BFOLDS Fire Regime Module v2.0

User Guide for LANDIS-II Extension

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Last Revised: March 27, 2014

Table of Contents

1 Introduction

This document introduces a new LANDIS II extension, BFOLDS Fire Regime Module v2.0 (BFOLDS-FRM). It is intended for simulating large-extent and long-term fire regimes mechanistically as a function of land cover, terrain, and climate. This extension is applicable in landscapes with contiguous or fragmented forest cover. For its use in non-boreal landscapes, LANDIS II *Dynamic Fuel Extension* is required.

1.1 Previous BFOLDS releases

1.1.1 Version 1.0

BFOLDS (Boreal Forest Landscape Dynamics Simulator) v 1.0 was designed as a non-modular model of integrated fire-succession processes (Perera et al 2008). It is a stand-alone GUI-based software package coded in C++; not compatible with LANDIS II.

1.1.2 Version 1.1

The v1.1 release included several additions of user assumptions, all on fuel availability and fire ignition (BFOLDS Tech note #1, 2010). This version is also a stand-alone GUI-based software package coded in C++; not compatible with LANDIS II.

1.2 What is new in version 2.0

BFOLDS 2.0 is entirely different in architecture and design. It is coded in C#, modular, and compatible with LANDIS II framework. The model logic and scientific concepts have not changed from v1.0, but its applicability has broadened due to addition of many user assumptions. It has separate modules for fire regime and forest succession. This user guide describes the structure and application of the BFOLDS Fire Regime Module v2.0. A similar document will be released soon on the BFOLDS Forest Succession Module v2.0.

1.2.1 Compatibility with LANDIS-II v6.0

BFOLDS Fire Regime Module v2.0 is fully compatible with LANDIS II.

1.2.2 Modularity

BFOLDS Fire Regime Module v2.0 contains several levels of modularity. At the highest level, it contains simulation modules for fire ignition, fire spread, and fire extinguishment. Each of these three modules contains a series of sub-modules that enhance efficiency of runtime execution, facilitate user interactions, and accommodate future improvements.

1.2.3 Open source

BFOLDS Fire Regime Module v2.0 source code, written in C#, is available for registered LANDIS II users upon request (Marc.ouellette@Ontario.ca).

2 BFOLDS –Fire Regime Module v2.0

BFOLDS Fire Regime Module v2.0 (BFOLDS-FRM) represents forest fire processes mechanistically in a spatially explicit manner. It simulates fire ignition, growth, and extinguishment based on input data of weather, forest composition, and terrain and scientific knowledge of Canadian Forest Fire Behavior Prediction System and Fire Weather Index system.

Fire regimes (for example, fire return intervals, fire size distributions, and spatial probabilities of burns) constructed using BFOLDS-FRM over large spatial extents and long time periods are not predictions of past, present, or future, but potential outcomes based on what-if scenarios.

We recommend BFOLDS-FRM for exploring the spatio-temporal variability in forest fire regimes, as a research tool and an aid to inform strategic land use planning and forest policy.

2.1 Overview of BFOLDS-FRM

BFOLDS-FRM simulates fire events as emergent properties of model logic based on synthesized knowledge, model assumptions, and user assumptions, including input data (Figure 1). It is capable of simulating multiple fires simultaneously over large study areas without any assumptions or constraints on how many fires could occur, or how large they should be. Each fire event thus simulated is independent of other fires that occur in the landscape at the same time.

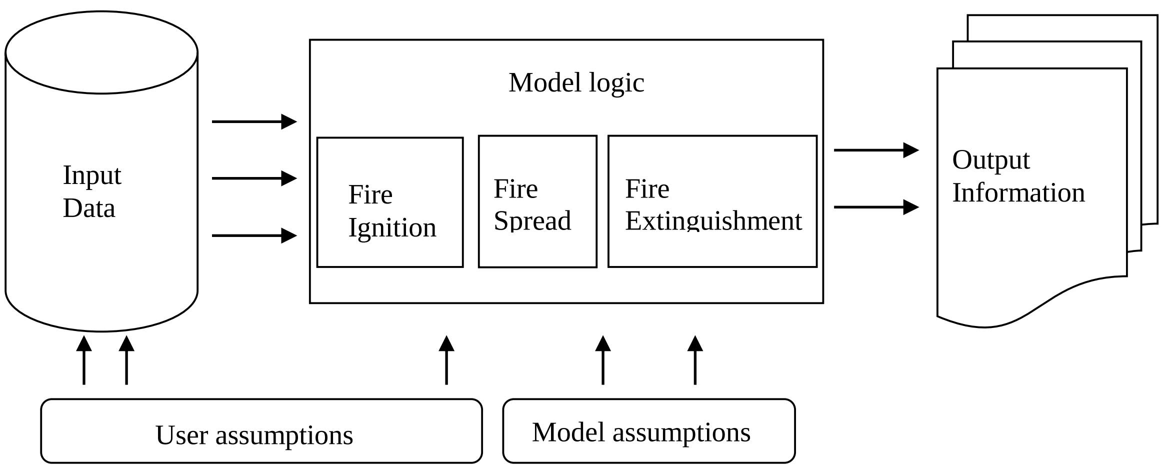

Figure 1. Major conceptual components of BFOLDS-FRM

BFOLDS-FRM simulates fire events for every day of a fire season, and for every year of a fire simulation period, consecutively. During any given day of a fire season, multiple fires may concurrently ignite, spread, and become extinguished across the simulated forest landscape, as guided by input data: temporal patterns of local weather and spatial patterns of fuel availability. Fire simulation is spatially explicit, responding to weather conditions and heterogeneity and juxtaposition of fuel and topography.

2.1.1 Use of weather information

BFOLDS-FRM uses the Canadian Forest Fire Weather Index System (FWI system) for fire simulation. The FWI system (Van Wagner and Pickett 1985) uses four weather parameters – temperature, relative humidity, rain, and wind – to derive six major synthetic components that describe condition of fuel and expected fire spread (Figure 2).

The first three components, i.e., Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and Drought Code (DC), are numeric ratings of potential moisture content in forest fuel. The remaining three components, i.e., Initial Spread Index (ISI), Buildup Index (BUI), and Fire Weather Index (FWI) are fire behavior indices that represent the rate of fire spread, the fuel available for combustion, and the frontal fire intensity.

These components are calculated within BFOLDS-FRM based on sequences of daily temperature, relative humidity, wind speed, and rainfall. For details of these indices and their computations, see Perera et al. 2008.

