User Guide to WFDS – this is a work in progress

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Chapter 1

Disclaimer

This document is an initial (draft) user guide for NIST's Wildland-urban interface Fire Dynamics Simulator (WFDS) which is an extension of NIST's Fire Dynamics Simulator (FDS).

The US Department of Commerce makes no warranty, expressed or implied, to users of the FDS or WFDS, and accepts no responsibility for its use. Users of FDS or WFDS assume sole responsibility under Federal law for determining the appropriateness of its use in any particular application; for any conclusions drawn from the results of its use; and for any actions taken or not taken as a result of analysis performed using these tools.

Users are warned that FDS and WFDS are intended for use only by those competent in the fields of fluid dynamics, thermodynamics, heat transfer, combustion, and fire science, and is intended only to supplement the informed judgment of the qualified user. The software package is a computer model that may or may not have predictive capability when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous conclusions with regard to fire safety. All results should be evaluated by an informed user.

Throughout this document, the mention of computer hardware or commercial software does not constitute endorsement by NIST, nor does it indicate that the products are necessarily those best suited for the intended purpose.

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Chapter 2

Overview of WFDS

The wildland-urban interface fire dynamics simulator (WFDS) extends the fire dynamics simulator (FDS), which has been developed for structural fires, to account for the presence of terrain and/or vegetation and the spread of fires through vegetation. This extension of FDS is underway as part of NIST's wildland-urban interface program. FDS has an associated suite of documents covering the modeling approach, validation and verification efforts, and a user guide. These documents are available from the FDS web site: http://fire.nist.gov/fds. The source code for WFDS is completely integrated within FDS. Also, modifications to the visualization tool Smokeview, for viewing WFDS predictions, have been made and are ongoing.

2.1 Vegetation models

Two approaches for modeling vegetation have been developed and are called the fuel element and the boundary fuel models. Details of the approach used for these two vegetation models is given in Chapter 4 and their specification via wfds input files in discussed in Secs. 3.2.4, 3.2.5, and 3.2.6. The fuel element method can be used to represent surface or raised vegetation. The boundary fuel method is used to represent surface fuels only and was designed to operate at coarser grid resolutions than the fuel element model. The current version of WFDS uses fuel elements to represent vegetation. The boundary fuel element was used in earlier versions of WFDS and is being added to the current version.

2.2 Status of WFDS Development

Validation studies have been conducted for both vegetation models. Australian grassland fire were simulated with the boundary fuel method (Mell et al., 2007). Results from the fuel element model were compared against measurements from tree burning experiments conducted in NIST's large fire laboratory using individual Douglas firs (Mell et al., 2009).

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Chapter 3

Running WFDS

3.1 The Basics

WFDS is run the same way as FDS is run. The program executable and an input file are needed. Smokeview can be used to view the results as WFDS is running and after it is completed. Please refer to the Smokeview user guide. WFDS runs on one processor or multiple processors. Please refer to the FDS user guide: Chapter 2 for computer hardware and software (e.g., MPI for parallel runs); Chapter 3 for instructions on running FDS; and Chapter 4 for User Support.

The most recent WFDS executables (for Windows 32bit and 64bit; and Linux) are available from the WFDS download web page. Since WFDS source code is completely integrated with FDS users can also obtain WFDS by downloading FDS from the FDS download web page; however the FDS download page may not have the most recent version of WFDS. The most recent version of Smokeview, the visualization tool for W/FDS, can be obtained via the FDS download web page.

3.2 Input Files

The majority of the entries in a WFDS input file are common to WFDS and FDS applications (such as domain size and number of grid points). In the following examples of WFDS input files, entries that are unique to, or predominantly used in, WFDS applications (i.e., vegetation, terrain) are described. Entries that are shared by FDS and WFDS may be presented but are not discussed, unless necessary for overall clarity. In other words, users unfamiliar with FDS also need to read section II of the FDS user guide.

