APPROACHES TO COLLECT, EXCHANGE, AND INTEGRATE NATIONAL AND GLOBAL DATASETS

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Cover Photo: Rain gauge, Kenya Credit: Francesco Fiondella, IRI

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ACRONYMS AND ABBREVIATIONS

ACMAD	African Centre of Meteorological Application for Development
AGM	WMO's Annual Global Monitoring
AGRHYMET	Agriculture, Hydrology and Meteorology Research Center of West Africa (based in Niamey, Niger)
APCC	APEC (Asia-Pacific Economic Cooperation) Climate Center
ARC	African Rainfall Climatology
CHIRPS	Climate Hazards Group Infrared Precipitation with Station
CIAT	Centro Internacional de Agricultura Tropical
CIS	Climate Information Services
CPT	Climate Predictability Tool
CSAG	Climate System Analysis Group (based at the University of Cape Town)
ECMWF	European Center for Medium Range Weather Forecasting
ENACTS	Enhancing NAtional ClimaTe Services
ESRI	Environmental Systems Research Institute, GIS software supplier
GIS	Geographic Information Science/Systems
GCM	Global Climate Model
GDP	Global Domestic Product
GDPFS	Global Data-Processing and Forecasting System
GFCS	Global Framework for Climate Services
GISC	Global Information System Centers
GPC	Global Producing Centres
GPCC	Global Precipitation Climatology Projects
GTS	WMO's Global Telecommunications System

ICPAC	IGAD (Inter-Governmental Authority on Development) Climate Prediction and Application Centre
ICPT	Abdus Salam International Center for Theoretical Physics in Trieste, Italy
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
NMHS	National Meteorological and Hydrological Services
NMME	North American Multi-Model Ensemble
PRECIS	Providing Regional Climates for Impact Studies
RCC	Regional Climate Centers
RCOF	Regional Climate Outlook Forums
RFE	African Rainfall Estimate
RSMC	Regional Specialized Meteorological Centers
SSA	Sub-Saharan Africa
SST	Sea Surface Temperature
SADC-CSC	South African Development Community Climate Services Centre
USAID	United States Agency for International Development
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

EXECUTIVE SUMMARY

African countries are exposed to a range of significant climate-related risks, including variability in water resources, presence of climate-sensitive diseases, and dependence on rain-fed agriculture. As such, there is a critical need for timely information on past, current and future climate monitoring to help inform decision-making across multiple sectors. Yet African populations have historically been underserved in this regard due to a variety of technical, financial, and logistical challenges.

The development of effective climate information services requires access to reliable climate and weather information, in most cases involving National Meteorological and Hydrological Services (NMHS) as key stakeholders. Accurate forecasting depends on a network of global, regional, and national in situ and remote observations of the atmosphere, oceans, and land. Climate and weather observations are also often made by other agencies (e.g., agriculture, aviation, water, and energy power) and increasingly the private sector, but these efforts are not often effectively coordinated. In many parts of Africa data sparsity persists, and coverage is thin and/or declining. A number of factors contribute to this, including difficult/remote geography, a decline in investment in NMHS, as well as conflict and civil unrest.

There is a clear need for investment in meteorological observations in Africa, and given the financial constraints, they must be cost-effective. One approach that may help reduce costs is to combine observations from different instruments and institutions, as well as integrate different datasets at global, regional and national levels. This report explores ways to integrate climate and weather data and forecasts from different sources as well as those from global, regional and national centers. It also reviews challenges to data sharing and communication of climate observations and forecasts and provides guidance on the best opportunities to reduce cost and improve data sharing in Africa.

Key recommendations

- Critical historical data are currently at risk of being lost due to outdated technology and deteriorating data storage capacity. Donors should therefore continue supporting NMHS to rescue these data increase access to it, and maximize the benefits of new investments in observation systems.
- NMHS need to make all efforts to collect, organize and make available climate data collected by other government departments and agencies, as well as private institutions.
- NMHS should strive to make optimum use of climate data from different sources such as combing surface observations and satellite products. In addition to helping to fill temporal and spatial gaps in conventional weather observations, this may also reduce cost of observations.
- NMHS may need to review data sharing policies in the context of a broader discussion on the benefits of climate services for national development. NMHS may contribute more to the national economy if climate data serve the public good rather than seeking to sell basic climate and weather data. Accordingly, governments need to support their NMHS to reduce their dependence on revenue from selling data. NMHS may derive revenue providing specialized data analysis and climate and weather services.
- Regional Climate Centers (RCC) can play a critical role assisting with capacity building, research, and development, including database support and training for NMHS. RCC can also provide data from global centers to NMHS. For example, some global model data are freely available, but it can be challenging for NMHS to directly access international data sources due to technology barriers. Online portals that provide tailored access to global datasets for regional and national scale use are a more cost-effective way of improving data sharing.
- As computing and financial costs for running Global Climate Models (GCMs), or even intermediate length seasonal predictive models, can be prohibitive, African NMHS should work in partnership with regional centers and international collaborators. While modeling and downscaling efforts should be promoted and climate services capacity built within NMHS, doing so should not come at the cost of the data collection and maintenance and shorter-term weather forecasting.

1. INTRODUCTION

1.1. Background

The Intergovernmental Panel on Climate Change (IPCC, 2014) has identified Africa as one of the most vulnerable continents to climate change due to its high exposure to climate stress and low adaptive capacity (i.e., poor infrastructure, limited access to markets, high illiteracy and poverty rates). The impacts from a changing climate are projected to be both far-reaching and spatially variable in Sub-Saharan Africa (SSA). During the last half of the 20th century, most of southern Africa has experienced upward trends in annual mean, maximum, and minimum temperature, with the most significant warming occurring during the last two decades (Cervigni et al., 2015). This changing weather patterns pose a particularly critical threat to African populations given that rain-fed agriculture contributes a significant portion of the national GDP of most countries in the region and provides livelihoods for a large percentage of rural populations -- up to 95 percent in some areas of SSA (Alexandratos and Bruinsma, 2012). . Further, rainfed agriculture tends to be especially important to the extreme poor – who are disproportionally women - and for whom even small changes in inter- or intra-annual rainfall distribution can have devastating impacts. Over the coming decades the situation is likely to be further exacerbated by continuing rapid population growth (United Nations, 2017) and climate change, increasing the need for significant investment in CIS data and services. Failure to adequately address the impacts (and causes of) climate change, especially changes in rainfall patterns, could jeopardize decades of development investments and improvements in livelihood conditions. There is a growing interest in using CIS to strengthen the adaptive capacity of rural communities to reduce their vulnerability to climate change and variability.

CIS encapsulates both the provision of climate and weather information and related advisory services at temporal and spatial scales relevant to a range of stakeholders, including decision-makers at a national (even regional) level and down to smallholder farmers. Successful CIS provide accurate, spatially resolved, daily, ten-day, monthly, and seasonal forecasts and advisories in a timely and accessible manner, as well as historical trends and monitoring products. CIS are important because they address the immediate needs of agricultural communities (e.g., what will happen tomorrow and what will this rainy season be like), while also building the foundation of national and regional information systems to support adaptation to longer-term and larger-magnitude climate shifts. CIS is also essential for insurance products tailored to the needs of small farmers which pay based on defined weather events (e.g., lack of rainfall). Insurance can facilitate access to credit allowing farmers to invest in measures that may improve productivity.

The development of effective CIS requires access to reliable climate and weather information, in most cases involving National Meteorological and Hydrological Services (NMHS) as key stakeholders. NMHS commonly serve a national mandate to observe, forecast, and issue warnings for pending weather, climate and water threats. Accurate forecasting depends on a network of global, regional, and national remote and in situ observations of the atmosphere, oceans, and land that are conducted by NMHS with multiple partners. Climate and weather observations are also often made by other agencies (e.g., agriculture, aviation, water, and energy power) and increasingly the private sector, but and these efforts are not often effectively coordinated. In many African countries, this results in an absence of timely and reliable local weather forecasts. Yet there has been limited research evaluating and synthesizing knowledge that can lead to sustainable CIS models and systems.

