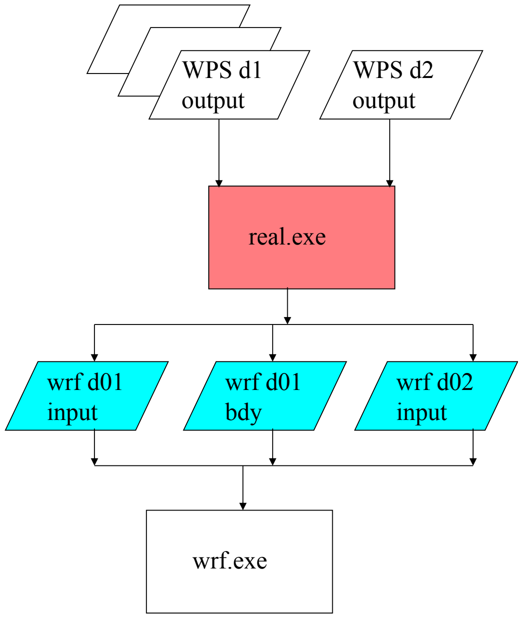
REAL

Description of General Functions

Ming Chen &
Dave Gill
gill@ucar.edu



Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

Loads of definitions …

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What are the required, optional variables?

From whence do they come?

What are the restrictions on metgrid vertical coordinates?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What defines the base state?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What are the mandatory files for success?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

How does the user change the vertical coordinate?

Are there recommendations?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

Why is the surface layer scheme special compared to the other physics options?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What is required in real to do nesting in WRF?

What is optional in real to do nesting in WRF?

Function

- The WRF model pre-processor is ***real.exe***
- The real.exe program is available ***serial*** or ***DM parallel*** (primarily for aggregate memory purposes, as opposed to timing performance)
- This program is automatically generated when the model is built and the requested use is for a real data case
- The real.exe program takes data ***from WPS*** and transform the data ***for WRF***
- Similar to the ARW idealized data pre-processor, real.exe is tightly coupled to the WRF model through the ***Registry***

Function

- ***3D forecast*** or simulation
- ***Meteorological input*** data that primarily originated from a previous forecast or analysis, probably via the WPS package
- Anticipated ***utilization of physics*** packages for microphysics, surface conditions, radiation, convection, and boundary layer (maybe usage of nudging capabilities)

Function

- A non-Cartesian ***projected domain***
  - Lambert conformal, Mercator, polar stereographic, rotated latitude/longitude (global or regional)
- Selection of ***realistic static fields*** of topography, land use, vegetation, and soil category data
- Requirement of ***time dependent*** lateral boundary conditions for a regional forecast

Function

- Generation of ***diagnostics*** necessary for assumed WRF model input
- Input field ***adjustment*** for consistency of static and time dependent fields (land mask with soil temperature, etc.)
- ARW: computation of ***reference*** and ***perturbation*** fields
- Generation of ***initial*** state for each of the requested domains
- Creation of a ***lateral boundary file*** for the most coarse domain
- ***Vertical interpolation*** for 3d meteorological fields and for sub-surface soil data

Function

- **Run-time options**
  - specified in the Fortran namelist file (namelist.input for real and WRF)
- **Compile-time options**
  - Changes inside of the source code
  - Compiler flags
  - CPP ifdefs
  - Modifications to the Registry file

Standard Input Variables

- The metgrid program typically provides meteorological data to the real program.
- Coordinate:
  - The real program is able to input and correctly process any ***strictly monotonic*** vertical coordinate
    - Isobaric: OK
    - Sigma: OK
    - Hybrid: OK

Standard Input Variables

- The metgrid program typically provides meteorological data to the real program.
- Mandatory:
  - 3d and surface: horizontal winds, temperature, relative humidity, geopotential height
  - 3d soil: soil temperature
  - 2d fields: surface pressure, sea-level pressure, land mask
- Optional (but desirable):
  - 3d soil: soil moisture
  - 2d fields: topography elevation of input data, SST, sea-ice, skin temperature

