Weather and Climate Science for Services Partnership (WCSSP) South Africa

2023

Science Highlights Report

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Prepared by

Senior Supplier: Joseph Daron

South African Partner Leads: Neville Sweijd (ACCESS), Johan Malherbe and Mokhele Moeletsi (ARC), Njabulo Siyakatshana (CSIR), Nico Kroese (SAWS), Coleen Vogel and Francois Engelbrecht (Wits)

Met Office WP Leads: Philip Brohan (WP1), Cath Senior and Douglas Boyd (WP2), Dave Rowell and Andrew Hartley (WP3), Hannah Susorney and Anna Steynor (WP4)

Authorised for issue by

Keith Williams, Project Executive - Head of Atmospheric Processes and Parametrizations

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Contents

Executive Summary ... 4

1. Introduction ... 5

   1.1 Overview and background to WCSSP South Africa ... 5

   1.2 Annual Meetings ... 6

   1.3 Updated Science Plan ... 7

2. Publications ... 8

3. Summaries of progress across work packages ... 9

4. Stakeholder driven climate services for South Africa (STADCLIM-SA) ... 12

5. Fusing bespoke UM simulations with novel observation campaigns in East Africa ... 16

6. Using Machine Learning to Advance Marine Forecasting ... 19

7. An Analysis of the Effects of Clouds in High-Resolution Forecasting of Surface Shortwave Radiation in South Africa ... 22

8. Application of Weather Pattern Definitions over South Africa in Impact-based Medium-range Forecasting ... 24

9. 21st century sea level rise for the coast of South Africa: Projections, extremes and stakeholder engagement ... 28

Executive Summary

Over the course of 2023, the Weather and Climate Science for Service Partnership (WCSSP) South Africa project has made great progress in advancing collaborative weather and climate science and service development for the benefit of the UK and South Africa. This report summarises key achievements in the past year, with examples chosen to highlight progress across underpinning science and service development.

Held in Pretoria in March 2023, the first in-person annual meeting since before the covid pandemic provided a fantastic opportunity to reinvigorate the partnership and agree new priorities. This informed an updated joint project Science Plan, articulating high-level objectives. The new plan guides the development of science and services over the coming years and describes how the work contributes to institutional scientific priorities.

Activities across the four Work Packages have led to new findings, innovations, and capabilities across partners. A project led by HR Wallingford, in partnership with SAWS, investigated the emerging needs of users for climate services across 10 priority sectors. The project found that despite the growth in availability and range of services, they are not currently sufficient to meet user's needs across all sectors, recommending enhancements to climate services through new information types, improved presentation of information, and improved engagement through co-production.

The Met Office have continued to support SAWS in developing their forecasting capabilities, while pushing frontiers of science across numerical weather prediction and climate timescales. Activities have focused on the use of IMPROVER to aid post-processing, trialling the latest physics configurations, upgrading the SAWS Data Assimilation system, and developing methods for a new impact-based forecasting capability for heat-health. The use of Machine Learning has also been advanced in partnership, applied to forecasts for the marine and renewable energy sectors, with productive engagement visits.

On climate timescales, new versions of the km-scale CP4-Africa simulations are running using the latest model physics. Analysis has shown the improvements in rainfall over Africa, and new research has been published on the value of convection-permitting simulations. Advances in km-scale simulations are also supporting innovation in attribution studies, with the University of Witwatersrand developing the first African-led attribution modelling system.

Wider collaborations amongst partners are emerging, particularly on studying and predicting the impacts associated with weather and climate, including compound risks. ACCESS launched the new South African Research Alliance for Climate and Health (REACH) and Extreme Climate Events Research Alliance (ECERA) initiatives, supported by WCSSP South Africa and linking to priority work in focal sectors.

Priorities for 2024 include the initiation of projects from UK research partners on historic data rescue and rip current forecasts for South Africa, ongoing support for the UK and South African National Frameworks for Climate Services, advancing the use of machine learning in forecast applications and climate modelling, attribution of extreme events, enhancing seasonal forecasts, and co-developing new impact-based services across timescales.

1. Introduction

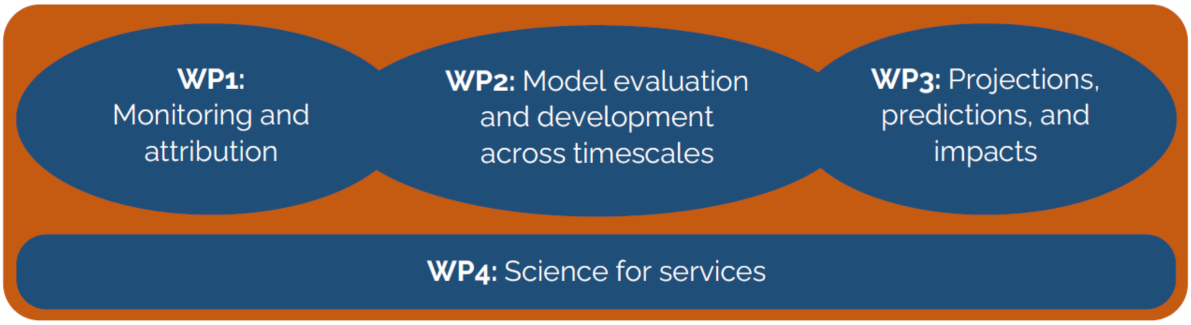
1.1 Overview and background to WCSSP South Africa

The Weather and Climate Science for Service Partnership (WCSSP) South Africa project aims to build and strengthen partnerships amongst the UK and South African weather and climate science and services community. It does so through advancing collaborative and innovative science and service development, in order to promote resilience, economic development, reduce risks and safeguard lives and livelihoods in a changing climate.

The project is a partnership between the Met Office, South African Weather Service (SAWS), Agricultural Research Council (ARC), Council for Scientific and Industrial Research (CSIR), University of Witwatersrand (Wits), and Alliance for Collaboration on Climate & Earth Systems Science (ACCESS).

Research addresses frontier scientific challenges to enhance understanding and improve simulations of the weather and climate in South Africa and the wider region, as well as opportunities to leverage new scientific innovations and progress in the development of impact-based weather and climate services. The project is advancing science and services relevant to different sectors but with particular emphasis on four priority sectors: marine and coastal, energy, agriculture, and health. These sectors have been jointly identified as areas where the partnership can develop new science, information and knowledge to advance understanding of risks facing these sectors. In addition, the scope of science covers multiple hazards, including compound and cascading hazards, with emphasis on heat, drought, inland and coastal flooding.

WCSSP South Africa is composed of four interlinking work packages (WPs). Work packages 1 to 3 are focused on advancing different areas of weather and climate science, modelling, and impacts. Work package 4 is focused on developing sector-relevant weather and climate services and supporting the broader development of services in South Africa. The work packages activities are designed to meet the overarching objectives of the project, recognising some activities will be conducted in collaboration across work package boundaries.



1.2 Annual Meetings

Over 3 years since scientists from the UK and South Africa last met in-person, the annual science meeting provided a much-needed opportunity for scientists to re-engage, marking a new phase in the collaboration. The meeting took place in Pretoria on 29 and 30 March as a hybrid event with 30 attendees in person. Other Met Office scientists attended from the hub at Exeter HQ with another 20 attendees online. The event began with opening remarks from Albert Klein Tank (project executive until December 2023), the British High Commission and South African partners, followed by interactive "getting to know you" activities, a variety of talks on science advances over the past year, a session exploring engagement to support weather and climate service development, and breakout and plenary group discussions mapping the way forward for the project.

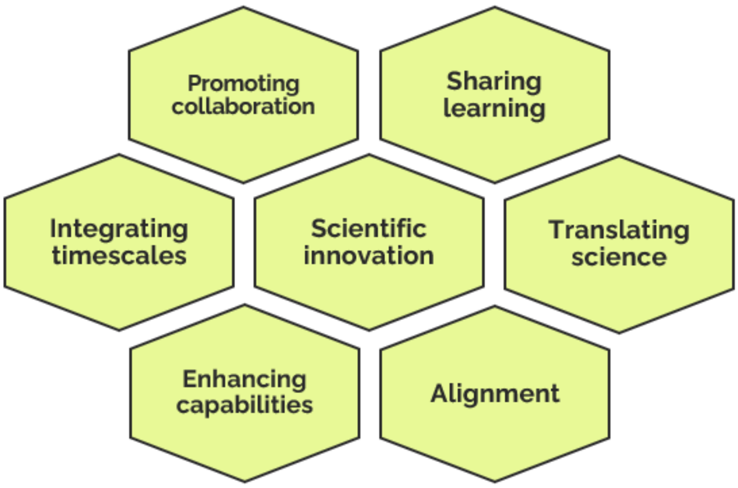
Photos: (top) In-person meeting participants in Pretoria, (bottom-left) participants at Met Office Hub and online, (bottom-right) interactions during the meeting.

