# Guidelines for Satellite-based Nowcasting in Africa

2023 edition

WEATHER CLIMATE WATER

WORLD
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# INTRODUCTION

Nowcasting services (that is, forecasting generally defined as from 0 to 6 hours) crucially provide an ultimate line of defence against high-impact weather and climate change-related events that otherwise would, and often do, result in high costs to society, in terms of lives lost and damage to infrastructure and the economy. Nowcasting early warning systems are therefore crucial in the United Nation's ambitious five-year deadline (United Nations, 2022) to protect global citizens from extreme weather.

Nowcasting by National Meteorological and Hydrological Services (NMHSs) provides warnings for their users, to support immediate action to reduce the impact of rapidly evolving severe weather hazards. The evolution of the hazard may have been monitored for several days prior, allowing for early warning and risk-based early action. With nowcasting based-warning comes the last chance to take action to reduce the impact of the hazard.

The present document provides guidelines for the implementation of a range of satellite nowcasting options available for Africa with the advent of the Meteosat Third Generation (MTG) satellite system. The guidelines aim to provide recommendations that will help facilitate near-term implementation, as well as the development of capacity and sustainability of services over time. The various options are broken down in the document into different technical, operational, logistical and management aspects. The guidelines can be used to create templates and roadmaps for the establishment and maintenance of nowcasting functions in African countries.

The authors' intention is that the present document will contribute to increased provision of useful nowcasting services in African countries, by providing guidance to NMHSs and their partners as to the practical solutions available. At the time of writing, robust, operational nowcasting services in Africa are very limited: while all countries offer a rudimentary nowcasting service to aviation, there is limited use of specialist nowcasting tools or procedures, and limited communication of nowcasts to other users and the wider public, for both societal as well as commercial benefit. The South African Weather Service (SAWS) provides high-quality nowcasting to 16 countries in southern Africa, and the High-Impact Weather Lake System (HIGHWAY) project (2017–2021) implemented storm warnings on Lake Victoria (Roberts et al., 2022c). Additional services have been successfully demonstrated in East and West Africa in the Global Challenges Research Fund (GCRF) African Science for Weather Information and Forecasting Techniques (SWIFT) programme (hereafter, the GCRF African SWIFT programme). With suitable coordination and support, it is hoped that many more countries and agencies may use the knowledge captured in the present document to support the implementation of nowcasting across Africa on a 5- to 10-year timescale.

The present guidelines aim to provide guidance to a range of nowcasting stakeholders in Africa. Therefore, the intended readership includes NMHSs in Africa, Regional Specialized Meteorological Centres (RSMCs), Regional Training Centres (RTCs), WMO-Coordination Group for Meteorological Satellites (CGMS) VLab Centres of Excellence for Training in Satellite Meteorology, and international agencies including the African Centre of Meteorological Applications for Development (ACMAD) and the Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar (ASECNA). WMO, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and other trainers and practitioners will be a secondary audience and should make use of the guidelines in their strategic plans and operational activities. In particular, the guidelines provide evidence that nowcasting solutions are feasible; the guidelines also set out the likely impact of implemented solutions.

The present guidelines are urgently needed, given that there is currently a lack of early warnings on this timescale in Africa. The HIGHWAY project and GCRF African SWIFT programme have demonstrated skill, impact and feasibility of early warnings. However, there are further challenges which these projects have not confronted. In particular, the transition to MTG will offer many opportunities for better-quality satellite nowcasting (such as the availability of a lightning product), but also presents technical challenges in the recalibration of algorithms and in the sharing of data with Africa. The *Abidjan Declaration on Next Generation of Satellite Products for Weather and Climate Services in Africa* (hereafter, the Abidjan Declaration), signed in September 2018 by the African Union Commission, the African Ministerial Conference on Meteorology (AMCOMET) and four African Regional Economic Communities (the Economic Community of West African States (ECOWAS), the Intergovernmental Authority on Development (IGAD), the Economic Community of Central African States (ECCAS) and the Southern African Development Community (SADC)) explicitly acknowledges the opportunities and challenges. The Declaration aims to:

> encourage and support the strengthening of African capacities … to ensure a smooth transition to MTG … and establishing, based on existing capacities, an African Meteorological Satellite Application Facility (AMSAF) leading to the generation of Africa-tailored satellite products … answering to African requirements ….

The present document presents guidelines for meeting these challenges. It focuses on implementing satellite-based nowcasting methods, tools and products, and does not include guidelines on the installation and application of radars. The reason for this is simple: radars are sparse in Africa. While radars are the best tools for operational nowcasting of rainfall and associated hazards after storms have formed, if no radars are available, then satellite solutions represent the only real-time option available for monitoring both the pre-storm environment and subsequent storm characteristics. Even in areas where radars are operating (notably South Africa), a hybrid solution combining radars with satellite (and other) products is likely to be optimal. Such a hybrid solution provides resilience against technical issues which cause loss of radar data from time to time. Numerical weather prediction (NWP) data are also a part of future nowcasting solutions, and indeed are an integral part of operational nowcasting algorithms, including the Nowcasting Satellite Application Facility (NWC SAF) algorithms. Due to the rapid nature of storm development and the real-time nature of nowcasting, NWP products (whether generated centrally or locally) cannot solve all nowcasting problems on their own. Nowcasting is a real-time data-driven process, with weather hazards occurring on a local level. Although NWP data are not the focus of the present document, they are still important and complementary to nowcasting algorithms derived from satellite data.

# 1. NEW SATELLITE DATA FOR NOWCASTING SERVICES FOR AFRICA

## 1.1 Meteosat Third Generation

The Meteosat Second Generation (MSG) satellite currently provides data every 15 minutes for an area covering Europe and Africa. Its successor, Meteosat Third Generation (MTG) (Holmlund et al., 2021), will provide observations over the entire African continent on a continuous and frequent basis for two decades from 2023. EUMETSAT generates and disseminates basic EUMETSAT NWC SAF products via EUMETCast to African users. These products are currently underutilized in many subregions of Africa. The present document provides guidance for increasing the utility of future satellite products and thereby reducing damage from hazardous weather events across all of Africa.

With the successful launch of the first MTG satellite, the imager MTG-I1, on 13 December 2022, which will be followed by the sounder MTG-S in 2024, updated instruments which include new capabilities, such as the Lightning Imager (LI), Infrared Sounder (IRS) and Ultraviolet Visible Near-infrared (UVN) Spectrometer, mark a major improvement over the previous geostationary satellite system. Data and products for full-disk imaging will be available every 10 minutes with improved spatial resolution. MTG will provide continuity of service and will substantially increase the observation spectrum compared to MSG. Namely, the MTG full-disk service will consist of 16 radiometric/spectral channels, versus 12 channels for MSG, and spatial resolution of 1 km at nadir, versus 3 km for MSG (500 m, versus 1 km for MSG, for the high-resolution channel). MTG will therefore provide much improved real-time information on fast-developing high-impact weather, including lightning observations, ocean and surface parameters (such as sea-surface temperature and turbidity of coastal waters), and will also extend to wildfires and incoming solar energy, as well as real-time monitoring of atmospheric profiles, air quality and dispersion of atmospheric pollution. Despite all the improvements and new services expected from MTG, the challenge remains of developing satellite-based nowcasting services for Africa, where data transmission rates will increase 30-fold compared to MSG.

EUMETSAT, through its cooperation with African countries and as part of its strategic objectives, aims to expand the user base for EUMETSAT data, products and services. This reflects a long-term commitment that facilitates sustainability of the investment made at the user level to exploit the data and generate regional or national weather and climate services in support of various socioeconomic sectors.

For MTG, EUMETCast Africa (a satellite-based dissemination system) will remain the primary dissemination channel for users in the region. Other access possibilities include EUMETCast Terrestrial for users with a high data-rate terrestrial connection, or a data store retrieval option. The current aim is for MTG data to be available over Africa from 2023 onward, with parallel dissemination of MSG products remaining available until 2024.

### 1.1.1 *Lightning Imager*

The detection of lightning activity is a useful source of information for nowcasting purposes. Thunderstorms always contain lightning, and this makes observations of lightning useful for establishing areas where convection is occurring, as well as for monitoring active thunderstorms in terms of location, movement and intensity.

Lightning activity is traditionally measured by ground-based systems. Ground-based networks for lightning detection provide accurate positions and timing of lightning activity and can distinguish between cloud-to-ground (CG) lightning activity and intra-cloud (IC) lightning. Some networks can provide total lightning observations (CG + IC), while others are designed more specifically for CG lightning detection, although with the ability to detect some IC. Total lightning measurements have shown favourable results in the early detection of severe weather, and greatly assist in determining the phase of thunderstorm evolution. Ground-based networks are also capable of distinguishing between positive and negative lightning discharges. At present, very few regional ground-based lightning detection networks are available in Africa. Several global lightning detection networks currently operate in Africa, but due to funding limitations, it is unlikely that many countries have access to this information.

Satellite-based lightning observations, on the other hand, are not capable of distinguishing between CG and IC lightning, nor can they provide information on positive and negative lightning discharges. However, such observations are very useful for nowcasting purposes because they provide near-real-time observations of lightning covering large areas. With the launch of the MTG and its Lightning Imager onboard, most of the African continent will, for the first time, have access to this data, bringing many advantages for African nowcasting.

Lightning information is updated frequently (as accumulated products within minutes), which provides valuable information to forecasters and is an excellent source of information to combine with other satellite products (or radar where available) to produce improved nowcasts.

#### 1.1.2 *Infrared Sounder*

The MTG Infrared Sounder (MTG-IRS) will provide atmospheric thermodynamic profiles of temperature, water vapour and ozone. This will allow for identification of potentially (very) unstable atmospheric profiles and for monitoring convection, from the preconvective clear environment through to mature convection and severe weather. The use of consecutive IRS data will foster an entirely new set of tools, such as calculation of wind products through the derivation of atmospheric motion vectors (AMVs). Such new tools will help anticipate changes in near-storm environments. The advantages of the IRS for nowcasting will include the detection of lower-level water vapour convergence preceding convection, together with the monitoring of changes in vertical temperature and stability profiles. The high-frequency IRS sounding products will also provide new inputs for limited area NWP models. The IRS will probe the entire African continent, albeit with a lower revisit time than over Europe: somewhere between one and three hours, depending on the location in Africa.

## 2. MOTIVATION FOR NEW SATELLITE-BASED NOWCASTING SERVICES FOR AFRICA

### 2.1 Nowcasting services for Africa to support adaptation

Nowcasting has enormous value and potential in Africa, where populations and economic activity are highly vulnerable to rapidly changing weather conditions, including rapidly developing storms, heavy rainfall and dust storms, which are becoming more frequent and intense with climate change. Timely issuing of warnings, a few hours before an event, can enable the public and decision makers to take action, which can save lives and livelihoods, as well as support national economies. The vulnerability of African countries to weather-related risks, combined with the underutilization of nowcasts (and reliable weather forecasts more generally), as well as the varying skill of numerical weather prediction (NWP) across the continent and the economic precarity of the African population (among the most heavily indebted and economically impoverished globally) make the continent a priority for the development of nowcasting. The main goal of an operational nowcasting service is to supply users with relevant and useable information, alerts and warnings. Many sectors of society can benefit from nowcasting services, to protect lives and infrastructure, as well as for planning purposes. There is a huge gap across the African continent for this type of service, with much potential for both public good and commercial benefit. Additionally, an increase in the number of observations across Africa would help develop the skill of NWP, particularly in West, Central and East Africa, as well as southern Africa, where global ensemble modelling systems typically show less skill than climatology (Vogel et al., 2018, 2020). The potential applications of nowcasting across the continent are wide ranging, and can cover various sectors and activities, including urban warning systems for flash floods, early warnings to fisherfolk at risk from drowning on lakes, protection of crops, water management systems, protection of cattle, aviation warnings as well as the transport sector.

The *2021 State of Climate Services: Water* (WMO-No. 1278) report indicates that storms and floods have led to the highest economic losses across the African continent (71% of the total economic losses recorded in 1970–2019). According to the *State of the Climate in Africa 2020* (WMO-No. 1275) report, in 2020 excess rainfall was recorded in certain parts of the continent, while rainfall deficits impacted others. Economic losses escalated by more than 50% between 2010 and 2019, compared to the previous decade, mainly due to floods, drought and storms. The report further outlines the numerous capacity gaps reported in an overview of early warning services – only 30% of Members on the continent have a multi-hazard early warning system in place. To reach the users who need this most, early warning systems must bridge the so-called "last mile gap", and while there is disaster risk knowledge, there is an urgent need to make this information actionable and accessible.

In parallel to the *2021 State of Climate Services: Water* (WMO-No. 1278) report, a report of the WMO HIGHWAY Project, which concluded in 2021, showed that the project helped to reduce deaths due to drowning on Lake Victoria by 30%, while boosting household incomes in poor fishing communities (*Stories of Success: Piloting a Regional Early Warning System for Increased Resilience in the Lake Victoria Region*). The deaths on the lake are mostly attributed to boat accidents. HIGHWAY developed a regional early warning system to alert fisherfolk and others travelling in small boats about high-impact weather on Lake Victoria. HIGHWAY also helped to improve surface-based meteorological observations in the Lake Victoria basin and optimize their use in forecasting: it found that satellite data (including NWC SAF products) are invaluable in diagnosing pre- and near-storm convection in areas with a sparse radar network. Studies done during the HIGHWAY project showed that lightning (as observed with the Earth Networks Global Lightning Network (ENGLN)) correlated well with storms.

The GCRF African SWIFT programme has similarly demonstrated the skill, potential and current status of nowcasting across the continent through provision of NWC SAF products and data to its partner NMHSs at two meteorological testbed events, held in April–May 2019 and September 2021. Roberts et al. (2022a) and Fletcher et al. (2022) summarized the barriers to nowcasting capability in Africa (lack of rainfall radars, low skill of NWP, and lack of funding for investment, training and technological infrastructure), and progress towards nowcasting capability in Africa (based on the GCRF African SWIFT testbed initiatives), as well as the great potential that further development (extending extrapolation lead times for convective systems, developing visualization products and disseminating warnings) and utilization could bring. Such potential includes improving aviation safety approaches across the continent, providing impact warnings to the energy, transport and agriculture sectors, building capability and exposure of African NMHSs, creating and maintaining intersectoral collaboration and development, and ultimately, improving NWC SAF products and nowcasting services to African users. The GCRF African SWIFT policy brief, *The Future of African Nowcasting* (Youds et al., 2021), implores the meteorological community to direct a collaborative programme over the next five years, focused on NWC SAF regional and national verification, evaluation and application across the continent. This could result in a significant number of African Members acquiring a sustainable capability and capacity to use and apply nowcasting products and services.

In 2017, WMO published the *Guidelines for Nowcasting Techniques* (WMO-No. 1198) with the purpose of providing NMHSs around the world with (a) information and knowledge on how to implement a nowcasting system, depending on the available resources, and (b) an understanding of the current state of nowcasting science and technology.

In order to benefit fully from the opportunity provided by satellite infrastructure, the main challenges for Africa are related to ensuring data access, extraction of suitable science-based products from satellite observations and their integration in actionable information services tailored to African needs. More capacity building in terms of user infrastructure and user training for the new generation of satellites is crucial to maintaining and developing sustainable African nowcasting capability.

**Recommendation related to nowcasting services for Africa to support adaptation:**

> Build knowledge and expertise within regional centres (hubs), from where satellite data and products can be accessed and disseminated, and from where training and nowcasting services can be delivered.

## 2.2 African Meteorological Satellite Application Facility (AMSAF)

African countries have indicated that they are willing and eager to have their own African Meteorological Satellite Application Facility (AMSAF), which will be run in Africa, by Africa and for African nations. The concept of an African Meteorological Satellite Application Facility was ratified by the Abidjan Declaration in 2019 at the African Ministerial Conference on Meteorology, where it was accepted with enthusiasm by African Members. The AMSAF nowcasting concept is the ideal foundation for the creation of regional hubs where satellite data and products can be accessed and disseminated to others.

The Abidjan Declaration was presented by Côte d'Ivoire at the 4th Session of the AMCOMET in Cairo in February 2019 and was included in the Cairo Declaration, with a request to establish a Joint Working Group to support the implementation of the Abidjan Declaration. The Joint Working Group was established in October 2019 and developed the concept note for AMSAF.

