EVALUATING AGRICULTURAL WEATHER AND CLIMATE SERVICES IN AFRICA

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Cover Photo: Francesco Fiondella, International Research Institute for Climate & Society, Columbia University

Report Authors: Catherine Vaughan, International Research Institute for Climate & Society, Columbia University
James Hansen, International Research Institute for Climate & Society, Columbia University
Philippe Roudier, Agence Française de Développement
Paul Watkiss, Paul Watkiss Associates
Edward Carr, Humanitarian Response and Development Lab, Clark University

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Prepared by: Catherine Vaughan, International Research Institute for Climate & Society, Columbia University

Principal Contacts: Catherine Vaughan, Senior Staff Associate
cvaughan@iri.columbia.edu

James Hansen, Senior Research Scientist
jhansen@iri.columbia.edu

EVALUATING AGRICULTURAL WEATHER AND CLIMATE SERVICES IN AFRICA

A Learning Agenda on Climate Information Services in sub-Saharan Africa

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Acronyms and Abbreviations

DEMETER	Development of a European Multimodel Ensemble system for seasonal to inTERannual prediction
GCM	General Circulation Model
GDP	Gross domestic product
GFCS	Global Framework for Climate Services
SST	Sea surface temperatures
SCF	Seasonal climate forecast
SDG	Sustainable Development Goal
WCS	Weather and climate services
WTP	Willingness to pay

EXECUTIVE SUMMARY

Weather and climate services (WCS) are expected to improve the capacity of Africa's agricultural sector to manage the risks of climate variability and change. Despite this, a lack of evidence regarding WCS prevents a realistic analysis of whether services are delivering on their potential. This paper reviews 59 studies that have evaluated outcomes and/or impacts of agricultural WCS in Africa, highlighting areas that have received relatively more attention, as well as persistent gaps. While the evaluation of WCS outcomes is relatively straightforward, estimates regarding access and use of these services are uneven (covering a small number of communities in 22 of 54 African countries) and highly variable (with access ranges from ~2-86%, depending on the service and the population). Meanwhile, just 16 documents estimate the impact of WCS with respect to yields and/or income. Developed with a variety of methods, these estimates are also wide ranging (some users lose, while others experience up to 66% marginal gains) and illustrate how impact is conditioned on a number of characteristics of the service, the user, and the context in which both operate. The paper uses lessons developed through this review to develop a "learning agenda," or evidence-building roadmap, to establish priorities that can guide future work to generate evidence that can improve the design, delivery, and impact of agricultural WCS in Africa. Priority learning areas include: broadening our view of potential users, and uses, of WCS; filling of geographic and demographic gaps; and quantifying the extent to which "good practice" leads to improved outcomes and impacts.

INTRODUCTION

Agriculture plays a critical role in most African economies and among the livelihood strategies of a majority of Africans[1]. Yet African agriculture is marked by low productivity, low levels of investment, and high levels of weather and climate-related risk[2]. Weather and climate services (WCS), which involve the production, translation, transfer, and use of scientific information for decision-making, are expected to improve the capacity of Africa's agricultural sector to manage the risks associated with climate variability and change – and, in doing so, to transform investment in this important sector. As such, agricultural WCS stand to play a critical role in Africa's efforts to meet the Sustainable Development Goals (SDG), including with respect to poverty (SDG1), hunger (SDG2), gender equality (SDG5), responsible consumption and production (SDG12), and climate action (SDG13)[3].

Given the degree to which weather and climate shape agricultural production, a great deal of research has explored how weather and climate affect African agriculture[4–8]. Research has also focused on: the kinds of weather and climate information that can inform agricultural decision making[9–11]; the quality of existing weather and climate information[12, 13]; and the ways in which African farmers can use such information to improve their livelihoods[14, 15]. Despite this, evidence regarding the effectiveness of agricultural WCS in Africa lags behind these other fields.

This evidence gap can be traced in part to idiosyncrasies of the WCS communities, originally dominated by scientists with more experience evaluating the quality of information than in understanding the impact of its use[16]. Even as the discipline has grown – including through Global Framework for Climate Services, implemented by the World Meteorological Organization in 2012 – a number of challenges continue to complicate the evaluation of WCS, thwarting the efforts of skilled evaluators and tempting information providers to defer evaluation, or to rely on more easily tracked but less meaningful metrics including web traffic, workshop participants, and peer-reviewed papers[17].

The resulting lack of objective evidence has prevented the community from developing a more complete understanding of the role that climate services can and do play in African agricultural development. How and to what extent do farmers access and use weather and climate information to inform their decisions? What impact do WCS have on farmers' livelihoods and on agricultural development goals? How do particular aspects of the design and implementation of WCS influence their effectiveness? Were they available, convincing answers to these questions could be used to improve the implementation of existing services; support adequate investment of public funds in National Meteorological Services; inform the appropriate balance of investment in the production, translation, transfer and use of climate information[18]; and shape the role that WCS play in national adaptation and climate finance plans, among other things.

To guide efforts to generate the evidence that can meet these needs, our paper develops a "learning agenda" for the evaluation of agricultural WCS in Africa. We begin by defining terms and the scope of our study in **section 2**. **Section 3** reviews existing evidence regarding the access, use, and impact of WCS in Africa's agricultural sector, while the methods used to develop this evidence are described in **section 4**. After considering these threads separately, the paper brings them together in **section 5**, where evidence and methodological gaps are synthesized before developing a learning agenda (**section 6**). The learning agenda serves as an evidence-building roadmap that prioritizes areas where additional work holds the most potential to advance our understanding of how WCS can and do contribute to improved agricultural outcomes in Africa.

SCOPE

The evaluation of weather and climate services should not be confused with the evaluation of weather and climate information; while the latter assesses the quality of the information itself (e.g., forecast verification), the former is primarily concerned with: (1) documenting the extent to which potential users are able to access and use services; (2) estimating the actual or potential impact and/or value of services; and (3) identifying those elements of design and implementation that lead to better outcomes with respect to (1) and (2).

As such, our paper reviews studies that provide evidence of access, use, and impact of agricultural WCS in Africa. Building on an earlier review[9], documents were identified with two online searches (Web of Knowledge, Google Scholar) and by word-of-mouth requests for evaluation documents made through the authors' professional networks; they were included if they generated qualitative or quantitative evidence that addressed one or more of the criteria listed above. Studies that focused only on the use of traditional, rather than scientific, weather or climate indicators were not included. Both peer-reviewed and grey-literature studies were included regardless of whether documents were originally intended as program evaluations or not.

These methods turned up 59 evaluation studies, conducted in 22 African countries over a span of 40 years. Studies were concentrated in West (26/59), East (21/59), and Southern (17/59) Africa (note some studies include more than one location); the review found just one study that met our criteria in Central Africa and none in North Africa. Even in regions where evaluations were relatively more common, certain countries (e.g., Burkina Faso, Kenya, Tanzania, Ethiopia, Zimbabwe) turned up frequently, while other countries (e.g., Angola, Eritrea, Cote d'Ivoire, Gambia) are not represented at all. The vast majority of studies evaluate services built on forecast information at weather, sub-seasonal, or seasonal climate time scales, or were ambiguous with regards to the kind of information that was provided.

Information regarding the geographical scope of these studies is presented in Figure 1. A full list of documents is found in Appendix 1.

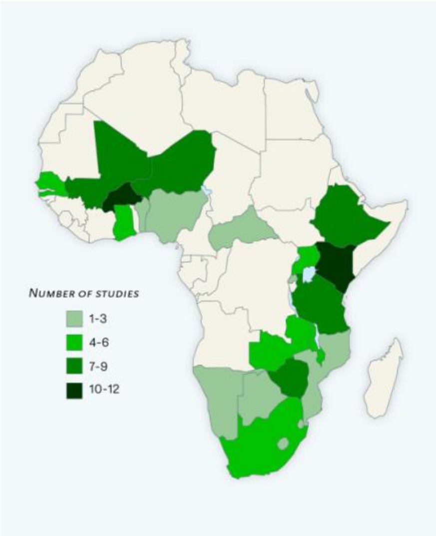

Figure 1: The geographical scope of the WCS evaluation studies included in the review.

EVIDENCE BASE

Evaluation efforts have generated evidence regarding the access, use, impact, and design of climate services; while evidence remains somewhat limited, particularly in certain regions, the evidence that does exist seems to indicate that WCS are more accessible in certain regions than in others; that when available, services are used more frequently by farmers than pastoralists; and that the impacts associated with WCS depend on a number of factors related to design, targeting, and implementation.

Variable access to information

Evidence indicates that Africans' access to weather and climate services varies based on region, livelihood strategy, demographic characteristics, and information type. In East Africa, for instance, studies in Kenya, Ethiopia, Tanzania, and Uganda estimate access in the range of 15-82%, with lower estimates for pastoralist versus farming communities and some indication that men are more able to access climate information than women[19–22]. In Southern Africa, estimates in Malawi, Mozambique, Namibia and Zimbabwe range from 27-86%, with an indication that radio is the primary source by which farmers access weather and climate information[15, 23–25]. Evidence also suggests that weather information is more accessible than seasonal forecasts in this region[26].

