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PRACTICE PAPER

A Regional Project in Support of the SADC Cyber-Infrastructure Framework Implementation: Weather and Climate

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Early warning systems in the areas of weather and climate for supporting decision making and strategic intervention in key sectors (e.g. water, health, energy, disaster risk management, and agriculture) rely on the use of earth observations and numerical models that require supercomputing resources. Such resources are now primarily provided through High Performance Computing (HPC) facilities. As a result of a global increase in availability and accessibility of supercomputing HPC facilities, numerical models that can now be employed have become more complex. Furthermore, resolutions now used and achievable have increased significantly.

The Southern African Development Community (SADC) Cyber-Infrastructure (CI) Framework aims to build increased capacity in regional research and education networks, data sharing infrastructure and trained human capital – to make efficient and effective use of the CI resources. Through the implementation of the regional CI framework and national initiatives, several member states in Southern Africa now have HPC facilities. The availability of this infrastructure in the region provides opportunities for domains, domain scientists and collaboration through research and development projects. For meteorology, this will support more local and regional weather and climate scientists. For meteorological services, this will mean increased in-house and in-country capacity to run models, with less reliance on external resources from developed countries. This paper discusses a regional weather and climate implementation project of the SADC CI.

Keywords: SADC, cyber-infrastructure; weather forecasting; climate change and variability; numerical modelling; remote sensing

1. Introduction

Natural hazards can significantly impact economies, and may seriously undermine sustainable development and the attainment of Sustainable Development Goals (SDGs) particularly in developing countries. Nearly twenty thousand people have been killed and 40 million affected by floods in Africa in the period 1900 to 2006, with damage costs estimated at about US$4 billion (ISCU, 2007). Lukamba (2010) analysed the impact of natural hazards over Africa, and found droughts and floods to be amongst the most frequently experienced natural hazards in Southern Africa. Recently, tropical cyclone Idai made landfall over Mozambique and resulted in over 1000 deaths in Mozambique, Zimbabwe and Malawi.

Both developed and developing countries are affected by hazards. High-upper-middle income countries mainly experience damage to property (reportedly estimated at 93% of the total global damage by storms), because they have more built infrastructure (World Bank, 2010). However, by contrast, most of the reported lives lost are in lower-middle-income countries (89%), even though these countries only experienced approximately 26% of the storms (CRED, 2015). Lower mortalities in developed countries are associated with well-developed early warning systems (e.g. Lubchenco and Karl, 2012), and disaster management systems.

Countries in Africa must adapt to a changing climate. Climate change manifests itself through changes in the mean climate, and in shifts in extremes (Meehl et al., 2000; IPCC, 2018). Engelbrecht et al. (2015) demonstrated, for example, that temperatures over the subtropics and central tropical Africa have been rising at double the global rate. The African continent is thought to be more vulnerable to the effects of climate change due to the reliance of its economies on weather and climate sensitive sectors such as agriculture, that supports a large base of its rural population.

When acted upon, timely, accurate and reliable weather warnings may help reduce the effects of weather and climate hazards (Lubchenco and Karl, 2012). Early warning systems rely on the use of earth observations and numerical models that require high-end supercomputing facilities to analyse or produce simulations with high spatial resolution (Dickinson et al., 2002) timeously. The earth observation and computing infrastructure needed to produce weather and climate services is prohibitively capital intensive (and requires regular upgrades and continuous maintenance- which are also both costly). As a result, most African countries have historically relied on simulations produced in developed countries.

In the recent past, supercomputing facilities have become increasingly available to the SADC region through national and regional initiatives. The availability of these facilities has a number of implications, including;

- Numerical models may now be run by those previously unable to do so;
- Simulations can be made with higher resolution (e.g. Mass et al., 2002);
- Physics and dynamics in models may be made more complex;
- A higher number of simulations (ensembles) can be produced to account for uncertainties associated with errors in observations and internal variability of the earth system (Hong and Dudhia, 2012); and
- Models may now be run with coupled components of the earth system (Valcke et al., 2012).