1.2. Assessing Sustainability and Effectiveness of Climate Information Services in Africa Project

In light of the needs for reliable, timely, and accurate CIS in Africa, the USAID-funded "Assessing Sustainability and Effectiveness of Climate Information Services (CIS) in Africa" (Sustainable CIS project) program has been designed to conduct research to better understand how to design and implement sustainable CIS models within and alongside NMHS. The project is being implemented by a consortium led by Winrock International, with the International Research Institute for Climate and Society (IRI), the Climate System Analysis Group (CSAG), the AGRHYMET Regional Center, and the Global Framework for Climate Services (GFCS)[1] as partners. The project objective is to develop models and options for the sustainable delivery of CIS in SSA, and to consolidate and extend knowledge on existing CIS in SSA. These project outputs are geared toward identifying and improving existing CIS programs provided by the public and private sectors, as well as to design and assess potential new CIS not yet implemented, but are promising options relevant to local contexts.

The project has three work streams:

1.) Sustainability assessment. This includes the development of metrics to assess effectiveness and sustainability of NMHS to deliver CIS, with a baseline assessment of select NMHS, and advice on how to bridge existing gaps.
2.) Identification of options to improve the sustainability of CIS. This includes an assessment of the market for CIS in SSA, private sector models that participate in CIS, and development of sustainable financial models for CIS delivery in SSA.
3.) Partnership building, synthesis, sharing and uptake of knowledge and lessons learned.

This report is part of the second work stream to identify options to improve sustainability of CIS. It includes some global data and examples but focuses primarily on SSA.

1.3. Report Objectives and methodology

The objective of this paper is to address three specific questions:

- What datasets, data sources, and techniques can be used in combination to overcome climate and weather observation gaps for SSA?
- What conditions improve dataset exchanges and communication between institutions?
- How can weather and climate forecasts at national and regional levels be harmonized in a more cost-effective manner?

[1] GFCS is a global partnership of the World Meteorological Organization (WMO) with the UN International Strategy for Disaster Reduction, the World Health Organization, the World Food Programme, the Food and Agriculture Organization of the UN, and others.

This paper was produced through a desk study of peer reviewed and grey literature, as well as the solicitation of expert opinions from project staff who offer many years of combined experience in these topic areas.

2. COMBINING DIFFERENT DATASETS TO OVERCOME OBSERVATION GAPS

2.1. Current status of climate observation in SSA

A primary source of climate observations is the NMHS observation network in each country whose data come mainly from conventional observation stations (synoptic, climatological, agrometeorological and rainfall stations). The main strength of station observations is that they represent the "true" measurements of the climate variable of interest. However, in many parts of SSA, data sparsity persists and coverage is thin and/or declining (Washington et al, 2006). This is exemplified in Figure 1, which compares station observations over Africa with those over other regions that are submitted to the World Meteorological Organization (WMO) during the Annual Global Monitoring (AGM) survey. Comparing the percentage of climate data reports received by the WMO across different regions during 2004-2017 with the number of reports required by the WMO, it is clear that Africa falls behind all regions and has failed to submit even half of the requirement for most of the years.. More worrying is that this includes South Africa, where the density of stations is significantly higher than those of other countries, skewing the average upward.

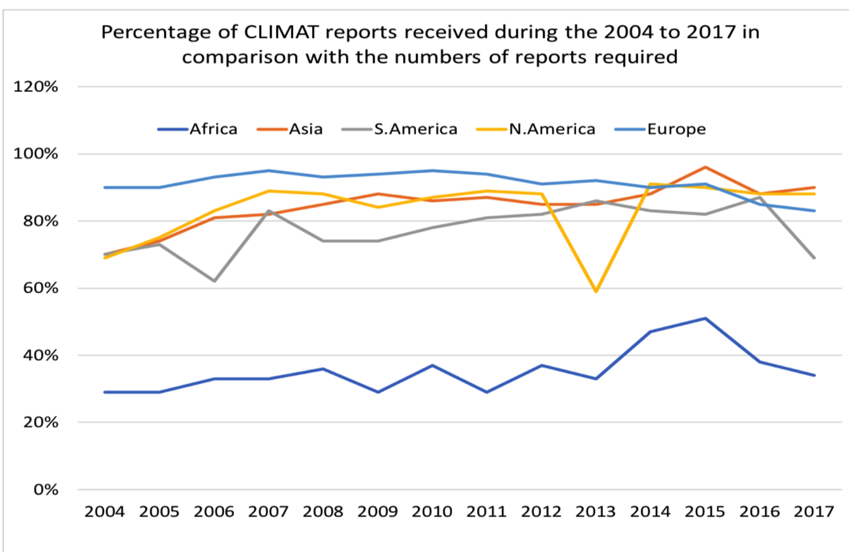


Figure 1. Percentage of minimum required reports from regional climatological networks achieved by region (Adopted from WMO's Annual Global Monitoring report, 2017).

2.2. Factors Contributing to the Scarcity of Climate Data in Africa

A number of factors contribute to the sparse station network and decline in the number weather stations over many parts of Africa. These include difficult geography, decline in NMHS and different conflicts and civil unrest.

Difficult geography and terrain contribute to the sparse distribution of the observation networks in many parts of the continent, as shown in Figure 2. Mountains, forest, and desert make installation and maintenance difficult, limiting the number of observation stations outside of cities and towns. For example, both the Sahara Desert and the Congo River Basin with its dense forest lack meaningful density of reporting stations. In addition, poor road access outside major cities and towns limits the number of stations in rural areas.

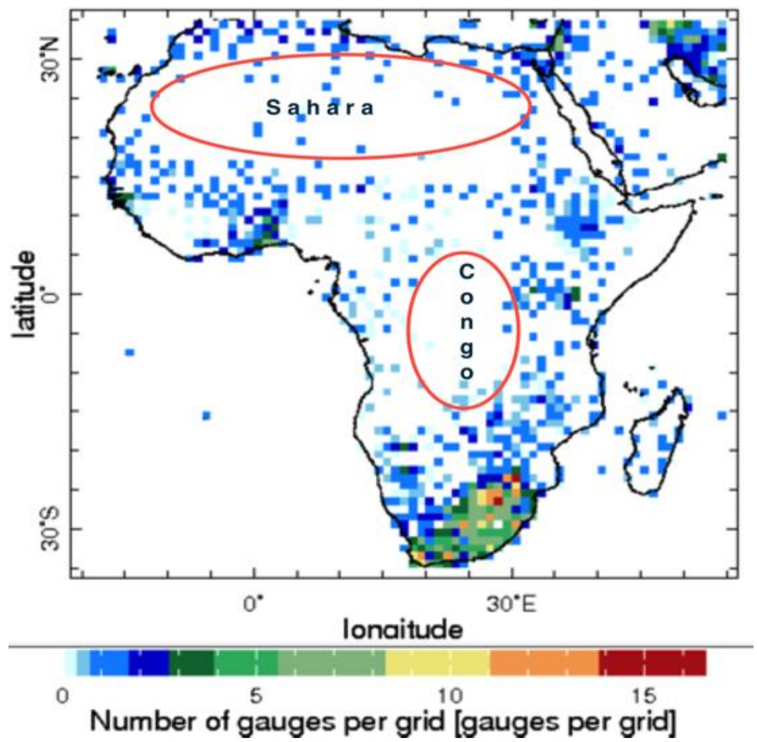


Figure 2. The average number of stations per 10,000 square km contributing to the widely used gridded rainfall product from the Global Precipitation Climatology Projects (GPCC; Becker et al 2013).

Lack of investment in climate infrastructure has also been a major impediment to the collection of climate data for many African countries. For example, in the 30 years from 1971-2001, the average number of stations from which the National Meteorological Agency of Madagascar was reporting declined from over 400 to under 50 (Figure 3).

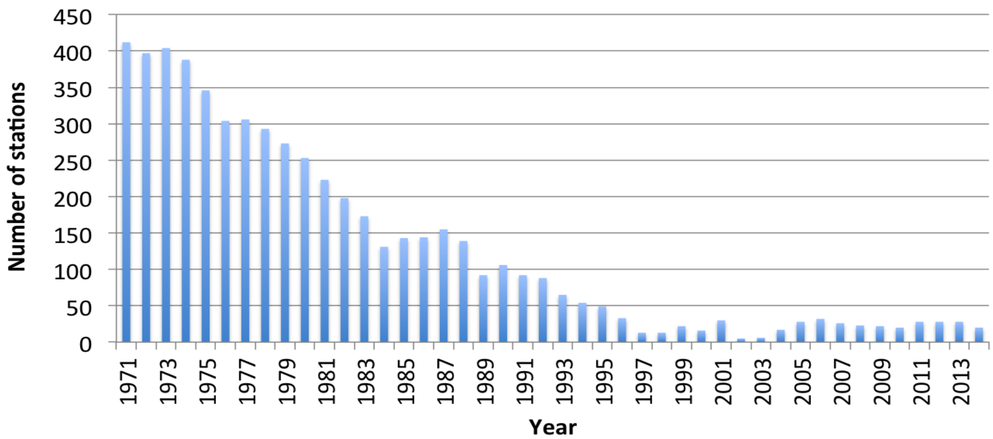


Figure 3. Average number of reporting weather stations in Madagascar during the 1971-2014 period (Data Source: Direction General de Meteorology, Madagascar).

