WRF Modeling System Overview

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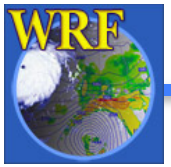
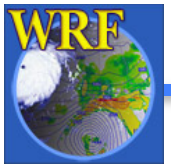


Outline

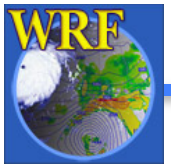
- Brief introduction of WRF
- Functions of each WRF components
- Compiling and running WRF programs
- WRF registry and code structure



What is WRF?

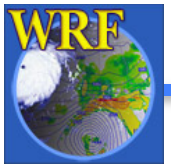
- WRF: Weather Research and Forecasting Model
  - Used for both research and operational forecasting
- Its development is led by NCAR, NOAA with partnerships with other federal agencies, and collaborations with universities and research laboratories in the US and overseas
- It is a supported "community model", i.e. a free and shared resource with distributed development and centralized support

  Examples: WRF physics, WRF chemistry



What is WRF?

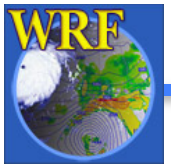
- WRF has two dynamical cores:
  - The Advanced Research WRF (ARW), and
  - Nonhydrostatic Mesoscale Model (NMM)
- ARW is developed and supported at NCAR, and it is the *focus* of this talk
- ARW is also the core WRF-Chemistry uses
- Physics, the software framework, and parts of data pre- and post-processing are shared between the dynamical cores



In this talk, WRF == ARW

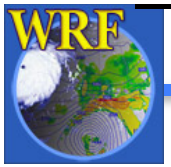
WRF Milestones and Releases

- Version 1.0 WRF was released December 2000
- Version 2.0: May 2004 (NMM released, ARW nesting added, WRF-Chem first release)
- Version 2.1: August 2005
- Version 2.2: December 2006 (WPS released)
- Version 3.0: April 2008 (includes global ARW version and WRFDA)
- Version 3.1: April 2009 (V3.1.1 July 2009)
- Version 3.2: April 2010 (V3.2.1 August 2010)
- Version 3.3 April 2011 (V3.3.1 September 2011)
- Version 3.4 April 2012 (V3.4.1 August 2012)