There's some indication that WCS may be more accessible in East and Southern Africa than in West Africa, though evidence is mixed[21, 27]. One West African study comprising Mali, Burkina Faso, Niger, and Nigeria found that 70% of 566 surveyed households were aware of and able to access climate information[28], though more recent studies have presented somewhat lower numbers. In Burkina Faso, for instance, Zongo et al. (2016) found 22% of sampled farmers (n=629) had access to climate information, while Rasmussen, et al (2014) found a minority of Burkinabé herders (n=61) had access to weather forecasts (30%), flood information (6-13%), and seasonal climate forecasts (SCFs) (7%)[27, 29]. Oyekale et al (2015), sampled 701 farmers in five West African countries, finding that slightly more than half were able to access climate information[21].

While just one study considers access in Central Africa, it finds only 2% of farmers in the Central African Republic have access to any kind of meteorological information[30]. A summary of access estimates is found in Table 1. More detailed information regarding access estimates is found in Appendices 2-4.

Table 1: Regional summary of estimates of access to agricultural CIS found in the literature

Region	Countries	Samples	Estimates Range	Key References
Central Africa	Central African Republic	315 individuals surveyed	2%	Ngana et al. 2013
East Africa	Kenya, Tanzania, Uganda, Ethiopia	3088 individuals surveyed; 122 interviews; 23 focus groups	15% - 82%	O'Brien et al 2000; Deressa 2008; Ngugi et al. 2011; Gebrehiwot & van der Veen 2013; Oyekale 2015; Coulibaly et al. 2015; Daly et al. 2016; Egeru 2016
Southern Africa	Mozambique, Malawi, Namibia, Zimbabwe	3744 individuals surveyed; 46 interviews	27% – 86%	O'Brien et al. 2000; Patt et al 2005; Mudombi & Nhamo 2014; Lazo 2015; Coulibaly et al. 2015; Mulwa et al. 2017

Region	Countries	Samples	Estimates Range	Key References
West Africa	Benin, Burkina Faso, Ghana, Mali, Niger, Senegal, Nigeria	2079 individuals surveyed; 192 interviews; 144 focus groups	5.6% - 75%	Roncoli et al. 2002; Tarhule & Lamb 2003; Roncoli et al. 2009; Oyekale 2015; Carr 2014; Rasmussen et al. 2014; Zongo et al. 2016; Amegnaglo et al. 2017

Differing levels of use

Evidence regarding the use of agricultural WCS varies based on livelihood strategy, among other things. In fact, several studies find evidence that farmers use WCS when they are accessible; these studies document farmers' application of weather and climate information to a range of decisions, including those regarding the choice of fields, crops, and/or crop varieties; the timing of agricultural tasks; the application of inputs, and the negotiation of annual loans[24, 28, 31–37].

Table 2: Summary of work evaluating the use of CIS, including the information and decisions most commonly explored, as well as the sample and key references by group and region.

User Group	Information Type	Key Decisions	West Africa	East Africa	Southern Africa
Farmers	daily weather info; seasonal forecasts; drought; rainfall onset; pests	choice of field; crop selection; crop variety; timing of farm activities	2912 individuals surveyed; 134 focus groups; 159 interviews (Carr et al. 2015 ; Zongo et al 2016)	3468 individuals surveyed; 73 interviews, 4 focus groups (Oyekale 2015; STAT4D 2017)	3186+ individuals surveyed; 46 interviews (Mulwa et al. 2017; Mudhombi & Nhamo 2014)
Pastoralists	flood forecasts; grazing forecasts; rainfall onset; sub-seasonal forecast; extreme events	shifting livestock; selling firewood; seeking military escort to grazing areas; purchasing veterinary drugs	61 individuals surveyed; 8 focus groups; 15 interviews (Rasmussen et al. 2014; Roncoli et al. 2002)	1023 individuals surveyed, 79 interviews (Lybbert et al. 2007; Egeru 2016; Nguigi et al. 2011)	-
Organizations	SCFs	food security planning	22 individuals surveyed (Tarhule & Lamb 2003)	33+ interviews (Broad & Agrawal 2000)	-

Working with Malian farmers, Carr et al. (2014) and Carr and Onzere (2017) found that farmers' use of climate information was dependent on the roles and responsibilities associated with particular identities, primarily seniority and gender[38, 39]. Contrary evidence was found in Malawi, where a roughly equal number of male and female farmers (n=320) report having access to climate information, but not using it – relying instead on indigenous knowledge and personal experience, which they perceive as more reliable and more relevant to local decision making[23]. Our review found no evidence that farmers use climate information to make costly investments (e.g., irrigation or agroforestry), a finding that was corroborated by Bryan et al. (2009) in both Ethiopia and South Africa[40].

While evidence indicates that farmers use WCS in a variety of circumstances, pastoralists' use of WCS appears more limited. In documenting the use of forecasts among herders of southern Ethiopia, for instance, Egeru et al. (2016) found that most (96%, n=200) rely on traditional, rather than scientific, forecast information[37]. Similarly, Luseno et al. (2002), found that a majority of Kenyan and Ethiopian pastoralists (n=323) did not use seasonal climate forecasts – a finding the authors attributed to the relatively large number of mid-season decisions that allowed herders to cope with unfavorable conditions as they developed, rather than in advance[41].

This is corroborated by studies that show that only certain types of information are useful to pastoralists, who face a very different suite of decisions than farmers. For instance, Rasmussen et al. (2014) found that Burkinabé pastoralists (n=61) were inclined to make changes to herd management based on information regarding the availability of grazing land (75%); onset date (6-53%); and rainfall during the first two weeks of the rainy season (17%) – though they did not adjust herding practices in response to seasonal forecasts[29]. In Uganda, pastoralists (n=198) reported using information on onset and drought to make decisions regarding shifting livestock to new grazing areas; seeking military escorts to those areas; selling firewood and charcoal; and purchasing veterinary drugs[37]. More detail regarding the access and use estimates are found in Appendices 2-4.

Context-dependent impacts

Evidence regarding the impact and potential impact of agricultural WCS on yields and/or incomes is generally positive – though also relatively varied, depending on the context, climate, and crop, as well as the type and accuracy of the information in question.

In Burkina Faso, for instance, evidence indicates that on-farm gains associated with the use of seasonal forecasts increased monthly cereal production[27]. Similarly, Ouédraogo et al. (2015), reports that Burkinabé cowpea farmers (n=170) with climate information showed higher yields than those without information (an average of 847 kg/ha compared to 685 kg/ha); information recipients were shown to have made decisions that resulted in savings in seed and pesticides, resulting in gross margin gains of 66% above the control group. The same study found that sesame farmers provided with climate information had slightly lower yields (550kg/ha compared to 605kg for the control group) and lower margins, as the information prompted an increased investment in fertilizer that did not lead to significant returns[42].

Also in West Africa, Roudier et al. (2014b) modelled (ex ante) the introduction of seasonal and 10-day forecasts in Senegal: their modelling findings indicate farmers who used both types of information were likely to experience yield gains in roughly one-third of the cases; this study also estimated that impacts vary according to the nature of rainy season, the accuracy of the forecast, and the type of response[44].

Reporting on the results of a multi-year project in Southern Africa, Patt et al. (2005) found that Zimbabwean farmers (n= 578) who used seasonal forecasts showed a small but insignificant difference in yields in the first year, and a larger and marginally significant difference in the second year[33]. A modeling study of the potential impact of SCFs in Lesotho found that while the use of forecast information had the potential to improve outcomes for marginal households, forecasts with poor skill were more likely to be associated with negative impacts[45]; a companion study found that the timescale of adoption for seasonal forecasts is likely to be very long[46].

In East Africa, Anuga and Gordon (2016) looked at the relationship between agricultural outcomes and the employment of "climate resilient" strategies in Ethiopia; they found that receiving training in the use of weather information had the greatest influence on yield (17% increase)[47]. Barrett and Ndegwa (2016),

Table 3: Ex post and ex ante estimate of impact of agricultural WCS as found in the literature

Country	Impact Estimate	Information Type	Approach	Reference
Burkina Faso	Cowpea farmers, gross margin is greater (66%) for climate-aware farmers than control	SCF	Ex post	Ouedraogo et al. 2015
Ghana	Farmers trained to access info increased yam yield by 17%. 21% of variation on maize yield caused by use of weather info	weather forecasts	Ex post	Anuga et al. 2016
Malawi, Tanzania	90% of farmers report information made them more confident in planning; more than 75% reported seeing agriculture as more of a business after the training	Weather forecasts, participatory planning tools, agro-advisories	Ex post	STATS4D 2017
Zimbabwe	Farmers who used SCF significantly improved harvests over baseline amounts	SCF	Ex post	Patt et al. 2005
Senegal	Test farm led to increase in yield of roughly 15% to 50%	SCF; 10-day forecasts; daily forecasts;	Ex post	Lo & Dieng 2015
Zimbabwe	Long-term mean production could increase in the presence of forecasts; production volatility also shown to increase	SCF	Ex post, ex ante	Philips et al. 2002
Kenya	Perfect knowledge of daily weather worth ~24%-69% of avg gross margin, GCM predictions based on observed sea surface temperature (SST) increased avg gross margins 9%-24%	SCF	Ex ante	Hansen et al. 2009
Kenya, Malawi, Mozambique, Tanzania, Zambia	Adopted by all farmers, SCF generates avg regional income gains of US$113 million/year ($317 million/yr perfect info)	SCF	Ex ante	Rodrigues et al. 2016
Niger	10-days forecasts alone, or with SCFs, beneficial for all types of farmers; those w more land & fertilizer benefit more	10-day forecasts; SCF	Ex ante	Roudier et al. 2016
Niger	Benefit is lowest with imperfect tercile forecasts (+6.9%), higher (+11%) with perfect tercile forecasts, and highest (+31%) when adaptation strategies and additional climatic indices are available	SCFs; advice; climate indices	Ex ante	Roudier et al. 2012
Senegal	Forecast use associated with gains in crop yields in 62 of the 177 cases, with losses in 22 cases	10-day forecasts; SCF	Ex ante	Roudier et al. 2014
Senegal	When a dryer-than-average rainy season is predicted, forecasts yield an increase of the farmers' income—13.8% for statistical model and 9.6% for DEMETER ensemble mean	SCF	Ex ante	Sultan et al. 2010

working in Kenya, found that farming households with access to local advisories and seasonal forecasts had consistently higher income levels[48]. Also in Kenya, an ex ante modeling study conducted by Hansen et al. (2009) found that that seasonal forecasts based on a general circulation model (GCM) led to gross margin increases of 9-24%, averaged across years, while perfect knowledge of daily weather was worth an estimated 24-69%[50].

