Ensemble forecasts of heavy rain

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Introduction

The Bureau of Meteorology currently generates ensemble forecasts of precipitation amount and probability over Australia using three ensemble prediction systems (EPSs): a global system, a regional system, and a poor man's ensemble. These provide objective guidance to forecasters for making weather forecasts and, increasingly, qualitative and quantitative guidance for hydrological forecasts in potential flood situations.

The ability of the Bureau's three ensemble systems to predict heavy rainfall is illustrated for a heavy rain event in eastern Australia in late June 2005. Verification is performed against the Bureau's operational daily rainfall analysis valid at 00 UTC (Weymouth et al., 1999). The performance of the ensemble systems for heavy rain is then compared over a three-month period from mid-May to mid-August 2005. A lagged poor man's ensemble is compared to the simple poor man's ensemble and shown to give superior probabilistic forecasts.

Ensemble prediction systems in the Bureau

The global EPS runs at 00 and 12 UTC using the Global Assimilation and Prediction System (GASP) model at T119 (approximately 150 km) resolution to produce 33 members (Bourke et al. 2004; see also http://gale.ho.bom.gov.au/bm/internal/daas/ensemble/index.html on the Bureau's internal web). Its main purpose is to provide likely weather and associated uncertainty information in the medium range, 4-7 days. Perturbations to the model initial conditions are generated using singular vector decomposition (SVD), and ensemble forecasts are made out to10 days. For heavy rain predicttion the GASP EPS gives a "heads up" concerning the possible location and amount of precipitation.

The regional EPS is a 25-member ensemble that runs once per day at 12 UTC using the Limited Area Prediction System (LAPS) model at 0.50° spatial resolution (Petithomme 2001; see also http://gale.ho.bom.gov.au/bm/internal/regn/expt/laps375-ensemble.forecast/forecast.html on the Bureau's internal web). In addition to SVD the LAPS EPS uses "stochastic physics" to increase the ensemble spread, thus making the ensemble more applicable for the short range, 1-3 days. Its focus is on high impact weather, producing probability forecasts for precipitation, thunderstorms, 10m wind, and maximum temperature.

The third ensemble run in the Bureau is a poor man's multi-model ensemble (PME) of eight global and regional models over Australia (Ebert 2001, 2002; see also http://gale.ho.bom.gov.au/bm/internal/wefor/staff/eee/PoorMansEnsemble/poorman.html on the Bureau's internal web). It makes forecasts of 24h rainfall accumulation to 7 days with a spatial resolution of 1°. The number of ensemble members varies with the forecast period according the availability of the input model quantitative precipitation forecasts (QPFs), with five to seven members at days 1-3, but only one to three members at days 4-7. Therefore the probability forecasts should only be used out to 3 days. Experiments to increase the number of ensemble members by including forecasts made 12 hours earlier are described later in this paper. Two ensemble mean products are generated, a simple ensemble average and a probability-matched mean with rain rates transformed to match the full ensemble (for details refer to Ebert, 2001).

Forecasters use the ensemble mean QPF as guidance for rain amounts, and the ensemble rain probabilities to suggest the uncertainty in predicted rain amount. The coarse spatial resolution of the ensemble products means that rain maxima will usually be underestimated. In practice forecasters typically double the maximum rainfall in the ensemble mean field to get an idea of maximum rainfall at individual sites (Julie Evans, personal communication). In this paper the probability of rain ≥ 25 mm d^{-1} is used to suggest the likelihood of heavy rain.

Case study: 29-30 June 2005 heavy rain event

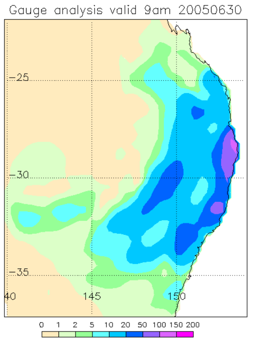

Fig. 1: 24h rainfall accumulation from the Bureau's operational 0.25° resolution rain gauge analysis valid at 00 UTC on 30 June 2005.

