

# Linear Wind Disturbance v1.0 LANDIS-II Extension User Guide

Eric J. Gustafson

Brian R. Miranda

Brian R. Sturtevant

US Forest Service, Northern Research Station  
Rhinelander, WI, USA

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# 1 Introduction

This document describes the **Linear Wind Disturbance** extension for the LANDIS-II model. Users should read the *LANDIS-II Model User's Guide* prior to reading this document.

This extension is designed to simulate linear wind disturbances such as tornadoes and derechos, and is loosely based on the Base Wind extension, primarily differing in the shape of wind events and producing variability in wind speed within wind events. Microbursts and other wind events that typically produce more circular patterns of disturbance are more simply simulated using the Base Wind v2.1 extension.

## 1.1 Wind Disturbances

During a wind time step, multiple wind events may occur on the landscape. The extension simulates tornadoes and derechos as distinct types of events, with parameters specific to each type. Although the terms tornado and derecho appear in parameter names, each type is simulated using the same algorithm, so the types in reality are distinguished solely by the input parameters used. Users may assign parameters to simulate other types of wind events as desired. Wind initiation and spread are not dependent upon forest condition, but damage can be.

Each wind event is simulated by randomly placing a line segment on the landscape and damaging cells on and parallel to the line according to a defined disturbance width. Wind intensity decreases linearly with distance from the line segment, with stochasticity of intensity introduced according to an intensity variation parameter. When the variation parameter=0.0, intensity values form perfect stadium shapes (bands) around the axis line; when the variation parameter is <0.5, the majority of cells within an intensity band have a higher intensity of wind speed and damage, with embedded patches of lower wind speed and damage; when the variation parameter is >0.5, the majority of cells within an intensity band have a lower intensity of wind speed and damage, with embedded patches of higher wind speed and damage.

## 1.2 Number of Wind Events

The probability of a linear wind event occurring in a time step is controlled by two input parameters giving the mean and standard deviation number of wind events per unit area (40,000 km<sup>2</sup>) per/year to

define a normal distribution. This distribution includes both types of events (tornadoes and derechos), with the proportion of each type also specified. Historic data is typically used to estimate these parameters, but they may also be estimated based on expectations under future climate conditions.

### 1.3 Tornadoes

Tornadoes typically produce a relatively narrow damage path, and are often shorter in length than derechos. The length of each tornado event is drawn from a Weibull distribution specified by two parameters,  $\lambda$  and  $\alpha$ .

### 1.4 Derechos

Derechos typically produce a relatively longer and wider damage path than tornadoes, sometimes exceeding 380 km in length and 65 km in width. The length of each derecho event is drawn from a separate Weibull distribution, specified by two parameters,  $\lambda$  and  $\alpha$ .

### 1.5 Intensity

The intensity (relative wind speed) within a disturbance event is characterized by an index that ranges between 0 and 1, with 1 equating to the maximum possible wind speed. Each event has a maximum intensity value selected from the user-defined distribution of intensity levels. The intensity along the centerline of the event will equal the maximum intensity, with intensity decreasing with distance from the centerline.

#### 1.5.1 Intensity Tables

For each event type (tornado and derecho) user inputs define the percentage of events that have maximum intensity values in each of 5 intensity classes. The intensity classes range from 0.2 to 1.0, at increments of 0.2. For each initiated wind event, the maximum intensity for the event will be randomly drawn from the distribution defined by the percentages for the 5 classes. The percentages for the 5 classes must sum to 100%.

#### 1.5.2 Intensity Variability (PropIntensityVar)

Wind speed intensity within a tornado or derecho event is typically variable. Tornadoes lift and touch down sporadically along their path, and derechos feature clusters of downbursts and embedded microbursts that

can cause uneven damage. The extension uses a proportional intensity variation parameter to control the pattern of intensity variability within a wind event.

Wind intensity (relative wind speed) within an event initially ranges from the event's maximum intensity (along the centerline) to 0 (on the edge of the event). Each cell in the event can have its intensity reduced by one intensity class (0.20) with a probability equal to PropIntensityVar. A value of 0 for this parameter will result in intensities that form perfect stadium shapes of nested intensity classes along the linear axis of the event. Any value greater than 0 for this parameter will introduce heterogeneity in the pattern of intensity values. A value of 0.5 results in maximum fragmentation and a value of 1.0 will reduce the intensity class of every cell in each intensity band surrounding the line segment.

