DEPARTMENT OF METEOROLOGY
UNIVERSITY OF UTAH

The Abdus Salam
International Centre
for Theoretical Physics

Introduction to WRF-Sfire.

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Outline

- What is WRF
- Structure of the WRF modeling system
- WRF model setup for real cases
- WRF model setup for idealized cases
- WRF setup for fire simulations

What is WRF?

- WRF Weather Research and Forecasting Model used for both research and operational forecasting
- It is a supported "community model", i.e. a free and shared resources with distributed development and centralized support
- Its development is led by NCAR, NOAA/NCEP with collaborations with universities and other government agencies in the US and overseas.

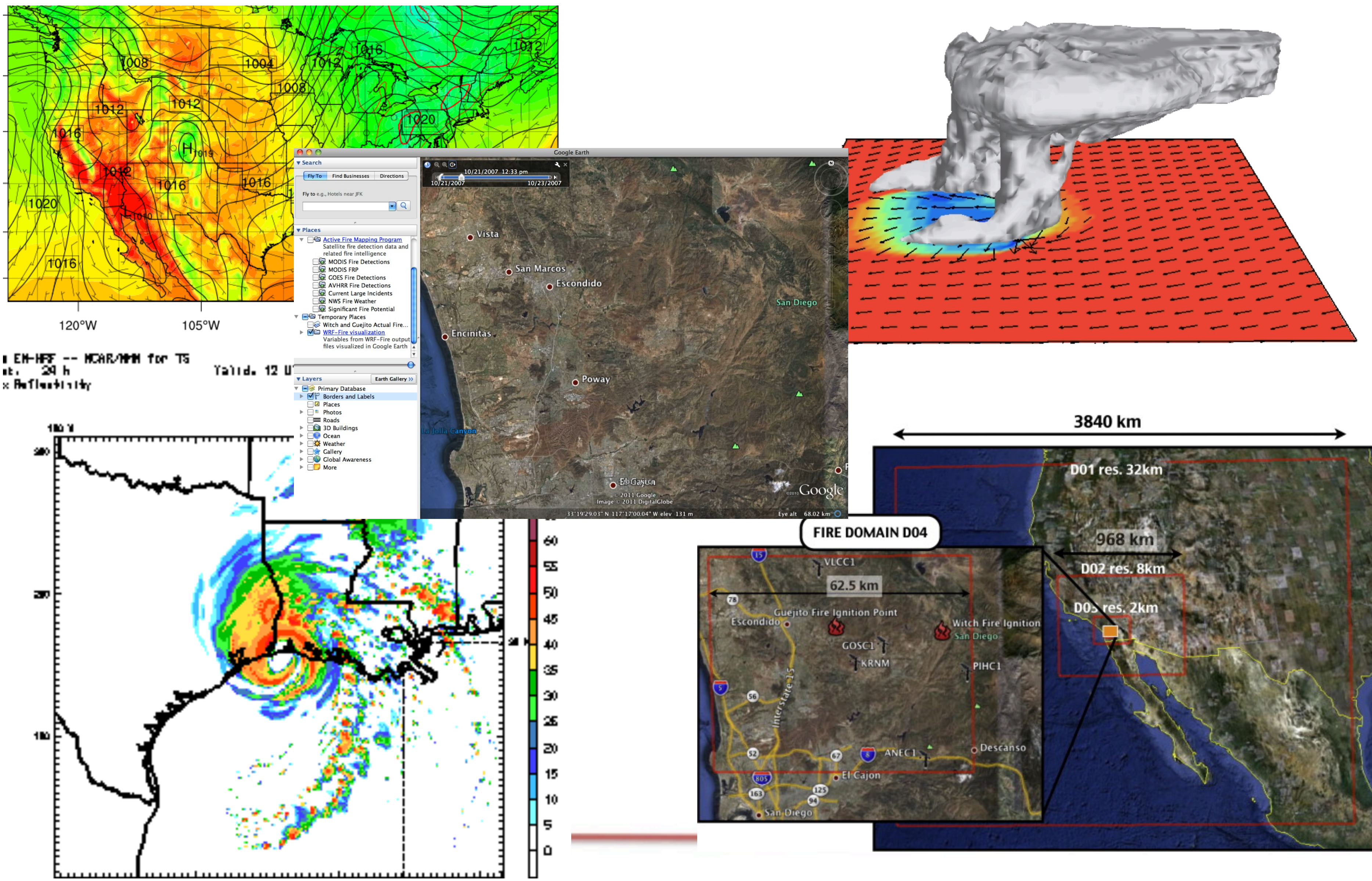
What is WRF?

The WRF model is a fully compressible, and nonhydrostatic model (with a runtime hydrostatic option). Its vertical coordinate is a terrain-following hydrostatic pressure coordinate. The grid staggering is the Arakawa C-grid. The model uses the Runge-Kutta 2nd and 3rd order time integration schemes, and 2nd to 6th order advection schemes in both horizontal and vertical. It uses a time-split small step for acoustic and gravity-wave modes. The dynamics conserves scalar variables.