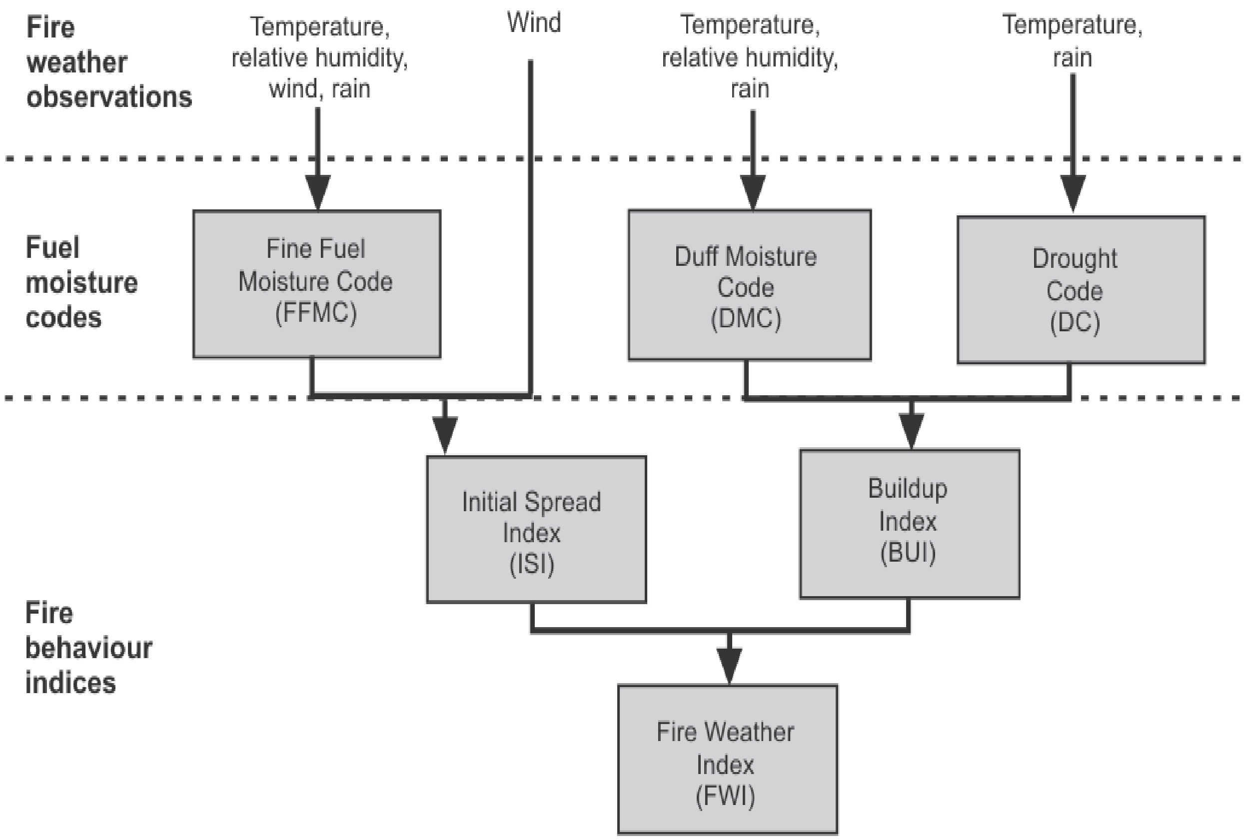

Figure 2. Structure of the Canadian Forest Fire Weather Index System (FWI system) (from http://cwfis.cfs.nrcan.gc.ca/en/background/bi_FWI_summary_e.php).

2.1.2 Use of forest fuel information

BFOLDS-FRM uses the Canadian Forest Fire Behavior Prediction System (FBP system) (Forestry Canada Fire Danger Group 1992, Wotton et al. 2009)to predict potential forest fire behavior.

The FBP system identifies 17 discrete fuel types, grouped by the major forest overstory types (coniferous, deciduous, and mixedwood), post-management conditions (slash), and non-forested area (Table 4).

Given weather, FWI system components, and topographic conditions, each fuel type dictates characteristics of fire behavior including rates of fire spread, crowning, and fuel consumption. For further details of their computations, see Perera et al. 2008.

For use of BFOLDS-FRM in non-boreal forest landscapes, LANDIS II *Dynamic Fuel Extension* is required to classify the vegetation as one of the 17 fuel types.

Table 4. Forest fire behavior prediction system fuel types used in BFOLDS-FRM.

Group	**Identifier**	**Descriptive name**
Coniferous	C-1	Spruce-lichen woodland
	C-2	Boreal spruce
	C-3	Mature jack or lodgepole pine
	C-4	Immature jack or lodgepole pine
	C-5	Red or white pine
	C-6	Conifer plantation
	C-7	Ponderosa pine/douglas fir
Deciduous	D-1	Leafless aspen
Mixedwood	M-1	Boreal mixedwood - leafless
	M-2	Boreal mixedwood - green
	M-3	Dead balsam fir mixedwood - leafless
	M-4	Dead balsam fir mixedwood - green
Slash	S-1	Jack or lodgepole pine slash
	S-2	White spruce-balsam fir slash
	S-3	Coastal cedar/hemlock/Douglas-fir slash
Open	O-1a	Matted grass
	O-1b	Standing grass

