



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 Eulerian mass dynamical cores with terrain-following 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 released)
- 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 3.1.1 August 2009
- Version 3.2: just released in April 2010

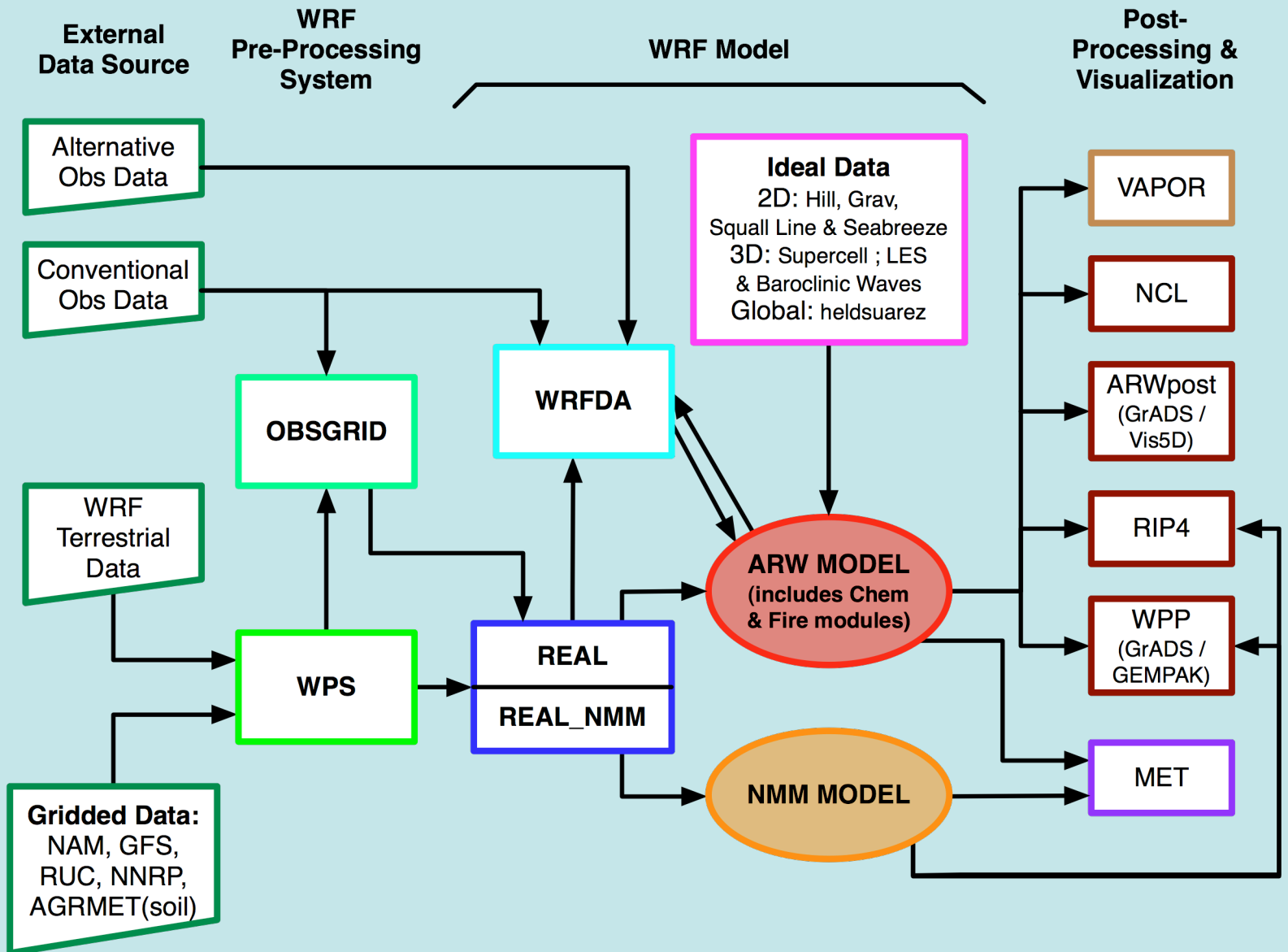
What can WRF be used for?