The meeting showcased collaborative work across the partnership. This included developing solar radiation forecasts for the renewable energy sector, applying machine learning for understanding offshore wave climates, advances in understanding km-scale simulations and their value to studying urban climates, the development of a new attribution capability at Wits, and new initiatives from ACCESS to improve understanding of extremes and warnings and a research collaboration on climate and health – elaborated later in this report. The breakout discussions showed how much passion and commitment there is from everyone to grow scientific collaborations and strengthen capabilities, whilst maintaining a focus on the impact of the work to build climate resilience and support national processes – such as the National Framework for Climate Services. The annual science meeting showcased the exciting science happening in the project and enabled joint identification of future priorities, with in-person interactions strengthening existing relationships and enabling many new ones to emerge.

From 17-18 October 2023, a further workshop took place at the Met Office bringing together Met Office scientists with UK-based partners to discuss progress on WCSSP South Africa. The workshop was attended by HR Wallingford and Kulima who presented the results of the Stakeholder driven climate services for South Africa (STADCLIM-SA) project – see section 4. Talks were given across the project, including the development of a new convective-scale evaluation tool (CSET), and new work assessing the performance of the Met Office seasonal forecast system GloSea6 in representing South Africa's seasonal climate. The workshop provided an opportunity to hear about plans and progress in other aligned projects (SALIENT, REPRESA, MECHANICS and WISER EWSA). Finally, a session was held on realising the impact and benefit from the science and service development.

1.3 Updated Science Plan

Following the annual science meeting, updates were made to the project Science Plan, which provides a high-level overview and roadmap to guide the scientific research, service development, and capability strengthening across the project. The updated plan represents an evolution, including areas of ongoing work that continue to meet the long-term project aims, and integrating new areas of scientific collaboration, innovation and service development identified and elaborated during the annual science meeting. It includes an update to the seven core project objectives (see below) as well as statements on alignment of the WCSSP South Africa project and institutional strategic goals across the partners – including the Met Office Research and Innovation strategy.



WCSSP South Africa Objectives

2. Publications

Journal papers published in 2023, supported by WCSSP South Africa

Allan, R., Stone, R., Gergis, J., Baillie, Z., Heidemann, H., Caputi, N., ... & Pudmenzky, C. (2023) The context of the 2018-2020 'protracted'El Niño episode: Australian drought, terrestrial, marine, and ecophysiological impacts. *Weather, Climate, and Society*. https://doi.org/10.1175/WCAS-D-22-0096.1

Ascott, M. J., Christelis, V., Lapworth, D. J., Macdonald, D. M. J., Tindimugaya, C., Iragena, A., ... & Rowell, D. P. (2023) On the application of rainfall projections from a convection-permitting climate model to lumped catchment models. *Journal of Hydrology*, 617, 129097. https://doi.org/10.1016/j.jhydrol.2023.129097

Brugnara, Y., Brönnimann, S., Grab, S., Steinkopf, J., Burgdorf, A. M., Wilkinson, C., & Allan, R. (2023) South African extreme weather during the 1877–1878 El Niño. *Weather*, 78(10), 286-293. https://doi.org/10.1002/wea.4468

Mathison, C., Burke, E., Hartley, A. J., Kelley, D. I., Burton, C., Robertson, E., ... & Jones, C. D. (2023) Description and evaluation of the JULES-ES set-up for ISIMIP2b. *Geoscientific Model Development*, 16(14), 4249-4264. https://doi.org/10.5194/gmd-16-4249-2023

Mendes, J., Zwane, N., Mabasa, B., Tazvinga, H., Walter, K., Morcrette, C. J., & Botai, J. (2023) An Analysis of the Effects of Clouds in High-Resolution Forecasting of Surface Short-wave Radiation in South Africa. *Journal of Applied Meteorology and Climatology*. https://doi.org/10.1175/JAMC-D-23-0058.1

Rowell, D.P. & Berthou, S. (2023) Fine-scale climate projections: What additional fixed spatial detail is provided by a convection-permitting model? *J. Climate*, **36**, 1229-1246. https://doi.org/10.1175/JCLI-D-22-0009.1

3. Summaries of progress across work packages

Work Package 1: Monitoring and attribution

WP Lead: Philip Brohan

WP1 is advancing work on climate data rescue, digitising historic records of atmospheric and marine observations. At the beginning of 2023, WP1 saw the completion of work by the University of Giessen and University of Bern, including digitisation and quality control of ship logs, to support data assimilation in the Atmospheric Circulation Reconstructions over the Earth (ACRE) reanalysis products.

Building on this work and acknowledging that digitisation of historical data by hand is unacceptably slow and expensive, a call for new work was announced to leverage recent developments in Machine Learning (ML) offering the potential of a fast, automatic data rescue process. New work in 2024 will combine state-of-the-art ML methods, and preexisting work on data rescue, to produce a recommended method for automatic observation transcription, building on strengthened partnerships between experts at the Met Office, SAWS and Wits.

Finally, efforts were made to scope potential future work on attribution, pending funding. This will focus on the development of capacities and exploiting advances in km-scale simulations to explore the value of convective-permitting scale data in attribution studies.

Work Package 2: Model evaluation and development across timescales

WP Leads: Cath Senior and Douglas Boyd

WP2 continues to build new modelling capability and evaluate regional processes that influence South African weather and climate across timescales (in conjunction with WP3).

This year work has built new physics (RAL3) in Met Office km-scale regional model configurations across timescales, and work has started towards a fully coupled km-scale regional model over the tropical belt. The team have evaluated the role of scale interaction on tropical process and are building a new convective-scale evaluation tool-kit (CSET) to support this process-based evaluation (see highlight from WP2.1 work in Section 5: Fusing bespoke UM simulations with novel observation campaigns in East Africa).

New this year is work to evaluate the physical-dynamical mechanisms responsible for ENSO teleconnections to South Africa surface climate in the Met Office seasonal climate prediction system. On climate timescales, new versions of the km-scale CP4-Africa (Stratton et al, 2018, Senior et al, 2020) pan-Africa simulations are running using the latest RAL3 physics. For the first time this will deliver an ensemble of convective-permitting simulations driven by a selected set of 5 CMIP6 global models to give a wider range of future response and allow exploration of the uncertainty in projections. The planned 5-year simulations are now each a few years in and some preliminary analysis has started; notably, rainfall over the pan-Africa domain in substantially improved with the RAL3 physics. This ensemble will provide a rich source of data for analysis across the WPs and to be shared with partners. A paper has been submitted documenting the role of the urban heat-island on local rainfall over Johannesburg (Keat et al, 2024 submitted) and a preliminary analysis to understand the physical representation of convective storms over South Africa has been undertaken, including the distribution of storms sizes and their contribution to overall rainfall.

WP2.3 continues work with SAWS to enhance NWP for South Africa and the wider Southern Africa region. Activities this year have focused on the use of IMPROVER to aid post-processing, application of the Regional Nesting Suite to trial latest RAL science configurations and upgrading the Data Assimilation system to support hourly 4D-Var and assimilation of radar reflectivity. The software and workflows for these activities have been implemented at SAWS and preparation for trials is underway.

Work Package 3: Projections, predictions, and impacts

WP Leads: Dave Rowell and Andy Hartley

WP3 continues to understand and utilise the capability of existing and new modelling to provide user-relevant predictions across weather and climate timescales.

The projected future risks of wet and dry extremes are being further compared between models with parameterised versus explicit representations of convection. The known tendencies for larger increases in storm intensity and dry-spells in the convection-permitting model are by no means ubiquitous. Large regional and seasonal variations in the magnitude of these changes are critical for stakeholders, especially their lack of robustness to different modelling approaches. Ongoing research is now working towards understanding this model sensitivity to convective representation, to better inform expert judgement on the reliability of these regional projections. Additional work has started to explore compound hazards and extreme events, and how these are represented in relevant datasets, aligning with the Extreme Climate Events Research Alliance (ECERA) launched by ACCESS in 2023.

Work also continues on the development of a weather pattern impact-based forecasting tool prototype for South Africa. This provides daily medium-range probability forecasts using a set of 30 mean sea-level pressure weather patterns (see Section 8 for further detail). The tool translates weather pattern forecasts into the likelihood of temperature thresholds being exceeded using empirical probabilities (ERA5 reanalysis data; 1979–2020). Tests are being conducted to implement a heat-health impact-based forecast application, utilising data for mortality, morbidity, and other heat stress factors. This work, and additional work on climate timescales, are aligning with the South African Research Alliance for Climate and Health (REACH)

Finally, research has continued to advance understanding of sea level rise for coastal decision making (see section 9). A report on sea level “allowances” was finalised and shared with stakeholders, providing estimates of the heights at which defences must be raised to preserve present-day levels of risk.

