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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Climate and water

Optimising weather forecast models to improve rainfall prediction

A completed Water Research Commission (WRC) study investigated the most suitable parameterisation of the Weather Research and Forecast (WRF) model to represent observed rainfall events.

Background

Numerical weather prediction models (NWPs) are tools used to forecast rainfall based on current meteorological conditions and how they are expected to develop. Some challenges when modelling are: it is impossible to solve all atmospheric processes explicitly as they are too numerous and often involve more unknown variables than those known, and a single process may be driven by multiple forces, which are represented to a greater or lesser extent in the model. The aim of this work is to simulate rainfall using a NWP, and determine which parameterisation schemes within the model produce the best results.

The Weather Research and Forecast (WRF) model is a numerical weather prediction model that simulates grid scale saturation and convective rainfall, which is a sub-grid scale process. Several parameterisation schemes are available for each of these processes, which perform with varying degrees of success.

Thus, when running a forecast which may cover a large area such as the whole of South Africa that experiences both rainfall types, only a single combination of schemes is applied. This may then favour one rainfall type, such as convective rainfall, to the detriment of non-convective rainfall forecasts.

WRC project objectives

The aim of this project was to determine the most suitable parameterisation of WRF to represent observed rainfall events in both convective and non-convective rainfall areas in South Africa and to create institutional and professional capacity in:

- Numerical weather prediction models in simulating and verifying rainfall using the WRF model v3.4.1)
- Hydrological modelling using the PyTopkapi model
- WRFChem modelling and its effect on rainfall.

These aims were achieved through simulation of rainfall over two catchments in South Africa: the Berg River catchment in the Western Cape and the Liebenbergsvlei catchment in the Free State. Verification of rainfall was achieved through 1) WRF to rain gauge comparison and 2) WRF rainfall entered into a hydrological model, PyTopkapi and compared to streamflow data.

The final objective was achieved through running WRFChem over the industrialised Highveld of South Africa, where emissions are expected to change the concentration of cloud condensation nuclei and therefore cloud droplet physics and rainfall patterns.

Main results

The research team found that WRF had a positive daily bias for the Liebenbergsvlei catchment, ranging from < 1 mm to > 4 mm for 12 km resolution domains. The Berg River catchment produced positive bias results of < 2 mm for the same domain.

Three factors that cause the positive bias over Liebenbergsvlei were identified. These were:

- Surplus rain days in the model
- Early triggering and formation of convective rainfall and
- Excessive grid scale saturation and rainfall at night.

The most defensible scenarios, in terms of physics and frequency of calls to the solvers, were WSM3-Tiedtke-cudtO and Lin-Tiedtke-cudt0 (radt=12 for both scenarios) and produced daily bias for less than 2 mm.

Both schemes stuck a balance between achieving hits, while minimising false alarms. Thus, considering all metrics presented, these two scenarios performed most favourably across the board.

It is shown that for these schemes, false alarm events are not as high (in terms of mm rainfall) as other schemes, and that over predictions are not as high (< 5 mm). In terms of total rainfall in the catchment over a three-month period, the WSM3-Tiedtke combination of schemes produced the most realistic results.

Observed rainfall shows a diurnal cycle where most rainfall occurs after midday. The WRF model shows that convective rainfall triggers too early for all scenarios.

Non-convective rainfall is the dominant observed rainfall for this catchment, and as such, the Betts-Miller-Janjic convective scheme, with either the WSM3 or Lin microphysics was suitable for the Berg River.

The 4 km domains produced lower positive bias over Liebenbergsvlei. Three scenarios were run; Thompson microphysics, WSM3-bmj AND wsm3-Grell-3D. The daily bias was 1.31 mm, 1.06 mm and 1.84 mm respectively.

PyTopkapi

Rainfall from WRF over the Berg domain performed surprisingly well, achieving a Nash-Sutcliffe Efficiency of 0.479. For Liebenbergsvlei further improvements to WRF rainfall simulations are required before use of WRF rainfall in PyTopkapi. It was decided, based on results, to cease any further hydrological modelling as it would not yield meaningful results.

WRFChem

WRFChem results showed an overall increase in rainfall over the region when emissions from the global emissions inventory was switched on. This increase was attained through an increase in non-convective rainfall. The increase in non-convective rainfall was achieved during low rainfall events when emissions of S02 and particulate matter and associated feedback mechanisms were implemented.

Conclusions

Each catchment required different schemes to suitably model daily rainfall when running 12 km model domains. The best performing schemes for modelling rainfall over Liebenbergsvlei were the WSM3-Tiedtke-cudt0 and Lin-Tiedt-cudt0.

These schemes were implemented at a 12 km resolution, but both schemes trigger too early in the day and cause excessive rain days. Subsequently, WRF is currently over-active at modelling convective rainfall over the eastern part of South Africa at this resolution and improvements to the model are required when modelling at this resolution.

The Liebenbergsvlei 4 km results did now show a significant improvement, but may indicate why the model is over predicting rainfall. These results suggest that there is either too much moisture in the model, which condenses and rains, or that the temperature profile is not correct causing too much cooling, or it is a combination of both.

The Betts-Miller-Janjic convective scheme, with either the WSM3 of Lin microphysics was suitable for the Berg River 12 km domain. However, these schemes did not perform well for Liebenbergsvlei.

Arguably, the 4 km domain results did not outperform the 12 km results presented in section 8.6, as the hit rates, hit ratios and daily bias results were less favourable compared to the WSM3-BMJ and Lin-BMJ scenarios.

Recommendations for future research

Two possibilities exist for future research. The first is to include a large sample size for comparing the mode to observed data. This would require modelling six months, instead of three, over five seasons. This may be long enough to negate any bias in choosing a single observed rainfall season, which may be the anomaly in a five- or ten-year period.

The second option is to investigate the model code and determine why rainfall is triggered early. If identified, this can be adjusted so that the early trigger is delayed. However, this requires much testing as it may create errors elsewhere in the model.

Two recommendations are made. The first is to model at 4 km resolution whenever possible using the correct microphysics scheme for the study area. However, this is not always feasible in which case the following suggestion is made for modelling rainfall at 12 km resolution: choose the correct schemes for your area of interest. If your domain contains both areas, eg Western Cape and Eastern Escarpment, and you are running a forecast, run two instances of the model, one with each set up.

Further reading:
To order the report, *WRF rainfall parameterisation and verification* (**Report No. 2162/1/14**) contact Publications at Tel: (012) 330-0340, Email: orders@wrc.org.za or Visit: www.wrc.org.za to download a free copy.