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Applications of interannual-to-decadal climate prediction: An exploratory discussion on rainfall in the Sahel region of Africa

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ABSTRACT

This perspective explores how climate services may potentially incorporate information emerging from the new science of interannual-to-decadal (I2D) climate prediction. The geographic focus is the Sahel region of West Africa, which has demonstrated prediction advances for rainfall on the I2D timescale, and vulnerability to climate hazards. The perspective draws on reviews of predictability and applications in the region and a national workshop in Sudan to explore applications. Decadal prediction is an emerging capability, to date being undertaken primarily as a learning process. However, for the multi-year forecast information, we identify a number of new dimensions that challenge product design and user uptake. Current experiments often present forecasts as the average conditions for a target first year, and then subsequent set of years raising a question of what a forecast of mean average conditions for years 2–5 represents in terms of climate to expect, and how annual updates to multi-year forecasts may be produced and communicated. Stakeholder consultations highlighted some of the concerns noted for existing seasonal forecasts, but now translated into terms for multi-year information, such as confidence in information, need for research on temporal downscaling (which may now include information on the risks of climate anomalies in the individual years that make up the forecast period), capacity development, and that communities would need to be convinced about effectiveness, alongside careful communication, especially in the context of multi-year planning. This perspective captures one of the first learning case studies on how I2D prediction may be explored in a given region, a first step towards climate services development that integrate I2D information.

Practical implications

This perspective explores how climate services may potentially incorporate information emerging from the new science of interannual-to-decadal (I2D) climate prediction in the Sahel region of West Africa. Over the last decade, a number of international climate modelling centres have been developing new forecasts targeting a timescale up to about 10 years into the future, although most of the evaluation effort to date has tended to focus on forecasts for one-year-ahead, and forecasts for the period 2–5 years ahead. The source of the new skill lies in longer-lead climate model forecasts for interannual timescales (such as related to El Niño) and improved representation of key processes that drive some of the observed multi-year climate anomalies, such as the Atlantic Multidecadal Oscillation. A WMO Lead Centre for Annual-to-Decadal Climate Prediction has been designated, responsible for collecting and providing hindcasts, forecasts and verification data from contributing centres worldwide (http://bit.ly/2MUGJAA).

Our focus here on the Sahel region of West Africa (boreal summer monsoon rainfall) has two practical advantages for exploring the potential of climate services to draw on the new science. First, there are clearly demonstrated prediction advances for Sahel rainfall on the I2D timescale, which provides for discussion of applications in the context of clearly presented forecasting science. Second, the Sahel region is well-known to be one of the most vulnerable regions in the world to I2D climate fluctuations, such that modestly skillful information can be expected to be of interest to at least some stakeholders.

In terms of potential uptake of the information, the new longer-lead interannual forecasts have substantially similar issues to those of the existing seasonal forecasts: the new information is, in large part, simply an extension of lead-time. However, there are many novel technical and application dimensions that challenge the product design and user uptake of the emerging multi-year forecast information on 2–5 year timescales.

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Stakeholder responses (explored during a national workshop in Sudan) suggest some interest in experimentation with operational probability forecasts of tercile-category (or other similar) summaries for regional indices of multi-year rainfall totals to explore interest in the topic, along the lines done initially with short-lead time seasonal forecasts. In addition, both national climate capacity and stakeholders emphasized the value of information in the dry season as well, especially temperature, but also notably wind speed. At least for temperature, good skill is anticipated, and so experimental tercile forecasts for temperature should be assessed. Longer-lead seasonal rainfall forecast potential for agriculture was clearly recognized: information available in March opens an array of new early-season management possibilities. However, the experimental and modest levels of skill suggest use may at this stage be best explored through national/regional strategies of stakeholders such as in the case of Sudan the World Food Programme. Potential applications of the new longer-term (multi-year) forecasts were especially identified in the water sector for effective infrastructure and operational management strategies at regional scales. Assessment of the planning applications for new forecast information on 2–5 year timescales is in its infancy and in locations where skill exists careful consideration of potential by user groups will be required. In terms of furthering discussions with stakeholders in Sudan, the potential of incorporation into indices for food security safety nets provided an example of a possible avenue.

Importantly, however, stakeholders noted that the current experimental multi-year product, a 2–5 year average forecast of seasonal rainfall (and temperature), could be misleading, and not give users what they need because there is more interest in information about individual years. This motivates approaches to temporally downscale the information, to generate information on, for example, the risk of an extreme drought, or run of droughts, within the forecast 2–5 year period. The level of skill of such temporally downscaled information is at this point not known and represents a topic for applied research. In some ways, this is analogous to the early challenge issued to seasonal forecasts on the need to downscale seasonal information to the statistics of the daily timescale that most impacted such activities as rain-fed crop production.

The demanding technical requirements and their experimental nature reinforce the need to consider the capacity of National Meteorological Agencies (NMAs) in many low income countries, including Sudan, to engage in this emerging area of forecasting. While infrastructure and capacity gaps and financial precarity are known to be important for many NMAs, recent extensive funding and initiatives are going some way to address these concerns, although progress varies considerably between countries. Beyond the technical issues are the demands on staff to co-produce products to make the most of their potential by adopting user-centred climate service design and recognizing the importance of interactions with wider stakeholder groups like non-state actors.

