Scoping, Options Analysis and Design of a 'Climate Information and Services Programme' for Africa (CIASA):

Literature Review

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CIASA has been renamed WISER - Weather and Climate Information Services for Africa

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Contents

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CLIMATE & ENVIRONMENT
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List of Figures

List of Tables

Executive Summary

DFID is considering a new programme on climate information and services in Sub-Saharan Africa (SSA), building on existing initiatives and a providing a step change in the use of climate information to support poverty reduction and promote socio-economic development.

As part of the scoping for the design of the Climate and Information Services for Africa programme (CIASA), this report provides a short literature review on user needs, gaps and potential intervention options. It adopts the structure of the Global Framework for Climate Services (GFCS, see Section 1) with individual sections on ‘Users’, ‘User Interface Platforms (UIPs)’, ‘Climate Services Information Systems’, ‘Observations and Monitoring’, ‘Research, Modelling and Prediction’ and ‘Capacity Development’. The review identified a number of gaps in climate services, which were then considered alongside other evidence in a synthesis report and for the design of intervention options.

The literature review found that the requirements of users of climate information are demanding relative to current levels of provider capacity in Africa (Section 2, Section 7). Needs are differentiated across a wide range of users working across decision time- and geographic scales (Section 2). Climate services should be reliable in terms of accuracy, robust in terms of operational delivery, relevant in terms of content and format and accessible in terms of channels of communication and language employed. To deliver the best possible climate services, at scales down to sub-national, synthesis of a wide range of information from global, regional and national centres is required together with the means for effective two-way communication. The appropriate operational hardware and expertise, institutional linkages, data exchanges (Section 4) and institutional capacity (Section 7) require development to facilitate this synthesis and a reliable operational service.

Some of the literature reviewed outlined the benefits[1] of investing in climate services:

- A focus on climate risk management and resilience (rather than climate change risks and adaptation) is more appropriate for poverty reduction (e.g. Ambani and Percy, 2014; Hansen et al., 2014); activities that improve the management of weather and climate risks are regarded as ‘low regrets’ adaptations to future climate change as well as offering good value for money (Watkiss and Savage, 2015).
- In particular, there is significant potential for the use of historical and ‘season-to-date’ daily rainfall to provide real-time monitoring and to provide information rapidly that largely illiterate communities can understand and act on (e.g. Tarhule and Lamb, 2003; Cornforth et al., 2013).
- A number of case studies highlight the social and economic benefits of services which have enabled weather and climate information to support communities to prepare for floods and protect lives and livelihoods, undertake health planning and make a range of agricultural decisions, including selection of crop and seed types.
- Investment in strengthening integrated frameworks for risk management offers significant, multiple benefits, for example:

[1] A separate piece of work is ongoing on Value for Money, which will be included in the Business Case. There is limited research published on costs and benefits of investing in meteorological services in Africa. In developed countries cost:benefit ratios of meteorological are reported between 1:2 and 1:6; higher values of 1:10 are reported in Central Asian countries (See Section 8).

- Development of User Interface Platforms should include strengthening of risk management structures at community, sub-national, national and regional levels and can therefore support more inclusive forms of risk governance (Visman, 2014).
- Likewise, where UIPs are developed through existing networks and frameworks, investment in climate services may simultaneously boost key public services, enabling livelihood groups to benefit from the multiple advantages of more accessible agricultural, health, education, DRR and climate information .

The literature review shows that current progress in the development of climate services is variable in different sectors (Section 2), different decision timescales and for important components or links in the GFCS framework (Sections 3-7). The following eight points are important considerations for the design of the CIASA programme (six of these are focused on capacity development in one form or another):

- **Progress in different sectors:** Unsurprisingly progress appears to be greatest in the Food Security and Agriculture sector, with many examples of successful small-scale projects and relatively well developed services generated and disseminated at Regional Climate Outlook Forums. Potential needs include strengthening existing mechanisms, greater integration into wider government frameworks and plans and scaling up of successful pilots. The literature suggests less progress in Health and a significant demand but limited progress in areas like energy and urban infrastructure that were not original priority areas for the GFCS (Section 2).
- **Information for different decision timescales**: While some capacity, with support from regional and global centres, exits for the short (1-5 days) and seasonal (3-6 months) timescales. There are notable gaps in information on the sub-seasonal (~50 day), decadal and multi-decadal timescales. The 50 day timescale is of key importance particularly to the agricultural sector – and has potential to provide valuable information on season onset and cessation timing and frequency of heavy rain and dry spells. A key opportunity here is the WWRP/THORPEX-WCRP research programme on sub-seasonal to seasonal timescales, which includes a dedicated Africa project to investigate sub-seasonal predictability over Africa. There are also key knowledge gaps in predicting changes in the probability and characteristics (intensity, spatial, temporal) of high impact weather and climate events, including the potential for unprecedented events. Finally, the peer-reviewed literature suggests that the overall uptake of climate information for long-term policy making is limited (Jones, 2015, Wise, 2014), although guidance on climate change risks and adaptation has been developed in some sectors, e.g. by the African Ministers Council for Water (AMCOW) and Global Water Partnership (GWP) in the Water sector.
- **Involvement of users:** In order for climate information to inform risk management and adaptation effectively, it is helpful to have it embedded within an institutional system that starts with monitoring of weather and climate events and ends with a community level response (e.g. Srinivasan et al., 2011). As recognised in the GFCS, an effective User Interface Platform and strong involvement of users are essential components of effective climate services (e.g. Challinor and Visman, 2014; Tall, et al., 2014; WMO, 2014c). This suggests that UIP and engagement needs to be extended to sub-national levels to reach the users of climate services and to feedback their requirements to national-regional-global ‘producers’ of services (e.g. Ambani and Percy, 2014; Visman et al. 2012b).
- **Capacity**: Many African National Meteorological and Hydrological Services (NMHSs) are currently able to provide only very basic climate services. There is therefore a need to develop greater capacity. There is also a need for NMHSs to develop links with global and regional centres to fill gaps in service provision; however, this in itself

requires capacity that is not available in many countries. Some African regional organisations and initiatives are providing support to NMHSs by providing rendered products for onward dissemination. However, the regional organisations themselves are not currently reaching minimum standards required by WMO. Poor NMHS capacity can lead to low organisational reputation – which further inhibits user trust and uptake of services – and can lead to lack of the necessary interactions/relationships to develop user-led services. Some recent initiatives have worked to strengthen the capacity of the regional organisations (e.g. ISACIP) however the impact is not yet fully quantified. There have been few coordinated efforts to strengthen national capabilities – though these are increasing (e.g. ENACTS, BRACED, StARCK+) and, where implemented, appear to be having a positive effect on user uptake of some services. Nevertheless, even in such instances, the resources provided to support NMHSs are quite limited in comparison to the amount invested in adaptation funds and initiatives, while these efforts are themselves reliant on reliable, relevant climate information. There is a clear need to invest in the structures and capacities required to develop climate information which can support appropriate resilience building and adaptation.

- **Institutional linkages**: Specific activities to support climate services in Africa, coordinated across global, regional and national centres, are most developed for the seasonal prediction activity. Coordination includes operational commitments on global centres to provide forecast guidance out to 3-months ahead to regional centres and NMHSs. However, the data exchanges are not yet optimal – with NMHSs requiring operational data feeds and tools, manuals and training to analyse and tailor the data to regional and national requirements, in preference to the currently provided visualised forecast maps on internet sites. For shorter ranges (1-5 days) the WMO Severe Weather Forecast Demonstration Project (SWFDP) is providing support to NMHSs through a process of cascading forecast information from global centres to regional centres – where it is synthesised and disseminated to NMHSs. However, the geographical reach of SWFDP is still limited and the process of moving from demonstration project to continuous operational services is incomplete. For predictions on sub-seasonal (~50 day) timescales and projections to multi-decadal timescale there is little coordinated support available. Climate monitoring activities are frequently rudimentary, with many NMHSs not possessing capacity to develop gridded analyses (though this has been introduced in some countries by the ENACTS programme), digital archiving of data is also relatively new in some countries – with an additional need for data rescue.
- **Knowledge development:** Climate prediction information is often available from a range of sources with little information on the reliability of each source – this hinders an objective synthesis of the information. For example the relative performance of differing climate model-based predictions is not well understood. The relative performance of model-based predictions relative to simple statistical prediction methods also requires clarification. Methodology to clearly delineate forecast uncertainties at all timescales is also required.
- **Capacity development**: In addition to institutional strengthening, climate science capacity also requires enhancement with the aims of creating sustainable growth of climate science in Africa (see, for example, Annex 6 in Wilby, 2014). There is a need to develop tools to interpret information from regional and global centres, including downscaling methodology, and for manuals on and training in the use of such tools. It is frequently observed that training needs to extend beyond the often used workshop format to include visiting scientist programmes with staff exchanges between NMHSs and regional and global centres. Roving workshops serving RCCs and NMHSs could also be used
- **Research:** Overall research outputs from Africa are growing but from a very low base and there are gaps in research in specific sectors, such as climate impacts on

the built environment, coastal zone and human health (Wilby, 2014). There is a requirement to improve the understanding of the African climate system as outlined at previous Climate Research for Development (CR4D) meetings[2] and the CR4D agenda as well as improving impacts, adaptation, vulnerability and risk research across all sectors. There are specific requirements for social science research, for example. The need to strengthen risk communication and methods for conveying uncertainties is widely recognized (WMO 2014b, Ranger 2013), but more research is needed on the relative effectiveness of different communication methods (Lumbroso et al., 2014).

What does this imply for interventions?

Overall the evidence from the literature review suggests that climate service programme design should consider options that (1) integrate with and strengthen existing complementary activities, (2) extend 'User Interface Platforms' ,(3) extend the services offered and finally, (4) integrate climate information with socio-economic information to support poverty reduction and economic growth. Potential activities based on the literature review are highlighted below (these have been considered alongside other evidence in the project's Synthesis Report):

1. Strengthening NMHS and existing GFCS global-regional-national activities inc. O&M, CSIS, RMP and capacity building (Sections 4-8)[3].
    a. Strengthening business strategies of NMHSs, raising profile with national government and other user sectors.
    b. Strengthening hardware facilities and technical support at NMHSs and RCCs.
    c. Establish modern climate system monitoring at RCCs and NMHSs including, data rescue, use of climate databases and gridded regional and national datasets - building on existing programmes to include use of satellite estimates (such as ENACTS).
    d. Strengthen links between national, regional and global centres. Providing better access to the climate model products of global centres, evaluation of their performance and benefits and tools to facilitate their use (e.g. downscaling).
    e. Several authors have argued that this should be linked to the establishment and operation of an agreed framework of accountability on the part of providers, users and supporting agencies (e.g. Wilby, 2014).
    f. There is considerable scope for further investment in developing tools and approaches which enable both providers and users of climate information to be able to better support and monitor uptake and application of climate information across decision making processes. In this regard, there are clear opportunities for enabling emerging learning to be shared across complementary initiatives, including DFID investments in FCFA and BRACED.
    g. Within this framework, there is huge potential for the use of historical and season-to-date daily rainfall to provide real-time monitoring guidance and nowcasting thereby helping to provide information rapidly that largely illiterate communities can understand and act on (Cornforth, *pers. comm*).
2. Extending the UIPs to sub-national level and ensuring the two-way communication between providers and users required to develop user-relevant climate information,

[2] http://www.wmo.int/amcomet/en/events/africa-climate-research-development-cr4d-strategy-meeting
[3] The points raised in this list were raised by multiple authors and, in many cases, are recognised in the WMO GFCS documents. We have not referenced each point to specific papers but have highlighted the most relevant report sections and or pillars of the GFCS.

support its appropriate application, track its use and impact and so create a well articulated and evidenced demand for improved services (Sections 2 and 3).

   a. Strengthening of Regional Climate Outlook Forums and National Climate Outlook Forums, including sector-based forums and forums dealing with different timescales.
   b. Developing strategies for two-way communication, which are based on comprehensive assessment of the most appropriate and sustainable channels for communication, which ensure reach to the marginalised and are tailored for specific contexts and user groups.
   c. Research on how local and indigenous weather and climate information can support the reliability, understanding and uptake of national climate services, including through locally-managed rain gauges, offers possibilities to build trust and ownership amongst users simultaneous with supporting sustainable national observations networks.
   d. Frameworks for climate information services need to be more inclusive of the range of user needs, across sectors, livelihood and marginalised groups, including women, older people and pastoralist groups.
   e. There is equally a need to more fully engage with the wider humanitarian, disaster risk reduction, development and climate change adaptation communities, to engage their extensive networks in ensuring the reach and benefits of enhanced climate services.

3. Extending the services offered (in response to 2) (Section 2).
   a. With users, develop products that fill current gaps in the timescales currently catered for and conduct operational trials. The sub-seasonal timescale (~50 days) is a key gap and there is an opportunity to build seamless provision from days to seasons by linking with existing activities, namely a) on 1-5 days ahead (SWFDP) and b) on seasonal timescales. Interaction of climate providers and users is also needed to bring multi-annual to decadal predictions into use and to develop operational provision of multi-decadal predictions from CMIP5 and CORDEX, together with guidance in interpretation and communication of uncertainty.
4. Better integration of social, economic, food, health, water and disaster risk information with climate information to add value to services offered (as part of 3) (Sections 2 and 3). Climate information is most useful when different knowledge sources are combined and 'translated' to relate to local livelihoods, contexts and experience (Ambani and Percy, 2014). This involves co- exploration to find out and understand what is available from different sources, highlighting any existing gaps in the information and barriers to understanding and using the information (see for example, Table 1, Boyd and Cornforth, 2013).

Finally, further situational analyses of the ability of specific NMHSs, national partners and associated regional centres to provide the identified user needs for climate services at national and sub-national levels will be needed (Sections 3-8). Such an analysis would be best conducted for selected regions and include assessing requirements for strengthening national networks of providers, intermediaries and users as well as links to global centres. Outcomes would be used to design and implement a programme of institutional strengthening and consolidation of networks. Prototype climate services for specific sectors could be defined and developed as a tangible means to demonstrate progress.

SECTION 1

Introduction

Project background

DFID is considering a new programme on climate information and services in Sub-Saharan Africa (SSA). This would build on other ongoing initiatives, such as ClimDev and the Science for Humanitarian Emergencies and Resilience (SHEAR) programme, providing a step change in the use of climate information to support poverty reduction and promote socio-economic development.

Since the original development of the Climate for Development in Africa (ClimDev) programme in 2008 a number of new global initiatives have started on climate information and services. In particular, the Global Framework for Climate Services (GFCS) provides a strategy for investments and a platform for the coordination of activities (WMO, 2014b). A number of WMO pilot projects were initiated in Africa in 2012 and 2013, which included the development of road maps to coordinate stakeholder engagement and implementation plans (WMO, 2013).

The proposed DFID Climate Information and Services for Africa (CIASA) programme needs to recognise this changing donor landscape, aligning with the GFCS and identifying effective climate service interventions. In November 2014 DFID procured the Met Office to gather evidence to support the Business Case for the programme.

This report

This report provides a literature review on the user needs for climate services in Africa, the current state of climate services and major gaps that could be addressed by the CIASA programme. Mirroring the GFCS framework, it has individual sections on ‘Users’, ‘User Interface Platforms’, ‘Climate Services Information Systems’, ‘Observations and Monitoring’, ‘Research, Modelling and Prediction’ and ‘Capacity Development’ (Figure 1). A final section discusses a number of cross-cutting themes and several annexes discuss the needs of individual sectors.

Other evidence gathering activities include a widespread consultation with users of climate information, climate service providers, academic institutions, NGOs, UN agencies and others. It also includes consultation with DFID and specific pieces of work on Value for Money (VfM) and gender. This evidence will be brought together in a short synthesis report (or recommendations paper) and provide text to support the Business Case.

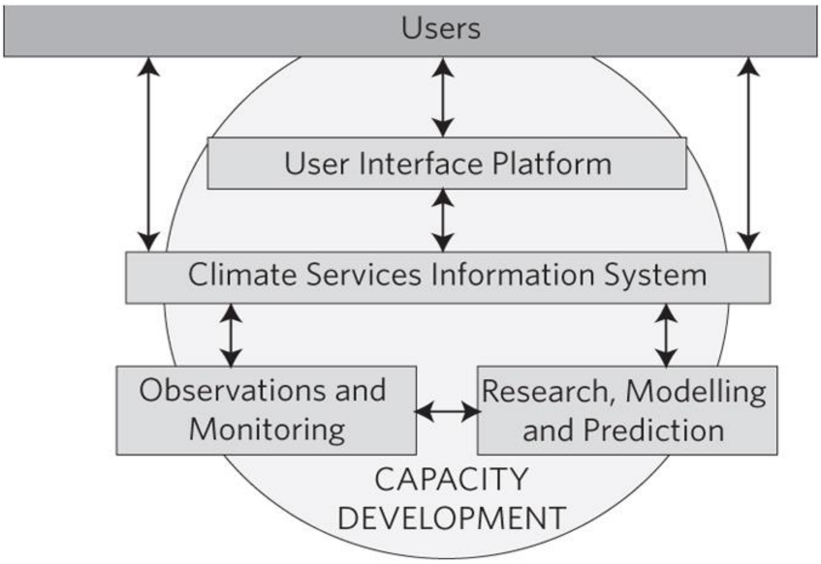
Climate services

The World Climate Conference-3 in 2009 brought together Heads of States, government ministers, industry representatives, and scientific and technical experts to discuss the needs for enhanced climate services and improved coordination. The Conference called for the implementation of a Global Framework for Climate Services (GFCS) to strengthen and coordinate existing initiatives and develop new infrastructure where needed to meet society's climate-related challenges. The World Meteorological Organisation definition of a climate service is as follows:

"A climate service can be considered as the provision of climate information in such a way as to assist decision-making. The service needs to be based on scientifically credible information and expertise, have appropriate engagement from users and providers, have an effective access mechanism and meet the users' needs."

The GFCS aims to enable society to improve the management of risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to such risks. The framework is outlined in Figure 1 and the definition of each component is provided in subsequent report sections. It emphasises user involvement and capacity development; its initial focus is on climate services for food security, health, water and disaster risk reduction because these are regarded as areas in which services can have the greatest impact.

Figure 1 The Global Framework for Climate Services (Hewitt et al., 2012)

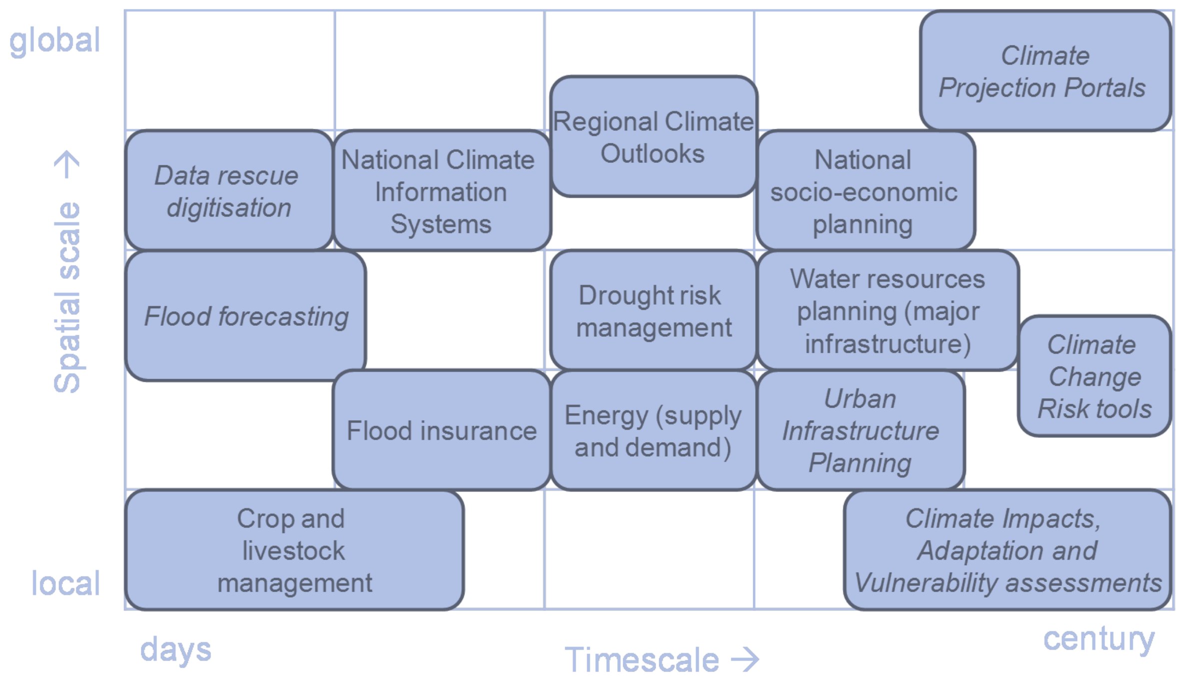


The GFCS framework is outlined in a series of ten reports (WMO, 2014a-j), which have been extensively referenced in this review. According to the Implementation Plan *"providing climate services is not new, but the Framework represents a major, concerted, coordinated global effort to improve the well-being of all the parts of society vulnerable to climate variability and climate change. There are already mechanisms and institutions that provide climate services in a less coordinated way, as well as other activities and development plans such as the Millennium Development Goals and the United Nations Framework Convention on Climate Change that address climate issues. The Global Framework for Climate Services will be aligned with such activities, will benefit from them and vice versa, but will go beyond them by creating the structures needed to deliver needs-driven climate services across the globe*" (WMO, 2014b).

A number of examples of climate services are outlined in the GFCS Implementation Plan. These cover a range of spatial scales and time-scales, from providing short-term forecasts for crop management to providing regional climate outlooks based on seasonal forecasting and future climate change information to support long term national adaptation planning (Figure 2). Examples of the potential benefits of climate services include greater use of seasonal forecasts, resulting in greater food production and reduced sensitivity to climate hazards; better asset protection and improved planning of responses to climate-related disasters and greater understanding of the linkages of diseases to climate factors as well as better planning of disease control and improved infrastructure planning (WMO, 2014b).

Leading proponents of climate services argue that the focus on climate risk management and resilience (rather than climate change risks and adaptation) is more appropriate for poverty reduction. For example, in the case of stressed smallholder farming systems in risk-prone environments, resilience to climate shocks can allow farmers to build wealth, which facilitates a transformation towards livelihoods that do not require asset depleting coping strategies (Hansen et al., 2014). Similarly, in other sectors, a focus on climate variability and current risks can start a process of adaptation and reduce risks of future climate change, while mindful that support for coping with current climate variability will need to be continuously reviewed against emerging knowledge on longer term changes. An increasing number of humanitarian and development agencies are, for example, seeking to strengthen resilience building within humanitarian response (e.g. DFID Disaster and Emergencies Preparedness Programme support for the multi agency START Network Linking Preparedness, Response and Resilience in Emergency Contexts).

Figure 2 Climate services based on examples in the GFCS Implementation Plan (WMO, 2014a)



The GFCS Implementation Plan describes key challenges, overarching goals and eight principles for guiding the programme (WMO, 2012b, Hewitt et al., 2012). The challenges are related to access, availability, capacity, interactions of users and providers and the quality of climate information. These challenges are as much about the users of climate information as the providers. Therefore the reach of GFCS is far beyond National Met Services and government departments and involves all those whose decision making could be supported by climate information. There is a strong user focus throughout the plan.

The User Interface Platform is described as the most novel component of the framework. It reflects the fact that the involvement of users in helping to establish the needs, develop appropriate products, identify capacity development requirements and influence the direction of observational investments and research efforts is crucial to achieving the framework's goals.

Approach to the literature review

The starting point for the CIASA literature review was the GFCS documentation (WMO, 2014a-j) and the ClimDev review (Wilby, 2014). Then a search for peer reviewed literature was completed using library resources at the Met Office and King's College London. Although the GFCS is a new framework there is a large historic literature on the use of climate information in some sectors such as food security (Section 2.1).

Some of the key literature as well as ongoing initiatives were recently reviewed by Wilby (2014); he highlighted (i) a low but growing research output on climate from African institutions (presently ~3% of the global share of publications), (ii) significant regional variations in research outputs and (iii) major research gaps recognised by African scientists in urban populations and migration, built environment, clean energy, coastal zone, and mainstreaming of science into practice (in agreement with findings from Edwards, 2013). The CIASA review focused on more recent publications since 2009, when GFCS was conceived, the four priority sectors of GFCS and the energy sector and urban environments.

Co-authors reviewed papers under each component of the framework and recorded information on each study following DFID guidelines[4]. They also incorporated information in the grey literature on ongoing and new climate research programmes in Africa. Where there was a lack of information co-authors approached experts at the Met Office or WMO for further information (marked as *pers comm* in the text).

[4] DFID How to Note on "assessing the strength of evidence"

SECTION 2

Users of climate information and services

Background

This section describes the users of climate information and services in Sub-Saharan Africa, firstly providing a general introduction and then discussing user needs in the food security, health, water, disaster risk reduction, energy and urban infrastructure sectors.

Who are the users of climate information?

The users of climate information include a wide range of groups and individuals across sectors, livelihood groups and decision making levels, with widely varying levels of access to information and resources to use this information appropriately. Users require climate information at different timeframes and geographical scales, in different formats and provided through different channels. Efforts to support the uptake and appropriate application of climate information within decision making have identified the importance of establishing processes which support co-production of user-relevant information (WMO, 2014b), as well as developing commonly shared principles for underpinning engagement in these processes (WMO, 2014b).

Various terminology have been employed to cover 'users' of climate services, with a differentiation in some literature between 'end users' and 'intermediaries'. Intermediaries have been defined as those who translate climate information into climate services relevant for different sectors, while "end-users" comprise a mix of stakeholders from national, sub-national and community levels who typically require these advisories or products as input into their decision-making activities.[5] In practice many individuals and organizations may be both intermediaries and users, integrating information within their own policies, programmes and activities, as well as acting as a conduit to communicate information with other users. The term 'end-user' is also not supportive of the two-way and continuous process of communication envisaged within the GFCS: users are not at the end of the information line but actively contribute to the process, inputting their own expertise and understanding (Visman, 2014). An example of the number and complexity of users is illustrated in Table 1 that summarises some of the users of climate information in the Water sector (below).

Information requirements for different groups

The GFCS Framework recognizes but does not provide much detail on the differences in information requirements across social groups, including women and youth. In a 2009 assessment of progress in implementation of the Hyogo Framework of Action at a local level undertaken by the Global Network of Civil Society Organisations for Disaster Reduction amongst its member organisation across 48 countries, women assessed progress lowest overall.[6] There have been calls to ensure a gender perspective in all components of the

[5] Tall, A., 2013. What do we mean by Climate Services? *WMO Bulletin, **62**, Special Issue – 2013.*
[6] Global Network of Civil Society Organisations for Disaster Reduction (2009) "Clouds but little rain…": Views from the Frontline: A local perspective of progress towards implementation of the Hyogo Framework for Action, June 2009

GFCS[7] and ensure inclusion of women and other socially marginalised groups in the design and delivery of climate services (Box 3). The framework makes no specific reference to older people and the climate knowledge which they have or their place in guiding local decision making[8]. A number of studies highlight the need to develop climate services for those living in areas where natural hazards cross boundaries, for example in international river basins. This requires that User Interface Platforms operate regionally in some cases (Lumbroso et al., 2014, Wilby, 2014).

Progress

Despite significant investments in recent years to strengthen climate services, only an estimated 20% of information informs policy and practice (DFID Terms of Reference). Use and uptake of climate information and services to inform long-term policy-making remains relatively limited both at national and sub-national levels (Jones, 2015, Wise, 2014).

There is current low uptake of climate information and services and as noted in the SHEAR scoping study, *'(t)he status (and effectiveness) of these systems depends upon dissemination/communication and response capacity as much as the existence, coverage, quality, spatial scale and 'skill' of risk assessments and early warning systems.*' (Lumbroso et al., 2014)

Various reasons for the limited uptake of climate information have been proposed, including the perception that climate information as currently disseminated lacks salience, credibility and legitimacy (Patt and Gwata, 2002). Climate information products generated currently fall short in terms of the critical needs of the users even though the research communities already have the tools and knowledge needed to address many of the user issues (See Table 1, Boyd and Cornforth, 2013). The usability of climate information depends on users' perception of information fit, how new knowledge interplays with other kinds of knowledge that are currently used by users, and the level and quality of interaction between producers and users (Lemos et al 2012). There is a communication gap due to a physical disconnect between climate scientists, government policy makers, NGO decision-makers and development practitioners. This is exacerbated by the lack of understanding of the language used and a lack of understanding of the local issues and summed up in a humanitarian policy brief by Suarez and Tall (2010).

As recognized within the GFCS and UIP framework, the process of making climate information relevant involves the co-production of information which is useful, useable and used[9]. This requires both that users better understand the decision making processes which the climate information is intended to support and that the climate literacy of users is strengthened to enable them to ask for information which it is feasible for providers to produce (Challinor and Visman 2014). Enabling effective engagement by user groups (See for example, Duncan et al., 2014) and allowing them the space to discuss their climate information needs directly with providers may lead to a prioritization of climate information services and research which are very different to those developed by providers or external agencies.

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[7] The WMO's 3rd Gender Conference in November 2014, focused on Gender dimensions of weather and climate services , http://www.wmo.int/pages/themes/gender/documents/ConferenceConceptNote_v.3.1.pdf

[8] HelpAge International, (2014), Disaster resilience in an Ageing world, file:///C:/Users/acer/Downloads/Disaster%20resilience%20in%20an%20ageing%20world%20-%20May%202014%20(1).pdf

[9] Hayden, C and A Boaz, 2000, Not checking but learning, Warwick Research Papers.

A number of climate literacy training courses have been developed, most tailored for specific groups, such as climate information services intermediaries (May and Tall 2013). There is considerable scope to identify and collate common content from across these trainings, while recognizing that this will then need to be tailored for the target sector, decision making body or user group.

For climate information to better support decision making there is a need to consider climate in context and support a much more holistic approach. Users want information with guidance – not just the climate information alone (Wilby, 2014). Lack of strong partnerships between NMHSs and other key departments and ministries has significantly hindered the development of climate information which can best support users' needs. Pilots undertaken within the GFCS have shown that it is possible to create national communication chains for climate services which support two-way communication and allow for the co-production and delivery of climate services as well as regular feedback and review (Tall 2013). Complementary initiatives have also demonstrated the possibility of establishing such frameworks for climate services at sub-national level, linking existing networks to support cross sectoral and multi-stakeholder engagement at local levels (Visman et al. 2012b).

Barriers to uptake

Commonly noted constraints to use of climate information and services include: language barriers, high levels of illiteracy, inadequate infrastructure, a lack of access to phones, radios or televisions and users who are either geographically remote, scattered or mobile (e.g. pastoralist communities in parts of Africa) (Lumbroso et al., 2014). Language barriers include the need to develop services in local rather than national languages, employ non-technical terms, integrate cultural and religious considerations, employ forms of communicating information accessible to those who are illiterate, develop agreed definitions of commonly used meteorological terms and identify appropriate ways of conveying these in local languages (ISACIP, 2014). There remains uncertainty about which communication methods are most appropriate and cost-effective (Lumbroso, et al., 2014).

