AN OBJECTIVE INTER-COMPARISON OF WRF, MM5, AND NCEP ETA SHORT-RANGE QUANTITATIVE PRECIPITATION FORECASTS FOR THE INTERNATIONAL H_2O PROJECT (IHOP) DOMAIN

Brent L. Shaw
NOAA Research/Forecast Systems Laboratory, Boulder, Colorado

Affiliation: Colorado State University/Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, Colorado

1. Introduction

The International H_2O Project was conducted over the Southern Plains between 13 May and 25 June 2002. The IHOP field experiment focused on intensive measurements of water vapor and its relationship with various forecast problems such as convective initiation (CI) and quantitative precipitation forecasts (QPF). During the campaign, the NOAA Forecast Systems Laboratory (FSL) provided various real-time, experimental numerical weather prediction (NWP) grids to the IHOP operations staff. Included in the experimental set was a version of the PSU/NCAR MM5 model, initialized with the FSL-developed Local Analysis and Prediction System (LAPS, Albers et al. 1996). By providing these experimental model runs, FSL hoped to determine whether or not the LAPS-initialized models provide significant value for short-range (0–12 h) precipitation forecasts. Value added was assessed qualitatively via the use of forecaster feedback forms and quantitatively via the FSL Real-Time Verification System (RTVS, Mahoney et al. 2002).

Using lessons learned from the real-time phase of IHOP, FSL has made improvements and corrections to the LAPS diabatic initialization technique. Additionally, the new Weather Research and Forecast (WRF) model significantly matured during the period after IHOP concluded. Using the archive of observational data collected at FSL during IHOP, the LAPS analyses for the IHOP period have been regenerated and used to initialize MM5 and WRF for all 6-hourly runs between 15 May and 26 June 2002. The QPF from these simulations have been verified using RTVS for comparison to each other, as well as the operational Eta model, which was run at the same horizontal resolution.

This paper presents the results of this post-IHOP study. Section 2 provides a brief description of the LAPS diabatic initialization. Section 3 describes the various model configurations. Section 4 will presents the RTVS results, and Section 5 provides conclusions and future work.

Corresponding Author: Brent L. Shaw, NOAA/FSL, 325 Broadway, R/FS1, Boulder, CO 80305
E-mail: Brent.Shaw@noaa.gov

2. The LAPS Diabatic Initialization

The LAPS diabatic initialization, or “hot start,” technique is designed to eliminate the model “spin-up” problem with a computationally efficient and relatively simple system that does not require the complexity of four-dimensional data assimilation systems typically used for local mesoscale NWP. Details of the LAPS diabatic initialization are contained in Shaw (2001).

One of LAPS strengths is its ability to ingest a wide variety of meteorological data sets and rapidly fuse them with a gridded first-guess field to rapidly produce a three-dimensional atmospheric analysis. The IHOP configuration of LAPS included ingest of surface observations (METARs and various mesonets, including the Oklahoma mesonet), operational NOAA wind profilers, GOES data (imagery, sounder, and NESDIS derived products), WSR-88D Level-II and Level-III reflectivity and radial velocity data from multiple sites, ACARS observations, and GPS-derived total precipitable water vapor measurements.

3. IHOP Model Configurations

Version 3.5 of MM5 and 1.3 of WRF were used in this study. In the case of the WRF model, the public release "off-the-shelf" version of the model and the standard initialization were used, with only a slight modification to zero out condensate mixing ratios less than 10^{-7} kg kg^{-1}. The MM5 code incorporated an improved version of the Schultz (1995) microphysics scheme developed by and in testing at FSL, as well as some minor modifications to the model and pre-processors to allow for initialization of the microphysical arrays.

Both models used the same horizontal and vertical domain configuration, with 12-km grid spacing and 41 vertical layers. Where possible, identical physics options for the two models were used in order to minimize the differences between the configurations. A summary of the two model configurations is shown in Table 1.

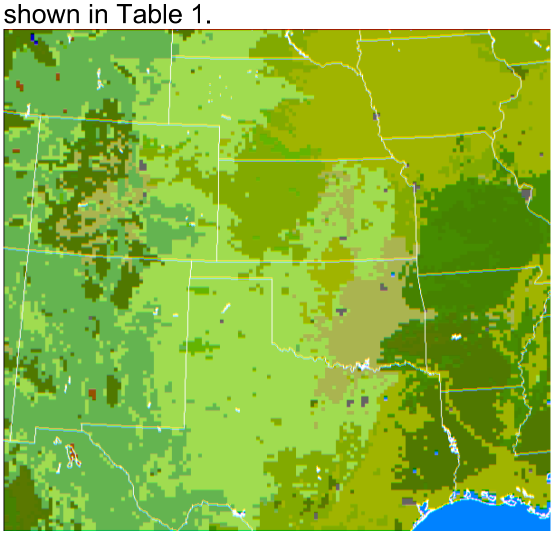

Fig. 1. IHOP MM5 and WRF model domain. Grid spacing is 12 km. Image is the USGS land categorization as prepared by the WRF standard initialization package.