Work Package 4: Science for services

WP Leads: Hannah Susorney and Anna Steynor

Work package 4 continues to support science for services through support to the South African National Framework on Climate Services and pulling through NWP to renewable energy and marine forecasting services.

Through support to the South African National Framework on Climate Services, this year has seen the establishment of relationships between key South Africa partners to begin collaboration on the implementation of the NFCS. This collaboration has included a major study to identify gaps in climate services across the key NFCS sectors (led by HR Wallingford – see section 4). The study included surveys and interviews across all the NFCS priority sectors. The identified gaps were also used within an exercise at the UK annual meeting to identify where these gaps are currently being addressed through the WCSSP project or other initiatives in the UK. A similar exercise is planned within a complementary South African workshop.

In the energy sector, the Met Office have worked with SAWS to develop a machine learning (ML) model for forecasting solar power using the site-specific forecasting capability at SAWS (built in previous years of the WCSSP-SA partnership). The ML model was delivered to SAWS and a training course was given by the Met Office to SAWS on using machine learning with forecasting data. In addition, the Met Office assisted SAWS in delivering a report on future options for wind energy forecasting at SAWS. Finally, a paper was published on 'An Analysis of the Effects of Clouds in High-Resolution Forecasting of Surface Shortwave Radiation in South Africa' in the Journal of Applied Meteorology and Climate, building on many years of collaboration between SAWS and the Met Office.

In the marine sector, machine learning techniques were used to improve wave forecasts and climate-scale wave future forecasts. This work was presented at the Africa Conference on Data Science & AI in October 2023 in Pretoria, and was followed by a visit from Met Office scientists to the SAWS Marine group in Cape Town to install the machine learning bias correction wave forecast model on the SAWS system.

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Senior, C. A., and Coauthors, 2021: Convection-Permitting Regional Climate Change Simulations for Understanding Future Climate and Informing Decision-Making in Africa. *Bull. Amer. Meteor. Soc.*, **102**, E1206–E1223, https://doi.org/10.1175/BAMS-D-20-0020.1.

Stratton, R. A., and Coauthors, 2018: A pan-Africa convection-permitting regional climate simulation with the Met Office unified model: CP4-Africa. J. Climate, 31, 3485–3508, https://doi.org/10.1175/JCLI-D-17-0503.1.

4. Stakeholder driven climate services for South Africa (STADCLIM-SA)

Authors: Darren Lumbroso (HR Wallingford), Anna Steynor (Met Office)

Summary

This project undertook secondary analysis of the current availability of climate services in South Africa, together with unaddressed needs from 10 priority sectors identified in the National Framework for Climate Services (NFCS) South Africa. The findings were obtained through 132 responses to surveys and 27 qualitative interviews conducted between March 2020 and June 2023. Findings show that weather and, to a lesser extent, climate information is used across all priority sectors, with the nature of demands in the sector influencing the specific products. However, despite the growth in availability and range of climate services, these are not currently sufficient to meet user's needs across all sectors. Further suggested enhancements to climate services include new information types, improved presentation of information and improved engagement. Many of these improvements can be enabled through enhanced co-production processes.

Extended Highlights

The existing climate services landscape in South Africa is complex and has developed rapidly over time. There have been a range of products and tools produced by government funded organisations such as the SAWS, research institutes, as well as the private sector. There are some climate services which cover the whole country (e.g. observations of meteorological data) and which are relevant to all the NFCS-SA sectors. Other climate services have been developed for specific NFCS-SA sectors and, in some cases, specific "sub-sectors" within these.

Users in all 10 NFCS-SA sectors are currently using climate services, although the types of climate services vary (Table 1). Future climate services needs span greater observational data, through to short and longer term forecasts and projections, and also sector-specific analyses (Table 2).

Additional observational data was requested by agriculture and food security, disaster risk reduction, energy and human settlements, who variously requested denser and more spatially distributed observations, or new information (for example improved air quality monitoring of PM2.5 particulates by human settlements). Similarly with regard to weather services, some user groups requested improvements in existing information, whilst others requested new information types. Impact-based forecasts, which have already begun to be implemented in South Africa, were requested by agriculture and food security, disaster risk reduction, and oceans and coasts. Improvements to existing information was requested by disaster risk reduction (fluvial flood forecasts and warnings) and water resources management (seasonal forecasting). New services were requested by energy (energy and wind forecasts), oceans and costs (nowcasting of flood risk), transport (wind forecasts) and water resources management (seasonal forecasting of river flows). There was less demand for future projections, with the exception of energy, where projected changes to energy production under climate change was requested; and oceans and coasts, where wave overtopping risk was requested. A number of sectors highlighted the need for derived projections and risk analysis – for example the biodiversity sector requested development of indicators that provide an evidence base for climate impacts; the health sector required information on the climate impacts on diseases; the human settlements sector required heat island hot spot analysis; and the transport sector required flood and landslide risk assessment.

Table 1: Summary of current use of climate services across user groups in ten sectors

	Observations/past data	**Short term (1 to 5 days)**	**Sub-seasonal to seasonal**	**Long term**
Agriculture and food security	Wind speed and direction	Daily weather forecasts	Seasonal forecasts	Climate projections
Biodiversity		Daily to weekly forecasts		
Disaster risk reduction	Past rainfall; Standardised Precipitation Index (SPI), Vegetation Condition Index (VCI) and Temperature Condition Index (TCI).	Flash flood warnings; Fire Danger Index (up to 3 days in advance)		
Energy		Weather forecasts (temperature, wind, UV radiation)		Wind atlas
Health		Disaster early warning alerts		
Human settlements	Air Quality monitoring (particulate matter (PM2.5, PM10), sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone)	Air Quality Index, heat advisories, advisories of extreme precipitation		
Infrastructure	(covered through other sectors)			
Oceans and coasts		Marine forecasts (waves, winds, storm surges, tides, sea ice edge in Antarctica, high seas, coastal forecast)		
Transport				
Water resources management	Observational data			

Table 2: Summary of climate services needs expressed across user groups in ten sectors

	Information types			**Service delivery**
	Observations	**Services (variety of timescales)**	**Analysis/ baselines**	
Agriculture and food security	Improved density and coverage of observation network	Improved accuracy of short term (1-5 day) forecasts; Impact-based forecasts		Improved communications, e.g. through visualisations;
Biodiversity			The development of climate-related biodiversity indicators to provide an evidence base regarding the impacts of past, present, and future climate.	
Disaster risk reduction	Improved density and coverage of hydrometeorological stations	Improvements to fluvial flood forecasts and warnings; impact-based forecasts for a range of hazards		Improvements in communication of warnings for weather-related hazards (to municipalities and to communities)
Energy	Increase in radiometric stations; more onshore monitoring stations for wind	Short-term forecasting of solar energy and wind (onshore and offshore); early warnings targeting electricity infrastructure	Projected changes to solar energy production under climate change	
Health			Climate change impacts on diseases; development of key weather thresholds	Improved communication of weather and climate information for the health sector, including through co-production
Human settlements	Improved air quality monitoring (PM2.5; SO2, NOx)		Heat island hot spot references	
Infrastructure				
Oceans and coasts		Nowcasting (0-6 hours) of urban surface water flood risk;	Wave overtopping risk	

		impact-based forecasts; rip forecasts		
Transport		Wind forecasts for transport routes	Flood risk assessment; Landslide risk assessment	
Water resources management		Drought forecasting; Improvements in seasonal forecasting of weather and river flows for water resources planning		

As well as new types of information, soliciting future needs also highlighted the need for improving the accessibility of current services. This can take place through better visualisation to make it easier to understand and interpret, and improved communication to ensure that it gets to the entirety of potential user groups. Improved engagement between producers and users of information can increase accessibility. From engagement with stakeholders across all the NFCS-SA sectors, it is clear that historically there has been little in the way of co-production of climate services in South Africa. For example in the agricultural sector, 87% of the farmers surveyed stated that they had never been asked for feedback on climate services. The few stakeholders who had been asked for feedback often indicated that it was via an informal, one-way process. Therefore, there is scope to improve co-production and, as highlighted in other contexts.

These findings are relevant as the NFCS is due to be reviewed in South Africa. The future needs expressed by stakeholders across sectors shows that there is need for scientific advancements, and also improvements in the communication of information.