Learning from across initiatives to enable climate information to better support at risk groups and livelihoods has highlighted the importance of salience (or relevance), access, legitimacy (or ownership), equity and integration, continuous provider-user interaction between technical services and users throughout the design, production and evaluation of climate services, producing information across timescales which is locally relevant and provided through channels which reach specific livelihood, at risk and social groups and integration of meteorological with local and indigenous knowledge (Tall, 2013).

Risk communication and conveying levels of confidence and uncertainty

The need to strengthen risk communication and methods for conveying uncertainties is widely recognized (WMO 2014a, Ranger 2013). Climate information which does not appropriately convey the levels of certainty within it may heighten risks and build distrust amongst users. If information is provided in appropriate ways, individual users are adept at making decisions in situations of uncertainty (Ewbank, 2012). To support uptake of information from scientific institutions, climate information will need to be provided in ways which are culturally and socially acceptable (IFRC, 2014), and which boost capacity and ensure access to the resources to act on the information provided (Visman, 2014). Historical data may challenge commonly held perceptions (Rao, 2012) and the concept of forecasting may challenge religious beliefs (IFRC, 2014). Organisational decision-takers and policymakers are often not comfortable with using probabilistic information. Some humanitarian agencies require 'hard data' prior to initiating a response (Brown, 2008), and there are projects underway to better understand the probability thresholds of key humanitarian decision making processes.

Given the complexity of developing effective approaches for enabling climate information to appropriately support specific decision making processes, it will be important to ensure regular opportunities for cross-fertilization and sharing of emerging learning between complementary initiatives, including the Integrated Research on Disaster Risk programme's Risk Interpretation and Action project[10], proposed components on this within the FCFA and other related programmes and projects.

Food security

Food security examples in the GFCS include the provision of agro-meteorological information (Agromet), seasonal forecasting and farmer extension services (WMO, 2014a). Fisheries are also mentioned (WMO, 2014a) and applications may include lake monitoring, lake or marine forecasting services and climate change risk assessments on freshwater and marine ecosystems. The GFCS makes little specific mention of pastoralists' climate information needs, although there are a number of pilots which are seeking to address these (e.g. the ongoing DFID-supported Adaptation Consortium in Kenya).

Weather and climate conditions on a variety of timescales are well-understood to be closely linked with agricultural productivity and food security. Extreme weather and climate events, such as sustained drought, floods, heat waves and storms can directly result in crop failure and livestock reduction, leading to food insecurity and destruction of key livelihood assets (WMO, 2014g). Small-holder farmers, fishers and pastoralists in sub-Saharan Africa are often highly vulnerable to these impacts, and could therefore benefit from user-oriented, timely and demand-driven weather and climate services to aid in reducing and managing the risk of these impacts on their livelihood and wellbeing.

Agricultural users of weather and climate services in sub-Saharan Africa typically require weather and climate products on a combination of timescales, including historical observations, monitored information throughout a growing season, daily/weekly weather forecasts, monthly outlooks, seasonal predictions, and decadal climate change projections (Tall *et al.*, 2014). In practice, the focal timescale for weather and climate services in sub-Saharan Africa has been the seasonal outlook for particular rainy seasons, as information on this timescale can directly advise on agricultural practices during the growing season. However, projects which have demonstrated benefits of climate services on seasonal timescales have highlighted the importance of sub seasonal updates to a rainy season outlook, which suggest the need for continued engagement with smallholder farmers and other agricultural practitioners through the seasons (Christian Aid, 2012). Weather and climate services on all timescales will contain an inherent level of uncertainty, thus requiring a good understanding for appropriate implementation of the information towards risk-management activities. In addition to appropriate user understanding, the services themselves should aim to be relevant or salient (i.e. specific to a users location or livelihood), easily accessible through a number of dissemination channels, co-designed and produced with user input, proactively targeted to marginalized groups, and promote broader integration with national scale development (Hellmuth *et al.*, 2007; Tall *et al*., 2014; WMO, 2014g, see Section on the UIP).

There are number of challenges in meeting all of these requirements, which existing climate services activities have been aiming to address in sub-Saharan Africa. Firstly, focussing on the issue of relevance, weather and climate information disseminated to users needs to be

10 http://www.irdrinternational.org/projects/ria/

specific to a given region or locality, whether this be through expert interpretation or the use of a downscaling tool. In actual practice, weather and climate forecast products are often communicated to national stakeholders in the original format and scale, without any adaptation to the needs of users within their countries (WMO, 2014g). However, a number of existing CS initiatives have attempted to address this issue through a range of different approaches. For example, Christian Aid have undertaken a number of projects across Africa (such as the SALI project) to promote enhanced community engagement in the uptake of CS through the co-development of community-based adaptation strategies through appropriate, 'localized' interpretation of weather and climate products from NMSs (Christian Aid, 2011; Christian Aid, 2012).

The Adaptation Learning Programme (ALP) for Africa, launched by CARE, takes a similar community-based approach to developing risk-management strategies, which involve participatory engagement of rural communities to assist with designing agricultural advisories based on probabilistic seasonal forecast information from NMSs (CARE ALP Brochure, 2011). To assist with increasing the relevancy of the CS products themselves, the Famine Early Warning Systems Network (FEWSNET – associated with USGS and USAID) have developed a statistical-based tool which can be used to downscale tercile-based seasonal forecast information, which is typically produced by African NMSs on large spatial scales and lacks finer details on scales relevant to local communities. This tool, known as the 'FIT Interpretation Tool' (Brown, 2008), allows for the effective 'localization' of seasonal forecast information prior to dissemination for a particular region, and is currently being piloted in 4 counties within Kenya as part of the StARCK+ Adaptation Consortium..

The relevance of CS products in Africa can also be improved through the translation of CS products into region-specific languages, which has been applied in projects such as the StARCK+ Adaptation Consortium, as well as recent work performed by the Uganda Meteorology Department, among other partners (Tall *et al.*, 2014). Furthermore, the uptake and relevancy of CS products in rural communities can be enhanced through the integration of local or indigenous knowledge of weather and climate into the decision-making and risk-management process, which has been undertaken in both the Indigenous Knowledge Bank project in Senegal (IKB; Tall *et al.*, 2014) and the SALI project in Kenya, lead by Christian Aid (Christian Aid, 2012; Kniveton et al., 2014). The general findings of these projects suggest an increased level of trust and willingness to consider scientific information for informed decision-making when the scientific information is combined with local, traditional methods of climate monitoring and seasonal forecasting (Tall *et al*., 2014).

In order to ensure that weather and climate information for use in agricultural decision-making activities is easily accessible, a number of different communication channels should be identified and implemented for any given user group (Tall *et al.*, 2014; WMO, 2014g; AGRA, 2014). Two-way and face-to-face communication between CS providers and user groups is consistently described as the most important and effective aspect of communication, and is a key component to many successful CS projects in the region. By breaking down the apparent barriers between CS providers and users, two-way communication opens the possibility for co-designed weather and climate products, appropriate feedback for future improvements to CS, and ultimately promotes a strong integration of user requirements into national level development plans. Communication tools that have been trialled in a number of projects include, but are not limited to, radio transmission, SMS messaging, TV broadcasting, online resources, the use of extension officers, local NGOs and other intermediaries, and community-based participatory activities. While these communication tools have proven to be useful in the dissemination of weather and climate information, a certain level of face-to-face interaction between users and CS providers or intermediaries is recommended, as the probabilistic and uncertain nature of weather and climate information is often hard to convey through short announcements delivered through TV, radio or mobile phones (Tall *et al.*, 2014). Support to strengthening understanding of respective knowledge sources highlights the crucial need for educational and training activities at all levels, promoting a constant flow of information to and from the developers of weather and climate information. Specialist Radio programmes in particular, provide an effective mechanism for scaling up delivery of tailored CIS e.g. Farm Radio and the successful Farmers' Voice Radio implemented in East Africa by the Lorna Young Foundation and soon to be piloted in West Africa through the newly-funded DfID/NERC UPGro Project called "BRAVE2" (Building understanding of climate variability into planning of groundwater supplies from low storage aquifers in Africa). A number of projects are working towards addressing this gap in understanding, through the funding of collaborative academic research (Feed the Future 2014), community-based participatory learning activities such as Roving Seminars, Farmer Field Schools, and Participatory Scenario Planning workshops or 'PSPs' (CARE, 2011; WMO, 2014g), and the education of intermediaries and extension officers, also denoted as the 'training of trainers' (May and Tall, 2013; Tall *et al.*, 2014). Two such projects attempting to address this gap in understanding through integration weather and climate information into school curricula, include a project undertaken by the Uganda Department of Meteorology (among other partners) and the Institute of Physics, Campaign for Africa. Both have ignited an innovative medium of conveying information to heads of households. It will be important to incorporate such innovative communication channels as well as addressing education requirements in any future attempts to upscale the successes of CS in sub-Saharan Africa.

Linked to the need for two-way dialogue between CS providers and user groups, successful CS initiatives for improved agricultural productivity and food security will contain an element of co-development and co-production of weather and climate products, building a degree of ownership and legitimacy in the user-oriented and demand-driven products and services. This two-way dialogue can typically be achieved through participatory activities in community-based forums and opportunities designed for interactive feedback, such as the interactive radio programme developed in the CCAFS Climate Services Kaffrine Pilot in Senegal (Ndiaye *et al.*, 2013; AGRA, 2014; Tall *et al.*, 2014). In addition to providing opportunities for feedback and two-way dialogue, integrating user groups in climate monitoring activities, both enhances weather and climate information and the level of engagement and feeling of ownership within rural farming and pastoralist communities requiring these services. One approach to integrating users in climate monitoring activities that has been widely used is the provision of rain gauge equipment to rural communities, which can directly enhance the quality of regional observations that would otherwise remain limited in scope (CARE,2013; Visman et al. 2012b). This type of activity also promotes an improved understanding of climate monitoring and climate variability, which can ultimately lead to a better appreciation of weather and climate information and increased uptake of CS.

Often the most difficult challenge facing the upscale of agricultural-based CS in sub-Saharan Africa is the need for wider integration and collaboration between interdisciplinary scientists, cross-sectoral agencies and national-level frameworks. While rural-focussed programs often do not go far by way of integrating weather and climate information with other advisory services and development plans (Tall *et al.*, 2014), there are existing national (see for example NCOF developed by Tanzania Met Agency) and regional activities which provide good opportunities for engagement between cross-sectoral agencies. For example, regional climate outlook forums such as the GHACOF (Greater Horn of Africa Climate Outlook Forum) focus on the dissemination of a consensus-built seasonal outlook, but promote cross-cutting sessions on the potential impacts of this seasonal outlook on sectors such as agriculture, food security and public health. In line with the GFCS recommendations, future climate services initiatives should strengthen and build up on existing cross-cutting partnerships on national, regional and international scales, such that resulting weather and climate services can be effectively integrated into wider government frameworks and development plans (WMO, 2014g).

In summary, food security, pastoralism, agricultural productivity and marine fisheries in sub-Saharan Africa are sensitive to weather and climate on all timescales. In order to make climate-smart decisions with respect to food security activities, smallholder farmers, pastoralists, fishers, and institutional users such as government, extension offices and local NGOs, require weather and climate services which are seamless across timescales ranging from daily to seasonal outlooks and beyond. However, the provision of this information is not enough to ensure its effective use in decision-making activities. In order to be successfully implemented, weather and climate services need to address the following five criteria: relevance (or salience), easily accessible and understood, co-designed with user input, inclusive of marginalised groups, and broadly integrated in cross-sectoral frameworks and national development plans. Through meeting these criteria, and taking an integrated approach to designing, producing, communication and evaluation, effective weather and climate services are possible, but not without challenges (Tall et al., 2014).

Food Security and Agriculture: Gaps identified in the literature review (including many cross-sectoral issues highlighted in the literature)

- Strengthening of Regional Climate Outlook Forums and integration with wider government frameworks and plans (WMO, 2014g)
- Further development of tools for downscaling of climate information to produce local information and forecasts (Brown, 2008)
- Develop the use of historical and season-to-date daily rainfall to provide real-time monitoring guidance and nowcasting, coupled with effective communication to provide information rapidly that largely illiterate communities can understand and act on (Cornforth et al., 2013 in UNISDR STAG Report).
- Further research into how local indigenous knowledge can be combined with climate services and support the GFCS (e.g. Masinde, 2014)
- Scaling up of successful climate services projects in the food security sector, which address the key criteria identified in recent studies (e.g. Tall et al., 2014)
- Developing tailored forecasts to meet user needs, including the use of local languages and a wide range of communication channels (Tall et al., 2014; Lumbroso et al., 2014)
- Provision of simple weather and hydrological monitoring equipment to local communities to raise awareness, promote dialogue and data exchange

Health

Health sector examples in the GFCS include information and services related to infectious diseases (leptosprirosis, meningitis), disease vectors (e.g. malaria warning systems) and future climate risks and non-infectious diseases (e.g. air quality, heat, UV and pollen) (WMO, 2014a). The health sector includes human, animal and plant health.

Weather and climate conditions on all timescales have both direct and indirect effects on public health and safety through extreme events such as heat waves, cyclones, floods and droughts, as well as the prevalence and severity of infectious, vector- and water-borne diseases such as meningitis, malaria, and diarrhoea (WMO, 2014h) and cholera (de Magny et al., 2007). Rapid urbanisation with a lack of modern drainage systems and wastewater systems has the potential for increasing the prevalence of water-borne diseases. While the impacts of weather and climate on public health are widely recognised, the uptake and implementation of weather and climate services in order to inform policy and decision-making activities within the health sector is relatively low (Jancloes *et al.*, 2014; WMO, 2014h).

Proposed reasons for the apparent non-existent demand for weather and climate services by the health community include limited capacity to effectively use and understand weather and climate services, the apparent inability to manage and monitor the risks of climate variability and change on public health, lack of access to the relevant datasets, and an institutional disconnect between the public health community and other sectors which consider public health as a downstream priority such as food security and water resource management (Connor *et al.*, 2010; Clim-Health Africa, 2013; Jancloes *et al*. 2014; WMO 2014h). For example, the livelihoods and nutritional security of African citizens, particularly women and children, are heavily dependent on rain-fed agriculture and seasonal water resources, and are therefore highly vulnerable to potential changes in these systems and associated impacts on their health and wellbeing (Clim-Health Africa, 2013). Ways to improve the effective integration of climate services into the decision-making in the health sector include (1) promoting two-way dialogue channels and strengthened partnerships between CS providers and the health community, (2) investing in human resource and institutional capacity development activities while promoting interdisciplinary research into the potential effects of climate variability and change on public health, and (3) improving the access, understanding and relevancy of both climate monitoring and health surveillance datasets (Connor *et al.*, 2010; Rogers *et al.*, 2010; Clim-Health Africa, 2013; Jancloes *et al.*, 2014; WMO, 2014h).

As has been mentioned previously in this review, two-way dialogue between weather and climate service providers and users of the information contained within these services is the first, and arguably most important, step towards scaling up the use, understanding and benefits of climate service initiatives. Ensuring a constant flow of information in both directions in the CS communication structure leads to the production and enhancement of demand-led, user-oriented weather and climate services, which are easily-understandable and applicable to decision-making activities in a given sector. In addition to active communication between CS providers and user groups, strong institutional partnerships between the climate community and health policy and practice communities need to be identified and sustained in order promote the effective and appropriate use of weather and climate information in the health community (Jancloes *et al*., 2014).

These partnerships will ideally include actors on global, regional, national and sub-national scales[11], in order to promote a good understanding of CS users at all levels of government, policy and practice. On global scales, the WHO and WMO have a long-standing partnership, and are fully committed to the provisions of technical frameworks and guidance on climate and health worldwide. On a regional scale, cross-boundary partnerships can act to fill knowledge gaps and build capacity through shared mechanisms within a select group of countries (ex. Malaria Outlook Forums - MALOFs). In many areas of Africa, national level partnerships are already being developed through the implementation of Climate and Health Working Groups (CHWGs), which have primarily been focussed in Ethiopia, Kenya, Madagascar and west Africa, and aim to establish strong national partnerships between the climate and health communities for the conduct of research, education and data exchange (Rogers *et al.*, 2010). Key outcomes of these CHWGs include improved service delivery and increased capacity of NMSs, which highlight an opportunity to build upon these successes through further-sustained partnerships, increasing cross-sectoral collaboration and maintaining effective two-way communication between CS provider and at-risk sectors. Furthermore, recommendations on methods for strengthening national level partnerships and cross-sectoral collaboration include the development of a public service platform within WMO Member institutions, which would allow for the development of decision-support tools on all timescales relevant to the health sector, and the cooperative development of weather and climate advisory services for practical use in the health community (Connor *et al.*, 2010).

[11] E.g. district/ county health departments to inform community health workers who are an important network for communicating and employing weather and climate information.

At present, human resource and institutional capacity to effectively utilize weather and climate information in public health practices are extremely low, and there is a prominent need for improved understanding in the uncertain nature of CS, the implications of adverse weather and climate conditions on various health conditions and diseases, and the preventative, preparedness and response measures available to improve resilience these impacts, among other cross-cutting concepts (WMO, 2014h). From a research perspective, there is an inherent requirement to promote high-quality, interdisciplinary research on the effects of weather and climate on public health, with a particular focus on vulnerable regions such as sub-Saharan Africa. Existing initiatives to address this research gap include Clim-Health Africa, whose overarching goal is to strengthen the resilience of African countries and communities by improving management of the effects of weather and climate on public health (Clim-Health Africa, 2013). Capacity building is a key component of this project, with efforts being made to offer hands-on training courses to public health practitioners in the use of early warning and response systems currently being developed by NMSs, in addition to promoting the development of a doctoral research programme to facilitate a new generation of young African and non-African scientists, specialising in the intricate links between climate and health. Both of these activities aim to improve human resource and institutional capacity, which will ultimately increase the awareness and demand for CS in the health sector. Other existing initiatives for capacity development include a core curriculum and training programme, developed by the International Research Institute for Climate and Society (IRI) among other partners, which provides training in a balance of concepts and methods from the health and climate communities, and has successfully trained over 100 professionals from 25 countries including Madagascar and Ethiopia (WMO, 2014h).

Through the effective collaboration of interdisciplinary researchers, both the number and quality of tools and products relevant to the health community will increase, leading to more effective uptake of weather and climate services in the future (Connor *et al.*, 2010).
As is the case in many other sectors, access to relevant datasets and tools for decision-making activities is a major challenge facing the increased uptake of weather and climate services by the public health sector. With regards to relevant timescales, many ministries of health are generally motivated to discuss “climate” in terms of climate change impacts, however the practical reality is that health practitioners typically react to observations on historical timescales, in addition to predictions on daily, monthly, and seasonal timescales, and often view ‘climate services’ as a continuum from ‘weather services’ on these shorter timescales (WMO, 2014h).

Specifically, the health community can benefit from high-quality observed or historical information to monitor the effects of weather and climate on health and better allocate resources in preparation for typical seasonal variations in climate. Unfortunately, observational datasets can be prohibitively expensive, and often lack sufficient quality and quantity assurance (Connor *et al.*, 2010). However, when combined with epidemiological data from field-based measurements, observational climate information can allow for linkages between climate and health to be explored, ultimately benefitting operational research and decision-making activities. An example of this combination can be seen in Malaria Early Warning Systems (MEWS), which combine information on recent rainfall conditions and epidemic malaria risk onto hazard maps which can be viewed and interpreted online with no charge as a means of improving the opportunity for preparedness and timely response in the event of a malarial outbreak (Grover-Kopec *et al.*, 2005).

On timescales of days, months and seasons, weather and climate predictions can inform longer-term preparedness strategies for potential outbreaks of disease, such as meningitis. The Meningitis Environmental Risk Information Technologies initiative (MERIT) has focussed on the development of risk maps of current and future conditions for meningococcal, leading to improved early warning systems, impact assessment methodologies for prevention, and the promotion of climate-related health products as a strategic planning tool in the health community (4th MERIT Technical Meeting: Synthesis Report, 2010).

Additional initiatives aimed at combining climate and health information for the development of useful preparedness tools include the QWeCI project (Quantifying Weather and Climate Impacts on health in developing countries), whose overall goal is to improve climate-health relations through the provision of database information on a range of weather and climate timescales, mapping tools for current and future distributions of disease risk areas, and the improvement of dynamic health models. These models, which were first developed in the EU FP5 DEMETER project and further refined in the EU FP6 ENSEMBLES project, aim to simulate the occurrence of diseases such as malaria and rift-valley fever using weather and climate information from historical, daily, and monthly timescales to seasonal, decadal and beyond (QWeCI Newsletter, 2013). All of these existing initiatives highlight the importance of developing a seamless prediction system on all weather and climate timescales, based on a combination of high-quality climate and health datasets, for use in a range of demand-led products and service relevant to the health community.

Long-term success of any initiatives aiming to address the challenges in the uptake of weather and climate services in the health sector outlined here, will need to be monitored and assessed in terms of their ability to improve climate-informed health decision-making activities that result in lives saved, climate-smart health investments, and the overall protection of human well-being from the risks of weather and climate hazards (WMO, 2014h), including the consideration of the impacts on the health of the animal, fish and plants on which their livelihoods depend. The development and operation of weather and climate service products tailored to the health sector require ongoing, cross-cutting collaboration across a number of disciplines, including meteorology, climate science, demography, epidemiology, social science, public health, economics, statistics, etc. (Clim-Health Africa, 2013). New knowledge and tools are required, such as high-profile interdisciplinary research and climate-informed early warning systems, in order to bridge the gap between existing research and the needs of decision-makers in the health sector (Jancloes *et al.*, 2014). By addressing these challenges, opportunities exist for public health professionals to effectively integrate weather and climate information into risk-management plans to reduce the detrimental health effects of weather and climate hazards (Rogers *et al.*, 2010).

Health: Gaps identified in the literature review

- Partnerships on climate services and health building on Malaria Outlook Forums and Climate and Health Working Groups
- Access to climate and health data sets, including epidemiological data to enable the development of warning systems
- Development of ‘seamless prediction systems’ on all weather and climate timescales, based on combining high-quality climate and health datasets
- Improving the capacity of the sector, including the research base to understand the linkages between health and climate
- Consideration of the impacts of weather and climate on animal, plant as well as human health
- The relative impacts of rapid urbanisation, drainage and sanitation versus climate variability on waterborne diseases

Water

The Water sector in the GFCS includes floods, droughts and changing quantity and quality (WMO, 2014a). User requirements are therefore very broad covering all aspects of flood risk management, drought planning for household and industrial water use and water resources planning, including surface water and groundwater.

According to African Ministers' Council on Water (AMCOW), Africa's water challenges arise from:

- Provision of safe drinking water and adequate sanitation;
- Trans-boundary river basins management and cooperation;
- Improving use of water for food security;
- Hydropower development;
- Meeting the forecast growth water demand;
- Preventing land degradation and water pollution;
- Managing water under future climate change;
- Enhancing the capacity to address these water challenges;
- Provision of early warning systems for the onset and duration of rainy seasons, intra-seasonal dry spells, and rainfall anomalies based on the impacts of El Niño and La Niña.

  (Source: AMCOW, 2014)

Vulnerable groundwater supplies - around 500 million people in sub-Saharan Africa depend upon groundwater supplies currently. Within a generation, that will rise still further, to close to a billion. Although groundwater resources are potentially more resilient to the combined pressures of climate variability, population growth, and land-use change, evidence suggests that, during extended periods of low rainfall, such supplies can fail. For this reason, together with the absence of long historical records of borehole levels, it is unclear whether the planned development of groundwater resources to meet increases in demand is feasible in all areas of sub-Saharan Africa. DfID UPGro programme is focusing on this challenge. See www.upgro.org.

The Integrated Water Resources Management (IWRM) approach (see Box 1) is now accepted in the majority of sub-Saharan African countries as the way forward for efficient, equitable and sustainable development and management of the world's limited water resources and for coping with conflicting demands (UN Water, 2008; AMCOW, 2012; WMO, 2014a) .

Box 1 Integrated Water Resources Management (IWRM)

Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

(Source: Global Water Partnership, 2014)

The supply of the information required for IWRM implementation in sub-Saharan Africa is a major challenge owing to poorly developed and/or the deteriorating state of climate services (World Water Council, 2003; Kadi et al., 2006; Adeaga, 2007; ClimDev-Africa, 2013). As a consequence many decisions ranging from policies to design of infrastructure are based on unreliable information which can result in the unsustainable management of water resources. Without effective climate services to implement IWRM, issues related to solving the water – energy – food security nexus together with other conflicts cannot be resolved in a sustainable manner. Without an improvement in climate services in sub-Saharan Africa, the implementation of IWRM and achieving the Africa Water Vision - 2025 will remain unattainable for a large number of countries in the region (United Nations et al., 2009).

Relevant stakeholders

Table 1 provides an overview of the range of stakeholders with an interest in climate services that are used in an IWRM context in sub-Saharan Africa. Table 1 is by no means comprehensive; however, it provides an idea of the range of organisations and their interests with respect to climate services and the implementation of IWRM in sub-Saharan Africa.

Table 1 Stakeholders with an interest in climate services for IWRM in sub-Saharan Africa

Level	Type or name of organisation	Interests
United Nations Agencies	UN-Water; UNESCO – International, Hydrological Programme; WMO; UNEP DEWA programme and GEMS/Water; UN-Habitat Water and Sanitation Programme; World Hydrological Cycle Observing System (WHYCOS) of WMO; UN-ECA, UNCCD; WHO UNICEF Joint Monitoring Programme for Water Supply and Sanitation; UNDP Cap-Net	• Global trends in the status, quality and quantity of water resources and improving access to water • Provision of in-situ networks and improving free exchange of climate data • Capacity building • Early warning and assessment
International	Group on Earth Observations (GEO) e.g. Africa Water Cycle Coordination Initiative and GEO Capacity Building task - Earth Observation for Economic Empowerment (EOPower); Committee on Earth Observation Satellites (CEOS); World Water Council; World Water Partnership; Ramsar; Secretariat; Global Energy and Water Experiment (GEWEX); ESA; NOAACPC; EUMETSAT and Satellite Application Facilities (SAF) Network(e.g. Hydrology SAF); GEONETCast; FAO-AquaSTAT Programme	• Climate services data providers for water management and dissemination • Promotion of improved water management practices in Africa • Strategic framework for Water Resource Management • Provision of in-situ networks for climate services • Capacity Building
Continental	African Union; African Ministers' Council on Water (AMCOW); African Ministerial Conference On Meteorology (AMCOMET), Expert centres for water science and technology promoted by New Partnership for Africa's Development (NEPAD); Regional Economic Communities in Africa; African Space Agencies; AMESD-MESA; TIGER; AFREF; AfricaArray; TrigNET; ARSIMEWA;AARSE; African Water Academy; Groundwater Commission of Africa and African Network for Basin Organizations, Pan African University	• Providing political direction regarding water management issues across Africa • Ensuring the provision of African climate services data to African stakeholders • Networking among African stakeholders involved in IWRM • Capacity building
Regional	Trans-boundary River Basin Authorities (e.g. Volta Basin Authority and the Réseau Africain des	• Networking, developing and implementing regional water

Level	Type or name of organisation	Interests
	Organismes de Bassin); Regional and trans-boundary organisations; Remote Sensing Centres in Africa (e.g. AGRHYMET, RCMRD, RECTAS); African meteorological centres of excellence (e.g. Institute for Meteorological Training and Research)	management plans in Africa including capacity building. • Potential providers of information in support of water management plans. • Provision of in-situ networks for climates services • Capacity building.
National	Ministries of Water Resources, National Meteorological and hydrological services, Water Resource management authorities, Soil conservation agencies, Hydropower agencies, Water supply including purification, industrial and urban water sectors, other relevant National institutions, Local universities; Research institutions.	• Developing and implementing national water management plans in Africa. • Real-time climate data collection. • Provision of in-situ networks for climate services. • Scientific research on water related issues in areas of jurisdiction. • Capacity building.
Local	River basin agencies; Local meteorological and hydrological services; Operators of irrigation and hydropower schemes; Water User Associations/Groups	• Developing and implementing basin management plans in Africa. • Real-time climate and water data collection. • Provision of in-situ networks for climate services. • Capacity building.
International Financing Agencies and donors	African Water Facility; African development Bank; European Commission; World Bank; Global Environmental Facility; Relevant development agencies	• Provision of resources aimed at supporting African countries to achieve Millennium and Sustainable Development Goal water targets
International and local Non-Governmental Organisations	WaterNET; Water Harvesting and Soil Conservation Networks; Health Agencies; Oxfam	• Capacity building • Water advocacy • Community based mobilisation

Within Sub-Saharan Africa the water sector is probably the most advanced in terms of incorporating climate services into strategic planning, at least in the more water-scarce countries (WMO, 2006). This is mainly because:

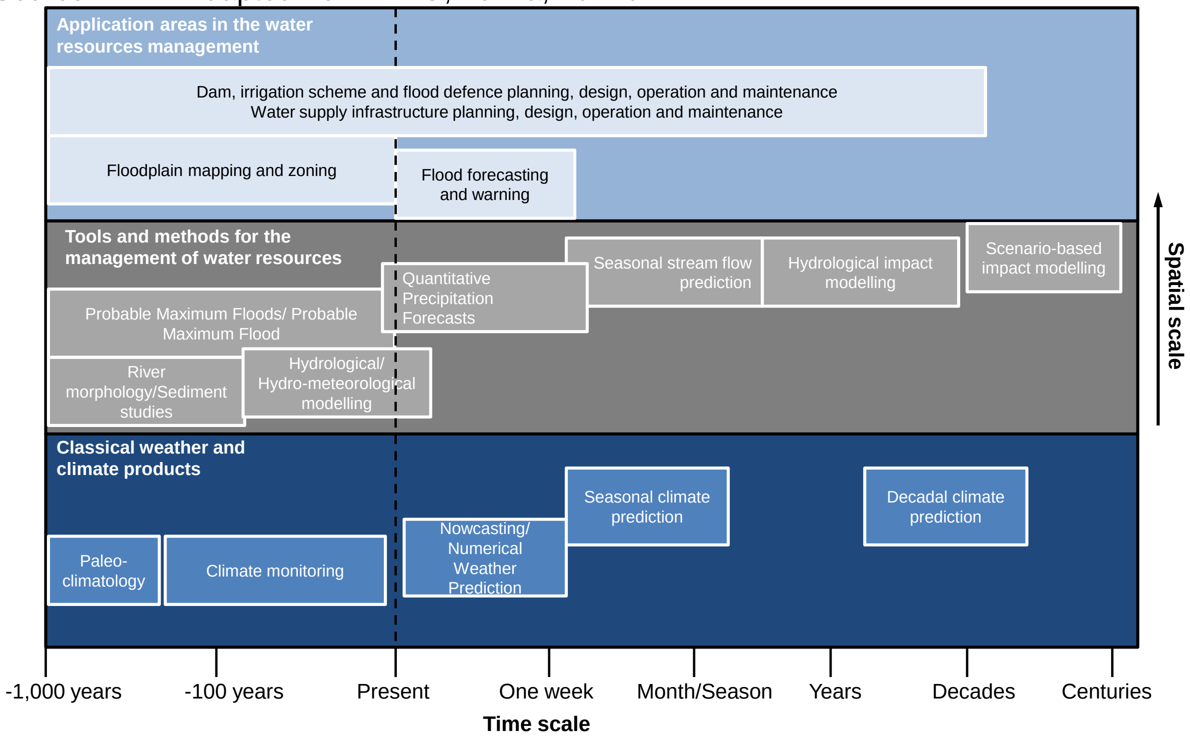
- The region experiences a particularly high level of hydrological variability, with large regional, seasonal and decadal changes in precipitation that has a significant impact on water resources (World Bank, 2014);
- The high cost and long timescale for the construction of large infrastructure projects (WMO, 2006) such as:
  - Dams;
  - Water supply schemes for large cities;
  - Irrigation schemes;

- The extent of political support and awareness for IWRM initiatives.

