Spotting

Spotting is a major, often dominant, mode of fire propagation particularly under hot, dry, windy conditions. Parameters that control spotting are specified on the `&SPOTTING` namelist group. Note that the current spotting model is different from the spotting model described in the original ELMFIRE paper

Spotting is disabled by default and can be enabled by setting `ENABLE_SPOTTING = .TRUE.` in the `&SPOTTING` namelist group. Spotting distance is modeled as a lognormal distribution with the mean and standard deviation determined semi-empirically as a function of ambient wind speed and fireline intensity. Shown below is a sample spotting configuration:

```
&SPOTTING
ENABLE_SPOTTING                      = .TRUE.
CROWN_FIRE_SPOTTING_PERCENT          = 1.0
ENABLE_SURFACE_FIRE_SPOTTING         = .TRUE.
SURFACE_FIRE_SPOTTING_PERCENT(:)     = 1.0
CRITICAL_SPOTTING_FIRELINE_INTENSITY = 2000.0
SPOTTING_DISTRIBUTION_TYPE           = 'LOGNORMAL'
MEAN_SPOTTING_DIST                   = 5.0
SPOT_FLIN_EXP                        = 0.3
SPOT_WS_EXP                          = 0.7
NORMALIZED_SPOTTING_DIST_VARIANCE    = 250.0
NEMBERS_MIN                          = 1
NEMBERS_MAX                          = 1
PIGN                                 = 100.0
/
```

Mean spotting distance (m) and its variance (v) are related to fireline intensity ($\dot{Q}'$) and 20-ft wind speed (u_{20}) as:

$$m = a\dot{Q}'^{b}u_{20}^{c}v = md$$

The empirical parameters a, b, c, and d may be specified directly or estimated by automated calibration and correspond to keywords in the `&SPOTTING` namelist group as follows:

a = `MEAN_SPOTTING_DISTANCE`

b = `SPOT_FLIN_EXP`

c = `SPOT_WS_EXP`

d = `NORMALIZED_SPOTTING_DIST_VARIANCE`

The normalized mean (μ) and standard deviation (σ of the lognormal distribution are then calculated from m and v as:

$$\mu = ln(\frac{m^2}{\sqrt{v+m^2}})\sigma = \sqrt{ln(1+\frac{v}{m^2})}$$

Spotting distance (x) is calculated probabilistically from a lognormal distribution:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma x}}exp(-\frac{1}{2}(\frac{lnx-\mu}{\sigma})^2)$$

By default, when `ENABLE_SPOTTING = .TRUE.`, only pixels that burn as passive or active crown fire trigger the spotting algorithm. The keyword `CROWN_FIRE_SPOTTING_PERCENT` controls spotting initiation from passive/active crown fire pixels, meaning if it is set to 1.0 then 1 out of every 100 pixels that burn as crown fire will initiate the spotting algorithm. When the spotting algorithm is initiated, the number of embers that is generated is determined randomly as constrained by the keywords `NEMBERS_MIN` and `NEMBERS_MAX`. More specifically, the number of embers generated will be greater than or equal to `NEMBERS_MIN` and less than or equal to `NEMBERS_MAX`.

For each ember that is generated, spotting distance is determined stochastically according to the probability density function given above. Each ember is then treated as a Lagrangian particle that moves under the influence of the wind direction field, with its landing location assigned when it has traveled the previously-determined spotting distance. Ignition probability is controlled by the keyword `PIGN`, which is the probability in percent that an ember, once it has landed, initiates a spot fire. To avoid allocating computational time to tracking embers that don't initiate spot fire, it is most computationally efficient to set `PIGN` to 100% and then set `CROWN_FIRE_SPOTTING_PERCENT` to a small number. As an example, `CROWN_FIRE_SPOTTING_PERCENT = 50.0` and `PIGN = 10.0` will produce comparable results to `CROWN_FIRE_SPOTTING_PERCENT = 5.0` and `PIGN = 100.0`, but the computational expense of the spotting algorithm is reduced by a factor of approximately 10x in the latter case.

