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Programme for the development of weather and climate numerical modelling systems in South Africa

Weather and climate numerical models have been in use in South Africa for many decades, both in operational and research mode.[1] All the models currently in use for operational purposes in the country were developed in developed countries. South African scientists started participating in the development or improvement of weather and climate numerical models in 2002, after being inactive in the area for over a decade.[2] The regeneration of model development activities started at the University of Pretoria through a Water Research Commission funded project in which a dynamical core of a non-hydrostatic sigma coordinate model (NSM) was developed from scratch.[3] These activities served to encourage others in the country to also contribute in the model development space. The NSM was later extended to include moisture and microphysics schemes at the Council for Scientific and Industrial Research (CSIR) in collaboration with the University of Pretoria.[4,5] This model is currently only available for use in research mode; however, the underlying dynamics are similar to those used in an operational model used at CSIR.

Most other model development activities in the country build on existing modelling systems from developed countries. For example, Abiodun et al.[6,7] improved the dynamical core of the Community Atmosphere Model (CAM) to use a stretched grid with higher resolution over an area or process of interest while at Iowa State University and continued the development after moving to the University of Cape Town. Model development activities in the country also include the coupling of different components of the earth system. Beraki et al.[8] coupled the European Centre Hamburg Model 4.5 (ECHAM4.5) to the Modular Ocean Model 3 (MOM3) at the South African Weather Service (SAWS).

A recent development is the configuration of the first African-based Earth System Model at the CSIR, through a collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO).[9,10] The Variable-resolution Earth System Model (VrESM) became the first African-based model to register for the Coupled Model Intercomparison Project (CMIP6) in 2016. It uses as atmospheric and land-surface components the Conformal Cubic Atmospheric Model (CCAM) and CSIRO Atmosphere Biosphere Land Exchange (CABLE) models of the CSIRO, whilst the ocean component VCOM (Variable-cubic Ocean Model) was developed at the CSIR. Development activities are focused on different aspects of the earth system, including the carbon cycle, and the project will allow Africa to contribute global simulations towards the generation of Assessment Report Six (AR6) of the Intergovernmental Panel on Climate Change (IPCC) and the associated CMIP6. In 2019, the Global Change Institute of the University of the Witwatersrand launched a new programme in Earth System Model Development, with an associated postgraduate programme.

Despite model development activities beginning over a decade ago, the progress in model development activities in the country has been slow, and the number of people who truly understand models and can contribute to the model development exercise remains low. Discussions on possible collaboration efforts and information sharing amongst those working on model development started in 2017. The intention is that when model developers in the country work together, model development activities will be accelerated. Although the different organisations use different models, similar issues such as a lack of solutions for certain resolutions apply to all models. Some sub-grid schemes are used in a number of models, and so an understanding of the performance of such schemes when linked to different dynamics can be of mutual benefit to all organisations involved. Together, the different organisations can identify common training needs and co-organise training workshops to deal with known shortcomings in the country. Furthermore, through working together, the country can become an independent developer of weather and climate models (whilst strengthening collaboration in this field with international model development centres).

A workshop on model development was held at SAWS on 28 October 2017 during which researchers from SAWS, CSIR, University of Pretoria and University of Cape Town who have made contributions met to discuss ideas on how the country can accelerate model development activities. Prof. David Randall from Colorado State University in the USA, Prof. Robert Plant from the University of Reading in the UK, as well as Dr John McGregor from CSIRO in Australia were invited to contribute through an online platform and provide advice to the workshop delegates. Modelling activities taking place in the participating organisations were discussed, as were future plans to inform the development of a programme that aligns with the strategic objectives of each of the participating organisations/institutions. A plan was developed in 2018 and shared with individuals who have model development experience at the University of Cape Town, University of Pretoria, SAWS and CSIR and was also presented to the meteorological community in South Africa at the 2018 annual conference of the South African Society for Atmospheric Sciences.

The purpose of the programme is to establish an environment that will enable the weather and climate operational obligations of South Africa to be met using homegrown models within 10 years. The homegrown models will also be used for research purposes and to meet policy requirements such as the National Communications on Climate Change and National Adaptation Strategy.