The WRF model Version 3 supports a variety of capabilities. These include:

- Real-data and idealized simulations
- Various lateral boundary condition options for real-data and idealized simulations
- Full physics options, and various filter options
- Positive-definite advection scheme
- Non-hydrostatic and hydrostatic (runtime option)
- One-way, two-way nesting and moving nest
- Three-dimensional analysis nudging
- Observation nudging
- Regional and global applications
- Digital filter initialization

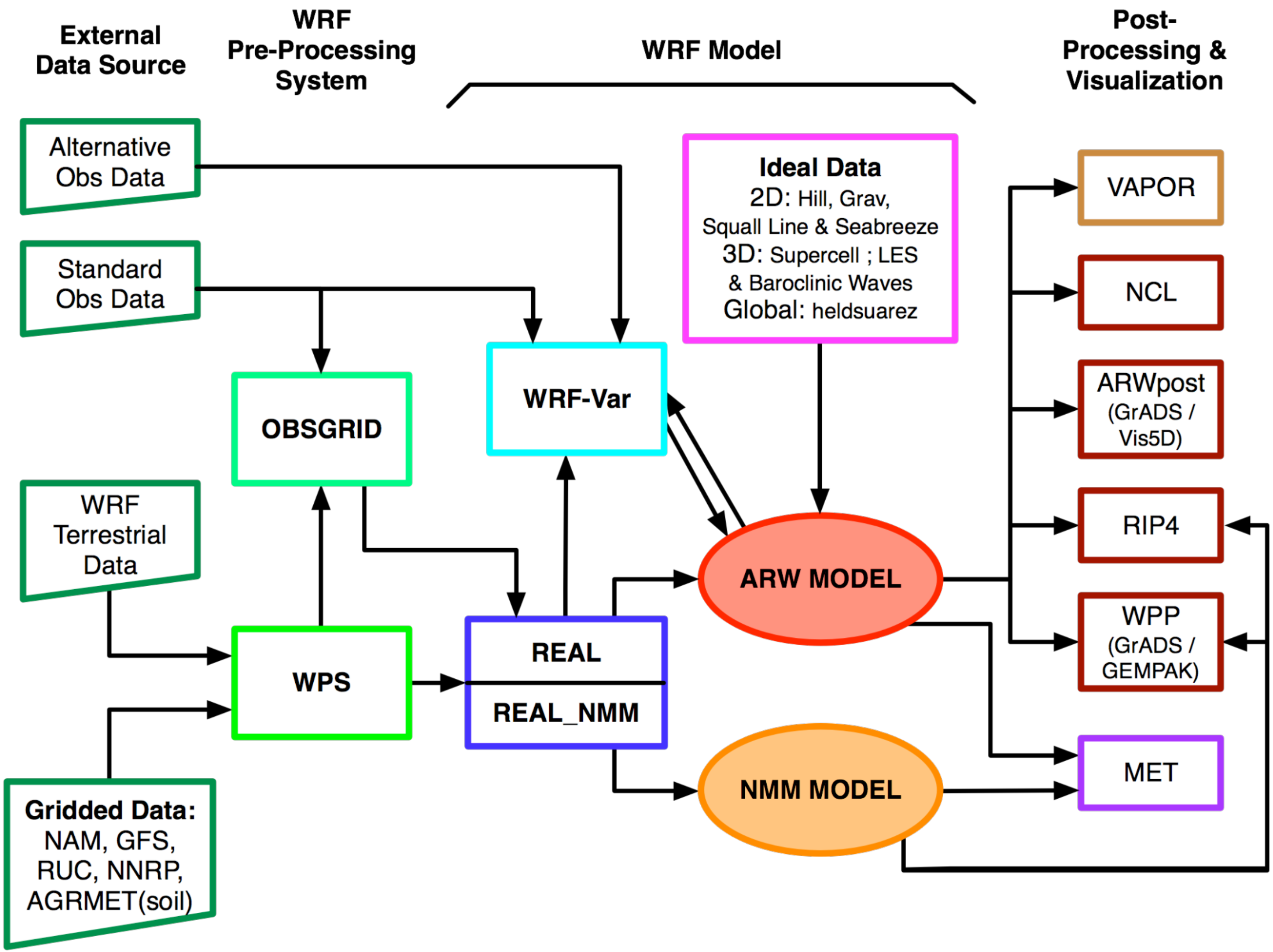
What can WRF-Sfire be used for?