3.2.1 Basic Input File Entries: Computational Domain, Boundary Conditions

The basic entries in an FDS or WFDS input file are given in the following namelist statements. Note no vegetation is defined here, examples of how to define vegetation are given in subsequent sections. This is included here for completeness. If more information is needed please see the FDS user guide document.

```
- Job name (used for output files)
&HEAD CHID='veg_burn',TITLE='Example of basic input entries' /

- Number of grid cells, domain dimensions in meters
&MESH IJK=100,100,50, XB=0,100,-50,50,0,50 /
&TIME T_END=60 /
```

```
- Specify parameters for combustion of fuel gases from pyrolysis of the solid
fuel(s)
&REAC ID='WOOD'
       FYI='Ritchie, et al., 5th IAFSS, C_3.4 H_6.2 O_2.5'
       SOOT_YIELD = 0.02
       O = 2.5
       C = 3.4
       H = 6.2
       HEAT_OF_COMBUSTION = 17700 /

- Set inflow velocity characteristics
&SURF ID='INFLOW',VEL=-2,RAMP_V='RAMPVEL' /
&RAMP ID='RAMPVEL',T=0.0,F=0.0 /
&RAMP ID='RAMPVEL',T=0.5,F=1.0 /

- Domain-Boundary conditions
&VENT XB=-4,-4,-3, 0,0,6,SURF_ID='INFLOW' / inflow through x=-4 (left side)
&VENT XB=12,12,-3, 0,0,6,SURF_ID='OPEN' /
&VENT XB=-4,12,-3,-3,0,6,SURF_ID='OPEN' /
&VENT XB=-4,12, 0, 0,0,6,SURF_ID='MIRROR' / symmetry along y=0 plane
&VENT XB=-4,12,-3, 0,6,6,SURF_ID='OPEN' /

- Time intervals at which data is output
&DUMP DT_SLCF=0.1,DT_PART=0.1,DT_BNDF=0.1,DT_PL3D=20.  /

- Two-dimensional slice files, can be visualized by Smokeview
&SLCF PBY= 0, QUANTITY='TEMPERATURE',VECTOR=.TRUE. /
&SLCF PBY= 0, QUANTITY='soot density' /
&SLCF PBY= 0, QUANTITY='water vapor' / H2O from combustion
&SLCF PBY= 0, QUANTITY='WATER VAPOR' / H2O from veg drying

-- Boundary files, can be visualized by Smokeview
&BNDF QUANTITY='HEAT_FLUX'/
&BNDF QUANTITY='RADIATIVE_FLUX'/
&BNDF QUANTITY='CONVECTIVE_FLUX'/

- Declare end of input file
&TAIL /
```

3.2.2 Input File Entries for Vegetation Fuel Element Model

When using the fuel element model, the input file entries that specify characteristics of the vegetation occur in namelists PART and TREE. The PART namelist contains thermophysical properties of the vegetation. The TREE namelist specifies the location and geometry of the vegetation. File entries related to timing of the output of vegetation information occur in the namelist DUMP. The quantities used for vegetation in the PART, TREE and DUMP namelists are listed below. If desired, the reader can skip this section and go to the subsequent sections which contain examples of using PART, TREE and DUMP. Note that hyper links exist in the document to aid the reader.

Items in the PART namelist, in alphabetical order, are:

ID: Character string used to match a vegetation volume, specified in the TREE namelist to the PART quantities.

TREE: either .TRUE. or .FALSE.. Default is .FALSE.. Purpose is to state that the particles are vegetation (as opposed to fuel droplets or massless Lagrangian particles for visualization).

QUANTITIES

VEG_BULK_DENSITY: Bulk density of vegetation in kg m^{-3}. Default is 0.3 kg m^{-3}. This can be determined from field measurements of of the fuel loading (kg m^{-2}) divided by the height of the vegetation (m). It is the mass of dry vegetation divided by the bulk volume containing that vegetation.

