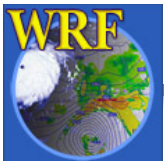




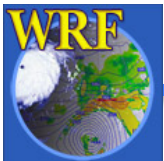
WRF Modeling System Overview

Jimmy Dudhia



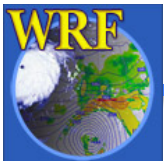
What is WRF?

- 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 resource with distributed development and centralized support
- Its development is led by NCAR, NOAA/ESRL and NOAA/NCEP/EMC with partnerships at AFWA, FAA, and collaborations with universities and other government agencies in the US and overseas



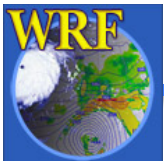
What are ARW and NMM?

- The Advanced Research WRF (ARW) and Nonhydrostatic Mesoscale Model (NMM) are dynamical cores
 - Dynamical core includes mostly advection, pressure-gradients, Coriolis, buoyancy, filters, diffusion, and time-stepping
- Both are nonhydrostatic Eulerian dynamical cores with terrain-following pressure-based vertical coordinates
- ARW support and development are centered at NCAR/MMM
- NMM development is centered at NCEP/EMC and support is provided by NCAR/DTC
- This tutorial is for both dynamical cores
- Both are downloadable in the same WRF tar file
- Physics, the software framework, and parts of data pre- and post-processing are shared between the dynamical cores



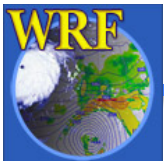
WRF as a Community Model

- Version 1.0 WRF was released December 2000
- Version 2.0: May 2004 (NMM added, EM nesting)
- Version 2.1: August 2005 (EM becomes ARW)
- Version 2.2: December 2006 (WPS released)
- Version 3.0: April 2008 (includes global ARW version)
- Version 3.1: April 2009
- Version 3.2: April 2010
- Version 3.3: April 2011
 - Version 3.3.1 September 2011
- Version 3.4: April 2012
 - Version 3.4.1 August 2012 (current version)



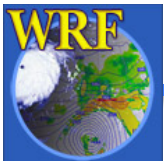
What can WRF be used for?

- ARW and NMM
 - Atmospheric physics/parameterization research
 - Case-study research
 - Real-time NWP and forecast system research
 - Data assimilation research
 - Teaching dynamics and NWP
- ARW only
 - Regional climate and seasonal time-scale research
 - Coupled-chemistry applications
 - Global simulations
 - Idealized simulations at many scales (e.g. convection, baroclinic waves, large eddy simulations)

