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Toward effective communication of agrometeorological services

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Abstract. Agrometeorological services are a subset of climate services targeted to support farmers' tactical and strategic decisions, with the potential to support farmers' capacity to cope with climate variability and change, as well as strengthen their resilience toward climatic risks. However, the effectiveness of such services is often limited by inadequate and unsuitable means of communication with farmers. Therefore, in recent years, the World Meteorological Organization (WMO) and partners have focussed their efforts on improving communication through these services. At the European Meteorological Society (EMS) Annual Meeting in September 2022, a workshop on effective communication of agrometeorological services was held as a hybrid side event, with the aim of answering the question: "How can we deliver efficient and effective agrometeorological services"? The workshop was a joint endeavour of Met Éireann, the International Society of Biometeorology, the EMS Media and Communication Committee, the Slovenian Environment Agency, the Slovenian Meteorological Society, and the S. W. Tromp Foundation. The aim of this workshop was to advance better communication of services to the agriculture sector as a basis for promoting adaptive strategies for weather and climate change, which would enable sufficient food production at present and in the future. The workshop also provided an opportunity for transdisciplinary discussions between national meteorological and hydrological services, universities, research institutes, private companies, and the WMO. The topics discussed at the workshop included learning about exemplar agrometeorological services at various national hydrometeorological services, strengthening communication of agrometeorological services to end-users, improving data and information sharing, and educating end-users. The workshop resulted in a list of recommendations for the future.

1 Introduction

Agricultural meteorology is the branch of applied meteorology that investigates the meteorological, climatological, and hydrological conditions that are important for agriculture (including crops and livestock). Agrometeorological theory and practice are closely related to some of the greatest challenges of the 21st century: food security, adaptation to climate change, vector-borne diseases, and climate-smart urban living through greener cities and enhanced urban agriculture. Moreover, polluted air, extreme weather, lack of drinking water, and food availability are all challenges exacerbated by climate change. Because the health and well-being of our society is inextricably linked to our natural environment, the World Health Organization (WHO) has called climate change "the single biggest health threat facing humanity" (WHO, 2021).

Climate change is projected to have considerable impacts on agriculture, not only because of the direct changes in conditions for crops and animals (e.g., milder winters, more drought, increase in carbon dioxide concentration), but also because of the indirect effects, such as new diseases and viruses, pests and plagues, a demand for different crops (e.g., bio-fuels), and the risks of business management (e.g., yield consistency, animal health). The agricultural sector is under great pressure to simultaneously:

- produce more food;
- reduce greenhouse-gas emissions;
- use less inputs, such as fertilizers and pesticides;
- cope with extreme weather and climate events, including droughts and water shortages;
- manage changes in the distribution and intensity of pests and disease outbreaks; and
- overcome price fluctuations.

The world has 570 million farms, of which 84 % are smallholdings of less than two hectares (Lowder et al., 2016). Unlike large corporations with specialized staff working in functional vertical areas like technology and climatology, the vast majority of the world's farms are run as small businesses, with perhaps only one or two staff responsible for a variety of general tasks. Decision-makers in the agrometeorology sector and agricultural sector must anticipate the risks and capitalize upon the opportunities of adaptation. To achieve this, they must receive from climate-service providers timely, understandable, usable, and reliable information based on the latest scientific findings. Within climate services, agrometeorological services involve the production, communication, comprehension, and use of agrometeorological knowledge and information in climate-informed agricultural decision-making. A recent assessment by the World Meteorological Organization (WMO) of the global state of climate services shows substantial technical improvements during the last decades, but also indicates that effective and equitable communication of climate services is still limited due to poor communication and interaction between producers of climate services and the intended users (WMO, 2020). Indeed, agrometeorological services often do not cover the "last mile" – not reaching, not being understood, nor being trusted by smallholder farmers living in remote areas (FAO, 2021).

To help bridge this gap across the last mile, the S. W. Tromp Foundation, with partners the WMO and the Food and Agriculture Organization (FAO), organized a three-day 2016 workshop in Ljubljana, Slovenia, called "Agrometeorologists for Farmers in Hotter, Drier, Wetter Future" (Ministry of the Environment and Spatial Planning, 2016). Its aim was to bring together agrometeorologists focused on the Mediterranean region and Europe to exchange information on present agrometeorological services provided by national meteorological and hydrological services (NMHSs), research institutions, and private companies to identify the best ways to tailor information for end-users, especially those smallholder farmers. The outcome of the workshop was that the present knowledge was not answering the question of how future climate change would affect agricultural production. Workshop attendees concluded that more information was needed to understand the impact of future climate on crops and domestic animals. Specifically, the available information at the time was not enough and was too vague to support decisions as there were too many uncertainties and no appropriate decision-making tools.

