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Real-time Storm-scale Forecast Support for IHOP 2002 at CAPS

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1. Introduction

In an effort to better characterize the four-dimensional distribution of water in the atmosphere with a view toward improving our understanding of its impact on deep convection, the International H_2O Project (IHOP-2002) field experiment took place over the Southern Great Plains from 13 May to 25 June 2002. The subsequent research will address scientific issues that are very important to weather forecasting, including quantitative precipitation forecasting, convective initiation, atmospheric boundary layer processes, and the optimal use of the latest technology for measuring atmospheric water vapor.

The Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma is supported through an NSF grant to contribute to the IHOP field experiment and to study the above issues using data collected during the experiment. Particular emphasis of our work is placed on the optimal utilization and assessing the impact of water vapor and other high-resolution observations in storm-scale quantitative precipitation forecasts (QPF).

To support the real time operations of IHOP, to obtain an initial assessment of the model performance during the period and to identify specific data sets and cases for extensive study after the field program, CAPS ran the Advanced Regional Prediction System (ARPS, Xue *et al.* 1995; Xue *et al*. 2000) in real time during the entire field campaign.

2. Forecast Configurations

Forecasts were produced on three grids with 27, 9 and 3 km grid resolutions, respectively. The fine resolution grids were nested inside the coarser ones in one-way nested mode. These three grids cover the Continental US, the Central Great Plains, and the entire state of Okalahoma plus south-central Kansas and Texas panhandle, respectively (Fig. 1). We will refer to these grids as the US, SPmeso, and SPstorm grids, respectively.

The US and SPmeso forecast start from initial conditions (IC) at 12 UTC each day, and forecast for 42 and 24 hours, respectively (Fig. 2). Six-hour (06 UTC) NCEP Eta forecast fields were used as the analysis background, and the forecasts from the same Eta forecast cycle were used as the boundary conditions (BC) for the US grid. The SPmeso grid obtained its BC from the US grid. The 3 km SPstorm grid was run twice a day, starting at 15 UTC and 00 UTC. The 15 UTC SPstorm analysis used the 3-hour SPmeso forecast as the background, while the 00 UTC SPstorm forecast used 9-hour SPmeso forecast for its analysis background fields. Boundary conditions for both SPstorm forecasts were from the 12 UTC SPmeso forecast.

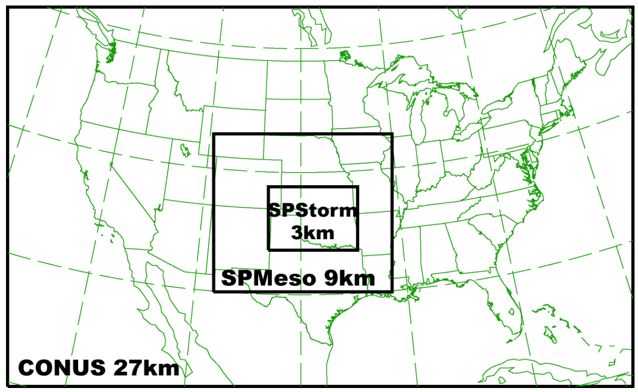

Figure 1. The 27, 9 and 3 km resolution ARPS forecast grids run during IHOP.

With the early morning start times, the first three forecasts intend to capture convective initiation processes that often occur late in the day. The 00 UTC (6 pm LST) forecast starts at a time when pre-existing convection is more likely. The goal of the 00 UTC forecast cycle is to study model initialization using radar observations of convection. We will evaluate the performance of various retrieval and diabatic initialization procedures and resulting forecasts that may include mesoscale convective systems extending into the early morning hours.

The initial conditions were produced using the ARPS Data Analysis System (ADAS, Brewster 1996). Data incorporated into the initial conditions included all available rawinsondes from the standard network and special launch soundings, wind profilers, standard surface observations, the Oklahoma and western Texas mesonet data and DOE/ARM surface observations. A unique aspect of this work is the use of broadband, Level-II data from a network of radars through the Collaborative Radar Acquisition Field Test (CRAFT, Droegemeier *et al.* 2002) project.

