$$b = 3 + \alpha + \sqrt{\alpha^2 + 4\alpha} \tag{7}$$

$$c = 4DBH_{max} + \alpha + \sqrt{\alpha^2 + 4\alpha} \tag{8}$$

$$d = 4DBH_{max} + \alpha - \sqrt{\alpha^2 + 4\alpha} \tag{9}$$

and

$$f = \frac{\alpha + 0.5\alpha^2}{\sqrt{\alpha^2 + 4\alpha}} \tag{10}$$

The parameter g is further modified within the model depending on shade tolerance, such that $g = g \times l$, where l ranges from 1.1 to 1.25 depending on

Table 3: Specieslist file parameters.

Column Number	Column Name	Description	Units	Data Source
1	**Group**	genus group number	integer	
2	**Genus**	genus of tree	character	
3	**Individual**	individual species number	integer	
4	**Scientific_Name**	latin name of species	character	
5	**English_Name**	common name of species	character	
6	AGE_{max}	average maximum age	years	
7	DBH_{max}	average maximum DBH	cm	
8	H_{max}	average maximum height	m	
9	s	initial height-diameter relationship	m cm^{-1}	Equation A4 from Botkin, Janak, and Wallis (1972) (Fig. 3 below)
10	g	growth parameter		Equation A4 from Botkin et al. (1972) (Eq. 3 below)
11	**bulk**	bulk density of wood	tonnes m^{-3}	Miles and Smith 2008
12	D_L	Scalar parameter for LA $D_{cbb}{}^2$ relationship		default = 0.15§
13	LMA	leaf mass per area	tonnes C ha^{-1}	default 0.5 for evergreen; 0.316 for deciduous
14	GDD_{min}	minimum degree day threshold (5°C base)	degree-days	
15	GDD_{opt}	optimum degree day threshold (5°C base)	degree-days	
16	GDD_{max}	maximum degree day threshold (5°C base)	degree-days	
17	**shade**	relative shade tolerance	1-5; 5 = least tolerant	
18	**drought**	relative drought tolerance	1-6; 6 = least tolerant	
19	**flood**	relative flood tolerance	1-6; 6 = least tolerant	
20	**permf**	relative permafrost tolerance	1-3; 3 = least tolerant	
21	**nutrient**	relative low nutrient tolerance	1-3; 3 = least tolerant	
22	**bark_thick**	bark thickness per cm DBH	cm bark cm DBH^{-1}	Keane, Loehman, and Holsinger (2011)
23	**fire_regen**	relative ability of plant to resprout, regrow, or produce seed after fire	1-6; 1 = high reproduction after fire; 6 = low reproduction after fire	
24	**stress**	relative ability to withstand low growth from stress	1-5; 5 = least tolerant	
25	**death**	relative ability to live to AGE$_{max}$	1-3; 3 = least likely	
26	**Evergreen**	evergreen or deciduous	evergreen = 1; deciduous = 0	
27	**litter_class**	integer for litter class		
28	**invader**	probability of inseeding from outside plot		wind dispersed seeds = 1
29	**seed**	seed numbers from within plot	seeds m^{-2}	e.g. cones ≈ 1; samaras ≈ 10; wind dispersed ≈ 100
30	**sprout**	average sprouts produced per individual		
31	**layering**	ability of species to reproduce by layering	0 or 1	
32	**org_resp**	relative ability of species to reproduce on deep organic layers	1-3; 3 = least tolerant	
33	NDE	proportion seedbank lost annually	0 to 1	
33	NDS	proportion seedling bank lost annually	0 to 1	
34	**species_id**	unique eight character code consisting of first four letters of genus and first four letters of species		

§: D_L is further modified based on the species-specific shade tolerance (**shade**, tol_{shade}); $D_L = adj \times tol_{shade}$, where adj ranges from 1.5 to 1.7 depending on shade tolerance.

