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From research to practice: Adapting agriculture to climate today for tomorrow in Ethiopia

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Eighty percent of the world's agriculture is rainfed, making it highly vulnerable to climate fluctuations and stresses, such as those brought about by climate variability and change. Sub-Saharan Africa and Ethiopia in particular have experienced a significant increase in climate variability over the past decade, which has led to more frequent weather extremes such as floods and droughts. Because 85% of Ethiopia depends upon agriculture for its livelihoods, such rainfall shortages or excesses can impede food production, access to financial and natural assets, and the ability to recover in subsequent crop seasons. This means that climate variability in agriculture not only affects the availability of the food Ethiopians consume, but also the income of its smallholder farmers. Variability in rainfall and temperature can also have adverse effects on livestock and the pastoralists whose livelihoods depend upon it. Thus, all development planning and practice in the agriculture and related sectors need to take climate variability and long-term climate change into account. Climate services can contribute to the alleviation of a range of climate-sensitive development challenges, including agricultural production and food security. The Adapting Agriculture to Climate Today for Tomorrow (ACToday) approach of the International Research Institute for Climate and Society (IRI), Columbia University, USA, aims to develop climate service solutions through enhancement of the availability and effectiveness of climate information in national policy, planning, management, and other decision-making processes in countries that are particularly dependent on agriculture and vulnerable to the effects of climate variability and change. It targets improved food security, nutrition, environmental sustainability and economic outcomes in these countries by promoting the use of climate information and services to manage current climate risks, while laying the foundation for adaptation to future climatic conditions. In this Perspective, we share experiences from the implementation of the ACToday project and approach in Ethiopia, outlining its accomplishments and challenges. In doing so, we characterize best practices and pitfalls to avoid to ensure climate knowledge and information truly meet the needs of climate-informed decision making and climate-smart policy and planning. We also outline pragmatic guidance to ensure activities designed to evolve climate research into services are done so appropriately, responsibly, and sustainably to bridge the gap between those who produce climate information and those who ultimately use it.

KEYWORDS

climate services, food security, SDG2: zero hunger, agriculture, Ethiopia, resilience, climate information, climate variability

Introduction

Changes in climate have resulted in widespread, pervasive impacts to ecosystems and people, including increases in the intensity of weather extremes such as droughts and floods (IPCC, 2021). Such shifting temperature and precipitation patterns have affected the productivity of many climate-sensitive sectors, especially agriculture, resulting in reduced food availability and increased food prices, ultimately jeopardizing food security, nutrition, and livelihoods of millions of people across the globe (IPCC, 2022). The implications of this challenge are especially pronounced in places like Ethiopia where over 85% of the population representing more than 70 million people (USAID, 2021) are reliant upon rain-fed agriculture sector for their livelihoods. It is here that climate extremes such as drought have caused widespread failure of seasonal crops, inadequate forage and massive deaths of livestock in pastoralist communities, and hunger affecting millions of people and resulting emergency food aid averaging $1.1. billion per year (Mera, 2018). And it is here that even in the absence of extremes, changing seasonality—such as rainy season onset, cessation, and duration of the rainy season (Wakjira et al., 2021)—necessitates the use of climate information to inform agricultural planning.

The availability of climate information, however, has not automatically resulted in its effective use in decision-making processes to support adaptation in Ethiopia or elsewhere generally. For this to happen, the information has needed to be made accessible and appropriately tailored to match what users need in terms of skill, scale, and lead time, and produced in formats that can be well-integrated within knowledge systems (Machingura et al., 2018; Singh et al., 2018). Indeed, successful examples of the use of climate information in decision-making in wider Africa have predominantly used daily, weekly, and seasonal climate information—in other words, information over short time horizons—with very little evidence of long-term climate projections being integrated into local decision-making, particularly for farmers, pastoralists and sub-national governments (Stone and Meinke, 2006; Jones et al., 2015; Singh et al., 2018).

Such is the case and the challenges confronting Ethiopia in the use of climate information in decision-making. Despite the priority placed on addressing issues of adaptation and resilience-building in strategic planning and a wide range of freely available and already existing climate information products, significant barriers still remain that inhibit theoretically useful information from actually being usable and ultimately used in adaptive decision-making. These barriers stem from a failure to recognize and account for the reality that the way theoretically useful information is transformed into sector-relevant and decision-relevant knowledge (translated), communicated to users (transferred), and the degree to which the user has the capacity to actually understand and act on the information (use), all of which affect whether and the degree to which the information enables climate adaptation. In other words, even the best-available climate information, when divorced from decision-making processes and poorly integrated within systems, institutions, and products that enable its use or fail to acknowledge the role of decision-makers in their design and refinement, can ultimately be doomed to be ineffective at supporting adaptation.

In this Perspective, we share experiences from the recently concluded Adapting Agriculture to Climate Today, for Tomorrow (ACToday) project in Ethiopia and its namesake approach, which acknowledges the ongoing and common disconnect between the availability of often high-quality climate information and its access and use on the ground. We do so with the purpose of outlining pragmatic guidance and examples of concrete strategies and decision support systems that can be employed to increase the relevance of climate information in decision-making at multiple levels in practice.

Approach

The Adapting Agriculture to Climate Today, for Tomorrow (ACToday) Columbia World Project (2017–2022) (Fiondella, 2021), which has been implemented in six agriculture-dependent countries (Figure 1) across the world (Ethiopia, Senegal, Vietnam, Bangladesh, Colombia, and Guatemala) embodies a holistic approach for improving the availability, access, and use of high-quality climate information that goes beyond its mere generation to recognize a broader ecosystem of actors and actions as necessary for enabling its effective application and design as services. In its mission to create