The overall objectives of the AMSAF concept are to: (a) support sustainable development in Africa in all socioeconomic sectors through the provision of climate and weather services; (b) strengthen African capacities to access meteorological and climate satellite data; and (c) deliver, through innovative products and services, adequate information to decision makers in various socioeconomic sectors. These will be achieved though accomplishment of the following outputs:

1. Each African country and subregion can access new generation meteorological satellite data and related information in an effective and guaranteed way.

2. Each African country and subregion can process and analyse meteorological satellite data and provide services to their user community.

3. An African Meteorological Satellite Application Facility is established and delivers added-value satellite-based products tailored to African needs.

4. Various socioeconomic sectors include improved weather and climate information in their decision-making processes.

5. Institutional and policy frameworks are strengthened, and knowledge is shared across the continent.

6. Human capacities across the entire service value chain are strengthened.

7. A network of research and development institutions is created, and it feeds operational applications with state-of-the-art research outputs.

# 3. DATA AND INFORMATION USED FOR NOWCASTING

The provision of any operational nowcasting service starts with good quality, high-resolution and rapidly updating observations, models or a combination thereof. A forecaster is dependent on this information to assess current weather conditions and forecast any changes that may occur in the following few hours. Observations that are often used in nowcasting include surface and upper-air observations as well as remote-sensing data such as from radar, satellite and lightning detection systems. These observation sources provide the crucial information required to assess the current state of the weather, to nowcast any expected changes, and to feed into NWP models by means of data assimilation. Accurate NWP models are used in conjunction with observations to provide nowcasting services, and therefore observations have a dual purpose of not only assessing and nowcasting weather events but also of feeding into the NWP models used to supplement the observations. This section provides the information on the NWP data and observations required for operational nowcasting.

## 3.1 **Surface observations**

Surface observations provide valuable information on meteorological elements on the ground, including, among others, precipitation, temperature, dewpoint temperature, wind and visibility. The information captured by sensors contributes to nowcasting specific weather events. The most common such event is rainfall, especially heavy rainfall which may lead to flooding. Rain gauges report precipitation rates and accumulations which are useful for determining rainfall intensity which may lead to floods. Surface wind measurements can also provide valuable information on the movement of weather systems and identify areas of wind shear. Unfortunately, Africa is a data-sparse continent in terms of surface observations, and of the limited observations available, some are poor quality. Insufficient funding, telecommunication constraints and limited training of skilled operators to maintain observation stations all result in information not being available in essential locations. The WMO Global Basic Observing Network (GBON) will, from 2023, improve the availability of the most essential surface-based data, which will have a direct impact on the quality of weather forecasts. The GBON will be achieved via a new mechanism for sustaining and financing these new observations, via the Systematic Observations Financing Facility (SOFF). SOFF will support individual countries to generate and exchange surface-based observational data for improved weather forecasts and services.

Any plan to expand fully automated surface observations over Africa needs to include making better use of METAR (METeorological Aerodrome Report) observations. Such observations are not uniformly available over all of Africa and can differ in quality and frequency. WMO has recently highlighted the need for enhancing these types of observations over Africa. This includes not only more reliability and completeness in the observations, but also timely transmission of all observations.

## 3.2 **Upper-air observations**

Reliable and accurate upper-air observations remain the backbone of any forecasting system. These observations provide important information on the vertical profile of the atmosphere. Temperature, humidity, pressure and wind measurements are used in nowcasting to determine the stability of the atmosphere, in order to predict areas where convection may initiate, and the possible severity thereof, as well as to identify areas of wind shear. Traditionally, upper-air observations are performed by means of radiosondes, however these are made only once or twice per day, and only at a limited number of sites over Africa. The lack of spatial and temporal coverage severely limits their utility for nowcasting. Fortunately, a ready means of providing and accessing tropospheric profiles throughout the day is already available at some locations through the WMO global Aircraft Meteorological DAta Relay (AMDAR) system.

In regions of the globe with an abundance of observations, AMDAR profiles have become the most important data source for very short-range NWP forecasts. South African Airlines already participates in the AMDAR system. Other airlines that fly between major cities could greatly increase the number of wind/temperature profiles. Because the data are collected and disseminated by reliable, existing International Civil Aviation Organization (ICAO) and WMO systems, the profiles could be available to forecasters within minutes of aircraft take-off and landing, all with minimal cost or infrastructure expansion. Another source of a broader array of higher density aircraft observations could be obtained in collaboration with regional air traffic monitoring systems: Automatic Dependent Surveillance (ADS) could be collected using existing international agreements and protocols to provide derived temperature and in situ wind observations that are lacking from most real-time satellite products.

## 3.3 Numerical weather prediction

Numerical weather prediction (NWP) guidance provides an important component for operational nowcasting, especially in the early phases of the nowcasting process, as described by Gravelle et al. (2016). The first step in generating a nowcast is usually to consider the wider meteorological context in which severe weather will (or will continue to) develop. NWP products provide a wealth of information in this regard. For much of Africa, simulated rainfall (even from convection-permitting simulations) would not be expected to reliably predict actual rainfall rates at a given time and location. However, a simulation is likely to capture the large-scale meteorology, including variables which are key to convective storm triggering and development. Currently, the NWP data available to African NMHSs can be broken down into two categories: (a) simulations performed externally and made available either publicly or directly to the NMHSs; and (b) simulations performed in-house.

There are several advantages to be gained from NMHSs generating their own NWP data. These include the ability to tune a model set-up through choices of parameterizations, grid spacing, domains, coupling to other models and additional variables (such as dust), to produce tailor-made NWP products. However, for most African NMHSs, in-house simulations are of secondary importance to externally produced model data. This is likely due to reliability issues encountered in both setting up and maintaining operational NWP simulations. These include infrastructure limitations, the cost of computing resources and being below a critical mass of trained staff. Therefore, most NWP data used in African NMHSs are from simulations performed by external parties. The EUMETCast Africa service, through the Preparation for the Use of Meteosat Second Generation in Africa (PUMA) stations, offers access to the European Centre for Medium-Range Weather Forecasts (ECMWF), United Kingdom Met Office (UKMO) and Météo-France models, which provide data on a synoptic scale. Generally, most externally generated NWP data are from global models that have relatively coarse horizontal grids, making them less well suited to regions where convective rainfall is dominant. Satellite data is thus key to filling the gap associated with sparse data observing networks.

Convection-permitting simulations are available for some parts of Africa, and while simulations of this type offer improved forecasting skill over many global simulations, some challenges remain.

## 3.4 Satellite

Across data-sparse Africa, satellite observations and products provide the primary source of information available for improving both nowcasting and short-range forecasting. Without satellite observations, many African countries would likely have been unable to provide operational nowcasting services, due to limited other observations available. Geostationary satellites provide excellent spatial and temporal coverage, making them ideal tools for satellite-based nowcasting, especially over Africa. Satellite nowcasting has significantly evolved, and provides valuable products for many different applications. Many products that exist today are capable of providing alternative solutions where other observations are not available. It should be noted that although satellite-based nowcasting products do come with larger uncertainties compared to other observations such as radar, they still provide valuable information to forecasters to issue nowcasting services with good skill. Satellite data complements other data sources and provides products and tendencies at scales and resolutions that are not available from the other data sources.

## 3.5 Radar

Where available, weather radar remains the most important instrument for nowcasting after storms have initiated. A weather radar performs 360-degree scans at multiple levels in the atmosphere, whereby transmitted electromagnetic pulses are reflected to the radar from precipitation particles inside and below a cloud. This provides a three-dimensional view of the structure of storm clouds and can therefore provide information on storm severity and rainfall estimates, as well as nowcast the movement of storms. Radars with doppler functionality can be used to measure the doppler velocities of precipitation particles relative to the radar, and can therefore be used to estimate the wind speed and direction, which are useful in warnings of tornadoes and in other situations with damaging winds. Some radars also have dual-polarization capabilities, whereby horizontal and vertical pulses are transmitted and received; this information can be used to identify precipitation types such as rain, hail and snow. Radar observations provide this information over a large area with high spatial and temporal resolution (every 5–10 minutes) making it the primary system used to issue severe weather warnings of hail, heavy rainfall, strong and damaging winds, and tornadoes. Other observations cannot provide the same level of confidence found in radar, and radar observations are therefore more suitable for issuing weather watches and alerts.

Radars are, however, expensive to purchase and maintain. Radar systems are complex and require sufficient funding (to operate, maintain and obtain spare parts) and infrastructure for distributing observations to nowcasting offices. In addition, operating a radar requires expert radar specialists to maintain, repair issues with and conduct quality checks on the data. Adequate information and computer technology infrastructure needs to be in place and managed in order to ensure: (a) data transmission from the radar to the forecasting office; (b) server and storage availability; and (c) operational display systems. Forecasters also need to be trained in radar interpretation to use a radar effectively. It is therefore advisable for any operator to have a long-term plan in place with the necessary funding to meet requirements.

# 4. DEVELOPING NEW SATELLITE-BASED NOWCASTING SERVICES FOR AFRICA

Nowcasting is a forecaster-intensive process. In delivering nowcasting services, forecaster attention is focused toward delivering very-short-range, event-driven information about the location and timing of potentially hazardous local weather events. To accomplish this goal, fast and reliable systems are needed, to acquire real-time observations and meteorological products, to display and analyse them and to provide user-oriented benefits. This section investigates real-time data access and display capabilities which can provide NMHSs with efficient and affordable ways of accessing a range of data sets necessary for nowcasting.

## 4.1 Data and infrastructure for operational nowcasting services

### 4.1.1 *Infrastructure needs*

Satellite data are the key near-real-time observations for nowcasting where radar data are not available. To take full advantage of satellite data for nowcasting, it is critical that NMHSs have the necessary infrastructure and expertise in place to receive, process, display and analyse satellite observations and derived products to support operational nowcasting. The need for infrastructure capacity-building and forecaster skill development in nowcasting will become even more critical as satellite technology is enhanced in the future.

Dedicated technical expertise is required for the management of computing infrastructure, for data reception, ingest, processing and display, and for related software maintenance, system security and upgrades. In contrast, the forecaster’s task is to use the systems and information available to produce nowcasts during their shift, and not necessarily to be involved in ensuring the availability and ingest of new data sets into software suites. Without a clear separation of responsibilities and requisite skills, many NMHSs may be forced to rely on outdated data ingest and display systems and may find it difficult to adapt to the challenges that nowcasting presents. Ideally, system support should come from internal information and communication technology. If not, dedicated personnel such as forecasters or scientists will need to be reassigned and trained with a comprehensive knowledge of these systems. Well-documented internal standard operating procedures, based on the guidance in documents such as the *Guidelines on the Role, Operation and Management of National Meteorological and Hydrological Services* (WMO-No. 1195) and the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO-No. 1083), Volume I, will be critical in transferring technical skills to new employees when needed over time.

Several options for receiving real-time satellite data for parts of Africa already exist. EUMETCast Satellite is a highly reliable, multicast dissemination system that has been used since 2003 to distribute satellite data and products to its user community. It is divided into two different systems, both using identical reception computers: EUMETCast Europe and EUMETCast Africa. Ku-band transponders covering the pan-Europe region and northern Africa are used in the Europe service, while C-band transponders are used in the Africa service.

EUMETCast Africa is a primary data dissemination mechanism to support the continent. It provides a large subset of observations and products covering mainland Africa and the surrounding areas, along with basic NWP and global telecommunication system (GTS) data that will be essential for many nowcasting applications. However, due to the increased spectral, spatial and temporal resolutions from the new generations of meteorological satellites, the limited bandwidth available on the EUMETCast Africa service will not be sufficient to carry the full data and product suites available from the MTG's enhanced observing capabilities (Holmlund et al., 2021), as well as other ancillary data. In view of this, African users in the WMO Regional Association (RA) I Dissemination Expert Group (RAIDEG) have developed, with EUMETSAT, a prioritized subset of data to be disseminated via EUMETCast Africa (https://www.eumetsat.int/media/47571). EUMETCast Africa provides the minimal necessary and sufficient data for nowcasting and forecasting.

Although not available via EUMETCast Africa, the full set of MTG data will be available via EUMETCast Terrestrial. The EUMETCast Terrestrial service augments the existing EUMETCast Satellite service, using high-bandwidth terrestrial networks rather than satellite transponders. It is therefore recommended that NMHSs have a terrestrial connection, to enable them to make full use of all the available data.

For EUMETCast Terrestrial, although connection via commercial internet is technically feasible, the most practical option for obtaining adequate bandwidth to obtain the full EUMETCast contents is by connecting through the National Research and Education Networks (NRENs), provided by GÉANT. Currently, about 20 sites in Africa have GÉANT connections. Data are ingested using the same hardware and software as for EUMETCast Satellite. Since any user across the globe with access to NRENs can receive the data from EUMETCast Terrestrial, African NMHSs may be well positioned to leverage GÉANT networks such as the Arab States Research and Education Network (ASREN) (https://asrenorg.net/) and projects such as AfricaConnect3 (https://africaconnect3.net/). Using these land-based approaches shifts much of the data acquisition infrastructure (including both hardware and software expertise) from NMHSs to local internet service providers. However, in areas where internet service is not reliable, which is the case for most of Africa, satellite communications might still be the only means of assuring consistent real-time data access.

A fundamental question is how the needs for expanding bandwidth to all users, given the constraints, can be best met. The EUMETSAT current baseline for MTG products distribution is described in *MTG Products Distribution Baseline [MTGDIS]* (EUMETSAT, 2020), which proposes the set of MTG products to be delivered at the time the new system goes into operation.

The two key approaches to data bandwidth reduction are:

(1) Reducing the spatial resolution of MTG data to the current resolution of MSG, which is 3 km, and/or using different time resolutions for different channels ranging from 10 min to 15 or 30 min. This approach would meet the timeliness needed for nowcasting by reducing data rates by about 30%. It would, however, reduce the ability to monitor rapidly developing events and would require different data formatting and data processing in the case of NWC SAF software than that used for EUMETCast Europe. The approach would leave room for the dissemination of other products such as specialized RGBs and nowcasting products at different spatial and temporal resolutions. This approach is described in the EUMETSAT current *MTG EUMETCast Africa Product User Guide [AfricaPUG]* (EUMETSAT, 2022);

(2) Using a combination of both EUMETCast Africa and EUMETCast Terrestrial, whereby NMHSs with access to fast and reliable internet could acquire full-resolution observations,

while those with more limited internet could rely on a slightly reduced satellite data stream. The satellite data stream could also serve as a backup to the full-resolution data source at all locations.

Thus, neither of the above options makes access to the full range of applications possible in real time in most of the African countries, due to reduced resolution of satellite data stream or limited internet bandwidth available. However, they are a necessary compromise given the bandwidth challenge.

The question that then arises is whether there are other mechanisms, driven by African expertise and collaboration, that enable stronger support to nowcasting services across Africa. Such mechanisms might also enable the countries with weaker IT system capacity to gain access to the full range of products and provide a starting point for regionally-based research to improve forecasting (and, subsequently, forecasting outcomes).

One approach, that could reduce the negative impact of limited near-real-time data access on individual NMHSs, would be to establish several regional nowcasting data hubs across Africa. Such an approach would be consistent with the intention expressed in the Abidjan Declaration. These hubs could take on the responsibility of receiving the full suite of satellite data, processing the data, running various processing software, such as EUMETSAT NWC SAF software (https://www.nwcsaf.org/), and providing tailored products and displays to several countries for which the hub is responsible. Looking into the future, it is expected that access to cloud computing facilities could have a substantial impact on the hub concept. The hub approach could assist many African countries which lack the necessary infrastructure, internet bandwidth or technical capabilities to receive nowcasting products and services. Ideally these nowcasting hubs should be connected to EUMETCast data sources and have adequate server and technical capacity to produce products and services according to member country needs. The hub approach could further enhance nowcasting activities by providing relevant support for specific weather hazards occurring in the region. Such hubs could also produce and develop tailored nowcasting services, not only for disaster risk reduction, but for many sector-specific applications such as agriculture, aviation and many more.