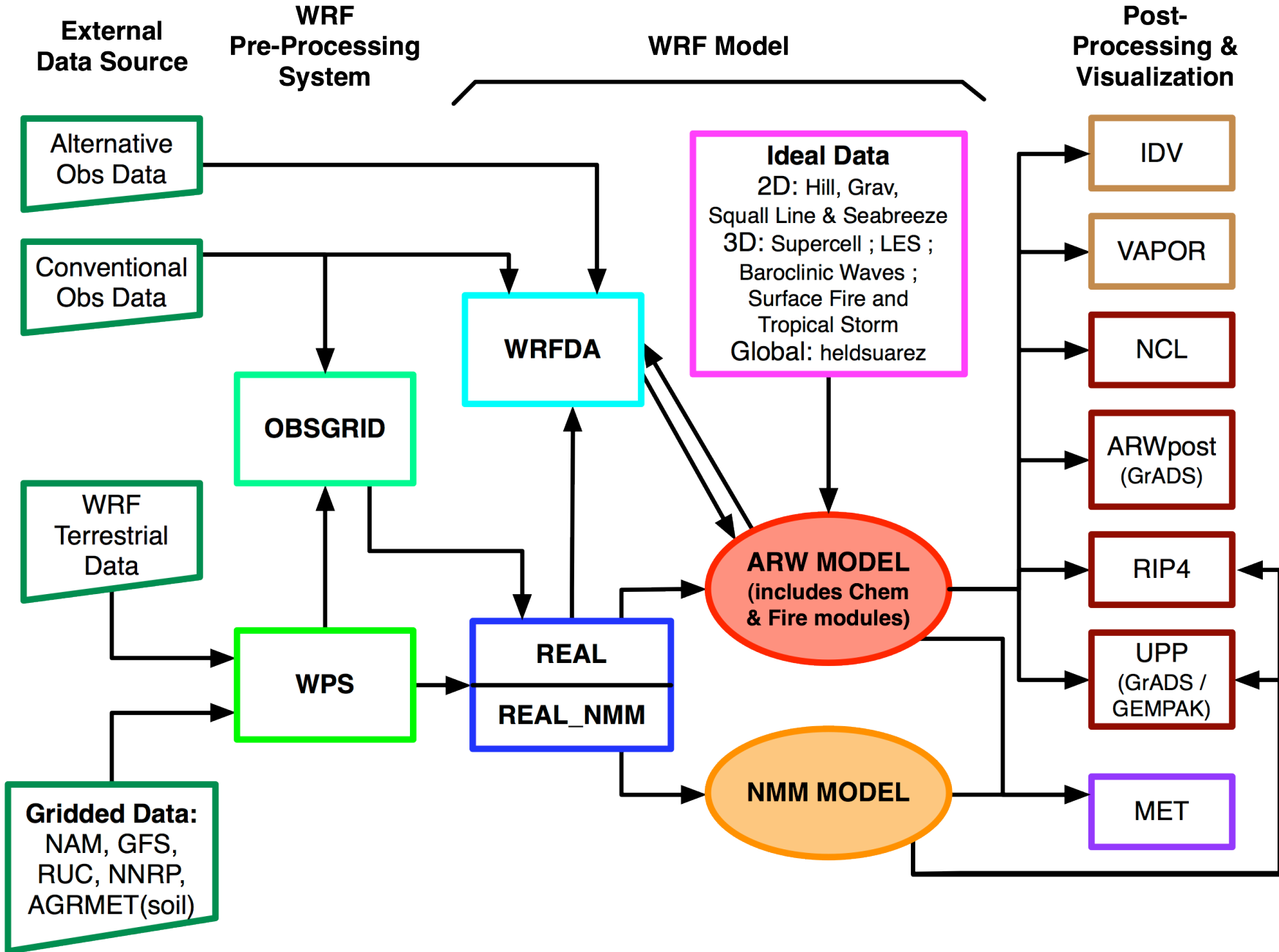


Who uses WRF?

- Academic atmospheric scientists (dynamics, physics, weather, climate research)
- Forecast teams at operational centers
- Applications scientists (e.g. Air Quality, Hydrology, Utilities)



WRF Modeling System Flow Chart

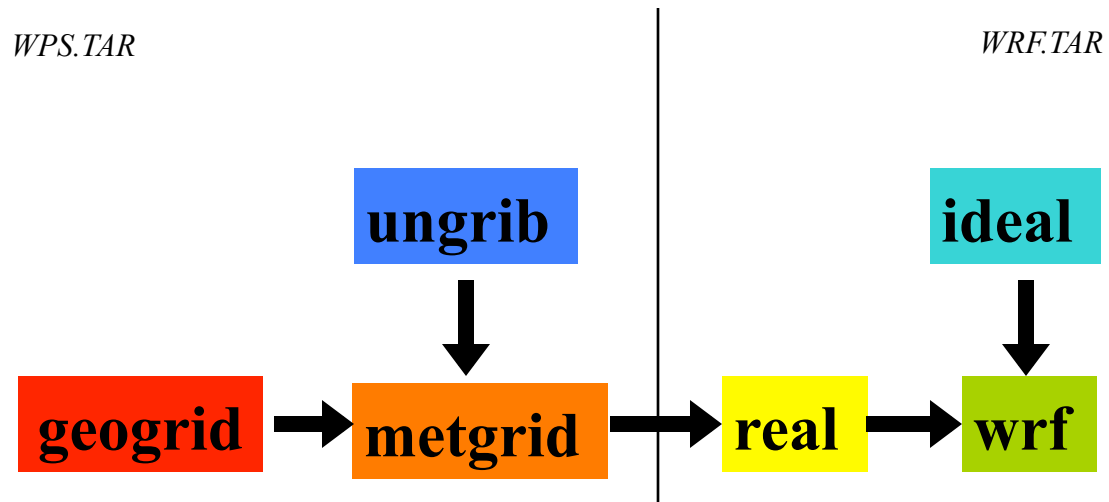


Modeling System Components

- WRF Pre-processing System
 - Real-data interpolation for NWP runs (WPS)
 - Program for adding more observations to analysis (obsgrid)
- WRF Model (ARW and NMM dynamical cores)
 - Initialization programs for real and (for ARW) idealized data (real.exe/ideal.exe)
 - Numerical integration program (wrf.exe)
- Graphics and verification tools including MET
- WRFDA (separate tutorial)
- WRF-Chem (separate tutorial)
- WRF-Fire – wildland model for forest fires

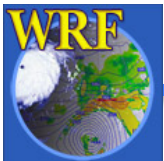


WPS and WRF Program Flow



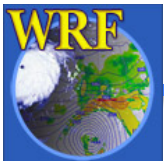
Real-Data Applications

- Numerical weather prediction
- Meteorological case studies
- Regional climate
- Applications: air quality, wind energy, hydrology, etc.



