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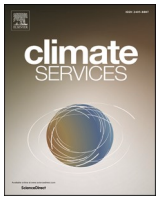

Editorial

Sub-seasonal to decadal predictions in support of climate services

Climate information is crucial to manage climate-related risks and to improve decision-making processes in many societal and economic sectors and disciplines sensitive to climate variability and change. Often decisions taken by planners, governments, businesses and other stakeholders happen on weekly to decadal timescales. In many instances the climate information must be delivered on these timescales in the form of forecasts. Advances in predictions on sub-seasonal to decadal (S2D) timescales are thus essential to the production of actionable forecast information to create climate services for agriculture, water resources, disaster risk, public health, energy and many other sectors.

In the past few years, the sub-seasonal to decadal prediction community has made significant progress in advancing and understanding forecast skill on these timescales (Merryfield et al. 2020), including the implementation of new observational networks, advances in climate models, and improved data assimilation methods. Nowadays, there are several prediction centers around the world that routinely produce predictions on seasonal and sub-seasonal timescales, as well as a few on annual to decadal timescales. Many of these predictions are collected and shared by the World Meteorological Organization Lead Centre for Seasonal Forecasts and the Lead Centre for Annual to Decadal Forecasts. A crucial element of this growth has been the establishment of coordinated activities that make large databases of numerical predictions from these centers available to the community, such as the Subseasonal to Seasonal (S2S, Vitart et al. 2017) database, the Climate Historical Forecast Project (CHFP, Tompkins et al. 2017) or the Climate Model Intercomparison Project (CMIP, Eyring et al. 2016) for the sub-seasonal, seasonal and decadal and climate projections, respectively. Statistical methods to produce forecasts are also widely used due to the good skill achieved by these models at a very low computational cost. However, despite the continuous progress on predictions for these timescales, advances in the use of these forecasts have been different for each timescale. While seasonal forecasts have been used for decision making for a long time, most of the predictions for sub-seasonal or annual-to-decadal timescales are still in an experimental phase and are not yet routinely used for decision making.

The expansion of the use of S2D predictions to help mitigate climate-related risks through early warning-early action and climate-smart resource management requires transforming this information into customized products for each sector, together with an assessment of its robustness and trustworthiness to inform about the added value of new forecast approaches over existing practices, as for example on sub-seasonal timescales (White et al, 2017; White et al., 2022), seasonal timescales (Becker et al. 2022) and for decadal timescales (Dunstone et al. 2022). Efforts in bridging the gap between useful and usable forecasts can then leverage the use of S2D predictions while making an effective use of this type of information in each sector. In this way, the research on the translation and transfer of climate forecasts into actionable information provides insight on how to meet users' expectations through the provision of customized forecasts, that are co-developed by forecasters and users.

This Special Issue *"Sub-seasonal to decadal predictions in support of climate services"* presents contributions from the Climate Services community, including research and products to underpin the production of climate services on scales from sub-seasonal to decadal and climate change projections. A brief description of the Special Collection contributions is presented in the following paragraphs.

Climate predictions are inherently uncertain, due to the chaotic nature of the system, the errors associated with the initial conditions of the coupled ocean–atmosphere-land-cryosphere system, unresolved physical processes that act on the sub-grid scale, as well as the numerical formulation of the dynamical models used to produce them. Therefore, probabilistic forecasts that correctly address the uncertainty in those predictions are needed. Different studies in this special issue explore the generation of well-calibrated probabilistic seasonal forecast products. These studies use either statistical models or multi-model ensembles to produce the forecasts. Precipitation over tropical domains is the preferred variable addressed in most of the studies (Acharya et al., 2021; Freire et al., 2022; Martinez et al., 2022). On the other hand, Chevuturi et al. (2023) focus on predicting the maximum water level of the Manaus River, while the work of Collazo et al. (2022) develops statistical forecasts of extremes of daily temperatures in Argentina on seasonal timescales.

