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Assessment of the RUC10 forecasts of storm initiation during IHOP

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Abstract. RUC 10 numerical model forecasts of quantitative precipitation are compared to detailed observations collected during the IHOP-2002 field experiment. Approximately two-thirds of the time the model is able to forecast the initiation of convection but frequently the precipitation is offset both in space and with time. The model does best in predicting the initiation of precipitation associated with cold fronts and the worse in predicting precipitation associated with smaller scale convergence boundaries. While the model is usually able to forecast the general structure and orientation of the initial convection, it is unable to predict the subsequent motion and evolution of the precipitating systems.

1 Introduction

The purpose of this paper is to examine the ability of an operational numerical model with very-short period prediction capabilities (3 and 6 h) to forecast the initiation and evolution of convective precipitation. The chosen model is the 10 km version of the Rapid Update Cycle (RUC10). This high resolution version of the operational 20 km RUC was run specifically by the NOAA Forecast System Laboratory (FSL) for the International H_2O Project (IHOP_2002). Readily available were three and six hour forecasts that were issued every 3 h. A primary objective of the International H_2O Project (IHOP_2002) was to better understand and predict the processes that determine where and when convective storms first form (Weckwerth et al., 2004).

A companion paper in this conference (Wilson and Roberts, 2004) identifies and assembles statistics concerning the initiation and evolution of all convective storms during all 44-days of the experiment. This present paper investigates the ability of the RUC10 to forecast the identified initiation episodes and stratify the results using the established forcing mechanism of the initiation episode. Also examined is the ability of the RUC10 to capture the evolution of the 11 most significant (size, intensity and organization) convective events.

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2 Data

The initiation episodes are based on data from 11 radars with overlapping coverage for the 650×650 km study area that covers portions of Kansas, Oklahoma and Texas (see Fig. 1 in Wilson and Roberts, 2004). An initiation episode is the initiation of a group of convective cells (cell must cover an area of at least 4 m^2 of >40 dBZ) that initiate closely in time and space and are not nearby existing storms. Thus the episodes are new initiations that are not caused by updrafts or downdrafts from existing storms. A total of 109 initiation episodes were identified. The number of cell initiations in an episode varied between 2 and 55 and the duration of an episode varied between 20 and 200 min.

Comparisons are made between the RUC10 6 h (3 h) forecasts of convective precipitation accumulation and radar reflectivity. The accumulation forecasts are for a three hour period 3–6 h (0–3 h) after forecast time, whereas, the radar reflectivity are instantaneous fields available every 10 min. While these are far from equivalent, comparisons are still informative.

3 Model description

The RUC is an analysis-forecast numerical model which is routinely run at the National Centers for Environmental Prediction (NCEP). It is described in detail in Benjamin et al. (2004a, b); we offer here only a brief description. The RUC is an advanced version of the hydrostatic primitive equation model developed by Bleck and Benjamin (1993). It is unique among operational numerical weather prediction models in two primary aspects: its hourly forward assimilation cycle and its use of a hybrid isentropic-terrain-following vertical coordinate for both assimilation and forecast model

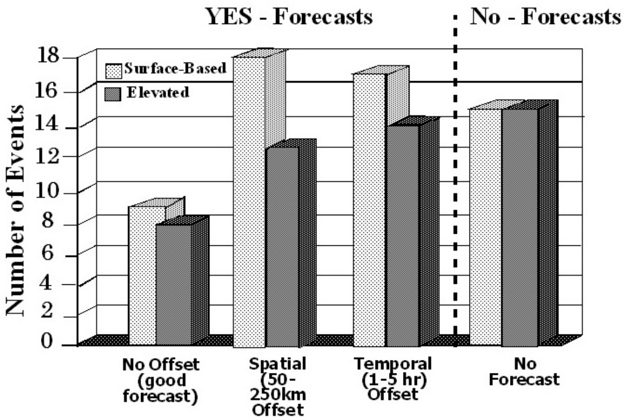

Fig. 1. Performance of the RUC10 3 h forecasts of convective precipitation to predict the storm initiation episodes. The cases are divided into elevated and surface based initiation. No means no precipitation forecast; the yes forecasts are sub-divided by the degree of time and space error.

components. The convective parameterization scheme is based on an ensemble approach described by Grell and Devenyi (2002).

