GCRF AFRICAN SWIFT
SCIENCE FOR WEATHER INFORMATION AND FORECASTING TECHNIQUES

SHEAR Science for Humanitarian Emergencies & Resilience

The future of African weather forecasting

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There is a huge opportunity for the African continent to benefit from the 'silent revolution' in weather forecasting that has been realised in the mid-latitudes throughout the twentieth century. While there are tremendous societal and economic benefits from advancing the science behind weather forecasting in sub-Saharan Africa, there are also significant barriers to realising advances. This policy brief examines the value of investment in African weather forecasting science and the technical & communication challenges that this will bring with wider implementation.

Key Messages

- In Africa, lives and livelihoods are directly and significantly impacted by weather-related events.
- Strengthening national and international meteorological and climate science capacity has the potential for transformational change across the African continent.
- Research remains to be done, to deliver adequate performance of forecasting systems, but significant improvements in accuracy and relevance are within our reach.
- Co-production of weather and climate services is needed, but depends on meteorological agencies having the tools and know-how to meet decision-makers' needs.
- Systematic and impact-based forecast evaluation is critical to forecast improvement, to economic sustainability of services, and for effective forecast use.
- Partnership between the academic and operational sectors offers sustainability to the scientific and operational improvements.
- Weather forecasting services should be economically self-sufficient, but this is not simple as there is also a need to maintain infrastructure such as observational networks.
- We outline what can be achieved on a 5-10 year timeframe and the key steps needed to realise the socio-economic benefits of improved weather forecasting across Africa.

Background

Over the past century, accurate and quality-controlled weather forecasting in the economically developed countries of the Global North has experienced a 'quiet revolution', considered one of the most remarkable triumphs of the physical sciences. We know that the value or economic benefit of these forecasts is great. The UK Met Office valued forecasting in the UK in the 2015 Public Weather Service Value for Money Review as close to £1.5 billion per annum. However, scientific and operational advances are not being realised in economically less developed countries, including nations within the African tropics. African populations have an even greater need for accurate weather predictions, with lives, livelihoods and national economies heavily dependent on weather-sensitive environments and sectors, including agriculture, water resources and fisheries. Africa is vulnerable to weather events: in 2019 alone, African floods, heat waves, droughts and storms affected 20 million people, leading to economic impacts amounting to billions of dollars. The uptake of weather information and services is still low in Africa, representing a threat to social and economic development.

We present here that substantial improvements in the skill of weather forecasting across all timescales in the African tropics is now within our reach on a 5-10 year timescale. Improvements in forecast products (both the models that drive them, and the interpretation and application by trained forecasters) along with better communication and understanding of these forecasts, together with ensuring the resources to enable forecast-based action, are fundamental to the protection of lives and livelihoods across Africa.

The value of African weather forecasting

There is a clear need in many African countries for significant and urgent steps towards providing better weather and climate forecasts on all timescales, from hourly, to seasonal. In Senegal, the warming of the Sahel is causing increases in high impact weather events with more intense rainfall and dry-spells, as evidenced in September 2020 flooding, alongside drought-reducing water supply for rain-fed cattle there. In Kenya, increased flooding events have become much more usual, destroying national infrastructure and resulting in the loss of lives and livelihoods. Being able to better predict these extreme events hours, weeks and months before they occur is vital in providing economic, societal and environmental security to the regions that most need it. Advances in the physical science of weather forecasting, alongside producing impact-based forecasts tailored for specific sectors, communicated through accessible channels with advice on remediation actions, and ensuring access to the resources and capacities required to make appropriate use of forecasts, offers huge gains across the whole continent.

Improving weather forecasts, on all timescales, has significant potential to strengthen resilience amongst people whose lives and livelihoods are directly affected by weather and climate related risks in tropical Africa. Communication of forecasts in understandable language and format, with decision-relevant metrics and accompanying advisories, provided through channels with assured reach to intended users, supports specific decision-