To improve water management through the use of climate services, it is important to identify the services required, the tools and methods that they inform and how they can be applied in IWRM. Relevant climate services will include climate predictions products, seasonal climate outlooks, downscaling products at various levels and different downscaling methodologies. Figure 3 provides an overview of the application of different climate services produced at different time scales that can be used to inform a variety of tools and methods (e.g. hydrological modelling) that are applied in the management of water resources.

Figure 3 Application of different climate services using data produced at different time scales for use in water resources management

Source: Adapted from WMO, 2014a, 2014b



Notes: *"Probable Maximum Floods/Probable Maximum Flood*" refers to specific engineering calculations that are completed to for dam spillway design based on available climate information.

Although climate services in sub-Saharan Africa are generally deteriorating, there are countries where progress is being made as Box 2 illustrates.

Box 2 Programmes to strengthen climate services

Cameroon is currently implementing several programmes to strengthen water monitoring. These include:

- The African Environmental Monitoring for Sustainable Development (AMESD), a pan-African initiative;
- A programme for the assessment of water resources that is being implemented by the Hydrological Research Centre intending to rehabilitate and reinforce the monitoring network for surface and groundwater;
- A programme for the conservation of coastal and maritime ecosystems.

Cameroon states that the "*Hydrological processes are presently better managed with the help of the treatment of planet observation data made available through servers within the framework of the AMESD programme. In addition, the hydrological network in Cameroon is gradually becoming functional with the help of programmes [such as] the Niger-Hycos*". Some countries, such as Rwanda, are reporting improved water monitoring and assessment systems through hydrological networks.

(Source: AMCOW, 2012)

In flood risk management there are specific requirements to estimate peak flood flows for infrastructure design (flood defences, bridge crossings) and floodplain mapping as well as flood forecasting and warning services. Climate information needs to be combined with vulnerability data for many applications (see Disaster Risk Reduction section). For drought risk management there are similar requirements for design and operational climate services. For water resources management climate and hydrological data are required to estimate resource potential, sustainable yields and allocation of resources through licensing or permitting at the catchment scale.

Climate change impacts assessment is particularly important for screening and design of large infrastructure projects and there is a significant grey literature offering guidance on how to incorporate climate change into decision making (e.g. DFID funded Global Water Partnership, DFID/NERC UPGro Programme and AMCOW).

Water: Gaps identified in the literature review

In terms of user requirements for climate services with respect to IWRM, the recurring needs that appear in various literature (e.g. ClimDev-Africa, 2013; Dinku et al., 2014; Donkor and Wolde, 2012; WMO, 2006, 2014a, 2014b, 2014c, 2014d) can be summarised as follows:

- A stronger enabling environment to support capacity building and international, regional and national collaboration in water management.
- Building national capacity in national hydro-meteorological services from data observation and retrieval through to long-term climate projections (see the Observation and Monitoring and Research, Modelling and Predictions section)
- Digitising and rescuing historical hydro-meteorological data (see the Observation and Monitoring section)
- Improving the hydro-meteorological monitoring network and data management and use (see the Observation and Monitoring section)
- Improving the collection and exchange of climate data including IT infrastructure to support remote access to data.
- Enhancing application of satellite observation data (e.g. Niger HYCOS)
- Improving the capacity of organisations for regional data management
- Developing a climate information partnerships between national hydro-meteorological services (See the UIP Section)

Disaster Risk Reduction (DRR)

The GFCS anticipates climate services related to hazard, risk or vulnerability mapping, early warning systems and risk based insurance products under the heading of Disaster Risk Reduction (DRR). Many of the user requirements for DRR were reviewed in the DFID SHEAR scoping study (Lumbroso et al., 2014) and this review build upon that work.

Disaster risk reduction (DRR) is the concept and practice of analysing and reducing the causal factors of disasters by decreasing exposure to hazards, lessening vulnerability of people and property, improving management of land and the environment, and enhancing preparedness for adverse events (WMO, 2014a). In terms of DRR this summary focuses on the two natural hazards that have the greatest humanitarian and economic impacts in sub-Saharan Africa; droughts and floods (CRED, 2013; Lumbroso et al., 2014; ARC[12]). This brief review focuses on the climate services requirements of vulnerable communities to floods and droughts in order to increase the resilience.

Droughts

Droughts have a significant impact in sub-Saharan Africa. This is because approximately 80% of poor people in the region depend on the agricultural sector for their livelihoods and rain-fed farming dominates agricultural production in sub-Saharan Africa, covering around 97% of the total cropland (Calzadilla et al., 2009). This form of agriculture is highly exposed to rainfall variability, which in sub-Saharan Africa is high across a range of spatial and temporal scales (Conway et al., 2008).

Drought warning systems

There has been considerable progress made in measuring drought and developing of food insecurity early warning systems, particularly those that look a few weeks or months ahead, based on a more nuanced understanding of drought and better regional climatology (Shepherd et al. 2013). Various authors (e.g. Nyabeze, 2011, Nyabeze et al., 2011; Graham et al., 2012; Iglesias and Garrote, 2012, UNESCO-IHE, 2011; UNDP, 2012; Sheffield et al., 2014) have discussed the status of drought early warning systems for Africa. Generally there is a need to improve the monitoring networks, forecast skill for extreme events, temporal aspects of the forecasts (e.g. season onset, duration, and dry spell frequency) and to improve the communication to the most vulnerable.

Progress on drought early warning systems is highly variable in sub-Saharan African countries although some regional systems have been reasonably successful. Notable examples include Famine Early Warning System Network (FEWS-NET) and the Food and Security Nutrition Working Group (FSNWG), which both provided timely information on the food insecurity crisis in East Africa in 2010 and 2011 although there has been some criticism as to how warnings were disseminated (Ververs, 2011). Some recent work indicated stakeholders based in the majority of countries in the Horn of Africa and the Sahel view drought warning systems as being “moderately effective” (Lumbroso et al., 2014).

Drought risk assessments

In terms of drought risk assessments recent engagement with stakeholders indicated that there are only three Sub-Saharan African states (Mali, Niger and Mozambique) where drought risk assessments are considered to be “effective” (Lumbroso et al., 2014). Africa Risk Capacity (ARC) has developed an index-based insurance product at sovereign-state level to allow states to pay a premium to join a pooled-insurance scheme. A country receives a pay out if predefined rules regarding the impact of a drought are met (ARC[13], 2012) and how these were acted on (Hillier and Dempsey, 2012). This scheme is not yet fully operational and it does not account for other risk factors that exacerbate drought and household vulnerability during a rainfall season, such as increasing food price.

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[12] Africa Risk Capacity: The Cost of Drought in Africa
http://www.africanriskcapacity.org/documents/350251/371107/ARC_Cost_of_Drought_EN.pdf

[13] Africa Risk Capacity: Overview
http://www.africanriskcapacity.org/documents/350251/371107/ARC_Overview_Brief_EN.pdf

Floods

Flood warning systems
Engagement with stakeholders has revealed that there are a significant number of flood forecasting initiatives ongoing in Africa, but information is not easily accessible (Thiemig et al., 2011). Work carried out recently found that in terms of stakeholder perceptions there are only three states in sub-Saharan, (South Africa, Cameroon and Djibouti), where early warning systems for floods were adjudged to be “effective”, and only a further six (Ghana, Kenya, Malawi, Madagascar, Mozambique and Tanzania) where early warning systems are “moderately effective” (Lumbroso et al., 2014).

Flood risk assessments
In terms of assessing risk, in sub-Saharan Africa only seven states were found to have “effective” risk assessments for floods. Of these seven countries, South Africa has produced flood hazard maps for the areas of highest risk for at least the past two decades and in Mozambique, since the floods of 2000. Flood hazard mapping in sub-Saharan Africa is piece-meal and flood risk mapping, where the exposure and/or the vulnerability of people is taken into account, has not been widely undertaken (Lumbroso et al., 2014).

User requirements

The sections below briefly outline some of the users’ requirements with respect to climate services for DRR.

The perspectives of a humanitarian organisation
A recent paper by the International Federation of Red Cross and Red Crescent Societies (IFRC), (see Coughlan de Perez & Mason, 2014), gave the following principles that should be followed in terms of the provision of climate information for humanitarian organisations working in low income countries:

- Give precedence to the needs of the users - Humanitarian organisations have well-established operating procedures that govern their decision-making. Climate services are often not perceived as being useful if they do not provide information that is actionable within their current systems;
- Only provide information that is relevant to the context of the user - The information provided needs to be directly relevant to the decisions to be made. The extent to which it directly addresses users’ questions determines the uptake;
- Forecasts should be actionable – Climate services are only useful to a humanitarian organisation if they increase the efficiency of their disaster mitigation or response. Many humanitarian organisations are used to responding to disasters where a crisis already exists or is imminent. The chances of their actions not yielding the desired outcomes are small. For example, because the IFRC’s current system does not provide tools for acting based on seasonal probabilistic information, some individuals within the IRFC fear personal culpability for making unconventional decisions based on new, probabilistic information (Suarez and Tall 2010; Coughlan de Perez & Mason, 2014);
- Partnership in the design and use of climate services - The successful use of climate services by humanitarian organisations is often founded on trust and confidence in the quality and reliability of the information being provided. The joint design of information and decision support tools promotes ownership and encourages their use.
  (Source: Coughlan de Perez & Mason, 2014)

It is important to note that climate scientists often see the potential value of climate services in humanitarian work and other sectors (Coughlan de Perez. and Mason, 2014). However, within humanitarian organizations, the same vision does not necessarily exist (Dilling and Lemos 2010). It should also be noted that the IFRC and its national societies have a specific mandate to support national disaster response. Other organisations who undertake humanitarian activities are not regularly included within disaster response planning at international, regional or national levels.

In sub-Saharan Africa, Regional Climate Outlook Forums (RCOFs) were initiated in 1997 and have been the primary mechanism for generating and disseminating seasonal climate forecasts (Ogallo et al. 2008). However, there is a reported tendency for the consensus of the forums to hedge on the side of caution when issuing drought forecasts (Hansen et al. 2011).

There is a clear need for stronger links between the meteorological and disaster risk reduction community (Wilton Park, 2014). Moreover, there is quite a lot of duplication of effort in certain regions of sub-Saharan Africa (e.g. the Horn of Africa). More collaboration could lead to more efficient use of scarce financial resources (Wilton Park, 2014).

The perspectives of vulnerable communities
The absence of dialogue between providers of climate services and vulnerable communities can be a barrier to the use of climate services (WMO, 2014a). For example, forecasts may not match the information needs and decision-making timelines of local actors and may be perceived as too technical at the community level (WMO, 2014a). Conversely, ensuring that communities receive, understand and are able to act on warnings of impending hazards may be vital to their survival.

In many cases in sub-Saharan Africa the communication of climate services is a one-way process, with those issuing warnings not fully aware of the needs and priorities of vulnerable communities, and therefore not responsive to their needs. Warning information is poorly disseminated to poor communities with limited capacity to respond (Gwimbi, 2007). There is also a need to strengthen local communities' capacity to play a key role in information dissemination (Gwimbi, 2007).

Methods via which climate services such as early warnings are communicated are important. For example in West Africa rural communities have proposed ideas to improve the communication of early warnings. These have included:

- Sending out SMS messages not only in French, but also in Wolof and Arabic;
- Writing the forecasts on blackboards placed in strategic locations and in village forums;
- Publicly designating people to serve as community relays of climate information and weather alerts.
  (Source: Tall et al., 2014)

Although there have been many early warning initiatives in Africa, the warning information from these is often not easily accessible especially to the most vulnerable groups in society (Lumbroso et al., 2014)

Summary of user requirements for climate services with respect to disaster risk reduction

In terms of user requirements the main issues related to climate services related to DRR for use by vulnerable communities can be summarised as follows:

- Format – Climate service information such as early warnings are often too technical and not disseminated in a suitable format for many end users (Ouma, 2014; Nyabeze, et al., 2011). The language employed is often inappropriate (national language where directly affected users employ local languages) or too technical.
- It is vital that the probabilistic nature of the forecast is conveyed, together with supporting understanding and appropriate application of the levels of certainty within the forecast. Without this, the forecasts risk raising vulnerability and losing trust where the forecast turns out contrary to users' expectations.
- Assisting decision making – Providing climate information in a way that assists decision making by individuals and organizations is important . Effective climate services require appropriate engagement along with an effective access mechanism and must respond to user needs (WMO, 2014b). There is often a significant under-use of climate services, partly because their translation into recommended actions has been poorly developed (with the lack of involvement of users in their development a contributing factor);
- Communication routes – A range of communication methods is required to effectively disseminate climate services;
- Spatial scale – For example, many drought forecasting products are produced a regional scale and thus are not spatially specific enough for many end users such as small-scale farmers;
- Temporal resolution – In terms of rainfall quantities, normally only the total quantity of rainfall over a season is forecast. Many users require the rainfall pattern in terms of the rainfall distribution over the growing season;
- Use and incorporation of indigenous forecasts – Linking traditional and community based forecasts and warnings with scientific ones can provide benefits. It ensures that local knowledge and expertise is recognised, links external and existing knowledge systems and improves the ownership of the resultant information (Masinde, 2014, Mountfield, 2014; IFRC, 2014).

DRR: Gaps based on the literature review

- Improvements in the format and communication related to climate services with a focus on outputs that aid decision making, including appropriate use of probabilistic information. (e.g. Ouma, 2014; WMO, 2014)
- Better drought monitoring networks and warning systems and effective dissemination to vulnerable communities (e.g. Lumbroso et al., 2014; Ververs, 2011); including information on the timing of rainfall rather than just seasonal totals (see the RMP section)
- Improve the quality, access to and effectiveness of flood forecasting systems (Lumbroso et al., 2014)
- General strengthening of the links between meteorological and DRR communities (Wilton Park, 2014) (See the UIP Section)
- Improve the dialogue between vulnerable communities and producers of weather climate information and the capacity of local communities to respond to warnings (e.g. Gwimbi, 2007) (see the UIP Section)
- Development of climate services specifically for women (Aguilar, 2009; Kinoti, 2008; Tall, 2014) and other marginalised groups, including pastoralists and older people.

Evidence from various literature (e.g. Tall et al., 2014; Coughlan de Perez and Mason, 2014; Kinoti, 2008) indicate that in developing climate services for low income countries the following steps should be carried out:

1. Involve users in the co-design, co-production and co-evaluation of climate services in order to address their needs.
2. Establish partnerships that bridge the gap between the service providers, relevant researchers and users.
3. Use diverse communication channels (e.g. various media, ICT, SMS) to bridge "the last mile" in effectively communicating.
4. Continuously assess how the quality of service delivery can be improved incorporating feedback from users to ensure that they meet their needs.
5. Ensure equity by engaging proactively with the requirements of the most vulnerable and women, from the commencement of the design of climate services

A proposed integrated framework for designing, producing, communicating and evaluating climate services for users in low income countries is shown in Figure 4.

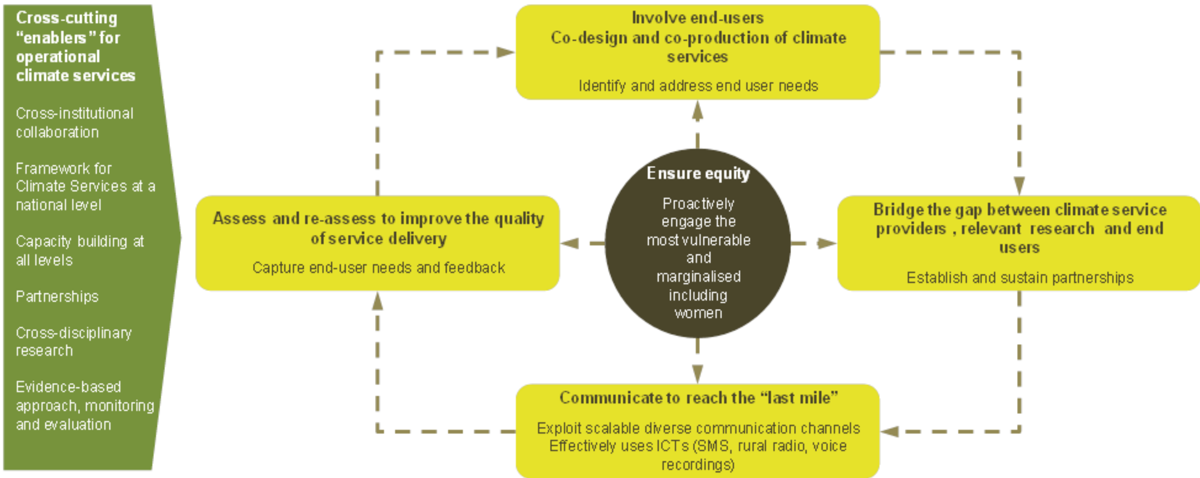

Figure 4 Proposed integrated framework for designing, producing, communicating and evaluating climate services for users in low income countries

Source: Adapted from Tall et al., 2014

Energy

The GFCS does not include energy as a priority sector but there is a strong interest in climate services partly linked to the development of large 'power pools' across Africa that aim to diversify power production and enhance resilience. In addition this research area was identified as a research gap (Wilby, 2014) and is likely to be prioritised in the later stages of the GFCS programme.

In developed economies the energy sector is one the largest users of climate information and related services. Terrestrial and marine climate services are required to support the design of energy infrastructure. Both energy supply (wind, tidal, nuclear, hydropower) and demand (for heating and cooling) are sensitive to weather and climate variability and a range of operational services are provided by NMHS and the private sector to meet the needs of the sector. Examples include short term forecasting of marine conditions, winter seasonal forecasting of wind energy and climate risk assessments of critical energy infrastructure (Met Office, *pers. comm*.)

In Africa, energy production is still primarily based on oil, biomass, gas and coal[14] and access to electricity grid is limited in Least Developed Countries (LDCs). Therefore climate sensitivities are mostly on the supply-side and particularly for the growing renewable energy sector and in locations where there is significant coastal infrastructure development for oil or gas[15]. Energy demand across the region generally outstrips supply and in many countries is projected to rise exponentially; any climate services that can help to balance supply and demand and improve the resilience of existing or new infrastructure and networks are likely to be welcomed by energy providers and governments.

Hydropower

The electricity supply in several African countries is largely based on hydropower (e.g. Ethiopia, Malawi, Zimbabwe, Zambia), which is sensitive to climate and changes to river flow. There is considerable anecdotal evidence on the lack of (or difficultly gaining access to) baseline climate and hydrological information for water resources management. Climate information is needed for screening the location of new hydropower sites, developing design conditions, water resources allocation and climate change risk assessments.

There is strong evidence that hydropower production is sensitive to climate variability and reduced significantly during droughts and that production is affected by water scarcity in non-drought years, particularly where upstream abstraction is not strongly regulated and licences/permits are not enforced. Understanding climate variability and baseline risks appears to be of more immediate concern for scheme operators and designers than future climate change. This requires access to high quality historical data on precipitation, evapotranspiration and river flows (Lumbroso et al., 2014).

Seasonal forecasts are used by some river authorities and hydropower operators in West Africa[16], for example the Met Office Hadley Centre provides seasonal predictions, issued before the rainy season begins, which give good forecasts for the accumulated rainfall over large river catchments in parts of West Africa (Met Office, *pers comm*). This work is being used by the Volta River Authority (VRA) for aiding management of hydro-electricity generation. According to the VRA the lake inflow prediction system forms an integral part of annual planning for hydroelectric generation capacity (Kwaku Wiafe, *pers comm*).

The sustainability of existing hydropower and the increasing number of new projects[17], such as the Grand Renaissance Dam in Ethiopia, has been challenged in the context of climate change, which may reduce flows or increase erosion/sedimentation in some African rivers and subsequently impact hydropower yields. Recent studies on the impacts of climate change on hydropower resource potential in Africa highlight the considerable uncertainties and suggest a decline in some parts of Africa, with the exception of East Africa (Kumar et al., 2011; Hamududu and Killingtveit, 2010). A recent review for DFID suggested that more guidance is required in including climate change in hydropower design alongside other socio-economic factors that affect performance (Lumbroso et al., 2014).

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[14] An overall balance for Africa is available from the International Energy Association http://www.iea.org/Sankey/#?c=Africa&s=Balance

[15] This is based on an internal Met Office workshop and our own knowledge of consultancy projects in Africa for the energy sector.

[16] Seasonal forecasts tend to be better in the tropics than at mid latitudes because the weather in the tropics is particularly dependent on slow variations of ocean conditions which are predictable up to six months ahead.

[17] The Programme for Infrastructure Development in Africa (PIDA) has set out ambitious plans to increase hydropower by 54000 MW and water storage by 24000 km^3; most development, to date, has not considered the potential impacts of climate change.

Energy and urban infrastructure: Gaps based on the literature review

- Development of a climate services programmes specifically for (i) the Sub-Saharan African energy sector, including hydropower, wind, solar and oil and gas and involving the private sector and national meteorological services and/or (ii) African coastal cities
- Development of information and services to support major new hydropower development, such as new historical gridded data sets for precipitation and evapo-transpiration (see the Observations and Monitoring section)
- Promotion of African research into climate resilient infrastructure in cities (Wilby, 2014); funding of universities and research institutes to develop a better understanding of risks and new climate services (see the Research, Modelling and Prediction section)

Urban infrastructure

The GFCS does not include urban infrastructure as a priority sector but urban environments are particularly relevant for health, water and disaster risk reduction. It was also identified as a research gap (Wilby, 2014). Urban infrastructure includes spatial planning, industrial and commercial buildings, transport (roads, rail, ports, airports), water (treatment and wastewater plants, drainage networks) and energy (sub-stations, networks).

There is less literature on climate sensitivity and future risks to African cities than in the flood, water and general DRR literature, although there are a growing number of research projects in this area (e.g. KCL and International Alert undertaking a DFID funded project in Nairobi on DRR and conflict, as well as in major cities in West Africa).

SECTION 3

User Interface Platforms

The UIP 'is the Framework pillar that provides a structured means for users, climate researchers and climate service providers to interact at the global, regional, and national levels to ensure that the GFCS meets user needs for climate services'[18]. The UIP aims to: (1) build dialogue, (2) improve climate literacy in the user community, (3) identify optimal methods for obtaining feedback from user communities and (4) develop monitoring and evaluation measures[19]. 'The UIP is neither an institution nor a stand-alone entity'[20] but an enabling space and 'a collection of methods, means, approaches, and processes of systematic and mutually beneficial collaboration.'[21]

The creation of relevant, credible, legitimate climate information requires platforms which bring together expertise from across knowledge sources, sectors, disciplines, risks, levels and timeframes of decision making. As such, UIPs need to be able to support a complex

[18] P1, Annex to the implementation plan of the GFCS – User Interface Platform Component.
[19] P8-9, GFCS framework.
[20] P3, Annex to the implementation plan of the GFCS – User Interface Platform Component.
[21] P3, Annex to the implementation plan of the GFCS – User Interface Platform Component.

web of multi-directional linkages between 'providers' and 'users' of climate information[22], as illustrated within Figure 5 below.

There have been significant investments in the creation of national frameworks, including NAPAs, national DRR platforms and national climate policies. There has been much less focus on the implementation of these together with their operationalisation at sub-state levels. 'The principal challenge faced by the GFCS in its initial stages will be to demonstrate its ability to add value'[23]. Given that realization of this added value is in large part reliant on establishing effective UIPs, it could be argued that this Pillar is not sufficiently prioritized within the list of proposed investments across the GFCS[24]. While recognizing the vital importance of developing two-way channels of communication and co-production of climate information, without sufficient investment in developing continuous two-way frameworks for provider-user communication, there is a danger that the Framework and initiatives to strengthen climate services which can better support users remain focused on what provider and external agencies consider users' needs to be.

There are important initiatives for establishing channels for dialogue between the providers and users of climate information at regional, national and sub-national level, but in many instances these remain irregular or dependent on external resources. The Economic Community of West African States (ECOWAS) has, for example, indicated its support for creating regional frameworks for strengthened dialogue between the providers and users of scientific information on risk and resilience building[25]. *Regional partnerships also include health outlook forums such as MALOF (Malaria Outlook Forum) (WMO, 2014h – Health Exemplar to the User Interface Platform of the Global Framework for Climate Services, 2014).* Many countries also have national mechanisms for integrating climate and health, including climate and health working groups, a forum established in Africa since 2008 (WMO 2014h). A number of countries, such as Tanzania, have established National Climate Outlook Forum. Here the Tanzania Meteorological Agency coordinates a forum together with technical experts from across key ministries, to present the seasonal forecast, discuss implications for each sector and agree on a consolidated, cross-sectoral advisory[26]. In line with the decentralisation process pursued in Kenya, Kenya Meteorological County Directors of Meteorology have been employing the Participatory Scenario Planning approach developed by CARE to support the development of county-specific cross-sectoral advisories based on the seasonal forecast[27].

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[22] P3, Visman, E, Knowledge is power, ODI HPN Network Paper 76, 2014, http://www.odihpn.org/hpn-resources/network-papers/knowledge-is-power-unlocking-the-potential-for-science-and-technology-to-enhance-community-resilience-through-knowledge-exchange

[23] Pv, GFCS DRR Exemplar and p12, Annex to the implementation of the GFCS – User Interface Platform Component.

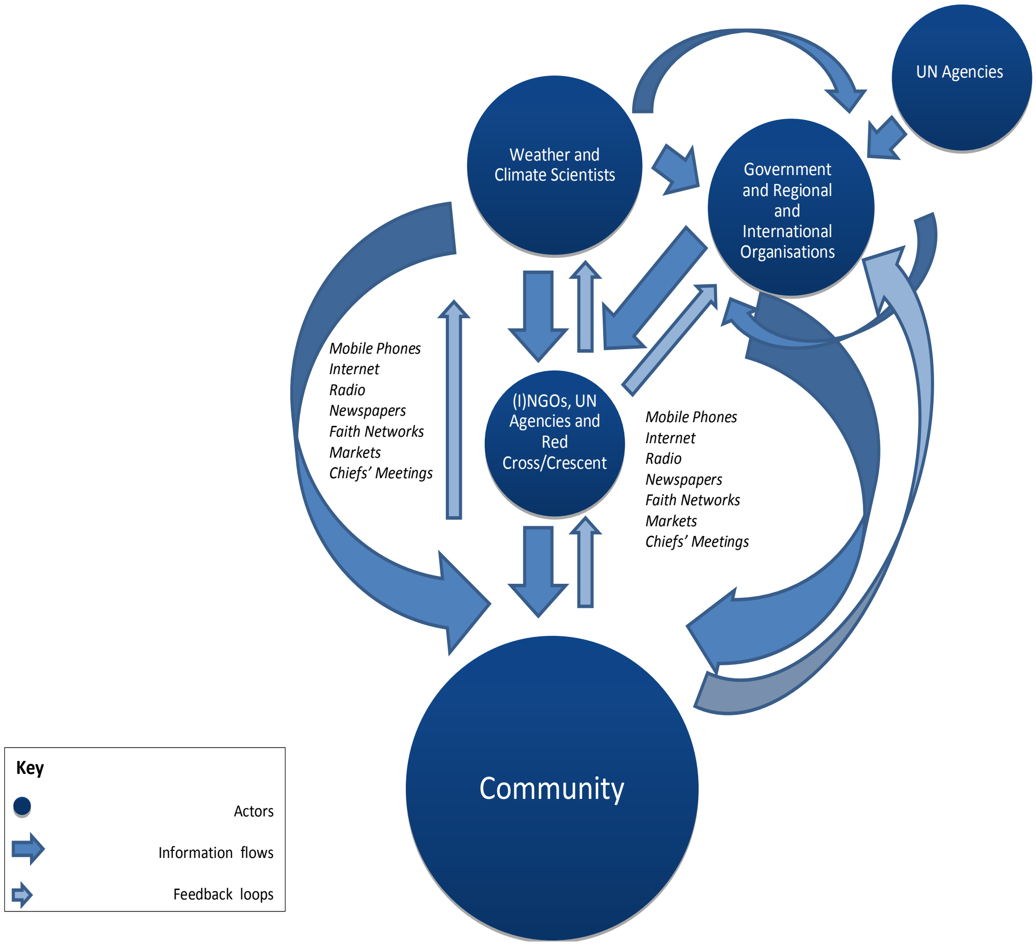
[24] P47, WMO 2014b, Main Implementation Plan. UIP is the third from bottom in terms of GFCS investments, below investments in climate change centres and observations.

[25] ECOWAS Regional Workshop on Information Sharing and Early Warning Coordination Mechanisms for Disaster Risk Reduction (2013) http://www.preventionweb.net/files/36258_ecowasdrrworkshopreportenglish.pdf

[26] Dr Chang'a, TMA, Personal communication.

[27] CARE (2014) Facing uncertainty: the value of climate information for adaptation risk reduction and resilience in Africa, http://www.careclimatechange.org/files/Facing_Uncertainty_ALP_Climate_Communications_Brief.pdf

Figure 5 Two-way flows of weather and climate information to support community resilience [28]



As the GFCS' name suggests, it is focused on creating a global framework, with more detailed coverage of the framework mechanisms at the global and regional levels and much less detail on the national and sub-national level, recognizing both that this is a prerogative of individual national governments and the importance of developing context relevant frameworks for engaging with users. While recognising the need for working on the framework simultaneously at all levels, the alignment of the GFCS's top-down approach with current infrastructure is better in some regions than in others. For example, the framework intends for regional climate centres to support national frameworks for climate services. However, in southern Africa the capacity of the regional centre is currently much less than some individual national institutions, while in Central Africa the regional centre is still at a planning stage. Some situational analysis of regional centre capacity and working arrangements with NMHSs would help clarify efficient resource allocation. Additionally, while significant resources are in some cases being invested in regional climate centres and national meteorological agencies, these do not seem to have yet led to a strengthening of the human resources and capacities to cover key areas required for climate services,

[28] Visman and Carpenter 2012a. A Proposed Framework for Systematic Use of Weather and Climate Information across Humanitarian, Disaster Risk Reduction and Development Communities, (2012) Workshop for the UK Government Office for Science Reducing Risks of Future Disasters, http://www.elrha.org/uploads/framework_for_use_of_weather_and_climate_inforacross_hum_drr_and_dev_no_pic.pdf

including in such areas as risk management, communications, user engagement and monitoring and evaluation.

