

Shorter contribution

An example of the utility of ensemble rainfall forecasting

Introduction

Rainfall prediction is a difficult problem on all time-scales, including the short range (< 48 hours), because many physical processes interact on different scales of motion and frequently expose the limitations of current numerical weather prediction (NWP) models. Improvements in short-range forecasting of rainfall, in terms of quality and timeliness, would have a profound socio-economic impact on many human activities. Currently, in Australia, short-range forecasting of the location and amount of rainfall is based essentially on guidance from short-range NWP models together with the forecaster's experience and knowledge of the relevant physical processes of the particular event. Increasingly, at the medium range of 48 hours out to two weeks, at various national weather centres, details of the large-scale circulation are produced in an ensemble forecasting mode as forecast guidance. For example, both the National Center for Environmental Prediction (NCEP) in Washington D.C. and the European Centre for Medium Range Weather Forecasts (ECMWF) routinely produce medium-range ensemble predictions for operational use. Ensemble forecasting in the short range is still in an embryonic stage and has been posed as an alternative, or supplement, to running models at increasingly higher resolutions particularly to help assess initial condition uncertainty owing to the poor spatial representation generally present in observational networks. As far as the authors are aware, this is the first attempt to apply short-range ensemble forecasting to total rainfall from a mesoscale system. Only one other study (Brooks et al. 1996) has looked at rainfall in a short-range ensemble forecast mode and this was in relation to rainfall due to convective processes.

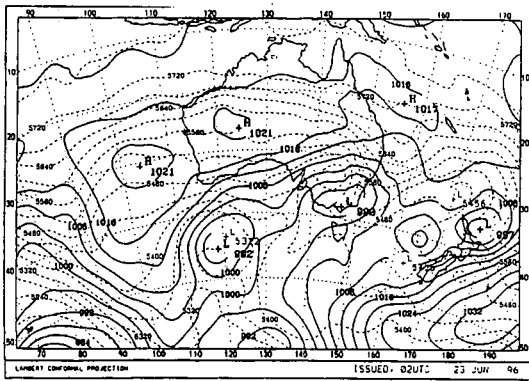
In this study, a high resolution limited area model (HLAM) centred over New South Wales (NSW) was run in a Monte Carlo forecasting mode for a rainfall event that produced widespread precipitation on the western slopes and plains of NSW which include the NSW winter crop growing areas. A total of 100 forecasts made up the ensemble. The ensemble mean prediction is compared with the single forecast approach and found to be markedly superior, particularly in terms of rainfall totals, but also in distribution.

Ensemble methodology

Ensemble forecasting methods attempt to take into account the uncertainty introduced by errors associated with predictions from the single forecast model approach. Presently, there are three main methods used to create an ensemble forecast. For example, NCEP uses the so-called 'breeding' method (Toth and Kalnay 1993) and ECMWF uses the singular vector decomposition approach (Molteni et al. 1995). Both methods are based on the notion that any single starting analysis for a forecast inherently contains errors because of the lack of observations needed to specify the true state of the atmosphere. Generally, an ensemble is generated by perturbing an analysis several times to give a spatial density of equally likely starting analyses around a true state. These analyses are then projected forward by model equations using a method such as above which then results in a spread of possible forecasts.

A third approach, the much older Monte Carlo procedure, has also been popular (Mullen and Baumhefner 1994) but suffered from the prohibitive computational cost of performing a sufficiently large ensemble. However, continued increases in computing capacity in recent years makes feasible now the performing of multiple runs of a limited area model in real time. For example, this has been achieved in research mode over an area the size of southeastern Australia using the boundary conditions of a large-scale model run to nest HLAM developed at UNSW by the second author (LML) (Speer and Leslie 1996, hereafter referred to as SL). In SL, a Monte Carlo ensemble of 100 initial states was used to perturb an east coast low, with the Monte Carlo approach successfully used by Mullen and Baumhefner (1994), by generating Gaussian noise within the bounds of the current Australian analysis errors. Errors for analysed winds were taken as 7 m/s, 5 m/s and 3 m/s for the upper, middle and surface/low levels respectively of the troposphere over Australia. Each of the 100 initial states was then advanced forward using the limited area model, over the same domain (see Fig.1) as the Bureau of Meteorology's then operational regional model, RA75 (Mills and Logan 1994) to provide lateral boundary conditions. In some forecast situations, as many as 100 perturbed runs might be needed to specify the spread of solutions. The resolution of the limited area model was 75 km, the same as RA75, but is effectively around 25 km because the model used in SL has higher order numerics than RA75.