VEG_BURNING_RATE_MAX: Maximum value allowed for the rate that fuel gases can be created per unit volume in a grid cell, kg $m^{-3}s^{-1}$. Default is 0.4 kg $m^{-3}s^{-1}$, based on Douglas fir tree burning experiments. For some problems this bound is needed to avoid too rapid of a burning rate. Whenever possible it should be based on experimental measurements.

VEG_CHAR_FRACTION: Fraction of virgin dry virgin vegetation that becomes char. Default value is 0.25.

VEG_DEHYDRATION_RATE_MAX: Maximum value allowed for the loss of moisture during the thermal degradation of the vegetation in kg $m^{-3}s^{-1}$. Default is 0.5 kg $m^{-3}s^{-1}$.

VEG_DENSITY: Density of vegetative fuel in kg m^{-3}. Default is 540 kg m^{-3}.

VEG_DRAG_COEFFICIENT: Nondimensional multiplicative factor used in the drag model (see tree burning paper). Default value is 1.

VEG_INITIAL_TEMPERATURE: Initial temperature of vegetation in °C. Default value is 20 °C or TMPA which is set in the MISC namelist (see FDS user guide about TMPA).

VEG_MOISTURE: Fraction of moisture on a dry mass basis (mass of moisture in vegetation / dry mass of vegetation). Default value is 10.

VEG_REMOVE_CHARRED: Either .TRUE. or .FALSE., default is .TRUE.. Specifies if, once the thermal degradation has reduced the vegetation to pure char, the fuel element should be removed (.TRUE.) or kept. If the vegetation is kept then it participates in the computation as a source of drag and head sink (or source) through radiative and convective heat transfer. Currently the thermal degradation model does not include char oxidation (smoldering combustion). See tree burning paper.

VEG_SV: Surface-to-volume ration of the vegetation element in m^{-1}. Default value is 4000 m^{-1}.

Items in the TREE namelist, alphabetical order, are:

CROWN_BASE_HEIGHT: Height, in meters and relative to XYZ, of the base or bottom of the bulk vegetation when it is cone, cylinder, or frustum shaped.

CROWN_WIDTH: Diameter, in meters and relative to XYZ, of the base of the bulk vegetation when it is cone or cylinder shaped.

CROWN_WIDTH_BOTTOM: Diameter, in meters and relative to XYZ, of the base of the bulk vegetation when it is frustum shaped.

CROWN_WIDTH_TOP: Diameter, in meters and relative to XYZ, of the top of the bulk vegetation when it is frustum shaped.

FUEL_GEOM: Declares the shape of the bulk volume containing the vegetation. Note that heights are relative to the ground. The choices are:

RECTANGULAR: This requires the user to specify the x, y, and z extents, in meters, of the vegetation using XB. See section 3.2.4 for an example.

CYLINDER: Requires the user to specify, in meters, the diameter of the cylinder, the height of the cylinder's base, and the height of the cylinder's top using CROWN_WIDTH, CROWN_BASE_HEIGHT, and TREE_HEIGHT, respectively.

CONE: Requires the user to specify, in meters, the diameter of the cone, the height of the cone's base, and the height of the cone's vertex using CROWN_WIDTH, CROWN_BASE_HEIGHT, and TREE_HEIGHT, respectively.

FRUSTUM: Requires the user to specify, in meters, the diameters of bottom and top of the vegetation (using CROWN_WIDTH_BOTTOM and CROWN_WIDTH_TOP, respectively) and the heights of the bottom and top of the vegetation (using CROWN_BASE_HEIGHT and TREE_HEIGHT, respectively).

LABEL: Character string used to create the name of the vegetation data output file if OUTPUT_TREE = .TRUE.. For example, if LABEL = 'tree1' and CHID = 'case1' then the filename will be case1_tree1_vegout.csv.

OUTPUT_TREE: Either .TRUE. or .FALSE, default is .FALSE. If .TRUE. then an output file is created with five columns: time (s), dry mass of vegetation (kg), moisture mass of vegetation (kg),

PART_ID: Identifies the PART namelist that contains the thermophysical properties of the vegetation.

