WRF compatible Freitas Model User Guide:

Version 2.0 BETA
Plume rise code developed by Saul Freitas, NASA Goddard
Code modified by Derek V. Mallia, University of Utah

Welcome! If you are reading this guide, you are likely interested in generating some wildfire plume rises using the 1-D cloud resolving smoke plume model developed in Freitas et al. (2007; 2010). Further details behind the model physics can be found in Freitas et al. (2007; 2010). This code further expands upon the original Freitas model by including code functionality that is directly compatible with WRF output (Mallia et al. 2018). This model is able to read fire data (heat flux, fire area) and meteorological boundary conditions to compute the height of the wildfire plume rise. The plume top height for each fire listed is then saved to a text file. As of right now, this code only works with WRF, however, the non-beta version (v2.0) will likely include solutions for working with other model types such as the GFS, CFSR, NAM ect…

If you are interested in using this model, continue with the instruction below. While these instructions are specifically geared for the University of Utah's Kingspeak sever, this code should work on any linux machine with PGI compilers and netcdf libraries. Note that this code is currently not compatible with other compilers, due to the coding style of the plume_alone_module.f90

1. University of Utah Kingspeak Installation instructions:

The latest version of the code can be downloaded from the following path:

/uufs/chpc.utah.edu/common/home/lin-group7/dvm/projects/plume_rise_model/freitas_plume_model_v2.0_beta/

Just copy all of the files in this directory to your working directory. These files should include a number of *.f90 files, a netcdf.inc file, and a make file (See image below).

```
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$ ls
find_metfile.f90       Makefile           plume_alone_module.f90  read_namelist.f90    write_plume.f90
format_column_wrf.f90  netcdf.inc         read_finput.f90         run_plume_model.f90
list_metfile.f90       netcdf_reader.f90  read_fsize.f90          working_directory
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$
```

Before we can compile the code, we need to load modules for pgi and netcdf-c and -f libraries. The can be accomplished by typing the following lines of text to your terminal command line.

module load pgi
module load netcdf-c
module load netcdf-f

Similarly, you can also add these lines to your .custom.sh file within your home directory under the following lines (this is a more permanent way of setting the necessary modules):

“# Do Kingspeak specific initializations elif [["$UUFSCELL" = "kingspeak.peaks"]] ; then”

add 3 lines of code:

module load pgi
module load netcdf-c
module load netcdf-f

Once this is done, close out your terminal session and log back in.

For the next step, you will need to compile the Freitas model. Since the environment variables in the Makefile are set dynamically, no changes are necessary in the Makefile.

Simply type the following command into the command line where your Makefile and fortran code resides:

make

If the installation goes bad or if you want to change the code, type:

