our future through science

Atmospheric modelling and prediction at time scales from days to seasons

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INTRODUCTION

Seamless prediction is the notion of using common forecast systems to predict for multiple time scales. There is a growing trend internationally towards seamless prediction systems that will bridge the gap between weather forecasts and forecasts for much longer time scales (Vitart *et al*. 2008). There are important alliances between the mathematical models of the atmosphere to predict the weather and those predicting the anomalies associated with climate variability and change.

The first one is that many of the important feedbacks that lead to uncertainty in climate predictions are associated with processes such as convection, whose intrinsic time scales lie within the domain of numerical weather prediction (NWP). Moreover, the NWP community has developed code optimisation tools and created a supercomputer environment. Both are also benefitting predictions at longer and much longer time scales, since these developments have – amongst others – led to increasing the horizontal and vertical resolutions of models configured for climate variability and change projections. However, NWP may also benefit from developments in climate prediction, especially by looking into model errors.

METHOD

The conformal-cubic atmospheric model (CCAM) (McGregor 1996) is an atmospheric global circulation model (AGCM) developed at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research in Australia. The CCAM may be integrated at quasi-uniform resolution or alternatively in stretched-grid variable-resolution mode to provide high resolution forecasts over an area of interest. The CCAM can be integrated at relatively large time steps and a message passing interface (MPI) formulation allows the code to be integrated using parallel processing capabilities on computer clusters.

These aspects, in combination with the great flexibility provided by the variable resolution formulation and nudging procedures, render the CCAM code one of only a few atmospheric models that can be applied in a truly seamless way.

The CCAM has been configured to run as a seamless forecasting system by constructing the forecasts in the following way:

1) Seasonal forecasts: A quasi-uniform resolution forecast (about 2° horizontal resolution) for the next five months is issued monthly. A lagged-average forecasting approach is used to form an ensemble of forecasts consisting of 12 members.
2) Medium-range forecasts: Using the exact same model code, a 10-day stretched-grid forecast with 0.5° resolution over southern and tropical Africa is issued daily – these forecasts are nudged within the 2° quasi-uniform resolution forecast.
3) Short-range forecasts: Finally, a forecast with 0.15° (about 15 km) resolution over South Africa is issued each day for a seven-day integration period. These short-range forecasts are nudged within the output of the 0.5° forecasts.

Although AGCMs, commonly configured with an effective resolution of 100-300 km (the CCAM's resolution is about 200 km when used for seasonal forecasting), have demonstrated seasonal forecast skill at global or even continental scale, they are unable to adequately represent local sub-grid features, subsequently producing rainfall over southern Africa that is overestimated (Joubert and Hewitson 1997). Also, the representation of rainfall at high latitudes is complex and often not well-estimated (Goddard and Mason 2002). Such systematic biases have created the need to downscale GCM simulations over southern Africa. Semi-empirical relationships exist between observed large-scale circulation and rainfall, and assuming that these relationships are valid under future climate conditions and also that the large-scale structure and variability is well-characterised by GCMs, mathematical equations can be constructed to predict local precipitation from the forecast large-scale circulation.

The Climate Predictability Tool (CPT; http://iri.columbia.edu) is used to downscale the coarse resolution 850 hPa geopotential height fields of the CCAM to the 0.5° x 0.5° resolution of the University of East Anglia Climatic Research Unit (CRU) global monthly rainfall data, Version 2.1 (Mitchell and Jones, 2005). In addition to seasonal rainfall forecasts, the rainfall forecasts of the CCAM are empirically downscaled in order to produce streamflow forecasts for 1946 catchments across South Africa by using the Quaternary catchment data produced by the University of KwaZulu-Natal (Schulze *et al*. 2005).

RESULTS

Short- to medium-range forecasts

The development of the high-resolution weather forecasting system at the CSIR is still in its infancy. Nonetheless, forecasts have been produced for a few months now. During that time, a number of extreme weather events occurred.

Figure 1 shows an example of one of the earliest forecasts made at a fairly coarse resolution of 0.5° (~50 km). The figure shows both the 24-hour accumulated rainfall forecast for 22 January 2010 made on the day before, that is, the 21st and the Meteosat geostationary satellite image (http://www.sat.dundee.ac.uk/) at 14:00 South African Standard Time (SAST) on the 22nd.