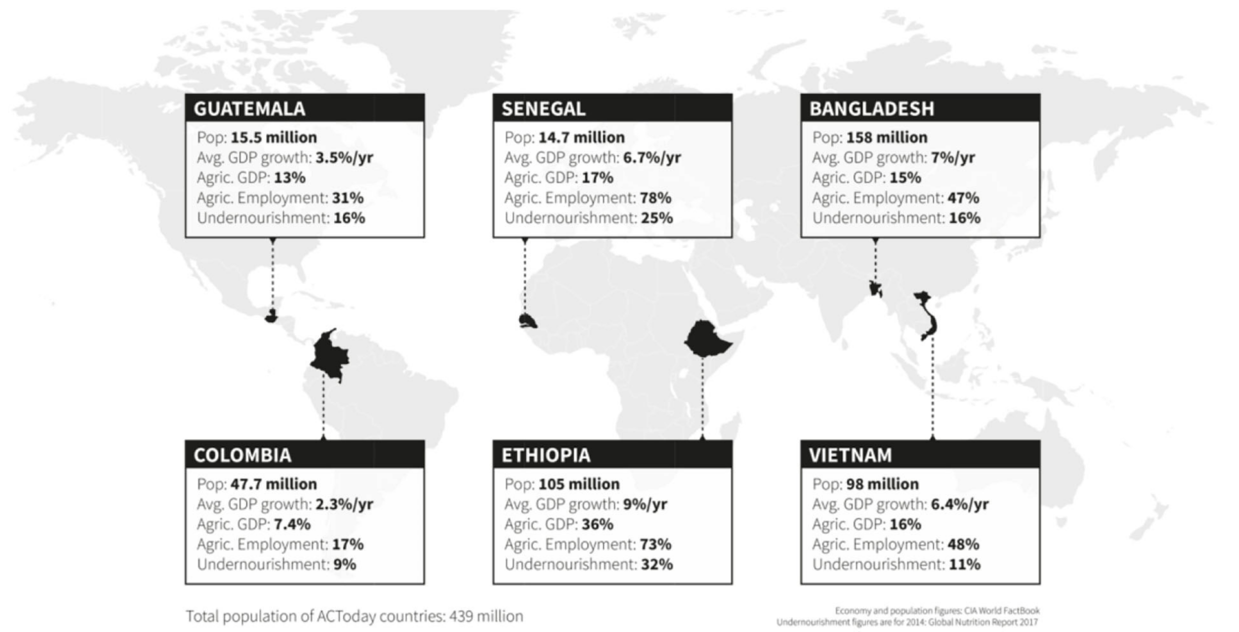

FIGURE 1
ACToday approach countries of implementation. The ACToday approach was intentionally mplemented in six agriculture-dependent countries with varying institutional arrangements, histories, cultures, and enabling environments across the world, in order to gain insights and lessons on how climate services might be best implemented in different contexts.

climate service solutions that help end hunger, achieve food security, improve nutrition, and promote sustainable agriculture (United Nations Sustainable Development Goal 2), it has adopted a framework that emphasizes four mutually reinforcing and interconnected "pillars" of climate services—generation, translation, transfer, and use—as foundational for supporting and enabling adaptive action (Figure 2).

Moreover, in its pursuit of advancing climate services that are useful, usable, and used, it recognizes that climate scenarios that project conditions 50 or 100 years in the future, while valuable for understanding longer-term climate change, are misaligned with the needs of decision-makers today, which are deeply impacted by shorter-term climate variability. Whether it is a farmer needing to make key agricultural decisions for a season or within a season based on temperature or rainfall patterns, a humanitarian aid worker who needs to anticipate and respond to climate extremes such as a drought or flood, or even a policymaker who must plan and arrange for agricultural inputs and investments annually, there is a need for climate information on shorter time and spatial scales that can pragmatically inform and be integrated within specific decisions and decision-making processes for adaptation (Stone and Meinke, 2006; Jones et al., 2015; Machingura et al., 2018; Singh et al., 2018). The ACToday approach rests on the premise that co-developing adaptive solutions that are relevant to the decision horizons and needs of today and accompanied by specific actions that are systematically integrated along the four pillars will also enable the kind of resilience building and systems architecture that enables adaptation tomorrow, in the long-run. And it was intentionally implemented in six agriculture-dependent countries with varying institutional arrangements, histories, cultures, and enabling environments across the world, in order to gain insights and lessons on how climate services might be best implemented in different contexts.

In Ethiopia, for example, the government has a clearly defined strategy for the implementation of the Sustainable Development Goals (SDGs), which have been integrated into its national Growth and Transformation Plan (GTP). All executive organs of the federal government, the regional states and city administrations implement SDGs as an integral part of the GTP. Moreover, the country has made significant investments in climate services information systems (Lennard et al., 2018) through the Ethiopian Meteorological Institute (EMI) and instituted a number of national and sectoral strategies, policies, programs, and plans including the Climate Resilient Green Economy (CRGE) strategy, the National Adaptation Plan (NAP), the second Five-Year Growth and Transformation Plan (GTP-II), the Agricultural Sector Policy and Investment Framework (PIF), and two phases of the Agricultural Growth Program (AGP). As such, the implementation of the ACToday approach in Ethiopia entailed supporting and strengthening the existing system and efforts by identifying key gaps in the provision of decision-relevant climate services and working with both national and international institutions along the entire