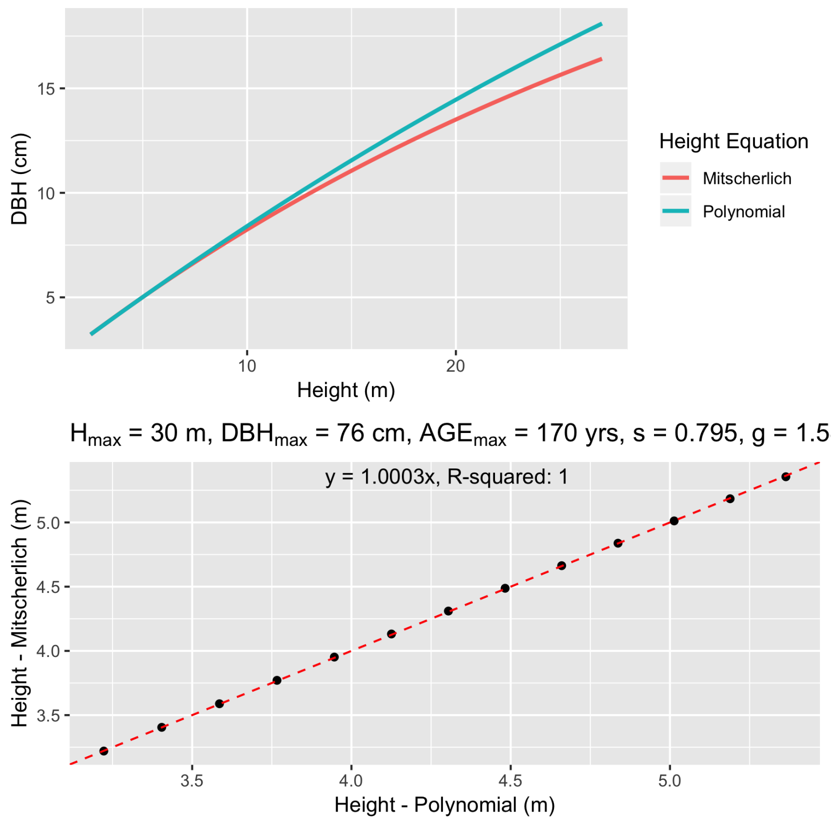

Figure 3: Example derivation of parameter s for a species with H_{max} = 30 m, DBH_{max} = 76 cm, and AGE_{max} = 170 years.

shade tolerance. The parameter s is derived by regressing the initial height-diameter (DBH = 2.5 to 5.5 cm) relationship calculated using Mitscherlich's equation (Botkin et al. (1972); Eq. 11) with different s values and that using a polynomial equation (Eq. 12) until the slope of a line with y-intercept 0 is closest to 1.0 and the R^2 is closest to 1.0 (Fig. 3).

$$H_m = 1.3 + (H_{max} - 1.3)(1 - e^{\frac{-sDBH}{H_{max}-1.3}}) \tag{11}$$

$$H_p = (137 + b_2 DBH - b_3 DBH^2)/100 \tag{12}$$

where $b_2 = 2\frac{H_{max_{cm}} - 137}{DBH_{max}}$ and $b_3 = \frac{H_{max_{cm}} - 137}{DBH^2_{max}}$.

1.2.4 Site File

The *UVAFME2018_site.csv* file contains site-specific parameters for each site, including latitude, longitude, topography, soil characteristics, disturbance

Table 4: Site file parameters.

Column Number	Column Name	Description	Units	Data Source
1	**site**	unique site ID	integer	user generated
2	**latitude**	latitude of site	decimal degrees	
3	**longitude**	longitude of site	decimal degrees	
4	**name**	site name	character	
5	**region**	region of site	character	
6	**elevation**	elevation of site	meters	DEM
7	**slope**	slope of site	degrees	DEM
8	**aspect**	aspect of site	degrees	DEM
9	**a_sat**	saturation capacity of mineral layer	volumetric	site description; soil maps
10	**a_fc**	saturation capacity of mineral layer	volumetric	site description; soil maps
11	**fire_prob**	fires in 1000 years	1000/FRI	fire history maps; literature; site descriptions
12	**wind_prob**	windthrow events in 1000 years	1000/WRI	literature; site descriptions
13	**gcm_year**	estimated stand age of site used to determine when to start climate change application	years	site description; literature; fire history
14-25	**tmp_lapse_month**	temperature lapse rate used to adjust monthly minimum and maximum temperatures according to altitude	°C km^{-1}	
26-27	**prcp_lapse_month**	precipitation lapse rate used to adjust monthly precipitation according to altitude	mm km^{-1}	

probabilities, and values for modifying temperature and precipitation if the elevation of the site is changed (i.e. climatic lapse rates) (Table 4). As with all other site-related files, the **siteID** column must match the site ids in all other files.

1.2.5 Rangelist File

The *UVAFME2018_rangelist.csv* file determines which species are eligible for colonization and growth at each site (Table 5). The column names are the species ids (8-character IDs set up in the *UVAFME2018_specieslist.csv* file), and the rows are each site. If a species is present at a site then the column/row will have a 1, and if the species is absent the column/row will have a 0. This is the only csv file where the column names are explicitly read by UVAFME and must match the species ids as set up in the Specieslist file. The order must also match the order of the Specieslist file. The presence/absence of each species is generally derived from species range maps (e.g. Little 1971) or site descriptions.

