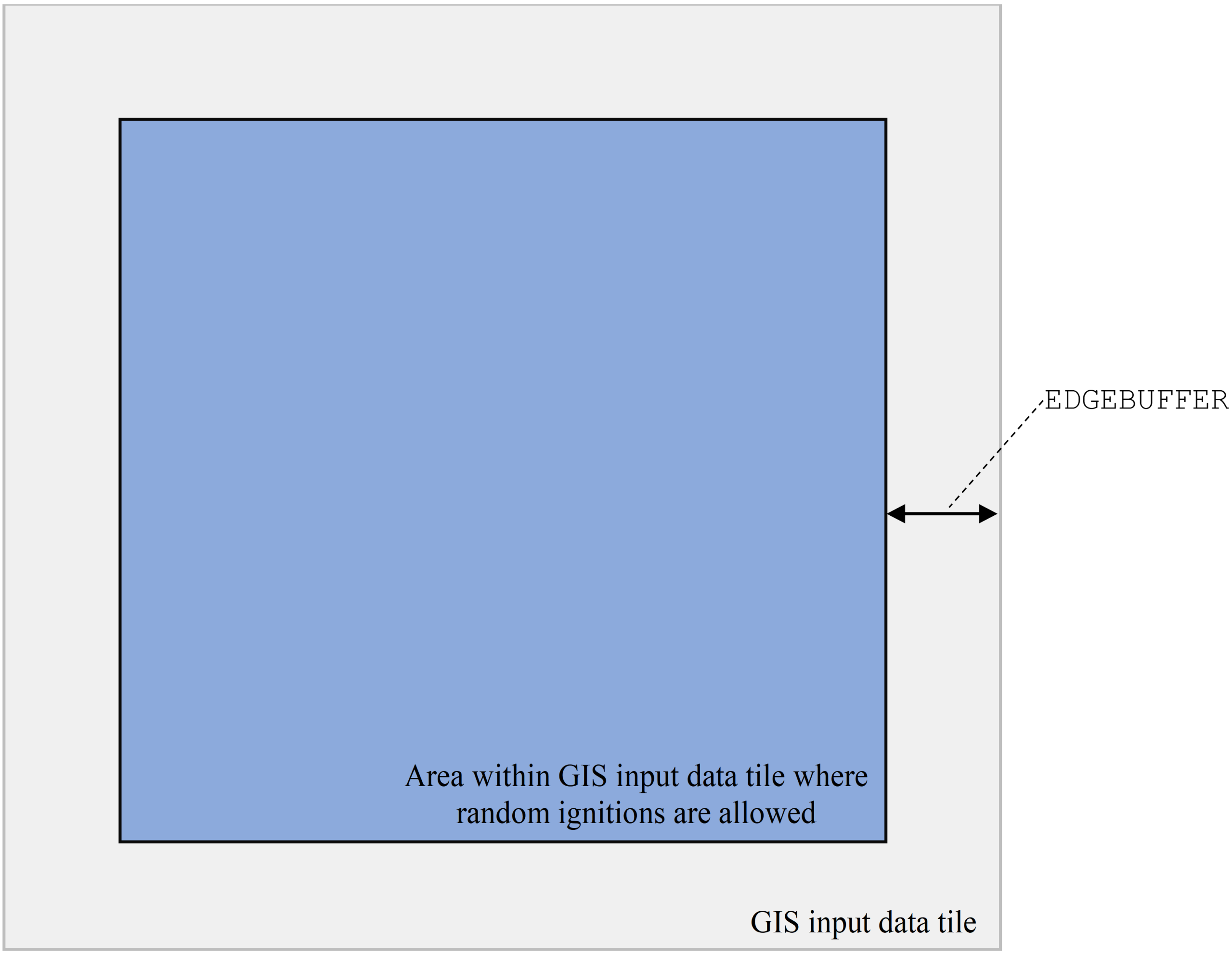
Monte Carlo Analysis

Keywords controlling Monte Carlo parameters are specified in the `&MONTE_CARLO` namelist group. Several types of Monte Carlo simulations can be performed with ELMFIRE. Point source ignitions may be placed randomly across the landscape, wind and weather inputs may be varied stochastically, and input rasters may be spatially and temporally perturbed.

