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Climate information services enhance farmers' resilience to climate change: Impacts on agricultural productivity

Seneshaw Tamru [a], James Hansen [b], Stephen Zebiak [b], Abonesh Tesfaye [c,*], Bart Minten [d], Teferi Demissie [c], Maren Radeny [c], Kindie Tesfaye [e], Dawit Solomon [c]

[a] International Growth Centre (IGC), Addis Ababa, Ethiopia
[b] International Research Institute for Climate and Society (IRI), NY, USA
[c] International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia
[d] International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia
[e] The International Maize and Wheat Improvement Center (CIMMYT), Addis Ababa, Ethiopia

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ABSTRACT

Ethiopia is a climate "hotspot" where the variable and changing climate periodically threatens agricultural production, food security, and human well-being. Using two-rounds of Feed the Future program survey data that cover 3,799 farming households in five major regions in Ethiopia, and employing panel data estimation methods, we analyze the potential impact of weather and climate services (WCS) on agricultural productivity and farmers' resilience in Ethiopia. We found that access to WCS increases the productivity of maize and wheat crops by 27 % and 17 %, respectively. These estimates are comparable to or higher than conventional yield-increasing production technologies such as fertilizer and improved seeds. Despite such a strong productivity effect, access to WCS is limited to only 18 % of the surveyed farmers. This study adds to the existing body of evidence on the significant positive impact of WCS, and affirms the importance of weather and climate information service products to enhance farmers' resilience to climate risk. Further analyses are needed to estimate the value to Ethiopia's smallholder farmers, especially those who are most vulnerable to climate-related hazards, of increasing investment in improving seasonal climate forecasts, mainstreaming weather and climate services in the agricultural extension system, including through National Framework for Climate Services (NFCS), and supporting farmer decision-making with climate-informed digital advisory tools and training.

1. Introduction

Agriculture is among the sectors most vulnerable to weather and climate risks (WMO, 2016). Reviews of the linkage between climate change and smallholder farmers (e.g., Phiiri et al., 2016) shows that unless strategic interventions are implemented, climate variability and extreme events will affect smallholder farmer's agricultural yields. Given the significant and growing yield gap to the global average for major food crops and food security in sub-Saharan Africa (SSA), the role of Climate-Smart Agriculture (CSA) in

* Corresponding author.
E-mail addresses: seni2y@yahoo.com (S. Tamru), jhansen@iri.columbia.edu (J. Hansen), steve@iri.columbia.edu (S. Zebiak), abonesh.tesfaye@gmail.com (A. Tesfaye), B.Minten@cgiar.org (B. Minten), T.Demissie@cgiar.org (T. Demissie), M.Radeny@cgiar.org (M. Radeny), k.tesfayefantaye@cgiar.org (K. Tesfaye), d.solomon@cgiar.org (D. Solomon).

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improving agricultural productivity is becoming increasingly important (Zougmoré et al., 2018). This is particularly relevant for SSA economies such as Ethiopia, whose heavily on subsistence and rainfed agriculture and pastoralism makes it highly vulnerable to climate impacts (FDRE, 2017). According to the Notre Dame Global Adaptation Initiative (ND-GAIN) 2022 country index,[1] Ethiopia's preparedness for climate risks falls at the median among 47 countries in SSA, and 155th out of 187 countries globally. Several studies (e.g., Shiferaw et al., 2014) have documented that extreme weather and rainfall variabilities have a considerable negative effect on agricultural productivity, GDP (e.g., Borgomeo et al., 2017), household welfare (e.g., Deressa and Hassan, 2009), and national economic output especially in agriculture (e.g., Lesk et al., 2016; Asfew and Bedemo, 2022).

Weather and Climate Services (WCS) are increasingly recognized as foundational for building resilience and adapting to the impacts of climate change on agriculture and other climate-sensitive sectors (Naab et al., 2019; Hansen et al., 2019). Effective use of weather and climate services, integrated with agrometeorological advisories, can reduce climate risks to farming communities, and provide them with well-adapted guidance on the management of agro-climatic resources at the local level (FAO, 2019). Public-sector support for WCS is strong in Ethiopia relative to much of SSA. The Ethiopian Meteorological Institute (EMI), the country's national meteorological service, produces localized weather and climate information tailored to agricultural needs. Ethiopia was the first country in SSA to produce operational seasonal climate forecasts. Ethiopia's National Framework for Climate Services in 2018 (NMA, 2021), aligned with the UN Global Framework for Climate Services (WMO, 2012), aims to support climate-sensitive sectors like agriculture, water resources, and health; and facilitate climate service development and delivery from federal to woreda levels.

