Referee Comment

Discussion paper: M. L. Warburton, R. E. Schulze, and G. P. W. Jewitt: Confirmation of ACRU model results for applications in land use and climate change studies.

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General Comments:

This paper is long overdue. It describes the principles of the ACRU model, its land cover sensitive variables, and the successful application in three different South African climates. This provides evidence that ACRU is well suited to simulate the impacts of climate change and land cover change.

While ACRU has been well respected in South Africa for more than two decades, the model is little known outside of southern Africa, although it has been applied in the USA and Germany, and more recently in New Zealand and Canada. The reason for the limited world-wide knowledge of ACRU is that its applications have been surprisingly modestly published in leading international hydrology journals (e.g. Everson, 2001; Kiker et al., 2006; Martinez et al., 2008). The publication of ACRU applications were mainly limited to South African journals (e.g. Schulze et al., 1990; Kienzle and Schulze, 1991; Jewitt and Schulze, 1999; Smithers et al., 2001; New, 2002), and occasional articles in IAHS (e.g. Kienzle, 1993; Smithers et al., 1997) or book chapters (e.g. Schulze et al., 2004). Most ACRU applications and successes were reported in South African Water Research Commission (WRC) Reports, because the WRC was the major funding agency for the development, refinement, and application of ACRU in South Africa. Recently, dynamic snow and basic glacier routines were incorporated into ACRU at the University of Lethbridge, Canada, through strong collaboration with the ACRU team in Pietermaritzburg and a PhD thesis at the University of Jena, Germany, which made ACRU capable of applications in all climates. The ACRU version “for cold regions” was applied in New Zealand and Canada (Kienzle and Schmidt, 2008; Schmidt et al., 2009; Forbes et al., 2010; Nemeth et al., 2010; Kienzle, 2010). The challenge for ACRU applications outside of South Africa is the establishment of relevant data sets required for physically based process models.

This discussion paper contributes to inform a wider audience about ACRU’s wide ranging simulation capabilities. It is an important contribution to summarize ACRU’s strong capabilities in hydrological simulations and describes well its capabilities in simulating the hydrological impacts of land cover or climate change.

The manuscript is well organized and well written. The Tables and Figures provide adequate information and detail about the ACRU model itself, variable settings, and a variety of simulation results. The paper is entirely within the scope of HESS, and while many of the concepts described are not novel in terms of when they were developed, they are presented and summarized in a novel way, and applied to convey a new massage. The scientific methods and assumptions are substantially described, and the objective functions to validate the success of the simulations are well chosen, although both the coefficient of determination and the Nash-Sutcliffe coefficient of efficiency are bias towards peak flow performance rather than low flow performance of the model (a point discussed later). The length and depth of the paper, as well as the inclusion of Tables and Figures, are appropriate.

Specific Comments:

On Calibration

In the Introduction, the authors state that by confirming the performance of a hydrological model through multiple studies, the probability increases that the model is not flawed. ACRU is applied in the studies without parameter fitting, or calibration, and uses well-established South African data sets as inputs. The authors clearly state in Chapter 6 (Discussion) that the simulations were based on nationally available data sets and on ACRU default values, and that no field work for carried out. The following remarks are made to encourage discussion, rather than critiquing the author's modelling approach.

As the authors only use streamflow as the variable to be confirmed, it cannot be ruled out that other combinations of variables, such as using different values for soil redistribution, or the amount of runoff or groundwater reaching the modeling unit, or different initial abstractions, would result in the same, or potentially even better, comparison statistics between simulated and observed time series.

Page 4597, starting Line 5: In my opinion, there is nothing wrong with calibrating certain ACRU variables after the first model run. Many variables, including precipitation, temperature, and many soil variables, particularly soil depth, or groundwater outflow rates, are not known at a high level of certainty. The authors use values described in Chapter 4.4. As each watershed has unique flow paths and velocities, I find it legitimate to calibrate those values using observed streamflow recession curves. For example, the value of 60% of stormflow outflow exiting the watershed on a given day could be calibrated according to observed recession curves. Similarly, the proportion of groundwater outflow on a day can be based on annual hydrographs.