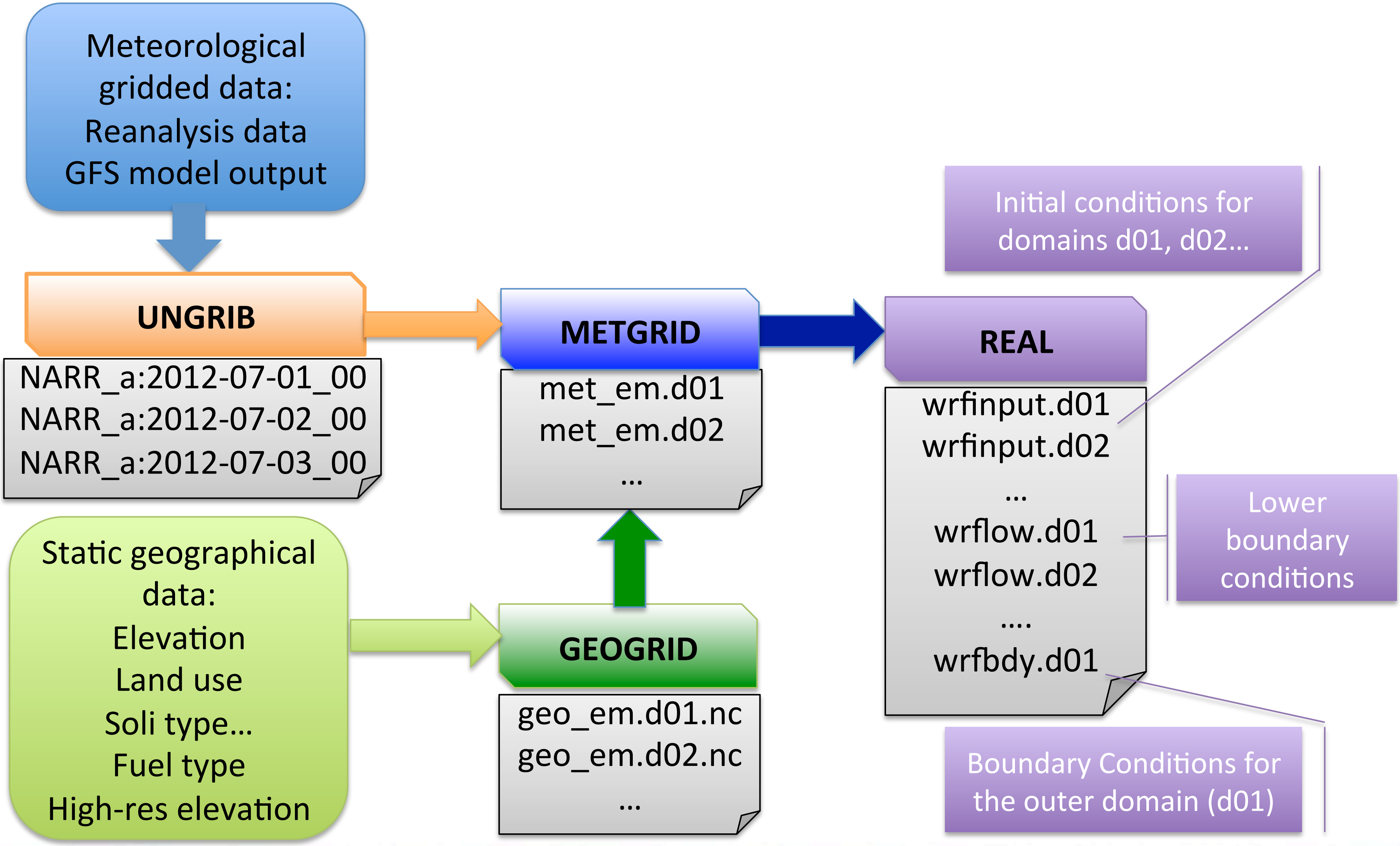
What can WRF-Sfire be used for?

- Atmospheric physics/parameterization research
- Case study research
- Real-time NWP and forecast system research
- Regional climate and seasonal time-scale research
- Coupled chemistry applications
- Global simulations
- Idealized simulations at various scales (convection, baroclinic waves, LES)
- Wildland fire simulations
- Idealized fire simulations
- Simulation of smoke emission and dispersion
- Simulation of smoke impact on air quality

