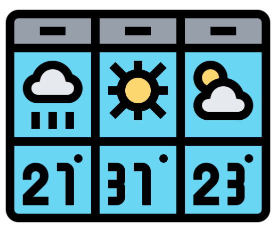
Opportunities to increase relevance of climate services for farmers

What are climate services?

Climate services describes the way in which climate information is created, transferred and used in climate-informed decision making, policy and planning.

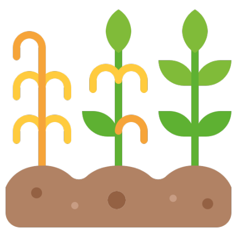
In agriculture, climate- informed decision making is particularly important because of the looming risks to food security posed by the climate crisis.

These include:



weather & climate data

information exchange between farmers and other collaborators



input goods for a farm (crop types/varieties)

How are climate services utilized by farmers?

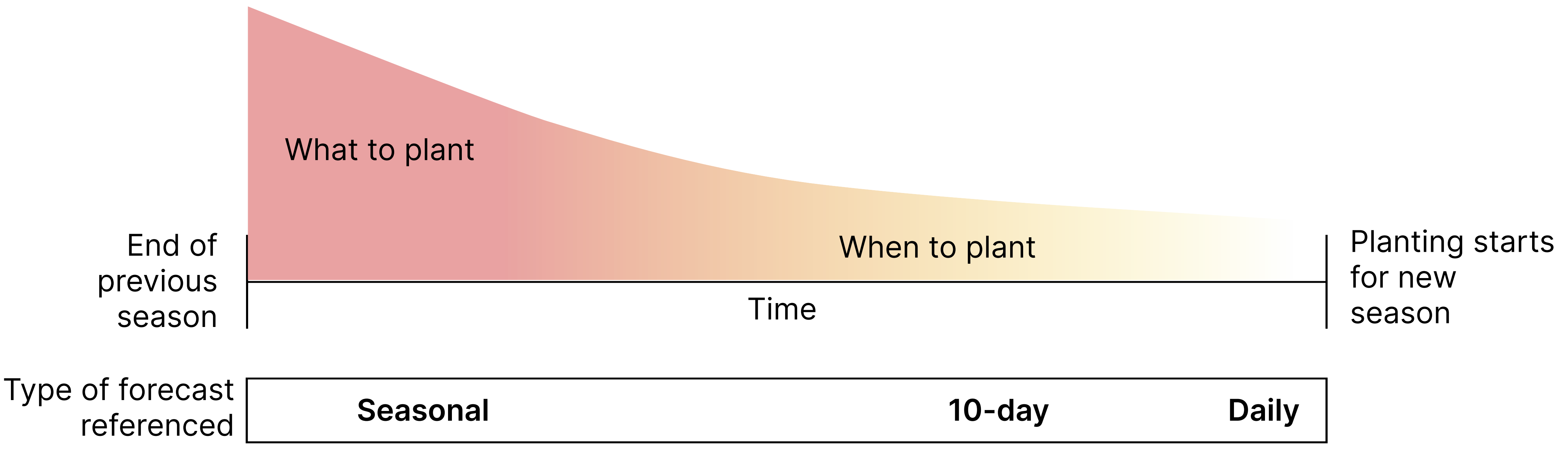
1 **At early stages of season planning, there are more decisions that must be made, and decisions that are more critical to economic outcomes for the farmer.**

eg. Crop type, crop variety, quantity of fertilizer to purchase

2 **Leading up to the beginning of the season, farmers rely on more near-term forecasts (weeks, days) to decide when to plant, to maximize yield.**

3 **Once the crop is in the ground, farmers rely on near-term forecasts to adjust on-farm management activities.**

eg. Irrigation, harvest date, extreme weather event preparation and management



Areas of opportunity

More localized information is needed to ensure services are relevant for farmer's needs.

This comes with scaling down spatial data and developing stronger capabilities for daily-to-seasonal weather information.

Recommendations

Up-front investment in understanding and meeting farmer's needs

Research at community scales will help capture specific needs that come from unique geographic, crop-specific and individual farmer circumstances.

Measure and evaluate climate service programs

Develop measures for service delivery to track farmer's perception, behavior and economic changes as a way to evaluate relevance.

Visual Abstract by Maya Korb for MLWS 2022
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Executive Summary

Climate services are the provision of information to support decision-making. Within the agriculture industry, climate services can offer farmers better resources to prepare for or respond to climate variability. These services take many forms including data, in-person collaboration, and evidence-based recommendations.

This report presents a review of the current state of global climate services to deliver relevant information for use on the farm. In doing so, it also provides an overview of the current challenges to meet farmers' needs that exist with both climate data and the explicit recommendations that come from climate service providers.

The data collected for this project was obtained by a literature review of global sources to understand what climate services recommendations can be used to address these outstanding challenges, utilizing research and implementation approaches from around the world.