In terms of creating an effective and sustainable UIP, the GFCS recognizes that it will be vital that climate services tap into relevant existing communities of practice and are integrated within existing frameworks across sectors and decision making levels[29]. As detailed within the GFCS Framework Exemplar for DRR, for example, climate services can be integrated within existing frameworks for DRR at international, regional and national levels. Integrated approaches to risk management support the development of more coherent cross-sectoral, multi-partner approaches for managing different types of risks and vulnerabilities as well as better understanding the complex inter-linkages between them. The GFCS has a number of pilots underway developing integrated systems of climate service delivery. The GFCS Adaptation Programme in Africa, for example, aims to support an integrated approach across the four initial priority areas (DRR, health, agriculture and food security and water) and is intended as 'a model of how agencies can work together under the GFCS umbrella'[30] While recognising that these pilots were only established in 2013, they do not yet appear to have mapped out the cross-sectoral, cross-ministerial, multi-partner and multi-scalar frameworks, business plans and comprehensive communications strategies required to underpin both the scale up and out of initiatives piloted in specific locations and with particular user and livelihood groups.

The funding mechanisms for supporting increased climate resilience are complex and insufficiently coordinated[31]. There is a lack of comprehensive mapping of existing programmes and projects related to climate services, together with an absence of ground truthing of their reach or assessment of their effectiveness and durability. This prevents national, regional and international institutions from maximising current and proposed investments and ensuring adequate accountability to both users and tax payers in donor agencies' nation states.

Although some actors in the production of climate information have well defined mandates (e.g. WMO GPCs and Regional Climate Centres) there is a lack of guidelines and minimum standards governing the roles and responsibilities of the wider range of stakeholders engaged in the provision of climate services, including partnering scientific institutions, local and national governments, the private sector, donors and operational agencies. There are a number of important initiatives to establish guidelines and minimum standards on use of climate information[32], but their development, uptake and monitoring is not widespread across sectors and decision making levels.

As noted in the Users section, there is equally a need to develop shared principles amongst providers and users to build the trust and respect required to build confidence in using probabilistic information to support appropriate decision making. There have been a considerable number of pilots which have sought to engage with local and indigenous climate knowledge. While a number of these including ICPAC's project 'linking traditional and modern forecasts in Western Kenya' have promoted increased interest in and uptake of

[29] P4, WMO 2014c, Annex to the implementation plan of the GFCS – User Interface Platform Component.
[30] P2, GFCS Adaptation Programme in Africa, Programme Brief, (2013).
[31] Wilby p17-18; McLaren, C, Climate change science and research, Review UKCDS 2012 unpublished
[32] Pv and p21 Wilby; Red Cross Red Crescent Climate Centre, 2013, Minimum standards for local climate-smart disaster risk reduction, http://www.climatecentre.org/downloads/File/Minimum%20Standards/Minimum%20Standards%20for%20climate-smart%20DRR%20%202.0%20NOV%202013.pdf; Duncan, M et al. 2014, Guidelines for integrating science into humanitarian and development planning, http://www.ukcds.org.uk/resources/integrating-science-into-humanitarian-and-development-planning

meteorological information, there have been few initiatives focused on systematically assessing how local knowledge can support understanding, uptake, appropriate application and downscaling of meteorological information.

Strengthening ties with the private sector, as well as between academic communities and practitioners, are common concerns of the GFCS, the framing of the post 2015 Hyogo Framework and a number of significant programmes including DFID BRACED. The GFCS can benefit from linkage with these complementary initiatives.

The GFCS framework recognizes the need to address the current 'considerable weaknesses in implementing and exploiting data communications systems in several parts of the world'[33]. A consultation undertaken in 2010 warned that '(t)he ability of African citizens to respond effectively to climate change will be determined by the quality of the information available to them and how easily they can access it.'[34] However, there is uncertainty about which communication methods are most appropriate and cost effective under which circumstances[35]. Research on communicating with those most at risk highlights the importance of establishing two-way communication and feedback mechanisms, developing multi-channel approaches, for example combining radio phone-in shows with social media, and engaging communications expertise and recognizing local capacities in this area[36]. Also highlighted was the importance of linkage with non-news channels, employing creative approaches, such as drama, tailored to specific user groups, and working with trusted social networks, particularly religious and faith leaders.[37]

There is a lack of shared understanding of the role of 'intermediaries' within climate services, who they are, what their role is and the capacity building which they require to fulfil their intermediary roles. There are a range of views regarding the prioritization of investment in boundary organizations (organizations which seek to interpret science on behalf of other organizations) as opposed to building the capacity of existing providers and users. This has major implications for the sustainability of the services created as well as the potential for integrating climate information within decision making. FCFA has, for example, supported the creation of a Coordination, Capacity Development and Knowledge Exchange Unit, which 'understands its role as situated within a boundary-spanning collaboration;'[38]. The important boundary activities undertaken through existing networks, including farmer group representatives, extension services, local radio, religious and faith leaders and non-governmental organizations, in their role as climate services intermediaries have been widely recognized.[39]

Monitoring and evaluation frameworks

There is considerable scope for further investment in developing tools and approaches which enable both providers and users of climate information to be able to better understand and track how best to communicate, support the uptake and application of climate information across decision making processes. IIED has developed the Tracking Adaptation and Measuring Development (TAMD) framework which includes indicators related to 'use of

[33] P25, GFCS Framework.
[34] P19, BBC World Service Trust, (2010), Africa Talks Climate.
[35] P52, SHEAR Scoping Study, 2014 – Lumbroso et al..
[36] BBC Media Action (2012), Still left in the dark.
[37] IFRC, (2011) Beneficiary Communication and Accountability
[38] CDKN/CCKE Unit, (2014), FCFA Inception report: Coordination Capacity Development and Knowledge Exchange Unit.
[39]Jost, C, 2013, Delivery models for climate information in East and West Africa, CCAFS Working Paper no 41.

climate information' (Indicator 5) and 'planning under uncertainty' (Indicator 6) (Brooks, 2011). CCAFS Climate Change and Social Learning group has coordinated a framework to assess how social learning approaches may support climate adaptation and food security. They are seeking to collate learning from across a number of partners willing to employ the tool within their respective projects (CCSL Draft framework, 2014). With integration of climate services being a new component for many humanitarian, disaster risk reduction and development initiatives, support for developing and operationalising robust frameworks for measuring which support shared learning will greatly support efforts to demonstrate the value of investments in climate information services.

The ability to attribute improved resilience and decreased vulnerability to investments in strengthened climate services will be key to building national commitments to budget for and invest in climate services and to promote uptake and systematic application across sectors and user groups. There is need to strengthen approaches for monitoring how climate science research is supporting climate risk management decision making (how it is, for example, strengthening the reliability of climate information and narrowing uncertainties within areas of greatest importance to key decision making processes) and how integration of relevant climate information can support individual and organizational capacities for risk management across timeframes.

User Interface Platforms investment opportunities

The following section outlines some opportunities for investing in User Interface Platforms. These were considered alongside other suggestions from consultation work in the final reports.

Capacity

Developing more inclusive and integrated frameworks for risk-governance: Investment in strengthening integrated frameworks for risk management offers significant, multiple benefits. Progress in the development of regional, national and sub-national frameworks for DRR are patchy and even where they have been developed, participation has not always been inclusive of directly affected groups[40]. Linking development of the UIP – within its focus on creating channels which support two way communication between the providers and users of climate information – with the strengthening of risk management structures at all levels would both enable climate information to be better integrated within existing frameworks which directly support policy and planning as well as supporting more inclusive and comprehensive forms of risk governance[41]. Where national governments and donors recognize the value of UIPs being implemented through existing networks and services, this may enable resources for UIPs to be channelled in ways which simultaneously boost key public services, enabling livelihood groups to benefit from the multiple benefits of more accessible agricultural, health, education, DRR and climate services.

Strengthened systems of accountability on the part of both providers and users of climate services, as well as supporting agencies The GFCS framework recognizes the need to set standards, establish guidelines and clearly delineate responsibilities for providing and using climate services (WMO 2014c). Investment in strengthened service provision

[40] Tall, A, A Patt and F Steffen, Reducing vulnerability to hydro-meteorological extremes in Africa. A qualitative assessment of national climate disaster management policies: Accounting for heterogeneity, Weather and Climate Extremes (2013), http://dx.doi.org/10.1016/j.wace.2013.07.007i ; ECOWAS ref as in footnote above; p8, SHEAR Scoping Study (2014), Global Network of Civil Society Organisations for Disaster Reduction of progress towards implementation of HFA (2009).
[41] P19, Visman 2014

should be linked to the establishment and operationalisation of an agreed framework of accountability on the part of providers, users and supporting agencies[42].

Scaling up: There needs to be much greater investment in developing the national and sub-national frameworks required to deliver user-driven climate services. Where pilots have been effective in supporting more effective use of climate information within decision making processes, there is often a lack of mechanisms for assessing how these approaches may best be continued, supported and scaled up.

Sustainability: Investing in NMHS capacities to develop context-relevant business plans for sustainable, user-led services, together with the communications strategies and capacities, will help ensure that investment in strengthened climate services are sustainable.

Access

Assess the most effective channels for establishing emergency and regular channels of communication with key user groups. Developing communications strategies which can underpin the development of effective UIP requires a comprehensive assessment of the reach and use of existing communications channels, and how these may be best combined to ensure reach. On line platforms, such as the European Climate Adapt network[43] or more international initiatives like weAdapt[44] may facilitate the development of, or support communities of users but these require basic IT infrastructure.

Clarification on intermediaries, who they are and the resources and training required to enable them to be effective: There is a need to ensure investments support the creation of sustainable climate information services intermediaries, building institutional capacities for knowledge exchange within existing providers and users.

Creating systematic channels for user-provider dialogue across sectors at regional, national and sub-national levels There is a clear need to support systematic frameworks for cross-sectoral provider-user discussion across decision making levels and climate timescales. In developing the UIP it will be important to map existing risk management channels and networks at all decision making levels to determine which may best support UIP operationalisation and where there remain significant gaps.[45] Support to such dialogue also requires significant investment in training, both in terms of risk communication for providers, and climate literacy for users.

Communities of practice and regular fora for sharing learning about effective approaches and systems: There is also a need to create systematic channels for sharing emerging learning about those approaches and systems which are proving effective in supporting access to, understanding and application of climate services[46]. Such learning would benefit from supporting cross-fertilisation across livelihood groups, countries, regions and continents. The establishment of such a shared body of learning would benefit from both virtual and face-to-face meetings, including direct interaction with at risk groups. It would also be greatly supported by a comprehensive review of approaches and processes which have been successful in supporting decision making and are proving sustainable[47].

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[42] P21-22, Wilby, 2014.
[43] http://climate-adapt.eea.europa.eu/
[44] https://weadapt.org/
[45] P8, WMO (2014c). Annex to the implementation plan of the GFCS – User Interface Platform Component.
[46] Wilby p 15-16 and P18, Visman, as above.
[47] P8, WMO (2014f). Annex to the implementation plan of the GFCS – User Interface Platform Component.

User Interface Platforms: Gaps based on the literature review

- Further clarity around regional centre role in GFCS; strengthening of regional centres, Ensure the reach of UIPs to all decision making levels and sectors, including sub-national levels to support frameworks inclusive of marginalised livelihoods and groups.
- Investing in NMHS capacities to develop the context-relevant business plans and, communications strategies required for sustainable, user-led services and which support scale up of effective pilots and approaches
- Increase capacities for risk management, user engagement, risk communication and M&E components of GFCS for NMHs and key technical extension services and intermediary networks, and build climate literacy amongst key user groups.
- Develop understanding of how local and indigenous climate knowledge can support and strengthen trust in, understanding and uptake of scientifically sourced climate information see Users section)
- Develop UIPs which simultaneously support more inclusive and integrated frameworks for risk-governance and strengthened systems of accountability on the part of both providers and users of climate services

SECTION 4

Climate Services Information Systems

The mechanisms that routinely collate, store and process information about past, present and future climate – i.e. the operational facility catering to all the climate information needs of users, are collectively described as the Climate Services Information System (CSIS) in the GFCS Implementation Plan. The CSIS forms one of the 5 pillars of the GFCS together with Observations and Monitoring, Research Modelling and Prediction, the User Interface Platform (UIP) and Capacity Development (CD) (Sections 2, 3, 5-7). Successful delivery and use of climate services at all levels down to local level is dependent on a well functioning CSIS making use of all available information from global, regional and national sources.

Many elements of the CSIS are already in place and functioning to various degrees. The GFCS vision is to build on existing infrastructure, strengthening where necessary and filling gaps, to develop a CSIS that can deliver the envisioned mainstreaming of climate information into decision making for all. The CSIS Annex to the Implementation Plan for the GFCS (WMO 2014e) - developed through wide consultation with international experts - describes steps and priorities for achieving this and provides an authoritative benchmark for assessing the status of CSIS entities (e.g. National Meteorological and Hydrological Services (NMHSs) and regional centres) in Africa as well as gaps in service provision of relevant climate information from global centres.

Brief summary of the Climate Services Information System (CSIS)

We first outline the general concept of the CSIS, its functions, scope and components – then focus on its current status for Africa and the key gaps and opportunities and priorities for intervention. Some current deficiencies are specific to Africa (for example, lack of capacity to generate and provide required climate services in many NMHSs and some regional centres), but others relate more to weaknesses in global data provision by global centres (e.g. ease of access to CMIP5 scenarios as well as tools to analyse them and training to interpret impacts). There are also areas where pull-through from the Research, Modelling and Prediction component (Section 6) needs accelerating to bring more user-relevant climate products into operations.

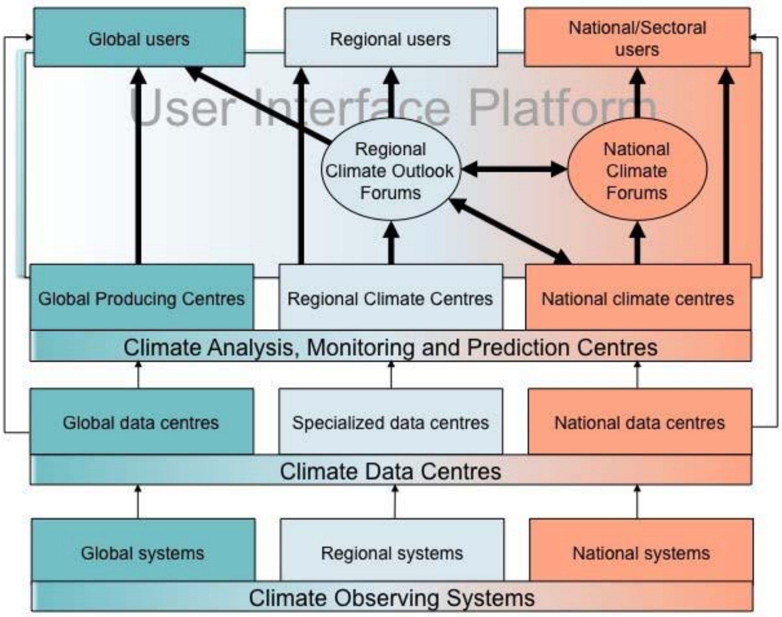
The priority functions of the CSIS include a set of initial, high priority minimum functions: (i) climate data rescue, management and mining; (ii) climate analysis and monitoring; (iii) climate prediction (sub-seasonal, seasonal and decadal timescales); and (iv) climate projection (multi-decadal, centennial timescales). Thus the CSIS is intended to coordinate, using standardised procedures and structures, climate information needs over all timescales from historical periods to time horizons associated with climate change adaptation planning. These functions comprise processes of data retrieval, analysis, interpretation and assessment, attribution, generation and verification of predictions and projections and communication (including the exchange/dissemination of data and products) that will be carried out over a global-regional-national system of inter-linked climate information producers/providers (WMO 2014e).

The key nodes in the interlinking global-regional-national structure are a) advanced global centres (e.g. data centres processing global coverage observational data, and centres making predictions and projections with global coverage); b) regional centres serving regional information needs, including tailoring of information from global centres, and supporting the NMHSs of the region and c) NMHSs with national partners with the role of synthesising information from national, regional and global sources to serve national and sub-national users.

In addition to the global, regional, national nodes of the CSIS discussed above Regional Climate Outlook Forums (RCOFs) and National Climate Outlook Forums (NCOFs) are considered important CSIS entities. RCOFs are typically coordinated by RCCs and provide platforms to bring together countries having common climatological characteristics and facilitate consistency in the access to and interpretation of the available information on current and expected seasonal conditions and to deliver a range of regional climate monitoring and outlook products. RCOFs also facilitate user-liaison efforts, and thus straddle both CSIS and UIP pillars of the GFCS, contributing to their linkages (WMO 2014e). NCOFs extend the benefits and concepts of RCOFs to the national scale, increasing access and use of climate outlooks and other climate information and products by users at the national level and facilitating consistency in the use of climate information by all national user sectors.

The network of entities and activities comprising the CSIS is illustrated schematically in Fig. 6. Knowing user requirements and understanding how users apply climate information will be essential for designing, disseminating and encouraging uptake of CSIS products and services. The CSIS will engage with the GFCS User Interface Platform (UIP) to achieve these objectives (note the RCOFs and NCOFs are important mechanisms for interaction between climate producers/providers and users and thus form part of the UIP). The CSIS will also work with the Observations and Monitoring (O&M) and Research, Modelling and Prediction (RM&P) pillars to obtain the inputs required for its operations.

Figure 6 Data flows (thin lines) and value-added information flows (thick lines) into and through the entities and functions required for generating and delivering climate services. Implicit are the linkages and respective data and information exchanges between climate observing systems, the various climate data centres, and the climate analysis, monitoring and prediction centres. Evident from this figure are the central roles played by the Regional Climate Outlook Forums and their national counterparts in synthesizing and clarifying information fed by the CSIS entities to the various elements of the User Interface Platform. This platform will be more diverse and complex than the three basic geographic scale elements shown here. (WMO 2014e)



Note: The provision of services does not need to focus on the nation state and it may be appropriate to work with other entities, such as transboundary river basin authorities.

The Global, Regional and National nodes in the CSIS - with reference to climate information needs in Africa

Global Centres

Activities conducted by various centres at global scale include: analysis and monitoring; prediction on sub-seasonal, seasonal and decadal timescales and projections to multi-decadal time horizons

Monitoring and analysis – global provision
Africa's climate is influenced by "teleconnections" to variability in the global oceans (e.g. El Nino). Monitoring and analysis of the global oceans and other aspects of the global climate is typically conducted by global centres. Although there is no existing formal structure within the WMO System for the global monitoring and analysis of climate, a number of centres undertake various aspects of global scale climate monitoring and generate a wide range of analysis products. A few examples of such centres are the National Climate Data Centre and National Centres for Environmental Prediction (USA), Tokyo Climate Centre (Japan), Met

Office (UK), European Centre for Medium-Range Weather Forecasts, Beijing Climate Center (China) and Global Precipitation Climatology Centre (Germany).

In the Africa context, considerable use is made of observed sea-surface temperature products to drive statistical prediction models (other variables including low- and high-level winds are also used) – and consequently there is a strong dependency on this global provision. Satellite rainfall estimates generated by some global centres are also fundamental to some monitoring operations in Africa, given the scarcity of station based rainfall observations (see also sections below and Section 5).

CSIS Intervention candidate 1: As suggested in WMO 2014e, there may be value in identifying a suite of standard essential global climate monitoring products that other designated centres could agree to generate and make available on a routine basis. Africa's needs would drive development – though the products would also benefit LDCs in other regions. This could include support for the Global Seasonal Climate Update (GSCU) – an international collaborative initiative, led by WMO, to provide authoritative monitoring of recent global climate (and prediction of temperature and rainfall for the upcoming 3 months) for use by RCCs and NMHSs as guidance in developing regional and national products.

Weather and climate prediction – global provision

Although there has been considerable international collaboration in provision of predictions for some of the range of timescales, substantial gaps exist. Decision making in Africa would benefit from filling these gaps – which are highlighted below.

Days to weeks ahead

Although some of the more advanced NMHSs of the LDCs in Africa run in-house implementations of regional models the vast majority do not have access to the state-of-the-art NWP prediction output that has revolutionalised public service weather warning in developed countries. Even those NMHSs that are running in-house NWP models often do so in an experimental way, with reliance on a single modelling system (BRACED scoping documents). The WMO-coordinated Severe Weather Forecasting Demonstration Projects (SWFDPs, see Box 4 and http://www.wmo.int/pages/prog/www/swfdp//) have opened up access to multi-model products from several state of the art medium range forecasting systems in two time-limited projects in southern and East Africa. The prediction information is synthesised by Regional Specialised Meteorological Centres (Pretoria and Nairobi) and "cascaded" to countries in the region. Training provided by the SWFDP is in two themes, a) training of forecasters to interpret prediction outputs and develop and issue warnings based on operating procedures and b) public weather service training on how to develop an effective warning service and build relationships with country infrastructure and authorities that are instrumental in taking effective action on warnings. Another WMO-coordinated project has used a similar principle, with addition of SMS based delivery - to develop storm warnings for fishing communities on Lake Victoria. The Lake Victoria project is closely coordinated with the SWFDP.

Some global centres provide a range of other unilateral services. Good examples include the specialised products served on a website portal by NCEP CPC and products from high resolution limited area models run by Met Office and the South African Weather Service (SAWS) in partnership (see Table 3 in Section 6).

Box 4 The Severe Weather Forecast Demonstration Project (SWFDP)

The Severe Weather Forecasting Demonstration Project (SWFDP) is successfully strengthening capacity in National Meteorological and Hydrological Services (NMHSs) in developing and least developed countries to deliver improved forecasts and warnings of severe weather to save lives, livelihoods and property. The project has improved the lead-time and reliability for alerts about high-impact events such as heavy precipitation, severe winds and high waves. It has strengthened interaction with disaster management and civil protection agencies, local communities and media. The forecast information is developed and delivered using a process of cascading information:

- Global NWP centres provide available model predictions, including in the form of probabilities, and satellite-based products cut to the project region;
- Regional centres interpret information received from global centres, prepare daily guidance products (out to 5 days ahead) for NMHSs, run limited-area model to refine products, maintain an information website, liaise with the participating NMHSs;
- NMHSs issue alerts, advisories, severe weather warnings; liaise with user communities, and contribute feedback and evaluation of the project;
- NMHSs have access to all products, and maintained responsibility and authority over national warnings and services.

Although much of the guidance input for SWFDP products comes from prediction models run at global centres (Met Office, ECMWF and NCEP), regional expertise in interpretation of the forecasts play an increasing role. Typical products include warnings of heavy rain, strong winds, lightning and marine wave height forecasts out to 3 days ahead. In southern Africa the regional centre responsible for cascading warning products to the national (NMHSs) level is the Regional Specialised Meteorological Centre (RSMC) Pretoria (South African Weather Service). In East Africa the regional centres responsible for the SWFDP are RSMC Nairobi (Kenya Met Service) and Regional Specialised Forecast Centre (RSFC) Dar-es-Salaam (Tanzanian Met Agency). The SWFDP includes a substantial training component covering visits of African forecasters to the prediction centres as well as workshops, training in effective communication of warnings and relationship building with national stakeholders who can take effective action is also covered. The SWFDP has been well received by NMHSs in the regions (personal communication, Ken Mylne).

CSIS Intervention candidate 2: Strengthening and formalising the global-regional-national partnerships and data exchanges involved in SWFDP activities to support progression from demonstration projects to ongoing operational activities embedded within the CSIS and scaling up to other regions.

Sub-seasonal (~50 days) ahead – global provision

Although many centres providing operational seasonal forecasts also generate sub-seasonal predictions, only a few (e.g. NOAA NCEP) make these available in real time. Considerable benefit would derive from international collaboration on predictions for this range along the lines of that begun for shorter ranges (SWFDP – see Box 4) and for seasonal times scales (see next subsection). The sub-seasonal range is particularly crucial to agricultural applications with potential to give information on rainfall onset and distribution at actionable lead times. Predicting for the 50-day range comes with specific research challenges, which is one reason why the operationalisation of predictions has lagged behind those for the seasonal timescale. However, Vellinga et al. 2013 have shown that global model predictions of the onset timing of African rainy seasons have reasonable success levels comparable with those of predictions of the seasonal total – and this supports a drive to accelerate research to bring sub-seasonal forecasts into the operational domain. More work on validation is needed as well refining user requirements and, where justified, developing and trailing products.

Similar applies for multi-annual skill. There is good skill in predicting multi-annual variations in North Atlantic temperature (correlation order 0.8) and North Atlantic Temperature is known to be correlated with Sahel rainfall – but full validation is needed.

Relevant current activities include the current WWRP-THORPEX/WCRP Subseasonal to Seasonal (S2S) research project[48] which is constructing a database of forecasts from international subseasonal forecast systems to conduct research and evaluate predictability. The database will also provide an opportunity to conduct demonstration projects (along the lines of the SWFDP) for this sub-seasonal timescale. The implementation plan includes a specific project addressing research and application priorities for subseasonal prediction for Africa[49] which has the following objectives:

1. Assess the performance of forecasts for 5-40 days ahead using the S2S project's forecast archive, with focus on daily weather characteristics including rain-day frequency, heavy rainfall events, dry spells and monsoon onset/cessation dates, with relevance to agriculture, water resources and public health;
2. Develop metrics for measuring the success of forecasts in ways that are useful to farmers and other stakeholder communities;
3. Improved understanding of the climate modes that drive subseasonal variability in Africa and their representation in models;
4. Connect the international and African climate science communities, as well as operational and user communities in participatory, multi-disciplinary interactions.

Although the S2S project is primarily a research initiative there is a parallel and coordinated WMO-led initiative to pilot an international multi-model of subseasonal forecasts available in real-time (final report of the March 2014 meeting of the WMO Expert Team on Operational Predictions from Sub-seasonal to Longer-Time Scales (ET-OPSLS)[50]. The coordinating centre is the Korean Meteorological Administration (KMA), who also operate the WMO Lead Centre for Long-Range Forecast Multi-Model Ensembles (LC-LRFMME) which serves multi-model seasonal forecast products. Thus sub-seasonal forecasts would be made available on the same platform as the seasonal forecasts – enhancing the seamlessness of delivery and providing an opportunity for real-time trials with users. Development of forecasts for the sub-seasonal range is also highlighted as high priority by the CR4D initiative (Shongwe et al. 2014 – online supplementary material).

CSIS Intervention candidate 3: Support to scale-up the scope of the Africa component of the WWRP-THORPEX/WCRP S2S project, including linkages with SWFDP and seasonal activities, to develop an ambitious demonstration project providing seamless information from days to seasons.

Seasonal prediction (typically to 6 months) – global provision

Provision of global seasonal forecasts using climate model-based systems began around the time of the large El Niño event in 1997. International collaboration in provision, coordinated

[48] Implementation plan available at: http://www.wmo.int/pages/prog/arep/wwrp/new/S2S_project_main_page.html; http://s2sprediction.net/

[49] http://s2sprediction.net/resources/documents/sub-projects/Africa.pdf

[50] http://www.wmo.int/pages/prog/www/CBS-Reports/documents/FinalReport_v1_25Aprr2014_final-master.doc

by WMO, has developed since that time with 12 Global Producing Centres of Long-range forecasts (GPCs) now providing prediction information in common agreed formats and service delivery specifications for use by RCCs, NMHSs and RCOFs in preparation of regional and national seasonal outlooks (Graham et al. 2011). This forecast information is used to a degree by African RCCs and RCOFs and has been shown to bring benefit to decision making (see Graham et al., 2013 and references therein). The main limitations in current usage include:

- reliance on visual “eyeballing” of mapped forecast data, rather than in-house access and manipulation of digital output which would allow combination with current statistical forecast inputs and tailoring to regional and national needs
- under use of longer range information (3 or 4 months lead) where there is evidence of value in long-range warnings of influential events such as El Niño (Graham et al. 2013). Strengthening of long-range early warning systems and their use in decision making has been noted as an important lesson of the 2010/11 severe drought in the Greater Horn of Africa (Hillier and Dempsey, 2012).

These conclusions were supported by recommendations from a WMO Workshop on Operational long-range forecasting: GPCs and RCCs in support of NMHSs and RCOFs[51]. The workshop highlighted the following as of high priority to enhance the capacity of RCCs and NMHSs to meet user needs for seasonal prediction information. Although the conclusions refer to needs of RCCs and NMHSs on all continents – they apply specifically to Africa where capacity and resource are generally low (see subsection on national centres).

a) The lack of ready access to GPC hindcast and forecast data products in the data formats required;
b) Insufficient information on the regional skill levels of the GPCs’ prediction systems to make informed judgements on their use in preparation of regional forecasts;
c) A lack of access to tools for RCCs to process GPC output – including forecast calibration, combination, downscaling and verification;
d) A lack of guidance, training and technical manuals on the interpretation of GPC output;
e) The need for earlier forecast issue time and longer lead forecasts from the LC-LRFMME;
f) The need for an expanded range of forecast products from GPCs, particularly for key climate indices such as the Indian Ocean Dipole;
g) The need for mechanisms/forums to strengthen GPC-RCC interaction and to facilitate the sharing of the operational experience of RCCs.

The above needs include important cross-cutting issues to both the Capacity Development pillar (c, d and g) as well as to the Research, Modelling and Prediction pillar (b, c). The DFID/Met Office Climate Science Research Partnership for Africa (CSRP-1 2014) has noted other important prediction research priorities, including improved modelling of ocean variability in the tropical Atlantic and Indian Ocean basins where current model performance lags behind that for the tropical Pacific.

It is worth noting that some GPCs disseminate considerably more than the minimum products required under commitments to WMO. A good example for Africa is GPC Washington that includes a range of climate products from monitoring, short-range and seasonal prediction[52].

[51] http://www.wmo.int/pages/prog/www/CBS-Reports/documents/FINAL-REPORT_GPC_RCCworkshop.pdf
[52] http://www.cpc.ncep.noaa.gov/products/african_desk/cpc_intl/africa/africa.shtml

Moreover there is a range of multi-modelling activities in addition to the WMO LC-LRFMME: these include the APEC Asian Pacific Climate Centre (APCC)[53]; EUROSIP[54] and the North American Multi-Model[55]. Thus there is a wealth of information and in light of these multiple sources a key issue is developing tools for regional and national centres to synthesise and consolidate the predicted information.

CSIS Intervention candidate 4: From the above, there is good evidence already available as to how the CSIS needs to be strengthened with regard to seasonal forecasting for Africa. High priorities are cross-cutting interventions to strengthen working partnerships and data exchanges between global, regional and national providers (including use of open data platforms), develop and trial tools for downscaling and combining of climate model-based and statistical predictions, develop technical manuals, training and guidance on procedures (including fellowships and visiting scientist exchanges). (Note: development of toolkits to help NMHSs synthesise available data, following standardised procedures, and generate climate service products is a high priority initiative (Project 2) of the CSIS (WMO 2014e))

Multi-annual to decadal prediction – global provision

As well as the subseasonal timescale, timescales beyond the seasonal time scale are also deficient in terms of availability of consolidated, authoritative prediction guidance from the various global centres generating predictions. This is a recognised gap in the CSIS (WMO 2014e) and there is an acknowledged need to develop both the prediction systems (through the Research, Modelling and Prediction pillar) and to coordinate currently available predictions with advice on model "trustworthiness".