make clean

to clean up the previous installation. For reference, attached below is what a successful compilation should look like:

```
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$ make
pgf90 -c -O3 -Munroll=c:1 -Mnoframe -mcmodel=medium -Mlarge_arrays -Mlre -Mvect=cachesize:1048576,sse,prefetch  plume_alone_module.f90 read_n
amelist.f90 read_fsize.f90 read_finput.f90 find_metfile.f90 list_metfile.f90 netcdf_reader.f90 format_column_wrf.f90 write_plume.f90 run_plum
e_model.f90
plume_alone_module.f90:
read_namelist.f90:
read_fsize.f90:
read_finput.f90:
find_metfile.f90:
list_metfile.f90:
netcdf_reader.f90:
format_column_wrf.f90:
write_plume.f90:
run_plume_model.f90:
ar r plume_alone_module.a *.o
ar: creating plume_alone_module.a
pgf90 -c -O3 -Munroll=c:1 -Mnoframe -mcmodel=medium -Mlarge_arrays -Mlre -Mvect=cachesize:1048576,sse,prefetch
pgf90-Warning-No files to process

rm -f *.o core.*
pgf90 -o plume_alone_module -v plume_alone_module.a -L/uufs/chpc.utah.edu/sys/installdir/netcdf-c/4.4.1-c7/lib -Wl,-rpath=/uufs/chpc.utah.edu
/sys/installdir/netcdf-c/4.4.1-c7/lib -lnetcdf -L/uufs/chpc.utah.edu/sys/installdir/netcdf-f/4.4.4p-c7/lib -Wl,-rpath=/uufs/chpc.utah.edu/sys
/installdir/netcdf-f/4.4.4p-c7/lib -lnetcdff
Export PGI_CURR_CUDA_HOME=/uufs/chpc.utah.edu/sys/installdir/pgi/18.7/linux86-64/2018/cuda/9.1
Export PGI=/uufs/chpc.utah.edu/sys/installdir/pgi/18.7

/usr/bin/ld /usr/lib64/crt1.o /usr/lib64/crti.o /uufs/chpc.utah.edu/sys/installdir/pgi/18.7/linux86-64/18.7/lib/trace_init.o /usr/lib/gcc/x86
_64-redhat-linux/4.8.5/crtbegin.o /uufs/chpc.utah.edu/sys/installdir/pgi/18.7/linux86-64/18.7/lib/initmp.o /uufs/chpc.utah.edu/sys/installdir
/pgi/18.7/linux86-64/18.7/lib/f90main.o --eh-frame-hdr -m elf_x86_64 -dynamic-linker /lib64/ld-linux-x86-64.so.2 /uufs/chpc.utah.edu/sys/inst
alldir/pgi/18.7/linux86-64/18.7/lib/pgi.ld -L/uufs/chpc.utah.edu/sys/installdir/netcdf-c/4.4.1-c7/lib -L/uufs/chpc.utah.edu/sys/installdir/ne
tcdf-f/4.4.4p-c7/lib -L/uufs/chpc.utah.edu/sys/installdir/pgi/18.7/linux86-64/18.7/lib -L/usr/lib64 -L/usr/lib/gcc/x86_64-redhat-linux/4.8.5
plume_alone_module.a -rpath=/uufs/chpc.utah.edu/sys/installdir/netcdf-c/4.4.1-c7/lib -lnetcdf -rpath=/uufs/chpc.utah.edu/sys/installdir/netcd
f-f/4.4.4p-c7/lib -lnetcdff -rpath /uufs/chpc.utah.edu/sys/installdir/pgi/18.7/linux86-64/18.7/lib -rpath /usr/lib/gcc/x86_64-redhat-linux/4.
8.5/../../../../lib64 -o plume_alone_module -L/usr/lib/gcc/x86_64-redhat-linux/4.8.5/../../../../lib64 -lpgf90rtl -lpgf90 -lpgf90_rpm1 -lpgf9
02 -lpgf90rtl -lpgftnrtl -lpgmp -lnuma -lpthread --start-group -lpgmath -lnspgc -lpgc --end-group -lrt -lpthread -lm -lgcc -lc -lgcc -lgcc_s
/usr/lib/gcc/x86_64-redhat-linux/4.8.5/crtend.o /usr/lib64/crtn.o
rm -f *.o core.*
[u0703457@kingspeak4 freitas_plume_model_v2.0_beta]$
```

If plume_alone_module and smk_plumerise.mod files are generated, the compilation was successful! If not, contact Derek at Derek.Mallia@utah.edu for more help!