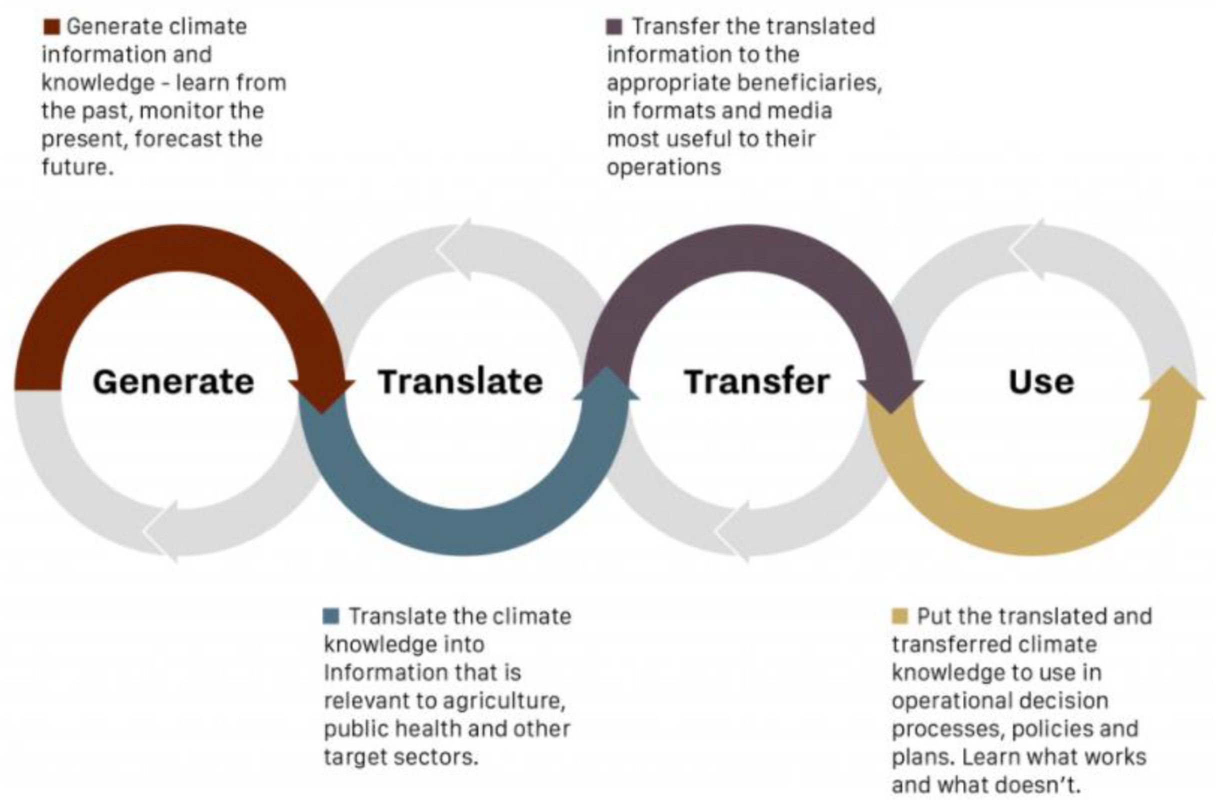

FIGURE 2
The four pillars of climate services. The four pillars of climate services include the generation, translation, transfer, and use of climate information. Source: Fiondella (2021).

spectrum of climate services and its functional pillars (Figure 3). This included the Ethiopian Meteorological Institute (the main institution for the "generation" and some "translation" of climate information), the Ethiopian Institute of Agricultural Research (the main gatekeeper of use of climate information and technology for the country responsible for its "translation and transfer"), and the Ministry of Agriculture (with its significant roles in both "transfer" and also "use" of climate information through its advisory and extension systems).

The goal of this Perspective, however, is not to unpack or compare the implementation of climate services amongst different ACToday project countries, which has been done elsewhere to some extent for Africa (Hansen et al., 2022). Rather, it is to give concrete examples of the implementation of a holistic approach to the development of climate services in the context of Ethiopia, accompanied by good practices arising from experience and research, that might inform the development of climate services in other contexts where strong political will and high-quality climate information have not materialized into climate-informed decision-making.

In what follows, therefore, we share experiences from the implementation of the ACToday approach in Ethiopia along each of the four climate services pillars, outlining accomplishments, challenges, and guidance shaped by both research and practice to ensure climate knowledge and information are transformed into services that meet the needs of climate-informed decision making and climate-smart policy and planning. In this context, the partnerships, initiatives, and tool development pursued were a direct reflection of an intentional strategy to address and connect the full spectrum of climate services along these pillars (Figure 3).

Decision-relevant climate services in action

Generation: Building the backbone of climate services

The generation of high-quality climate data underpins the quality of both the information and the services which are derived from it. As such, actions to improve the availability of reliable, timely, and trustworthy climate data are a critical first step in the development of effective climate services.