Conflict or political upheavals can also result in the disruption of observation networks. Following the 1994 genocide in Rwanda, the meteorological observation network was devastated and took nearly 15-years to return to the pre-genocide level (Figure 4). These are data lost forever and these gaps are problematic when attempting to analyze past patterns and project future long-term trends.

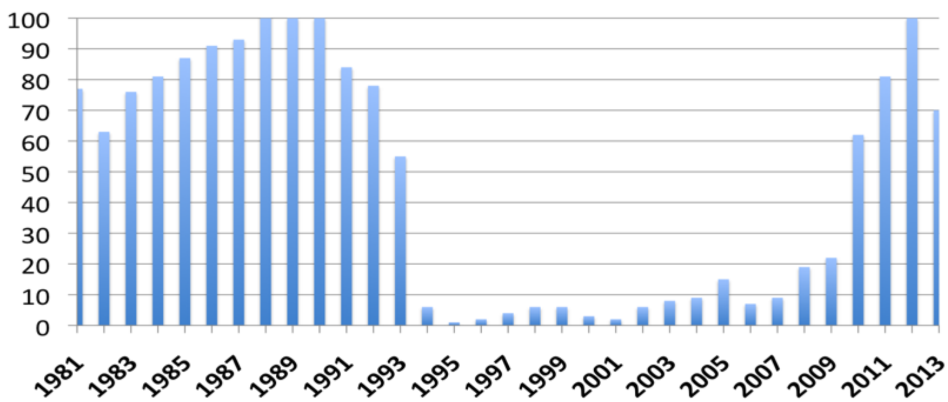


Figure 4. Average number of reporting weather stations in Rwanda during 1981 to 2013. Note the drastic drop in 1994. (Data obtained from Meteo Rwanda)

2.2.1. The Introduction of Automatic Weather Stations

In recent years, some NMHS in Africa have installed automatic weather stations. However, data from these stations are not yet being fully exploited or processed due to lack of technical capacity. Further, the quality of the data from these automatic weather stations must be closely examined for integration into NMHS climate database management systems.

2.2.2. Making best use of all existing climate data

Data rescue is critical to preserve that which is currently in danger of being lost due to deteriorating mediums and increase ease of access. Data rescue needs are still major challenges to data availability and use and should be a priority for maximizing benefits of new investments in observing systems. Renovating stations that once gathered data but are out of commission currently would also allow archived data to be used in combination with new data.

Government departments and agencies aside from NMHS, as well as private institutions often maintain some meteorological observation networks, though usually only operated for short periods. Sometimes these stations are maintained in collaboration with the NMHS, but in many instances NMHS do not have access to observation data collected by other organizations. If NMH data are missing or absent, as can often occur in fragile states, local non-governmental organizations focused on farming or conservation, for example, may have historical records of rainfall and temperature that can be shared. Thus, NMHS need to make efforts to collect, organize and use data from these other sources. However, given the same standards required by the NMHS are not always applied, the quality of these data must be carefully considered (Mason et al, 2015).

Because they are often reliant on human observers, station measurements are prone to human, instrumental and other measurement errors. Station data received from NMHS may be of high or low quality depending on the quality control methods in place, and thus data quality control is a critical component of all data processing and analysis. Station observations must undergo a comprehensive quality check procedure involving checking, and whenever possible, fixing erroneous observations and erroneous coordinates, as well as checking and fixing inhomogeneities in station time series. This is challenging and time-consuming, yet very important for ensuring data quality.

2.3 Other sources of climate data

A brief summary of climate data sources is provided below. For a more in-depth description of the data sources and their strengths and weaknesses, please see the report on combinations of technologies for weather observation, storage and analysis (Siebert et al., 2018).

2.3.1. Weather Radars

Some NMHS in Africa have weather radar, which are mainly used by forecasters to track the evolution of storm systems over time and monitor severe weather events. Following the storm/event, weather radar data are then stored and no longer used, and sometimes disposed of. However, these weather radar data should also be used to improve weather observation by combining with weather station data using suitable methods.

2.3.2. Satellite rainfall estimates

Satellite estimates are derived from measurements taken by satellite sensors that estimate climate variables such as rainfall, temperature, wind, cloud type and properties, and atmospheric water vapor. Rainfall is the most widely used climate variable derived from satellite measurements, though they generally incorporate observations to adjust satellite rainfall estimates for bias errors. Satellite estimates offer complete global coverage, improved temporal and spatial resolution, and data are freely available from different centers, making them an important resource for NMHS.

Several satellite-based rainfall products are available that provide over 30 years of rainfall time series including the Global Precipitation Climatology Project (GPCP, Adler et al., 2003), African Rainfall Climatology version 2 (ARC2, Novella and Thiaw, 2013), and the Tropical Applications of

Meteorology using SATellite and ground-based observations (TAMSAT) rainfall estimate (Maidment et al. 2014). The ARC and TAMSAT products are available only over Africa. There are also relatively new satellite-based rainfall products with good spatial (0.05° latitude/longitude) and temporal (daily, pentad, and dekadal) resolution, as well as quasi-global coverage (50°S-50°N). These are the Climate Hazards Group Infrared Precipitation (CHIRP) and CHIRP combined with station data (CHIRPS) from the University of California at Santa Barbara and US Geological Survey (Funk et al., 2015). Most of these products could be accessed either directly from the producers of the products or global data portals such as the IRI Data Library(http://iridl.ldeo.columbia.edu/)

Yet satellite observations have several shortcomings, including accuracy, short time series (except for rainfall), coarse spatial resolutions for some of the variables, temporal heterogeneity, and limited climate variables. Accuracy can be improved in some instances by ground-truthing with station observations, or using more observations where available, though this is more difficult in data sparse areas. In the past few years, several studies have been conducted to evaluate the accuracy of satellite rainfall estimates over different regions of Africa (Dinku et al., 2008; Hirpa et al., 2010; Romilly and Gebremichael, 2011; Young et al., 2014; Maidment et al., 2014; Diem et al., 2015; Awange et al., 2016; Maidment et al., 2017; Dinku et al., 2018). The results have shown that overall, progress has been made in terms of the quality and the exploitability of those data, which allow their potential use over SSA, although rainfall detection is less accurate over mountainous areas with high relief and complex terrain.

2.3.3. Climate Model Reanalysis Products

Data assimilation or reanalysis is the process by which observational data are combined with a physics-based climate model to produce gridded time series data, including for data sparse regions[2]. Reanalysis can produce long time series (i.e., several decades or longer) of hundreds of climate variables at global coverage (Parker, 2016). Information generated through reanalysis is also freely available from different centers, offering an important source of data for investigating the climate in Africa where stations are sparse. It is shown that reanalysis datasets reproduce the long-term record in the instrumental data with good accuracy, and in regions where the station density is high, the performance of reanalysis data is considerably better, as it is produced by combining models with past meteorological observations.

The great advantage of reanalysis data is that it provides better spatial and temporal coverage. Reanalysis data are available at 3 or 6-hour intervals and production can extend back as far as 1948. However, reanalysis data sets also suffer from several weaknesses, including reliability (due to reliance on observations and imperfect models), artificial variability and spurious trends (due to the varying number of observations assimilated over time), and coarse spatial resolution (>50km). Model correction is necessary to account for the weak representation of local climate variations that result from the influence of local factors that the coarse resolution analyses cannot capture, such as orography. Reanalysis data can then be downscaled to a very fine resolution.