Among the technical challenges, a key concern was the importance of attribution of recent multi-year anomalies in the regional climate system, as a starting point for interpretation of multi-year forecasts. This was emphasized in the stakeholder discussions, and was expressed by the national meteorological community in Sudan as something that, with capacity support (to make progress on attribution), would assist greatly in their interaction with climate service customers. In terms of fully effective climate service development, this analysis in Sudan is an exploratory phase, drawing on research outputs still in experimental stages. It motivates assessment of multi-year climate predictability in terms closer to those needed for applications, and co-production research into the implications and potential for climate services drawing on the multi-year information.

1. Introduction

This perspective aims to contribute to thinking on how climate services may potentially incorporate information that is emerging from the new science of interannual-to-decadal (I2D) climate prediction. The geographic focus is the Sahel region of West Africa, which has two practical advantages for such exploration. First, there are demonstrated prediction advances for Sahel rainfall on the I2D timescale (Sheen et al., 2017), which provides for discussion of applications in the context of clearly presented forecasting science. Second, the Sahel region is well-known to be one of the most vulnerable regions in the world to I2D climate fluctuations, such that modestly skillful information can be expected to be of interest to at least some stakeholders.

The development of climate services is now well recognized to be substantially beyond a challenge of science communication but rather, extends to effective use of intermediaries and co-production of information to support actions (e.g. van den Hurk et al., 2018; Christel et al., 2018). This frames a further dimension of the perspective, which draws on a consultation with stakeholders in the Sudan during a workshop, for exploration of possible applications. Many constraints and challenges have been noted in the uptake of existing short-lead time seasonal forecasts (Hansen et al., 2011; Vaughan et al., 2019). The importance of framing any new information in the context of existing risk management practices was a key lesson from early attempts at seasonal forecast applications. Building on this work, discussions at the workshop were conducted in the context of any new climate information's credibility, legitimacy and salience, leading to the emergence of possible avenues for the development of information which could potentially be acted upon. This included consideration of how the new forecast information may best be framed within some existing knowledge, including the added value of contextualizing forecasts against recent trends, and presenting the information as a further development of the current short-lead seasonal forecast.

The perspective draws on reviews of predictability and applications in the region (Conway and Ward, 2019; Ward, 2019), as well as the national workshop to explore applications in a first-step co-production environment with stakeholders. As such, this perspective may also be considered as capturing, to our knowledge, one of the first learning case studies on how I2D prediction may be explored in a given region.

The perspective therefore examines the potential for application of recent advances in understanding of Sahel rainfall predictability on I2D timescales drawing on previously conducted reviews as well as workshop outcomes that highlighted operational and practitioner perspectives from the Sudan. The overall methodology followed is described in Section 2. Section 3 reviews the recent advances in understanding of Sahel rainfall variability and predictability and Section 4 examines the technical considerations relevant for linking forecast products with their application. In Section 5 practical insights are highlighted from three sectoral perspectives (agriculture, food security and water) elicited through a consultation exercise in Khartoum, Sudan. The perspective concludes (Section 6) with a discussion of key considerations for next steps towards operationalizing usable products.

2. Methodology

2.1. The overall approach

The work initially proceeded with two reviews, one on the predictability in the region on the I2D timescale, the other on key applications issues for the region.

For predictability, initially a search engine was used with selected key words, which yielded around 500 publications. Areas included in the search covered the existing seasonal forecast capacity, the new I2D prediction science in general, and emerging studies that had mentioned explicitly, or focused upon I2D in the Sahel. It was useful to review the extent to which I2D built upon existing seasonal prediction capability, including mechanisms. At the interannual timescale, this primarily relates to capture of evolution of coupled ocean-atmosphere features that up to now, were being used with only modest evolution for short-lead time seasonal forecasts. The discussion of mechanisms on the multi-year timescale was considered to represent an important component to support the interpretation of any operational I2D capacity.

For applications, the review drew on experiences with attempts to apply short-lead seasonal forecasts, with specific attention to the key climate risk issues for the region. Several key review papers (Hansen et al., 2011; Vaughan et al., 2019) were augmented with specific examples from the agriculture, water resources and humanitarian/forecast-based finance sectors to provide the main source of literature. This led to focus on credibility, legitimacy and salience as key factors in the uptake of information, and helped to frame a set of questions that were used to guide the discussion during the applications part of the exploratory national workshop. These questions addressed the timing of critical activities in relation to both forecast timescales and the operational responsibilities and actions required to utilise the forecasts, from information production to use. The aim was to include examples where there is some degree of multi-year behaviour in environmental systems (e.g. reservoirs) and management or planning activities (food stores, contingency planning).