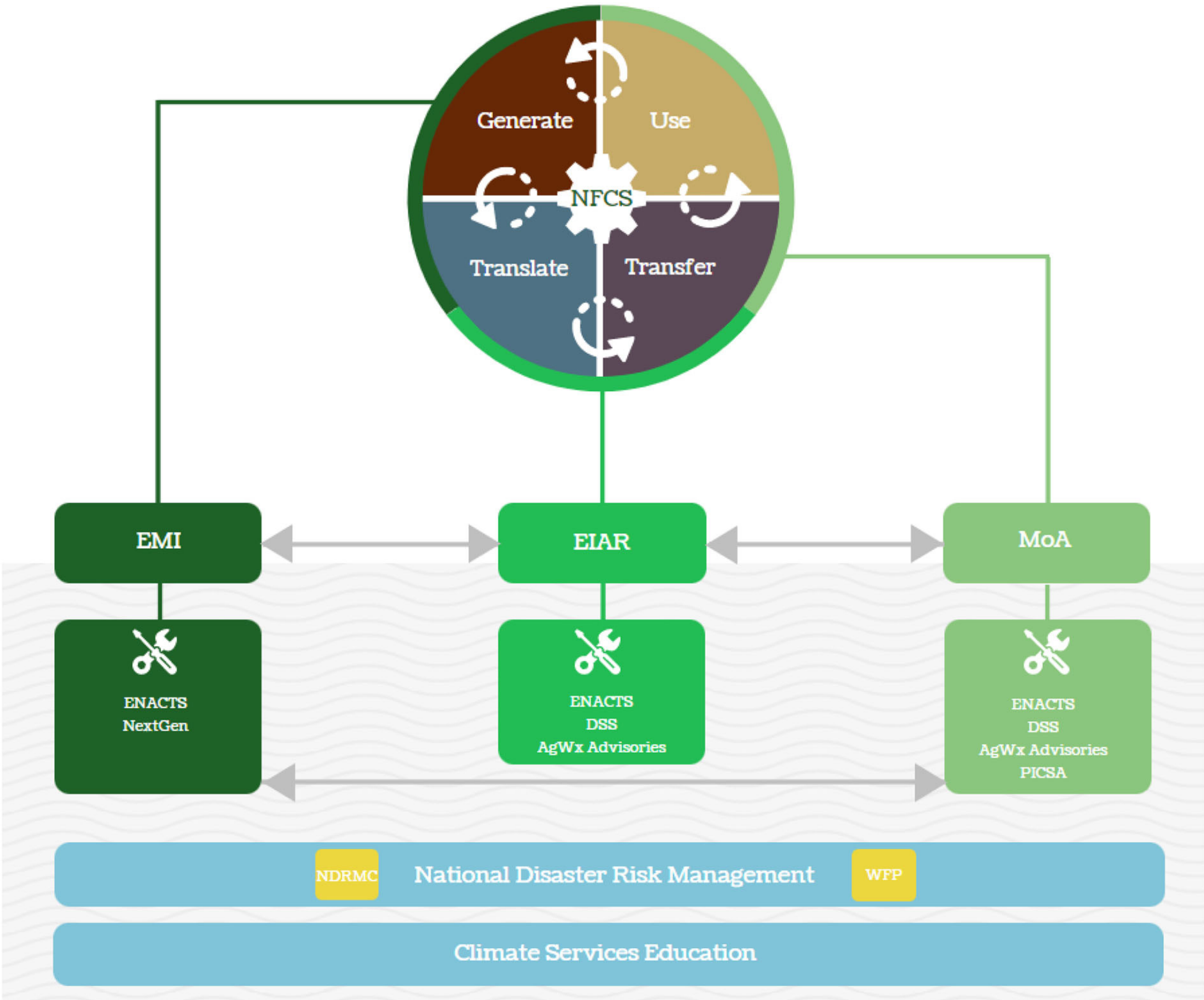

FIGURE 3
ACToday core national partners in Ethiopia—The Ethiopian Meteorological Institute (EMI), Ethiopian Institute of Agricultural Research (EIAR), and Ministry of Agriculture (MoA)—and their relationship to the four pillars of climate services. The National Framework for Climate Services (NFCS) drives coordination of institutions and actions across each of these pillars, as depicted in the center of the wheel, while actions to support national disaster risk management and foundational capacity building and education on climate risk management are considered cross-cutting and support all pillars and institutions.

In Ethiopia, as in many parts of Africa, the Ethiopian Meteorological Institute (EMI), which is mandated with collecting and providing weather and climate information, has confronted challenges around the collection of climate data arising from geographically sparse and poorly maintained surface and upper air stations alongside underinvestment in satellite data reception and processing systems (Dinku et al., 2018a; Lennard et al., 2018). The result of these challenges is a shortfall of meteorological information generally but with particular implications for agricultural and food security planning, monitoring, and early warning, though meteorological data observations have continued to be collected over the years.

To address this sub-optimal information environment, the ACToday project and approach in Ethiopia, as in the other five countries where it was implemented, leveraged the IRI's Enhancing National Climate Services (ENACTS) initiative to advance the availability of high-quality climate data. This was done by introducing a methodology to blend rainfall and temperature observations collected by national weather services with freely available global products derived from satellite data and climate model reanalysis products (Nsengiyumva et al., 2021). Through this merging method of on-the-ground station data with satellite rainfall estimates and climate model reanalysis products, ENACTS enabled Ethiopia to fill temporal and spatial gaps in the observational record extending back to 1981, helping the country to better characterize its past and current climate as well as predict its future one (Research Outreach, 2020; Dinku et al., 2022a). Moreover, the ACToday approach's incorporation of ENACTS advanced the use of an open-source R-based software with an easy-to use graphical user interface called the Climate Data Tool (CDT) in Ethiopia and 23 other primarily African countries, which ensures quality-control of rainfall and temperature observations, alongside the performance of an array of analyses and visualization capabilities that are important for other pillars of climate services (Dinku et al., 2022b). It did this by carrying out targeted capacity building trainings not just with the EMI, but with agricultural research institutions such as the Ethiopian Institute of Agricultural Research (EIAR), which is the main gatekeeper for the introduction of new technology, including climate services, in the country, as well as universities like Arba Minch University, which carry out research to understand linkages between climate and multiple sectors such as that of agriculture. In this same way, the web-based Automatic Weather Station Data Tool (ADT), has helped to address challenges in accessing and processing Automatic Weather Station (AWS) data collected by different systems and networks such as Vaisala, Edkon, Campbell, and KOICA, which are on different servers and in different formats, by enabling data quality control, processing, and visualization (Faniriantsoa and Dinku, 2022).

Because of both ENACTS and its component tools, such as CDT and ADT, Ethiopia has been able to evolve its historical, monitoring, and forecast capabilities using the best-available, quality-controlled data. And, most recently, because of these foundational improvements to underlying data, the country has also advanced its seasonal forecasting capabilities through the implementation of the Next Generation (NextGen) forecasting system. The NextGen forecasting system, which is based on more than 25 years of research and now implemented in 6 countries and two regional climate centers, has helped forecasters such as those at EMI to select the best climate models for any area of interest through a process-based evaluation. Moreover, it automates the generation and verification of tailored predictions at multiple timescales (weeks to months) and at multiple levels—regional (East Africa), national, or even sub-national (Columbia University, 2020; Acharya et al., 2021; Ehsan et al., 2021). While there are many advantages of the NextGen forecasting system in terms of improving the tailoring, communication, and ultimately usability of information, which will be discussed later in the paper, its enormous contribution in transitioning the country from subjective consensus forecasting to operational objective climate information that forms the backbone of any successful climate service cannot be overstated.

These free, open-source innovations (CDT, ADT, and NextGen), all of which have been co-produced and arisen out of the ENACTS initiative and accompanying datasets, might therefore be considered for adaptation and use by countries and organizations seeking to improve the quality of the climate data that underlies climate information and services such as forecasts. Moreover, regional climate centers such as the IGAD Climate Prediction and Applications Center (ICPAC) in East Africa and the Regional Center for Training and Application in Agrometeorology and Operational Hydrology (AGRHYMET) in West Africa might be considered resources for expanding the use of and capacitating new users on these tools to improve the generation of high-quality climate information beyond the Ethiopian context, since these centers have been intentionally capacitated on these innovations.

Translation: Transforming data into actionable information

While high-quality climate data underpins high-quality climate information, it is not sufficient to ensure that such information is actually useful or even usable as a climate service. Even the best-available data can be rendered useless if it is not appropriately tailored to the needs of various decision-makers as information, if it is poorly accessible or communicated, or if users are not capacitated to understand or even access it. There is a difference between information that is theoretically useful, usable, and actually used (Grossi and Dinku, 2022), and climate services aim to bring into harmony all of these qualities to inform decision-making and support adaptation.