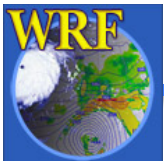
Real-Data Applications

- Need time-independent information for chosen *domain* (simulation grid area)
- GEOGRID program
 - Map projection information
 - 2d gridded latitude, longitude, Coriolis parameter, map-scale factors, etc.
 - Topographic information
 - 2d gridded elevation, vegetation and soil categories, etc.



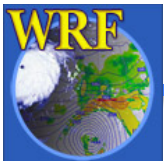
Real-Data Applications

- Need initial conditions (initial analysis time)
- UNGRIB and METGRID programs
 - 3d fields of horizontal wind, temperature, geopotential height, relative humidity
 - 2d fields of surface or sea-level pressure, surface temperature, relative humidity, horizontal winds
 - Time-sensitive land-surface fields: snow-cover, soil temperature, soil moisture



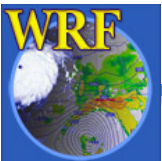
Real-Data Applications

- Regional domains need *specified* lateral boundary conditions at later times (e.g. every 6 hours) through forecast period
 - 3d fields of horizontal wind, temperature, geopotential height, water vapor
 - 2d field of surface pressure
- Long simulations (> 1 week) also need lower boundary condition at later analysis times
 - 2d fields of sea-surface temperature, sea-ice



Real-Data Applications

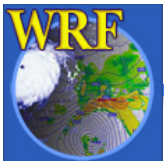
- Lateral Boundary Conditions (linear in time)
 - The *wrfbdy* file contains later gridded information at model points in a zone (e.g.) 5 points wide around the domain
 - The boundary fields are linearly time-interpolated from boundary times to the current model time
 - This specifies the outer values, and is used to nudge the next 4 interior points
- Lower Boundary Condition (step-wise)
 - New SSTs are read in and overwritten at each analysis time from *wrflowinp* file



Real-Data Applications

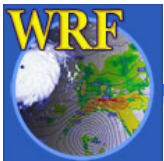
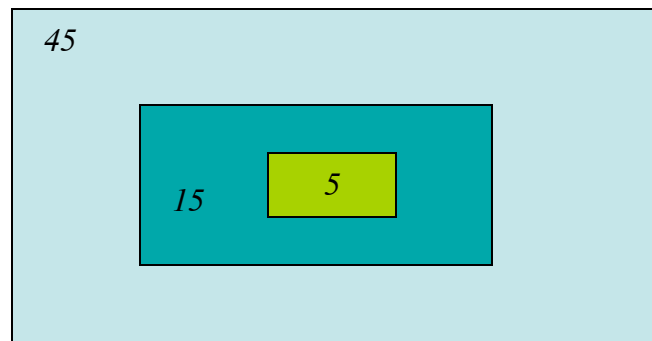
Summary

- Pre-processing for regional domains therefore needs multiple times for lateral boundary conditions during whole forecast period (UNGRIB and METGRID should be run for all needed analysis times)
 - Note: Global models only need initial analysis
 - Real-time regional NWP often uses global forecast for boundary conditions
- Long simulations also need lower boundary information on SST and sea ice to update them over periods of weeks, months, years



Nesting

- Running multiple domains with increasing resolution in nested areas
- Parent has *specified* boundary conditions from *wrfbdy* file
- *Nested* boundary conditions come from parent



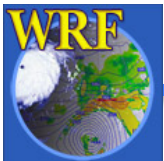
Nesting (Two-Way)

- Lateral boundary condition is provided by parent domain at every parent step
- Method is same as for outer domain (specified and relaxation zones)
- Additional fields include vertical motion and microphysics species
- Feedback: Interior of nest overwrites overlapped parent area



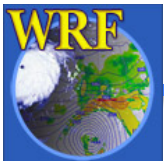
Nesting (Two-Way)