A few empirical studies have shown relationships between WCS use for farm management, and crop productivity. In Burkina Faso, farmers with access to WCS obtained significantly higher cowpea yields than farmers in a control sample of villages without WCS access (Ouedraogo et al., 2023). In Senegal, Diouf et al. (2020) found that seasonal forecast use was associated with increased millet, sorghum and rice yields, but decreased maize and groundnut yields; and Chiputwa et al. (2022) found that weather and climate information supported by subnational multidisciplinary working groups increased the value of crop production. In Ghana, access to weather forecasts and training was associated with increased yam and maize yields (Anuga and Gordon, 2016). In Kenya, seasonal forecasts bundled with training and advisories, alone or in combination, were associated with increased maize yields (Rao et al., 2015). Weaker evidence of productivity impacts comes from ex-ante modelling studies (e.g., Hansen et al., 2009), and small-sample field plots that compare recommended and conventional agronomic practices (e.g., Tarchiani et al., 2018). Reviews of the available published evidence highlight substantial challenges to evaluating the impacts of WCS use for agriculture, including: self-selection bias due to differences between adopter and non-adopter populations, informal information sharing that makes it difficult to isolate a control sample without information access, the confounding influence of other interventions and service that interact with WCS, and the stochastic nature of climate which causes impacts to vary from year to year (Hansen et al., 2022; Tall et al., 2018; Vaughan et al., 2019).

There are few published empirical studies in Ethiopia, and none that capture the country's diversity. Our study aims to address the gap in quantitative evidence of the impacts of WCS across Ethiopia's heterogeneous agricultural environments and farming systems – needed to guide public investment in agricultural WCS in the face of competing demands. Using a representative panel data set and widely accepted methodology, we analyze the impact of WCS on productivity of major crops in Ethiopia: cereals, pulses, oilseeds, and coffee. Section two describes data and methodology used, Section three provides results and discussion. The last Section concludes with some policy implications.

2. Methodology

2.1. Data

To estimate the effect of WCS on outcome variables, we relied on a primary data from a large-scale survey implemented as part of a Feed the Future (FtF) Population-Based Survey (PBS), conducted by USAID/Ethiopia and the International Food Policy Research Institute (IFPRI). The survey was undertaken across four major administrative regions of Ethiopia (i.e., Amhara, Oromia, Tigray, and SNNP) (Fig. 1). In each region, zones[2] were selected based on USAID/Ethiopia's pre-identified so-called Zones of Influence (ZOI) covering 149 administrative woredas.[3] The USAID FtF program requires each country-level FtF Mission to concentrate its efforts in a defined area in order to measure impact. USAID/Ethiopia selected these ZOI for its 2013–2017 implementation activities based on: the level of need, potential for agricultural growth, partnership opportunities, other existing U.S. Government resources, and national priorities. Feed the Future in Ethiopia aimed to work across "drought prone," "moisture reliable" and "pastoral" agroecology (USAID, 2019).

Data were collected in three rounds (i.e., 2013, 2015, and 2018) for baseline (2013), midline (2015), and end-line surveys (2018). We have a total of 3,799 households for each survey round in 168 enumeration areas (EA). We collected data on WCS only in the 2018 end-line survey, as coordinated generation, translation, and dissemination of WCS for farmers only began in 2014 in Ethiopia. We had the opportunity to include a dedicated WCS section in the endline survey. The questions include: (i) household's access to weather and climate services, (ii) types of weather and climate services provided, (iii) frequency and timing of weather and climate services

[1] The ND-Gain Country Index summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience.

[2] The next administrative unit below regions.

[3] The next administrative unit below zones.

