The atmospheric water balance of the Murray-Darling Basin based on LAPS output

Clara Draper and Graham Mills
Bureau of Meteorology Centre Research Centre
Melbourne, Australia

Introduction

This paper explores the hydroclimatology of the Murray-Darling Basin in southeast Australia, by discussing the Basin's atmospheric water balance, based on output from the Australian Bureau of Meteorology's numerical weather prediction (NWP) model, Limited Area Prediction System (LAPS). This work is part of the GEWEX Murray-Darling Basin Catchment Scale Experiment, and has focussed on characterising the annual cycle of the Basin's water balance, for the period 2000 – 2004. Rainfall in the Basin was below average during this time, which included a severe drought in 2002-03, making this research relevant only to dry conditions in the Basin. A preliminary goal of the project has been to assess the ability of LAPS to forecast an accurate and viable water balance. This is necessary as there has been little previous research into the atmospheric water balances in Australia, or in similarly arid regions. Additionally water balance studies based on NWP model output are known to contain significant residual terms, related to the model error (Kanamitsu and Saha 1996; Roads et al 1998).

Methodology

The atmospheric water balance over the Murray-Darling Basin has been estimated using the vertically integrated atmospheric water balance equation:

$$\overline{\left\langle \frac{dW}{dt} \right\rangle} = \overline{\langle E \rangle} - \overline{\langle P \rangle} - \overline{\langle \nabla Q \rangle} + \langle \overline{R} \rangle \qquad \text{Eqn 1}$$

dW/dt is the rate of change of the vertically integrated atmospheric water (precipitable water) over time. ***E*** and ***P*** are evapotranspiration and precipitation, respectively. ∇***Q*** is the vertically integrated moisture flux divergence. The vertical integration is from the top of the atmosphere (estimated as 250 hPa) to the surface. **R** is the water balance residual, which is calculated as equal and opposite to the remaining terms. The overbars indicate a three hour time integral, and **<.>** indicates the area average over the Murray-Darling Basin. The water balance terms have been estimated from the average of the two daily model runs (at 12:00 UTC and 00:00 UTC), on the same 0.375° grid used by LAPS, before being summed across the Murray-Darling Basin. For full details of the LAPS model refer to Puri et al (1997).

The ability of LAPS to forecast accurate and viable water balances has been assessed by verifying the LAPS predicted precipitation against the real time analysis of rain gauge observations, and by investigating the behaviour of the water balance residual term.

Results

The estimated annual water balance is provided in Table 1 for each year of the study period. Precipitation and evaporation are the leading terms in the budget. The moisture flux divergence is an order of magnitude smaller than the leading terms. dW/dt is small, consistent with the assumption that W is constant over long time periods. The residual is of the same order of magnitude although smaller than the leading terms. It is not uncommon for the residual to be amongst the leading terms of water balance experiments (eg. Roads and co-authors 2002).

Table 1 – The Murray-Darling Basin Annual Water Balance
(all figures are mm/year)

	P	E	∇Q	dW/dt	R
2000	697	746	-9	10	-47
2001	473	703	93	-5	-142
2002	425	647	-96	6	-311
2003	440	659	35	28	-157
2004	520	675	24	20	-111

The annual cycles of each of the water balance terms are illustrated by the monthly totals plotted in Figure 1. The maximum of both precipitation and evaporation occurs in the warmer months, and there is less inter-annual variation in evaporation than in any of the other fields. The moisture flux divergence is noisy, and has a weak trend toward convergence in winter and divergence in the warmer months. Precipitable water is determined by atmospheric temperature, producing a tendency toward negative (positive) dW/dt in the first (second) half of the year. The residual term tends to be negative and has the largest magnitudes in summer.

Discussion and conclusions

Water balance characteristics

Comparison of the water balance over the Murray-Darling Basin to that of other regions highlights the aridity of the Murray-Darling. In contrast to this study, the moisture flux divergence is usually a leading term in regional scale water balances (eg Zangvil et al 2001; Smirnov and Moore 1999). The small magnitude of the moisture flux divergence estimated here is consistent with the Basin's low surface discharge, as these two terms should equate over long time periods. The nature of the net surface water budget, defined here as precipitation minus evaporation, also differs from that of other regions. There is a net negative surface water budget across the study period, inferring that the surface has supplied moisture to the atmosphere over this time. Both the (P-E) and (-divQ-dW/dt) fields infer a net negative surface water budget, and (P-E) estimates a negative budget for each individual year. A consistently negative water budget over such a long time period is not often observed. The surface water budget for the Murray-Darling Basin must be positive over the long term as basin discharge is observed, although this discharge could be maintained from the terrestrial water store during occasional periods with a negative budget. The question is then raised as to whether the negative surface moisture budget forecast here is artificial and due to model drift, or whether it is a real phenomenon. The small negative surface water budget in 2001 is likely a model error, as precipitation was above average in that year, and flooding occurred in large areas of the Basin in November. However, the later part of the study period was unusually dry, particularly in 2002-03, and surface drying could reasonably be expected to have occurred then. It must be emphasised that these results pertain only to dry conditions, and the water balance during periods of higher rainfall will be quite different.

