Basic Inputs and Outputs

ELMFIRE requires two primary types of inputs:

1. Configuration parameters specified in a plain text input file (often, `elmfire.data`) consisting of several Fortran namelists. This file format and its associated syntax is not specific to ELMFIRE and is used by other Fortran-based scientific models such as the Fire Dynamics Simulator and Weather Research and Forecasting model.

2. Geospatial inputs such as fuel, weather, topography, and structure density. ELMFIRE reads only raster (e.g., GeoTiff) inputs. Vector inputs such as a polygon corresponding to the perimeter of an actively burning fire must be burned into a raster.

Inputs

Fuels, weather, and topography

The `$ELMFIRE_BASE_DIR/tutorials/01-constant-wind/elmfire.data.in` file contains an `&INPUTS` namelist group with the following entries:

```
&INPUTS
FUELS_AND_TOPOGRAPHY_DIRECTORY = './inputs'
ASP_FILENAME                   = 'asp'
CBD_FILENAME                   = 'cbd'
CBH_FILENAME                   = 'cbh'
CC_FILENAME                    = 'cc'
CH_FILENAME                    = 'ch'
DEM_FILENAME                   = 'dem'
FBFM_FILENAME                  = 'fbfm40'
SLP_FILENAME                   = 'slp'
ADJ_FILENAME                   = 'adj'
PHI_FILENAME                   = 'phi'
DT_METEOROLOGY                 = 3600.0
WEATHER_DIRECTORY              = './inputs'
WS_FILENAME                    = 'ws'
WD_FILENAME                    = 'wd'
M1_FILENAME                    = 'm1'
M10_FILENAME                   = 'm10'
M100_FILENAME                  = 'm100'
LH_MOISTURE_CONTENT            = 30.0
LW_MOISTURE_CONTENT            = 60.0
/
```

ELMFIRE reads GIS inputs in GeoTiff format. The keyword `FUELS_AND_TOPOGRAPHY_DIRECTORY` points ELMFIRE to the directory containing ten single-band fuels/topography raster:

1. `ASP_FILENAME`: Topographic aspect in degrees (16-bit integer)
2. `CBD_FILENAME`: Canopy bulk density in units of 100 kg per meter cubed (16-bit integer)
3. `CBH_FILENAME`: Canopy base height in units of 10 meters (16-bit integer)
4. `CC_FILENAME`: Canopy cover in units of percent (16-bit integer)
5. `CH_FILENAME`: Canopy height in units of 10 meters (16-bit integer)
6. `DEM_FILENAME`: Digital elevation model data in units of meters (16-bit integer)
7. `FBFM_FILENAME`: Fire behavior fuel model file (16-bit integer)
8. `SLP_FILENAME`: Topographic slope in degrees (16-bit integer)
9. `ADJ_FILENAME`: Surface spread rate adjustment factor (32-bit float)
10. `PHI_FILENAME`: Initial ϕ (level set variable) field (32-bit float)

Filenames should be specified without a suffix (*e.g.*, `'slp'`, not `'slp.tif'` because ELMFIRE automatically appends the .tif suffix to filenames. All GIS inputs must have the same projection, resolution/cell size, and extents. ELMFIRE does not reproject, warp, or clip GIS inputs and there is currently no error trapping to catch mismatched inputs. The user must ensure that all GIS inputs are self-consistent.

In addition to the above ten fuels/topography inputs, ELMFIRE may be configured to read additional rasters to quantify impacts to assets at risk (structures, timber, *etc.*).

The keyword `WEATHER_DIRECTORY` points ELMFIRE to a directory containing five multi-band (or single-band) wind/weather 32-bit float rasters:

1. `WS_FILENAME`: 20-ft wind speed in mph
2. `WD_FILENAME`: 20-ft wind direction in degrees
3. `M1_FILENAME`: 1-hour dead fuel moisture content in %
4. `M10_FILENAME`: 10-hour dead fuel moisture content in %
5. `M100_FILENAME`: 100-hour dead fuel moisture content in %

If the rasters specified above are single-band, then wind/weather conditions are assumed to be unchanging for the duration of the simulation. Transient wind/weather streams can be provided as input by using multi-band, or “stacked”, rasters. In that case, the parameter `DT_METEOROLOGY` should be specified on the `&INPUT` line. `DT_METEOROLOGY` is the time interval (in seconds) between bands in the weather rasters. `DT_METEOROLOGY` is commonly set to 3600 seconds due to the use of hourly reanalysis or forecast products to drive fire spread simulation. If wind speed is provided at 10 meters instead of 20 feet, the parameter `WS_AT_10M` should be set to `.TRUE.`.