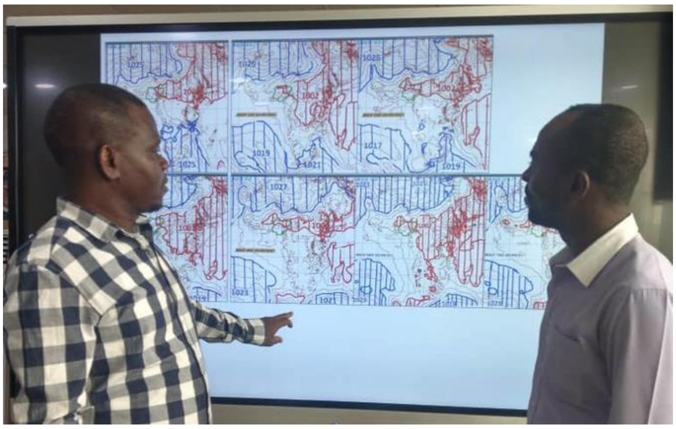
Weather forecasting and climate change

- **Weather prediction** is an operational activity that provides forecast information to various users on a day-to-day basis, and is needed for humanitarian, economic and environmental reasons on a tactical decision-making timescale.
- **Climate change** will be felt through increasing frequency and severity of hazardous weather. There is already strong evidence that global warming is changing the statistics of extremes such as flood-producing storms.
- **A future response to climate change** is dependent on advances in weather forecasting now: increasing capacities and capabilities for weather prediction today increases our chances of responding to a change in future climate. Improving the quality and usability of forecasts sensitises decision-makers to the value of adaptation to climate change.
- **Effective weather predictions** are based on a close link with the user. The link is supported by long-term evaluation of the performance of the system, through experience of past forecasts. The state of knowledge of the information contained in a weather forecast is high, both for a provider and for a user, because the system has been evaluated over time and uncertainty can be measured and communicated.
- **The delivery of forecast information** is time-limited and demands an operational management system; robust and reliable data handling systems; and robust communications. Information needs to be delivered regularly and reliably, with some users needing information on an hourly basis. These requirements represent high scientific, engineering and organisational management demands.
- **Delivery of climate change projections** requires significant trust of users in scientists. Knowledge of the future is based on the degree of confidence in a range of scientific methods (observations, theory, models). Uncertainty in the future is high and has complicated dimensions (physics of models; natural variability in the climate system; economics and greenhouse gas emissions). Delivery of information involves interpretation and communication of the results of models run internationally, by third-party scientists, and sharing this information with non-specialists. Delivery of the information is typically not time-limited, but involves considerable learning, which is hampered by distance between practitioners, researchers and users of climate projections.

making processes and adds significant value to the forecast information. There is a growing body of evidence demonstrating the socio-economic value of weather forecasting, with significant wider benefits across sectors beyond those already analysed. Research undertaken by the GCRF (Global Challenges Research Fund) African SWIFT (Science for Weather Information and Forecasting Techniques) and SHEAR (Science for Humanitarian Emergencies and Resilience) ForPAc (Towards Forecast-based Preparedness Action) programmes has shown that even modest investments in the science and communication of weather forecasts in Africa have enormous economic, social and environmental benefits, specifically related to 0-6 hour nowcasting, sub-seasonal forecast use and seasonal East African rains prediction.

Opportunities across forecast timescales

Sub-seasonal to seasonal (S2S) prediction (2-6 weeks)



For the first time, sub-seasonal-to-seasonal ensemble forecast products are becoming available, and show significant statistical skill for parts of Africa. We need to evaluate these systems and co-produce new forecast products tailored to support the decision-making processes most impacted by weather and climate-related risks across these timescales.

- Understanding what drives predictability on S2S timescales and being able to accurately model its impact on local weather over Africa is a necessary process, but not sufficient to produce useful and actionable forecast information. There remains a further important gap in knowledge: how to improve the appropriate use of operational S2S forecasting products for actionable decision-making.
- Processes enabling co-production of weather and climate services need to be institutionalised. Co-production approaches have been predominantly employed in project-initiated services, which have devoted significant time and resources to the development and ongoing evaluation of the products. Increasing the range of users and decisions being supported by S2S forecasts will require increased institutional capacity in the African agencies in terms of scientifically skilled staff with training and experience in co-production of services.
- It is becoming increasingly clear that evaluation of the skill of S2S forecasts is not only a question of meteorological verification, but a comprehensive process, which should combine meteorological skill with evaluation from decision-makers. Ongoing research and development must continue to assess impact-based evaluation.

Synoptic forecasting (1-5 days)

It must be recognised that computational forecast skill for daily rainfall is low in tropical Africa right now. Global models, which show excellent skill in the mid-latitudes, perform poorly over Africa. Scientific research is needed to improve this skill, and the role of a scientifically trained forecaster in forecast production remains much more important in Africa than in Europe or the USA. Convection-permitting (CP) models, such as the Met Office Tropical Africa Model, offer an opportunity to break the deadlock in 1-day rainfall prediction, but evaluation and improvement of the models is needed. Forecasters need high levels of understanding of tropical synoptic dynamics, in order to forecast rainfall from the large-scale circulation patterns.