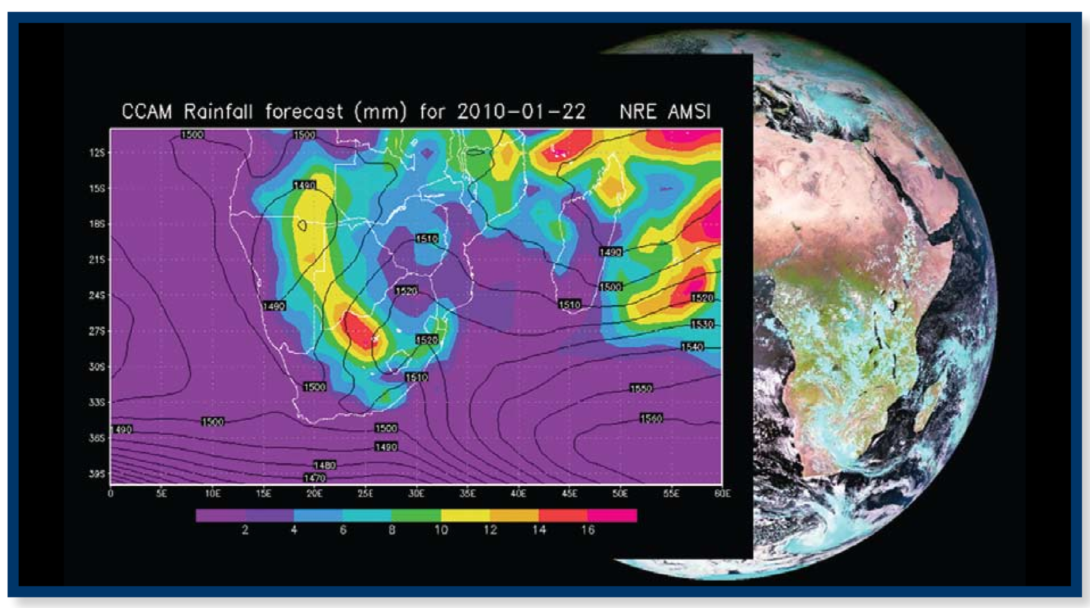

Figure 1

Figure 2 shows 15 km resolution rainfall forecasts for the four days of 23 to 26 April 2010 produced on the morning of the 23rd and the Meteosat satellite images of the 24th and 26th at 14:00 SAST. This was a period of high rainfall totals: parts of Pretoria received more than 50 mm during this period and maximum temperatures only reached about 15 °C, which is cool for April. The satellite images of the 24th and 26th show the well-developed cloud structures responsible for the wet and cool conditions.

The high-resolution CCAM weather forecasts produced by the CSIR's atmospheric modelling strategic initiative are also geared towards applications modelling. These forecasts are further planned to feed into the southern African ocean modelling research supporting operational activities, and combined with a flood prediction hydrological model and suite to run automated in real time for early warning for extreme flood events in urban areas.