- 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 (WPS)
 - Real-data interpolation for NWP runs
 - New obsgrid program for adding more obs to analysis
- 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)

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 and WRF

Running WPS

- Several executable stages with namelist input
 - geogrid.exe (interpolate maps and time-independent fields)
 - ungrib.exe (convert time-dependent Grib-formatted data to simple binary format)
 - metgrid.exe (interpolate time-dependent initial and boundary data)
 - obsgrid.exe (optional stage to add more observations)

Running WRF

- Two executable stages with namelist input
 - real.exe or real_nmm.exe (set up vertical model levels for model input and boundary files)
 - wrf.exe (run model)

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

WRFDA

- Supported data types
 - Conventional surface and upper air, wind profiler, aircraft
 - Remote sensing data: Cloud-tracked winds, satellite-retrieved profiles, ground-based/satellite GPS, scatterometer ocean surface winds, radar radial velocity and reflectivity, satellite radiance
- Background error covariance for ARW from
 - NMC method
 - Ensemble method

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

WRF real and ideal functions

- REAL
 - 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
- IDEAL (ARW only)
 - Programs for setting up idealized case
 - Simple physics and usually single sounding
 - Initial conditions and dynamic balance

WRF Model

- WRF
 - Dynamical core (ARW or NMM) is compile-time selectable
 - Uses initial conditions from REAL or IDEAL
 - Real-data cases use boundary conditions from REAL
 - Runs the model simulation with run-time selected namelist switches (such as physics choices, timestep, length of simulation, etc.)
 - Outputs history and restart files

ARW Dynamics

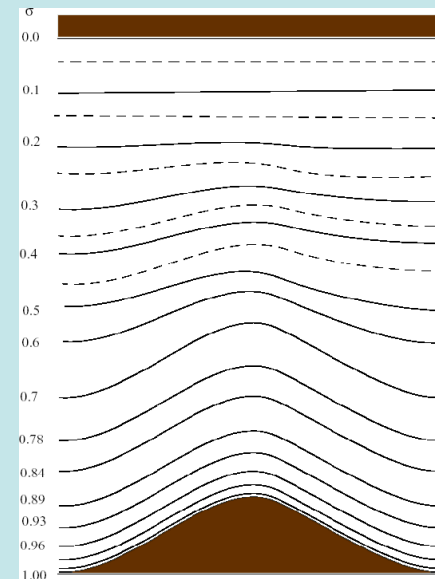
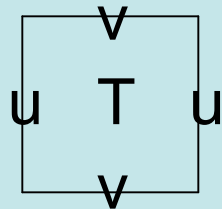
Key features:

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

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

where π is hydrostatic pressure,
 μ is column mass

- Arakawa C-grid staggering



ARW Model

Key features:

- 3rd-order Runge-Kutta time integration scheme
- High-order advection scheme
- Scalar-conserving (positive definite option)
- Complete Coriolis, curvature and mapping terms
- Two-way and one-way nesting

ARW Model

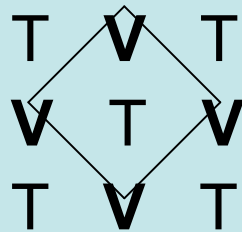
Key features:

- Choices of lateral boundary conditions suitable for real-data and idealized simulations
 - Specified, Periodic, Open, Symmetric, Nested
- Full physics options to represent atmospheric radiation, surface and boundary layer, and cloud and precipitation processes
- Grid-nudging and obs-nudging (FDDA)
- New Digital Filter Initialization option

