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Re-prioritizing climate services for agriculture: Insights from Bangladesh

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ABSTRACT

Considerable progress has been made in establishing climate service capabilities over the last few decades, but the gap between the resulting services and national needs remains large. Using climate services for agriculture in Bangladesh as a case study example, we highlight mismatches between local needs on the one hand, and international initiatives that have focused largely on prediction on the other, and we make suggestions for addressing such mismatches in similar settings. To achieve greater benefit at the national level, there should be a stronger focus on addressing important preliminaries for building services. These preliminaries include the identification of priorities, the definition of responsibilities and expectations, the development of climate services skills, and the construction of a high-quality and easily usable national climate record. Once appropriate institutional, human resources and data infrastructure are in place, the implementation of a climate monitoring and watch system would form a more logical basis for initial climate service implementation than attempting to promote sub-seasonal to seasonal climate forecasting, especially when and where the inherent predictability is limited at best. When and where forecasting at these scales is viable, efforts should focus on defining and predicting high-impact events important for decision making, rather than on simple seasonal aggregates that often correlate poorly with outcomes. Some such forecasts may be more skillful than the 3- to 4-month seasonal aggregates that have become the internationally adopted standard. By establishing a firm foundation for climate services within National Meteorological Services, there is a greater chance that individual climate service development initiatives will be sustainable after their respective project lifetimes.

1. Introduction

The purpose of a climate service is “to provide people and organizations with timely, tailored climate-related knowledge and information that they can use to reduce climate-related losses and enhance benefits, including the protection of lives, livelihoods, and property” (Vaughan and Dessai, 2014). Over the last three decades, there have been major developments in establishing climate service capabilities globally (Vaughan and Dessai, 2014; Allis et al., 2019). There are numerous catalysts underlying this development, including scientific and technological advances in observations and forecasting (Dutton, 2002), and a growing awareness of the need for climate change adaptation (Smit et al., 2000). The World Meteorological Organization (WMO) has taken a key role in trying to ensure that all countries can benefit from advances in climate services, and has promoted various national, regional and global initiatives to build their capacities.

A major focus of international efforts to develop national climate service capabilities has been on forecasting, primarily at seasonal timescales. At the regional level, for example, Regional Climate Outlook Forums (RCOFs) were initiated in the late-1990s (Buizer et al., 2000; Ogallo et al., 2000), and have been implemented across much of the globe. This focus on seasonal forecasting is partly a reflection of the

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strong roles that the World Climate Research Programme and WMO Climate Information and Prediction Services (CLIPS) took in developing early climate service capacities (Carson, 1998; Ogallo et al., 2000; Sivakumar, 2006; Busalacchi and Asrar, 2009).

The Global Framework for Climate Services (GFCS) was formally adopted in 2012 (Hewitt et al., 2012), and has made progress in formalizing national institutional arrangements for climate services, encouraged data-rescue efforts, strengthened regional support for climate services, and fulfilled a need for international coordination (Hewitt et al., 2020). These, and related initiatives, have helped to strengthen the capacity of many National Meteorological and Hydrological Services (NMHSs) to generate climate information that most NMHSs were unable to produce just a few years ago (Allis et al., 2019; Hewitt et al., 2020). However, the generation of such information is only one part of functioning and effective climate services. Much of the effort needed to develop the capabilities to tailor and apply climate information for real-world decision-making lies well beyond the role of NMHSs (Mahon et al., 2019). It is unclear how much progress has been made in areas of tailoring and realizing effective use (Brooks, 2013; Vaughan et al., 2016; Bruno Soares et al., 2018), but it is clear that demand for climate services continues to exceed capacity to provide them.

In this paper, we reflect on reasons why efforts to develop national climate services may make disappointing progress towards fulfilling national needs for such services. Using agricultural applications in Bangladesh as a case study example, we highlight mismatches between local needs on the one hand, and international initiatives that have focused largely on prediction on the other. We propose ways in which climate services could be facilitated more effectively to directly link to actions and decisions in settings in other countries and contexts similar to Bangladesh.

2. Climate services in Bangladesh – A historical overview

2.1. Agrometeorological services in Bangladesh

South Asia has one of the longest histories of agrometeorological services (Normand, 1953; Decker, 1994; Stigter, 2008). The India Meteorological Department (IMD) was established in 1875 after a devastating tropical cyclone in 1864 and a series of subsequent famines resulting from monsoon failures. IMD has been producing seasonal forecasts for longer than any other country, and now provides a wide range of monitoring products that include maps of daily rainfall departure, temperature, and standard precipitation indices (IMD, 2021). After the partition of India in 1947, the Pakistan Meteorological Department (PMD) was established, and, in turn, the Bangladesh Meteorological Department (BMD) was formed after the liberation of Bangladesh in 1971. The BMD is a government organization under the administrative control of the Ministry of Defense, Government of the People's Republic of Bangladesh. Its main responsibilities are to monitor the weather and climate, provide routine forecasts at multiple time scales, and to issue warnings of extreme meteorological events.