1.2.6 Climate Files

The *UVAFME2018_climate.csv*, *UVAFME2018_climate_stddev.csv*, *UVAFME2018_climate_ex.csv*, and *UVAFME2018_climate_ex_stddev.csv* files contain the average and standard deviations of monthly minimum and maximum temperatures, precipitation, and cloud cover for each site (Tables 6 - 9). These data are generally derived from at least 30 years of historical

Table 5: Rangelist file parameters.

Column Number	Column Name	Description	Units
1	**site**	unique site ID	integer
2	**latitude**	latitude of site	decimal degrees
3	**longitude**	longitude of site	decimal degrees
4 ... $n_{species}$	unique species ID	presence or absence of species at site	0: absent; 1: present

Table 6: *UVAFME2018_climate.csv* file parameters.

Column Number	Column Name	Description	Units
1	**site**	unique site ID	integer
2	**latitude**	latitude of site	decimal degrees
3	**longitude**	longitude of site	decimal degrees
4 - 15	**tmin_month**	mean monthly minimum temperature	°C
16 - 27	**tmax_month**	mean monthly maximum temperature	°C
28 - 39	**prcp_month**	monthly precipitation	mm

climate data and are used to generate monthly and daily weather conditions within UVAFME.

1.2.7 Litter Parameters File

The *UVAFME2018_litterpars.csv* file contains the litter parameters used in the decomposition routine (Section **??**).

1.3 Optional Input Files

1.3.1 Climate GCM File

UVAFME has the option of applying climate change in the form of changing monthly minimum and maximum temperatures and precipitation (Section

Table 7: *UVAFME2018_climate_stddev.csv* file parameters.

Column Number	Column Name	Description	Units
1	**site**	unique site ID	integer
2	**latitude**	latitude of site	decimal degrees
3	**longitude**	longitude of site	decimal degrees
4 - 15	**tmin_std_month**	standard deviation of monthly minimum temperature	°C
16 - 27	**tmax_std_month**	standard deviation of monthly maximum temperature	°C
28 - 39	**prcp_std_month**	standard deviation of monthly precipitation	mm

Table 8: *UVAFME2018_ex_climate.csv* file parameters.

Column Number	Column Name	Description	Units
1	**site**	unique site ID	integer
2	**latitude**	latitude of site	decimal degrees
3	**longitude**	longitude of site	decimal degrees
4 - 15	**cld_month**	mean monthly cloudiness	%

Table 9: *UVAFME2018_climate_ex_stddev.csv* file parameters.

Column Number	Column Name	Description	Units
1	**site**	unique site ID	integer
2	**latitude**	latitude of site	decimal degrees
3	**longitude**	longitude of site	decimal degrees
4 - 15	**cld_std_month**	standard deviation of mean monthly cloudiness	%

Table 10: *UVAFME2018_litterpars.csv* file parameters. All parameter values are taken from Bonan (1990) and Pastor and Post (1985).

Column Number	Column Name	Description	Units
1	**name**	cohort name	character
2	**InitialN**	initial N percent	0 to 1
3	**gImmob_gwtloss**	g N immobilized per g weight loss	g g^{-1}
4	**critN**	percent N at which a decaying litter cohort is transferred to well-decayed wood or humus	0 to 1
5	**litter_type**	litter type ID	integer
6	**destination**	if cohort is transferred to well-decayed wood or humus	1 = humus; 2 = well-decayed wood
7	**initialLignin**	initial percent lignin of cohort	0 to 1
8	**ligParA**	lignin parameter A	
9	**ligParB**	lignin parameter B	
10	**Ash**	ash correction factor	0 to 1

Table 11: *UVAFME2018_climate_GCM.csv* file parameters.

Column Number	Column Name	Description	Units
1	**site**	unique site ID	integer
2	**latitude**	latitude of site	decimal degrees
3	**longitude**	longitude of site	decimal degrees
4	**year**	year of climate change application	integer
5-16	**tmin_month**	mean monthly minimum temperature	°C
17-28	**tmax_month**	mean monthly maximum temperature	°C
29-40	**prcp_month**	mean monthly precipitation	mm

??). The input file required for this application is the *UVAFME2018_climate_GCM.csv* file and contains the site ID, year,, and monthly climate variables for each year of the climate change application (Table 11). Data for this file can be taken from output from earth system models or created by the user.

2 Running the Model

To run UVAFME interactively from the command line simply enter:

```
./UVAFME.exe file_list.txt
```

This will run the model at each site specified in the Sitelist file, in order. Once the model has finished running, the output files will be in the **output_data** directory. These output files will be rewritten every time the model is run, so be sure to save them elsewhere or with a different name (if desired) before re-running.