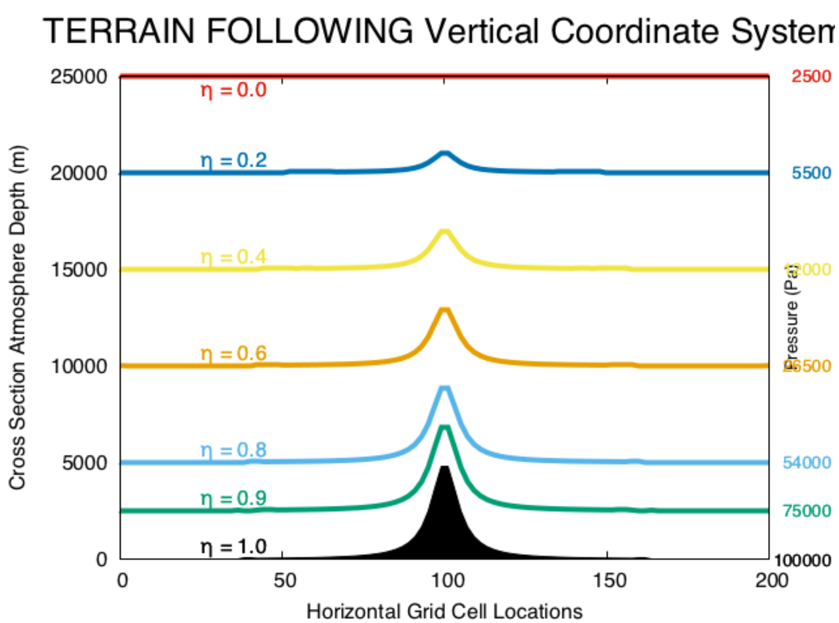
Base State

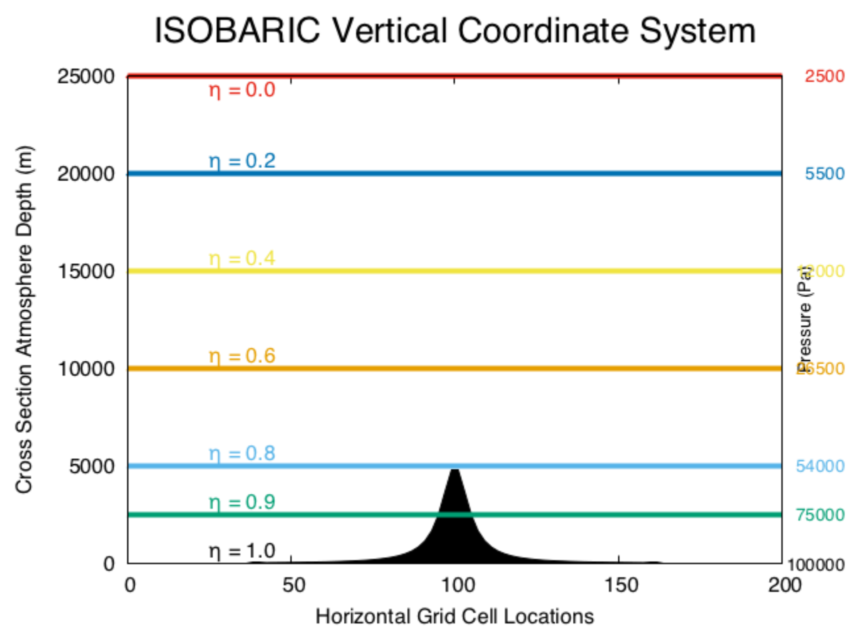
- Several of the mass-point fields are ***separated*** into a time-independent ***base state*** (also called a reference state) and a ***perturbation*** from the base state
- The base state fields are only functions of the ***topography*** and a few user-selectable constants
- If the ***topography changes***, such as with a moving nest, the base state fields are modified
- ***Feedback*** for 2-way nesting also impacts base state fields through topographic averaging – ***inside of the WRF model***
- No base state computations are required ***prior to the real program***