Such possibilities also mean that the amount of data generated and that needs to be analysed, will increase significantly. Furthermore, data from earth observations (that are also crucial for the development of early warning systems) also increases as more satellites are launched. In addition, temporal and spatial resolutions have also increased (Siewert et al., 2010).

This paper discusses a weather and climate project that responds to, and addresses the Research and Development pillar of the SADC CI Framework discussed next. The project will help support the development of weather and climate early warning systems; help with decision making to enable adaptation to climate change; and allow different countries to build and exchange data and expertise, through efficient usage of available infrastructure.

2. SADC Cyber-Infrastructure Framework

The SADC CI Framework was approved in June 2016 by SADC Ministers responsible for Education, Science, Technology and Innovation. The components of CI are High Performance Computing (HPC), National Research and Education networks (NRENs), Data, Policies and Human Capital Development (SADC, 2016 & Motshegwa et al., 2018.) The Framework is aimed at providing a roadmap to enhance and develop a holistic cyber-infrastructure System in the SADC region to:

- Impact socio-economic development and industrialization;
- Enhance education, not simply in educating people in developing technologies, but also in their use; and
- Support collaborative research development and innovation (SADC, 2016).

The SADC CI Framework proposes a number of focus and areas, namely

1. Infrastructure Development;
2. Human Capital Development;
3. Education, Research & Development and Innovation;
4. Policy/Strategy Development, institutionalisation, implementation support;
5. Resource Mobilization, Communication, Awareness & Advocacy; and
6. Strategic Partnerships.

Through the implementation of the infrastructure development pillar of the Framework, a number of countries within the SADC region have acquired and deployed HPC facilities. To make the CI impactful, there is a need for regional projects in sectors of regional importance. During the SADC CI technical experts meeting, which took place on 4–5 December 2017 in Pretoria, South Africa, a project on weather and climate was discussed for consideration as part of the SADC CI Framework implementation plan.

3. Methodology

A situational analysis study was conducted through a questionnaire to inform the development of the project plans and objectives. A questionnaire was sent out through email by the SADC secretariat to the Science and Technology Permanent Representatives (PRs), as well as Meteorology PRs in April 2018. The Meteorological Association of Southern Africa (MASA) assisted with the distribution and reminders to Meteorological and Hydrological Services to respond to the questionnaire. The questions were more geared towards the meteorology sector, since they sought to find out information regarding operational weather and climate activities, and access to weather related remote sensing data – which are services aligned with mandates of meteorological services. The questionnaire also included questions regarding the available HPC systems in the different countries. The respondents answered the following questions:

– Do you produce weather, extended range, seasonal forecasts on an operational basis?
– Do you conduct research on weather, extended range, seasonal, and multi-decadal timescales?
– In order to produce the forecasts or conduct research, do you run models?
– If you run models, which models and grid spacing do you use?
– If you use simulations generated elsewhere, do you get access to the data or only images?
– Do you have a storage facility to save data and a platform to analyse data?
– Do you have an inhouse HPC system? If yes, what is the number of nodes, number of cores per node and storage facility size? If no, is there a system that you can access nationally?
– Do you have a weather radar or lightning detection network?
– Do you have access to the Meteosat Second Generation data operationally?
– Which softwares do you use to analyse data you generate/receive?
– Do you run application models (e.g. crop, hydrology, energy, health) that use weather and climate data as input?
– Does your data policy allow you to share your observation and simulations for research purposes?

Information on the available HPC infrastructure nationally was further obtained through CI experts, who are the developers of the SADC CI Framework. While the questionnaires were sent to 15 countries, responses were received from eight, primarily from Meteorological Services. The countries that responded are as follows:

- Angola
- Botswana
- Eswatini
- Mauritius
- Namibia
- South Africa
- Tanzania
- Zambia

4. Results

In this section, results obtained from the survey are summarised and discussed. The first part of the discussion focuses on remote sensing data used in the region, while the second part discusses HPC facilities available in different countries. The last section focuses on numerical modelling at different timescales, and also includes a discussion of models used in the region.