The capacities of national meteorological services in South Asia vary considerably (Ramakrishna, 2013). India has perhaps the most advanced services: the country operates a large number of weather stations, and has a well-developed weather and climate modeling capability (Kumar et al., 2017). In contrast, the meteorological services of Bangladesh, Bhutan, Nepal, Pakistan, and Sri Lanka are relatively resource-constrained, but they are currently all undergoing significant development. Similarly, the capacities of agricultural advisory services vary throughout the region. India leads the region in the provision of agricultural advisory services, producing detailed weather forecasts, and operating services that enable farmers to consult with experts in near-real time (Rathore, 2013). At the other extreme, the meteorological departments in Nepal and Bhutan struggle to maintain consistent staffing for their agrometeorological divisions. In Bangladesh, the BMD does operate an agrometeorological division that issues one-month long-range forecasts for agricultural planning and 7-day agrometeorological forecasts for regular agricultural operations, in addition to supporting five-day weather-advisories for multiple crops for all 491 sub-districts[1]. In addition, since February 2017[2] the Department of Agricultural Extension (DAE) under the Ministry of Agriculture has been engaged in project activities aimed at improving climate services. Under these activities, agro-meteorological bulletins are distributed twice a week by district and once in a week at the national level. In addition, special emergency bulletins are issued in the event that an extreme weather event is predicted. These efforts, however, come with considerable additional investment from partner organizations and donors.

Although not exclusively for the agricultural sector, Bangladesh does have a well-developed climate- and weather-services system for extreme events. For example, the Cyclone Preparedness Programme (CPP) is known in the Disaster Risk Reduction community to be one of the prime examples of a system built and sustained at the national level, while being trusted in the communities (Habib et al., 2012). More recently, Forecast-based Financing (FbF) has been developed to link thresholds within a forecast indicating significant risk of socioeconomic impact for pre-agreed anticipatory actions to decrease potential impact with those actions being funded by a pre-agreed set of protocols linked to a sustainable pot of funding (Lopez et al., 2020). FbF has been tested for cold waves, heat waves, tropical cyclones and floods in Bangladesh, on the weather timescale, and is in the process of being integrated into the national-level disaster-management programming. As climate services for crop diseases are a long-standing objective (Thomson et al., 2000), BMD has also recently worked with national and international agricultural research, training, and extension organizations to develop suites of extreme-weather and crop-disease forecasting advisories for farmers[3], though integration of sub-seasonal and seasonal forecasts in these efforts remains nascent.

2.2. Climatechange services in Bangladesh

The Government of Bangladesh and national and international research and development organizations have invested considerable efforts in recognizing and mainstreaming climate change into policies to improve adaptation planning and in building the country's resilience to climate change (Huq, 2001; Rahman and Alam, 2003; Huq and Ayers, 2008; Ayers et al., 2014). Bangladesh was the one of the first countries to develop a National Adaptation Programme of Action (NAPA), and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) provides a climate change strategic framework for Bangladesh.

The Bangladesh Delta Plan includes climate change considerations as part of its comprehensive strategy for delta development over the next 50–100 years (de Heer et al., 2012; Zevenbergen et al., 2018). Climate change has also been integrated in sectoral policies including national agriculture, water and disaster management plans, in addition to infrastructural development to improve climate resilience[4]. Challenges

[1] See https://live4.bmd.gov.bd/p/Agromet/ and https://www.agvisely.com, respectively.

[2] See: https://www.bamis.gov.bd.

[3] Examples include Agvisely (https://www.agvisely.com/register), a sub-district level automated agro-advisory forecast for wheat, maize, rice, potato, lentil, and mungbean, interactive voice response services (https://www.cimmyt.org/projects/climate-and-market-smart-mung-bean-advisories-camasma/) to alert farmers of extreme rainfall risks of crop damage, crop disease early warning systems (https://beattheblastews.net), and agricultural advisory bulletins at the district and national levels (https://www.bamis.gov.bd/bulletin/district/).

[4] Efforts to use climate change projections in Bangladesh exist within the line agencies of the Ministry of Agriculture, Ministry of Water Resources, the Ministry of Local Government, Rural Development and Co-operatives, as well as by the Ministry of Environment, Forest and Climate Change, among others.

remain, including lack of a single overarching climate change policy, and the need for greater coherence between existing policies, improved sectoral integration and improved coordination and knowledge sharing (The Asia Foundation, 2012)[5]. However, Bangladesh has taken a leadership position on the international adaptation community, leading many development organizations to turn towards the country to learn from its experience on adaptation.

Despite the prevalence of both climate change specific policies and scientific literature, climate change information has arguably been inconsistently integrated into practical adaptation to climate impacts (Ahmed, 2019; Uddin et al., 2021). Bangladesh has implemented only a small fraction of the priority projects outlined in the NAPA[6], partly because of inadequate funding and limited integration with national policy and institutional frameworks (Ayers, 2011; Dodman and Mitlin, 2011; Pervin and Moin, 2014). A major focus of adaptation projects in Bangladesh are large-scale infrastructure projects to address impacts of floods, salinity intrusion, coastal storm surges, and anticipated sea-level rise, leaving many sectors and regions of the country still vulnerable (Zamudio and Parry, 2016).

Although the impacts of weather and climate variability on Bangladesh have been deeply considered (Yu et al., 2010; Faroque et al., 2013; Amin et al., 2015; Goosen et al., 2018), most notably in disaster-risk management (Bangladesh Government, 2017; Baten et al., 2018), the bulk of the country's national planning documents focus on adapting to long-term climate change. There is a prevalent focus on mid- to end-of-the-century climate projections, with less integration of climate at other timescales, despite the importance of past, present, short- and medium-term climate impacts and climate variability. Such a hyperopic perspective is often characteristic of countries where the NMHS has had an insufficient role in helping to shape the country's climate change policies (Furlow et al., 2018). Conversely, research on climate change impacts for agriculture in Bangladesh is common (Rahman et al., 2018), as are development initiatives focused on agricultural adaptation, though linkages between BMD and the agricultural research community have only recently developed and remain weak. This weakness indicates an area of significant need to address gaps between climate data generation and evidence-based real-world adaptation efforts.