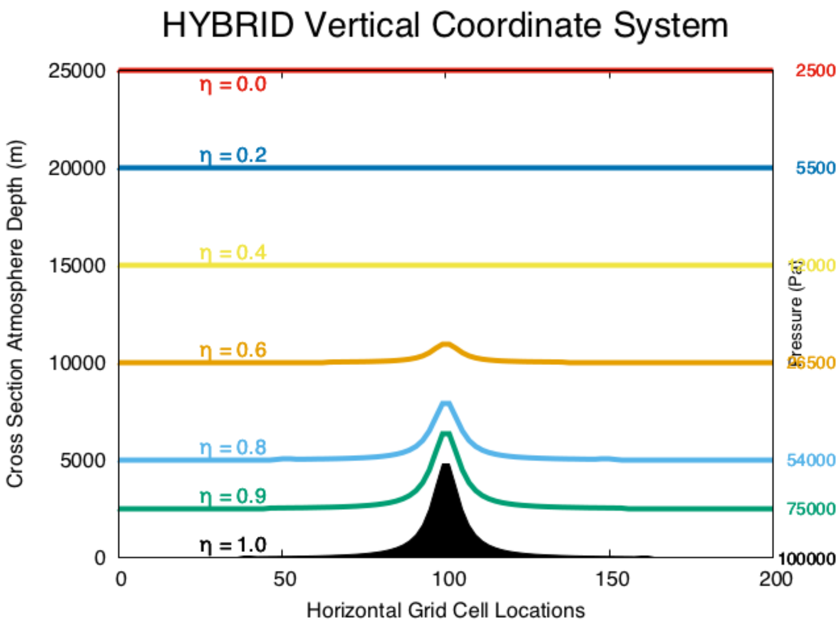
Hybrid Vertical Coordinate

- Since WRF v3.9 the capability to have a hybrid vertical coordinate is available: a terrain following coordinate near the surface and relaxing to isobaric surfaces aloft
- It is default option in WRFV4.0
  (A compile-time option for WRFV3.9 is required **`configure -hyb)`**)
- A run-time option is required (default in WRFV4.0):

```
&dynamics
hybrid_opt = 2
/
```



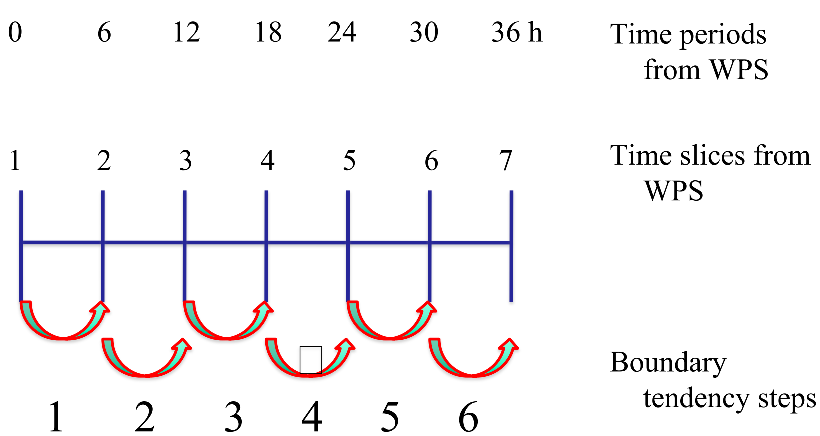




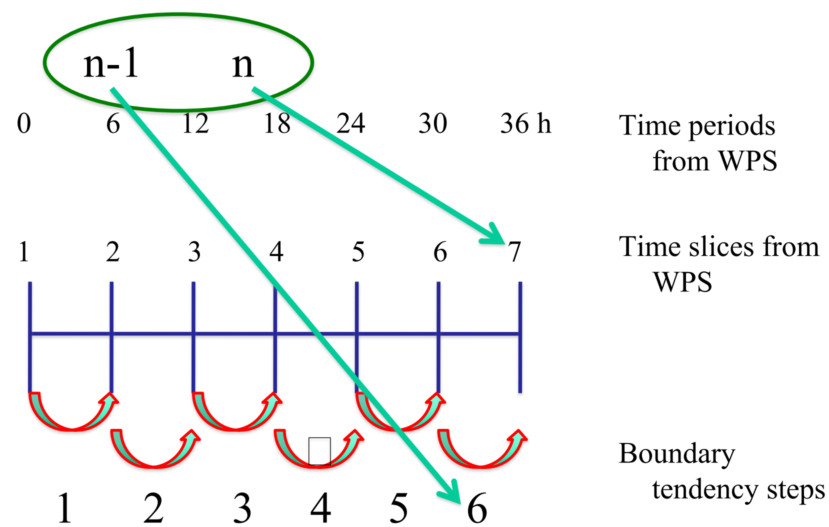
Standard Generated Output

- For regional forecasts, the real program generates both an both an initial (***wrfinput_d01***) and a lateral boundary (***wrfbdy_d01***)
- The boundary file is not required for ***global forecasts*** with ARW (look at MPAS for global simulations)
- The ***initial condition*** file contains a ***single time period*** of data
- These files contain data used directly by the WRF model
- The initial condition file may be ingested by the ***WRFDA*** code (referred to as a *cold-start*)
- If ***n*** times were processed with WPS and real, the lateral boundary file contains ***n-1*** time slices

