

A Globally Relocatable Numerical Weather Prediction System Based on WRF and ADAS

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1. INTRODUCTION

We describe a globally relocatable forecast system based on the Weather Research and Forecasting Model (WRF) and the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS).

WRF is designed to improve forecast accuracy and efficiency over existing forecast models through the application of improved numerical methods and software engineering (Michalakes, 1999). In particular, its 3rd-order Runge-Kutta time differencing (Wicker and Skamarock, 2002) allows it to run at a much larger time step than existing models while generating realistic mesoscale structures (Skamarock et al., 2004).

The WRF variational data assimilation system (3DVAR) is still in its infancy, however, and does not include a cloud analysis component. Most WRF real-time forecasting applications have simply interpolated data from larger-scale operational forecast models to provide initial conditions for the forward model using the WRF Standard Initialization (WRFSI), without using observational data. For these reasons we have chosen to use ADAS.

ADAS is a mesoscale analysis tool capable of incorporating data on many different scales (Brewster, 1996). ADAS uses a Bratseth successive correction method which converges to the optimal interpolation solution. It includes a cloud analysis that utilizes surface observations, satellite, and radar data (Zhang et al. 1998). ADAS has been deployed at several sites globally (e.g., Case et al., 2002; Lazarus et al., 2002).

The forecast system is being built for the Paraguay National Center for Emergency Alerting (CAEN), which is responsible for issuing watches and warnings in that country. The system is being built by a consortium led by the International Center for Natural Hazards and Disaster Research (ICNHDR) at the University of Oklahoma (OU) and consisting of Weather Decision Technologies (WDT), the Center for

Analysis and Prediction of Storms (CAPS) at OU, and IPS MeteStar. An important consideration in the placement of the forecast domains is the hydropower and flooding potential of Paraná and Paraguay rivers, which originate in the Brazilian Highlands and the Mato Grosso Plateau, respectively (Fig. 1).

2. FORECAST SYSTEM CONFIGURATION

The analysis and pre-processing are performed in the ARPS framework using ADAS and associated tools. The resulting output is then translated into the WRF mass-coordinate framework for the forecast integration.

2.1 Observational Data

The National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS) is used for the background for the analysis as well as the lateral boundary conditions for the outermost grid.

Other data sources include:

- Rawinsondes, including special Paraguay releases;
- Surface observations, including ship, buoy, and the 26-station Paraguay mesonet;
- Infrared and visible GOES satellite data;



Figure 1. Possible WRF forecast domains for Paraguay.

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- C-band Doppler radar near Asunción.

2.2 Background Field and Objective Analysis

For the outermost forecast grid, ADAS uses for its background GFS output on NCEP grid 3 ($1^\circ \times 1^\circ$). (The inner grid is a one-way nest inside the outer grid.) The EXT2ARPS utility converts GFS to ARPS format. It utilizes data on pressure levels, within the atmospheric surface layer, and in soil layers. Fields are interpolated to the model grid points quadratically in the horizontal and linearly in the vertical.

We have enhanced EXT2ARPS so that GFS output in the atmospheric surface layer (2-m temperature and humidity, 10-m winds) is incorporated in a special manner to account for differences between GFS and WRF (and ADAS) terrain. (Previously EXT2ARPS utilized only pressure-level data.) This results in an improved interpolation near the surface, particularly where the WRF terrain lay below the GFS terrain.

This enhancement involves three steps. First, a local linear gradient of the temperature with respect to terrain is found along the GFS 2-m surface. This slope is used to reduce the 2-m temperature on the GFS terrain to the WRF terrain. Second, a least-squares gradient of temperature with height in the lowest layers of the GFS model is used to represent the near-surface lapse rate. The terrain-adjusted surface temperature combined with this near-surface lapse rate yields a profile of temperature in the boundary layer of the high-resolution model. Finally, this profile is blended with the temperatures obtained by directly interpolating the pressure-level GFS gridded data. The blending is done to ensure there are no discontinuities in the final profile.

ADAS combines observational with the GFS background in a five-pass correction with successively smaller correlation distances. Rawinsonde data are used in the first three passes, and surface data are used in the third and subsequent passes.

