MODEL RESOLUTION DEPENDENCE OF SIMULATIONS OF EXTREME RAINFALL EVENTS

John W. Nielsen-Gammon* and John Strack
Texas A&M University, College Station, Texas

1. INTRODUCTION

One of the major remaining challenges in short-range weather forecasting is the accurate forecasting of extreme rainfall events, defined here as precipitation rates exceeding 300 mm (one foot) per day. Many factors probably contribute to the failure of NWP models, but one factor is likely to be model resolution. Most extreme rainfall events either develop mesoscale organization or involve a complex interaction between convection and topography, and both processes are sensitive to model resolution. Conventional NWP models operate at effective resolutions of between 10 km and 80 km, and therefore must parameterize convection. This may make a realistic simulation of the special combination of circumstances which come together to produce flash floods difficult, if not impossible.

Even if the models were to be run at high resolution with explicit convection, it is not clear to what extent they would converge to a particular solution, let alone the correct one. Most research studies of systems producing heavy rainfall test only one or two resolutions, making it impossible to say whether the numerical simulations are stable or well-behaved. One recent two-dimensional study by Weisman et al. (MWR 1997) tested a wide range of resolutions and concluded that the simulation of an idealized squall line converged to a particular solution once the resolution was reduced to 4 km and below.

The purpose of this study is to determine the sensitivity of mesoscale simulations of extreme rainfall events to grid resolution. Rather than only using two or three resolutions, we use a range of resolutions that include both parameterized convection and explicit convection. The overall goal of our research is to determine what technological improvements (observations, analyses, and simulations) would lead to improved forecasts of extreme rainfall events.

2. EXPERIMENTAL DESIGN

We use the Penn State-NCAR Mesoscale Model (MM5V2.11), configured with 36 vertical levels. Since we are interested only on the resolution dependence of the simulations, we use the model “out of the box”, with the Blackadar PBL, Goddard microphysics, and initial conditions taken from global NCEP analyses and supplemented by rawinsonde observations. The Betts-Miller parameterization of convection was chosen because of our favorable experience with its performance in summertime onshore flow situations in the southern United States; its use is also justifiable on philosophical grounds, given the nature of the rainfall events. Both the Betts-Miller and Kain-Fritsch parameterizations produced poor forecasts at 36 km resolution.

Simulations were conducted on four events; three will be summarized here. The Southeast Texas flood of October 1994 produced up to 850 mm of rainfall, including as much as 500 mm of rainfall in a six hour period. The Del Rio, Texas flood of August 1998 was associated with the remnants of Tropical Storm Charlie. Between 0000 UTC and 0800 UTC on August 24, two separate episodes of heavy rain struck the Del Rio area, producing about 400 mm of rain at the Del Rio Airport. Finally, the Southcentral Texas flood of October 1998 produced up to 800 mm of rainfall in a 24-hour period and caused reconsideration of many 500-year flood levels.

Simulations were conducted with a variety of resolutions and nesting configurations, with parameterized convection (36 km, 18 km, 12 km, and 9 km) and with explicit convection (9 km, 6 km, and 4 km).

---

*Corresponding author address: John W. Nielsen-Gammon, MS 3150, Texas A&M University, College Station, TX 77843-3150; e-mail n-g@tamu.edu

3. POINT AND AREAL-AVERAGE COMPARISONS

Differences among precipitation forecasts can be caused by a variety of mechanisms, such as position differences, amount differences, and differences in detail. We employ a variety of measures in order to differentiate among the simulations.

In terms of the overall precipitation production of the various simulations, the 36 km forecast appears to be deficient, producing less rain than any of the higher-resolution simulations. While the parameterized runs converge on a particular amount of rainfall production as resolution increases, the explicit runs produce more precipitation and the amounts increase with decreasing resolution, with no evidence of convergence toward a solution even at 4 km.

The peak amount of precipitation within any individual grid box automatically favors higher resolution simulations with higher peak accumulations. Surprisingly, the 9 km parameterized run sometimes produced lower peak amounts than the 12 km or 18 km runs, suggesting that the performance of the parameterization is being compromised as the resolution decreases. The explicit run at 9 km also seems to produce anomalously low peak rainfall totals compared to other resolutions. The explicit runs again have increasing precipitation totals with decreasing resolution. Total amounts are similar to or higher than observed rainfall totals.

4. SPATIAL VARIATION OF PRECIPITATION

As resolution increases in the runs with the Betts-Miller convective parameterization, finer-scale details become apparent, but the overall pattern tends to remain unchanged from the 36 km run. Indeed, a greater difference is found between the 9 km explicit and Betts-Miller runs than between the Betts-Miller 9 km and 36 km runs. The explicit runs have somewhat narrower bands of precipitation. Also, the details are different in character, with a tendency for localized areas of high precipitation. This tendency, which is most pronounced in the 4 km run, appears to be consistent with the observed precipitation patterns as determined from rain gauge and radar data. These localized maxima were not tied to orographic features, and appear to be a consequence of the convective environment. So while the overall distribution of rainfall is not noticeably improved with the higher-resolution simulations, the high-resolution runs do appear to provide useful information on the peak point totals and the small-scale variability of precipitation.

An exception to the above characteristics occurred in high-resolution simulations of the Southeast Texas flood. Near the southern boundary of the inner domain, a single bull's-eye appeared with precipitation totals approaching 1500 mm. This feature is deemed to be artificial and a consequence of the combination of one-way nesting and the transition from parameterized convection to no parameterization. No such bull's-eye was found in a test with two-way nesting.

How might the high-resolution simulation information be used to provide flash flood guidance? One possibility would be to graph a time series of the peak three-hour precipitation totals within the domain. This sort of product is likely to be more useful in this situation than a succession of three-hourly maps of accumulated precipitation, since the specific locations of peak rainfall are not necessarily reliable.

An alternative method we are exploring is to graph the accumulated precipitation amounts against the fraction (or area) of the domain receiving at least that amount. This sort of product does not include spatial or temporal information, but it would allow a forecaster to quickly determine the peak basin-averaged precipitation amounts according to the numerical forecasts. Based on our results, we expect high-resolution numerical models to be more likely to accurately simulate the peak amounts of precipitation than the location of the peak amounts when the event is not strongly orographically forced.

5. SUMMARY

Simulations of three extreme rainfall events in the southern United States suggests that high-resolution explicit runs are needed to successfully simulate the extreme rainfall rates. Further, it seems possible for useful information to be obtained from the high-resolution simulations despite the lack of high resolution data for initialization. Finally, resolution improvements alone are not sufficient to permit adequate forecasting of the location of extreme rainfall, although they may be adequate in some circumstances for forecasting peak amounts.

For the Betts-Miller parameterization, little or no benefit is found for reducing the grid spacing below 18 km. With no cumulus parameterization, a grid spacing of 6 km or smaller is necessary for these events to be consistently simulated.