Use of weather and climate information essential for SDG implementation

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Owing to a lack of understanding, and data being unavailable, unusable or unsuitable, weather and climate information is currently underutilized in Sustainable Development Goal implementation. Improvements are essential in knowledge brokering, clarifying responsibilities, multi-institutional and multi-stakeholder governance arrangements and research on systemic risks and decisions.

The United Nations' 2030 Agenda for Sustainable Development[1] is an ambitious plan for "people, planet and prosperity", aimed at achieving a sustainable future for all. At its core are 17 Sustainable Development Goals (SDGs), the achievement of which is widely affected by weather and a changing climate[2]. To that end, emphasis has been given to delivering weather and climate services, such as identified through the Global Framework for Climate Services[3], with information packaged in ways that support timely decision-making.

Yet these approaches tend not to address which decision-making processes need what information, or why they need it[4]. Climate services also tend to be limited to specific situations and SDGs (such as SDG 14, 15) where the need for weather and climate information is clear and obvious. However, it has been demonstrated that weather and climate substantially impinge across all SDGs[2], for example, flooding in Thailand affecting global computer supply chains for hard disc drives (SDG 8), or droughts affecting food shortages that intersected with social unrest and contributed to the 'Arab Spring' in 2010–2011 (SDG 16).

Here, through identifying a continuum of decision-making contexts, we demonstrate how weather and climate services may be tailored to improve decision-making across all the SDGs.

Decision-making contexts

It is not just the nature of the weather and climate risk that matters, but also the decision process and whether decision-makers are resourced, experienced and able to interpret and use the data. Weather and climate impacts deliver various levels of complexity for decision-makers. For example, weather and climate impacts can be relatively direct and simple for decision-makers to interpret and take action on, such as heat waves requiring health warnings (SDG 3) or extreme snow and ice conditions requiring road gritting (SDG 11). Conversely, the impacts can be indirect and harder to infer, such as rainfall and evapotranspiration affecting soil moisture for farming and food security (SDG 2), or changing climate zones affecting insect-borne disease distributions (SDG 3). The impacts can also be systemic, which are usually harder to predict than indirect impacts, such as seasonal effects on the spread of a pandemic such as COVID-19 and consequent economic impacts (SDGs 3, 8).

Considering the state of knowledge and praxis, four categories of decision-making contexts and related responses to the information about weather and climate conditions can be identified, although in practice they do not have hard boundaries (TABLE 1).

Short term reactions to weather forecasts requiring little processing: where the direct effects of weather are readily understood, there are mature relationships between providers and decision-makers, and decision-makers have the capacity to respond. The short term nature of forecasts and early warning systems allows relatively rapid feedback and learning.

Long term responses to climate change projections requiring limited processing: where adaptation and resilience design and implementation decisions are in sectors that have the capacity to analyse the impacts of longer-term climate change risks, and there is a mature relationship between providers and decision-makers, who may have their own embedded processing capacity. However, the longer timeframes increase uncertainty and the complexity of issues, and the resulting decisions are often plagued by limited learning feedback.

Long term responses to climate change projections requiring substantial further processing: where the relationship between providers and decision-makers is less mature, and decision-makers are less able to use the weather or climate data directly, although in principle it is often known what processing is needed and how to

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Table 1 | **Engagement and processing needs for climate data in different decision-making contexts**

Decision-making context	Description	Examples	Implications	Need for 2-way engagement, knowledge brokering, data processing	Readiness of technical climate data for use in decision-making	Clarity of roles and responsibilities
Short term reactions to weather forecasts needing little processing	Actions on weather forecasts that are easily interpreted by decision-makers with little processing; or processing is well understood and adopted, with quick feedback	Early warning on hours-to-days time frames for cyclones (SDG 11), or processed forecasts of UV or air quality risk (SDG 3); seasonal forecasts of droughts or ocean warming, or processed for famine risks (SDGs 2, 6)	Useful forecasts can be created by meteorologists; engagement aimed at accessibility. Build capacity and develop institutions in lower income countries	Low	Very high	High
Long term responses to climate change projections needing limited processing	Climate change responses where climate outputs are either directly useful to decision-making, or the target sector is sophisticated in its own analysis of raw climate data	Heatwaves where the climate data makes sense directly (e.g. days over 40 °C per year) (SDG 3); or decisions in sectors that are good at processing climate data, such as agriculture and water (SDGs 2, 6), insurance (SDG 8) or energy (SDG 7)	Climate projections can be provided by climate scientists, though guidance on their use in adaptation may be needed. Build capacity and develop institutions in lower income countries	Medium	High	High
Long term responses to climate change projections needing much more processing	Longer term climate change responses where much more processing is needed into forms that fit the target sector's normal decision-making and business practices	Data on extreme events for infrastructure design where engineers need flood return times or peak flow rates (SDG 9); or in health where vector transmission must be modelled (SDG 3), for cities (SDG 11) or circular economies (SDG 12)	Needs close engagement and (new) bridging institutions everywhere to co-design the research, processing and delivery of useful information, as well as institutions for processing. Support sectoral best practice in lower income countries	High	Low	Low
Responses to changing systemic risks needing new forms of information	Decisions on systemic risks where climate data needs major, often poorly understood, processing to help decision-makers see how climate affects diverse sectors, places and times systemically	Acting on changing correlations in space and time, such as crop failures and flooding across continents driving social unrest (SDG 16), or systemic action on climate adaptation and mitigation affecting industry and jobs (SDGs 13, 9, 8), or disasters increasing poverty and inequality (SDGs 1, 10)	Complex, cross-sectoral, local and global institutional partnerships needed to research, project and act on systemic risks from climate and other interacting drivers. Ensure analysis for lower income countries	Very high	Very low (or unknown)	Low