2.3 Land Surface Fields

Because the WRF and ARPS models use different category definitions for soil types and vegetation types, we define transformations between the ARPS and WRF categories. ARPS defines 13 soil types based on USDA definitions (Xue et al. 2001), while the WRF model uses the same 16 soil category definitions as MM5. In particular, ARPS does not have corresponding categories for silt, organic materials and bedrock that appear in WRF soil categories, and ARPS defines ice as a soil type not found in the WRF soil categories. For vegetation types, ARPS (14 categories) and WRF differ significantly. Transformation tables are constructed by comparing the physical parameters and finding the closest relationship among the variables.

ARPS soil and vegetation types are available at 30-min and 10-min resolution, respectively. In a future version the 30-sec WRF databases will be used exclusively.

2.4 Conversion between ARPS and WRF Frameworks

Conversion from the ARPS to WRF frameworks is accomplished using the ARPS2WRF utility, which was developed to utilize ADAS and other ARPS data analysis system components to improve WRF model initialization. The development of ARPS2WRF was funded primarily by the Modeling Environment for Atmospheric Discovery (MEAD) Expedition project at the National Center for Supercomputer Applications (NCSA) and the National Science Foundation (NSF).

ARPS2WRF produces both the initialization file and boundary files for the WRF model in NetCDF format, and can generate a Fortran *namelist* input file for the WRF model. ARPS2WRF software requires an ARPS history file at the initial time and lateral boundary condition files created by EXT2ARPS. It uses bilinear interpolation to convert ARPS data files to the WRF mass coordinate system. The resulting WRF data files contain the full suite of static and time-dependent data.

This process replaces the WRFSI and *real.exe* steps within the WRF system. Although options exist for mixing initialization components from both modeling systems (e.g., using of WRF surface characteristics), it is recommended that only one or the other initialization system be used to generate initial conditions for the WRF model to avoid incompatibilities.

WRF2ARPS performs the complementary task of converting WRF forecasts back to the ARPS framework for post-processing. It also converts output from the outermost grid for use on the inner grid.

2.5 WRF Execution

Forecasts are scheduled as follows:

Domain	Duration	Freq	First guess and Boundary Conds
40 km	60 h	6 h	GFS
10 km	24 h	3 h	WRF 40 km

The forecasts run on computers with dual 2.4-GHz Intel Xeon processors under the Linux operating system. Forecasts on the 40- and 10-km domains run on a total of 8 computational nodes, two of which are used for pre-processing and product generation. Computational parallelism is achieved through the MPICH implementation of the Message Passing Interface.

The forecast system control software, known as ARPSControl, is written in Perl. A Java-based forecast management tool is employed (Fig. 3; Carpenter and Bassett, 2001).

NCEP's WRFPOST utility is used to derive a suite of products from WRF's native NetCDF output and translate them into GRIB format.

For Paraguay, all data are integrated through the IPS MeteoStar Leading Environmental Analysis and Display System (LEADS).

2.6 Timing Experiments

Timing experiments with WRF and ARPS were performed using two forecast configurations, representing mesoscale-synoptic and storm-scale environments.

Sixty Intel Pentium-4 2.0 GHz processors at the Oklahoma Supercomputing Center for Education and Research (OSCER) were used to generate 84-h forecasts on a continental U.S. domain consisting of 210×128×50 grid points with a horizontal grid spacing of 27 km. WRF completed the simulation in 20% less time than ARPS and used a large time step (representing the advective, gravity wave, computational and turbulent mixing, and Rossby wave processes) about 3.3 times that of ARPS. (Both the ARPS and WRF model time step selection is under further consideration to obtain optimal performance. The theoretical ratio for the WRF to ARPS large time step constraint is approximately 2:1 and thus indicates that the current ARPS large time step is less than optimal for the given grid spacing.)