In late June 2005 a deep surface trough off the east coast combined with an inflow of moist air from the Tasman Sea brought widespread heavy rainfall to northeastern New South Wales and southeastern Queensland. Over 500 mm was recorded in some locations during a 48 h period ending 3 pm on 30 June, resulting in major floods in Lismore, NSW and flash flooding along the Gold Coast. The daily rainfall analysis valid at 00 UTC on 30 June 2005, corresponding to the day with the greatest rain accumulation, shows a maximum of 267 mm located near 28°S, 153°E (Fig. 1). Values exceeding 300 mm were recorded at some sites.

The probability forecasts from the GASP ensemble gave hints of heavy rain over the sea to the east of the Gold Coast as early as 7 days ahead of the event, as shown in Fig. 2. The probability increased to greater than 75% for rain exceeding by day 3, although the placement of the heavy rain was much farther to the south than observed. After a change of heart in a later forecast run, the 1d forecast put the heavy rain in approximately the correct location, with a maximum value of 78 mm d^{-1} in the ensemble mean QPF.

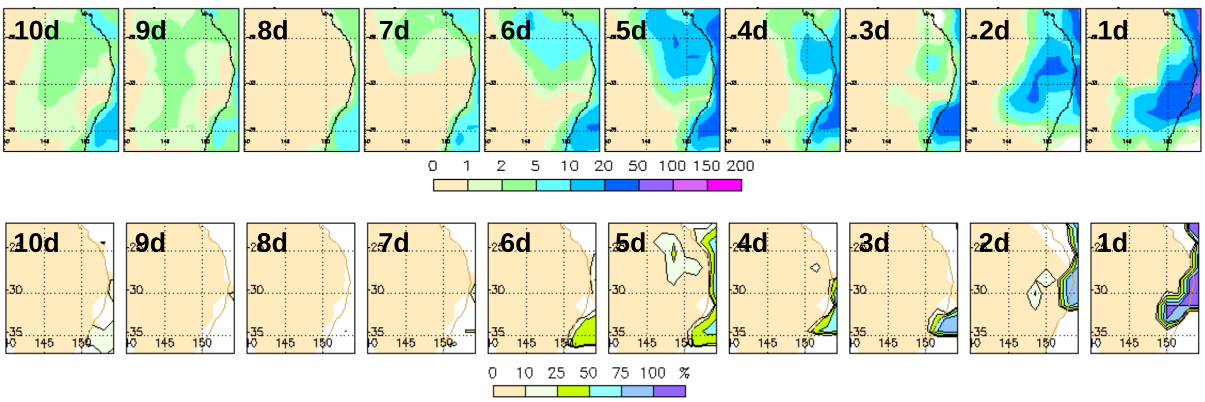

Fig. 2: Ensemble mean precipitation (mm) and probability of 24 h accumulated precipitation exceeding 25 mm d^{-1} from the GASP EPS for forecasts valid at 00 UTC on 30 June 2005.

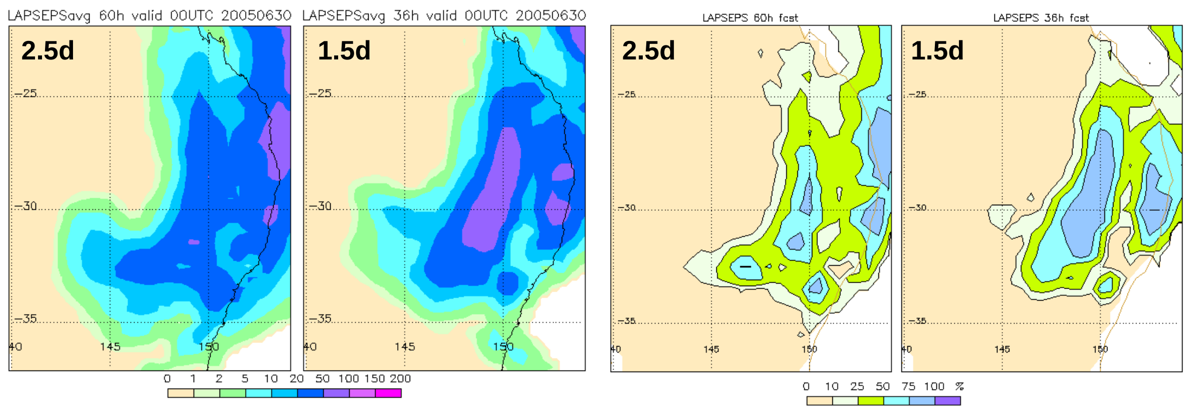

Fig. 3: As in Fig. 2, for the LAPS EPS.