Cognizant of this reality, the ACToday approach in Ethiopia and elsewhere has centered on advancing decision-relevant climate information through the translation of climate data into information products driven by user needs. In practice, this has meant advocating for and supporting increased interactions between the EMI (the national meteorological service) and various current and potential users of its information products, in line with the recommendations of the literature for decision-relevant, fit-for-purpose services (Vincent et al., 2017, 2018; Christel et al., 2018; Hansen et al., 2019a,b; Ncoyini et al., 2022). Through these interactions, a process called co-production has enabled the co-development of decision support systems, tools, visualizations, and even financial instruments that have allowed shapeless data to take form as useful knowledge products and services. Instead of a one-way "push" of information to users, such co-production has involved a two-way, iterative and collaborative process of knowledge construction between those who generate climate information at the EMI and those who use it. This process has manifested itself as various coproduction workshops with the EMI and actors from across various sectors and national institutions involved in supporting food security and nutrition in Ethiopia, such as the Ministry of Agriculture (MoA), the National Disaster Risk Management Commission (NDRMC), Ministry of Health, EIAR, and the Ministry of Water, Irrigation and Electricity (EIAR), as well as international nonprofits such as the World Food Programme (WFP), the Food and Agriculture Organization (FAO), and the Global Alliance for Improved Nutrition (GAIN).

While we cannot outline each decision support system or tool co-developed through the ACToday project or its concomitant approach here, three illustrative examples demonstrate the impact and importance of translating climate data and information into products that are useful for the agricultural sector: the Enhancing National Climate Services (ENACTS) maprooms, the NextGen Agricultural Drought Monitoring and Warning System (NADMWS), and the SIMAGRI decision support tool. In doing so, each of these products add to the expansive body of evidence demonstrating the insufficiency of merely generating high-quality climate information divorced from accompanying efforts to ensure easy access, clear communication, appropriate delivery, and capacity building (Sarewitz and Pielke, 2007; Goddard et al., 2010; Dilling and Lemos, 2011; Lemos et al., 2012; McNie, 2013; Jones et al., 2015; Vincent et al., 2017; Nkiaka et al., 2019; Photiadou et al., 2021), and the importance of coproduction processes in ensuring services are both driven by and truly meet user needs (Christel et al., 2018; Vincent et al., 2018; Hansen et al., 2019a; Ncoyini et al., 2022).

High-resolution visualizations and analyses: The ENACTS maprooms

In Ethiopia, like many African countries, a major obstacle for making climate information available and supporting its analysis is limited human capital, a lack of financial resources, and poor technical capacity (Dinku et al., 2018b). Earlier in this paper, we described how the Enhancing National Climate Services (ENACTS) initiative is improving the availability and generation of high-quality climate data through its merging method of station and satellite data, as well as through derived tools like CDT and ADT. It has also, however, contributed greatly to the translation and transformation of this data into a rich suite of downloadable interactive visualizations and analytics tools known as “maprooms” that are feely and openly accessible on the web (Ethiopian Meteorological Institute, 2022a). Through these dynamic visualizations, users can access information that has been translated, or transformed, into products that inform specific decisions and which have been co-produced with people from different sectors such as agriculture (Ethiopian Meteorological Institute, 2022b), water (Ethiopian Meteorological Institute, 2022c), and even health (Ethiopian Meteorological Institute, 2022d).

Within the ACToday project, which primarily targeted the agriculture sector, Climate and Agriculture maprooms (Ethiopian Meteorological Institute, 2022b) allowed for easy organization of a collection of interactive historical maps and location-specific analyses. This, in turn, enabled actors in the agriculture sector to more easily visualize things like frequency of rainy days, wet and dry spells, and the onset and duration of the rainy season (Grossi and Dinku, 2022), while downscaled seasonal rainfall forecasts at high resolution also provided locally-relevant information to facilitate agricultural planning (Hansen et al., 2019a). These freely available interactive “maproom” visuals and graphs of climate data have played large role in making EMI’s climate information more accessible and usable by translating past, present, or future climate conditions into expected impacts and management advisories for different decision-makers. With index insurance, for example, a key risk management tool for farmers, ENACTS data and maprooms have enabled insurance experts to visualize rainfall patterns over wide areas, in turn creating conditions to scale up insurance in Ethiopia by giving these local experts the tools they need to tailor products to specific areas of coverage (Enenkel et al., 2019; International Research Institute for Climate and Society, 2021).

Contextualized and tailored information: The NextGen agricultural drought monitoring and warning system

Another knowledge product made possible by ENACTS data but rendered impactful from the translation of this underlying data into a decision-relevant format is the NextGen Agricultural Drought Monitoring and Warning System (NADMWS). In Ethiopia, drought is a persistent and devastating challenge to the lives and livelihoods of millions of people, with increasing frequency and magnitude at both long and short time scales (Kassaye et al., 2021). While the challenge is not new, part of the problem for mitigating their persistent and devastating effects has arisen from an unmet need for timely and accurate climate information about the onset and development of country-wide drought conditions (AICCRA, 2022). This part of the challenge can and was addressed through the generation of high-quality, spatially and temporally complete climate data through ENACTS and derived NextGen forecasts, which were combined with agricultural datasets and information. However, another significant part of the problem has emerged from the reality that even when available, the information is not easily accessible or in a decision-relevant format for those working in the humanitarian space to act upon (AICCRA, 2022). The development of NADMWS tackled these component challenges in parallel by addressing the issues related to data and information provision in tandem with those related to their translation and communication. Using satellite-based remote sensing technology, combined with detailed land-use maps, seasonal forecasts, national crop statistics, crop phenology and other country-specific data, any user can now freely monitor agricultural areas or “hotspots” with a high likelihood of water stress at the national, regional, zonal and woreda (district) levels (Ethiopian Institute of Agricultural Research, 2022). But perhaps most critically for decision-makers, the system simulates and automates the analysis that an expert in remote sensing would undertake and simplifies the interpretation and use of the data for users who are not remote sensing experts. The development of this tool is an example of a situation where use of climate information in decision-making, particularly by those in the disaster risk reduction and management (DRR/M) sector, was constrained not only by a lack of high-quality information but poor communication of that information. Tackling the former without addressing the latter through an easily accessible and automated NADMWS interface would have resulted in an incomplete solution to a complex problem rooted not just in information asymmetry but communication inefficiencies and poor analytical capacity.

