Nowcasting for Africa: advances, potential and value

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GCRF African SWIFT

The Global Challenges Research Fund (GCRF) African SWIFT (Science for Weather Information and Forecasting Techniques) project is a £9 million programme of work led by the National Centre for Atmospheric Science (NCAS) at the University of Leeds, United Kingdom. SWIFT focuses on forecasting research for sub-Saharan Africa across temporal scales from hours to seasons, as well as capacity building for four partner countries (Figure 1; Senegal, Ghana, Nigeria and Kenya). SWIFT brings together scientists and meteorologists from 10 African and five UK-based organisations with the World Meteorological Organization (WMO) as an advisory partner.[1] Each African country has their national meteorological service (NMS) and one university as partners.

A major research theme of SWIFT is the improved use of satellite data, especially in the context of nowcasting. Nowcasting is the evaluation of the current weather and the production of short term predictions to provide warnings. A more detailed definition of African nowcasting is provided in Box 1.

Nowcasting for Africa: A missed opportunity

Almost 50 years of nowcasting

In the preface to the book *Nowcasting* (Browning, 1982), Keith Browning laments that '*the relative lack of material [at the 1981 nowcasting symposium] from the Tropics is regrettable, because nowcasting methods based on remote sensing are likely to prove particularly helpful in areas rich in mesoscale events but poor in terms of existing forecasting facilities*'. At the time, nowcasting in some countries had been performed for almost a decade, driven in part by the increasing prevalence of rainfall radars. The lack of radars in the tropics prevented similar nowcasting activities. However, this period also marks the beginning of satellite Earth observations. This is not overlooked in Browning's book and there are three chapters dedicated to the use of satellites for nowcasting (Kelly *et al*., 1982; Shapiro *et al*., 1982; Smith *et al*., 1982)

Satellite Earth observations have been available in the intervening 39 years. However, there are almost no automated operational nowcasting systems used in Africa today. Nowcasting performed by the South African Weather Service (SAWS) being a notable exception (de Coning *et al*., 2015; Gijben and de Coning, 2017). The WMO Nowcasting Guidelines (World Meteorological Organization [WMO], 2017) outline that: *[in] 'data-sparse regions, "low-cost" nowcasting systems are created by using satellite and lightning data (blended with numerical weather prediction)'*. This is not true for most of Africa where nowcasting is manual: viewing satellite imagery, calculating storm speeds and predicting storm positions, usually limited to aviation purposes.

Figure 1. Map of the African continent with GCRF African SWIFT partner countries marked.

[1]A full list is available at https://africanswift.org/about/

Box 1: A definition of African nowcasting

Nowcasting is the description of the current state of the atmosphere and predictions for the next few hours (WMO, 2017). More detailed definitions are hard to find, because the process varies regionally and according to the availability of data. The authors propose that African nowcasting be defined using three criteria:

1. **Nowcasting includes analysis of near-real-time observations**, to describe current weather conditions.
2. **Nowcasting forward propagates observed weather features**, by extrapolation but also more sophisticated methods using a wide range of data and dynamical understanding.
3. **Nowcasting requires continued monitoring** made possible by a rapid workflow of data acquisition, processing and the dissemination of warnings and updates.

In addition, nowcasting is typically:

- **Applied to high impact weather**, such as thunderstorms and lightning, fog and atmospheric dust.
- **Focused on stakeholders who are vulnerable to those events** such as aviation and fisheries.
- **Focused on localised forecast domains**, so alerts for high-impact weather on the scale of hours can be accurate.
- **Not strictly defined by a forward timescale** as the utility of nowcasting techniques depends on the meteorological phenomenon.
- **Facilitated by computer systems** that bring together disparate data and process them ready for **human interpretation by seasoned forecasters.**

The fact that nowcasting technology, data and guidelines have existed for many years without nowcasting becoming widespread, suggests one of two possibilities: (1) there is little value in African nowcasting or (2) there are barriers to nowcasting. The first of these points is clearly untrue as heavy rainfall, strong winds and lightning are abundant in Africa. Therefore, we must conclude that there are conditions that prevent African nowcasting.

Barriers for African nowcasting

Often, high impact weather is poorly represented by numerical weather prediction (NWP) methods. Recent work has shown that global ensemble modelling systems typically show less skill than climatology across western and central tropical Africa and that skill in eastern and southern Africa is also low (Vogel *et al*., 2018, 2020). In particular, the ability to predict extremes can be especially poor (Vogel *et al*., 2020). Even convection permitting simulations (over East Africa) show low skill, with rainfall variability dominated by time of day (Woodhams *et al*., 2018). This increases the demand for nowcasting as a method of providing extreme weather warnings.