The main goal of the framework is to ensure that there is a coordinated weather and climate numerical model development effort in South Africa which can lead to the following outcomes:

- South Africa becomes an independent developer of numerical weather and climate models.
- South Africa contributes to new trends in model development instead of waiting for others to develop schemes suitable for Africa.

- Local domain expertise on different systems such as African thunderstorms, aerosols and the Southern Ocean is incorporated into the models.
- A closer relationship between model developers at universities and SAWS to ensure that research conducted outside of SAWS benefits operational activities of SAWS, and earth system modelling at the CSIR and University of the Witwatersrand.
- Expertise is developed not only to identify biases and weaknesses in models, but to also improve models.
- Strengthened synergies between the institutions involved in model development and the Centre for High Performance Computing of the CSIR, towards also strengthening high-performance computing skills in South Africa.
- Increased support for postgraduate students working on model development activities at universities and hosting of some of the students by research organisations.
- Model development activities support policymaking and national initiatives.
- Improved understanding of local processes and hence improvement in models.
- Increased collaboration with model developers internationally.
- More opportunities for programming training necessary for model development.

The planned activities consider the past and ongoing efforts in the country, which will provide a good launch pad to enhanced model development. The implementation of the programme will be led by a steering committee comprising individuals from a number of participating local organisations and will also include two international experts as well as one PhD student. Contributions will be made in two main ways:

- Creation of models that are fully developed in South Africa. These may include atmospheric, ocean, land-surface and sea-ice models. This contribution includes model development that builds on existing models with a significant contribution from South Africa to the extent that South Africa can be considered as a lead in the development process.
- Participation in open/partnership model development activities internationally. This contribution will include model development activities in open-source models such as CCAM, Weather Research and Forecasting (WRF) and CAM, as well as somewhat closed/licenced models for which a formalised relationship is required before model contributions can be made.

International working groups focusing on models provide opportunities for the scientific community to discuss common issues in models. One such group is the Working Group on Numerical Experimentation (WGNE), which is responsible for fostering the development of atmospheric circulation models for use in weather, climate, water and environmental prediction on all time scales and diagnosing and resolving shortcomings. WGNE was jointly established by the World Climate Research Programme (WCRP) Joint Scientific Committee and the WMO Commission for Atmospheric Sciences (CAS). Another working group is the Panel on Global Atmospheric Systems Studies (Pan GASS) which is under the Global Energy and Water cycle Exchanges (GEWEX) project. Pan GASS facilitates and supports the international community that carries out and uses observations, process studies and numerical model experiments with the goal of developing and improving the representation of the atmosphere in weather and climate models. Model development activities in the country will consider work done by these international bodies and others. The model development activities will also be conducted in collaboration with partners globally.

Work will be conducted across timescales so that activities are able to benefit weather forecasting as well as climate predictions and projections. South African scientists are involved in a wide range of modelling studies, and some are related to the WGNE or Pan GASS identified topics, as well as the model intercomparisons undertaken through CMIP6 and Co-ordinated Regional Downscaling Experiment (CORDEX). Topics of interest which will be addressed using models with different complexities, including idealised models, are, among others:

- thunderstorms;
- direct and indirect effects of aerosols;
- stratospheric variability influence on weather and climate;
- mid-latitude synoptic storms prediction and changes under climate change;
- precipitation and temperature diurnal cycle;
- heatwave frequency, intensity and duration in the current and future climate;
- ocean-atmosphere and land-atmosphere feedbacks;
- stratospheric-tropospheric coupling problems; and
- baroclinic instability and baroclinic life cycles.

In diagnosing sources of errors identified in the simulations, sensitivity studies will consider different aspects of the model. The different areas to be considered are:

- convection schemes;
- microphysics schemes;
- atmospheric turbulence schemes;
- surface representation;
- interactions of different components; and
- dynamical cores and numerical methods.

Human resource capital development steps will be undertaken through postgraduate studies, and winter/summer schools to increase the critical mass with model development skills. Workshops, seminars and tutorials organised internationally will also be considered. The model development research will be conducted by scientists who are permanently employed at science councils and institutions of higher learning, postdoctoral fellows as well as PhD students.

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