Any effort to supply the full array of essential observations and products for nowcasting over Africa will involve EUMETSAT NWC SAF, whose mission is to develop NWC SAF software for generating near-real-time nowcasting products. For NWC SAF software to work optimally, a complete set of channels at full spatial and temporal resolution is needed in coincident time slots, excluding very high-resolution and rapid-scan data. The NWC SAF software can be installed locally at an NMHS or other institution, provided that there is a sufficient server, storage capacity and bandwidth for data access, as well as technical expertise to implement the software, maintain the operational system and display the output data. Although software installation on a dedicated Linux system can be quite straightforward, the process of setting up the data flow (satellite, NWP and ancillary data) in the correct formats, as well as displaying the output files, can be daunting for some potential users. Several initiatives and centres across Africa have enabled some of the NWC SAF products to be made available as images on websites to support certain NMHSs with their operational nowcasting activities. These include the GCRF African SWIFT (https://africanswift.org/), ACMAD (http://154.66.220.45:8080/thredds/fileServer/RDT/index.html) and SAWS, in its role as RSMC for southern Africa (de Coning et al., 2015; Gijben and de Coning, 2017), with some supporting installation of NWC SAF software and real-time demonstrations.

Near-real-time and historical data will also be available through the EUMETSAT Data Store (https://www.eumetsat.int/eumetsat-data-store) which provides users with a single point of access to a growing catalogue of EUMETSAT data. This could be especially useful for retrospective analyses and research through case studies of high-impact events.

Generally, data are managed using the PUMA system, and are displayed with the widely used Synergie visualization software. This software enables forecasters to view and interpret the various broadcast data sets, including satellite data and products alongside observational data and radiosonde (upper-air sounding) data. Although the PUMA system is widely used in some locations to support operations, at other sites forecasters are often limited by their lack of technical and skill-dependent capabilities, as well as system shortcomings. In the most extreme cases, users are not adequately aware of the data available on the PUMA system, leaving useful data resources untapped. Capacity development in the exploration and use of all the data in the PUMA system would ensure maximum utilization of the data in all application areas. In addition, visualization systems may not be able to display all PUMA products, or to easily reproduce advanced visualizations that need to be regularly accessed, or to ingest regional data sets, thereby reducing their utility for event-driven forecasting. In addition, existing forecaster workstations will need to be updated to ingest and blend retrieved imagery with other local data sources necessary to increase emphasis on real-time nowcasting services.

The example of images from the Synergie-PUMA system illustrates the value of products in the existing EUMETCast Africa data stream (Figure 1).

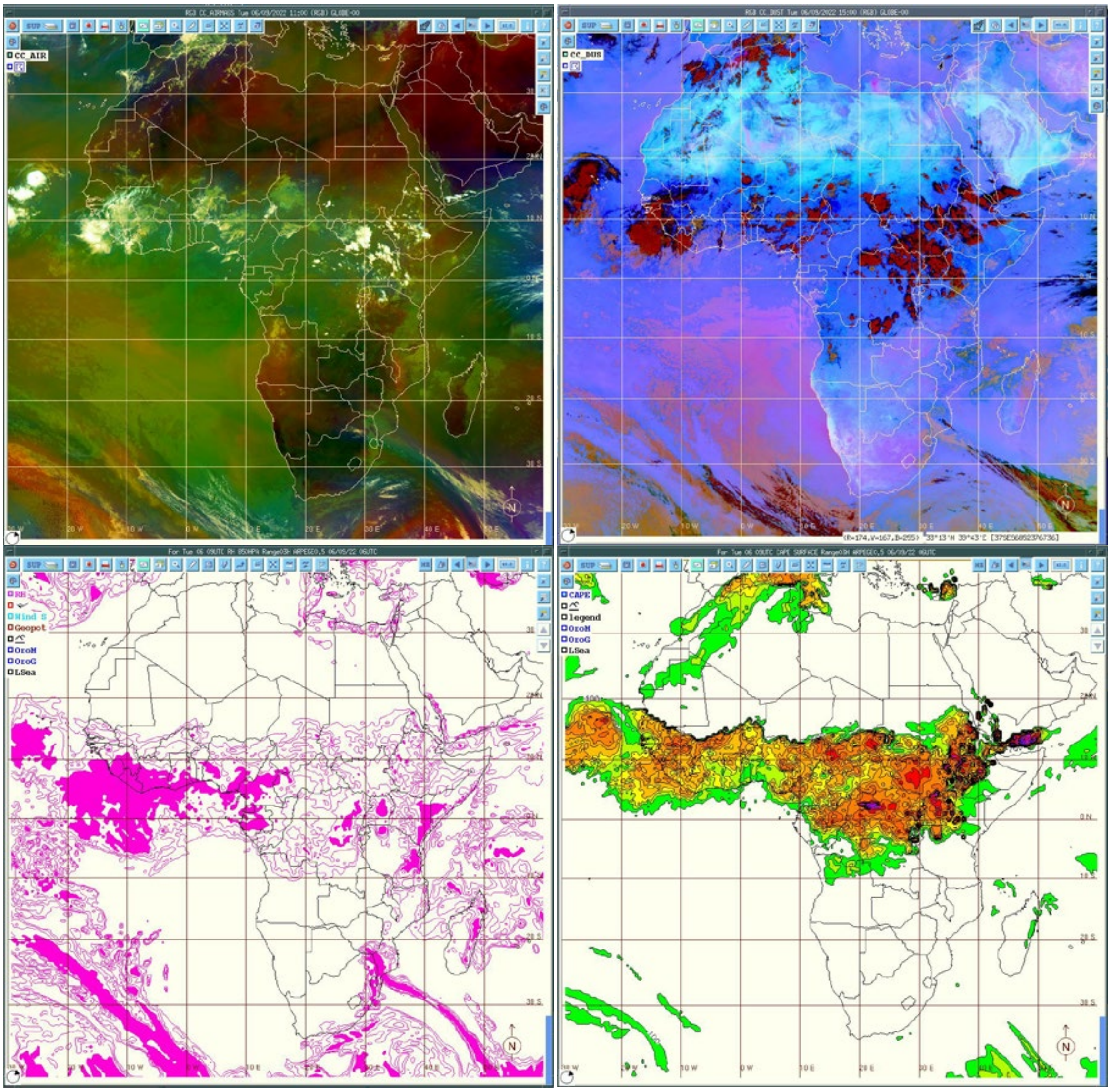

**Figure 1. Images from the Synergie-PUMA system illustrating Airmass RGB and Dust RGB (top panel) and relative humidity and convective available potential energy (CAPE) (lower panel), used at NMHSs in Africa**

Another system, EUMETView (https://view.eumetsat.int), has been developed by EUMETSAT to display a wide variety of satellite data and products via an efficient and easy to use Web User Interface (WebUI). The system is suitable to a variety of different user needs, ranging from interactive display and analysis to systematic and automated access to data and imagery in a well-defined GIS standard. This flexibility allows the data to be harmonized with local geospatial data sources to meet the specific needs of a variety of end users, especially emergency managers and public communications officials.

Over the past several decades, many African NMHSs made substantial leaps in their ability to improve skill in synoptic-scale forecasts through reliance of increasingly accurate NWP products during the forecast process. In addition to acquiring access to digital NWP output using WMO coding and telecommunications standards, the success of those efforts required implementation of new visualization systems designed to allow forecasters to access and interrogate the NWP products directly and easily. A similar challenge now exists for NMHSs as they embrace new nowcasting services, in this case adopting display systems capable of ingesting and appraising the large volume of real-time satellite observations that will become available and that will form the backbone of these new, localized "event triggered" forecast services.

### 4.1.2 ***Satellite products and algorithms***

*NWC SAF products available for Africa*

The EUMETSAT User Forum for Africa technical sessions from 29 to 30 September 2021 confirmed that NWC SAF software use and application is minimal in Africa, outside of southern African nations. Nowcasting in most of Africa is currently performed manually and focuses on thunderstorm-related hazards. This issue can be addressed, at least in part, through publicly available applications software from EUMETSAT NWC SAF. These include a suite of nowcasting products that merge multiple satellite channels, observations and NWP data to derive a variety of near-real-time products. These tools have been shown to assist forecasters by providing enhanced insight into cloud evolution and growth potential, as well as extrapolations of cloud characteristics up to 90 minutes ahead in time, which in turn reduces the nowcaster's workload.

The current version of the software package for geostationary satellites, NWC SAF GEO v2021, was distributed to users in April 2022 and supports all MSG operational satellites. A new version of NWCSAF GEO, supporting MTG satellite data, will become available during the commissioning of MTG. The software is freely distributed to registered users and the NWC SAF team offers user-support. For users to obtain the nowcasting satellite-derived products, they must install the software at their premises and provide the input data to the software, mainly imagery data and a numerical model. The software is configurable, and users can select the geographical area for which the satellite products will be generated. However, the full MTG data set will be needed in order to use NWC SAF software. Thus, the MTG Africa dissemination data set alone is not applicable for running NWC SAF software.

Products that can be generated with the NWC SAF GEO software include (https://www.nwcsaf.org/web/guest/nwc/geo-geostationary-near-real-time-v2021):

- Cloud products (Cloud Mask, Cloud Type, Cloud Top Temperature and Height, and Cloud Microphysics);
- Stability indices and precipitable water content in different layers;
- Precipitation products (probability of precipitation and rainfall rate);
- Convection products (Convection Initiation, and identification of convective cells);
- Wind products (High-Resolution Winds – AMV levels, speed and trajectories);
- Time extrapolation of satellite images and NWC SAF products;
- Identification of meteorological features such as the presence of tropopause folding and gravity waves.

The Convective Rainfall Rate (CRR) product provides information about the intensity of precipitation and is optimized for convective precipitation. The Rapid Developing Thunderstorms-Convection Warning (RDT-CW) identifies, characterizes and tracks convective cells. It can identify thunderstorms and provides information on their development stage (growing, mature, decaying), and on the direction of the thunderstorm (Figure 2).

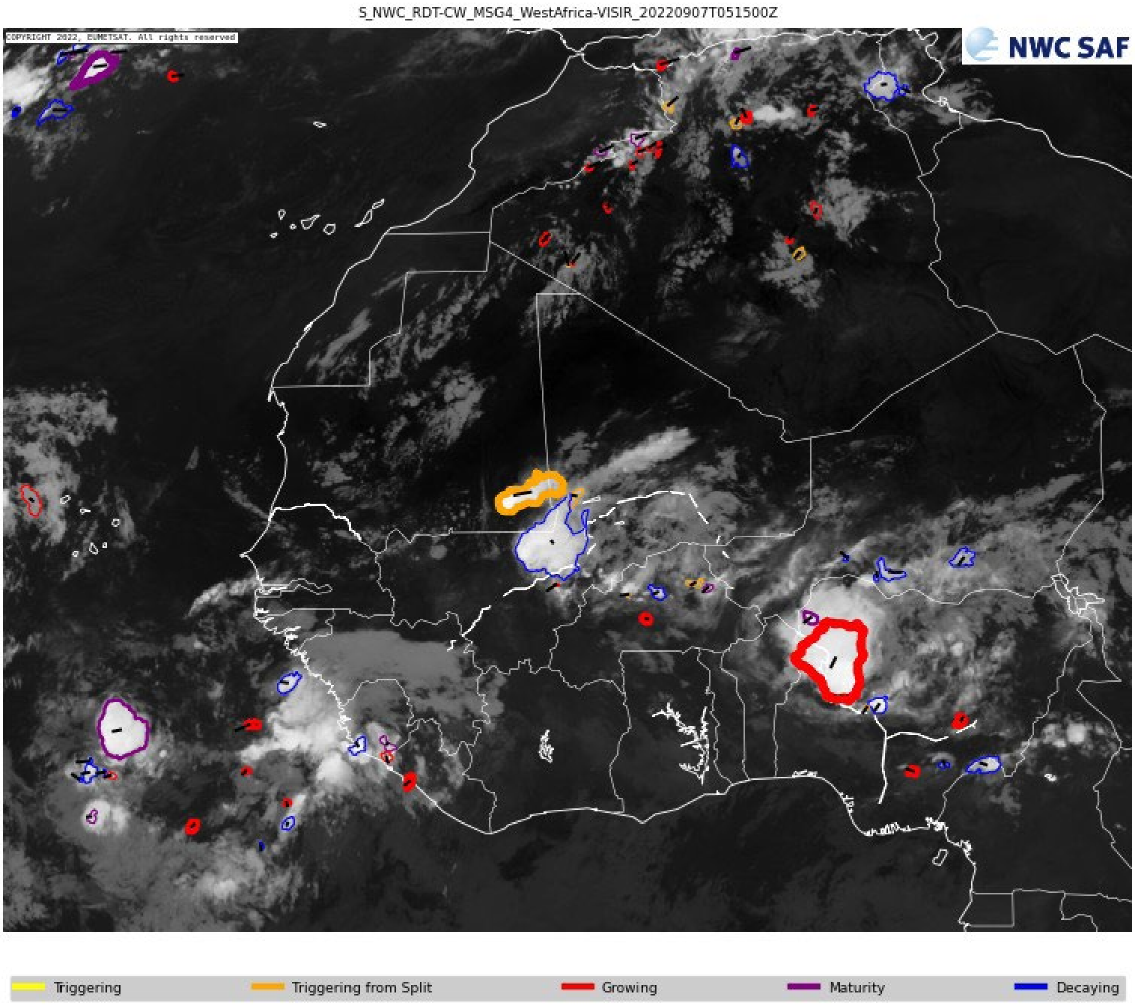


**Figure 2. Example of the RDT-CW product. Coloured contours indicate convective cell outlines, with the colours representing various stages of convective activity. Black arrows indicate the motion associated with each convective cell.**

*Source:* GCRF African SWIFT Nowcasting Catalogue – Resources Summary: ncas.ac.uk (sign in required, requests for access to University of Leeds)

EUMETSAT is distributing these products through EUMETCast Africa, making access to them in near real-time easier for institutions that have difficulty installing and running the NWC SAF GEO software at their premises.

Some studies have been conducted to evaluate the skill of the CRR and RDT-CW products in Africa. It was found that these products are useful nowcasting tools (Hill et al., 2020). Furthermore, RDT-CW has been improved since these studies, in the 2018 and 2021 NWC SAF GEO versions. The CRR product was shown to produce very different rainfall climatologies for day and night in tropical Africa, associated with greater skill of the product during the daytime, particularly for heavier rain rates. The RDT-CW product is able to identify around 60% of heavy rainfall events with the fraction detected increasing with increasing rainfall rate. For both products, extrapolation forwards in time maintains useful skill, motivating work to develop longer lead time nowcasts. The usefulness of the RDT-CW product in regions not covered by radars, and the improvement of the RDT-CW product if lightning data is used as an additional data source, has been demonstrated previously (de Coning et al., 2015; Gijben and de Coning, 2017).

Although these studies are helpful, there is no systematic and ongoing evaluation of new products and their validity and applicability. Such studies, as well as trials in testbed environments, are very much needed to support transition from research to operations, and, consequently, forecast skill.

Another approach in which satellite data is used for nowcasting is where observations of atmospheric objects and derived object-based information is used (for example, tracing storm growth). The geospatial coherent structures of objects are associated with underlying atmospheric processes. Tracing the spatio-temporal evolution of atmospheric objects provides information about underlying processes relevant for nowcasting.

The motion of clouds and/or areas of water vapour in consecutive satellite images can be used to derive so-called motion vectors (Figure 3). Tracking clouds associated with weather phenomena, such as frontal zones or thunderstorms, is already being used to monitor these weather phenomena. The cloud motion also reveals underlying wind patterns and can be used for data assimilation to improve weather forecast models.