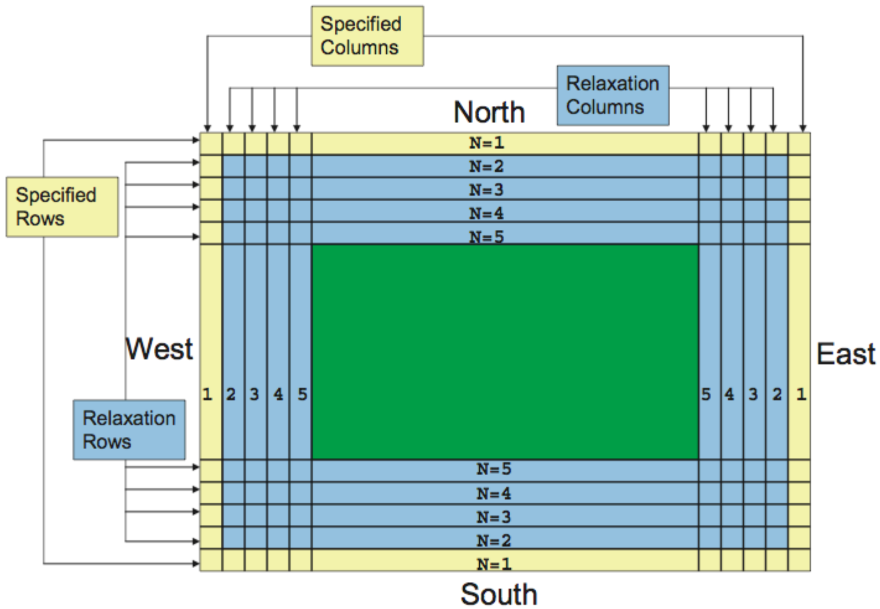
Lateral Boundary Condition Times



Lateral Boundary Condition Times



Real-Data Lateral Boundary Condition: Location of Specified and Relaxation Zones



Vertical Interpolation

- Select reasonable η levels, or let the real program do it for you
- Verify that the ***"thicknesses" are acceptable***, generally about the same value in the free-atmosphere and less than 1000 m
- It is ***SAFEST to NOT initially choose η values***
  - Initially, ***select the number*** of ετα levels
  - ***Plot profiles*** of the resultant heights
  - ***Adjust the η levels*** accordingly
- A few namelist options, the terrain elevation, and eta levels completely define the model coordinate for the WRF code

Vertical Interpolation

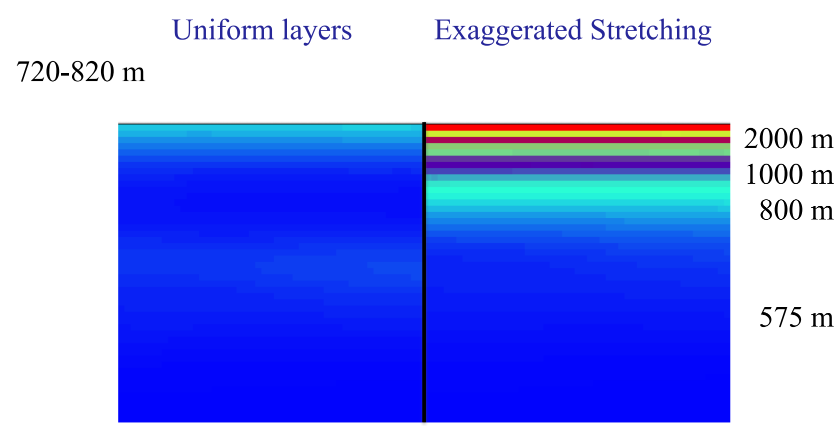
- The ***η surfaces*** are computed with a few NML parameters:

```
&domains
e_vert              = 50,    50,   50
p_top_requested     = 1000,

&dynamics
base_temp           = 290.
iso_temp            = 200
```

Vertical Interpolation

Vertical cross sections of THICKNESS of each model layer, with 50 vertical levels above the PBL, ptop = 10 hPa.

