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SIMBOL: A method to co-produce impact-based seasonal outlooks

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HIGHLIGHTS

- Seasonal outlooks often fail to translate into probabilistic impact information.
- Impact-Based Forecasting methods can be adapted to seasonal timescales.
- Potential impacts can be characterized prior to the release of seasonal outlooks.
- Co-production sessions at Regional/National Climate Outlook Forums play a vital role.
- The SIMBOL method provides a scalable approach for impact-based seasonal outlooks.

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ABSTRACT

Communities across the world are sensitive to the impacts of seasonal climate variability, particularly in regions where distinct rainfall seasons support livelihoods and economic activities. Timely and actionable warnings of hazardous seasonal conditions and advisories tailored to different sectors can enable people to respond, reduce risks, and seize opportunities. Yet despite advances in seasonal forecasting methods and capabilities, there remains a lack of "impact-based" seasonal climate outlooks that more directly serve societal needs while preserving uncertainty information for risk-based decision making. Here we present a new method to address this gap, focusing on implementation in Regional and National Climate Outlook Forums and targeted at intermediary users who support the communication of seasonal outlooks across scales. The Seasonal IMpact-Based OutLook (SIMBOL) method provides a simple and scalable approach for use in regions across the world. We describe the conceptual basis for the method, embedded in the Impact-Based Forecasting (IBF) framework, and demonstrate its application through a case study of seasonal total rainfall impacts on groundwater in Somalia, trialled at the Greater Horn of Africa Climate Outlook Forum (GHACOF) in February 2024. We elaborate the critical role of co-production amongst different knowledge holders for characterizing impacts across all potential outlook outcomes, avoiding advisories that are biased towards the "most likely" outcome. We also discuss the importance of objective evidence from impact modelling and observations to consider antecedent conditions. Lessons learned and challenges encountered in developing the method are discussed to inform opportunities for future development and implementation in different contexts.

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1. Introduction

1.1. Enhancing seasonal climate outlooks

Coping with seasonal climate variability is critical to lives and livelihoods, especially in regions experiencing an increase in climate-related hazards in a changing climate (Pörtner et al., 2022). For example, in the Horn of Africa Drylands (HAD), many communities rely on seasonal rainfall and groundwater resources for drinking water and economic activities, with successive poor rainfall seasons leading to long-term negative consequences (Anderson et al., 2023). The effective characterisation and communication of seasonal climate outlooks (hereafter simply seasonal outlooks) is important to ensure governments and communities have actionable information to avoid and mitigate potential damages (e.g., higher rainfall leading to greater flood risk) or to exploit opportunities (e.g., fewer frost nights leading to favorable crop conditions). However, at present, information is often unfit for purpose because it can be irrelevant to local decision-making contexts and overly technical, precluding understanding by communities (Bruno Soares et al., 2018). With some exceptions (e.g., MacLeod et al., 2023), seasonal outlooks also typically only provide information about atmospheric variables such as rainfall and temperature, rather than societally-relevant impacts information (e.g., water availability, flood risk, vegetation health).

In the past two decades, there have been considerable advances in seasonal and subseasonal forecasts (WMO, 2019), with increased access to model data (e.g., Copernicus Climate Change Service). Using outputs from forecast models, seasonal outlooks are now provided in regions across the world for a range of climate variables, often using a tercile approach indicating whether places are likely to experience "above-normal", "below-normal" or "near-normal" conditions in the upcoming season compared to climatology. Despite progress in the science and delivery of seasonal outlooks, there are however currently no consistent and widely used methods to translate seasonal outlooks into impact-based outlooks and warnings.

Information on seasonal climate impacts is widely called for (MacLeod et al., 2024; Nkiaka et al., 2020; Shyrokaya et al., 2024; Steynor and Pasquini, 2022) and improvements in climate impact modeling (e.g., hydrological and land surface models) provide opportunities to better serve decision needs. However, in synthesizing and simplifying the content of seasonal outlooks for impact statements to society, current approaches often place most or all of the emphasis on the "most likely" tercile outcome. For example, in the Towards Forecast Based Preparedness (ForPAc) project in Kenya, it was recognized that "the tendency is for stakeholders to consider the highest probability in decisions and actions, often disregarding other lower probabilities" (ICHA, 2020). By orienting impact statements towards deterministic messages, information content from seasonal outlooks can be lost or misinterpreted, risking maladaptive decisions and increased risks to society. A central challenge is how to translate seasonal outlooks into *probabilistic impact-based* seasonal outlooks.

1.2. Regional and National Climate Outlook Forums

Seasonal forecasts are provided by many institutions across the public and private sectors. In many parts of the world, Regional Climate Outlook Forums (RCOFs) provide a key role in generating and communicating seasonal outlooks to a range of stakeholders. Coordinated by the World Meteorological Organisation (WMO), in collaboration with Regional Climate Centres (RCCs) and National Meteorological and Hydrological Services (NMHSs), RCOFs were initiated in the late 1990s and are aligned to WMO Regional Associations. In some countries, RCOF outputs are translated to the national level via National Climate Outlook Forums (NCOFs, sometimes referred to as National Monsoon Forums). RCOFs and NCOFs bring together climate experts and stakeholders to communicate seasonal outlooks and inform decision making, as well as enabling opportunities for engagement, capability building and networking (Daly and Dessai, 2018). Such forums have evolved independently to align with the needs and capabilities of their respective region, and vary in their level of maturity and sustainability (WMO 2016). While most remain provider dominated, climate service user forums held at RCOFs and NCOFs are gaining prominence to enable interactions amongst users and stakeholders across sectors.

One of the most mature RCOFs is the Greater Horn of Africa Climate Outlook Forum (GHACOF) in East Africa, convened by the Intergovernmental Authority on Development (IGAD) Climate Prediction & Applications Centre (ICPAC) as the RCC for East Africa. GHACOF has been operational for over 25 years, with extensive engagement across climate information provider and user communities, including scientists, government and non-governmental organizations, development partners, media, industry, and civil society stakeholders. In addition to disseminating seasonal outlooks three times a year ahead of important rainfall seasons, GHACOF organizes co-production sessions across different sectors (water and energy, agriculture and food security, livestock, health and nutrition, and disaster risk management) to tailor the seasonal outlook. These sessions include opportunities to review impacts experienced in past seasons, and to determine advisories for the coming season across ten East African countries: Burundi, Djibouti, Ethiopia, Kenya, Rwanda, Somalia, South Sudan, Sudan, Tanzania, and Uganda.

A key output of the GHACOF is the "summary for decision makers" – a sector-specific impact analysis and advisory report issued to stakeholders in different member countries. To simplify the information, the impact statements contained in this report focus on the expected impacts for the most probable tercile outcome. For example, if the seasonal climate outlook suggests a 50 % likelihood of above-normal rainfall in a region and 25 % each for near-normal and below-normal rainfall, the advisories might exclusively focus on the risks of above-normal rainfall and recommend flood adaptation measures. Conversely, if below-normal rainfall is the most probable tercile outcome, the advisories may focus solely on drought measures. While this approach provides clear and actionable guidance, it does not account for the less likely but still possible and potentially high-impact scenarios. As a result, stakeholders will be less prepared for the range of potential outcomes. This gap highlights the need to enhance advisories to support decision strategies that are robust to the uncertainty (Lempert, 2019).

1.3. Efforts to advance seasonal forecasting for impacts and decision making

The development of impact-based seasonal outlooks is not an entirely new endeavor. Different approaches have attempted to bridge the gap between seasonal forecasting and the information required for decisions. For example, Hopper et al., (2017) describe the development of local impact-based seasonal outlooks (LIBSOs) in Texas, USA, delivered through information products and webinars. Their approach involves collaboration between climate and sectoral experts to assess antecedent conditions and produce forecasts of above-, near-, or below-normal impacts for key risks (e.g., fire weather, river flooding), showing good skill, uptake and trust in the information amongst users (Dickinson et al., 2018). The WMO and United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP) have developed a training manual to support impact-based forecasting (IBF, defined and elaborated in section 2) and warning services (UNESCAP, 2021), presenting a method for communicating seasonal outlooks, expressed as the chances of exceeding risk thresholds overlaid on vulnerability and exposure datasets. While this approach can offer insight to technically proficient users, for more general audiences the outputs would likely require further simplification.