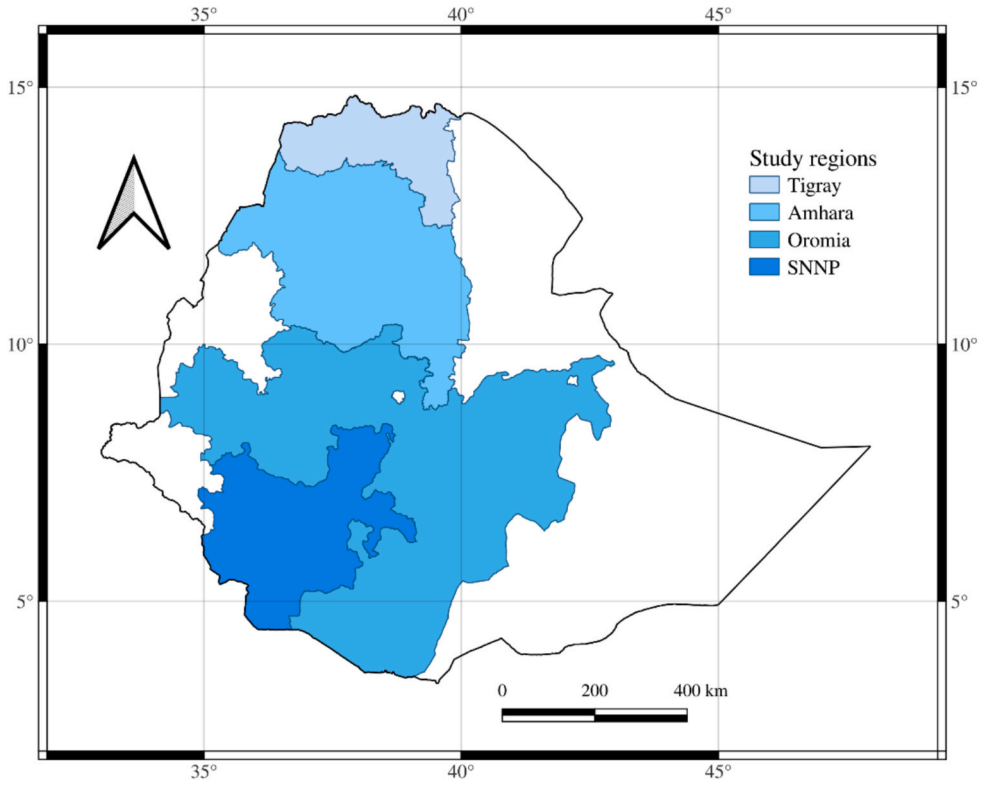

Fig. 1. Map of Ethiopia and study locations.

delivery, and (iv) any problems associated with the delivery of the services. The survey also provided data on other important variables such as household's socio-demographic characteristics, farming practices, use of labor (differentiated by age and gender groups) and production inputs (e.g., seed, fertilizer, chemical inputs), production practices (e.g., tilling, weeding, harvesting and technology adoption), marketing, and access to service centers. The households surveyed covered more than 55 different crop types ranging from major staple annual cereals (e.g., maize, *tef*, wheat, and sorghum) to perennial (e.g., coffee, fruits) crops. However, due to variations in the number of observations, our analysis focused on the four major crop types: cereals, pulses, oilseeds, and coffee. Among cereals, we focused our analysis on the most important staple crops, i.e., maize, tef, wheat, and sorghum. In this paper, we employed the baseline and end-line rounds.

2.2. Approach

To estimate the causal effect of accessing weather and climate services on crop productivity, we employed the panel data estimation method. The panel data analysis method takes advantage of both the cross-sectional and time-series aspects of the household data that were observed at different points in time. The underlying reason for using panel data lies in its effectiveness in allowing to examine the cause-and-effect relationship using before-and after observation. The Panel data analysis approach also helps minimize some of the bias resulting from unobserved heterogeneity (Wooldridge, 2006). Previous studies such as Amare et al. (2018), who modeled the impact of rainfall shocks on agricultural productivity also employed the panel data estimation approach.

The baseline and end-line survey results provided two rounds of panel data surveyed within five years, tracking the same household surveyed during the baseline survey. The dependent variables consist of farm productivity (yields) for the selected major staple groups (cereals, pulses, oilseeds, and coffee), including for the four important crops grown (tef, maize, wheat, and sorghum) in the country. Farm productivity is defined as the total output of crop production in kilograms per hectare. Having access to weather and climate services, our variable of interest, is a dummy variable that takes "1″ for households that receive WCS and "0″ for those who do not receive WCS.

To empirically test the hypothesis that exogenous WCS significantly affects crop yield, we use the following panel data estimation method:

$$Y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \varepsilon_{it} \quad (1)$$

where Y_{it} is household 'i's log crop production per hectare at time t. Our variable of interest (WCS) is denoted by x_1, and β_1 quantifies the impact of weather & climate services while β_2 captures the impact of other yield impacting controls, including agricultural input

use such as fertilizer, improved seed, agrochemical, and total labor. β_3 captures the effect of additional household characteristics (including the gender of the household head, age, head education, total asset, and whether the household is selected as a model farmer). The last term in Eq. (1) is a stochastic error term that captures the remaining sources of variation in farm productivity. When appropriate, we use fixed effects, random effects, and pooled data estimation methods. In fixed effect estimation, the error term consists of two components. The first part is individual heterogeneity which is not varying over time, and the second is some random shock to the yield function that is also unobserved by the household. In the estimation of the panel data model, controlling for the unobserved effect is important. Under certain circumstances, the fixed effect transformation is applied to eliminate the fixed unobserved effect.