The period 1-10 years ahead represents an important planning time horizon for many planners and decision makers. New initialised decadal prediction systems are being developed by some global centres which specifically target this period. Steps to foster international collaboration in multi-annual decadal prediction – developing a real-time multi-model prediction system - following similar lines to those developed for seasonal prediction - are in place[56] (Smith et al. 2012) with 9 centres so far contributing. Consolidation of this experimental multi-model with a designated operational Lead Centre is part of WMO planning for the CSIS.

Although an area of active research and model development, there are some regions, including in Africa, where potential benefit from multi-annual predictions warrants opening a dialogue with users to begin development and trialling of operational services. For example relatively high levels of prediction skill for multi-annual variability in Atlantic sea temperature, known to influence Sahel rainfall, leads to good potential for predictions of multi-annual rainfall averages (out to 5 years ahead) for that region (Hermanson, 2014; CSRP-1 final report, 2014)

CSIS Intervention candidate 5: Include with candidate 3 and/or 4, a component to develop and trial, with regional/national providers and users multi-annual temperature and rainfall prediction services for the Sahel and other regions of Africa with sufficient predictability.

Climate projections – global provision

WMO 2014e notes that an important activity for CSIS will be to promote the implementation of online climate projections as an efficient mechanism for delivering essential and

53 http://www.apcc21.org/eng/index.jsp
54 http://old.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/eurosip/
55 http://www.cpc.ncep.noaa.gov/products/NMME/
56 http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/decadal-multimodel

consistent information to underpin national adaptation to climate change. It further notes that the databases of the fifth generation of the Coupled Model Intercomparison Project (CMIP5) and the CORDEX project of the WCRP can serve as comprehensive archives for the research community concerning climate simulations and climate change projections, though they are not in a suitable forms to support the potentially wide range of specialized applications, especially at the national level. Creation of online regional and national sites for efficient access to climate change data and information services is highlighted, with a key requirement being to achieve a significant shift from the current situation of ad hoc servicing by the research community towards a fully operational climate change information service.

Examples of current “off the peg” resources available to African countries include those supported by UNDP[57] and by DECC through a UK consortium for a number of African countries[58]. The University of Cape Town Climate Systems Analysis Group also provide the Climate Information Portal serving CMIP3 and CMIP5 predictions[59].

Development and application of new understanding and techniques to reduce large uncertainty in rainfall predictions (e.g. at the 2050 time horizon) – by differentiating the more “trustworthy” model predictions, will also be a requirement. The need for such techniques has been highlighted by the CSRP programme (CSRP-2 final report, 2014) and may become available as an output of future climate research projects for Africa (e.g. FCFA).

CSIS Intervention candidate 6: Develop operational provision of user-led information on multi-decadal climate projections for Africa at the national and regional level, based on CMIP5 and CORDEX projections and on new processed-based techniques, currently being researched, for selecting the more “trustworthy” scenarios and including downscaling to sub-national scale. It may be desirable to include with options 3&4 in trial seamless provision from days to multi-decadal timescales.

Institutional development of global centres

Although institutional development of global centres will be largely out of scope, strengthening of the South African Weather Service (SAWS), which is one of the 12 WMO GPCs, could be considered. With additional resource SAWS could take on more continent-wide responsibilities as a GPC, working with partners such as University of Cape Town and CSIR to provide services to Africa’s RCCs.

Regional Centres

Regional Climate Centres in Africa – functions, status and need for strengthening

WMO has defined mandatory functions for Regional Climate Centres which set standards for RCC services to the regions NMHSs and regional users (WMO Manual on the GDPFS). Namely:

- Interpret and assess long-range forecast products from GPCs, including the exchange of basic forecasts and hindcast data;
- Generate regional tailored products, including consensus-based seasonal climate outlooks;
- Provide online access to RCC products;
- Perform regional climate diagnostics;
- Develop regional climate datasets;
- Establish a regional historical reference climatology;
- Provide climate archiving services;

57 http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/
58 http://www.metoffice.gov.uk/media/pdf/b/j/Kenya.pdf
59 http://cip.csag.uct.ac.za/webclient2/app/

- Implement a regional Climate Watch;
- Coordinate training for RCC users;
- Provide information on RCC products and guidance on their use.

In addition, depending on a region's specific requirements, WMO RCCs should perform "highly recommended functions" in the areas of climate predictions and projections, data services, research and development, coordination, training, and capacity-building.

Existing climate organisations are in various stages of establishing the capacity required to fulfil these functions. A number of centres in Asia and Europe have achieved RCC designation. In Africa most centres require capacity strengthening to enable them to achieve RCC status. There is currently provision for 4 RCCs in sub-Saharan Africa, one in each of the economic communities and one pan-African centre, namely:

- RCC Network ECOWAS (AGRHYMET, ACMAD) – West Africa
- RCC IGAD (ICPAC) - East Africa[60]
- RCC SADC (SADC-CSC) – Southern Africa
- RCC Central Africa
- RCC Africa (ACMAD)[61]

Of these, RCC Africa and RCC IGAD have been in demonstration phase since 2011 and it is understood that ACMAD is close to designation. The RCC Network ECOWAS and RCC SADC are preparing for demonstration phase, while identification of stakeholders to operate an RCC for Central Africa is still at the planning stage.

Thus, in general, there is a great deal of institutional strengthening required to bring regional centres to the capacity needed to carry out the mandatory and highly recommended functions. This includes both investment in hardware, software and sustainable and trained human resource.

There have been a number of initiatives aimed at institutional strengthening of RCCs in Africa. A pan-African initiative is the AfDB supported ISACIP (Institutional Support to African Climate Institutions Project). ISACIP (total value $30 million) was coordinated by ACMAD with beneficiaries ACMAD, AGRHYMET, ICPAC and SADC-CSC. Objectives covered included:

- improved production and delivery of climate related information and services
    - access to climate observations and information networks
    - operationalisation of climate information systems
    - downscaling global climate data and scenarios
    - dissemination strategy and implementation.
- Institutional strengthening
    - Enhanced capacity of scientists
    - Student professional training and sensitisation
    - Development of physical infrastructure

Lessons learnt so far from this project have not been widely shared and would provide good input into CIASA scoping.

In East Africa a WMO-KOICA GFCS Trust Fund Project ($150,000) is establishing a Computer Cluster at ICPAC running the NOAA NCEP Global Model and a Regional Model. A second phase of the project will establish a network of server computers, linked to the

60 http://rcc.icpac.net/
61 http://acmad.net/new/?q=en/home

ICPAC hub, in each of the IGAD member states – strengthening two-way exchanges of climate data and information. There is little information currently available on the impact of this programme.

In will be necessary to add regional specificity to the mandatory and highly recommended RCC products and in this context a WMO workshop on “NMHS capacity development requirements for GFCS” concluded that “the role and functions of Regional Climate Centres should be clearly identified in Memorandums of Understanding signed by the NMHSs the regions support” (WMO, 2012a).

CSIS intervention candidate 7: Situational analysis of Africa RCCs, with focus on ability to fulfil RCC functions and serve the regions NMHSs, followed by programme of institutional development designed with input from the regions NMHSs and user communities.

Monitoring and analysis – regional provision

Regional monitoring and analysis is a key specified activity of RCCs. ACMAD generate continental monitoring bulletins for the past 10 days, 1-month and seasonal periods, and the other regional centres generate similar products for their regions, though not all centres do this for all 3 time periods. A trawl of the respective websites suggests analyses are not gridded – but based on expert interpretation of the scarce and irregularly spaced observations. At some centres there appears to be complete reliance on products generated by global centres (i.e. no value adding from additional observations available in the region). A website trawl also indicates patchy availability of products, little information on how the products are constructed and little consistency between the products of different centres. Internet connectivity is also generally slow.

Thus, in addition to strengthening regional observation networks, strengthening of tools and procedures for regional monitoring and analysis are required. The CSIS priority implementation project 3 (WMO 2014e) “Establish modern Climate System Monitoring based on improved operational monitoring products” is relevant here both at the national and regional scales.

The Enhancing National Climate Services (ENACTS) programme (Dinku et al. 2014), implemented by the International Research Institute for Climate and Society (IRI) and funded by ClimDev and DFID’s Roll Back Malaria programme has made some progress in strengthening historical climate data analysis and monitoring at the national level using blended gauge and satellite observations (see section on national centres). These activities could possibly be scaled up to regional level, working through the RCCs. In West Africa, AGRHYMET are taking some regional responsibility for maintenance of ENACTs systems implemented at NMHSs as well as with training associated with the data analysis (Madeleine Thomson, *personal communication*).

CSIS Intervention candidate 8
Establish modern Climate System Monitoring (e.g. gridded datasets, standard monitoring products) for the regions based on improved operational techniques and procedures, standardising as far as possible across regions, harmonising with national products where they exist and providing ready access.

Weather and climate prediction – regional provision

Definitive inventories of the product suites of all African regional centres are not readily available and would be a useful resource. The following has been compiled largely from information available on the websites of those centres seeking WMO Regional Climate Centre status.

ICPAC: http://www.icpac.net/products/products.html#
ACMAD: http://www.acmad.net/new/
SADC-CSC: http://www.sadc.int/sadc-secretariat/services-centres/climate-services-centre/

Days to weeks
Regionally coordinated services on this timescale can be largely categorised into two types: those resulting from WMO's Severe Weather Forecast Demonstration Project SWFDP[62] with demonstrations so far in southern Africa and East Africa and those issued with pan-African coverage by ACMAD (Box 4).

There has not yet been an SWFDP in West Africa, however ACMAD provide warnings with similar content with pan-African coverage (Fig. 7). Forecast products from global centres the key inputs used to generate these products (ECMWF, NOAA NCEP, Met Office, Meteo-France).

The relatively short-range nature of the SWFDP forecasts has meant the coordination is better placed at NMHSs with RSMC status, rather than at regional climate organisations. This may present some challenges when moving to a more seamless serving of climate information across timescales – since the regional seasonal forecasting is generally coordinated (with the exception of ACMAD) at different centres. Specifically, the SADC-Climate Services Centre, based in Gabarone, Botswana, for southern Africa and ICPAC, Nairobi for the Greater Horn of Africa. ACMAD provide pan-African services for both timescales. This distributed responsibility for different timescales may first become an issue when considering which centres should lead operationalisation of sub-seasonal predictions which "bridge the gap" between short/medium range and seasonal forecasts.

Figure 7 Example ACMAD 3 day flood warning forecast issued 11/12/2014.

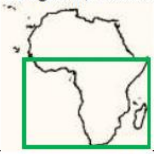
62 http://www.wmo.int/pages/prog/www/swfdp//

1. FLOOD RISK FORECAST VALID FOR THE NEXT THREE (03) DAYS.

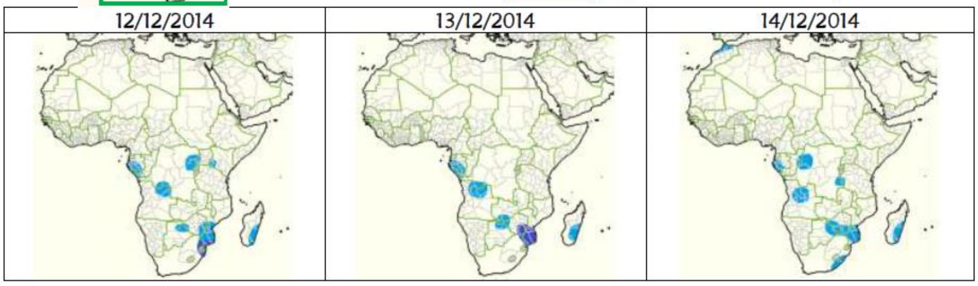
2. High risk of flood expected over: NIL.

Medium risk of flood expected over: East of South Africa, East Zimbabwe, Swaziland and South Mozambique.

Low risk of flood expected over: South/West Gabon, South Congo, South-west/East DRC, West Uganda/Tanzania, South-west Kenya, North Angola, East Botswana, West/South Zimbabwe, South-east/Central Madagascar, South-east of South Africa and North-west Morocco.



Color	Severity of risk
(cyan)	Low
(blue)	Medium
(red)	High



No risk of flood over: Cape Verde, Mauritius, Reunion, Comoros, Sao Tome and Principe, Seychelles.

Our flood risk forecast concerns only rainfed floods that could be caused by heavy rains.

Source: *Synthesis of:*
1) Dynamic of atmosphere by different global models (ECMWF, GFS, ARPEGE, UKMO),
2) Index of extreme events from ECMWF (http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/efi/efi_tp/),
3) Occurrence probability of extreme precipitation from TIGGE project ensemble models (http://tparc.mri-jma.go.jp/TIGGE/tigge_extreme_prob.html), probability exceeding the 90th percentile [%]
4) MJO active phase.

For more and detailed information, please visit our website: http://www.acmad.org and watch for the next issue of this bulletin.

Sub-seasonal (~50 days) ahead and seasonal prediction – regional provision

In addition to that provided by the prospective RCCs there is also (in southern Africa) a wealth of seasonal prediction information available from the Climate Systems Analysis Group of the University of Cape Town (UCT) and the Council for Scientific Research (CSIR). See http://www.gfcsa.net/CSAG/rain_sa.html and links contained therein.

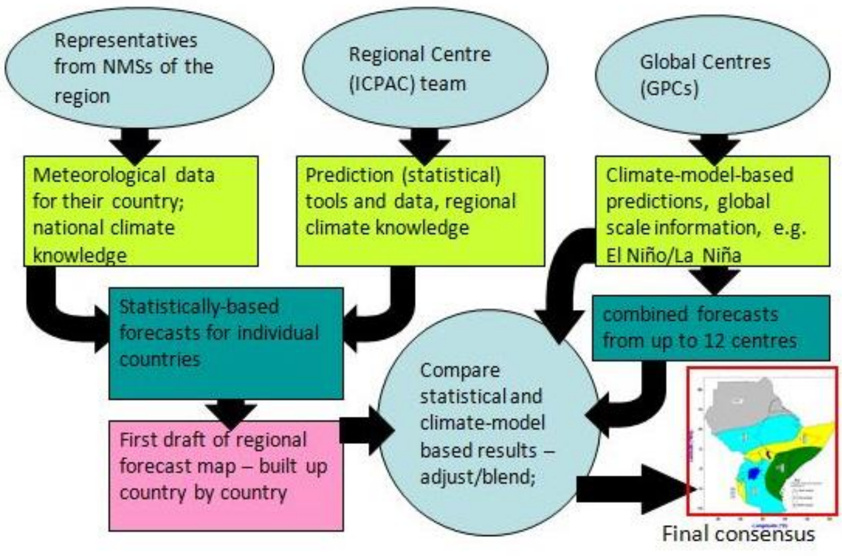
Most African regional climate organisations generate outlooks for precipitation for the next month ahead and the next 3-months ahead, with forecasts for both timescales updated each month. The outlooks may form a component of observational monitoring bulletins for the previous month or 3-months. However, there is little information on the sequence of conditions over the first month – as will be explored by the WWRP-THORPEX/WCRP Subseasonal to Seasonal (S2S) research project.

The outlooks are generated using a mix of statistical models run in house and dynamical model outputs from global centres. There is a lack of specific information on the methodology for combining the various inputs into a consolidated forecast.

Regional Climate Outlook Forums (RCOFs) and regional consensus seasonal forecasts

In addition to the monthly updating forecasts the regional centres also coordinate RCOFs ahead of the main rainy seasons for the region. A key output of the RCOFs are consensus forecasts for the region developed by all key national, regional and global stakeholders. The consensus forecasts are for the “fixed” period of the main season only. The typical process for generating a consensus outlook is provided in Figure 8 and involves contributions from national, regional and global levels. As mentioned previously, RCOFs also provide key platforms for interaction between climate information providers and users, as well as a means to initiate the communication of forecast information.

Figure 8. Schematic flow diagram showing the general processes in developing the consensus forecast (based on the process at GHACOF). (From Graham et al. 2013)



The sequence of "rolling" monthly updated forecasts issued by the regional centres serve as update guidance on these regional consensus forecast to assist NMHSs to update their national forecasts.

Multi-annual, decadal and multi-decadal prediction – regional provision

There is little information on the degree to which the needs of the regions for multi-annual predictions and beyond are served by the prospective RCCs. From information available on organisation websites there is very little activity at these ranges, although there may be some bespoke provision. ICPAC provide research results for the Greater Horn Region from the CORDEX output – though not yet tailored for user uptake. In general terms it is not clear how multi-annual and multi-decadal would be used although there is potential for use areas such as water resources for major reservoirs and investment planning.

CSIS Intervention candidate 9:
Potential intervention on subseasonal timescales is covered in candidate 3. From the above it is clear that for seasonal timescales there is a wide range of statistical methodology and climate model-based inputs available for regional centres to construct regional seasonal outlooks. Currently much of the consolidation is done subjectively. Work to assess the relative value (accuracy) each of the inputs and to develop and promulgate standard ways of combining inputs objectively would be beneficial. Improvement of the forecast process has been highlighted as a key objective of 2 reviews of RCOFs in 2000 and 2008 (IRI, 2000)[63]. Extension of the RCOF concept to cover adaptation timescales should also serve to increase awareness and strengthen interaction between the climate producers and users for these timescales.

[63] http://www.wmo.int/pages/prog/wcp/wcasp/RCOFReview2008.html

National Centres

National Meteorological and Hydrological Services – climate service functions, status and need for strengthening

Major priorities for the GFCS (WMO 2014e) are to establish national-scale CSIS entities, with a particular focus on developing countries, and to provide regional support to those entities. Within this framework, key objectives include identifying the national climate providers and the national CSIS entity or entities responsible for maintaining the official climate record (normally the NMHS), developing climate science inputs and capacity to provide required climate services (normally the NMHS), providing advice that is valuable to users and to establish and to expand dialogue with users at the national and sub-national levels.

It is widely recognised that the above will require significant institutional strengthening, capacity development and training. This is illustrated by Fig 9 (WMO 2012b) which shows the categorisation of NMHSs capabilities and Fig 10 which shows the estimated distribution of capacity over NMHSs internationally. Most are only capable of basic services or less, covering some climate monitoring but not extending to prediction – and many of these will be in the LDCs of Africa (34 of Africa's 54 countries are categorised as LDCs).

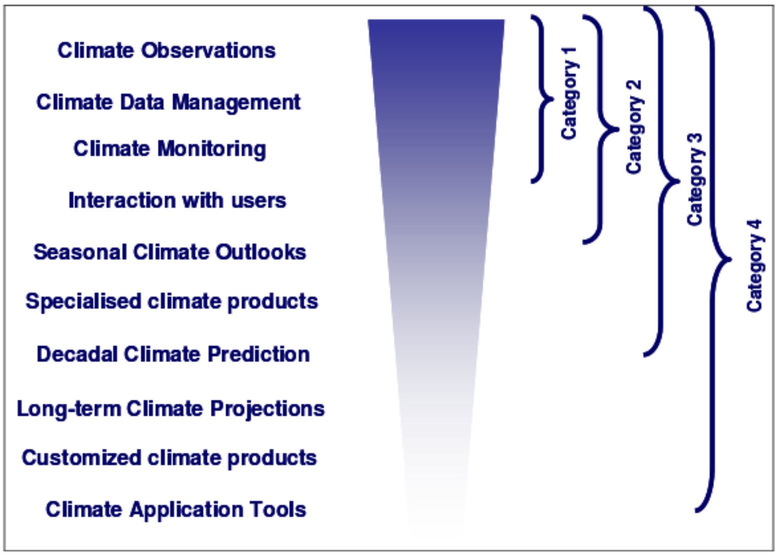


Figure 9 Hierarchy of national climate services capabilities. Categories 1, 2, 3 and 4 are referred to respectively as basic, essential, full and advanced services.

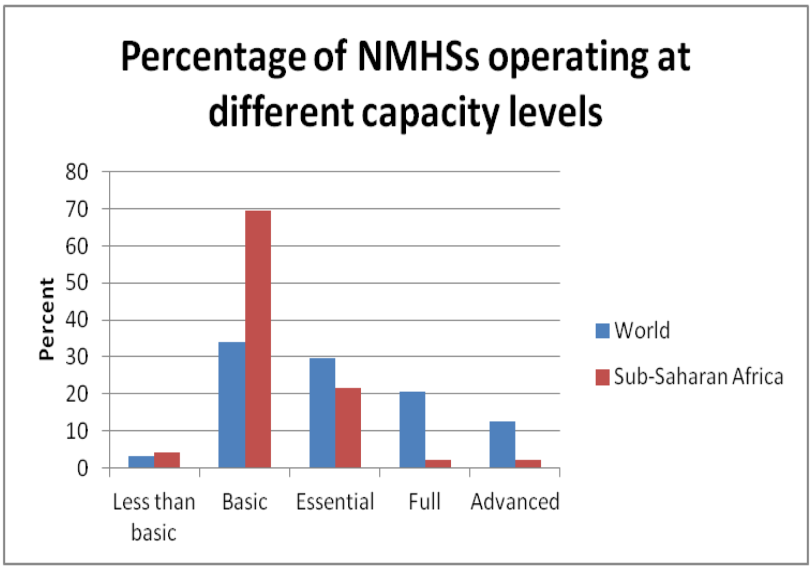


Figure 10: Estimated percentage of NMHSs as a function of capacity for climate services World (blue) and sub-Saharan Africa (red). Estimates are based on team expert assessment. Right: Hierarchy of climate service capabilities. Categories 1, 2, 3 and 4 correspond to basic, essential, full and advanced services.

A common consequence of poor capacity is that the reputation of the NMHS within the country can be poor – as it cannot provide the required services. This leads to a low level of trust such that the public do not act on weather/climate warnings (UK Met Office report for World Bank, 2012). To move forward from such a situation a programme of institutional strengthening is required that encompasses not only technical and scientific capabilities but also aspects of management and strategic planning. Strengthening NMHSs should encompass strengthening of regional (sub-national) offices as well as HQs – sub-national offices are often the entity responsible for tailoring and disseminating information to local users. In addition there needs to be a strategy for retaining skilled staff.

CSIS Intervention candidate 10: Situational analysis of NMHSs followed by a programme of comprehensive institutional development of NMHSs, including sub-offices serving local communities, in selected countries. This should include also the development of national climate networks, interactions with user communities and development of National Climate Outlook Forums (NCOFs).

Climate data rescue, management and mining

The maintenance of climate records in a useful form provides a major challenge for some NMHSs in Africa. It is only recently that observations have been recorded electronically in a systematic way in some countries, and a vast quantity of climate data is still held on paper records. Not only can this information not be easily shared with others or used in model analysis, there is a risk that this data could be lost altogether as many of these paper records can deteriorate in poor environmental conditions. Therefore there has recently been a concerted effort to establish 'data rescue and digitization schemes' to enable these archives to be preserved and to be used for climate applications (UK Met Office report for the World Bank, 2012)

The WMO, through the ACRE (Atmospheric Circulation Reconstructions over the Earth) initiative and IEDRO (International Environmental Data Rescue Organization), initiates and facilitates such data rescue and digitization projects. The data are then freely available to all and can be used to provide climate reconstructions for a period where previously the data had been too sparse. These reanalyses can be tailored, shaped and downscaled for the needs of climate scientists for assessments of risks, impacts and extremes, and are also available to the NMSs, educators, students and the general public.

The ENACTS programme (Dinku et al. 2014) has made progress in modernising climate data management in a number of African countries by quality controlling in situ rainfall data, blending with satellite estimates to fill temporal and spatial gaps and implementing a flexible database storage with graphical interfaces. The quality of the blending process will depend on the density of station observations – and thus a programme of data rescue as well as strengthening the observation network would complement the work of ENACTS. There is evidence that such programmes are increasing the use of climate data within country (UK Met Office, 2014).

CSIS Intervention candidate 11: Strengthen programmes of data rescue and implementation of climate data management systems at NMHSs.

Weather and climate prediction – national provision

WMO 2014a notes that a significant number of countries (particularly developing ones) can at present provide only minimal (or no) climate services, and human and computing resource as well as tools for climate data management, processing and prediction are lacking. Since 34 of Africa's nations are categorised as LDCs, lack of capacity to provide climate services is a key issue for African NMHSs. This is consistent with the large number of countries with capability for only basic or less than basic services (Fig. 4).

Some of the more developed countries maintain their own systems and tools for prediction. For example, some such as Ethiopia and Kenya run regional NWP models, obtained from Global Centres (the NCAR Weather Research and Forecasting model (WRF) is one model used) and driven by boundary data obtained routinely from global centres. Many also maintain statistical models for seasonal prediction which are relatively cheap to run (requiring only desktop computing systems) and provide a viable stepping stone on the way to using more sophisticated tools.

In contrast to the growing capabilities in some countries, a large number of countries are dependent on external sources, from both regional and global centres, to serve their national requirements for weather and climate services. In a survey (UK Met 2012) a sample of African NMHSs were asked how access to this data could be improved. Telecommunication capacity was top of the list, in terms of increased bandwidth or high-speed internet connections. Access to model data in some cases was difficult due to bandwidth restrictions, or website issues; most websites display model data as simple images, but forecasters need to overlay fields and perform tailoring of information to provide services to national and sub-national users. Another issue with access to prediction data (both seasonal and climate change predictions from e.g. CMIP5) is that it is generally served as global fields, which can be large and prohibitive to download with the low bandwidth generally available.

CSIS Intervention option 12 (linked with candidate 4): programme to enhance the serving of prediction data (all timescales) to the national level, including use of open data platforms, together with development and provision of tools to interpret the data and develop national and subnational climate service products.

SECTION 5

Observations and Monitoring

The GFCS O&M pillar

The GFCS framework (WMO 2014b) includes an annex on observations and monitoring, which describes linkages to other framework components, the needs of the four priority sectors, initial implementation plans and gaps.

There are overarching climate science requirements for high quality data as well as specific requirements to manage risks and reduce vulnerability in priority sectors. Long-term, well-calibrated, global observations of variables such as air temperature, rainfall, sea-surface temperature, sea-level, and concentrations of greenhouse gases and aerosols are critical for defining the evolving state of the Earth's climate. The observational data record is fundamental for defining the initial states for model runs, for validating the numerical models used for weather and short-term climate forecasting, and for longer-term scenario-based climate projections. The specific requirements for sectors are outlined in WMO (2014f) and these include socio-economic data as well as climate data, for example data on crop yields, production statistics and water quality are required for agriculture and food security.

A number of existing mechanisms, activities and plans exist for coordinating observational networks and systems, including projects under the World Climate Programme (WCP) and WMO. There are many projects to improve the availability of observational data through 'Data rescue and Digitization (DARE&D)' or by supplementing the observational network with satellite data or with community based operated networks (WMO, 2014f).

Significant gaps of relevance to Africa include shortcomings in atmospheric observations due to the inability to maintain networks, lack of training and capacity and inadequate communications systems; incomplete or missing observations of vital land-surface parameters such as river discharge and lake levels; restrictive data policies and ineffective information infrastructures; and the need to rescue, digitize and develop historical climate data sets (WMO, 2014f). International reviews of the state of NMHS report that capacity is very poor, with more than 50 NMHS in Africa needing transformative modernization following 15-20 years of underfunding, low visibility, economic reforms and in some instances military conflict (Rogers and Tsirkunov, 2014).

Implementation of the O&M pillar requires a wide range of conditions to be satisfied, most notably adequate in-country capacity to ingest, process, quality control and manage climate data and link it to climate services. The GFCS defines 14 initial implementation priorities under this pillar (with a cost estimate of over $60 million) but it also recognises the imperative to sustain observational networks in countries where coverage has declined in recent years. It suggests that "*projects should be aimed at enhancing these observational programmes where this is essential to providing the data needed to support services to the priority sectors*" and *"[s]uch enhancements might include filling observational gaps,* *increasing observational frequency, measuring new climate-system variables, and/or implementing improvements to telecommunications systems for data exchange*."

The links between global, regional and National Meteorological Services

A key factor is coordination and integration of global, regional and national activities (WMO, 2014b). This is because 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 NMHSs and their partners. These observations are assimilated by a network of global and regional forecast centres, which have differentiated responsibilities for the production of global, regional and national products. This system ensures that large-scale numerical predictions, which are needed for a good national forecast but require enormous computing power, are created cost-effectively by a few NMHSs and supporting organizations on behalf of all Members of the WMO. Alone, no nation would be able to provide the meteorological and hydrological services necessary to meet the essential needs of its citizens, but as WMO Members, countries agree on data-sharing arrangements, establish operational guidelines, implement best practices, and develop and use training opportunities" (Rogers and Tsirkunov, 2014).

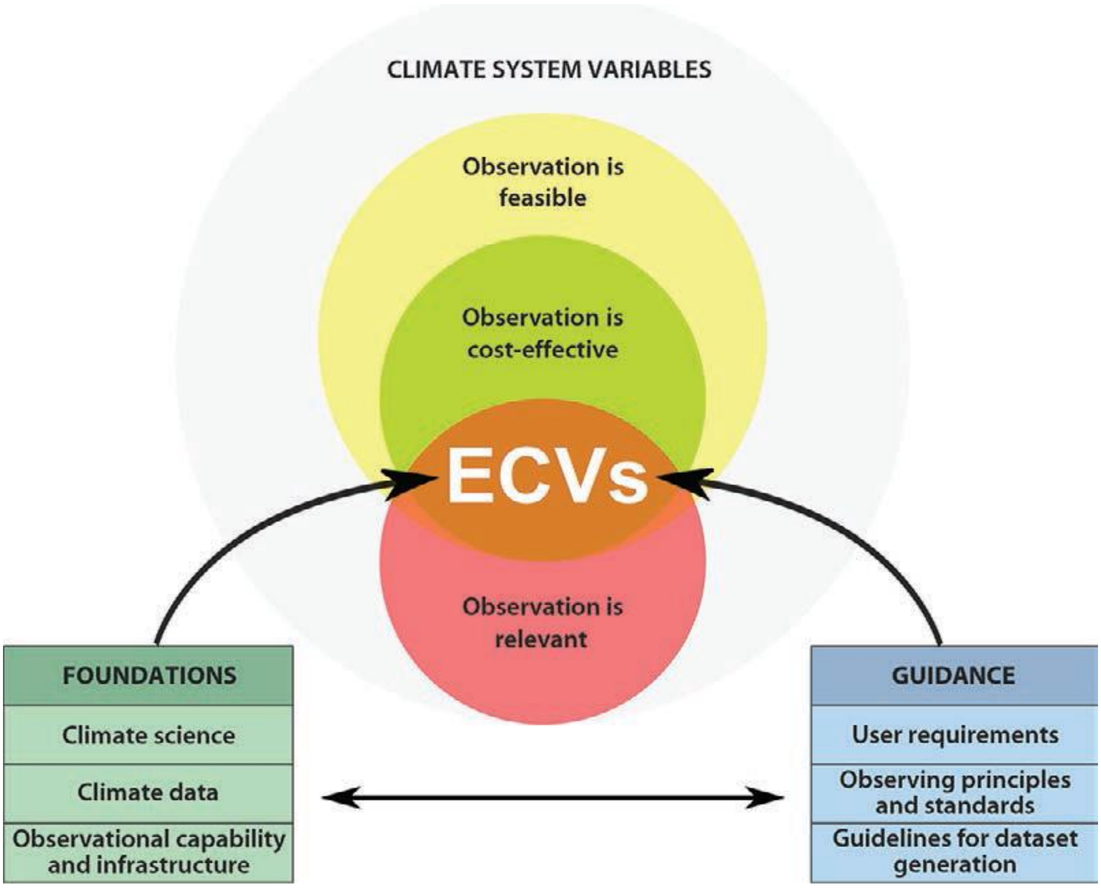
Observational data sets and reanalysis products

What data need to be collected?