The need to balance scientific quality and practical feasibility for different audiences has been recognized in the development of impact-based services (e.g., Shyrokaya et al., 2024). It has also been shown that that users are more likely to respond to warnings if advice is tailored to their decision contexts and practices (e.g., Calvel et al., 2020). One decision-centered approach for drought IBF proposed by Boult et al., (2022) argues for dynamic risk thresholds that are modified on an event-by-event basis, using assessments of current vulnerability. This enables decision-makers to choose to act on a lower forecasted likelihood of the hazard, should they believe that current vulnerability levels are particularly high (e.g., due to conflict).

A commonality between all current approaches to impact-based seasonal outlooks is that they integrate impact information after the seasonal climate forecast information has been released, and are therefore directly or indirectly influenced (and potentially biased) by the likelihood of different outcomes. Building on existing research and practice, here we introduce a new scalable method for generating impact-based seasonal outlooks that characterizes potential impacts prior to the release of seasonal outlooks, removing this bias and aiming to provide simple and actionable information.

In section 2 we provide the conceptual basis for the new method. In section 3 we introduce a case study of groundwater in Somalia, before elaborating the different methodological steps in section 4 using the case study. Section 5 discusses the lessons learned in developing the method and trialing it at the GHACOF, detailing the challenges and opportunities for implementing the method at scale. We conclude in section 6 on the value of the approach and next steps for development.

2. Conceptual approach: Adapting Impact-Based Forecasting

To improve the translation of probabilistic seasonal outlooks into impact-based seasonal outlooks and warnings, the UK Met Office and University of Bristol partnered with ICPAC through the Seasonal IMpact-Based OutLook (SIMBOL) project. The aim was to develop a new method, as a proof-of-concept, adapting Impact-Based Forecasting (IBF) approaches (Harrowsmith et al., 2020) that are now widely used in severe weather warning systems, evolving the focus of forecasts from "what the weather might be" to "what the weather might do" (WMO, 2015).

A central component of IBF is the use of a risk matrix (Fig. 1) that uses colored risk levels to express the combined likelihood of hazardous weather (e.g., a heatwave) and its expected impacts (e.g., heat-related hospital admissions). Using this approach, a yellow warning would be issued for a low likelihood of a high impact event, or high likelihood of a modest impact event, while a red warning would be issued when a severe impact from a hazardous weather event is highly likely. The risk level and any warnings issued result from the combined assessment of likelihood and impact.

Adapted to seasonal timescales, IBF has the potential to inform longer-term anticipatory actions to increase preparedness and help mitigate risks, but there are important considerations in extending the approach to longer lead-times. For example, while IBF is typically used when anticipating a hazardous weather event, such as a heatwave or windstorm, seasonal outlooks are provided ahead of every season and the impacts of a season can be hazardous, negligible, or even advantageous (e.g., ample rains leading to high crop yields). And over the course of a season, individual weather events may lead to losses at some times and gains at others, so the overall aggregate impact could be mixed. In developing impact-based seasonal outlooks at RCOFs and NCOFs, it is necessary to consider if and how to characterize and communicate potential positive impacts. In the SIMBOL method, elaborated fully in section 4, a seasonal climate variable is therefore not referred to as a "hazard" (as in IBF) but rather the more generalized term "seasonal climatic impact driver", consistent with the terminology used by the Intergovernmental Panel on Climate Change (IPCC) in the sixth assessment report (see IPCC AR6 Chapter 12, FAQ 12.1 – Ranasinghe et al., 2021).

Another key difference is that on seasonal climate timescales the term "outlook" rather than "forecast" is adopted to reflect the reduced level of accuracy and precision associated with longer-range seasonal predictions. Generating a seasonal outlook involves estimating the future state of the atmosphere in a region of interest many weeks or months in advance. Due to the chaotic nature of the atmosphere, this takes us beyond the time horizons where precise and skillful weather forecasts are feasible using forecasts initialized with observations of the atmosphere. For lead times of several weeks to a season ahead, the predictability for atmospheric variables of interest (e.g., temperature, humidity) comes from slower evolving climate processes (e.g., remote ocean surface temperatures, soil moisture content) and their influence on a region's weather. Unlike weather forecasts used in IBF, seasonal outlooks provide information about how the coming season may differ from "normal" conditions (seasonal anomalies from a long-term average) arising from the sustained influence of internal climate variability.

Seasonal outlooks produced at RCOFs and NCOFs are typically expressed as the likelihood of a season being above-normal, below-normal, or near-normal, calculated for each location compared to a historical reference period (climatology). Using these three "tercile" categories, over many years we would expect near-normal seasons to occur 1/3 (33 %) of the time and, similarly, above-normal and below-normal seasons to each occur 1/3 (33 %) of the time. A seasonal outlook then provides an estimate of how these probabilities are altered for the next season due to the influence of seasonal climate processes. For example, a seasonal outlook may give a 50 % chance of above-normal conditions, 30 % chance of near-normal, and 20 % chance of below-normal conditions, if the situation favors an above-normal season. Other common ways of expressing a seasonal outlook include splitting the forecast distribution into two categories (e.g., chance of being above and below a long-term average) or more categories (e.g., "quintiles" where each category has a 20 % chance of occurring with reference to climatology). In all cases, we must consider multiple future outcomes and different potential impacts.

A final important consideration in the application of IBF on seasonal timescales is that skillful outlooks are not always available, either due to

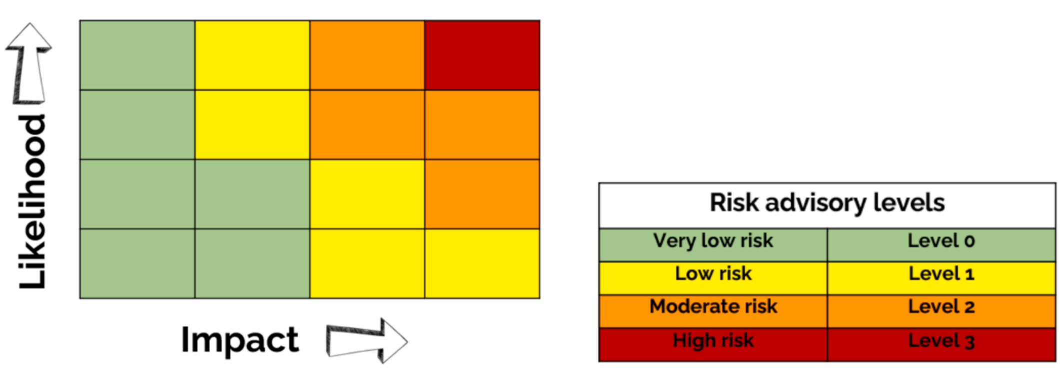

Fig. 1. Example of a 4x4 impact-based forecasting risk matrix, and corresponding risk advisory levels.

limited predictability or model inadequacy. In some parts of the world seasonal predictability is low or absent altogether (Doblas-Reyes et al., 2013). In general, extratropical regions are considered to have lower predictability because internal high-frequency variations in synoptic systems dominate, with greater predictability in the tropics where the influence of the El Niño Southern Oscillation and other modes of tropical variability are stronger (Sun and Wang, 2013). However, there is considerable spatio-temporal variability in predictability around the world, and in some places there is high predictability for some seasons and low predictability for others (Doblas-Reyes et al., 2013; Pirret et al., 2020). In East Africa, the skill of the October-November-December (OND) "short rains" season is greater than the March-April-May (MAM) "long rains" season (Busker et al., 2022). Gudoshava et al., (2024) notes that the "low skill in the long rains has the potential to erode the public trust thereby reducing the uptake of the early warning information, and reducing preparedness to the extreme events". The implication for impact-based seasonal outlooks is that careful interpretation of likelihood information is required, and low skill must be accounted for within the provision of information.