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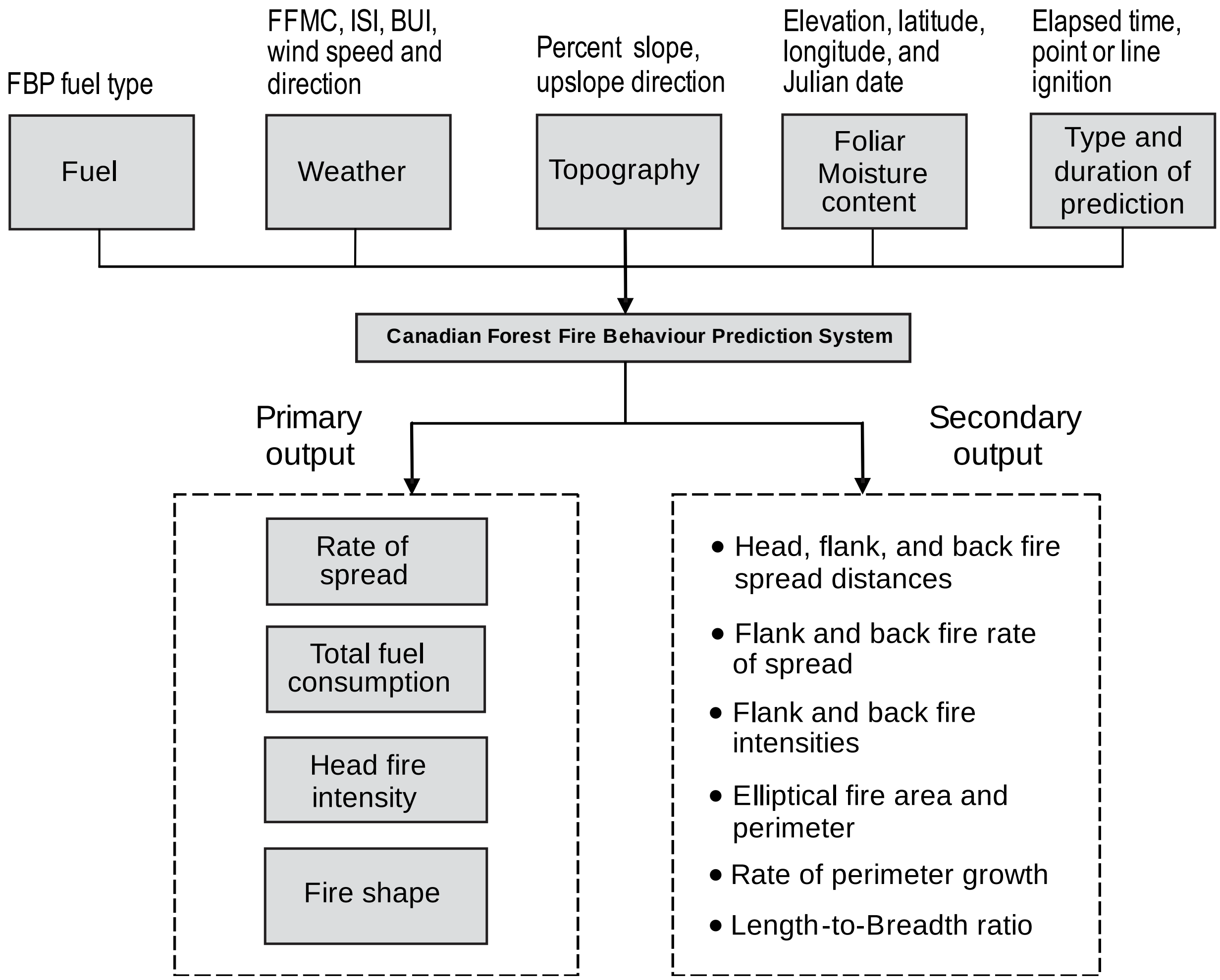
2.2 Simulating Fire Events

BFOLDS-FRM simulates fire events by three mechanisms: ignition of fires, spread of ignited fires, and extinguishment of fires. The fire behavior, given weather and fuel, is based on the FBP system (Figure 3[1]). No presumptions are made of the location, duration, size, and shape of fires; total number of fires; total area burned; and fire size distribution during a fire season. These are emergent properties of the model and input data.



[1] Note that in this figure, the FBP system provides spatial measures such as fire shape, elliptical fire area and perimeter, rate of perimeter growth, and length-to-breadth ratio. These are for idealized elliptical fires burning under constant weather conditions in homogeneous fuels, not for fires simulated with BFOLDS-FRM.

Figure 3. Properties of simulated fires are based on the Canadian Forest Fire Behaviour Prediction System (Forestry Canada Fire Danger Group 1992).

2.2.1 Fire ignition

Fire ignition is guided by local moisture conditions and fuel type. The model uses potential daily seeds (data input) to cause ignitions during the fire season. The actual number of seeds for day is a Poisson-distributed random variable with the mean of potential daily seeds.

The realized number of fires can be lower than the potential number of seeds from the input data, depending on the fuel moisture conditions. Daily DMC over at least part of the landscape has to be above a threshold value (using a range specified as a user assumption), for ignitions to occur that day.

An ignition seed landing on a pixel with burnable fuel will ignite a fire if the DMC levels are conducive. Pixels that are inherently non-burnable (for example, water bodies and bedrock) would never ignite, so any potential ignition seeds placed on those pixels are immediately redistributed elsewhere. Potential ignition seeds landing on pixels with temporarily unburnable (for example, immediately after a fire) are redistributed or not (i.e., sampling with/out replacement) as a user assumption.

2.2.2 Fire Spread

Fire spread in BFOLDS-FRM is a mechanistic process based on the principles of the FBP system (Forestry Canada Fire Danger Group 1992). It simulates the spread of fire to neighboring pixels from a burning pixel, as well as smoldering *in situ.* Fire spread is a deterministic cellular automation process, driven by the spatial patterns of fuel and topography, as well as daily fire weather indices, wind speed, and wind direction. Different rates of spread are estimated directionally (forward, backward, and flanks) based on the FBP system.

Once a pixel (source pixel) is ignited, the fire spread algorithm uses a 9 x 9 search window around the ignited pixel and directionally varying rate of spread to determine the potential spread to neighboring pixels. For each burnable target pixel, the future time at which the fire will reach that pixel is estimated based on the fire's rate of spread (ROS) at each pixel, including the source pixel, the target pixel, and any pixels in between. These ROS values are determined specifically for each pixel, based on the prevailing weather condition, topography, and the fuel type in each pixel. For further details of fire spread computations, see Perera et al. 2008.

A just-ignited or just-burned pixel might not immediately spread fire to its neighbors. If the fire rate of spread is below a threshold, then the pixel enters a smoldering state. At periodic future intervals (the interval is a user assumption), smoldering pixels are re-examined to determine if weather conditions have changed for the fire to either spread from it to its neighbors, or be extinguished.

2.2.3 Fire Extinguishment

The above fire spread algorithm will grow or smolder fires indefinitely unless all spread at the fire perimeter is blocked by non-burnable pixels, the weather becomes too wet, or the fire season ends.

Complete extinguishment of pixels with fires, i.e., cessation of spread and smoldering, is also a mechanistic process that is driven by spatio-temporal patterns in weather in the simulated landscape. During a fire season, all pixels that are either burning or smoldering are extinguished when the weather is too wet, when DMC drops below a threshold drawn from a uniform probability distribution of DMC with a user-specified mean (default is 20) and a range (default is ±10%). This procedure introduces a stochastic element to fire extinguishment and thus fire regime simulations. Regardless of DMC, all burning and smoldering fires are extinguished at the end of each simulated fire season.

2.2.4 Fire Simulation algorithm

A discrete-event simulation algorithm is used to advance time and schedule the fire processes that permit multiple fires to ignite, spread, and extinguish simultaneously in a simulated landscape. The major decision steps associated with simulating fire processes daily are illustrated in Figure 4.