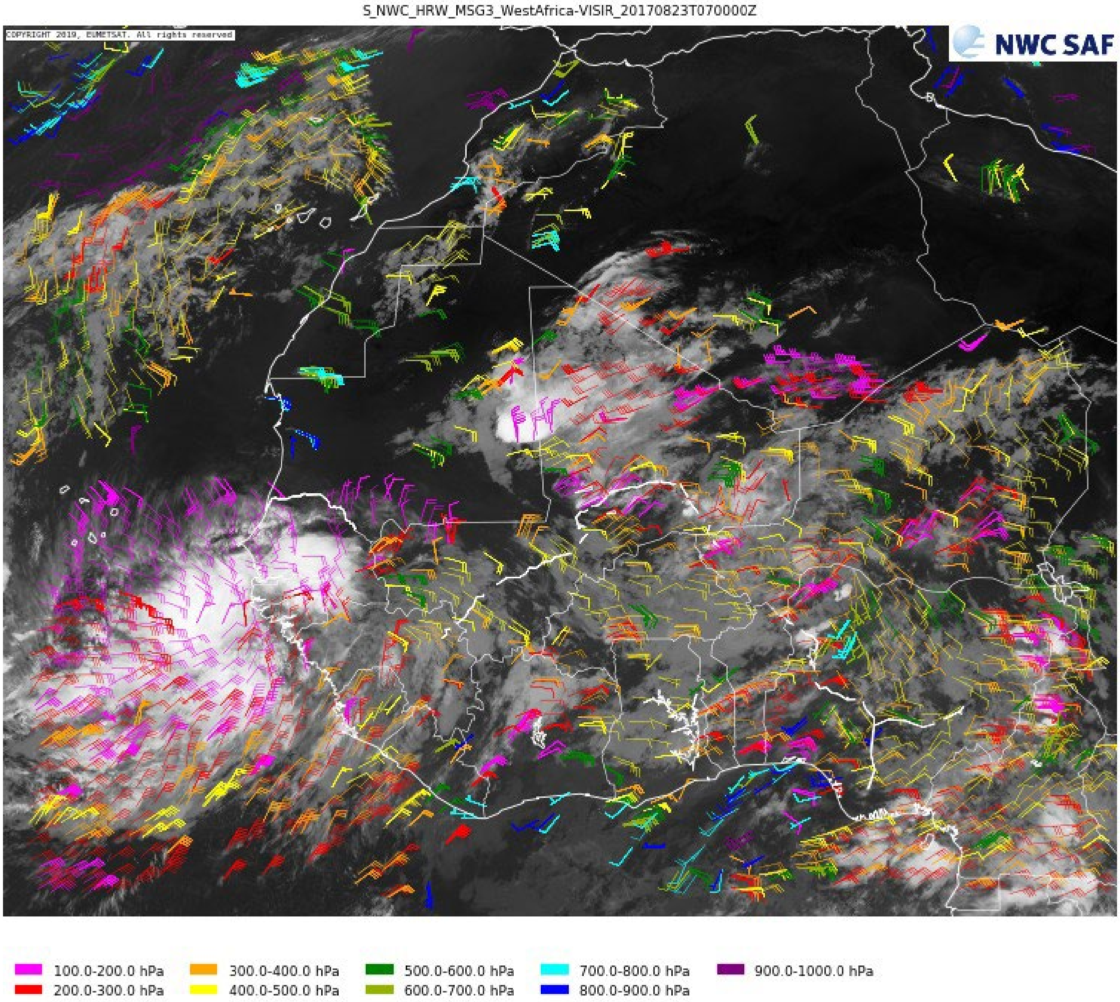


**Figure 3. An example of atmospheric motion vectors derived from cloud motions on 23 August 2017 at 0700 UTC. Colours indicate the pressure height of the wind vectors, with barbs (wind speeds) based on standard meteorological wind barb definitions.**

*Source:* GCRF African SWIFT Nowcasting Catalogue – Resources Summary: ncas.ac.uk (sign in required, requests for access to University of Leeds)

Similarly, cloud and air mass patterns can be used to identify gravity waves and tropopause folds, both relevant for identifying regions of potential heavy turbulence, which is of high importance for aviation. It is worth mentioning two relevant NWC SAF products, Automatic Satellite Image Interpretation-Gravity Wave pattern detection (ASII-GW) and Automatic Satellite Image Interpretation-Tropopause Folding detection (ASII-TF). ASII-GW allows detection of grating patterns (alternating bright and dark stripes) in the water vapour image. These are indicative of gravity waves, which may become unstable, eventually resulting in the notorious "clear-air turbulence" (https://www.nwcsaf.org/aviation-guide/ASII-GW1). ASII-TF detects tropopause folds from a combination of satellite and NWP input data. Tropopause folds are known for their potential for clear-air turbulence as they mark an area of upper-tropospheric boundaries with strong vertical wind shear at the jet stream. The ASII-TF product is designed to locate these regions in the atmosphere, where turbulent flight conditions for aircraft are more likely than elsewhere (https://www.nwcsaf.org/asii-ng_description).

An important step in nowcasting is the forward extrapolation of current conditions to make predictions about the near future. Some products (such as the NWC SAF GEO RDT-CW) indicate the direction and speed of movement of storms automatically. However, the current situation for most nowcasting activities in African NMHSs is to manually extrapolate the position of storms (or other relevant features, such as atmospheric dust) by observing previous motion and making predictions about future motion. A major drawback of this type of manual extrapolation is that it is intensive work that can only be performed for relatively small areas (possibly suggesting why nowcasting activities have been limited to aviation for the majority of nowcasting techniques in Africa). It is important for NMHSs to embrace technological solutions for forward extrapolation, most importantly the use of automated extrapolation techniques.

Within the NWC SAF GEO suite, the Extrapolated Imagery (EXIM) tool allows automated extrapolation of a wide range of NWC SAF products, including the CRR product. Extrapolation of cloud products can also be useful for nowcasters, especially in the field of aviation. It enables nowcasters to make predictions about the location of storms (and extreme rainfall) over a short time period. Work done within the GCRF African SWIFT programme has shown that extrapolations of CRR remain usefully skilful over a 90-minute extrapolation period, and feedback from forecasters during the GCRF African SWIFT testbeds indicated utility far beyond this time frame (up to five hours). The EXIM product functions by using the NWC SAF wind product as a source of motion vectors to distort the latest image. This is stepped forward in time in 15-minute increments to provide an extrapolation consistent with previous retrievals. Additional tools developed by other international satellite applications groups should also be included in future systems. These could expand the use of satellite products in nowcasting to allow forecasters to understand the evolution of stability and precipitable water environments prior to storm formation.

SAWS has been successfully running the NWC SAF software since 2014 for the southern Africa domain (south of the equator). SAWS, in its role as RSMC for southern Africa, has been an active participant in the WMO Severe Weather Forecasting Demonstration Project (SWFDP), which was initiated in 2006 with the aim of strengthening capacity of WMO Members to deliver improved forecasts and severe weather warnings. In 2014, a gap in NWC SAF nowcasting services for the southern Africa subregion was identified, and SAWS decided to run the NWC SAF software locally over the entire domain in order to provide additional nowcasting products (such as the RDT-CW and CRR) and services on the RSMC Pretoria website (http://rsmc.weathersa.co.za/) for beneficiary countries. This initiative has proved to be highly successful in both the provision of the nowcasting products as well as the capacity development of NMHSs in the application of nowcasting services.

GCRF African SWIFT partners in Africa have made significant progress in installing and running the NWC SAF software. It is expected that the expertise and capacity developed during the GCRF African SWIFT programme will be expanded upon and become a self-sustaining pan-African network of scientific support into the future. Considering this, maintenance of the satellite data is needed and will have a considerable impact on the ambitions of Senegal, Ghana, Nigeria and Kenya to generate, use and share nowcasting products. Note that in Senegal, Nigeria and Kenya, each NMHS has regional forecasting responsibilities beyond its own borders, and the benefits of the nowcasting products will be felt widely.

It is clear from the status of nowcasting services in Africa (and from feedback from African NMHSs on the awareness of, use of and access to products generated by NWC SAF software) that forecast centres need solutions for data dissemination from the MTG system to Africa. Such solutions must consider the progress made in securing NWC SAF data dissemination to a significant number of partners across the continent and the growing potential. Additionally, individual forecasters need: (a) adequate training in the use of nowcasting products; (b) the opportunity to develop links with users to generate a market for these products; and (c) sufficient government funding for staff time to generate and issue public warnings based on a nowcast process. The financial model to support nowcasting by weather services is therefore key, both for public warnings, and bespoke forecasts for users.

It is noteworthy that research agendas have been driven from Europe, and the importance of driving this development from the African hubs and centres needs to be more of a priority.

*Lightning detection*

A special case of object-based information is satellite-based lightning detection. The MTG Lightning Imager (MTG LI) will perform the geostationary detection of lightning optical cloud top emissions from space. The LI senses such emission within a 1.9 nm-wide band centred on

777 nm, with a 4.5 km resolution at sub-satellite point, and 1 kHz acquisition frequency. Similar instruments are already operational on the American Geostationary Operational Environmental Satellites (GOES) (Figure 4).

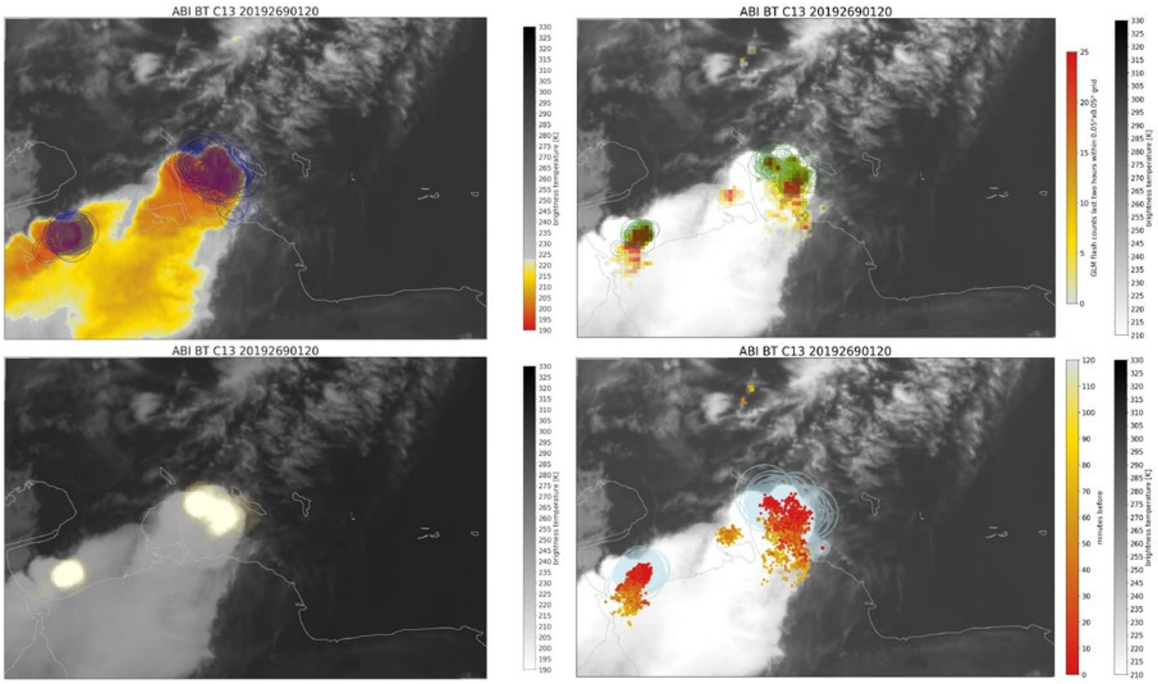


**Figure 4. Different visualizations of Global Lightning Mapper (GLM) data for 26 September 2019 over the Caribbean islands Aruba, Bonaire and Curacao, just north of the Bolivarian Republic of Venezuela. Transparent coloured green and blue circles are indicative of the area coverage of GLM-detected lightning flashes. Grey colours show the GOES-16 Advanced Baseline Imager (ABI) brightness temperature for band 14 (11.2 μm).**

*Source:* EUMETSAT/Royal Netherlands Meteorological Institute (KNMI)

The basic lightning data consists of events, defined as pixel-based exceedance of a certain threshold that is assumed to be lightning. Adjacent (neighbouring, diagonal) simultaneous events are combined into a group. Sequential groups with limited separation in space and time then make up a flash (within 330 milliseconds and within 16.5 km). These flashes are most commonly used by forecasters for detection of lightning, to monitor thunderstorm growth, thunderstorm convective mode and thunderstorm evolution. MTG LI Level 2 products disseminated in chunks are Lightning Flashes and Lightning Groups (10-s chunks), and Accumulated Flash Area, Accumulated Flash Radiance and Accumulated Flashes (30-s chunks). LI Level 1 products are not disseminated.

The use of lightning data is not dissimilar from RDT-CW, for which lightning activity – if available from ground-based data – is used to characterize the storm phase. Since the introduction of NWC SAF GEO v2021, RDT-CW can manage satellite lightning data in addition to ground-based lightning data to characterize storms. Currently this is applicable to RDT-CW from GOES data and can be seen as preparation for MTG. Satellite-detected lightning flashes are thus also coherent structures associated with underlying processes. Changes in lightning – lightning jumps – can indicate, for example, (de)intensification of thunderstorms.

*Artificial intelligence and machine learning*

Aside from new satellites being launched and deployed, the past decade has seen a rapid increase in the use of artificial intelligence and machine learning (AI/ML) in Earth observation.

With ever and rapidly increasing amounts and varieties of Earth observation data, demand for algorithms that can process vast amounts of data is also growing. Increased efforts to start combining various data sources and data types further puts pressure on computational resources and limitations. At the same time, many data applications require fast access to the most recent data.

In addition, AI/ML techniques and tooling have started to rapidly evolve over the past 5–10 years. Standard computer code packages are now readily available. Much effort has also been put into developing trustworthy AI/ML, that is, methods and tools to analyse and explain the information on which the output of AI/ML algorithms is based.

What makes AI/ML techniques particularly interesting is that they allow for detecting specific information from large amounts of data that would be more difficult – or even impossible – to achieve with more traditional satellite retrieval techniques.

For example, small-scale hazardous weather phenomena, such as hail, wind gusts or tornadoes, are not directly observable with Earth observation satellites, nor are they likely to be detectable in the near future – if ever. However, impactful weather phenomena such as these have been associated with atmospheric conditions and cloud properties and structures, for example overshooting cloud tops (Bedka, 2011) and above-anvil cirrus plumes (Bedka et al., 2018). They can also be used for data assimilation to improve weather forecast models. AI/ML techniques have already been shown to allow for detection of such atmospheric conditions and for short-term probabilistic prediction of the occurrence of such phenomena (Cintineo et al., 2020), including lightning (Cintineo et al., 2018), albeit not yet for the Euro-African view of MSG. Similarly, AI/ML applications may improve the process for determining upper-level winds, which is highly valuable for NWP.

Other potential AI/ML applications under development focus on improving the short-term (0–3 hour) spatial translation and dynamical development of hazardous weather systems. Such information is highly valued by forecasters, but it has proven difficult to achieve translation algorithms meeting forecaster requirements and needs beyond the standard approaches.

In Europe, there are a number of AI/ML projects associated with using MTG data for nowcasting. Given that the algorithms have been developed in Europe, their portability to other geographic areas needs to be tested. These tests would be aided by easier access to data and computing resources. These barriers are high in Africa at this time and would be lessened with the existence of data and computing hubs.

An example of applying AI/ML techniques for lightning prediction using data from a GOES satellite is provided in Figure 5.

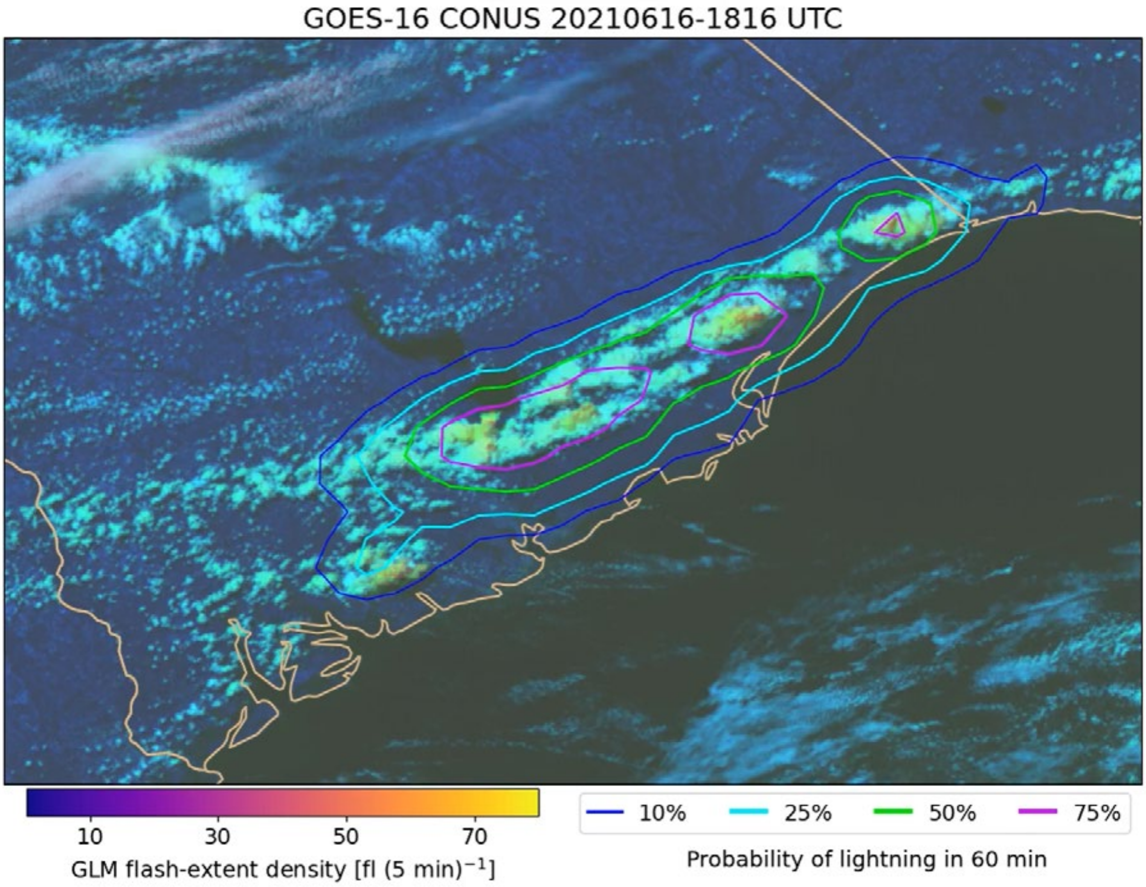


**Figure 5. AI/ML-based probability of lightning occurring in the following 60 minutes near the South Carolina coast in the United States of America on 14 July 2021, based on GOES satellite data**

*Source:* National Oceanic and Atmospheric Administration (NOAA)/ Cooperative Institute for Meteorological Satellite Studies (CIMSS) (https://youtu.be/uOCTI2Mw97M)

**Recommendations related to data and infrastructure for operational nowcasting services:**

(a) Based on African expertise and collaboration, develop a hierarchy of data distribution plans that both meets the local needs for nowcasting services and recognizes the different communications and computing capabilities available across Africa.