At a regional level, Rodrigues et al. (2014) modelled economy-wide impacts of national seasonal forecast systems in Kenya, Malawi, Mozambique, Tanzania, and Zambia. The study estimated that perfect information adopted by all farmers would generate regional GDP gains averaging $113 million USD per year ($3 USD per hectare) relative to a no forecast baseline. The study estimated benefits are higher for poorer households as they are more likely to be engaged in farming[51].

Perception of value

While the impact estimates described above are developed using surveys or modelled analysis, other studies solicit the "value" of WCS from potential users directly. These studies ask or elicit what users would be willing to pay for WCS information or services in the future, and thus the benefit farmers would expect to receive from the use of such services. Adjusted to 2017 rates (USD), these estimates have ranged from $1.19 27 to $15.36[42] for improved seasonal forecasts (see Table 4).

Individual studies elaborate on this range: Ouédraogo et al. (2015), for instance, found that seasonal information ($15.36) is much more highly valued than decadal information ($3.55) or even contextualized agro-meteorological advisories ($5.77) in Burkina Faso[42]. Rao et al. (2015) found men and women valued different services (e.g., training, advisories, etc.) differently, and Zongo et al. (2016) showed variations in willingness to pay (WTP) for seasonal information depending on agro-ecological zone[27, 35]. In addition to the WTP estimates, Amegnaglo et al. (2017) used a ranking system to identify which information is perceived to be more valuable to farmers[52].

Table 4: WTP for SCF, adjusted to 2017 USD, from studies included in the review. Most studies offer more detail, breaking down averages by gender or location.

Country	Sample Size	Average WTP for SCFs (2017 USD)	Reference
Benin	354 farmers, 18 villages	$13.52	Amegnaglo et al. 2017
Burkina Faso	629 farmers, 11 villages	$1.19	Zongo et al. 2016
Burkina Faso	170 farmers, 11 villages	$15.36	Ouedraogo et al. 2015
Kenya	120 farmers, 12 villages	$3.35	Rao et al. 2015
Zimbabwe	1125 farmers, 9 districts	$5.69	Makaudze 2005

Design and targeting

As earlier sections make clear, many studies have generated evidence regarding the degree that elements of design, implementation, and targeting affect access, use, and/or impact; evidence regarding several of these factors are discussed below and presented in Table 5.

User characteristics - A number of studies have focused on the role that user characteristics have played in conditioning the access, use, and impact of weather and climate services. These studies have primarily focused on livelihood strategy and identity, including for instance, gender, education, and socioeconomic status[19, 21, 53, 54]. Several studies have also explored understanding of climate forecasts, showing that users are able to recognize and adapt to the uncertainty implicit in such forecasts[20, 55].

Table 5: The frequency with which the relative effectiveness of implementation and/or design factors have been explored in the literature. Each factor is categorized as follows: U = user; S = service; C = context.

Topic of study	Number of studies					References
	Factor Type	Access	Use	Impact	WTP	
Accuracy for forecasts	Service			4	1	Amegnaglo et al. 2017; Hansen et al. 2009; Hulme et al. 1992; Roudier et al. 2012; Roudier et al. 2014; Sultan et al. 2010
Additional resources or information for decision making	User		3		1	Luseno et al. 2003; Mudombi & Nhamo 2014; Ngugi et al. 2011; Rasmussen et al. 2014; Roncoli et al. 2002
Climate conditions	Context	1	1	3	1	Ngugi et al. 2011; Oyekale 2015; Rodrigues et al. 2016; Roudier et al. 2014; Ziervogel et al. 2005; Zongo et al. 2016;
Costs / prices	Context,			2		Hansen et al. 2009; Rodrigues et al. 2016
Dissemination (channel, presentation, timing)	Service	9	6	1	3	Amegnaglo et al. 2017; Anuga & Gordon 2016; Coulibaly et al. 2015a; Coulibaly et al. 2015b; Daly et al. 2016; Egeru 2016; Luseno et al. 2003; Mudombi & Nhamo 2014; Ngugi et al. 2011; Patt et al. 2005; Rao et al. 2015; Rasmussen et al. 2015; Roncoli et al. 2002; Roncoli et al. 2009; Zongo et al. 2016
Gender	User, context	4	4		2	Amegnaglo et al. 2017; Carr 2014; Carr et al. 2016 ; Carr & Onzere 2017; Coulibaly et al. 2015a; Coulibaly et al. 2015b; Jost et al. 2016; Luseno et al. 2003; Rao et al. 2015
Information type	Service	4	4	4	4	Amegnaglo et al. 2017; Coulibaly et al. 2015a; Daly et al. 2016; Hansen et al. 2009; Hulme et al. 1992; Luseno et al. 2003; Ngugi et al. 2011; Ouédraogo et al. 2015; Oyekale 2015; Rodrigues et al. 2016; Roncoli et al. 2002; Roudier et al. 2012; Roudier et al. 2016; Sultan et al. 2010; Zare et al. 2017
Institutional capacity	User, context	1	1		2	Broad &Agrawal 2000; Glantz 1977; Hulme et al. 1992; Suarez 2004
Livelihood strategy	User		2	6	2	Carr 2014; Carr & Onzere 2017; Hellmuth et al. 2011; Hulme et al. 1992; Luseno et al. 2003; Ouédraogo et al. 2015; Oyekale 2015; Roudier et al. 2012; Roudier et al. 2014; Roudier et al. 2016; Ziervogel et al. 2005
Location / agro-ecological zone	Context	6	1	1	3	Amegnaglo et al. 2017; Carr et al. 2014 ; Carr et al. 2015 ; Coulibaly et al. 2015a; Coulibaly et al. 2015b; Daly et al. 2016; Hellmuth et al. 2011; Makaudze 2014; Oyekale 2015; Roncoli et al. 2002; Tarhule & Lamb 2003; Zare et al. 2017
Socio-economic status	User, context	2	1	1	1	Amegnaglo et al. 2017; Carr 2014; Carr & Onzere 2017; Daly et al. 2016; Luseno et al. 2003; Makaudze 2014; Roncoli et al. 2009; Ziervogel et al. 2005
Risk aversion	User			2		Hansen et al. 2009; Roudier et al. 2016

Topic of study	Number of studies					References
	Factor Type	Access	Use	Impact	WTP	
Trust / credibility	User, service, context,	1	1		1	Daly et al. 2016; Egeru 2016; Luseno et al. 2003;
Understanding	User	2				Luseno et al. 2003; Lybbert et al. 2007

Service design - With respect to the service itself, studies have considered the role of information type (e.g., weather-scale information, flood forecasts, grazing forecasts, onset date, seasonal forecasts) and dissemination channel (e.g., radio, TV, internet, SMS, and in participatory workshops) in influencing access and use[23, 24, 27, 36, 47, 56, 57]. Forecast accuracy has also been shown to be a determinant in the potential impact of WCS[33, 44, 49].

Context - With respect to broader context, several authors have shown that information is more impactful under certain conditions (i.e., drier than normal, wetter than normal) and certain agro-ecozones[38, 58]. Relatively few studies have considered how broad issues related to supply or institutionality, influence access and use of weather and climate information in African agriculture – though Ngugi et al. (2011) and Suarez et al. (2004) are notable exceptions, exploring the influence of the 1997-98 El Niño on forecast use and the various factors that may motivate providers to develop conservative forecasts, respectively[19, 59].

EVALUATION METHODOLOGIES

The evidence presented above was generated using a variety of methods; here we consider these methods more directly, paying attention to how current approaches have been able to deliver useful information regarding agricultural WCS and the extent to which they are suited to address the unique challenges of WCS evaluation.

Evaluation challenges

Several characteristics of WCS impose challenges to its evaluation. First, the non-rival, non-exclusionary nature of WCS means that information can easily be passed along social and family networks. But the information transferred through informal networks may be incomplete or distorted. This makes it difficult to distinguish between those who receive the service and those who do not, complicating efforts to identify a control sample that does not have access to the information, as required for a randomized control trial.

