P2.6 USING A PERTURBATION METHODOLOGY IN A MESOSCALE ATMOSPHERIC MODEL TO ASSESS THE VARIABILITY OF A FLASH FLOOD RAINFALL AMOUNT IN A WATERSHED UNDER CURRENT CLIMATE CONDITIONS

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1. INTRODUCTION

There is considerable uncertainty about the frequency and intensity of extreme events under current climate conditions, especially rainfall amounts that can produce severe flash flooding. On 23 November, 1996 Coffs Harbour, a city on the Australian east coast with a population of approximately 30,000, experienced a flash flood following intense, short duration rainfall rates in excess of 100 mm/hr. Speer and Leslie (2000) carried out a series of quantitative precipitation forecast (QPF) model simulations that provided the motivation for this study, namely, to estimate extreme precipitation totals over the Coffs Harbour Creek catchment.

In Australia, the frequency and intensity of rainfall have been assessed for locations where rainfall gauges have long been in place (Bureau of Meteorology, 1987). Locations with long-term reliable rainfall records are predominantly clustered around population centres. However, rainfall that can cause an extreme flash flood in or close to a population centre often originates from data sparse regions upstream of the main impact area. Such areas may be as close as ten kilometres or less from the area affected.

Intense rainfall is focussed by processes also acting on small horizontal scales. In the case of the November 23, 1996 flash flood that affected Coffs Harbour, a 24 hour rainfall total of 168 mm was recorded at Coffs Harbour Airport. The airport is closer to the coast than is the city, being less than one kilometre from the ocean. In contrast, at two locations just three to four kilometres further west on higher ground, 24 hour totals exceeded 500 mm. In this study our main aim is to quantify the maximum possible rainfall totals over the catchment, within the accepted range of values of key variables. For Coffs Harbour, the primary variables are known to be surface temperature (SST), wind strength, and the central pressure and central pressure gradients of the weather systems responsible. First, a perturbation methodology is used to generate a distribution of predicted rainfall total for the Coffs Harbour flash flood rainfall of 23 November, 1996. Then, the perturbation methodology is applied to two other flood events and the results are compared with the November 1996 storm.

2. METHODOLOGY

In attempting to estimate the uncertainty associated with single model forecasts, a number of weather centres routinely produce deterministic and ensemble forecasts of meteorological variables, including precipitation, out to as far as two weeks in advance. These centres include the European Centre for Medium Range Weather Forecasting (EC) (Molteni et al. 1996), the National Center for Environmental Prediction (NCEP) (Toth and Kalnay 1993), The United Kingdom Meteorological Office (UKMO), The US Fleet Numerical and Oceanographic Center (FNMOC) and the Bureau of Meteorology, Australia. Other institutions such as Florida State University (FSU) also routinely produce ensemble precipitation forecasts (Krishnamurti et al. 2000). Examples of the ensemble methodologies employed are the so-called ‘breeding’ method used at NCEP and the singular vector approach used at the EC. However, in attempting to produce a possible forecast spread of rainfall for a single event such as the Coffs Harbour flash flood, a simple scenario approach is appropriate, and possibly preferable, because the important mechanisms that produced the heavy rainfall causing the flash flood are known (Speer and Leslie 2000). The methodology in this study is to focus on generating a range of input variables to produce a distribution of forecast rainfall amounts. The key input variables identified by Speer and Leslie (2000) were: sea-surface temperatures (SST); sea level pressure gradients in the trough over the ocean adjacent to Coffs Harbour; and the strength of the low level (900 hPa) winds along the coast, just south of Coffs Harbour. The distribution of rainfall totals is subject to a very simple cluster analysis in which the rainfall totals are grouped into three categories consisting of totals within plus and minus one standard deviation for two of the groups and the remainder in the third group.

Model

The model used here is the same as that used by Speer and Leslie (2000). It is The University of New South Wales HIRES model. This model is a hydrostatic model formulated in terms of the advective form of the primitive equations for momentum, mass, moisture, and thermal energy

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with integrations carried out on the staggered Arakawa C grid. The most recent version of HIRES also includes the Kain-Fritsch (1990) scheme (KF), which has a realistic one-dimensional entraining/detraining plume model and some cloud microphysics. There is also a non-hydrostatic option providing an explicit 6-water phase microphysics scheme. However, in this study we used only the hydrostatic version with the KF option at a nesting horizontal resolution of 1 km, because the rainfall of the Coffs Harbour flash flood event was dominated by large scale processes that were further focussed by orography. Coarse mesh boundary conditions were provided by the Bureau of Meteorology's 75 km LAPS system. The number of levels was 34 of which 5 evenly spaced levels (25 hPa spacing) were distributed between 850 hPa and 950 hPa. The 900 hPa level therefore provided an average of the low level wind maximum in the southerly jet along the coast. The SST input to HIRES was provided by a running 5 day average, 1.0 degree resolution, latitude/longitude data set.