[2] For information on Reanalysis may be found at http://reanalyses.org/ and https://climatedataguide.ucar.edu/climate-data/atmospheric-reanalysis-overview-comparison-tables

2.4. Combining station measurements with proxies

2.4.1. The case for merged data

It is widely recognized that the station observations can provide more accurate measurements at or very close to the location of the stations. However, uncertainty from gauges increases when the measurement is extrapolated beyond station locations. This limitation of station observation can be much worse over difficult geography and terrain such as desert, forest, or mountains where the observation network is generally sparse. Satellite rainfall estimates provide an alternative for precipitation measurements for regions where ground observations are limited or not available. A range of satellite-based rainfall products have been developed during the past three decades. However, without direct reference to ground-based measurements, satellite rainfall estimates are subject to systematic bias. Several methods have been tested and used for combining data from different sources over the last two decades, particularly from point measurements (stations) and gridded data (satellite, radar and reanalysis data). Most satellite rainfall estimation methods do blend satellite rainfall data with station measurements and these include the Climate Hazards Group Infrared Precipitation with Station (CHIRPS), the African Rainfall Estimate (RFE), the African Rainfall Climatology (ARC), among others. However, many global centers can only access limited number of station data from NMHS in Africa, making these improvements in blended products more limited for the region.

CHIRPS could be the exception, in that it was able to access many more stations relative to other similar products, yet the number of stations used in CHIRPS has been declining steadily over many parts of Africa (Figure 5).

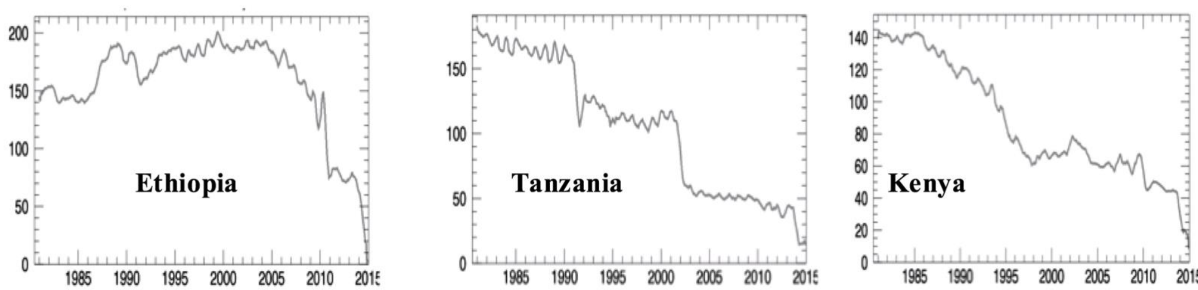


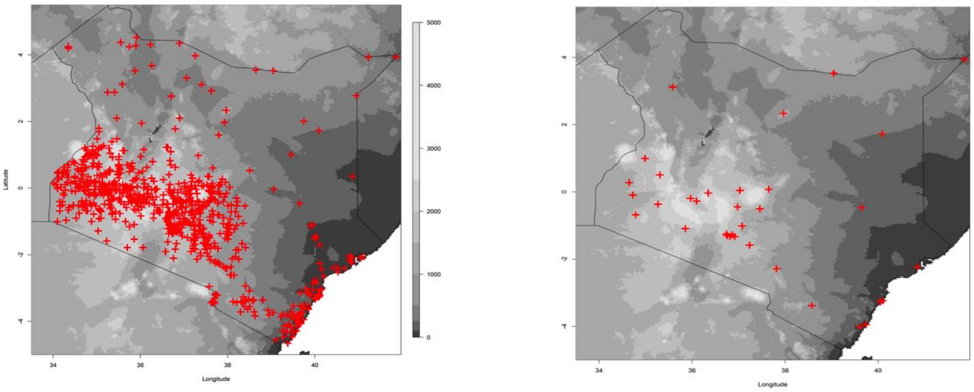
Figure 5. Number of stations used in monthly CHIRPS product over Ethiopia, Tanzania and Kenya for the month of July (Funk et al, 2015)

2.4.2. The ENACTS approach

The ENACTS (Enhancing National Climate Services)[3] initiative lead by IRI overcomes the challenge of accessing station data by directly working with NMHS in Africa (Dinku et al. 2014, 2016, 2017). The approach works with NMHS to improve the availability of climate data by both organizing and instituting quality control measures on all available national observation networks and combines these data with data from proxies such as satellite estimates for rainfall, digital elevation models, and reanalysis products for temperature. By working directly with NMHS, the ENACTS approach has been able to access and use many more stations than globally available.

[3] https://iri.columbia.edu/resources/enacts/

Figure 6 shows an example of stations made available for use in ENACTS dataset compared to those available globally through WMO's Global Telecommunications System (GTS).



Rainfall Stations used in ENACTS

Rainfall Stations available globally

Figure 6. Comparison of stations made available to ENACTS (left) to those made available through WMO's Global Telecommunications System (left).

The first step taken through the ENACTS is a comprehensive quality check procedure of station observations. This process involves checking, and whenever possible fixing, erroneous observations and erroneous station coordinates. The quality-controlled station data are then combined with satellite rainfall estimates (for rainfall) or reanalysis proxies (for temperature). Reanalysis products are climate data generated by systematically combining climate observations (analyses) with climate model forecasts using data assimilation schemes and climate models. The main advantages of these proxies are that they: (i) offer spatially complete data; (ii) are freely available; (iii) have a relatively long time series of 30+ years for satellite rainfall products and 50+ years for reanalysis products, thus providing broader coverage over a longer time-frame at a lower cost.

The method has been applied in several African countries and has resulted in the production of climatologies at relatively high temporal and spatial resolutions that simultaneously improve the observed data sets. In addition, new observations are automatically added to the data record. While the approach requires time, technical expertise, and resources, once it is in place it can be updated in real time. Figure 7 shows an example where data from about 30 stations over Zambia are combined with satellite-only products, resulting a merged product that overcomes the weaknesses of the two inputs (i.e., the station network is sparse and the satellite underestimates rainfall amounts).

The final products are datasets with 30 or more years of rainfall and temperature time series for every 4km grid across a country at daily or 10-day and monthly timescales. While the quality of the final products is inevitably dependent on the number, spatial distribution, and quality of the station observations, the result is a great improvement over what was previously available. ENACTS has thus far been implemented in 12 countries (Ethiopia, Gambia, Ghana, Kenya, Madagascar, Malawi, Mali, Rwanda, Tanzania, Senegal, Uganda, and Zambia) and two Regional Climate Centers (ICAPC and AGRHYMET).

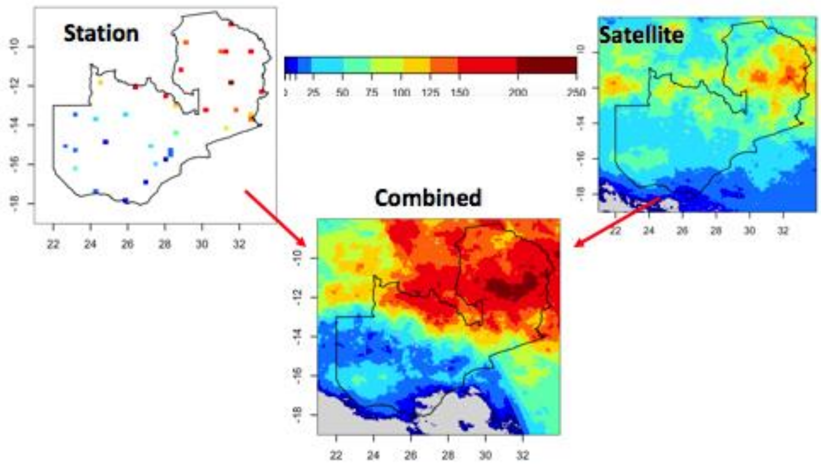


Figure 7. Station observation (top left), satellite estimate (top right) and merged product (bottom) of rainfall over Zambia.

2.4.3. Comparison of some data products

The different products and sources of data presented above have their own strengths and weakness. Table 1 summarizes the strengths and weakness of the different datasets. The main strength of station data is that they are actual measurements, while the strength of satellite and reanalysis products is their spatial coverage and the fact that most of these data they are free available. The main strength of ENACTS data products are the fact that they combine the strengths of station observations with that of global data products (satellite and reanalysis).