Second, because of the stochastic nature of the climate, the use, impact and even the mechanism of impact, can vary considerably from year to year. The number of years required to sample the range of variability, and hence provide reliable estimates of use and impact, can be expected to exceed a typical project cycle. Furthermore, climate conditions during project baseline and end-line surveys may confound cumulative indicators of impact, making it difficult to distinguish between benefits of the service, and the influence of climatic conditions in the baseline and evaluation years.

Third, the impact of climate information comes through changes in management decisions, which are also influenced by other agricultural development interventions, and by farmers' varying goals, skills and constraints. Information has no intrinsic economic value. The fact that weather and climate information is one of many interacting factors that influences decisions and determines livelihood impacts makes it difficult to isolate the relative contribution of WCS. It also means that causal pathways between access to climate information and livelihood impact can vary among farmers.

While not unique to WCS, this is a particular concern when the evaluation calls for input from farmers who may not be comfortable discussing the nature of their productivity or economic performance. Even in cases in which farmers are willing to report, they may be unable to correctly estimate harvests or production costs; they might also prefer to over- or underestimate harvests, if they perceive that those estimates might lead to some potential gain (e.g., food aid).

Outcome evaluation

Studies regarding the access and use of WCS fall under the heading of outcome evaluation, since they take stock of changes in the behaviors and practices that result from an intervention. Table 6 summarizes the frequency of use of particular methods to evaluate access and use of WCS in Africa.

To date, most of what is known about access to WCS in Africa's agricultural sector has been gathered through household surveys and analyzed using descriptive statistics. This includes studies that use panel survey methods to collect data over several years and others that have sampled progressively (e.g., surveying the population before, during, and after the agricultural season) to document changes over time, or differences between farmers' expectations regarding access and reality once the season had begun [24, 37].

Table 6: Frequency with which methods have been used regarding access and use of CIS in Africa's agricultural sector.

Region	Data Collection				Data Analysis			References
	Surveys	Interviews	Focus Groups	Workshops	Qualitative Analysis	Descriptive Statistics	Econometrics	
West Africa	8	5	3	2	6	9	2	Roncoli et al. 2002, 2009; Tarhule & Lamb 2003; Oyekale 2015; Carr 2014; Rasmussen et al. 2014; Zongo et al. 2016; Amegnaglo et al. 2017;
East Africa	12	5	2	1	4	8	6	O'Brien et al. 2000; Deressa 2008; Ngugi et al. 2011; Gebrehiwot & van der Veen 2013; Oyekale 2015; Coulibaly et al. 2015a; Daly et al. 2016; Egeru 2016; Lybbert et al. 2007; Broad and Agrawal 2000; Luseno et al. 2003; Bryan et al. 2013
Southern Africa	6	3	-	2	3	6	2	O'Brien et al. 2000; Patt et al. 2005; Mudombi & Nhamo 2014; Lazo 2015; Coulibaly et al. 2015b; Mulwa et al. 2017
Central Africa	1	-	-	-	-	1	-	Ngana et al. 2013

Surveys are well suited to capturing the number of individuals who access particular information products. Since access reflects both availability and demand for particular information products, its evaluation may seek evidence of either or both. Surveys can be expanded to answer questions such as: What is the reach of particular communication channels? What is the demand for a particular information product, or relative demand among different information products? What are the most effective communication channels? How do farmer characteristics (e.g., gender, age, farming system) influence access to particular information products and use of particular communication channels?

Studies that explore the use of WCS employ similar, though a wider variety of, methods to those that engage with issues of access: Data on use is gathered through focus groups, workshops, interviews, and/or household surveys, and results are reported using statistics[40, 60–62] and/or qualitative methods[27, 28, 33, 34, 38 27, 28, 34, 38, 64]. This wider variety of methods reflects the fact that studies of use require the establishment of some kind of counterfactual, i.e., what the decision would have been without the information.

Indeed, eliciting how individuals use WCS depends on the ability of those individuals to attribute changes in particular management decisions to the information they contain. Since many conscious and sub-conscious factors can influence decisions, this may be a strong assumption. Obtaining management plans from individuals before and after they have been exposed to predictive information (e.g., seasonal forecasts) increases confidence by providing a reasonable counterfactual. The non-excludability of information makes it difficult to compare management decisions between samples of farmers with and without access. Since management can vary as a function of forecast conditions – which are stochastic -- many seasons may be required to provide a complete understanding of use of predictive information.

Impact evaluation

Impact evaluations are designed to generate evidence regarding the ultimate impacts of an intervention, whether those impacts are direct or indirect, intended or unintended. While this type of evidence is critical for understanding the role that agricultural WCS can play in building the resilience of Africa's agricultural sector, there is far less evidence regarding impact than access and use: only 16 out of the 59 documents reviewed for this study used this approach and many of these involve modelled estimates. While there is a broader range of methods used than in evaluations of access and use, each of these methods has significant limitations, and provides rather indirect evidence of the actual benefit of use of climate information.

Methods to evaluate the impact of WCS can be classified into two distinct categories: ex-post empirical studies of the benefits of WCS-informed decisions (i.e. investigating existing WCS); and ex-ante methods that model or estimate how potential uses of information could improve production, livelihoods or other impacts of interest. A summary of the frequency with which different methods have been used to evaluate the impact of agricultural WCS in Africa is found in Table 7.

Ex post studies - Six studies have used ex post analysis to evaluate the impact of WCS on African agriculture[32, 33, 36, 42, 47, 65]; those that have are generally based on household surveys and/or interviews, and focused on yields and/or marginal income[42, 47]. While these methods are time and resource intensive, they have been used in a variety of contexts, allowing for the development of a relatively large literature that explores the difficulties of survey-based ex post evaluation, including the attendant strengths and weaknesses of experimental and quasi-experimental design[66, 67].

Another method that has been used to generate evidence regarding the impact of WCS involves test plots. In this case, WCS are used to make decisions regarding a specific plot of land throughout the season, after which yields from the test plot are compared to those of plots where more traditional practices were employed[36]. If well designed, test plots have the advantages of providing a counterfactual, capturing farmer decision-making, and potentially overcoming challenges of farmer recall and the elicitation of sensitive economic information.

The test plot studies reviewed as part of this work were limited to the management of individual crops, and therefore missed potentially important resource allocation decisions made in response to WCS. They also focused on yield – but since many uses of WCS many involve saving costs of inputs, gross margin (i.e., market price of harvest minus costs of production, per unit area) may be a useful metric. It is important to note as well that test plots are only useful when they compare farmers' management based on WCS to farmers' management without WCS; trials that compare climate-based expert recommendations with farmers' normal practice, the difference between the expert's and the farmer's decision criteria

Table 7: Methods used to evaluate the impact of WCS on African agriculture.

Ex post/ Ex ante	Methodology	Data Needs	Question Addressed	Possible Uses of Evidence	Strengths of Methodology	Weakness of Methodology	References
Ex post	**Survey methods and descriptive / inferential statistics**	Household surveys	What impacts were experienced by intended targets of an actual WCS?	Describing actual return on investment; identifying factors that condition impact; deciding whether a similar service will provide benefit	May allow for evidence to be gleaned through information collected for other purposes	May not capture impacts over time, since cost constraints may not allow for data collection across many years	Anuga et al. 2016; Ouedraogo et al. 2015
Ex post	**Test plots**	Harvest data	To what extent could WCS improve yields?	Design of WCS	Provides first-hand experience of impacts of use of SCF; allows for testing different use strategies	Often compares decisions made by resource-constrained small-scale farmers with those made by agronomists who have access to more resources	Lo & Dieng 2016
Ex ante	**Experimental economics**	Workshops, surveys	How do target individuals perceive potential impacts?	Design of WCS; identifying & accounting for multiple uses of information	Existing groups may provide opportunities for low-cost data collection	Requires good facilitation and an understanding of the community; participant fatigue	Jost et al. 2015; Patt et al. 2005; Roudier et al. 2014
Ex ante	**Crop simulation / economic models**	Weather, crop, economic data	To what extent might individual farmers stand to benefit from WCS?	Design of WCS; estimating impact over many years; estimating impact when difficult to establish counterfactual	Can sample many years of climate information and weather observations. Flexible model specification	Limited by ability to capture decisions and economic impacts; ignores market impacts of adoption at scale	Hansen et al. 2009; Sultan et al. 2010; Roudier et al. 2012; Roudier et al. 2016
Ex ante	**Agent-based modelling**	Weather, crop, ethnographic data	How might impacts evolve overtime and/or for different types of actors?	Identifying whether services are likely to benefit certain actors; estimating impact when difficult to establish counterfactual	Captures competition or coordination among decision-makers	Limited by ability to capture decisions and economic impacts	Ziervogel et al. 2005; Bharwani et al. 2005
Ex ante	**Computable General Equilibrium models**	Weather, crop, economic data	How might the impact of WCS be felt at national or regional scale?	Justifying investment; exploring how services will impact scale	Captures market impacts of adoption at scale and wider economy effects	Limited by ability to capture decisions and economic impacts	Rodrigues et al. 2016
Ex ante / Ex post	**Contingent valuation**	Household surveys	What value might individuals assign to WCS?	Justifying / planning investment and design of WCS; exploring fee-for-service or other business models	Simple data requirements; contingent valuation methods could be combined with experimental economics	Difficult to estimate value of new products. WTP expected to be lower than average economic benefit	Amegnaglo et al. 2017; Zongo et al. 2015; Ouedraogo et al. 2015; Rao et al. 2015; Makaudze 2005

confound the influence of WCS. Because of the stochasticity challenge, it is generally not feasible to run a test plot for enough years to provide stable estimates of the value of the information.