By default, live fuel moisture content (herbaceous, woody, and foliar) are spatially uniform and temporally unchanging. They are specified in the `&INPUTS` namelist group via the keywords `LH_MOISTURE_CONTENT`, `LW_MOISTURE_CONTENT`, and `FOLIAR_MOISTURE_CONTENT`, respectively. Spatially varying live fuel moisture content can be specified by setting `USE_CONSTANT_LH = .FALSE.`, `USE_CONSTANT_LW = .FALSE.`, and `USE_CONSTANT_FMC = .FALSE.`. This directs ELMFIRE to read live fuel moisture from the rasters specified by `MLH_FILENAME`, `MLW_FILENAME`, `FMC_FILENAME` (live herbaceous, live woody, and foliar, respectively). Even though live fuel moistures will typically change very little during a fire forecast (or hindcast), ELMFIRE expects the live fuel moisture rasters to have the same number of bands as the weather rasters, with the time interval between bands specified by `DT_METEOROLOGY`.

Assets at Risk

An important part of quantifying fire risk is assessing potential impacts to assets at risk. ELMFIRE is currently capable of quantifying impacts to three assets at risk. Since some of the most relevant assets at risk are population, real estate/structures, and land/timber, the keywords that are used to specify assets at risk in the `&INPUTS` namelist group are hardcoded as `REAL_ESTATE`, `POPULATION_DENSITY`, and `LAND_VALUE` although each of these is treated identically. Since other assets at risk may be relevant (cultural resources, sensitive habitat, watershed, *etc.*), the total number of assets at risk eventually will be expanded. However, for the time being, assets at risk are specified as follows:

- Land value: Set `USE_LAND_VALUE = .TRUE.` and specify the land value filename via `LAND_VALUE_FILENAME`
- Real estate value: Set `USE_REAL_ESTATE_VALUE = .TRUE.` and specify the real estate value filename via `REAL_ESTATE_VALUE_FILENAME`
- Population density: Set `USE_POPULATION_DENSITY = .TRUE.` and specify the population density filename via `POPULATION_DENSITY_FILENAME`

> **Note**
>
> Assets at risk are read in from the `FUELS_AND_TOPOGRAPHY` directory. Additionally, all assets at risk should be Float32 GeoTiff rasters. Units should be quantity per acre, *e.g.* structures per acre, population per acre, $ per acre, *etc.*

If assets at risk rasters are provided as input, ELMFIRE will sum total impacts by integrating fire area over asset at risk density and report this in the `fire_size_stats.csv` output file. ELMFIRE will also create impact rasters `affected_land_value.tif`, `affected_real_estate_value.tif`, and `affected_population.tif`.

Computational domain size, extents, and resolution

Input parameters controlling configuration of the computational domain are specified via the `&COMPUTATIONAL_DOMAIN` namelist group. The computational domain has the same extents of the input GIS fuels data, but its resolution can be the same or finer than the fuels inputs, meaning a computational domain with 10 m grid spacing can be used even if fuels inputs have a spatial resolution of 30 m.

The primary constraint is that the computational domain must fall completely within the GIS input data. This means that the computational domain can be the same size as or smaller than the input GIS data. Its spatial resolution can also be the same or finer than the input GIS fuels data,

The computational domain is specified by the following parameters:

- `A_SRS`: Projection of output files. Typically, a proj string would be used, i.e. `A_SRS = 'EPSG:32610'`.
- `COMPUTATIONAL_DOMAIN_CELLSIZE`: spatial resolution of the computational domain, uniform in the x and y directions. This is commonly set to the spatial resolution of the input fuels layers (often 30 m) but can be set to a smaller value (e.g., 10 m) if a more highly resolved simulation is desired.
- `COMPUTATIONAL_DOMAIN_XLLCORNER`: x-coordinate of the lower left corner of the fuels inputs.
- `COMPUTATIONAL_DOMAIN_YLLCORNER`: y-coordinate of the lower left corner of the fuels inputs.

> **Note**
>
> This namelist group will soon be deleted since `COMPUTATIONAL_DOMAIN_XLLCORNER`, `COMPUTATIONAL_DOMAIN_YLLCORNER`, and `A_SRS` can be determined internally from the fuels inputs' metadata. When this happens, `COMPUTATIONAL_DOMAIN_CELLSIZE` will be moved to the `&SIMULATOR` namelist group.