In addition to the conceptual challenges related to the information content of seasonal outlooks, a key consideration in adapting IBF methods to seasonal timescales is determining how to leverage opportunities for co-produced impact-based outlooks, drawing on co-production principles such as inclusivity and collaboration (Vincent et al., 2018; McClure et al., 2024). In particular, co-production "as a process" can provide considerable value in addition to its role in generating improved outputs (Jack et al., 2021) and the conversations required to distill diverse sources of information and expertise can yield useful outcomes beyond the actual outlook product. Importantly, however, the intent here is not to create bespoke co-produced outlooks for each unique decision context but rather develop a standardized operational service for broader applications. Therefore, some co-production principles (e.g., flexibility) have to be considered carefully, balancing the role of co-production approaches with standardized automated processes.

Within the SIMBOL method (section 4) we view co-production through a normative lens as a form of iterative interaction (Bremer and Meisch, 2017), promoting consultation amongst information users and providers to generate more useful information to guide actions. With a focus on RCOFs and NCOFs, providers refer to RCCs and NMHSs and users are primarily government stakeholders (e.g., ministries responsible for disaster risk reduction or key sectors like agriculture and energy), NGOs, humanitarian agencies and donors, as well as broader intermediaries working with vulnerable communities or sector-based organisations. Target users therefore represent individuals and organisations further upstream in the climate services "value chain" or "value web" (Hewitt and Stone, 2021) than vulnerable communities and households dealing directly with climate risks. Yet outlooks produced using the SIMBOL method may also be communicated and further tailored for a range of end-users by those with local expertise and knowledge.

3. Case study: Groundwater in Somalia

We now introduce our case study, ahead of elaborating the different steps in the SIMBOL method introduced fully in section 4.

The GHACOF provides a forum to develop sector-specific advisories for stakeholders in countries across East Africa (see section 1.2). In support of the GHACOF, the DOWN2EARTH project, funded by the European Union's Horizon 2020 programme, aimed to improve regional climate services delivery with a focus on water and food security. Through collaborating with scientists on DOWN2EARTH, an opportunity arose to introduce and trial the SIMBOL method within the co-production session for the water and energy sector at the 66th GHACOF held in Uganda, February 2024. The session included people from different East African countries spanning provider organizations (e.g., NMHSs), intermediaries and climate service professionals, and users of the seasonal outlooks (e.g., hydropower stakeholders, officials from water ministries). A relevant example of seasonal climate impacts was required to introduce the SIMBOL method and trial the approach with attendees at the co-production session.

A specific focus on groundwater in Somalia was chosen because of a newly developed hydrological impact-based modelling capability developed in DOWN2EARTH (Quichimbo et al., 2021), and the importance of groundwater to lives and livelihoods in dryland regions, such as Somalia. For many parts of Somalia, groundwater is the primary source of drinking water for humans and livestock, especially during drought periods. The groundwater system in Somalia is dominated by thick consolidated sedimentary aquifers, with small outcrops of metamorphic and intrusive rocks located in northern and southern coastal areas. Aquifers are deep and some have water quality issues, such as salinity. Shallow groundwater systems are mainly located in alluvial settings along river corridors, with recharge during runoff events via infiltration through the riverbeds of ephemeral streams (FAO-SWALIM, 2012; Macdonald et al., 2010; Quiroga et al., 2022).

It has been observed that groundwater storage is increasing across the HAD region (Ethiopia, Kenya and Somalia), due in part to contributions from the increasing intensity of extreme rainfall (Adloff et al., 2022). However, there may be unfavorable water availability in any given season, and groundwater status at a particular location (e.g., a well) is not directly tied to the rainfall that occurs there since groundwater is influenced by a region's geology and moves from locations of high recharge along head gradients into lowlands. Forecasting changes to groundwater status for an upcoming season cannot therefore be simply inferred from seasonal rainfall outlooks, and requires additional evidence and expertise.

Hydrological modelling provides a useful tool for analyzing water fluxes and stores across a landscape, accounting for temporal lags between rainfall occurrence and rises in water tables, as well as recharge accumulated over multiple seasons. The DRYP hydrological model (Quichimbo et al., 2021) was used to provide example high resolution data as contextual antecedent information for the SIMBOL co-creation phase (see section 4.2). The model has been calibrated for the HAD region and supports the analysis of how rainfall is partitioned into evaporative losses, groundwater, soil moisture, and runoff (Quichimbo et al., 2023). Although the model considers all sources of water contributing to water storage fluctuations, the model does not characterize the quality or potential accessibility of groundwater resources, which would be relevant to warnings and advisories. Additionally, current simulations do not include human activities, such as groundwater abstractions which could potentially affect the groundwater status. Alternative sources of knowledge and evidence are therefore needed to interpret these factors, and provide a more holistic view of water security in regions reliant on groundwater.

4. SIMBOL method

The SIMBOL method consists of nine steps across three phases: 1) preparation ahead of a RCOF or NCOF, 2) co-creation within the forum, and 3) communication and evaluation of the impact-based outlooks (Fig. 2). The novelty of the method is in analyzing potential impacts for an upcoming season prior to the use of probability information from the seasonal outlook, contrasting with other approaches to generating impact-based seasonal outlooks that are created after the outlook is released (effectively starting at step 8). The SIMBOL method is also situated within the broader framework of IBF (Harrowsmith et al., 2020), which comprises a foundational co-design stage to understand needs for early actions and establish effective partnerships and collaborations amongst relevant users and stakeholders. In order for the SIMBOL method to be implemented, these partnerships and opportunities for collaboration must exist; at present, these conditions often do not exist across different RCOFs and NCOFs.

Fig. 2. SIMBOL method for co-developing impact-based seasonal outlooks.

4.1. Phase 1 – preparation

A preparation phase is the first important part of the method. This phase requires active engagement amongst impact specialists, decision makers and climate service providers at regional or national levels, which can take time and resources to achieve. Depending on the complexity of the impact and number of stakeholders to engage, this phase may take several months or longer to complete.

4.1.1. Step 1: Define the impact, region and seasonal climatic impact driver

The first step is to articulate key parameters for the impact-based seasonal outlook. The seasonal variable or seasonal climatic impact driver (CID) is equivalent to the "hazard" in IBF. It could be a seasonal statistic, such as seasonal-mean daily temperature, or a more specific variable characterizing the behavior of the atmosphere within a season – e.g., date of rainfall onset, or a sector-specific variable such as "growing degree days". Crucially, it must be an atmospheric variable, or combined variable (e.g., heat index that combines temperature and humidity) that can be determined from seasonal forecast information produced at a RCOF or NCOF.

Defining the nature of the impact is the most important but complex part of this initial step. Typically, in using IBF for severe weather warnings to the public, all impacts associated with a particular hazard are usually considered. For example, if the hazard is heavy rainfall, potential impacts might include flooding, landslides, crop losses and disruption to services. However, at RCOFs and NCOFs seasonal climate impacts are typically considered separately across different societal sectors – e.g., priority sectors of the Global Framework for Climate Services (Hewitt et al., 2012). In developing advisories for a specific sector (e.g., health), impacts of interest would then be limited to those which are most relevant (e.g., hospital admissions, damage to health facilities). Characterizing the impact also provides an opportunity to consider the disproportionate impacts on people who are particularly exposed or vulnerable to variable seasonal climate conditions. For example, if the impact of interest is the number of people displaced, we may further consider the number of men, women and children displaced, or the impacts on other marginalized communities.

Finally, we also need to specify the geographical region of interest. This could be a country, a province within a country, or a transboundary region. It does not need to be the entire spatial area covered by the seasonal outlook. We reflect on the challenges in identifying an appropriate scale in section 5.2.