- Sequence
 - Parent domain runs a time-step to $t+dt$
 - Nest boundaries from beginning and end of time-step interpolated
 - Nest runs typically three steps ($dt/3$) using time-interpolated parent info at nest boundaries
 - After nest reaches $t+dt$, feedback overwrites parent in overlapped region
 - Repeat



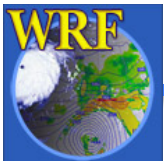
One-Way Nesting

- As two-way nesting but no feedback
- Can also be done with NDOWN program to take a previous WRF run output and provide nest boundary conditions at parent output frequency
 - Uses parent WRF run instead of analysis for initial and lateral boundary conditions



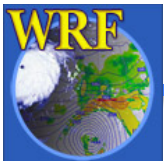
WPS Functions

- Define simulation domain area (and nests)
- Produce terrain, landuse, soil type etc. on the simulation domain (“static” fields)
- De-grib GRIB files for meteorological data (u, v, T, q, surface pressure, soil data, snow data, sea-surface temperature, etc.)
- Interpolate meteorological data to WRF model grid (horizontally)
- Optionally add more observations to analysis (separate obsgrid program)

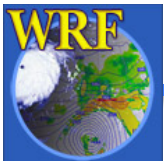
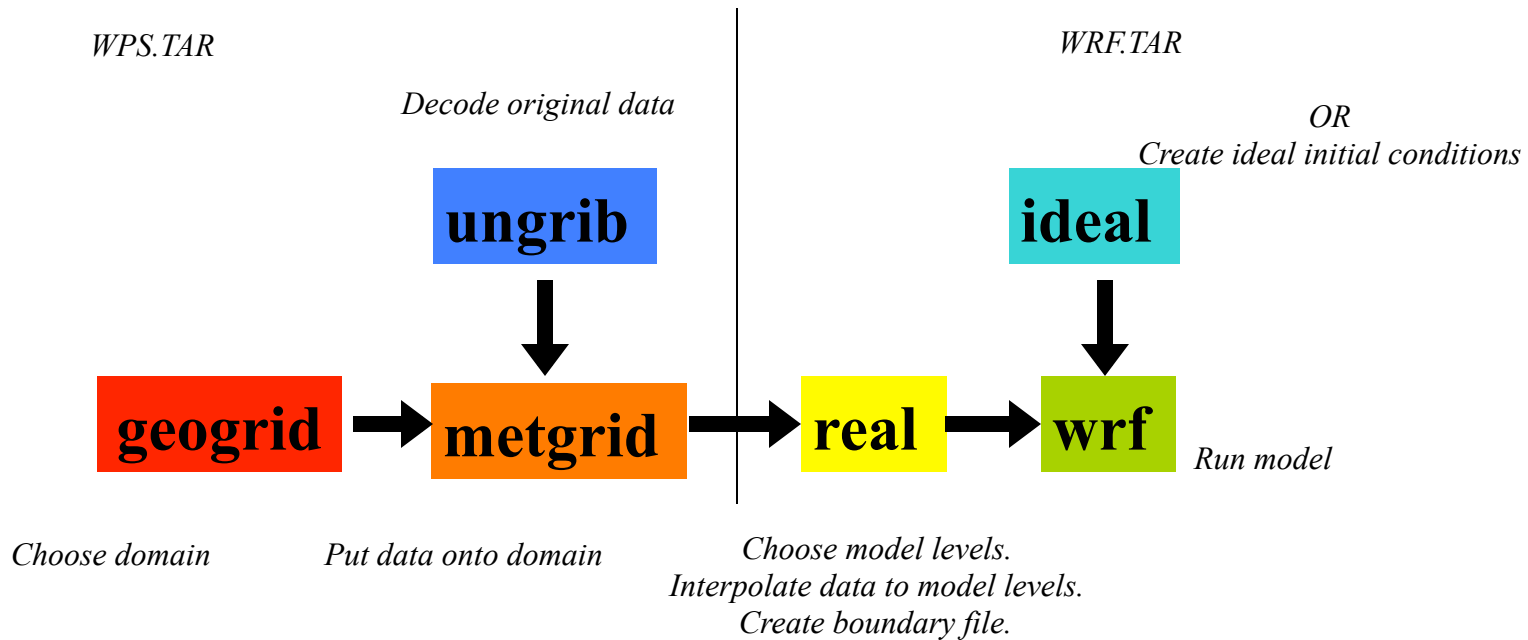