Any calibration should be undertaken very carefully, starting with the most uncertain variable and one variable at a time. The modeller must ensure that the variables are within physically possible bounds and, if possible, are based on local expert knowledge.

The generally high values of the Nash-Sutcliffe efficiency coefficient, particularly in the Lions River, Mpendle, and Koekedou simulations (Tables 6,7 and 8) indicate a strong association with the observed streamflow time series. Through calibration, important verification statistics, such as annual water yield, difference in streamflow variance, or the slope of the regression line, could be improved.

ACRU is clearly confirmed as a model with the required sensitivity to simulate the key hydrological processes that govern the hydrological impacts of land cover or climate change. One requirement for the simulation of climate change or land cover impacts on catchment behaviour is that the water yields must be correctly simulated. Daily streamflows are under-simulated in the Mgeni catchment, and over-simulated in the Luvuvhu and Upper Breede catchments (why is the reported difference of means of streamflow negative, when the simulation is higher than the observed?). In the case of the Mgeni catchment, is this the result of under-simulating the total evapotranspiration, or the result of an over-estimation of precipitation? Beven (2001) states that precipitation correction is legitimate where precipitation surfaces are questionable, such as in mountainous areas. Judging by the number and location of the rainfall stations (Figure 3) used in this study, precipitation is measured at relatively high and relatively representative locations. Therefore, the precipitation surfaces used in ACRU are likely quite realistic. Is the difference between simulated and observed water yields based on poorly calibrated gauging stations, which potentially report streamflows to be lower than they actually are (in which case ACRU's simulated water yield would be correct)? As the streamflow measurement error is typically with 5%, one of the other two systematic errors (precipitation or total evapotranspiration) could be calibrated in the simulation to better match the observed streamflow record. As ACRU has incorporated many routines to calculate potential evapotranspiration, the use of another method would likely change the simulation results.

Is it preferable to apply initial best estimates, or to adjust those values on one's best knowledge?

On Enhanced Evaporation Associated with Forests

ACRU has a "Forest" option to allow for enhanced evaporation from forest canopies. One current weakness of ACRU appears to be that a land cover is either a dense forest or no forest. No transitions between various degrees of canopy cover with associated levels of evaporation enhancements are possible, and are simulated by changing land cover specific interception rates, crop coefficients, or soil water extraction coefficients. The introduction of a seamless transition of levels of evaporation enhancement by means of declaring the percent coverage of trees within a modelling segment may be useful. This may not have significant impacts on the simulated streamflow, and can only be investigated with an appropriate sensitivity analysis in a research catchment.

On Crop Coefficients

ACRU, having its roots from agro-hydrology and later being extended to simulate forest hydrology, uses the term "crop coefficient" to define transpiration coefficients and associated soil evaporation rates relative to a reference evaporation rate. It is suggested that this widely used approach in hydrological modelling be given a more meaningful name, a term that includes all plants, naturally occurring or artificially planted, a herb or a tree. Such a term could be "plant transpiration coefficient", or "vegetation water use coefficient".

On Reported Numerical Values

I have always been a believer that any numerical values reported reflect the uncertainty of the value. The Mgeni catchment is reported to be 4349.42 km^2. As watersheds are delineated from digital elevation models, and as each DEM has inherent errors and inaccuracies, the area should not include decimals. The value of 4350 km^2 is probably accurate enough. The same applies for the Luvuvhu catchment and Upper Breede catchment areas.

The differences in standard deviations are very small for the Luvuvhu and Upper Breede catchments, but could potentially be improved for the Mgeni catchment, particularly in the Henley, but also in the Lions River and Mpendle catchments.