Table 1. Summary of some source of climate data and data products

Data source	Strength	Weakness
Station Observations	- Actual measurement	- Represented limited area - Limited coverage and access - Missing data and quality issues - May not be freely available
Model Reanalysis	- Global coverage - Multiple variables - Long time series - Freely available - Gridded format that makes it easier to use in GIS environment	- Poor accuracy - Quality depends on observations - Use requires access to the Internet and some skills
Satellite Estimates	- Near global coverage - Good resolutions - Freely available - Gridded format that makes it easier to use in GIS environment	- Poor accuracy (particularly at high resolutions) - Limited variables - Short time series - Use requires access to the Internet and some skills
ENACTS	- National ownership - Better accuracy - Good spatial resolution - Gridded format	- Limited variables (rainfall, temperature) - Quality depends on observations - Requires time and skills to develop - Availability depends on NMHS data policy

To provide some insight into the relative qualities of the different products, Figure 8 compares monthly rainfall amounts over central Ethiopia from the different data sources (station, satellite, reanalysis, and merged (ENACTS)). To use the best possible reference data, the comparison is done over a relatively data-rich part of Ethiopia containing about 170 rain gauges. The ENACTS product is created with data from very few (about 80 for the whole country) operational stations. It could be seen that the quality of the ENACTS product is much better than other existing products. The satellite product underestimates rainfall amounts while the reanalysis exhibits a large overestimation. However, there is a general agreement among all the products at a monthly time scale and over a large area and the results will likely not be as good if compared at higher spatial and temporal resolutions. This comparison demonstrates the differences among the evaluated products, while also showing that multiple sources of information can be used to understand and define the uncertainty associated with a particular variable. More rigorous evaluations would be needed to better understand the qualities of the different data types over different parts of the world.

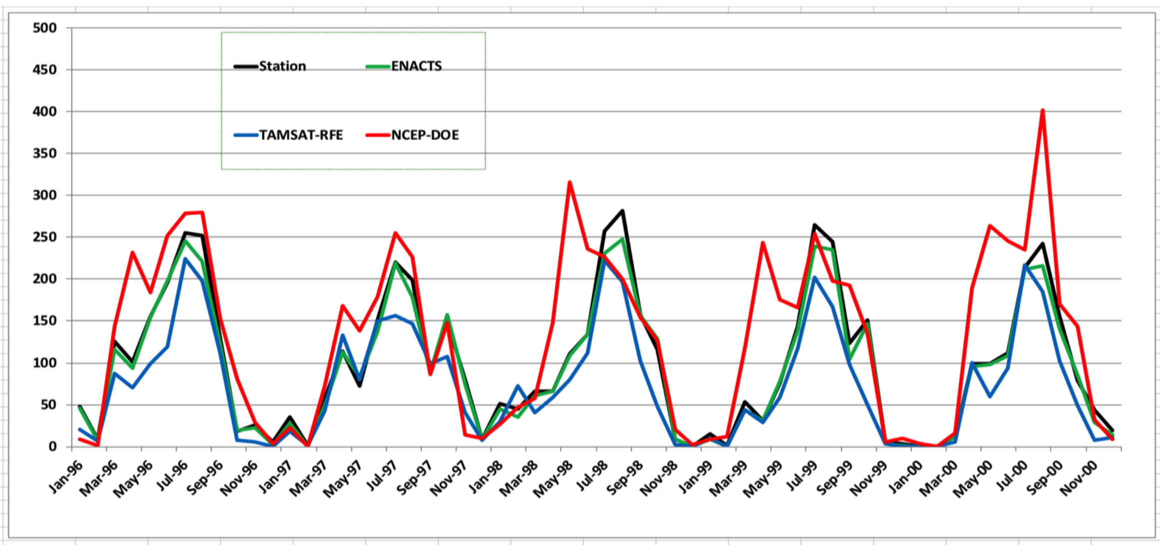


Figure 8. Comparison of monthly totals of satellite rainfall estimate (TAMSAT), model reanalysis product (NCEP-DOE) and ENACTS with station observations. The comparison is done for a 3° X 3° box over central part of Ethiopia containing about 170 rain gauges. The merged product is created by combing satellite data with about 80 operational stations while the gridded product includes some stations from both the 170-station and 80-station sets.

3. DATA SHARING AND EXCHANGE

3.1. Frameworks and flows for data sharing

The availability and accessibility of climate information are both critical to the successful provision of climate services, as described in the requirements for the Global Framework for Climate Services

(Hewitt et al, 2012). Although technological barriers are most often the focus of efforts to improve data sharing throughout SSA and beyond, policy and legal barriers are also critical considerations.

Structural frameworks for data sharing are effective for addressing the legal implications of sharing, in addition to technical considerations. Contreras and Reichman (2105) describe a range of frameworks based on their degree of centralization. When *fully centralized* all data are managed in one repository. An *intermediate distributed* framework includes multiple data repositories that are all interconnected (e.g. via a web portal) and have shared technical and data structures. *Fully distributed* frameworks involve separate data repositories that are not technically connected but operate and allow legal access under common policy arrangements. *Noncommons* are fully distinct databases without any common legal or technical framework, and therefore sharing may be limited to common catalog of variables. The relative benefits and costs to the four framework models as described in Table 2 highlight that a balance can be struck between the potential enhanced value of data in more centralized structures and the lower costs and resource needs for less centralized structures. These frameworks are also compatible with the prohibitive, constrained, and permissive systems as described in the CIS Market Assessment and Business Model Review Report(Usher et al., 2018). Furthermore, it is worth noting that when more data is freely available, for example when legally mandated to exceed WMO policies, there is a greater incentive to develop the technology to access and share the data, such as an online portal and vice versa.

Table 2. From Contreras and Reichman (2015).

Structural models for scientific data pools

Data-sharing options

BENEFITS AND COSTS	CENTRALIZED	INTERMEDIATE DISTRIBUTED	FULLY DISTRIBUTED	NONCOMMONS
Incremental research benefits				
Data access	Access to all data in unified manner	Access to multiple repositories through central portal	Access to each repository separately, but under a common usage/access policy and single approval	Ad hoc coordination with other repositories only
Data analytics	Most powerful search, analysis, quality assurance of aggregated data	Cross-repository searching and analytics; Metadata and aggregate statistics can be developed by central authority	Index/catalog only	Index/catalog only
Costs				
Up-front costs	Structure and build centralized repository; Develop data interoperability mechanisms; Develop common usage policy	Develop data interoperability mechanisms; Develop common usage policy	Develop common usage policy	Few up-front costs
Ongoing centralized costs	Operating and maintaining central repository; administering policies	Operating and maintaining portal; administering policies	Administering policies	No central costs
Ongoing distributed costs	Few distributed costs	Operating and maintaining repositories	Operating and maintaining repositories	Operating and maintaining repositories
Governance overhead	Central repository	Central portal/services, each distributed repository, and interrelationships	Each distributed repository and interrelationships	Each distributed repository with minimal coordination

WMO sets out specific policies for the sharing of meteorological and climate data through Resolution 40 of the 12th WMO Congress. The Resolution requires free international exchange of essential data and products, and highly encourages data sharing more broadly, highlighting the importance for safety, economic welfare and environmental protection. WMO policy does allow

NMHS to restrict data for commercial purposes, including limiting use of data to specific situations and charging for data, and climate products.

The WMO's vision for data sharing presented in Figure 9 is also useful to highlight, as flows of information between national, regional, and global scales are critical for optimal provision of climate information services. The following sections will take a closer look at structural frameworks and data networks for CIS provision at each spatial scale.