3. National climate service capacity development priorities in Bangladesh

Much of the initiative to develop climate service capacity, such as climate observations and forecasting, have been driven by international efforts. Due to these efforts, climate services have been shaped to-date in ways that do not always match well with priorities at the national level, and by following international standards, they may involve opportunity costs in developing customized national services. In contrast, initiatives to develop climate service capacity at national scale, including in Bangladesh, are typically more sensitive to national priorities, as, for example, through notable funding by the United States Agency for International Development (USAID) and the World Bank (Krupnik et al., 2019). Recognizing that there may be other considerations and priorities, we utilize insights generated from focus group discussions held in 2017–2018 with farmers and the DAE and BMD in Bangladesh (Krupnik et al., 2019) to frame and discuss some of the national climate service priorities for the agricultural communities in Bangladesh. Because of the scope of the potential demand for climate services, a balance is needed between meeting context-specific needs and implementing general services in a cost-effective manner (Hansen et al., 2019). At least some of the priorities listed here are likely to be relevant for other countries and other sectors.

3.1. Historical climate record

A high-quality national climate record is fundamental to developing climate services (Bojinski et al., 2014; Ceccato et al., 2014). One distinction between a weather and a climate service is that a climate service interprets current or expected conditions in the context of the past, whereas weather services focus on the characteristics of specific phenomena. Without high-quality data, such interpretation is restricted. Considering the agricultural sector, data are essential for crop risk- and suitability-mapping, for detection and diagnosis of emerging or ongoing pest and disease outbreaks, for advisories related to thermal or drought stresses, for initializing crop- and farming-system models, and for contextualizing, interpreting and verifying forecasts at scales relevant to farm decision-making. In countries with poor national climate databases, starting with a focus on developing accurate climatological data that closely match on-the-ground experience, is likely to be a more effective means of developing credibility than is trying to develop forecasts that cannot be adequately contextualized or validated from an agricultural perspective.

Internationally-driven improvements in the collection and use of climate observations have led to the generation of datasets that have become essential to the global climate and agricultural research community. Examples of such data include ocean temperature profiles from the Tropical Atmosphere Ocean array (Hayes et al., 1991; McPhaden et al., 1998), various satellite-based observations (Reynolds et al., 2002; Wentz and Schabel, 2000; Knapp et al., 2011; Hollmann et al., 2013), and a suite of data products based on historical climate model reanalyses (Gibson et al., 1997; Kalnay et al., 1996; Kistler et al., 2001). However, despite support for national data-rescue efforts that have fed into improvements in these global climate datasets (Page et al., 2004; Brunet and Jones, 2011; Kaspar et al., 2015), there have been fewer efforts to develop and archive national climate records that are designed for building publicly accessible, high-quality climate products and services.

One noteworthy example of an international initiative to develop national climate records is the work of the Expert Team on Climate Change Detection Indices (ETCCDI; Peterson et al., 1998; Peterson and Manton, 2008). Well over 100 countries, including Bangladesh, have participated in ETCCDI workshops where the objective is to develop national datasets that can be used to measure observed changes in climate. However, with the limited resources available, the indices are not routinely updated by all countries, and often only a highly restricted set of data is developed. In the case of Bangladesh, data for only four stations were prepared, although the BMD has more than 50 years of digitized meteorological data collected from 23 stations, more than 100 years from 14 stations, and 11 stations with fewer than 50 years of data.

The ETCCDI initiative has focused on developing climate datasets suitable for a specific purpose – climate change detection – and other meteorological station data may be inadequate for such purposes. However, there are multiple other needs for climate data that must be addressed. Many NMHSs however still lack comprehensive, quality-controlled national climate datasets and tools that together are essential for building an effective climate service (Jones et al., 2009). For example, despite BMD's relative wealth of digitized climate data, because of insufficient support for database-management and of inadequate inter-operability (Giuliani et al., 2017), BMD has had to invest considerable effort in pre-processing data for use within a multitude of software applications internally, ancd to service external data requests.

Developing a high-quality database per se is insufficient for an effective climate service: the data need to be made available. Data access is both protected and guaranteed by WMO Resolutions (Moura, 2006), but in many countries accessing data remains a challenge (Mason et al., 2019). Making raw climate data freely and easily available is not necessarily beneficial to all. While some applications do require access

5 https://asiafoundation.org/resources/pdfs/SituationAnalysisofCCinitiatives.pdf.

6 https://www.adaptation-undp.org/sites/default/files/downloads/bangladesh_napa.pdf.https://unfccc.int/topics/resilience/workstreams/national-adaptation-programmes-of-action/ldc-napa-projects.

to data, what would be beneficial for others is access to interactive information products so that users can perform at least some level of tailoring themselves. Access to such products could help to avoid imposing an unwieldy demand on NMHSs, the meeting of which would otherwise require a re-prioritization of current tasks (Dinku et al., 2011, 2018; Overpeck et al., 2011; Hewitt et al., 2017).

This basic need for high-quality national climate databases and interactive tools is beginning to receive greater attention through initiatives such as Enhancing National Climate Services (ENACTS; Dinku et al., 2014, 2018; Mason et al., 2019; Siebert et al., 2019). The ENACTS initiative aims to develop high-resolution, quality-controlled, gridded historical datasets, and to produce from these datasets derived climate information products that can be disseminated through a web-based platform. Initially implemented in Africa (Dinku, 2019), ENACTS is being introduced in other parts of the world, including Bangladesh.