2.2. On the relevant learning from uptake with seasonal forecasts

The range of challenges identified in the literature from seasonal forecasting is a reasonable starting point for considering approaches to utilizing the new I2D climate information, including trust and confidence in the forecasts, the utility of the information, and the spatial resolution of forecasts. These have been broadly categorized as credibility (perceived technical quality of information), legitimacy (belief that the information seeks to serve the users' interests) and salience (relevance to users' needs) (see Hansen et al., 2011, also Patt et al., 2007; Zebiak et al., 2015). Another categorization uses fit, interplay and interaction (Soares and Dessai, 2015). Fit includes users' perceptions of how climate information fits with the organizational context; interplay considers how well information can integrate with pre-existing knowledge or information in the organization; and interaction deals with the relationship between the information producers and the users (Soares and Dessai, 2016). Many studies find that a process of co-production between users, boundary agents and scientists would likely improve the effective use of seasonal forecasts. These types of challenges need to be explored in relation to the design and uptake of the I2D products.

Credibility (Risk of a 'wrong' forecast) – there are considerable institutional and political barriers to using uncertain forecast information. Risk perception is a key factor to consider in the design of applications. Accessible skill scores are required that can give decision-makers an understanding of the consequences of acting in vain (e.g. the False Alarm Ratio which indicates the likelihood of acting in vain given a specific forecast probability). Calculating the probability on which to take action requires understanding the costs of not acting and acting in vain, but these costs are difficult to quantify given that the effect of false alarms on future behaviour is not well known (Stephens et al., 2015).

Salience – there is often a major gap between seasonal forecast information and users' requirements for decision-making. For example, in agriculture for use at the farm-scale, forecasts need to: be downscaled and interpreted locally; include information about growing season weather beyond the seasonal average (e.g. risk of dry spells); express accuracy in transparent, probabilistic terms; and be interpreted in terms of agricultural impacts and management implications (Hansen et al., 2011). Users are generally most interested in the scale and likelihood of specific impacts and these need to be derived from the forecast.

Legitimacy – all the evidence points towards the importance of joint involvement in the design of information, dissemination and guidance on use, between producers and users (especially at the initial uptake phase). This requires consultation right from the outset of all the actors involved in the forecast and application process.

3. Extending short-lead seasonal forecasts to one-year-ahead and multi-year information: the case of the Sahel

During the 1980s and 1990s, a capability was operationalized to make skillful seasonal climate forecasts for many regions including boreal summer rainfall in the Sahel (Lamb, 1978; Folland et al., 1986; Folland et al., 1989; subsequent contributions including Giannini et al., 2003; Rodríguez-Fonseca et al., 2015; Rowell et al., 1995). Such forecasts for the Sahel are typically available in April/May, so represent a lead-time on the July-September rainfall season of about 2–3 months (reviewed in Colman et al., 2017).

In the last 10–15 years, a major initiative has been to develop and evaluate predictions from General Circulation Models (GCMs) for multiple years ahead (Meehl et al., 2009, 2014, Smith et al., 2013, 2019). Forecasts are initialized with prevailing climate conditions, with potential for predictability to be derived not just from ocean conditions, but also from prevailing atmospheric composition including aerosols, as well as conditions on the land surface, including moisture and ice. Sets of hindcasts have been run and evaluation approaches have often focused on skill of the hindcasts for 1-year-ahead, and skill of the mean of years 2–5. Early results were quite promising for the Sahel (e.g. Doblas-Reyes et al., 2013; Martin and Thorncroft, 2014) and this potential has now been studied in detail by Sheen et al. (2017) drawing on a set of hindcasts from the UK Met Office Decadal Climate Prediction system (termed DePreSys3). The hindcasts span the period from 1960 to 2014. Hindcasts have not been made for every year (or set of years), but there are sufficient to provide a good representative sample across the period 1960 to 2014.

For the Sahel, in the current hindcasting methodology, the 1-year-ahead prediction effectively uses November conditions of the previous year to anticipate the rainfall season (effectively a lead-time of about eight months). For rainfall averaged across the Sahel, the correlation skill is $r = 0.48$. This level of skill is somewhat lower than the short-lead seasonal forecasts (Colman et al., 2017), but nonetheless, is at a level with clear potential to give an early approximate indication of the upcoming Sahel rainfall season, with a lead time of eight months.

A further, and probably even more significant, advance in the Sheen et al. (2017) paper is the demonstrated ability of the DePreSys3 model to successfully forecast the 4-year mean Sahel rainfall with a lead time of over one year. For example, a model forecast initialized in November 1960 successfully forecasts the mean rainfall for 1962–1965. These forecasts are termed "years 2–5", and in Sheen et al. (2017) they successfully capture the relatively wet Sahel period in the 1960s, the very dry period of the 1970s and 1980s, and the subsequent moderately wetter average conditions. Correlation skill is about $r = 0.70$, which is actually comparable to that achieved for the existing short-lead time seasonal forecasts (as reviewed in Colman et al., 2017). Similar multi-year skill is present for indices of both West Sahel and East Sahel rainfall. Sheen et al. (2017) explain the ability to make such multi-year forecasts primarily through moisture convergence changes: a warmer North Atlantic (as in the positive phase of the Atlantic Multidecadal Oscillation, Knight et al., 2006) and warmer Mediterranean lead to enhanced moisture convergence and precipitation in the Sahel, although there is debate in the literature on the exact balance of prevailing mechanisms on the multi-year timescale, which may be considered an added uncertainty factor to such multi-year forecasts (returned to below, in considerations of possible operationalization).