5. Fusing bespoke UM simulations with novel observation campaigns in East Africa

Authors: James Warner (Met Office)

Summary

Process-evaluation is a cornerstone to improving the Unified Model (UM) and understanding where biases arise from. Work within Work Package 2 has enabled new collaborations with Oxford University, who have been proactive in fieldwork across Africa, measuring atmospheric processes that have never been directly quantified. These observations have provided a basis for assessing model performance across East Africa. Building on this, extensive model evaluation has been undertaken to understand how the model simulates jets and convection within crucial areas such as the Turkana Channel; a gateway for moisture to enter central Africa from the Indian Ocean, and over Lake Victoria. These results have ramifications across weather and climate timescales, and provide testing opportunities for the UM in a tropical context. This work feeds into the Met Office “path to high resolution” strategic research theme, and diagnostics produced are now being applied to tropical channel simulations (K-SCALE) to understand the upscale impact of regional processes on the larger scale atmospheric circulation.

Extended Highlights

Process-based evaluation is a vital part of the model development cycle, enabling scientists to understand how and why a dynamical model simulates the weather and climate system the way it does. Many important atmospheric processes, such as jets, convection, and flow over orography are poorly understood and are seldom sampled in the real world. Work Package 2 encompasses a wide range of model evaluation activities across weather and climate timescales, and has supported new collaborations with Oxford University in their fieldwork campaigns over East Africa. This has enabled, for the first time, an insight into model performance in regions of socio-economic vulnerability to weather and climate in East Africa.

The Turkana Jet is a low level south-easterly jet that passes through the rift between the Ethiopian and East Africa highlands. Characterised by a strong diurnal cycle, the jet transports huge quantities of water vapour into the interior of Africa. On weather timescales, it impacts the significant wind energy sector in Kenya and dictates regional rainfall patterns. On longer climate timescales, the jet has a strong control on the wider water budget across Africa. The jet experiences considerable intraday variability in strength, through a combination of large-scale prevailing wind patterns, representation of local terrain and phenomena in the boundary layer such as the development of an elevated inversion.

Oxford University led a novel field campaign within the channel, releasing radiosondes every

3 hours between March-April 2021, providing the first in-situ observations of the jet since the seminal pilot balloon measurements by Kinuthia in 1982 (Kinuthia and Asnani 1982). Working with Oxford, work revealed that even ERA5 reanalysis at order 30km resolution is insufficient to represent the strength of the jet through the channel (Munday et al. 2023). This may explain why climate models at much coarser resolutions may have significant continent-wide biases if they are unable to represent these regional but instrumental jets.

New work has developed a framework of sensitivity tests to determine how the Met Office regional UM model configuration performs across resolutions (both horizontal and vertical) systematically, to understand what resolution is required to represent both jet intensity and variability accurately. The study explored the link between the elevated inversion, which is strongly tied to the jet, and found that resolutions of 4.4km or below are required to realistically represent the jet strength. Interestingly, increased resolution also improves the predictability of the jet; perhaps through improved representation of land-atmosphere interactions, where predictability might arise. A paper is currently in review within JGR: atmospheres.

Understanding the representation of the Turkana Jet across regional UM model configurations has transferable understanding to other low-level jets, such as the Limpopo jet which is of considerable importance to South Africa (Spavins-Hick et al. 2021). The work has also stimulated new collaborations with the Centre of Ecology and Hydrology (CEH), who are investigating how soil moisture can play a role in dictating the strength of the jet through modifying the heating profile across the channel. Looking forward, the diagnostics produced in this analysis will be implemented in a community tool available to UM partners called the Convective Scale Evaluation Toolkit (CSET). This will enable diagnostics to be applied to flagship model simulations under WCSSP South Africa such as the new CP4-A simulations to address questions such as the intraseasonal and interannual variability, along with future projections of this important jet.

More recently, the model framework used to investigate resolution sensitivity in the simulation of the Turkana Jet has been extended to additionally investigate the role of science configuration and domain size in a systematic way over Lake Victoria. Many millions depend on the lake for both sustenance and employment, and sadly thousands die each year on the lake due to capsized vessels, as a result of strong winds associated with thunderstorms over the lake. While a lot of progress has been made in numerical weather prediction in this region, an evaluation of the representation of atmospheric processes across a systematic model hierarchy has not yet been performed. A paper is in preparation which looks at competing controls of convection on the lake, including static stability, low level convergence, and links to the Turkana Jet. Again, diagnostics from this research will be made available to the community via CSET for all partners to adapt/apply.

Underpinning this work to understand regional atmospheric processes, is considering how these are represented in large tropical-wide domains and how they can be impacted by the representation of downstream processes. This scale-interaction is being explored within the Met Office flagship K-SCALE project, embedded in the path to high resolution strategic theme. A crucial determinant of rainfall variability in East Africa is the Walker circulation, where large-scale subsidence suppresses convection. A major component of the Walker circulation is the upper tropospheric easterly jet, which is simulated very differently when comparing a parameterised model to an explicit convection model, despite holding resolution and domain size constant. Dynamical theory is applied to understand how the differing treatment of diabatic heating and mass flux from convection arises and projects onto to the jet, and a paper is in preparation. This work under WCSSP South Africa was showcased in the annual Met Office Science Advisory Committee (MOSAC) event in January 2024.

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6. Using Machine Learning to Advance Marine Forecasting

Authors: Nefeli Makrygianni (Met Office)

Summary

As part of WP4, the Marine Applications team at the Met Office is leading work on the application of Machine Learning (ML) techniques to improve weather predictions and climate projections. Continuing work initiated in previous years, this has resulted in a new prototype Random Forest (RF)-based model for the bias correction of ocean wave forecasts, and an Artificial Neural Network (ANN)-based model for the emulation of future wave climates. The RF model has shown promising results for the improvement of 7-day weather forecasts, while the ANN produces a high-resolution wave climate prediction dataset, at considerably lower computational cost than a traditional, coupled, dynamical equivalent. Results were presented in a number of internal and external meetings, as well as conferences (e.g., Leeds - Africa Conference on Data Science & AI). In October 2023 the tools developed were handed over to the SAWS Marine team, and in-person training was provided during an in-country visit using Python Jupyter notebooks that included the code and step-by-step description of the process. Further work on model feature selection, operational implementation and public dissemination are ongoing, as well as benchmarking against existing datasets.

Extended Highlights

Bias Correction

In order to automatically bias correct raw ocean wave forecasts from the Numerical Weather Prediction (NWP) model, a RF model (Breiman, 2001) was built to calculate the bias between forecasts and in-situ observations, based on previously found biases. Since very large amounts of forecasts and in-situ observations are required to train the model, initial development was done using UK data to minimise the need for transferring substantial quantities of data between partners, albeit with adapters provided to enable the tools to be used directly by the team at SAWS, using data for South Africa (also further facilitating opportunities for knowledge exchange, practical learning and collaboration).

The RF bias is then used to correct new/unseen forecasts. The forecasts and observations used for training the model cover the period between 2017 and 2021, while for testing the years 2022 and 2023 were used. 2017 was chosen as a starting year, since the Met Office operational wave model has undergone significant changes from this point, with the implementation of the coupling of the ocean and atmosphere taking place in 2019 (Valiente et al. 2023). For now, the model is trained in three months rolling periods (e.g., March – April – May) and subsequently applied/tested for the middle month (in this case April). Initial results (Figure 1) show that comparing the root mean squared error (RMSE) between the ML-corrected forecasts and the in-situ observations is reduced compared to that of the corresponding original forecasts. Further work on model feature selection, operational implementation and public dissemination are ongoing.