3.2. Climate monitoring systems

The development of a climate monitoring infrastructure has recently become a high priority of the GFCS. While there are many urgent needs that can benefit from forecasting information, it makes most sense to build climate services initially on a strong historical and real-time monitoring system, rather than starting with forecasting capability in-and-of itself. High-quality historical data and real-time monitoring provide the foundation for using seasonal forecasts effectively. Being able to comment on what is happening in real-time may help establish credibility, despite the uncertainty of forecasts.

A climate monitoring system can contribute to impact-based forecasting, even where climate forecasts might not be skillful (Thomson et al., 2005; Mason and Thomson, 2019). For example, observed rainfall is one of the major forcing variables for process-based crop models or soil–water-balance models, which are the main components of pre- and in-season yield-forecasting systems. A significant proportion of the total uncertainty in crop yields comes from unknown weather for the coming growing season, but that uncertainty can be reduced by integrating monitored weather observations as the season progresses (Hansen et al., 2006). In addition, monitored rainfall data can be used to estimate initial soil-moisture conditions for process-based crop models. Therefore, several yield-forecasting systems initialize crop models with observed weather data, and replace seasonal climate predictors, or weather data conditioned on climate forecasts, with observed weather data as the growing season progresses (Cantelaube and Terres, 2005; Lawless and Semenov, 2005; Hansen et al., 2006; Ferrise et al., 2015; Asfaw et al., 2018; Shelia et al., 2019). Furthermore, climate shocks and disasters (in this case, extreme rainfall and/or strong winds that may damage crops) are not necessarily well parameterized in many crop models, leaving a gap in representation of the risk of impact at the tails of the probability distribution of potential impact-based outcomes (Ming et al., 2015; Wang et al., 2018).

Climate watch systems are now being promoted internationally (Del Corral et al., 2012; Pulwarty and Sivakumar, 2014; Mason et al., 2019). A climate watch system provides advisories and alerts about important climate anomalies and extremes that are developing and/or expected to occur (Muñoz et al., 2010). Although Bangladesh has not yet implemented a formal climate-watch system, agrometeorological bulletins have been disseminated since 2009 (section 2.1). These bulletins are issued weekly, and contain reports on agrometeorological observations from 12 stations (section 3.1) and 7-day deterministic forecasts of rainfall and temperature that are based on interpretation of a variety of global model outputs. There is activity to upgrade this system, and BMD is experimentally operating a numerical weather prediction model using model inputs from the National Center for Environmental Prediction in the USA. The bulletins are disseminated by e-mail, website, fax and postal service to different users, mainly within government, and are used to develop advisories for farmers on decisions such as selection of production technology, and timing of application of fertilizers, irrigation, and pest- and disease-control measures. Information on the extent to which these bulletins have influenced farmers' decision-making processes in practice has, however, not been systematically collected or made publically available. This lack of information may be because NMHSs tend to consider themselves as producers of information, with less emphasis on translating or assuring that this information is put to practical use. While this gap is a clear constraint for improvement of the utility of climate information and its use for services, it also presents an important area of research that could help inform improvements in climate-watch systems.

Climate watches and warnings are most effective when they can be translated into impacts. Communicating the range of impacts is an integral element of translation of climate services. For example, an improved understanding of thresholds for amounts of precipitation, hail size, wind magnitude, as well as complex multi-hazard disaster thresholds (such as the combination of intense rainfall and strong winds) that indicate an increased risk of crop failure and/or damage, is clearly desirable (Yu et al., 2010). If the climate-watch communication is presented from a user-centric perspective, rather than from the perspective of NMHSs alone, there is an increased likelihood of moving from availability of climate information towards building trust and subsequent use of that information in agricultural and other decision making (Crane et al., 2010; Palttala et al., 2012; Bostrom et al., 2016; Jacobs and Street, 2020; Kruczkiewicz et al., 2021).

3.3. Tailored forecasts

The emphasis on prediction within many international efforts to develop national climate service capabilities reflects the fact that the physical climate research community understandably has a strong innovative and theoretical, rather than applied, motivation. As a result, international research-programme priorities have not necessarily matched climate service priorities at national level. They may also neglect more mundane, but fundamental, elements of climate services such as developing a national climate record and implementing a climate monitoring service including watches and warnings – which can be increasingly crowdsourced (Zhu et al., 2019) – as discussed above. In many countries, therefore, progress made to-date in developing NMHS climate service capacity has been disproportionately focused on seasonal climate forecasting, while historical analyses and monitoring services that can inform decision-making remain less-developed, as do shorter-term forecasts of some high-impact weather and climate events. Bangladesh is somewhat exceptional in this respect: climate services related to extreme events, particularly cyclones, are relatively well-developed (see Section 2.1).