Time

Parameters related to time (simulation duration, computational timestep, *etc.*) are specified via the `&TIME_CONTROL` namelist group. A sample `&TIME_CONTROL` namelist group with key inputs is shown below:

```
&TIME_CONTROL
SIMULATION_TSTART   = 0.0
SIMULATION_TSTOP    = 3600.0
SIMULATION_DT       = 5.0
SIMULATION_DTMAX    = 600.0
TARGET_CFL          = 0.4
DT_INTERPOLATE_M1   = 300.0
DT_INTERPOLATE_M10  = 3000.0
DT_INTERPOLATE_M100 = 30000.0
DT_INTERPOLATE_MLH  = 9E8
DT_INTERPOLATE_MLW  = 9E8
DT_INTERPOLATE_FMC  = 9E8
DT_INTERPOLATE_WIND = 300.0
/
```

Simulation start and stop times are specified via the keywords `SIMULATION_TSTART` and `SIMULATION_TSTOP`, respectively. These parameters have units of seconds, so a 12-hour simulation corresponds to `SIMULATION_TSTOP = 43200`. The default value of `SIMULATION_TSTART` is 0 seconds, meaning computations start at t = 0 seconds. This is generally appropriate for simulations driven by idealized or synthetic weather data. For transient wind/weather/fuel moisture multi-band rasters, Band 1 always corresponds to t = 0 seconds in ELMFIRE.

When simulating real fires driven by transient, often hourly, weather streams it is usually desirable to start a fire spread simulation at a time > 0 seconds. Assuming that hourly weather fields are provided as input and fire's time of ignition is 14:20, `SIMULATION_TSTART` should be set to `1200.0`, *i.e.*, 20 minutes after the hour. In this particular case, Band 1 in all transient raster inputs should correspond to 14:00 and Band 2 should correspond to 15:00.

The initial timestep is specified with the `SIMULATION_DT` keyword. The timestep is automatically adjusted at runtime based on the Courant-Friedrichs-Lewy (CFL) conditions. The target CFL number can be specified by `TARGET_CFL`. Since the internal timestep will change during a simulation, an upper limit on the allowable timestep can be specified with the `SIMULATION_DTMAX` keyword.

Since wind/weather fields are often provided at hourly intervals but ELMFIRE's computational timestep is usually on the order of a few to at most tens of seconds, ELMFIRE uses linear interpolation to determine wind/weather/fuel moisture conditions at intermediate times. This interpolation can be computationally expensive, so the user is provided with some control over the interpolation frequency. The keywords `DT_INTERPOLATE_M1`, `DT_INTERPOLATE_M10`, and `DT_INTERPOLATE_M100` control the time between interpolations for 1-hour, 10-hour, and 100-hour fuel moistures. Wind speed and wind direction are controlled by `DT_INTERPOLATE_WS` and `DT_INTERPOLATE_WD`. As with other temporal inputs, units are seconds.

Fire Initialization

The two primary methods to initialize a fire spread simulation include point source ignitions and active fire perimeter initialization. These methods can be used concurrently, *e.g.* to simulate an active fire perimeter with additional point ignitions or spot fire initiation outside of the fire perimeter.

Point source ignitions

One or more point source ignitions can be specified on the `&SIMULATOR` namelist group via the keywords `X_IGN(:)`, `Y_IGN(:)`, and `T_IGN(:)` which respectively control point ignitions' x- and y-coordinates, and time of ignitions. As an example, the following lines specify two separate point source ignitions:

```
NUM_IGNITIONS = 2
X_IGN(1)      = 1000.0
Y_IGN(1)      = 1000.0
T_IGN(1)      = 0.0
X_IGN(2)      = 2000.0
Y_IGN(2)      = 2000.0
T_IGN(2)      = 7200.0
```

The first ignition occurs at (x, y) = (1000.0, 1000.0) at simulation time 0.0 seconds and the second occurs at (x, y) = (2000.0, 2000.0) at simulation time = 7200.0 seconds. The keyword `NUM_IGNITIONS` specifies the total number of point source ignitions. Ignitions should be numbered sequentially starting at 1 and ending at `NUM_IGNITIONS`. The number of point source ignitions is currently limited to 100.