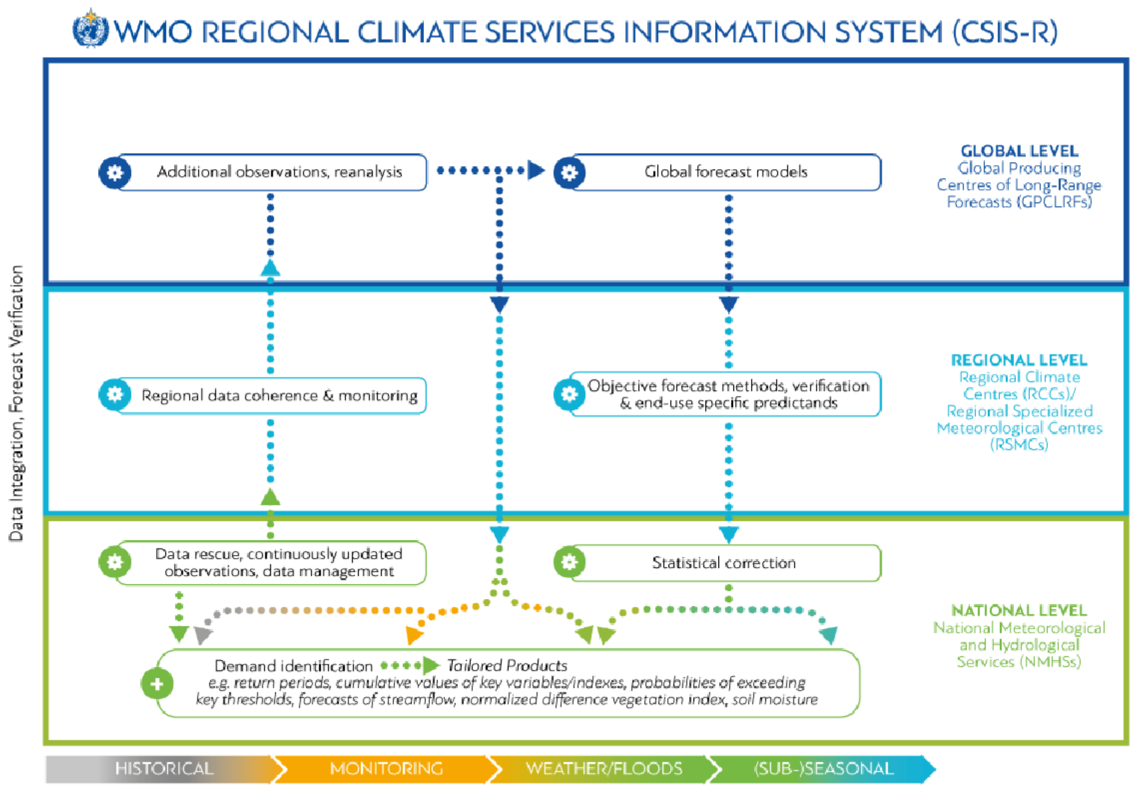


Figure 9. WMO's Regional Climate Services Information System[4].

3.2. Data sharing technologies

There are several technological components required to support dataset exchanges at national, regional and global levels, based on the degree of centralization and required flows of data as described earlier. Some of these can be found on the WMO's webpage of Software Tools [5]. National observation networks must be functional and able to share data and products, requiring computing capabilities for management, organization, and transformation of data must be in place, as well as tools to obtain data inputs. Technical requirements for a data sharing system include metadata catalogues, an internet portal, data acquisition services, services for acquiring, discovering and distributing data, monitoring, as well as data synchronization, back up and administrative issues. Furthermore, the cost-effectiveness of the technology is an important consideration given that the

[4] http://www.wmo.int/pages/prog/wcp/meetings/wmo-gfcs.html
[5] http://www.wmo.int/cst/software-tools

NMHS are mandated to obtain and share national level data are often functioning under considerable resource constraints.

3.2.1. The WMO Information System and Integrated Global Observing System

The WMO delivers on its mandate for data sharing through a comprehensive framework for data management and access called the WMO Information System (WIS)[6]. The foundation of the WIS is the Global Telecommunications System (GTS), a secure communications network transmitting meteorological data in real time to support essential meteorological operations worldwide. The WIS aims to meet all WMO information exchange requirements though standardized information and communications technologies and overcome problems with data incompatibilities and other data sharing challenges. It also supports the need to transmit increasingly large volumes of data, including both more types of data and at finer resolutions. WIS information and products would be available to all NMHS and also national disaster authorities as needed for timely alerts.

WIS is fully integrated at all spatial scales. NMHS provide operational data and products at the national level and regional climate centers and other regional level centers are responsible for metadata catalogues, internet portals, and data access management. Global Information System Centers (GISC) operate as a centralized framework to collect and share data at a global level, including access to all data within the WIS by responding to specific data requests or via a web portal. The flexibility of WMO Resolution 40 allows data policies and responsibilities to be defined as needed.

3.2.2. Examples of Data Sharing Initiatives and Platforms

Technology must be used in line with existing data sharing data policies and laws. However, some of the technology now available can help bypass political barriers, in addition to providing much needed technological solutions to data sharing challenges. One solution for circumventing data sharing obstacles is to provide public access to information products and services derived from the station or other restricted data without allowing access to the original data source itself. Datasets of merged station and remotely sensed data are especially valuable, as they can be useful for both data providers and users.

There are a number of initiatives and platforms across the globe that facilitate the access to and use of diverse climate datasets. The WMO has made efforts to compile and share many of these tools, which can be found at http://www.wmo.int/cst/. Here we will present two the web portals (KNMI Climate explore and IRI Data Library) and one of the initiatives (ENACTS).

The Royal Netherlands Meteorological Institute (KNMI) Climate Explorer[7] is a web application that can be used for access and statistical analysis climate data. It started in late 1999 as a tool for analyses of ENSO and has grown over the years to more than 10 TB of climate data and dozens of analysis tools. It is now part of the WMO Regional Climate Centre at KNMI. The code of the

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6 www.wmo.int/pages/prog/www/WIS/

7 https://climexp.knmi.nl/about.cgi?id=someone@somewhere

Climate Explorer itself is freely available and consists of a set of shell scripts and Fortran programs and runs under Linux and Mac OS X.

The IRI Data Library[8] and Maprooms are a powerful platform for visualizing, analyzing, and transferring data (Blumenthal et al, 2014) and can be classified as an intermediate distributed framework in this context. The Data Library is a collection of datasets and a powerful open-source computational tool and the Maprooms are used to visualize the data in an inactive map viewer, tailored to meet specific user needs. The Data Library simplifies access to many large climate datasets and provides tools for transforming and combining data at local, regional and global scales. Data Library technology has been installed at many NMHS and regional climate centers in SSA and beyond for free. The Data Library includes a content delivery service allowing data to be shared either through a local network (e.g., classroom use) or a wider network (e.g., as a website). Information from the Data Library can also be easily extracted in a wide range of data formats for interoperability with other platforms.

The ENACTS initiative, as described earlier, provides a technological solution to data availability, access, and use that may help to overcome data sharing barriers. ENACTS can enable sharing of derived data and information products without the need to share the raw data. This solution allows the raw data to be kept private at the NMHS in line with existing national data policies, while the derived data and information products generated through the merging of raw station and proxy data, as well as derived products, can then be made freely and widely shared. So far, only few NMHS share ENACTS data freely, while all the NMHS that have implemented ENACTS do share derived climate in formation products freely through web interface (Maprooms). For example ESRI's online interface for Rwanda includes ENACTS data pulled directly from Meteo Rwanda Maproom[9]. In Zambia and Senegal, ENACTS data can also be freely downloaded via the Data Library installed at the NMHS. In Senegal, ENACTS data are now being shared with university partners for research purposes. In other ENACTS countries, such as Rwanda and Tanzania, the NMHS can selectively share data using a password-based Data Library authorization framework.

3.3. Data sharing at different levels

3.3.1. National level data sharing

Within each country there could be multiple institutions managing observation networks, including NHMSs, universities, research institutes and the private sector. As defined earlier, these arrangements are typically *noncommons* in SSA. A common data policy is central to any effort to aggregate data between institutions and the lack of one can be a significant barrier to greater centralization of data. Increased advocacy for collection of third party network data by NMHS using compatible data formats and database technologies allow direct access to shared data from multiple institutions, moving the framework closer to the intermediate distributed framework which is arguably the ideal framework for the national level. This option is most sensible to pursue when resources exist to support the NMHS beyond their regular responsibilities --otherwise there is a risk

[8] http://iridl.ldeo.columbia.edu/
[9] http://maproom.meteorwanda.gov.rw/maproom/

that taking on additional responsibilities may overstretch their resources and compromise their ability to provide critical roles and services prioritized within their existing mandates.

Sharing of NMHS data with other institutions is still quite limited and often includes fees for provision when available (Overpeck, 2011). All NMHS are mandated to share national data via WMO's GTS and Information System as described above, yet that which is made available is typically only a small subset of the full body of data managed by the NMHS. Part of the reticence NMHS have regarding data sharing is a function of mistrust (on the part of the NMHS) of how meteorological data might be used (or misused) without their consent. If private sector or university actors share meteorological data they may become the preferred source of these data, undermining demand for or attention to NMHS products. Further, there is also concern that this could lead to private profiteering at the expense of NMHS. In other cases, data restrictions may stem from the lack of resources available within the NMHS to deliver data. In such a scenario, fees collected to cover the cost of preparing and sharing data with specific users may limit the requests for data in general.

While these concerns and barriers are important, legal and contractual approaches may allow for NMHS data to be available to a wider range of third parties while protecting the interests of the NMHS and simultaneously facilitating the provision of additional climate adaptive services through university, research center and private sector engagement.