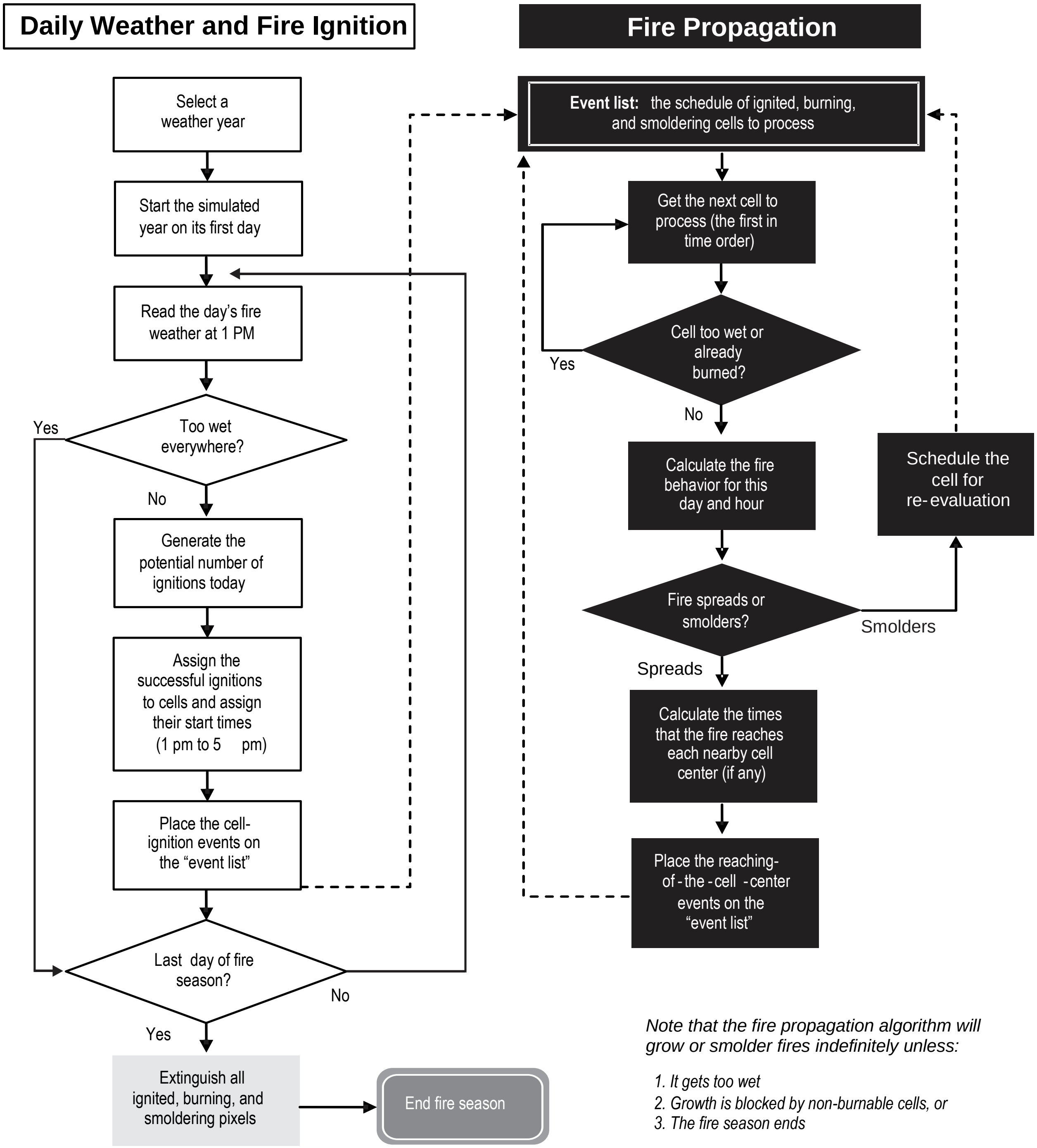


Figure 4. Major decision steps in BFOLDS-FRM fire simulation algorithm.

2.3 Model assumptions

2.3.1 Not modifiable by user

- Spatially, a simulated landscape consists of square pixels and the information provided for fire simulation processes (fuel, weather, terrain) within a pixel are considered spatially and categorically uniform (i.e., sub-pixel variability is not considered).
- Fire ignition is possible between only 1:00 and 5:00 PM, at random times.
- Number of successful ignitions for a day is a Poisson process. The daily ignition data input by users represents the mean of that probability distribution.
- Temporally, most weather indices for a given pixel change daily (some hourly) during simulations.
- Fires can only occur and spread within the time window of a fire season, based on start and end dates defined by users. No fires smolder beyond a fire season.

2.3.2 Modifiable by user

- Weather surfaces are derived from point data (weather stations) using a cubic spline interpolation algorithm based on Flannigan and Wotton (1989).
- Ignition seeds are randomly placed across the landscape.
- If a pixel is burned at a sufficiently high intensity, all fuel is consumed and the forest cover is destroyed
- A pixel burned at a sufficiently high intensity cannot reburn within 10 years and acts as a fire break.
- During a fire season, fire processes (ignition and spread) occur only while DMC is higher than 20 (±10%).

2.4 User assumptions

2.4.1 Required

- Simulation resolution (recommended resolution is 1 ha pixels)

- Validity and quality of all input data
- Forest cover types-to- FBP fuel types conversion rules
- Dates when a fire season begins and ends, and when the summer begins and ends in the simulation study area

2.4.2 Optional

- Spatial distribution of potential fire ignitions (successful lightning strikes) may be assumed to be non-random (i.e., with spatial biases within a simulated landscape). Inserting a spatial weighting pattern will ensure that every pixel in the landscape does not have an equal probability of an ignition placement
- Ignition seeds landing on temporarily unburnable pixels (for example, immediately after a fire) may be redistributed (i.e., sampling with replacement).
- The DMC threshold (and the range) at which fires ignite and survive may be changed.
- Weather input can be a surface that will replace the use of the default interpolation of point data within the model
- Users may assume a fire intensity threshold below which a pixel may be declared unburned. This threshold may be set generally, across all cover types, or as a cover type- and/or site type-specific value.

3 Input Files

3.1 Input File Rules

The input rules for BFOLDS-FRM extension are identical to those of the LANDIS-II Core Model except where stated. Please see the LANDIS-II Core User's Guide for further instruction.

A sample project was provided with the BFOLDS-FRM installation which contains a sample input file which can be used as reference.