Since the 2016 workshop, the geopolitical and socioeconomic situation has changed dramatically, and technology and weather/climate science has progressed, offering a wider range of methods of communication with end-users. Meanwhile, food security has become a greater concern in many European countries. Linkages between food production and climate are becoming better understood, and the effects of climate change have already had a negative impact on agriculture in Europe (European Environment Agency, 2019). Indeed, recent extreme-weather events in Europe have impacted crop production, such as the heavy rainfall, waterlogging, and flooding that resulted in United Kingdom wheat production at a 30-year low in 2020 (Defra, 2021) and the drought and extreme heat of summer 2022 (Toreti et al., 2022). Moreover, there is an increasing recognition of the potential importance of carbon sequestration in agriculture as a means of climate-change adaptation. Thus, meteorologists can, and must, provide adequate services to the agriculture sector to cope with these challenges.

These types of events provided the motivation for a second workshop, this time held as a hybrid side event at the European Meteorological Society (EMS) Annual Meeting in Bonn, Germany, in September 2022. The workshop was entitled "Effective Communication of Agrometeorological Services" and was a joint endeavour of Met Éireann, the International Society of Biometeorology, the EMS Media and Communication Committee, the Slovenian Environment Agency, the Slovenian Meteorological Society, and the S. W. Tromp Foundation. The questions to which the participants of the workshop were asked to respond were the following: The means for disseminating information have increased, but are we communicating more effectively, and how can we improve further? The workshop gathered experiences from Europe and abroad, with a focus on the communication of agrometeorological services from a wide angle. The presentations at the workshop revealed that many NMHSs are strengthening their activities at communicating agrometeorological services, but differences are found from country to country, largely depending on the structure of each country's agricultural sector. Specifically, the workshop addressed four main perspectives: services provided, communication, data and information sharing, and education. This paper discusses these four topics next in sequence, followed by the recommendations from the workshop.

2 Exemplar services provided by NMHSs

Presentations from several NMHSs in Europe and beyond showed that many NMHSs have developed agrometeorological services to support agricultural sustainable development and adaptation to climate change and variability. Specific examples from the United Kingdom, Hungary, Germany, Ireland, Slovenia, and Niger followed.

In the UK, the Met Office delivers meteorological services to the whole agricultural industry, from farmers to government, through a diverse array of products, including personalized weather forecasts and weather sensitivity analysis. To enhance the relevance of its services, the Met Office has incorporated farmers into the development process of new tools, such as the Land Management Tool, which was developed as a prototype for delivering seasonal climate services to farmers in southwest England (Falloon et al., 2018). The Met Office also works closely with the Department for Environment Food and Rural Affairs (Defra) to establish climate services for food, farming, and the natural environment, including the climate-pest risk webtool (https://www.metoffice.gov.uk/hadobs/pests_1km_v1/, last access: 25 January 2023), which is used by Defra to inform actions on plant pests and to enhance UK plant biosecurity.

In Hungary, the Hungarian Meteorological Service (OMSZ) provides a variety of agrometeorological services to farmers through a dedicated subpage, which features observations and anomalies together with specialized forecasts, drought-monitoring information, and regular analysis of the state of the main arable crops, with an outlook for the wider region. Social-media platforms share weather and climate events that impact crop production. Experts give advice by telephone, give interviews to radio and TV, and publish articles in hard-copy magazines for farmers. OMSZ also supports the Agricultural Risk Management System by providing a web-query facility to farmers for the occurrence of frost, drought, downpours, and storms on their arable land. In addition, consultation workshops were organized with the participation of farmers to create a publicly available climate database with historical observations and projections to support decision-making in adaptation to climate change.

In Germany, the main task of the Department of Agrometeorology, Deutscher Wetterdienst (DWD), is to consult agriculture, especially policy makers, on hazard prevention and environmentally-friendly cultivation. The main software package called AMBER calculates more than 300 agrometeorological elements that serve as a basis for products and information on different time scales, and which are offered via internet, email and other avenues. Most of the information is freely available, while only some is available to closed user groups or charged for. Agrometeorological information is also distributed via mainstream media, social media, lectures, expert meetings, presentations for farmers, and advertisements at exhibitions.