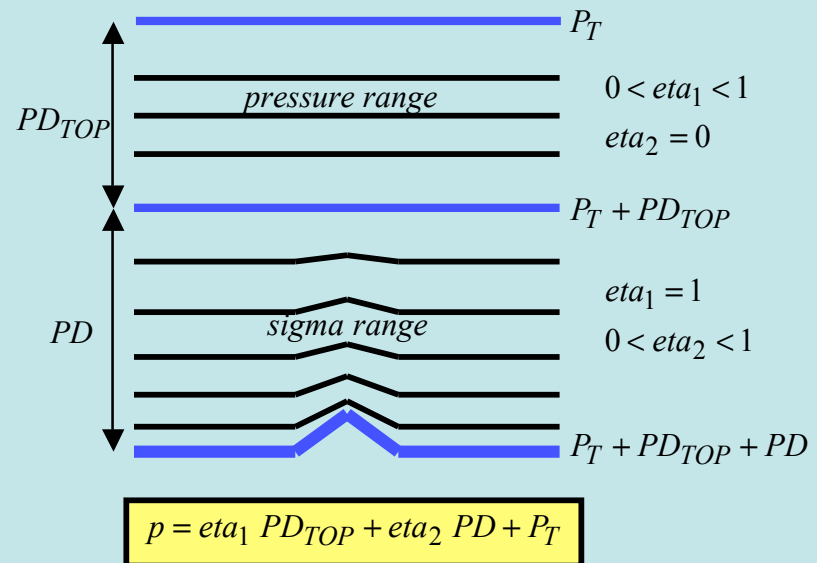
NMM Dynamics

Key features:

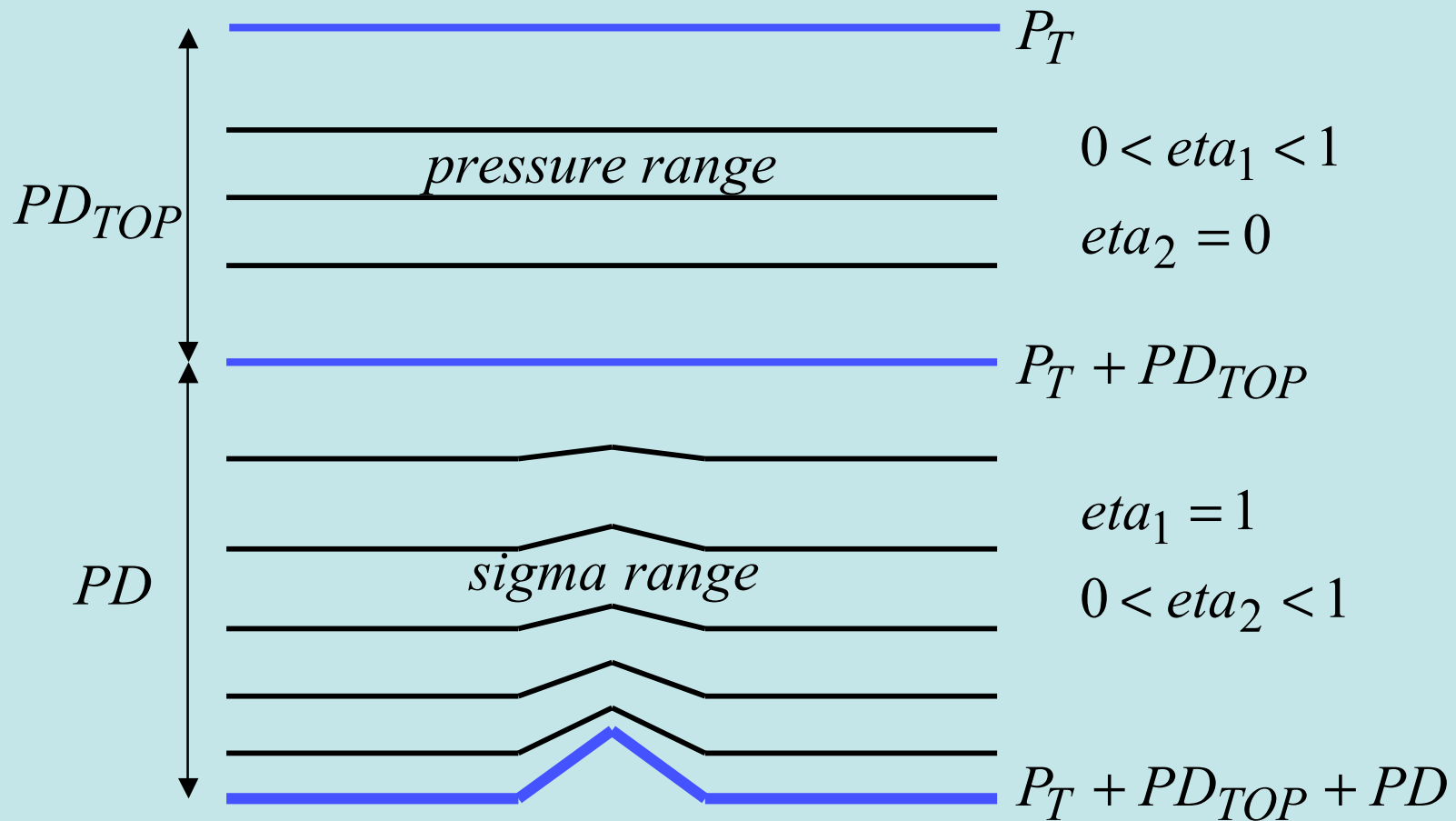
- Fully compressible, non-hydrostatic or hydrostatic
- Mass-based sigma-pressure hybrid terrain following coordinate similar to ARW but with constant pressure surfaces above 400 hPa
- Arakawa E-grid staggering