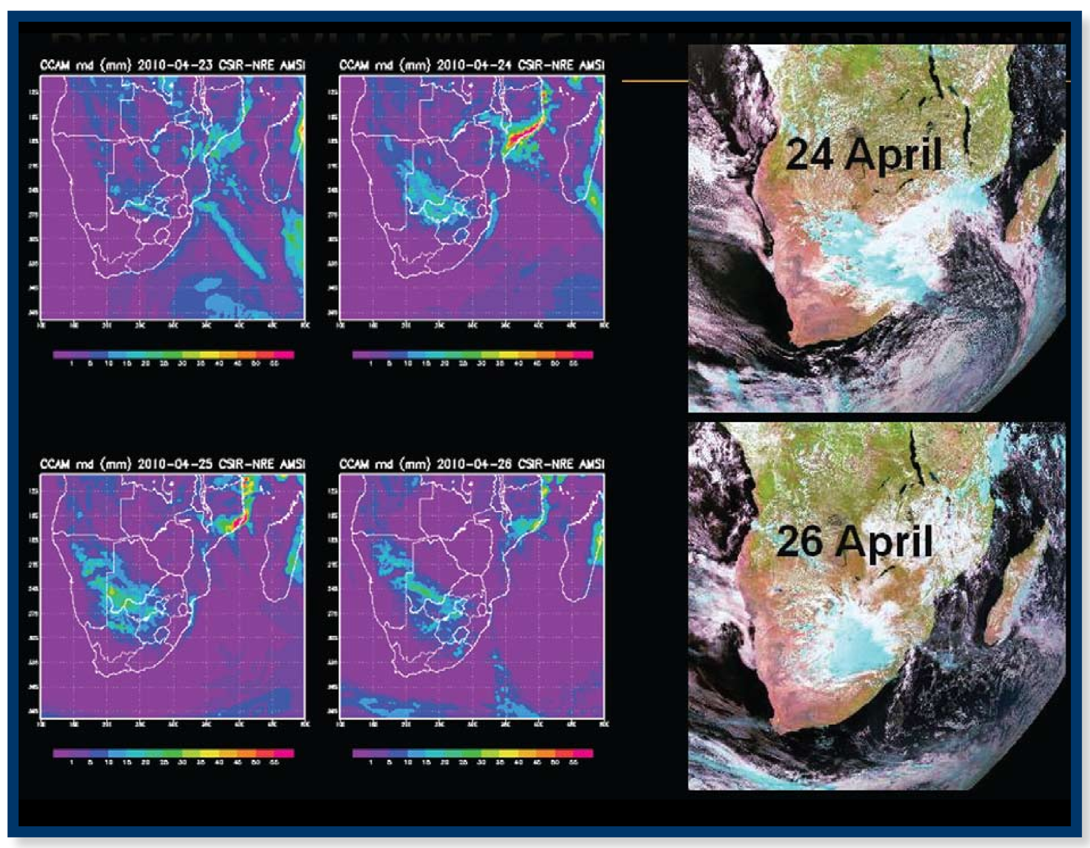

Figure 2

Long-range forecasts

The scientific basis for doing seasonal forecasting originates from the observation that slowly evolving SST anomalies influence seasonal-mean weather conditions (Goddard and Mason, 2002). The CCAM model is forced by prescribed SST anomalies, persisted over a five-month period.

Figure 3 shows the CCAM's forecast performance over 23 years (1979/80 to 2001/02) predicting December-January-February (DJF) rainfall totals over southern Africa at about a one-month lead-time. The 850 hPa geopotential height fields of the model were downscaled to a 0.5°x0.5° resolution using model output statistics (MOS). The forecasts are cross-validated using a five-year-out window, and on the figure Spearman's correlation values between ensemble mean forecasts and observed data over the 23 years are shown.

The CCAM's simulated rainfall fields are also downscaled to catchment level using MOS. The 20-year test period is 1979/80 to 1998/99 for the prediction of DJF accumulated quaternary catchment streamflows at about a one-month lead-time.