4.1 Remote Sensing

All meteorological services indicated that they have access to the Meteosat Second Generation (MSG) products, which is a project of European Space Agency (ESA) and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) (**Figure 1**). MSG is a geostationary satellite, and is therefore able to provide the high temporal resolution necessary for tracking storms over Europe, Africa and Middle East, which are regions covered by this satellite. One country has access to a radar network, while another indicated plans to acquire an operational radar by the end of 2018. This is in contrast to the radar network availability in Europe, where countries of comparatively small size have 10 or more radars covering the country. Two of the countries surveyed have access to a lightning detection network data. These near real time observations are crucial for nowcasting purposes, and if dissemination techniques are advanced, the public can be warned of impending storms from a few minutes to about two hours in advance. Satellite remains the most accessible form of near real-time observation in the region. Remote sensing data may also be used as input to numerical models for data assimilation, as well as for verification purposes. It may be noted that the data coverage of some of these remote sensing instruments may also include areas outside of the country in which they are deployed. For example, the radar network of South Africa (**Figure 2**) also covers the

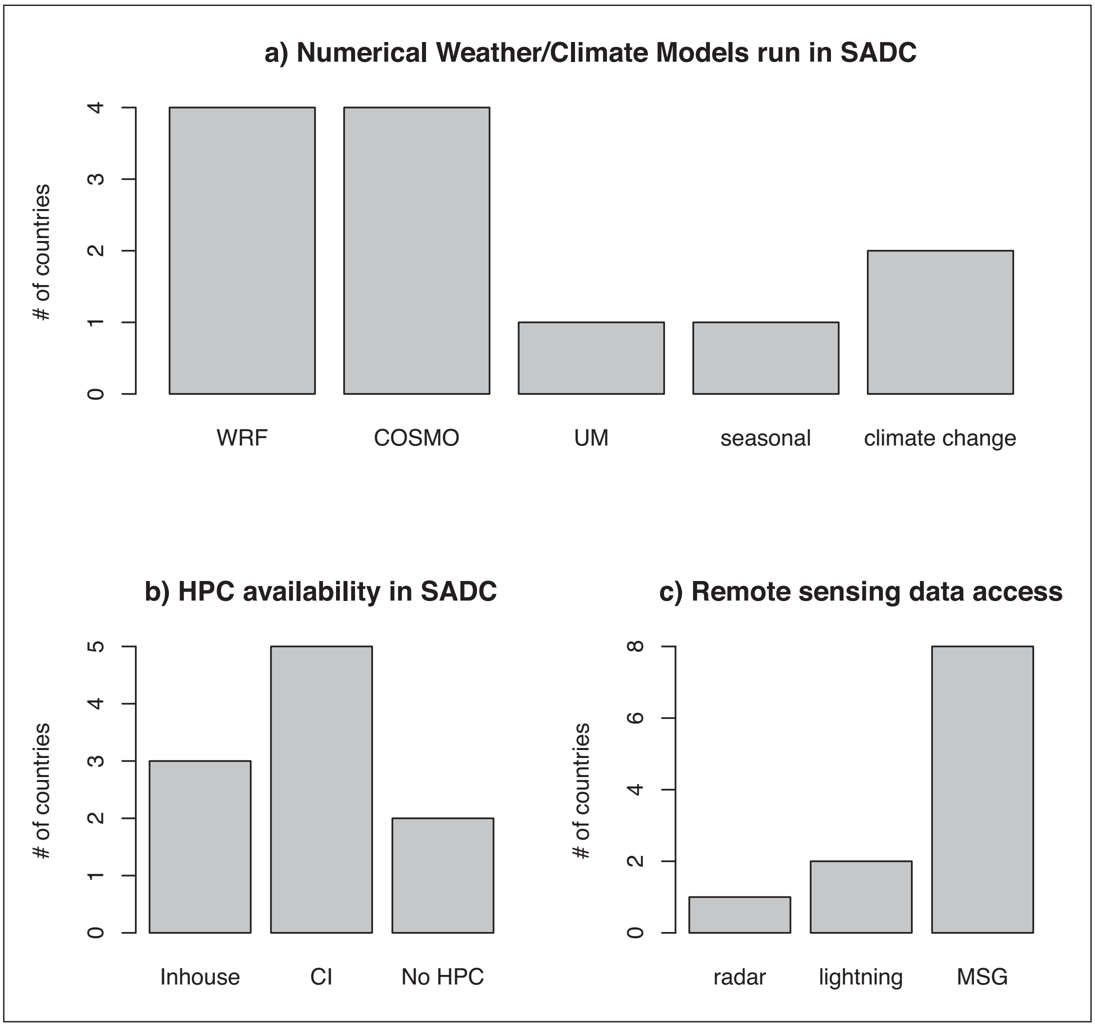

Figure 1: Survey results from the questionnaire with **a)** showing numerical models used for NWP purposes, the number of countries running a numerical model at seasonal timescale and those running for multi-decadal timescale, **b)** the HPC system availability, **c)** availability of remote sensing data in the 8 countries that responded to the questionnaire.

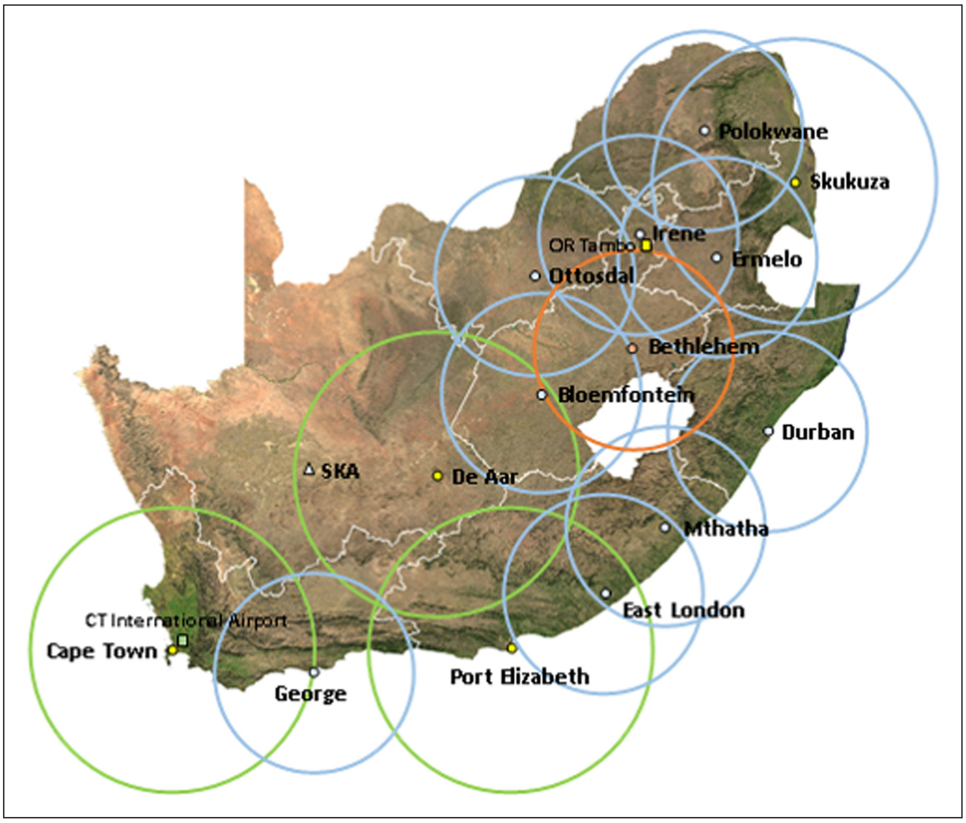

Figure 2: Radar network of the South African Weather Service.

whole of Swaziland and Lesotho and parts of Mozambique, Zimbabwe and Botswana. There is also benefit in merging different radar datasets and, therefore, if different countries have radar systems, merging radar data can improve radar data quality control, as well as product development, which can be made possible by cross-border data sharing. It may be noted that data policies of Meteorological Services within the region are generally not available publicly. This project may thus serve as a vehicle to allow engagements amongst scientists from different countries around data sharing for research purposes.