This is manifest as an aspiration to operate rainfall radars (Lamptey *et al*., 2009). However, anecdotally, investment in radar systems in Africa is often followed by a short operational period. Problems of funding repairs or limited local expertise then lead to equipment being non-operational for long periods or indefinitely. Once again, the exception is the South African radar network. However, the maintenance difficulties faced by the SAWS are well documented (Saltikoff, 2015; du Preez, 2017). Thus, Keith Browning's prediction that remote sensing (satellite data) would be useful for tropical nowcasting holds true even today.

In Africa, NMSs are often closely associated with or part of government departments (Tall, 2010). Despite the political capital of meteorological themes such as food production, water resource management and public health, funding of NMSs in Africa remains low (WMO, 2019). As such, maintaining current systems is prioritised, limiting funds available for investment to improve capacity. As such, training opportunities are not always abundant. This can prevent a critical mass of knowledge being reached, leaving NMSs vulnerable to the loss of a few members of staff.

The divergence in global uptake of nowcasting in the twentieth century can in part be attributed to existing infrastructure (television, radio, telecoms). The ability to disseminate warnings to almost the entire population in Europe, North America and Japan lent itself to nowcasting in a way not matched in Africa. Thankfully, increased connectivity (especially with respect to mobile communications) means that this barrier is far smaller than in previous decades. However, there are other technological barriers faced by NMSs in Africa. SWIFT partner organisations have regular issues of intermittent power and disrupted internet connectivity. While solutions such as the use of uninterruptible power supplies or mobile internet failovers can provide some mitigation they have associated costs and are untenable solutions for long-term operational use.

African nowcasting data (and its accessibility)

The use of satellite data for nowcasting has been recognised as providing an opportunity, not so complex or expensive to preclude African NMSs (WMO, 2012). The EUMETSAT Satellite Application Facility on Support to NoWCasting and very short range forecasts (NWC SAF) software, known as NWCSAF/GEO can produce a large number of nowcasting products. It extracts useful information from different satellite channels (and NWP data) and generates combined products for nowcasting (see Figures 2(a) and (b) for examples and Figures S4-S6, S8 and S10 (available in the Supporting Information) for further information). These products give greater insight than simple visualisations and can be produced rapidly in near-real-time. A number of products can also be temporally extrapolated.

The authors are unaware of NWCSAF/GEO being run in Africa outside of the SAWS. While the SAWS products are for southern Africa (up to the equator), and are shared with nearby nations, there are many nations within Africa whose forecasters do not have access to relevant nowcasting products. NWCSAF/GEO is not new; it has been freely available (over several iterations) for over 10 years. The issues preventing its use within Africa are largely due to the lack of knowledge of how to implement and maintain the software and how to access satellite data from Preparation for the Use of Meteosat in Africa (PUMA) systems.

African NMSs have access to satellite data (as well as a raft of other observational and model data) via the EUMETCast service, a multicast system for the transmission of data operated by EUMETSAT. Received data are generally managed within PUMA systems (Maathuis, 2017) and are visualised via Synergie software (Le Gallou, 2017). While the software allows users to navigate and visualise a wide variety of data it is clear from communication with forecasters that there are a number of limitations.