Decadal prediction is an emerging capability, with ongoing exploratory experiments within the framework of CMIP6 (Boer et al., 2016), as well ongoing production of what are termed "quasi-operational" forecasts, to date being undertaken primarily as a learning process (Smith et al., 2013). A WMO Lead Centre for Annual-to-Decadal Climate Prediction has been designated, responsible for collecting and providing hindcasts, forecasts and verification data from contributing centres worldwide (http://bit.ly/2MUGJAA). Presentation of forecasts reflects the early stage of a new product being primarily created for the science community to learn through the process, with forecasts presented simply as time-mean full anomaly fields. This then represents the departure point for discussions on applications, to consider if this emerging operational capability could be translated into products that may enhance climate risk management on these timescales.

4. Technical forecast issues in the development of user-oriented products

The new longer-lead interannual forecasts (that are naturally produced as part of the I2D experiments) have substantially similar issues to those of the existing seasonal forecasts: the new information is, in large part, simply an extension of lead-time. A valuable diagnostic is the relation of the skill of short-lead seasonal forecasts (for which there is about 20-years of operational experience) versus the new, in this case 8-month, longer-lead forecasts.

Such skill comparisons are also helpful for the multi-year forecast, but there are many new dimensions that challenge the product design and user uptake, to extend thinking beyond the existing seasonal forecast. Some specific aspects envisioned and then discussed at the Khartoum workshop to stimulate discussion were as follows:

i) What does a forecast of mean average conditions for years 2–5 actually mean in terms of climate to expect?

Some of the technical issues are similar to seasonal forecasting, for example, the spatial scale question. Many users point to the need for high resolution information, but from both a climate science and applications perspective, high resolution may be best reserved for once the I2D work becomes more mature. Regional indices may be the most appropriate for I2D at this stage, as was the starting point for seasonal forecasting.

A unique question though concerns the statistics of interannual variability to expect within the multi-year period? This may be considered analogous to the temporal downscaling question for existing seasonal predictions, for which the question concerns the statistics of daily weather. Now, the question concerns the statistics of interannual variability within the multi-year period (as well as, subsequently, questions on the daily weather statistics). Statistical approaches may initially be used to answer questions such as the risk of extreme dry years in a multi-year period, or risk of a run of two or more extreme dry years back-to-back. For example, typically it may not be possible to specify which year has greater drought risk than others in the forecast, but given a relatively dry mean forecast for years 2–5, it should be possible to derive a meaningful estimate of the increased drought risk applicable to each year. This would be an important start in establishing credibility for this key aspect of decadal forecasts as brought up by stakeholder interactions.

ii) Format of a possible experimental product

The tercile of a regional index provides a starting point, but raises the question of what base period to use? This will be an even more critical question than it is for existing seasonal forecasts, given the higher variance of interannual rainfall totals, as compared to multi-year totals (returned to in point (iii) below). There is potential to extend the forecast to drought indices such as SPI (Dutra et al., 2013) or WRSI (reflecting a role for daily rainfall distribution, Zhang et al., 2018), through simple statistical approaches. It is important to consider whether degradation of skill when moving from seasonal rains to drought indices occurs similarly for the multi-year forecasts (as compared to single year forecasts). Some fairly quick advances may be possible with drought indices, but extension through biophysical models to drought and hydrologic impacts is still just emerging in seasonal prediction (Sheffield et al., 2014; Shukla et al., 2014; Yuan et al., 2015), and could be expected to be useful but requiring longer-term project development for the new I2D information.

iii) How does a user interpret the multi-year information, in the context of recent climate experiences?

The multi-year information will likely be expressed relative to a given base period, typically to now, an approximately 30-year period over recent years has been considered sufficient. For rainfall, a product may be expressed as a percent of the average experienced in that base period. Alternatively, a forecast may be expressed in terms of the probability of specified rainfall categories (often terciles for seasonal forecasts), with boundaries appropriate to the base period. If the forecast is for years 2–5, an important question may concern the extent to which the forecast is different from the last five years or ten years? If the forecast is for 80% of normal, is that really different from the last ten years, over which rainfall may have averaged 80% of the 30-year base period? This is an issue that is amplified for multi-year forecasts compared to the existing seasonal forecast – the variance of a multi-year time series is smaller than that of individual years, and therefore the multi-year forecast is more sensitive to choice of base period for its expression. A further complication is the often-present need to detrend the output of multi-year forecasts (as was the case in Sheen et al., 2017); this creates practical but not insurmountable challenges for model output post-processing to arrive at the most meaningful product.

iv) Confidence in the mechanisms delivering skill and the challenge of attribution

It would be unwise to generate multi-year products without insights on their physical basis in areas targeted for use. Uncertainty is added to by the literature on Sahel decadal anomalies; this should not be considered a constraint to stop product development (if a model shows convincing skill in an extended hindcast period), but it does imply that capacity is needed in modelling centres to diagnose the forecasts, at least at this initial stage. In the context of the Sahel, some additional expert best judgement of uncertainty would be appropriate, given the presence in the literature of debates surrounding just how much fraction of multi-year variance is attributable to sea-surface temperature (SST) variations. For example, while some literature emphasizes for a direct role of greenhouse gases in the recent decadal enhanced precipitation in the Sahel, others (e.g. Nicholson et al., 2018) suggest recent decadal SST changes should have moistened the Sahel even more strongly than has been observed, and therefore a missing additional factor is also operating in the opposite direction i.e. suppressing rainfall. Any issued decadal prediction should be aware of these debates in the literature, and able to interpret the forecasts produced.