## 1.6 Wind Direction Table

Linear wind events are not typically oriented randomly. A wind direction table specifies the directionality probabilities. Because directional spread is not explicitly simulated, opposite compass directions can be simulated as having the same direction (e.g., N to S and S to N have the same directional axis). Therefore, the table includes the 4 possible directional combinations resulting from 8 cardinal directions [N-S, NE-SW, E-W, SE-NW]. The user defines the percentage of events that occur in each direction. The percentages for the 4 directions must sum to 100%. The dominant wind event direction is randomly selected based on the probabilities in the wind direction table, and the actual azimuth of the wind event is randomly deviated up to 22.5 degrees from the dominant wind direction using a uniform probability distribution.

## 1.7 Ecoregion Modifiers

Wind damage can be less under some abiotic conditions, typically related to topography. For example, lowlands or lee slopes may experience less wind intensity and therefore less damage. Users can specify a modification factor applied to wind intensity for specific ecoregions. Wind-disturbed sites within such ecoregions will have this amount added to the wind intensity for the site, with negative values resulting in a reduction in wind intensity.

## 1.8 Wind Damage

Wind damage at each site affected by an event is dependent upon the age of the cohorts (relative to species longevity) and wind intensity

(speed). The oldest cohorts are more vulnerable than younger cohorts. If a cohort is damaged by wind, the entire cohort is killed.

Wind severity is a damage classification variable that is written to the wind severity output maps. It is not to be confused with wind intensity (speed). The wind severity table specifies the relationship between wind intensity and cohort mortality, and assigns a wind severity label to each level of mortality. The following is an example of a wind severity table:

Wind Severity Class	Relative Cohort Age (% of species longevity)	Windspeed Mortality Threshold (WMT)
5	0% to 20%	0.95
4	20% to 50%	0.90
3	50% to 70%	0.50
2	70% to 85%	0.15
1	85% to 100%	0.05

Whether a cohort is killed depends on its relative age (% of species longevity) and wind intensity. To determine if a cohort is killed, the wind mortality threshold (WMT) associated with the cohort's relative age in the wind severity table is compared to the wind event intensity, which ranges from 0.0 – 1.0 (low to high). If the wind intensity is **greater than the WMT** associated with the cohort's relative age, then the cohort is killed.

Wind Intensity > WMT[cohort's age] => cohort killed

Each dead cohort has an associated wind severity value based on its age (see table above). Wind severity indicates the level of wind **damage** (not intensity); more severe storms kill younger cohorts. For each site in an event, the maximum wind severity is selected from the severities of all the site's dead cohorts. A wind event has an associated mean wind severity, which is the average of the severities at all of the event's sites, which is recorded in the log file. Wind severity and wind intensity can also be reported in the wind output maps.

## 1.9 Major Releases

### 1.9.1 v1.0

The initial release.

## 1.10 References

Hjelmfelt MR. 2007. Convective storms and downbursts. p. 74 in Johnson EA and Miyanishi K (eds.), Plant disturbance ecology, Academic Press, Burlington, MA, USA.

Peterson CJ, JB Cannon and CM Godfrey. 2016. First steps toward defining the wind disturbance regime in central hardwood forests. in Greenberg, CH, Collins BS (eds.). Natural Disturbance and Historic Range of Variability: Type, frequency, severity and post-disturbance structure in Central hardwood forests USA. Springer, Heidelberg.

Scheller RM, JB Domingo. 2013. LANDIS-II Base Wind v2.1 Extension User Guide. Published online (<http://www.landis-ii.org/extensions/base-wind>).

## 1.11 Acknowledgements

Funding for the development of LANDIS-II has been provided by the Northern Research Station (Rhinelander, Wisconsin) of the U.S. Forest Service.



## 2 Input File

The input parameters for this extension are specified in one input file. This text file must comply with the general format requirements described in section 3.1 *Text Input Files* in the *LANDIS-II Model User Guide*.