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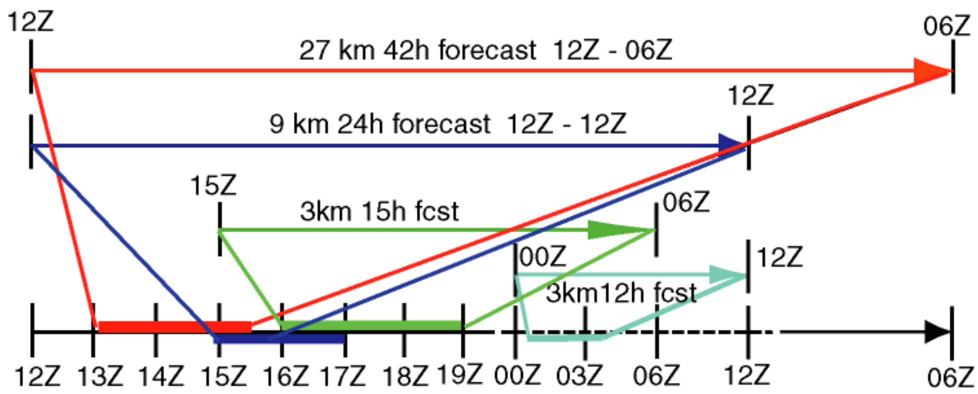

Figure 2. Forecast timeline, showing the start and end times of forecasts, and wall clock times of the operations.

Level-II data from 12 radars and Level-III (NIDS) data from 12 others in the Central Great Plains were ingested in real-time, remapped to the ARPS Cartesian grids, and used in a cloud analysis procedure (Zhang *et al*. 1998; Brewster 2002) to improve the representation of water vapor, cloud water and other microphysical variables. The IC analysis includes a diabatic adjustment to modify the temperature field in the presence of cloud and vertical motion in the initial condition. Furthermore, where Level-II data were not available, the radar data from Level-III NIDS products were used. The cloud analysis also utilized visible and infrared channel data from GOES-8 satellite and surface observations of clouds. In addition to the forecasts performed at three resolutions, hourly analyses were produced on the SPmeso grid, making use of all of the data mentioned above.

To reduce the effect of imbalances in the initial condition, an incremental analysis update procedure (IAU, Bloom *et al*. 1996) was employed for the later part of the forecast period. This procedure is particularly effective for the 3 km forecast, where the analysis background was ARPS forecast. In this case, the analysis increment is introduced over a 10-minute period into the model, minimizing oscillations that can be introduced by imbalances in the analysis.

The number of horizontal grid points for the US, SPmeso and SPstorm grids were 213×131, 183×163 and 273×195, respectively, and all grids used 53 vertical levels with the model top being placed at 20 km above sea level. The vertical resolutions range from 20 m at the surface to nearly 800 m at the top. The first scalar level, where all atmospheric state variables except for vertical velocity are defined, was about 10 m above ground. The full array of the ARPS physics package were employed, including a three-ice microphysics scheme, a new version of Kain-Fritsch cumulus parameterization scheme (except for the 3 km grid), long and short wave radiation parameterization including cloud interactions, 1.5-order TKE-based three-dimensional subgrid-scale turbulence and TKE-based PBL parameterizations, stability-dependent surface layer physics as well as a two-layer soil model (Xue *et al*. 2000; Xue *et al*. 2001). Recent improvements through validations against the Oklahoma Mesonet soil moisture measurements were incorporated into the soil model. A recently developed soil skin temperature initialization procedure that uses the Eta first guess field and the air temperature analysis was employed. The fourth-order advection and numerical diffusion options in the model were selected. The latest distributed-memory-parallel version of ARPS (Version 5.0) based on MPI was used.

The data ingest, preprocessing, analysis and boundary condition preparation were performed locally on three networked two-processor Pentium 4 Linux workstations. The model input data were then shipped to remote supercomputers at the Pittsburgh Supercomputing Center (PSC) or the National Center for Supercomputing Applications (NCSA). The three morning forecasts were run on one of the two Compaq Alpha-based clusters at PSC using 240 processors. The 00 UTC SPstorm forecast was run on NCSA's Intel Itanium-based Linux cluster, also using 240 processors. The model outputs were shipped back to local workstations and processed. Graphical products were posted on the Worldwide Web. The entire operation was automated by a sophisticated *Perl*-based control system. It is worth noting that both of the primary supercomputer systems used at NCSA and PSC were very new at the time of our forecast operations. The NCSA Itanium cluster did not enter production until April 15, 2002 and the PSC Alpha ES45 cluster also had gone into production shortly before the field program. Both systems were the first of their kind, so considerable system-wide tuning was still necessary. Our forecast operations required close interactions with the supporting staff of both centers, and such interactions significantly improved the overall timeliness of forecast during the period of operation.