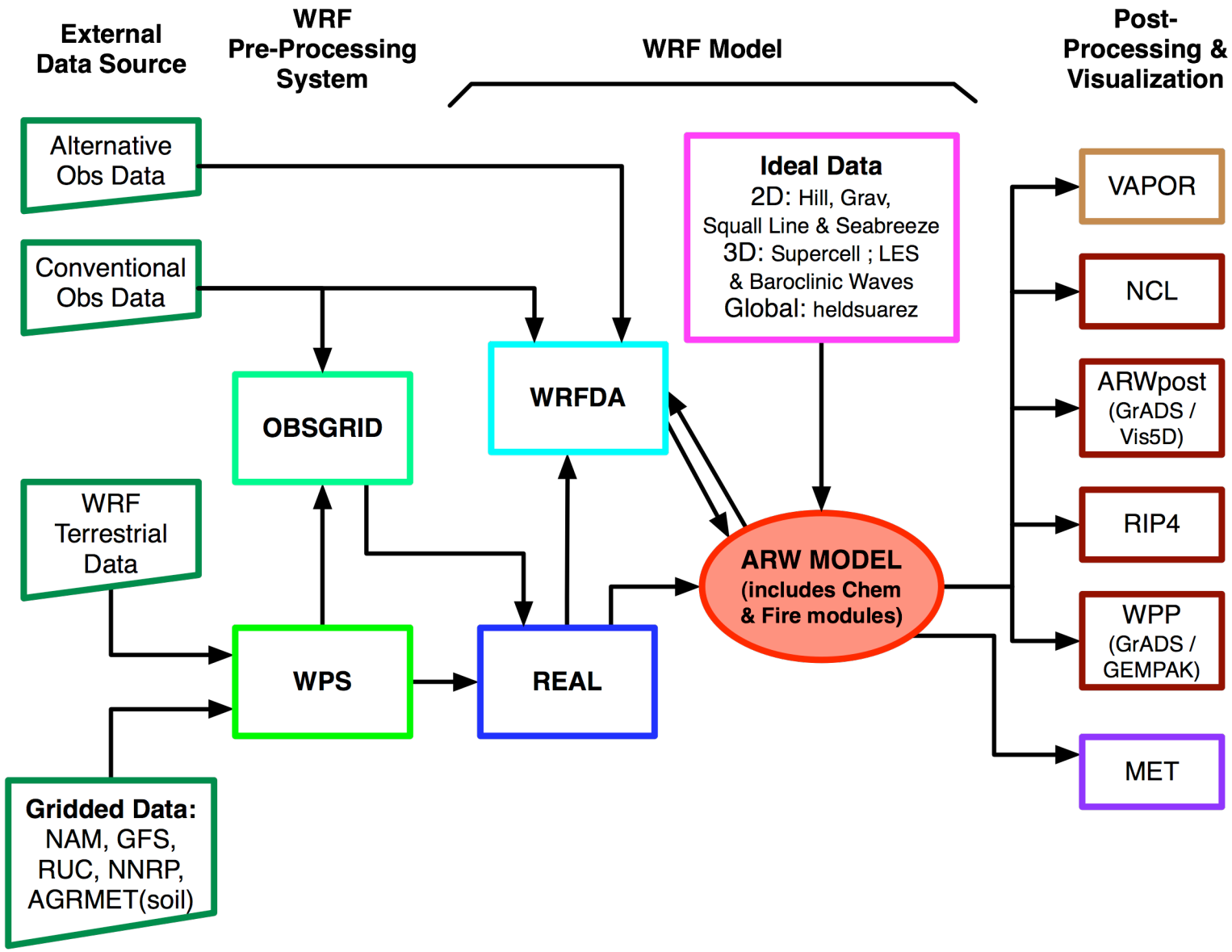


WRF Applications

- Atmospheric physics/parameterization research
- Case-study research
- Real-time NWP and forecast system research
- Data assimilation research
- Teaching dynamics and NWP
- Regional climate and seasonal time-scale research
- Coupled-chemistry applications
- Idealized simulations at many scales (e.g. convection, baroclinic waves, large eddy simulations)
- Coupled with ground spread fire
- Coupled with hydrology (to be released in 3.5)
- Coupled with ocean and wave (some users have done so)

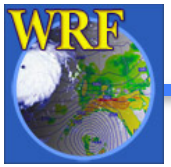


WRF Modeling System Flow Chart



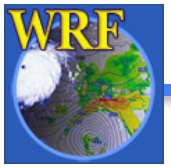
Modeling System Components

- WRF Pre-processing Programs
  - Real-data preparation for NWP runs (*WPS*)
  - Program for adding more observations to analysis (*obsgrid*)
- WRF Model
  - Initialization programs for real and idealized data (*real.exe/ ideal.exe*)
  - Numerical integration program (*wrf.exe*)
  - One-way nesting in separate runs (*ndown.exe*)
  - WRF-Chemistry
  - WRF-Fire
- Graphics and verification tools including MET
- WRF Data Assimilation (WRFDA)



What to do produce a WRF simulation?

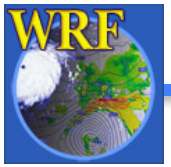
- Define simulation domain area (and nests)
- Produce terrain, landuse, soil type etc. on the simulation domain ("*static*" fields) (prog. *geogrid*)
- Get GRIB files for meteorological data (u, v, T, q, surface pressure, soil data, snow data, sea-surface temperature, etc.) that covers the forecast period, and convert it to simple internal format or "*intermediate-formatted" data (ungrib)*
- Interpolate meteorological data to WRF model grid (horizontally) (*metgrid*)
- Interpolate vertically to model coordinate (terrain-following) – generate model input and lateral boundary file (*real*)



⟶ Run wrf model

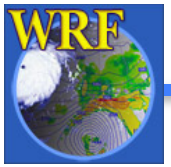
What are the needed data?