### 2.1 Example File

```
LandisData "Linear Wind"

Timestep 10

NumEventsMean 0.84 <<Mean number of events/40,000 km2/year
NumEventsStDev 0.08 <<Standard deviation number of events

>> Tornadoes <<
TornadoLengthLambda 25.300 <<Lambda length of events (km)
TornadoLengthAlpha 1.200 <<Alpha length of events (km)
TornadoWidth 0.420 <<Width of small events (km)
TornadoIntensityTable
>> Percent      Having this
>>of events     Intensity
>> -----
      0          << 0.2
      5          << 0.4
     20          << 0.6
     50          << 0.8
     25          << 1.0
TornadoProp 0.7 <<Proportion of events w/ small width (0-1)

>> Derechos <<
DerechoLengthLambda 160.000 <<Lambda length of events (km)
DerechoLengthAlpha 50.000 <<Alpha length of events (km)
DerechoWidth 40.000 <<Width of large events (km)
DerechoIntensityTable
```

```
>> Percent      Having this
>>of events     Intensity
>> -----
      5          << 0.2
     15         << 0.4
     50         << 0.6
     25         << 0.8
      5         << 1.0
```

```
PropIntensityVar      0.65 <<Proportion of event with
intensity reduced by 1< intensity class defined by distance
```

WindDirectionTable

```
>> Percent      Having this
>> of events     Directionality
>> -----
      0          << N-S
     30         << NE-SW
     60         << E-W
     10         << SE-NW
```

EcoregionModifiers << Modify lowlands

```
MN101          -0.5
```

WindSeverities

```
>> Cohort Age      Windspeed Mortality
>>Severity         % of longevity      Threshold
>>-----
      5             0% to 20%          0.8
      4             20% to 40%         0.75
      3             40% to 60%         0.7
      2             60% to 80%         0.5
      1             80% to 100%        0.4
```

```
MapNames wind/severity-{timestep}.img
```

```
LogFile wind/log.csv.
```

## 2.2 LandisData

The value of this parameter must be "Linear Wind".

## 2.3 Timestep

This parameter is the time step of the wind extension. Value: integer > 0.  
Units: years.

## 2.4 NumEventsMean

This parameter is the mean number of wind events of all types per unit area per year. Value: real > 0. Units: events/40,000 km<sup>2</sup>/year.

## 2.5 NumEventsStDev

This parameter is the standard deviation of the number of wind events. Value: real > 0. Units: events/40,000 km<sup>2</sup>/year.

## 2.6 TornadoLengthLambda

This parameter is the mean length of the first type of linear wind events, typically tornadoes. This is the first of two parameters used to specify the Weibull distribution of event lengths. Value: real > 0. Units: km.

## 2.7 TornadoLengthAlpha

This parameter is the second of two parameters used to specify the Weibull distribution of the length of this type of wind event. Value: real > 0. Units: km.

## 2.8 TornadoWidth

This parameter is the mean width of linear wind events, typically tornadoes. Value: real > 0. Units: km.

## 2.9 TornadoIntensityTable

The keyword TornadoIntensityTable precedes the table of wind intensity percentages. The following five lines define the percentage of events with maximum intensity of 0.2, 0.4, 0.6, 0.8, and 1.0, respectively. The listed percentages must sum to 100%. The intensities of simulated wind events will approximate the intensity class percentages provided in this table. See section 2.1 for an example. Value: percentage (0 – 100). Units: %.

## 2.10 TornadoProp

This parameter is the proportion of wind events that are of the first type, typically tornadoes. The proportion of the second type of wind event is calculated by the extension as  $1 - \text{TornadoProp}$ . Value:  $0 \leq \text{real} \leq 1.0$ . Units: proportion.

## 2.11 DerechoLengthLambda

This parameter is the mean length of the second type of linear wind events, typically derechos. This is the first of two parameters used to specify the Weibull distribution of event lengths. Value:  $\text{real} > 0$ . Units: km.

## 2.12 DerechoLengthAlpha

This parameter is the second of two parameters used to specify the Weibull distribution of the length of this type of wind event. Value:  $\text{real} > 0$ . Units: km.

## 2.13 DerechoWidth

This parameter is the mean width of this type of wind event, typically derechos. Value:  $\text{real} > 0$ . Units: km.

## 2.14 DerechoIntensityTable

The keyword `DerechoIntensityTable` precedes the table of wind intensity percentages. The following five lines define the percentage of events with maximum intensity of 0.2, 0.4, 0.6, 0.8, and 1.0, respectively. The listed percentages must sum to 100%. The intensities of simulated wind events will approximate the intensity class percentages provided in this table. See section 2.1 for an example. Value: percentage (0 – 100). Units: %.