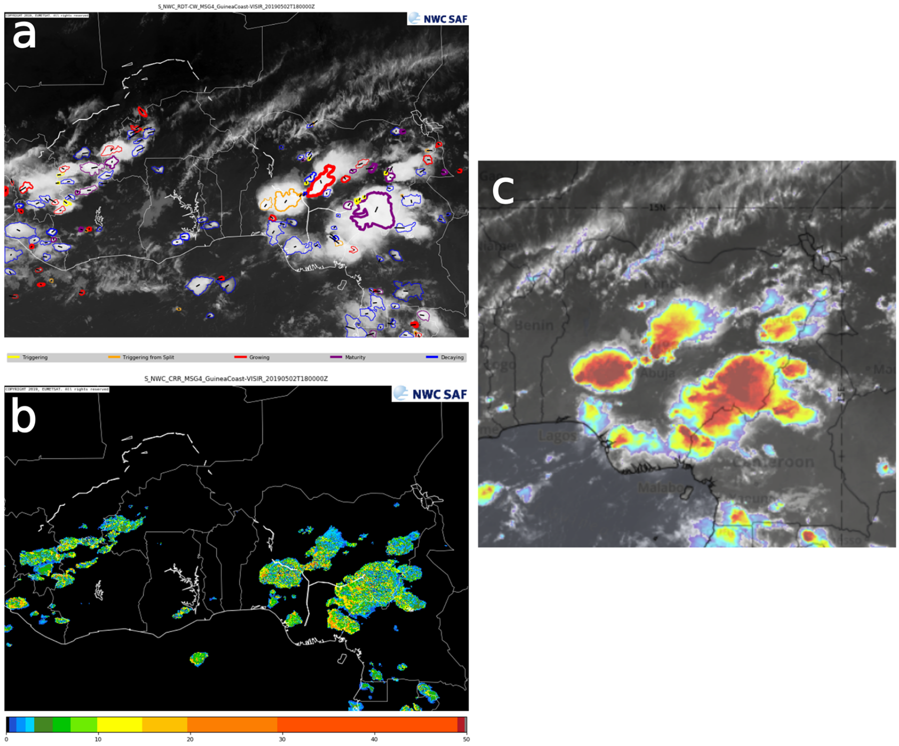

Figure 2. Examples of products available for nowcasting exercises during the SWIFT testbed 1b. All panels show 1800 UTC *2 May 2019. (a) is the NWCSAF/GEO rapidly developing thunderstorm (RDT) product, (b) is the NWCSAF/GEO convective rainfall rate (CRR) product and (c) is the Met Office provided Meteosat imagery where brightness temperature is shown with cold cloud-top temperatures indicated by a colour scale.*

Anecdotal evidence from forecasters in SWIFT partner NMSs and the authors' first-hand experiences indicate that once within the PUMA system, access to data is difficult. Users of the system are often unsure as to what data they have access to and can be unaware of the management of the EUMETCast system. Some products cannot be visualised via Synergie and so go unnoticed and are automatically deleted without being used. The problem is compounded by the automated management of incoming files, including changing file names so they are different from the 'typical file names' provided by EUMETCast and directory names that defy simple common-sense navigation. Ingesting local data (e.g. local surface observations) to display alongside received data is also complicated and so is generally not attempted, hampering analysis and verification of satellite or model data. Within Synergie configurations may be locked for forecasters and settings for complex visualisations cannot be saved to be used repeatedly. This means that generating the most useful visualisations can be time consuming for forecast staff.

In the summer of 2019, 10 years after NWCSAF/GEO was first released (and following the release of a wide range of near-real-time products by the SWIFT project) two products (Rapidly Developing Thunderstorms (RDT) and Convective Rainfall Rate (CRR)) were made available on the EUMETCast African service. While this is a positive step, it has not been particularly useful. As with other products, they are not readily viewable using Synergie and so, for the SWIFT partner NMSs at least, these files continue to go unused and are automatically deleted by the system.

Current nowcasting methods

A feature common to modern operational nowcasting systems (including NWCSAF/GEO) is the automated forward propagation of existing storms through the application of storm motion or optical flow vectors (Dixon and Wiener, 1993; Hand, 1996; Mueller *et al.*, 2003; Sills *et al.*, 2003; Bowler *et al.*, 2004, 2006; Brovelli *et al.*, 2005; James *et al.*, 2018). While extrapolation of this type can work very well, it has limitations. It is well suited to analysing frontal systems where features all move in the same direction and at the same speed or if convective storms do not change significantly in size or intensity over the extrapolation period. However, convective storms can vary significantly in their size and intensity over short periods of time. Also, the extrapolation approach does not predict the triggering of new storms and as such has a clear predictive limitation, especially in the tropics. That said, once storms transition into organised systems, forward propagation is likely to be a useful technique.

To better represent the development of deep convective storms, some nowcasting systems also represent growth and decay. However, the past state of a convective storm has been shown to be a poor predictor of its future behaviour (Tsonis and Austin, 1981; Radhakrishna *et al.*, 2012). As such, one method to enhance predictability is to consider the effects of known geographic or atmospheric features. Examples include mountain ranges that enhance precipitation; sea, land and lake breezes producing convergence; or dry lines which are associated with storm triggering (Figure 3).