Another key consideration is that most NMHS have either a mandate (or at least an aspiration) to support climate services as well as raw climate information and forecasts. There are many tools and applications that could be developed in collaboration by the NMHS and other organizations (e.g., cessation and water balance Maproom functions hosted by Meteo Rwanda). Such specialized tools and applications cannot be created without disclosure of NMHS data to partner organizations. Assessment of the optimal data sharing structure for each individual country also must match technological and financial needs with available resources, for which the degree of framework centralization provides a useful reference.

3.3.2. Regional level data sharing

NMHS are also mandated to share data with regional centers, which are well placed to maintain regional data banks, including availing national data for regional use. Current regional centers for climate information in Africa include ACMAD (African Centre of Meteorological Application for Development) at continental level, ICPAC (IGAD (Inter-Governmental Authority on Development) Climate Prediction and Application Centre) for the Greater Horn of Africa, SADC-CSC (South African Development Community Climate Services Centre) for Southern Africa, and the AGRHYMET Center for West Africa. WMO is promoting the establishment of official WMO Regional Climate Centers (RCCs), ("Regional Climate Centres Implementation in Africa," World Climate Services Programme, Climate Applications and Services, WMO Extranet, 2017) and RCC-Networks at the regional centers listed above, including a pan-Africa coordinating role for ACMAD.

RCCs aim to support WMO member states in providing climate services. The criteria for RCC[10] includes not only climate service products but also requirements for producing regional quality

[10] http://www.wmo.int/pages/prog/wcp/wcasp/rcc/rcc.php

controlled climate datasets and maintaining national databases with metadata, accessible to each specific NMHS. RCCs are also encouraged to assist with capacity building, research, and development, including database support and training at the national level for both operational and non-operational data services. This *intermediate distributed* framework hits a theoretical sweet spot by providing access to multiple data repositories through a central portal but with lowered costs and governance overhead than a fully centralized database structure. Online portals such as these can simplify centralized administration and allow users to access and analyze data from many separate sources or repositories.

Regional sharing of seasonal climate information also occurs at Regional Climate Outlook Forums (RCOFs), facilitated by WMO. RCOFs bring together climate experts from national, regional, and global levels with climate services users and policy makers to produce seasonal climate outlooks, tailoring them to specific user needs. These regular forums provide an opportunity to generate and strengthen networks between those supplying and using climate information across the spectrum of spatial scales and sectors. The forums also build technical skills, including those relevant for data sharing. The need for new climate services (and therefore also new data requirements) is also shared at these events which have been ongoing regionally across Africa since 1997.

Global data can also be provided by regional centers for regional or national level use. For example, some global model data are freely available (e.g., model outputs from the GPCs and NMME), but access to this data directly from international sources can be challenging due to technology barriers such as database size, format, and ease of access online. Online portals may lower these barriers by providing tailored access to global datasets and offer a cost-effective way of improving data sharing. One such example is the portal at ICPAC which provides access to international climate models via the IRI Data Library and Maprooms[11].

3.3.3. Global level data sharing

WMO's Information System and WIGOS (as described above) are used for data sharing at the global level. These communications and data management platforms enable the global exchange of data for CIS in accordance with WMO's Resolution 40 on data sharing. These data can be freely accessed from sources outside the country (e.g., IRI's Data Library). Other international entities such as the APEC Climate Center (APCC), ("Climate Information Services, Forecasts, Notice, P.R." APEC Climate Center (APCC), 2015.) and IRI exist outside the formal organization and mandates of the WMO but play similar roles in data sharing as the GPCs and RCCs by providing freely available climate forecasts and products online at the regional and global scale and promoting best practices.

4. HARMONIZATION OF WEATHER/CLIMATE FORECASTS AT NATIONAL AND REGIONAL LEVELS

4.1 Introduction

11 http://scipea.icpac.net/maproom/index.html

This section explores more efficient ways for integrating climate and weather forecasts from global, regional and national centers. Climate forecasts are regularly provided, mostly free of charge, by different global centers. Regional climate centers also run climate models, but mostly to downscale to regional level at higher spatial resolution. Some NMHS have started their own downscaling activities, as well as some other institutions. This section will explore different approaches for maximizing the benefits from the activities at the different levels.

4.2. Products that could be integrated into a climate risk management framework

4.2.1. At the global level

The climate science literature shows that patterns of SST, especially in the tropical oceans, have a significant impact on patterns of rainfall, particularly in the tropics (including most of Africa). While some of the precipitation that falls in SSA as well as Mediterranean and North African countries can be characterized as mid-latitude frontal precipitation (particularly in winter months), most of the rainfall on the continent is driven by tropical convective processes. Since the tropical ocean and atmosphere operate as a closely coupled system, patterns of sea surface temperature and pressure gradient and sea-land temperature and pressure gradients directly drive horizontal and vertical wind patterns and moisture advection which are responsible for weather patterns.

While the most dominant signal in the global tropics is the El Nino-Southern Oscillation phenomenon, other important processes and oscillations, such as the Indian Ocean Dipole and the Atlantic Dipole, contribute to climatic variability on interannual to decadal time scales. Global climate modeling centers produce projections of a wide range of atmospheric and oceanic variables on a range of time scales and other modeling centers focus less on long term climate change and more on short-term climate variability (such as the European Center for Medium Range Weather Forecasting (ECMWF).

As no individual model-based approach to seasonal forecasting provides the optimum range of information for all parts of Africa, seasons, and timeframes, exploring the output of multiple models and multi-model ensemble forecasts may prove advantageous at a regional level, provided that skill and variability are properly addressed. For long-term climate sensitive decisions (such as citing infrastructure and development investment), it is critical to consider the role of anthropogenic climate change. Here again, global climate models can give insight on expected impacts, such as rising sea levels and reduction of mountain glaciers.

Most of the products are available from many sources at a global level and play a vital role in making region-specific or national-level forecasts. Understanding projected patterns of sea surface temperature and wind anomalies can help NMHS anticipate the timing and strength of monsoonal rains and model-based projections of variables other than rainfall can help inform other adaptive actions. Longer-term global climate model data, available from various portals, can help NMHS and regional institutions anticipate evolving climate risks on longer time horizons (e.g., multiple decades).

4.2.2. At the regional level

Products available at the regional level include:

a.) Downscaled GCM and/or RCM information (e.g., WRF)
b.) Statistically-based forecast information from SST forcing

Regional and continental climate analysis centers within Africa (such as ICPAC, AGRHYMET, SADC-CSC and ACMAD) often have modeling or model interpretation capacities that are more robust than individual national meteorological services. These capacities are often built on international collaboration with global initiatives, funders and make extensive use of global climate model output (emanating primarily from modeling centers in North America, Europe and Asia).

Regional and continental analysis centers may have the personnel and computational/budgetary resources to do statistical downscaling of Global Climate model output to more specific geographic domains and/or to run dynamically downscaled regional climate models (such as WRF) forced with boundary conditions. Additionally, regional climate analysis centers may be able to provide historical statistical relationships between various patterns of sea surface temperature anomaly and regional rainfall. This type of information may be of use both at a national and regional level. To the degree that such modeling/forecasting efforts can be done and verified at such modeling centers, it is in the interest of regional climate services to do so.

4.2.3. At the national and subnational level

Products available at the national and subnational level include:
a.) Further downscaled GCM data and/or RCM data
b.) Statistically based forecast information from SST forcing
c.) If/when data sharing is initiated, forecast information from neighboring countries

Throughout much of Africa, the NMHS are responsible for maintaining a network of weather observations, including ground stations and rawinsonde equipment. NMHS typically also do a considerable amount of analysis of remotely sensed observations. While this is critical for monitoring climatic conditions and making daily to weekly weather forecasts, forecasting on a longer time horizon requires input from other modeling and/or forecasting sources. Further statistical and/or dynamical downscaling from the regional level to a national level and further extrapolation of statistical SST forcing may serve this function. Furthermore, understanding the forecasts and observations of climatic conditions in neighboring countries may help and individual NMHS refine forecasts. Training in low cost or free forecasting software (such as the Climate Predictability Tool (CPT) and geoCOF) and familiarity with the IRI Data Library may also be valuable for NMHS seeking to improve capacity.