In summary, the findings of this research suggest a push towards greater investment in localized climate service operations, which allow climate services providers to better deliver information for more narrow time scales and spatial scales. These localized climate services are more tailored to local communities or specific farmers' needs. These investments could also provide opportunities for farmers to collect their own weather data for more specific forecasts. Furthermore, this report recommends that climate service providers focus on supporting farmers through variable weather events throughout the season through stronger knowledge transfer approaches, which allow farmers to understand potential sources of uncertainty using these recommendations.

Insights from the evaluation of climate services can help support local decision-making – on the farm, within a community and in policy.

Introduction

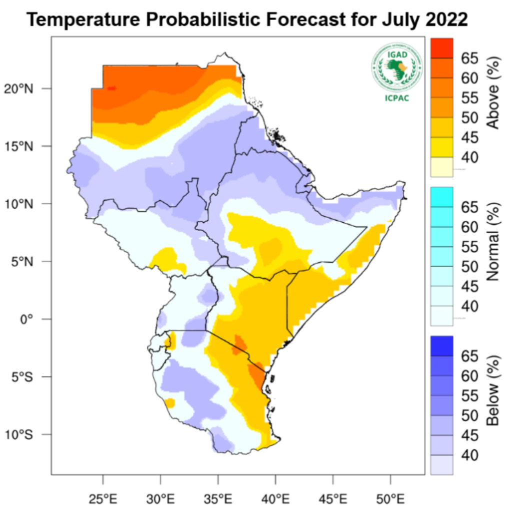
Overview

A recent study from the National Aeronautics and Space Administration (NASA) determined that climate impacts to several main crop producing regions around the globe will be felt by 2040 (Jägermeyr et al., 2021). But a more urgent report seems to be coming out of the field, both in the intensity and frequency of extreme climatic events. For example, in the summer of 2021, the British Columbia Fruit Grower Associate estimated that 50-70% of the cherry crop was damaged in the extreme heat wave which occurred between June 25 and July 1 (Gomez, 2021). The intensification and frequency of the extreme climatic events being reported around the world highlights an immediate need for robust climate services to be implemented to prevent losses in food production which threaten food security at all scales.

Climate services is a term that generally describes the way in which climate information is created, transferred and used in climate-informed decision-making, policy and planning (Climate Services for Farmers, (n.d.)). The intended use of climate services is what makes them distinct from climate information. Climate information is developed with the goal of extending our understanding of climate systems, while climate services are designed by public or private institutions with the intention of serving its user's needs, which broadly focus on actions that can manage climate-related risks, including those in agriculture (Nkiaka, 2019; Vaughan & Dessai, 2014). The advancement of these services, which include climate data, direct recommendations as well as plans for mitigation, adaptation and disaster risk reduction, is critical to how society understands and reacts to the climate crisis by building resilience for farmers to better adapt to climate change.

A climate service can be anything that communicates climate information in a way that assists with decision-making (Hewitt et al., 2012). The development of these services allow for scientific information, which forecasts environmental conditions at different future time scales, to be shared, translated and utilized by farmers to make the best decisions for their farm. Considering this broad definition, climate services can take many forms. They can be simple maps or tables, specific farming recommendations that have already factored in the climate information, or even educational resources that allow farmers to build their own capacity to generate evidence-based decisions. Two different examples are provided in Figure 1.

Figure 1: Two different climate services for agriculture. A precipitation forecast for July 2022 in Eastern Africa (left) and an advisory in Northern Ethiopia of expected conditions and recommended farm-management practices based on forecasts (right).
Source: IGAD Climate Prediction and Applications Center (ICPAC), Summary for Decision Makers Seasonal Forecast Report, June-September 2022



Agriculture and Food Security

JJAS, locally known as Kiremt, is the main cropping season in many parts of central and northern Ethiopia. Enhanced rains together with the forecasted early onset is good for early planting. However, enhanced rains might result into flooding and waterlogging of farmlands, soil erosion incidences, increased crop diseases due to increased moisture, and high weed infestation.

Advisory

- Undertake early land preparation and planting.
- Rehabilitate the drainage structures to ease water logging issues.
- Undertake appropriate soil management practices especially in mountainous regions e.g. terracing.
- Mobilize plant protection teams to be ready for any pest and disease outbreaks.
- Undertake timely weeding.

The effects of climate change on agriculture

Climate services are being developed for every sector, but are arguably the most advanced in agriculture due to their explicit link between weather and climatological factors, such as rainfall and temperature, two factors that drove farmers and others concerned with crop production to observe, understand and respond to these conditions for centuries (Vaughan et al., 2018).

The report by the Intergovernmental Panel on Climate Change (IPCC) on food security concluded that climate change is already threatening food security as agricultural production is reduced, which has knock-on effects to food access and stability of food supplies (FAO, 2008). Knock-on effects to food security arise from the observed and expected increase in temperature over time, changing precipitation patterns, and a greater frequency and duration of extreme weather events (IPCC, 2019a). This can manifest as the shift in the suitability of crops for a given area and the presence of pests and disease in agriculture (FAO, 2008).