Short, convection-permitting simulations are now feasible data sources for nowcasting systems (Bowler *et al.*, 2006). NWP simulations initialised frequently and using data assimilation techniques are able to provide improvements over purely deterministic forecasts (Sun *et al.*, 2014). Similarly, ensemble systems if initialised at short intervals have the potential to provide useful information. The interpretation of such simulations is inevitably probabilistic, as such this approach lends itself to the production of probabilistic risk nowcasts. Given the unpredictability of convective storms, this type of nowcast is appropriate for Africa but might prove a challenge to communicate to the public who often expect yes/no answers to questions like 'will it rain?'.

To predict storm triggering, fuzzy logic systems can be used (Mueller *et al.*, 2003; James *et al.*, 2018). These represent the inherent uncertainty of the input data and through the application of rules (informed by statistical analyses, expert knowledge and dynamical understanding) give probabilistic predictions of storm initiation.

In contrast to these techniques (which are driven by a dynamical understanding), there is now much research being focused on machine learning (Shi *et al.*, 2017; Agrawal *et al.*, 2019; Lebedev *et al.*, 2019; Tran and Song, 2019), in particular convolutional neural networks (CNNs). This field holds great promise for short-term prediction but gives

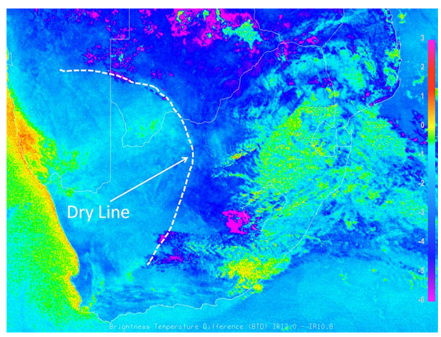

Figure 3. A SAWS brightness temperature difference image (IR12.0–IR10.8) over South Africa on 28 November 2013. A dry line is indicated on the image. This feature was associated with the initiation of a very large convective system later the same day. (© 2019 EUMETSAT.)

limited opportunity to develop understanding of physical processes. To the authors' knowledge, no operational nowcasting systems yet use CNN techniques. However, it seems likely that in the future CNNs will be a powerful tool for nowcasting.

The role of human interpretation is also important to consider. Local forecasters that know the system they are using are able to adjust forward projections and account for spurious features prior to warnings being issued. Despite technological advances, the role of the human nowcaster remains an important step in the production of nowcast warnings.

SWIFT progress in the provision of nowcasting products

Testbeds

SWIFT has a programme of weather forecasting 'testbeds', bringing researchers and forecasters together in real-time forecasting settings (to the authors' knowledge the first of their kind in Africa). Testbeds have been successful in the USA in accelerating the operational use of new tools (Ralph *et al*., 2013). The SWIFT testbeds are helping to engender a sense of shared purpose across meteorological institutions from both Africa and the UK.

SWIFT Testbed 1b was hosted in April/May 2019 at the Kenya Meteorological Department (KMD), Nairobi (Figure 4) and in partnership with the WMO-led High Impact Weather Lake System project (HIGHWAY). Testbed 1b produced operational forecasts for East and West Africa and evaluated the use of data and techniques (Fletcher *et al*., 2020). The participants represent a wealth of expertise in the fields of East and West African meteorology. Researchers learnt about the techniques employed by forecasters and how meteorological fields are interpreted in specialised ways and forecasters were exposed to research ideas, products and techniques they had not previously used. This exchange of ideas was only possible due to the hard work of the participants and their willingness to share knowledge and learn from others. Nowcasting was one of the three main strands of Testbed 1b along with synoptic forecasting and forecast evaluation. These fed into one another: forecasts informed nowcasts and nowcasting products enabled the evaluation of earlier forecasts.

The testbeds are a showcase for nowcasting products. A major achievement was the provision of NWCSAF/GEO products by NCAS and the University of Leeds (Figures 2(a) and (b) RDT and CRR respectively) and Meteosat derived imagery (Figure 2(c)) and ATDNet Sferics (lightning) by the UK Met Office. All these products were generated in the UK and made available online for the testbed.

Figure 4. Photos from the GCRF African SWIFT Testbed 1b hosted at the IMTR at the KMD, Nairobi, Kenya.