Surface fire spotting may be enabled by setting `ENABLE_SURFACE_FIRE_SPOTTING = .TRUE.`. Ember generation is treated analogously to crown fire ember generation, except that the surface fire ember generation probability is controlled by the keyword `SURFACE_FIRE_SPOTTING_PERCENT(:)`. The index for the array

`SURFACE_FIRE_SPOTTING_PERCENT(:)` is fuel model number so that surface fire spotting initiation can be controlled by fuel model. As an example, the following lines would disable surface fire spotting for all fuel types except for fuel models 141 - 149 (shrub fuel models in the conventional US system):

```
SURFACE_FIRE_SPOTTING_PERCENT(  1:140) = 0.0
SURFACE_FIRE_SPOTTING_PERCENT(141:149) = 1.0
SURFACE_FIRE_SPOTTING_PERCENT(150:256) = 1.0
```

The keyword `CRITICAL_SPOTTING_FIRELINE_INTENSITY` (default value of 0.0) is the fireline intensity in units of kW/m below which surface fire spotting does not occur. This parameter has no impact on crown fire spotting.

Particularly under high winds, the parameters that control spotting exert a significant influence on overall fire progression. For that reason, it is often desirable to treat these parameters stochastically and, for fire hindcasts, as calibration coefficients. Setting the parameter `STOCHASTIC_SPOTTING = .TRUE.` directs ELMFIRE to treat the parameters that control spotting stochastically and, when `CALIBRATION = .TRUE.`, automatically adjust these spotting parameters are automatically adjusted to optimize agreement between modeled and observed fire perimeters. When `STOCHASTIC_SPOTTING = .TRUE.`, the following eight parameters are randomly generated within a user-specified range as will be described later:

- `CROWN_FIRE_SPOTTING_PERCENT`
- `GLOBAL_SURFACE_FIRE_SPOTTING_PERCENT`
- `MEAN_SPOTTING_DIST`
- `NEMBERS_MAX`
- `NORMALIZED_SPOTTING_DIST_VARIANCE`
- `PIGN`
- `SPOT_FLIN_EXP`
- `SPOT_WS_EXP`

Note that `GLOBAL_SURFACE_FIRE_SPOTTING_PERCENT` is applied to all fuel models. Shown below is a `&SPOTTING` configuration with stochastic spotting enabled and the 16 parameters that constrain the allowable range of the eight spotting parameters in **bold**:

```
&SPOTTING
ENABLE_SPOTTING                          = .TRUE.
STOCHASTIC_SPOTTING                      = .TRUE.
CROWN_FIRE_SPOTTING_PERCENT_MIN          = 0.2
CROWN_FIRE_SPOTTING_PERCENT_MAX          = 0.8
ENABLE_SURFACE_FIRE_SPOTTING             = .TRUE.
GLOBAL_SURFACE_FIRE_SPOTTING_PERCENT_MIN = 0.2
GLOBAL_SURFACE_FIRE_SPOTTING_PERCENT_MAX = 0.8
CRITICAL_SPOTTING_FIRELINE_INTENSITY     = 2000.0
SPOTTING_DISTRIBUTION_TYPE               = 'LOGNORMAL'
MEAN_SPOTTING_DIST_MIN                   = 5.0
MEAN_SPOTTING_DIST_MAX                   = 10.0
NORMALIZED_SPOTTING_DIST_VARIANCE_MIN    = 250.0
NORMALIZED_SPOTTING_DIST_VARIANCE_MAX    = 600.0
SPOT_WS_EXP_LO                           = 0.4
SPOT_WS_EXP_HI                           = 0.7
SPOT_FLIN_EXP_LO                         = 0.2
SPOT_FLIN_EXP_HI                         = 0.4
NEMBERS_MIN                              = 1
NEMBERS_MAX_LO                           = 1
NEMBERS_MAX_HI                           = 1
PIGN_MIN                                 = 100.0
PIGN_MAX                                 = 100.0
/
```