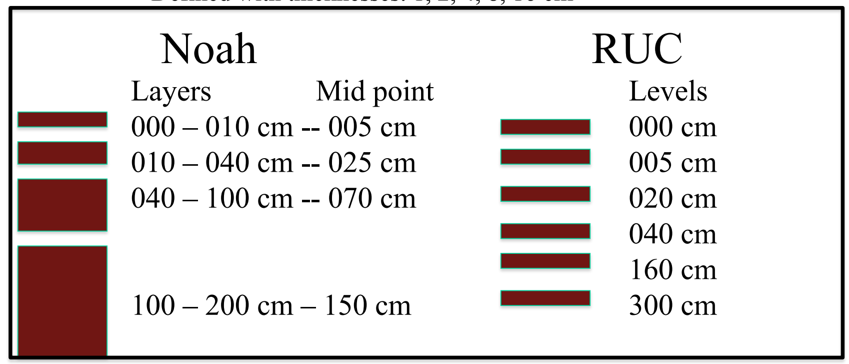


Physical Parameterization Settings

- The real program and the WRF model are tightly coupled
- Most physical parameterization settings in the namlist.input are IGNORED by real
- EXCEPT
  - ***sf_surface_physics***
  - Land surface model (processes soil temperature and soil moisture)
  - Different schemes in WRF use ***differing numbers of layers***
  - The layers are defined in real from the metgrid output

Soil Level Interpolation

- The WRF model supports several Land Surface schemes:
  - sf_surface_physics = 1, Slab scheme
  - 5 layers
  - Defined with thicknesses: 1, 2, 4, 8, 16 cm



Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What are the required, optional variables?

From where do they come?

What are the restrictions on metgrid vertical coordinates?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What defines the base state?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

What are the mandatory files for success?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

How does the user change the vertical coordinate?

Are there recommendations?

Real program in a nutshell

- Function
- Standard input variables
- Base State
- Standard generated output
- Vertical interpolation
- Soil level interpolation

Why is the surface layer scheme special compared to the other physics options?

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Access to Everything

- The primary location to modify the real program is the **dyn_em/module_initialize_real.F** file
- Contains:
  - Registry information
  - All of the namelist settings selected
  - Variables **from** the metgrid program
  - Variables to be **sent to** the WRF model
- Called for **every time period**, for **every domain**

Access to Everything

- The value of **every variable input** into the WRF model is controlled through module_initialize_real.F
- All variables are accessed through the **derived data type** "grid"

```
DO j=jts,MIN(jde-1,jte)
   DO i=its,MIN(ide-1,ite)
      grid%sst(i,j) = grid%sst(i,j) + 1
   END DO
END DO
```

Access to Everything

- The dynamics variables have **two time levels**, indicated by the _1 and _2 suffixes. Only the _2 variables are sent to WRF.
- Some variables sent to WRF are **diagnostic** only

```
DO j = jts, min(jde-1,jte)
   DO i = its, min(ide,ite)
      grid%u10(i,j)=grid%u_gc(i,1,j)
   END DO
END DO
```

Eta Levels

- The **vertical coordinate**, eta, used in the WRF model is defined inside of the real program.
- The user may allow the real program to choose the levels (select only the number of levels in the namelist.input file)

```
&domains
e_vert    = 30,    30,    30,
/
```

```
&domains
e_vert    = 30,    40,    50,
/
```

Eta Levels

- Often the user needs to **specify the eta levels** (coordinate this with your model top)
- Use the automatic generation to your advantage
- Specify how many levels **ABOVE the PBL** that you require. Add 8 to this value. For example, you require 50 vertical levels above the PBL.

```
&domains
e_vert    = 58,    58,    58,
/
```

Eta Levels

- Run the real program (single or **small domain, one time level**), make sure the level thicknesses are OK (< 1000 m)

```
 Converged znw(kte) should be about 0.0 =  -5.2081142E-04
Full level index =    1     Height =    0.0 m
Full level index =    2     Height =   56.6 m     Thickness =   56.6 m
Full level index =    3     Height =  137.9 m     Thickness =   81.4 m
Full level index =    4     Height =  244.7 m     Thickness =  106.8 m
Full level index =    5     Height =  377.6 m     Thickness =  132.9 m
Full level index =    6     Height =  546.3 m     Thickness =  168.7 m
Full level index =    7     Height =  761.1 m     Thickness =  214.8 m
Full level index =    8     Height = 1016.2 m     Thickness =  255.0 m
Full level index =    9     Height = 1207.1 m     Thickness =  190.9 m
Full level index =   10     Height = 1401.8 m     Thickness =  194.6 m
Full level index =   11     Height = 1600.3 m     Thickness =  198.5 m
Full level index =   12     Height = 1802.8 m     Thickness =  202.5 m
Full level index =   13     Height = 2196.1 m     Thickness =  393.3 m
```