The impacts of climate change on agriculture are not uniform across the world, which adds to the complexity of developing generalized climate services. For instance, countries in temperate regions, like Canada, are expected to generally see an increase in food production capabilities, while countries along the equator are expected to see a decline. This has huge ramifications on economic development, and will further exacerbate the Global North and Global South divide. Even at a subnational scale, climate impacts will be felt unequally based on the type of unique environmental risk the area falls under, social dynamics and the associated adaptation strategies (Islam & Winkel, 2017).

The effects of climate change on farmers

Given the variable impact of climate change by region, certain farmers are also more vulnerable to climate impacts than others. The greatest concern is for small farmers, who have fewer resources and safety nets to respond to extreme weather events. The definition of small-scale farming varies by country and considers either land area or economic profits per year. In Canada, small scale farms are operations under 130 acres in size (Statistics Canada, 2022; Soubry et al., 2020). Climate services are growing in importance as more and more small farmers are being replaced by larger scale operations. Climate change operates as a threat multiplier to remaining small operations and their survival is contingent on being able to produce enough crops to make a living. As a result, services that allow farmers to adapt to these threats are critical to the long-term viability of small scale farming.

Other factors are also worth considering when assessing additional factors that contribute to a farm’s vulnerability to climate threats. For example, farmer age may be a concern: British Columbia has on average the oldest farmers among all provinces in Canada (Statistics Canada, 2017). This introduces risk in the preservation of small scale operations as more farmers near retirement. All farmers are familiar with managing risk that comes with variable weather conditions, but the increase of extreme variability that comes with climate change puts farmers in a far more precarious position to have to adapt for economic gain and global production needs (Crane et al., 2011).

The legacy of agriculture and extension services

It is also worth noting that agriculture is not only affected by climate change, but it is a major contributor. Agriculture contributes to roughly 20% of total global greenhouse gas emissions (FAO, 2008). These come largely from the production of methane, nitrous oxide and carbon dioxide from the cultivation of certain crops like rice or livestock production and management, application of fertilizers, and the clearing of forests for agricultural land (FAO, 2008).

Traditional agricultural services, such as agriculture extension, have generally been used as a means to increase production since The Green Revolution in the 1960’s (Danso-Abbeam et al., 2018). This has involved the sidelining of farmers' knowledge in favor of formal knowledge structures. Extension, through its traditional mode of “top down” delivery, has a legacy of enforcing an epistemological hierarchy which positions Western science at the center of identifying and solving all agricultural problems (Anderson et al., 2006). In these contexts, extension fails to legitimize local and informal knowledge systems. This approach also threatens to undermine what should be the central goal of extension by failing to seek out and include farmers and their needs in the service design. This critique is well-recognized among the literature, and countless publications have focused on ways to design more inclusive agriculture service programs (Dillings & Lemos, 2011; Vaughan & Dessai, 2014; Vincent et al., 2018) Additionally, these services are being used to promote the adoption of more sustainable farming practices.

Despite these conditions, the IPCC outlines that designing and developing climate services is among one of the best near-term actions every government, region or community can take to manage and adapt to the risks that climate change poses to agricultural production (IPCC, 2019b).

Goals of this report

There is a need to assess how climate services are designed and delivered to small farmers by looking at the nature of climate information, such as forecasts, and how they are utilized by farmers. This report examines the nature and uptake of climate services by looking at how information is created for farmers to adapt to climate events. In short, it evaluates what climate services exist, and how relevant they are for farmers based on their decision-making. This report identifies potential reasons through which relevance (also referred to as uptake) is lost, focusing particularly on scaling issues. Due to its focus on tailoring climate services to specific needs, this project is directed to policy and decision makers at local and regional scales which can support the development of more relevant and specific adaptation strategies.

Methods

Objectives

The objectives of this project are to:

1. Conduct a global review the current state of climate services in agriculture and evaluate the relevance of climate services in agriculture at different spatial and temporal scales based on the decisions made by farmers, identifying strengths and gaps within the existing inventory
2. Provide recommendations to strengthen climate service development and delivery to improve relevance for decision-making by farmers

Approach

The data collected for this project was obtained using a literature review. This approach was selected because the project objectives focus largely on synthesizing and critically reviewing the existing research field. In this way, this methodology can address the research objectives of the project “with a power that no single study has” by integrating findings and perspectives from a variety of empirical studies and gray literature – policy literature, working papers etc. (Snyder, 2019).

This approach is also relevant for the topic of climate services given that both existing theory and applied work is arguably housed equally among academia, public institutions and the private sector. Finally, there is growing interest in the centralization of the design and development of climate services indicated by the establishment of a number of programs, including the Global Framework for Climate Services by the World Meteorological Organization in 2012 (Vaughan & Dessai, 2014). This report aims to contribute to that effort, through the evaluation of existing climate services across scales.

