WRF Modeling System Overview

Jimy 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/GSD and NOAA/NCEP/EMC with partnerships at AFWA, FAA, NRL, and collaborations with universities and other government agencies in the US and overseas

What are ARW and NMM?

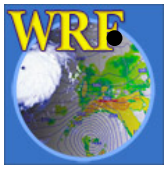
- The Advanced Research WRF (ARW) and Nonhydrostatic Mesoscale Model (NMM) are dynamical cores
  - Dynamical core includes mostly advection, pressure-gradients, Coriolis, buoyancy, filters, diffusion, and time-stepping
- Both are Eulerian mass dynamical cores with terrain-following vertical coordinates
- 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

What WRF does not include

- WRF does not include (yet) in its community release
  - WRF-Chem - coupled on-line chemistry
    - Available from NOAA
  - Coupled Ocean/Wave models
  - Adjoint model (4DVAR)

WRF as a Community Model

- Version 1.0 WRF was released December 2000
- Version 2.0 May 2004 (NMM added, EM nesting released)
  - Version 2.0.1 Jun 2004
  - Version 2.0.2 Jun 2004
  - Version 2.0.3.1 Dec 2004
- Version 2.1 August 2005 (EM becomes ARW)
  - Version 2.1.1 Nov 2005 (NMM released)
  - Version 2.1.2 Jan 2006
- Version 2.2 December 2006 (WPS released)
  - NMM nesting released in 2007
  - 2.2.1 released in Nov 2007
- Version 3.0 released in April 2008



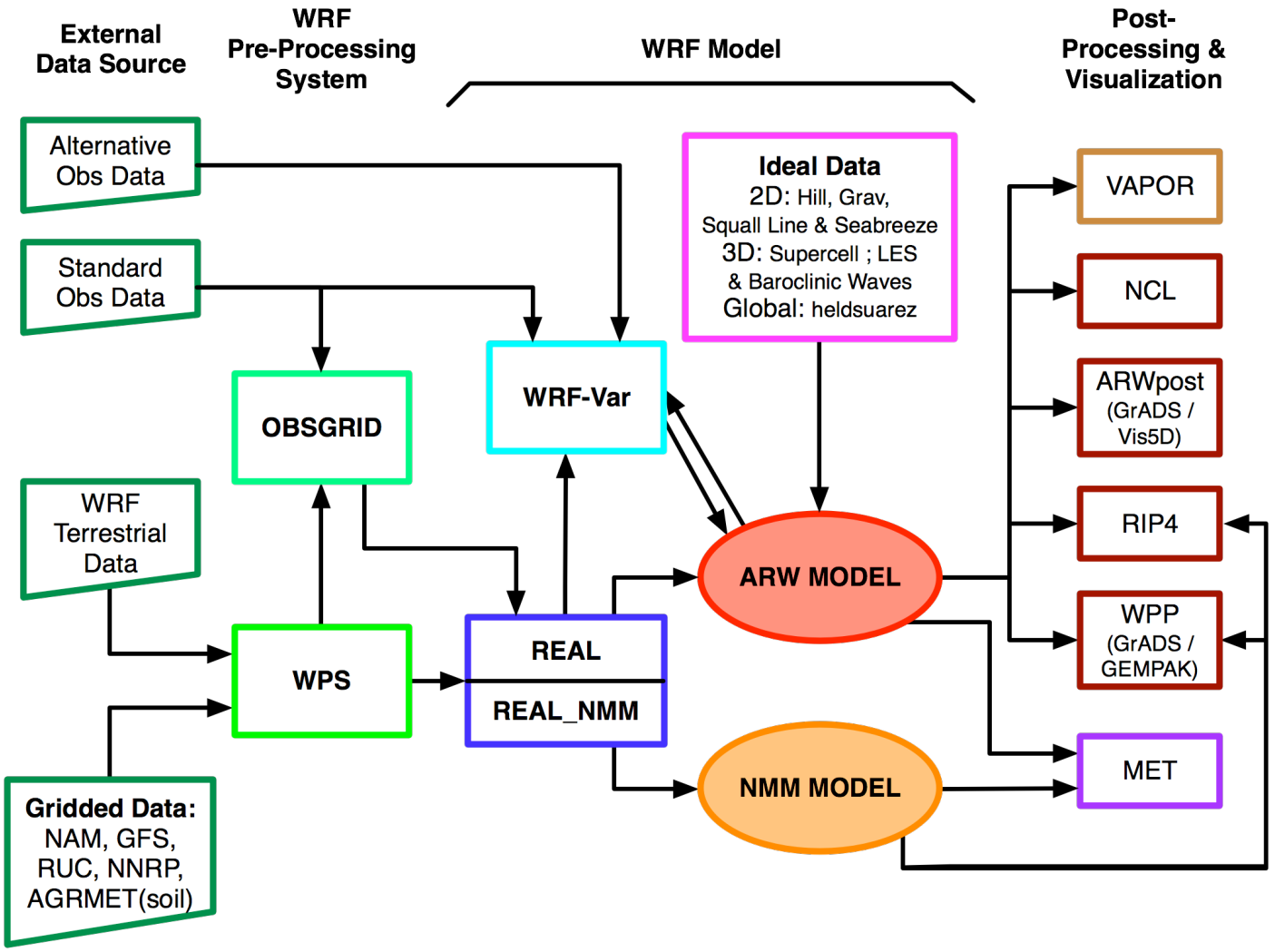
What can WRF be used for?