3.2 Input File Parameters

3.2.1 Extension title, time step

The first parameter is the title of the input file:

```
LandisData  "BFOLDS Fire Regime Module v2.0"
```

The second parameter is the time step in years. For example:

```
Timestep 1
```

3.2.2 Verbose Output

While BFOLDS-FRM is simulating a fire season, verbose output will determine how much information is outputted to the LANDIS output window. Using 'N' will only show a progress bar during the simulation of a fire year. Using 'Y' will display more information on a day by day basis. Values are 'Y' or 'N', For example:

```
VerboseOutput N
```

3.2.3 Reseed Fires

The next parameter, **ReseedFire** determines if the model will reseed an ignition, if the ignition landed on a pixel that burned within the same simulation year. For example:

```
ReseedFire Y
```

3.2.4 Age Burnable

The next parameter, **AgeBurnable**, allows the model to decide when there is valid fuel for a site for it to burn based on site age. If **AgeBurnable** is set to '10', no fire will take place for that site until site age is greater than 10. For example:

```
AgeBurnable 10
```

3.2.5 Reseed Fire Age Burnable

The next parameter, **ReseedFireAgeBurnable** determines if model will reseed fire ignitions if they land on a site where siteage is less than **AgeBurnable** value, if the value is ‘Y’ then the model will attempt to reseed the ignition**.** For example:

```
ReseedFireAgeBurnable Y
```

3.2.6 DMC Spread Limit Mean

The next parameter, **DMCSpreadLimitMean** mean value is used for fire spread. This is used in conjunction with **DMCSpreadAdjustment**. For example:

```
DMCSpreadLimitMean 20
```

3.2.7 DMC Spread Adjustment

The next parameter, **DMCSpreadAdjustment** is the adjustment that is applied to the **DMCSpreadLimitMean** to determine if a fire should keep spreading/smolder or should extinguish. A value of' ‘0.1’ and a **DMCSpreadLimitMean** of ‘20’ will yield a range of 18-22. A uniformly distributed random number is picked every day in that range to determine if fires should spread or become extinguished. If the DMC for the site is less than or equal to the randomly generated number, then any fire spread event that executes during that day will result in that pixel becoming extinguished. For example:

```
DMCSpreadAdjustment 0.1
```

A value of 0.0 will mean there is no range and the **DMCSpreadLimitMean** value will be used as the DMC limit.

3.2.8 Threshold Intensity Limit

The next parameter, **ThresholdIntensityLimit** determines when all cohorts on a site are killed. When the intensity of a site is higher than the **ThresholdIntensityLimit**, all cohorts on a site will be killed. If a value of ‘-1’ is used no cohorts will ever be killed and another extension, or the source code to BFOLDS-FRM will need to be modified to selectively kill cohorts. The fire intensity is used for this limit and is measure in kW/m. For example:

```
ThreholdIntensityLimit 200
```

3.2.9 Use Ignition Biasing

The next parameter, **UseIgnitionBiasing** determines if the model will use ignition biasing to seed ignitions. While the ignitions will still be random, they will be biased as to where they are placed, according to an input file. For example:

```
UseIgnitionBiasing Y
```

If this is ‘Y’ then than the parameter **IgnitionBiasing** must include a valid GIS file.

3.2.10 Ignition Factor

The next parameter, **IgnitionFactor** multiples the ignition count input from the ignition count file. This allows the user to easily increase or decrease the mean number of potential ignitions. For example:

```
IgnitionFactor 1.0
```

3.2.11 FWI Start Year

The next parameter, **fwiStartYear** determines the first year of weather data that is available to the model. For example:

```
fwiStartYear 1990
```

3.2.12 FWI End Year

The next parameter, **fwiEndYear** determines the last year of weather data that is available to the model. For example:

```
fwiEndYear 2050
```

3.2.13 Ignition DMC Limit

The next parameter, **IgnitionDMCLimit** value at a site determines if an ignition will take place. The DMC value must be greater than the **IgnitionDMCLimit** for an ignition to be successful. For example:

```
IgnitionDMCLimit 20
```

3.2.14 Use Dynamic Fuels

The next parameter, **UseDynamicFuels** determines how BFOLDS-FRM will select a fuel type for a site. If set to 'Y', BFOLDS-FRM will use the LANDIS II *Dynamic Fuels Extension* to determine the fuel type for a given site. If set to 'N' BFOLDS-FRM will use the **ForestCoverToFuelRules** to determine the fuel type. For example:

```
UseDynamicFuels Y
```

Note that the LANDIS II *Dynamic Fuels Extension* must be enabled as well in the LANDIS scenario file.

3.2.15 Forest Cover To Fuel Rules

The next parameter, **ForestCoverToFuelRules** determines the location of the file that contains the forest cover to fuel conversion rules. For example:

```
ForestCoverToFuelRules  "fuel lookup.csv"
```

See Section 3.3.3 for file format for ignition files.

When using Dynamic Fuels this should be set to 'None'. For example:

```
ForestCoverToFuelRules  None
```

3.2.16 Spring End Date

The next parameter, **SpringEndDate** value determines the Julian day value the model uses for the end of spring. This used to determine what fuel type to pick based on time of year. For example:

```
SpringEndDate 140
```

3.2.17 Fall Start Date

The next parameter, **FallStartDate** value determines the Julian day value the model uses for the start of fall season. This used to determine what fuel type to pick based on time of year. For example:

```
FallStartDate 250
```

3.2.18 Smolder Evaluation Interval

The next parameter, **SmolderEvalInterval** determines the period of time before the fire from the current site attempts to spread again if it was smoldering. The fire will continue to try spreading until it has nowhere left to spread to, goes out due to weather or the fire season ends. The unit of measure is hours. For example:

```
SmolderEvalInterval 3
```

3.2.19 Weather Data

The next parameter, **WeatherData** value contains the name of the folder where the weather data files are located. For example:

```
WeatherData weather
```

3.2.20 Weather Years

The next parameter, **WeatherYears** determines the filename and path of the file that describes the weather years. For example:

```
WeatherYears weather.txt
```

See Section 3.3.4 for file format.

3.2.21 Use Simple Weather Years

The next parameter, **UseSimpleWeatherYears** determines whether BFOLDS-FRM will use one weather stream or spline weather surfaces containing many weather streams to create the surface. For example:

```
UseSimpleWeatherYears   N
```

Depending on the value assigned, different procedures need to be followed to provide the weather input data to BFOLDS-FRM.

If the value of **UseSimpleWeatherYears** is ‘Y’ then the data input procedures are outlined in section 3.3.6 Simple Weather Data, otherwise section 3.3.7 outlines the procedures to create spline weather surfaces.

3.2.22 Ignition Seed Folder

The next parameter, **IgnitionSeedFolder** determines where BFOLDS-FRM will look for ignition data. For example:

```
IgnitionSeedFolder ignitions
```

See Section 3.3.5 for file format.

3.2.23 Site Age

The next parameter, **SiteAge** determines the location and name of the GIS file that contains site age (age since last disturbance) for a site. If 'None' is used it will use the age of the oldest cohort for the site age. For example:

```
SiteAge siteage.img
```

3.2.24 Slope and Aspect

The next parameter, **Slope** determines the location and name of the GIS file that contains slope for each site. For example:

```
Slope slope.img
```

The second parameter, **Aspect** determines the location and name of the GIS file that contains aspect for each site For example:

```
Aspect aspect.img
```

3.2.25 Use Site Factors

The next parameter, **UseSiteFactors** determines if site factors will be loaded and used in BFOLDS-FRM logic. For example:

```
UseSiteFactors Y
```

Using site factors is useful when using **ForestCoverToFuelRules** to help refine your logic in selecting a fuel type for example. If using site factors is not needed then processing will be faster if **UseSiteFactors** is set to 'N'.