Sources within the literature review were collected and evaluated in a systematic way. Google Scholar and the University of British Columbia library were the primary repositories utilized. Examples of keywords for source identification included: “climate services in agriculture” and “farmer decision-making” for different scales, such as:

1. Temporal scales: “daily”, “dekadal (10-day precipitation forecast)”, “short-term”, “seasonal”, “long-term”
2. Spatial scales: “farm-level”, “national”, “regional”, and “global”

Sources were evaluated based on date of publication, publication journal or organization and the inclusion of data which considered the outcomes achieved by farmers. Weight was given to publications within the last decade to favor sources that rely on more current forecasting technologies and evidence on the impact of climate change on agriculture. Publications retrieved from the libraries largely came from the World Meteorological Organization, CGIAR’s Climate Services and Safety program, the International Research Institute for Climate and Society (IRI), the journal of Climate Services and the American Meteorological Society, given their prominence in the field. Finally, the contents of the literature were evaluated to identify how climate services were designed and deployed, as well as the impact they have on outcomes for farmers, by way of the decisions they make. This was important to ensure that the relevance of the certain services for farmers could be considered, as their outcomes are what climates services in agriculture are primarily intended to be designed around.

The literature review led to the development of a risk assessment for narrowing temporal scales that climate services are developed at. This offered an overview of how services are developed and deployed at different scales, and where challenges and opportunities exist as contexts become more specific for farm use. This report also draws on specific case studies from around the world to demonstrate practical examples of conditions, challenges and potential responses to climate issues that can affect farmers. From here, the report provides a set of recommendations to address these outstanding challenges, utilizing research and implementation approaches from around the world.

Results and Discussion

The development of the theory and framework of high quality climate services necessitates that these services must be relevant for their “end-users". As mentioned, climate service users can include policy makers, engineers, researchers, farmers and the general public (Nkiaka et al., 2019). Despite the various interest groups listed, there is consensus within the literature that climate services must be salient, legitimate, and accessible (Climate Services for Farmers (n.d.); Brasseur, 2016).

This report will deal largely with the issue of evaluating relevance of information, making sure that information is timely, specific and therefore useful for farmers specifically. This involves bridging the gap between scientific information and on-farm application.

To meet the objectives of the report, the following questions were presented as a means to understand the state of current climate services, and to identify strengths and gaps within their capacity to deliver salient information to farmers:

1. What data sources and variables are relied upon?
2. What temporal scales for climate information are available?
3. What spatial scales of climate information are available?

All questions were considered whether or not the existing technologies met the needs of the farmer, indicated by perceived accuracy, adoption of corresponding behaviors or decisions, and other measures noted in the literature.

The central variable considered here is farmer certainty in potential decisions that come from the climate information. This is what empowers farmers to adopt new strategic decisions or practices on their farm in an effort to avoid yield losses (Naab et al., 2019). Decisions with higher certainty are generally those that farmers are used to making, have shorter lead times to react to, and are based on familiar information sources. For example, farmers may generally practice utilizing 1-3 day weather forecasts to determine when to apply fertilizer or to irrigate (Sarku et al., 2022).

The area of greatest interest among climate service producers is creating information that prompts adaptive decisions. These decisions are considered ones that are strategic for the season. They may be less frequent practice by the farmer throughout the season, but needed to adapt their farm to the more frequent and extreme climatic events affecting the growing season. In terms of user needs, this type of decision is considered to be the highest priority based on lack of information availability and expressed demand by farmers.

Finally, services produced with information sources at large scales (global and with long lead times) have low perceived certainty. Decision-making is also expected to occur further from the present time for farmers. This can include the transition to entirely different crops and land uses (Meinke & Stone, 2005). For this reason, farmers are less inclined to act, and this is often a domain for other interest groups, such as researchers or policymakers, to get involved.

According to one study, “current forecast products generally lack the spatial, temporal and element specificity that users seek for their particular decision-making needs” in that “forecasts are generally made for 3-month seasons, large regions over 1,000 km in width, and mean temperature and precipitation totals only” (Sun & Ward 2007). The subsequent sections will explore this claim and future opportunities by assessing the existing capacities from different data, at different scales.

Weather and Climate

It is worth noting the distinction between climate and weather, and the respective services associated with each for farmers. Weather describes an environmental condition (eg. temperature, precipitation, wind speed) at a given time (Tall et al., 2014). Weather data is forward looking, generally focused days to a couple of weeks out (Edwards, 2013). Climate is a “statistical characterization” of weather (Moore et al,. 2010). It is produced by pulling together averages, variability and extremes of high quality historical weather data along with projections of how greenhouse gasses, introduced through human activity, can affect climate. Climate forecasting is becoming increasingly more relevant for decision-making because it considers both natural and anthropogenic influences that have been proven to result in climate variability (Salinger et al., 2005) In other words, a climate service utilizes data from past contexts to interpret current or expected conditions, while a weather service relies on the characteristics of specific phenomena (Mason et al., 2022). Climate and weather consider similar environmental variables like precipitation or temperature, but have distinct functional purposes, priorities and utilize different data sources (Edwards, 2013). Both are relevant within agriculture, because they also consider different time scales which farmers must utilize for management decisions.