In Ireland, the Agmet Unit of Met Éireann disseminates operational products, as well as provides agrometeorological services and forecasts related to animal diseases, plant diseases, plant growth, forest-fire danger, soil-moisture deficit, and daily farm commentary. Electronic means of communication (e.g., websites, mobile app, social media, podcasts), printed media (e.g., Farmers Journal, weekly agricultural newspaper), other media (e.g., radio, television, telephone), and events (e.g., Ploughing Championships, garden shows) are used to reach the general public, government agencies, and targeted users. The Agmet Unit collaborates closely with Teagasc (i.e., the Irish Agricultural Research and Advisory Service) in many ways, including facilitating the availability of weather and climate data to support agricultural research, participating in joint research projects, and engaging with outreach and educational events for the agricultural and agri-business sectors.

In Slovenia, the Slovenian Agrometeorological Service provides a wide range of information to the customers in the agricultural sector on a national level. At a time when new sources of data and modern communications are available, Drought Watch, Droughtmeter, and the Agrometeorological Forecast were introduced with the aim to help all stakeholders involved in drought management become more efficient during drought emergency response and prepare better for the next drought. The goal of these efforts is to move from recovery to protection, from crisis management to risk management, and from reactive to proactive actions.

In Niger, the Nigerian Meteorological Agency (NiMet) provides seasonal climate forecasts, 10 d agrometeorological forecasts at the municipality level directly to the farmers by SMS and WhatsApp. Moreover, 10 d agrometeorological bulletins are related advice for crop management are broadcasted by rural radios in local languages.

3 Strengthening communication of agrometeorological services

The communication of agrometeorological services relies on formal and informal channels. The first are usually official NMHSs' websites, social media, public-service broadcast media (e.g., radios, television), or extension officers. Farmers, households and communities also have informal channels of communication involving family, friends, professional, and religious networks. These informal channels present advantages and disadvantages to the communication of agrometeorological information. On the one hand, they empower information spreading, which is cost-effective and stimulates development (Tall et al., 2018). On the other hand, informal channels reduce the governance and monitoring of the information and can distort the message.

Digital technology is gaining momentum for the last-mile communication of agrometeorological services, not only in Europe, but also in developing countries such as in Niger and Burkina Faso. Digital technologies (particularly WhatsApp and other apps for smartphones) enhance the interaction and information exchange within the system actors and contribute to building trust and changing the relations between information providers, extension officers, and farmers (Munthali et al., 2018). Digital technology also empowers communities to contribute to the service co-production with observed data on local conditions and timely feedback on information received and its performance, thereby improving their engagement with agrometeorological services (Bacci et al., 2020). Despite all these new technologies, rural radios remain the most powerful tool for reaching farmers directly in developing countries (Bacci et al., 2023). However, the effective use of these channels requires preparation. The first is training of radio operators, who must be able to understand the content of the agrometeorological advice. The next step is the translation of the advice into the various local languages by the radio operator. The final step is the training of farmers in the appropriate use of the advice received by radio.

Weather forecasts, seasonal climate forecasts, and climate projections are all important information for decision-making in agriculture. However, they each demand different ways of communication. For example, weather forecasts are typically communicated through a variety of media, including television, radio, newspapers, and online platforms. They are usually presented in clear and concise information about what the weather is expected to be like in the near future. Most users have experience with weather forecasts. On the other hand, while weather forecasts are presented in a straightforward manner, seasonal forecasts and climate projections involve more complex statistical probabilities and uncertainties that need to be conveyed to the user. Indeed, a special challenge concerns the communication of probabilistic forecasts. Two different approaches exist: (i) explicitly present the forecast as uncertain, quantifying predictability and representing geographical and temporal uncertainty, or (ii) withhold uncertainty and present the best estimate of what will happen. In agriculture, telling people what to do presents risks of credibility, while farmers are used to making tradeoffs between expected outcome (the possible event) and risks. Therefore, telling them what to do risks one's credibility. On the other hand, the concepts of "probabilitstic" and "predictability" require further explanation and risk leading to misunderstanding. In order to reduce this knowledge gap, forecast producers have moved to talking about the confidence of the forecast (Hirons et al., 2021). Nevertheless, more effort is required to communicate the implications that lower forecast skills have on different times and regions for farmers.

Weather forecasts are typically communicated through a variety of media, including television, radio, newspapers, and online platforms. They are usually presented in clear and concise information about what the weather is expected to be like in the near future.