As mentioned above, the independence of the UVAFME sites allows for batches of sites to be distributed across several nodes of a computing cluster. This can be done iteratively, using different *file_list.txt* files which point the model to different input/output directories. It can also be accomplished using a job manager such as SLURM.

3 Model Outputs

3.1 Standard Outputs

3.1.1 Species and Genus Output

UVAFME outputs two standard files related to species- and genus-level forest characteristics, the *Species_Data.csv* file and the *Genus_Data.csv* file. For both files, at the specified year print interval (Section 1), the average (i.e. across plot) conditions for each species or genus are printed. If a species is specified as absent at a site in the input Rangelist file, the row is still printed but −999's (i.e. the NA signifier) are printed in the data columns.

UVAFME also outputs species- and genus-level files on the characteristics of trees that died each year, the *Dead_Species_Data.csv* file and the *Dead_Genus_Data.csv* file. For both files, at the specified year print interval (Section 1), the average (i.e. across plot) conditions for trees that died from each species or genus are printed. If a species is specified as absent at a site in the input Rangelist file, the row is still printed but −999's are printed in the data columns.

Table 12: *Species_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**genus**	the genus of the species	character
5	**species**	the species ID	character
6-16	**[xx] to [xx]**	stem density in DBH bins	trees ha^{-1}
17-27	**[xx] to [xx] biom**	biomass in DBH bins	tC ha^{-1}
28	**degday_resp**	growth response to temperature	0 to 1
29	**drought_resp**	growth response to drought	0 to 1
30	**shade_resp**	growth response to shade	0 to 1
31	**perm_resp**	growth response to permafrost	0 to 1
32	**nutrient_resp**	growth response to nutrients	0 to 1
33	**max_diam**	maximum DBH	cm
34	**mean_diam**	average DBH	cm
35	**mean_age**	average tree age	years
36	**max_hgt**	maximum height	m
37	**leaf_area_ind**	leaf area	m^2 m^{-2}
38	**basal_area**	basal area	m^2 ha^{-1}
39	**basal_sd**	standard deviation of basal area	m^2 ha^{-1}
40	**total_biomC**	biomass	tC ha^{-1}
41	**biomC_sd**	standard deviation of biomass	tC ha^{-1}

Table 13: *Genus_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**genus**	genus name	character
5-15	**[xx] to [xx]**	stem density in DBH bins	trees ha^{-1}
16-26	**[xx] to [xx] biom**	biomass in DBH bins	tC ha^{-1}
27	**degday_resp**	growth response to temperature	0 to 1
28	**drought_resp**	growth response to drought	0 to 1
29	**shade_resp**	growth response to shade	0 to 1
30	**perm_resp**	growth response to permafrost	0 to 1
31	**nutrient_resp**	growth response to nutrients	0 to 1
32	**max_diam**	maximum DBH	cm
33	**mean_diam**	average DBH	cm
34	**mean_age**	average tree age	years
35	**max_hgt**	maximum height	m
36	**leaf_area_ind**	leaf area index	m^2 m^{-2}
37	**basal_area**	basal area	m^2 ha^{-1}
38	**basal_sd**	standard deviation of basal area	m^2 ha^{-1}
39	**total_biomC**	biomass	tC ha^{-1}
40	**biomC_sd**	standard deviation of biomass	tC ha^{-1}

Table 14: *Dead_Species_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**genus**	the genus of the species	character
5	**species**	the species ID	character
6	**degday_death**	biomass of trees that died from temperature stress	tC ha^{-1}
7	**drought_death**	biomass of trees that died from drought stress	tC ha^{-1}
8	**shade_death**	biomass of trees that died from shade stress	tC ha^{-1}
9	**perm_death**	biomass of trees that died from permafrost	tC ha^{-1}
10	**nutrient_death**	biomass of trees that died from nutrient stress	tC ha^{-1}
11	**fire_death**	biomass of trees that died from wildfire	tC ha^{-1}
12	**wind_death**	biomass of trees that died from windthrow	tC ha^{-1}
13	**mean_diam**	average DBH	cm
14	**total_biomC**	average biomass	tC ha^{-1}
15	**biomC_sd**	standard deviation of biomass	tC ha^{-1}

Table 15: *Dead_Genus_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**genus**	genus anme	character
5	**degday_death**	biomass of trees that died from temperature stress	tC ha^{-1}
6	**drought_death**	biomass of trees that died from drought stress	tC ha^{-1}
7	**shade_death**	biomass of trees that died from shade stress	tC ha^{-1}
8	**perm_death**	biomass of trees that died from permafrost	tC ha^{-1}
9	**nutrient_death**	biomass of trees that died from nutrient stress	tC ha^{-1}
10	**fire_death**	biomass of trees that died from wildfire	tC ha^{-1}
11	**wind_death**	biomass of trees that died from windthrow	tC ha^{-1}
12	**mean_diam**	average DBH	cm
13	**total_biomC**	average biomass	tC ha^{-1}
14	**biomC_sd**	standard deviation of biomass	tC ha^{-1}

3.1.2 Across-Species/Genus Output

UVAFME outputs a file related to across-species/genus forest characteristics, the *Total_Plot_Values.csv* file. For this file, at the specified year print interval (Section 1), the average (i.e. across plot) conditions for all genera are printed.