WRF Modeling System



WRF Structure for real cases



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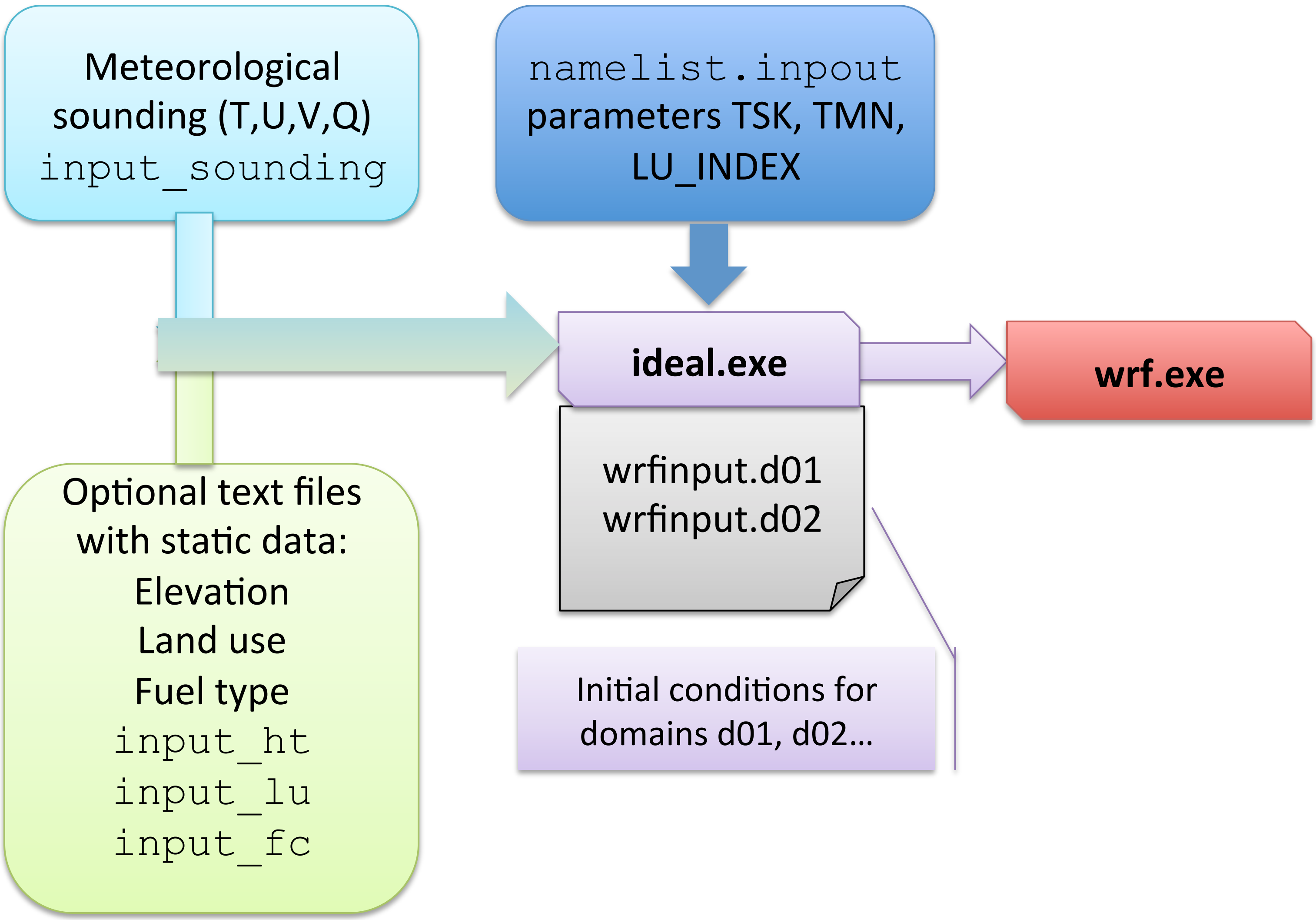
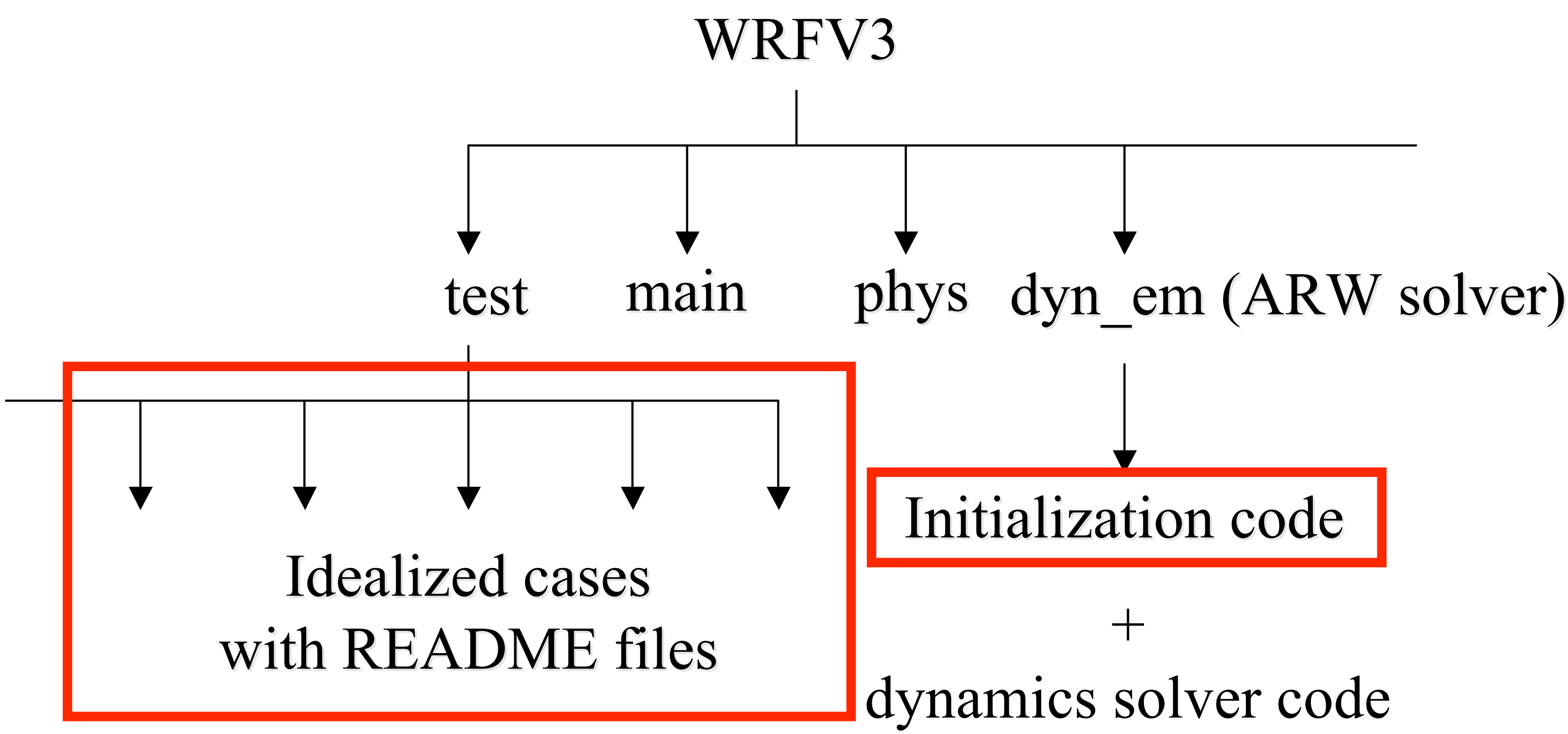
WRF Structure for ideal cases