3.2.26 Site Factor 1 and Site Factor 2

The next parameter, **SiteFactor1** determines the location and name of the GIS file that contains Site Factor information and is used for selecting fuel rules in **ForestCoverToFuelRules**. For example:

```
SiteFactor1 moisture.img
```

The second parameter, **SiteFactor2** determines the location and name of the GIS file that contains Site Factor information and is used for selecting fuel rules in **ForestCoverToFuelRules**. For example:

```
SiteFactor2 Nutrient.img
```

Both Site Factor 1 and 2 can be set to 'None' if they are not used. If only 1 is used it has to be **SiteFactor1**.

3.2.27 Spatial Biasing for Ignitions

The next parameter, **IgnitionBiasing** determines the location and name of the GIS file that contains ignition biasing information. For example:

```
IgnitionBiasing biasing.img
```

This should be set to 'None' when biasing is not used.

3.2.28 Latitude

The next parameter, **Latitude** determines the location and name of the GIS file that contains latitude information in floating point format. The file format used must be ASCII grid format as that is the only import format that LANDIS supports that can contain floating point values. For example:

```
Latitude latitude.asc
```

This should be set to 'None' when using **UseSimpleWeatherFile**.

3.2.29 Longitude

The next parameter, **Longitude** determines the location and name of the GIS file that contains longitude information in floating point format. The file format used must be ASCII grid format as that is the only import format that LANDIS supports that can contain floating point values. For example:

```
Longitude longitude.asc
```

This should be set to 'None' when using **UseSimpleWeatherFile**.

3.2.30 File Output Extension

The next parameter, **FileOutputExtension** determines the GIS output format that will be used to save the BFOLDS-FRM spatial data by LANDIS. For example:

```
FileOutputExtension img
```

3.2.31 Output Files

The next parameter, **OutputFiles** determines where BFOLDS-FRM log files and GIS output will be stored. For example:

```
OutputFiles output
```

3.2.32 Fuel Type Table

The next parameter is a table, **FuelTypeTable** and is discussed in section 3.3.1.

3.2.33 Grass Type Table

The next parameter is a table, **GrassTypeTable** and is discussed in section

3.3 Individual Parameter Tables and Files

Each BFOLDS-FRM table or input file requires a separate suite of parameters.

3.3.1 Fuel Type Table

BFOLDS-FRM uses the same Fuel Type Table as Dynamic Fire System Version 2.0.3.

Index	BaseType	SurfaceType	InitProb	a	b	c	q	BUI	maxBE	CBH
1	Conifer	C1	1	90	0.0649	4.5	0.9	72	1.076	2
2	Conifer	C2	1	110	0.0282	1.5	0.7	64	1.321	3
3	Conifer	C3	1	110	0.0444	3	0.75	62	1.261	8
4	Conifer	C4	1	110	0.0293	1.5	0.8	66	1.184	4
5	Conifer	C5	1	30	0.0697	4	0.8	56	1.22	18
6	ConiferPlantation	C6	1	30	0.08	3	0.8	62	1.197	7

7	Conifer	C7	1	45	0.0305	2	0.85	106	1.134	10
8	Deciduous	D1	0.5	30	0.0232	1.6	0.9	32	1.179	0
9	Conifer	M1	1	110	0.0282	1.5	0.8	50	1.25	6
10	Conifer	M2	1	110	0.0282	1.5	0.8	50	1.25	6
11	Conifer	M3	1	120	0.0572	1.4	0.8	50	1.25	6
12	Conifer	M4	1	100	0.0404	1.48	0.8	50	1.25	6
13	Slash	S1	1	75	0.0297	1.3	0.75	38	1.46	0
14	Slash	S2	1	40	0.0438	1.7	0.75	63	1.256	0
15	Slash	S3	1	55	0.0829	3.2	0.75	31	1.59	0
16	Open	O1a	1	190	0.031	1.4	1	1	1	0
17	Open	O1b	1	250	0.035	1.7	1	1	1	0

The fuel type table is mostly copied from Appendix 1 and Tables 6, 7 and 8 of the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992).

The Index, BaseType are only used when BFOLDS-FRM is use in conjunction with the Dynamic Fuel System. The InitProb and maxBE are never used in BFOLDS-FRM.

Standard values for all other values can be found in the FBP. These parameter values can be adjusted by the user to produce desired behavior, which may be particularly useful if the standard Canadian fuel types to not adequately model certain local fuel types. The fuel type table must have at least one entry each with a surface type of M1 and M2, unlike the Dynamic Fire System the parameters for these types must be defined by the user in the fuel table. If using the BDA extension, or any other extension that produces dead conifers, the table must also include entries with surface types M3 and M4 when used with Dynamic Fuel System.

3.3.1.1 Index

The first column in the table (Index), lists an integer index value for each fuel type. The index value in this table should correspond with index values used in the accompanying Dynamic Fuel System Extension. All index values that appear in the Dynamic Fuel System Extension need to be listed in this FuelTypeTable.

3.3.1.2 Base Types

All fuel types must be assigned to a base type, which can be Conifer, ConiferPlantation, Deciduous, Slash, or Open. These values are not used by BFOLDS-FRM.

3.3.1.3 Surface Fuel Types

All fuel types must be assigned to a fuel type on which to base surface fuel consumption (SFC) calculations. SFC is used in the calculation of fire intensity, and uses fixed equations for each Canadian fuel type. Any custom fuel type needs to be assigned to a similar Canadian fuel type to allow calculation of SFC. Acceptable value for this parameter are C1-C7, D1, M1-M4, S1-S3, O1a, O1b.

3.3.2 Grass Type Table

The Grass Type Table is used to enter different seasonal values for the % Curing and Grass Fuel Load(GFL) parameters

Grass Type	Spring Curing	Spring GFL	Summer Curing	Summer GFL	Fall Curing	Fall GFL
O1a	25	0.25	50	0.5	75	0.75
O1b	30	0.3	60	0.6	80	0.8

The Seasons is controlled by the **SpringEndDate** and the **FallStartDate**.

3.3.3 Forest Cover to Fuel Rules File

The forest cover to fuel rules is used to determine a fuel type on a site. When multiple cohorts are present on a site then the oldest cohort is used to select the fuel type. If site factors are not used the columns must still be entered in the file but must be set to ‘0’.