Data

The single, unperturbed, HIRES forecast at 1 km horizontal resolution was produced by triple nesting. First, the 75 km LAPS fields were interpolated onto a HIRES domain covering the Australian continent and adjacent oceans at 50 km horizontal resolution. Forecasts were then generated at this resolution. Next, these forecast fields were used to nest a forecast at 15 km resolution over eastern Australia, which in turn was used to generate nested simulations at 5 km and finally at 1 km. The 1 km domain is the entire 1 km forecast domain but we show results only for the Coffs Harbour catchment. To generate an envelope of possible initial model states within those of the current climate spread, the range of perturbation values for each variable was confined to lie within two standard deviations of the mean. The perturbed variables were those known to affect the position, intensity and duration of the meteorological systems. Specifically, SSTs were perturbed within the range ± 2.5 deg. C of mean values and analysed MSLP values were perturbed in the range ± 2 hPa over a lattice of grid points. Analysed wind speeds at levels between 950 hPa and 850 hPa in the vertical and within an oval-shaped region in the horizontal, were perturbed in the range ± 15%. Each model run using a perturbed analysis was preceded by a data assimilation step commencing at t = -12 h. For the SST and MSLP fields there were 25 points covering the region of interest. From these, 13 points were considered sufficient to represent the area. Gridded values at these 13 points were perturbed and comprised of three values of MSLP (-2.5 hPa, 0 (control), +2.5 hPa), and SST (-2.5 deg.C, 0 (control), +2.5 deg.C). Perturbations were also made at 13 grid points of analyzed wind speed consisting of three values (-15%, 0 (control), +15%), as indicated above. Thus, a total of 351 (13x3x3x3) forecasts were performed, using control and perturbed analyses. Perturbations were applied to grid points, as indicated above, but only to the analysis fields at 5 km horizontal resolution.

3. RESULTS AND DISCUSSION

The unperturbed 1 km single model forecast 24 hour rainfall from 9 am 23 November, 1996 to 9 am 24 November 1996 of just under 150 mm at Coffs Harbour Airport compares very favourably with the observed value of 168 mm recorded at the station itself. Also, the model predicted a 24 hr rainfall total of about 500 mm over the higher orography to the southwest of Coffs Harbour. This compares well with the observed totals of about 500 mm recorded there. Finally, the model forecast of between 350 mm and 375 mm at Sealy Lookout, while exceptionally high, underestimated the observed value of 515 mm recorded at Sandra Close, located in the same area. The ratio of the unperturbed forecast rainfall amount at Sealy Lookout was about 2.5 times the observed amount at Coffs Harbour Airport. On the high topography in the southwest of the catchment the ratio was just over 4.0.

The tail of the distribution of rainfall totals with the highest (approx. 16%) of the 351 rainfall forecasts had a mean value of between 475 mm and 500 mm at Sealy Lookout. The rainfall amount at Coffs Harbour Airport remains just under 150 mm. The corresponding ratio of 24 hour forecast rainfall to Coffs Harbour Airport rainfall indicates that the rainfall amount over the highest topography at Sealy Lookout is nearly 3.5 times that of the amounts along the coastal strip at Coffs Harbour Airport. On the highest topography in the southwest of the catchment the total of about 675 mm gives a ratio of 4.8. Combining the scenarios from the tail of the distribution of rainfall totals with the lowest (approx. 16 %) rainfall amounts gives a mean value of between 300 mm and 325 mm positioned over Sealy Lookout, whereas the value indicated at Coffs Harbour Airport is between 175 mm and 200 mm. The corresponding ratio of Sealy Lookout rainfall to the Coffs Harbour Airport rainfall amount therefore is reduced to 1.8 and on the high topography in the southwest of the catchment the ratio was 2.0.

From the above results the QPF maximum for the catchment is approximately a factor of 5 times that relative to Coffs Harbour Airport. The lower and upper limits on the maximum QPF ratio then is between 2 and 5.

The local influence of topography on the amount of rainfall clearly is very large. For larger dynamical scale rainfall systems that have affected Coffs Harbour (see Speer and Leslie, 2000), the topographical influence, while still present, is not as pronounced as in the November 1996 flash flood event. For example, the single unperturbed 24 hour rainfall forecast for the 24 hour period when most rain fell during the east coast low of May, 1977 shows a much smaller difference between the forecast amounts of just over 250 mm at Sealy Lookout and just over 175 mm at Coffs Harbour Airport. Similarly, the single unperturbed 24 hr rainfall forecast for the wettest day for TC 'Zoe' in March 1974, shows a difference of only about 50 mm between the locations of Sealy Lookout and Coffs Harbour Airport.

4. CONCLUSIONS

Estimates of quantitative precipitation for an intense rainfall event were made using a simple, but effective, perturbation methodology applied to numerical analyses of surface and low level wind speed, SSTs and SLP off the east Australian coast near Coffs Harbour. The aim was to generate a range of scenario forecasts, within current climate limits, for the 24 hour period from 9 am 23 November, 1996 to 9 am 24 November, 1996. This was a period during which very heavy rainfall of short duration from an orographically anchored storm caused a devastating flash flood to flow through Coffs Harbour. It was found that for the perturbations that produced the largest rainfall amounts (approx. the top 16%), the ratio of the rainfall amount at Sealy Lookout, on the hills just to the west of the CBD, reached 3.5 times that of the rainfall produced at Coffs Harbour Airport but up to 4.8 times on the higher topography in the far southwest part of the catchment. The single unperturbed model forecast rainfall at Sealy Lookout was only 2.5 times that of Coffs Harbour Airport. The results suggest that rainfall amounts on the hills could be up to *double* the largest observed amounts for the entire catchment area. Such a large difference has very significant implications for QPF estimates and flood mitigation strategies.

The surface and low-level features that were perturbed in this work were a surrogate for mid-tropospheric features, such as a strong temperature gradient at 500 hPa, present to the northwest of Coffs Harbour. Therefore, while mid-tropospheric variables were not directly perturbed in this study, the surface features can be regarded as an adequate representation of the variability in meteorological inputs requiring representation in the study. A future study is planned to investigate possible variations in values of mid-tropospheric variables. Finally, the period during which the heaviest rain occurred was about four hours. Clearly, this period could have been shorter or longer, depending on the speed of movement of the large scale environmental features. In a future study, This will also be addressed in a future study, by perturbing the mid-tropospheric variables.

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