

University of Virginia Forest Model Enhanced

Version 3 - October 2018

How to Run UVAFME

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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.vx*: the UVAFME executable file for the model, the vx denoting version
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**

```

&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'
rt_directory='input_data'
speclist_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_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*
- **rt_directory**

– *UVAFME2018_runtime.txt*

- **speclist_directory** (optional)

– *UVAFME2018_specieslist.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.

```

&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_precip_by
!incr_or_decr_precip=decr
!incr_or_decr_temp=incr
year_print_interval=5
fixed_seed=.true.

numyears=100
numplots=200
plotsize=500
maxcells=30

!with clim change = use GCM data or linear CC in temp or precip, true or false
!use GCM = use outside GCM scenario data, true or false
!start GCM = year of GCM data to start with
!duration of change = how long to run GCM or CC data

!with_clim_change=.true.
!use_gcm=.false.
!linear_cc=.true.
!gcm_duration=100
!start_gcm=100
!end_gcm=200
!tree_level_data=.true.
!plot_level_data=.true.
/

```

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 “/”.

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, 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:

$$t' = \begin{cases} \frac{incr_t_by}{gcm_duration+1}, & incr_or_decr_temp = 'incr' \\ \frac{-decr_t_by}{gcm_duration+1}, & incr_or_decr_temp = 'decr' \end{cases} \quad (1)$$

and

$$p' = \begin{cases} \frac{incr_precip_by}{gcm_duration+1}, & incr_or_decr_prcp = 'incr' \\ \frac{-decr_precip_by}{gcm_duration+1}, & incr_or_decr_prcp = 'decr' \end{cases} \quad (2)$$

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 the 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 at 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.

Table 1: Parameters set up in runtime file.

Parameter Name	Description	Default Value
incr_tmin_by	amount to increase t_{min} under linear climate change application	0.0 °C
incr_tmax_by	amount to increase 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 t_{min} under linear climate change application	0.0 °C
decr_tmax_by	amount to decrease 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.
numyears	number of years to run model	1000
numplots	number of plots to run per site	200
plotsize	size of plot	500 m ²
maxcells	maximum possible rows/columns for plot grid, maxcells*maxcells = maximum trees on plot	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

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 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} :

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

where:

$$\alpha = 1 - 1.37/H_{max} \quad (4)$$

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

$$a = 3 + \alpha - \sqrt{\alpha^2 + 4\alpha} \quad (6)$$

$$b = 3 + \alpha + \sqrt{\alpha^2 + 4\alpha} \quad (7)$$

$$c = 4DBH_{max} + \alpha + \sqrt{\alpha^2 + 4\alpha} \quad (8)$$

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

and

$$f = \frac{\alpha + 0.5\alpha^2}{\sqrt{\alpha^2 + 4\alpha}} \quad (10)$$