where **V** is u and v



NMM Dynamics



$$p = eta_1 PD_{TOP} + eta_2 PD + P_T$$

NMM Model

Key features:

- Adams-Bashforth and Crank-Nicholson time integration schemes
- High-order advection scheme
- Scalar and energy conserving
- Coriolis, curvature and mapping terms
- One-way and two-way nesting

NMM Model

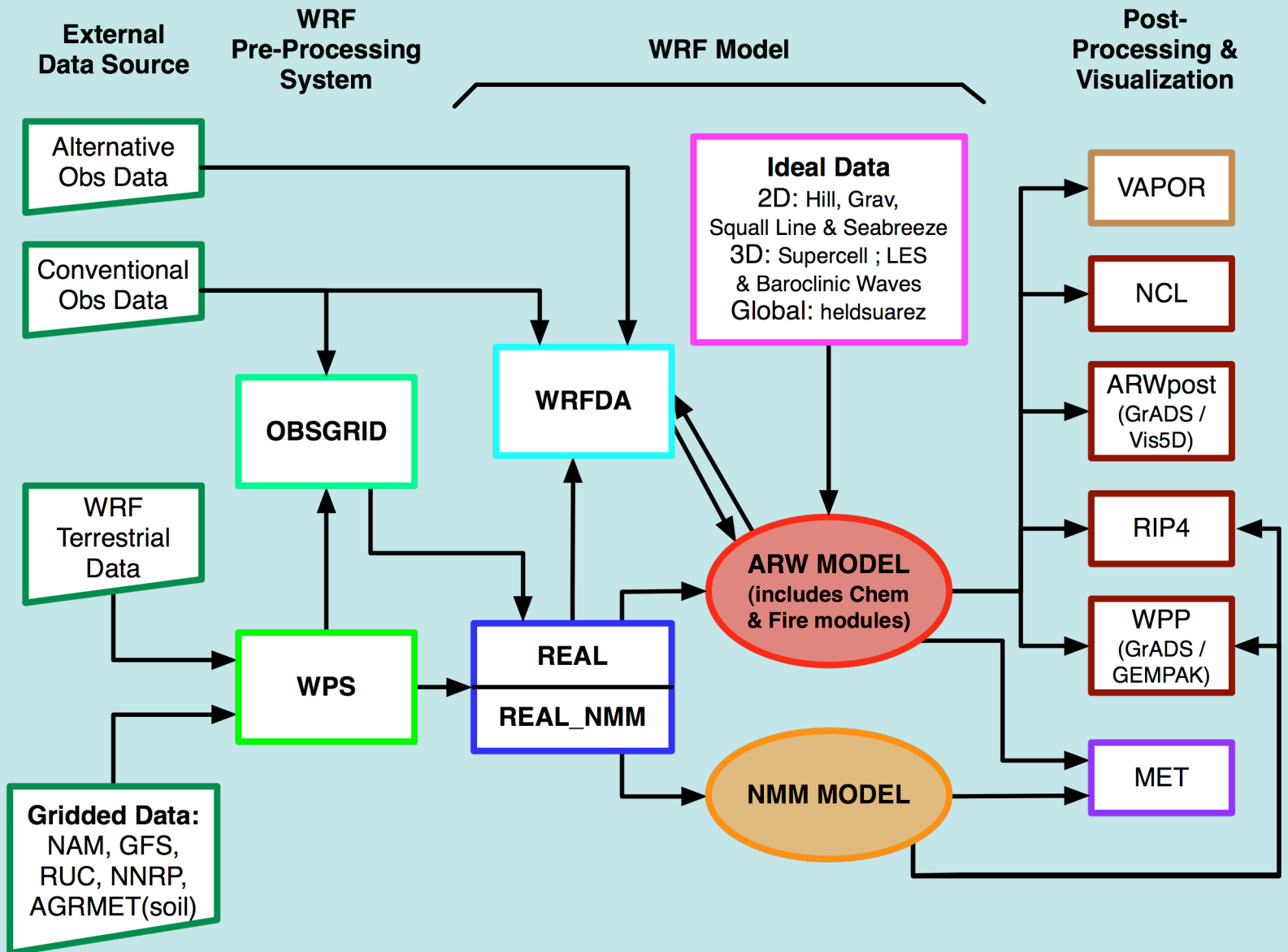
Key features:

- Lateral boundary conditions suitable for real-data and nesting
- Full physics options to represent atmospheric radiation, surface and boundary layer, and cloud and precipitation processes

Graphics and Verification Tools

- ARW and NMM
 - RIP4 (Read, Interpolate and Plot)
 - WRF Post-Processor (WPP)
 - Conversion to GriB (for GrADS and GEMPAK)
 - MET (Model Evaluation Toolkit)
- ARW
 - NCAR Graphics Command Language (NCL)
 - ARWPost
 - Conversion program for GrADS and Vis5D

WRF Modeling System Flow Chart



Basic Software Requirement

- Fortran 90/95 compiler
- C compiler
- Perl
- netCDF library
- Public domain mpich for MPI

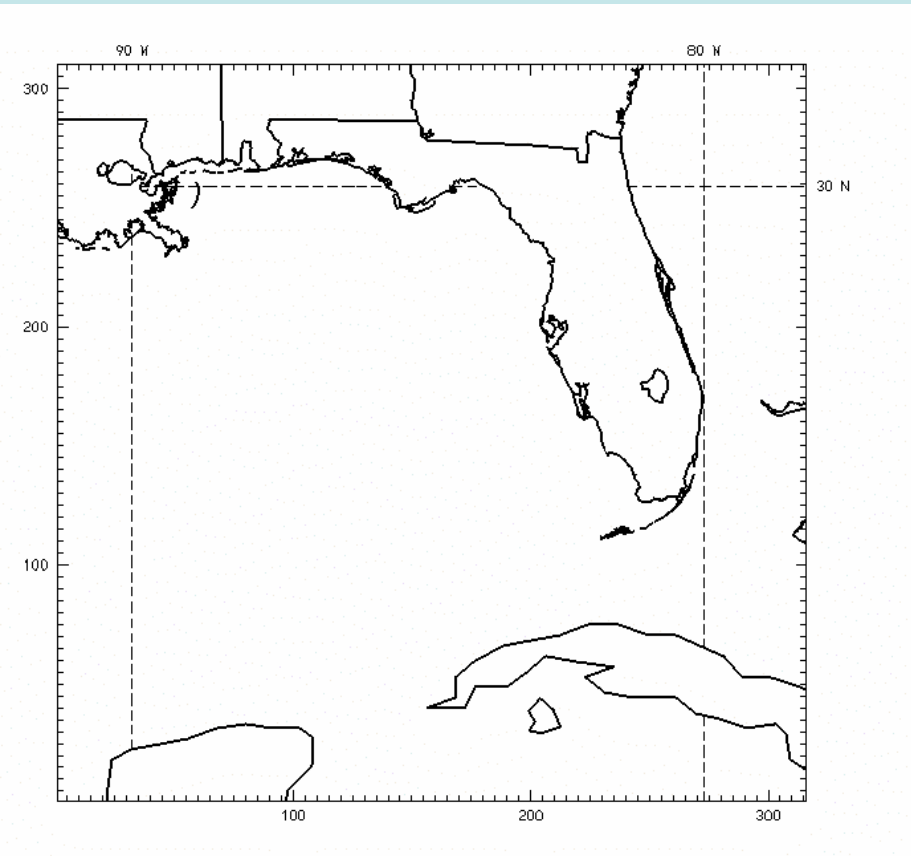
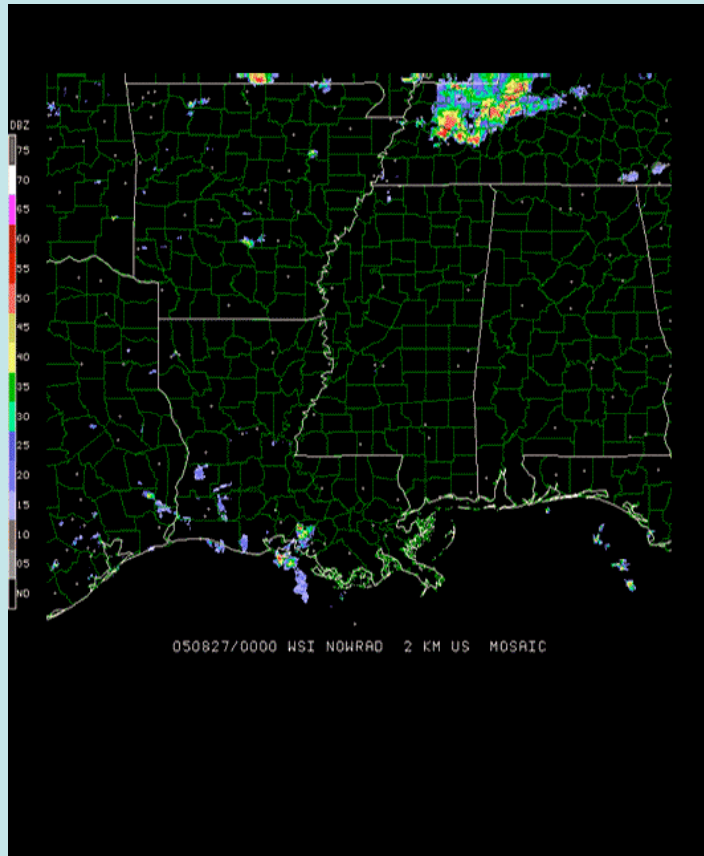
Portability

- Runs on Unix single, OpenMP and MPI platforms:
 - IBM SP AIX (xlf)
 - Linux (PGI, Intel, g95, gfortran, Pathscale compilers)
 - SGI Altix (Intel)
 - Cray XT (PGI, Pathscale)
 - Mac Darwin (xlf, PGI, Intel, g95 compilers)
 - Others (HP, Sun, SGI Origin, Compaq)