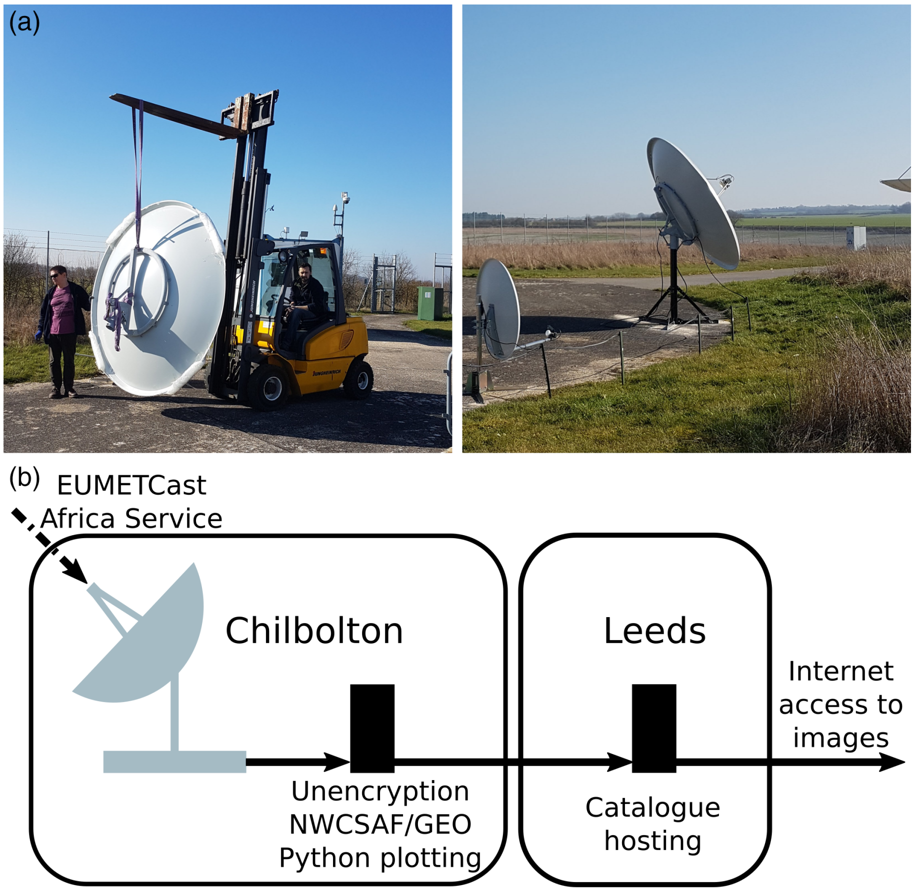

Figure 5. (a) The installation and position of the 2.4m C band satellite antenna located at the Chilbolton observatory. (b) A schematic indicating the location of the hardware and processing required to produce NWCSAF/GEO products and make images available for African forecasters and researchers.

A 2.4m satellite antenna has been installed at the Chilbolton Observatory, UK (Figure 5). Data is processed using NWCSAF/GEO and the resultant images are then catalogued and made publicly available online.[2] At the time of writing, images are being produced

[2]https://ncas.ac.uk/

with a typical latency of 30min (the first time this has ever been done for East and West Africa). The use of this system was, in part, to highlight what is possible for African NMSs to achieve with respect to operational nowcasting as much of the equipment required is extant within NMSs and the rest is readily available and relatively low cost.

NWCSAF/GEO products provided by SWIFT have since been used operationally and during a joint SAtellite and Weather Information for Disaster Resilience in Africa (SAWIDRA) and the African Centre of Meteorological Application for Development (ACMAD) forecast demonstration exercise. Feedback is currently being gathered with the aim of improving visualisation methods and providing development feedback to NWC SAF.

Building capacity to implement nowcasting in Africa

The experience gained setting up the nowcasting system described above means that NCAS can provide advice and training to build capacity for operational nowcasting in Africa. In August 2019, training was delivered to staff from the SWIFT partner institutions on how to set up receiving hardware and run NWCSAF/GEO, this covered data preprocessing, software use, visualisation and automation. The supporting material for this course was provided as a website.[3] Further training scheduled for June 2020 has been postponed due to the Covid-19 global pandemic. Meanwhile technical support for groups managing local hardware and software is being provided. Alongside support and training there is an ongoing discussion about getting NWCSAF/GEO run operationally within African NMSs. Additionally, four satellite antennas have been purchased for partner universities. The Kwame Nkrumah University of Science and Technology (KNUST), Ghana have received and set up their receiving station. SWIFT aims to facilitate African partners in commissioning and maintaining such systems. African ownership of these responsibilities will prevent reliance on UK generated products beyond the lifetime of SWIFT (ending December 2021).