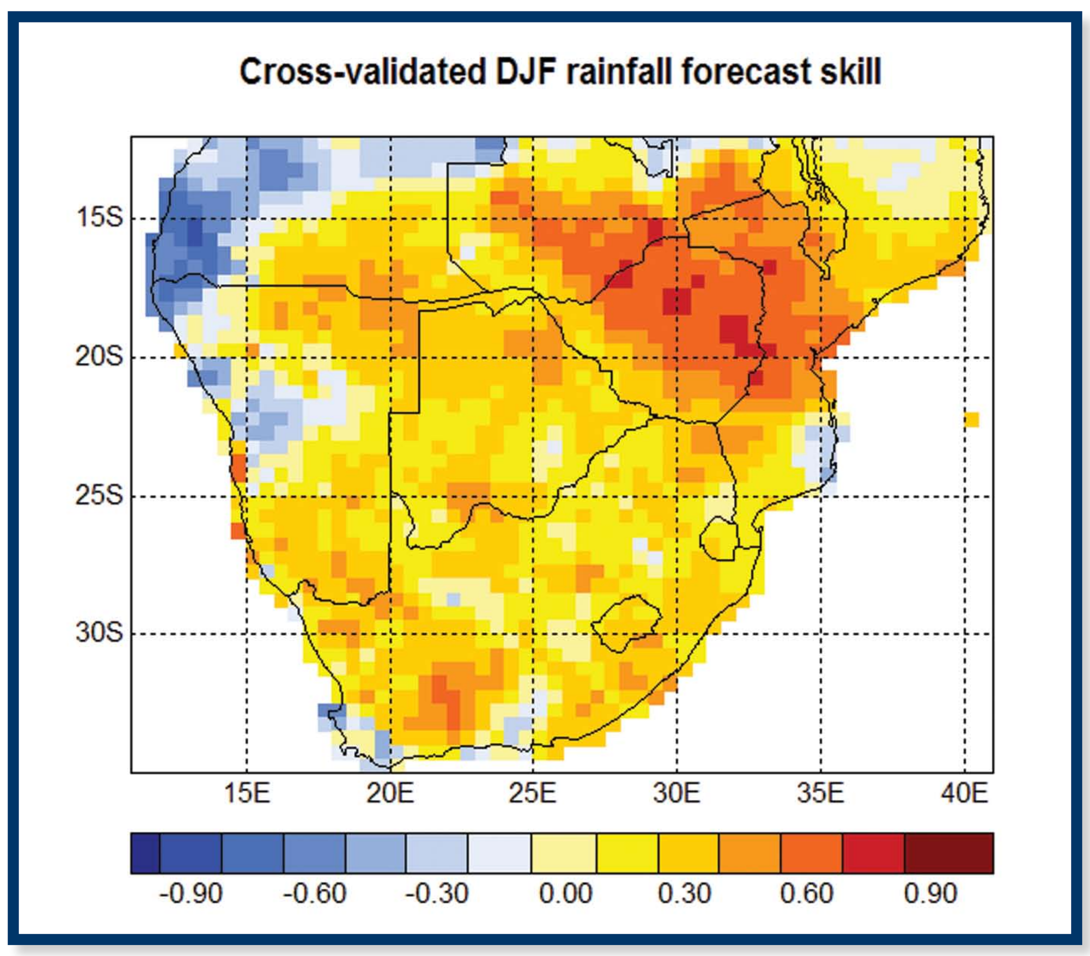

Figure 3

Figure 4 shows the five-year-out cross-validation Spearman's correlation values between forecast and observed flows. Take note of the high skill found over the Lowveld and adjacent areas. This forecasting system was subsequently used to predict the accumulated streamflows during the 1999/2000 austral summer season which was associated with flooding over the Lowveld and southern Mozambique as a result of tropical cyclone landfall. The forecast for this season shows enhanced probabilities for above-normal flows to occur, therefore demonstrating this forecast system's ability to predict the likelihood of flood seasons.

The CSIR has developed an innovative capability that can predict weather and seasonal climate extremes over southern Africa by using a physical model that describes the evolution of general circulation patterns over the next few days, weeks and months.

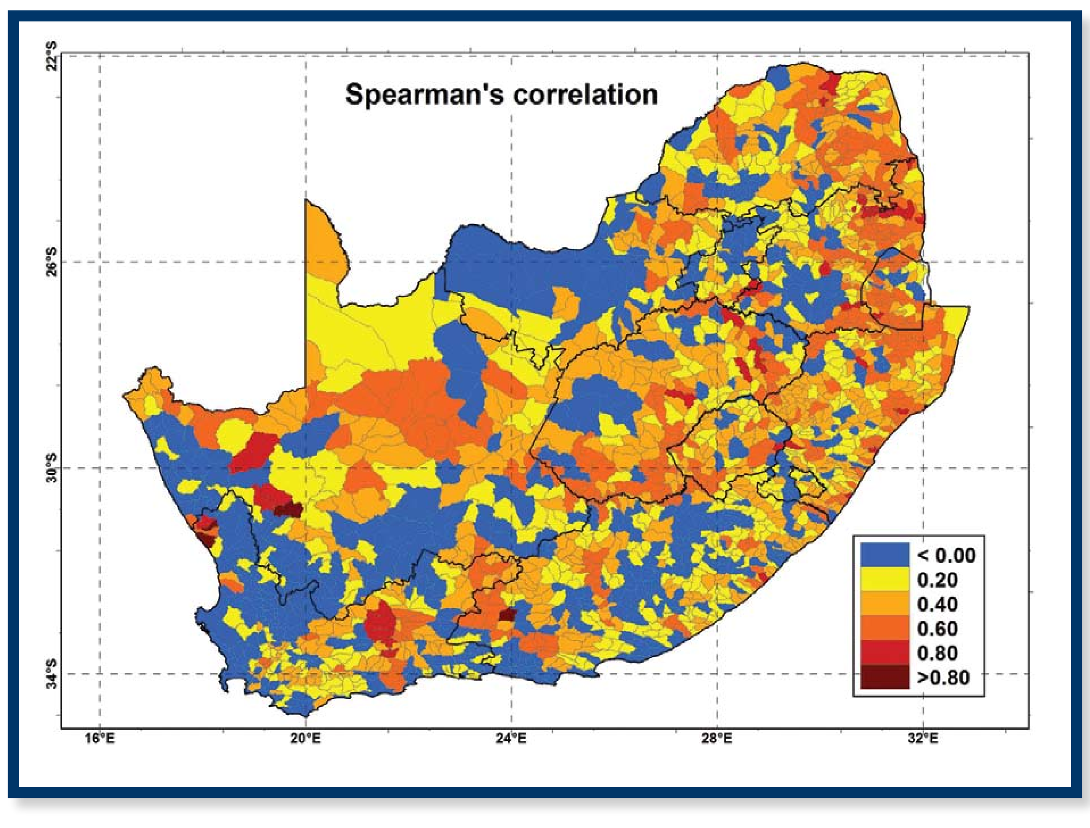

Figure 4

CONCLUSION

The CSIR has developed the capability to produce skillful operational weather and seasonal forecasts. The CCAM forecasts will be further expanded by producing an ensemble of forecasts from weather through to seasonal time scales. Optimal ensemble forecasts should produce forecasts that are reliable and can be linked with a number of application models such as runoff/streamflow, crop yield and health.

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