The regression is done in a stepwise fashion. We initially estimate Eq. (1) without additional controls except for access to WCS. Then, we extend the specification through a stepwise inclusion of relevant covariates.

3. Results and discussion

3.1. Household characteristics of sample respondents

Table 1 compares household characteristics over the baseline (2013) and end line (2018). The average household size is slightly bigger (5.1) in the end-line relative to the average (4.8) in the baseline. We categorized years of schooling into three levels of education, as presented in Table 1. Within each category, the education variable shows the highest level of education achieved by the head of the household. The level of education is almost the same over the two rounds, with most household heads (about 64 %) with a primary level education. The share of male-headed households slightly declined from 73 % in 2013 to 71 % in 2018. Considerable improvement is observed in the value of the total household asset owned, which was more than triple over the 2013–2018 period. Looking at the change in land characteristics of the household over the two periods, the average farm size and the fertility of the soil

Table 1
Trend of household characteristics over the two-survey period.

Household Characteristics	2013	2018
Household size	4.8	5.1
HHH gender(1 = male)	73.0	71.0
HHH age	42.0	47.0
Education (percentage)		
Primary	64.2	64.6
Secondary	14.0	15.0
higher	1.8	1.8
Value of total asset (Birr)	916.0	3256.0
Total active labour (number)	2.4	2.5
Land characteristics		
Area(ha)	0.4	0.3
Plot distance(minutes)	11.7	16.0
Fertile soil(1 = yes)	74.7	67.5
flat land(1 = yes)	77.6	76.5
HH soil conservation(1 = yes)	43.3	44.1
Yield and input uses		
Yield (kg/ha)		
Maize	1662.7	2050.6
Teff	805.8	712.8
Wheat	1477.5	1699.3
Input uses		
total fertilizer(kg)	93.58	174.68
Improved seed use(1 = yes)	24.00	40.00
Agro-chemical(kg)	0.75	0.80
Total labor	10.71	8.29
Irrigation use(1 = yes)	1.03	1.00
Crop damage variables		
Storm Wind affect crop(1 = yes)	7.4	1.2
Frost affect crop(1 = yes)	3.6	1.3
Waterlogging affect crop(1 = yes)	5.0	0.9
Plant disease affect crop(1 = yes)	4.9	0.9
Insects affect crop (1 = yes)	4.8	0.5
Weed affect crop(1 = yes)	18.6	1.5

Source: Authors' computation

have declined slightly from what it was in 2013. This result is consistent with other studies (e.g., Dorosh et al., 2018) that also showed a contraction of cultivated areas in the country. In each round, less than 50 % of respondents reported engaging in soil and water conservation practices.

On the other hand, there is a significant improvement in adopting modern agricultural inputs such as fertilizers and improved seeds. While fertilizer application increased by 87 %, improved seed application rose by 67 % between 2013 and 2018. In contrast, the percentage of crop damage declined considerably over the five years. Probably owing to these positive changes, enhanced use of modern inputs, and improved crop management practices, yields of maize (23 %) and wheat (15 %) considerably increased over the 2013 and 2018 period even though tef yields have declined (by 12 %) during the same period.

3.2. Access to weather and climate services

Table 2 presents a descriptive summary of WCS from the end-line survey. Only 705 (18 %) of the 3,887 farming households accessed weather and climate services. Of those farmers who accessed these WCS, 73 % confirmed to have understood the information they received, 45 % stated that they received the services on time (e.g., well before the growing season), and 40 % believed that the services they received were adequate. Of the farmers with access to WCS, 31 % received daily weather forecasts, 27 % received rainfall

Table 2
Access, modality, and constraints to weather and climate service use (N = 705).