WRF Structure for idealized cases

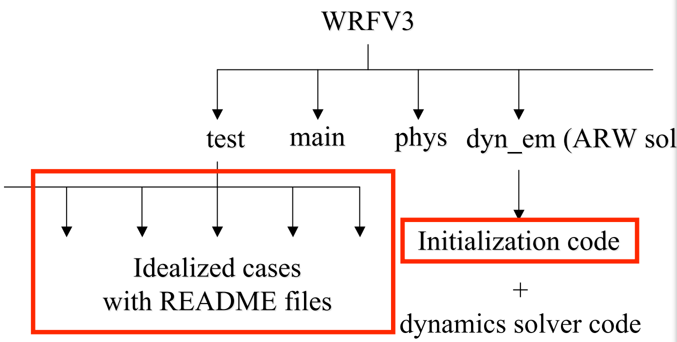


em_b_wave
em_esmf_exp
em_fire
em_grav2d_x
em_heldsuarez
em_hill2d_x

em_les
em_quarter_ss
em_real
em_scm_xy
em_seabreeze2d_x
em_squall2d_x

em_squall2d_y
em_tropical_cyclone
exp_real
nmm_real

WRF Structure for idealized cases



Idealized cases in:
WRFV3/dyn_em/
module_init_utilities.F
module_initialize_fire.F
Module_initialize…

namelist.input
input_sounding
Input_lu
Input_ht
Input_fc

IDEAL
WRFV3/test/em_fire/
chem
fireflux_small
heatflux_2d
heatflux_ronan
hill
hill_coarse
hill_med
hill_simple
moisture
nested
rain
small
[…]

wrfinput.d01
wrfinput.d02

wrflow.d01
wrflow.d02
….
wrfbdy.d01

ideal.exe DOES NOT generate boundary condition files. Generally, one of the idealized boundary conditions provided by WRF (open, cyclic, symmetric) should be used in ideal cases

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Input_sounding file structure

line 1 → surface Pressure (mb), surface potential Temperature (K), Surface vapor mixing ratio (g/kg)

1000.00	300.00	14.00		
250.00	300.45	14.00	-7.88	-3.58
750.00	301.25	14.00	-6.94	-0.89
1250.00	302.47	13.50	-5.17	1.33
1750.00	303.93	11.10	-2.76	2.84
2250.00	305.31	9.06	0.01	3.47
2750.00	306.81	7.36	2.87	3.49
3250.00	308.46	5.95	5.73	3.49
3750.00	310.03	4.78	8.58	3.49
4250.00	311.74	3.82	11.44	3.49
4750.00	313.48	3.01	14.30	3.49

each successive line is a point in the sounding

Columns of each successive line: Height (m), Potential temperature (K), Water vapor Mixing ratio (g/kg), U wind speed (m/s), V wind speed (m/s)

Input files structure

In order to allow users to easily create more realistic yet simple cases the model can ingest additional surface data from external ASCII files:

input_ht - allows the user to define custom topography in an ideal case
input_lu – allows the user to add a custom land use in an ideal case
input_fc – allows the user to add a custom fuel map in an ideal case

How to generate the input_XX files?

```
wrf-fire/other/Matlab/util1_jan/write_array_2d.m
```

Other useful matlab tools:

```
read_array_2d.m
image_array_2d.m
...
```

namelist.input

```
&time_control
 run_days                            = 0,
 run_hours                           = 0,
 run_minutes                         = 20,
 run_seconds                         = 0,
 start_year                          = 2006, 0001, 0001,
 start_month                         = 02,   01,   01,
 start_day                           = 23,   01,   01,
 start_hour                          = 12,   00,   00,
 start_minute                        = 43,   01,   01,
 start_second                        = 00,   00,   00,
 end_year                            = 2006, 0001, 0001,
 end_month                           = 02,   01,   01,
 end_day                             = 23,   01,   01,
 end_hour                            = 13,   00,   00,
 end_minute                          = 00,   600,   600,
 end_second                          = 0,   00,   00,
 history_interval_s                  = 5,   30,   30,
 frames_per_outfile                  = 1000, 1000, 1000,
 restart                             = .false.,
 restart_interval                    = 5
 io_form_history                     = 2
 io_form_restart                     = 2
 io_form_input                       = 2
 io_form_boundary                    = 2
 debug_level                         = 1
/
```