Eta Levels

- Get the computed levels from ncdump, after running the real program

```
> ncdump -v ZNW wrfinput_d01
data:

 ZNW =
  1, 0.993, 0.983, 0.97, 0.954, 0.934, 0.909, 0.88, 0.8587637, 0.8375274,
    0.8162911, 0.7950548, 0.7550299, 0.7165666, 0.6796144, 0.6441237,
    0.6100466, 0.5773363, 0.5459476, 0.5158363, 0.4869595, 0.4592754,
    0.4327437, 0.407325, 0.382981, 0.3596745, 0.3373697, 0.3160312,
    0.2956253, 0.2761188, 0.2574798, 0.2396769, 0.2226802, 0.2064602,
    0.1909885, 0.1762376, 0.1621807, 0.1487919, 0.1360459, 0.1239184,
    0.1124378, 0.1017038, 0.09166772, 0.08228429, 0.07351105, 0.06530831,
    0.05763897, 0.05046835, 0.04376402, 0.03749565, 0.0316349, 0.02615526,
    0.02103195, 0.01624179, 0.01176313, 0.007575703, 0.003660574, 0 ;
```

Eta Levels

- Re-run the real program (all domains, all time periods) with the new levels in the nml variable **`eta_levels`**
- Replace the **PBL values** with those of your choosing.
- Augment the number of vertical levels (e_vert)
- Note that both e_vert and eta_levels are **full levels**

Eta Levels

```
&domains
eta_levels =
    1, 0.993, 0.983, 0.97, 0.954, 0.934, 0.909, 0.88,
    0.8587637, 0.8375274,
    0.8162911, 0.7950548, 0.7550299, 0.7165666, 0.6796144, 0.6441237,
    0.6100466, 0.5773363, 0.5459476, 0.5158363, 0.4869595, 0.4592754,
    0.4327437, 0.407325, 0.382981, 0.3596745, 0.3373697, 0.3160312,
    0.2956253, 0.2761188, 0.2574798, 0.2396769, 0.2226802, 0.2064602,
    0.1909885, 0.1762376, 0.1621807, 0.1487919, 0.1360459, 0.1239184,
    0.1124378, 0.1017038, 0.09166772, 0.08228429, 0.07351105, 0.06530831,
    0.05763897, 0.05046835, 0.04376402, 0.03749565, 0.0316349, 0.02615526,
    0.02103195, 0.01624179, 0.01176313, 0.007575703, 0.003660574, 0
/
```

- Maybe replace with

```
1, 0.999, 0.998, 0.996, 0.993, 0.990, 0.980. 0.970, 0.960, 0.950,
   0.940, 0.930, 0.920, 0.910, 0.900, 0.890, 0.880, 0.870,
```

Eta Levels

- For **vertical nesting refinement**, follow the similar procedure for each domain.
- **Each domain** will need a specification of eta levels
- The assignment of the single **eta_levels array is split** into pieces for easier understanding

Eta Levels

```
&domains
max_dom            = 2,
e_vert             = 35,     45,
eta_levels(1:35)   = 1., 0.993, 0.983, 0.97, 0.954, 0.934,
                     0.909, 0.88, 0.840, 0.801, 0.761, 0.722,
                     0.652, 0.587, 0.527, 0.472, 0.421, 0.374,
                     0.331, 0.291, 0.255, 0.222, 0.191, 0.163,
                     0.138, 0.115, 0.095, 0.077, 0.061, 0.047,
                     0.035, 0.024, 0.015, 0.007, 0.
eta_levels(36:81)  = 1.0000, 0.9946, 0.9875, 0.9789, 0.9685,
                     0.9562, 0.9413, 0.9238, 0.9037, 0.8813,
                     0.8514, 0.8210, 0.7906, 0.7602, 0.7298,
                     0.6812, 0.6290, 0.5796, 0.5333, 0.4901,
                     0.4493, 0.4109, 0.3746, 0.3412, 0.3098,
                     0.2802, 0.2524, 0.2267, 0.2028, 0.1803,
                     0.1593, 0.1398, 0.1219, 0.1054, 0.0904,
                     0.0766, 0.0645, 0.0534, 0.0433, 0.0341,
                     0.0259, 0.0185, 0.0118, 0.0056, 0.
vert_refine_method = 0,     2,
```