During IHOP the RUC10 ingested a number of special data sets including mesonets (like the Oklahoma mesonet), profilers (including RASS), integrated precipitable water from GPS sites, satellite cloud drift winds, VAD winds from Doppler radar and winds and temperatures from commercial aircraft. In addition empirical methods were used to adjust relative humidity at model grid points based on the presence or not of satellite observed clouds. This can aid the initiation of convective precipitation at grid points where there is positive CAPE (Benjamin et al. 2004b).

4 Initiation Results

Model performance assessment was done by overlaying the initiation episode contour onto the RUC precipitation forecast fields valid for the initiation episode time period or very close to that time period. For example, for an initiation episode on 15 May (Initiation time = 19:00–22:00 UTC), the 3 and 6 h forecast fields valid at 1800 and 2100 UTC were examined to determine if the model forecasted new precipitation within or in the vicinity of the initiation episode contour zone. Spatial coverage, orientation and offset (distance and direction) of precipitation from the initiation zones were noted. Additional forecast time periods surrounding the initiation time period (e.g. 15:00 and 00:00 UTC) were also examined to document any timing errors in the forecasts. As discussed in Sect. 2 the RUC10 forecasts are for 3 h accumulations. For example the 6 h forecast for 12:00 UTC is a forecast for an accumulation for the period from 09:00 to 12:00 TC. Since the initiation episodes are also for a time period (ranging between 20 and 200 min) the discrepancy was not felt to be a significant factor. Only a small portion of the

Table 1. RUC 10 model performance statistics.

Initiation Mechanism	No. of Events	% Time Precip. Fcast	% Time Precip. too large	% Time Fcast is late
Fronts	23	83	40	30
Surface Lows	4	100	75	25
Elevated (frontal)	11	83	56	56
Elevated (isolated)	39	68	35	35
Convergence Boundaries	32	62	40	50

tendency for the RUC10 to over-forecast the extent of precipitation could be contributed to the fact the RUC10 forecasts are 3 h accumulations and not instantaneous precipitation rates.

Figure 1 shows the performance of the model in the 3 h prediction of storm initiation for all of the episodes, stratified into surface-based and elevated categories. A plot of the 6 h forecast performance (not shown) showed a similar distribution of yes/no forecasts. Failure of the model to predict the initiation of precipitation for an episode was tabulated as a "no" forecast episode. While two-thirds (62%) of the time the model was able to forecast the initiation of a convective storm episode (see "yes" forecasts in Fig. 1) closer examination shows that only 25% of the "yes" forecasts episodes (15% of all episodes) were good forecasts in time and space. A good initiation precipitation forecast is one that had $<$50 km spatial or $<$1 h temporal offsets relative to the initiation episode. The majority of the time the RUC10 had difficulty in producing precipitation in the correct area for the correct time period. Note also that there was no preferential bias in the ability of the model to predict precipitation initiation for the surface-based versus elevated episodes; an unexpected result.

Comparison was made of the model forecast performance relative to the different initiation mechanisms (see Table 1). It is clear that the model does the best job predicting storm initiation (19 out of 23 episodes) when the initiation mechanism is associated with a frontal boundary. But in a large percentage (40%) of those forecasts, the area of the forecasted precipitation is 2–4 times too large compared to the storms that actually occur and the model had difficulty in dissipating the precipitation with time. The model was able to predict storm initiation for all 4 surface low pressure episodes but similar to the frontal episodes, the forecasted spatial coverage was 3 times too large. Taking into consideration that the model forecast is a 3 h accumulation and the radar is a series of instantaneous precipitation image throughout the initiation episode we still conclude that there is a tendency for the model to often over-forecast the area of precipitation. While it would be less obvious in a 3 h accumulation we noted a lack of realism to the precipitation structures. For example the model did not replicate the spiral band structure