- Static data to define terrain, landuse, soil state, etc. – we provide (global coverage, multiple resolution)
  - User can input own static data in same easy-to-write format
- Time-varying meteorological data – from internet, i.e. NCEP ftp site, NOAA data portal, reanalysis
  - User can also write own data in the same format

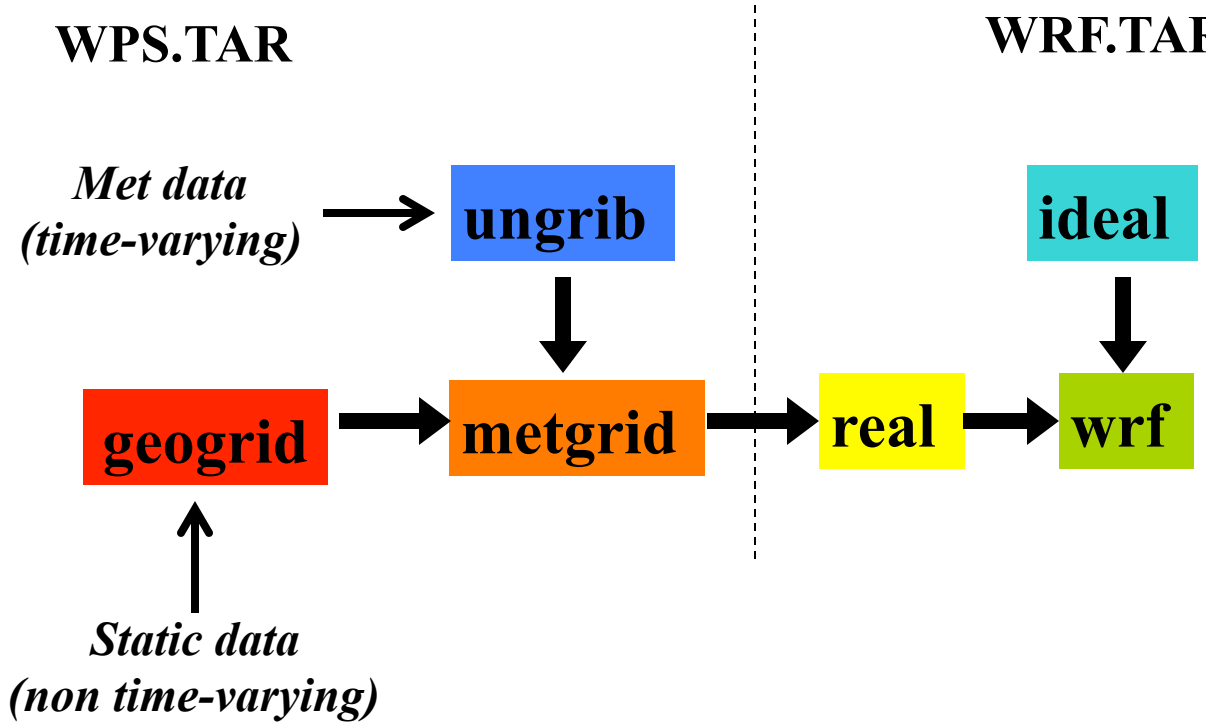


WPS Programs

- *geogrid.exe:* define model grid with a chosen map projection and interpolate time-independent fields to the grid
  - Supported map projections: Mercator, Lambert-Comformal, Polar stereographic and regular lat/lon
- *ungrib.exe*: convert time-dependent Grib-formatted Met data to simple binary format
  - grib 1 and 2 from various sources
- *metgrid.exe:* interpolate time-dependent met data to model grid, and combine met data with geogrid data



WPS and WRF Program Flow

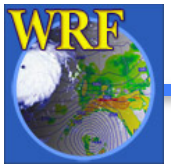


WRF Programs

- Initialization*: real.exe*
  - Creates initial and boundary condition files for real-data cases
  - Does vertical interpolation to model levels (when using WPS)
  - Does vertical dynamic (hydrostatic) balance
  - Does soil vertical interpolations and land-use mask checks
- Initialization: *ideal.exe*
  - ICs come from a single sounding or pre-defined fields
  - Does vertical interpolation and dynamic balance
  - Can set ICs for surface physics

WRF Programs

- WRF model: *wrf.exe*
  - Performs time integration
  - Uses initial and boundary conditions from *real.exe*
  - Runs the model simulation with run-time selected namelist options (such as physics choices, timestep, length of simulation, etc.)
  - Supports two-way, one-way and moving nests
  - Outputs history and restart files



WRF ARW Dynamics

Key features:

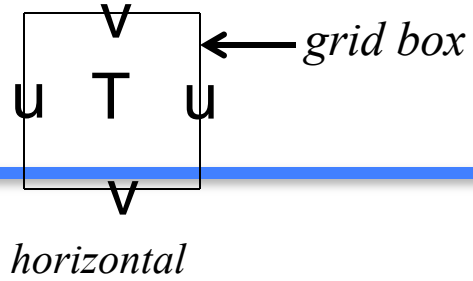
- Fully compressible, non-hydrostatic (with hydrostatic option)
- Mass-based terrain following coordinate, η

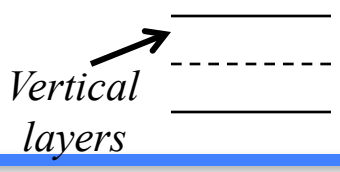
$$\eta = \frac{(\pi - \pi_t)}{\mu}, \qquad \mu = \pi_s - \pi_t$$

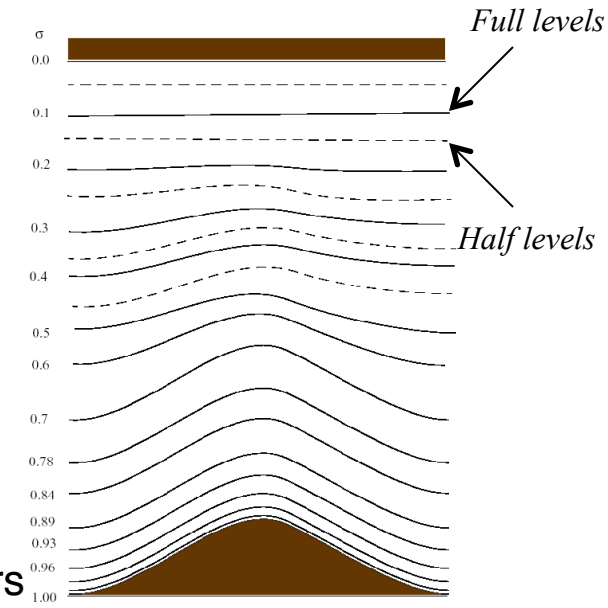
where π is hydrostatic dry pressure,

μ is column mass

- Arakawa C-grid staggering



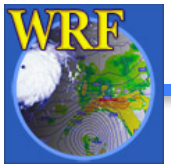




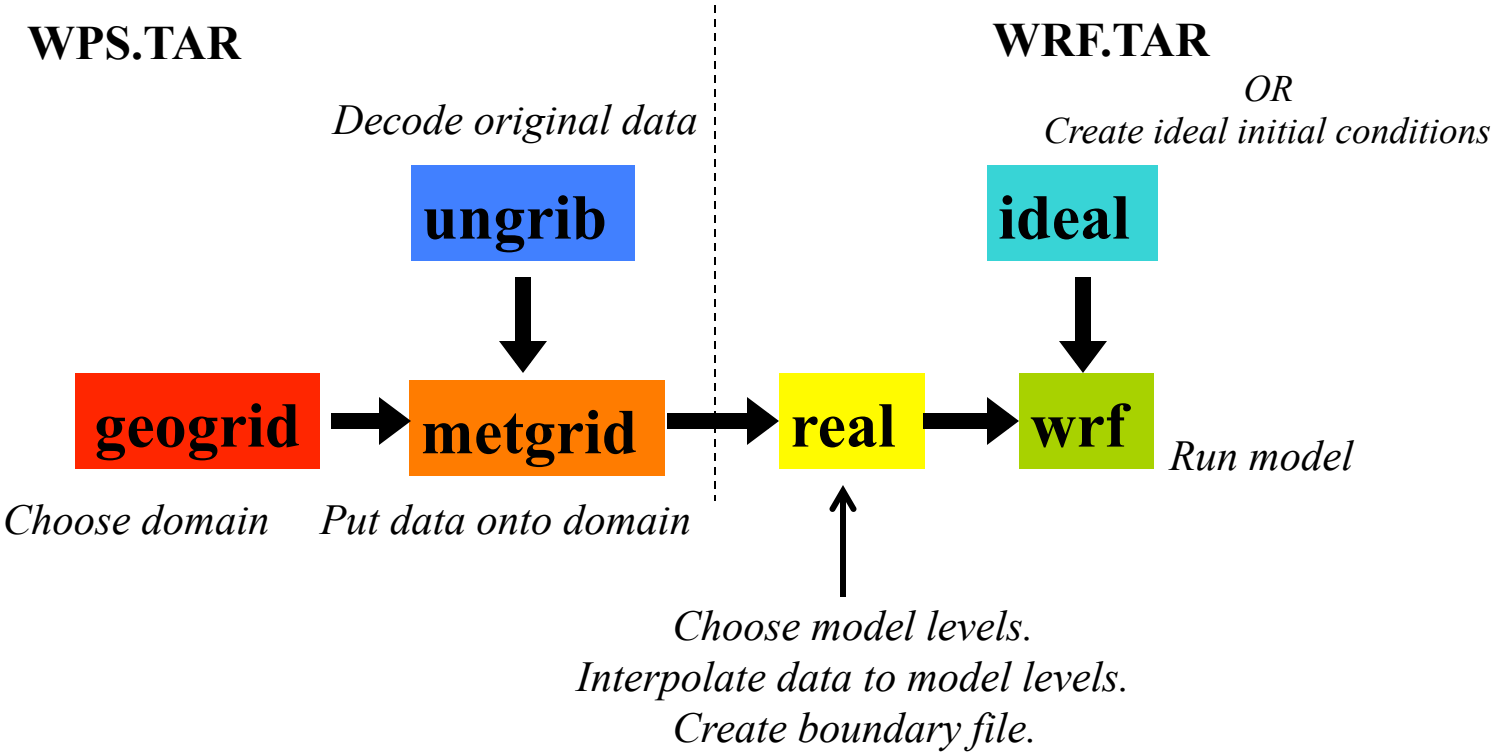
WRF ARW Model

Key features:

- Higher-order numerics
- Mass and scalar conservation
- Full physics options to represent atmospheric radiation, surface and boundary layer, and cloud and precipitation processes
- Nesting: one-way, two-way, and moving nests
- Grid-nudging and obs-nudging (FDDA)
- Digital Filter Initialization option



WPS and WRF Program Flow

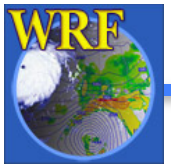


WRFDA (Data Assimilation)

- Variational data assimilation (3D-Var and 4D-Var)
- Ensemble DA
- Hybrid variational/ensemble DA

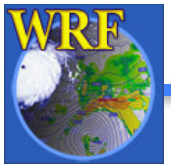
Function

- Ingest observations to improve WRF input analysis from WPS
- May be used in cycling mode for updating WRF initial conditions after WRF run
- Also used for observation impact data studies



WRF-Chem

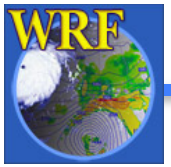
- Developed by the community and supported by NOAA/ESRL/GSD