4.2 HPC facilities

Three of the countries indicated that they have in-house HPC facilities hosted by their Meteorological Services. Note that in **Figure 1b**, whilst the systems' architecture specifications were not requested, the number of nodes and cores on the HPC system were requested. One Meteorological Service hosts an HPC system with 168 nodes with 24 processors each, and a storage facility of 1.7PB; while the second country indicated 16 nodes in total which are split into 8 nodes with 16 cores and 8 cores, and a total storage of 25.2 TB. The third country indicated that they have a system with 12 nodes, but did not indicate the number of cores nor amount of storage available. Two of the countries do not have HPC systems, and there is no indication that such system are hosted anywhere within the country.

Five of the countries that responded to the questionnaire also have HPC systems that were acquired though the SADC HPC ecosystems project (from the infrastructure development pillar of the Framework). The HPC ecosystems project commissioned sites with the deployments of decommissioned HPC systems in SKA partner countries. The first system that was deployed is the Texas Advanced Computing Center (TACC) SunBlade X6048 series – compute racks were sent to institutions in Botswana, Tanzania, Namibia, Zambia and Mauritius (**Table 1**; **Figure 3**). The University of Cambridge Dell M1000e was deployed in Madagascar. Parts of the two decommissioned systems mentioned above, as well as the CHPC Sun cluster system were deployed in a number of universities in South Africa for training purposes. There are planned deployments in Mozambique and Kenya. Two of these countries already have HPC systems within their Meteorological Services, while for three of the countries, there is a need for the Meteorological Services to work closely with hosts of the HPC systems. Two of the eight countries have additional HPC systems that were procured through national initiatives. The Meteorological Services were, in general, found not be aware of opportunities made possible through the SADC CI framework, and there is thus a need for a platform that will allow close collaboration between CI specialists and meteorologists.

Table 1: Showing specification of SADC HPC Ecosystems Hardware deployments.

Name	System	Cores per rack	RAM per rack
Ranger	Sun Blade 604	768	3TB (upto 64GB per node)
Cambridge	Dell M100e	192	2TB
Dell Westmere	Dell C6100	2880	8.6TB

Figure 3: A map showing countries in which HPC systems decommissioned from TACC and Cambridge were deployed.

4.3 Numerical Modelling

Numerical models are helpful for producing forecasts beyond the nowcasting timescale, where extrapolating near real-time observations has little value. These models are used for weather forecasting up to two weeks, for seasonal predictions, as well as multi-decadal climate change projections. The use of HPC systems allows for these models to be run with high resolution, and produce simulations in a timely manner for use by forecasters, as well as users of simulations in different sectors.

4.3.1 Numerical Weather Prediction

Six of the countries indicated that they run Numerical Weather Prediction (NWP) models for either research or operational purposes, with three countries running these models on HPC systems. The models used include the Weather Research and Forecasting (WRF) model (Powers et al., 2017), the Consortium for Small-scale Modeling (COSMO) system (Baldauf et al., 2011), and UK Met Office (UKMO) Unified Model (UM) (Davies et al., 2005). COSMO and UM are associated with licence or collaboration fees when used operationally, while WRF is open source. WRF and COSMO are used in four of the countries each that responded to the questionnaire, while the UM is used in one country (**Figure 1**).

Three of the countries run NWP models with a horizontal grid spacing of 5km and less, which is considered as convective scale. The only numerical model which is an atmosphere-ocean model run in the region for seasonal timescales is run with a grid spacing of approximately 250km. One country did not specify the resolution used, while another uses a grid spacing of 12km and 14km-this is about the same as the resolution used by global NWP models.

Limitations indicated by the survey in the region highlight a need for resources, data sharing, and skills transfer. Tropical cyclone Dineo is a good example of the type of weather system that may affect a number of countries at once, indicating a clear need for regional collaboration – affecting Mozambique, Swaziland, and Zimbabwe, South Africa, as well as Botswana (**Figure 4**). More recently, in March 2019, tropical cyclone Idai significantly impacted Mozambique, Malawi and Zimbabwe. To maximise the probability of forecasting high impact events, there is a need to run multi-models or ensemble members (potentially run in different countries) over overlapping transboundary regions (Hong and Dudhia, 2012).