TREE_HEIGHT: Height, in meters, of the top of the bulk vegetation when it is cone, cylinder, or frustum shaped.

XB: When the bulk volume containing the vegetation is rectangular in shape XB gives the extent, in meters, of the vegetation in the x, y, and z directions: XB = x_{min}, x_{max}, y_{min}, y_{max}, z_{min} ,z_{max}, where x is left-to-right, y is front-to-back, and z is lower-to-upper when the scene is first displayed in Smokeview.

XYZ: When the bulk volume containing the vegetation is cylindrical, conical, or a frustum XYZ=x, y, z are the coordinates, in meters, of the origin of the bulk volume.

3.2.3 Input File Entries for Vegetation Boundary Fuel Model

this section will be completed after the boundary fuel model has been incorporated into the current version of FDS

3.2.4 Example of Input File for Surface Vegetation Using the Fuel Element Model

Figure 3.1 illustrates the use of the fuel element model to represent a pine needle fuel bed 8 m long, 2 m wide, and 5 cm high. The PART, TREE and DUMP entries in the input file that define the thermophysical properties of the vegetation and the time interval between outputs to the vegetation data file are:

```
- Pinus Ponderosa needles ground fuel elements
   Uses Catchpole CST, 131, pp.1-37, 1998 values of case PPMC59
&PART ID='GROUND NEEDLES', TREE=.TRUE., QUANTITIES='VEG_TEMPERATURE',
      VEG_INITIAL_TEMPERATURE=20.,
      VEG_SV=5710., VEG_MOISTURE=0.07, VEG_CHAR_FRACTION=0.25,
      VEG_DRAG_COEFFICIENT=0.375, VEG_DENSITY=510., VEG_BULK_DENSITY=10.,
      VEG_BURNING_RATE_MAX=2, VEG_DEHYDRATION_RATE_MAX=2,
      VEG_REMOVE_CHARRED=.TRUE. /
&TREE XB=0,8,-2,0,0,0.05, PART_ID='GROUND NEEDLES', FUEL_GEOM='RECTANGLE',
      OUTPUT_TREE=.TRUE., LABEL='ground_needles' /
&DUMP DT_VEG=0.1
```

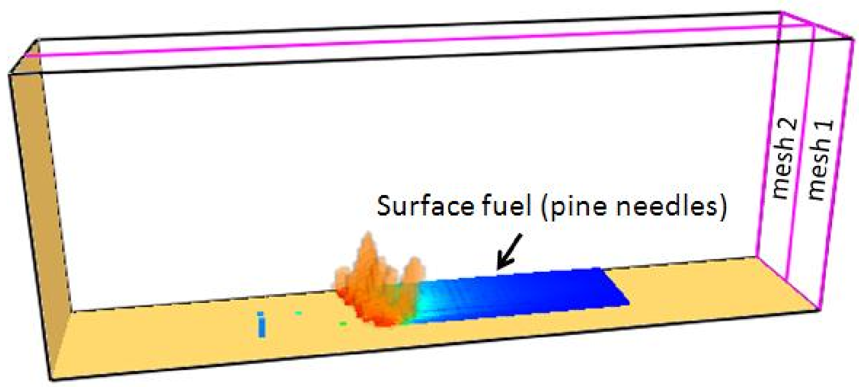

Figure 3.1: Example of a pine needle fuel bed represented by the fuel element model in WFDS. This figure is an annotated image created by Smokeview. The vegetation is colored by temperature blue (ambient) to red (hottest). The location of the fire front, which is spreading from left to right, is shown as an orange surface of constant heat release rate. This case used two meshes which are outlined in red/pink and labeled in the figure.