- Chemistry species are advected in the model, and interact with physics
- Chemical processes, reactions
- Separate pre-processors for chemical data initialization



Graphics and Verification Tools

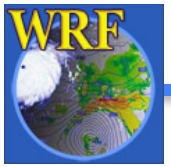
Supported tools:

- RIP4 (Read, Interpolate and Plot)
- NCAR Graphics Command Language (NCL)
- ARWpost
  - Conversion program for GrADS
- VAPOR (3D visualization tool)
- IDV (3D visualization tool)
- Unified Post-Processor (UPP)
  - Conversion to GriB (for GrADS and GEMPAK)
- MET (Model Evaluation Toolkit)



WRF/WPS Installation

- Download source codes:
  - http://www.mmm.ucar.edu/wrf/users
- Download static datasets
- Make sure to have the necessary libraries built first:
  - netCDF, mpich, zlib, png, and jasper
- Compile WRF first: requires netCDF, mpich
- Compile WPS: requies: netCDF, zlib, png, jasper



WRF/WPS Installation

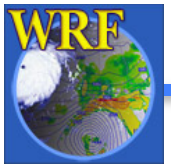
- To compile WRF:
  - Type the following to create a configure file:

    ./configure
  - Choose an option:
    - ✓ serial, or parallel
    - ✓ Nesting or no nesting
  - Type the following to compile:

    ./compile em_real >& compile.out

If successful, these executables should show up in WRFV3/main/:

wrf.exe, real.exe, ndown.exe



WRF/WPS Installation

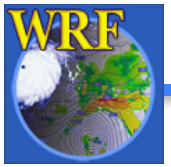
- To compile WPS:
  - Type the following to create a configure file:

    ./configure
  - Choose an option:
    - ✓ serial, or parallel – serial should work for most cases
    - ✓ grib 1 or grib 2
  - Type the following to compile:

    ./compile >& compile_wps.out

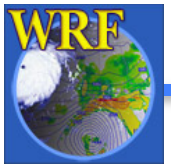
If successful, these executables should show up in top WPS/:

geogrid.exe, ungrib.exe, metgrid.exe



Running WPS

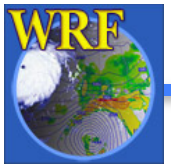
- To run WPS:
  - Start with *geogrid.exe*:
    - ✓ Use *util/plotgrids.ncl* to configure domains
    - ✓ Edit *namelist.wps* to change dates, grid dimensions, map projection, input data resolution, etc.
    - ✓ Find more options in *namelist.wps_all_options*
    - ✓ Run *geogrid.exe* → output: *geo_em.d01.nc*
  - Run *ungrib.exe*:
    - ✓ Obtain grib meteorological files, select *Vtable*
    - ✓ Run *ungrib.exe* → output: {*prefix*}:<date-string>
  - Run *metgrid.exe* → output: *met_em.d01.<date-string>*



Running real/WRF

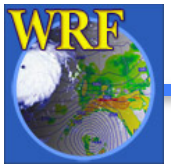
- To run WRF:
  - Run *real.exe*:
    - ✓ Edit *namelist.input* to change dates, grid dimensions (again), define vertical levels, and select physics options. Also set history_interval for output, time_step for model integration
    - ✓ Move or link metgrid output files to the working directory
    - ✓ Run *real.exe* → output: *wrfinput_d0*, wrfbdy_d01*
  - Run *wrf.exe*:
    - ✓ Edit *namelist.input* to see if anything else is needed
    - ✓ To run *wrf.exe*: e.g. mpirun –np 4 wrf.exe

      → output: *wrfout_d0*_<date-string>*



Code Layers

- Top-level (framework): allocates space, handles nested domains and interpolation/ feedback functions, time-stepping, solver calls, and i/o file contents and calls
- Intermediate level: "start" routine for initial calls, "solve" routine for run-time advancing, MPI handling
- Low-level: science code in plain Fortran (no MPI or I/O calls, code in *dyn_em, phys* directories)



Dynamics and Physics Routines

- Code in *dyn_em/*:

  e.g. *solve_em.F*

  module_advect_em.F, model_diffusion_em.F

  module_initialize_*.F

- Code in *phys/*:

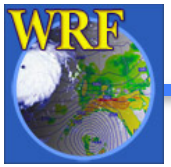
  e.g. *module_cumulus_driver.F, module_cu_*.F*

  module_microphysics_driver.F, module_mp_*.F

  module_radiation_driver.F, module_ra_*.F

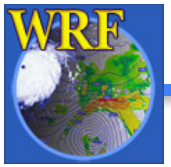
  module_pbl_driver.F, module_bl_*.F

  module_surface_driver.F, module_sf_*.F



Registry File

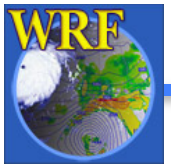
- Designed to make adding arrays or new namelist parameters easy
- IO declaration for input, output, restart
- Declare nest interpolation, feedback
- Declare communication “halos” for MPI (only sometimes needed)
- Allocates, passes, and declares listed arrays for “solver” routines
  - From solver, it can be passed to parts of the low-level code via argument lists



Basic Software Requirement

- Fortran 90/95 compiler
  - Code uses standard f90 (very portable)
- C compiler
  - "Registry"-based automatic Fortran code generation (for argument lists, declarations, nesting functions, I/O routines)
- Perl
  - configure/compile scripts
- netCDF library
  - for I/O (other I/O formats semi-supported)
- Public domain mpich for MPI or OpenMPI
  - if using distributed memory option

→ Code is very portable



User Support

- email for basic WRF: wrfhelp@ucar.edu
  for WRF-Chem: wrfchemhelp.gsd@noaa.gov
- User Web pages:
  http://www.mmm.ucar.edu/wrf/users/
  - Online tutorial
  - Tutorial lecture slides
  - Latest update for the modeling system
  - WRF software download
  - Various documentation
    - User's Guides
    - Technical Note (ARW Description)