Ex ante studies - Eleven studies have attempted to characterize the potential impact of agricultural WCS in Africa using ex ante methods. These include appraisal studies (undertaken as part of design or in advance of WCS implementation) but also the use of ex ante methods, such as models, to estimate the potential impact of existing WCS. These studies have employed a range of approaches – including experimental economics, models, and surveys – as a means to estimate, rather than analyze ex post, the possible benefits of planned or existing services.

Sometimes described as participatory methods or "serious games," experimental economics approaches provide farmers with an opportunity to simulate how they might use WCS, were they to be provided, and to report their perception of potential results. While recent work has shown that these methods can be very useful in helping to estimate the impact of WCS, several challenges have been noted: In order for these methods to work, for instance, they must be run by skilled facilitators who can ensure that all participants feel they can share and explore – and issues of power, gender, and hierarchy may distort the results if facilitators are not aware of them. In addition, participatory methods are time consuming; they may lead to fatigue among participants, and potentially expose them to uncomfortable or challenging situations[68, 69].

Several modeling approaches have also been used to estimate the potential value of agricultural WCS in Africa. For instance, crop simulation and economic models have been useful in helping evaluators to estimate the value of WCS. Bio-physical models may be used on their own to estimate yield changes, or linked directly with economic models (e.g., bio-economic models) so as to characterize the impacts of different decisions informed by WCS. Simple field- and farm-level bio-economic models have been used to estimate potential impacts of weather and climate information in Kenya, Niger and Senegal; these models have also allowed researchers to explore the range of possible outcomes associated with different contexts and/or the design and implementation of the services themselves[49, 70, 71].

Agent-based models have also been used to reveal how agents interact with other agents and the environment – allowing for the exploration of the impact of WCS in complex systems, as well as how interactions producing emergent effects may differ from effects of individual agents. These analyses have helped to characterize which types of actors are likely to be impacted, and in what capacity, by the use of climate information[46, 72].

A limitation of farm-level and agent-based modeling approaches is that they ignore the potential impact that the collective action of many farmers can have on market prices or on other sectors of the economy. One study in Africa undertook such an economic analysis, using computable general equilibrium modeling to estimate the potential economy-wide impacts of large-scale farmer adoption of seasonal climate forecasts across several countries[51].

Where long-term records are available, bio-economic modeling approaches can sample many years of weather observations and climate information, and can provide insight that may address the stochasticity challenge. The main weakness of model-based impact estimates, however, is that their realism can be limited by the ability of the models to capture farmer decisions and resulting economic impacts, particularly when weakly grounded in empirical data. In most instances, globally and in Africa, these modeling approaches have been applied in a stylized manner to hypothetical uses of information; realistic evaluation was often not the objective[73]. However, this is not an intrinsic limitation of the approach – and though bio-economic modeling tools tend to have demanding data requirements, it is feasible for analyses to be well grounded in empirical data, as is often the case for ex-ante evaluation of agricultural production technologies.

Finally, contingent valuation is a survey-based econometric technique that elicits the amount that potential users would be willing to pay for specific services, and thus implicitly their benefit (to these users). The contingent valuation, or WTP approach, estimates the maximum price that a user will pay for the information or service directly, whereas the other ex ante approaches estimate value through the expected economic benefits of the use of the new information. Nonetheless, all these techniques seek to derive the (economic) value of information[74].

Contingent valuation assumes the potential user can adequately estimate the expected economic gain, averaged across years, from using the new information; as such, it avoids the need for an explicit counterfactual. It is simpler for the analyst, but has significant limitations, especially for new or planned information products. Farmers cannot asses, and typically underestimate, the value of information that they don't have a lot of experience with. For a stylized seasonal forecast system, Pope et al. (2017) estimated that users would have to experience at least 30 forecasts in order to provide a realistic estimate of the value of the information. However, training or accelerated experience through games can help to reduce this bias.

SYNTHESIS

Improving our understanding of WCS outcomes

Evidence regarding the access and use of agricultural WCS in Africa is more plentiful and more homogenous than evidence regarding the impact of those services, making it relatively more straightforward to compare estimates of access and use across regions and/or populations. Our analysis has pointed to several key evidence gaps, however.

For instance, it is clear that estimates regarding access to weather and climate information vary considerably – and while there's been some effort to understand the factors that cause this disparity, a more complete mapping of who has access to what kind of information, as well as the factors that enable or constrain access, would help to inform the investment and design of weather and climate services. As Table 1 makes clear, evidence regarding access to agricultural WCS – or at least evaluation information on access - is particularly lacking in Central and Northern Africa – though no region boasts a preponderance of evidence, particularly given the diversity of actors that contribute to Africa's agricultural sector.

The review also highlights the uneven nature of evidence regarding the use of agricultural WCS. As seen in Figure 1, our analysis includes data from just 22 of Africa's 54 countries – and even within these countries, certain populations are relatively more studied than others (e.g., farmers vs. pastoralists). What's more, with a few exceptions (e.g., Daly et al. 2016; Glantz 1977; Hulme et al. 1992) the literature rarely explores the extent to which WCS are used by government and non-government agencies – and it makes almost no mention of how/whether private organizations (e.g., input suppliers, wholesalers, etc.) use such information.

With regards to methodology, two gaps stand out as well. The first is linked to the fact that many of the studies included in our analysis were performed without baseline analyses, making it difficult to identify changes in access and use over time, or as a result of a particular intervention. Fortunately, the kind of baseline survey that can help to build this sort of evidence is becoming more common in Africa and elsewhere[22, 23, 56, 78] and will likely improve the evaluation of agricultural WCS in the future.

Finally, studies that consider the role that aspects of identity, context, and/or design play in determining WCS outcomes highlight the need for both qualitative and quantitative methods to build a complete understanding of access and use. Qualitative methods, for instance, are particularly useful in helping to ensure that quantitative analysis covers both the most common and most impactful uses of WCS. In some cases, combining methods reveals patterns that might otherwise have been overlooked: Carr and Onzere

(2017), for instance, used a combined qualitative and quantitative approach to show that including women among the estimates of people unfamiliar with Mali's agro-advisories overstated the need to improve dissemination, as the service in question was specifically targeted to senior men with the authority to make decisions regarding the cultivation of rain-fed staple crops[39].

Improving our understanding of WCS impact

The landscape of evidence regarding the impact of WCS is both scarcer and more complicated than that regarding access and use, displaying a wide array of ex post and ex ante methodologies that rely on a range of different assumptions to help characterize the contribution of the services in question. These methodologies respond to the various challenges associated with the evaluation of WCS, though they also generate evidence that is somewhat more indirect than the evidence regarding access and use.

Several evidence gaps call for particular attention – especially regarding the extent to which different groups benefit differently from WCS. It is also important to note that the studies included in this review have defined impact almost entirely with regards to yields and/or incomes, despite the fact that WCS can be expected to have a host of impacts (e.g., improved decision processes, time saved, more efficient allocation of resources, changes in social organization, etc.), and that these impacts can be expected to accrue to the individual, the society and the environment. To date, no studies have explored the impact of agricultural WCS on African societies (e.g., does the promotion of scientific information isolate young, educated cohorts from traditional knowledge?) or the environment (e.g., do WCS facilitate more intensive farming practices? Could they lead to increased greenhouse gas emissions?).

There are also some clear methodological gaps. While several studies are based on models, for instance, these models have rarely been fully validated – making it difficult to assess the robustness of their results. Another key gap is regarding the use of economic approaches to appraise (ex ante) the socio-economic benefits of WCS, to help better design new services, to justify prior and existing investments, and to help develop the case to continue (or increase) allocation of resources for WCS into the future. This requires additional methodological development for costs as well as benefits[18, 79]. Ensuring that methods capture the full range of costs and benefits requires new techniques and will require guidance and support, but further development in this area has a key role to play in the scale-up of WCS in Africa.

Combining methods provides promising opportunities to triangulate estimates of the impact of WCS, take advantage of complementary strengths, and overcome some of the most problematic limitations. For example, if bio-economic modeling were combined with participatory approaches and/or survey-based data, the empirical results could be used to validate and, if needed, drive modeled farmer management response to climate information, while the models could then sample more of the range of variability of observed weather and climate information (e.g., Jochec et al. 2001).

Finally, there is a need to advance the knowledge base on how to generate and use impact information to improve the *design and/or implementation* of agricultural WCS. Documenting how services are able to deliver outcomes and impacts, and good practice, will be critical to improving design and delivery, providing insights. With the exception of Rao et al. (2015), there is little robust analysis regarding how different strategies (e.g., user engagement, co-production, dissemination, capacity building, use) lead to different outcomes or impacts. Developing a broader suite of methods to generate this kind of information – and use this in design - has huge potential to improve future WCS.