3.2.5 Example of Input File for Surface Vegetation Using the Boundary Fuel Model

Results of this model, using an older version of FDS, were compared to Australian grassland experiments (Mell et al., 2007). The inclusion of this vegetation model in the current version of FDS is underway.

this section will be completed after the boundary fuel model has been incorporated into the current version of FDS

3.2.6 Example of Input File for Raised Vegetation Represented as a Cone, Cylinder, and Frustum

Figure 3.2 shows raised vegetation represented, in bulk, as a cone, cylinder, or frustum. The `PART, TREE` and `DUMP` entries in the input file that define the thermophysical properties of the vegetation and the time interval between outputs to the vegetation data file are:

```
-Tree vegetation
&PART ID='FOLIAGE1', TREE=.TRUE., QUANTITIES='VEG_TEMPERATURE',
      VEG_INITIAL_TEMPERATURE=20.,
```

```
      VEG_SV=3900., VEG_MOISTURE=0.14, VEG_CHAR_FRACTION=0.25,
      VEG_DRAG_COEFFICIENT=0.375, VEG_DENSITY=514., VEG_BULK_DENSITY=2.76,
      VEG_BURNING_RATE_MAX=0.4, VEG_DEHYDRATION_RATE_MAX=0.4,
      VEG_REMOVE_CHARRED=.TRUE. /
&TREE XYZ=1.5,1.5,0, IDPART_ID='FOLIAGE1', FUEL_GEOM='CONE',
      CROWN_WIDTH=1.0, CROWN_BASE_HEIGHT=0.3, TREE_HEIGHT=4,
      OUTPUT_TREE=.TRUE., LABEL='cone_tree' /
&TREE XYZ=-1.5,1.5,0, IDPART_ID='FOLIAGE1', FUEL_GEOM='CYLINDER',
      CROWN_WIDTH=1.0, CROWN_BASE_HEIGHT=0.3, TREE_HEIGHT=4,
      OUTPUT_TREE=.TRUE., LABEL='cylinder_tree' /
&TREE XYZ=0,-1.5,0, IDPART_ID='FOLIAGE1', FUEL_GEOM='FRUSTUM',
      CROWN_WIDTH_BOTTOM=1.0, CROWN_WIDTH_TOP=0.5,
      CROWN_BASE_HEIGHT=0.3, TREE_HEIGHT=4,
      OUTPUT_TREE=.TRUE., LABEL='frustum_tree' /
&DUMP DT_VEG=0.1 /
```

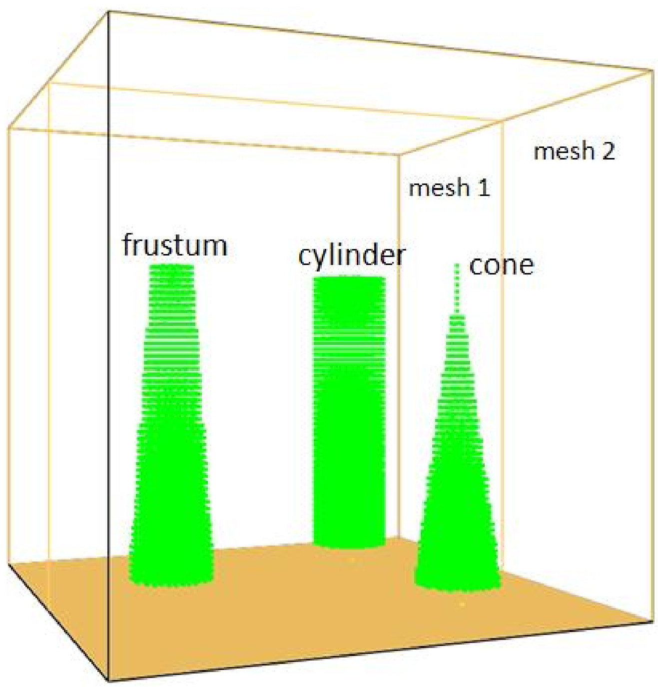

Figure 3.2: Example of cone, cylinder, and frustum shaped trees as represented by the fuel element model in WFDS. This figure is an annotated image created by Smokeview. This case used two meshes which are outlined in red/pink and labeled in the figure. The image has been rotated from Smokeview's default initial view so that into the page is predominantly in the negative x direction (rather than the negative y direction).