Fig. 1 Bureau of Meteorology's operational MSLP (heavy lines) and 1000-500 hPa thickness (dashed lines) analyses for 9 am 23 June 1996.



Following the success of the study by SL, it was decided to address the potentially more difficult problem of ensemble rainfall prediction. The event was similar in that a surface low pressure system developed on a cold front. Perturbations to the moisture field (mixing ratio) were confined to the range ± 0.5 to ± 1.0 g/kg and ± 0.25 g/kg in the low and middle levels respectively. These values are a function of position (especially latitude) and season, and are up to about ten per cent of the observed values. Because of the 'threshold' nature of rainfall it is difficult to anticipate the impact of the perturbations on the rainfall amount and distribution, which makes the rainfall ensemble approach even more challenging. The perturbations to the wind field were the same as in SL.

The wind and moisture perturbations were independent but all fields are passed through the initialisation procedure, which does effectively couple them.

Case study

Description. On 21 June 1996 a cold frontal system was approaching NSW accompanied by a cloud mass moving quickly east across Australia under the influence of a strong subtropical jet stream. Development of a surface low pressure system occurred over Victoria on June 22 (Fig.1) resulting in further cloud development, an unstable west to southwesterly airflow and a prolonged period of rain over inland NSW. The area of rain that fell in the 24 hours to 9 am 23 June 1996 is shown in Fig. 2. These rainfall amounts are certainly not extreme but the area generally contained within the 20 mm contour corresponds with the area currently sown to winter crops in NSW. Just before the rain much of this area was suffering from drought. The unperturbed corresponding 24-hour rainfall forecast to 9 am 23 June 1996 is shown in Fig. 3. This indicates a reasonable

Fig. 2 Observed rainfall (mm) for the 24 hours to 9 am 23 June 1996.

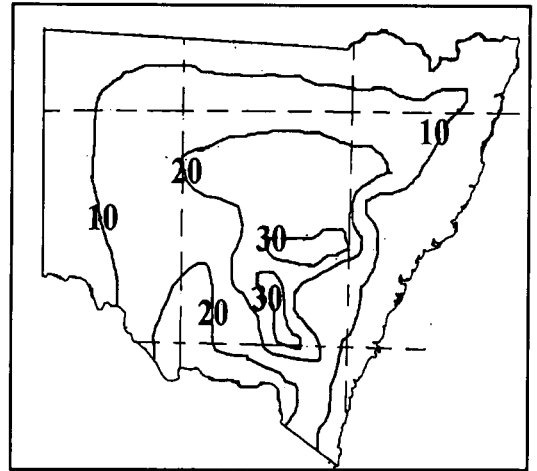
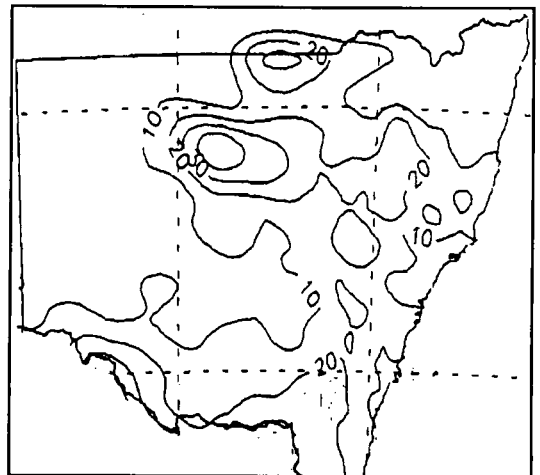


Fig. 3 HLAM unperturbed 24-hour rainfall forecast (mm) for 9 am 23 June 1996.



distribution pattern over NSW except that it underestimates the maxima observed over inland NSW generally by a factor of about two.

Results of ensemble forecasts. The unperturbed HLAM forecast position for the MSLP low centre, U , was predicted very well in this case (Fig.4(a)). It lies within the spread of the perturbed forecasts, which was small, indicating that the low centre position was insensitive to the initial conditions. The ensemble mean, E , is closer to the verifying analysis, V , because the spread is small in this example. V was based on a detailed manu-

Fig. 4(a) Ensemble 24-hour forecast for 9 am 23 June 1996 showing central pressure locations for initial analysis, HLAM unperturbed forecast, HLAM ensemble mean forecast and verifying analysis. Also shown is the envelope of 100 ensemble central pressure positions denoted by the closed contour.