- ARW and NMM
  - Atmospheric physics/parameterization research
  - Case-study research
  - Real-time NWP and forecast system 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)
  - Data assimilation research

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
- WRF-Var (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)

ARW only

WRF-Var Functions

- Variational data assimilation
- Ingest observations into 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 3DVAR

- Supported data types
  - Conventional surface and upper air, wind profiler
  - Remote sensing data: Cloud-track winds, ATOVS thickness, ground-based GPS TPW, SSM/I, SSM/T1, SSM/T2, SSM/I brightness temp, Quikscat ocean surface winds, radar radial velocity and reflectivity
- Background error covariance for ARW from
  - NMC method
  - Ensemble method

WRF-Chem

- Supported by NOAA/ESRL
- Includes chemistry species and processes
- 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:

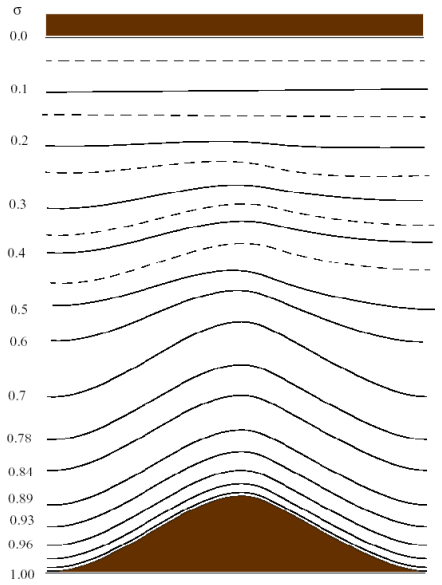
- Fully compressible, non-hydrostatic (with hydrostatic option)
- Mass-based terrain following coordinate, η

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

where π is hydrostatic pressure,
μ is column mass

- Arakawa C-grid staggering

v
u T u
v



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

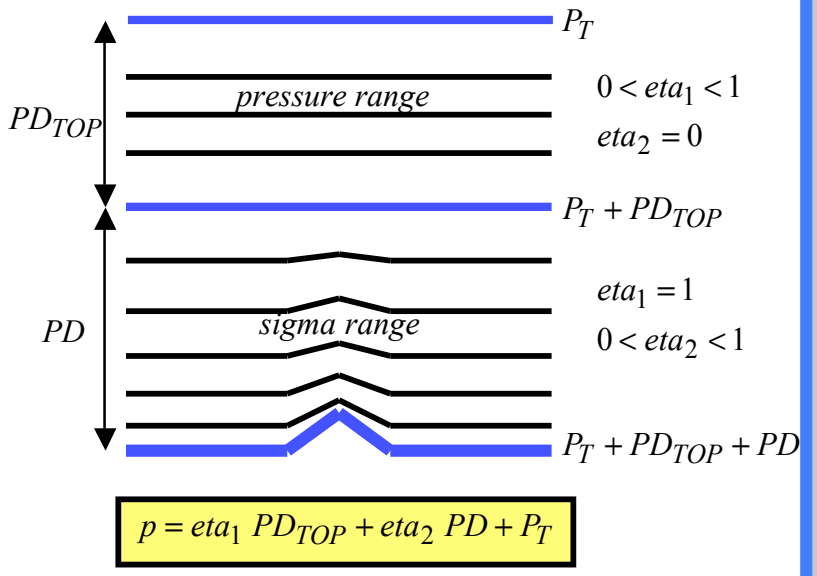
NMM Dynamics

Key features:

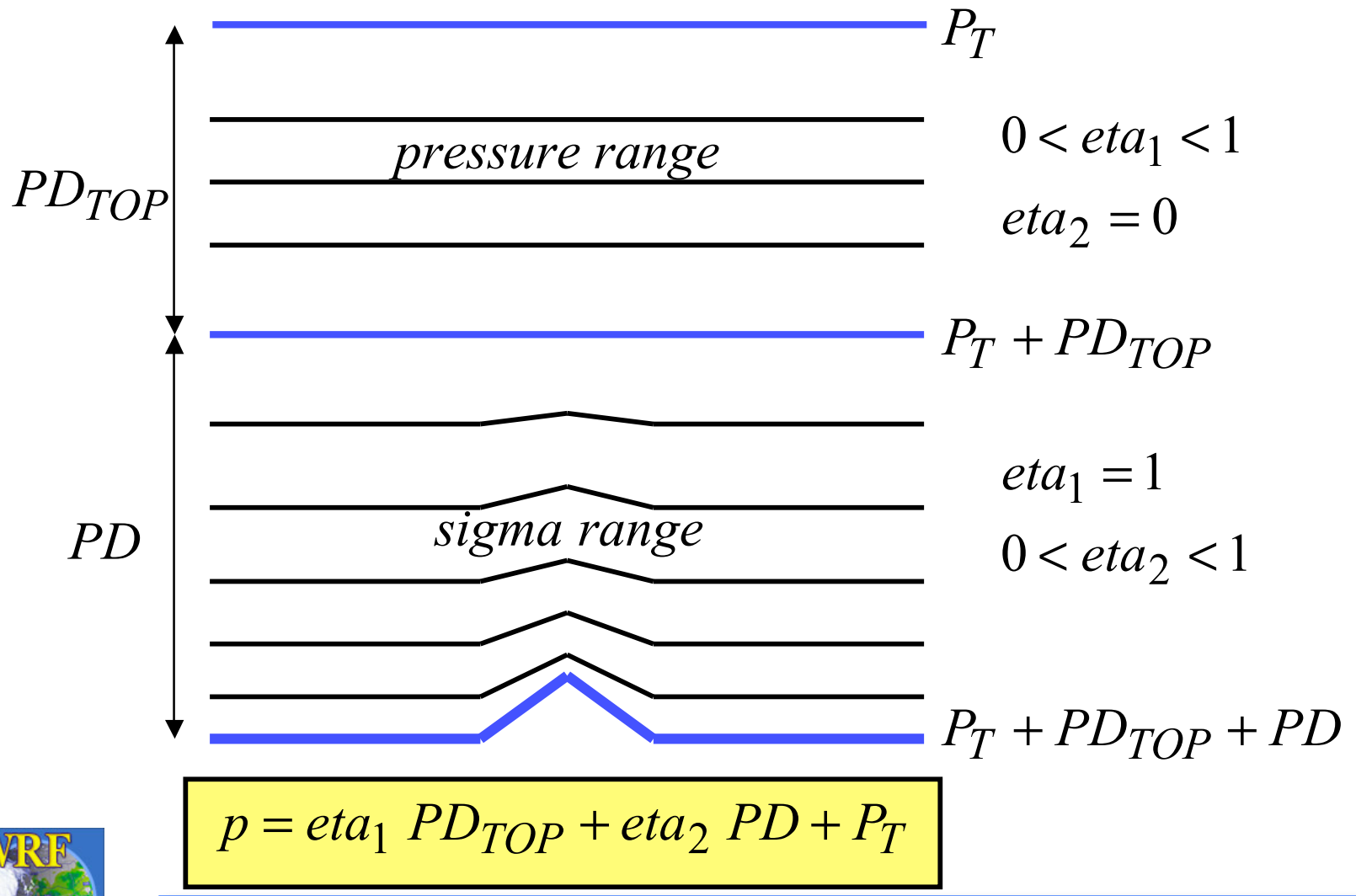
- Fully compressible, non-hydrostatic or hydrostatic
- Mass-based sigma-pressure hybrid terrain following coordinate similar to ARW but with constant pressure surfaces above 400 hPa
- Arakawa E-grid staggering