d01 d02 d03

namelist.input

```
&domains
 time_step                          = 0,
 time_step_fract_num                = 3,
 time_step_fract_den                = 10,
 max_dom                            = 1,
 s_we                               = 1,      1,      1,
 e_we                               = 20,     43,     43,
 s_sn                               = 1,      1,      1,
 e_sn                               = 32,     43,     43,
 s_vert                             = 1,      1,      1,
 e_vert                             = 41,     41,     41,
 dx                                 = 50,     30,     10,
 dy                                 = 50,     30,     10,
 ztop                               = 600, 1500, 1500,
 grid_id                            = 1,      2,      3,
 parent_id                          = 0,      1,      2,
 i_parent_start                     = 0,      1,     1,
 j_parent_start                     = 0,      1,     1,
 parent_grid_ratio                  = 1,      2,      3,
 parent_time_step_ratio             = 1,      2,      3,
 feedback                           = 1,
 smooth_option                      = 0
 sr_x                               = 10,      0,      0
 sr_y                               = 10,      0,      0
/
```

namelist.input

```
&physics
 mp_physics                          = 0,      0,      0,
 ra_lw_physics                       = 0,      0,      0,
 ra_sw_physics                       = 0,      0,      0,
 radt                                = 30,     30,     30,
 sf_sfclay_physics                   = 1,      0,      0,
 sf_surface_physics                  = 1,      0,      0,
 bl_pbl_physics                      = 0,      0,      0,
 bldt                                = 0,      0,      0,
 cu_physics                          = 0,      0,      0,
 cudt                                = 0,      0,      0,
 isfflx                              = 1,
 ifsnow                              = 0,
 icloud                              = 0,
 num_soil_layers                     = 5,
 mp_zero_out                         = 0,
 /
```

namelist.input

```
&dynamics
 rk_ord                              = 3,
 diff_opt                            = 2,
 km_opt                              = 2,
 damp_opt                            = 2 ,
 zdamp                               = 100.,  5000.,  5000.,
 dampcoef                            = 0.2,    0.2,    0.2
 khdif                               = 0.05,   0.05,   0.05,
 kvdif                               = 0.05,   0.05,   0.05,
 smdiv                               = 0.1,    0.1,    0.1,
 emdiv                               = 0.01,   0.01,   0.01,
 epssm                               = 0.1,    0.1,    0.1
 mix_full_fields                     = .true., .true., .true.,
 non_hydrostatic                     = .true., .true., .true.,
 h_mom_adv_order                     = 5,      5,      5,
 v_mom_adv_order                     = 3,      3,      3,
 h_sca_adv_order                     = 5,      5,      5,
 v_sca_adv_order                     = 3,      3,      3,
 time_step_sound                     = 20,     20,     20,
 moist_adv_opt                       = 1,      1,      1,
 scalar_adv_opt                      = 1,      1,      1,
 tracer_opt                          = 2,      2,      2,
 /
```

namelist.input

```
&bdy_control
periodic_x                          = .false.,.false.,.false.,
symmetric_xs                        = .false.,.false.,.false.,
symmetric_xe                        = .false.,.false.,.false.,
open_xs                             = .true., .false.,.false.,
open_xe                             = .true., .false.,.false.,
periodic_y                          = .false.,.false.,.false.,
symmetric_ys                        = .false.,.false.,.false.,
symmetric_ye                        = .false.,.false.,.false.,
open_ys                             = .true., .false.,.false.,
open_ye                             = .true., .false.,.false.,
nested                              = .false., .true., .true.,
/
```

namelist.input

```
 &fire
 ifire              = 2,    ! integer, = 0: no fire, 2=turn on fire model
 fire_fuel_read     = 2,    ! integer, -1: from WPS, 0= use fire_fuel_cat, 1= by altitude,
2=from file input_fc
 fire_fuel_cat      = 3,    ! integer, fuel category if constant
! ignition
 fire_num_ignitions = 2,        ! integer, only the first fire_num_ignition used, up to 5
allowed
 fire_ignition_ros1 =   0.05,  ! start points of ignition lines, in m from lower left corner
 fire_ignition_start_x1 =  475,  ! start points of ignition lines, in m from lower left corner
 fire_ignition_start_y1 = 1075,  ! start points of ignition lines, in m from lower left corner
 fire_ignition_end_x1 =    305,  ! end points of ignition lines, in m from lower left corner
 fire_ignition_end_y1 =   1075,  ! end points of ignition lines, in m from lower left corner
 fire_ignition_radius1 =    20,  ! all within this radius will ignite, > fire mesh step
 fire_ignition_start_time1 = 30,  ! sec for ignition from the start
 fire_ignition_end_time1  = 184,  ! sec for ignition from the start
 fire_ignition_ros2 =   0.05,  ! start points of ignition lines, in m from lower left corner
 fire_ignition_start_x2 =  475,  ! start points of ignition lines, in m from lower left corner
 fire_ignition_start_y2 = 1075,  ! start points of ignition lines, in m from lower left corner
 fire_ignition_end_x2 =    690,  ! end points of ignition lines, in m from lower left corner
 fire_ignition_end_y2 =   1075,  ! end points of ignition lines, in m from lower left corner
 fire_ignition_radius2 =    20,  ! all within this radius will ignite, > fire mesh step
 fire_ignition_start_time2 = 30,  ! sec for ignition from the start! end ignition for sfire
 fire_ignition_end_time2  = 194,  ! sec for ignition from the start! end ignition for sfire
```