Bojinksi et al. (2014) describe the concept of Essential Climate Variables (ECVs) for which increased observation is cost effective (Figure 11). This can be refined further by considering user requirements in specific sectors, which are outlined in WMO (2014c).

Long historical records of are of particularly high value for developing climatologies, so there is a need to maintain existing sites, rescue and digitise historical data and manage data effectively, alongside filling the major gaps in the density of observations. The GFCS acknowledges problems related to the operating costs and sustainability of networks and this is a key issue for designing of interventions. The Appendices to the Observations and Monitoring Annex of WMO (2014f) list and describe projects or potential remedial projects such as the rehabilitation of silent observing stations and the establishment of new stations in data-sparse regions; and, importantly for Africa, improving ground-based and space-based networks for measuring precipitation.

Also for precipitation, it is essential to acquire, quality-control and homogenise many more daily and sub-daily *in situ* precipitation data than are currently available, in particular for improving analyses of changes in short-duration extremes. Lack of data constrained Panthou et al. (2014) to use only a limited sector of the Sahel in their assessment of changes in extremes of daily rainfall since the mid 20th Century. Also, changes in extremes are likely to be dependent on the duration of precipitation (Westra et al., 2013): hence the need for sub-daily as well as daily data. The INTENSE project, funded by the European Research Council and aligned with a Global Energy and Water Exchanges (GEWEX) cross-cutting activity on sub-daily precipitation, is beginning to co-ordinate progress in this field. Owing to the sparse distribution of rain gauges, it would be beneficial to include ground-based radar data also where possible, allowing a spatial as well as temporal analyses of extreme events (Westra et al., 2014). Ground-based radar data may not be ubiquitous in Africa, but they have been used at least in South Africa to guide the interpolation of rain gauge data (Gyasi-Agyei and Pegram, 2014). Increased knowledge and understanding of short-duration extremes of precipitation will lead to appropriate adaptation actions.



Atmospheric

- *Surface*: Air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget
- *Upper air*: Temperature, wind speed and direction, water vapour, cloud properties, Earth radiation budget (including solar irradiance)
- *Composition*: Carbon dioxide, methane, other long-lived greenhouse gases ozone and aerosol supported by their precursors

Oceanic

- *Surface*: Sea surface temperature, sea surface salinity, sea level, sea state, sea ice, surface current, ocean colour, carbon dioxide partial pressure, ocean acidity, phytoplankton
- *Subsurface*: Temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers

Terrestrial

- River discharge, water use, groundwater, lakes, snow cover, glaciers and ice caps, ice sheets, permafrost, albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, soil carbon, fire disturbance, soil moisture.

Figure 11 The Essential Climate Variables concept (Bojinski et al., 2014).

How should data be quality assured?

The World Meteorological Organization's Guide to Climatological Practices (WMO No. 100)[64] gives guidance on making observations, covers the principles of quality assurance, and re-iterates the important Global Climate Observing System Climate Monitoring Principles. This ~100 page document gives guidance on making observations, covers the principles of quality assurance, and re-iterates the important Global Climate Observing System Climate Monitoring Principles.

What are the pros and cons of different data sets?

i) *Precipitation*

For precipitation, arguably the most important ECV for Africa, gauge-based datasets, satellite-gauge merged products, purely satellite products and dynamical model-based reanalysis data can all be used for weather observation and the development of climatologies, each with their own benefits and shortcomings. Traditional observations from weather stations benefit from their local accuracy and in some cases a long historical record, but can be hampered by gaps in the time series or poor exposure. Weather station data in Africa also suffer widely from uneven spatial distribution, causing particular limitations for remote communities. Satellite observations offer information over areas with no in-situ data availability, but can be hampered by their short time period of observation, heterogeneity (because of e.g. changes to satellite instrumentation or overpass time) or poor accuracy, particularly at higher temporal and spatial resolutions.

Manzanas et al. (2014) assessed the ability of various observational and dynamical model-based reanalysis products to reproduce observed annual and seasonal trends in precipitation in Ghana from 1961-2010. Gauge-based products were shown to reproduce the trends most effectively, with GPCC v6 (the observations-based Global Precipitation Climatology Centre Full Reanalysis version 6) (Becker et al. 2013), showing the highest correlation of 0.9 and nearly null biases when compared to the Ghana Meteorological Agency (GMet)'s quality controlled reference dataset. Purely satellite derived products were comparable to combined products but produced larger biases and over-pronounced trends. All the assessed dynamical model-based products exhibited some unrealistic characteristics in their results; trends were either significantly stronger than the observations or contradicted the observations (Manzanas et al. 2014), highlighting the serious limitations of these reanalyses for reproducing observed inter-annual variability in this region, where their representation of observed climatology was inaccurate. Products such as these which omit local gauge data may not be realistic owing to the region's large seasonal and spatial variability. This is particularly pronounced in Ghana since different precipitation regimes coexist from the coast to the Sahelian region, yielding a complex spatial variability (Cooper et al., 2008).

Many wider-ranging efforts have been made to assess satellite-based precipitation data over Africa, owing to their importance given the sparse in situ networks. The satellite-based microwave-radar product Tropical Rainfall Measurement Mission (TRMM) 3B42 tends to indicate less precipitation than the Global Precipitation Climatology Program (GPCP) satellite-based estimates, but shows biases of geographically-dependent sign relative to the gauge-based U.S. Agency for International Development Famine Early Warning Systems Network (FEWS NET) analysis (Figure 12, taken from Liebmann et al., 2012). Sylla et al. (2013) obtain relative biases compatible with Liebmann et al's but also find that FEWS NET shows mostly higher precipitation frequency and lower intensity events than TRMM 3B42 V6

[64] Updated in 2011 and available at www.wmo.int/pages/prog/wcp/ccl/guide/documents/WMO_100_en.pdf

and GPCP (Figure 13): this leads to uncertainty in assessing model simulations and extremes. Thiemig et al. (2012) validated 6 satellite-based precipitation products over 4 sparsely-gauged African river basins. The Climate Prediction Center (CPC) Rain Fall Estimate (RFE) version 2.0 and TRMM 3B42 performed best overall, but accuracy was reduced over semiarid and mountainous regions, daily precipitation extremes were underestimated and the number of rainy days was overestimated. Over the West African monsoon region the CPC Morphing method (CMORPH) may overestimate precipitation in cirrus-covered regions but RFE 2 and TRMM 3B42 are likely to underestimate it especially when microwave data are unavailable (Tompkins and Adebiyi, 2012). Novella and Thiaw (2013) confirm this overestimation by CMORPH. Habib et al. (2012) support this assessment in finding significant overestimation and underestimation by CMORPH and TRMM-3B42v6 respectively over most of the Nile basin. Overestimation was largely confined to low-elevation regions whereas underestimation was a feature of mountainous regions. They attribute the underestimation by the gauge-adjusted TRMM-3B42v6 to the sparsity of operational gauges. They reported that the upcoming TRMM-3B42v7 would use a new gauge data base, the GPCC monitoring precipitation gauge analysis. Tsidu (2012) also found that TRMM-3B42v6 underestimates Ethiopian rainfall, except for small rainfalls. The new Africa Rainfall Climatology for FEWS (ARC2) and CMORPH also underestimate Ethiopian precipitation (Novella and Thiaw, 2013). The bias in ARC2 is greater at high elevations, but ARC2 also has a general dry bias in northern summer which could be ameliorated by improving the input of *in situ* gauge data. In view of these uncertainties, ongoing research in this field is essential, ideally based on programmes like TAMSAT that have long climatologies (see below) along with sub-daily rainfall available from the shorter-term TRMM for researching rainfall extremes.

Since the 1990s, the Tropical Applications of Meteorology using SATellite data and ground-based observations (TAMSAT) project at the University of Reading (Grimes et al., 1999; http://www.met.reading.ac.uk/tamsat/about/) has provided real time 10-daily (dekadal), monthly and seasonal satellite rainfall estimates (SRFEs) for East and Sahelian Africa. The dataset has recently been extended to cover all seasons and the whole of Africa. Rainfall estimates are provided at 4km resolution, from 1982-delayed present, far longer than TRMM and other satellite-based records. A new daily dataset, TARCAT[65], back calculated for the whole TAMSAT period, is now available. TARCAT provides more information on extremes than the original 10-day TAMSAT, but underestimates the most intense events (>40mm)[66] Nevertheless several comparison studies have demonstrated that TAMSAT performs at least as well as other datasets (e.g. TRMM) over many parts of Africa. Young et al. (2014) found that TAMSAT had good skill overall in detecting rainy events but underestimated rainfall amount, while ARC underestimated both rainfall amount and rainy event frequency. TRMM consistently performed best in detecting rainy events and capturing the mean rainfall and seasonal variability, while CMORPH tended to over-detect rainy events. The difference in daily rainfall between the products and rain gauges showed increasing underestimation with increasing elevation, but with considerable scatter. Case studies using high-resolution simulations suggested that underestimation in the satellite algorithms is likely due to undetected shallow convective precipitation with warm cloud-top temperatures, as already concluded by Novella and Thiaw (2013), in addition to beam-filling effects in microwave-based retrievals from localized convective cells as observed by Liu and Zipser (2014). Overestimation by infra-red-based algorithms was attributed by Young et al. (2014) to non-raining cirrus with cold cloud-top temperatures. Young et al. (2014) stressed the importance of understanding regional precipitation systems causing uncertainties in satellite rainfall estimates, in order to improve rainfall algorithms. Owing to the large remaining uncertainties in the TRMM precipitation climatology over some regions Liu and Zipser (2014) advocated further ground validation campaigns.

[65] http://www.met.reading.ac.uk/tamsat/public_data/
[66] http://www.met.reading.ac.uk/~tamsat/docs/TAMSAT_DailyRainfallEstimates_UsersGuide.pdf

TRMM has just been succeeded by the multi-satellite Global Precipitation Mission (GPM: see http://www.nasa.gov/mission_pages/GPM/main/#.VIB6p0RCK0A), launched in February 2014. GPM will act as a reference standard for satellite-borne microwave sensors: its data, which will include dual-band radar, will be available through a coordinated network of data services as is currently used to distribute TRMM (Liu et al., 2012). Petty and Li (2013a, b) have developed an improved algorithm for retrieval of precipitation using TRMM Microwave Imager, and validated it against TRMM Precipitation radar: the same methods are under development for the GPM microwave imager. The GPM retrievals will further benefit the analysis of extreme rainfalls and its data should be made freely accessible to African users through the above-mentioned coordinated network of data services.

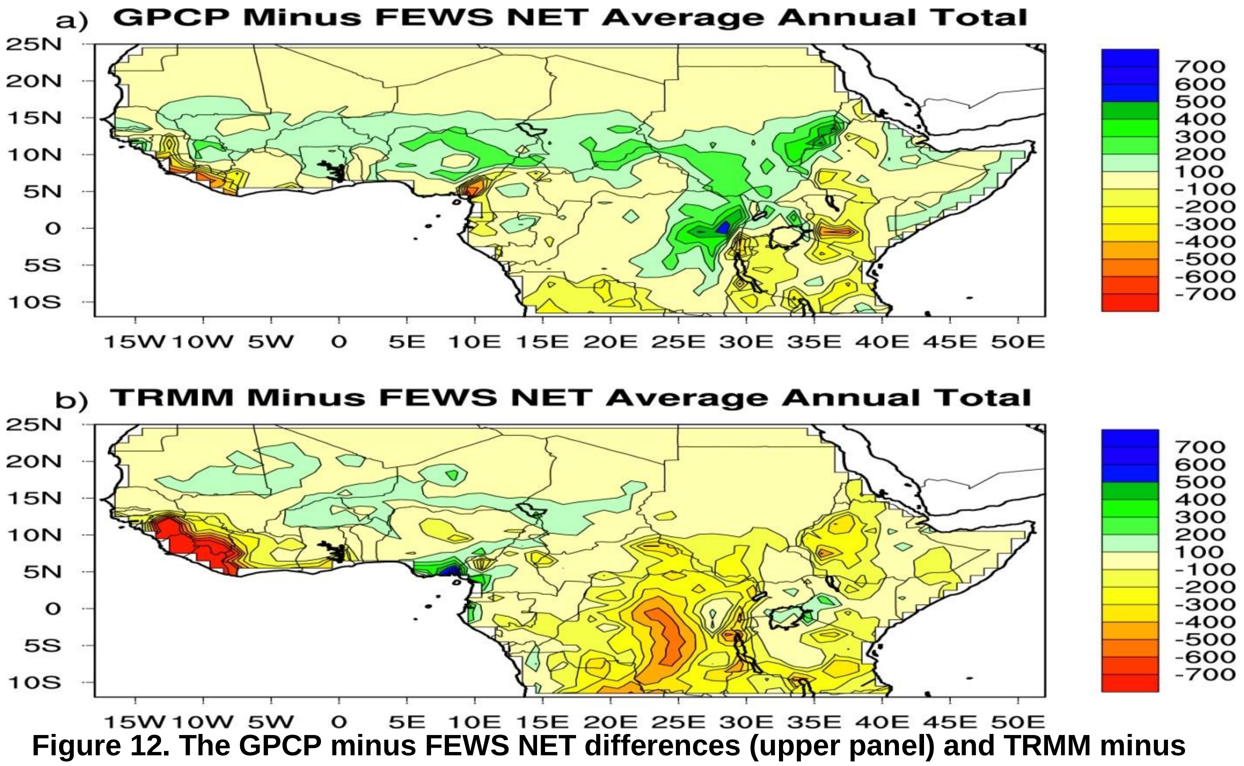
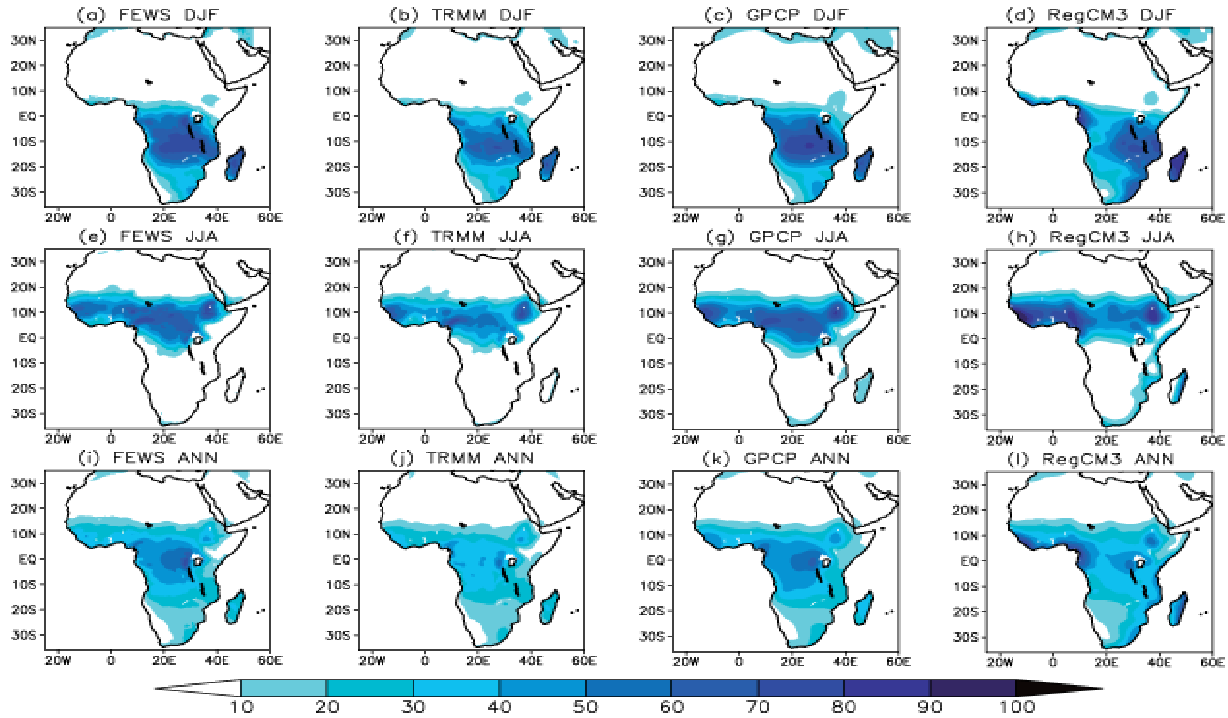


Figure 12. The GPCP minus FEWS NET differences (upper panel) and TRMM minus FEWS NET differences (lower panel) in annual total precipitation (mm) during 1998–2008. From Liebmann et al. (2012).



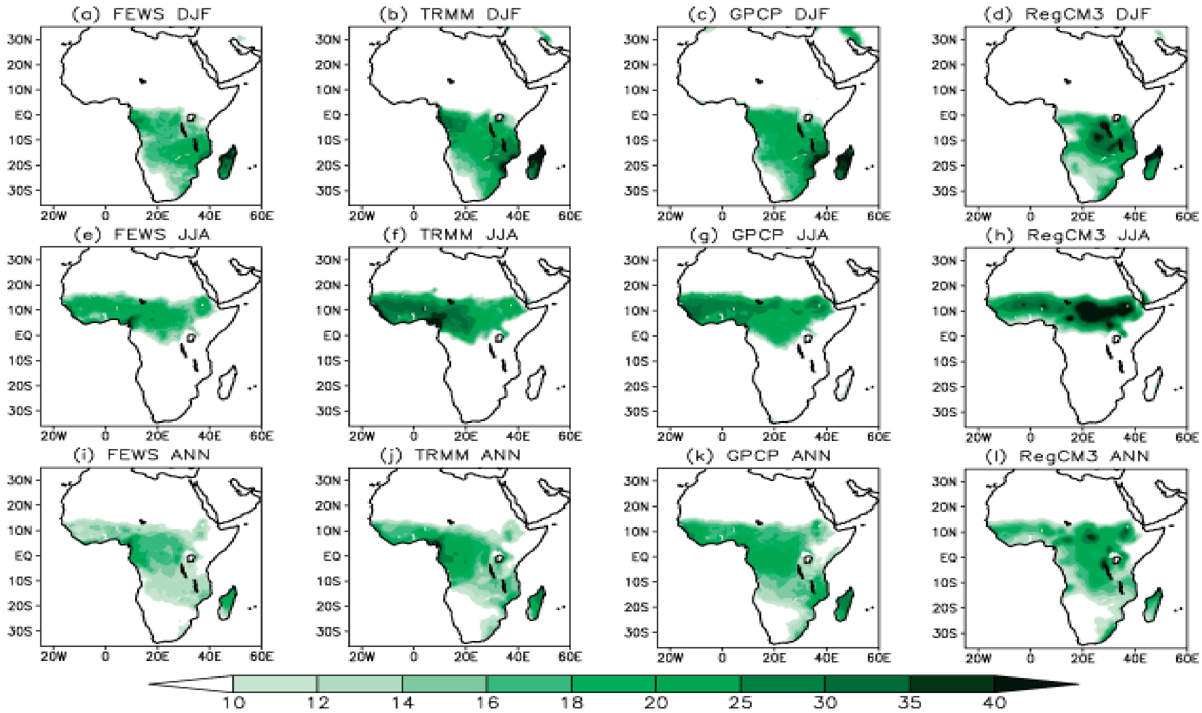


Figure 13 The Daily precipitation frequency (percentage of days with over 1mm rain, upper panels) and 95th percentile of daily precipitation (mm, lower panels)from FEWS (first column), TRMM (second column), GPCP (third column) and RegCM3 (fourth column). From Sylla et al. (2013).

ii) Other variables

In their review of observational data available over Africa for monitoring, attribution and forecast evaluation, Parker et al. (2011) focused mainly on precipitation but also considered temperature, stressing the need for satellite observations of land surface temperature (which differs from near-surface air temperature) to supplement in situ surface air temperature analyses especially on daily time-scales. To blend these disparate data would require the acquisition of national station maximum, minimum and fixed-hour surface air temperature data for development and validation of blending techniques. This would in particular benefit drought-monitoring because of the associated increase in surface temperature when moisture availability for evaporation is limited.

A new European Union Horizon2020 project, EUSTACE (EU Surface Temperatures for All Corners of Earth), beginning in January 2015, has therefore been established to produce a spatially-complete near-surface air temperature analysis for the globe for every day since 1850. The consortium, led by the Met Office, includes partners from Universities of Leicester, Reading, Bath and Bern, Royal Netherlands Meteorological Institute (KNMI), Danish Meteorological Institute (DMI) and the Science & Technology Facilities Council (STFC). The aim of the project is to produce a coherent analysis using both satellite and in situ data sets over land, sea, ice and lakes. In addition to outreach and user interaction, there are four main areas of work: 1) homogenisation and break-point detection in station air temperature data, 2) empirical/physical model relationship building between satellite 'skin' temperatures and near-surface air temperatures, 3) spatial analysis techniques for blending the different data sets and 4) validation. A related European Space Agency project, GlobTemperature, is to improve and enhance use of satellite land surface temperature data sets, by providing multiple data sets in a common format through a single point of contact, developing new user-driven products (e.g. a merged geostationary/polar-orbiting climate data record of satellite land surface temperature), and improving cloud-screening over land. GlobTemperature will produce multi-year satellite-based land surface air temperature estimates based on the empirical/physical model relationships developed in EUSTACE, and these will then be compared with satellite land surface temperatures, reanalysis skin and land surface air temperatures, and gridded land surface air temperature products. Investigations will be done at different space and time scales to examine how relationships change at these different scales. Particular attention will be given to extreme temperature events. Uncertainty information will be provided in the analyses.

Parker et al. (2011) also summarised availability of soil moisture and atmospheric aerosol data over Africa, in catalogues in their Annex B but without specific recommendations.

The use of remote sensing and development of integrated data sets

Although Manzanas et al. (2014) concluded that observations from local weather stations yield the most accurate results, weather stations are unevenly distributed throughout Africa, resulting in limitations for rural communities. In gauge sparse areas, globally available satellite data are vital. The use of blended satellite and ground observation data sets has been successful in some parts of Africa. Several examples are provided below from those based primarily on rain-gauge data (e.g. Rainwatch), satellite data (e.g. TAMSAT) and those that integrate a wide range of data sets (Water Observation and Information System - WOIS).

Rainwatch-AfClix (RWX) is a data management, monitoring, and visualization system designed to increase interactions between local climate information users, their providers, and supporting group. It is used by National Meteorological-Hydrological Services (NMHSs), other government and regional agencies (e.g., Departments of Agriculture, River Basin Authorities, African Centre of Meteorological Applications for Development [ACMAD]), "boundary" organizations that link climate information users with the best available climate science (e.g., Africa Climate Exchange, AfClix, http://www.afclix.org/elgg/), and nongovernmental and humanitarian organizations (e.g., Oxfam, CARE). The purposes of

RWX include the more rapid collection of daily weather observations (especially rainfall) and application of the resulting information in near-term to seasonal environmental monitoring and forecasting with respect to food security and disaster risk reduction. A key component of Rainwatch involves the real-time visualization of season-to-date rainfall trends in comparison with 30-year historical percentiles and recent or earlier well-known extreme years. The monitoring and visualization process is updated every 10 days (using daily station rainfall totals) during the July-August-September core of the Sahel rainy season, and twice monthly during the less important rainfall months of May, June, and October. ***RWX is a simple yet effective tool to help NMHSs use routine daily observations in a value-added manner that is immediately actionable*** to minimize the adverse impacts of Sahelian rainfall variability. For example, RWX was able to identify the impending 2011 drought in Niger before the Sahel monsoon's mid-point, enabling the Niger government to set up famine relief activities several months earlier than would have otherwise been possible (Cornforth et al., 2013). The bulletins are accessible from the local Met Services, are distributed to a wide set of users and also accessible on http://www.afclix.org/elgg/groups/profile/159801/rainwatchafclix. It is important to note that this RWX "early warning was not based on a dynamical forecast system, but instead involves anticipation rooted in the rainfall deficit to date plus assumptions of the physically possible range of subsequent rainfall' (Boyd et al., 2013). In 2014, the restrictions on the wider deployment of RWX were removed by markedly upgrading its software system to open source to facilitate a full technology transfer to participating DMNs in 2015 (Mali, Niger, Burkina Faso, and Ghana, with planned extensions to Guinea, Nigeria and Sudan). In 2015, and in collaboration with TAMSAT, also at the University of Reading, a new integrated RWX/TAMSAT product will be piloted for participating RWX DMNs. This will provision additional products at new spatial and temporal scales to allow users to aggregate the data to suitable scales for specific applications.

Satellite products often utilise gauge data operationally available from the Global Telecommunications System (GTS) for bias correction. However, in Ethiopia for example, the GTS provides data from only about 20 synoptic stations, whereas there is a national network of over 500 rain gauge stations. By combining satellite data with all the available gauge data, Dinku et al. (2014) obtained analyses at least as reliable as those of other satellite products for station-dense areas, and crucially, better quality precipitation monitoring over areas with few or no in situ observations (Figure 13). The climate data are available to the public for viewing and basic analyses at the National Meteorological Agency's web page.

Dinku et al. (2014) worked in partnership with TAMSAT to develop a new rainfall dataset for Ethiopia. The methodologies and computer codes used for this Ethiopia project could easily be adopted for another country, thus expanding this work to other countries in Africa would be faster and cheaper than the initial project. It should be noted that further development is required to adapt the methodologies used in Ethiopia for countries where the gauge network is sparse and the satellite estimates less skilful. However, similar projects, completed in Tanzania and Madagascar in collaboration with the National Meteorological Agencies, have had promising results. The method is currently being implemented in West Africa, at a regional level, in collaboration with the AGRHYMET Centre. Planning is also underway to implement the project in some other countries in Africa.

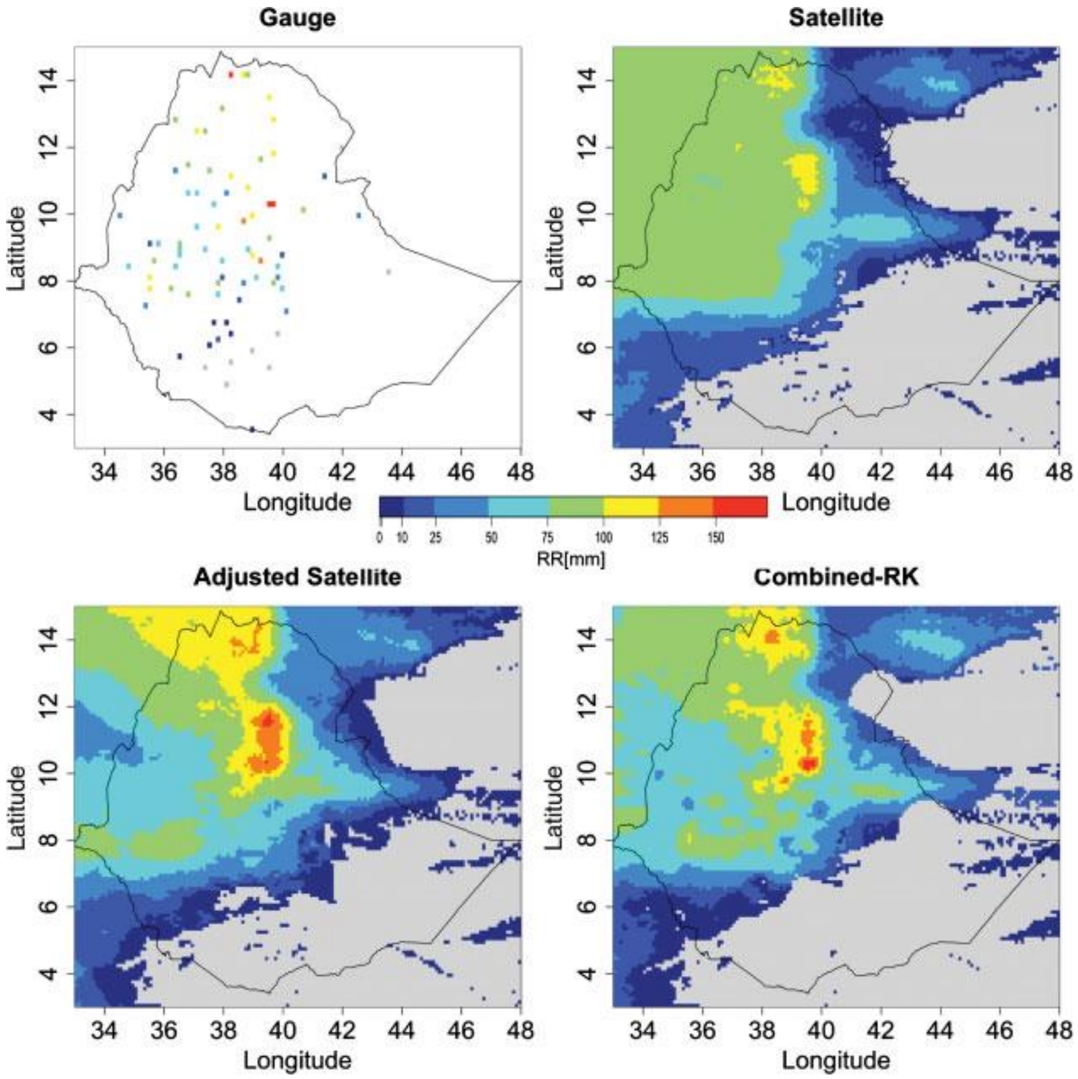


Figure 14. The Combining station measurements and satellite precipitation estimates over Ethiopia. The four maps are station observation (upper left), satellite estimate (upper right), bias-adjusted satellite (lower left), and station-satellite combined using regression kriging (lower right). (From Dinku et al., 2014).

The methodology described above for combining satellite (and other) data with all the available national gauge data to generate spatial and temporally complete gridded datasets has been successfully implemented in a number of African countries as part of the Enhancing National Climate Services (ENACTS) initiative, ENACTS aims to overcome issues of data scarcity and poor quality, introducing quality-assessed and spatially complete data services into national meteorological agencies to serve stakeholder needs (IRI, 2014 *project sheet*).

The development of hydrological monitoring and modelling

The Great Lakes of the East African Rift Valley serve as a crucial water supply for their neighbouring countries, making monitoring for the purpose of water management an essential activity. Satellite observations are vital for monitoring lake level change and total water discharge in areas such as this which suffer from a lack of in-situ observations or regional hydrological models. A variety of monitoring products such as GRACE (Gravity Recovery and Climate Experiment), TRMM (Tropical Rainfall

Measurement Mission) and WGHM (WaterGAP Global Hydrology Model) have been used for this purpose and their results agree that the major lakes in this area experienced significant decline in water level between 2003 and 2006 (Hassan and Jin, 2014).