Weather services provide farmers information that can help with quick, logistical information such as adjusting irrigation schedules based on expected precipitation within hours to days. Transitioning from weather services to climate services, more communication transfer issues arise as information becomes more uncertain and therefore more challenging for farmers to use, considering their specific farm contexts (Hansen et al., 2014). These services are produced through the translation of climate data into practical insights and management recommendations that can help farmers make agricultural decisions.

It is also clear that decision-making on the farm is complex, and farmers often rely on a number of different factors to make a decision. In comparison to short and medium term weather forecasting, seasonal or interannual climate forecasting is relied upon less by farmers. This is because of the perceived uncertainty of the forecasts and the lack of data translation offered for on-farm use (WMO, 2019). These uncertainties are from the natural climate variability, climate model inaccuracies and varying estimates of future greenhouse gas emissions (Charron, 2016).

Still, short-term weather data comes with its own limitations. More and more farmers in North America are seeking on-farm technologies for daily weather forecasts in an effort to obtain specific and accurate data for the conditions expected on their farm (Pierce & Elliot, 2008). This comes as a result of existing weather services being designed for the general public, and lacking the hyperlocal specificity that farmers seek.

Temporal Scales

Generally, farmers have relied upon a combination of long-term weather forecasts (such as The Farmer's Almanac) and short-term weather forecasts that predict the weather on the scale of hours to a few days. The former offers information to support pre-season planning while the latter provides the support for more immediate decisions throughout the season, such as the quantity and schedule or fertilizer or water applied to an area of land on the farm.

There has been a big push among researchers to develop and assess the potential of seasonal climate forecasts for decision-making or disaster management. Seasonal forecasts lack a shared definition of a timescale, but generally cover information 1-12 months out (Goddard et al., 2011). This ambiguity has to do with the variability of season length based on location and crop, but are generally reported or updated on a monthly cadence. These forecasts can offer value to farmers through the introduction of timely information on probabilistic season conditions, which can inform key decisions early in the farming season such as what to plant and when to start sowing (An-Vo et al., 2021; Born et al., 2021). They also introduce the potential for longer lead times for farmers to prepare for extreme weather events such as a heatwave, which may help minimize the damage to their crop under those conditions. These forecasts can help farmers determine what to plant and when, and put together a strategy to deal with these events through the investment or collection in other resources. For example, a delayed rainfall during a season can result in a lag time in crop growth for rainfed agriculture, which introduces the risk of the crop running into dry season conditions that may compromise yield as well as delay planting of the next crop (Naylor et al., 2001). To adapt, farmers may choose to opt for drought or heat tolerant crops, crops with shorter growing times, or crops that come with better insurance or government support (Crane et al. 2010). Research has shown that even without 100% accurate seasonal climate forecasts, utilizing these forecasts over historical climate averages resulted in higher agricultural productivity (An-Vo et al., 2021).

Uptake of seasonal climate forecasts is still low for two main reasons. The first reason is due to the current forecast quality, specificity and reliability. Climate variability predictions vary from the actual observed conditions measured throughout the season. The longer time scale also means that evaluation of forecasts can only happen as frequently as the growing season. The second reason is due to how information is communicated. Seasonal predictions are probabilistic, and the way in which they are communicated is often through these probabilities. For instance, a report may indicate that there is an equal likelihood of above normal, normal or below normal rainfall (33% likelihood for each outcome). While reliable, this information is not useful to farmers who are seeking greater certainty on the expected conditions to use for decision-making (Haines, 2019). Consequently, use of these forecasts is low.

Spatial Scales

To fully understand the context around which the shortcomings through which climate services exist, there is value in understanding the origin of climate services. Climate services are historically housed in national and international meteorological institutions, which serve as data and service providers. This origin, while important for centralizing and consolidating information for use at large scales, holds the consequence that service providers produce forecasts for a number of industries or uses, outside of agriculture. This means the data is "uncorrelated to specific societal challenges and decisions", thereby limiting the relevance for users (Lourenço et al. 2016, p.14). Additionally, the growing private sector involvement in the field, coupled with the increased availability of data, skews development away from user's needs. Instead, more focus is given to issues of data quality and advancement of forecasting models (Borns et al., 2021). While important, the benefits brought about by these improvements will be limited without the relevance introduced by a user-centered approach.

Considering that most climate services were built out of existing national or international agencies, it is also important to assess how various spatial scales impact relevance for farming. As an alternative to these "top-down" approaches and their associated challenges, several "bottom-up" strategies have emerged incorporating social dimensions to the scientific research on climate and adaptation needs (Brasseur & Gallardo, 2016). Smaller organizations can facilitate this approach, but reporting is largely published through academic and research facilities. These programs are distinct because of their interdisciplinary nature, where social science research questions, methods and analysis can be relied on as well to understand user needs and build programs as a direct response to and in partnership with farmers.

There are numerous case studies of these efforts. One example is the Climate Forecasting for Agricultural Resources project in Burkina Faso. It housed a series of program initiatives where farmers were interviewed directly, collaborated with other farmers to develop response plans, and helped manage rainfall data collection to feed back to the national meteorological service (Tall et al., 2014). This research resulted in contextual findings, like an understanding that radio messaging is an effective way to reach farmers and support to understand probabilistic forecasts is best done in person. This format also allowed for program feedback from farmers to enhance the delivery of climate services.