4.2.4 Optimum use forecasting resources

As computing and financial costs for running GCMs or even intermediate length seasonal predictive models at a global scale can be prohibitive (on the order of at least hundreds of thousands of USD per year), small, budget-constrained African NMHS should work in partnership with regional centers and international collaborators for larger scale modeling efforts. This recommendation does not imply that regional climate centers such as ICPAC or AGRHYMET should try to supplant the role of global modeling centers or national meteorological agencies - rather, it is an acknowledgement that different scales of budget and mandates exist between the various institutions. Regional centers may already have or are able to attract funding to support downscaling efforts and model calibration efforts across their region of interest.

However, if every NMHS seeks to establish a stand-alone downscaling approach for managing GCM output (especially without coordination with neighboring states or regional centers), there is significant potential to duplicate efforts. The most central functions of the NMHS are managing the national observational data network, performing quality control, providing operational weather forecasts, and communicating seasonal climate forecasts. While seasonal climate forecasting, modeling and downscaling efforts should be promoted and climate services capacity built, doing so should not come at the cost of the data collection and maintenance and shorter-term weather forecasting, which are clearly under the mandate of the NMHS alone.

A an example of a more efficient approach is WMO's "Cascading Forecasting Process" project, which aims to ensure that forecast information from Global Data-Processing and Forecasting System (GDPFS) is used effectively in operations by NMHS in developing countries.[12] This project makes GDPFS products available to Regional Specialized Meteorological Centers (RSMC), and the RSMS integrate and synthesize the products to provide daily guidance for NMHS in their geographical region. The primarily focus of the GDPFS is developing automated products, while the role of the RSMC is to combine and synthesize global-scale products, information from other regional centers, and their own limited-area models to provide daily guidance for short-range (1-2 days) and medium range (up to 5 days) high impact meteorological hazards to NMHS within their region of responsibility (Figure 10). The RSMCs also maintain websites and data portals and liaise directly with the NMHS, providing human guidance as needed. This enables the NMHS to focus on producing timely and accurate advisories and warnings.

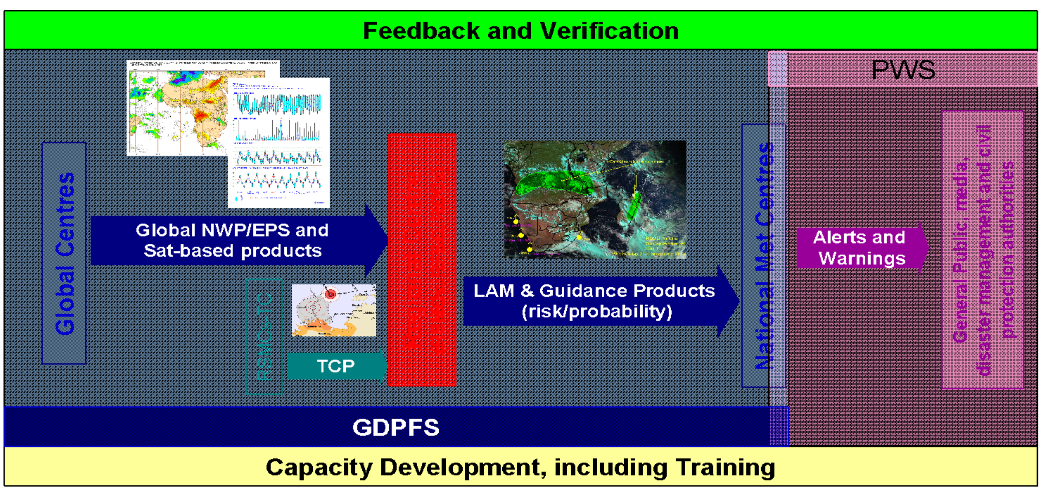

Figure 10. WMO's Cascading Forecasting Process (WMO, 2012).

Another important international effort providing regional climate modeling for developing world application and to foster both "South-South" and "North-South" collaboration is the RegCNET project (Pal et al. 2007) initially led by ICTP (Abdus Salam International Center for Theoretical Physics in Trieste, Italy). Conceived in 2003, this initiative encourages scientists from developing nations to lead and collaborate on international research and helps share computing costs for regional modeling among wealthier partners. The UK Met Office has also created an initiative called PRECIS (Providing Regional Climates for Impact Studies) which is designed to run on a Linux PC so does not have the same computing costs or IT infrastructure requirements of other climate modeling initiatives (Marthews 2014, Mounkaila 2014, Williams 2014).

Amazon Web Services can run WRF as high-performance computing (portability from laptops to the cloud) (Jorissen, 2015). Using cloud computing for various forecasting activities can significantly reduce computational demand in resource constrained environments and expand upon numerical prediction capabilities (Jorrisen, 2015; Molthan et al. 2015). Potentially reduced monetary costs and better resolved modeling of micro-scale features such as microclimatic interactions with topography are among the potential benefits of cloud computing.

Usage of seasonal forecast output information from the IRI Data Library may also be beneficial to many regional and national centers. A great deal of GCM data are also available to the public for free through project portal pages, such as the North American Multi-Model Ensemble (NMME) and the Earth System Grid. Furthermore, there are several "community GCMs" that enable running specialized experiments on laptops around the world and where the main computation is hosted by a well-funded climate modeling center. An example of this is the Community Earth System model hosted at the National Center for Atmospheric Research (NCAR) ("World-Class Research in Earth System Science" National Center For Atmospheric Research, University Corporation for Atmospheric Research (UCAR), 2018) in the US that offers five different component models and enables researchers to conduct their own experiments using NCAR computational resources.

Larger and more climatically complex nations within Africa may have the resources to fund some dynamical downscaling initiatives on their own, but in most cases, dynamical downscaling efforts, GCM and intermediate range modeling efforts will require collaboration with partners at regional centers (such as ICPAC, AGRHYMET and ACMAD) and partnerships with research organizations in Europe and North America.

5. SUMMARY AND RECOMMENDATIONS

African countries are exposed to a range of significant climate-related risks, including variability in water resources, presence of climate-sensitive diseases, and dependence on rain-fed agriculture. To enhance resilience and lower the potential impacts of these risks, it is essential that climate information be used effectively in planning and incorporated routinely into development decisions. This requires the development of robust climate information services, which depend on the availability of timely information on past, current and future climate conditions.

Yet access to reliable climate data is very limited in SSA because weather station coverage is sparse and/or declining over many parts of Africa. This is due to vast remote areas that are difficult to access, a decline in investment in NMHS, and conflicts and civil unrest. Thus, there is a need for investment in improving the availability of, access to, and use of climate data information products. Given financial constraints, these investments need to be cost-effective. One way to reduce cost would be through combination of observation from different instruments, different institutions, as well as integration of datasets at global, regional and national levels. This report explored different approaches for integrating climate and weather data and forecasts across different sources and reviewed challenges with data sharing and communicating climate observations and forecasts. Additionally, the report provided suggestions for approaches that could help reduce costs and highlighted opportunities to improve data sharing.

Key recommendations

- Critical historical data are currently at risk of being lost due to outdated technology and deteriorating data storage capacity. Donors should therefore continue supporting NMHS to rescue these data increase access to it, and maximize the benefits of new investments in observation systems.
- NMHS need to make all efforts to collect, organize and make available climate data collected by other government departments and agencies, as well as private institutions.
- NMHS should strive to make optimum use of climate data from different sources such as combing surface observations and satellite products. In addition to helping to fill temporal and spatial gaps in conventional weather observations, this may also reduce cost of observations.
- NMHS may need to review data sharing policies in the context of a broader discussion on the benefits of climate services for national development. NMHS may contribute more to the national economy if climate data serve the public good rather than seeking to sell basic climate and weather data. Accordingly, governments need to support their NMHS to reduce their dependence on revenue from selling data. NMHS may derive revenue providing specialized data analysis and climate and weather services.
- Regional Climate Centers (RCC) can play a critical role assisting with capacity building, research, and development, including database support and training for NMHS. RCC can also provide data from global centers to NMHS. For example, some global model data are freely available, but it can be challenging for NMHS to directly access international data sources due to technology barriers. Online portals that provide tailored access to global datasets for regional and national scale use are a more cost-effective way of improving data sharing.
- As computing and financial costs for running Global Climate Models (GCMs), or even intermediate length seasonal predictive models, can be prohibitive, African NMHS should work in partnership with regional centers and international collaborators. While modeling and downscaling efforts should be promoted and climate services capacity built within NMHS, doing so should not come at the cost of the data collection and maintenance and shorter-term weather forecasting.

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