Communication between the University of Leeds/NCAS and NWC SAF is ongoing and there is mutual interest in collaboration on the development/evaluation of NWCSAF/GEO and the delivery of training in Africa. SWIFT NWCSAF/GEO evaluation work conducted at the University of Reading (Hill *et al.*, 2020) helps us understand how NWCSAF/GEO products should be used over Africa. The role of ACMAD within SWIFT will help to generate interest in using NWCSAF/GEO products and provide a pathway for future training in Africa. Nowcasting products have been generated for SWIFT research case studies, these will be useful to understand how such products can be used as a resource to conduct research.

[3]https://sites.google.com/ncas.ac.uk/swiftsafnwc-training

Nowcasting potential in Africa

There is great potential for increasing nowcasting capacity across Africa. The provision of nowcasting products through SWIFT has allowed nowcasting to be possible operationally across East and West Africa. However, there is considerable work needed for African NMSs to make nowcasting routine.

Training

A major element of making this a reality is training of future forecasters. Educational centres such as partner universities, ACMAD, the NiMet (Nigerian Meteorological Agency) Regional Training Centre (RTC), the KMD Institute for Meteorological Training and Research (IMTR), Ecole Africaine de la Météorologie et de l'Aviation Civile (EAMAC) and workshops run as part of the Severe Weather Forecasting Programme in regional specialised meteorological centres will not only educate forecasters in partner countries but more broadly across Africa. This ensures a legacy of nowcasting skills that will outlast the SWIFT funding period.

Development

SWIFT development of additional nowcasting tools is ongoing; for example, investigating methods for extending extrapolation lead-times for convective systems. It is suspected that large, well-developed systems that are able to persist for many hours (and have the highest impact) are likely to be predictable for several hours.

While local generation of nowcasting products in Africa is a target, there is a need to take an holistic approach to nowcasting. Without a means of interrogating incoming data and enabling input from a forecaster, there is no way to easily generate meaningful warnings. Similarly, without a mechanism to rapidly distribute warnings the process of data collection, processing, analysis and warning production is a waste of resources. Therefore, SWIFT is also involved in solutions to these issues.

NCAS are already working alongside the UK Met Office in the development of FOREST (Forecast Observations and Research Evaluation and Survey Toolkit). FOREST is a new visualisation tool developed by the UK Met Office as part of the Weather and Climate Science for Service Partnership (WCSSP). The use of such a tool in Africa would be beneficial as it broadens access to model products and enables visualisation of near-real-time nowcasting products produced locally.

Dissemination on timescales useful for nowcasting is a great challenge and requires a change in operating methods. SWIFT is working with partner NMSs to help in the use of the Common Alerting Protocol (CAP) to disseminate warnings through a wide range of media. In addition to this, a SWIFT extension project is working on an application programming interface (API) for use with mobile applications for the delivery of nowcasting warnings (Forecasting African STorms Application (FASTA)), for which African partner institutions will provide local meteorological expertise and warnings.

Planning for the future

The Meteosat Third Generation (MTG) satellites represent a major technological step forward and could greatly enhance opportunities for nowcasting in Africa (Stuhlmann *et al.*, 2005). Specifically, the new lightning imager will provide information on electrically active storms across the whole continent. However, the sheer scale of data generated by the MTG satellites means that it is likely that the EUMETCast Africa service (the primary source of forecast/nowcast data for many African NMSs) will only contain a subset of the data produced. SWIFT is working alongside NWC SAF, the SAWS and the WMO to highlight the effects of downgrading the Africa service and mitigate the effect of subsetting satellite data to protect nowcasting capability. It is currently still uncertain whether the introduction of MTG will be beneficial to African users.

Value of satellite and nowcasting research for Africa

The value of making automated nowcasting products available to African NMSs is undoubtedly great. The manual approach used for aviation safety is labour intensive and so is difficult to expand to national scales. However, augmenting it with the techniques discussed earlier and introducing automation will allow forecasters to produce warnings quickly for much wider regions.

Many industries would benefit from greater access to warnings of imminent high impact weather that are currently not widely available from African NMSs. For example: the energy sector (wind, oil and gas), commercial/state logistics and haulage, ports, fisheries, military and agriculture to name a few. NMSs could provide commercial nowcasting services; as such, this represents potential new sources of funds.