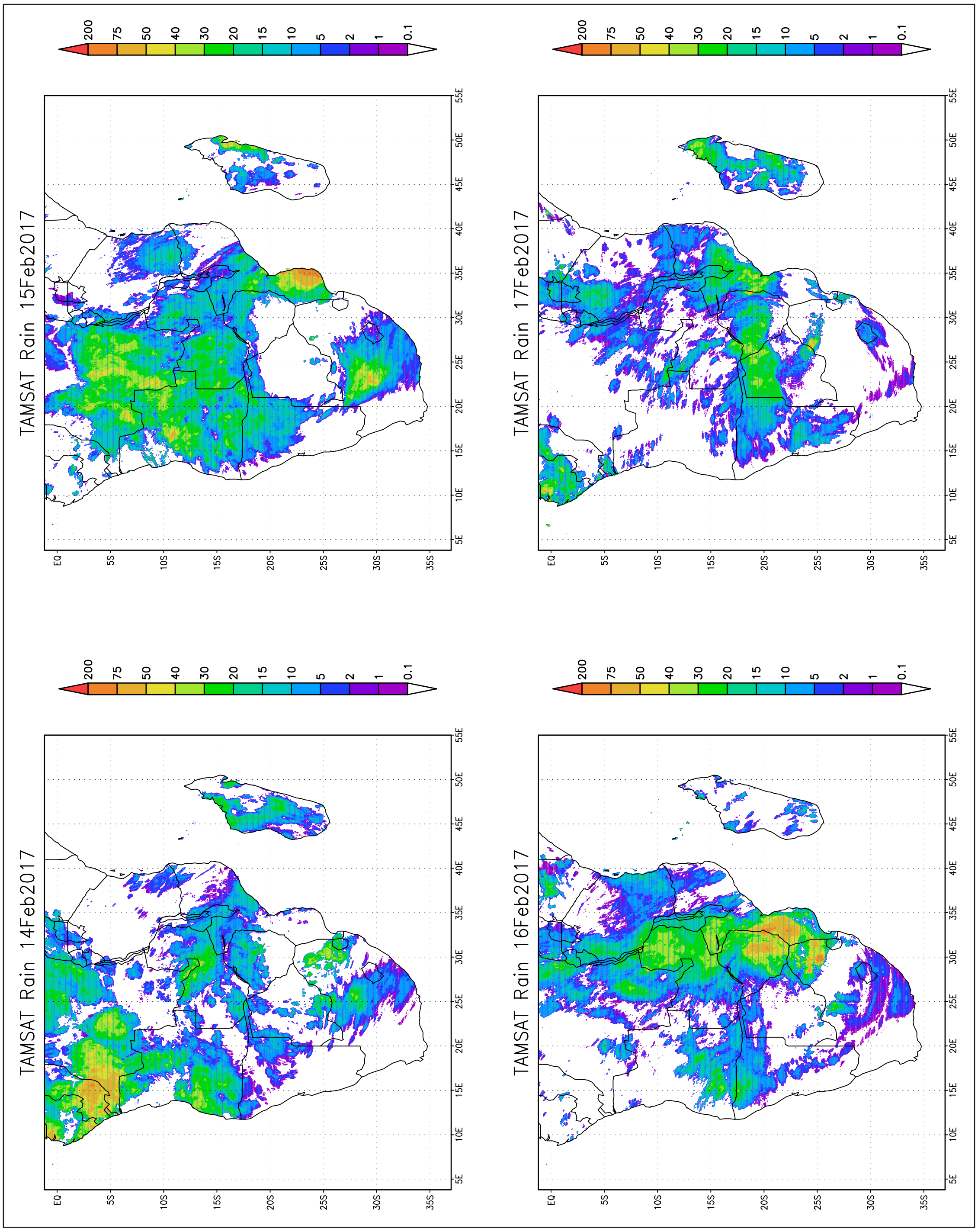

Figure 4: Precipitation estimation of the Tropical Applications of Meteorology using SATellite data and ground-based observations (TAMSAT Maidment et al., 2017) for the 14, 15, 16, and 17th of February 2017 over Southern Africa.