Table 16: *Total_Plot_Values.csv* file variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**gdd_death**	biomass loss due to low temperature stress	tC ha^{-1}
5	**drought_death**	biomass loss due to drought stress	tC ha^{-1}
6	**shade_death**	biomass loss due to shade stress	tC ha^{-1}
7	**perm_death**	biomass loss due to permafrost stress	tC ha^{-1}
8	**nutrient_death**	biomass loss due to low nutrient stress	tC ha^{-1}
9	**fire_death**	biomass loss due to fire	tC ha^{-1}
10	**wind_death**	biomass loss due to windthrow	tC ha^{-1}
11	**gddresp_1**	growth response to temperature for trees 0-10 m in height	0 to 1
12	**droughtresp_1**	growth response to drought for trees 0-10 m in height	0 to 1
13	**shaderesp_1**	growth response to shade for trees 0-10 m in height	0 to 1
14	**permresp_1**	growth response to permafrost for trees 0-10 m in height	0 to 1
15	**nutrientresp_1**	growth response to nutrients for trees 0-10 m in height	0 to 1
16	**gddresp_2**	growth response to temperature for trees 10-20 m in height	0 to 1
17	**droughtresp_2**	growth response to drought for trees 10-20 m in height	0 to 1
18	**shaderesp_2**	growth response to shade for trees 10-20 m in height	0 to 1
19	**permresp_2**	growth response to permafrost for trees 10-20 m in height	0 to 1
20	**nutrientresp_2**	growth response to nutrients for trees 10-20 m in height	0 to 1
21	**gddresp_3**	growth response to temperature for trees 20+ m in height	0 to 1
22	**droughtresp_3**	growth response to drought for trees 20+ m in height	0 to 1
23	**shaderesp_3**	growth response to shade for trees 20+ m in height	0 to 1
24	**permresp_3**	growth response to permafrost for trees 20+ m in height	0 to 1
25	**nutrientresp_3**	growth response to nutrients for trees 20+ m in height	0 to 1
26	**gddlim_1**	proportion trees most limited by temperature - 0-10 m	0 to 1
27	**droughtlim_1**	proportion trees most limited by drought - 0-10 m	0 to 1
28	**shadelim_1**	proportion trees most limited by shade - 0-10 m	0 to 1
29	**permlim_1**	proportion trees most limited by permafrost - 0-10 m	0 to 1
30	**nutrientlim_1**	proportion trees most limited by nutrients - 0-10 m	0 to 1
31	**gddlim_2**	proportion trees most limited by temperature - 10-20 m	0 to 1
32	**droughtlim_2**	proportion trees most limited by drought - 10-20 m	0 to 1
33	**shadelim_2**	proportion trees most limited by shade - 10-20 m	0 to 1
34	**permlim_2**	proportion trees most limited by permafrost - 10-20 m	0 to 1
35	**nutrientlim_2**	proportion trees most limited by nutrients - 10-20 m	0 to 1
36	**gddlim_3**	proportion trees most limited by temperature - 20+ m	0 to 1
37	**droughtlim_3**	proportion trees most limited by drought - 20+ m	0 to 1
38	**shadelim_3**	proportion trees most limited by shade - 20+ m	0 to 1
39	**permlim_3**	proportion trees most limited by permafrost - 20+ m	0 to 1
40	**nutrientlim_3**	proportion trees most limited by nutrients - 20+ m	0 to 1
41	**Loreys_height**	average Loreys height	m
42	**Loreys_height_sd**	standard deviation of Loreys height	m
43	**Max_height**	average maximum height	m
44	**Max_height_sd**	standard deviation of maximum height	m
45	**Total_plot_biomc**	average biomass	tC ha^{-1}
46	**Total_plot_biomc_sd**	standard deviation of biomass	tC ha^{-1}
47	**Total_basal_area**	average basal area	cm^2 ha^{-1}
48	**Total_basal_area_sd**	standard deviation of basal area	cm^2 ha^{-1}
49	**Total_stems**	average stem density	trees ha^{-1}
50	**Total_stems_sd**	standard deviation of stem density	trees ha^{-1}
51	**Stand_age**	average stand age	years
52	**Stand_age_sd**	standard deviation of stand age	years
53	**Weighted_age**	average stand age weighted by biomass	years
54	**Weight_age_sd**	standard deviation of stand age weighted by biomass	years
55	**LAI_[1-12]**	LAI in 5-m canopy sections (0-5...55-60)	m^2 m^{-2}

3.1.3 Site and Climate Output

UVAFME outputs a file related to climate and site characteristics, the *Climate.csv* file. For this file, at the specified year print interval (Section 1), the several climate variables are printed out. Note output variables **thaw_depth**, **organic_depth**, **avail_n**, **dryd_upper** and **dryd_lower** are averaged across all plots, all others are equal across all plots.