S2D forecasts for time-averaged temperature and precipitation may not be directly usable for many decision-makers. Different factors can affect the usability of climate information, such as the format of the forecasts (text, graphical, etc), the timing of the release of forecast information, among others. Developing dedicated forecasts for different sectors then requires exploring the relationship between the variables relevant to those sectors and the climate, and generating specific forecasts of those variables. Agriculture is the most extensively explored sector in this special issue. The work of Chinyoka and Steeneveld (2023) develops a system for predicting rain-fed crop yields in Zimbabwe, based on 7-month forecasts that are downscaled to high spatial resolution. They show that downscaling improves the estimated growing season onset date and maize yield in all studied regions across Zimbabwe, concluding that downscaling of seasonal forecasts may assist in food security in a crucial area in southern Africa. A simple seasonal forecast system of local rainfall and hydrological conditions for small-scale farmers in South Africa is developed in Graham et al. (2022). An agro-hydrological model provides expected hydrological responses from

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observed years representative of the large-scale rainfall anomalies predicted by the CSIR global seasonal forecast, and its evaluation in three forecast seasons shows good indications in the two pilot areas of the Limpopo River Basin. In Streefkerk et al. (2022) the integration of farmers' local knowledge in three districts in central and southern Malawi has proven to increase the predictive value in forecasting locally relevant dry conditions, in comparison to traditional climate indicators such as El Niño Southern Oscillation (ENSO). Tailored forecasts for the agriculture sector to inform crop production are presented in Thomasz et al. (2023) for soybean production in Argentina. The integration of forecasts into decision making processes also encompasses an assessment of their robustness and trustworthiness to inform about the added value of new forecast approaches over existing practices. In this context, the work of Roy et al. (2022) explores the use of sub-seasonal to seasonal predictions for real-time water management for grape farmers in India, showing that advancing knowledge and planning can save up to 25% of water, depending on the season, without a loss of yield as compared to making near real-time decisions. This approach shows promising results for water scarce regions that can be applied beyond the study region. The application of seasonal forecasts in aquaculture production is explored in Montes et al. (2022) for two locations in Bangladesh. In the work, linear models are used to predict the number of warm days and heavy rain days using seasonal predictions from the North American Multi-Model Ensemble (NMME) project, obtaining good skill for the number of warm days, particularly using the CanSIPSv2 and GFDL-SPEAR models.

The energy sector has gained attention in recent years as the rapid development of renewable energy sources to decarbonize the energy matrix has gained importance. Both energy generation by renewable sources and energy demand are highly sensitive to weather and climate variability, making S2D forecasts potentially crucial for efficient management. Cionni et al. (2022) explore to what extent remote factors that drive local weather can be used to predict local conditions for power production on seasonal timescales in Europe. By employing hybrid methods based on a combination of dynamical and statistical prediction systems, they show that these methods can provide advanced information and improvements over traditional forecasting approaches for the prediction of energy-relevant variables. Bett et al. (2022) explore the utility of seasonal climate forecasts to help manage wind and solar power generation in Europe. The study indicates that on seasonal and regional scales, wind and solar power generation potential are highly correlated with wind speed and irradiance, respectively. Simple linear regression is then used to make calibrated probabilistic seasonal forecasts of generation potential based on the ensemble means from Copernicus Climate Change Service (C3S) models.

Climate forecasts are also an important tool to trigger anticipatory actions to avert climate-related risk. In Polkova et al. (2022) the potential of seasonal predictions for marine climate services and risk assessment in the Barents Sea is investigated. Marine risk is assessed through wind speed, temperature, and wind chill, and converted to maps of real-time predicted risk probability, allowing for an integration of real-time meteorological information into risk predictions, expanding on previously used risk maps based on historical risk data. A new approach for triggering anticipatory action to avert the ravages of droughts is developed and demonstrated in Guimarães Nobre et al. (2023). The article describes the World Food Programme Forecast-based Financing system for droughts that is being tested in Mozambique, based on ECMWF 7-month rainfall ensemble forecasts. The system is able to detect most of the drought events up to 6 months in advance, from which the authors developed an operational trigger system for drought anticipatory action. Their results demonstrate important new opportunities to help humanitarian organizations reduce losses to livelihoods and their costs of operations, while supporting communities in a more dignified manner.