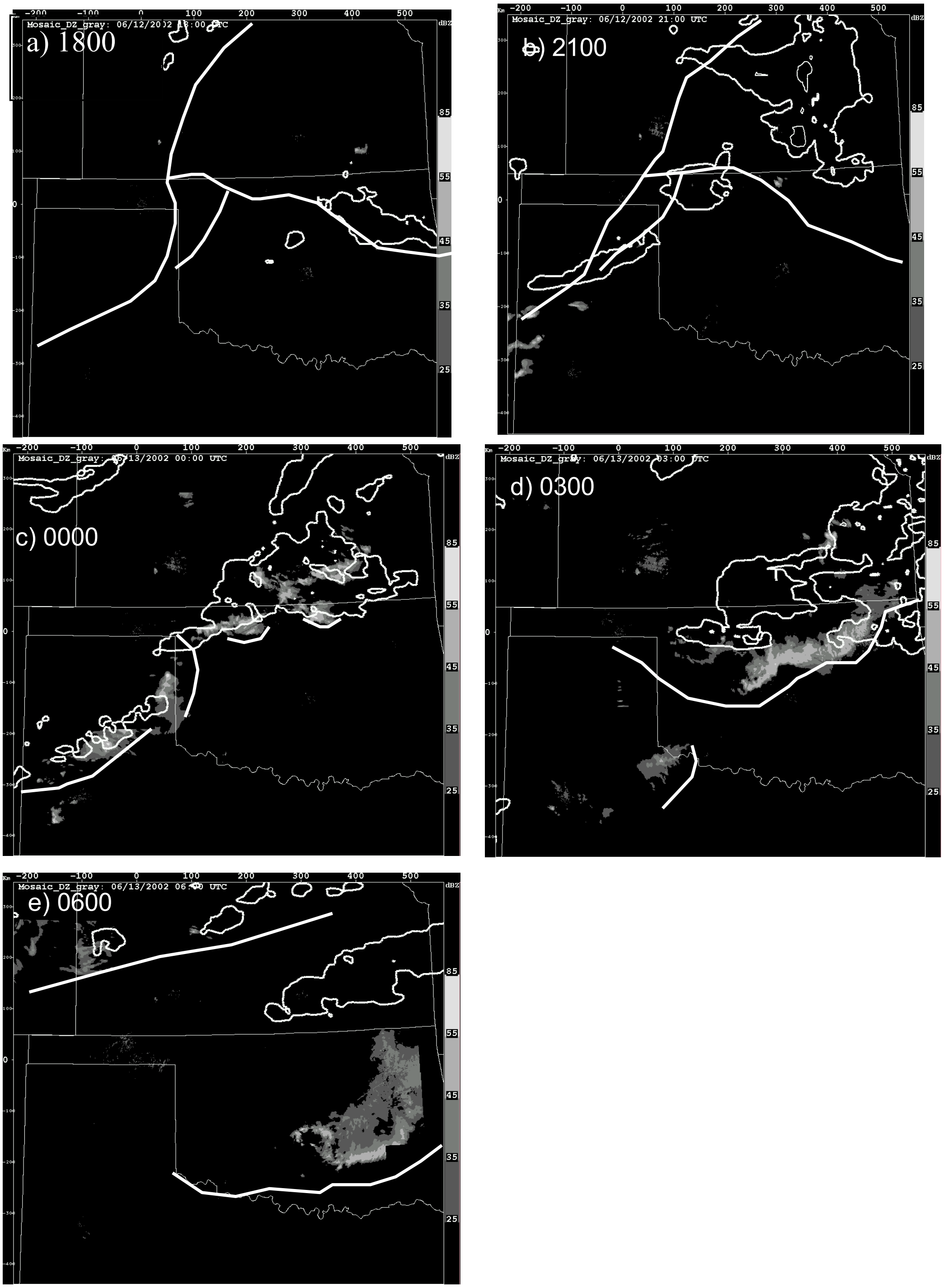

Fig. 2. June 12–13 RUC 6 h precipitation forecasts (solid white contour) overlaid on radar reflectivity (gray shade scale in dBZ on right) at 3 h intervals (a–e). The forecasts are 3 h accumulations ending at the given time. The reflectivity is the instantaneous field at at the given time. The first precipitation contour represents an accumulation of 1 mm during the 3 h period; the second contour (only reached in b) is 10 mm. Boundaries are shown by thick white lines.