(b) Develop plans whereby NMHSs can assess and adopt display systems capable of ingesting and appraising the potentially large volume of real-time satellite observations that form the backbone of these new, localized "event triggered" forecast services.

(c) Recognizing that many existing nowcasting tools have been designed for mid-latitude use, develop an inventory of existing, planned and desired satellite products that could serve the needs of nowcasters across all parts of Africa, both for monitoring changes in the pre-storm environment and for assessing subsequent storm growth and possible impacts. Each NMHS should then study this list and identify those products that are likely to be most useful for their local nowcasting needs, including the necessary training for these.

## 4.2 Operational service development

The goal of any nowcasting service is to provide the public, clients or stakeholders with reliable, timely and useable information on potentially hazardous weather events that may pose a risk to lives, infrastructure and operations. These events often develop on a very short-range timescale and require the delivery of an operational service whereby watches, alerts and warnings can be disseminated rapidly to users in a useable format. Robust operational nowcasting services in Africa remain limited. Most countries in Africa offer a rudimentary nowcasting service for aviation, but specialist services for societal and commercial applications are lacking. This can be attributed to several gaps, including gaps in access to data, products, tools and software, in necessary information and computing technology resources, as well as gaps in capacity development. The aim of this section is to provide guidance on the requirements and implementation of operational nowcasting services.

### *Operational services framework*

A nowcasting service can have many applications across a wide spectrum of users. Different sectors of society can benefit from watches, alerts and warnings to ensure the safety of humans and animals and the protection of infrastructure and systems, or to plan and adapt daily operations and activities during adverse weather events. Nowcasting services need to be tailored for the specific requirements of different users, which can range from the public to specialized sectors such as aviation, energy or agriculture. Regardless of the sector-specific applications, every operational nowcasting service should follow the information and data value cycle framework as illustrated in Figure 6.

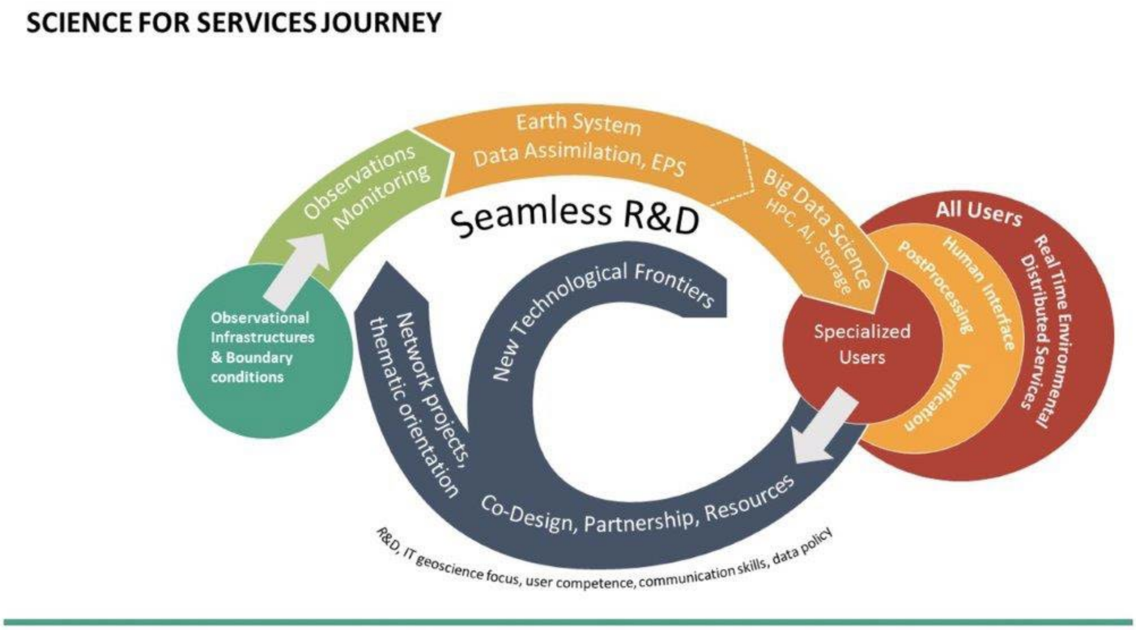


**Figure 6. Value cycle framework of an operational nowcasting service**

*Source:* Adjusted from Ruti et al. (2020)

*Operational feeds*

Operational feeds form the backbone of any operational nowcasting service. They consist of high-resolution observations, NWP guidance, an essential operational supply of data, and the availability of various algorithms and methods to supply relevant and useable information for providing nowcasting services. For the African continent, satellite observations remain the most useful observational source for nowcasting purposes, together with NWP for guidance and blending with observational sources. Apart from the availability of raw observational data sets and NWP fields, it is also critical to process and visualize these data using various algorithms and methods to supply forecasters with a suite of products and tools which are useable and required for event-driven nowcasts.

The development of nowcasting services is ideally a process of co-production involving both forecasters and users. One outcome of the co-production of services should be a standard operating procedure (SOP) for the delivery and evaluation of the service. SOPs are an essential element in quality control of the service. They act as a template for the expansion of services to new clients and new regions, and they contribute to the definition of appropriate training standards. Generally, SOPs are a matter for national agencies, and are elaborated through direct collaboration between NMHSs and stakeholders.

Given the relative lack of nowcasting in much of Africa, there has also been a lack of SOPs. The GCRF African SWIFT programme, in collaboration with SAWS, has created a prototype SOP for African nowcasting, available in Roberts et al. (2022b). This SOP was created primarily based on the methods currently employed by SAWS, and was tested and fine-tuned during testbed events in Senegal, Ghana, Nigeria and Kenya in the period from September to November 2021.

The nowcasting activities within the GCRF African SWIFT programme were strongly focused on convective storms, however the approach outlined in Roberts et al. (2022b) can easily be applied to other hazards, such as the occurrence of fog or dust. The purpose of the SOP is to provide a high-level methodology that can be followed in an operational setting, enabling the production of impact-based nowcasts. When African NMHSs develop their own nowcasting SOPs, it is expected that they will contain much more detail on the tools and methods to be used. This is because: (a) different NMHSs have access to a variety of different tools that are appropriate for nowcasting; (b) the varying meteorological conditions (both day-to-day and seasonally) in different locations mean that a nowcast might look significantly different for different NMHSs; and (c) the needs of nowcast end users across different NMHSs are likely to vary considerably.

Despite the GCRF African SWIFT Nowcasting SOP not directly advising on the use of products or on the methodology to be employed for assessing risk, it does clearly outline an approach for the generation of nowcasting outputs. Alongside this, an overarching workflow (template shown in Figure 7) is recommended with the aim of helping NMHSs to produce effective nowcasts efficiently and reliably. The *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150) and the *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services Part II: Putting Multi-hazard IBFWS into Practice* (WMO-No. 1150) provide information on how to identify the likelihood of an expected hazard and its potential severity.

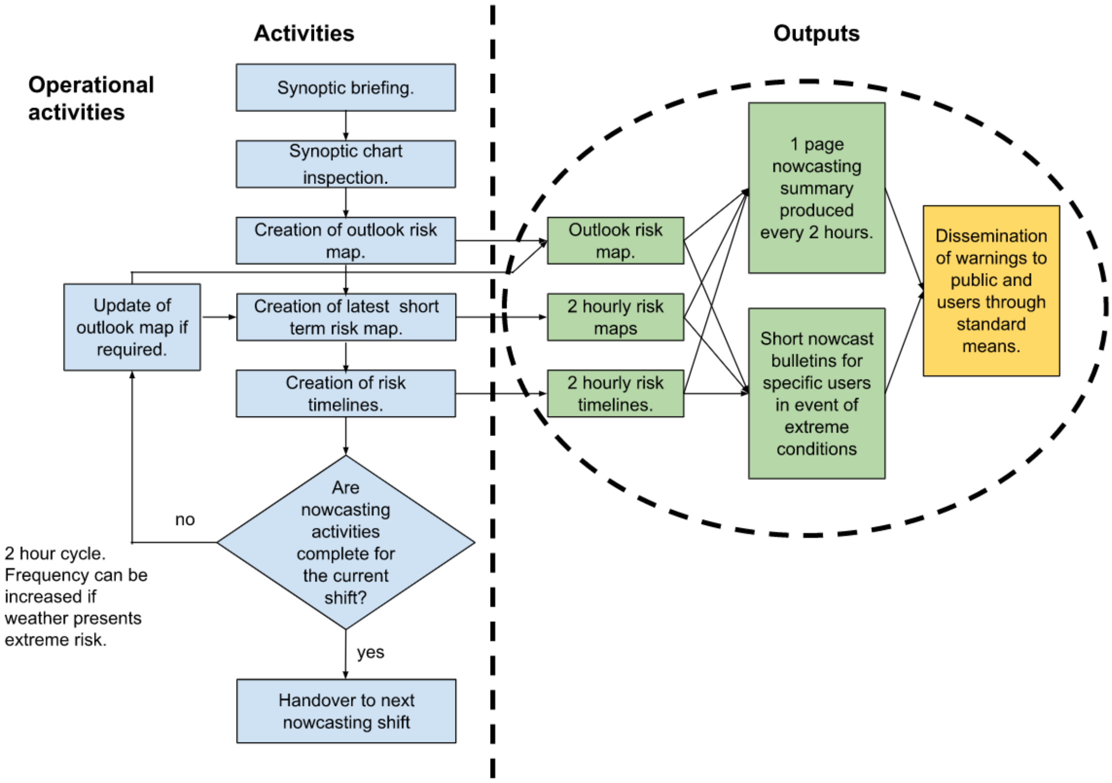


**Figure 7. Nowcasting standard operating procedure workflow. The blue boxes on the left-hand side indicate the activities that are required to be undertaken. The right-hand side of the schematic indicates the outputs, with green representing products and yellow representing the dissemination of nowcasts.**

*Source:* Roberts et al. (2022b)

Briefly, the activities outlined in the GCRF African SWIFT Nowcasting SOP are:

(1) A briefing/handover from the operational forecast desk that gives an overview of the synoptic meteorology. This briefing enables nowcasters to understand the large-scale situation within which high-impact weather might (or continue to) develop.

(2) An inspection of synoptic charts provided by forecasters (and any additional information such as nowcast products).

(3) Production of a nowcast outlook. It is envisioned that a nowcast outlook risk map will indicate likely risks on a national scale, over the 0–6-hour period. A brief written description of the current and future conditions should also be produced to help in the interpretation of a national outlook risk map.

(4) Production of nowcast risk maps. In contrast to the longer 6-hour window for the outlook risk maps, the nowcast risk maps should indicate risk for the following 2 hours. As such, their production should rely more heavily on the latest nowcasting products available (and the extrapolation of these products), rather than on synoptic forecasts. As with outlook maps, a short written description should also be generated to aid interpretation.

(5) Production of risk timelines for specific locations (selected by nowcasters for their importance to users and their risk from current and future weather). Such timelines indicate the risk posed to a specific location (such as a city) over the following 6 hours.

(6) An iterative approach is recommended for the updating of nowcasting outputs, such that steps 3 to 5 above are performed in a 2-hourly cycle, with new outputs generated and disseminated every 2 hours. Production of the outputs is designed to be achievable within

this 2-hour time frame, with the expectation that in circumstances where there is rapid deviation from previous predictions, or very high-impact weather, then a rapid cycling can be implemented to provide more useful information to users.

It is recommended that all risk maps and timelines be produced using the same colour scheme aligned with a corresponding risk matrix (see Figure 8). The colour scheme and methodology were chosen due to the similarity with existing risk warnings generated for Africa (such as ACMAD meningitis vigilance maps) and further to input from both forecasters and end users during the co-production process. The alphanumeric markers within the risk matrix enable users to understand the difference between the different types of warning with the same colour scheme. This is because the action taken by a user might vary considerably if there is a very high likelihood of a low-impact event compared with a low likelihood of a very high-impact event. For example, users will behave very differently to predictions of almost certain light rain compared to being on the edge of a tropical cyclone track.

**Nowcasting risk matrix**

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Very high** | E1 | E2 | E3 | E4 | E5 |
| | **High** | D1 | D2 | D3 | D4 | D5 |
| **Likelihood** | **Medium** | C1 | C2 | C3 | C4 | C5 |
| | **Low** | B1 | B2 | B3 | B4 | B5 |
| | **Very low** | A1 | A2 | A3 | A4 | A5 |
| | | **Very low** | **Low** | **Medium** | **High** | **Very High** |
| | | | | **Impact** | | |

| |
|---|
| **Take Action** |
| **Be Prepared** |
| **Be aware** |
| **Low risk** |

**Figure 8. GCRF African SWIFT nowcasting standard operating procedure risk matrix and accompanying legend. The risk is a combination of the impact and likelihood scores ranging from very low to very high for each. Alphanumeric identifiers are also provided to assist in communicating the type of risks present. The impact levels are based on the thresholds determined by engaging with users. The likelihood is based on the probabilities.**

*Source:* Roberts et al. (2022b)

The RSMC Pretoria web page (http://rsmc.weathersa.co.za/login.php) is an example of an operational service provided by SAWS to southern African countries that addresses some of the GCRF African SWIFT Nowcasting SOP elements. SAWS makes available several NWPs, ensemble prediction systems, guidance forecasts and nowcasting products on the RSMC website to assist countries in southern Africa to provide good nowcasting and forecasting services.

Several products are available to assist forecasters to produce nowcasts following the GCRF African SWIFT Nowcasting SOP approach. One such example is the rapidly developing thunderstorm (RDT) product available on the SAWS RSMC website. Figure 9(a) shows an example of the RDT for 14 March 2019 at 0845 UTC, overlaid on a satellite image. Figure 9(b) depicts the RDT product plotted on an interactive map, whereby nowcasters have the option to zoom into regions of interest and click on a polygon to see useful information on the storm cell characteristics. The different colours on the image show the phase of the storm, while the arrows indicate the direction in which the cell is moving. Nowcasters can make use of RDT products to identify rapidly developing and intense storm cells, and to nowcast their movement.

