Institution: University of Leeds

Unit of Assessment: 7 - Earth Systems and Environmental Sciences

Title of case study: Improved weather forecasting systems in Africa delivered through meteorological service partnerships

Period when the underpinning research was undertaken: 2003 - 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Douglas Parker	Professor	01/02/1997 – present
John Marsham	Associate Professor	01/04/2003 – present
Cathryn Birch	University Academic Fellow	01/07/2015 – present
Luis Garcia-Carreras	Research Fellow	01/10/2007 – 13/11/2017
Peter Knippertz	Professor	01/06/2009 – 31/10/2013

Period when the claimed impact occurred: 2013 - 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

A step change in the design, use and exploitation of Numerical Weather Prediction models for Africa has been steered by Leeds research in partnership with the UK Met Office. The improved models better represent the physical processes that influence the most damaging weather conditions. The weather services of 17 African nations are using the models, enabling more accurate operational forecasts. During 2019 and 2020, in Kenya and Senegal, the models informed warnings of severe weather and other natural hazards. Uptake of the models was accelerated through co-developed training resources and test-bed workshops, and through integration into the syllabuses of two leading African institutions that train meteorologists.

2. Underpinning research (indicative maximum 500 words)

Our pioneering papers on convection-permitting weather forecasting modelling for Africa, underpinned by our observations and theoretical analysis, demonstrated the step-change in capability offered by "convection-permitting" (CP) models [1,2] and their improved forecast skill [3]. The research has been at the forefront of a revolution in tropical Numerical Weather Prediction (NWP) modelling skill.

Africa has a limited weather observation network, and the theory of tropical atmospheric dynamics is not well developed. Leeds research has used novel observations, theory and computational models to understand the physics of convective storms and atmospheric circulation in tropical Africa. The research involved close collaboration with the Met Office [e.g. 1,3,4], across multiple projects, supported and enabled through the University of Leeds-Met Office academic partnership, chaired by Parker, then Marsham, since 2010. Interdisciplinary (land-atmosphere) collaboration with the Centre for Ecology and Hydrology (CEH) Wallingford also resulted in influential outputs [e.g., 2,4,5].

Parker led the UK's contribution to the African Monsoon Multidisciplinary Analysis (AMMA), representing the largest interdisciplinary research programme exploring African weather and climate ever carried out, funded by agencies including the EU, NERC and the US DoE. Parker was one of the 6-strong core-group of the AMMA International Scientific Steering Committee, and co-led the AMMA upper air programme (winning the Royal Meteorological Society's Vaisala

award), which delivered observations on which many international researchers relied. AMMA generated more than 600 research outputs.

Using field observations, the Leeds research has developed case studies and statistical analyses to explain the physics of high-impact African weather systems. (i) The research explained the large-scale circulations driven by deep convective storms [1, 6], and evaluated the initiation of storms through land-atmosphere interaction [2]. (ii) The first detailed analysis of an African Easterly Wave event was made using AMMA measurements [4]. (iii) The Sahara is the world's primary source of airborne mineral dust, which has a major effect on transportation, agriculture and human health. As part of the "Fennec" project, the Leeds team built and co-deployed unique instruments and aircraft observations over the Sahara, demonstrating how Saharan dust is lifted into the atmosphere and how this needs to be represented in different models [7]. Each of these studies provided insight into the performance of the Met Office NWP model for Africa.

The observational studies have been used to understand biases in the weather and climate prediction models used operationally to deliver predictions to the public, governments and commercial users. As part of the "Cascade" project, the Leeds team analysed world-first Met Office CP simulations for West Africa, and our research demonstrated the step-change in improvements offered by this new generation of CP models. Taylor et al. [5] demonstrated how CP models correct the biases in representation of land-atmosphere coupling. Garcia-Carreras et al. [1] demonstrated how the failure of models to represent the circulations caused by deep convective storms account for most of the known biases in Saharan and North African temperatures and circulation. Birch et al. [6] showed more generally how the misrepresentation of the deep convective storms explains model biases for the entire West African region.

The improvement of weather forecast practice in Africa has been accelerated by the Leeds-led GCRF African SWIFT (Science for Weather Information and Forecasting Techniques) Programme, which forms part of the UK's Official Development Assistance commitment.