There are many reasons why an initial focus on seasonal forecasting is potentially problematic. Providing seasonal forecasts in the absence of more fundamental climate information is like providing a blue-tooth keyboard to someone with no computer. In fact, there is the potential to do more harm than good (Suarez and Patt, 2004) if, for example, a NMHS is trying to build a positive reputation through forecasts that may be inherently low-skill, whilst failing to provide more fundamental information that may be more accurate and useful (Crane et al., 2010). Seasonal forecast skill is relatively low or even zero for much of the world and for much of the year (Weisheimer and Palmer, 2014; Mason, 2019), and so the usefulness of seasonal forecasts is inherently restricted. Even if there is predictability, expectations of forecast accuracy – especially among less-educated users – may be unrealistic, and inappropriate levels of confidence in forecasts can erode trust, even if the forecasts are properly calibrated (Hartmann et al., 2002; Otto et al., 2016). Evidence indicates that the seasonal predictability of climate over Bangladesh is relatively low (Kelley et al., 2020; cf. Rahman et al., 2013) compared with that in many other areas of the tropics (Fig. 1). This weak predictability is, in part, because of a complex relationship with the El Niño – Southern Oscillation (de la Poterie et al., 2018; Chowdhury, 2003; Acharya et al., 2021), and weak relationships to sea-

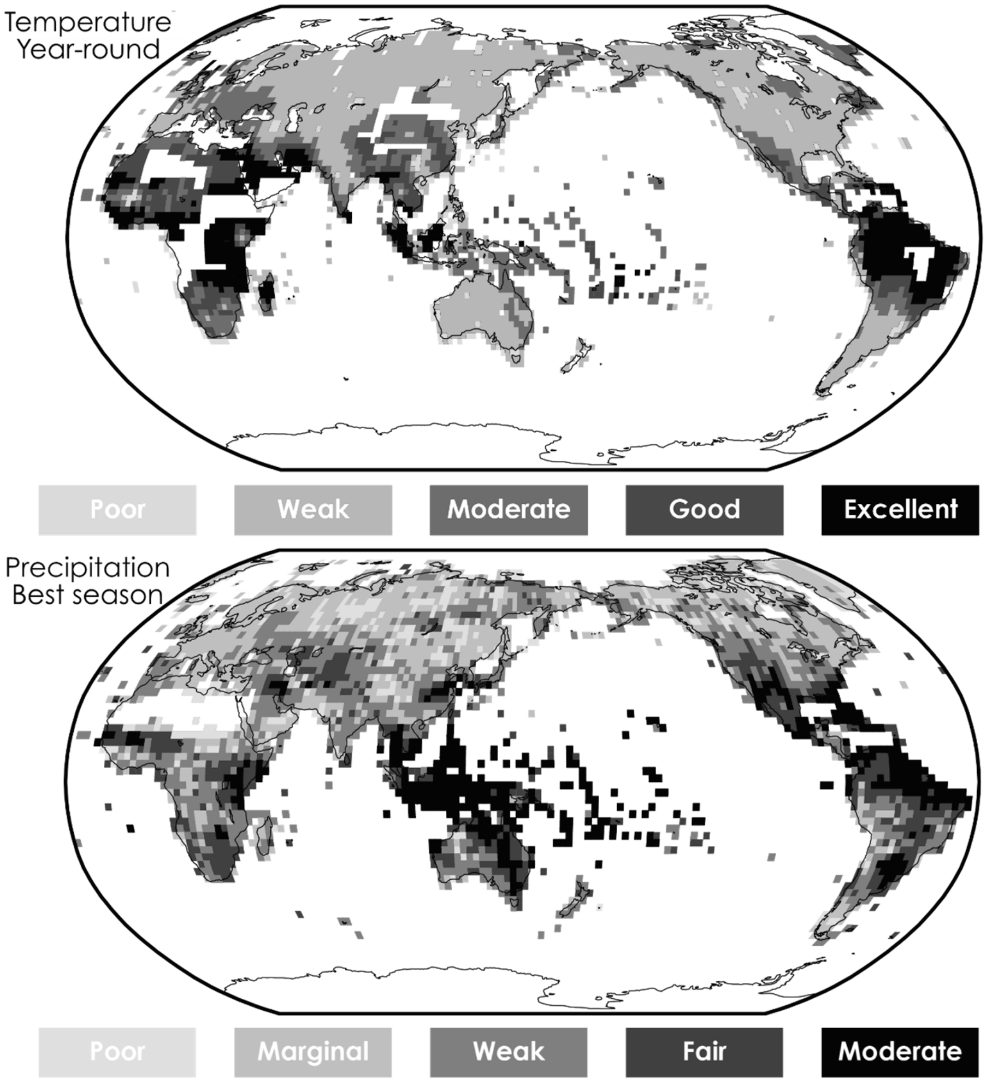

Fig. 1. Estimates of the skill of IRI's seasonal (three-month) average temperature (top) and accumulated rainfall (bottom) forecasts for 1997–2017. Skill is estimated using a measure of forecast value. For further details see Mason (2019).

surface temperatures in the Indian Ocean. Given the complex nature of teleconnections in the Bangladesh region, multi-model prediction systems may provide higher skill forecasts than can more traditional empirically-based models (Acharya et al., 2021).