v) Updating forecasts: methodological challenges to arrive at the best strategy

Each year, when a forecast is made, the target years 2–5 represent a different period (stepped forward by one year from the previous year's forecast). So the forecast is technically not an update for a given period, but rather an update on outlook tendencies. This would require careful communication to users, to avoid an impression of inconsistencies in forecasts from one year to the next. Again, there would be an important role for interpretation of forecast, and in particular, reasons for any differences in the current 2–5 year forecast compared to the one issued in the previous year. It is not clear if users would wish a fixed period (say a four year period 2020–2023, first forecast in 2018) to be gradually updated – for example in late 2021, this would use observations for the 2020–2021 rainy seasons, combined with forecasts for 2022–2023.

vi) Multi-model and multi-run (ensemble) forecasting

The development of a multi-model forecast would be preferable, as per protocol with seasonal forecasts. However, the simple multi-model averaging approach tested in Sheen et al. (2017) is not very effective. A better approach would be to diagnose each input model using criteria to identify which models to include at this experimental stage (e.g. hindcast skill level above a given threshold, confirmation of a given mechanism being present in a model). Even once confidence is established in a given model or set of models, it is then, like in seasonal forecasting, a matter of developing a practical forecasting approach to best estimate the range of possible outcomes. Ensemble approaches attempt to sample a realistic range of starting conditions from which model forecasts are run, with the aim of best sampling the true possible spread of forecast outcomes. This inherently communicates uncertainty in forecasts, although ensembles need to be compared with actual outcomes to check that they are properly calibrated in their representation of uncertainty, with the option of further statistical adjustment. The magnitude of benefits and optimal choices of increasing ensemble size and model combination are still being explored for decadal predictions (e.g., Sienz et al. 2016). At this stage, it is useful to note this dimension of model forecasting and implied uncertainty, but it represents an issue that has been adequately addressed for seasonal forecasts and best practices can be expected to be found by modeling centres for these longer timescale forecasts.

vii) Prospects for downscaled information (smaller spatial scales and weather within climate)

As noted in (i) above, many users indicate the potential value of information at relevant (high) resolutions, a request found for climate information at other timescales (such as seasonal, global change) as well. While stakeholder discussions in Sudan suggested this may not need to be an immediate prerequisite for the initial communication and assessment of I2D predictions, it is nonetheless relevant to consider the future prospects for such information. To date, there are very few studies explicitly addressing downscaling of I2D forecasts. The basic downscaling concepts of translating large scale climate forecasts (from global climate models) into higher resolution information are well-established (e.g. Hewitson and Crane, 1996; Fowler et al., 2007), and these can in principle be applied to decadal predictions (general discussion in Marotzke et al., 2016; illustrative application to wind power in Reyers et al., 2015). For seasonal forecasts, downscaling approaches have often proved effective for creating information at scales for impact assessment in agriculture and water resources (e.g. Hansen and Indeje, 2004; Hansen et al., 2011; Yuan et al., 2015). It is not always clear that traditional forecast skill measures show discernable increase through the application of such techniques (e.g. discussion in Manzanas et al., 2018), but the information may be considered to carry value in enabling the impact assessments, as well as having the potential to deliver better reliability (realistic ensemble spread) in a statistical sense (Marotzke et al., 2016). In addition, it may be cautiously noted that the new generation of very high resolution climate models (convection permitting models), run for global or regional domains (e.g. Pal et al., 2019; Stratton et al., 2018) are showing promising improvements in the representation of weather features such as rainfall systems that cause intense rainfall events, which implies the potential to better estimate risks of flooding through such models, as well as detailed climate variations related to surface features such as small-scale orography or water bodies. Overall, it is considered that there are realistic prospects for addressing many of the scale needs of users, but for I2D forecasts explicitly, the topic currently remains largely unexplored and ripe for practical research. One caveat for many regions though is the role played by high resolution observed data for validation, without which, confidence in the downscaled information remains problematic.

viii) Capacity to develop and deliver the forecast

At modelling centres, multi-year prediction has an implied longer-term investment, including the subsequent evaluation of forecasts and their diagnostic interpretation. For issuing forecasts, there may also need to be capacity to diagnose the mechanisms giving rise to hindcast skill, and for the experimental operational forecast, the approximate large-scale source of the forecast anomaly signal present in the model, to give legitimacy to the information. Capacity considerations go beyond those of modelling centres producing the forecasts to include National Meteorological Agencies or other actors involved in forecast dissemination and use. Given the complex technical issues associated with developing the types of end products described above, the demands (and opportunities) at the receiving end are likely to be considerable and require detailed consideration. Section 5 discusses these issues with respect to perspectives in Sudan.

Table 1
Organisations with members present at the workshop.