Access to weather and climate services	Unit (%)
Receive WCS	18
- Yes	
Do you receive WCS (e.g., before planting season)?	55
- Yes	
Do you understand the content of the WCS you receive?	73
- Yes	
Do you think the WCS you received are sufficient?	40
- Yes	
How frequently do you receive weather and climate information?	
- Daily	23
- Every other day	16
- Once per week	33
- Twice per week	24
- Other	4
What type of weather and climate information do you receive?	
- Daily forecasts	31
- Ten-day forecasts	6
- Rainfall onset and cessation	27
- Forecasts of the start of rain	20
- Occurrence of flood and drought	2
- Combination/other	16
For which activity do you need WCS?	
- Planting	16
- Application of agrochemicals (e.g., fertilizer, pesticides, etc.)	35
- Extreme events (e.g., drought, flooding, etc.)	15
- Combination of all	34
- Other	0.3
Which type of weather and climate information is most important to you?	
- Daily forecasts	20
- Ten-day forecasts	5
- Rainfall onset and cessation	31
- Forecasts of the start of rain	16
- Occurrence of flood and drought	5
- Combination/other	23
Which WCS dissemination media do you prefer?	
- Radio	63
- TV	19
- Mobile phone/SMS	2
- Extension agents	8
- Friends/neighbors	4
- Combination/other	4
What are the main barriers to the use of WCS?	
- Media of disseminating the services	18
- Language of disseminating the services	8
- Lack of financial resources	18
- Lack of decision making	6
- Combination/other	17
- No barrier	33

Source: Authors' computation

onset and cessation dates, 20 % forecast of the start of the rain, 15 % reported receiving ten-day forecasts, and 6 % received warnings of the occurrence of flood and drought, while 16 % received combinations of these services. Respondents were also asked about their most important weather and climate service type they wished to have received. Respondents gave the highest priority to information on onset and cessation dates (as reported by 31 % of farmers), followed by daily forecasts (20 %), forecasts of the start of rain (16 %), and combinations of the different types (23 %). In contrast, the occurrence of flood and drought (5 %) and ten-day forecasts (5 %) were cited as less preferred. As stated by farmers with access to weather and climate services, the crucial times for receiving weather and climate services were during planting (16 %), agrochemical application (35 %), extreme events (15 %), the combination of all (34 %), and other (0.3 %). Table 2 also provides information on the preferred media for weather and climate services dissemination. While 63 % and 19 % of the farmers respectively identified radio and TV as their preferred mode of dissemination of the services, 8 % and 4 % of these farmers also mentioned extension agents and friends/neighbors respectively as their preferred mode of dissemination. Interestingly, only a few farmers (2 %) identify mobile phones (SMS) as a good modality of dissemination. This could be due to the low literacy rate in rural Ethiopia, since one needs to read SMS messages to understand the content.

Farmers identified media use (either access to media or suitable timing) and financial constraints as the two most important challenges, each mentioned by 18 % of the farmers. Language of service communications was a major challenge for 8 % of the respondents, while 6 % reported a lack of decision-making among the challenges. More than a third (33 %) of them reported no constraint to act on the information. This may be because they were not interested in using these services or perceived that the information provided to them was sufficient.

Table 3 compares selected variables across households with access to WCS and those without access. Differences were significant between the two groups of households for socio-economic characteristics (gender, household size, value of total assets) with the exception of education level. Households with access to WCS have more members, and more active labourers (i.e., members aged 14–64). The total asset value for a household receiving climate service is three times (i.e., Birr 5,522) higher than households with no access (i.e., Birr 1,819). Looking at the yield difference between the two households, the average yield of maize and wheat is significantly higher for a household that received WCS. However, there is no statistical difference between the two households in the case of tef yield. Similarly, farmers with access to weather and climate services seem to apply more fertilizer and are more likely to use improved seeds.

Fig. 2 shows the effect of access to WCS on the average yield of cereal and pulses. The figure on the left displays the association between households' access to climate service and cereal yield. The effect of WCS on the yield of cereal crops is higher, as seen from the right shift of the kernel curve for the household with access to WCS. However, there is no such observed effect of receiving WCS on the yield of pulses.

Table 3
Comparison of variables for HH that received weather and climate information and HH that didn't receive.

	No WCS received	WCS received	Sig.
Household Characteristics	4.8	5.8	***
Household size			
Head gender(1 = male)	70.0	84.7	***
Education (percentage)			
Primary	64.0	65.0	n/s
Secondary	14.0	16.6	n/s
higher	1.7	2.4	n/s
Value of total asset (Birr)	1819.0	5522.0	***
Total active labour (number)	2.4	2.9	***
Yield(kg/ha)			
Maize	1839.0	2106.0	**
Teff	765.0	695.0	*
Wheat	1541.0	1885.0	***
Land characteristics			
Area(ha)	0.4	0.3	**
Plot distance(minutes)	13.7	14.2	n/s
Fertile soil(1 = yes)	71.7	64.7	***
flat land(1 = yes)	77.0	74.0	n/s
HH soil conservation(1 = yes)	42.0	59.8	***
Input uses			
total fertilizer(kg)	62.8	84.1	***
Improved seed(1 = yes)	30.1	47.3	***
Agrochemical(kg)	1.3	1.3	n/s
Irrigation use(1 = yes)	2.5	4.5	**

Source: Authors' computation. Significance tests were performed to determine whether there is a statistical difference b/n HH receiving climate info and those that didn't receive across different variables. Associations found to be statistically significant are indicated by level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; n/s = not significant.