The metgrid Flags

- The **real program and the WRF model** are able to communicate directly through the **Registry** file
- The real program is only able to talk with the **metgrid** program through the **input data** stream
- Specific information about the incoming data is contained in **special flags** that the user may set in the metgrid table file – usually, related to THIS VARIABLE EXISTS

```
========================================
name=PMSL
        interp_option=sixteen_pt+four_pt+average_4pt
        flag_in_output=FLAG_SLP
========================================
```

The metgrid Flags

```
> ncdump -h met_em.d01.2000-01-24_12:00:00.nc | grep FLAG
                 :FLAG_METGRID = 1 ;
                 :FLAG_EXCLUDED_MIDDLE = 0 ;
                 :FLAG_SOIL_LAYERS = 1 ;
                 :FLAG_SNOW = 1 ;
                 :FLAG_PSFC = 1 ;
                 :FLAG_SM000010 = 1 ;
                 :FLAG_SM010040 = 1 ;
                 :FLAG_SM040100 = 1 ;
                 :FLAG_SM100200 = 1 ;
                 :FLAG_ST000010 = 1 ;
                 :FLAG_ST010040 = 1 ;
                 :FLAG_ST040100 = 1 ;
                 :FLAG_ST100200 = 1 ;
                 :FLAG_SLP = 1 ;
                 :FLAG_TAVGSFC = 1 ;
                 :FLAG_QNWFA = 1 ;
                 :FLAG_QNIFA = 1 ;
                 :FLAG_SOILHGT = 1 ;
                 :FLAG_MF_XY = 1 ;
```

The metgrid Flags

- The real program uses this **information** when deciding how to do many operations:
  - Is the input from metgrid?
  - Method to compute surface pressure
  - Use RH vs mixing ratio vs specific humidity computations
  - Excluded middle processing
  - Average surface air temperature for lake temperatures
  - Water/Ice friendly vertical interpolation
  - Which levels of soil data are present
- All **flags** for the metgrid to real data transfer are contained in **share/module_optional_input.F**

The metgrid Flags

```
flag_slp      = 0

flag_name(1:8) = 'SLP     '
CALL wrf_get_dom_ti_integer ( fid, 'FLAG_' // &
     flag_name, itmp, 1, icnt, ierr )
IF ( ierr .EQ. 0 ) THEN
   flag_slp      = itmp
END IF
```

Adding a Variable for Vertical Interpolation

- This process is **manual**
- Every new **input 3d variable** that needs to be interpolated needs to have an **explicit block of code** added
- **Mass-point variables** (such as would be used in all physics schemes) are straight forward, as they may be largely copied using the existing templates already in place
- Most vertical interpolation options are supplied from the namelist.input file
- All interpolation is handled in **dry pressure**

Adding a Variable for Vertical Interpolation

```
CALL vert_interp ( grid%t_gc , grid%pd_gc , &
     grid%t_2 , grid%pb , &
     grid%tmaxw , grid%ttrop , grid%pmaxw , grid%ptrop , &
     grid%pmaxwnn , grid%ptropnn , &
     flag_tmaxw , flag_ttrop , &
     config_flags%maxw_horiz_pres_diff , &
     config_flags%trop_horiz_pres_diff , &
     config_flags%maxw_above_this_level , &
     num_metgrid_levels , 'T' , &
     interp_type , lagrange_order , t_extrap_type , &
     lowest_lev_from_sfc , use_levels_below_ground , &
     use_surface , zap_close_levels , force_sfc_in_vinterp , &
     ids , ide , jds , jde , kds , kde , &
     ims , ime , jms , jme , kms , kme , &
     its , ite , jts , jte , kts , kte )
```

Tracers

- The WRF model is able to **advect arrays of passive scalars** (tracer 4d array)
- As with all other variables going into the WRF model, this data is available to **be set in the real program**
- These variables must be **coordinated with the Registry names**, as the tracer index is an automatically manufactured name

```
# Tracer Scalars
#
state real tr17_1 ikjftb  tracer 1 -  irhusdf=(bdy_interp:dt) \
       "tr17_1" "tr17_1" "Dimensionless"
```