Organisation	
Swedish Embassy/Swedish International Development Cooperation Agency	Ministry of Water Resources, Irrigation and Electricity – MOWRIE-General
Sudan Meteorological Authority	World Food Programme
Tufts University	UNDP – Climate Risk Finance
University of Medical Science and Technology	Catholic Relief Services
UN Habitat	MOWRIE-Dams Directorate
UNDP	DFID
UNEP	FAO
UNHCR	UNRCO
UNICEF	IOM
University of Khartoum – Institute of Environmental Studies	MOWRIE-Ground Water & Wadi Directorate-Wadis Department
MOWRIE-Dams Implementation Unit	WHO

5. Stakeholder perspectives in Sudan

A one-day workshop – Exploring applications of multi-year predictability of Sahel rainfall – was held in Khartoum, October 2018. A range of government, multi-laterals and academic participants attended (see organization list in Table 1). Presentations covered the latest science on: Sahel climate predictability (timescales, variables and skill); and lessons from seasonal forecast use considered relevant for multi-year applications. Thematic break-out groups were organized around (i) Agriculture, (ii) Water and (iii) Food Security/Social Safety Nets, to discuss examples of potential applications of the two new forecast products (longer-lead seasonal forecast, and multi-year forecast) and their challenges and opportunities.

In the workshop discussion some key points recurred as follows. First, confidence in the information (Credibility) was a major concern, with the Sudan Meteorological Authority (SMA) particularly concerned about trust and reliability and moreover a widely held concern that communities would need to be convinced about effectiveness. How the new multi-year forecast would be communicated and received given existing challenges with dissemination and use of seasonal forecasts was also a concern. To address this, discussions suggested higher-level technical recipients, who could use general indications from regional indices, were likely best placed to explore uptake at testing stages, where credibility may be established through technical discussion.

Second, the forecast variables and climate features of interest (Salience). Forecasts of rainy season characteristics were of interest, but there was also substantial interest in forecasts of temperatures (and wind speed) during the dry season due to a range of impacts including on livestock, irrigation, crop production and human health. Participants noted that a 2–5 year average would not give users what they need because there is more interest in information about individual years. This was considered an important issue to develop as some progress could be achieved with relatively modest additional climate analysis. Furthermore, the incorporation of more information or downscaling forecasts to local areas was something that users desired, but this requires considerable capacity and resources. A desire for information on rainfall onset and cessation also emerged.

Third, various questions about understanding what underlies the information, from national to local perspectives (Legitimacy building). These included questions on the main influencing processes of relevance to Sudan climate that are represented in the model, and the reasons behind skill reductions with longer lead times. A further general issue discussed was that research institutions in Sudan were also potential users of the new science, developing and applying in national context the new findings presented at the workshop.

Common to these discussions was concern about capacity of the SMA to engage in this novel but technically demanding activity. These concerns related to lack of financial resources to support the considerable additional staff activities required to collaborate with the forecast producers and co-produce products with users in country, due to the pressing need to concentrate on existing operational forecasting duties.

5.1. Agriculture

For agricultural purposes, the increased lead-time for seasonal forecasts was considered to be of particular interest, noting that having information available in March would be a valuable target, as many plans for the upcoming season are set at that time. There was interest in information about mean anomalies of recent periods (5-year, 10-year, 30-year), to help appreciate areas already under climate stress, and therefore help interpret the implications of the multi-year forecast. There was recognition that a sequence of severe dry years has not been experienced since the 1980s, and while there is some evidence of greater drought resilience after learning from the 1980s experience, it is unclear what the impact now would be of a series (given multi-year tendency) of severe dry years. This led to discussion on the importance of understanding the causes of recent shifts in climatic zones, with implicit attribution of the drivers of Sudan's climate.

It was noted that SMA is experimenting with working with agricultural extension in several areas, providing a package of products from weather to seasonal forecasts. The general feeling in the discussion was that multi-year forecasts were for now better targeted at higher-level users, rather than for agriculture extension/farmer uptake at this stage. Banks (and insurance companies) in general were considered likely to have the capacity to assimilate the probability multi-year forecast into their risk management strategies related to agriculture. Large agriculture companies might also have the capacity and flexibility to benefit from multi-year forecasts (such as planning for herbicide use, crops with multi-year growth cycles and seed strategies).

In addition to applications in rainfed agriculture, opportunities for supporting pastoralist migration were highlighted. In Darfur, for example, pastoralists are using north to south movement corridors, following the rains and grazing areas. There is potential to support interventions using forecasts to delay movement of animals going south, to take full advantage of grazing resources, where good rainfall is expected. But reliability of forecasts was emphasized as critical with an example given of Darfur during the 2015/16 El Niño when northern areas had reasonable rainfall but southern areas were dry. Whilst the Sheen et al. (2017) information is not at this spatial scale such levels of spatial detail may subsequently become possible with further high resolution research, including through the use of higher resolution GCMs that are intended to capture such spatial variation detail when there is a physical driver, perhaps resulting from interactions with heterogenous surface conditions (such as lakes and mountains) (e.g. Stratton et al., 2018).

5.1.1. On potential products

Discussion of potential products highlighted both rainy season and dry season information that could be advanced through a co-production process with a high level partner initially, such as strategy for practices and policies within the World Food Programme (WFP). In the context of an entity such as WFP, this could include facilitating earlier and more effective project preparations and implementation.