Table 17: *Climate.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**rain**	annual precipitation (snow and liquid)	cm
5	**pet**	annual potential evapotranspiration	cm
6	**solar_rad**	surface solar radiation	cal cm^2
7	**tdd**	cumulative thawing degree-days	°C-days
8	**thaw_depth**	active layer depth	m
9	**organic_depth**	organic layer depth	m
10	**avail_n**	plant-availble N	tN ha^{-1}
11	**aet**	actual evapotranspiration	cm
12	**grow**	growing season length	days
13	**degd**	growing degree-days	°C-days
14	**dryd_upper**	drought index (upper)	0-1
15	**dryd_lower**	drought index (lower)	0-1
16	**flood_d**	flooding index	0-1

3.1.4 Soil Output

UVAFME outputs a file related to soil characteristics, the *SoilDecomp.csv* file. For this file, at the specified year print interval (Section 1), the several soil-related variables are printed out, averaged across all plots.

Table 18: *SoilDecomp.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**odepth**	average organic layer depth	m
5	**odepth_sd**	standard deviation of organic layer depth	m
6	**mdepth**	live moss depth	m
7	**moss_biom**	live moss biomass	t ha^{-1}
8	**active**	active layer depth	m
9	**OM**	humus organic matter weight	t ha^{-1}
10	**OM_N**	organic matter N	t ha^{-1}
11	**lit_cornus**	*Cornus* leaf litter weight	t ha^{-1}
12	**lit_acerfrax**	*Acer* and *Fraxinus* leaf litter weight	t ha^{-1}
13	**lit_prunus**	*Prunus* leaf litter weight	t ha^{-1}
14	**lit_betula**	*Betula* leaf litter weight	t ha^{-1}
15	**lit_queralba**	*Quercus alba* leaf litter weight	t ha^{-1}
16	**lit_tsugthuj**	*Tsuga* and *Thuja* leaf litter weight	t ha^{-1}
17	**lit_populus**	*Populus* leaf litter weight	t ha^{-1}
18	**lit_fagus**	*Fagus* leaf litter weight	t ha^{-1}
19	**lit_querrubr**	*Quercus rubra* leaf litter weight	t ha^{-1}
20	**lit_abies**	*Abies* leaf litter weight	t ha^{-1}
21	**lit_picea**	*Picea* leaf litter weight	t ha^{-1}
22	**lit_pinus**	*Pinus* leaf litter weight	t ha^{-1}
23	**lit_roots**	root litter cohort weight	t ha^{-1}
24	**lit_smboles**	small bole (¡ 10 cm DBH) litter cohort weight	t ha^{-1}
25	**lit_lboles**	large bole (¿ 10 cm DBH) litter cohort weight	t ha^{-1}
26	**lit_twigs**	twig litter cohort weight	t ha^{-1}
27	**lit_WDW**	well-decayed wood litter cohort weight	t ha^{-1}
28	**lit_moss**	moss litter cohort weight	t ha^{-1}
29	**avail_n**	plant-available N	tN ha^{-1}

3.1.5 Other Output Files

UVAFME also outputs two text files, *log.txt* and *site_log.txt*, that print messages regarding site and species data that are read in and initialized (for *log.txt*) and whether each site run was successfully completed (for *site_log.txt*).

For the *log.txt* file, UVAFME will write "Site data initialized. Total read in: [X]", where X is the number of sites read in from the site input file. It will also write "Species data initialized. Total read in: [X]", where X is the number of species read in from the species parameter input file. Following this, it will write "Species data initialized for site [X], where X is the site ID of each site run, each time the species data is initialized for that site.

This file may also contain other messages if no climate data is found for a specific site: (e.g. "No climate data for site number [X]". If any issues come up during runtime, the *log.txt* file is a good first place to check. UVAFME also prints some error messages directly to the screen, especially if these errors cause the program to exit.

For the *site_log.txt* file, UVAFME will print "Finished site [X]" (where X is the site ID) for each site it finished simulating. This file can be used to check to make sure all sites completed in a larger run.