Cover Type	Ecosite	SF1	SF2	Site Age Max	Spring/Fall Season Fuel	Summer Season Fuel
BfDom	1	2	0	15	O1b	M2 50% Conifer
BfDom	1	2	0	25	C2	C2
BfDom	1	2	0	40	M3 30% Dead Fir	M4 30% Dead Fir
BfDom	1	2	0	60	M3 60% Dead Fir	M4 60% Dead Fir
BfDom	1	2	0	80	M3 60% Dead Fir	M4 60% Dead Fir
BfDom	1	2	0	100	M3 100% Dead Fir	M4 100% Dead Fir
BfDom	1	2	0	380	M3 100% Dead Fir	M4 100% Dead Fir
Brush/Alder	1	2	0	380	S2	M2 25% Conifer
BwDom	1	2	0	380	D1	M2 25% Conifer
BwDom	1	2	0	19	S2	M2 25% Conifer

Valid fuel types to assign in the file are:
C1, C2, C3, C4, C5, C6, C7, D1, D2, M1 25% Conifer, M1 50% Conifer, M1 75% Conifer, M2 25% Conifer, M2 50% Conifer, M2 75% Conifer, M3 30% Dead Fir, M3 60% Dead Fir, M3 100% Dead Fir, M4 30% Dead Fir, M4 60% Dead Fir, M4 100% Dead Fir, O1a, O1b, S1, S2, S3.

3.3.4 Weather Years File

The data in the weather file is comma delimited and contains the weather year, start Julian day and end Julian day of the fire season. Example of weather date in the file:

```
2000,92,305
2001,90,280
2002,91,295
```

Note that for any years and start-end range, weather data and ignition data must also be present for the model to function.

3.3.5 Ignition Seed Folder Folders

For each weather year that is entered in the **WeatherYear** file, a comma delimited ignition file with the weather year name (e.g., 2000.txt) must be provided. These files contains the year, Julian day and mean number of potential ignitions. Each year's data must be entered in its own file. For example:

```
2000,160,0
2000,161,0
2000,162,1
2000,163,0
2000,164,0
2000,165,3
2000,166,0
2000,167,0
```

The above example lists all Julian days available. But just the ones with ignitions can be provided as any Julian day without ignitions defaults to zero.

3.3.6 Simple Weather Data

For each weather year that is entered in the **WeatherYear** file, a comma delimited weather file with the weather year name (e.g., 2000.txt) must be provided in the **WeatherData** folder. Each year's data must be entered in its own file. For example:

STATION	DATE	JULIAN	WIND_DIR	WIND_SPEED	FFMC	DMC	BUI
10100	28/03/2000	88	0	0	85	6	0
10100	29/03/2000	89	45	8	84.2	6	6
10100	30/03/2000	90	90	6	86.6	7	7
10100	31/03/2000	91	45	18	85.3	8	8
10100	1/4/2000	92	225	8	22.5	4	4
10100	2/4/2000	93	45	9	46.9	5	5
10100	3/4/2000	94	315	12	60.3	5	5
10100	4/4/2000	95	270	7	72.2	5	5
10100	5/4/2000	96	135	18	79.9	6	6
10100	6/4/2000	97	270	10	28.4	2	1
10100	7/4/2000	98	270	5	47.8	2	2
10100	8/4/2000	99	225	14	62.2	2	2
10100	9/4/2000	100	270	14	72	2	2
10100	10/4/2000	101	270	5	79.3	2	2
10100	11/4/2000	102	270	9	83.9	2	2
10100	12/4/2000	103	180	19	85.2	3	3
10100	13/04/2000	104	225	19	50	2	3
10100	14/04/2000	105	0	0	0	0	0
10100	15/04/2000	106	0	0	0	0	0

The STATION and DATE field are not used by BFOLDS-FRM and are for the user's reference, but must be provided.

3.3.7 Spline Weather Surfaces

For each weather year that is entered in the **WeatherYear** file, 5 splines surfaces must be provided. FFMC (*.ffmc), DMC (*.dmc), BUI (*.bui), Wind Speed and Wind Direction (*.u, *.v). For example for year 2000 you would have the following files: 2000.ffmc, 2000.dmc, 2000.bui, 2000.u, and 2000.v.

Several steps must be taken to produce these files. For each year of weather data you wish to use you will need to provide two tab or space delimited text files that contain weather information.

3.3.7.1 FFMC, BUI, DMC

To create the FFMC, BUI and DMC, a file containing the appropriate weather information containing the following columns must be provided: Point ID, Latitude, Longitude, Year, Month, Day, Julian Day, FFMC, DMC, and BUI.

Example of a partial file (note the file cannot have a header to the columns):

PointID	Latitude	Longitude	Year	Month	Day	JulianDay	FFMC	DMC	BUI
21016	52.98	-87.37	2000	5	4	125	43.9	8	10
10407	49.82	-93.45	2000	5	4	125	92.2	27	27
10404	50.33	-93.17	2000	5	4	125	87.8	20	22
10600	48.6	-93.37	2000	5	4	125	84.3	19	22
10400	49.79	-92.6	2000	5	4	125	89.9	22	23
42117	47.5	-84.23	2000	5	4	125	43.5	23	23
42110	48.3	-84.09	2000	5	4	125	48	10	13
42405	46.37	-81.57	2000	5	4	125	76	31	35
10158	50.73	-94.06	2000	5	4	125	90.4	26	26
10200	50.03	-91.91	2000	5	4	125	89.2	20	21
10201	51.47	-90.18	2000	5	4	125	84.4	15	15
10302	50.26	-94.96	2000	5	4	125	91.4	17	17
10114	50.61	-94.04	2000	5	4	125	90.4	26	26
10115	53.06	-93.34	2000	5	4	125	82.6	11	11
10120	50.68	-93.52	2000	5	4	125	88.1	25	25
31804	48.49	-81.18	2000	5	4	125	42.8	17	20
42650	47.04	-79.8	2000	5	5	126	78.6	11	13
42602	47.38	-79.75	2000	5	5	126	77.3	31	31
52800	45.35	-80.02	2000	5	5	126	51	9	12
53100	45.52	-78.27	2000	5	5	126	76	33	33
73905	42.96	-82.33	2000	5	5	126	87.1	16	17
73907	42.27	-82.97	2000	5	5	126	85.6	16	17
73922	44.15	-79.87	2000	5	5	126	85.2	21	21
84000	45.21	-81.53	2000	5	5	126	47.6	8	10
31901	47.2	-81.42	2000	5	5	126	58.8	27	27
42150	47.73	-84.8	2000	5	5	126	70.3	19	19
42151	48.7	-85.74	2000	5	5	126	72.1	5	7

31608	49.62	-80.79	2000	5	5	126	76.4	14	16
31600	49.05	-81.04	2000	5	5	126	68.6	13	15
20809	48.44	-90.71	2000	5	5	126	51.8	13	15
21000	49.78	-86.87	2000	5	5	126	78.6	19	20
31708	48.42	-83.09	2000	5	5	126	76.9	23	23

Field Descriptions

PointID: Number representing the point ID or weather station ID.
Latitude: Latitude of the location.
Longitude: Longitude of the location.
Year: Year of the data point.
Month: Month of the data point.
Day: Day of the month of the data point.
JulianDay: The Julian day or day of year of the data point.
FFMC: FFMC value of the data point.
DMC: DMC value of the data point.
BUI: BUI value of a data point.