Seasonal forecasts, on the other hand, are medium-term predictions (up to several months) often based on statistical analysis and/or probabilistic. They provide a probabilistic estimate of how climatic parameters may develop in the coming months, and be useful for a range of decision-making (Bruno Soares and Dessai, 2016). Seasonal forecasts are communicated through various media channels, including bulletins, as well as online platforms. The communication of seasonal forecasts is more complex than weather forecasts, as they involve statistical probabilities and uncertainties that need to be conveyed to the user. The information is usually presented in the form of maps, graphs, and other visual aids that help users to understand the likelihood of different climate scenarios. Studies have shown that a lack of uptake of seasonal forecasts is due, in part, to a perceived lack of reliability (Bruno Soares et al., 2018) and unknown skill (Bruno Soares and Dessai, 2015). However, this barrier can be removed through a forecast "goodness" rating system, which can aid understanding of forecast reliability and indicate whether a small ensemble spread also means low ensemble forecast error (Weisheimer and Palmer, 2014).

Climate projections, on the other hand, are long-term predictions (up to several decades or even centuries) of future climate conditions, based on climatic models that simulate the behaviour of the climate system. Climate projections are typically communicated through scientific reports, as well as summaries for policymakers and the public. The communication of climate projections is the most complex of the three, as they involve uncertainties that are much larger than those associated with weather and seasonal forecasts.

4 Improving data and information sharing

Ground-truth data is essential for reliable and accurate agricultural research and to monitor crop productivity, crop location, biomass, and yield. Ground-truth data is also essential to develop and validate agrometeorological services. However, access to this data is often lacking, limiting the potential of these services (Teucher et al., 2022). Published and open data could be used to fill this gap, yet these data are scattered over many different sources, lack standardization, and have incomplete metadata. Incompatibility of provided climate information with existing in-house systems has been demonstrated to be a barrier to uptake (Bruno Soares et al., 2018). Most advanced agrometeorological services adopt the paradigm of open data and standard web services, paving the way to increase distributed NMHSs' interoperability. Moreover, sharing of data, models, information, and the use of open-source software, expands the knowledge of climatic risk and allows earlier warnings (Giuliani et al., 2017).

On the other hand, clarifying the inherent difference between agro-meteorological services and data is necessary. The conceptual principle of service includes a distillation of data from observations, models or forecasts into targeted information that can be used directly as decision-support. Indeed, the huge amount of collected data that is needed to produce a service is impractical for direct use. Therefore, NMHSs have the key role of processing these data to best meet the practical need of the user in a service co-production perspective, where the user is at the center of the process. The data are just one of the inputs, along with the specifications of the operational needs to which the service is directed, including the users' capabilities for access, understanding, uptake, and use in the field.

Concerning input data, although larger initiatives may have resources and facilities to eventually reach Findability, Accessibility, Interoperability, and Reuse standards for digital assets (FAIR; https://www.go-fair.org/, last access: 25 January 2023), this is challenging for individual researchers and small initiatives. Usually, these users lack the right expertise and technical solutions to publish data according to FAIR standards. In such cases the second-best option is that data is published in a way that the data is findable and, if possible, accessible. Consequently, there is a need for a community-specific solution to further FAIRify and harmonize in-situ data and make it ready for reuse (Top et al., 2022; Lalic et al., 2022). Furthermore, results of an online survey by Bruno Soares et al. (2018) showed a desire amongst end-users for a centralised body to coordinate this data and reduce its fragmentation. To address this need, the AGROSTAC repository (https://agrostac.org, last access: 25 January 2023) was initiated to collect from published and open datasets key agronomy observations such as crop type, phenology, biomass, yield, and leaf area. Selected data are combined and harmonized to ensure reuse of data beyond its original purpose of collection, saving potential users of in-situ data time and money. Still the community needs to find ways to further sustain and strengthen such harmonization tasks.

5 End-user education

The operational implementation of agrometeorological services is a multi-fold challenge. Although there is the need to develop useful information and products tailored to end-users' needs (Vincent et al., 2018), there is also the challenge of building local capacities through public-education institutions (e.g., high schools, universities), permanent-education programs (e.g., tailor-made courses and videos), training initiatives, and knowledge-sharing tools. Building local capacities allows end-users to uptake and adopt the information provided. For developing countries especially, there are numerous challenges, including (1) communicating with farmers in a bidirectional educational process, (2) strengthening the capacities of NMHSs' staff to interact and include farmers in the agrometeorological-service co-development processes, and (3) training farmers in accessing, using, and evaluating the co-developed services. These challenges are overcome by bringing end-users into the co-development process from the start, part of the end-to-end-to-end process described by Morss et al. (2005).