By improving their ability to produce and disseminate warnings there is the potential to raise the public profile and trust in African NMSs. Skilled human interpretation of nowcasting fields is highly valuable for even the most advanced nowcasting systems, and as such, experienced forecasters play an important role in successful operational nowcasting. The wealth of forecasting expertise within SWIFT partner NMSs means they are well placed to take advantage of the current market gap.

SWIFT nowcasting work also has a series of less obvious benefits. Cooperation between African universities and NMSs (including across national boundaries) is a requirement for SWIFT, creating a greater capacity to share experiences, knowledge and innovations. Centres of education can make use of connections to NMSs to understand what training is valuable and tailor content as required. Similarly, the use of nowcasting systems in universities for research will produce results useful for NMSs.

Support from centres such as ACMAD (who have created a new Department of Research and Development; DRD) will allow for the development of new Africa focused nowcasting techniques. Partner universities will be in a stronger position to lead and collaborate on meteorology research and be able to use their research to steer NWCSAF/GEO development. In the past NWC SAF focus has mostly been on mid-latitude improvements (reflecting their users). Increasing the user base in Africa and active participation in NWC SAF user engagement will inevitably lead to product improvements for tropical Africa.

Concluding remarks

It is hoped that the nowcasting work of SWIFT can provide a roadmap for how African nowcasting can be achieved. While we accept that this is an ambitious plan there is a great need and much potential for improvement. We recognise the risk that advances might be temporary as with previous nowcasting projects in Africa that have had initially impressive results (UK Met Office [UKMO], 2014; Thiery *et al*., 2017). The SWIFT approach of: avoiding complicated or expensive infrastructure, providing technical training and support and encouraging the cooperation of African institutions will hopefully encourage self-sufficiency and with it effect long-lasting change.

Acknowledgements

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Supporting Information

Figures S1–S11. Examples of how nowcasting images routinely generated as part of the Global Challenges Research Fund (GCRF) African SWIFT (Science for Weather Information and Forecasting Techniques) project were used for operational nowcasting during the SWIFT testbed 1b.

All Supporting Information is available with the online edition of the article (which is free for members to access).

Locating the anemometers of the US ASOS network and classifying their local shelter

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Introduction

The anemometers of the US Automated Surface Observation System (ASOS) have been providing surface mean and gust wind speeds and directions at 1min intervals since 1 January 2000, with the number of stations distributed across the contiguous US (CONUS) growing to 864 by the end of that decade. This is a most valuable resource in Wind Engineering[1] studies because it allows short-duration events, such as thunderstorm downbursts (Chen and Lombardo, 2020), to be assessed over much longer periods than is possible from targeted measurement campaigns.

It is important to know the exact location of an anemometer so that the data it provides can be homogenised (Cook, 1996; Pirooz *et al*., 2000; Masters *et al*., 2010) to compensate for the effects of orography, surface roughness changes and shelter from upwind obstacles, especially when the wind data are to be used in engineering design. The US National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) maintains publicly accessible online archives of the ASOS data. The Historical Observing Metadata Repository (HOMR) database (NOAA, 2021) provides detailed information of locations, installation dates and equipment. But, despite the sophistication of the user interface, the metadata HOMR provides is often inaccurate or out of date. The locations of ASOS anemometers are at best correct within 10m, but at worst may be in error by more than 20km – for example, KHOT[2] at Memorial Field, Hot Springs National Park, AR, is 20km north and 1km west of the HOMR location. When the position has not been surveyed, HOMR substitutes the Federal Aviation Administration (FAA) airfield locations corresponding to the centre of the main runway. Development of airfields sometimes affects the exposure of ASOS instrumentation, requiring it to be moved to a new location: six such moves are recorded in HOMR, but 26 are not. Also, the locations in HOMR correspond to the surface package of instruments, and the anemometer is sometimes sited elsewhere. In this study, precise locations of the anemometers are found at each of these ASOS stations to correct errors in the current station metadata, by using only open access tools and datasets.

Finding the anemometers

Figure 1 shows the most common layout of the ASOS equipment package. Google Earth Pro[3] (GEP) is a most convenient tool

[1]http://iawe.org

[2]The four-character ICAO codes for all stations mentioned in this paper are hyperlinked to their corresponding current Google Earth image at https://earth.google.com/web/

[3]The Pro version of Google Earth is needed as the web version does not have the necessary measurement tools nor does it show historical images.