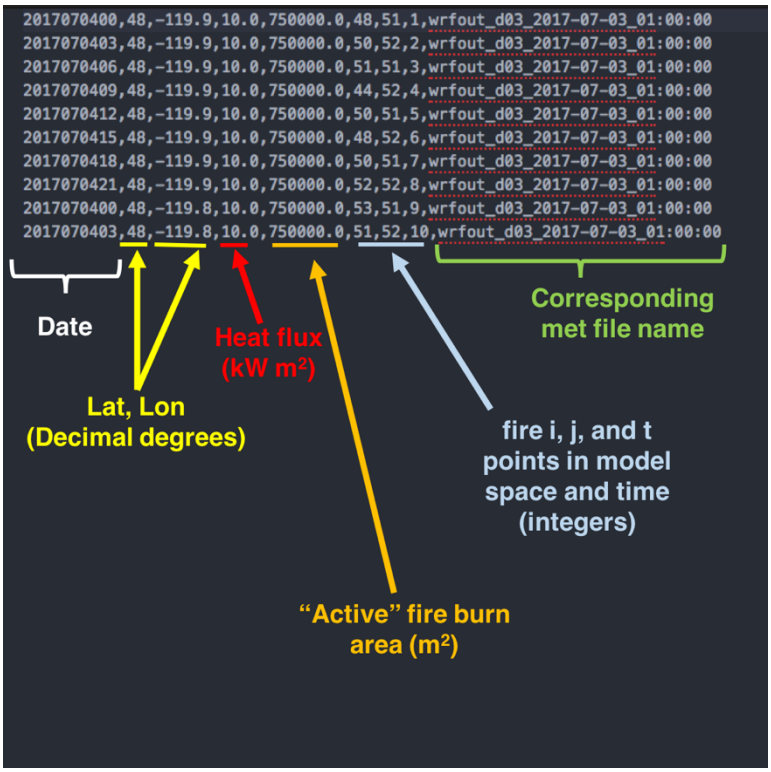
2. Preparing Freitas model input data

Before we can run the Freitas plume rise model, certain inputs are required to run the model! These inputs include fire properties such as the fire location in model time and space, burned area, heat flux, and the meteorological input file that the fire is associated with. In addition, meteorological input data will also be needed to provide atmospheric environmental conditions for our model. Finally, a namelist file also needs to be provided the plume rise code to specify runtime options such as the name of the fire input text file, and the meteorological model data and name. An example of the input data can be found in the following directory:

/uufs/chpc.utah.edu/common/home/lin-group7/dvm/projects/plume_rise_model/freitas_plume_model_v2.0_beta/working_directory