namelist.input

```
 fire_mountain_type=0,          ! in ideal: 0=none, 1= hill, 2=EW ridge, 3=NS ridge
 fire_mountain_height=500.,     ! (m) ideal mountain height
 fire_mountain_start_x=1000.,   ! (m) coord of start of the mountain from lower left corder
(just like ignition)
 fire_mountain_start_y=1100.,   ! (m) coord of start of the mountain from lower left corder
(just like ignition)
 fire_mountain_end_x=1500.,     ! (m) coord of end of the mountain from lower left corder (just
like ignition)
 fire_mountain_end_y=1400.,     ! (m) coord of end of the mountain from lower left corder (just
like ignition)
 fire_topo_from_atm=1,          ! 0 = fire mesh topo set from fine-res data, 1 = populate by
interpolating from atmosphere
 delt_perturbation = 0.0,       ! Temperature perturbation for creating cold (negative) / warm
(positive) bubble [K], 0 turns it off
 !xrad_perturbation = 10000.0,   ! Horizontal radius of the bubble in E-W direction [m]
 !yrad_perturbation = 10000.0,   ! Horizontal radius of the bubble in N-S direction [m]
 !zrad_perturbation = 1500.0,    ! Vertical radius of the bubble [m]
 !hght_perturbation = 1500.0,    ! Perturbation height - height at which the warm/cold bubble
will be suspended [m]
!
!
```

namelist.input

```
! stretched grid variables
!
 stretch_grd = .true.,
 stretch_hyp = .true.,
 z_grd_scale = 2.35
!
! Surface initialization
!
 sfc_full_init =.true.
 sfc_lu_index = 28,             ! Defines USGS surface category used for surface initialization
based on LANDUSE.TBL (roughness, albedo etc)
 sfc_tsk = 285.0,                ! Skin surface temperature [K]
 sfc_tmn = 280.0,                ! Mean soil temperature [K]
! sfc_ivgtyp = 18,                 ! Dominant vegetation category, needed only with Noah LSM
(sf_surface_physics=2)
! sfc_isltyp = 7,                  ! Dominant soil type, needed only with Noah LSM
(sf_surface_physics=2)
! sfc_canwat = 0.2,                ! Canopy water content, needed only with Noah LSM
(sf_surface_physics=2)
! sfc_vegfra = 0.5,                ! Vegetation fraction, needed only with Noah LSM
(sf_surface_physics=2)
!
! files
fire_read_atm_ht = .false.,      ! read terrain height from file ht_input
fire_read_lu = .true.,          ! read land use data from input_lu file
```

namelist.fire

```
&fuel_scalars                          ! scalar fuel constants
cmbcnst  = 17.433e+06,                 ! J/kg combustion heat dry fuel
hfgl     = 17.e4 ,                     ! W/m^2 heat flux to ignite canopy
fuelmc_g = 0.18,                       ! ground fuel moisture, set = 0 for dry
!jc fuelmc_g = 0.09,                     ! ground fuel moisture, set = 0 for dry
fuelmc_c = 1.00,                       ! canopy fuel moisture, set = 0 for dry
nfuelcats = 13,                        ! number of fuel categories used
no_fuel_cat = 14                       ! extra category for no fuel
/

&fuel_categories
 fuel_name =
'1: Short grass (1 ft)',
'2: Timber (grass and understory)',
'3: Tall grass (2.5 ft)',
'4: Chaparral (6 ft)',
'5: Brush (2 ft) ',
'6: Dormant brush, hardwood slash',
'7: Southern rough',
'8: Closed timber litter',
'9: Hardwood litter',
'10: Timber (litter + understory)',
'11: Light logging slash',
'12: Medium logging slash',
'13: Heavy logging slash',
'14: no fuel'
```

namelist.fire

Fuel category 1 2 3 4 5 6 7

```
windrf= 0.36, 0.36, 0.44,  0.55,  0.42,  0.44,  0.44,
        0.36, 0.36, 0.36,  0.36,  0.43,  0.46, 1e-7
```

8 9 10 11 12 13 14

```
fgi =  0.166, 0.897, 1.08, 2.468, 0.785, 1.345, 1.092,          ! Initial total mass of
    1.121, 0.780, 2.694, 2.582, 7.749, 13.024, 1.e-7,           ! surface fuel (kg/m2)
fueldepthm=0.305, 0.305, 1.5, 1.829, 0.61,  0.762, 0.762,
          0.061, 0.061, 0.305, 0.305, 0.701, 0.914, 0.305,      !Fuel depth (m)
savr = 3500., 2784., 1500., 1739., 1683., 1564., 1562.,         !Surface area to volume ratio
       1889., 2484., 1764., 1182., 1145., 1159., 3500.,
fuelmce = 0.12, 0.15, 0.25, 0.20, 0.20, 0.25, 0.40,             !Fuel moisture of extinction
          0.30, 0.25, 0.25, 0.15, 0.20, 0.25, 0.12,
fueldens = 32.,32.,32.,32.,32.,32.,32. ,
          32.,32.,32.,32.,32.,32.,32. ,                         ! Particle Density
st = 0.0555, 0.0555, 0.0555, 0.0555, 0.0555, 0.0555, 0.0555,    ! Fuel particle total mineral
     0.0555, 0.0555, 0.0555, 0.0555, 0.0555, 0.0555, 0.0555,    ! content
se = 0.010, 0.010, 0.010, 0.010, 0.010, 0.010, 0.010,           ! Effective mineral content
```