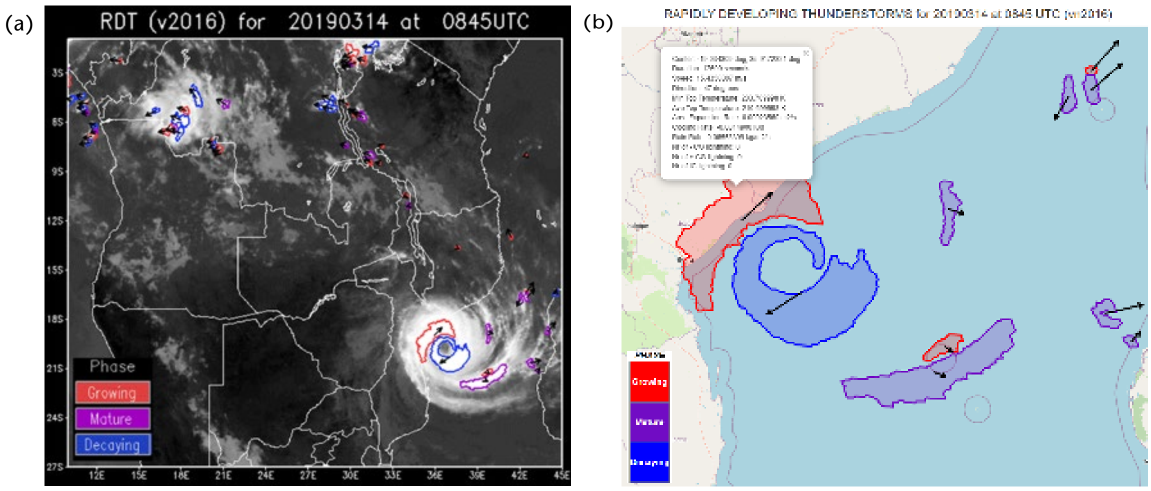


**Figure 9. RDT product for 14 March 2019 at 0845 UTC (a) overlaid on a satellite image and (b) displayed on an interactive map with zoom capability. Colours represent phase of the storm, arrows the direction of movement. Storm cells on the interactive map are clickable, to view storm information.**

*Source:* SAWS RSMC Pretoria (http://rsmc.weathersa.co.za/login.php)

Satellite-based rainfall estimates provide nowcasters with valuable information, on the day, for estimating rain rates, for example during tropical cyclones. Figure 10 is an example of the hourly accumulation of the Convective Rainfall Rate (CRR) product on 15 March 2019 at 0900 UTC, which clearly shows the heavy rainfall experienced.

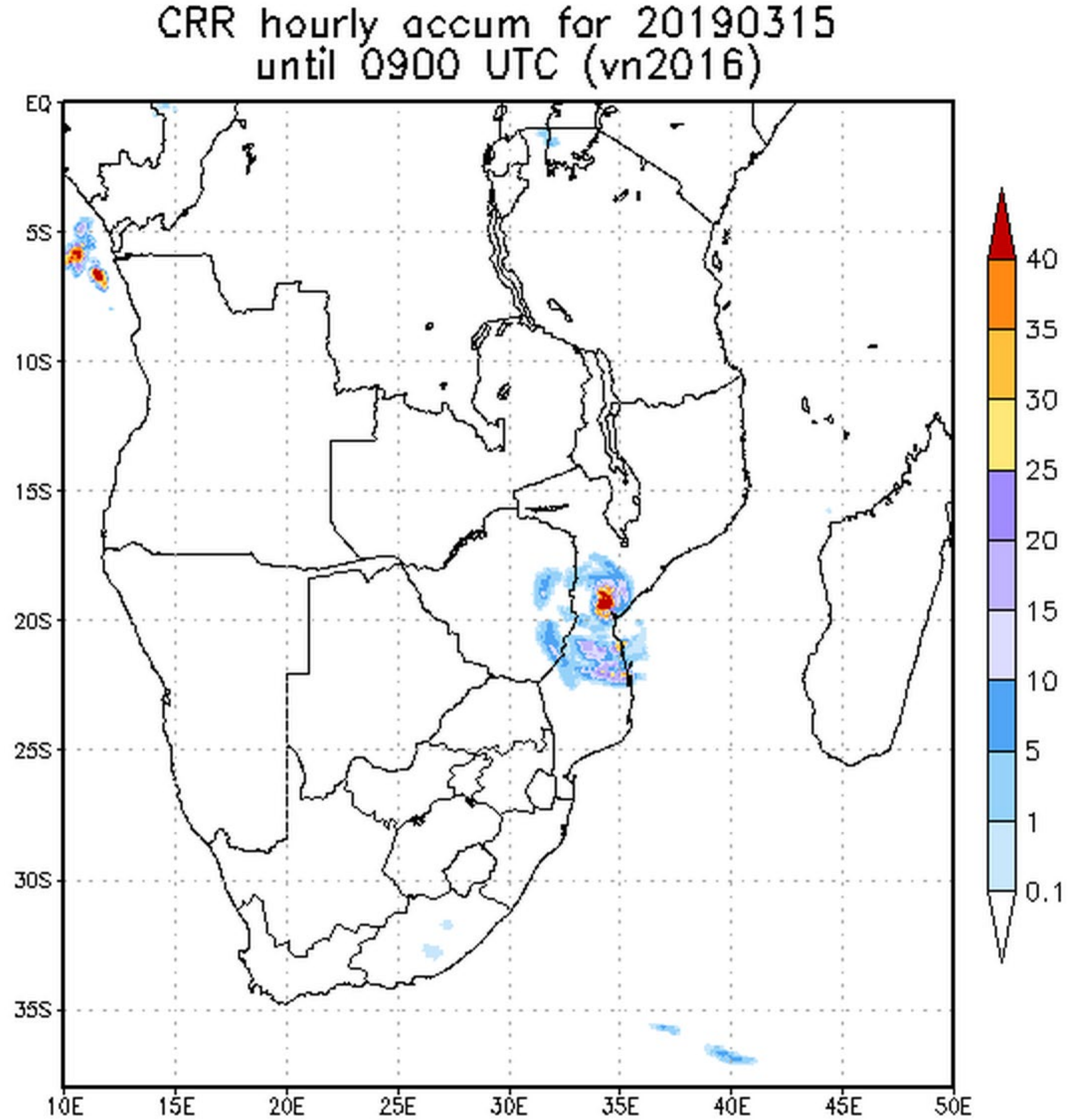


**Figure 10. Hourly accumulation of the CRR product on 15 March 2019 at 0900 UTC**

*Source:* SAWS RSMC Pretoria (http://rsmc.weathersa.co.za/login.php)

Following the successful GCRF African SWIFT programme, which demonstrated operational nowcasting services to sub-Saharan Africa (Roberts et al., 2022a), a new weather forecasting application (app) known as the Forecasting African Storms Application (FASTA) was developed by scientists at the University of Leeds and National Centre for Atmospheric Science, in partnership with the Kenya Meteorological Department. The FASTA app utilizes satellite-based nowcasting products from the EUMETSAT NWC SAF to provide weather information and short-term warnings to users. Apps have become a common feature on smartphones, and the FASTA app will enable users to make timely decisions to save lives and livelihoods. Figure 11 displays example screenshots of the FASTA app. Figure 11(a) shows the CRR product depicting the estimated rainfall rate, with blue colours showing light rain and red colours heavy rain. Figure 11(b) is a display of the RDT product, with red polygons showing the storm cells, grey lines showing the past movements of the storm centre and black lines showing the directions the storms are moving. The FASTA app is currently available for users in Kenya and can be downloaded from the Google Play Store. The long-term plan is to roll it out across sub-Saharan Africa, embrace new technologies and showcase the potential for future nowcasting in Africa to provide users with vital weather information in the palm of their hands.

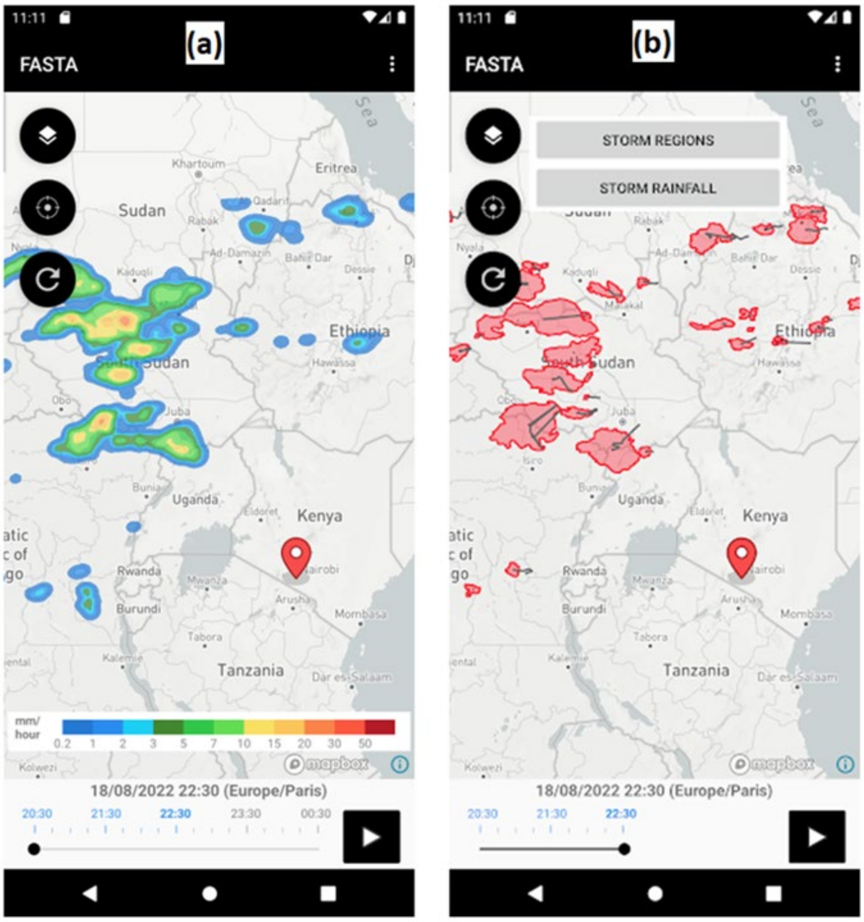


**Figure 11. FASTA app, depicting the (a) CRR and (b) RDT products from the NWC SAF software over East Africa (https://fastaweather.com)**

**Recommendations related to operational service development:**

(a) Promote the development of early warning systems based on satellite-based nowcasting products for various hazards, to be determined in interaction with defined users.

(b) Determine and understand the regional and national users' requirements.

(c) Develop SOPs for national forecasters based on nowcasting guidelines provided by WMO, and taking into account the experience gained from the GCRF African SWIFT programme.

# 5. SUSTAINING NEW SATELLITE-BASED NOWCASTING PRACTICES FOR AFRICA

## 5.1 Capacity development and training in satellite-based nowcasting

Satellite observations (primarily from geostationary orbit satellites) will in many cases be the primary real-time mesoscale data source for nowcasting in Africa. Providing forecasters with the training required to understand the meteorological value of the satellite observations and to use satellite products is key in enabling them to provide an entirely new level of forecast services, including for the nowcasting time frame of 0–6 hours. This time frame often falls between numerical model output times, and hence is why real-time data, satellite data and products, in particular, can add much value to the nowcasting process. This section aims to highlight the skills required of forecasters for nowcasting when using satellite data as, opposed to those required for short-range forecasting. It will also discuss the rapid evolution of satellite technology, which brings with it the need for continuous professional development. Finally, this section will provide valuable information to assist users to find training opportunities and resources.

### 5.1.1 *Skills requirements for nowcasting*

Basic training most commonly follows the guidance available in the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO-No. 1083). However, a much greater emphasis will be needed on understanding and interpreting a wide variety of satellite observations applicable to local forecast issues, especially for forecasting swiftly changing environments and rapidly developing events. Providing such training requires the expertise of a dedicated local trainer, which in turn requires a robust and active "Train the Trainer" programme. The WMO *Guidelines for Nowcasting Techniques* (WMO-No. 1198) summarize the competencies needed for successful nowcasting, which includes the skills and components listed in the table below.

**Table. Key skills extracted from the *Guidelines on Satellite Skills and Knowledge for Operational Meteorologists* (SP-No. 12) for forecasters working on nowcasting**

| *Skills* | *Applicable performance components for nowcasting* |
|---|---|
| IDENTIFY CLOUD TYPES AND THEIR CHARACTERISTICS | Identify cumulonimbus clouds, their intensity, organization and stage of development.<br>Identify fog and discriminate between fog and low cloud.<br>Deduce cloud top heights based on brightness temperatures, surface observations and sounding data (observed, satellite-derived and numerical models).<br>Identify clouds made of water droplets, ice particles or a mixture.<br>Discriminate between clouds with small or large cloud particles. |
| IDENTIFY AND INTERPRET BROADSCALE, SYNOPTIC AND MESOSCALE SYSTEMS | Identify and locate the following mesoscale systems and features:<br>• Convective environments and areas of instability, convective initiation, inhibition and the breakdown of inhibition.<br>• Convective cells and cloud systems (including pulse convection, multicells, supercells, squall lines, mesoscale convective complexes and systems) and associated mesoscale features including outflow boundaries and storm-top features.<br>• Convergence lines (mesoscale boundaries and interactions, dry lines, cloud streets). |
| IDENTIFY AND INTERPRET ATMOSPHERIC PHENOMENA | Dust and sandstorms, and plumes and areas of raised dust.<br>Fires and smoke.<br>Moisture features, precipitation types and amounts. |
| COMPARE SATELLITE DATA WITH NUMERICAL WEATHER PREDICTION (NWP) OUTPUTS | Deduce when and how to use satellite imagery to address NWP limitations.<br>Use satellite data in conjunction with NWP at different stages of the analysis and forecast process. |

For much of Africa, the necessary skills include a comprehensive understanding of what satellite data, products and tools are available to detect, monitor and predict the strength, growth and movement of the relevant phenomena, and who they might affect. The *Guidelines on Satellite Skills and Knowledge for Operational Meteorologists* (SP-No. 12), published in 2018 and continuously revised and updated, gives a comprehensive list of skills that the operational meteorologist is required to master (see table above). Applicable skills for nowcasting extracted from that document give a baseline of the skills required to be able to use satellite imagery as a part of a nowcasting process. However, it does not include the skills required for using new instruments, such as a lightning instrument. These can, of course, be included in updates to the 2018 document.

The table outlines the following essential skills for nowcasting:

(1) Forecasters need to identify various clouds and how they appear in satellite imagery, using appropriate satellite products.

(2) Forecasters´ understanding must be grounded in an understanding of mesoscale phenomena and the underlying dynamical and thermodynamical processes. They need to have insight into the dynamics of the synoptic environment and how this influences the mesoscale phenomena, in their own particular location and climate. This insight will include conceptual models of weather evolution, and a knowledge of the local climatology, which can be very much location-specific, that is, dependent on local topography and season. In the African context, especially in the tropics, there is a different set of synoptic and mesoscale conceptual models (such as African easterly waves) compared to the northern and southern African conceptual models (such as mid-latitude fronts) (Parker and Diop-Kane, 2017).

(3) Forecasters need to be able to use NWP guidance in conjunction with satellite data, keeping in mind that at nowcasting timescales (0–6 hours) the NWP models often have limitations (Parker and Diop-Kane, 2017).

The development of new nowcasting services with clients should be done through a process of co-production. Those responsible for the co-production will need appropriate training and experience.

### 5.1.2 ***The future of capacity development and training in satellite-based nowcasting***

Nowcasting is a quickly evolving field. New knowledge on how to carry out nowcasting is being developed in operational forecast offices, universities, testbeds, and so forth. That knowledge is codified in national procedures and regional guidance documents. Once knowledge matures, it can be further implemented, included and updated to competencies, enabling skills and curricula. This step is essential in supporting training across regions.

As the codified knowledge develops, training resources and courses are then implemented. These courses generate resources that can be shared and used by others.

Operational meteorologists will learn from experience, resources, courses and each other. The development of professional communities of practice can assist greatly here.

In the planning of future training programmes, it will be essential to recognize that the field is evolving quickly, with new data sets and new visualization systems becoming available every year. Experience is growing in a number of countries in regard to developing new nowcasting services and new communications systems, in co-production with different sectors. For these reasons, practitioners need to be retrained periodically on these advancing methods.

Given the limited provision of nowcasting services currently in Africa, there is relatively limited opportunity for training within existing training programmes. The significant opportunities to expand nowcasting services demand that in the near future there should be an increase in training provision in this area.

In order to implement appropriate training, nowcasting curricula need to be established and formalized on the basis of approved learning objectives and skills requirements. Guidance for these skills requirements is given in the Skills requirements for nowcasting section. Where SOPs have been developed for nowcasting services, the skills requirements should be consistent with these, and ensure that a successful trainee has the skills to follow the SOP in practice.