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 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

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	β	stem shape parameter		default 1.32 for coniferous; 1.52 for broadleaf
12	bulk	bulk density of wood	tonnes m ⁻³	Miles and Smith 2008
13	D_L	Scalar parameter for $LA D_{db}^2$ relationship		default 0.184 for coniferous; § 0.175 for broadleaf
14	LMA	leaf mass per area	tonnes C ha ⁻¹	default 0.2 for coniferous; 0.095 for broadleaf
15	GDD_{min}	minimum degree day threshold (5°C base)	degree-days	
16	GDD_{opt}	optimum degree day threshold (5°C base)	degree-days	
17	GDD_{max}	maximum degree day threshold (5°C base)	degree-days	
18	shade	relative shade tolerance	1-5; 5 = least tolerant	
19	drought	relative drought tolerance	1-6; 6 = least tolerant	
20	flood	relative flood tolerance¶	1-6; 6 = least tolerant	
21	permf	relative permafrost tolerance	1-2; 2 = least tolerant	
22	nutrient	relative low nutrient tolerance	1-3; 3 = least tolerant	
23	bark_thick	bark thickness per cm DBH	cm bark cm DBH ⁻¹	Keane, Loehman, and Holsinger (2011)
24	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	
25	stress_tol	relative ability to withstand low growth from stress	1-5; 5 = least tolerant	
26	age_tol	relative ability to live to AGE_{max}	1-3; 3 = least likely	
27	dbh_min	minimum diameter increment growth before "stressed"	cm	
28	Evergreen	evergreen or deciduous	evergreen = 1; deciduous = 0	
29	litter_class	integer for litter class		
30	invader	seed numbers from outside the plot	seeds m ⁻²	wind dispersed seeds = 1
31	seed	seed numbers from within plot	seeds m ⁻²	e.g. cones ≈ 1; samaras ≈ 10; wind dispersed ≈ 100
32	sprout	average sprouts produced per individual		
33	layering	ability of species to reproduce by layering	0 or 1	
34	org_tol	relative ability of species to reproduce on deep organic layers	1-3; 3 = least tolerant	
35	recr_age	age at which species can reproduce	years	
36	seed_surv	proportion seedbank lost annually	0 to 1	
37	seedling_surv	proportion seedling bank lost annually	0 to 1	
38	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.				
¶: flood tolerance is currently non-operational. Updates are in progress to add this functionality.				

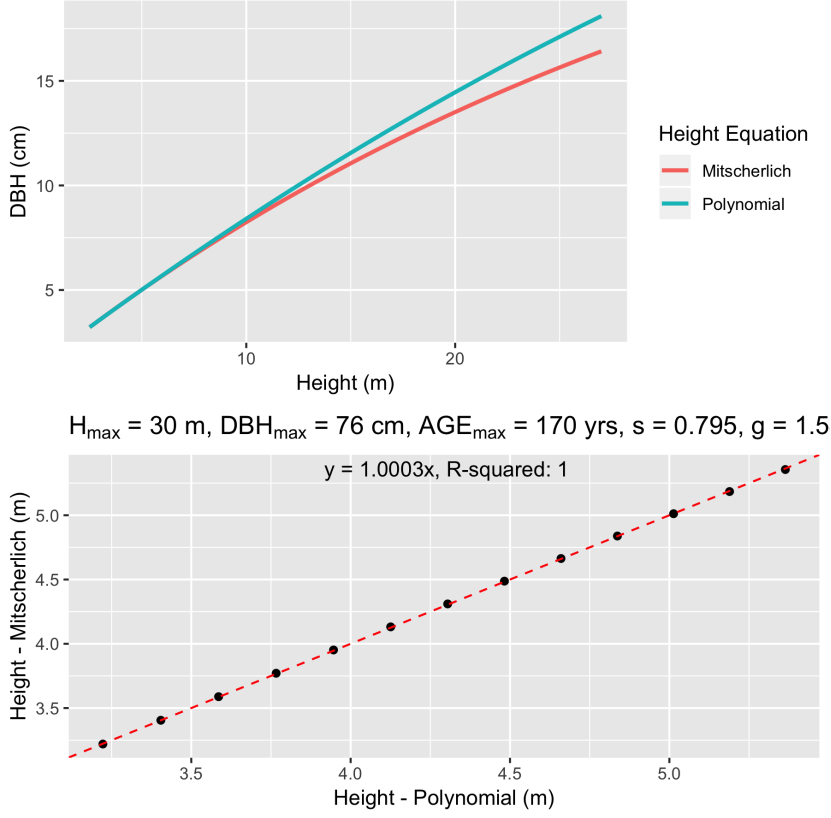


Figure 3: Example derivation of parameter s for a species with $H_{max} = 30$ m, $DBH_{max} = 76$ cm, and $AGE_{max} = 170$ years.

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).

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

$$H_p = (137 + b_2DBH - b_3DBH^2)/100 \quad (12)$$

where $b_2 = 2\frac{H_{maxcm}-137}{DBH_{max}}$ and $b_3 = \frac{H_{maxcm}-137}{DBH_{max}^2}$.

1.2.4 Site File

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

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	field capacity of mineral layer	volumetric	site description; soil maps
11	a_pwp	permanent wilting point of mineral layer	volumetric	site description; soil maps
12	o_sat	saturation capacity of organic layer	volumetric	site description; soil maps
13	o_fc	field capacity of organic layer	volumetric	site description; soil maps
14	o_pwp	permanent wilting point of organic layer	volumetric	site description; soil maps
15	a_bd	bulk density of mineral layer	kg m ⁻³	site description; soil maps
16	a_bd	bulk density of organic layer	kg m ⁻³	site description; soil maps