WPS Data

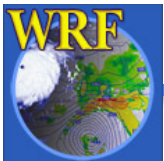
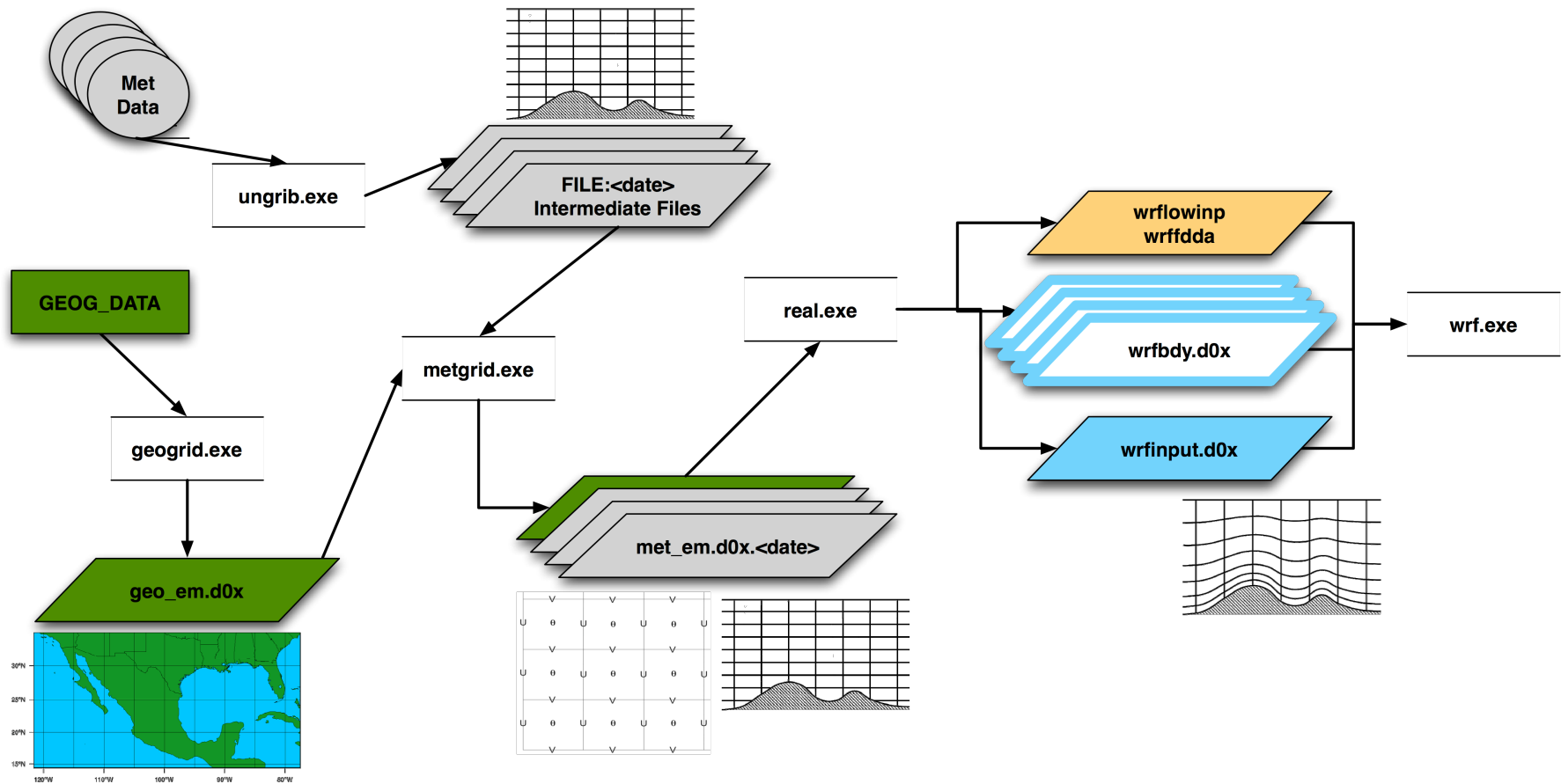
- Geogrid: We provide elevation, land-use, soil type data (static fields)
 - Or user can input own static data in same easy-to-write format
- Metgrid: Supports input of time-dependent data (dynamic fields)
 - UNGRIB can provide these from GriB files
 - Or user can input own data in same “intermediate format” (simple binary files)