3. References to the research (indicative maximum of six references)

1. Garcia-Carreras, L., Marsham, J.H., Parker, D.J., Bain, C.L., Milton, S., Saci, A., Salah-Ferroudj, M., Ouchene, B., Washington, R., 2013. The impact of convective cold pool outflows on model biases in the Sahara. *Geophysical Research Letters,* 40, pp. 1647-1652. http://dx.doi.org/10.1002/grl.50239
2. Birch, C.E., Parker, D.J., O'Leary, A., Marsham, J.H., Taylor, C.M., Harris, P.P., Lister, G.M.S., 2013. Impact of soil moisture and convectively generated waves on the initiation of a West African mesoscale convective system. *Quarterly Journal of the Meteorological Society,* 139, pp. 1712-1730. https://doi.org/10.1002/qj.2062
3. Woodhams, B.J., Birch, C.E., Marsham, J.H., Bain, C.L., Roberts, N.M., Boyd, D.F.A., 2018. What is the added-value of a convection-permitting model for forecasting extreme rainfall over tropical East Africa? *Monthly Weather Review,* 146, pp. 2757-2780. https://doi.org/10.1175/MWR-D-17-0396.1
4. Bain, C.L., Parker, D.J., Dixon, N., Fink, A.H., Taylor, C.M., Brooks, B., Milton, S.F., 2011. Anatomy of an observed African easterly wave in July 2006. *Quarterly Journal of the Meteorological Society,* 137, pp. 923-933. https://doi.org/10.1002/qj.812
5. Taylor, C.M., Birch, C.E., Parker, D.J., Dixon, N., Guichard, F., Nikulin, G., Lister, G.M.S., 2013. Modeling soil moisture-precipitation feedback in the Sahel: Importance of spatial scale versus convective parameterization. *Geophysical Research Letters,* 40, pp. 6213-6218. https://doi.org/10.1002/2013GL058511
6. Birch, C.E., Parker, D.J., Marsham, J.H., Copsey, D., Garcia-Carreras, L., 2014. A seamless assessment of the role of convection in the water cycle of the west African Monsoon. *Journal of Geophysical Research*, 119, pp. 2890-2912. https://doi.org/10.1002/2013JD020887
7. Marsham, J.H., Knippertz, P., Dixon, N.S., Parker, D.J., Lister, G.M.S., 2011. The importance of the representation of deep convection for modeled dust-generating winds over

West Africa during summer. *Geophysical Research Letters,* 38, L16803. https://doi.org/10.1029/2011GL048368

Research Funding
- African Monsoon Multidisciplinary Analysis (AMMA, 2004-2013). International project c.GBP35million, AMMA UK (NERC), led by Leeds, c.GBP2million.
- NERC Fennec – The Saharan Climate System (Fennec, 2010-2013), GBP909K
- NERC Cloud System Resolving Modelling of the Tropical Atmosphere (Cascade, 2008-2011), GBP331K
- NERC GCRF Science for Weather Information and Forecasting Techniques (SWIFT 2017 - 2021), GBP8million

4. Details of the impact (indicative maximum 750 words)

Partnership between researchers at Leeds and the UK Met Office has facilitated the sustained translation of research on African weather systems, as detailed at the end of this section, into improvements to the global (low-resolution) Numerical Weather Prediction (NWP) model and the regional (high-resolution (CP)) "Tropical Africa" (TA4) model being used operationally by African national weather services to deliver public weather forecasting services.

Model Implementation by African Weather Services

At the time of submission, 17 of the 53 World Meteorological Organisation (WMO) listed African national weather services are using the Met Office models on a regular basis (at least daily on average); this usage is evidenced in model data access statistics provided by the Met Office [A]. In total, 1196 users from 43 countries have accessed the models from 2019 - 2020. Detailed analysis of model usage for two countries has been undertaken as part of the SWIFT project. SWIFT has pioneered the use of weather forecast "testbed" events in Africa, where researchers worked alongside forecasters from the African weather centres to test the Tropical Africa Model in real time.

The Kenya Meteorological Department (KMD [B]) and Senegalese Weather Service (ANACIM [C]) are using the Met Office's Tropical Africa model as part of their daily short-range forecasts of severe weather. *"Following the SWIFT testbed, KMD has continued to use the Tropical Africa model in our severe weather forecasts (which are shared across East Africa through SWFP* [the WMO's Severe Weather Forecasting Programme]*). The model has given KMD forecasters much greater confidence in the details of the location and timing of heavy rains, which are critical to our forecast users."* [B]**.** Our work has also underpinned several instances in which the Tropical Africa Model enabled KMD to make accurate high-impact weather forecasts, leading to successful interventions: *"Forecasts based on the Tropical Africa model have been used to warn the public and to alert the search and rescue authorities. It has resulted in the evacuation of the people affected by landslides and mudslides in western Kenya, in West Pokot on 23rd November, 2019 and Marakwet counties, as well as during the flooding on Lake Victoria and in Budulangi on 29th May, 2020."*" and "*Forecasts from the model have also been used in successful guidance provided by KMD to the regional task team brought together by the Kenyan government to tackle the locust outbreaks which occurred late in 2019."* [B].

In Senegal, ANACIM are delivering forecasts using the Tropical Africa model: *"This model has much better performance for representation of intense rainfall over our region, both in spatial resolution (4km enables us to predict rainfall on the scale which matters to forecast users) and in terms of forecast accuracy"* [C]. The improved forecasts are communicated to millions of people in Senegal [C], Kenya [B] and 15 other countries, enabling them to protect lives and livelihoods.

The South African Weather Service (SAWS) is utilising the same high-resolution regional model developed and supported by the UK Met Office, which is shared with the 16 national meteorological offices in the southern Africa region [D]. Operationally this is used as part of national severe weather forecasts and at the Aviation Weather Centre at O.R. Tambo

International Airport. Evaluation of this model [E] "…*shows considerable improvement in the prediction of convective storms, relative to global model simulations*." [D].