3.2 Optional Outputs

3.2.1 Plot-level Output

UVAFME can optionally (see Section 1) output files which print plot-level species- and genus-level forest characteristics, the *Plot_Species_Data.csv* and *Plot_Genus_Data.csv* files. For these files, at the specified year print interval (Section 1), the plot conditions for trees from each species or genus are printed. If a species is specified as absent at a site in the input Rangelist file, the row is still printed but −999's are printed in the data columns. Note: this will result in a lot of output data and will slow down your runs considerably, thus the plot_level_data flag in the runtime file should be used sparingly and only if necessary.

Table 19: *Plot_Species_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**plot**	plot number	integer
5	**genus**	the genus of the species	character
6	**species**	the species ID	character
7-17	**[xx] to [xx]**	stem density in DBH bins	trees ha^{-1}
18-28	**[xx] to [xx] biom**	biomass in DBH bins	tC ha^{-1}
29	**max_diam**	maximum DBH	cm
30	**mean_diam**	average DBH	cm
31	**max_hgt**	maximum height	m
32	**leaf_area_ind**	leaf area index	m^2 m^{-2}
33	**basal_area**	basal area	m^2 ha^{-1}
34	**total_biomC**	biomass	tC ha^{-1}
35	**total_biomC_sd**	standard deviation of biomass	tC ha^{-1}

Table 20: *Plot_Genus_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**plot**	plot number	integer
5	**genus**	genus name	character
6-16	**[xx] to [xx]**	stem density in DBH bins	trees ha^{-1}
17-27	**[xx] to [xx] biom**	biomass in DBH bins	tC ha^{-1}
28	**max_diam**	maximum DBH	cm
29	**mean_diam**	average DBH	cm
30	**max_hgt**	maximum height	m
31	**leaf_area_ind**	leaf area index	m^2 m^{-2}
32	**basal_area**	basal area	m^2 ha^{-1}
33	**total_biomC**	biomass	tC ha^{-1}
34	**total_biomC_sd**	standard deviation of biomass	tC ha^{-1}

If outputting plot-level data, UVAFME will also output plot-level species- and genus-level files on the characteristics of trees that died each year, the *Plot_Dead_Species.csv* file and the *Plot_Dead_Genus.csv* files. For both files, at the specified year print interval (Section 1), the individual plot conditions for trees that died from each species or genus are printed. If a species is specified as absent at a site in the input Rangelist file, the row is still printed but -999's are printed in the data columns.

Table 21: *Plot_Dead_Species.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**plot**	plot number	integer
5	**genus**	genus of species	character
6	**species**	unique species ID	character
7	**degday_death**	biomass mortality due to temperature stress	tC ha^{-1}
8	**drought_death**	biomass mortality due to drought stress	tC ha^{-1}
9	**shade_death**	biomass mortality due to shade stress	tC ha^{-1}
10	**perm_death**	biomass mortality due to permafrost	tC ha^{-1}
11	**nutrient_death**	biomass mortality due to nutrient stress	tC ha^{-1}
12	**fire_death**	biomass mortality due to fire	tC ha^{-1}
13	**wind_death**	biomass mortality due to windthrow	tC ha^{-1}
14	**mean_diam**	average DBH	cm
15	**total_biomC**	biomass	tC ha^{-1}

Table 22: *Plot_Dead_Genus.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**plot**	plot number	integer
5	**genus**	genus name	character
6	**degday_death**	biomass mortality due to temperature stress	tC ha^{-1}
7	**drought_death**	biomass mortality due to drought stress	tC ha^{-1}
8	**shade_death**	biomass mortality due to shade stress	tC ha^{-1}
9	**perm_death**	biomass mortality due to permafrost	tC ha^{-1}
10	**nutrient_death**	biomass mortality due to nutrient stress	tC ha^{-1}
11	**fire_death**	biomass mortality due to fire	tC ha^{-1}
12	**wind_death**	biomass mortality due to windthrow	tC ha^{-1}
13	**mean_diam**	average DBH	cm
14	**total_biomC**	biomass	tC ha^{-1}

3.2.2 Tree-level Output

UVAFME can also optionally (see Section 1) output files which print tree-level characteristics for each plot, the *Plot_Tree_Data.csv* file. For this file, at the specified year print interval (Section 1), tree characteristics for each plot are printed. Note: this will result in an even larger amount of output data and will slow down your runs considerably, thus the tree_level_data flag in the runtime file should be used extremely sparingly and only if necessary.

Table 23: *Plot_Tree_Data.csv* file output variables.