WPS and WRF Program Flow



Data Flow



Dynamical Cores

- Dynamical cores include
 - Basic Dynamical Equations: Advection, Coriolis, pressure gradient terms, buoyancy, diffusion
 - Finite differencing: Staggered grid-structure, time-stepping method and numerical filters
- ARW dynamical core
 - Designed for research as well as NWP
 - Idealized cases, regional climate, WRF-Chem, more options
- NMM dynamical core
 - Used in NCEP operational regional models (i.e. NAM and HWRF)
 - Focused on NWP applications, more limited options

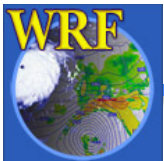


WRFDA (Data Assimilation)

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

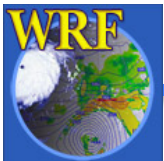
Function

- 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



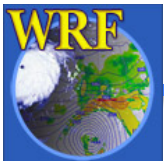
WRF-Chem

- Supported by NOAA/ESRL
- Includes chemistry species and processes, many chemistry options
- Also needs emissions data
- Included in WRF tar file, but requires special compilation option



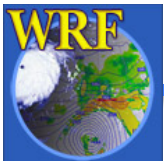
Graphics and Verification Tools

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



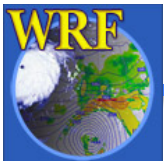
Basic Software Requirement

- 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
 - if using distributed memory option



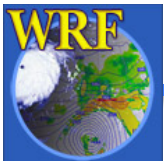
Code Layers

- 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)



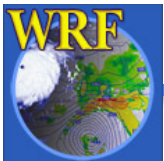
Registry File

- Designed to make adding arrays or new namelist parameters easy
- Also can add them to “halo” for MPI communications (only sometimes needed)
- Allocates, passes, and declares, listed arrays for nesting, i/o and “solver” routines
 - Solver advances one domain by one time step
 - From solver, it can be passed to parts of the low-level code via argument lists



User Support

- Email: wrfhelp@ucar.edu
- User Web pages:
 - ARW: <http://www.mmm.ucar.edu/wrf/users/>
 - NMM: <http://www.dtcenter.org/wrf-nmm/users/>
- Latest update for the modeling system
- WRF software download
- Various documentation
 - Users' Guides (both cores)
 - Technical Note (ARW Description)
 - Technical Note (NMM Description)