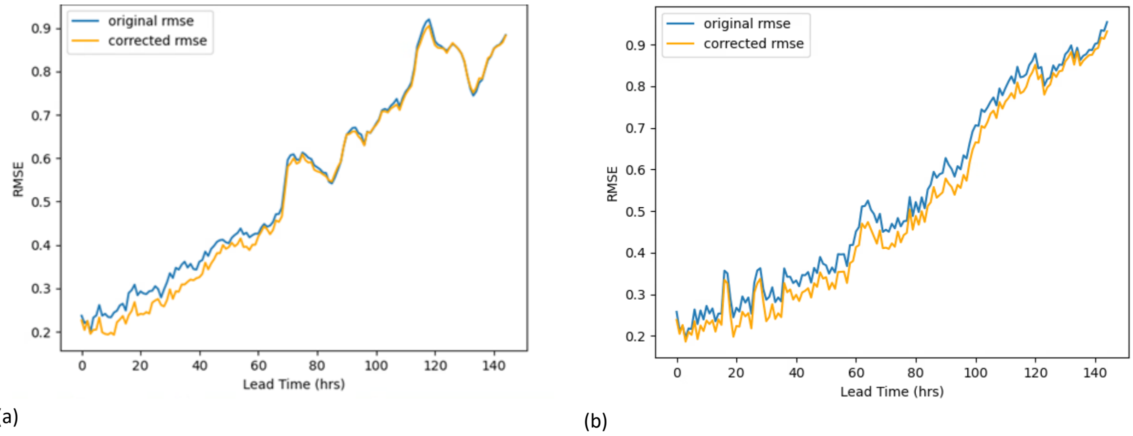


Figure 1: RMSE between forecasts (original NWP and corrected) and observations (all March forecasting files) for an example platform location in the central North Sea (a) and buoy 6201054 (b)

Wave Climate Projections

Climate projections were calculated for the area of South Africa using an ANN (Abraham et al., 2005) emulator. The emulator was trained using ERA5 atmospheric and ocean wave parameters, while it was applied using CMIP mean sea level pressure. The application resulted in a dataset of historic and future wave climates (Figure 2).

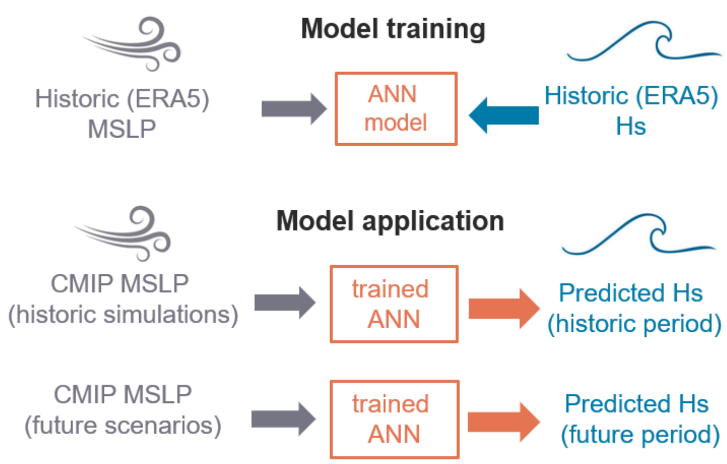
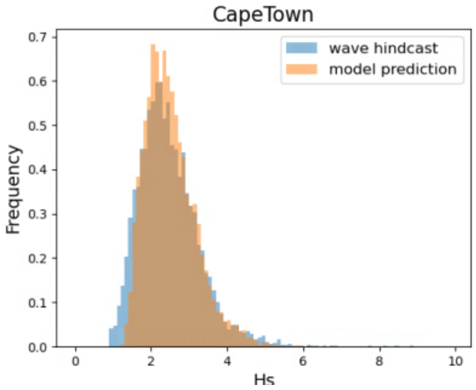


Figure 2: ANN process for climate projections.

Historic outputs were compared to wave hindcasts showing good agreement (Figure 3 and 4). This indicates that the model developed has good potential to predict also future climates.



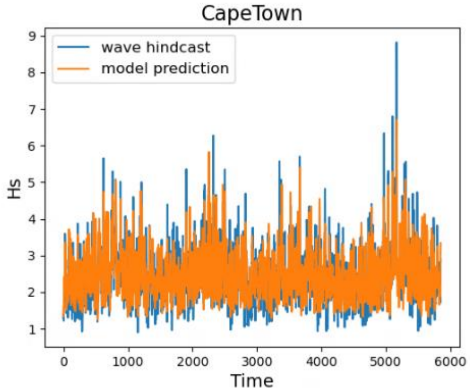


Figure 3: Frequency distribution of Hs for wave hindcast (blue) and ANN emulator (orange) for an example location at Cape Town.

Figure 4: Hs timeseries for wave hindcast (blue) and historical model prediction (orange) for an example location at Cape Town.

Initial results of future minus historic spatial means of the significant wave height (H_S) fields were then calculated to examine the wave climate changes around South Africa (Figure 5). Findings also show good potential, based on expected results from literature. Further work on benchmarking these outputs against traditional climate projection datasets are ongoing.

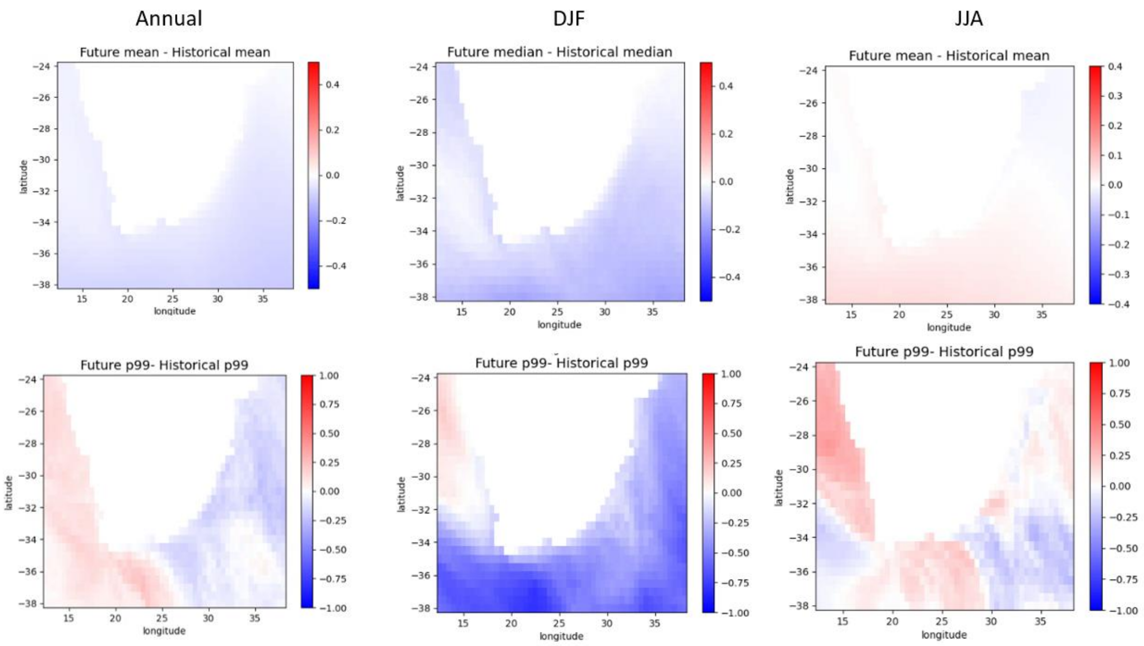


Figure 5: Seasonal and annual spatial differences between historical and future significant wave height (Hs) conditions on an annual (left hand column), winter (DJF, middle column) and summer (JJA, right hand column) basis are shown for their mean values (top row) and extreme 99th percentiles (bottom row), respectively.

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7. An Analysis of the Effects of Clouds in High-Resolution Forecasting of Surface Shortwave Radiation in South Africa

Authors: Joana Mendes (Met Office), Nosipho Zwane (SAWS), Brighton Mabasa (SAWS), Henerica Tazvinga (SAWS), Karen Walter (Met Office), Cyril Morcrette (Met Office), and Joel Botai (SAWS)

Summary

In 2023, a joint Met Office and SAWS study on the effects of clouds in high-resolution forecasting of surface shortwave radiation in South Africa was published in Journal of Applied Meteorology and Climatology. This study is the result of the joint collaborative work between SAWS and the Met Office and advances the forecasting capabilities in South Africa.

Full journal paper available at: https://doi.org/10.1175/JAMC-D-23-0058.1

Extended Highlights

For the first time, a comprehensive assessment of high-resolution site-specific Numerical Weather Prediction (NWP) forecasts of surface short-wave radiation in South Africa has been conducted, exploring clouds as the main drivers of prediction biases. Forecasts from the South African Weather Service NWP model, at 4 km (SA4) and 1.5 km (SA1.5) horizontal resolutions were evaluated. These models demonstrated good skill overall, with zero median error for all radiation components: global horizontal (GHI), direct (DHI) and diffuse (DIF) irradiances.

Further model performance analyses have shown an imbalance between cloud and solar radiation forecasting errors, where cloud over-prediction may not equate to the under-estimation of solar radiation. Overcast cloud regimes are predicted too often, whereas the relative abundance of partly cloudy regimes is under-predicted by the models. Figure 1 illustrates the frequency of occurrence of each cloud regime, highlighting how overcast skies are associated with a positive mean radiation bias, and the partial cloud categories present mixed radiation biases.