Regardless of whether seasonal forecast skill for Bangladesh could be improved, realizing benefit from conventional seasonal forecasts, presented as the probability that upcoming rainfall will fall in the "below-normal," "normal" or "above-normal" tercile categories, is far from straightforward (Hammer, 2000; Ogallo et al., 2000; Vogel, 2000; Ingram et al., 2002; Hansen et al., 2006; Klopper et al., 2006; Vogel and O'Brien, 2006; Ash et al., 2007; Meza et al., 2008). Focus-group data from Bangladesh indicate that such forecasts can also be challenging for users to interpret (Krupnik et al., 2019). There are many reasons why the potential benefits of seasonal forecasting may be unrealized, but one important reason is that the standard seasonal forecast format is hard to understand and use (Hartmann et al., 2002; Patt et al., 2007). This standard forecast format, which follows conventions adopted in the RCOFs (Mason et al., 1999; Buizer et al., 2000; Ogallo et al., 2008), makes sense at global and regional scales to provide a general overview. However, for local decision-making, the format is sub-optimal: seasonal total rainfall is not necessarily the most useful or predictable parameter; and the tercile format decouples forecast probability shifts from the underlying climatology, making the forecast difficult to understand. In addition, tercile boundaries do not necessarily align with thresholds that are relevant to decision making, and the terciles often fail to distinguish more extreme, high-impact, seasons from ones that are marginally below- and above-normal (Broad and Agrawala, 2000; Hansen et al., 2019). Rather than focusing too much effort on producing overly generic forecasts, forecasts could likely be more useful if they were tailored (Goddard et al., 2010), co-produced (Crane et al., 2010) and driven by a connection to a suite of decisions and actions (Buizer et al., 2016).

The case of rice cultivation in Bangladesh illustrates the limitations to the value of standard seasonal forecasts. The productivity of rice is susceptible to both low- and high-temperature stress depending on cultivar and physiological growth stage (Sánchez et al., 2014; Shelley et al., 2016; Arshad et al., 2017). Rice is primarily rainfed during the monsoon '*aman*' season, which contributes approximately 40% of total rice production in Bangladesh. The rice crop can also be vulnerable to extreme-weather-related risks including drought and floods that can significantly curtail productivity (Mahmood et al., 2003, 2004; Hussain, 2017). However, from the 1990s forward, dry '*boro*' season rice has become the largest contributor to total rice production in Bangladesh, rendering it the world's fourth largest rice-producing country (Shelley et al., 2016; FAOSTAT, 2021). In both seasons, although rice cultivation is highly dependent on water availability during the respective growing season, yields are sensitive to rainfall, water deficit (drought) and temperature characteristics (e.g., timing relative to critical growth stages, frequency of exceeding thresholds) rather than to seasonally aggregated conditions, which are the focus of most seasonal forecasts (Koide et al., 2013; Nahar et al., 2009; Wassmann et al., 2009; Kabir et al., 2014; Mahmood et al., 2004; Shelley et al., 2016).

Despite the importance of temperatures to agriculture (and other sectors), seasonal temperature forecasts are still not routinely implemented in all RCOFs, or in many countries. The implementation of temperature forecasts would also be of potential benefit well beyond the agricultural sector (Connor et al., 2008). For example, there is an increased attention from the humanitarian community to address the 'silent killer' (Loughnan, 2014) of heat waves and cold waves (Singh et al., 2019). In addition, although there has been considerably more effort to produce seasonal forecasts of rainfall rather than of temperature, the heavy focus on predicting only the seasonal total rainfall is highly limiting, as discussed above. Predicting all the rainfall and temperature parameters that affect yields is an unrealistic goal, but providing some shorter-term forecasts about high-impact weather events, together with information about the weather-within-the-season, are options that may be both more useful and more predictable than are conventional seasonal predictands (Hansen et al., 2006; Kanda, 2012). For example, rainfall frequencies are often easier to predict than rainfall total over a season (Robertson et al., 2009), including over Bangladesh (Kelley et al., 2020), and they may have stronger relationships with impacts. However, the utility of subseasonal-to-seasonal and seasonal outlooks for agricultural decision-making may be less useful for farmers in comparison to the pragmatic decisions made at the weather forecast (Fig. 2). There are some attempts within the RCOFs to predict aspects of weather-within-the-season, such as wet- and dry-spells, and heavy rainfall frequencies (Gerlak et al., 2018). However, this practice has yet to become widespread, and the connection between extreme rainfall and flooding requires improved understanding and documentation (Coughlan de Perez et al., 2017; Alfieri et al., 2018).

There also have been calls to provide information about rainfall onset since the first RCOF review (WMO, 2000), and there may be some potential to provide skillful forecasts in some parts of the world (Moron et al., 2009). However, onset definitions (at least ones that have any potential to be predicted more than a few days in advance) are in terms of large-scale dynamics (Goswami and Gouda, 2010; Montes et al., 2019) that may not always necessarily translate into on-the-ground local experience.

3.4. Improved coordination and engagement

Generating timely, credible, and actionable information is only one part of developing effective climate services (Crane et al., 2010). Climate services need to be developed with engagement of all relevant parties (Dilling, 2007; McNie, 2007; Sarewitz and Pielke, 2007), otherwise the information that is developed will remain largely unused. More specifically, sufficient resources should be allocated for structured