Similarly, the Livelihoods, Early Assessment and Protection (LEAP) early warning-early response tool (World Food Programme Ethiopia Country Office, 2013) in use by the Government of Ethiopia and other humanitarian actors is another example of a tool built on a foundation of high-quality ENACTS data but made actually impactful from its design to translate this ground and satellite data across the nation into early warning and early response information that allows the critical programs such as the Government of Ethiopia's Productive Safety Net Programme (PSNP), which serves millions of chronically food-insecure rural households, to be scaled up immediately in case of a climate disaster.

User-friendly interfaces and sectoral relevance: The SIMAGRI decision support tool

SIMAGRI, another example of a user-friendly decision support tool developed to translate climate information into agricultural and economic terms that can support strategic and tactical decisions in crop production, was first successfully developed by the IRI and its partners in the context of South America (Han et al., 2019). With the support and collaboration with key actors and programs such as EIAR, EMI, IRI, and CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), it was adapted and co-developed for the African context for the first time in Ethiopia, as both a desktop and web tool (SIMAGRI-Ethiopia, 2022) through the ACToday project. The tool helps users such as agricultural experts and extension officers to translate both historical climate and downscaled forecast information (Han and Ines, 2017) into agricultural and economic terms for decision-making, by enabling the exploration of different "what-if" scenarios with various inputs (including weather, soil conditions, fertilizers, and planting dates) to estimate yield and determine optimal management practices. This tool can be taken as an example of and emulated as a resource that helps bring together traditionally disparate agricultural, climate, and price information into one place to transform it into something relevant for decision-making and planning.

Transfer: Communicating information in useful formats

Communication refers to the transfer of the translated information to the appropriate users or beneficiaries in formats and media most useful for their operation (Fiondella, 2021). In the same way that having limited and poor quality climate data (generation) or poorly tailored and contextualized information (translation) can stymie the ultimate uptake and usefulness of climate information within decision-making, so too can inappropriate and poorly designed communication methods, means, and channels limit the effectiveness climate services.

In the context of Ethiopia, working with and through partners with long-standing relationships with various user communities, as well as directly interfacing with user communities through co-production workshops with EMI has been invaluable in understanding not only the kinds of information needed but how it might be best communicated and systematized to scale and sustain its use. This is in line with literature demonstrating the importance and effectiveness of climate information producers and users interacting to create truly decision-relevant products, and good practices of users playing an active role in informing and even leading the development of products intended to serve them (Christel et al., 2018; Vincent et al., 2018; Hansen et al., 2019a; Ncoyini et al., 2022).

In the three aforementioned examples of knowledge products and tools (ENACTS, NADMWS, and SIMAGRI), for example, having the translated and sector-relevant climate information freely available online and formatted even for mobile phones has been important means of communicating and making available these products. For example, with SIMAGRI, transitioning the tool online and formatting the web page for mobile phones was an important communication choice, as the initial desktop version required users to install the software package on their computer. This was problematic because computer access is limited in Ethiopia, with less than a percent (0.22%) of people having access to desktop or laptop computers (Adam, 2012). This access is even more limited in rural areas. Similarly, how the information is presented is also very important. For instance, in the NextGen forecast maproom (Ethiopian Meteorological Institute, 2022e), the choice to display the forecast in a flexible format (Figure 4) was an important communication choice, as users can now choose their own probabilistic thresholds of interest to determine if rainfall will exceed certain amount or percentile of the average, precipitation of a region, rather than having them predefined (Grieser, 2014; Hansen et al., 2021). This format has been transformative for those in the agriculture sector, who need

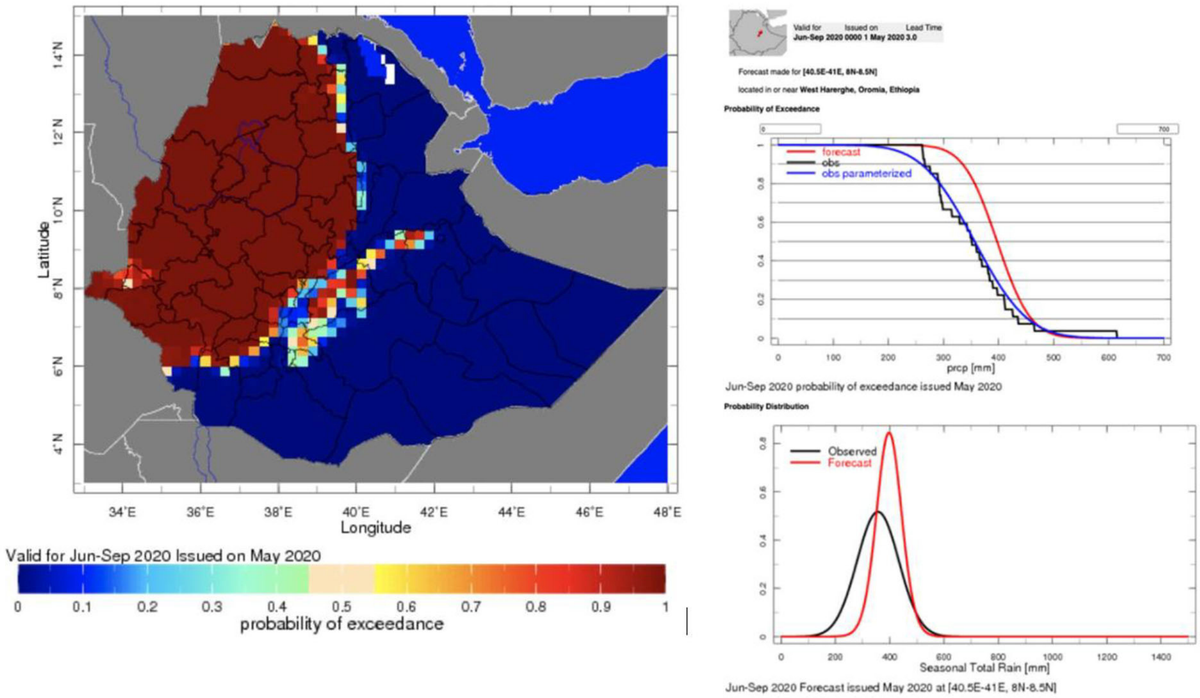

FIGURE 4
The NextGen flexible seasonal forecast format for Ethiopia. Both the map and graphs above, screenshots from the EMI's NextGen maproom (Ethiopian Meteorological Institute, 2022e), show in different formats the probability of seasonal rainfall exceeding 600 mm for the Kiremt (June–September) 2020 rainy season for any point in the country, as forecasted in May 2020. With the choice to communicate the seasonal forecast in this flexible format, any user can define any threshold (600 mm in this example) of interest to examine probability of exceedance of rainfall, rather than having those values predetermined in terciles, making the forecast more sector-relevant for agricultural decision-making.

such information to choose crop and cultivar choice, amongst other things.