17	itxt	soil texture	0: very coarse 1: coarse 2: fine	site description; soil maps
16	hum_int	initial humus amount	t ha ⁻¹	site description; soil maps
17	fire_prob	fires in 1000 years	1000/FRI	fire history maps; literature; site descriptions
18	wind_prob	windthrow events in 1000 years	1000/WRI	literature; site descriptions
19	gcm_year	estimated stand age of site used to determine when to start climate change application	years	site description; literature; fire history

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.

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. The input

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 <i>A</i>	
9	ligParB	lignin parameter <i>B</i>	
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

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_vx 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 index	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	aboveground biomass	tC ha ⁻¹
41	biomC_sd	standard deviation of aboveground biomass	tC ha ⁻¹
42	biomC_lg	aboveground biomass of trees ≥ 9 cm DBH	tC ha ⁻¹
43	biomC_std_lg	standard deviation of aboveground biomass of trees ≥ 9 cm DBH	tC ha ⁻¹
44	biomC_sm	aboveground biomass of trees < 9 cm DBH	tC ha ⁻¹
45	biomC_std_sm	standard deviation of aboveground biomass of trees < 9 cm DBH	tC ha ⁻¹
46	basal_lg	basal area of trees ≥ 9 cm DBH	m ² ha ⁻¹
47	basal_std_lg	standard deviation of basal area of trees ≥ 9 cm DBH	m ² ha ⁻¹
48	basal_sm	basal area of trees < 9 cm DBH	m ² ha ⁻¹
49	basal_std_sm	standard deviation of basal area of trees < 9 cm DBH	m ² ha ⁻¹
50	dens_lg	stem density of trees ≥ 9 cm DBH	trees ha ⁻¹
51	dens_std_lg	standard deviation of stem density of trees ≥ 9 cm DBH	trees ha ⁻¹
52	dens_sm	stem density of trees < 9 cm DBH	trees ha ⁻¹
53	dens_std_sm	standard deviation of stem density of trees < 9 cm DBH	trees ha ⁻¹
54	dbh_lg	average diameter of trees ≥ 9 cm DBH	cm
55	dbh_std_lg	standard deviation of average diameter of trees ≥ 9 cm DBH	cm
56	dbh_sm	average diameter of trees < 9 cm DBH	cm
57	dbh_std_sm	standard deviation of average diameter of trees < 9 cm DBH	cm

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	the genus of the species	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	aboveground biomass	tC ha ⁻¹
40	biomC_sd	standard deviation of aboveground biomass	tC ha ⁻¹
41	biomC_lg	aboveground biomass of trees ≥ 9cm DBH	tC ha ⁻¹
42	biomC_std_lg	standard deviation of aboveground biomass of trees ≥ 9cm DBH	tC ha ⁻¹
43	biomC_sm	aboveground biomass of trees < 9cm DBH	tC ha ⁻¹
44	biomC_std_sm	standard deviation of aboveground biomass of trees < 9cm DBH	tC ha ⁻¹
45	basal_lg	basal area of trees ≥ 9cm DBH	m ² ha ⁻¹
46	basal_std_lg	standard deviation of basal area of trees ≥ 9cm DBH	m ² ha ⁻¹
47	basal_sm	basal area of trees < 9cm DBH	m ² ha ⁻¹
48	basal_std_sm	standard deviation of basal area of trees < 9cm DBH	m ² ha ⁻¹
49	dens_lg	stem density of trees ≥ 9cm DBH	trees ha ⁻¹
50	dens_std_lg	standard deviation of stem density of trees ≥ 9cm DBH	trees ha ⁻¹
51	dens_sm	stem density of trees < 9cm DBH	trees ha ⁻¹
52	dens_std_sm	standard deviation of stem density of trees < 9cm DBH	trees ha ⁻¹
53	dbh_lg	average diameter of trees ≥ 9cm DBH	cm
54	dbh_std_lg	standard deviation of average diameter of trees ≥ 9cm DBH	cm