Active fire perimeters

As described in ELMFIRE's Technical Reference, fire front position is tracked by solving a conservation equation for the level set variable ϕ where unburned areas correspond to $\phi > 0$, burned areas correspond to $\phi < 0$, and the fire front position is the level set corresponding to $\phi = 0$. At the start of a simulation ELMFIRE reads the initial ϕ field from a 32-bit floating point raster with filename `PHI_FILENAME` as specified in the `&INPUTS` namelist group.

If there is no active fire at the start of a simulation, then all pixels in the `PHI_FILENAME` raster should be initialized with a single start value greater than 0 (usually 1.0). An initial fire front position can be specified by burning a value less than 0 (usually -1.0) into the `PHI_FILENAME` raster. All pixels with an initial ϕ value less than 0 will be marked as burned and fire spread will be initiated from those pixels.

Extinguished or "cold" segments of the fire perimeter can be simulated by modifying the fuel model raster to have a non-burnable fuel model in extinguished segments of the fire perimeter.

Outputs

A sample `&OUTPUTS` namelist group is shown below:

```
&OUTPUTS
OUTPUTS_DIRECTORY           = './outputs'
DTDUMP                      = 3600.
DUMP_FLIN                   = .TRUE.
DUMP_SPREAD_RATE            = .TRUE.
DUMP_SURFACE_FIRE           = .TRUE.
DUMP_TIME_OF_ARRIVAL        = .TRUE.
/
```

The keyword `OUTPUTS_DIRECTORY` specifies the directory to which ELMFIRE will write its output files. This output directory must exist at run-time; it will not be automatically created. Outputs will be dumped every `DTDUMP` seconds.

In general, outputs to be dumped are specified using a logical keyword that begins with `DUMP_`. The following is a summary of primary raster outputs and the logical keywords that control whether they are written to disk:

- Crown fire occurrence (-): `DUMP_CROWN_FIRE`
- Flame length (ft): `DUMP_FLAME_LENGTH`
- Fireline intensity (kW/m): `DUMP_FLIN`
- Heat per unit area (kJ/m^2): `DUMP_HPUA`
- Reaction intensity (kW/m^2): `DUMP_REACTION_INTENSITY`
- Surface fire occurrence (%): `DUMP_SURFACE_FIRE`
- Time of arrival (s): `DUMP_TIME_OF_ARRIVAL`
- Spread rate (ft/min): `DUMP_SPREAD_RATE`
- 20-ft wind direction (): `DUMP_WD20`
- 20-ft wind speed (mph): `DUMP_WS20`

Output filenames are hardcoded but should be readily discernable, *e.g.* fireline intensity outputs begin with `flin_`, time of arrival outputs begin with `toa_`, *etc*. Since ELMFIRE is sometimes used to run multiple cases as part of a Monte Carlo analysis or sensitivity analysis, a seven-digit sequential identifier is prepended to the name of each output raster, and the time at which the raster was dumped is appended to the filename.

In addition to raster-based outputs, ESRI Shapefiles with fire front isochrones can be written to disk. To enable this, set `DUMP_ISOCHRONE_SHAPEFILES = .TRUE.`.

Several text output files can also be written to disk. Fire area as a function of time can be written to Disk by setting `DUMP_TRANSIENT_ACREAGE = .TRUE.`, and overall fire size statistics at the end of each run can be requested with `DUMP_FIRE_SIZE_STATS = .TRUE.`.

Virtual weather stations can be specified by setting `NUM_VIRTUAL_STATIONS` to an integer greater than zero, and then specifying x and y coordinates of each station. As a simple example, data from two virtual stations would be written to disk by adding the following lines to the `&OUTPUTS` namelist group:

```
NUM_VIRTUAL_STATIONS = 2
VIRTUAL_STATION_X(1) = 12345.0
VIRTUAL_STATION_Y(1) = 67890.0
VIRTUAL_STATION_X(2) = 98765.0
VIRTUAL_STATION_Y(2) = 43210.0
```

The index inside the parentheses denotes the station number. For each virtual station a separate .csv file will be written that includes transient and fixed quantities as a function of time. These quantities are currently:

- Elevation
- Slope
- Aspect
- Canopy Bulk Density
- Canopy Base Height
- Canopy Cover
- Canopy Height
- Fuel model
- 1-hour dead fuel moisture
- 10-hour dead fuel moisture
- 100-hour dead fuel moisture
- Live herbaceous fuel moisture
- Live woody fuel moisture
- Foliar fuel moisture
- 20-ft wind speed
- 20-ft wind direction
- ϕ (level set variable)

Note

Virtual stations have been temporarily disabled