The development of nowcasting training curricula can take advantage of the training modules that have been developed in some centres recently (notably in two universities, the Kwame Nkrumah University of Science and Technology (KNUST) and the University of Nairobi, as part of the GCRF African SWIFT programme). However, it is also essential that the development of curricula be forward-looking and take account of the opportunities offered in the new environment provided by MTG, as well as the possibility of new radars becoming operational in some places.

Given the lack of nowcasting in Africa, training curricula also need to be forward-looking in order to enable expansion of nowcasting services to more sectors, through co-production with stakeholders. It is therefore recommended that co-production be an element of future training. Nowcasting is regionally dependent, because of the different local characteristics of weather systems, and nowcasting practice is very much dependent on user needs. The expansion of nowcasting to a new country or subregion will therefore require adaptation of the methods, incorporating the existing knowledge and skills of experienced forecasters. One novel approach to future training in Africa for nowcasting, which may prove valuable, both to the technical training and to the co-production of new operational services with users, would be to make use of testbed approaches using real-time cases. Testbeds have been performed in the USA and Europe for a number of years and were introduced to Africa in the GCRF African SWIFT programme. By bringing together forecasters, product developers, researchers and forecast users, testbeds offer the opportunity for a rapid translation of research, technical innovation and co-production into new operational tools.

In Africa, the high socioeconomic impact of weather events means that there are opportunities to develop new services, which may be unique to the continent and globally leading. This endeavour will require a new generation of African forecasters with the skills to bring nowcasting to their communities.

### 5.1.3 ***Existing structures for capacity development in nowcasting***

Training opportunities on nowcasting are available as part of existing formal scientific training (in undergraduate and postgraduate meteorology courses at university level). They should also be provided on a continuous basis in order for forecasters to learn the new and enhanced tools regularly being made available. In practice, this means frequent on-the-job training through various international and regional training programmes, as well as training offered within each NMHS.

Several training networks exist to support NMHSs to improve the nowcasting skills of their operational staff. These networks, briefly introduced below, are comprised of both virtual and physical training institutions, offering learning opportunities both in-person and now increasingly in an online format. The growing offering of online training reduces the cost of training substantially and makes it more widely accessible.

The WMO Global Campus Calendar of Events (https://learningevents.wmo.int/) is a platform where available training is listed, and it is possible to subscribe and receive notifications when an event is added on a topic of interest (such as nowcasting or satellite-based training).

#### 5.1.3.1 **Regional Training Centres/institutions**

A WMO Regional Training Centre (RTC) is an institution, or coordinated group of institutions, that delivers training in meteorology, hydrology and related fields to meet the needs of the region. There are currently 28 RTCs worldwide and 8 in Africa. The RTCs are tasked with providing advice and assistance on education and training matters as well as training opportunities for WMO Members in the region, particularly NMHS staff.

RTCs continuously monitor the advancement of applications and observing systems for operational meteorology and nowcasting. One of their tasks is to provide training opportunities within the region, including in the newest nowcasting applications as these become available. Readers are advised to contact their local RTC to express their training requirements and discuss which training is available.

#### 5.1.3.2 **VLab – Virtual Laboratory for Education and Training in Satellite Meteorology**

Established in 2000 by WMO and the Coordination Group for Meteorological Satellites (CGMS), the Virtual Laboratory for Training and Education in Satellite Meteorology (VLab) is a global network of 13 specialized training centres (called Centres of Excellence) and 8 satellite operators worldwide, working together to improve the utilization of data and products from meteorological and environmental satellites.

The Centres of Excellence, often co-located with RTCs, are established in all WMO Regions, including four in Africa (Region I) (Kenya (Nairobi), Morocco (Casablanca), Niger (Niamey), Pretoria (South Africa)), to meet user needs for increased skills and knowledge in using satellite data within their region.

The VLab long-term goals are: (a) to continuously improve the utilization of data from the space-based component of the WMO Integrated Global Observing System (WIGOS) for services that are increasingly reliant on satellite data; and (b) to globally share knowledge, experience, methods and tools related to access and usage of satellite data, especially in support of WMO Members that have limited resources. The existence of the VLab network has been crucial for building various international satellite training opportunities available to meteorologists beyond the activities related to the Basic Instruction Package for Meteorologists (BIP-M) (https://community.wmo.int/bip-m-and-bip-mt-compliance), completed during formal scientific training. For example, in recent years, the Satellite Application Courses (E-SAC) run by African VLab Centres of Excellence in partnership with EUMETSAT have been advertised and made available to all NMHSs in Regional Association I annually. It has been recommended that these E-SAC courses be run more frequently in order to allow more participants to attend. The improving online capabilities have enabled these courses to be delivered in an online format, making them more accessible for a larger number of African forecasters. The E-SAC courses focus on operational use of satellite products. The topic of nowcasting has been noted as an area of enhancement to this course and should be implemented from 2023 onwards.

#### 5.1.3.3 African Satellite Meteorology Education and Training

The African Satellite Meteorology Education and Training (ASMET) project produces free, self-paced online learning resources that teach African forecasters how to enhance their forecasts and nowcasts by making better use of meteorological satellite images and products. Lessons are published on the ASMET site (https://asmet.africa/about-us/) and can also be accessed through the MetEd site (https://www.meted.ucar.edu/index.php), and are completely free of charge for forecasters. The lessons have been published and used by African forecasters for over 20 years and thus constitute a vast resource pool to which forecasters from NMHSs can refer in order to learn and improve their skills. The data used for the lessons include satellite data and derived products from EUMETSAT geostationary satellites, and NWP model data.

Several case studies used in the ASMET lessons are based on meteorological phenomena such as fog, convection, dust, tropical cyclones and so forth, which cause devastating effects in the areas impacted. Some of the lessons also take the learner through the forecasting process, step-by-step, highlighting which data to use and the significant thresholds to look for that could trigger dangerous hazards and pose a risk to communities. Forecasters apply such knowledge and forecasting skill in their operational duties of nowcasting and in producing short-range forecasts or issuing warnings and advisories.

#### 5.1.3.4 WMO Severe Weather Forecasting Programme

WMO currently runs a Severe Weather Forecasting Programme (SWFP), with the aim of strengthening the capacity of NMHSs in developing countries to provide improved forecasts and severe weather warnings. As a result of the programme, various participating NMHSs in Africa have gained valuable experience in the entire forecasting process, with forecasters acquiring knowledge in the use of tools such as NWP and remote sensing (specifically satellite), and in producing improved guidance for hazardous weather and in issuing warnings and alerts. The Programme was preceded by the Severe Weather Forecasting Demonstration Project (SWFDP), launched in 2006. Nowcasting services formed an important part of the demonstration project and resulted in many nowcasting satellite products being provided to NMHSs across Africa through the RSMC websites. This earlier SWFDP was an excellent example of how a demonstration project can improve nowcasting (and forecasting) services across Africa. In fact, the project was so successful that WMO converted the SWFDP into the SWFP in 2019, and it now benefits 80 developing countries in 9 subregions, with 4 of the subregions being in Africa (https://community.wmo.int/activity-areas/severe-weather-forecasting-programme-swfp).

**Recommendations related to capacity development and training in satellite-based nowcasting:**

(a) Use, and build on the expertise of VLab Centres of Excellence, which have consolidated knowledge and training programmes related to both satellite data/information and the delivery/development of nowcasting techniques and services.

(b) Provide training on all aspects of the nowcasting process to technical support staff, forecasters and prioritized users, with a particular emphasis on the use and value of satellite-based products.

(c) Decide on the best sustained approach for training forecast staff; consider international and online training activities, events and available materials.

(d) Consider development of a Train the Trainers course approach in each hub in order to sustain expertise over time.

(e) Consider development of training activities based on the testbed approach, proven to be efficient by the GCRF African SWIFT programme.

## 5.2 Enabling sustainable nowcasting services

### 5.2.1 *Regional strengths and Centres of Excellence*

The success and continued use of nowcasting services across subregions and within nations depends, at least partially, on the organizational and institutional capacity developed during demonstration and service delivery phases of nowcasting initiatives. Regional centres delivering the nowcasts will need to raise awareness of the importance of nowcast services and the positive benefits it can bring at many levels, including (but not limited to): NMHS forecasters and senior managers and directors; the general public across the service delivery countries in the region; key economic sectors within the region; humanitarian and disaster risk reduction agencies; and governmental decision makers within countries. Monitoring and communicating the benefit of nowcasts and the impact that early warning and action can have on this timescale is resource intensive, and is additional to delivering a nowcasting services, and should be considered strategically when developing and implementing nowcasting service provision.

To address the challenges of ensuring longevity of nowcasting services, implementation of services should be sought in strong regional centres in Africa, including: the WMO-CGMS VLab Centres of Excellence; WMO RSMCs; and WMO Regional Climate Centres (RCCs). Across Africa, these are located as follows:

– VLab Centre of Excellence at the Direction de la météorologie nationale, Morocco;

– VLab Centre of Excellence at the Institute for Meteorological Training and Research, Kenya Meteorological Department;

– VLab Centre of Excellence at the Ecole africaine de la météorologie et de l’aviation civile (EAMAC), Niger;

– VLab Centre of Excellence at the South African Weather Service (SAWS);

– RSMC Dakar at the Agence nationale de l'aviation civile et de la météorologie (ANACIM), Senegal;

– RSMC Nairobi at the Kenya Meteorological Department (KMD);

– RSMC Pretoria at the South African Weather Service (SAWS);

– RCC at the African Centre of Meteorological Applications for Development (ACMAD), Niger;

– RCC at the IGAD (Intergovernmental Authority on Development) Climate Prediction and Applications Centre (ICPAC), Kenya.

For optimal nowcasting, as outlined in the WMO *Guidelines for Nowcasting Techniques* (WMO-No. 1198), skilled forecasters and trainers in many meteorological disciplines are necessary, which is usually impossible for one training institute to accommodate. The synergy of networking will yield more efficient nowcasting training. Such networking is also specifically recommended and encouraged for the provision of nowcasting services in Africa, and especially in West Africa, where Centre of Excellence expertise is spread across several centres in two nations.

The following section explores the centre competencies in terms of how each institution can develop, support and deliver nowcasting services regionally.

### 5.2.2 ***International cooperation***

International cooperation is fundamental to the success of regional nowcasting services in Africa (WMO Region I). Without international cooperation, data would not be delivered to African NMHSs, training in nowcasting, service development and service delivery could not take place and wider capacity development of African Centres of Excellence would likely be impaired. The sharing of case studies, expertise, challenges and solutions between African nations should also be acknowledged as an important pathway for African NMHSs to subsequently build equitable partnerships and relationships outside the continent, a good example of which is the Climate Risk and Early Warning Systems (CREWS) work programme. This model could also help other developing regions outside the EUMETCast area of coverage (for example, Central and South America, which are within NOAA's coverage domains). Including international cooperation and partnerships during the development of these efforts will streamline future activities and help save lives in other parts of the globe. In recent years, a number of initiatives have demonstrated the potential of collaboration and cooperation between sectors and nations in Africa to access and develop nowcasting services (including the GCRF African SWIFT and WMO SWFP programmes). These initiatives have:

(1) Trained forecasters to use state-of-the-art satellite products and tools for nowcasting and forecasting, to support anticipatory actions;

(2) Provided developers with the opportunity to improve their understanding of the functional requirements for products, to best fit the operational environment;

(3) Strengthened partnerships within the subregions (for example, between universities and NMHSs).

These initiatives have increased the reach and sustainability of programmes such as GCRF African SWIFT and WMO SWFP, by designing and sharing case-based training, and training of trainers for using and continuously developing these packages. It is worth noting that, due to the COVID-19 pandemic, more virtual collaboration and training options are now available to foster increased interaction at little cost.

#### Public-private engagement

The role of the private sector in the delivery of nowcasting data and services should be acknowledged as a possible solution, or series of solutions, for making nowcasting services regionally sustainable. With the increased pressure on NMHSs to handle more complex, frequent, and voluminous ("big") data, and with the focus on tailoring services to diverse users, nowcasting services may not only be broad (that is, covering many and diverse users and sectors), but may also require innovative solutions for receiving and storing data and delivering services. There is an open question as to whether, and to what extent, some of the provision in nowcasting can be delivered through public-private engagement (PPE). The WMO *Guidelines for Public-Private Engagement* (WMO-No. 1258), were produced to inform and facilitate global, regional and national actions by WMO and its Members to encourage proactive engagement among stakeholders in the public, private and academic sectors in order to provide better services to governments, economies and citizens for the benefit of society. The Guidelines address:

(a) The evolving potential for engagement with stakeholders in the public, private and academic sectors and civil society in the areas of weather, climate and water;

(b) Principles for public-private sector engagement based on Annex 2 to Decision 73 (EC-68) – Key issues to be addressed in developing policies and principles for engagement (*Executive Council – Sixty-eighth Session: Abridged Final Report with Resolutions and Decisions* (WMO-No. 1168));

(c) The evolving roles of stakeholders at the global, regional and national levels;

(d) Options for public-private engagement in the legislative landscape, capacity development and other societal issues, with a view to developing a WMO guidance for Members.

The role of WMO within the brokering of PPE is to facilitate worldwide activities and cooperation around weather, climate and water for the benefit of all nations and peoples. WMO will:

(a) Modernize and clearly articulate standards and recommended practices;

(b) Encourage the free and unrestricted exchange of data;

(c) Facilitate dialogue among all stakeholders;

(d) Investigate emerging issues and changing roles.

At the regional level, the mandate of regional associations is to interface with their Members, liaise with other stakeholders, and designate and support regional centres in the delivery of regional services to Members. To support engagement with actors in the private sector and with other stakeholders, regional associations are urged to take on other roles, including:

(a) Gathering and disseminating information and guidance;

(b) Raising awareness and promoting the capacity development of Members;

(c) Exploring further cooperation in service provision at the regional and subregional levels.

At the national level, the NMHS mandate is to take action to maintain and improve stakeholder engagement with the aim of maximizing the corresponding socioeconomic benefits in the short and long term. Effective engagement offers opportunities to strengthen NMHSs, or other designated agencies, and the weather enterprise as a whole. The evolving role of Members in this regard includes:

(a) Fostering structured dialogue with the private sector;

(b) Putting in place appropriate legislation and business models, performing change management and building on core strengths;

(c) Promoting the uptake of WMO standards and guidance;

(d) Fostering partnerships with civil society entities;

(e) Exploring new national and cross-border partnerships.

A stakeholder analysis within each subregion will allow identification of the key partners that are directly or indirectly essential to the implementation of concrete activities. As stated earlier, non-State partners are also critical at the level of facilitating the delivery of nowcasting products and services. These partners include subregional economic communities, research, training and policy-related institutions, non-governmental organizations, the private sector, academia, the media and communications sector, parliamentarians and United Nations agencies operating in the region. Resource partners are also important given that resource mobilization for implementing the present guidelines remains a key requirement for the future. In order for weather and climate services in Africa to be effective and developed, there are important and critical players that must work together, including at national, regional and international levels.

In particular, the Regional Economic Communities (RECs) in Africa can facilitate close cooperation between NMHSs and relevant African institutions to support the production and delivery of nowcasting services. Such communities include: the East African Community (EAC); the Intergovernmental Authority on Development (IGAD); the Economic Community of West African States (ECOWAS); the Common Market for Eastern and Southern Africa (COMESA); and the Southern African Development Community (SADC).

### 5.2.3 *Regional differences*

Many external programmes and initiatives have been conducted on nowcasting research and innovation projects across Africa. The projects have advanced the knowledge around how to design, implement and deliver nowcasting activities and services across sub-Saharan Africa. It should be acknowledged that the specific conditions across the subregions and indeed, in individual African countries, vary enormously in terms of: needs of the population; partnerships; climatology; economic development; capacity of NMHSs; economic sectors and nowcasting service users.

In order to ensure that this heterogeneity is taken into account, a stakeholder and situational analysis is needed for subregions; from this, standard operating procedures can be developed in order to facilitate tailored nowcasting services. Training may then also be tailored according to subregional needs, in conjunction with the regional Centres of Excellence, as listed earlier in this section.

Delivery and sustainability of an African Meteorological Satellite Application Facility, or AMSAF, as ratified by the Abidjan Declaration in 2019 at the African Ministerial Conference on Meteorology, is the foundation upon which regional hubs can be developed and sustained.

**Recommendations related to enabling sustainable nowcasting services:**

(a) Cooperate with other African nations and subregions developing and implementing nowcasting services.