Forecaster Training and Practice

Use of the improved NWP models in African forecasting has been accelerated by new forecaster training resources in National Weather Services and in African university degree programmes. Parker led an international process of knowledge exchange (2006 to 2013), resulting in a training guide for operational forecasters; "*Meteorology of Tropical West Africa: The Forecasters' Handbook"* [F]. The *Handbook* has been translated into French (2018), and >300 copies have been distributed by the Met Office and Météo-France to 20 of the 50 African national weather services, 5 African Regional Training Centres and the 10 tropical African universities offering meteorological degrees. *"This book has become an essential resource for ANACIM forecasters and our community in Africa more widely. We have copies of the book in English and French, and they are kept in our operational forecast office where forecasters consult them every day."* [C]. SWIFT developed training materials on the practical use of NWP based on the methods described in the Forecasters' Handbook and developed new visualisation software, to enable trainees to work hands-on with images generated from NWP. In February 2020, the WMO Regional Training Centre in Oshodi, Lagos, delivered training using our new software to 28 forecasters from the main weather forecast centres of Nigeria, including Nigeria's 4 international airports [G] (which are among the busiest in Africa, serving more than 10 million passengers *per annum*). At KNUST, a new undergraduate module using our software was introduced into the undergraduate curriculum in 2019, to train 80 undergraduate students *per annum* [H] in practical use of NWP outputs and has become part of the formal ongoing syllabus for the course.

Informing Numerical Weather Prediction at the UK Met Office

Integration of the research into Met Office model improvement has been supported by joint "Process Evaluation Groups" (PEGs). Birch (Leeds & formerly Met Office 2013-2015) co-chaired the Africa PEG alongside the Manager of Regional Systems Evaluation at the Met Office (former PGR at Leeds). The research has informed the representation of physical processes within model code, and the selection of different model configurations and domains. The Met Office have said that: *"…sustained contribution and expertise of the group at Leeds on NWP modelling for Africa has influenced how we use and interpret our modelling systems, enabled the development of better tools to evaluate model output, the development of new code that improves models and the quality of the system, reducing key systematic errors over Africa and improving the accuracy of operational forecasts. Recognizing the value of the Leeds research we took the step of embedding staff within the department* [at Leeds] *to further facilitate the pull through of the Leeds research into our modelling systems and their use*." [I]

In 2017, the Met Office made a commitment to develop a new "cold-pool" parametrisation scheme [I], (as part of a major NERC-Met Office investment to develop the new convective parametrisation, named CoMorph, influenced by [1]). The research also influenced the model's improved representation of dust, by demonstrating the value of prognostic representation of dust uplift [7, I]. "*These improvements while critical for Africa stretch to regions beyond Africa such as in Asian-Australian, East Asian and North American Monsoon systems and in other dust generation regions of the globe (e.g. Tibetan Plateau, Australia), impacting key partners in India, Australia, China and South East Asia."* [I]

Specifically, these collaborations have shaped the design and accelerated the development of a Tropical Africa Model at 4.4km resolution. *"The Leeds group have been at the forefront in evaluating these* [convection-permitting] *models in the context of African weather systems" "...with key improvements in the prediction of high impact precipitation events. This research helped to define the requirements for convection permitting models over Africa and accelerate the development of a Tropical Africa model at 4.4km which became operational in September 2018 and is serving data to numerous African countries on a daily basis."* [I, A]

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. Met Office African Web Viewer Statistics demonstrating the use of the operational global and regional convection-permitting Unified Model between October 2019 and September 2020. 17 national weather services have used the models more than 365 times (daily on average).
B. Letter from Deputy Director in Charge of Forecasting Services, KMD, Kenya Meteorological Department
C. Letter from Director of Meteorological Service, ANACIM, meteorological service of Senegal describing how the Tropical Africa model benefits the users of their forecasters, and the benefits of the training materials supplied by Leeds).
D. Letter from Senior Manager: Research, South African Weather Service
E. Publication. Stein, T. H. M., Keat, W., Maidment, R. I., Landman, S., Becker, E., Boyd, D. F. A., Bodas-Salcedo, A., Pankiewicz, G., & Webster, S. (2019). An Evaluation of Clouds and Precipitation in Convection-Permitting Forecasts for South Africa, Weather and Forecasting, 34(1), 233-254. Publication from University of Reading, South African Weather Service and UK Met Office evaluating regional model forecasts for South Africa. References Leeds research including [3] and [6].
F. Book. *Meteorology of Tropical West Africa: The Forecaster's Handbook*. (2017) Published by Wiley-Blackwell
G. Letter from General Manager, Meteorological Research, NiMet, the meteorological service of Nigeria.
H. Letter from Provost, College of Science, KNUST describing how they use the synoptic methods of analysing NWP to train 80 students every year.
I. Letter from Director of Science, UK Met Office detailing influence on modelling capability.