On Land Cover Data

Table 1 contains monthly values for crop coefficients, interception, proportion of rooting depth, and coefficient of initial abstractions for many land uses. This Table alone contains the most important data required for land cover modelling. The collection of these values is extremely useful for any hydrological modeller. These types of values should be compiled for all major land use types in the world. Currently, the application of ACRU is limited to those climate zones similar to southern Africa, for which ACRU was developed. For recent applications in Canada (Forbes et al., 2010; Nemeth et al., 2010; Kienzle, 2010), considerable effort was required to compile the plant specific hydrological variables, such as calculating the monthly plant transpiration coefficients (PTCs) from FluxNet data, as there were no data found in the literature. In the studies by Nemeth et al. (2010) and Kienzle (2010), values for PTCs were calculated from observed meteorological and flux data from grassland, aspen forest, and coniferous forest sites from Fluxnet Canada (2010), and AmeriFlux (2010) flux towers in Alberta, Saskatchewan, and Colorado respectively. Measured latent heat flux data from each station were used to calculate the actual evapotranspiration (AET) for each site, using equation (1) (Hornberger et al. 1998):

$$ET = El / \rho_w * \lambda_v \qquad (1)$$

with

ET = evapotranspiration rate [$m\ s^{-1}$],

El = latent heat flux [$J\ m^{-2}\ s^{-1}$],

ρ_w = density of water [$kg\ m^{-3}$], and

λ_v = latent heat of vaporization [$2.45 \times 10^6\ J\ kg^{-1}$].

One of the main powers of ACRU is not the sophisticated model itself, but it is the extensive and comprehensive datasets that the ACRU team compiled over many years for the southern African sub-continent. Hydrological models that are land cover sensitive rely on these important datasets. Therefore, states or provinces, and certainly countries, should facilitate the establishment of hydrological land cover variables. Through remote sensing and GIS analyses, detailed land cover files become available at increasing frequencies and detail with decreasing costs for many regions of the world. The translation of these land cover maps into required hydrological variables would improve the quality, and certainly the preparation time, of hydrological simulations.

On Delineating Modelling Units

Figure 6 presents a very interesting way to further subdivide the subcatchments. The concept is a hydrid between an HRU approach and a strict watershed approach, honouring the processes within one subcatchment boundary, while distinguishing different runoff behaviours based on land cover, and maintaining a conceptually realistic, cascading flow routing through the watershed. The question is whether the cascading flow routing is necessary, as the subwatersheds are all a few hundred km^2 large, and one would expect that most streamflow produced on a given day would run off the same day. A comparison of the cascading vs non-cascading, i.e. all land use units flow directly to the outlet, would shed light into this question.

On Simulation Results

The simulation results of monthly streamflow presented in Figure 7, 8 and 9 is commendable. The visual comparison of simulated and observed streamflow using a logarithmic y-axis would facilitate the evaluation of the success of the simulation of low flows. As low flows are typically more sensitive to land cover or climate change than peak flow, and thus are under more severe risk to sustain the needs of water users, and in particular the aquatic habitat, special attention should be given when evaluating the simulation success of low flows. It appears that the simulated low flows in the Upper Breede catchment are consistently over-simulated. The question of potential re-calibration re-appears.

The statement made on Page 4605, Line 7, on the Nash-Sutcliffe coefficient is weak, when the authors state that values of E_f of greater than zero are preferred. An E_f of zero means that the simulation is as good a using the mean of all streamflow values, rendering the simulation useless. Therefore, E_f must be clearly above zero, similar in magnitude than the coefficient of determination, to demonstrate a meaningful simulation.

Technical Corrections:

Abstract:

- Line 4: change “will be” to “are”
- Line 9: add comma after “thereof”
- Line 14: either add a comma or “and” after “semi-arid”
- Line 25: replace “could” with “can”

Introduction:

- Page 4593, Line 3: add a comma before “such as”
- Page 4594, Line 17, and Page 4608, Line 15: replace “models” with “model’s”
- Line 21: add comma before “i.e.”, or better, finish sentence after “validated”, then start new sentence with “By”.
- Page 4595, Line 19: add comma after “(Table 1)”

- Page 4596, Line 2: add comma before "which"
- Page 4598, Line 9 and throughout the document: replace "mm.p.a" with "mm p.a."
- Page 4599, Line 6: Can quality be good? It can be high or low, or poor or rich.
- Page 4599, Line 26: add comma after "(2004)"
- Page 4601, Line 6: replace the second "delineated" in this sentence with "subdivided"
- Page 4608, Line 21, and Page 4609, Line 24: Delete comma after "Although"
- Page 4609, Line 5, and Page 4610, Line 7: Add commas before and after "therefore"

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