An example of a research tool that could be operationalised is the Water Observation and Information System (WOIS). This is an open source software tool for monitoring and assessing water resources in a cost-effective manner using Earth Observation (EO) data. It was developed as part of the TIGER-NET project, which is a major component of the TIGER initiative of the European Space Agency (ESA), whose main goal is to support the African Earth Observation Capacity for Water Resource Monitoring[67]. More than 28 EO data processing solutions for water resource management tasks have been developed, in correspondence with the requirements of the participating key African water authorities, and demonstrated with dedicated case studies utilizing the software in operational scenarios. They cover a wide range of themes and information products, including basin-wide characterization of land and water resources, lake water quality monitoring (e.g. Figure 14), hydrological modelling and flood forecasting and mapping. For each monitoring task, step-by-step workflows were developed, which can either be adjusted by the user or largely automated to feed into existing data streams and reporting schemes. The WOIS potentially enables African water authorities to fully exploit the increasing EO capacity offered by current and upcoming generations of satellites, including the Sentinel missions (Guzinski, et al., 2014).

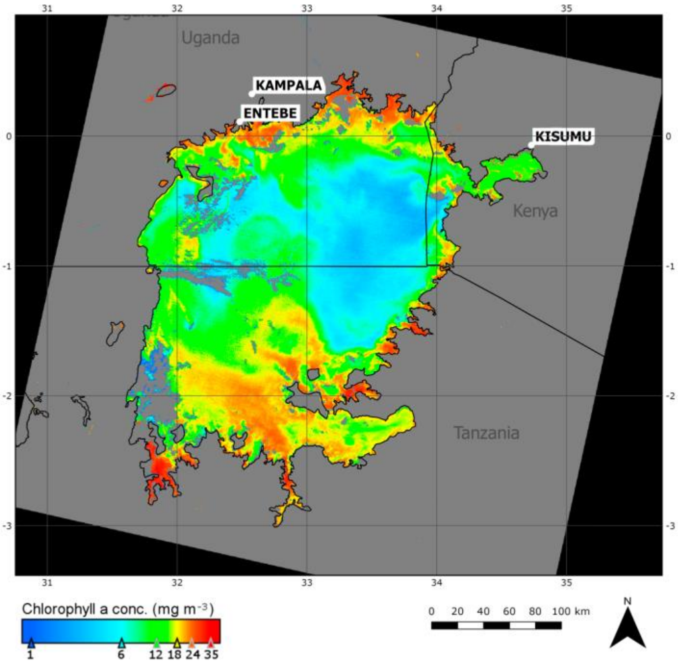


Figure 15 An example product from the WOIS workflow for monitoring lake water quality (Guzinski et al., 2014).

67 The initial key host institutions already actively involved in TIGER-NET encompass major river basin authorities (Nile Basin Initiative, Lake Chad Basin Commission, Zambezi Watercourse Commission and Volta Basin Authority), national ministries and agencies (Department of Water Affairs South Africa; the Hydrologic Division of the Namibian Ministry of Agriculture, Water and Forestry; the Department of Water Affairs of the Zambian Ministry of Mines, Energy and Water Development; DR Congo National Agency of Meteorology and Teledetection by Satellite; Instituto Nacional de Meteorologia of Mozambique), as well as international research and humanitarian organizations (International Water Management Institute, United Nations World Food program and Action Against Hunger).

Observations and Monitoring: Potential interventions or activities based on the literature review

- Further strengthening of national, regional and global linkages between NMHS and other key stakeholders (also highlighted in the UIP) (Rogers and Tsirkunov 2014) and support to co-design effective user-relevant monitoring and communication systems (e.g. Rainwatch, Cornforth et al., 2013)
- Further development of integrated remote sensing and ground observation products for P and T, observations and impact modelling, including (i) assimilation of RS T for drought monitoring and pull through of EU and ESA research projects on surface T to benefit African users and (ii) 'operationalising' water observation and modelling systems using RS data e.g. WOIS under the TIGER-NET project (Guzinksi et al., 2014; also highlighted in RMP section)
- Inclusion of ground based RADAR for the development of rainfall products
- Continued activity on rehabilitation of existing networks, ensuring that these work effectively as well as data rescue and digitisation (including data held on private commodity estates)
- Overall improvement of Information and Communication Technology (ICT) infrastructure for climate science including capacity for data management, IT, programming skills and research using large data sets (also highlighted in the CSIS and RMPs sections)

SECTION 6

Research, Modelling and Prediction

The GFCS Research, Modelling & Prediction pillar

The GFCS framework includes an annex on Research, Modelling and Prediction (RMP, **WMO, 2014d**). The document sets out the importance of including the fundamental links through from science to services as well as the need for science to be more interactive and targeted to user needs.

The aims of the RMP pillar are summarised as:

- Developing and improving practical science applications;
- Enhancing cooperation in research communities and interaction between climate information providers and users;
- Improving climate information products, and
- Improving understanding of Earth's climate system.

The GFCS recognises that progress in developing climate services will benefit from research across a wide range of disciplines including: 'atmospheric sciences, oceanography, hydrology, cryospheric sciences, terrestrial and marine biogeochemistry, research on socio-economic and human systems, and research on climate–dependent applications in key areas of human activity'. In sections 2 and 3 we have discussed recent and ongoing initiatives in social science research related to the communication of climate information (see e.g. Visman 2014; Kniveton et al. 2014; May et al. 2013; Tall et al. 2014), and in Section 4 we have discussed African and international activities in African weather and climate prediction.

In this section we therefore deal primarily with weather and climate research and modelling activities. We begin by summarising conclusions of three recent initiatives which have included examination of climate research priorities for Africa, namely: the joint African Climate Policy Centre (ACPC) and WCRP priority agenda for Climate Research for Development (CR4D); a review of strategic research opportunities for the ClimDev programme conducted by Wilby (2014); and research gaps for Africa as identified by authors of the IPCC AR5 Working Group two (WGII) report (IPCC, 2014). This provides a broad view of research needs across physical understanding of climate, science application and communication. We then focus more narrowly on requirements for research to improve understanding, modelling and prediction of the climate system.

Capacity for Climate Research and Modelling in Africa

An important contextual issue is that most research and modelling for Africa is conducted by non-African organisations. Major research initiatives such as the African Monsoon Multi-disciplinary Analysis (AMMA - Redelsperger et al. 2006) have been led by non-African groups. While AMMA built up a relatively strong community of researchers from Africa, there remains insufficient critical mass and resources to foster scientific leadership. Despite general investments to develop young emerging African scientists within the climate related arena, few become recognized leaders in the international community whilst also staying within the Africa continent (Wilby, 2014 – Annex 6). There are severe limitations in resources, technical capacity, available staff and computational capacity, and a chronic lack of investment in postgraduate education and research infrastructure. This is manifest in the relatively low level of engagement of African scientists in major international activities like the IPCC. Wilby (2014) notes that although there is an accelerating output of climate change research from Africa, its starts from a low base (~3% of the global share of publications). Other than in South Africa, there is no active climate model development on the continent. Of all the CMIP models developed by the international science community, none of the core development teams sit in African institutions. This is mirrored at weather timescales in that no operational models that are being used for weather forecasting by NMHSs in Africa are being developed in Africa. As noted in section 4, very few countries other than South Africa are running numerical prediction models. Prominent organisations conducting weather and climate research in South Africa include the South African Weather Service (SAWS), the Climate Systems Analysis Group (CSAG) of the University of Cape Town, Pretoria University and the Council for Scientific and Industrial Research (CSIR).

A further indication of low model development activity in Africa comes from WMO's published summary of activities from the Working Group on Numerical Experimentation (WGNE) where there has been only one author from Africa from 2002-2014 (Tennant, 2007) and only one African sits on the WGNE committee (F. Engelbrecht from CSIR).

The priority research agenda – Climate Research for Development (CR4D)

Recent developments to foster a continental agenda for Africa-led climate science include the recent joint ACPC and WCRP African Climate Conference, held in 2013 in Arusha, Tanzania (ACC2013) which brought together researchers from across the continent and also internationally. The conference declaration for ACC2013[68] formed the basis of a continuing initiative known as the priority agenda for Climate Research for Development (CR4D). The

[68] http://www.wmo.int/amcomet/sites/default/files/field/doc/events/acc2013_final_declaration.pdf

agenda is described in Shongwe et al. 2014 as comprising 8 activities endorsed by the conference, namely.

CR4D-1: develop sustainable observational networks; engage in intensive observational campaigns; and recover, digitize, and analyze existing historical climate data;
CR4D-2: develop impact data sets across climate-sensitive sectors to enable the development and evaluation of application models;
CR4D-3: undertake research on processes and feedbacks relating to the carbon and water cycles, land-atmosphere coupling, and mechanisms communicating the climate change signal on temperature and rainfall in Africa;
CR4D-4: undertake detection and attribution studies of past and future climate, particularly extreme events;
CR4D-5: improve the understanding of local and remote drivers of climate variability at short to multi-decadal time scales to improve climate prediction skill;
CR4D-6: under take multidisciplinary research involving social and natural scientists;
CR4D-7: overcome barriers and limits to the flow of knowledge between scientists and user communities; and
CR4D-8: build the research capacity of African institutions.

Strategic review of research opportunities for ClimDev

In a review of over 90 ongoing or recently completed climate research projects and programmes in Africa Wilby (2014) noted that research topics that are currently under-represented include knowledge and climate service development on climate impacts for the built environment, coastal zones, human health, tourism and transport, as well as cross-sector aspects such as the water-energy or coastal-urban nexus. Opportunities were also noted for expanding research in social science fields as well as strengthening activities in regions where research activity is current relatively low, such as for North and middle Africa. The six proposed options for a ClimDev research focus were defined as:

W-1: Expanded data rescue initiative: To locate, rescue, digitize, archive and share historical climate data in order to better estimate sustainable resources and track environmental change, to contribute to global climate modelling and evaluation efforts, and to provide a common resource for research and capacity development within Africa.
W-2: New frontiers research programme: To build a more holistic knowledge of climate change impacts and adaptation options for regions (north and middle Africa) and sectors (built environment, coastal zone, human health, transport, and tourism) receiving relatively little attention to date.
W-3: Climate service forums: To better understand and meet the climate information needs of communities by commencing the outreach process from the starting point of information needed to achieve adaptation objectives for most vulnerable groups.
W-4: Operationalizing evidence of climate risks and response strategies: To pilot the implementation of climate risk information through development of planning guidance or technical advice for practitioners.
W-5: Research fellowship and mentoring programme: To prioritise capacity building and retention especially within non-Anglophone countries in north and middle Africa. The resources would provide in situ long-term support for regional hubs that contribute to wider collaboration across Africa and improve security of tenure for early career researchers in educational facilities.
W-6: Living data platform to support resource allocation and collaboration: To develop a knowledge-sharing web-platform to ensure that climate information and relevant studies, reports and policy documents are accessible. New technologies such as ‘Big Data’ are deployed to harvest information for the platform.

IPCC AR5 WGII - Africa
African needs for climate change research are summarised in the IPCC's fifth assessment WG2 report (IPCC, 2014) as follows (see also Table 2). The needs are focussed on impacts because of the "Impacts, Adaptation and Vulnerability" context of the report. With regard to direct climate science, Table 2 stresses the need for more open sharing of data and research into downscaling of GCM output to, for example, take account of detailed topographic influences not well resolved in GCMs.

WGII-1: Training needed to understand the limitations of current science capability and ensure climate information communicators are presenting a realistic picture of skill and uncertainty to users.
WGII-2: Data management and monitoring of climate and hydroclimate parameters and development of climate change scenarios as well as monitoring systems to address climate change impacts in the different sectors (e.g., the impacts of pests and diseases on crops and livestock) and systems;
WGII-3: Research and improved methodologies to assess and quantify the impact of climate change on different sectors and systems;
WGII-4: Socioeconomic consequences of the loss of ecosystems and also of economic activities as well as of certain choices in terms of mitigation (e.g., biofuels and their links with food and livelihood security) and adaptation to climate change;
WGII-5: The influence of climate change in emerging issues such as migration and urban food security;
WGII-6: Developing decision-making tools to enable policy and other decisions based on the complexity of the world under climate change, taking into consideration gender, age, and the potential contribution of local communities.

There is considerable consistency between the three lists, though each has different emphasis. Data rescue and digitisation are present explicitly in the CR4D and Wilby lists and WG-II (Table 2) stresses the need for greater data sharing. Various aspects related to research into the use of climate information including decision aids and into methods of communication are present in all three (CR4D-6,7; W-3,4,6; WGII-6). These areas perhaps fit more readily under the Observations and Monitoring and UIP Pillars (Sections 5 and 3). The lists also stress the need for sustainable climate science capacity development in Africa (CR4D-8; W-5, WGII-1). As regards more direct climate science research, Wilby and WGII place more emphasis on improving understanding of climate change impacts and adaptation options for currently understudied regions and sectors and including cross-sector issues such as water-energy, coastal-urban, food security-conflict. CR4D includes more underpinning research on improving understanding of the local and remote drivers of variability and change, land-atmosphere interactions, detection and attribution (CR4D-5, 3, 4). WG-II table 2, stresses the need for research in downscaling activities to take account of topographic influences on climate change signals.

In the next sections we focus on recent climate science research activities for Africa to gain a perspective on potential focus areas for CIASA.

Table 2: Climate research gaps for Africa (from IPCC, AR5 WGII report, Part B, 2014)

Key sectors	Gaps observed
Climate science	• Research in climate and climate impacts would be greatly enhanced if data custodians and researchers worked together to use observed station data in scientific studies. Research into regional climate change and climate impacts relies on observed climate and hydrological data as an evaluative base. These data are most often recorded by meteorological institutions in each country and sold to support data collection efforts. However, African researchers are generally excluded from access to these critical data because of the high costs involved, which hinders both climate and climate impacts research. • Downscaling General Circulation Model (GCM) data to the regional scale captures the influence of topography on the regional climate. Regional climate information is essential for understanding regional climate processes, regional impacts, and potential future changes in these. In addition, impacts models such as hydrology and crop models generally require input data at a resolution higher than what GCMs can provide. Regional downscaling, either statistically or through use of regional climate models, can provide information at these scales and can also change the sign of GCM-projected rainfall change over topographically complex areas (Section 22.2.2.2).
Ecosystems	• Monitoring networks for assessing long-term changes to critical ecosystems such as coastal ecosystems, lakes, mountains, grasslands, forests, wetlands, deserts, and savannas to enhance understanding of long-term ecological dynamics, feedbacks between climate and ecosystems, the effects of natural climate variability on ecosystems, the limits of natural climate variability, and the marginal additional effects of global climate forcing • Develop the status of protected areas to include climate change effects
Food systems	• Socioeconomic and environmental trade-offs of biofuel production, especially the effect on land use change and food and livelihood security; better agronomic characterization of biofuel crops to avoid maladaptive decisions with respect to biofuel production • Vulnerability to and impacts of climate change on food systems (production, transport, processing, storage, marketing, and consumption) • Impacts of climate change on urban food security, and dynamic of rural–urban linkages in vulnerability and adaptive capacity • Impacts of climate change on food safety and quality
Water resources	• Characterization of Africa's groundwater resource potential; understanding interactions between non-climate and climate drivers as related to future groundwater resources • Impacts of climate change on water quality, and how this links to food and health security • Decision making under uncertainty with respect to water resources given limitations of climate models for adequately capturing future rainfall projections
Human security and urban areas	• Research to explore and monitor the links between climate change and migration and its potential negative effects on environmental degradation; the potential positive role of migration in climate change adaptation • Improved methods and research to analyze the relation between climate change and violent conflict.
Livelihoods and poverty	• Methodologies for cyclical learning and decision support to enable anticipatory adaptation in contexts of high poverty and vulnerability (Tschakert and Dietrich, 2010) • Frameworks to integrate differentiated views of poverty into adaptation and disaster risk reduction, and to better link these with social protection in different contexts • Ethical and political dimensions of engaging with local and traditional knowledge on climate change
Health	• Research and improved methodologies (including longitudinal studies) to assess and quantify the impact of climate change on vector-borne, food-borne, water-borne, nutrition, heat stress, and indirect impacts on HIV • Research to quantify the direct and indirect health impacts of extreme weather events in Africa; injuries, mental illness; health infrastructure • Frameworks and research platforms to be developed with other sectors to determine how underlying risks (e.g., food security) will be addressed to improve health outcomes
Adaptation	• Research to develop home-grown and to localize global adaptation technologies to build resilience • Equitable adaptation frameworks to deal with high uncertainty levels and integrate marginalized groups; and that identify and eliminate multi-level constraints to women's adaptive ability • Multi-tiered approach to building institutional and community capacity to respond to climate risk • Potential changes in economic and social systems under different climate scenarios, to understand the implications of adaptation and planning choices (Clements et al., 2011) • Principles/determining factors for effective adaptation, including community-based adaptation • Understanding synergies and trade-offs between different adaptation and mitigation approaches (Chambwera and Anderson, 2011) • Additional national and sub-national modeling and analysis of the economic costs of impacts and adaptation, including of the "soft" costs of impacts and adaptation • Monitoring adaptation
Other	• Methods in vulnerability analysis for capturing the complex interactions in systems across scales • Understanding compound impacts from concomitant temperature and precipitation stress, e.g., effect on a particular threshold of a heat wave occurring during a period of below normal precipitation

Overview of climate science activities and opportunities

It is generally considered that there is a lack of understanding of African climate and its drivers and a strong need for focused research to address this. For example, the Africa Climate Report (Washington et al. 2004) noted that "...the scientific understanding of the African climate system as a whole is low…". While there has been some progress since that time, notably from the AMMA programme in West Africa – there are still many gaps in understanding. In as much as climate models represent the embodiment of understanding, this is supported by the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) which concluded that current climate models have only a modest ability to capture those phenomena that are most important in driving African climate. Others (e.g. Rowell, 2013) have noted that there has been little net improvement in some aspects of modelling African climate between the CMIP3 and CMIP5 experiments (i.e. in the last 5-10 years). This need for research to improve understanding and modelling of the African climate system and its drivers is supported by the CR4D agenda.

The predominant hazards on daily timescales – and thus of prime interest to short-term prediction - are heavy rain and damaging winds from violent thunderstorms – a consequence of tropical convective processes. Processes that control the triggering and evolution of such systems and their development into large (order 100km) scale systems (Mesoscale Convective Systems or MCSs – Houze 1977) that can give rise to particularly severe weather are not well understood or modelled (Stephens et al. 2010) making accurate prediction a challenge and highlighting the need for research in better representation of tropical convection.

Below we consider recent activities and potential research opportunities relevant to improving understanding and prediction of weather and climate over all timescales.

Observation campaigns

Intensive observation campaigns are necessary to provide the basis for analysis that can develop new understanding of African weather and climate processes and for testing model fidelity at simulating processes. A recent example of a successful observation campaign in Africa with many research outputs is that conducted as part of AMMA (Redelsperger et al. 2006; Lafore et al. 2010) which has led to significant new understanding of the large-scale structure of the West African Monsoon system, as well as smaller-scale component processes such as convection, land-atmosphere interaction and transient wave activity (Janicot et al. 2011). Research has supported development of a valuable practical product, namely the "Forecasters' Handbook for West Africa", through which robust, reliable and up-to-date scientific weather forecasting methods, covering timescales out to one season ahead, will be documented for the first time, and made available to the operational prediction community in West Africa.

It is notable that observations campaigns on a similar scale to that undertaken in AMMA have not yet been undertaken in other parts of Africa. There are plans to undertake observation campaigns around the Lake Victoria Basin, as part of the LVB-HyNEWS consortium of projects, but these are so far unfunded. The intended campaigns would investigate the drivers of violent convective activity over the lake as well as the longer-term hydrological cycle. Similar documentation and findings (e.g. following the example of the West Africa Forecaster's Handbook) could be generated to support the climate community in the region – helping sustainable improvements in weather and climate services to users.

Monitoring

The ENACTS programme has already been mentioned in Section 4 (CSIS) and Section 5 (Observations and Monitoring). There are opportunities to support research in science areas underlying the ENACTS activity, for example in improving calibration methods for satellite based rainfall estimates and incorporating use of new satellite-based technology (e.g. the NASA GPM Core Observatory satellite). As mentioned in Section 5, all satellite-based estimates are subject to measurement biases (see e.g. Thiemig et al.2012), and it is an active area of research to develop improved methodology for generating the estimates. There is a need for further research to develop corresponding estimates for near-surface air temperature and work in this field is just beginning (see Section 5). The ENACTS programme has developed methodology for several countries in Africa that combines satellite rainfall estimates with observations from national station networks (often more extensive than those available outside the country), to provide temporally and spatially complete gridded rainfall analyses over the country. Similar datasets have been constructed using temperature observations and spatially complete temperature fields from reanalysis datasets. In terms of future research options, Dinku et al. (2014) note that extension of current work on 10-day average rainfall needs extension to the daily timescale to aid development application models requiring input parameters at daily frequency (e.g. crop models).

Short-term prediction

As noted above, convective activity dominates rainfall over most of sub-Saharan Africa. Activity shows a strong diurnal cycle with fewer storms in the morning and early afternoon, and storms developing across the continent in the late afternoon and evening. Getting this diurnal cycle correct in numerical models is a significant challenge (Stirling and Stratton, 2011; Stratton and Stirling 2012) – with most models simulating peak activity around local midday rather than evening time. Moreover, the atmospheric processes controlling the initiation, maintenance and longevity of convection are typically very localised. This means that small, local disturbances in the atmospheric balance can lead to large weather events or storms. As such, the representation of convection in numerical models is highly challenging and small biases or inaccuracies in the representation of the initial conditions or physical processes in the model can lead to large errors in the forecast at weather timescales (0-3 days). Errors in representing convective processes can also impact predictions on longer timescales (see later).

Difficulties in simulating convection arise primarily because the scale of individual convective cells is considerably smaller than the grid spacing of most operational numerical models. As a result convective processes cannot be represented explicitly and their bulk effects must therefore be diagnosed and represented by reference to large scale parameters such vertical stability (a process known as “parameterisation”). Stephens et al. (2010) reviews the errors in regional tropical precipitation from a number of state-of-the-art models and notes that all generate precipitation too frequently and too lightly – with best results achieved with high resolution models that resolve convection explicitly (i.e. without parameterisation). Use of convection-resolving models also improves other aspects of simulation such as the diurnal cycle and overall water budget (Marsham et al. 2013; Birch et al. 2014) and Chamberlain et al. (2013) have shown that improved convection leads to an increase in forecast skill in an operational model over Lake Victoria. There is therefore much research interest in developing and deploying high-resolution convection-resolving models (e.g. in the FCFA IMPALA[69] model development project). It will be sometime before long global climate simulations can be run at the high resolutions necessary to resolve convection – thus use of convection-resolving very high resolution limited area models as well as improved means of parameterising convection in global models remain important areas of research of direct relevance to providing improved weather and climate services for Africa. Some high-

[69] Improving Model Processes for African Climate

resolution limited area short-range prediction models run over Africa regions are listed in Table 3. The Met Office 4km East Africa LAM is convection resolving for deep convection.

Small scale processes that have significant impacts on weather structures are not just limited to the convective processes themselves. Convection is in turn, highly influenced by land surface and vegetation (Taylor et al. 2012), dust and aerosol processes (Todd et al., 2013) and orographic effects (Seleshi and Zanke (2004) mention mechanisms for rainfall generation in the Ethiopian highlands) as well as the structure of the boundary layer which has been shown to be highly complex in Africa (Bain et al., 2010).

In addition to research to improve predictions themselves, another key area of research particularly important in the African context is impact-based forecasting – which aims to go further than just predicting meteorological parameters by predicting, in addition, the attendant impact, i.e. given a forecast of 40mm of rain in 2 hours, what level of urban flooding can be expected in a certain district. International coordination on Impact forecasting is being led through the WWRP High Impact Weather[70] (HIWeather) programme. HIWeather will focus on the following hazards: localised wind extremes, wildfire, urban flooding, heat and air pollution in megacities and disruptive winter weather.

[70] http://www.wmo.int/pages/prog/arep/wwrp/new/high_impact_weather_project.html

Table 3: High resolution limiter area models run operationally over sub-regions of Africa for short-range prediction

Modelling Centre	Model, resolution and domain	Evidence of performance assessment	Availability of output	Current/ Future plans
South African Weather Service (SAWS)	Unified Model 12km over Southern Africa (south of equator)	Tennant (2007) introduced initial case study with model.	Plots available on the SWFDP website for NMSs in Southern Africa	Plans to upgrade to a 4km model in 2015/ 2016 for southern Africa and a 1.5km model for South Africa
Kenya Met Service (KMS)	WRF 12km over East Africa	No formal performance assessment published	Plots are available on the SWFDP website for NMSs in East Africa	No knowledge or published plans of upgrades or changes
Kenya Met Service (KMS)	COSMO 12km over East Africa	No formal performance assessment published	Plots are available on the SWFDP website for NMSs in East Africa	No knowledge or published plans of upgrades or changes
Tanzanian Met Service (TMA)	COSMO 12km over East Africa	No formal performance assessment published	Plots are available on the SWFDP website for NMSs in East Africa	No knowledge or published plans of upgrades or changes
Met Office	Unified Model, 12km over north Africa (north of equator)	No published performance review but some studies have used the data - Bain et al. (2011)	RETIRED Plots were available on WMO VCP website for NMSs in Africa	RETIRED in Feb 2014, replaced on website by a cut out of global model (which performs comparably)
Met Office	Unified Model, 4km over East Africa (Lake Victoria only 2012-2014)	Chamberlain et al (2014)	Plots available on WMO VCP website for NMSs in Africa	Website upgrade early 2015
Meteo France	ARPEGE-Tropiques, T538L60 over West Africa	Available on PUMA workstations		There have been many experiments with LAM version Meso-NH which show improvement but not clear what will become operational http://mesonh.aero.obs-mip.fr/cgi-bin/mesonh/publi.pl?art=on&phd=on
Meteo France	ALADIN-Reunion, 10km over SE Africa/ Indian ocean for tropical cyclones [0-32S, 31.5-88.5E] 84hr forecasts	Montroty et al. (2008)	Run in Toulouse, info passed to RSMC La Reunion (TCs in Indian Ocean)	Continuation of service with ongoing research into upgrading model (CRNM, La Reunion)

Sub-seasonal prediction

The sub-seasonal time horizon represents a key information gap between medium range (out 15 days) and seasonal (typically 1-6 months ahead) forecasts – there are currently very few operational forecasting systems with products widely available. Development of forecasts on this timescale has lagged behind that of the short and seasonal ranges because the target period is particularly challenging – lying between the shorter range when initial conditions provide predictability, and the seasonal range where slowly changing boundary influences (e.g. from SST) becomes the dominant source of predictability. One source of predictability on the sub-seasonal timescale that is a current focus of research is the Madden-Julian Oscillation (MJO), a tropical disturbance that propagates eastward around the global tropics with a cycle on the order of 30-60 days. The MJO is associated with regions of suppressed and enhanced rainfall around the tropics that shift with the phase of the oscillation. Influences have been documented on both West African (Alaka and Maloney, 2012) and East African rainfall (Pohl and Camberlin, 2006). Monitoring and predicting the progress of MJO events holds potential for developing predictions on the sub-seasonal timescale. Global hazards prediction maps, for next two weeks ahead, developed in part by monitoring and prediction of the MJO, are available from NOAA CPC (Fig. 16). There are key opportunities to improve understanding of the regional specific impacts of the MJO over Africa and to develop and evaluate information products for users.

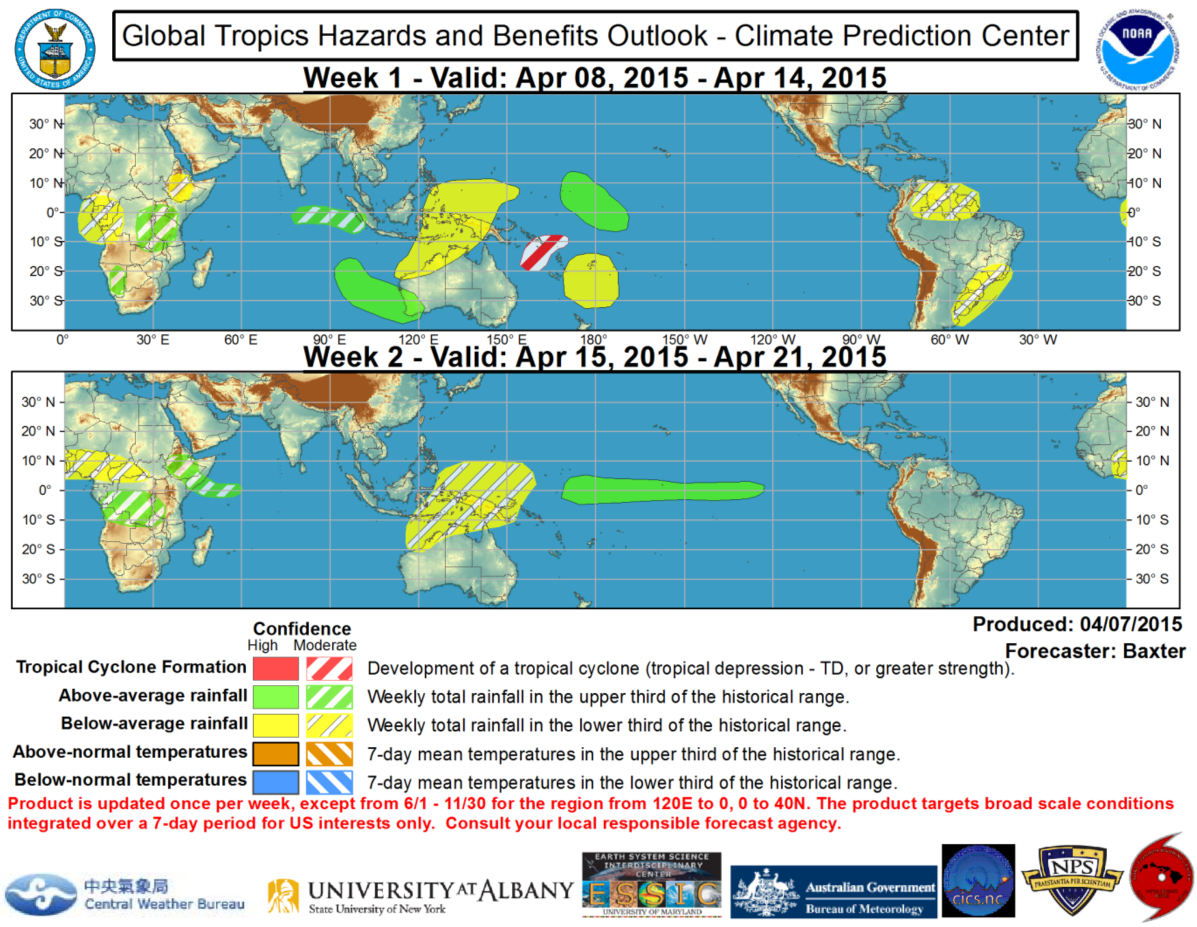


Figure 16: Global hazards map issued 7 April 2015 and valid for the following 2 week period (source: NOAA CPC)

Convective processes are crucial in driving the MJO and model simulation is also improved when convection is explicit rather than parameterised (Holloway et al. 2013) – increasing the need for research to improve representation of convection in models.