Those seeking to develop climate information services in similar or other contexts, therefore, should consider not only the availability of information, but think critically about questions relating to communication (most appropriate mediums of communication for the population, frequency of communication, interactivity and inclusivity of the communication method) in their design.

Use: Integrating with systems, policy, processes, and plans

Beyond format and presentation, however, linking and integrating translated products within wider systems, both digital and human, has been critical for promoting their use. With SIMAGRI, for example, the system is not a standalone system, but rather is being integrated with Ethiopia's Digital AgroClimate Advisory Platform (EDACaP) to enable its use and be harmonized with a wider package of climate services for humanitarians, extension, and other actors interfacing with farmers. Similarly, with ENACTS maprooms, the generation and translation of climate data into sector- and decision-relevant knowledge products is insufficient if decoupled from the foundational capacity building on how to use these tools that has taken place iteratively both with national and sub-national EMI staff, but also others users including the extension system. Capacity building workshops with various sectoral users, from UN agencies to NGOs, university students, disaster risk management, agricultural extension, and even meteorological service staff themselves have been crucial for promoting uptake. This is also critical for ensuring regular, iterative feedback to improve, evolve, and co-develop new tools to meet specific user needs. This is how the sector-specific parts of the ENACTS maproom been developed over time.

Beyond this, the development of new climate risk management curricula and short training courses (Figure 5) targeting each of the aforementioned groups, including instruction on how to access maprooms and other EMI climate information products, has been key for ensuring these capacity building efforts will be sustained and continue to evolve beyond the life of the project (Braun et al., 2022). These efforts have targeted Ethiopia's Agricultural Vocational Education and Training (ATVET) program and colleges. They have also targeted farmers with the Participatory Integrated Climate Services for Agriculture (PICSA) approach

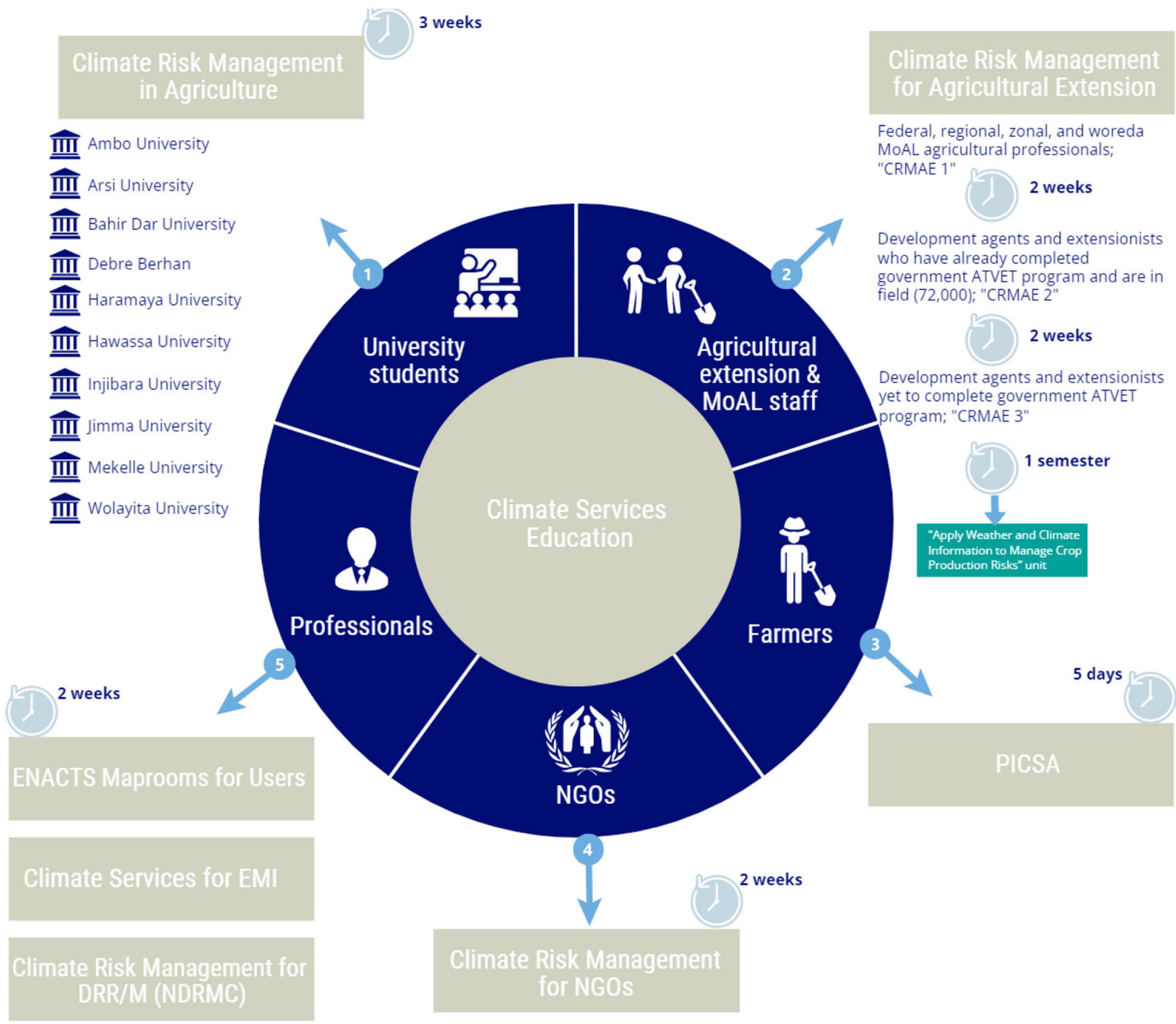

FIGURE 5
Groups targeted with foundational capacity building and curricula on climate risk management in Ethiopia. Each brown box represents a different curriculum or training package developed through the ACToday approach on climate risk management, while clocks represent the recommended implementation time for each curriculum.