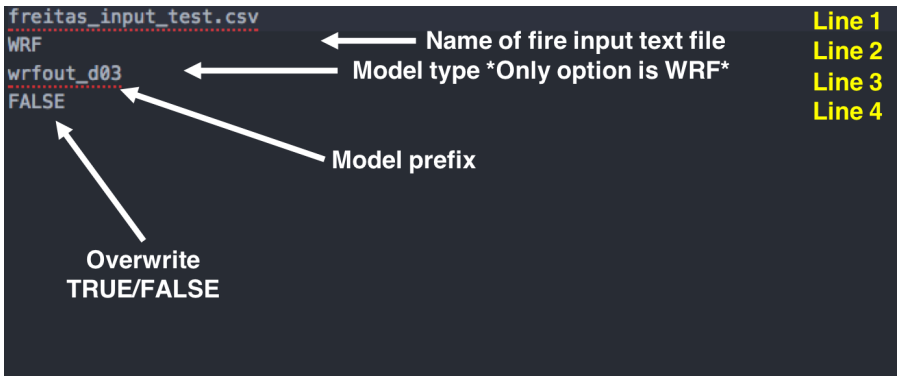
```
[u0703457@kingspeak4 working_directory]$
[u0703457@kingspeak4 working_directory]$ ls
final_plume.dat                 wrfout_d01_2017-05-03_12:00:00  wrfout_d02_2017-04-02_15:00:00  wrfout_d03_2017-03-03_01:00:00
freitas_input_test.csv          wrfout_d01_2017-06-03_00:00:00  wrfout_d02_2017-05-03_03:00:00  wrfout_d03_2017-04-02_13:00:00
plume_alone_module              wrfout_d01_2017-07-03_12:00:00  wrfout_d02_2017-06-02_15:00:00  wrfout_d03_2017-05-03_01:00:00
plumegen.dat                    wrfout_d01_2017-08-03_00:00:00  wrfout_d02_2017-07-03_03:00:00  wrfout_d03_2017-06-02_13:00:00
plumegen.gra                    wrfout_d01_2017-09-02_12:00:00  wrfout_d02_2017-08-02_15:00:00  wrfout_d03_2017-07-03_01:00:00
plume_namelist                  wrfout_d01_2017-10-03_00:00:00  wrfout_d02_2017-09-02_03:00:00  wrfout_d03_2017-08-02_13:00:00
plume_output.dat                wrfout_d01_2017-11-02_12:00:00  wrfout_d02_2017-10-02_15:00:00  wrfout_d03_2017-09-02_01:00:00
wrfout_d01_2017-01-01_00:00:00  wrfout_d01_2017-12-03_00:00:00  wrfout_d02_2017-11-02_03:00:00  wrfout_d03_2017-10-02_13:00:00
wrfout_d01_2017-02-01_00:00:00  wrfout_d02_2017-01-01_00:00:00  wrfout_d02_2017-12-02_15:00:00  wrfout_d03_2017-11-02_01:00:00
wrfout_d01_2017-03-03_12:00:00  wrfout_d02_2017-01-31_15:00:00  wrfout_d03_2017-01-01_00:00:00  wrfout_d03_2017-12-02_13:00:00
wrfout_d01_2017-04-03_00:00:00  wrfout_d02_2017-03-03_03:00:00  wrfout_d03_2017-01-31_13:00:00
[u0703457@kingspeak4 working_directory]$
[u0703457@kingspeak4 working_directory]$
[u0703457@kingspeak4 working_directory]$ pwd
/uufs/chpc.utah.edu/common/home/lin-group7/dvm/projects/plume_rise_model/freitas_plume_model_v2.0_beta/working_directory
[u0703457@kingspeak4 working_directory]$
```

For an example of a fire input text file, refer to *freitas_input_test.csv.* Sample WRF data can be found at the following path: /uufs/chpc.utah.edu/common/home/kochanski-group3/surbanski/WRF_output/



Here, each line represents a separate fire at some time and place, along with its fire properties (burned area and heat flux). Note that this is made up data! The first column represents the fire's data and time in the format of YYYYMMDDHH. The second and third columns represents the fires location in lat lon, in units of decimal degrees. The fourth column is the fire heat flux in units of kW m^2. The "active" fire area (5^{th} column) is provided in units of meters squared (m^2). The 6^{th}, 7^{th} and 8^{th} columns represents the fire location in model time and space. Essentially, these are the index values for the east-west direction (i), north-south direction (j), and time slice # (t). These indexes must fall within the corresponding meteorological input file listed in the last column. As a result, preparing the proper input file may require some preprocessing on the users end. Future versions of this code will hopefully eliminate the need for columns 6-9.

Meteorological input data should be located in the same directory as the plume rise model executable (plume_alone_module). **Currently, this plume rise model will ONLY work for WRF output files!** However, there are plans to make this code compatible with other model types, so stay tuned for future updates!



Lastly, a namelist file must also be provided. The name of this namelist file must be "plume_namelist". As of right now, there are only 3 inputs required. These inputs include the fire input text file name, the name of the model type being ingested (WRF is the only option), along with the model prefix that should be long enough to be unique from other file names. The final line is a TRUE/FALSE overwrite statement, which tells the model whether it should overwrite out fire specific thermodynamic plume profiles for each fire. If set to FALSE, the Freitas model code will save the plume specific thermodynamic data to its own text file. If set to TRUE, the Freitas model will overwrite the plume specific data during each iteration. For small data sets, you can set this as FALSE. If you are working with a data set with thousands of fires, you will want to set overwrite as TRUE. All namelist lines MUST be included else the model code will crash.