T **V** T
V T **V**
T **V** T

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

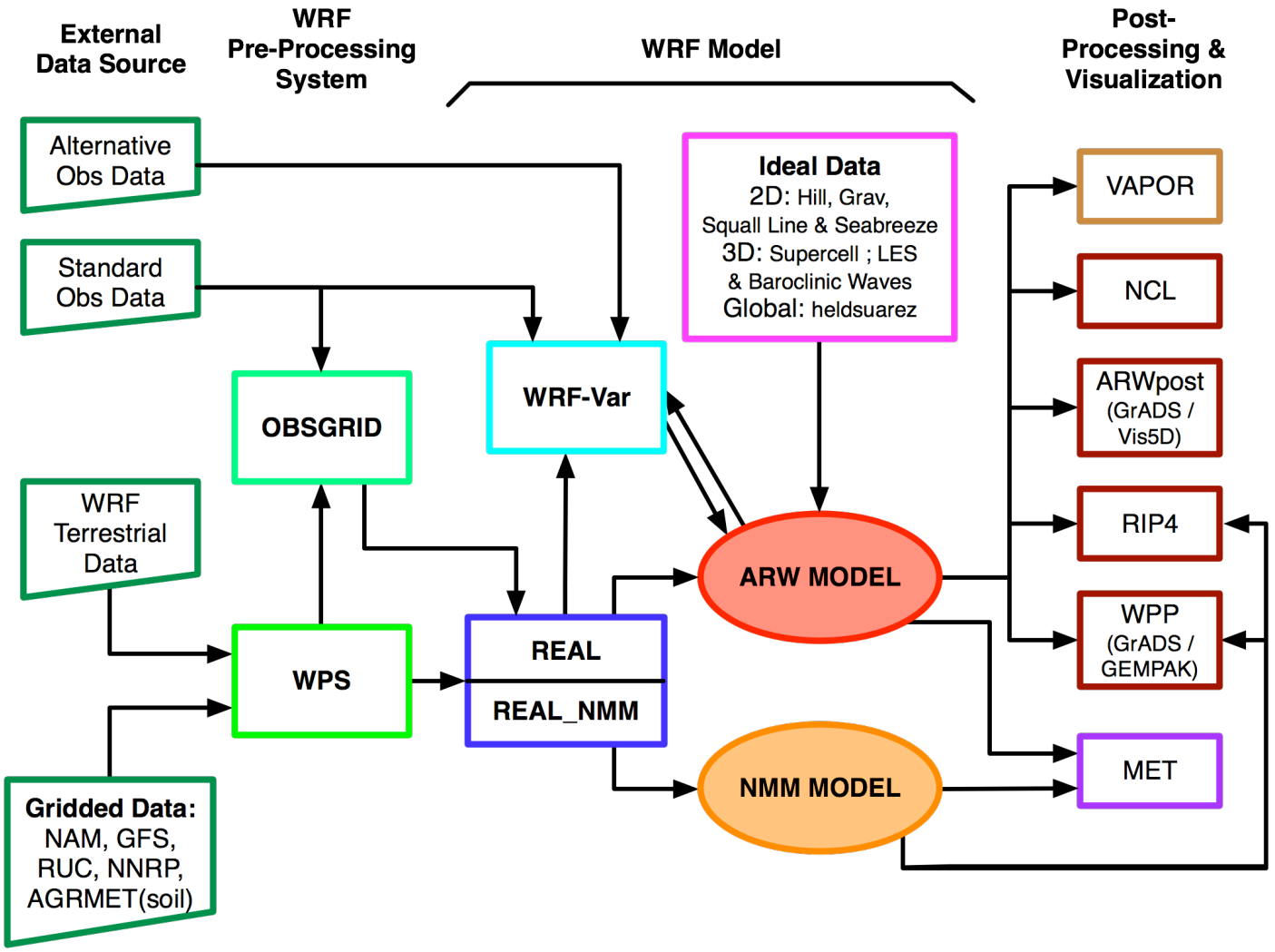
Key features:

- 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

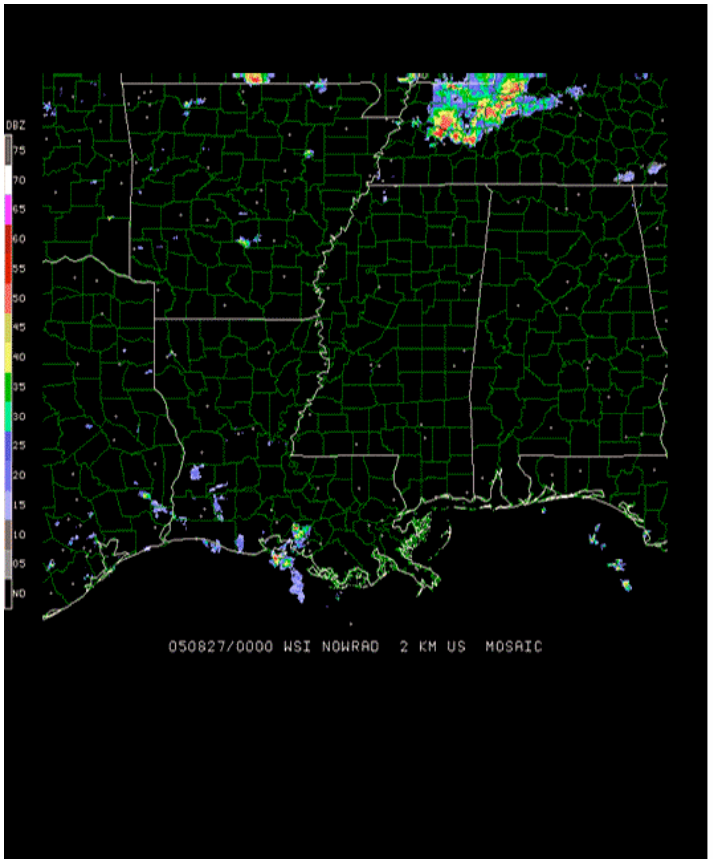
- Email: wrfhelp@ucar.edu
- User Web pages:

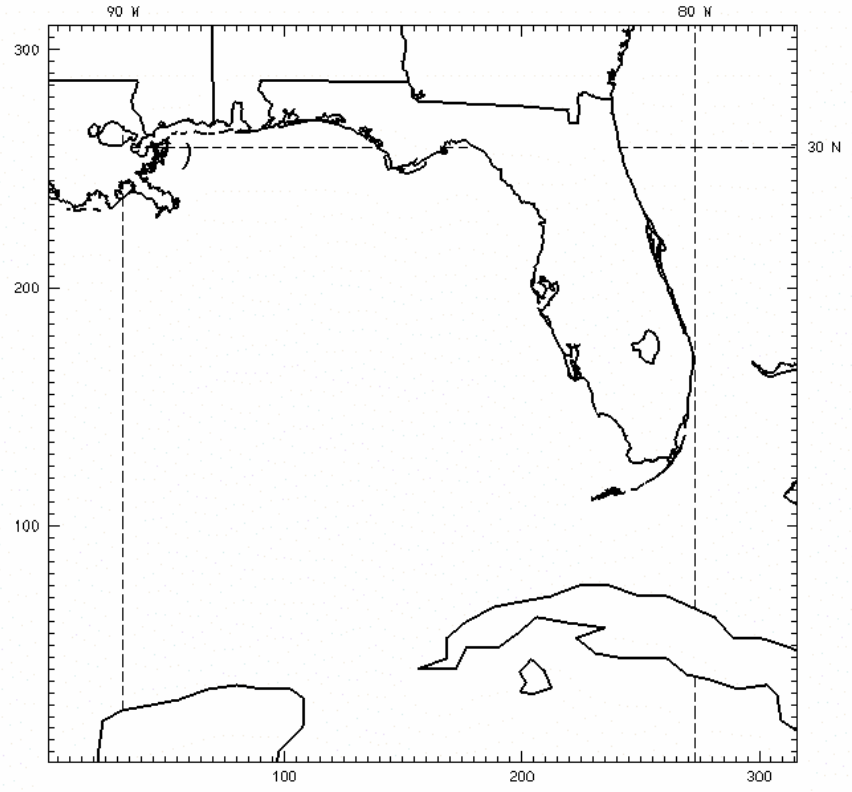
  ARW:http://www.mmm.ucar.edu/wrf/users/

  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)

Hurricane Katrina Simulation (4km)





Convective-scale Forecasting (4km)