Information on the main rainy season: For the multi-year product, given its new nature and uncertainty, higher-level interventions were initially considered most appropriate to explore (see next sub-section, including food security). For the extended-lead seasonal forecast, many possible interventions were envisioned provided reliable probabilistic information on the upcoming rainy season could be made available, with the provision of information around March for the upcoming rainy season considered particularly useful. This would require a detailed examination of the skill over Sudan, and based on this, further stakeholder discussions could be undertaken to explore specific experimental product design, such as between SMA and WFP. One aspect that was noted is that sparse verification data may be leading to an underestimate of skill in Sheen et al. (2017) such that evaluations targeting national application with access to more data through collaboration may give better skill estimates.

Information on the winter dry season: Given the clear expression for demand for agricultural purposes during the winter cropping season, this was considered a fruitful area to explore with a regional partner such as WFP. In addition to day-mean temperature over the season, information on maximum and minimum temperature and wind speed would all be able to inform specific aspects of agricultural activity. For example, excessive maximum temperatures in February to March can lead to crop failure. There was interest in seasonal forecasts as well as multi-year forecast information. This may be explored through predictability in regional Sahel indices (e.g. an index for February-March mean maximum temperature), as well as in the context of specific indices and applications at the national level.

5.2. Discussion of risk management entry points in water, food security and social safety nets

Substantial potential was noted in the area of *reservoir management for hydropower and irrigation* **–** most notably for use in the Nile system because of the storage facility of reservoirs (particularly Merowe and Roseries) and presence of major irrigation schemes. This was considered a good entry point for both products (long-lead seasonal and multi-year) because there are already established some early warning measures (particularly for flood risk) that could be built upon. There was interest in forecasting deficits in electricity generation related to problems in the flood season (too much water) and dry season (too little). The information could help with reservoir management decisions and this could become more critical with the completion of the Grand Ethiopian Renaissance Dam as multiple dry years could lead to problems in Sudan particularly during the filling stage and because of the dam's over-year storage function.

Some potential was also noted for advance warning of particularly wet years for an operational *flood early warning system* for the Blue Nile that uses combined data sources for input derived from meteorological stations, hydromet stations and satellite data (includes critical river levels as trigger points for action).

Two other opportunities were discussed in brief: beyond areas served by the Nile there is extensive reliance on rainwater harvesting particularly in drier areas. Communities are reliant on alluvial aquifers in some eastern areas and are impacted by low groundwater levels associated with low rainfall seasons. Whilst early warning would be helpful, information including rainfall intensity and distribution and evaporation was considered most useful.

In terms of food security and social safety nets, seasonal forecasting was considered to have good potential for contingency planning with due consideration of precision and reliability of the climate information. Index-based triggers in social protection programmes (e.g. Bastagli and Hardman, 2015) are potentially a strong candidate for adopting the longer-lead seasonal or multi-year forecasts. Such programmes may be constructed to be responsive to regional indices, with action triggered among larger-scale actors. This may be the most appropriate way to start with I2D predictions, given the indications in the science literature, and the concerns of stakeholders (as reported in Section 5.1), and also reflects early discussion of ways to start with seasonal forecasts in the Sahel (Hulme et al., 1992), although the methodology of index-based triggers was not available at that time.

It was emphasized that the seasonal forecast must be one of many tools so that decisions are based on multiple sources of information; the forecast should integrate with existing knowledge and risk management methods already in place. Discussions also explored micro-finance and risk using weather index insurance. The potential was noted to undertake some product development with general agricultural priorities in mind. Also, an operational index for safety net actions was considered a good potential application of the new climate forecast information. An example was discussed of a productive safety net programme in North Kordofan which delivers cash transfers using a proxy. This was considered to have potential to explore how reactive the system could be if it had a longer lead forecast and whether it would be able to incorporate that predictability for earlier fundraising. At the moment, cash is calculated based on a minimum or accepted wage for unskilled labour and if paid earlier, beneficiaries might be able to avoid losing their assets in drought years.

6. Concluding discussion

There are some specific insights that have emerged relating to I2D prediction and its application in the Sahel and specifically in the Sudan (see (i) below). There are also some observations based on the experience with the process of exploring I2D relevance and potential for applications in a given region (see (ii) below).

(i) Specific insights

The new longer-lead interannual forecasts have similar issues to those of the existing seasonal forecasts (e.g. forecast format, confidence in mechanisms delivering skill, capacity to develop, deliver and use the forecast), albeit, with new challenges of effectively managing the information multiple months ahead of the rainy season. For the multi-year forecast information (specifically here, years 2–5), the response from stakeholders, particularly ones working at larger scales, suggests some interest to engage on the information. This could be in the form of experimentation with operational tercile-style (or other similar) forecasts for regional indices to explore interest in the topic. In addition, both national climate capacity and stakeholders emphasized the value of information in the dry season as well, especially temperature, but also notably wind speed. At least for temperature, good skill is anticipated, and so experimental tercile forecasts for temperature should be assessed. Such generic products may be complemented by assessments of recent anomalies for context, to assess the extent to which the multi-year forecast represents a continuation of recent patterns/trends, or a departure from recent conditions.