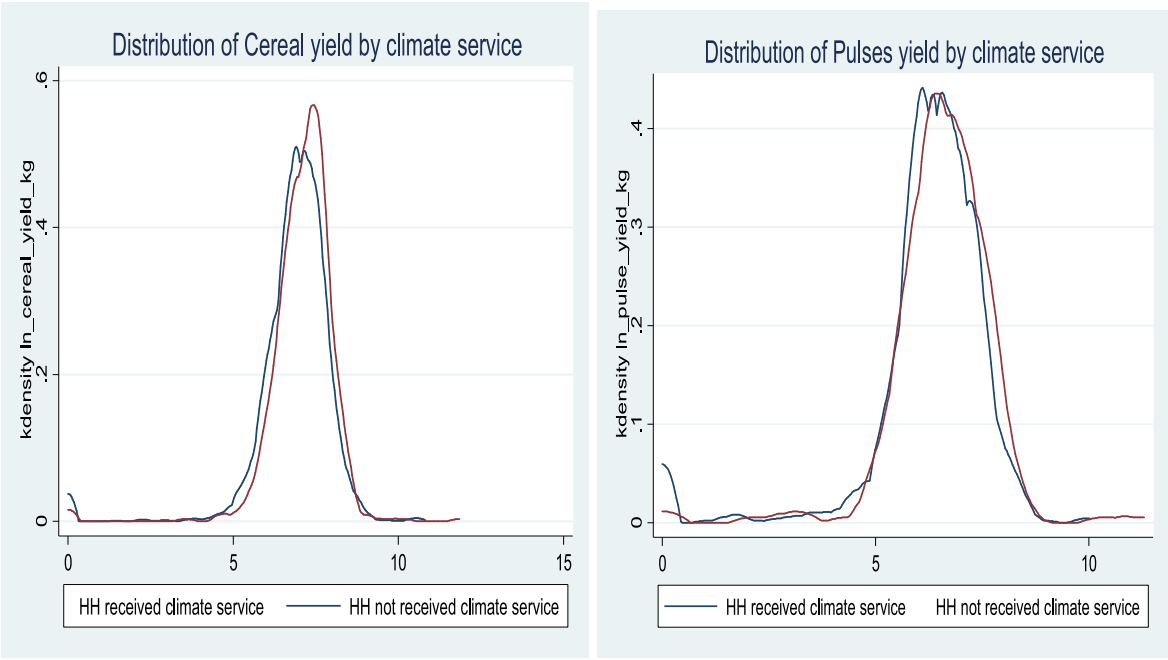

Fig. 2. Effect of access to climate service on the average yield of cereal and pulses crop.

While EMI produces localized weather and climate information tailored to agricultural needs, the low WCS access rates indicate that relevant information from EMI does not reach most farmers. Ethiopia has the strongest public sector agricultural extension system in SSA, with more than 70,000 extension workers. In addition to these national institutions, a large set of governmental, non-governmental, civil society, faith-based and international organizations are actively involved in WCS in Ethiopia. Analysis of this network of institutions identified factors that limit their effectiveness at supporting farmers to access and use WCS, including lack of formal government partnership or mandate, lack of staff expertise or training in WCS, lack of coordination among organizations, and slow delivery of time-sensitive information (Tesfaye et al., 2020).

3.3. Impact of weather and climate services on agricultural productivity

Table 4 presents two sets of results from panel data estimation techniques. Table 4 (a) presents determinants of crop productivity for four crop groups: cereals, pulses, oilseeds, and coffee. For each crop group, we regress the dependent variable, which is the logarithm of yield (kg/ha), against a host of controls. Access to WCS (a dummy indicating whether a given farmer received WCS) is included among the explanatory variables. For each crop, we test the impact of WCS under two specifications. First, we use a parsimonious specification where we only include the climate service variable. Second, we control several variables that could potentially affect crop productivity in less parsimonious regression. The model choices (fixed effects, random effects, or pooled) and justifications (i.e., statistical tests) are also indicated in the table. According to the results in table 4 (a), there is no evidence that access to WCS lead, at least in the current settings, to higher productivity for pulses, oilseeds, and coffee. However, the results show that access to weather and climate services leads to substantially higher productivity gains for cereal crops. On average, farmers that received WCS achieved 17 % higher cereal productivity than those who did not receive WCS.