(Dorward et al., 2015) for climate-informed decision and agricultural planning at the farmer level. For PICSA, high-quality climate products and automated analyses have been integrated within the approach's field implementation through the development of a PICSA Maproom interface (National Meteorological Agency, 2022) that allows users to easily display and download a batch of products required for the training of farmers, such as the season onset and cessation, seasonal rain forecasts (NextGen), and a variety of other information products. Such location-specific climate information is important for informing a variety of choices and planning decisions at the farm level in Ethiopia's various agro-ecological zones, from planting date to cultivar selection, timing of fertilizer application, and other practices affected by the crop calendar.

In this same vein, the launch of Ethiopia's National Framework for Climate Services (NFCS), an institutional mechanism to coordinate, facilitate and strengthen collaboration among national institutions to improve the co-production, tailoring, delivery and use of science-based climate predictions and services, has been paramount in institutionalizing and sustaining the actions necessitated by the four pillars just described.

Discussion and future directions

Even when researchers or meteorological agencies strive to produce the best-available information that users need, significant barriers may still remain that inhibit that "useful" information from actually being both "usable" and "used" (McNie, 2013; Vincent et al., 2018; Grossi and Dinku, 2022). The way theoretically useful information is developed (generated) and then transformed into decision-relevant knowledge (translated), communicated to users (transferred), the degree to which the user has the capacity to actually understand and act on the information, and the enabling environment and how well this information is integrated within national systems, processes, policies, and plans (use) all affect whether and the degree to which information actually enables climate adaptation.

In Ethiopia, even where there is a strong national meteorological service producing high-quality historical, monitoring, and forecast data, actions to ensure this information is freely accessible, broadly disseminated in various formats, tailored to user needs, and coupled with foundational capacity building have been essential in transitioning climate data to climate information and ultimately climate services that meet the needs of decision-makers at multiple levels. Those seeking to implement climate services in similar contexts where a strong meteorological service has not resulted in similarly strong climate-informed decision-making on the ground, therefore, should take special heed of and learn from the lessons already outlined in this paper, as well as those summarized below:

- **When working to advance climate services within a particular country or context, ensure the partnership strategy reflects each component of a holistic climate services framework.** In other words, partners should include the full spectrum of actors, ministries, or organizations working to generate, translate, transfer, and promote use of climate services. Working myopically with actors or institutions who only work on one or some of these aspects without bringing them together with others along the spectrum of the climate services pillars will likely result in climate services that may be useful or usable, but not ultimately used in practice.
- **While different institutions may have different roles along the climate services framework, one should strive to create spaces for sustained and iterative interactions between and amongst them. Policy can be an efficient way of doing this.** In promoting interactions between producers and users of climate information, for example, the NFCS as a policy framework has been and can be an important mechanism for systematizing, institutionalizing, formalizing, or even initiating interactions between climate information generators and various sectoral communities that may have only occurred on an *ad hoc* basis (or not at all) in the past. In this same way, it can align expectations on the mandates and roles of different institutions in advancing climate services within a country, and create a positive enabling environment for inclusivity in these efforts.
- **When undertaking the co-production process, it is not always necessary to start from scratch, and the process to identify and co-develop new products can be informed and benefit from capacity building on existing products.** With EMI and its users, for example, especially those who have been historically underserved with climate services such as those in the pastoral or nutrition sectors, users may suffer from the "you don't know what you don't know" paradox, whereby they may have difficulty articulating their needs if they are unaware of what is feasible or even already existing in the technological realm. Demonstrating existing products within the country or even elsewhere can serve as an important reference and jumping-off-point for discussion on co-developing and adapting new tools for various users. For instance, training and demonstration on EMI's Agriculture Maproom to agricultural experts and having participants work with its different components led to their realization that a new Maproom tool to determine crop suitability using rainfall and temperature thresholds was needed and would be useful in their work.
- **Climate services should be well-integrated within knowledge systems and leverage educational infrastructure—both formal and informal– where possible.** As described earlier, the ACToday approach in Ethiopia advanced the co-development of both climate risk management curricula and short training courses targeting agricultural experts and extension staff, university students and researchers, NGOs, disaster risk management staff, and EMI itself to promote the use of climate information (the use pillar). Rather than one-off trainings at these various institutions, the approach was mindful to design for and embed the co-produced curricula within existing educational ecosystems and architecture, such as university structures and the ATVET program (formal) and short in-service trainings (informal), to ensure outcomes and capacity building could be sustained and scaled in the long-term. Moreover, the training and curricular efforts were designed not in isolation but to strengthen relationships and connections between capacity building target groups. Those trained in climate risk management at the university level doing studies in climate-sensitive topics such as agriculture or natural resource management, for example, may go on to work within the extension system as subject matter specialists guiding the development agents who work most closely with farmers at the local level or even the National Disaster Risk Management Commission (NDRMC), the main government agency dealing with all food security and disaster warning activities in Ethiopia. Capacity building strategies should therefore consider how informal and formal educational architecture can be leveraged to sustain the development of knowledge and skills to use climate services in the long-run, but also bear in mind how these informal and formal systems might

reinforce, build upon, or otherwise interact with each other to maximize learning and impact.

- **Look before you leap when engaging with user communities.** In seeking to co-identify useful climate information and services, bear in mind that there may be pre-existing programming, experiences, and relationships that can be leveraged. In Ethiopia, there is a long history of engagement with the EMI and various users from the NDRMC, MoA, and elsewhere. Additionally, longstanding research programs such as CCAFS have heavily shaped and gained experiences and valuable lessons from implementation of climate services both in Ethiopia and the wider continent. Consultation with such stakeholders regarding past efforts to co-identify and co-prioritize climate services needs with users can prevent redundant efforts and wasting of resources that can be used elsewhere along the pillars of producing effective climate services.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

AG wrote the first draft of the manuscript. TD provided review as the leader of the ACToday project in Ethiopia. Both authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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