Assessment of the planning applications for new forecast information on 2–5 year timescales is in its infancy and in locations where skill exists careful consideration of potential by user groups will be required. This timescale may not be relevant to most users targeted with seasonal timescale information, only those that have over-year and multi-year requirements in their planning and management, along with sufficient capacity to engage with the new process. In terms of furthering discussions with stakeholders in Sudan, the potential of incorporating regional indices into food security oriented safety nets was strongly encouraged, and such discussions may be coupled with national/regional development considerations on investments, to make those as efficiently as possible in risk management contexts. Emphasis on properly calibrated probabilities is especially key for such actors, who are well-placed to integrate such information. Therefore, this suggests need for applied climate science work to ensure information from hindcasts as well as ensemble (within and across models) outputs are used in the best way possible to generate probabilistic information.

Longer-lead seasonal forecast potential for agriculture was clearly recognized: information available in March opens an array of new early-season management possibilities. However, the experimental and modest levels of skill suggest use may at this stage be best explored through national/regional strategies of stakeholders such as in the case of Sudan the World Food Programme.

Longer-term initiatives were especially identified in the water sector, where there is emerging potential to integrate climate information across timescales for effective infrastructure and operational management strategies at regional scales. The potential to influence water harvesting was also noted, with a national research centre in Sudan a potential partner to explore co-production of products at interannual and multi-year timescales.

Additional forecast variables of interest included rainy season characteristics (e.g. onset and cessation) and the risk of high temperatures, especially during the dry season. Perhaps most pertinent of all, workshop participants noted that a 2–5 year average could be misleading, and clearly not give users what they need because there is more interest in information about individual years (including risk of a drought year in the forecast period), motivating approaches to temporally downscale the information, in some ways analogous to the challenge to downscale a seasonal prediction to the daily timescale. Even a quantification of relatively uniform risks across years within the forecast period would begin to provide credibility on this question, but there is need for research to establish best practices in making such estimates.

(ii) Overall process

As different regions come to consider the possible extension of seasonal forecasting to include the I2D information, it may be helpful to reflect on the overall experience and process followed here. A review of the climate science from the perspective of readiness for operationalization (both logistical and in terms of system understanding) provides scientific framing from the climate perspective. For multi-year (primarily here up to 5-year) forecasts, several new practical technical issues emerge (as compared to existing short-lead time seasonal forecasting) including: existence of interannual variability within the forecast period; need for knowledge on the recent multi-year mean (e.g. 5-year) climate anomalies for reference interpretation of the 5-year forecast; questions on attribution of the 5-year climate anomaly, including across natural and anthropogenic sources; questions on forecast updating strategy, so that the update has greatest meaning to a user; 5-years is a long time over which a forecast validation unfolds, and implies monitoring and final evaluation after the 5-year period.

Likewise, a framing of the main climate impacts in the region on the I2D timeframe and experiences with integration of the existing seasonal forecast into sectoral risk management practices provides an important knowledge base from the applications perspective. Indeed, most regions now have about 20 years of experience with the new generation of seasonal forecasts, and this provides an invaluable knowledge and practice base to build on. Indeed, these perspectives provided key inputs to stakeholder discussions and, we believe, helped substantially in generating the constructive feedback that is reported in this perspective.

As forecasts represent longer averaging periods (e.g. years 2–5), decadal variation becomes more dominant, and presentation of information requires careful choice of base line climatology (to define anomalies) and communication of information in that context. A key outcome concerned the importance of attribution of recent multi-year anomalies in the regional climate system, as a starting point for interpretation of multi-year forecasts. This was emphasized in the stakeholder discussions, and was expressed by the national meteorological community in Sudan as something that, with capacity support (to make progress on attribution), would assist greatly in their interaction with climate service customers. The potential for confusion is high, which if it takes hold in a region, would likely inhibit the optimal application of multi-year forecasts.

The demanding technical requirements and their experimental nature reinforce the need to consider the capacity of National Meteorological Agencies (NMAs) in many low income countries, including Sudan, to engage in this emerging area of forecasting. While infrastructure and capacity gaps and financial precarity are known to be important for many NMAs, recent extensive funding and initiatives are going some way to address these concerns (Harvey et al., 2019), although progress varies considerably between countries. Beyond the technical issues are the demands on staff to co-produce products to make the most of their potential by adopting user-centred climate service design and recognizing the importance of interactions with wider stakeholder groups like non-state actors (Dinku et al. 2014; Harvey et al., 2019; Vaughan et al., 2019). As noted for climate services in sub-Saharan Africa more broadly by Harvey et al. (2019) greater effort on I2D forecasting specifically would require careful focus on the priorities of NMAs in the context of not just technical capacity but also their political and economic operation.

Stimulation of some generic user-oriented climate products for I2D in the Sahel or specifically for the Sudan, such as well-calibrated multi-year rainfall tercile probability estimates, may be significantly advanced by the process reported here to date. But as with the seasonal forecasting experience, this must be viewed as just the beginning. In terms of fully effective climate service development, this analysis in Sudan is recognized to be an exploratory phase, a first step along the pathway to climate services development that integrate I2D information.

Author contributions

Both authors conceived the paper, NW led the drafting and Sections 2–4, DC led Section 5, both authors contributed equally to other sections and subsequent edits.

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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