In our case study, the impact sector chosen is water, with a more specific focus on groundwater noting its societal importance in dryland regions. The region is defined as Somalia, with northern, central, and southern Somalia as sub-regions of interest. The seasonal CID of interest is the seasonal total rainfall for the MAM long rains season, since this impacts on groundwater availability and the long rains season is also the main focus of the February GHACOF.

4.1.2. Step 2: Define likelihood thresholds

The y-axis of the IBF matrix (see section 2) represents the likelihood of the impact associated with the seasonal CID, comprising likelihood categories separated by thresholds. The number of categories may vary depending on the application, but most often three or four categories are used.

In communicating likelihood information to users, precise probabilities do not need to be explicitly stated as such quantitative information can be confusing for some users (Handmer and Proudley, 2007). Instead, words such as "high" or "low" likelihood are used to help people understand the relative chance of different outcomes. Carefully defining these words and the thresholds that separate each likelihood category in the matrix, provides the framework for characterizing likelihood.

For tercile-based seasonal outlooks, if an outcome has a probability greater than 33 % that means an increased likelihood of that outcome since each outcome has a 33 % chance based on climatology. Similarly, if the outlook probability is lower than 33 %, that would represent a decreased likelihood. The choice of thresholds for a very low, low, medium or high likelihood may therefore pivot around a 33 % chance as a central threshold (i.e., separating low from medium), but what constitutes a very low or high likelihood is subjective and needs defining at an appropriate level. Note that if two outcomes (e.g., above-normal and near-normal) result in the same impact, then is it the likelihood of that impact that is plotted in the IBF matrix – i.e., the combined likelihood of above-normal and near-normal conditions. We critically examine these choices further in section 5.4.

Following step 2, likelihood categories and thresholds were determined (Table 1), noting seasonal outlooks at the GHACOF (like many

Table 1
Likelihoods categories and thresholds for seasonal rainfall impacts on groundwater in Somalia.

Likelihood Category	Probability Thresholds
High	≥ 70 %
Medium	35 – 65 %
Low	15 – 30 %
Very Low	≤ 10 %

RCOFs) are given to the nearest 5 %. A “high” likelihood was considered to be a probability of 70 % or higher, as this represents more than a doubling of the 33 % climatological probability. Similarly, a “very low” likelihood was considered to be greater than a halving of the climatological chance. “Low” and “medium” likelihood ranges were then assigned to values in between, where climatology (33 %) separates low from medium. Crucially, should the expected impact from more than one outlook outcome be the same, the likelihood of that impact is a combined probability (following the IBF method). For example, if the expected impact for either near-normal or above-normal conditions is a “very low” impact, then we combine the probability of near-normal (e.g., 20 %) and above-normal (e.g., 40 %) conditions, resulting in a likelihood of 60 % of a very low impact.

4.1.3. Step 3: Define impact categories and co-develop impact table

The next step is to consider the impact in more detail. An “impact table” is used to define and characterize the severity of impacts on the x-axis of the IBF matrix. As with likelihood, a decision is required on how many impact levels are appropriate, and it needs to be decided whether or not to include positive outcomes, such as ample rains leading to high crop productivity – see section 5.3. Usually, impact levels range from minimal to severe (or low to high) with text describing the types and extent of impact expected at each level. Once created, the impact table is used to support discussions within the co-creation phase (section 4.2).

For severe weather early warning systems, impact tables are produced for each hazard and incorporate a wide range of impacts across sectors. However, when using the approach to provide sector-specific advice and warnings at RCOFs and NCOFs, it would be more appropriate for an impact table to be constrained to sector-based impacts (e.g., impacts on the water sector).

In articulating the different impact levels, a range of information sources may be used, including historical records and events, publications about the impacts of past seasonal variability, and news articles of damaging seasons. Climate impact models (e.g., hydrological models) are a particularly valuable source of information for climate impact assessment, since they are able to simulate key relationships linking climate and impact-relevant indices (e.g., rainfall-driven flooding). Models can also be particularly helpful for considering events that may not have happened in the past but which are plausible (e.g., impact of a category 5 tropical cyclone in a region with no recorded events), as well as being used to assess dynamic risk based on antecedent conditions (see section 3.2.1). Integrating evidence from lived experiences of communities, determined through participatory research or represented through community leaders, provides a way to incorporate local impact information that values local perspectives and real-world experiences of seasonal climate impacts.

In the case study, a simple impact table (Table 2) was produced with four categories, from minimal to severe impacts. Under the constraints of the SIMBOL research project, the impact table was created by climate service researchers and hydrological impact scientists from the DOWN2EARTH project. In practice the impact table would be co-produced through wider and deeper engagement with relevant experts and users of the impact-based outlooks, as well as integrating perspectives of impacted communities, and may be much richer in detail. As a result, the impact table shown here, which was used in the GHACOF co-production session to demonstrate the method, should not be used operationally.

Table 2
Impact table (step 3) for seasonal rainfall impacts on groundwater in Somalia.

Minimal	Minor	Significant	Severe
Groundwater levels are healthy and within the range of normal levels. Status is good for most places in the region.	Groundwater levels are lower than normal. Status is mixed across the region, with some areas showing bad status.	Groundwater levels are very low. Status is mainly bad across the region. Shallow wells and boreholes are dry.	Groundwater levels are exceptionally low. Status is bad across the region. All wells and boreholes dry.

4.1.4. Step 4: Articulate standard advisories for each risk level

The final step of phase 1 is the development of standard advisories to inform actions, that would be triggered at different risk or warning levels. To ensure consistency and efficiency at RCOFs and NCOFs, standard advisories should be co-produced for each risk level, informed through engagement with key stakeholders; this could be done at the same time as co-creating impact tables (step 3).

IBF methods typically use a traffic-light system of risk levels for warnings and advisories (e.g., green, yellow, amber, red), where each level triggers a set of responses and actions to mitigate risks. Some specific actions may be dynamic and dependent on the decision context when the warning is issued (e.g., recommending postponing a cultural festival during hazardous weather), and this is dealt with in step 7, but many actions can be triggered automatically when a risk level is reached. For example, a yellow warning triggering an action to raise awareness of potential impacts to targeted communities. Within this step, it is important to consider how advisories may hinder or support social inclusion and vulnerable households in responding to the risks.

Engagement with relevant stakeholders ahead of the GHACOF was not possible in the SIMBOL project. However, the “summary for decision makers” issued by ICPAC following each GHACOF, offers a valuable source of existing advisories relevant to risk management in the water and energy sector. Examples of possible advisories, taken from those issued in GHACOF, include:

- monitor monthly and weekly forecasts
- monitor water sources continuously
- increase community awareness of potential reduced availability from water source
- encourage rainwater harvesting and conservation

Such standard advisories provide a starting point and could be adapted to include more tailored advice depending on the context and situation when issuing an impact-based seasonal outlook.

4.2. Phase 2 – co-creation

In most regions, seasonal outlooks have progressed from subjective consensus-based outlooks towards objective model-based outlooks (WMO, 2019), improving both their quality and reproducibility. A similar ambition towards objective impact-based outlooks is desirable. However, for many impacts, objective impact assessment is currently hindered by limited monitoring, observations, models, understanding and impact-relevant datasets. Given these constraints, and the nascent stage of impact-based seasonal outlooks, the SIMBOL method recommends using co-production sessions to assess seasonal impacts using multiple sources of evidence and expert knowledge.

Co-production sessions at RCOFs and NCOFs provide an opportunity for impact specialists and sector-based users to review impacts from the last year and consider potential impacts for the coming season. It is within these sessions where steps 5 to 7 would enable the co-creation of impact-based outlooks. Crucially, this phase is designed to be conducted prior to the release of the seasonal outlook, so that the likelihood of outcomes do not influence or bias the discussion of future impacts. Fig. 3 summarizes the process, where forecasters and impact specialists work in parallel to provide content for both axes of the IBF matrix – impact information for the x-axis (impacts) and seasonal outlooks for the y-axis (likelihood).