Given the lack of similar error attribution analyses in this part of the world, the study contributes to understanding how cloud and radiation schemes perform over South Africa. Challenges highlighted by the misrepresentation of partly cloudy regimes in solar radiation error attribution may be used to inform improvements to the numerical core, namely the cloud and radiation schemes. In addition to the scientific insights, the outcomes from this work could further benefit South Africa, by contributing to progress the renewable energy sector. In a country where energy security is of critical relevance, the availability of high-quality and useful weather information is paramount to support its industry and socio-economic growth.

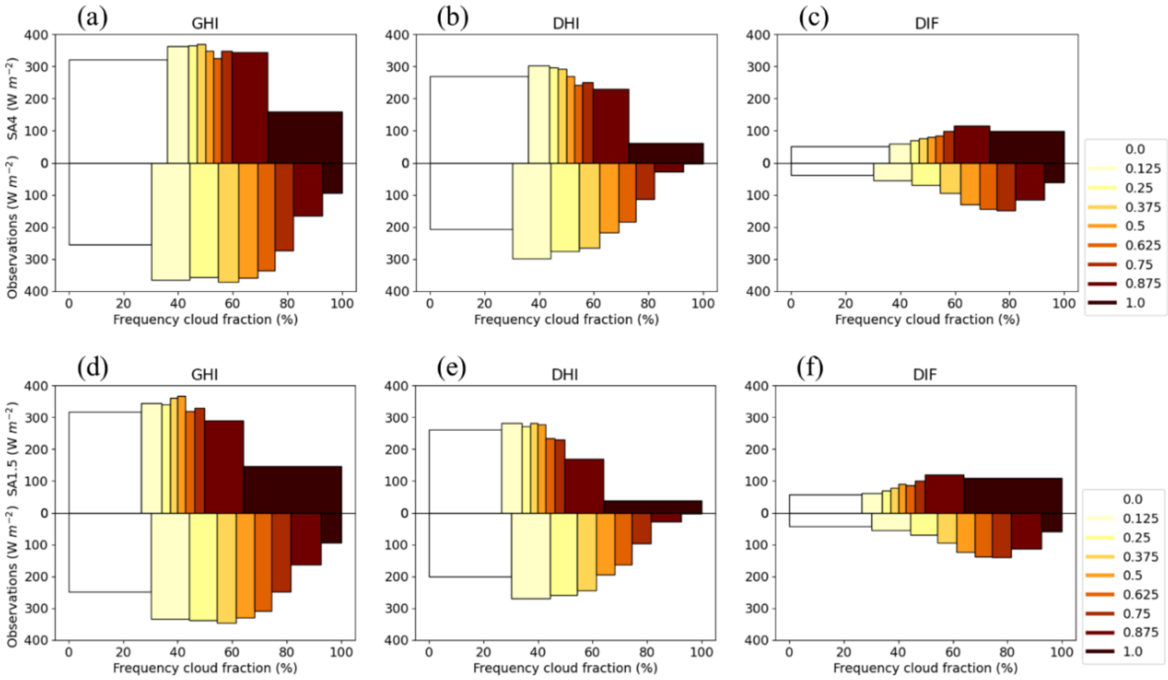

Figure 1: Frequency of occurrence for each cloud fraction category (width) and their respective impact on the mean surface short-wave radiation (height); comparing forecasts (top half) against observations (bottom half) for all radiation components. (a) GHI SA4; (b) DHI SA4; (c) DIF SA4; (d) GHI SA1.5; (e) DHI SA1.5; (f) DIF SA1.5.

8. Application of Weather Pattern Definitions over South Africa in Impact-based Medium-range Forecasting

Authors: Lewis G. Ireland (Met Office), Joanne Robbins (Met Office), Robert Neal (Met Office), Rosa Barciela (Met Office), and Rebecca Gilbert (Met Office)

Summary

This work in WP3 aims to define a set of representative weather patterns for South Africa that can be utilized to support impact-based forecasting of heatwave events. Sets of weather patterns have been generated using k-means clustering on daily ERA5 reanalysis data between 1979 and 2020. The results indicate that a set of 30 weather patterns generated using mean sea-level pressure (MSLP), with a clustering domain in the range 15°–34°E 21°–36°S, provides a reasonable representation of daily maximum temperature variability across South Africa. A medium-range forecasting tool utilising this weather pattern set is currently under development, and has the potential to extend the prediction of high-impact weather events in South Africa, such as heatwaves, and also the possibility of highlighting specific heat-health impacts to the population.

Extended Highlights

This research aims to generate a representative set of weather patterns over South Africa that can be utilised to support impact-based forecasting through the development of a medium-range forecasting application for heat. The motivation behind the weather pattern approach is to improve forecast lead time for high-impact events, extending the window for pre-preparedness activities, and to provide a direct description of the circulation driving these events. Accurate temperature and precipitation forecasts beyond several days can be challenging for traditional numerical weather prediction forecasts. However, with this approach, one can make informed assumptions for future temperature trends based on an accurate forecast for a specific weather pattern, along with its associated climatologies.

By varying the clustering atmospheric variable, clustering domain, and number of weather patterns, a set of weather patterns was chosen to best represent the daily maximum temperature variability. This set consists of 30 weather patterns, generated using k-means clustering on mean daily MSLP ERA5 reanalysis data covering 1979–2020, with a spatial domain that encompasses the South African landmass (Figure 1). Strong seasonality exhibited by the weather patterns reduces the need to have different sets for different times of the year, allowing weather patterns to occur at any point of the year, which could prove useful in forecasting tools as an indicator of severe weather or to even highlight seasonal changes in weather patterns potentially due to climate change.

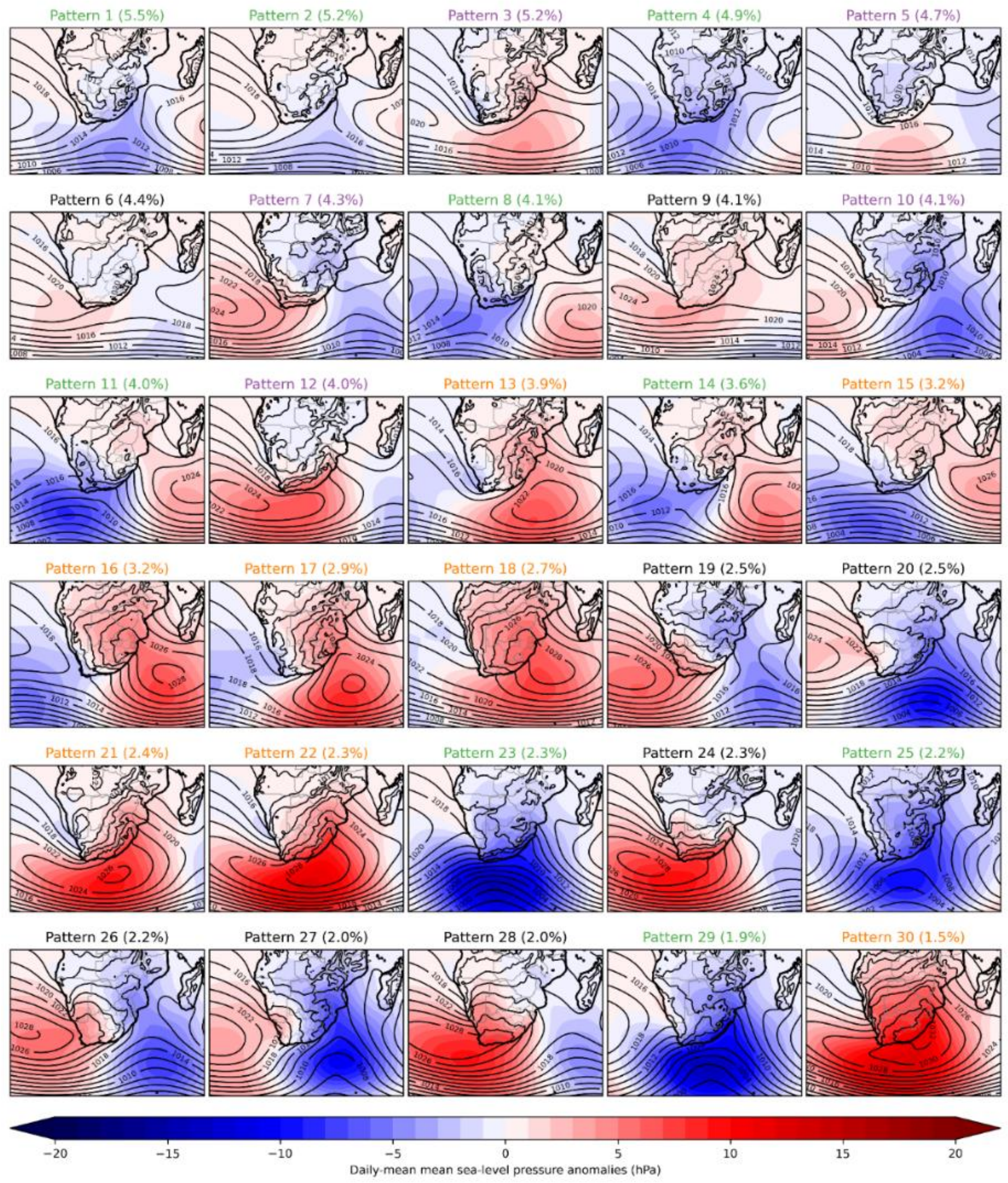

Figure 1: The chosen set of weather patterns for reproducing the variability of daily maximum temperature for the period 1979–2020. The contour levels represent annual average MSLP for each weather pattern. The filled colour contours represent annual average MSLP anomalies for each weather pattern. Percentages in brackets represent the mean annual occurrence for each weather pattern. Weather pattern label colour represents the weather regime category of each weather pattern (see Figure 2): CAH (black); CIH (orange); CL (green); SAH (purple).