namelist.fire

Fuel moisture contribution per fuel category

```
               1         2         3         4         5         6         7
fmc_gw01 = 1.00000, 0.15385, 1.00000, 0.31253, 0.28571, 0.25000, 0.23203,
           0.30000, 0.06625, 0.25042, 0.13021, 0.11600, 0.12065, 0.00000,
fmc_gw02 = 0.00000, 0.07692, 0.00000, 0.25316, 0.14286, 0.41667, 0.38298,
           0.20000, 0.93034, 0.16639, 0.39149, 0.40584, 0.39656, 0.00000,
fmc_gw03 = 0.00000, 0.38462, 0.00000, 0.12477, 0.00000, 0.33333, 0.30801,
           0.50000, 0.00341, 0.41680, 0.47830, 0.47816, 0.48279, 0.00000,
fmc_gw04 = 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
           0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
fmc_gw05 = 0.00000, 0.38462, 0.00000, 0.31254, 0.57143, 0.00000, 0.07598,
           0.00000, 0.00000, 0.16639, 0.00000, 0.00000, 0.00000, 0.00000,
               8         9        10        11        12        13        14
/
     &moisture
     moisture_class_name =
     '1 hour fuel',
     '10 hour fuel',
     '100 hour fuel',
     '1000 hour fuel',
     'live fuel'

moisture_classes=        5,                ! number of classes, max 5 (see comments in module_fr_sfire_phys.F how to increase)
drying_model=            1,     1,     1,     1,     1, ! number of model - only 1= equilibrium moisture Van Wagner (1972) per Viney (1991) allowed
drying_lag=              1,    10,   100,  1000,   1e9,! so-called 10hr and 100hr fuel
wetting_model=           1,     1,     1,     1,     1, ! number of model - only 1= allowed at this moment
wetting_lag=            14,   1e9,   1e9,   1e9,   1e9, !
saturation_moisture=   2.5,   2.5,   2.5,   2.5,   2.5, ! ditto
saturation_rain =      8.0,   8.0,   8.0,   8.0,   8.0, ! stronger rain than this (mm/h) does not make much difference.
rain_threshold =      0.05,  0.05,  0.05,  0.05,  0.05,! mm/h rain too weak to wet anything.
fmc_gc_initialization =  2,     2,     2,     2,     2,! 0 = from input, 1 = from fuelmc_g in namelist.input 2 = from equibrium
/
```

WRF output

WRF generates files in the netcdf format
They can be accessed by any visualization package with the nectdf support:

- Ncview
- Ncbrowser
- NCL
- Matlab
- Vapor
- etc…

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Experiments

Ideal cases:

Experiment1. Flat simple, uniform fuel, idealized

Experiment2. Idealized with additional features - topography, smoke
HGT, tr17_1, no LU_INDEX, no T2 no TSLB

Experiment3. Flat uniform fuel and initialized surface, everything from namelists
we have T2, LU_INDEX, U*, TSLB,

Experiment4. Flat non-uniform fuel and surface, idealized - FireFlux:
LU non uniform, TSK non uniform, see T2, see U* effects of the surface
data comes form external text files:

```
input_fc        fire_fuel_read / fire_fuel_cat
input_ht        fire_read_atm_ht
input_lu        fire_read_lu
input_zsf       fire_read_fire_ht
```

Experiments

Ideal cases:

5. Terrain non uniform fuel, non uniform landuse:
source data in ./matlabfiles/

matlab files: HGT.mat -> input_ht
LU_INDEX.mat -> input_lu
ZSF.mat -> input_zsf
NFUEL_CAT.mat -> input_fc
HGT_V(121,:)=HGT_V(120,:); fix HGT

```
input_fc       fire_fuel_read / fire_fuel_cat
input_ht       fire_read_atm_ht
input_lu       fire_read_lu
input_zsf      fire_read_fire_ht
```

Tools:

- wrf-fire/other/Matlab/util1_jan/write_array_2d.m
- wrf-fire/other/Matlab/util1_jan/read_array_2d.m

- special flags to use external files for idealized cases

```
fire_read_atm_ht= .true.,   ! read terrain height from file input_ht
fire_red_fire_ht=.true.      ! read terrain height from file input_zsf
fire_read_lu = .true.,       ! read land use data from input_lu file
fire_fuel_read    = 2,       ! integer, -1: from WPS, 0= use
fire_fuel_cat, 2=from file input_fc
```

How to set up and run WRF?

1. Install git to be able to download git repositories
2. Get the code from openwfm git repository:
   `git clone git://github.com/jbeezley/wrf-fire.git`
3. Install netcdf and fortran compiler in macports it will be:
   `sudo port install netcdf-fortran`
4. Set up your environment
   `export NETCDF=/opt/local`
5. Configure the model:
   `/WRFV3/configure`
6. Compile the model
   `/WRFV3/compile em_fire >& compile.log&`
7. Compile the preprocessing system WPS
   `/WPS/compile >& compile.log&`
8. Set up the model parameters in namelist.input and namelist.fire
9. Create wrfinput files (initialization): go to a selected case in /WRFV3/test/em_fire/ and run
   `/WRFV3/test/em_fire/your_case/ideal.exe` – it will create wrfinput_d01 file.
10. Run the model
   `/WRFV3/test/your_case/wrf.exe`