This phase was trialled in the GHACOF-66 co-production session for the water and energy sector, attended by approximately 25 people spanning climate information providers, government officials from

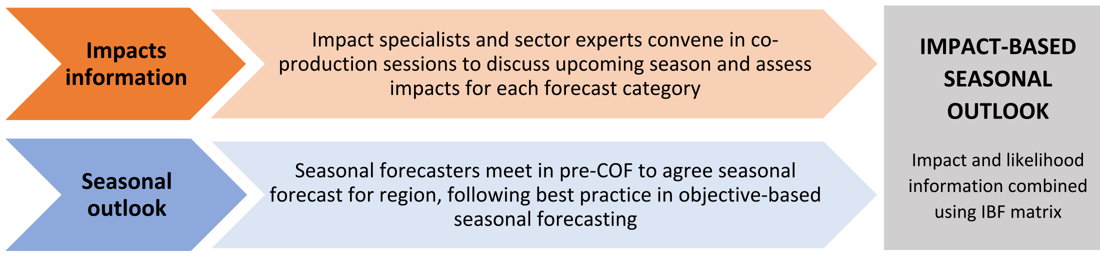

Fig. 3. Parallel approach to co-developing impact and likelihood information for impact-based seasonal outlooks.

different countries, humanitarian organisations, and the private sector (hydropower). Following an introduction to the SIMBOL approach, attendees were split into equally sized groups (approximately 6 to 7 people per group) to consider the potential impacts from total rainfall in the upcoming MAM season, each focusing on a sub-region (northern, central, and southern Somalia) to mimic how the approach might be used operationally. Each group contained a mix of information providers and users, some with significant expertise in water resources including groundwater, and others with less immediate knowledge or experience. However, because those who attended this co-production session were self-selected (they could have attended other sector co-production sessions at the GHACOF), they all had relevant and valuable knowledge related to the water sector. As the target audience for the SIMBOL approach, their perspectives are critical to evaluate the challenges and opportunities for future implementation and development of the method.

4.2.1. Step 5: Assign impacts and their severity to each seasonal outlook outcome

Using the information in the impact table (step 3) as a starting point, impact specialists and sector stakeholders jointly consider the potential impacts for the coming season. The task is to assign an impact severity level (e.g., minimal, minor, significant, or severe) for each of the outlook outcomes. In other words, participants should ask themselves, what would the impact be if the outcome was below-normal, near-normal, or above-normal for the seasonal CID(s) in question?

Taking each outcome in turn, participants can draw on different sources of knowledge and evidence, and where possible utilize objective methods of impact assessment, such as climate impact modeling (e.g., hydrological or crop models). A critical element is the consideration of antecedent conditions. For example, if there have been several consecutive below-normal rainfall seasons preceding the upcoming season, communities may already be experiencing severe impacts from food and water insecurity. Below-normal rainfall in the next season would therefore produce a higher impact than if the preceding seasons had been near-normal. Another example is conflict, which can increase vulnerabilities even under normal seasonal climate conditions. Appreciating the current context, and the interaction of different climatic and non-climatic stressors, will inform impact assessments for the upcoming season. It is also important to assess how impacts may affect people differently. For example, a winter season with below-normal temperatures may affect elderly people and poorer households disproportionately.

Once the different sources of evidence have been reviewed, participants should reach consensus and assign an impact severity level to each outcome. Key co-production principles, such as collaboration, inclusivity, and process-based (Vincent et al., 2018), should be promoted in this step to ensure impact assessment is both as accurate as possible but also a fair and open process. Where there is significant disagreement this is important to capture, and time afforded to explore the sensitivity of outcomes to different impact levels – see section 5.3 for further discussion.

Attendees at the GHACOF co-production session for water and energy were given information about antecedent conditions to assist in assigning impact severity levels for each seasonal outlook tercile outcome: below-normal, near-normal, and above-normal. Generated by the DRYP model (described in section 3) a map of groundwater status – expressed simply as “good” or “not good” – was provided and groups were told the information represented the current groundwater situation prior to the upcoming season (Fig. 4). Supported by a facilitator, each group considered the information provided but were also encouraged to draw on their own expertise and knowledge regarding groundwater in Somalia and its relationship to MAM seasonal rainfall. After discussion, groups reached consensus and assigned impact severity levels for each of the three outcomes (Table 3).

4.2.2. Step 6: Incorporate likelihoods to create impact-based outlook

The next step is to combine the likelihood and impact information using the IBF matrix. This is simply a mapping of the impact severity levels for the different outcomes (step 5) and their likelihood given the seasonal outlook over the relevant region.

In our case study, groups were provided with the February 2023 seasonal outlook for MAM rainfall issued at GHACOF-63 as example forecast data (Fig. 5). Somalia, and the bordering regions where rainfall can contribute to groundwater recharge in Somalia, was mostly in Zone III (yellow), with a 35 % likelihood of above-normal rainfall, 15 % likelihood of near-normal rainfall, and 50 % likelihood of below-normal rainfall. Using this information, groups completed the IBF matrix for the different outcomes.

Fig. 6 shows the combined impacts and likelihood information using the IBF matrix for each sub-region. The results for northern and southern Somalia are the same, while central Somalia has two outcomes: a medium likelihood of minor impacts from below-normal rainfall, and a

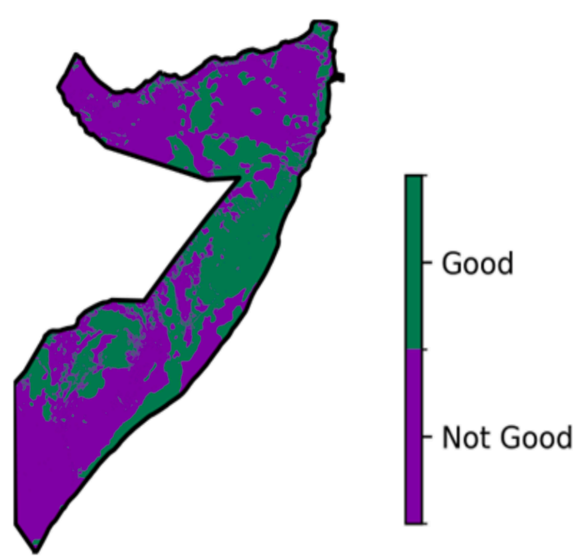

Fig. 4. Groundwater status data from the DRYP model (Quichimbo et al., 2023) used as illustrative data in the water and energy sector co-production session at GHACOF-66.

Table 3
Table showing assigned impact levels for each tercile outcome for MAM seasonal rainfall impacts on groundwater status in Somalia.

Region	Below-normal	Near-normal	Above-normal
Northern Somalia	severe	minor	minimal
Central Somalia	minor	minimal	minimal
Southern Somalia	severe	minor	minimal

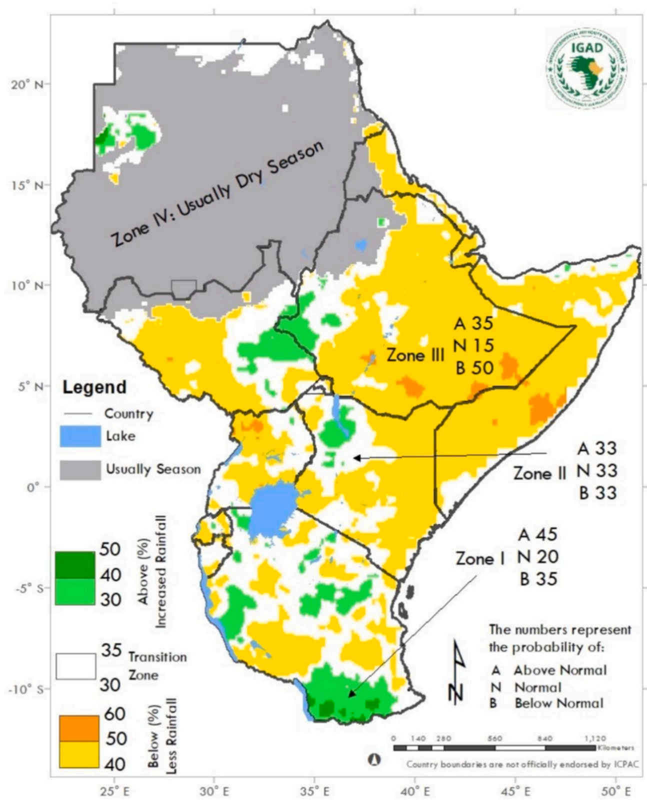

Fig. 5. GHACOF-63 seasonal outlook for total March, April and May (MAM) rainfall, used as data for likelihood information in the GHACOF-66 water and energy co-production session (
reproduced from ICPAC, 2023).

medium likelihood of minimal impacts from above or near-normal rainfall.