Interestingly, this productivity gain is considerably higher than the productivity gain pertaining to fertilizer application. The second set of results of Table 4 (4b) presents estimates for the four most important cereals: tef, maize, wheat, and sorghum, which together account for 76 % of overall grain production (CSA 2019). Here, we also use similar dependent variables, explanatory variables, and specifications in Table 4a. Looking at the estimates presented in Table 4b, the impact of access to weather and climate services seems to vary by crop. While access to WCS seems to have little effect on the productivity of tef and sorghum, estimates show that it leads to a considerable productivity gain both for maize and wheat. Access to tailored weather and climate services is found to lead to 27 % and 17 % productivity gains for maize and wheat, respectively. To put this into perspective, we compared the productivity gains from access to WCS to the conventional productivity-enhancing inputs (such as the application of fertilizer). We found that gains from the application of fertilizers lead to only 8 % and 12 % productivity gains in maize and wheat fields, respectively.

Although the study design did not allow us to identify reasons for the productivity gains, agronomic principles suggest likely mechanisms. Crops use a given resource most efficiently when all resources are supplied at optimal levels (de Wit, 1992). Because of climate variability, crop management that is optimal on average can be far from optimal in most growing seasons.

In the case of rainfed agriculture, optimal fertilizer rates and planting densities vary with the supply of rainwater; and optimal cultivar choice varies with the timing of the rainfed growing season. Forecast information enables farmers to better match varieties and

Table 4
Impact of climate information on agricultural productivity: Panel data model estimation.

(a)

Dependent variable		**Log (Yield (kg/ha))**							
		Cereals		**Pulses**		**Oilseeds**		**Coffee**	
Explanatory variable		**Spec. 1**	**Spec. 2**	**Spec. 1**	**Spec. 2**	**Spec. 1**	**Spec. 2**	**Spec. 1**	**Spec. 2**
HH received WCS	**yes = 1**	**0.183****	**0.168****	**0.278****	**0.064**	**0.145**	**−0.176**	**0.156**	**−2.657**
Farm size	Log (ha)		−0.488***		−0.908***		−0.654***		−3.684*
Fertilizer	Log (kg/ha)		0.052***		0.057		0.006		0.080
Improved seed	Log (kg/ha)		0.010		0.041		−0.054		−0.455
Extension visits	yes = 1		0.196**		−0.004		0.191		0.291
Land indicators (soil quality, land slope, and soil conservation)		No	Yes	No	Yes	No	Yes	No	Yes
Environmental and agronomic factors (frost, insect, waterlogging, disease, birds)		No	Yes	No	Yes	No	Yes	No	Yes
Extension service (advise on land preparation, fertilizer application, planting)		No	Yes	No	Yes	No	Yes	No	Yes
HH characteristics (gender, age, education, religion, total asset, and model farmer)		No	Yes	No	Yes	No	Yes	No	Yes
Intercept		6.809***	7.092***	6.279***	2.984***	5.74***	5.95***	6.158***	5.95***
No. of observation		6071	1,392	1,694	435	519	151	534	144
F (,)/ Wald chi2		8.20***	2.18***	8.46***	2.61***	0.7	–	0.56	1.92
Hausman test (Chi2(,))		6.39***	49.96***	0.37	22.65	0.01	28.75	1.93	31.32*
Bruesch Pagan LM test		–	–	0	0	1.84*	0.01	2.25*	–
Preferred Model		FE	FE	Pooled OLS	Pooled OLS	RE	Pooled OLS	RE	RE

(b)