The timing of season onset may be considered part of sub-seasonal variability. The prediction of rainy season onset timing is one of the most frequently stated requirements for agricultural applications in Africa (see e.g. Graham et al. 2012). Vellinga et al. (2013) have shown that dynamical models have skill in predicting the onset of the West African Monsoon in the Sahel, though further research is needed to improve the methodology and tailor prediction formats to the needs of users. Predicting the frequency of in-season dry spells and risk of damaging heavy rain are also key requirements.

Thus improved understanding, modelling and prediction of the MJO and other drivers of subseasonal variability represent major research opportunities for developing climate services in Africa. A major initiative that CIASA can exploit in this field is the WWRP-THORPEX/WCRP sub-seasonal to seasonal (S2S) research programme[71] which seeks to increase capabilities for prediction on the 10- to 50-day time horizon and has a specific sub-project for Africa with potential for a real-time forecast demonstration phase.

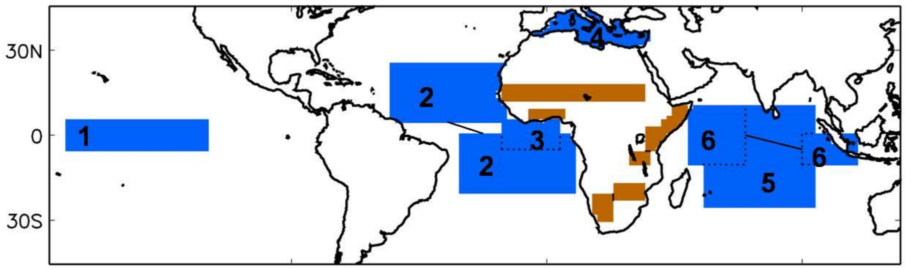


Figure 17: Modes of sea surface temperature variability influential on Africa seasonal rainfall; 1) ENSO; 2) Tropical Atlantic Dipole; 3) Equatorial East Atlantic; 4) Mediterranean; 5) Central Indian Ocean; 6) Indian Ocean Dipole. Brown shading indicates main regions influenced, only areas where seasonal rainfall exhibits high spatial and temporal (month to month through the season) coherency are shown. *From Rowell (2013).*

Seasonal Prediction

Statistical seasonal forecasting for the African continent has a long heritage (see e.g. Ogallo, 1989; Mutai et al., 1998; Folland et al. 1991; Landman and Mason, 1999). Typically, statistical prediction methods use historical relationships between seasonal rainfall and preceding mainly tropical Sea Surface Temperature (SST) variability. There is relatively good prediction skill in many regions of Africa because of strong relationships been Pacific, Atlantic and Indian Ocean temperatures and seasonal rainfall. A summary of SST modes influential on African seasonal rainfall is given by Rowell (2013) and reproduced in Fig. 17.

[71] http://s2sprediction.net/static/about

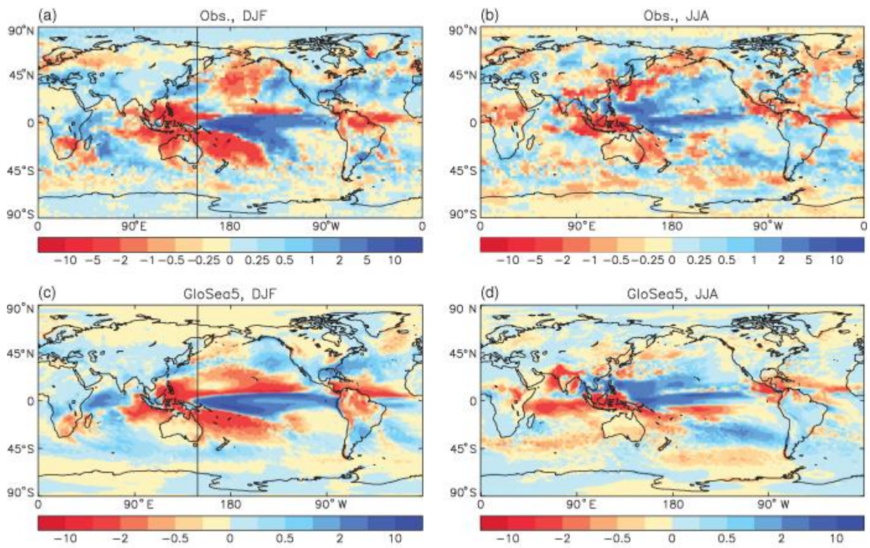


Figure 18: Observed and modelled ENSO teleconnections to rainfall. Precipitation difference (mm day−1) between El Niño and La Niña years for (a, b) observations, (c, d) GloSea5 N216, in (a, c) DJF and (b, d) JJA. The DJF means are derived from November starts and the JJA means are derived from May starts. In (c, d), the pattern correlations with observations are 0.80, 0.61 (all ±0.01), respectively. (*adapted from MacLachlan et al 2014*)

As discussed in Section 4 developments in dynamical seasonal prediction represent a major opportunity for Africa. Rainfall teleconnections to Africa (and to rest of the globe) from ENSO are well produced by some models (Fig. 18). Models have relatively good skill at predicting ENSO from some months ahead – and thus, with research into making best use of dynamical predictions, there is strong potential to increase the lead time of climate warnings from that currently available from statistical methods (Graham et al. 2013).

Importantly, current model abilities to predict variability in other ocean basins (e.g. the Atlantic and Indian Oceans) are much lower than for the tropical Pacific (Graham et al. 2013). Improving model representation of SST variability in these regions and the teleconnections to African rainfall are key opportunities for research that will benefit early warning systems over Africa.

RMP intervention/link option 6: Support model development to improve predictions of SST variability and representation of teleconnection processes to African rainfall – enhancing potential for more reliable seasonal forecasting for the continent.

Multi-annual to decadal Prediction

Although, when initialised with the current climate state, models can simulate ENSO teleconnections to African rainfall reasonably well, climate drift tends to set in in long integrations and this is one factor that degrades model simulations of teleconnection effects. In a study of the quality of teleconnection links in CMIP3 and CMIP5 models Rowell (2013) assessed the modelled and observed influence of the 6 SST mode of Fig. 17 to various African rainfall regions. It was found that although some teleconnections are simulated reasonably well by most models, adequate simulation of others defeated most models. Little improvement was seen across CMIP3 to CMIP5. Correct model representation of these remote influences on African rainfall is an important requirement for improved prediction on climate timescales.

Thus improvement of model representation of remote influences on African climate remains a key priority for future research. Improved model representation of remote influences should contribute to improved predictions on seasonal and multi-annual to decadal timescales. As mentioned in Section 4, currently levels of skill are best for the Sahel region[72] (Fig. 19), and research into the potential usefulness of such forecasts is another key opportunity. As for short-range and sub-seasonal/seasonal prediction, improvement of local processes such as convection is also needed to improve predictions at these longer timescales, because of complex timescale interactions (Vellinga, 2015).

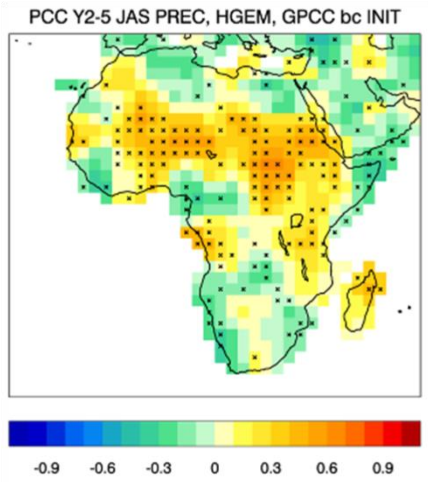


Figure 19: Correlation skill from DePreSys2 re-forecasts of precipitation averaged over July-August-September seasons of years 2-5 of November-start forecasts. Calculated over the period 1960-2010. Stippling indicates correlations significantly different from zero at the 90% level. Note coherent areas of significant skill in the central and eastern Sahel.

Climate Change Scenarios

As reported in AR5, for the CMIP5 models, Roehrig et al. (2012) found projected changes in surface air temperature and precipitation which are similar to those produced by the CMIP3 models. Specifically, for the period 2071-2100, they found clear warming trends over the Sahel region of ~4.5±1.5°C which is larger by 10-50% than the mean global temperature rise for each model. This increase is significant for impact on farming practices. For example, studies have shown that systematic increases in temperatures have a detrimental impact on millet farming which is one of the staple crops in West Africa (Sultan et al. 2013).

This accelerated temperature rise is also echoed in Hawkins and Sutton (2012). A consensus of all climate models examined showed that the African continent had the fastest rate of warming, with the increase in temperatures (or 'time of emergence' of the climate change signal) already occurring in the early part of this century. This suggests that the effects of climate change on temperature may already be being felt across Africa.

Projected changes of precipitation in future climate scenarios are far more uncertain. Figure 20 shows the projections from the IPCC (Kirtman et. al 2013). The climate change signal is small when compared to internal variability (hatched areas on Fig. 20) in most parts of the globe, including all of Africa, in these near future projections out to 2035. Research to improve climate models in their representation of both remote and local process important to African weather and climate provides an opportunity to reduce the envelope of uncertainty. In addition, it is important to understand the processes by which the influence of anthropogenic CO_2 and aerosol translate into in regional climate change, both in terms of observations and as simulated in models – so that a processed-based evaluation of models might be used to "cull" poorer performing ones with potential for reducing the uncertainty

72 CSRP-2 final report: http://www.metoffice.gov.uk/csrp/csrp2-results

envelope and increasing the actionability of information. Rowell et al. 2015 recommends this approach after a preliminary study to understand the “East Africa Paradox” – which refers to the apparent conflict between drying in the East Africa MAM season and a model consensus for wetting by 2050.

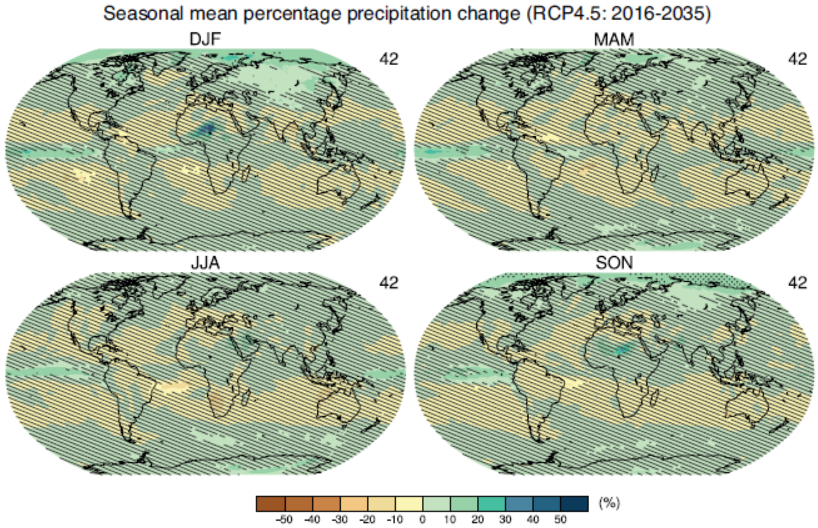


Figure 20: CMIP5 multi-model mean projections of precipitation change 2016-2035, taken from IPCC WG1. The hatching is where the climate change signal is small compared to the climate variability suggesting uncertainty in the predicted change.

Cross-cutting research themes

Downscaling
Variation in rainfall drives a major vulnerability to climate in Africa. The global models used to make global climate predictions are at too coarse a resolution to provide rainfall patterns at the scales required for impact studies, which are often at the catchment scale. Hence there is a continuing need to develop methods to add required geographical and temporal detail as well as to improve representation of extreme events which typically occur at small scales. Such “downscaling” of forecasts may be undertaken using statistical approaches or physical modelling with Regional Climate Models (RCMs) – with physical modelling the more fundamental approach. There is a need to research the performance of very high resolution (including convection-resolving) Regional Climate Models. Downscaling is required for all prediction timescales from seasonal and beyond to enable provision of information at geographical scales needed by users and with accurate representation of extremes.

Applications modelling
Research on integration of monthly-decadal and longer climate predictions with application modelling remains a priority to help optimise usefulness to users. Key areas include: agriculture and food security (regional crop yields; crop pests and diseases); health (movement and onset of diseases); water resources/energy (river flows, irrigation systems, hydro-electric systems).

Climate event attribution
To reduce the risk of (potentially expensive) mal-adaptation, development planners need rigorous advice on climate change detection and attribution. As an example, an experimental real-time attribution system was developed as part of the CSRP-1 project and has been applied to assess the role of human-induced climate change in the severe drought in the

Greater Horn of Africa 2010/11 (Lott et al. 2013). Results indicate that human influence has increased the probability of drought in the long-rains seasons of the region, though there is uncertainty in the degree of increased risk. Event attribution is a new science and further development of methodology is needed as understanding of the processes driving regional climate change increases and the ability of models to represent key drivers improves.

Needs for Capacity, Access and Effectiveness in Africa

These have been split into three categories from immediate to long-term needs. Short term capacity building will have benefit immediately but long-term sustainable capacity building needs to take place at the same time for progress to be made and the next level of development achieved. The below ideas were informed by situational assessments and visits that Met Office has conducted in several Met Services in Africa (Malawi, Rwanda, Burkina Faso, South Africa, Kenya, Tanzania, Ethiopia, Ghana) as well as personal communication with Dr. B. Lamptey, ACMAD on his visit to Met Office.

Immediate to short term needs

Improvements in the understanding of how to use available information (short term)

- Training needed to understand the limitations of current science capability and ensure climate information communicators are presenting a realistic picture of skill and uncertainty to users.
- Fellowships and visiting scientist exchanges: In addition to traditional training approaches (e.g. workshops). Fellowship schemes with international centres (see e.g. CSRP-1 final report) have proved very successful. Other forms of more sustained interaction should be strengthened, such as long-term visiting scientist exchanges or establishment of a joint research and applications centre.
- More uptake of available information – there is more information available for use in African climate services than is currently being used. The barriers may be lack of knowledge or understanding of how to apply the science. Especially notable is the lack of use of medium range forecasts and dynamical models for seasonal forecasts.
- Systematic validation practices that are appropriate to the existing levels of skill – evaluation of forecast/ climate product skill needs to be owned by African institutions. Currently very little systematic monitoring of quality and skill is completed, or if it is, it is not published outside of the institutions for sharing.
- Access to information needs to be improved. With higher resolution models and more climate and weather information produced daily by the international research and operational community, there needs to be more efficient mechanisms of making this information flow to the NMHSs in Africa in a format that they can readily digest and use

Short to medium term needs

Better use of primary information (e.g. models, observations) and efficient creation of products, programming skills to plot and produce (medium term)

- The design of weather and climate information products and an appropriate portfolio of products needs to be informed by the users. Users should be involved in testing and refining if possible, so links between the research, production, social science and user community need to be strengthened.
- Capacity in software, programming and scientific research skills to produce products needs to be strengthened so that Africans can independently create what is needed for their users rather than relying on external sources (which are expensive and unsustainable in the long term).
- Research and production of climate services need to be integrated into strategic planning, time and duties for NMHS staff. Often, the time needed for realisation of products is limited and services are not as automated as they could be.

- Attention needs to be paid to the IT infrastructure to gather information, translate science to impacts and create automated services – this includes maintaining and upgrading message switching systems (such as the Global Telecommunications System and WMO Information System), internet connectivity and access to software and hardware.
- Links between academic institutions and NMHSs could be strengthened and research goals aligned so that academic research can be pulled through more efficiently to realisation. For example, more masters students/ PhD students at local Universities using model output, contributing to potential application development and gaining understanding of limitations.

Medium to long term needs

Building of research community in Africa and capability to independently run models and lead research (long term)

- Running and joint development of research models by regional institutions such as ACMAD and ICPAC, building through to NMHSs and Universities.
- Strong, leading research community in Africa contributing to peer-reviewed publications and research.
- Investment in skills, staff and infrastructure (e.g. IT, data storage and observations) to ensure long term sustainability – building a pipeline of capability for the future.
- More observations including existing observations uploaded onto GTS to be made available outside country, more upper air stations, REMS and lightning stations (See Section 5).

Research, modelling and prediction: Potential interventions or activities based on the literature review

- Promoting African leadership in climate science within a more integrated and sustainable research community (see, for example, the comments of Hewitson in Wilby, 2014). This could include joint modelling/applications centres and meeting the demand for training programmes in specific areas (see above).
- Development of climate service and applications research programmes responding to user needs (Section 2) and accelerating research into use. This includes research on weather and climate monitoring and multi-disciplinary work on risk management, establishing climate sensitivity and impact for specific sectors (particularly those currently under-represented) and on developing and communication of climate information and products.
- Research to improve understanding and modelling of African weather and climate processes and their drivers, including both remote influences (teleconnections) and local factors (convection, land-atmosphere interactions). Comprehensive assessment of model simulations and predictions.
- New observation programmes aimed at supporting global, regional and national climate research. This includes, for example, intensive observational campaigns, refurbishment of observational networks (including radiosonde stations) and development of new rainfall products (see Section 6).
- Research to accelerate the development of seamless forecast products for Africa covering all timescales (including a focus on medium and sub-seaonal ranges which are currently neglected/under-utilised in SSA);
- Engage with a wide range of international research programmes with parallel objectives. For example, WWRP-THORPEX/WCRP S2S, WWRP HIWeather, Lake Victoria Basin HyNEWS project.

SECTION 7

Capacity Development

The GFCS includes capacity development as a cross-cutting theme and as such potential capacity building interventions were highlighted in Sections 2 to 6. As well as strengthening NHMS as outlined in the GFCS, there are similar requirements to build capacity the research community (see annex in Wilby, 2014) and user communities across all sectors. Capacity development is also required in risk management, insurance, agriculture and engineering, so that climate information is mainstreamed into decision making processes. There is a need for basic climate literacy training tailored for each specific user group. Organisations such as the Global Water Partnership (GWP), World Health Organisation (WHO) and World Food Programme are involved in training initiatives in specific sectors and some of these programmes are already supported by DFID.

Interventions to build capacity should also include strategies to retain capacity, the latter being frequently neglected (see, for example, the comments regarding research capacity from Hewitson in Wilby, 2014).

This section focuses on the training requirements of African Met Services[73]. The need for building capacity and capability within the WMO Regional Training Centres (RTC's) in Africa is recognised and current WMO plans focus on Kenya and South Africa. This lists of activities outlined below focus on meteorological training requirements.

Ongoing WMO activities include:

- Improving the quality of the RTC training materials and the competence of their training staff to enable them to reach a much wider audience via a variety of training mediums and platforms.
- Provision of a wide range of meteorological, climate, technical and management training to support end to end service development and improvement.
- Improving the capability of the National Meteorological Services (NMHSs) training centres to provide more bespoke training and additional training that complements core content delivered at the RTC'S.
- Exploring commercial training opportunities within African met services focusing on their specific national industries that will extend their reach increase the overall credibility of the Met service.

[73] The Business Case is likely to take a broader perspective using evidence from consultation and workshops in Africa.

- Co-ordinating and aligning the RTC and national curriculums and improve access to education (Currently a large portion of the population cannot afford or gain access to university education – a greater percentage of Women).
- A blended approach to training programmes that includes online modules integrated into the course, and the competence assessment programmes, deriving maximum benefit from the WMO Global Campus content.

Specific WMO focus areas for training include:

- Assessment of Competence - Meteorological and climate training provision is fundamentally academic in nature and ethos. More emphasis should be placed on assessment of competency, particularly work based competency checks, that should be undertaken in line with WMO recommendations.
- Train the Trainer - linked to the above, outside of South Africa, little or no train the trainer currently exists to help met services undertake competency assessment.
- Competency assessment, when it is applied, is carried out at varying standards without an internal or external verification process. More formal train the trainer would provide a more consistent standard with the appropriate checks and balance to maintain quality.
- Weather and Climate services training – in addition to improving the meteorological and climatological content of training, training in communicating probability and uncertainty and providing impact based advice.
- Technical training – Equipment installation, maintenance, calibration and first line support. Ensure the skills exist to maintain equipment that is provided as part of any overall support package.
- Observing and data management training – ensure that the quality of observational data is recording accurately and archived effectively.
- Management Training - customer service and product development training to improve and maintain the overall quality services.
- Implementing QMS to monitor service levels.
- Training in the use of remote sensing data (satellite, radar, observations) to support NWP interpretation, and verification, and provide an effective severe weather warning service.
- Online training and case study development – training in the development of online case studies to spread knowledge and expertise to remote areas where time and costs of travel are often prohibitive to undertake face to face training.

Capacity Development: Potential interventions or activities based on the literature review

- The development of specific capacity building activities for both producers and users of climate information and services, as outlined in previous sections under specific GFCS components.
- Supporting existing WMO training initiatives delivered through regional training centres, focusing on general and specific areas as defined above.
- Delivering training and capacity building for the users either through UIPs or other ongoing sector initiatives

SECTION 8

Cross Cutting Themes

This section introduces some cross-cutting themes that will be developed further to support the business case and part of a final recommendations paper or synthesis report. These themes include importantly gender dimensions of climate information services and GFCS funding sources.

Gender dimensions of CIS

Over the past decade scholars and practitioners have argued that climate change is likely to impact vulnerable communities disproportionately (Denton, 2002; Dankleman, 2010). In particular, gender-related inequalities are pervasive in the developing world. Women comprise almost 80 per cent of the agricultural sector in Africa and are vulnerable and poor. Of the 1.3 billion people in the developing world living below the threshold of poverty seventy percent are women. Climate change risks should not result in already marginalised sections of communities falling into further deprivation. Climate information and services can be a real benefit to help specific users to overcome some of these gendered challenges. Still, this can occur at the expense of some, as demonstrated by numerous case studies where some users have had greater access to forecasts than others, and where gender (as well as politics and ethnicity) influence these dynamics (Vaughan and Dessai, 2014).

Given these challenges, gender-related questions can be asked about how are gendered inequalities implicated in climate change, and how do these inequalities shape adaptation choice? Can proactive approaches to provisioning climate services to women lead to transformations or do they lead to further gendered inequalities? And how do you sustain and institutionalise a systematic change in the way gender is considered in all efforts to provision climate services?

Evidence suggests that it is important when developing and communicating weather and climate-related products for use in the agricultural sector to proactively target socially marginalized groups, as it is often these groups who are most vulnerable to the impacts of weather and climate events, and through appropriate engagement these groups can help ensure inclusiveness in the design and dissemination of weather and climate services. One noteworthy example of proactively targeting the most vulnerable within communities is the project entitled *Gender-Specific Climate Service Needs in Kaffrine*, which aimed to provide weather and climate information relevant to female farmers and demonstrated that women could be active participants in the design and evaluation of climate services (Tall *et al.*, 2014). Through inclusion and continual consideration of marginalized groups in the design of future CS initiatives in sub-Saharan Africa, successes such as those described in Senegal can be scaled up to reach a larger number of groups which typically may not have access to the weather and climate information required for informed agricultural decision making.

McOmber et al (2013) showed that women farmers were overwhelmingly left out of many forms of climate communication channels in instances where communication approaches overlooked women. They concluded that context-dependent hybridization of traditional methods of communication familiar to communities, and modern technologies, should be blended to share new scientific climate knowledge with farmers.

The work of Tall et al., (2013) and others has demonstrated a shift in discussions on climate information services to include equity issues (Furman et al., 2014).. Gender dimensions are given more attention than they used to. For example, the Climate Change, Agriculture, and Food Security (CCAFS) promote the use of climate information in agricultural risk management to address the challenges faced by women farmers in particular (Furman et al., 2014). While it is clearly important to adopt a gendered approach in the provision of CIS it is also worthwhile noting that by adopting a purely binary approach (men and women) to gender, may also result in other social exclusions (e.g. caste, ethnicity etc) being overlooked in certain contexts with potential consequences for maladaptation (Carr and Thompson, 2014) or resulting in barriers to adaptation choices among socially differentiated groups (Jones and Boyd, 2011).

Sources of funding

In 2013, the main sources of GFCS funding were Member contributions to the GFCS Trust Fund or to project specific trust funds, through bilateral and multi-lateral investments for projects in selected countries or regions. In addition, various actors can support projects contained in a compendium of GFCS projects or designate their activities as contributing to the GFCS by fulfilling criteria to be approved by the Intergovernmental Board on Climate Services. As of June 2013, contributions and pledges total some CHF 29 millions, mainly from Australia, Canada, China, Finland, France, Greece, Hong Kong China, India, Ireland, Japan, South Korea, Norway, Switzerland and the UK (WMO, 2013).

Costs and Benefits

There is limited synthesised evidence on the available of costs and benefits of investing in NHMS and more broadly climate adaptation in the peer reviewed literature.

Rogers and Tsirkunov (2014) argue that *“investment needs in developing countries exceed US$ 1.5 billion to US$ 2.0 billion. In addition, a minimum of US$ 400 million to US$ 500 million per year will be needed to support operations of the modernized systems (staff costs plus operating and maintenance costs). These recurrent costs should be covered by national governments, but few have been able to do so. Moreover, the amount of international support for the NMHSs is significantly below what is needed just for the high-priority items”.*

Another study (Hallegatte 2012) conservatively estimated that upgrading all hydrometeorological information production and early-warning capacity in developing countries would save an average of 23 000 lives annually and would provide between US$ 3 billion and US$ 30 billion per year in additional economic benefits related to disaster reduction. Rogers and Tsirkunov (2014) argue that modernizing NMHSs in developing countries is a high-value investment. In developed countries cost:benefit ratios of meteorological service investments are reported between 1:2 and 1:6; higher values of 1:10 are reported in Central Asian countries.

In their ongoing work on Value for Money, Watkiss and Savage (2015) have collated some evidence on costs and benefits that will be incorporated into the project/business case.

Value for Money

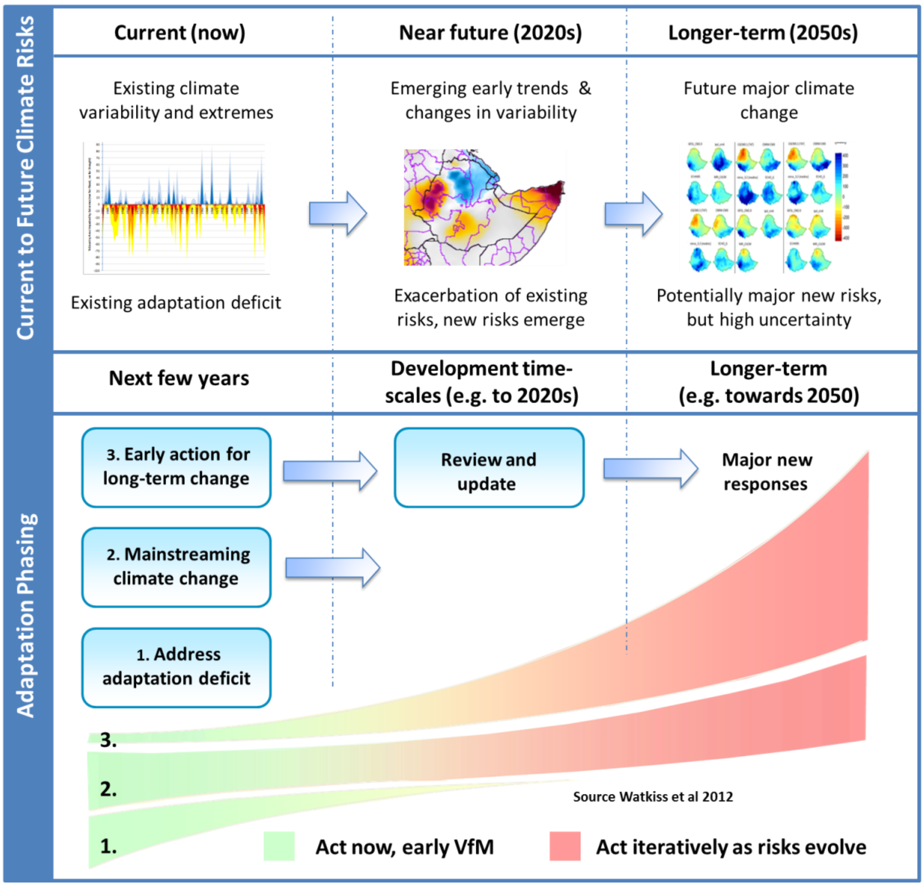
DFID’s VfM framework for climate adaptation recommends an iterative climate risk management approach, following recommendations in the IPCC SREX report (IPCC, 2012) and the IPCC 5th Assessment Report (IPCC, 2014), to advance early value-for-money adaptation.

According to Watkiss and Savage (2015), these iterative frameworks can help maximise value for money adaptation. They consider three areas as outlined in Figure 21 and below:

- Firstly target the current adaptation deficit, to reduce the impacts of climate variability while also building resilience for the future. This often includes interventions that are focused on no- or low-regret options, i.e. which are good to do anyway (even without climate change). These generate immediate economic benefits and also build resilience for the future.
- Secondly target the changes in risk over the medium-term, focusing on near-term decisions with long life-times, i.e. existing plans or investment that will be exposed to climate change in the future (e.g. infrastructure, development planning decisions). This can be implemented using risk screening and mainstreaming, with early priorities around low-cost robustness and flexibility that offer economic benefits through avoided future losses or enhanced opportunities.
- Finally address the long-term but more uncertain major risks of future climate change, building iterative response pathways. These identify early actions to allow learning (through the value of information, maximising option values and reducing lock-in).

The initial focus on climate risks is similar to that advocated by Hansen et al (2014) and the overall framework places emphasis on decisions that need to be made in the short term[74].

Figure 21: An iterative framework to maximise value for money adaptation (Watkiss and Savage, 2015)



[74] In the context of climate services rather than climate change, the 'adaptation deficit' and 'mainstreaming climate change' terms could be replaced by 'management deficit' and 'risk management.'

For CIASA this suggests potential approaches for the business case, for example:

- Making the case for improved weather and climate services on the basis of existing studies on the return on investment and cost benefit analysis.
- Defining principles or approaches that you would expect to see in a well designed climate information and services programme
- Including an early work stream on VfM to support the later stages of CIASA.

SECTION 9

Conclusions

The Global Framework for Climate Services (GFCS) aims to strengthen and coordinate existing initiatives and develop new infrastructure where needed to meet society's climate-related challenges. The report provides a short literature framed around the GFCS, which aims to highlight existing gaps and potential opportunities to strengthen climate services in Sub-Saharan Africa.

Overall the evidence from the literature review suggests that investing in climate services provides a 'low regrets' adaptation to future climate change and can improve the overall management of environmental risks and promote sustainable development. Rainfall data is particularly important in Africa, more so than any other part of the world, yet rainfall data is the most difficult to obtain. One possible approach for the CIASA programme would be to strengthen existing activities, extend 'User Interface Platforms' and, in response to demand, extend the services offered. *A detailed summary of the main findings of the literature review and what this means for the programme is provided in the Executive Summary.*

The literature review will be combined with evidence from consultation in Africa and specific additional tasks, for example on Value for Money, to inform the DFID Business Case.

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