4.2.3. *Step 7: Extract risk level and determine advisory actions*

With the completed IBF matrix, it is now possible to extract the risk level from the highest level of risk across the potential outcomes (i.e., green, yellow, amber or red). Once determined, the final part of the co-creation phase is to agree advisory actions, using the standardized advisories (step 4) as a starting point. Co-production sessions at RCOFs and NCOFs, like those run at GHACOF, offer participants an opportunity to consider adapting advisories or introducing new ones, given knowledge of the current decision context and which actions may be more effective.

In the case study, for the northern and southern regions where the current groundwater status is generally poor, the highest risk level is "amber" associated with a medium chance of severe impacts from below-normal rainfall. In the central region, where the groundwater status is mostly good, the highest risk level is "yellow", associated with a medium chance of minor impacts from below-normal rainfall. In all regions, the implication is that below-normal rainfall in the upcoming season would make the situation worse, but those with amber warnings would warrant more urgent and extensive actions. Note that all regions have approximately the same likelihood of below-normal rainfall, so the additional impact information is what helps to inform advisories and prioritize actions by region.

4.3. *Phase 3 – communication and evaluation*

4.3.1. *Step 8: Communicate outlooks and issue warnings*

Following an IBF framing (Harrowsmith et al., 2020), standard operating procedures between information providers and users promote efficient and consistent use of impact-based outlooks and warnings. This requires clear communication channels amongst relevant organisations and communities, in accordance with institutional mandates.

Multiple modes of communication and technologies can be used to share information and issue warnings as appropriate, tailored to different audiences. The types of information communicated may include succinct messages on the level of risk and advisories determined (e.g., as currently communicated in the GHACOF summary for decision makers), or more detailed descriptions of the risks with visibility of the completed IBF matrix showing the different seasonal outlook outcomes. Informed by seasonal forecast climate services good practice (e.g., Knudson and Guido, 2019; Taylor et al., 2015), layering information and utilizing intermediary organisations enables people with limited time or skills to access succinct messages, supported with more detailed information available to more skilled or interested users.

Our example of seasonal rainfall impacts on groundwater in Somalia was trialled in a hypothetical context, and therefore risks and advisories were not communicated to stakeholders. However, to illustrate how the information could be presented, Fig. 7 shows a map of Somalia with administrative region boundaries, alongside headline messages for the three regions. Such information could be included in the GHACOF summary for decision makers, with different layers of information available depending on the audience and requirement for detail.

Effective communication of seasonal climate risk information is challenging. While the SIMBOL method is an attempt to simplify this process for users at the regional and national scales, the onward communication of outputs, through dissemination and engagement in different contexts, is highly non-trivial. Taylor et al., (2015) show that many users of seasonal forecasts struggle with interpretation but prefer familiar formats for receiving information about uncertainty, implying that optimal solutions will be highly context and audience dependent. Therefore, since many countries are advancing IBF methods for severe weather warnings, the use of similar products on seasonal timescales may have the advantage of being familiar, though not withstanding issues of potential confusion about warnings issued on different timescales (discussed in section 5).

4.3.2. *Step 9: Evaluate and learn*

The SIMBOL approach aims to provide a transferable and simple-to-use method for co-producing impact-based seasonal outlooks. However, each context is different and in applying to diverse contexts it is critical to evaluate the different phases and steps from both provider and user perspectives, to ensure the approach is implemented appropriately and continues to be fit for purpose. To support the evaluation and feedback, learning questions might include:

1. Is the characterisation of the seasonal CID, geographic scale, and impact of interest appropriate for effective actions and communication of the outlook?
2. Do different participants in the co-creation phase fully understand and engage with the approach?
3. Do the warnings, advisories and information provided improve understanding of the probabilistic nature of the seasonal outlooks?
4. Are the warnings and advisories acted on?
5. Are there impacts or spatial scales where the approach is inappropriate and alternative approaches should be used?
6. What level of resource and modes of engagement best achieve the co-development of the impact-based outlooks?

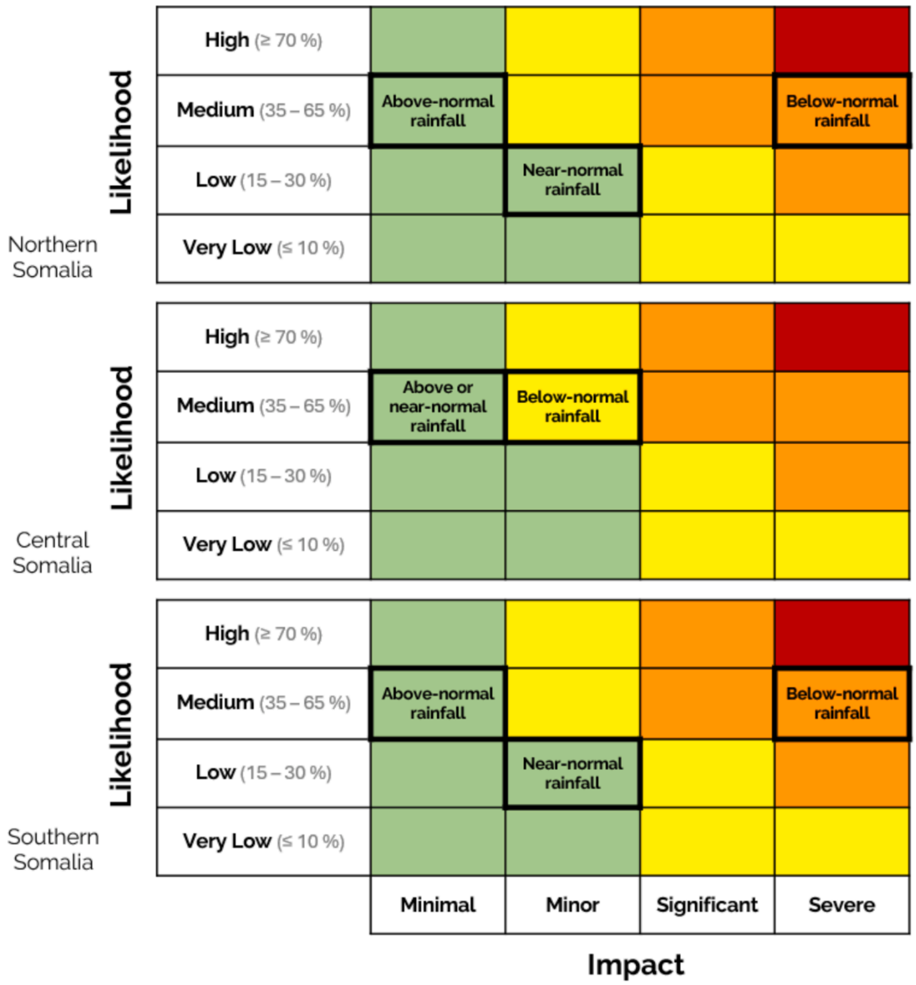

Fig. 6. IBF matrix for an impact-based seasonal outlook of groundwater availability in regions of Somalia.