Dependent variable		**Log (Yield (kg/ha))**							
		Teff		**Maize**		**Wheat**		**Sorghum**	
Explanatory variable		**Spec. 1**	**Spec. 2**	**Spec. 1**	**Spec. 2**	**Spec. 1**	**Spec. 2**	**Spec. 1**	**Spec. 2**
HH received WCS	**yes = 1**	**−0.052**	**0.027**	**0.508****	**0.272****	**0.190*****	**0.167***	**0.254**	**0.241**
Farm size	Log (ha)		−1.287***		−1.577***		−0.861***		−5.09**
Fertilizer	Log (kg/ha)		0.071***		0.078***		0.121***		−0.018
Improved seed	Log (kg/ha)		0.059***		−0.040		0.046		0.076
Extension visits	yes = 1		0.211***		0.208**		0.121*		0.020
Land indicators (soil quality, land slope, and soil conservation)		No	Yes	No	Yes	No	Yes	No	Yes
Environmental and agronomic factors (frost, insect, waterlogging, disease, birds)		No	Yes	No	Yes	No	Yes	No	Yes
Extension service (advise on land preparation, fertilizer application, planting)		No	Yes	No	Yes	No	Yes	No	Yes
HH characteristics (gender, age, education, religion, total asset, and model farmer)		No	Yes	No	Yes	No	Yes	No	Yes
Intercept		6.357***	6.064***	7.095***	5.593**	7.044***	6.523***	6.701***	8.912***
No. of observation		2,508	704	3,074	2,045	519	571	641	156
F (,)/ Wald chi2		0.81	8.40***	28.03***	5.39***	11.63***	74.57***	2.40	2.61***
Hausman test (Chi2(,))		1.28	18.21	12.37***	67.70***	1.33	24.59	1.93	26.82
Bruesch Pagan LM test		10.46***	0	–	–	21.29***	4.47**	0	0.03
Preferred Model		RE	Pooled OLS	FE	FE	RE	RE	Pooled OLS	Pooled OLS

Source: *, **, *** indicate significance at 0.1, 0.05 and 0.01 significance levels; robust standard errors .
Authors' computation is based on Feed the Future data.

planting dates to varying growing season length; match fertilizer and seed inputs to available rainfall; and hence use purchased inputs and variable rainfall more efficiently. A crop model-based optimization study in a semiarid location of Kenya showed that adjusting maize fertilizer amounts and planting density based on seasonal rainfall forecasts – generally intensifying or reducing input use with increasing or decreasing forecast rainfall totals – increased average maize yields and fertilizer nitrogen use efficiency relatively to the optimal fixed management for the local historical climate (Hansen et al., 2009).

It is possible that the comparison was affected by contamination bias, in which the control groups (in our case, farmers who do not receive WCS) was inadvertently exposed to the treatment in the form of access to weather or climate information through peer or kin networks, or other informal channels. However, weather and climate information that farmers receive through informal means would likely be of poor quality or distorted, which would have little benefit to their productivity.

4. Conclusion

This study found that access to existing weather and climate services boosts maize and wheat productivity by about 27 % and 17 %, respectively. This productivity impact is comparable to or higher than the conventional yield-increasing production technologies such as fertilizer and, at times, improved seeds. The contribution of WCS to productivity affirms the importance of the existing weather and climate information provided in Ethiopia. It provides new evidence needed to guide the efforts of national public and private sector actors, funding agencies, and international development partners to improve the overall quality and range of weather and climate services and strengthen the resilience of agriculture to climate risks (WMO, 2015).

Although farmers who access WCS use and benefit from the information, the very low WCS access rates observed in our study suggest that weak last mile delivery mechanisms constrain the benefits. These results suggest that the nation's agricultural productivity would benefit from greater investment in the capacity of agricultural extension and other relevant organizations to support WCS access, interpretation and use at the farm level, and greater use of broadcast media and mobile phone WCS communication channels.

The main limitation of this study is that it only considered the suite of information products that are routinely available to farmers and not the added value of improving the design of information or aspects of WCS such as last-mile communication processes, training, and decision support systems. Furthermore, survey questions focused on forecast information at short lead times: daily and ten-day weather forecasts, forecasts of the start of rains, warnings of the occurrence of flood and drought. Further analyses are needed to estimate the value to Ethiopia's smallholder farmers of improving seasonal climate forecasts, mainstreaming weather and climate services in Ethiopia's agricultural extension system, and supporting farmer decision-making with advisory tools and training. To enhance access to such services, we believe it would be useful to disaggregate and analyze different components of climate and weather information, including the nature of information and how it is communicated and interpreted. Further analyses are needed to estimate the value to smallholder farmers of better seasonal climate forecasts, as well as the cost effectiveness of alternative channels for delivering time-sensitive information, whether through continued reliance on radio/TV media, mainstreaming into Ethiopia's agricultural extension system, or supporting farmer decision-making with advisory tools and training.

CRediT authorship contribution statement

Seneshaw Tamru: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **James Hansen:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Stephen Zebiak:** Writing – review & editing. **Abonesh Tesfaye:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Bart Minten:** Writing – review & editing. **Teferi Demissie:** Writing – review & editing. **Maren Radeny:** Writing – review & editing. **Kindie Tesfaye:** Writing – review & editing. **Dawit Solomon:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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