Only 36 h and 60 h forecasts could be verified for the LAPS EPS. It gave skillful probabilistic and deterministic rain predictions for this event, correctly diagnosing the double maximum but predicting too much rain in the western region (Fig. 3). The 60 h predicted heavy rain probabilities were 50% or higher in the region of greatest observed rainfall. The maximum rainfall in the 36 h ensemble mean QPF was 104 mm d^{-1}.

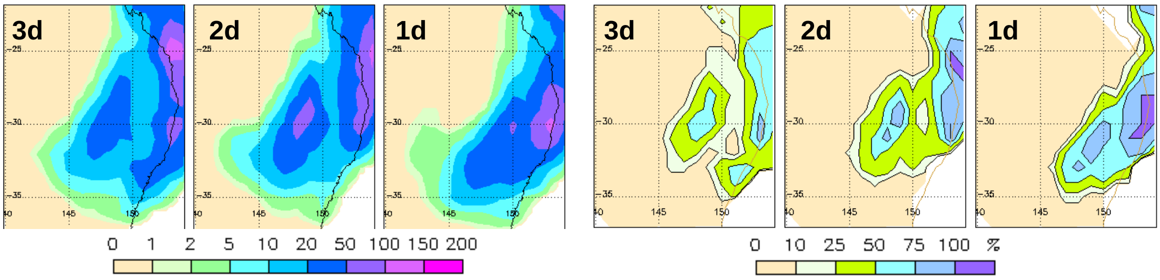

Fig. 4: Probability matched ensemble mean precipitation (mm) and probability of 24 h accumulated precipitation exceeding 25 mm d^{-1} from the PME for forecasts valid at 00 UTC on 30 June 2005.

The poor man's ensemble also gave a strong indication of heavy rain near the Gold Coast well ahead of the event (Fig. 4). Day 3 probabilities of heavy rain exceeded 50% along the coast between 24° and 31.5° latitude, increasing to 100% (i.e., consensus among all ensemble members) in a more focused zone by day 1. The PME probability-matched ensemble mean gives better estimates of rain maxima than the simple ensemble mean (Ebert, 2002). In this case the maximum rainfall was 123 mm d^{-1}, the greatest of the three ensembles examined and which, when doubled, gives values that were close to the observed maximum rainfall.

Heavy rain forecasts

The ensemble performance for heavy rain during the three-month period 15 May-15 August 2005 is compared for all three systems in Fig. 5. Each system was verified on its own grid.

All three systems underestimate the frequency of rain greater than 25 mm d^{-1} (Fig. 5a). This underprediction is particularly noticeable for the GASP EPS and may be related to its coarse resolution. Since the "smearing" of an ensemble average increases with time into the forecast, it is not surprising to see a decreasing frequency of the more extreme values, and many would argue that an ensemble mean should have limited usefulness beyond the first few days. The equitable threat score measures the ability of the QPF to predict rain occurrence and is sensitive to both false alarms and misses. The latter is usually the dominant cause of errors in heavy rain prediction. The PME showed significantly greater skill than either the LAPS or GASP EPS.