4.3.2 Seasonal Timescales

Six of the countries that responded indicated that they produce seasonal forecasts. This is, in part, indicative of the influence of the Southern African Regional Climate Outlook Forum (SARCOF) process, which makes it possible for SADC member states to meet on an annual basis to discuss and consolidate regional forecasts. The majority of the countries downscale global simulations using statistical methods. South Africa produces seasonal forecasts using an ocean-atmosphere coupled model, and also has the World Meteorological Organization status of a global producing centre. As in the case of NWP, there is benefit at seasonal timescales in using multi-models, ensembles and increasing resolution.

4.3.3 Climate Change

Three of the countries that responded indicated that they conduct climate change research. One Meteorological service uses the WRF model, while another uses simulations from the Coordinated Research Downscaling Experiment (CORDEX) project. It may be noted that the Council for Scientific and Industrial Research (CSIR) in South Africa also produces dynamical downscaled simulations for the whole African continent (e.g. Engelbrecht et al., 2015). The same institution is in the process of developing an Earth System model that will be used to contribute to the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report. The development of this model is a collaborative effort with Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia and with the University of the Witwatersrand (Wits). The atmospheric component of the system is based on the Conformal Cubic Atmospheric Model (CCAM), land surface on CSIRO Atmosphere Biosphere Land. Exchange (CABLE) developed at CSIRO, whilst the ocean component VCOM (Variable-cubic Ocean Model) is developed at CSIR and Wits (Engelbrecht et al., 2012).

5. Summary, Conclusions and Way Forward

A project on weather and climate was agreed on by the Cyber-Infrastructure experts in December of 2017, to respond to clear existing needs. In order to inform the focus areas of the project, a situational analysis was conducted to establish whether Meteorological Services and/or Universities in the SADC region analyse weather and climate data, run models, use remote sensing data, and to investigate which software tools are being used. The results received indicate the presence of modelling and data analysis activities in the region across all timescales, yet there is limited capacity regarding the use of HPC systems to run models, and the capacity varies across the region.

Meteorological Services were in general not aware of HPC facilities that were available within their countries through the HPC ecosystems project. There is thus also a need for the Meteorological Services to engage with the cyber-infrastructure experts in their countries, so they are aware of the infrastructure that is available either for research or potentially for operations. This project intends to provide that opportunity regionally. When asked if they can share data for non-commercial purposes, all the countries indicated that their data policy allows for sharing of data – however with some applicable conditions. The Meteorological Services are members of the WMO, and therefore follow the WMO resolutions 40 and 25 on data sharing, which make provision for the sharing of data necessary for the safety of life and property.

All the countries that responded to the questionnaire have indicated an interest in participating in the project, with the intent of working together as a region for mutual benefit. Such an approach will also ensure that, as a region, we co-learn new areas, and exchange expertise that already exists within the region. Such cooperation will further support data sharing, as well as the development of early warning systems. This will help support decision making across a number of weather climate sensitive sectors. In this area, future work will rely on the SADC CI development of a robust data sharing policies, data frameworks and network infrastructure leveraging regional National Research and Education Network (NREN) advances, data services such as Science DMZs and regional data transfer nodes (DTNs).

The project will allow the region and the continent to participate in the science enterprise in the area of weather and climate modelling, and help address the global data and weather and climate modelling gap currently over the continent, as well as also allow data sharing. Regarding infrastructure , the next phase of the SADC HPC ecosystems project will involve new deployments and upgrades of existing sites with the TACC Stampede 1 Xeon Phi processor based compute nodes. The scientific work to be conducted in this project is necessary for Meteorological services to deliver on their mandates, and can therefore be operationalised and maintained by the responsible organisations.

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Competing Interests
The authors have no competing interests to declare.

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