A weather pattern impact-based forecasting tool prototype for South Africa is currently under development. It provides daily 00/12 UTC ECMWF medium-range weather pattern probability forecasts, based on the number of ensemble members objectively assigned to each weather pattern (Figure 2). Additionally, weather patterns are categorised into four different broadscale regimes based on the dominant pressure system, which helps identify transitions in large-scale circulation and is especially useful when there is a lot of ensemble spread. Weather patterns are also categorised according to their dominant circulation characteristics to show circulation trends for several recent forecasts, allowing for a rapid assessment of forecast consistency over consecutive model runs.

Once weather pattern characteristics are understood, in terms of their climatologies or impacts, it becomes possible to interpret forecast output and describe likely consequences. The temperature application of the tool translates weather pattern forecasts into the likelihood compared to normal, with temperature thresholds being exceeded by calculating empirical probabilities of threshold exceedance for each weather pattern on each day of the year, using ERA5 reanalysis data from 1979–2020. Thresholds include the SAWS heatwave threshold[1] (Figure 3), and 97th, 99th and 99.7th daily maximum temperature percentiles. Tests are being conducted to implement a heat-health impact-based forecast application, by utilising data for mortality, morbidity, and other heat stress factors, as well as introducing heat-health metrics such as wet bulb globe temperature, excess heat factor, and universal thermal climate index.

	Sun 2 Oct	Mon 3 Oct	Tue 4 Oct	Wed 5 Oct	Thu 6 Oct	Fri 7 Oct	Sat 8 Oct	Sun 9 Oct	Mon 10 Oct	Tue 11 Oct	Wed 12 Oct	Thu 13 Oct	Fri 14 Oct	Sat 15 Oct	Sun 16 Oct	Pattern Category	Historical frequency occurrences (September)	Historical frequency occurrences (October)	Historical frequency occurrences (November)
Pattern 1	2%			8%	2%			25%	8%	6%	6%	6%	6%	8%	6%	Dominant Coastal Low	4.0%	6.8%	8.1%
Pattern 2	2%							8%	2%			6%	2%	2%	2%	Dominant Coastal Low	8.4%	7.8%	4.9%
Pattern 3	76%		2%				14%		6%	6%	4%	12%	10%	14%	2%	Dominant South Atlantic High	0.6%	3.0%	8.9%
Pattern 4				63%				12%	4%	10%	12%	8%	2%	4%	8%	Dominant Coastal Low	0.5%	1.4%	5.8%
Pattern 5			51%	4%					4%	14%	25%	14%	10%	18%	16%	Dominant South Atlantic High	0.2%	1.5%	7.4%
Pattern 6																Continental South Atlantic High	8.1%	2.9%	0.8%
Pattern 7			41%		33%			6%	27%	14%	12%	16%	14%	12%	12%	Dominant South Atlantic High	1.3%	8.9%	10.3%
Pattern 8				22%			8%	16%		10%	4%	4%	18%	2%	8%	Dominant Coastal Low	1.8%	2.7%	5.6%
Pattern 9																Continental South Atlantic High	3.0%	0.0%	0.0%
Pattern 10		100%		4%	41%			4%	20%	8%	10%	8%	6%	6%	12%	Dominant South Atlantic High	0.4%	3.4%	9.0%
Pattern 11							2%									Dominant Coastal Low	4.9%	2.5%	0.6%
Pattern 12			6%			55%			18%	14%	6%	16%	14%	14%	16%	Dominant South Atlantic High	2.6%	8.8%	9.8%
Pattern 13							41%			6%	8%	2%	10%	2%	14%	Continental South Indian High	4.2%	8.7%	6.3%
Pattern 14	20%						18%	4%		2%	10%			10%	2%	Dominant Coastal Low	3.9%	5.4%	4.3%
Pattern 15																Continental South Indian High	1.3%	0.3%	0.0%
Pattern 16																Continental South Indian High	2.5%	0.8%	0.1%
Pattern 17							2%									Continental South Indian High	5.9%	4.3%	1.7%
Pattern 18																Continental South Indian High	0.8%	0.2%	0.0%
Pattern 19					4%	2%							4%	2%		Continental South Atlantic High	9.4%	6.6%	2.8%
Pattern 20																Continental South Atlantic High	1.6%	0.1%	0.1%
Pattern 21						10%	16%		2%	8%		2%	2%	4%	2%	Continental South Indian High	4.5%	8.5%	3.7%
Pattern 22																Continental South Indian High	5.8%	2.7%	0.5%
Pattern 23								8%								Dominant Coastal Low	3.1%	0.2%	0.3%
Pattern 24						33%			4%					2%		Continental South Atlantic High	8.5%	4.1%	1.3%
Pattern 25									4%	4%	4%	6%	2%	2%	2%	Dominant Coastal Low	0.3%	1.2%	3.6%
Pattern 26																Continental South Atlantic High	2.1%	0.0%	0.0%
Pattern 27					20%			2%	2%			2%	2%			Continental South Atlantic High	5.2%	4.9%	1.6%
Pattern 28																Continental South Atlantic High	1.0%	0.1%	0.0%
Pattern 29								16%								Dominant Coastal Low	3.3%	2.4%	2.7%
Pattern 30																Continental South Indian High	0.8%	0.2%	0.0%

Figure 2: Weather pattern forecast probabilities (valid at 12 UTC) for the 2 October 2022 00 UTC ECMWF medium-range forecast. Pattern categories are shown for each weather pattern. Historical frequency occurrences are based on ERA5 reanalysis data for the period 1979–2020.

[1] If the maximum temperature at a given location meets or exceeds 5°C above the mean maximum temperature for the "hottest month" for that location, for at least three consecutive days.