In addition to the changes to the LAPS initialization procedure implemented after IHOP, the configuration of MM5 was also changed for the post-IHOP simulations. First, the updated Schultz microphysical scheme discussed earlier was not available in the original real-time runs. Second, the Kain-Fritsch convective parameterization was used in the original real-time runs, but not in the post-IHOP phase. Subjective feedback from many forecasters and FSL staff during the past few years has indicated that for mesoscale NWP forecasts using grid spacing near 10 km, more realistic precipitation forecasts are generated when only using the explicit microphysics. The side effect of not using the parameterization is that simulated convection often initiates later than reality and can become more intense than observed.

Table 1. IHOP Model Configuration

	MM5 v3.5	**WRF v1.3**
Grid Spacing	12 km	12 km
Horiz. Dim	151 x 139	151 x 139
Vertical Dim.	42 levels	42 levels
Timestep	30 s	50 s
Solver	2^{nd} order leapfrog with time splitting	3^{rd} order Runge-Kutta EM core
Microphysics	Schultz II	NCEP 5-class
Conv. Param.	None	None
Sfc. Phys.	5-Layer	5-Layer
PBL Phys.	MRF	MRF
LW Radiation	RRTM	RRTM
SW Radiation	Dudhia	Dudhia

4. RTVS Results

Fig. 2 shows the ESS and bias scores for the 3-h, 6-h, and 12-h accumulation periods for all three models. Note that RTVS employs event equalization, so these statistics were computed only for model cycles where all three model runs were available, using the exact same set of observations. Furthermore, since all three models were running at the same horizontal spatial resolution, the resulting numbers are as fair of a comparison that can be done with traditional ESS and bias QPF scores.

For the very 3-h forecast period, MM5 and WRF performed equally well, with perhaps a very slight advantage with the MM5. Because the LAPS diabatic initialization has the most influence during the earliest hours of the forecast and the LAPS cloud analysis is better tuned for the MM5 Schultz microphysics, it is not surprising MM5 might have a slight advantage over the WRF during this portion of the forecast. However, the advantage is very slight and likely not statistically significant. What is significant, however, is the clear improvement in QPF from both the MM5 and WRF compared to the operational Eta forecasts. For ESS, this advantage is demonstrated for all thresholds, but the greatest advantage is for the highest thresholds (greater than 0.50 in), where the Eta had no forecast skill for the 3-h time frame.

As forecast length increases to 6-h and 12-h, both MM5 and WRF maintain their QPF skill advantage over the Eta, although the advantage is reduced compared to the 3-h forecast, particularly for the lower thresholds.

MM5 and WRF have similar skill, but by the 12-h point the WRF begins to show an advantage for the higher threshold amounts, largely because of a better bias score than MM5, which appears to have increasing bias with forecast length.

Another interesting feature shown in these statistics is the difference between the models with regard to the characteristic of the bias score as a function of threshold. For all forecast periods, the Eta has a high bias for the low thresholds and a low bias for the high thresholds. For MM5 and WRF, the bias values are low for all but the highest thresholds. The original real-time MM5 runs (not shown) had a bias curve more similar to the Eta, with the exception that the bias increased with time. It is hypothesized that the Eta bias values are a result of using a convective parameterization, which tends to reduce atmospheric instability by releasing areas of light precipitation. This tends to reduce available moisture for future more intense convective cells, causing a low bias for the high thresholds. In the explicit models, more instability is required to generate the precipitation, such that when it finally develops in the simulation, it tends to be more intense. This would lead one to believe that the decision to utilize a current-generation convective parameterization for these grid scales is largely a function of whether one is more concerned with forecasting all of the events with the best overall accuracy or whether capturing the most intense events is most important.

5. Conclusions and Future Work

The results of this inter-comparison show that it is possible to provide improved short-term QPF using either MM5 or WRF initialized with LAPS compared to the current operational Eta initialized with the Eta Data Assimilation System (EDAS). Despite the more sophisticated 3DVAR and cycling scheme used by the Eta, it would appear the advantage of having radar and satellite imagery within LAPS provides enough benefit to offset the relative simplicity of the diabatic initialization.

It is also readily apparent, at least for QPF, that the WRF model has reached a state where it is producing results equal to or better than the MM5 model, an important point for the general mesoscale modeling community as NCAR support for MM5 begins to wane in favor of ramping up support for WRF. As WRF continues to mature, the question for operational NWP applications will be whether or not the forecast quality improves enough to justify the longer run time of the WRF, compared to MM5 and Eta.