(b) Consider public-private engagement and resource mobilization to deliver some aspect(s) of nowcasting infrastructure and/or services, for example, by engaging with Regional Economic Communities to leverage resources and build upon the strengths of each sector.

## 6. SUMMARY AND RECOMMENDATIONS

With the launch of the MTG series of satellites from 2022, updated instruments – including new capabilities like the Lightning Imager (LI), Infrared Sounder (IRS) and Ultraviolet Visible Near-infrared (UVN) Spectrometer – will mark major improvement over the previous geostationary satellite system. Data and products will be available every 10 minutes with improved spatial resolution. WMO, in collaboration with EUMETSAT, and through their cooperation with African countries, aims to expand the user base for EUMETSAT data, products and services. There is a long-term commitment to sustain the data and generate regional or national weather and climate services in support of various socioeconomic sectors.

For Africa to benefit fully from the opportunity provided by satellite infrastructure, the main challenges are related to ensuring data access, creating science-based products and integrating them in actionable information services tailored to African needs. Continued capacity building – in terms of user infrastructure and user training – for the new generation of satellites is crucial to maintain and develop sustainable African nowcasting capability. The AMSAF concept aims to support the provision of climate and weather services and to strengthen African capacities to access and deliver suitable information to decision makers.

To provide an operational nowcasting service, a forecaster is dependent on in situ and remote observations, as well as NWP, to assess current weather conditions and forecast any changes that may occur in the following few hours. This requires specific infrastructure (computing power, bandwidth, and so forth) as well as software (such as the NWC SAF package and display options). The NWC SAF software has been demonstrated (through programmes such as GCRF African SWIFT, and also through comparison studies done in southern Africa by SAWS) to serve as a good proxy to radar data in order to have fast updates on severe weather events. For satellite-based nowcasting practices to be included in operational duties for forecasters, standard procedures need to be put in place to guide the process of nowcasting in easy steps. The risks associated with severe weather events could be communicated through websites or smartphone apps, but should be clear and useful for all users and decision makers. Using a colour-coded risk matrix could be very efficient.

Given the current lack of nowcasting procedures in Africa, capacity development is crucial and needs to take into account regional differences, because of the different local characteristics of weather systems. One novel approach to future training in Africa for nowcasting could be to make use of testbed approaches using real-time cases. Testbeds were organized in the USA and Europe for a number of years and were introduced to Africa in the GCRF African SWIFT programme. Such efforts should be well coordinated between the African users, WMO and EUMETSAT.

International cooperation is fundamental to the success of regional nowcasting services in Africa for ensuring that data will be delivered to African NMHSs in real time. Training in nowcasting, co-development of relevant services and optimal communication for the delivery of the services will be needed, and international collaboration with other NMHSs as well as the private sector would be beneficial.

The concepts discussed in the preceding sections have led to the following recommendations:

(a) Build knowledge and expertise within regional centres (hubs) from where satellite data and products can be accessed and disseminated, and from where training and nowcasting services can be delivered.

*Audience: managers and international agencies*

(b) Based on African expertise and collaboration, develop a hierarchy of data distribution plans that both meets the local needs for nowcasting services and recognizes the different communications and computing capabilities available across Africa.

*Audience: managers, international agencies and IT specialists*

(c) Develop plans whereby NMHSs can assess and adopt display systems capable of ingesting and appraising the potentially large volume of real-time satellite observations that form the backbone of these new, localized "event triggered" forecast services.

*Audience: managers, forecasters and IT specialists*

(d) Recognizing that many existing nowcasting tools have been designed for mid-latitude use, develop an inventory of existing, planned and desired satellite products that could serve the needs of nowcasters across all parts of Africa, both for monitoring changes in the pre-storm environment and for assessing subsequent storm growth and possible impacts. Each NMHS should then study this list and identify those products that are likely to be most useful for their local nowcasting needs, including the necessary training for these.

*Audience: managers, trainers and forecasters*

(e) Promote the development of early warning systems based on satellite-based nowcasting products for various hazards, to be determined in interaction with defined users.

*Audience: forecasters and managers*

(f) Determine and understand the regional and national users' requirements.

*Audience: forecasters and managers*

(g) Develop SOPs for national forecasters based on nowcasting guidelines provided by WMO, and taking into account the experience gained from the GCRF African SWIFT programme.

*Audience: trainers and forecasters*

(h) Use, and build on the expertise of VLab Centres of Excellence, which have consolidated knowledge and training programmes related to both satellite data/information and the delivery/development of nowcasting techniques and services.

*Audience: trainers*

(i) Provide training on all aspects of the nowcasting process to technical support staff, forecasters and prioritized users, with a particular emphasis on the use and value of satellite-based products.

*Audience: trainers*

(j) Decide on the best sustained approach for training forecast staff; consider international and online training activities, events and available materials.

*Audience: trainers*

(k) Consider development of a Train the Trainers course approach in each hub in order to sustain expertise over time.

*Audience: trainers and managers*

(l) Consider development of training activities based on the testbed approach, proven to be efficient by the GCRF African SWIFT programme.

*Audience: trainers and managers*

(m) Cooperate with other African nations and subregions developing and implementing nowcasting services.

*Audience: managers*

(n) Consider public-private engagement and resource mobilization to deliver some aspect(s) of nowcasting infrastructure and/or services, for example, by engaging with Regional Economic Communities to leverage resources and build upon the strengths of each sector.

*Audience: managers*

# REFERENCES


Bedka, K. M. Overshooting Cloud Top Detections Using MSG SEVIRI Infrared Brightness Temperatures and Their Relationship to Severe Weather over Europe. *Atmospheric Research* **2011**, *99* (2), 175–189. https://doi.org/10.1016/j.atmosres.2010.10.001.

Bedka, K.; Murillo, E. M.; Homeyer, C. R. et al. The Above-Anvil Cirrus Plume: An Important Severe Weather Indicator in Visible and Infrared Satellite Imagery. *Weather and Forecasting* **2018**, *33* (5), 1159–1181. https://journals.ametsoc.org/view/journals/wefo/33/5/waf-d-18-0040_1.xml.

Cintineo, J. L.; Pavolonis, M. J.; Sieglaff, J. M. et al. The NOAA/CIMSS ProbSevere Model: Incorporation of Total Lightning and Validation. *Weather and Forecasting* **2018**, *33* (1), 331–345. https://journals.ametsoc.org/view/journals/wefo/33/1/waf-d-17-0099_1.xml.

Cintineo, J. L.; Pavolonis, M. J.; Sieglaff, J. M. NOAA ProbSevere v2.0 – ProbHail, ProbWind, and ProbTor. *Weather and Forecasting* **2020**, *35* (4), 1523–1543. https://journals.ametsoc.org/view/journals/wefo/35/4/wafD190242.xml.

De Coning, E.; Gijben, M.; Maseko, B. et al. Using Satellite Data to Identify and Track Intense Thunderstorms in South and Southern Africa. *South African Journal of Science* **2015**, *111* (7/8). https://doi.org/10.17159/sajs.2015/20140402.

EUMETSAT. *MTG Products Distribution Baseline [MTGDIS]*; EUM/MTG/DOC/17/946090; EUMETSAT: Germany, 2020. https://www.eumetsat.int/de/media/43010.

EUMETSAT. *MTG EUMETCast Africa Product User Guide [AfricaPUG]*; EUM/MTG/USR/19/1148454; EUMETSAT: Germany, 2022. https://www.eumetsat.int/media/47571.

Fletcher, J. K.; Diop, C. A.; Adefisan, E. et al. Tropical Africa's First Testbed for High-impact Weather Forecasting and Nowcasting. *Bulletin of the American Meteorological Society* **2022**, advance online publication. https://journals.ametsoc.org/view/journals/bams/aop/BAMS-D-21-0156.1/BAMS-D-21-0156.1.xml.

Gijben, M.; de Coning, E. Using Satellite and Lightning Data to Track Rapidly Developing Thunderstorms in Data Sparse Regions. *Atmosphere* **2017**, *8* (4), 67. https://doi.org/10.3390/atmos8040067.

Gravelle, C. M.; Mecikalski, J. R.; Line, W. E. et al. Demonstration of a GOES-R Satellite Convective Toolkit to "Bridge the Gap" between Severe Weather Watches and Warnings: An Example from the 20 May 2013 Moore, Oklahoma, Tornado Outbreak. *Bulletin of the American Meteorological Society* **2016**, *97* (1), 69–84. https://doi.org/10.1175/BAMS-D-14-00054.1.

Hill, P. G.; Stein, T. H. M.; Roberts, A. J. et al. How Skilful Are Nowcasting Satellite Applications Facility Products for Tropical Africa? *Meteorological Applications* **2020**, *27* (6). https://doi.org/10.1002/met.1966.

Holmlund, K.; Grandell, J.; Stuhlmann, R. et al. Meteosat Third Generation (MTG): Continuation and Innovation of Observations from Geostationary Orbit. *Bulletin of the American Meteorological Society* **2021**, *102* (5), E990–E1015. https://doi.org/10.1175/BAMS-D-19-0304.1.

Parker, D. J.; Diop-Kane, M., Eds. *Meteorology of Tropical West Africa: The Forecasters' Handbook*; Wiley Blackwell, 2017. https://www.wiley.com/en-us/Meteorology+of+Tropical+West+Africa%3A+The+Forecasters%27+Handbook-p-9781118391303.

Roberts, A. J.; Fletcher, J. K.; Groves, J. et al. Nowcasting for Africa: Advances, Potential and Value. *Weather* **2022a**, *77* (7), 250–256. https://doi.org/10.1002/wea.3936.

Roberts, A. J.; Parker, D. J.; Marsham, J. H. et al. *GCRF African SWIFT Nowcasting Standard Operating Procedure (SOP)*, grant number NE/P021077/1. University of Leeds, 2022b. https://doi.org/10.48785/100/96.

Roberts, R. D.; Goodman, S. J.; Wilson, J. W. et al. Taking the HIGHWAY to Save Lives on Lake Victoria. *Bulletin of the American Meteorological Society* **2022c**, *103* (2), E485-E510. https://journals.ametsoc.org/view/journals/bams/103/2/BAMS-D-20-0290.1.xml.

Ruti, P. M.; Tarasova, O.; Keller, J. H. et al. Advancing Research for Seamless Earth System Prediction. *Bulletin of the American Meteorological Society* **2020**, *101* (1), E23–E35. https://journals.ametsoc.org/view/journals/bams/101/1/bams-d-17-0302.1.xml.

World Meteorological Organization (WMO). *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150). Geneva, 2015.

World Meteorological Organization (WMO). *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO-No. 1083), Volume I. Geneva, 2015.

World Meteorological Organization (WMO). *Executive Council – Sixty-eighth Session: Abridged Final Report with Resolutions and Decisions* (WMO-No. 1168). Geneva, 2016.

World Meteorological Organization (WMO). *Guidelines for Nowcasting Techniques* (WMO-No. 1198). Geneva, 2017.
World Meteorological Organization (WMO). *Guidelines on the Role, Operation and Management of National Meteorological and Hydrological Services* (WMO-No. 1195). Geneva, 2017.
World Meteorological Organization (WMO). *Guidelines on Satellite Skills and Knowledge for Operational Meteorologists* (SP-No. 12). Geneva, 2018.
World Meteorological Organization (WMO). *2021 State of Climate Services: Water* (WMO-No. 1278). Geneva, 2021.
World Meteorological Organization (WMO). *Guidelines for Public-Private Engagement* (WMO-No. 1258). Geneva, 2021.
World Meteorological Organization (WMO). *State of the Climate in Africa 2020* (WMO-No. 1275). Geneva, 2021.
World Meteorological Organization (WMO). *Stories of Success: Piloting a Regional Early Warning System for Increased Resilience in the Lake Victoria Region*; WMO: Geneva, 2021.
World Meteorological Organization (WMO). *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services Part II: Putting Multi-hazard IBFWS into Practice* (WMO-No. 1150). Geneva, 2021.
United Nations News. *UN Weather Agency to Spearhead 5-Year Early Warning Plan, Boosting Climate Action*, 23 March 2022. https://news.un.org/en/story/2022/03/1114462.
Vogel, P.; Knippertz, P.; Fink, A. H. et al. Skill of Global Raw and Postprocessed Ensemble Predictions of Rainfall over Northern Tropical Africa. *Weather and Forecasting* **2018**, *33* (2), 369–388. https://journals.ametsoc.org/view/journals/wefo/33/2/waf-d-17-0127_1.xml.
Vogel, P.; Knippertz, P.; Fink, A. H. et al. Skill of Global Raw and Postprocessed Ensemble Predictions of Rainfall in the Tropics. *Weather and Forecasting* **2020**, *35* (6), 2367–2385. https://journals.ametsoc.org/view/journals/wefo/35/6/WAF-D-20-0082.1.xml.
Youds, L. H.; Parker, D. J.; Adefisan, E. A. et al. *The Future of African Nowcasting*. University of Leeds, 2021. https://doi.org/10.5518/100/68.

## LIST OF ACRONYMS

ACMAD – African Centre of Meteorological Applications for Development
ADS – Automatic Dependent Surveillance
AeMET – Agencia Estatal de Meteorología
AMSAF – African Meteorological Satellite Application Facility
ANACIM – Agence Nationale de l'Aviation Civile et de la Météorologie
AI/ML – Artificial intelligence and machine learning
AMCOMET – African Ministerial Conference on Meteorology
AMDAR – Aircraft Meteorological DAta Relay
AMV – Atmospheric Motion Vector
ASECNA – Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar
ASREN – Arab States Research and Education Network
ASII-GW – Automatic Satellite Image Interpretation-Gravity Waves
ASII-TF – Automatic Satellite Image Interpretation-Tropopause Folding
ASMET – African Satellite Meteorology Education and Training
BIP-M – Basic Instruction Package for Meteorologists
CG – Cloud-to-ground
CGMS – Coordination Group for Meteorological Satellites
COMESA – Common Market for Eastern and Southern Africa
CREWS – Climate Risk and Early Warning Systems
CRR – Convective Rainfall Rate
ENGLN – Earth Networks Global Lightning Network
EAC – East African Community
EAMAC – Ecole Africaine de la Météorologie et de l'Aviation Civile
ECCAS – Economic Community of Central African States
ECMWF – European Centre for Medium-Range Weather Forecasts
ECOWAS – Economic Community of West African States
EUMETSAT – European Organisation for the Exploitation of Meteorological Satellites
EXIM – Extrapolated Imagery

FASTA – Forecasting African Storms Application
GBON – Global Basic Observing Network
GCRF – Global Challenges Research Fund
GLM – Global Lightning Mapper
GOES – Geostationary Operational Environmental Satellite
ICAO – International Civil Aviation Organization
IGAD – Intergovernmental Authority on Development
ICPAC – IGAD Climate Predictions and Applications Centre
IRS – Infrared Sounder
IC – Intra-cloud
LI – Lightning Imager
KNUST – Kwame Nkrumah University of Science and Technology
METAR – METeorological Aerodrome Report
MSG – Meteosat Second Generation
MTG – Meteosat Third Generation
MTG-IRS – MTG Infrared Sounder
MTG LI – MTG Lightning Imager
NMHS – National Meteorological and Hydrological Service
NREN – National Research and Education Network
NWC SAF – Nowcasting Satellite Application Facility
NWP – Numerical weather prediction
NWC SAF/GEO – NWC SAF software for geostationary satellites
PUMA – Preparation for the Use of Meteosat Second Generation in Africa
PPE – Public-private engagement
RA – Regional Association
RAIDEG – RA I Dissemination Expert Group
RDT-CW – Rapid Developing Thunderstorms-Convection Warning
RCC – Regional Climate Centre
REC – Regional Economic Community
RSMC – Regional Specialized Meteorological Centres
RTC – Regional Training Centre
SWFDP – Severe Weather Forecasting Demonstration Project
SWFP – Severe Weather Forecasting Programme
SAWS – South African Weather Service
SADC – Southern African Development Community
SOP – Standard operating procedure
SOFF – Systematic Observations Financing Facility
SWIFT – African Science for Weather Information and Forecasting Techniques
UKMO – United Kingdom Met Office
UVN – Ultraviolet Visible Near-infrared
VLab – Virtual Laboratory for Training and Education in Satellite Meteorology
WebUI – Web User Interface
WIGOS – WMO Integrated Global Observing System
WMO – World Meteorological Organization

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