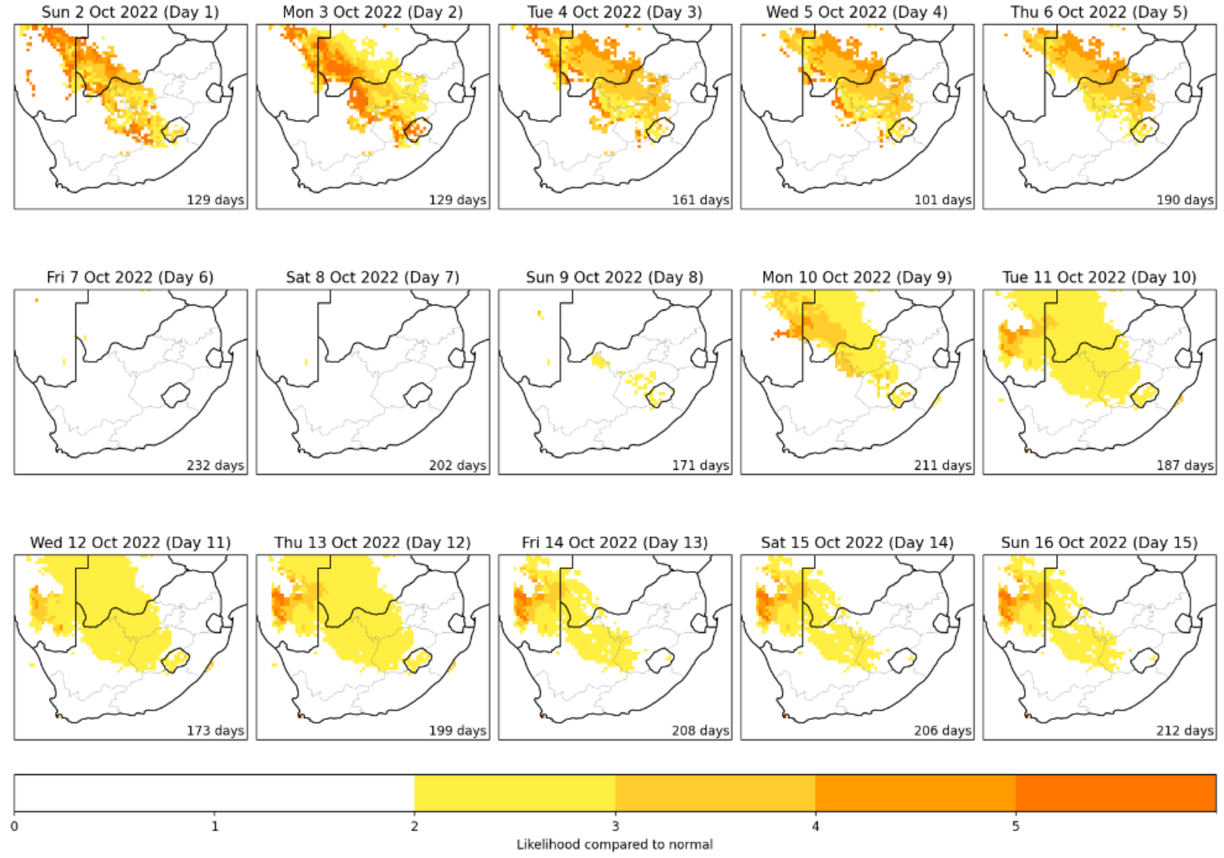

Figure 3: Likelihood compared to normal for daily maximum temperature to exceed the SAWS heatwave threshold (valid at 12 UTC) based on the 2 October 2022 00 UTC ECMWF medium-range weather pattern probability forecast, using a 101-day climatology centred on each forecast day (ERA5; 1979-2020).

9. 21st century sea level rise for the coast of South Africa: Projections, extremes and stakeholder engagement

Authors: Lesley Allison (Met Office), Tom Howard (Met Office) and Joseph Daron (Met Office)

Summary

As part of WP3, projections of sea level rise over the 21st century for locations around the South African coast have been produced, under high and low future emissions scenarios. These projections, along with information about local coastal water level variability, help exploration of future changes in the frequency of extreme sea level events. In collaboration with WP4 scientists, the work has also involved engagement with in-country stakeholders and summary information briefs have been produced to make relevant sea level information available and usable to local planners and coastal researchers.

Extended Highlights

1) Mean sea level rise

Sea level rise is an important facet of climate change, driven mainly by the melting of land ice and the expansion of ocean water as it warms. An understanding of current and future sea level change is key for coastal planners and other stakeholders to make decisions for adaptation. Three strands of work are summarised, focusing on understanding recent and future changes in sea level around the coast of South Africa, future changes in the frequency of extreme events, and the development of information sources for engagement with local stakeholders.

Through an observational analysis of recent sea level variations using tide gauges and satellite altimetry it is found that sea level around the coast of South Africa has increased at a rate of approximately 3 mm per year since 1993, which is similar to the rate of global mean sea level rise over that time. Projections of future sea level rise over the 21st century were produced for eight locations around the coast of South Africa for low and high emissions scenarios. This was done by combining information on ocean thermal expansion and surface temperature from an ensemble of CMIP5 models along with simple models for changes in ice sheets, glaciers and land water storage, and including the local effects of ocean dynamics, changes in the gravitational field due to ice sheet depletion and vertical land motion associated with glacial isostatic adjustment. The observed and projected sea level changes for low (RCP2.6) and high (RCP8.5) emissions scenarios are shown in Figure 1 for Durban (as an example of the eight South African locations examined in the study). In the year 2100, Durban and other locations around South Africa are projected to experience sea level rise (relative to 1986–2005) of approximately 0.5 m (5th - 95th percentile uncertainty range 0.3–0.8 m) following RCP2.6, or around 0.8 m (0.6–1.3 m) following RCP8.5. These increases are slightly larger than projections of global mean sea level due to the local amplification of several components of the sea level budget.

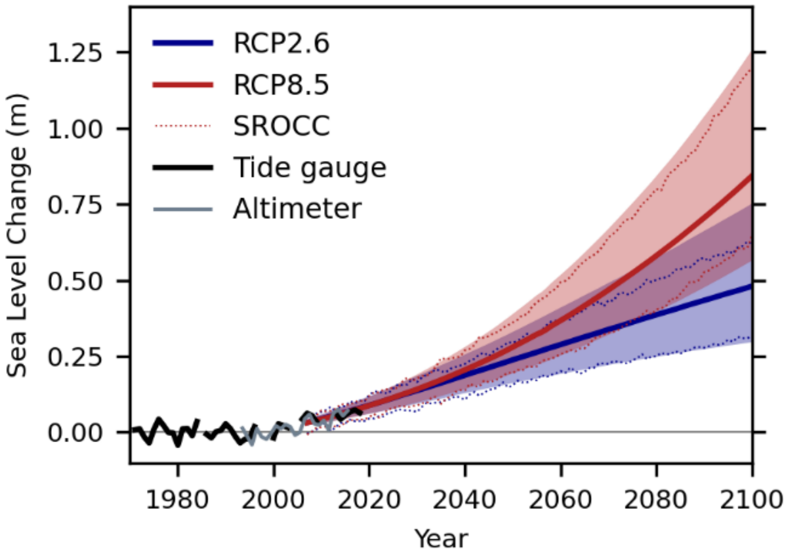

Figure 1: Projections of mean sea level change for the 21st century (2007–2100) for Durban. Shown are the projections for low (RCP2.6, blue) and high (RCP8.5, red) emissions scenarios. The solid lines show the median of the distribution of the projections, with the shading indicating the 5th-95th percentile uncertainty range. Tide gauge observations are shown by the heavy black lines. Satellite altimeter observations are shown in grey. The dotted coloured lines show the 5th and 95th percentiles from the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC; Oppenheimer et al 2019) for comparison. Each time series is presented relative to a baseline period of 1986–2005. Adapted from Allison et al. (2022).

2) Allowances for sea level extremes

The earliest and most severe effects of sea level rise will be felt at the coast during extreme events, which typically occur when a storm surge coincides with a high tide. The statistical frequency of these extreme water level events at a particular location depends on local characteristics. One adaptation option available to coastal planners to protect against the impacts of mean sea level rise is to raise the level of flood defences (or assets themselves) by a height sufficient to maintain the same expected frequency of flooding in the future as is experienced in the present climate. The nonlinear relationship between mean sea level and expected frequency of extremes means that this height increase (referred to as the 'allowance') is always higher than the central estimate of the mean sea level projection. To calculate allowances for locations around South Africa, information about the local present-day extreme water level statistics was combined with the probability distribution from the 21st sea level projections described above. The resulting allowance for Durban following RCP8.5 over the 21st century is shown in Figure 2. Over the course of the century, the sea level allowance required to maintain the present-day flooding risk rises significantly faster than the central estimate of the mean sea level projections.

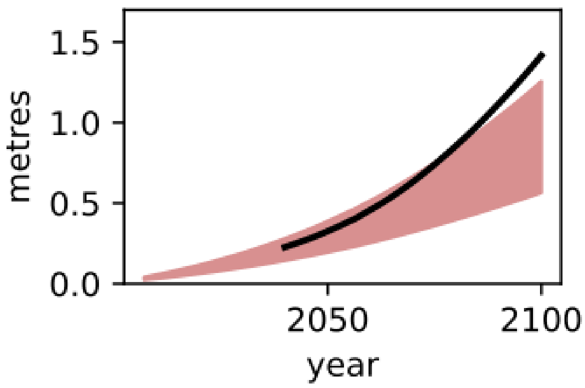

Figure 2: Sea level rise allowances for Durban to 2100 for the high (RCP8.5) emissions scenarios, with the 5th-95th percentile uncertainty range for the mean sea level projections shaded. Adapted from Howard et al (2023).

3) Communication with in-country stakeholders

Ongoing dialogue has supported engagement with stakeholders, focused on Cape Town and the Western Cape, as well as eThekwini and KwaZulu Natal. Building on online engagement sessions and webinars held in 2022, the new information on allowances was added to summary information briefs and share with stakeholders. Work is now being advanced on high-end, low likelihood storylines of sea level rise, which are of relevance to critical infrastructure and long-term planning. Re-engagement with stakeholders and continuation of the dialogue is planned for 2024, including in-person interactions to better appreciate decision contexts.

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Met Office
FitzRoy Road
Exeter
Devon
EX1 3PB
United Kingdom