These results also tend to counter the common NWP philosophy that one must use a convective parameterization when the grid spacing is 10 – 20 km. However, at least with the current generation of parameterization, this may not be true if the goal is to capture the more intense events.

The archive of IHOP data available at FSL, along with the scripts developed to streamline the LAPS and model rerun provides an excellent resource to test various mesoscale model configurations and verify QPF performance. In the future, we hope to use these data to test new version of WRF, new microphysics packages, and changes to the LAPS diabatic initialization.

6. References

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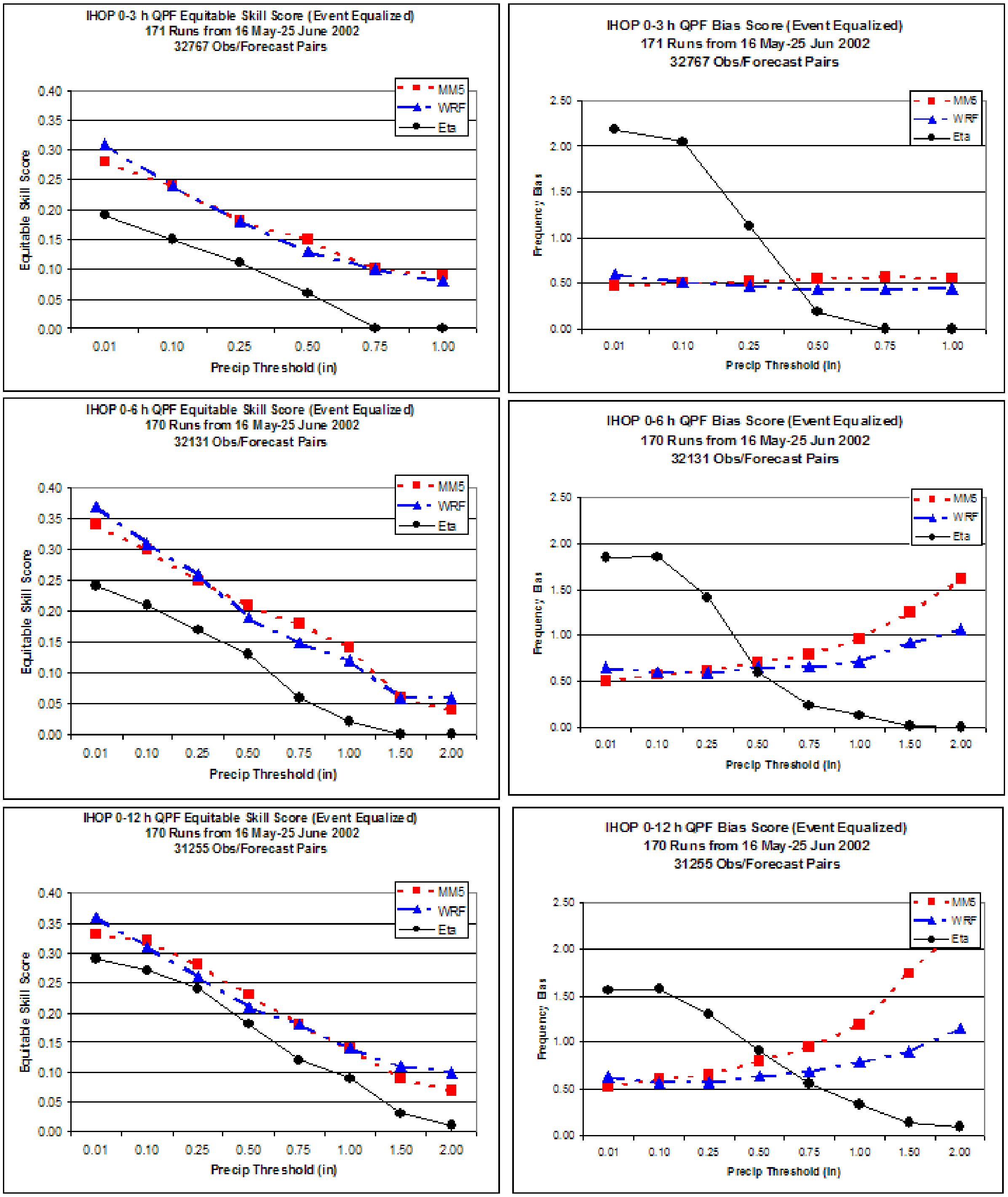

Fig 2. ESS (left column) and frequency bias (right column) for the 3 (top), 6 (middle), and 12-h (bottom) QPF from MM5, WRF, and Eta.