When the simulation is completed, a text file called plume_output.dat should be generated. This contains the maximum plume rise height generated for each fire that was provided in the fire input text file described above. An example of this can be seen below. Heat fluxes are in units of kW m^2, fire area is listed in units of meters squared, and the plume top is in units of kmAGL.

```
[u0703457@kingspeak4 test_directory]$ more plume_output.dat
date       lat       lon       heatflux       burnedA       plume_top
  2017070400      48.0    -119.9      10.0  750000.0       2.8
  2017070403      48.0    -119.9      10.0  750000.0       2.6
  2017070406      48.0    -119.9      10.0  750000.0       0.9
  2017070409      48.0    -119.9      10.0  750000.0       0.6
  2017070412      48.0    -119.9      10.0  750000.0       0.6
  2017070415      48.0    -119.9      10.0  750000.0       0.6
  2017070418      48.0    -119.9      10.0  750000.0       0.6
  2017070421      48.0    -119.9      10.0  750000.0       0.6
  2017070400      48.0    -119.8      10.0  750000.0       0.5
  2017070403      48.0    -119.8      10.0  750000.0       0.6
[u0703457@kingspeak4 test_directory]$
[u0703457@kingspeak4 test_directory]$
[u0703457@kingspeak4 test_directory]$
[u0703457@kingspeak4 test_directory]$
[u0703457@kingspeak4 test_directory]$
```

To test the code yourself, feel free to download the inputs in my working directory:

/uufs/chpc.utah.edu/common/home/lin-group7/dvm/projects/plume_rise_model/freitas_plume_model_v2.0_beta/working_directory

These inputs include namelist file (plume_namelist), meteorological inputs (wrfout_d03*), and the fire input text file (freitas_input_test.csv). Be sure that the plume_alone_module executable resides in the same directory as these files, else the code will crash. (I simply just create a symbolic link to the location of the aforementioned executable via an ln -sf command).

3. Running the model

After preparing the input for the Freitas model, you are ready to run the model code!

(a) If you have not compiled the code, do so now, following the instructions in section 1.
(b) Create a working directory, which will contain you input file that you prepared in section 2, your Freitas model executable file (which can just be linked via an ln -sf function), and your model output files which will provide the environmental conditions to the model.
(c) Execute the plume_alone_module executable

4. Model output

The Freitas plume rise model generates 3 types of output files. The first file that is generated is the plume_output.dat file. The file outputs the plume height for each fire simulated by the Freitas model. Each row represents a single fire simulated by the Freitas plume rise model. Here, the time is given via the data column (YYYYMMDDHH) where the time is given in UTC. Latitude and longitude are the fire location in decimal degrees, while fire properties such as heat fluxes (kW/m^2) are area (m^2) are outputs. Finally, the plume height is outputted in the last column in units of kmAGL.

In addition to the plume_output.dat file, more specific plume height properties can be obtained from the final_plume_0*.dat file, which outputs the thermodynamic properties of the wildfire plume rise for the final time step of the model simulation. There should be one text file per fire, where the file names "Index number" corresponds to the row number of the fire outputted in plume_output.dat. Whether this file is written for each fire can be specified in the namelist file in line 4. For more details about the namelist, refer to **section 2**.

References:

Freitas, S. R., and Coauthors, 2007: Including the sub-grid scale plume rise of vegetation fires in low resolution atmospheric transport models. *Atmos. Chem. Phys.*, **7**, 3385–3398.

Freitas, S. R., K. M. Longo, J. Trentmann, and D. Latham, 2010: Technical note: Sensitivity of 1-D smoke plume rise models to the inclusion of environmental wind drag. *Atmos. Chem. Phys.*, **10**, 585–594.

Mallia, D. V., A. Kochanski, S. Urbanski, and J. C. Lin, 2018: Optimizing smoke and plume rise modeling approaches at local scales. *Atmosphere*, **9**, 116..