As it turned out, on the PSC system, the biggest bottleneck was the data I/O. In the worst case, the job that collects ARPS outputs from individual processors and join them together into single files for the entire model domain took twice as long as the model forecast. By working closely with PSC, various strategies were tested and implemented so that the I/O bottleneck was significantly reduced. Another efficiency improvement needed was to increase the complexity to the control script so that the preprocessing of the multiple radars could proceed in parallel, and the ADAS analysis could begin when the first of the needed background and BC files arrived from the coarser grid forecasts. Continued optimization of the systems and procedures will be performed through the rest of IHOP period to further improve the overall efficiency. The operation timeline given in Fig. 2 is based on the system performance at the end of May 2002.

3. Forecast Productions

Graphical products, including fields and sounding animations, were generated and posted on the web as the hourly model outputs became available. A workstation dedicated to displaying forecast products was placed at the IHOP operation center. As part of the real time CAPS support for IHOP, a CAPS scientist was on duty daily to evaluate and assist in the interpretation of the forecast products. A web-based evaluation form was used to provide an archive of forecast evaluations and other related information. Because the IHOP field program is still in progress at the time of the preprint deadline, we will present some sample results of our real time forecasts at the conference. The forecast products are available at ***http://ihop.caps.ou.edu***, and it is our intention to keep the web products for the entire period online for at least two years to facilitate later evaluation and case studies.

4. Future Work

Because of the real time availability of Level-II radar data from a dozen radars in the region, we had initially hoped to perform single-Doppler velocity and thermodynamic retrievals using these data and analyze the retrieved data into the 3 km initial conditions. Due to the delay in the installation of two local supercomputer systems, this was not done in real time. Such work will, however, be performed in post-real time, and the impact of such data on the forecast performance will be carefully assessed. Quantitative verification against observations of the real-time forecasts as well as reruns will be conducted, with particular emphasis on QPF. Some of these results will be presented at the conference.

5. Acknowledgement

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References

Bloom, S. C., L. L. Takacs, A. M. d. Silva, and D. Ledvina, 1996: Data assimilation using incremental analysis updates. *Mon. Wea. Rev*., **124,** 1256-1271.

Brewster, K., 1996: Application of a Bratseth analysis scheme including Doppler radar data. *Preprints, 15th Conf. Wea. Anal. Forecasting*, Norfolk, VA, Amer. Meteor. Soc., 92-95.

——, 2002: Recent advances in the diabatic initialization of a non-hydrostatic numerical model. *Preprints, 15th Conf on Numerical Weather Prediction and 21st Conf on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., J6.3.

Droegemeier, K. K., K. Kelleher, T. D. Crum, J. J. Levit, S. A. D. Greco, L. Miller, C. Sinclair, M. Benner, D. W. Fulker, and H. Edmon, 2002: Project CRAFT: A test bed for demonstrating the real time acquisition and archival of WSR-88D base (Level II) data. *Preprint, 18th Int. Conf. IIPS Meteor. Ocean. Hydrology*, Orlando, FL, Amer. Meteor. Soc.

Xue, M., K. K. Droegemeier, and V. Wong, 2000: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. *Meteor. Atmos. Physics*, **75,** 161-193.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, and K. Brewster, 1995: *ARPS Version 4.0 User's Guide*. [Available at http://www.caps.ou.edu/ARPS], 380 pp.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D.-H. Wang, 2001: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. *Meteor. Atmos. Physics*, **76,** 143-165.

Zhang, J., F. Carr, and K. Brewster, 1998: ADAS cloud analysis. *Preprints, 12th Conf. on Num. Wea. Pred*., Phoenix, AZ., Amer. Met. Soc., 185-188.