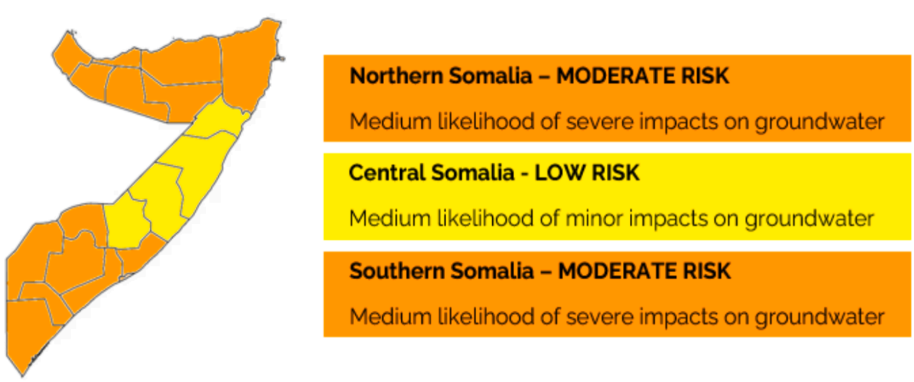

Fig. 7. Map of Somalia showing risk levels triggered for MAM rainfall impacts on groundwater.

Evaluation should also include verification of the actual impacts experienced and any actions taken based on the information and warnings issued. This will help inform skill assessments of the impact-based seasonal outlooks and inform future research and development.

Although not all steps of the SIMBOL method have been fully tested, feedback was provided by attendees in the water and energy co-production session at GHACOF-66. Positive feedback centred on the relevance and simplicity of the approach for application. For example:

"It's designed for advisories and helps to make it simple, through down-scaling the language."

"Very workable for sector advisories as it's scaled down."

"Method is good, it adds value, starts from current condition, before using the forecast."

In addition, attendees provided constructive feedback, reflecting on the example and considering how the method might apply to other seasonal CIDs, impacts and regions of interest:

"It makes more sense to focus on surface water resources, not ground-water as there are so many assumptions."

"One resource is considered independently of another, but if there's no surface water, people will go to groundwater. So water resources must be considered together."

"There is a need to better understand the relationship between forecast rainfall and groundwater (and other factors affecting water availability)."

"A subset of impacts may be appropriate, but not all would be (too complex). Heat-health combines heat and humidity, but the tools get a bit more complicated to apply."

The feedback highlights the complexities of moving from hazard-based outlooks to impact-based outlooks, where climate is not the only driving factor and decision-making contexts deal with multiple elements. Careful consideration of the impact and sector context are needed, and there are likely to be impacts that are too complex to distill into simple risk messages and advisories. However, users of seasonal outlooks who attended the session provided overwhelmingly positive feedback, demonstrating the potential of the SIMBOL method to address the current gap and provide actionable impact-based guidance and warnings for key impacts.

The next section further explores the challenges and opportunities for developing and implementing the SIMBOL method, informed by the case study and broader learning from related literature.

5. Lessons learned and areas for development

There are several challenges to overcome before implementing the SIMBOL method in operational systems. Some challenges are common across prediction timescales, and solutions can therefore be informed by emerging lessons from the development and use of IBF (Potter et al., 2024). Here we focus on five key areas.

5.1. Audience and tailoring

For most RCOFs and NCOFs, audiences are diverse and encompass government, industry and civil society stakeholders. However, some users of seasonal outlooks operate largely outside of these forums, particularly the private sector. While elements of the SIMBOL approach may be valuable for businesses and private sector stakeholders, there is a trade-off in developing a method which is scalable and transferable to different user contexts, with the desire for tailored seasonal forecast information to support individual businesses sensitive to different seasonal climate risks (Goodess et al., 2022). Tailoring requires deep and sustained user engagement and often development of bespoke products that is impractical at RCOFs and NCOFs where outlooks serve a wide range of contexts across a region or country. The move to co-produced impact-based seasonal outlooks issued by RCOFs and NCOFs represents a step forward to better serve the broader stakeholder community, though it does not replace alternative approaches to developing tailored solutions for specific audiences.

5.2. Scale

Impact-based seasonal outlooks, developed using the SIMBOL method, aim to guide regional and national level actions that support vulnerable communities across regions and countries, such as where to prioritize government funding for disaster risk reduction interventions. Yet many climate resilience and preparedness decisions are taken at local levels. Calvel et al., (2020) show that when preparing for upcoming seasons, local-scale farmers are seeking advice on local agricultural practices rather than simply broad-scale weather-related information.

Given the fundamental challenges associated with the reliability of seasonal forecast information at local scales (Doblas-Reyes et al., 2013), and often limited availability of local vulnerability and exposure datasets, it is unreasonable to expect regional or national impact-based seasonal outlooks to provide the level of detail required to trigger specific local-level decisions. Moreover, local decision making processes can be complex, involving different actors and multiple sources of climate and non-climate information, including traditional knowledge. Aggregated regional or national impact-based outlooks should be used to complement locally led processes, where such information combines with knowledge of the local context. There remains a key role for trained intermediaries and local experts to interpret the larger scale information with knowledge of the local decision needs and context, and help maintain trust in the information at the scales where impact-based seasonal outlooks have skill and relevance. Ongoing verification of outlooks (step 9, section 4.3.2) will support intermediaries and local experts understand these dimensions.

Temporal scale also remains a challenge, since seasonal outlooks are only one source of weather-based information available to guide decisions. Combining information from near-term weather, sub-seasonal, seasonal and longer-term climate information is key to ensure robust decisions, and this also applies to impact-based outlooks and warnings. By using the language and framing of IBF, the SIMBOL method attempts to bridge these time-scales but further work is needed to consolidate warning systems and risk information across timescales, especially to avoid confusion if different time-horizon predictions imply different actions to manage risks.

5.3. Impact assessment using co-production

In theory, the characterisation of impacts for an upcoming season could be achieved through objective impact assessments, using quantitative impact models underpinned by monitoring and observation datasets. This would bring the quantification of "impact" in line with the quantification of "likelihood" (using seasonal forecast models), so that objective modelling approaches are used throughout the generation of impact-based seasonal outlooks. However, in reality information on impacts is imperfect and subject to considerable uncertainties. Depending on the region and nature of the impacts, impact datasets and monitoring information may be limited, hindering the quantification of potential future impacts. Therefore, a combination of objective quantitative data and qualitative expert judgment is more feasible to characterize impact severity using the SIMBOL approach. For some seasonal CIDs, there could be a straightforward relationship between the seasonal climate and an impact of interest, with potential for objective impact assessment. However, for most impacts of concern (e.g., in health or agriculture) complexity arises from the influence of multiple relevant climatic and non-climatic hazards, with physical and human influences. Learning from the groundwater example used in this study, evident in feedback in section 4.3.2, showed that impact characterisation and analysis of severity levels is challenging due to the combination of information sources and the complexity of societal impacts.

The SIMBOL method aims to provide a pragmatic approach, even in cases of complex climate-impact interactions. However, there will be occasions where experts disagree about impact severity levels across different potential seasonal climate outcomes. In such cases, co-production sessions at RCOFs and NCOFs need to have mechanisms in place to deal with disagreement. This is an important area for further development of the SIMBOL method, but there are strategies that can be considered, informed by recommendations for co-production from other contexts (Cvitanovic et al., 2019).

One strategy is sensitivity testing. For example, if there is disagreement between significant or severe impacts for an outcome, and the likelihood of that outcome was medium, then both significant or severe impacts would yield the same amber advisory; there is low sensitivity to this disagreement. However, if the likelihood was high, disagreement on significant versus severe impacts would be the difference between an amber and red advisory, highlighting a key sensitivity in the assessment. Here, it would be critical to allow more time for consideration and incorporation of different voices and sources of evidence, guided by co-production principles and best practice (Djenontin and Meadow, 2018;

McClure et al., 2024; Bremer and Meisch, 2017; Vincent, 2018). The final decision on risk and advisory levels should sit with the responsible organization(s) for issuing the outlooks; for RCOFs this is typically the designated RCC.