Column Number	Column Name	Description	Units
1	**siteID**	unique site ID	integer
2	**runID**	unique run ID	integer
3	**year**	simulation year	integer
4	**plot**	plot number	integer
5	**treenum**	tree number	integer
6	**genus**	the genus of the tree	character
7	**species**	the species ID	character
8	**row**	the row location of the tree	integer
9	**col**	the column location of the tree	integer
10	**diam**	diameter at breast height	cm
11	**height**	height	m
12	**cbb_hieght**	clear branch bole height	m
13	**leaf_biomass**	leaf biomass	tC
14	**stem_biomC**	woody biomass	tC

4 Modifying UVAFME Code

UVAFME source code files (.f90/.F90 files) can be modified using any text editing software. Geany, Gedit, and TextWrangler are all good options that have Fortan-specific syntax highlighting. Once you have finished making changes you must recompile and remake the executable file. Recompiling requires the Fortran compiler ifort. Another Fortran compiler may be used, but this will require further modifications to the *Makefile* and the source code.

Use the command "`make`" within the source directory to make the new executable. Sometimes (especially if you have only made small changes) **ifort** doesn't work very well and may not see all of the changes you have made. If you are having strange issues, try clearing all compiled files with the command "`make clean`" before recompiling the whole model anew.

Tip: the UVAFME *Makefile* (in the source code folder) can be changed as well. It may be especially useful to rename the executable (first line "`PROG = UVAFME.exe`") for different versions so that you can keep track of all the different UVAFME versions (i.e. "`PROG = UVAFME_fire.exe`", etc.). Then when you run this new executable you would simply replace the command `UVAFME.exe` with your new executable name (i.e. "`./UVAFME_fire.exe`").

5 Tips and Tricks

Below are some common errors that may occur when running UVAFME and modifying input files and source code.

5.0.1 Column Names and Order

Except for the Rangelist file, UVAFME ***does not*** read the column headers for the input csv files. This means that if your order is not exactly correct (see above sections) UVAFME will read in variables incorrectly, but show no errors (though an error should occur if UVAFME reads in a variable type it is not expecting, i.e. a character when it is expecting a real). Make sure the column order in your input files exactly matches the above tables. This also means that you can change the column names for all but the Rangelist file as you see fit.

5.0.2 NAs in Sitelist File

Though most of the columns (i.e. all but the **siteID** column) may be left blank in the *UVAFME2018_sitelist.csv* file, make sure they are not written as NA/NaN's, etc. They must be blank or UVAFME will not be able to read the file and this error will be thrown:

```
acfoster@above101:.../AK$ ./UVAFME2018.exe file_list_GC.txt
forrtl: severe (64): input conversion error, unit -5, file Internal Formatted Read
Image              PC                Routine            Line        Source
UVAFME2018.exe     0000000000478BB8  Unknown               Unknown  Unknown
UVAFME2018.exe     00000000004771BA  Unknown               Unknown  Unknown
UVAFME2018.exe     0000000000406CB4  Unknown               Unknown  Unknown
UVAFME2018.exe     00000000004506BE  Unknown               Unknown  Unknown
UVAFME2018.exe     0000000000402846  Unknown               Unknown  Unknown
libc.so.6          00007FB2B4F1CB45  Unknown               Unknown  Unknown
UVAFME2018.exe     0000000000402729  Unknown               Unknown  Unknown
acfoster@above101:.../AK$
```

5.0.3 Rangelist File

As stated in Section 1, the *UVAFME2018_rangelist.csv* file is the only csv file where the column **names** are specifically read in by UVAFME and used to compare to the species IDs set up in the Specieslist file. This means that these column names **cannot** be in quotes or an error will occur. If using a software such as **R** to create the Rangelist file, be sure to write the file without quotes in the column names. If quotes are present, the model will determine that no species are present at the sites and will skip all sites, diplaying the warning message:

```
No species present in site  <siteID>
Skipping site <site name>
```

5.0.4 End of Line Issues

If you have I/O errors and aren't sure what is going on (especially if you have a Mac) you may have an end of line issue. The Mac version of MS Excel does not communicate well with Fortran. If you modify any .csv files on a Mac MS Excel, be sure to save them as "Windows Comma Separated," which should solve end of line issues.

5.0.5 Adding Object Attributes

Currently, sometimes errors arise when a new attribute is added to an object (i.e. a new attribute is added to the **Plot** object; see *Plot.f90*). It seems that **ifort** doesn't always catch these additions and then memory-related issues arise. A simple solution when these errors occur is to "`make clean`" the entire source code folder and recompile all files.

5.0.6 Everything Else...

Otherwise, if you cannot determine what is wrong, you can add the "`-traceback`" flag to the `DBG` line in the UVAFME *Makefile*. This will give you the exact line number and module where the error occurred, and is sometimes very helpful in finding errors. Be sure to take this flag out when you are finished debugging as it adds a lot of time to runs.

References

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