In the second configuration, a warm bubble was released in a conditionally unstable atmosphere on a grid with 2 km grid spacing (WRF *em_quarter_ss_test*). Simulations were performed on a single Pentium-4 2.0 GHz processor. The results indicate that the advantage of the more accurate Runge-Kutta scheme is reduced due to the additional computations associated with evaluating the forcing terms 3 times per time step integration. The maximum allowable large time step for the WRF was less than twice that of the ARPS and as a result, the WRF test required significantly more computational cycles to complete than the ARPS. (Note that WRF was compiled with Portland Group compiler while ARPS used Intel Fortran compiler. It is known, via tests with the ARPS model, that the Intel compiler generates more efficient code, on the order of 20%, for execution on the Intel Pentium-4 processor family. The WRF Intel Fortran option did not exist at the time of the tests.)

The WRF model has been ported to several massively-parallel computing platforms. The range of efficiency, gauged by the floating point/second rating versus the theoretical peak varies from 5-20% and from 140 Mflops to 500 Mflops for a continental US scale forecast using scalar processor technology. These performance figures are similar to other numerical weather prediction models (e.g., Eta, MM5, ARPS) but further work is needed to optimize the WRF model cores (J. Michalakes, personal communication).

REFERENCES

- Brewster, K., 1996: Application of a Bratseth analysis scheme including Doppler radar data. Preprints, *15th Conf. on Wea. Analysis and Forecasting*, Amer. Meteor. Soc., Norfolk, VA.
- Carpenter, R. L., Jr., and G. M. Bassett, 2001: Commercial application of the Advanced Regional Prediction System (ARPS). Preprints, *14th Conf. on Num. Wea. Pred.*,

Forecast Model	Continental US 27 km 84 h forecast Large time step (s) / Runtime (min)	Convective Scale Test (2 km 2 h) Large time step (s) / Runtime (s)
ARPS	30 / 167	12 / 332
WRF	100 / 130	20 / 453

Table 1. WRF and ARPS timing results.

- Amer. Meteor. Soc., Fort Lauderdale.
- Case, J. L., J. Manobianco, T. D. Oram, T. Garner, P. F. Blottman, S. M. Spratt, 2002: Local Data Integration over East-Central Florida Using the ARPS Data Analysis System. *Wea. and Forecasting*, **17**, 3–26.
- Lazarus, Steven M., Ciliberti, Carol M., Horel, John D., Brewster, Keith A. 2002: Near-Real-Time Applications of a Mesoscale Analysis System to Complex Terrain. *Wea. and Forecasting*, **17**, 971–1000.
- Michalakes, J., J. Dudhia, D. Gill, J. Klemp, and W. Skamarock, 1999: "Design of a next-generation regional weather research and forecast model," *Towards Teracomputing*, World Scientific, River Edge, NJ, 1999, 117-124.
- Skamarock, W. C., M. E. Baldwin, and W. Wang, 2004: Evaluating dissipation in NWP models using kinetic energy spectra. Preprints, *16th Conf. on Num. Wea. Pred.*, Amer. Meteor. Soc., Seattle, WA.
- Wicker, L., J. and W. C. Skamarock, 2002: Time-splitting methods for elastic models using forward time schemes. *Mon. Wea. Rev.*, **130**, 2088-2097.
- Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, D. Wang, 2001: The Advanced Regional Prediction System (ARPS)—A multi-scale nonhydrostatic atmospheric simulation and prediction model. Part II: Model physics and applications. *Meteorol. Atmos. Phys.* **76**, 143-165
- Zhang, J., F. H. Carr, and K. Brewster, 1998: ADAS cloud analysis. Preprints, *12th Conf. on Num. Wea. Pred.*, Amer. Meteor. Soc., Phoenix.

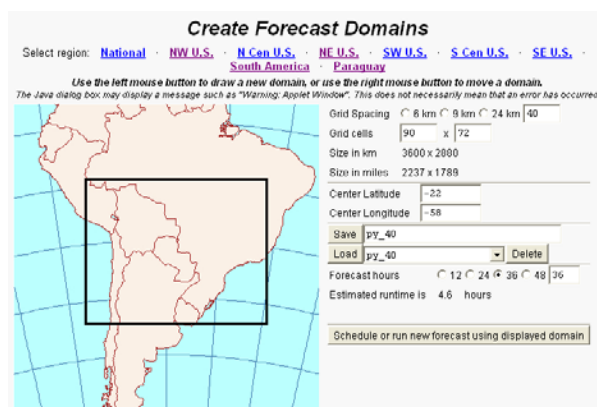


Figure 3. A Java-based forecast management tool is used to generate forecast domains.