55	dbh_sm	average diameter of trees < 9cm DBH	cm
56	dbh_std_sm	standard deviation of average diameter of trees < 9cm DBH	cm

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 name	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	gddresp_2	growth response to temperature for trees 10-20 m in height	0 to 1
13	gddresp_3	growth response to temperature for trees 20+ m in height	0 to 1
14	droughtresp_1	growth response to drought for trees 0-10 m in height	0 to 1
15	droughtresp_2	growth response to drought for trees 10-20 m in height	0 to 1
16	droughtresp_3	growth response to drought for trees 20+ m in height	0 to 1
17	shaderesp_1	growth response to shade for trees 0-10 m in height	0 to 1
18	shaderesp_2	growth response to shade for trees 10-20 m in height	0 to 1
19	shaderesp_3	growth response to shade for trees 20+ m in height	0 to 1
20	permresp_1	growth response to permafrost for trees 0-10 m in height	0 to 1
21	permresp_2	growth response to permafrost for trees 10-20 m in height	0 to 1
22	permresp_3	growth response to permafrost for trees 20+ m in height	0 to 1
23	nutrientresp_1	growth response to nutrients for trees 0-10 m in height	0 to 1
24	permresp_2	growth response to permafrost for trees 10-20 m in height	0 to 1
25	permresp_3	growth response to permafrost for trees 20+ m in height	0 to 1
26	Loreys_height	average Loreys height	m
27	Loreys_height_sd	standard deviation of Loreys height	m
28	max_height	average maximum height	m
29	max_height_sd	standard deviation of maximum height	m
30	total_biomC	average aboveground biomass	tC ha ⁻¹
31	total_biomC_sd	standard deviation of biomass	tC ha ⁻¹
32	basal_area	average basal area	m ² ha ⁻¹
33	basal_area_sd	standard deviation of basal area	m ² ha ⁻¹
34	total_stems	average stem density	trees ha ⁻¹
35	total_stems_sd	standard deviation of stem density	trees ha ⁻¹
36	small_stems	average stem density for trees ≤ 5 cm DBH	trees ha ⁻¹
37	small_stems_sd	standard deviation of stem density for trees ≤ 5 cm DBH	trees ha ⁻¹
38	med_stems	average stem density for trees > 5 cm and ≤ 20 cm DBH	trees ha ⁻¹
39	med_stems_sd	standard deviation of stem density for trees > 5 cm and ≤ 20 cm DBH	trees ha ⁻¹
40	lg_stems	average stem density for trees > 20 cm DBH	trees ha ⁻¹
41	lg_stems_sd	standard deviation of stem density for trees > 20 cm DBH	trees ha ⁻¹
42	stand_age	average stand age	years
43	stand_age_sd	standard deviation of stand age	years
44-55	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	annual surface solar radiation	cal cm ²
7	tdd	cumulative thawing degree-days	°C-days
8	thaw_depth	active layer depth	cm
9	organic_depth	organic layer depth	cm
10	avail_n	plant-available N	kgN ha ⁻¹
11	aet	actual evapotranspiration	cm
12	grow	growing season length	days
13	degd	growing degree-days	°C-days
14	drydays	drought index	0-1
15	saw0_ByFC	average mineral layer moisture scaled by field capacity	
16	saw0_BySAT	average mineral layer moisture scaled by saturation capacity	
17	aow0_ByMin	average organic layer moisture scaled by wilting point	
18	wilt_days	proportion of growing season below wilting point	0-1
19	flood_d	proportion of growing season with flooded conditions	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	cm
5	odepth_sd	standard deviation of organic layer depth	cm
6	mdepth	live moss depth	cm