These approaches are considered to be among the best in ensuring relevance for farmers when considering natural dynamics as well, This is because the land use or landscape at the regional or watershed scales change the types of risks that farmers are likely to be exposed to, which can get lost at national or international service scales. For example, if a farm is located in an area where irrigation water is sourced from surface water originating from snowmelt or glaciers, the farm is likely to be at a risk of insufficient water during the growing season (Pons et al., 2021). Similarly, a farm near a large urban area may be at risk of limited water supply and poor water quality due to the number of impervious surfaces resulting in runoff and urban contaminants, respectively. Consequently, it is not enough to focus exclusively on delivering climate or weather information, climate services must consider information that is relevant to the context the farm is situated in to be effective. This can be offered through close partnership with farmers or other local stakeholders to allow large scale service providers to produce high quality, high resolution recommendations.

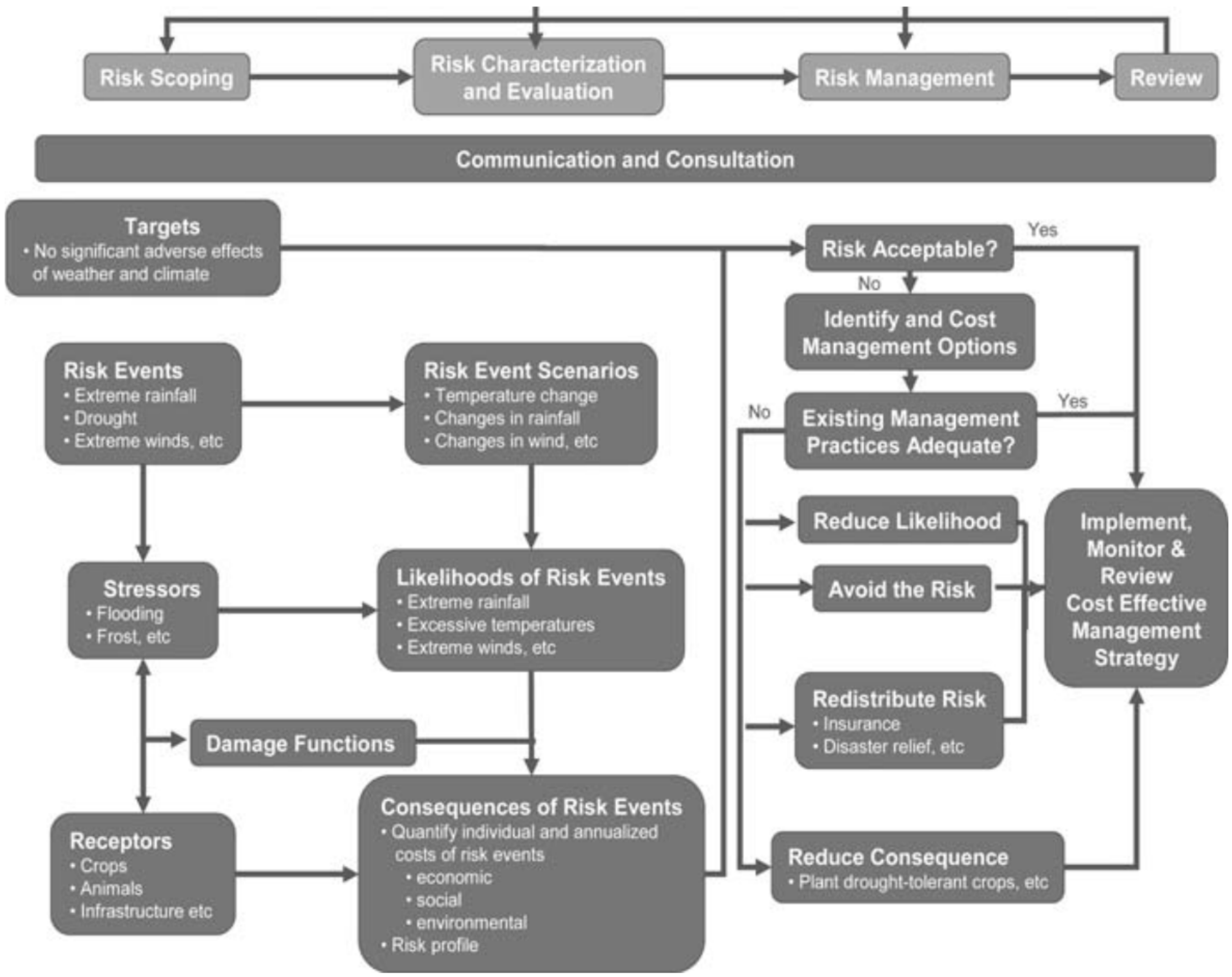
Scaling these services to meet farmer’s needs around a region or country is challenging given the limited funding or buy-in from stakeholders on the ground such as extension officers, NGOs, media and private industry. The best chance of preserving and expanding climate services in this way is through the uptake and leadership by national institutions, such as national meteorological or agriculture departments (Miles et al., 2006). Again, this requires funding by governments of international organizations.