LEARNING AGENDA

This review has characterized the state of evidence and methods regarding the evaluation of agricultural WCS in Africa. It has identified where our knowledge of access, use and impacts of weather and climate services is relatively strong, but also where there are persistent gaps. Building on this analysis, we have developed a "learning agenda," or evidence-building roadmap, to establish priorities that can guide future work to generate evidence that can improve the design, delivery, and impact of agricultural WCS in Africa. In particular, the learning agenda identifies areas where further evidence and improved methods can help (1) develop information that can improve the extent to which WCS are targeted to people who can access and use them; (2) generate a greater sense of the relative contribution of WCS; and (3) illustrate how certain design considerations affect this contribution. More details are included below.

Improving the targeting of WCS

1. **Fill geographical gaps -** There is very little evidence regarding access and use of WCS in Central and Northern Africa. Even in the relatively well studied regions of West, East, and Southern Africa, there are sizable evidence gaps, with no evidence at all for many countries (including Djibouti, Eritrea, Somalia, Sudan, Zambia, Botswana, Gambia, Guinea-Bissau, Cote d'Ivoire, Liberia, and Togo). Geographical gaps also exist within countries, where certain agro-ecological zones are more studied than others.

2. **Broaden evidence regarding users and uses -** There is more evidence regarding access and use by farmers than by pastoralists, and for staple rather than cash crops. There is also very little information regarding government and/or nonprofit organizations and none regarding the private sector. A priority is to address these gaps, continuing to disaggregate populations by the identities that shape their roles and responsibilities, and exploring access and use for other uses (e.g., input suppliers, insurance companies, wholesalers, extension services, etc.).

3. **Explore enablers and barriers -** Further qualitative and quantitative approaches are needed to flesh out enabling and constraining factors, such as the role of communication strategies (e.g., messaging, visualization, etc.) as well as different dissemination mechanisms (e.g., radio, SMS, etc.). The business models that sustain WCS have rarely been evaluated, despite the important role that they play in conditioning access, use, and impact on both short and long timeframes.

Improving the impact of WCS

1. **Explore a broader range of impacts -** Most WCS studies have estimated impacts as yields and/or income at the farm level. There is a need to broaden this analysis to develop information regarding the impact of WCS on the wider economy, society, and the environment (i.e., greenhouse gases). At the same time, economic analyses (see Clements et al. 2013, for a review) have the potential to improve design of WCS, and are a priority for appraisal. These methods also provide information of high relevance for national meteorological services, national government and ministries and development partners (funders), to justify the allocation of resources to WCS.

2. **Compare and validate results -** Comparing impact estimates from different approaches will help to characterize the applicability, use and performance of particular methodologies, and the credibility, consistency, and comparability of evidence. Validating models will improve impact estimates and help build confidence in those results; this can help guide innovation in the design of those services, and shape efforts to invest in climate services.

3. **Comparative analysis -** Very few studies consider how WCS compare to alternative interventions that may build agricultural resilience. Econometric approaches à la Bryan et al. (2009) and Deressa et al. (2009) offer a way to fill this gap; other methods, including validated models and benefits transfer methods, should also be explored. In particular, further studies should attempt to characterize how improvements and/or combinations impact evaluations can improve confidence in results.

Improving design of WCS

1. **Understanding the influence of stochasticity -** Given the interaction between use and impact, and the stochastic variability of climate, future studies should develop a better sense of the relationship between the stability of impact estimates and the number of years sampled. It will also be important to explore the available options for capturing variability and for increasing confidence during the limited number of years of any particular project.

2. **Interpreting existing results -** Many existing WCS in Africa's agriculture sector are operating sub-optimally and this limits the understanding of what constitutes good practice. There is currently no guidance on how this existing information could be used to improve outcomes and impacts; developing this guidance will help advance the field. Given the variability in the design of climate information that has been evaluated, future work can help identify how the quality of services can best be factored into the body of evaluation results.

3. **Developing guidelines for benefits transfer -** While the general field of economics has generated guidance regarding benefits transfer methodologies, these have not yet been applied to the WCS context. Further work to understand the factors that condition the relative success of WCS in various contexts, and thus the likelihood that comparable outcomes and impacts will be experienced when WCS are transferred to new locations are needed.

SUMMARY AND CONCLUSIONS

This paper reviewed existing evidence regarding the access, use, and impact of agricultural weather and climate services in Africa; it has found evidence that access varies predominantly by region, while use depends more on livelihood strategy, with farmers more likely to employ WCS than pastoralists. Evidence also suggests that the impact of agricultural WCS varies (with some users losing, while others gain as much as 60% of gross margin) based on a number of service, user, and contextual characteristics. Generated with a variety of methodologies, this evidence helps to shed light on the potential contribution of WCS to African agriculture. Nevertheless, significant gaps remain; the paper prioritizes these gaps within a learning agenda, designed to serve as a roadmap of evidence needed to improve the design, delivery, and development impact of WCS. Priority learning areas include: broadening our view of potential users, and uses, of WCS; filling of geographic and demographic gaps; and quantifying the extent to which "good practice" leads to improved outcomes and impacts, among others.

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APPENDICES

APPENDIX 1: FULL LIST OF DOCUMENTS IN THE STUDY

Authors	Title	Year	Type	Country
Amegnaglo, C.J., Anaman, K.A., Mensah-Bonsu, A., Onumha, E.E., & Gero, F.A.	Contingent valuation study of the benefits of seasonal climate forecasts for maize farmers in the Republic of Benin, West Africa	2017	journal article	Benin
Anuga, S.W. & Gordon, C.	Adoption of climate-smart weather practices among smallholder food crop farmers in the Techiman municipal: Implication for crop yield	2016	journal article	Ghana
Barrett, S. and Ndegwa, W.	An economic valuation of the Kenya Meteorological Department's Decentralized Provision	2016	project report	Kenya
Bharwani, S., Bithell, M., Downing,T. E., New, M., Washington, R. & Ziervogel, G.	Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa	2005	journal article	South Africa
Broad, K. & Agrawala, S.	The Ethiopia food crisis – uses and limits of climate forecasts. Science 289: 1693-1694.	2000	journal article	Ethiopia
Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., & Herrero, M.	Adapting agriculture to climate change in Kenya: Household strategies and determinants	2013	journal article	Kenya
Carr, E.R.(ed)	Assessing Mali’s Direction Nationale de la Meteorologie Agrometeorological Advisory Program	2014	project report	Mali
Carr, E.R. & Onzere, S.N.	Really effective (for 15% of the men): Lessons in Understanding and Addressing User Needs in Climate Services from Mali	2017	journal article	Mali
Carr, E.R. & Owusu-Daaku	The shifting epistemologies of vulnerability in climate services for development: the case of Mali's Agrometeorological Advisory Programme	2016	journal article	Mali
Chemura, A., Kutywayo, D., Chidoko, P. & Majoya, C.	Bioclimatic modelling of current and projected suitabiltiy of coffee (Coffee arabaica) production in Zimbabwe	2016	journal article	Zimbabwe
Coulibaly, J. Y., Mango, J., Swamila, M., Tall, A., Kaur, H., & Hansen, J.	Which climate services do farmers and pastoralists need in Malawi?	2015	CCAFS working paper	Malawi

Authors	Title	Year	Type	Country
Coulibaly, J. Y., Mango, J., Swamila, M., Tall, A., Kaur, H., & Hansen, J.	What climate services do farmers and pastoralists need in Tanzania? Baseline study for the GFCS Adaptation Program in Africa.	2015	CCAFS working paper	Tanzania
Coulibaly, J.Y., Birachi, E.A., Kagabo, & D.M., Motua.	Climate services for agriculture in Rwanda	2017	CCAFS working paper	Rwanda
Dabire, W.P.I, Barbier, B., & N. Andrieu	Evaluation ex ante de la prévision saisonnière climatique en petit paysannat burkinabé. Revue d'élevage et de médecine vétérinaire des pays tropicaux,	2011	journal article	Burkina Faso
Daly, M.E., West, J.J., &Yanda, P.Z.	Establishing a baseline for monitoring and evaluating user satisfaction with climate services in Tanzania	2016	CICERO / GFCS Report	Tanzania
Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M.	Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia	2009	journal article	Ethiopia
Egeru, A.	Climate risk management information, sources and responses in a pastoral region in East Africa	2016	journal article	Uganda
Gebrehiwot, T., & van der Veen, A.	Farm level adaptation to climate change: the case of farmers in the Ethiopian Highlands	2013	journal article	Ethiopia
Glantz, M. H.	The Value of a Long-Range Weather Forecast for the West African Sahel	1977	journal article	Sahelian states
Hansen, J. W., Mishra, A., Rao, K. P. C., Indeje, M. & Ngugi, R. K.	Potential value of GCM-based seasonal rainfall forecasts for maize management in semi-arid Kenya	2009	journal article	Kenya
Hellmuth, M.E., Diarra, D.Z., Vaughan, C., & Cousin, R.	Increasing Food Security with Agrometeorological Information: Mali's National Meteorological Service Helps Farmers Manage Climate Risk	2011	WRI Case Study	Mali
Hulme, M., Biot, Y., Borton, J., Buchanan-Smith, M., Davies, S., Folland, C., Nicholds, N., Seddon, D. & Ward, N.	Seasonal rainfall forecasting for Africa part II – application and impact assessment.	1992	journal article	Sahel
Jiri, O., Mafongoya, P.L., Mubaya, C., & Mafongoya, O.	Seasonal Climate Prediction and Adaptation Using Indigenous Knowledge Systems in Agriculture Systems in Southern Africa: A Review.	2016	journal article	Botswana, Malawi, South Africa, Swaziland, Zimbabwe, Zambia,