Tracers

- As with all 4d arrays, no space is allocated unless the packaged variables are requested for processing at run-time

```
package   tracer_test1  tracer_opt==2 -  tracer:tr17_1
```

Tracers

```
!  Template for initializing tracer arrays.
!  A small plane in the middle of the domain at
!  lowest model level is defined.

IF (config_flags%tracer_opt .eq. 2) THEN
  DO j = (jde + jds)/2 - 4, (jde + jds)/2 + 4, 1
    DO i = (ide + ids)/2 - 4, (ide + ids)/2 + 4, 1
      IF ( ( its .LE. i .and. ite .GE. i ) .and. &
           ( jts .LE. j .and. jte .GE. j ) ) THEN
        tracer(i, 1, j, P_tr17_1) = 1.
      END IF
    END DO
  END DO
END IF
```

Trajectories

- The user may **specify (i,j,k) locations** in the model domain to follow parcels: traj_i, traj_j, traj_k (hard coded in the module_initialize_real.F file)
- The current **number of trajectory locations** is small, 25, and is a run-time option that the **user sets in the nml file**

```
&domain
 num_traj            = 25,

&physics
 traj_opt            = 1,
```

Trajectories

- The trajectory code uses the lat,lon locations, so the initial (i,j) value of the lat,lon is assigned

```
IF (config_flags%num_traj .gt. 0 .and.
    config_flags%traj_opt .gt. 0) THEN
  DO j = (jde + jds)/2 - 2, (jde + jds)/2 + 2, 1
    DO i = (ide + ids)/2 - 2, (ide + ids)/2 + 2, 1
      IF ( its .LE. i    .and. ite .GE. i   .and.  &
           jts .LE. j    .and. jte .GE. j ) THEN
        grid%traj_i    (icount) = i
        grid%traj_j    (icount) = j
        grid%traj_k    (icount) = 10
        grid%traj_lat  (icount) = grid%xlat(i,j)
        grid%traj_long(icount) = grid%xlong(i,j)
      END IF
```

Options

- When there are **strong normal topo gradients** along the outer rows and columns of the most-coarse domain, smoothing the topography to match the incoming first guess data is a good idea.
- This is **the same** sort processing that is done to make the child and parent domains more consistent in the area of the **LBC** forcing

```
&domains
 smooth_cg_topo = .true.
/
```

Options

- **Time varying fields** for longer simulations are available from the technique set up for "SST Update"
- A new field will be automatically added to the input file to the WRF model (provided by the real program) with a few changes to the Registry file (**Registry.EM_COMMON**), specifying **stream 4**

```
state  real my_new_field  ij misc 1  - \
i024rhdu "MY_NEW_FIELD" \
"SOME DESCRIPTION" "SOME UNITS"
```

Options

- Information for **using time varying data** is specified at run-time in the namelist file

```
&time_control
 auxinput4_inname    = "wrflowinp_d<domain>"
 auxinput4_interval = 360
 io_form_auxinput4  = 2

&physics
 sst_update          = 1
```

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Real program in a nutshell: PART 3

- Access to everything — The Derived Data Type: grid
- Eta levels
- Metgrid flags — Example: grid%sst
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Completely user defined

May be different per domain

Be careful of the thicknesses

Tightly coupled with the model lid

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

The metgrid program provides flags for some internal communication real to metgrid

These flags are defined inside the METGRID.TBL file (for WPS) and in the file share/module_optional_input.F (real)

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Requires new code inside real

Examples are easily available

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Always in dry pressure

Input vertical coordinate neutral

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Simple way to initialize passive scalars

Users should provide info for which tracers in the Registry, and select the accompanying option in the namelist

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

A simple (i,j,k) initialization for the starting locations of trajectory points is available

Choose the number of trajectory points

Real program in a nutshell: PART 3

- Access to everything
- Eta levels
- Metgrid flags
- Adding a variable for vertical interpolation
- Vertical interpolation
- Tracers
- Trajectories
- Options

Users may smooth the outer rows and columns so that the topography on the coarse grid and the external model are consistent

Users may add variables to streams easily, an example is that the SST update option could have a new field included (for example, soil moisture)