of the precipitation evident in 3 of the 4 surface low pressure episodes. Inaccurate representation of detailed precipitation structure was not confined to surface lows alone; rather it was a common problem observed in forecasts associated with all categories of triggering mechanisms. Thus, even though the model was run on a higher resolution (10 km) grid, it appeared that realistic precipitation structures were frequently absent and likely a result of limitations in the cumulus cloud and boundary layer parameterization schemes (personal communication, Steve Weygandt and John Brown of FSL).

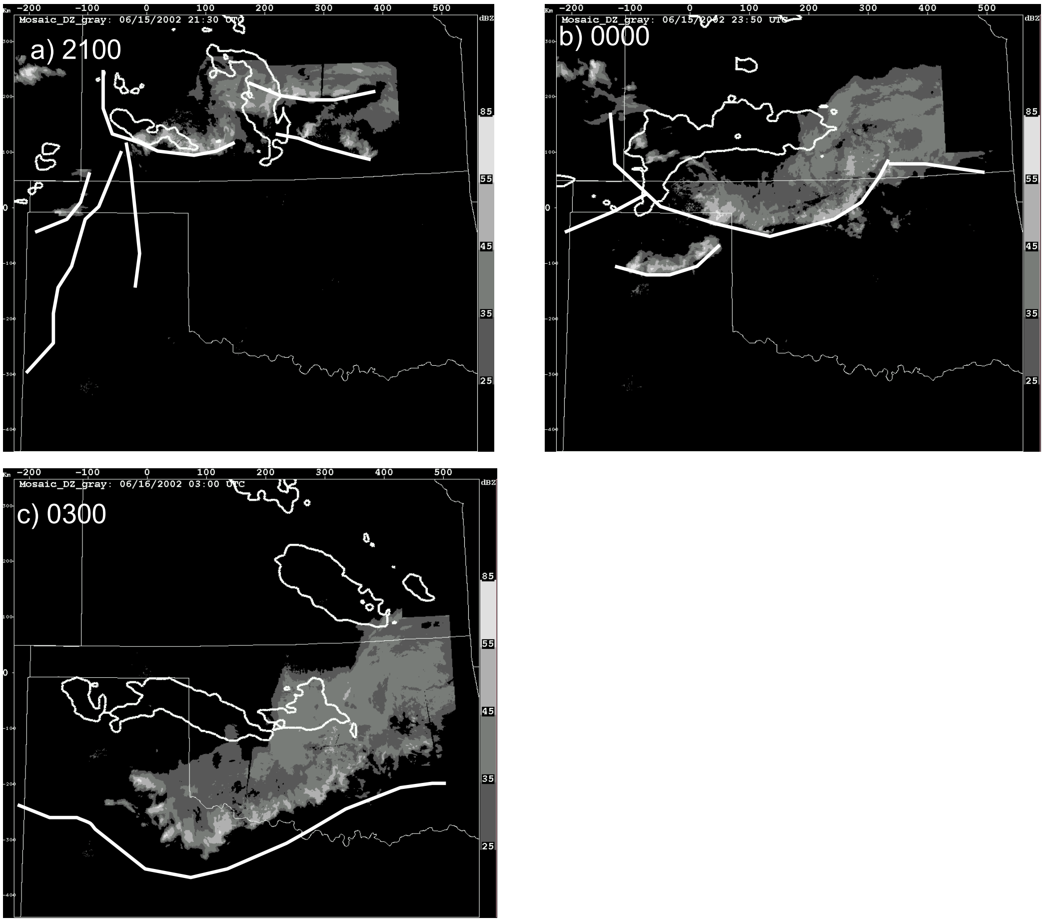

Fig. 3. Same as Fig. 2 except for 15–16 June.