7	moss_biom	live moss biomass	kg ha ⁻¹
8	active	active layer depth	cm
9	OM	humus organic matter weight	t ha ⁻¹
10	OM_N	organic matter N	tN ha ⁻¹
11	lit_cornus	<i>Cornus</i> leaf litter weight	t ha ⁻¹
12	lit_acerfrax	<i>Acer</i> and <i>Fraxinus</i> leaf litter weight	t ha ⁻¹
13	lit_prunus	<i>Prunus</i> leaf litter weight	t ha ⁻¹
14	lit_betula	<i>Betula</i> leaf litter weight	t ha ⁻¹
15	lit_queralba	<i>Quercus alba</i> leaf litter weight	t ha ⁻¹
16	lit_tsugthuj	<i>Tsuga</i> and <i>Thuja</i> leaf litter weight	t ha ⁻¹
17	lit_populus	<i>Populus</i> leaf litter weight	t ha ⁻¹
18	lit_fagus	<i>Fagus</i> leaf litter weight	t ha ⁻¹
19	lit_querrubr	<i>Quercus rubra</i> leaf litter weight	t ha ⁻¹
20	lit_abies	<i>Abies</i> leaf litter weight	t ha ⁻¹
21	lit_picea	<i>Picea</i> leaf litter weight	t ha ⁻¹
22	lit_pinus	<i>Pinus</i> 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_smbranch	small branch litter cohort weight	t ha ⁻¹
28	lit_lbranch	large branch litter cohort weight	t ha ⁻¹
29	lit_WDW	well-decayed wood litter cohort weight	t ha ⁻¹
30	lit_moss	moss litter cohort weight	t ha ⁻¹
31	avail_n	plant-available N	kgN 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

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

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
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	age	age of tree	years
11	diam	diameter at breast height	cm
12	dcbb	diameter at clear branch bole height	cm
13	height	height	m
14	cbb_height	clear branch bole height	m
15	leaf_biomass	leaf biomass	tC
16	leaf_area	leaf area	m ²
17	woody_biomC	aboveground woody biomass	tC
18	degd_resp	growth response to temperature	0-1
19	drought_resp	growth response to soil moisture	0-1
20	shade_resp	growth response to shading	0-1
21	perm_resp	growth response to permafrost	0-1
22	nutrient_resp	growth response to nutrients	0-1

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 Fortran-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.v1_NABoreal**”) for different versions so that you can keep track of all the different UVAFME versions (i.e. “**PROG = UVAFME_fire**”, etc.). Then when you run this new executable you would simply replace the command

UVAFME_v1 with your new executable name (i.e. “./UVAFME_fire”).

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:

```
parallels@testing> ./UVAFME_v1_NABoreal file_list.txt
forrtl: severe (64): input conversion error, unit -5, file Internal Formatted Read
Image          PC          Routine          Line          Source
UVAFME_v1_NABorea 00000000005955DB Unknown          Unknown          Unknown
UVAFME_v1_NABorea 00000000005BBE9B Unknown          Unknown          Unknown
UVAFME_v1_NABorea 00000000005BA845 Unknown          Unknown          Unknown
UVAFME_v1_NABorea 0000000000410999 input_mp_read_sit 336 Input.f90
UVAFME_v1_NABorea 0000000000585EE0 MAIN__          71 UVAFME.f90
UVAFME_v1_NABorea 0000000000403002 Unknown          Unknown          Unknown
libc-2.27.so      00007F818D237B97 __libc_start_main Unknown          Unknown
UVAFME_v1_NABorea 0000000000402EEA Unknown          Unknown          Unknown
parallels@testing> █
```

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, displaying 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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