do it. For example, road designers may expect to have standard tables of average return times of extreme events or policy makers may need to integrate weather and climate information and policy within multilevel sustainable development priorities and policies for cities[5]. Institutional responsibility for data processing is often unclear, falling in gaps between institutions and public and private interests.

Responses to systemic risks: where it is often not well-established what weather and climate information is needed nor how to use it. Decision-making systems are poorly designed for policy responses to systemic risks that cut across sectoral and institutional silos[6]; and in many cases, it is unknown how to combine and present data on spatial and temporal patterns in weather and climate with data on social and biophysical interactions in ways that might be helpful for decision-makers.

While the first two categories are often adequately serviced by current approaches to climate and weather data, the latter two require transformational changes in the ways we design, develop and provide access to data and information, including weather and climate.

Enabling action

To improve integration of weather and climate data into SDG-related decision-making, we highlight three key action areas that should be addressed.

Knowledge brokering and engagement: data production and processing capability remains a challenge in many policy spaces, particularly in lower income countries where increased financial and capacity support for meteorological services is needed. However, there additionally needs to be better knowledge brokering, knowledge exchange and engagement between data providers, researchers and decision-makers, for example by utilizing boundary organizations[7]. Levels of engagement depend on context[8] from mostly consultative (where considerable capacity exists), to a greater level of collaborative co-production (of information and interfaces) and deep co-design (to understand the decision needs and define and deliver research on addressing existing and emerging requirements). Issues of equitable access to information and decision-making are crucial to avoid entrenching power imbalances[9]. We therefore recommend that governments and international funding agencies should promote context-appropriate knowledge brokering and boundary organizations and invest strongly in them, building on existing national and international efforts.

Institutions and governance: institutional requirements are also differentially important across decision contexts. Governance and institutional arrangements, even where data provision is mainly by public meteorological services and is relatively simple, are challenging the provision and delivery of effective climate services. The lack of necessary institutional capacity, especially in some lower income countries, is adding to this challenge. Where substantial data processing and tailoring is required, the challenge is the so-called 'valley of death' whereby national providers, governments and business each see it as someone else's responsibility to convert the data into decision-ready form, and so it fails to be converted and fails to be used. The responsibility for undertaking this task is unclear, especially where the benefits are both public and private and there are no accepted standards. Here, new public-private-citizen partnerships could fill this gap, and may or may not also play a knowledge brokering role. Systemic risks are even more challenging, where the crucial task of preparing for these is undermined by a lack of policy and practice coherence among disciplinary and sector-based silos in both public and private bureaucracies[5]. We therefore recommend that governments and international bodies should take the lead in facilitating the establishment of, and investing in, multi-stakeholder institutional and governance arrangements that better integrate knowledge and evidence across the SDG framework and, once roles and responsibilities for such are clearly defined, to ensure the development, processing and availability of decision-ready information for users.

Knowledge needs and research: there are many areas where weather and climate-related risks and how to integrate them in policy and decision-making remain poorly understood. These limits to knowledge and capacity, especially for systemic risks, increase as the impacts become longer term and more system-wide. In all types and in both higher and lower income countries, care must be taken to ensure that weather and climate services do not entrench inequities (SDG 10) and power imbalances. We therefore recommend investment in interdisciplinary research and innovation on systemic climate and weather-related risks and on which forms of cross-temporal and cross-spatial data analysis is needed to inform policy responses in different contexts. Research funders should promote in depth engagement with users and other research funders in setting such research and innovation agendas.

Though not a panacea, weather and climate information is an important component of achieving the SDGs. But current services fail to be sensitive enough to the different decision-making needs; in particular, they fail to deliver information in the right form for long term responses to climate change by sectors that are unused to processing weather and climate data, and fail even more to support decision-makers faced with systemic risks, where co-designed research is needed to understand needs. Improvements in institutional arrangements that assist with knowledge brokering, and a greater focus on tailoring information to decision-making processes, are essential steps towards better SDG outcomes. Special attention must be paid to building the right capacity in lower income countries, in order to avoid entrenching an inequitable status quo.

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Competing interests
The authors declare no competing interests.