## 2.15 PropIntensityVar

This parameter specifies the variability in wind intensity within a wind event. Value:  $0 \leq \text{real} \leq 1.0$ . Units: proportion.

## 2.16 WindDirectionTable

The keyword `WindDirectionTable` precedes the table of wind direction percentages. The following four lines define the percentage of events with primary directions of N-S, NE-SW, E-W, SE-NW, respectively. The listed percentages must sum to 100%. The directionality of

simulated wind events will approximate the directional percentages provided in this table. Value: percentage (0 – 100). Units: %.

## 2.17 EcoregionModifiers

This table defines probability modifiers that can reduce wind intensity values for specific ecoregions. Ecoregions not appearing in the table will be assigned a value of 0.0 (no modification) by default.

### 2.17.1 Table Name

The keyword for the table is "EcoregionModifiers"

### 2.17.2 Ecoregion

The first value in a table entry is the ecoregion name.

### 2.17.3 Modifier

The second value in a table entry is the modifier value. Wind intensity values in the ecoregion will be modified by this amount. Value:  $-1.0 \leq \text{real} \leq 1.0$ . Units: proportion.

## 2.18 Wind Severity Table

The wind severity table specifies the relationship between wind intensity (speed) and cohort mortality, and assigns a wind severity class to each level of mortality for use in wind output maps.

### 2.18.1 Table Name

The keyword for the table is "WindSeverities"

### 2.18.2 Severity Column

The severities must appear in decreasing order in the table, with zero representing the least severe wind event. Value: integer  $\geq 0$ . Units: years.

### 2.18.3 Cohort Age

This parameter specifies the range of relative cohort ages with a common Windspeed Mortality Threshold. Relative cohort ages are given as a percentage of species longevity, and the range is expressed as “lower bound to upper bound”. The relative age is applied to all species and it is not possible to differentiate Windspeed Mortality Threshold by species. Valid values for both lower and upper bounds:  $0\% \leq \text{integer} \leq 100\%$ . Units: Percentage of species’ longevity.

### 2.18.4 Windspeed Mortality Threshold

This parameter is the minimum wind intensity value that will kill the cohorts given in the Cohort Age column. Value:  $0.0 \leq \text{decimal number} \leq 1.0$ .

Example:

WindSeverities

```
>> Severity      Cohort Age          Windspeed Mortality
>> class         (% of longevity)      Threshold
>>-----
      5           0% to 20%           0.8
      4           20% to 40%          0.75
      3           40% to 60%          0.7
      2           60% to 80%          0.5
      1           80% to 100%         0.4
```

### 2.19 MapNames

This file parameter is the template for the names of the output maps (see section 3.1). Two types of maps can optionally be chosen for output: wind intensity (keyword `IntensityMapNames`) and wind severity (keyword `SeverityMapNames`). The parameter value must include the variable “timestep” to ensure that the maps have unique names (see section 3.1.8.1, Variables in the LANDIS-II Model User Guide). The user must indicate the file extension. The user must also include sub-directory name(s) as needed.

Examples:

```
IntensityMapNames linearwind/intensity-{timestep}.img
SeverityMapNames  linearwind/severity-{timestep}.img
```

### 2.20 LogFile

The file parameter is the name of the extension’s event log file (see section 3.2).

## 3 Output Files

The wind extension generates two types of output files: a) maps of wind events for each time step, and b) a log of wind events for the entire scenario.

### 3.1 Wind Intensity Maps

The map of wind intensity uses values of [wind intensity \*100] for all sites. Sites outside of any wind event (including non-active sites) have a value of 0. A map is produced for each wind time step.

### 3.2 Wind Severity Maps

The map of wind severity uses a code of 0 for non-active sites, 1 for active and not disturbed sites, [wind severity + 1] for all disturbed sites. A map is produced for each wind time step.

### 3.3 Wind Event Log

The event log is a text file that contains information about every event over the course of the scenario: year, initiation cell coordinates, type of event, length and width, direction class, intensity, number of sites in the event, number of damaged sites, total event size (ha), damaged area (ha), total number of cohorts killed, mean wind severity across all damaged sites. The information is stored as comma-separated values (CSV).