Assessment of Responses to Risk

Considering the barriers these scaling issues bring to the relevance of climate information for farm use, it is also worth outlining what risk management approaches exist within the climate service inventory. In this case, the perspective of risk considers not only the magnitude of the extreme event, but the duration and timing of the event as well. For example, high temperatures can damage crops in early stages of growth, even for short periods of time (Shah et al., 2021). Recommendations that come from an understanding of these events and their probability of occurrence have the potential to offer farmer's timely information to change planning or practices based on the nature of the extreme event.

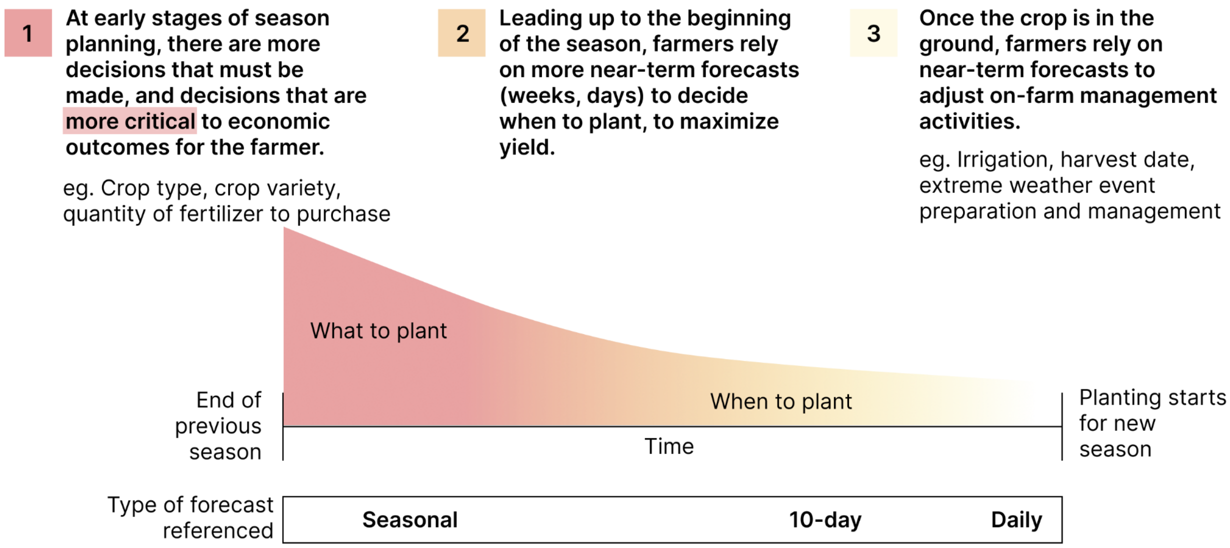
The approach of assessing and including risk management strategies was adapted from the procedures outlined by John Hay in the book "Managing Weather And Climate Risks" (see Figure 2). It involves understanding what the magnitude and frequency of the weather event will be, the associated consequences, and a set of evaluators to assess the acceptability of risk before implementing management practices.

Figure 2: Procedures for characterizing risks, and their application to the agriculture sector. Source: Extreme weather and climate events, and farming risks (Hay, 2007)



These recommendations are also categorized by lead time, which is the time between when a forecast is provided and when a farmer acts on the information from the forecast (Nyamekye et al., 2021). This categorization was selected in order to consider the limited flexibility farmers have as they transition from preparing for the growing season to once the crop is planted (see Figure 3). Aside from having sufficient time to act, associated costs to react are an important consideration when considering feasibility and relevance of the recommendation. This is not included in the scope of this risk assessment, as it is highly dependent on the specific farm's existing infrastructure, capacity and location. These adaptive practices, as a response to weather and climate events, are also considered climate services which offer direct recommendations for farmers to consider for their own use.

Figure 3: Decision-making by farmers leading up to a new season.



Risk assessment is a challenge because of the temporal, spatial and data types outlined above, which limit certainty around decision-making during time periods farmers need to make decisions. For instance, farmers must prepare for the upcoming season months in advance, ordering seeds, fertilizer and other raw materials. To make these decisions, farmers rely on seasonal forecasts to get a sense of the general conditions of the upcoming growing season, and plan what varieties of crops they may plant. For instance, if a particularly hot, dry season is expected, farmers may opt for crops that are more drought tolerant or shorter cycle varieties (see Table 1). These decisions have longer lead times before the outcomes of these decisions can be assessed based on the observed weather during the season, and therefore comes with more risk and uncertainty. These decisions are important because, unlike other decisions on the farm, they are fixed once the crop is selected.

Table 1: Risks and potential responses highlighted through seasonal forecasts.