Authors	Title	Year	Type	Country
Jost, C., Kyazze, F., Naab, J., Neelormi, S., Kinyangi, J., Zougmoure, R., Aggarwal, P., Bhatta, G., Chaudhury, M., Tapio-Bistrom, M.-L., Nelson, S. & Kristjanson, P.	Understanding gender dimensions of agriculture and climate change in smallholder farming communities	2015	journal article	Uganda, Ghana
Klopper & Bartman	Forecasts and Commercial Agriculture: A Survey of User Needs in South Africa	2003	book chapter	South Africa
Lazo, J.	Survey of Mozambique Public on Weather, Water and Climate Information	2015	NCAR technical report	Mozambique
Lo & Dieng	Impact assessment of communicating seasonal climate forecasts in Kaffrine, Diourbel, Louga, Theis and Fatick regions in Senegal	2015	CCAFS working paper	Senegal
Luseno, W.K., McPeak, J.G., Barrett, C.B., Gebru, G., & Little, P.D.	Assessing the value of climate forecast information for pastoralists: Evidence from southern Ethiopia and northern Kenya	2003	journal article	Ethiopia, Kenya
Lybbert, T. J., Barrett, C., McPeak, J. G. & Luseno, W. K.	Bayesian herders: asymmetric updating of rainfall beliefs in response to external forecasts	2007	journal article	Ethiopia, Kenya
Makaudze, E.M.	Assessing the Economic Value of Seasonal Climate Forecasts for Smallholder Farmers in Zimbabwe: Using Contingency Valuation Approach	2014	journal article	Zimbabwe
Mertz, O., Rasmussen, K., & Rasmussen, L. V.	Weather and resource information as tools for dealing with farmer-pastoralist conflicts in the Sahel	2016	journal article	Burkina Faso, Mali, Niger
Mudombi & Nhamo 2014	Access to weather forecasting and early warning information by communal farmers in Seke and Murewa districts, Zimbabwe	2014	journal article	Zimbabwe
Mulwa, C., Marenya, P., Rahut, D.B., & Kassie, M.	Response to climate risks among smallholder farmers in Malawi: A multi-variate probit assessment of the role of information, household demographics, and farm characteristics	2017	journal article	Malawi
Ngana, F., Ababa, A.M., Gapia, M., & Kossi, L.K.	Traditional meteorology and rural activities by the Mandja of Sibut, Central African Republic.	2013	journal article	Central African Republic

Authors	Title	Year	Type	Country
Ngugi et al. 2011	Climate forecast information: the status, needs, and expectations among smallholder agro-pastoralists in Machakos District, Kenya	2011	journal article	Kenya
Nhemachena, C. &Hassan, R.M.	Micro-level analysis of farmers' adaptation to climate change in Southern Africa	2007	IFPRI report	South Africa, Zambia, Zimbabwe
O'Brien, K., Sygna, L., Otto Naess, L., Kingamkono, R. & Hochobeb, B.	Is information enough? User responses to seasonal climate forecasts in Southern Africa	2000	Cicero Report	Namibia, Tanzania
Ouedraogo, M., Zougmoré, R., Barry, S., Somé, L., & Grégoire, B.	The value and benefits of using seasonal climate forecasts in agriculture: evidence from cowpea and sesame sectors in climate-smarty villages of Burkina Faso	2015	CCAFS Info Note	Burkina Faso
Oyekale, A. S.	Access to Risk Mitigating Weather Forecasts and Changes in Farming Operations in East and West Africa: Evidence from a Baseline Survey	2015	journal article	Ethiopia, Kenya, Tanzania, Uganda, Burkina Faso, Ghana, Mali, Niger, and Senegal
Patt, A., Suarez, P. & Gwata, C.	Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe	2005	journal article	Zimbabwe
Phillips, J.G., Dean, D. Unganai, L. & Chimeli, A.	Implications of farm-level response to seasonal climate forecasts for aggregate grain production in Zimbabwe	2002	journal article	Zimbabwe
Rao, K.P.C., Hansen, J., Njiru, E., Githungo, W.N., & Oyoo, A.	Impacts of seasonal climate communication strategies on farm management and livelihoods in Wote, Kenya	2015	CCAFS working paper	Kenya
Rasmussen, L.V., Mertz, O., Rasmussen, K., & Nieto, H.	Improving how meteorological information is used by pastoralists through adequate communication tools	2015	journal article	Burkina Faso
Rasmussen, L. V., Mertz, O., Rasmussen, K., Nieto Solana, H., Ali, A., & Maiga, I.	Weather, climate, and resource Information should meet the needs of Sahelian pastoralists	2014	journal article	Burkina Faso
Rodrigues, J., Thurlow, J., Landman, W., Ringler, C., Robertson, R., & Zhu, T.	The economic value of seasonal forecasts stochastic economy-wide analysis for East Africa.	2016	IFPRI report	Kenya, Malawi, Mozambique, Tanzania, Zambia
Roncoli, C., Ingram, K.T., Jost, C.C., Kirshen, P.H., & Yaka, P.	Farmers' behavioral responses to seasonal rainfall forecasts in the Sahel-Sudan	2002	journal article	Burkina Faso

Authors	Title	Year	Type	Country
Roncoli, C., Jost, C., Kirshen, P., Sanon, M., Ingram, K.T., Woodin, M., Somé, L., Outtara, F., Sanfo, B.J., Sia, C., Yaka, P., & Hoogenboom, G.	From accessing to assessing forecasts: an end-to-end study of participatory climate forecast dissemination in Burkina Faso	2009	journal article	Burkina Faso
Roncoli, C., Orlove, B.S., Kabugo, M.R., & Waiswa, M.M.	Cultural styles of participation in farmers' discussions of seasonal climate forecasts in Uganda	2010	journal article	Uganda
Roudier, P., Alhassane, A., Baron, C., Louvet, S., & Sultan, B.	Assessing the benefits of weather and seasonal forecasts to millet growers in Niger	2016	journal article	Niger
Roudier, P., Muller, B., d'Aquino, P., Roncoli, C., Soumaré, M.A., Batté, L., Sultan, B.	The role of climate forecasts in smallholder agriculture: Lessons from participatory research in two communities in Senegal	2014	journal article	Senegal
Roudier, P., Sultan, B., Quirion, P., Baron, C., Alhassane, A., Traoré, S. B., & Muller, B.	An ex-ante evaluation of the use of seasonal climate forecasts for millet growers in SW Niger	2012	journal article	Niger
Stats4SD	Evaluation of Climate Services Interventions in the GFCS Adaptation Programme for Africa	2017	project report	Malawi, Tanzania
Suarez, P.	Caution, cognition, and credibility: the risks of climate forecast application	2004	journal article	Zimbabwe
Sultan, B., Barbier, B., Fortilus, J., Mbaye, S. M., & Leclerc, G.	Estimating the potential economic value of seasonal forecasts in West Africa: a long-term ex-ante assessment in Senegal	2010	journal article	Senegal
Tarhule, A. & Lamb, P. J.	Climate Research and Seasonal Forecasting for West Africans: Perceptions, Dissemination and Use?	2003	journal article	Mali, Burkina Faso, Niger, Nigeria
Wood, S. A., Jina, A. S., Jain, M., Kristjanson, P., & DeFries, R. S.	Smallholder farmer cropping decisions related to climate variability across multiple regions	2014	journal article	Burkina Faso, Ghana, Mali, Niger, Senegal, Ethiopia, Uganda, Kenya, Tanzania
Zare, A., Barbier, B., Bolongo-Traore, M., Diarra, A., Mahe, G., & Paturel, J.E.	Climate Forecast Perception and Needs in Wetlands: A Case Study in the Inner Niger Delta in Malian Wetlands	2017	journal article	Niger, Mali
Ziervogel, G., Bithell, M., Washington, R. & Downing, T.	Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers	2005	Journal article	Lesotho
Zongo, B., Diarra, A., Barbier, B., Zorom, M., Yacouba, H., & Dogot, T.	Farmers' perceptions and willingness to pay for climate information in Burkina Faso	2016	journal article	Burkina Faso

APPENDIX 2: WEST AFRICA ACCESS AND USE ESTIMATES

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
West Africa						
Burkina Faso	21.78% of farmer have access to climate info	-	seasonal forecast	farmers	629 surveys, 4 districts	Zongo et al. 2016
	2/3 of farmers that did not participate in workshop received forecasts from participants, less in areas of social strife	workshop participants were more likely to use SCFs for farm-level management	seasonal forecast	farmers	159 interviews	Roncoli et al. 2009
	7% (seasonal); 30% (2-3 day); 6-13% (flooding)	flooding (100%); availability of grazing (75%); onset date (6-53%); subseasonal forecast (17%), seasonal forecast (0%)	various	pastoralists	61 surveys, 2 sites; 8 focus groups, 2 sites	Rasmussen et al. 2014
	-	farmers use SCF for choice of field, crop varieties, timing of tasks, etc., constrained by presentation & resources; pastoralists do not use forecasts	seasonal forecast	farmers, pastoralists	15 interviews	Roncoli et al. 2002
	62.7% of farmers have access to forecasts on rainfall onset; 39.3% had access to forecasts on outbreak of pests/disease	24% used info on timing farming activities	onset	farmers	140 surveys	Oyekale 2015
	18.6% aware of SCF; drought info received from media, NGOs & the gov; farmers were more likely to seek SCF from NGOs than gov	-	seasonal forecast, drought info	farmers	130 surveys, 3 communities	Tarhule and Lamb 2003
Benin	farmers receive SCF through radio (75.1%), elders (50.3%), meetings (26.3%), extension agents (24.3%), mobile phone (18.2%), friends (16.8%), research institutes (12.7%)	95% of farmers report that they would change at least one strategy in response to SCFs.	seasonal forecast, rainfall distribution, onset, amount	farmers	354 surveys	Amegnaglo et al. 2017