Quality of LAPS forecast water balance

The LAPS model is capturing the main characteristics of the water balance, although it has less skill during extreme hot and dry conditions. This is demonstrated both by comparing the forecast precipitation to observations, and by investigating the water balance residual term. In general the LAPS forecast precipitation for the Murray-Darling Basin agrees well with analysed observations of rainfall (not shown). However, during hot and dry conditions there is a strong tendency to over-predict precipitation.

The greatest negative water balance residuals also occur during hot and dry conditions. A negative residual indicates that the LAPS model has a tendency to accumulate excess moisture in its atmosphere. The generation of the residual can be understood by considering the time series of the precipitable water that was

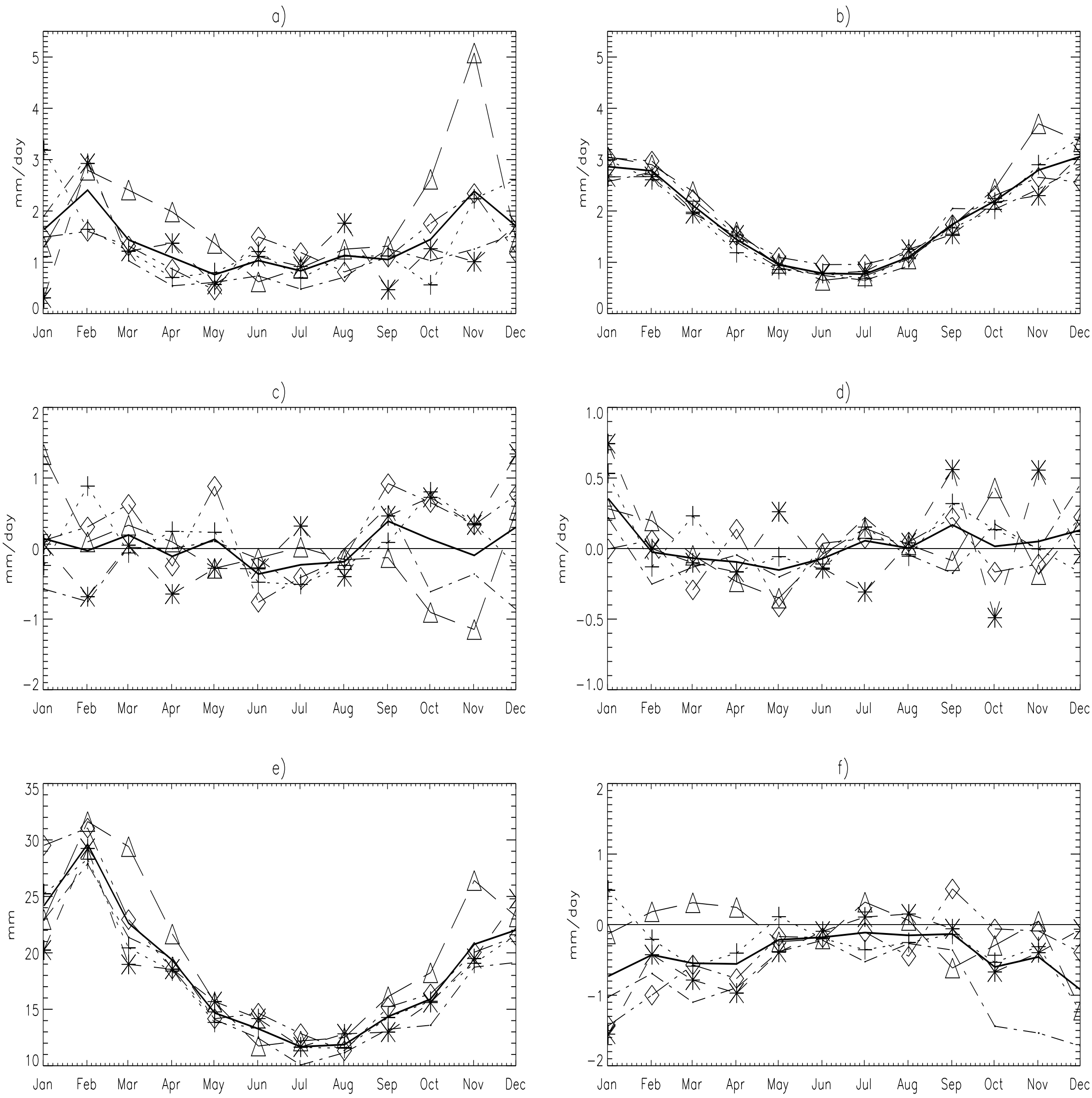

Figure 1 - Monthly LAPS forecasts of (a) precipitation, (b) evaporation, (c) moisture flux divergence, (d) change in precipitable water over time, (e) precipitable water, and (f) the residual. Triangles are results for 2000, diamonds for 2001, horizontal dashes for 2002, asterisks for 2003, and crosses for 2004. The bold line is the average.

used to calculate the water balance. A regular discontinuity occurs in the time series at the introduction of each new model run, when the humidity fields are initialised with observations, removing the errors that were accumulated during the previous run. The discontinuity represents an artificial adjustment to the humidity, which violates the mass conservation law for water, and so contaminates the derived water balance with a residual. If there is an erroneous model tendency toward increasing the precipitable water, as has occurred during this study, then the discontinuities at the introduction of each new model run will be systematically (monotonic) downward, causing a large negative water balance residual to accumulate over time. The magnitude of a negative residual represents the net mass of water removed from the model atmosphere to keep it close to observations, and so quantifies the systematic tendency in LAPS to accumulate excess atmospheric moisture.

For each of the water balance terms likely sources of error and their relation to the residual have been suggested below. There appears to be significant error in the forecast evaporation, which has little inter-annual variability, indicating a weak dependency on surface water availability. Caution must be applied when attributing possible causes to the water balance residual, as it cannot be partitioned