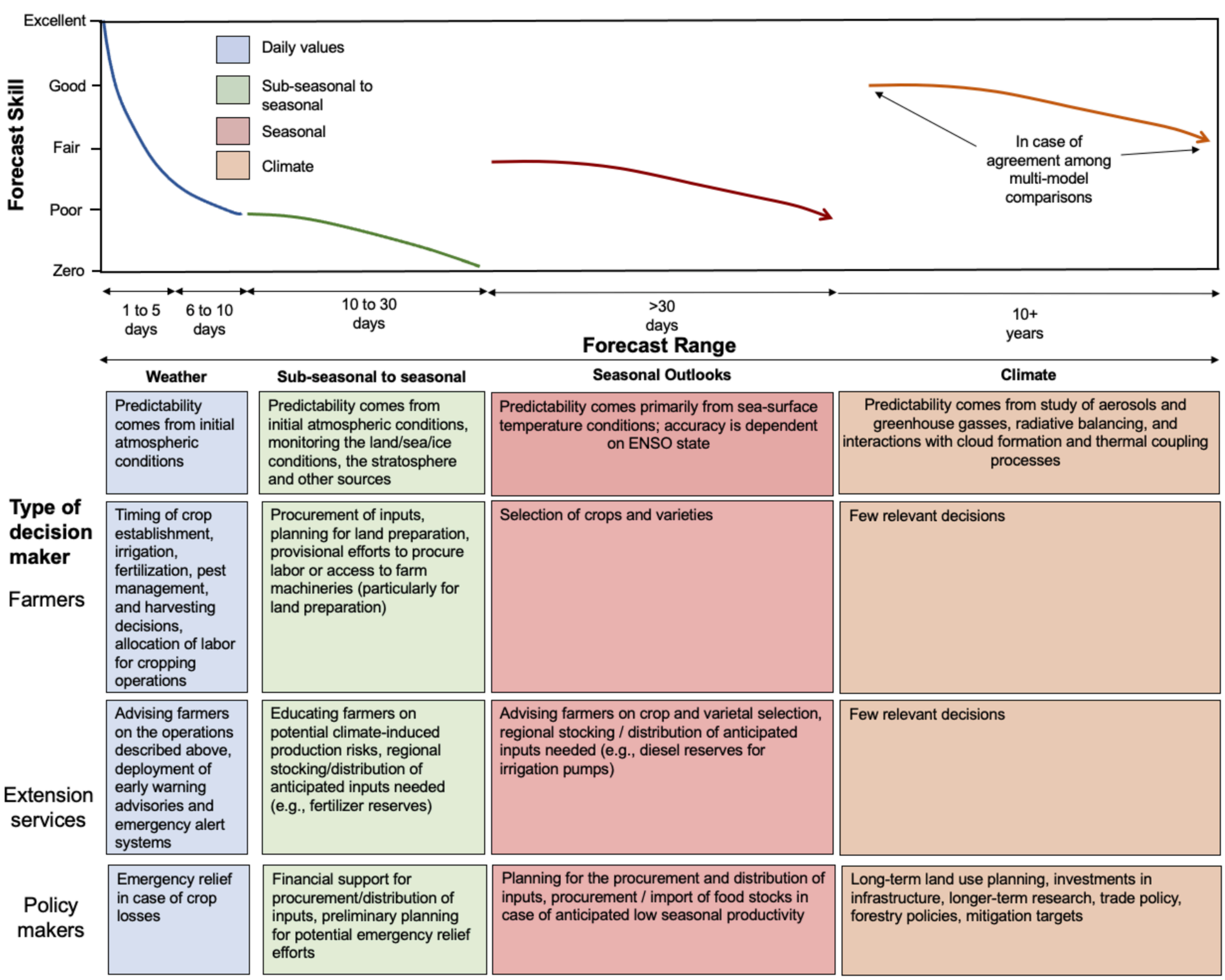

Fig. 2. Examples of agricultural decision making types among agricultural stakeholders as they pertain to annual crop production in Bangladesh at multiple climate forecasting scales. Data generated from focus group discussions held in 2017–2018 with the Bangladesh Meteorological Department and the Department of Agricultural Extension in Bangladesh (Krupnik et al., 2018). Figure adapted from White et al. (2017).

interactions between stakeholders – ideally brokered by a climate science translator, whose role is to bridge gaps between the NMHS and end-users (Agrawala et al., 2001; Kruczkiewicz et al., 2021).

Despite the many climate change plans and policies now in place in Bangladesh, insufficient coordination between the many agencies, donors, and projects currently working, risks continued compartmentalization, limiting effectiveness (Ahmed, 2019). Inter-ministerial coordination remains a challenge because of the fragmentation of tasks and agencies, insufficient human resources, technical knowledge, and the competition for funding (Uddin et al., 2021). Beyond government, there is limited coordination between agencies and institutions, partly due to the multiplicity of existing initiatives originating from different and uncoordinated donor funding.

Climate services face similar coordination challenges. At the government level, the Ministry of Environment, Forest and Climate Change serves as focal point on climate change. The BMD under the Ministry of Defense, is the mandated organization to provide meteorological services and to circulate climate and weather information. The Bangladesh Water Development Board (BWDB), under the Ministry of Water Resources (MoWR), is responsible for the dissemination of hydrological information and flood forecasting and warning, through its Hydrology Division and Flood Forecasting and Warning Center (FFWC). All agricultural activities conversely fall under the Ministry of Agriculture and Ministry of Fisheries and Livestock (MoFL), respectively. The Ministry of Disaster Management and Relief has the role of coordinating disaster management efforts and disseminating information provided by BMD and BWDB to District-level Disaster Management Committees, media and local communities. Although BMD and BWDB are the two mandated organizations for meteorological and hydrological services in the country, it is not uncommon for other ministerial line-agencies to install their own weather observation equipment. Furthermore, there is no inter-ministerial coordinating committee to link their efforts across Ministries. The Department of Agricultural Extension (DAE), under the Ministry of Agriculture, has a general mandate to provide information and advisories to the country's farmers, but its role in delivering more advanced climate services (beyond agrometeorology bulletins) has only recently begun to develop.