Randomized ignition locations

Setting `RANDOM_IGNITIONS = .TRUE.` directs ELMFIRE to conduct a Monte Carlo analysis with ignition locations distributed randomly within the computational domain. Allowable locations of those ignitions are constrained by the parameter `EDGEBUFFER` which is the distance from the edge of the GIS input data tile where ignitions will not be placed as shown graphically below:



Random ignition location may also be constrained by an ignition mask raster. To do this, set `USE_IGNITION_MASK = .TRUE.` and specify `IGNITION_MASK_FILENAME` on the the `&INPUTS` line. This directs ELMFIRE to read a Float32 raster named `IGNITION_MASK_FILENAME.tif` from the

`FUELS_AND_TOPOGRAPHY_DIRECTORY`. Distribution of ignitions across the landscape is controlled by the parameter `RANDOM_IGNITIONS_TYPE`:

- `RANDOM_IGNITIONS_TYPE=1` (default): Ignitions are spatially distributed uniformly across the landscape in any pixels where the ignition mask raster is greater than zero. This is useful for modeling ignitions originating from powerlines or roads, for example.
- `RANDOM_IGNITIONS_TYPE=2`: Ignitions are spatially distributed across the landscape at a density that is proportional to the ignition mask raster. This is useful for burn probability modeling where some locations across the landscape have higher ignition probabilities than other locations.

The number of randomly-generated ignition points can be specified in two ways:

1. By directly specifying `NUM_ENSEMBLE_MEMBERS`, or
2. By specifying `PERCENT_OF_PIXELS_TO_IGNITE` and setting `NUM_ENSEMBLE_MEMBERS` to a value less than 0.

In the first case, ELMFIRE will randomly generate `NUM_ENSEMBLE_MEMBERS` ignition locations in the allowable ignition area as defined by `EDGEBUFFER` (and, if `USE_IGNITION_MASK = .TRUE.`, the user-specified ignition mask raster as well). In the second case, ELMFIRE will count all pixels within the allowable ignition area and randomly ignite the user-specified percent of those pixels. In some cases, a pixel may be selected more than once to be ignited. This can be disabled by setting `ALLOW_MULTIPLE_IGNITIONS_AT_A_PIXEL = .FALSE.`.

Randomized weather streams

In the example discussed in Randomized ignition locations, ignition locations are selected randomly and a single weather stream (hindcast or forecast) is provided as input to those simulations. Often, as part of a climatological fire risk analysis, it is desirable to simulate wind and weather conditions under a range of historical (or forecasted) wind and weather conditions. This can be accomplished in ELMFIRE using stacked/multiband weather/meteorology rasters.

The manner in which these rasters are used is controlled by the parameters `NUM_METEOROLOGY_TIMES`, `METEOROLOGY_BAND_START`, `METEOROLOGY_BAND_STOP`, and `METEOROLOGY_BAND_SKIP_INTERVAL`. This is perhaps best illustrated by an example. Assume that numerical weather prediction has been used to generate 100 24-hour “blocks” of historical wind/weather data at hourly intervals that will be provided as input to a Monte Carlo analysis. The goal is to simulate 24-hours of fire spread, for each of these 24-hour blocks. However, these 24-hour blocks are not temporally contiguous, meaning the first 24-hour block could be from August 1983 and the next 24-hour block could be from October 2012, and so on.

Each 24-hour block consists of 25 bands since Band 1 is t = 0 and Band 25 is t = 24 hours. Therefore, each meteorology raster would contain 2,500 separate bands (100 blocks $\times$ 25 bands per block). Since ELMFIRE needs 25 bands of wind/weather data to drive each 24-hour simulation, we would set `METEOROLOGY_BAND_START=1`, `METEOROLOGY_BAND_STOP=2476`, and `METEOROLOGY_BAND_SKIP_INTERVAL=25`. This tells ELMFIRE to use every 25th band as the starting band for a 24-hour simulation and ensures that each 24-hour simulation starts with Band 1, 26, 51, and so on until the final 24-hour block is reached at meteorology band 2476.

If, instead, the 100 24-hour blocks were temporally contiguous (for example, a continuous hindcast from mid-July through the end of October) and the purpose of the Monte Carlo analysis is to ignite fires every 3 hours and model their spread, we would set `METEOROLOGY_BAND_SKIP_INTERVAL=4`.