3.2.7 Vegetation-Data Outputs

There are a number of variables that can be output (as defined in the input file) to track the evolution of the vegetation. The vegetation can be viewed with Smokeview by choosing to load particles from the Smokeview drop down menu. Each particle type can then be viewed, or not, from the Show/Hide drop

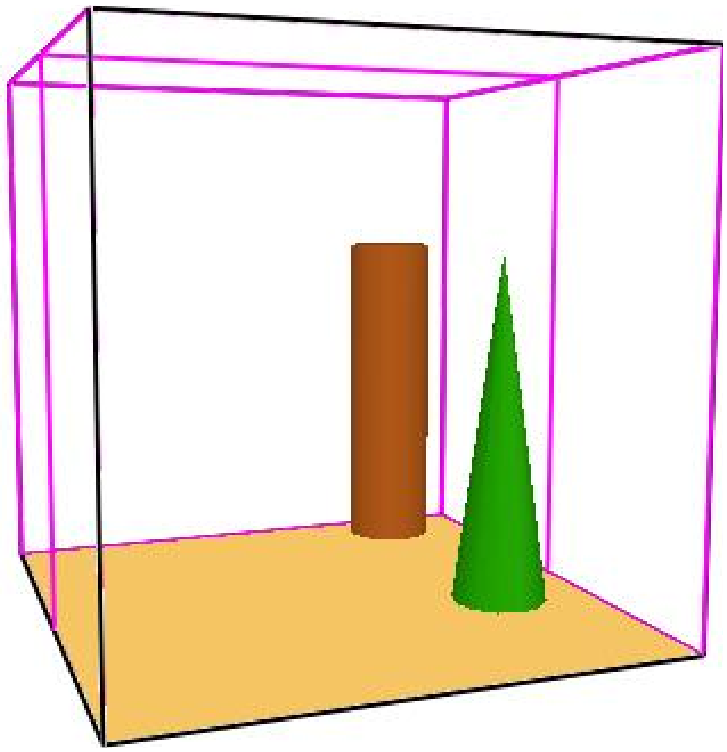

Figure 3.3: The same cone and cylinder of Fig. 3.2 but displayed with devices (solid volumes) instead of particle. There are currently no devices for a frustum. This is the default view. The use of devices is especially helpful when many vegetation volumes are present in the domain as in, for example, a forest stand with shrubs and trees of various shapes and sizes. Representing the vegetation with solid devices allows the user to zoom into specific regions while retaining the visual fidelity of the vegetation. If particles are used and the user zooms in closer then different vegetation volumes cannot be distinguished from each other (the view becomes a cloud of particles). However, only particles can be used to display vegetation properties (such as temperature) and their evolution. Work is ongoing to make this possible with devices.

down menu. Please refer to the FDS user guide for more information on what particle attributes can be viewed. This type of output is specified by the `QUANTITIES` entry in the `PART` namelist.

Vegetation data, to be post-processed by the user, is written to a text (ASCII) file if `OUTPUT_TREE=.TRUE.` on a `TREE` namelist. The file name is determined by `CHID` and `LABEL`. Currently the following columns of data are output:

1. time, s
2. total dry mass of vegetation, kg
3. total moisture mass of vegetation, kg
4. total net convective heat transfer summed over all fuel elements in the particular TREE, kW
5. total net radiative heat transfer summed over all fuel elements in the particular TREE, kW

The last two quantities are:

$$\sum_j \int \nabla \cdot q_{\mathrm{rad}} \, dV_j \tag{3.1}$$

where q is the radiative or convective flux, the sum is over all j fuel elements in the tree, and V_j is the volume of fuel element j.

Chapter 4

Overview of Modeling Approach