- The staff of African national weather services and their supporting partners need better skills in core data manipulation and management, so that the African centres are able to manipulate data locally and generate their own products. Without these skills, the African centres will always be reliant on international assistance.
- More observations (&/or more reliable functioning of the defined network) are needed to initialise models, including observations made away from population centres.
- Across Africa, forecasters are not using conceptual models consistently, and are not blending numerical weather prediction (NWP) products with their conceptual understanding. Plotting of the synoptic situation is not being done automatically from NWP. Forecasters are in danger of using the NWP products uncritically, to deliver unreliable forecasts.
- Operational training in the use of NWP, including CP models and ensembles, needs to be linked to training in the conceptual understanding of tropical weather systems.

Nowcasting (0-6 hour warnings and alerts)

The 24-hour forecast of tropical rainfall will always contain uncertainty. As such, nowcasting is vital, to inform stakeholders of prevailing risks associated with rapidly evolving current weather systems. Implementation of nowcasting, which before SWIFT was almost non-existent in tropical Africa, has the potential to transform the provision of storm warnings to vulnerable communities.

- For nowcasting in Africa, there is a gap in awareness of forecasters of the opportunity and the potential use the products already available. It is desirable for forecasters to receive and generate products locally, a task GCRF African SWIFT has started in four African nations.
- Forecasters need adequate training in the use of nowcasting products; and user-focussed Standard Operating Procedures for nowcasting need to be developed.

There is a large opportunity to develop links with different clients to generate a market for nowcasting products, and build the case for sufficient government investment in the staff time required to generate and issue public warnings based on a nowcasting process. The development of business models to support nowcasting by weather services is therefore key, both for public warnings, and for bespoke forecasts for specific users.

Increasing the capacity of operational centres

Institutional capacity

African weather services typically identify the challenges of lack of funding for infrastructure and observations, and lack of access to staff training and continuing professional development (CPD). While scientific progress is required, to accelerate the improvement of African forecasts this needs to be balanced with institutional support to the services delivering the forecasts.

Infrastructure and critical mass

Modern weather forecasting relies on advanced computational and communications systems, with which to: acquire, exchange, process, visualise and archive data; run models and generate locally relevant diagnostics; and translate the numerical data into visualisations and messages, which can be understood by both forecasters and forecast users. African weather services typically lack the state-of-the-art facilities for these functions, and lack the human capacity to update and maintain their systems. Basic expertise in computational methods and data handling is a key area in which capacity needs to be built. A priority for the advancement of African forecasting services is to build local capacity to undertake co-production of new services. We recommend that the building of a critical mass of scientists with computational and technical skills needed to maintain weather forecasting systems is essential for improvement of forecasting quality in Africa. Partnership with the academic sector is an important route to building this critical mass. Additionally, co-production of tailored forecast products requires access to raw forecast data, rather than just access to generic forecast plots. Therefore, there is also a need to increase the sharing of forecast data between global producing centres and African national meteorological services (NMSs).

African partnerships for capacity building.

The university sector in Africa holds vital capability in climate science, and is responsible for developing the skills of the next generation of practitioners. Academic institutions also offer an important route to sustainable capacity building, where advances gained in research projects influence student education over many years. Typically, the research-active African universities are maintaining a critical mass of scientists with the technical skills needed to keep up with advances in computational and data science. Many universities are also taking a lead in advancing research and education on the socio-economic impacts of climate services. Partnership with the academic sector is a way for operational agencies to be able to engage with the state-of-the-art in weather prediction.

Training within institutions

A weakness of current international efforts in training is that events are piecemeal, and lack coordination or collective evaluation, for instance against skills frameworks, notably the WMO's Basic Instruction Package in Meteorology (BIP-M). Training needs to be commensurate with the aims of improving quality and sustainable capacities. Ideally, training should be directly linked to

Standard Operating Procedures for forecasting, and should include some forms of evaluation. A syllabus for training (giving a regional focus to the WMO Global Campus) needs to be developed, with a clearly defined set of skills and competencies linked to career progression pathways. Training modules should be linked to learning outcomes for students and assessment should be included in international programmes and training events.

Robust funding for activities

A range of funding routes for long-term support of weather forecasting services exists now (government/public weather service, aviation, commercial). There is evidence from the success of some private-sector enterprises in Africa (e.g. Ignitia) that commercial funding is viable. Ideally, the funding of weather forecast services should be linked directly to the services it supports. Core funding is also needed to maintain infrastructure, in particular those functions where the benefit of an activity is indirectly connected to the resulting forecast.