Spatial and temporal perturbations of input rasters

All inputs are subject to inherent uncertainty. To address this uncertainty, input rasters may be perturbed stochastically from their baseline values in a Monte Carlo analysis. Currently, the following rasters may be perturbed:

- `ADJ`: Spread rate adjustment factor (-)
- `CBD`: Canopy bulk density (kg/m^3)
- `CBH`: Canopy base height (m)
- `CC`: Canopy cover (-)
- `CH`: Canopy height (m)
- `FMC`: Foliar moisture content (-)
- `M1`: 1-hour fuel moisture (-)
- `M10`: 10-hour fuel moisture (-)
- `M100`: 100-hour fuel moisture (-)
- `MLH`: Live herbaceous fuel moisture (-)
- `MLW`: Live woody fuel moisture (-)
- `WAF`: Wind adjustment factor (-)
- `WD`: Wind direction (deg)
- `WS`: Wind speed (mph)

Parameters controlling stochastic perturbations of input rasters are specified in the `&MONTE_CARLO` namelist group. A random sampling procedure is implemented such that the spatial perturbation to be applied to a given input raster sampled from a probability density function (pdf). Currently, only a uniform pdf is implemented (`PDF_TYPE(:) = 'UNIFORM'`) although this will eventually be generalized to additional distributions such as Gaussian and lognormal. The keyword `NUM_RASTERS_TO_PERTURB` prescribes the number of input rasters to be perturbed and the keyword `RASTER_TO_PERTURB(:)` is a string corresponding to one of the raster names in the bulleted list above (`ADJ`, `CBD`, *etc.*). As an example, consider the following lines:

```
NUM_RASTERS_TO_PERTURB   = 1
RASTER_TO_PERTUB(1)      = 'ADJ'
SPATIAL_PERTURBATION(1)  = 'GLOBAL'
TEMPORAL_PERTURBATION(1) = 'STATIC'
PDF_TYPE(1)              = 'UNIFORM'
PDF_LOWER_LIMIT(1)       = -0.10
PDF_UPPER_LIMIT(1)       = 0.10
```

These lines specify that a randomly selected value between -0.1 and 0.1 should be added to the spread rate adjustment factor(`ADJ`). This perturbation will be applied globally to all pixels (`SPATIAL_PERTURBATION = 'GLOBAL'`) and is temporally invariant for the duration of the simulation (`TEMPORAL_PERTURBATION = 'STATIC')`. Rather than applying such perturbations globally to all pixels, different perturbations can be applied to different pixels by setting `SPATIAL_PERTURBATION = 'PIXEL'`. Some raster inputs, such as wind speed and direction, are multi-band rasters that vary temporally. Different perturbations may be applied at each time by setting `TEMPORAL_PERTURBATION = 'DYNAMIC'`. Normally, this would only be done for wind speed and direction.

The number of ensemble members in the Monte Carlo analysis should be specified using the keyword `NUM_ENSEMBLE_MEMBERS` (`&MONTE_CARLO` namelist group). However, when using randomly-placed ignitions it may instead be preferable to specify the total number of ensemble members by specifying the percentage of pixels within the computational domain and possibly within a user-specified ignition mask to ignite. This is described in Randomized ignition locations.

Randomized wind fluctuation intensities

Wind fluctuations are implemented via the `&SIMULATOR` namelist group. The keywords that control these fluctuations are `WIND_SPEED_FLUCTUATION_INTENSITY` and `WIND_DIRECTION_FLUCTUATION_INTENSITY`. These values can be randomized by setting the following four parameters (in the `&MONTE_CARLO` namelist group):

- `WIND_DIRECTION_FLUCTUATION_INTENSITY_MIN`: Minimum wind direction fluctuation intensity value
- `WIND_DIRECTION_FLUCTUATION_INTENSITY_MAX`: Maximum wind direction fluctuation intensity value
- `WIND_SPEED_FLUCTUATION_INTENSITY_MIN`: Minimum wind speed fluctuation intensity value
- `WIND_SPEED_FLUCTUATION_INTENSITY_MAX`: Maximum wind speed fluctuation intensity value

The wind fluctuation intensities are then randomly generated according to a uniform probability density function, with the upper and lower values specified by the above four parameters.

Outputs

Several outputs are specific to Monte Carlo analyses. Often, when conducting a Monte Carlo analysis with randomly distributed ignitions, it is informative to view spatial burn probabilities, defined as the fraction of simulations in which a given pixel burned. To enable this calculation (which adds some computational and network overhead), set `CALCULATE_BURN_PROBABILITY = .TRUE.` in the `&OUTPUTS` namelist group. This instructs ELMFIRE to aggregate all simulated fire perimeters and calculate the burn probability across all runs and write the results to disk (in a file called `burn_probability.tif`). The output raster has three bands. The first is the conventional burn probability. The second is passive crown fire burn probability, meaning the fraction of times in which a pixel burned as passive crown fire. The third band is active crown fire burn probability.