One commonly adopted tool for education in developing countries is the so-called "roving seminars" where technicians, farmers, and extensionists meet to learn from each other and exchange perceptions and knowledge (e.g., Tarchiani et al., 2017, 2018, 2021; Bacci et al., 2023). The WMO, through its Regional Centers (e.g., Regional Training Center Italy, Regional Agrometeorology Center Romania), also promotes competencies-based training solutions for NMHSs and other national technical services through face-to-face and distance learning, using a mix of formats and tools (Tarchiani et al., 2020). For example, the Regional Agrometeorology Center Romania has already been providing training courses, mainly as virtual courses due to the COVID-19 pandemic.

One approach to accelerate the adoption of proven mitigation technologies is the use of demonstration farmers, as focal points for farmer-to-farmer learning. Experience shows that farmers learn the best from other farmers. In Ireland, the Signpost programme provides exemplars of climate action by Irish farmers (Teagasc, 2017). A network of 120 Signpost farmers are central to the new, Teagasc-led, whole-of-industry Signpost Programme. Such farmers can be amongst the first to apply the latest scientific findings and new technologies on their farms, while also sharing their experiences of innovative farming approaches and showcasing the financial viability of incorporating climate-friendly activities into good farm management. Farmer-to-farmer learning, facilitated by high-quality on-farm events and a range of other communications and training activities, can accelerate the uptake of climate-mitigation technologies amongst the wider farming population.

6 Recommendations

With these services and perspectives in mind, we make the following recommendations:

- Involve users and information brokers in the early stage of development of agrometeorological services, as well in their evaluation, to create an iterative learning process fostering uptake, use, and further improvements (i.e., the end-to-end-to-end process; Morss et al., 2005).
- Design and implement training activities for NMHSs staff on communication and interaction with users.
- Acknowledge the growing – and potentially untapped – audience of end-users, which includes insurance and pharmaceutical companies, food-production industries, and research and innovation organizations (including academia).
- Spread the farmer-to-farmer learning approach for accelerating the uptake of climate adaptation and mitigation technologies amongst the wider farming population.
- Consider the specific challenges in conveying climate predictions, which are fundamentally probabilistic, to properly communicate and incorporate probabilities into the decision-making processes by both providers and users.
- Organize further meetings to stimulate the network of NMHSs and provide platforms to learn from each other and share ideas on how to improve effective communication to end-users, with a broad focus on networking, knowledge, data and information sharing, education, and raising awareness.
- Stimulate publishing in-situ data following the open-science and open-data principles and support initiatives that collect and harmonize in-situ data ready for reuse.

7 Conclusions

By providing agrometeorological services, NMHSs contribute to several of the United Nations sustainable development goals (SDGs), including SDG2 Zero Hunger, SDG3 Good Health and Well-being, and SDG13 Climate Action. Experiences gathered during the workshop demonstrate that better communication arises from a number of key concerns: (1) co-creating agrometeorological services with the early involvement of the users, (2) transforming research and technical information into understandable and useful messaging, (3) building trust and reliability, and (4) capitalizing on the comparative advantages of different media and information-communications technology. International and intersectoral cooperation appears crucial, as it is the basis for building awareness and knowledge capital.

Although services provided by NMHSs in recent years have improved and been extended, the need to work more effectively in the field with end-users still remains. NMHSs often need intermediaries to fill the gap between themselves and end-users. These knowledge brokers can facilitate the establishment of mutual trust and the "translation" of science into the languages easily understandable by end-users. Depending on the context, these knowledge brokers can be other farmers, private companies, agricultural extensionists, or well-informed presenters and journalists working in the media.

Communication is not an addendum, nor a negligible component, of agrometeorological services, but rather an essential component of it. The absence of good communication can lead to misinformation or lack of information being conveyed, resulting in underutilization of investments in these services. Designing a good communication plan requires the participation of all actors from the start. Communication is not only broadcasting, but is also sharing and exchanging knowledge, information and data, building trust and democratizing science. NMHSs need to acknowledge that there is still room for them to improve their communication towards the agriculture sector, while cooperating with other actors involved in designing and providing agrometeorological information.

Data availability. All the presentations are published on the website: https://agmet.ie/events/effective-communication-of-agro-meteorological-services/ (EMS, 2022).

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