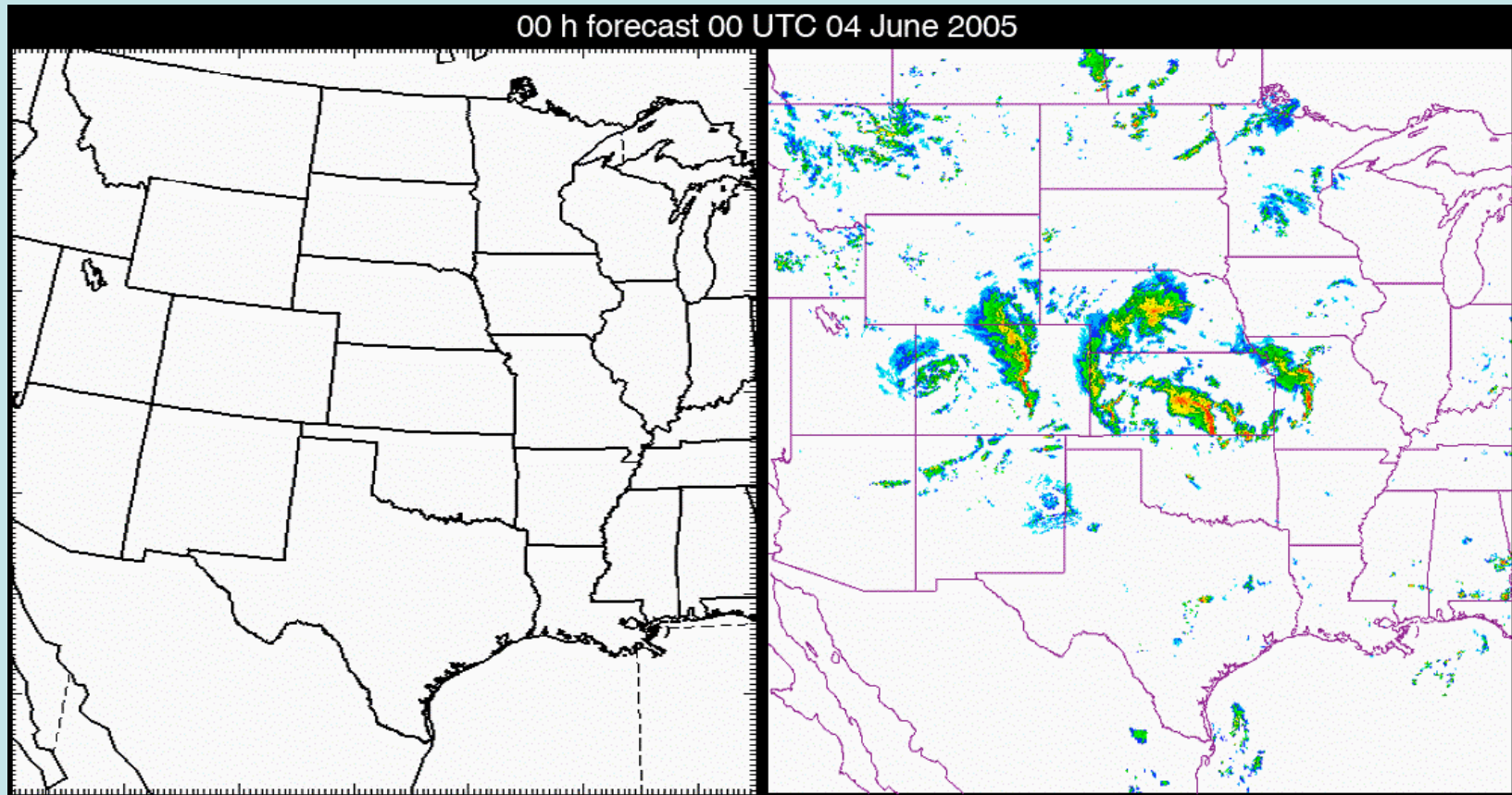
User Support

- 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' Guide
 - Technical Note (ARW Description)

ARW Hurricane Katrina Simulation (4km)



ARW Convective-scale Forecasting (4km)



Tutorial Schedule

- Lectures for WRF: Mon.-Fri.
- Practice for WRF: Mon.-Fri.
 - 2 Groups (a.m./p.m.)
- WRF-Chem tutorial: Next Mon.-Tue.
- WRFDA tutorial: Next Tue.-Thu.
- MET tutorial: Next Thu.-Fri.