directly into its constituent term(s), due to the interdependence of the moisture processes involved. This results in some suspiciously large evaporation excesses over precipitation during extremely dry conditions, in particular during the 2002-03 summer, and this is likely a significant contributor to the large systematic tendency error during these periods. The forecast moisture flux divergence will contain some error, as it is extremely sensitive to errors in the wind fields, however, it would require a 100% relative error for the moisture flux divergence to be solely responsible for the systematic tendency error. The over-estimation of precipitation during hot and dry conditions produces an error of the opposite sign to the negative residual, and is likely symptomatic of the model tendency to accumulate excess atmospheric moisture during these times.

Future research

The assessment of NWP model forecast water balances, and in particular of their residual term, is a valuable tool for assessing model skill and can be used to complement traditional methods. This research has identified some of strengths and weaknesses of the LAPS model, and this information can now be usefully applied to improving model performance. The apparent over prediction of evaporation during hot dry conditions may well be related to the model's treatment of soil moisture, which provides the source water for evaporation. Soil moisture is currently given an unsophisticated treatment in LAPS, as well is in other state of the art NWP models, and this is an area of on-going research at the Bureau of Meteorology.

References

Kanamitsu, M. and Saha, S. 1996: Systematic tendency errors in budget calculations, *Mon. Weather Rev.*, **124**, 1145-1160.

Puri, K., Dietachmayer, G.S., Mills, G.A., Davidson, N.E., Bowen, R.A. and L.W. Logan. 1998: The new BMRC Limited Area Prediction System, LAPS, *Aust. Met. Mag.*, **47(3)**, 203-223.

Roads, J.O, Chen, S.-C., Kanamitsu, M. and Juang, H. 1998: Vertical structure of humidity and temperature budget residuals over the Mississippi River basin. *J. Geophys. Res.*, **103**, 3741-3759.

Roads, J.O., and co-authors, 2003: GCIP Water and Energy Budget Synthesis (WEBS) *J. Geophys. Res***.** **108**, 8609.

Smirnov, V.V. and Moore, G.W.K. 1999. Spatial and temporal structures of atmospheric water vapor transport in the Mackenzie River Basin, *J. Climate*, **12(3)**, 681-686.

Zangvil, A., Portis, D.H. and Lamb, P.J. 2001. Investigation of the large-scale atmopsheric moisture field over the midwestern United States in relation to summer precipitation. Part 1., *J. Climate*, **14(4)**, 582-597.