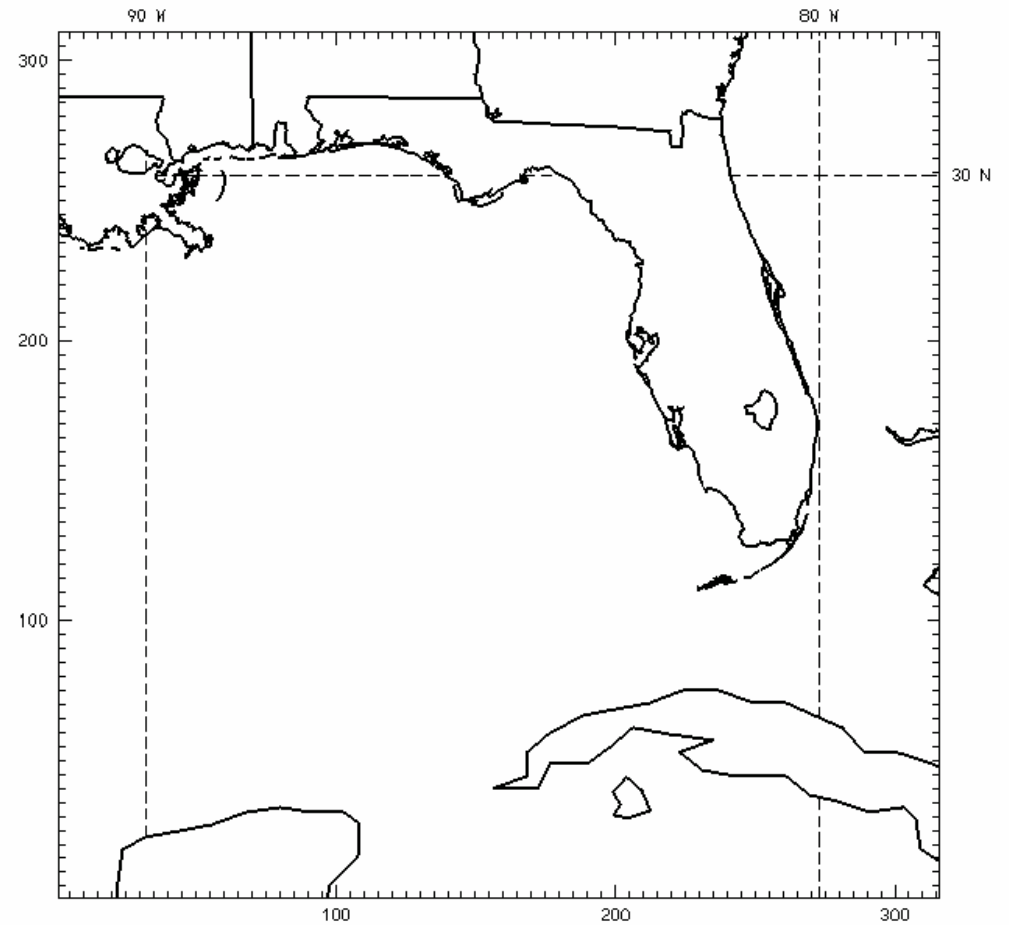
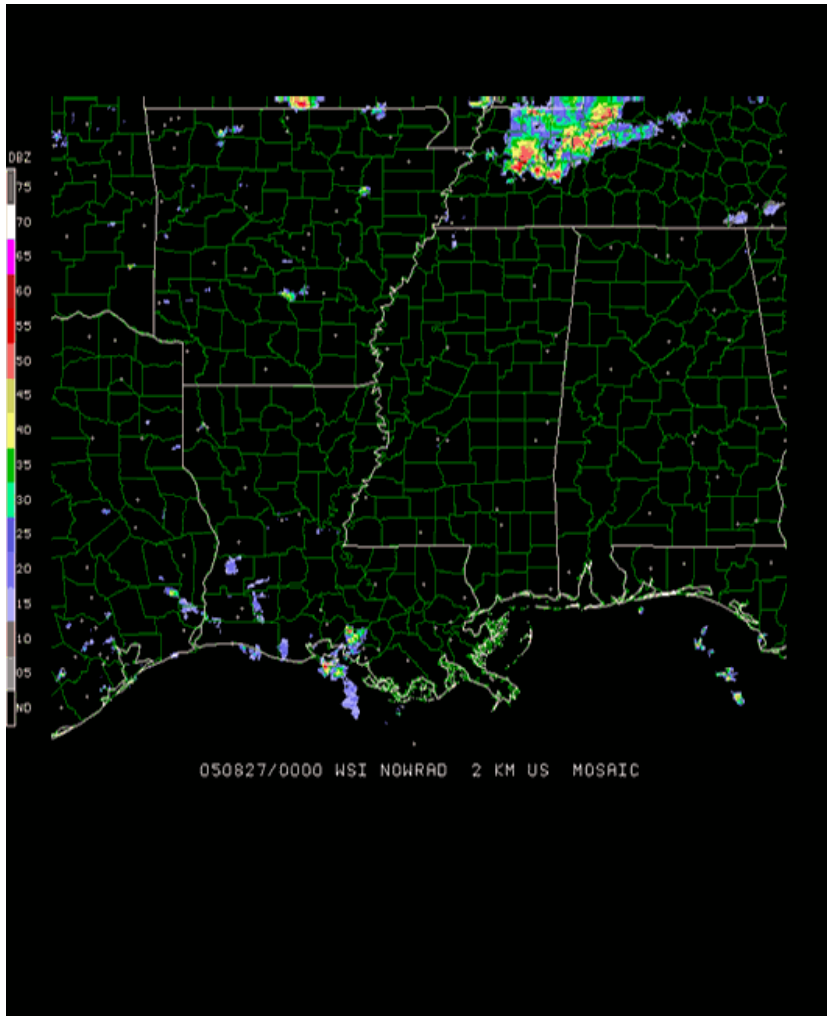


Example: Real-time WRF

- <http://www.mmm.ucar.edu/prod/rt/pages/rt.html>
- 15 km US domain
- Initialized from NCEP GFS initial and boundary conditions
- 00Z and 12Z daily
- RIP graphics



ARW Hurricane Katrina Simulation (4km)



ARW Convective-scale Forecasting (4km)

00 h forecast 00 UTC 04 June 2005