Climate change poses great risks for humans as well as ecosystems. Exploring decadal scenarios helps to assess these risks as well as adapt to them. Two studies combine climate change scenarios with user needs to inform risk in the infrastructure of communities and forestry productivity, respectively. Medeiros et al. (2023) address the freshwater availability for two remote Canadian Arctic communities through a framework quantifying liquid water availability for a range of climate and demand scenarios. The study finds that the available reservoirs tend to be highly affected by air temperature and ice thickness, which can lead to frequent complete reservoir depletion. As a result, the infrastructure in the studied communities often tends to be unable to provide sufficient freshwater over a typical planning horizon. Sondermann et al. (2022) develop climate projections over central Brazil to assess climate change impacts on eucalyptus plantations in terms of thermal and water stress. These projections show that most investigated locations may be at risk in terms of productivity due to more frequent water stress conditions and that six locations may also meet thermal stress conditions, becoming unsuitable for eucalyptus plantations, if only climate factors are considered.

In recent years, the development of climate services has adopted a so-called co-production approach, which enables users to participate in the design of the products. Dione et al. (2022) describes the co-production of climate services to support preparedness and response actions for meningitis outbreaks in West Africa during the dry season, which are linked to atmospheric variability, in collaboration with the African Center of Meteorological Applications for Development (ACMAD) and the WHO African Regional Office (AFRO). The goal is to defeat meningitis by 2030 in the region based on the co-development of these climate services. A roadmap was established to identify vulnerability in the context of climate change and to respond to outbreaks. The study describes the operationalization of a meningitis early warning system, showing that sub-seasonal to seasonal (S2S) forecasts can contribute to predicting the atmospheric conditions that precede meningitis outbreaks. In Gudoshava et al. (2022) the co-production of climate services to increase forecast uptake in eastern Africa for the impact of weather and climate extremes on food security is explored. Two case studies based on an extreme rainfall event and a tropical cyclone are evaluated, showing that the extreme rainfall and flood risk could have been at least partially predicted and therefore could have contributed to S2S forecast potential in this region. The study relies on the real time S2S forecasts from the Real Time Pilot Initiative in sub-saharan Africa (https://africanswift.org/testbed-2/), which highlights the role of international collaborations in promoting the uptake of forecasts by climate services.

Weather and climate centers make constant efforts to generate, produce and deliver climate information operationally. This information is used by the research and user communities in the subsequent development of climate services. Paxian et al., (2023) introduces the DWD climate predictions website, which provides a consistent and seamless outlook for the next months to years, with a focus on German users' needs. The website contains statistically downscaled and calibrated information about temperature and precipitation predictions and their skill in the form of maps, time series and tables.

Finally, perspectives on the status of the application of sub-seasonal to decadal predictions in relation to climate services are also part of this special issue. The study of Solaraju-Murali et al. (2022) explores the emerging area of the potential value of decadal predictions for climate services for food production and security. A decadal forecast product is developed to provide tailored and user-friendly information about multi-year dry conditions for the coming five years over global wheat harvesting regions. The findings emphasize the importance of a co-production approach, where the interaction between the user and climate service provider is established at an early stage of forecast product development. The authors shed light on the reasons for the delayed entry of decadal predictions into climate services, obtained from surveying climate scientists and decadal prediction experts, and highlight the key challenges that this new source of climate information still faces. A perspective on climate services in Brazil is described in Escada

et al. (2021). The article goes from the devastating effects of the 1877–1879 Great Drought in the Northeast region to the creation of the Center for Weather Forecast and Climate Studies (CPTEC) at the National Institute for Space Research (INPE) in the early 1990s. It describes how Brazil went from relatively limited meteorological expertise to becoming a member of a select group of nations with the infrastructure and technical expertise to build and run a global general circulation model. It covers the development of its infrastructure for observation, monitoring, modeling and prediction, the still incipient efforts in systematically understanding users' perspectives and needs, and developing the co-production paradigm. The article finishes off with a set of actions for the strengthening of Brazil's climate services framework.

This special issue presents the current status of representative case studies of the different efforts to support climate services through subseasonal to decadal predictions, offering a broad perspective on applications to different sectors and regions across the world.

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