For each Julian day that a spline surface is to be created at least 3 data points are required. Up to 250 data points can be used per day.

Once the each text file is created for every year of data specified in Weather Years file, the weather surfaces need to be created so they can be used to interpolate within BFOLDS-FRM. To create the surfaces you use the program called weather.exe that was provided with the BFOLDS-FRM extension. Run weather.exe with the following arguments:

```
Weather.exe InputFile Year OutputFolder
```

InputFile: The full path to the input file containing the weather data.
Year: The weather year the input file contains.
OutputFolder: Where the weather surfaces will be created.

Example:

```
Weather.exe "c:\temp\2000yearweather.txt" 2000 "c:\final BFOLDS
weather"
```

Note that if there are any spaces in path names “” must be use around the parameters.

Once the weather surfaces are created they can be copied to the **WeatherData** folder.

3.3.7.2 Wind Speed and Direction

To create the Wind speed and direction files, a file containing the appropriate weather information with the following columns must be provided: Point ID, Latitude, Longitude, Year, Month, Day, Julian Day, Wind Speed, and Wind Direction.

Example of a partial file (note the file cannot have a header to the columns):

PointID	Latitude	Longitude	Year	Month	Day	JulianDay	WindSpeed	WindDir
21003	49.8	-85.87	2000	5	4	125	14	360
31900	47.67	-81.71	2000	5	4	125	7	248
32000	48.11	-80.09	2000	5	4	125	8	247
42509	47.11	-80.48	2000	5	4	125	8	180
42551	46	-81.45	2000	5	4	125	21	233
10300	49.88	-94.45	2000	5	4	125	13	60
10302	50.26	-94.96	2000	5	4	125	13	315
10500	49.4	-91.63	2000	5	4	125	12	45
21007	52.22	-87.87	2000	5	4	125	11	270
20811	48.81	-89.12	2000	5	4	125	14	360
20809	48.44	-90.71	2000	5	4	125	6	45
20810	49.48	-89.99	2000	5	4	125	17	64
20813	49.18	-89.42	2000	5	4	125	16	315
20812	48.17	-90.14	2000	5	4	125	9	45
31404	49.76	-84.52	2000	5	4	125	7	315
31403	49.05	-84.11	2000	5	4	125	13	360
42650	47.04	-79.8	2000	5	4	125	8	180
42602	47.38	-79.75	2000	5	4	125	11	202
20805	49.84	-90.19	2000	5	4	125	15	5
42106	48.58	-85.29	2000	5	5	126	11	180
42105	48.08	-84.55	2000	5	5	126	5	360
42110	48.3	-84.09	2000	5	5	126	8	225
42150	47.73	-84.8	2000	5	5	126	10	135
42151	48.7	-85.74	2000	5	5	126	11	180
42117	47.5	-84.23	2000	5	5	126	10	135
42508	46.62	-80.8	2000	5	5	126	3	45

63407	44.22	-76.6	2000	5	5	126	2	160
63408	44.56	-76.44	2000	5	5	126	7	180
10602	49.04	-93.9	2000	5	5	126	5	360
20855	49.43	-90.54	2000	5	5	126	7	100
20818	48.4	-89.62	2000	5	5	126	7	157
32050	48.53	-79.75	2000	5	5	126	8	180

Field Descriptions

PointID: Number representing the point ID or weather station ID.
Latitude: Latitude of the location.
Longitude: Longitude of the location.
Year: Year of the data point.
Month: Month of the data point.
Day: Day of the month of the data point.
JulianDay: The Julian day or day of year of the data point.
WindSpeed: Wind speed value of the data point.
WindDir: Wind direction value of the data point.

For each Julian day that a spline surface is to be created at least 3 data points are required. Up to 250 data points can be used per day.

Once the each text file is create for every year of data specified in Weather Years file, the weather surfaces need to be created so they can be used to interpolate within BFOLDS-FRM. To create the surfaces you use the program called weather.exe that was provided with the BFOLDS-FRM extension. Run weather.exe with the following arguments:

```
wind.exe InputFile Year OutputFolder
```

InputFile: The full path to the input file containing the weather data.
Year: The weather year the input file contains.
OutputFolder: Where the weather surfaces will be created.

Example:

```
wind.exe “c:\temp\2000yearwind.txt” 2000 “c:\final BFOLDS weather”
```

Note that if there are any spaces in path names “” must be use around the parameters.

Once the weather surfaces are created they can be copied to the **WeatherData** folder.

4 Output Files

4.1 Fire Intensity Map

The map of fire intensity for the whole landscape.

4.2 Fire ID Map

Each fire is assigned a unique ID in a BFOLDS-FRM simulation. This maps lets you see where fires ID occurred spatially in a simulation.

4.3 Burned Map

If a **ThresholdIntensityLimit** is used to kill cohorts then this map will be produced. In contrast the Fire ID map shows every site that burned. This will let you know which one of those site had cohorts killed due to intensity. If a **ThresholdIntensityLimit** isn’t used this file will not be generated.

4.4 Time Since Last Fire Map

The map of the number of years elapsed since last burn for each pixel on the landscape

4.5 Total Burn Count Map

If a **ThresholdIntensityLimit** is used to kill cohorts then this map will be produced. The value at each site in this map will increase by 1 when the site is burned. This gives the count of the number of times that a site burned in a simulation. If a **ThresholdIntensityLimit** isn’t used this file will not be generated.

4.6 BFOLDS-FRM Log file

This log file contains extra information that isn’t available in the LANDIS window. Various events that occur over a fire season are saved to this log file.

4.7 BFOLDS-FRM Fires Log file

This log file contains information for all fires that occur in BFOLDS-FRM. It contains for each fire: FireID, start day, end day, start row, start column, and number of sites burned. Note: Number of sites burned will not be number be equal to the number of sites where all cohorts are killed unless the **ThresholdIntensityLimit** is set to 0.

5 Future Development

5.1 Forest succession module

An empirical forest succession module, BFOLDS-FSM, is in development. This LANDIS II extension will simulate pixel-based transition of forest cover over time as well as after disturbances. It employs a time-dependent Markov chain that will be parameterized by synthesized scientific knowledge and/or expert knowledge, while accounting for spatially explicit geo-environmental factors.

5.2 Forest Cover mortality sub-module

A companion sub-module to BFOLDS-FRM that simulates post-fire mortality based on the interaction between frontal fire intensity and forest cover (species-age-site) is in development.

6 References

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6.2 Further reading

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