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
Ghana	farmers occasionally receive daily rainfall and temp forecasts from the radio; no access to seasonal forecasts; prefer the radio, in their local dialect	Men use weather info regarding varieties and cropping area; women use it for planning household chores.	daily weather and SCFs	farmers	4 focus groups, 15-20 people each	Jost et al. 2016
	56.4% of farmers from West Africa had access to info on rainfall onset; 18.2% access to pest/disease forecast	17.6% (rainfall onset) and 4.3% (prevalence of disease) of West African farmers report changes in practice because of forecasts	Rainfall onset outbreak of pests	farmers	140 surveys	Oyekale 2015
Mali	2500 trained / had access as part of the project	-	seasonal forecast	farmers	-	Hellmuth et al. 2011
	62.4% aware of SCFs; 62% of West African orgs do not think their understanding of SCF to have improved	82% of West African orgs have not found any published climate info useful to their user groups	seasonal forecast, drought info	farmers; intermediary orgs	160 surveys, 3 communities	Tarhule and Lamb 2003
	-	use estimates ranged for 8% to 24% across communities; use varies by agro-ecological zone and by social position (e.g., for senior men)	seasonal forecast info; onset date	farmers	132 focus groups, 660 interviews, 36 communities	Carr 2014; Carr and Onzere 2017
Niger	29.2% (outbreak of pests) and 56.4% (rainfall onset) of farmers in East Africa received info; roughly 25% reported men & women having equal access to forecasts	17.6% (start of rainfall) and 4.3% (prevalence of disease) of East African farmers report changes in practice because of forecasts	start of rainfall, prevalence of disease	farmers	140 surveys	Oyekale 2015
	5.6% aware of SCFs; 62% of West African orgs do not think their understanding of SCF improved	82% of West African orgs have not found any published climate info useful to their user groups	seasonal forecast, drought info	farmers; intermediary orgs	151 surveys in 3 communities; 18 intermediary orgs	Tarhule and Lamb 2003
Senegal	56.4% of farmers from West Africa had access to info on start of rainfall; 18.2% access to pest/disease forecast	17.6% (start of rainfall) and 4.3% (prevalence of disease) of West African farmers report changes in practice because of forecasts	start of rainfall, prevalence of disease	farmers	140 surveys	Oyekale 2015

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
Nigeria	62% of West African orgs do not think their understanding of SCF to have improved	82% of West African orgs have not found any published climate info useful to their user groups	seasonal forecast, drought info	farmers; intermediary orgs	109 surveys in 4 communities; 4 orgs	Tarhule and Lamb 2003

APPENDIX 3: EAST AFRICA ACCESS AND USE ESTIMATES

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
East Africa						
Kenya	-	significant change in planning & mgmt re: land prep, seed selection, fertilizer, harvesting, planting, livestock mgmt	seasonal forecast	farmers	120 surveys	Rao et al. 2015
	62.7% (pests) & 48.4% (rainfall onset rainfall) of East African farmers received info; roughly 25% reported men & women having equal access	24% (rainfall onset) & 5.3% (disease) of East African farmers report changes in practice	start of rainfall, outbreak of pests	farmers	280 surveys	Oyekale 2015
	82% of farmers have access to weather or climate info; main access point is through the radio (84%)	majority who received info apply it in farm mgmt; use of info influenced by tercile; main decisions crop selection, water storage, food storage, early planting, hire more labor, etc.	seasonal forecast	agro-pastoralists	240 surveys, 40 interviews	Ngugi et al. 2011
	49% of respondents had access to forecasts in first survey; only 4% had access in second survey	73% of farmers who received SCF used them to prepare for emergencies; 41% changed in planting date; 14% changed crop location; 9% crop type	seasonal forecast	farmers	198 pilot survey, 299 second survey; 3 sites	O'Brien et al. 2000
Tanzania	At local level: access to climate info is highly variable; generally < 50%; women have less access than men; At national and district level, all respondents had access.	-	climate advisories, climate services	varied	33 semi-structured interviews at district level; range of data collection methods at local level	Daly et al. 2016

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
	> 50% of farmers have access to weather forecasts; slightly less access to seasonal forecasts; info regarding pests/diseases least accessible	38% of farmers use info on extreme events; 62% onset forecast; 22% SCF; 38% pest forecast; 0% weather forecasts	Extremes; onset; weather; SCF; pests/diseases	farmers, agro-pastoralists	340 households, 17 villages (9 experimental, 8 control), 2 sites; 39 interviews	Coulibaly et al. 2015
	62.7% (outbreak of pests) and 48.4% (start of rainfall) of the farmers from East Africa received info; 25% reported men & women having equal access	24% (rainfall onset) and 5.3% (disease) of East African farmers report changes in practice bc of forecasts	start of rainfall, outbreak of pests	farmers	280 surveys	Oyekale 2015
Uganda	Farmers report receiving weather info on radio and SMS; most do not understand it, or find it salient or credible	-	weather, climate info	farmers	4 focus groups, 15-20 people each	Jost et al. 2016
	Info received from sources including; radio, diviners, community meetings, elders, humanitarian agencies, and Uganda Defense Force	info used to for shifting livestock; selling firewood and charcoal; seeking military escort to grazing areas; purchasing veterinary drugs;	Flood, drought, pest & disease forecast, onset	pastoralists	198 multi-stage surveys; 10 interviews; 29 focus groups	Egeru 2016
Ethiopia	39% have access to info on climate	Info on temp and rainfall used to choose crop varieties (18.5), soil conservation (9.5), changing planting dates (5.1%) and irrigation measures (5.4%).	temperature, rainfall	farmers	400 surveys, 3 districts	Gebrehiwot & van der Veen 2013
	15% of households had access to seasonal forecasts; language and access to media are limitations	Recipients update beliefs based on below-normal, but not above-normal rainfall forecasts	seasonal forecast	pastoralists	surveys, 245 households	Lybbert et al. 2007
	62.7% (outbreak of pests) and 48.4% (rainfall onset) of the farmers from East Africa received info; roughly one-quarter reported men & women having equal access to forecasts	24% (rainfall onset) and 5.3% (disease) of East African farmers report changes in practice bc of forecasts	start of rainfall, outbreak of pests	farmers	280 surveys	Oyekale 2015

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
	gov and non-gov agencies access seasonal forecast	Gov and donor decisions not based on seasonal forecasts, but lagging indicators of crisis	seasonal forecast	gov & NGOs	interviews, narrative	Broad and Agrawal 2000
	37% have access to climate info	info on temp and rainfall increases the likelihood of changing crop varieties by 17.6 percent	temperature, rainfall	farmers	1000 surveys, 4 regions	Deressa et al. 2008

APPENDIX 4: SOUTHERN AND CENTRAL AFRICAN ACCESS AND USE ESTIMATES

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
Southern Africa						
Mozambique	86% have access, primarily through TV or radio	Respondents use forecasts, on average 780 times per year	weather, SCF	general public	576 surveys	Lazo 2015
Namibia	35% of farmers access pre-season forecasts; 85% access info through radio	60% of farmers who accessed forecasts reported using it; common action was to change planting dates (40%); substitution (35%)	SCF	farmers	90 pilot survey, 112 second survey	O'Brien et al. 2000
Zimbabwe	65% access to seasonal forecasts	57% of those with access reported changing decisions based on forecasts	SCF	farmers	4 villages, 578 surveys	Patt et al. 2005
	59% of farmers access to rainfall info; 48% access drought info; 33% access storm info	choice of planting dates (37%) and choice of crop varieties (37%) were most common	rainfall forecasts; drought info; storm warnings	farmers	300 surveys	Mudombi & Nhamo 2014
Malawi	27% of farmers access to climate info	access to climate info positively correlated to climate change adaptation	seasonal and long-term info	farmers	Survey, 1786 farmers, 3 districts	Mulwa et al. 2017

	Access Estimates	Use Estimates	Information Type	Target Population	Data Collection, Sample Size	Reference
	> 80% of farmers access to 2-3 day forecasts, onset of rains, extreme events; slightly less access to disease info	69% report using onset info on onset; 49% on seasonal forecast; 48% on extremes; 38% on weather; 34% on pests/disease forecasts	onset, SCF, weather, extremes, pests	farmers	320 surveys, 20 villages (12 exp, 8 cont); 46 interviews	Coulibaly et al. 2015
Central Africa						
Central African Republic	only 2% of farmers report access to scientific climate or meteorological information; 98% rely on traditional weather and climate indicators	-	weather, seasonal	farmers	315 surveys	Ngana et al. 2013