Type of forecast	Forecast description		Response: Immediate action	Response: Preparation
Seasonal (months)	Temperature	Delayed temperature increase at the beginning of the growing season	Utilize daily/weekly forecasts	Delay planting
		Early temperature increase at the beginning of the growing season	Utilize daily/weekly forecasts	Plant early/staggered planting
		Below average seasonal temperature	-	Select crops that withstand lower temperatures
		Above average seasonal temperature	-	Plant deeper, Plan to harvest earlier, Water harvesting/storage, Select crops that withstand higher temperatures
		Below average temperature at the end of the growing season	-	
		Above average temperature at the end of the growing season	-	
	Precipitation	Early rain at the beginning of the growing season	-	Plant early/staggered planting
		Delayed rain at the beginning of the growing season	-	Delay planting
		Below average seasonal rain	-	Select more drought tolerant variety/crops
		Above average seasonal rain	-	Select more water tolerant variety/crops
	Wind	High wind	-	No/Low till, Plant crops deeper

Data from Europe shows that the likelihood of two extreme weather events per season is now six times more likely in the most severe projections, compared to the baseline (Shah et al, 2021; Trnka et al, 2014). This illustrates the importance of having reliable forecasts with long lead times, so farmers can plan strategically to avoid the full extent of these events.

The second most critical decision beyond crop selection is determining planting dates (Crane et al., 2011). This can only be determined within weeks and days leading up to the start of the season, as farmers look at the first set of weeks and days of the season to determine whether conditions are ideal (see Table 2, Table 3). This timeframe is critical as it will be when the crop is most vulnerable. Once planting or sowing has begun, responses and decisions with respect to risk are more reactive. Farmers utilize information from weather forecasts to adjust nutrient and water inputs or other land management practices.

Table 2: Risks and potential responses highlighted through 10-day forecasts

Type of forecast	Forecast description		Response	
			Immediate action	Preparation
10-day	Temperature	Delayed temperature increase at the beginning of the growing season, over several days/weeks	Delay planting	-
		Early temperature increase at the beginning of the growing season, over several days/weeks	Plant early/staggered planting	-
		Extreme heat expected during the growing season	Irrigation	Water harvesting/storage
		Higher temperature at the end of the growing season	Irrigation, Harvest early	

		Lower temperature at the end of the growing season	-	-
	Precipitation	Early rain at the beginning of the growing season	Look at consecutive dekads (10-day) Delay planting if rain continues for several dekads (10-day)	
		Delayed rain at the beginning of the growing season	Delay planting, Irrigation	-
		Above average rain during end of growing season	Harvest early if mature or apply pesticides to avoid damage from pests/disease	-
		Below average rain during end of growing season	-	-

Table 3: Risks and potential responses highlighted through daily forecasts

Type of forecast	Forecast description		Response	
			Immediate action	Preparation
Daily	Temperature	Extreme cold expected in early growth	Delay planting	-
		Extreme heat	Irrigation	-
	Precipitation	Extreme drought during growing season	Irrigation	-
		Extreme rain during growing season	Avoid fertilizer application	-

Conclusions

The WMO reports that “climate services investments overall have a cost benefit ratio of 10:1,” indicating that investment in current design and delivery improvements offer the best possible way to inform climate adaptation approaches (2019, p.4). In spite of this promising opportunity, there is a need for a global and coordinated effort in order to share learnings from unique contexts and conditions, as well as limit duplicated research or initiatives (Goddard et al., 2012). This must also be done while ensuring that the development of these programs put the utility and usability for farmers at the center of their initiatives. These centralized and localized needs which exist simultaneously should not be ranked, rather they must be prioritized equally given the opportunities each present. Recommendations of how to navigate these competing scale demands are offered below.

Recommendations

Countless studies have demonstrated the provision of climate services at more site specific scales can have meaningful effects on a farmer's ability to maximize crop production. This will require either downscaling efforts at an international and national scale, or a transition to more locally developed climate service infrastructure which take the form of bottom-up initiatives. Regardless, pursuing these local efforts is arguably the greatest challenge present to climate service providers. Two main hurdles include securing funding beyond proof of concept work and clearly demonstrating the value these services bring to small farmers through a localized approach. This paper's summary of existing literature reveals several opportunities for a way forward, listed below:

1. Up-front investment in understanding the farmer's needs. These will have to consider the distinct climatic conditions of the region, information farmers seek, and modes of delivery that fit farmer's expectations.
2. This project is a simplified overview of the dynamics of scale and climate information sources that are the basis of climate services. The main objective is to highlight opportunities to ensure relevance of user needs in climate service development, and to pull out persistent gaps found in the field around the world, regardless of crop, environmental conditions or the farmer's decision-making. However, user needs are complex and distinct so climate service providers should also rely on local case studies and insights when available.

3. An appropriate follow up to this project would be an evaluation of climate service delivery mechanisms among different contexts.
4. An evaluation framework should be developed by all climate service providers to track the perception, behavior and economic changes that come from the decision making supported by climate services. This should contain both qualitative and quantitative measures in order to demonstrate the value of bottom-up approaches over the status quo.

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