5.4. Thresholds, extremes and sub-seasonal conditions

In IBF early warning systems, Jenkins et al., (2022) assert that warning thresholds should be monitored to ensure they are being used consistently and accurately across provider and user communities. With the introduction of impact-based seasonal outlooks, particularly in regions that are poorly adapted to present-day climate and highly susceptible to impacts, there is a risk of frequent triggering of warnings. This may lead to warning fatigue and, potentially, inaction following a warning. Adjustments in the warning levels, impact and likelihood thresholds may be required to avoid such situations, as well as careful communication amongst trusted brokers and intermediaries.

In our example, we considered the doubling of climatological likelihood ($\geq$ 70 %) as a “high” likelihood (section 4.1.2). This is a relatively high likelihood for a seasonal forecast but since we’re characterizing the likelihood of impact, and two outcomes could result in the same level of impact, it would be prudent to consider raising this threshold, as well as altering thresholds for other likelihood levels (e.g., high $\geq$ 80 %, medium 50 $\leq$ 75 %, low 20 $\leq$ 45 % and very low $\leq$ 15 %). Crucially, the choices should be informed both by considering the statistical risk but also research in how such thresholds are understood and interpreted by target audiences. Building on social science research examining thresholds and perceptions of risk by providers and users of severe weather IBF (Jenkins et al., 2022, Potter et al., 2025), there is a need to carefully evaluate risk perceptions amongst target users to inform thresholds in the impact matrix and the levels at which the SIMBOL method would trigger risk-based warnings or advisories.

Often the most significant seasonal climate impacts occur due to extreme weather conditions or due to an extreme season overall. Extremes are not dealt with well using conventional quantile-based forecast approaches, particularly terciles. However, progress is being made to forecast extremes at the seasonal timescale (e.g., Trentini et al., 2022, Dunstone et al., 2023) and such work calls into question the value of terciles as a way to analyze and communicate seasonal climate risks. The SIMBOL approach can be applied to other ways of characterizing the forecast distribution (e.g., quintiles, deciles) or could be applied to extreme indices (e.g., tropical storm frequency) that constitute a seasonal CID. Further iterations and development of the SIMBOL approach should consider extreme events and extreme seasons, given their importance to impacts and decisions.

However, caution must be taken in adapting the SIMBOL method to consider extremes and low likelihood outcomes, due to the risk of warning fatigue or actions taken in vain. The risk matrix used in the groundwater example would result in a yellow risk level for any likelihood ascribed to a significant or severe impact, resulting in frequent warnings. It may therefore be appropriate for seasonal climate outlook providers to exercise judgement in issuing such advisories or adapt the risk matrix to avoid such scenarios. One option is to only issue warnings when the likelihood of a significant or severe outcome is above a given likelihood threshold (to be determined in phase 1, supported by co-production amongst providers and users), to avoid the influence of outliers in ensemble-based forecasting systems. Yet given the aim of the SIMBOL method is to remove the bias towards higher likelihood but low-impact outcomes in impact-based outlooks, it is important to examine this problem further. Part of the solution could lie in linking seasonal outlooks with nearer-term forecasts in seamless systems, where sub-seasonal and monthly forecasts are also assessed and if there is congruency of a “reasonable” likelihood of high-impact conditions on the shorter-term, then a yellow risk level for the upcoming season would have greater weight. Learning from severe weather IBF implementation, which is more mature, will provide useful insights to address this tension.

5.5. Operational implementation

To advance the SIMBOL method towards implementation, and evaluate the method fully, further examples and research are needed. The SIMBOL method should be tested in pseudo-operational environments, run in parallel with existing practices. In doing so, it is important to align with regional-to-national communication processes, so that warnings and advice issued at regional levels are consistent with processes at national levels, avoiding contradictory messages and confusion. Also, as highlighted in section 4.3.1, there is need for research to more thoroughly investigate alternative methods for communicating impact-based seasonal outlooks (e.g., SMS, web-based tools, decision-maker summaries), and provide evidence-based recommendations to guide implementation.

There are also further practical limitations. In particular, co-production sessions at RCOFs or NCOFs offer an important opportunity to consider potential impacts and their severity, but not all forums are at the stage where co-production is possible, and those that exist provide limited scope for in-depth co-production processes. Creating enabling conditions for multiple stakeholders to participate is a precursor to the use of the SIMBOL method.

6. Conclusions

Advances in seasonal forecasting over recent decades have focused primarily on developing models and methods for generating skillful forecasts and creating access to data. Yet to guide actions that reduce risks, climate service providers must strive to advance the decision-relevance of information provided. Learning from the successes and challenges of developing IBF on weather prediction timescales, the SIMBOL method has been developed to create impact-based seasonal outlooks, focusing on Regional and National Climate Outlook Forums.

In developing and trialing the SIMBOL method, it has emerged that the approach provides value in different ways. First, it provides a method for communicating potential impacts associated with seasonal outlooks while maintaining probabilistic information. It does so by determining potential impacts from all possible outcomes ahead of the release of a seasonal outlook, so that impact statements and warnings are not biased towards higher likelihood outcomes. The method helps in characterizing and communicating important high impact, low likelihood outcomes that may otherwise be ignored.

Second, the method can be applied in situations when seasonal forecast skill is lower than desired. By considering antecedent conditions and the severity of potential impacts across all outcomes, in parallel to generating information on the likelihood of the outcomes, it is possible to constrain the possibility space of future impacts. For example, if antecedent societal conditions are positive, then impacts for the upcoming seasons may be minor at worst, removing the possibility of high risk levels irrespective of the seasonal forecast. Conversely, if antecedent conditions are negative, impacts may be moderate or severe for all seasonal climate outcomes and actions to support exposed communities will not be taken in vain. While good skill in seasonal forecasts remains desirable, in situations or locations where skill is lower or more variable, the SIMBOL method can still add value by reducing the risk of relying only on likelihood information, which could lead to maladaptive responses.

Finally, the SIMBOL method provides a standard and scalable approach for application across regions, countries, and sectors, aligning with the UN goal of Early Warnings for All. By adopting and building on good practice in IBF methods, and maintaining a simple-to-understand system of risk levels and warnings, the method can be easily adapted and implemented in different contexts without significant investment in bespoke technology, systems, or technical capacity. Nevertheless, it does not replace tailored seasonal forecasts and impacts information where beneficial for specific use cases (e.g., private sector).

There are several challenges, such as the spatial scale of information and addressing extremes, that require careful consideration in operationalizing the approach, and there is a need for further research to advance and evaluate the method. Future development and implementation of the approach should draw on evolving good practice and learning in IBF and early warning systems, as well as learning in climate services co-production. The SIMBOL method has the potential to create relevant and actionable impact-based seasonal outlooks at scale, to strengthen preparedness, exploit opportunities, and mitigate against seasonal climate risks in regions across the world.

CRediT authorship contribution statement

Joseph Daron: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Katerina Michaelides:** Writing – original draft, Investigation, Conceptualization. **Khalid Hassaballah:** Writing – original draft, Investigation. **Andrés Quichimbo:** Writing – original draft, Visualization, Formal analysis. **Rebecca Parfitt:** Writing – original draft, Investigation, Conceptualization. **Jessica Stacey:** Writing – original draft, Conceptualization. **Anna Steynor:** Writing – original draft, Conceptualization. **Catrina Johnson:** Writing – original draft, Conceptualization. **David MacLeod:** Writing – original draft. **Michael Bliss Singer:** Writing – original draft.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Joseph Daron reports financial support was provided by UK Government Foreign Commonwealth & Development Office. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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