Elevated episode are divided into two categories in Table 1: those that are related to frontal boundaries and isolated events. While it is encouraging that the RUC10 forecasts storm initiation for 83% of the elevated-frontal episodes, this result is likely misleading as most of these precipitation regions are connected to precipitation forecasts that are associated with surface based forcing along the fronts. Thus it is not clear if the model is actually able to discriminate and forecast precipitation caused by surface based frontal forcing versus elevated processes near a front.

The model predicted precipitation for 68% of the isolated-elevated episodes. However, a third of these forecasts ranged from 1–5 h late suggesting that the model was introducing precipitation into the forecast only after it was observed. The observational studies in Wilson and Roberts (2004) noted there was convergence between 900 and 600 mb in two-thirds of these cases in the RUC wind analysis. The RUC did successfully forecast precipitation in 20 of these 23 cases. However, as mentioned above the forecasts were often late (10 of the 20 were late).

Gust fronts, dry lines, trough and boundaries of unknown origin were all lumped together into the Convergence Boundary category in Table 1. Thus, this category contains a wide spectrum of scales. Of the 18 events (62%) that had valid forecasts from the model, half of these forecasts were 1–5 h late. Strictly speaking, that means that only 25% of the 30 episodes had good, timely forecasts from the model.

In summary the RUC10 correctly forecast storm initiation for 62% of the convective storm initiation episodes; however, only 25% of these were accurate in space and time. The most successful initiation forecasts were along fronts (83% correct), although there was a tendency for the area coverage to be too large. The ability of the model to forecast the initiation of elevated convection was uncertain. First, it was not apparent whether it could distinguish between surface based initiation along a front and elevated initiation behind the front. In other cases the forecasts were often late by 1–5 h so it was unknown if the initiation was triggered by the observation of its occurrence.

5 Evolution of the 10 most significant systems

The 10 most significant convective systems that evolved from the initiation episodes were examined in relation to how the RUC handled the evolution. Significance was based on size, intensity and organization. These storm complexes had almost continuous lines of storms >40 dBZ with lengths from 350 to >800 km. There were four cases where the forecasts could be considered mostly a failure in that either nothing was forecast, the forecast for initiation was 6–24 h too early or the system was immediately dissipated. For the other six cases the RUC generally captured the initiation but once the gust fronts developed and the system propagated with the gust front the RUC failed in all but one case to move the precipitation. The case of 24–25 May demonstrated this behavior of the RUC particularly well. The northern part of the line did not develop a gust front while the southern part did. The RUC forecast position for the northern portion was good while for the southern portion it did not capture the accelerated eastward propagation caused by the gust front. Two examples are presented in Figs. 2 and 3 for the cases of 12–13 June and 15–16 June respectively that are representative of the RUC handling of the initiation and propagation phases.

6 Conclusions and Implications

The RUC10 3 h convective precipitation forecasts were able to correctly forecast precipitation for 62% of the initiation episodes given a tolerance of 50 km in space and 1 h in time; if no tolerance is allowed 15% were correct. The ability to forecast surface based and elevated initiation associated with fronts is somewhat better than for the non-frontal boundaries and elevated initiations. Particularly for the larger better organized squall lines the RUC10 frequently had the wrong motion. This is undoubtedly because the motion of the squall line was influenced by the gust front and the model failed to produce a sufficient gust front. This is a likely problem for nearly all models.

Given the observed importance of gust fronts and their characteristics on the evolution and motion of the initiated storm complexes it is essential for very short period forecasting models to anticipate which storms will produce gust fronts and their characteristics; this is a major research challenge for observational and numerical model scientists. Precipitation microphysics probably plays a key role in determining the timing and characteristics of the downdraft and associated gust front. This suggests that particle type and drop size distributions derived from polarimetric radar should prove a profitable avenue for research.

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