A more comprehensive solution to the coordination and engagement challenge in Bangladesh requires changes to policy and institutional arrangements. The development of a National Framework for Climate Services (NFCS) offers a promising mechanism for achieving this goal. Under the auspices of the Global Framework for Climate Services (GFCS), WMO offers technical support to national governments wishing to develop their NFCS (Golding et al., 2017) to "coordinate, facilitate and strengthen collaboration among national institutions to improve the co-production, tailoring, delivery and use" of climate services (WMO, 2018).

It is imperative to build climate services around mutually agreed upon, appropriate, and pre-identified priorities and roles, responsibilities and expectations – perhaps through interdisciplinary working groups and other types of NFCS discussions – with a specific focus on membership within, and content and frequency of those interactions (Vaughan and Dessai, 2014; Kruczkiewicz et al., 2018). The NFCS development process incorporates extensive consultations with stakeholders in key climate sensitive sectors to identify priorities and define responsibilities. If the NMHS does take a facilitating role, a key challenge is to ensure that stakeholders on the demand side are fully engaged, and co-own the resulting climate services policy and governance framework (Crane et al., 2010). In setting priorities and establishing services, there is a set of ethical questions that cannot be ignored or postponed without adopting what may well be unacceptable default answers (Pfaff et al., 1999; Brasseur and Gallardo, 2016; Webber and Donner, 2017; Gerlak and Greene, 2019). For example, although there is a well-recognized need to ensure that climate services are demand-driven (McNie, 2012; Lourenço et al., 2015), this recognition must deal with practical questions of whose demand is important, and whether the potential users of these services have the capacity to understand and articulate demand for information that might not yet be available (Carr et al., 2019; Hansen et al., 2019). In summary, the NFCS's importance is rooted in coordination. Coordination allows not only for the necessary multi-disciplinary entities involved in climate services to seek guidance for conducting their discipline-specific activities, but also, and perhaps more importantly so, for the coordination, incentivization and mobilization of discussions between those entities.

4. Conclusions and recommendations

International efforts to support the development of national climate services have made considerable progress in countries that formally had only very limited capacities. However, in many cases such initiatives leave only a limited capability to fulfill national needs for such services. Among the many reasons for this limited impact, experience in Bangladesh highlights mismatches between the focus of many initiatives to promote climate services development on the one hand, and local needs and practical application for such services on the other.

In many cases, initiatives have focused on creating products while neglecting the development of essential elements of an enabling environment to assure the continued *process* of climate services generation and deployment. We argue that such efforts could achieve improved benefits at the national level by focusing on important preliminaries for building climate services. These include identifying national priorities that climate services can help achieve, defining responsibilities and expectations of the various stakeholders involved, and establishing effective coordination mechanisms. These preliminaries can be facilitated through the establishment of a National Framework for Climate Service, or similar mechanisms suited to a particular national context.

In the context of improving the provision of national climate information products, we argue that the historical focus on seasonal climate forecasting and downscaling of climate change projections has been premature and unbalanced. We propose that international efforts to build the capacity of NMHSs to provide climate services should give greater attention to the following areas:

- Building a high-quality and easily usable national climate record, as part of systematic efforts to implement a climate monitoring and watch system.
- Development of high-quality historical and real-time climate databases, as a foundation for products and services (Dinku et al., 2011; Overpeck et al., 2011).
- Capacity building of professionals and communities to assess, monitor, manage, and advise on climate and weather-based risks in agriculture and associated sectors, and thus build a stronger atmosphere of responsive (Crane et al., 2010).
- Improved monitoring and diagnostics products, including timely monitoring products that support skillful forecasts of climate impacts, and diagnostics products that build credibility by demonstrating an understanding of what is happening now.
- Improved characterization of seasonal weather statistics beyond averages, recognizing that seasonal averages are often poorly correlated with impacts (such as crop yields and flooding), while other statistics (e.g., rainfall frequencies, heavy-rainfall frequencies, heat-wave occurrences, frost counts) may be more useful and more predictable (Hansen et al., 2006).
- Improved saliency of information, e.g., by removing unnecessary jargon and including more user-specific information, and working to assure that technical professionals are trained to be able to communicate to multiple stakeholder audiences (Crane et al., 2010).
- Greater focus on extended-range weather and sub-seasonal forecast products for impactful weather, rather than just seasonal (or longer-range) forecasts (Luseno et al., 2003).
- A better-defined communication process of the constraints for using climate information for specific sectors, applications and decisions.

By clearly defining the constraints, such as the lack of appropriateness of use for some applications, there could be an increased chance of matching expectations and thus building trust (Lacey et al., 2018).
- To address the coordination and governance challenges, across timescales and sectors, for climate services in Bangladesh, the current status of these systems needs to be assessed, in order to identify opportunities for resolution.

CRediT authorship contribution statement

Simon J. Mason: Conceptualization, Methodology, Investigation, Writing – original draft and revisions. **Timothy J. Krupnik:** Conceptualization, Methodology, Investigation, Writing – original draft and revisions, Visualization, Funding acquisition and project management. **James W. Hansen:** Conceptualization, Writing – original draft. **Melody Braun:** Conceptualization, Writing – original draft. **S. Ghulam Hussain:** Conceptualization, Investigation, Writing – original draft. **Md. Shah Kamal Khan:** Conceptualization, Writing – original draft. **Abdu Mannan:** Conceptualization, Writing – original draft. **Ashley Curtis:** Conceptualization, Writing – original draft. **Eunjin Han:** Conceptualization, Writing – original draft. **Andrew Kruczkiewicz:** Conceptualization, Writing – original draft.

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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