Observational data

It is widely acknowledged that there is a lack of sufficient meteorological observational data across the African continent. Whilst we recognise that alternative solutions, such as satellite data, have transformed the skill of global NWP and demonstrate skill for nowcasting applications, real-time surface observations remain vital for the monitoring of many societally important weather parameters, and are needed to evaluate other technologies and data. It is essential that sustainable funding for a cross-continental observation network is sought and solutions for data monitoring, capture, management and dissemination are implemented. This will require leadership from international agencies such as WMO in providing support to NMSs in strengthening their national monitoring infrastructure and may include independent networks such as the Trans-African Hydro-Meteorological Observatory (TAHMO).

Models and infrastructure

The case for the ownership and running of an NWP model in Africa is strong. An NWP programme gives national and regional institutions the ability to develop a research community in forecasting and meteorology across timescales and the autonomy to run and improve models for African conditions. Expertise in NWP leads to a community of specialists who can generate new diagnostic products for stakeholders in the co-production process. Partnership with universities in which researchers are running models and analysing model data is an invaluable part of such a community.

High performance computing (HPC) is a significant barrier to the ownership and development of models. The international community can seek to overcome this by providing HPC and data analysis facilities for forecasting purposes, allowing African meteorological agencies to develop significant skill in modelling without the expensive installation and upkeep of HPC. Such initiatives are already gaining traction in a number of centres, including those of Senegal and Ghana.

Forecast evaluation

- There is little evaluation being carried out across Africa. International NWP centres, Regional Climate Centres (RCCs) and NMSs lack feedback on model performance.
- For an increasingly competitive commercial market for weather prediction products, evaluation is necessary, for customer confidence and for motivating investment.
- Good evaluation methods for deep convective regimes remain a scientific and statistical challenge. This is an ongoing area of research and off-the-shelf methods need expertise in applying.
- Impact-based evaluation, including user feedback, is needed. This should include a range of evaluation evidence, from quantitative/statistical to qualitative and consultative.

Summary and recommendations

Throughout Africa, lives and livelihoods are directly impacted by weather- and climate-related risks. Strengthening national meteorological capacities holds transformational potential for strengthening the continent's climate-resilience in the coming decade.

The translation of best practice, research and methods across the continent will maximise the ability of the meteorological services and science community to better protect lives and livelihoods throughout Africa. Weather

forecasting research and development (throughout the full chain from model development to user communication and feedback) should be a key aim of climate preparedness for the future, strengthening the United National Framework Convention on Climate Change (UNFCCC) and the Paris Agreement for all African nations, as well as supporting fulfilment of national commitments to support the Sendai Framework and the Sustainable Development Goals.

Co-production of a range of services is needed, but this depends on African meteorological agencies having the technical tools and know-how to adequately meet decision-makers' information requirements.

Investment should be made into transdisciplinary weather and climate research projects to ensure full end-to-end chain forecast development, delivery and evaluation. WMO can promote this approach and fill gaps in specific needs-based research gaps, so that investment can readily produce tangible results.

There is significant progress to be made based on scientific development and exploitation of existing, and next-generation know-how, e.g. satellite nowcasting, convection-permitting NWP ensembles, and S2S databases.

It should be recognised that some existing forecast products, which work effectively in the mid-latitudes, are inadequate for Africa at present, particularly for prediction of rainfall on daily timescales. Skill in the management and manipulation of data; use and application of forecast models and products; and fundamental research to improve prediction skill across all timescales should be key areas for future programmes. Directed research projects that can fill this fundamental research gap should be supported and implemented by WMO. Training programmes, focused on capacity building in the use and manipulation of data, and the application of forecast products, should be a key priority for international agencies such as WMO and EUMETSAT.

Systematic and impact-based forecast evaluation is critical to forecast improvement, to economic sustainability of services, and to effective forecast use.

Directed efforts into evaluation and socio-economic assessment of the benefits of weather forecasting will strengthen the investments from both private and public funders to NMSs. National Frameworks for Climate Services in Africa should share learning to support the development of a transferable, cost-effective evaluation methodology, together with capacity building through directed training programmes. This will allow nations to keep their frameworks flexible, applying evaluations to sectors and users of highest priority in each country.

Cooperation between the academic and operational sectors within Africa is a tremendous opportunity for increasing the long-term sustainability of solutions developed within projects and programmes. Partnership with the private sector offers an opportunity for more sustainable resources to support forecast services financially.

In improving African weather forecasting services, the role of international partnerships cannot be neglected. Major elements of the forecasting delivery process, including models, observing systems and know-how, are held in international centres outside Africa. The improvement in such systems cannot be achieved without effecting change within international as well as African partners.

Core funding, led by international agencies, should be directed to the long-term investment in and maintenance of observational networks.

The above recommendations outline the key steps needed to realise the socio-economic and environmental benefits of improved weather forecasting across the African continent.

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