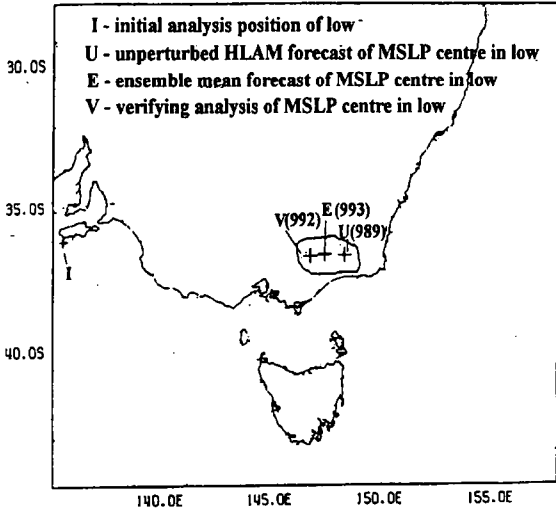
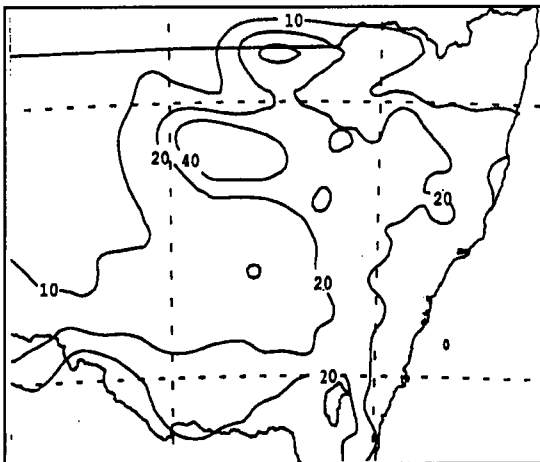


Fig.4(b) Ensemble mean 24-hour rainfall (mm) forecast valid to 9 am 23 June 1996.



al analysis including satellite imagery rather than on the location of the low centre from the operational computer analysis in Fig.1. A large gain over *V* is hard to achieve, so the gain achieved by *E* is made more valuable. The unperturbed value of 989 hPa in the low centre was less than the verifying value of 992 hPa indicating a sensitivity to the dynamical development of the low in a strong-

ly baroclinic environment. The pattern of rainfall showed relatively little variation among ensemble members as well as being nearly normally distributed about the mean. It was found that there was little gain beyond about 30 or 40 Monte Carlo runs. There was very little divergence of ensemble members in the positioning of the low centre because the verifying analysis, *V*, and the ensemble mean, *E*, are contained within the small envelope of 100 possible solutions as denoted by the closed contour (Fig. 4(a)). However, within the small range of position error for the 100 ensemble, there was considerable range in the lowest central pressure (989 hPa) to the highest central pressure (995 hPa).

The ensemble mean rainfall forecast over inland NSW is shown in Fig. 4(b) and compares favourably with the observed rainfall (Fig. 2) in that the important drought-relieving 20 mm contour extends through central NSW into the north of the State where it expands in area similar to the observed pattern. On the other hand, there is very little area greater than 20 mm in the unperturbed forecast (Fig. 3). Most notably, the area of NSW receiving greater than 10 mm covers almost all of the State in the observed and ensemble mean forecast, whereas the area over 10 mm in the unperturbed forecast covers only about half of the State, and the predicted amount is in fact below 10 mm over much of the central west plains. The unperturbed forecast (Fig. 3) is better than the ensemble mean forecast over the coastal strip and also where the 40 mm contour maximum is located (Fig. 4(b)).

Conclusions

A 24-hour ensemble mean rainfall forecast over NSW was found to provide considerably enhanced guidance relative to the standard single (unperturbed) forecast when comparing both the area of observed rainfall and the amounts. The ensemble mean forecast provided rainfall estimates twice that from the unperturbed forecast owing to the significantly more extensive area in central NSW enclosed by the 20 mm contour. This is an extremely encouraging result. However, the unperturbed forecast was slightly better than the ensemble mean forecast over the coastal strip and in one of the maxima in the north of the State. More cases of ensemble forecasts similar to the one in this study need to be performed to help clarify the error distribution associated with forecasts of various phenomena inherently due to initial condition uncertainty.

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