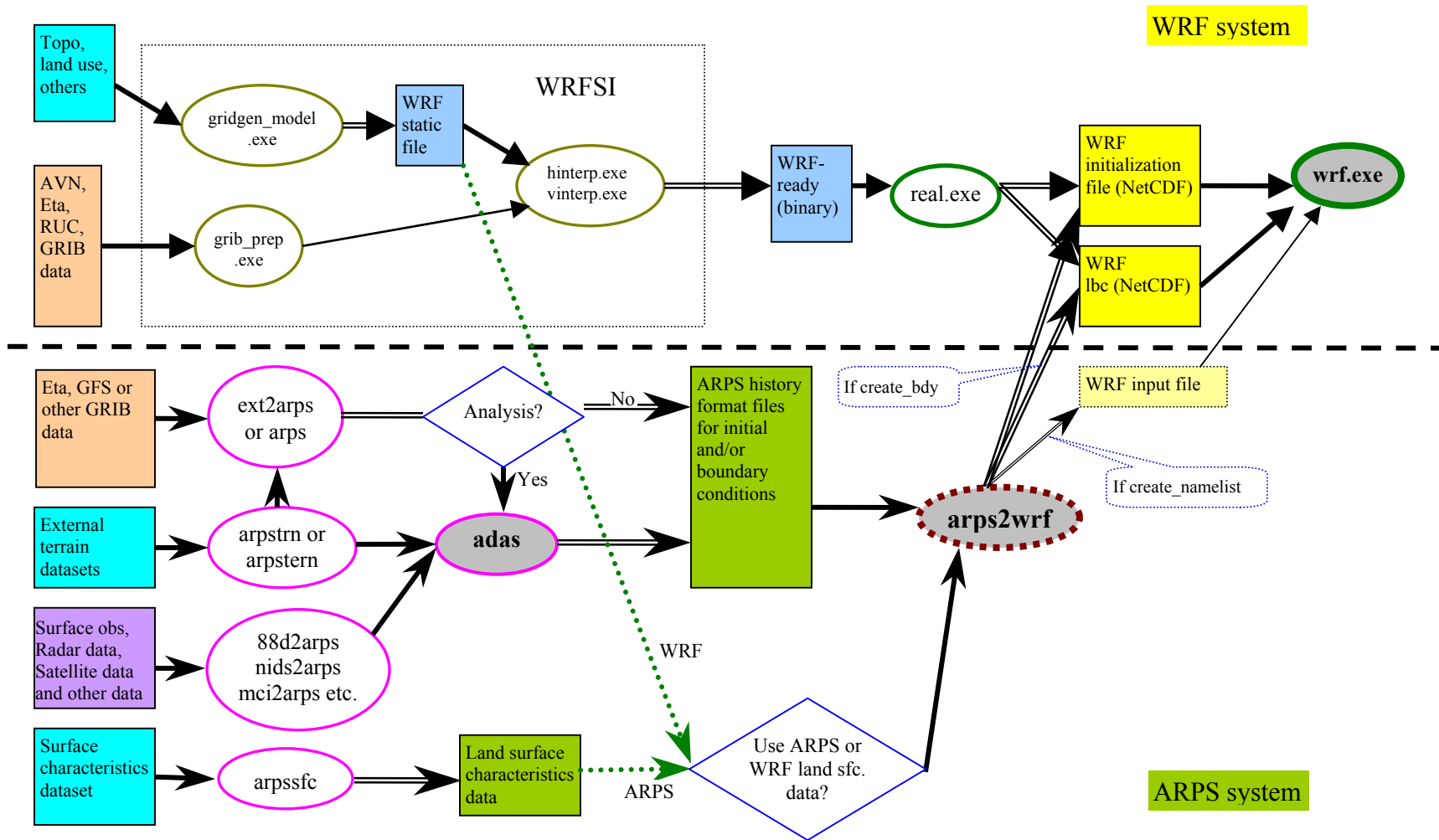


Figure 2. Methodology for utilizing ARPS analysis tools (including ADAS) for initializing WRF.