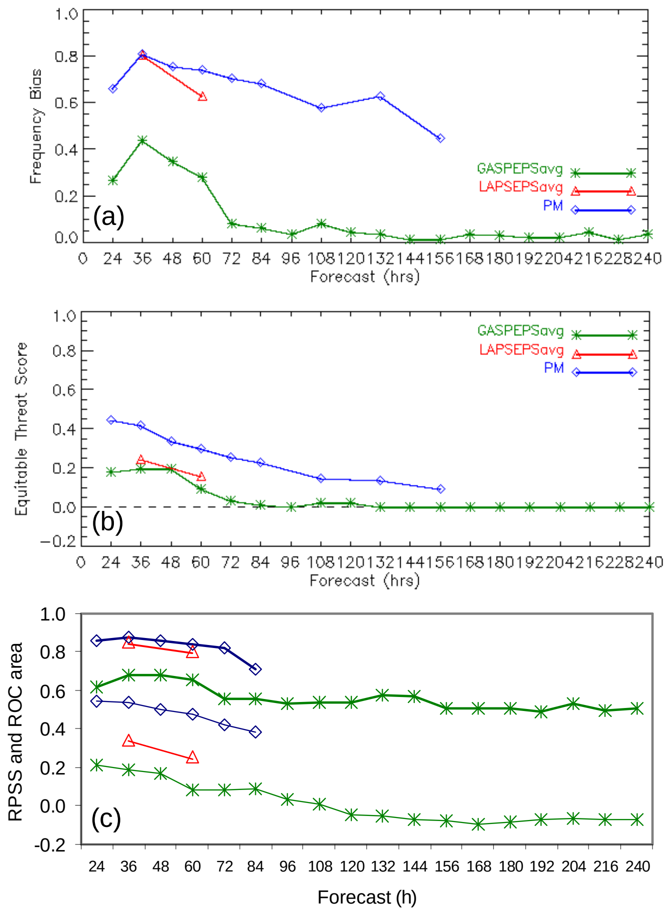

Fig. 5: Verification of ensemble mean and probabilistic forecasts of rain exceeding 25 mm d^{-1}. In the lower plot the heavy line shows the area under the ROC curve while the light line shows the ranked probability skill score (RPSS).

The PME also showed greater probabilistic skill than the single-model ensembles. The area under the relative operating characteristic (ROC) curve reflects the skill in discriminating between heavy and light/no rain, with a value of 0.5 indicating no skill. The ranked probability skill score compares the probabilistic skill of the forecast with that of climatology.

Lagged ensemble

The PME has access to only a small number of models beyond day 3, limiting its usefulness particularly for probabilistic forecasts. A simple way to increase the size of an ensemble is to include forecasts made earlier for the same valid time (Dalcher et al., 1988). This approach, known as a "lagged" ensemble, was tested for a six-month period, 1 January-30 June 2005, by adding in forecasts that were 12 h old to the most recent set of model QPFs included in the poor man's ensemble. It was not clear in advance whether including less accurate 12 h old forecasts would benefit or degrade the ensemble performance.

The additional ensemble members had little impact on the deterministic forecast performance, as shown in Fig. 6. There was virtually no change in the frequency bias or equitable threat score out to 3½ days, with both showing gradual deterioration with increasing forecast length. (Note: The scores in Fig. 6a are for rain exceeding 1 mm d^{-1} although the same similarity between simple and lagged ensemble also occurred at the higher thresholds.) However, the increase in ensemble size provided by the lagged ensemble allowed it to better define the rain probabilities, resulting in improved probabilistic performance (Fig. 6b) and, importantly, an extension of the useful life of the forecast.

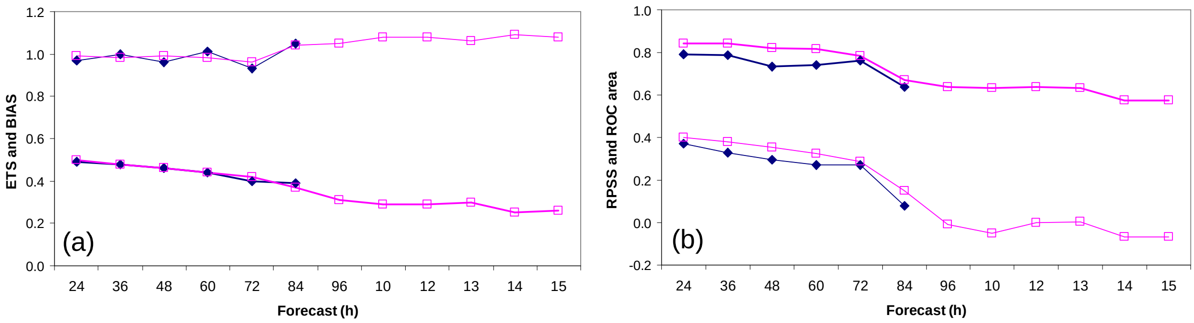

Fig. 6: (a) Equitable threat score (heavy lines) and frequency bias (light lines) for rain exceeding 1 mm d^{-1}, and (b) area under the ROC curve (heavy lines) and ranked probability skill score (light lines) for probabilistic forecasts of rain exceeding 25 mm d^{-1}, for the simple PME (diamonds) and lagged PME (squares).

References

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