CMF CLIMATE MAINSTREAMING FACILITY

Good practice in the use of climate information for resilience and adaptation

Guidance note for FCDO Climate and Environment Advisers on engaging with third party climate information providers

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UK aid from the British people

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SOUTH SOUTH NORTH TOWARDS CLIMATE RESILIENCE

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Summary

Climate information is widely viewed as critical for building resilience to evolving climate hazards and enabling adaptation to climate change, whether in the form of short-term weather forecasts, seasonal forecasts, or projections of future climate change. However, there are a number of significant shortcomings in the way climate science is currently used in resilience and adaptation practice. These result in low uptake of already-available information, emphasising the need to bridge the gap between producers and users, translate existing information into appropriate forms, and co-produce useable information.

Climate information for longer-term resilience and adaptation is focused on projections from global climate models (GCMs). Climate projections need to be used with caution, given limitations in their ability to reflect the variability of the actual climate system, and the frequent mismatch between timescales represented by projections and those of interest to decision-makers. Ensembles of climate projections provide only a lower bound on uncertainty, and do not capture the full range of possible changes in climate. Similar issues pertain to the use of downscaled data, and there is a risk that users mistake the extra precision of downscaled data with greater predictive accuracy. Poor understanding of these factors among users, and a lack of capacity on the part of providers to communicate these issues, means there is significant potential for the inadvertent misuse of longer-term climate information, which amplifies climate risks.

Consequently, decision-making frameworks are required that allow for the consideration of changes outside the range of projections. These need to replace a projection-driven 'predict-then-act' approach with 'bottom-up' approaches that identify the range of conditions under which decisions and systems are (not) robust, and use climate projections as an aid to explore which decisions and development pathways are most or least robust. A number of frameworks for such analyses have emerged in recent years, based on decision scaling and robust decision-making, and incorporating 'surprise scenarios' outside the range of climate projections.

Nonetheless, used appropriately, climate information can inform resilience and adaptation decision-making. To do so, it must be (i) useful, based on a proper understanding of the geographic, sectoral and decision-making contexts in which it will be used, and on appropriate metrics tailored to these contexts, (ii) useable, in that it is seen as credible and legitimate, and is communicated via appropriate media and in formats that are accessible and understandable by users, and (iii) supported by enabling environments involving supporting institutions and policy frameworks that address constraints on uptake and action.

The generation of climate knowledge, information and services that is useful and useable can be facilitated through processes of co-production. These should go beyond linear 'bridging' approaches between producers and users and the 'translation' of scientific information, to involve users in the production process throughout, and to address contextual factors that influence the uptake of information and users' ability to act on it. Knowledge brokers and boundary organisations have a key role to play in bringing together users, producers and other

stakeholders, to facilitate co-production and create institutional mechanisms to manage and inform resilience and adaptation actions.

When engaging third party producers of climate information, commissioning bodies such as FCDO should ensure that the production of information is based on the following principles:

1. **Co-design** approaches should be followed from the commissioning and design stage, to bring together diverse actors and ensure that the development of information is based on a full understanding of user needs and contexts. This can be achieved through sustained interaction between users and producers, facilitated by specialist knowledge brokers, where appropriate.
2. **Information should be useful and relevant**, available at appropriate scales, tailored to user contexts, and based on relevant and appropriate metrics.
3. **Information should be useable** as a result of being viewed as salient and legitimate, communicated via appropriate media, presented in appropriate formats tailored to different users, accompanied by appropriate guidance/advisories, incorporating local information, and complementing and respecting local knowledge systems.
4. **Enabling environments should be supported** that enhance user capacity, address barriers to uptake and action, and ensure sustainability and free and open access to information. This would need to be based on an understanding of institutional contexts, the political economy of climate information and its use, and analysis of barriers.
5. **Climate projections** should be based on multiple models and used in a way that recognises the limits of their utility and representation of uncertainty, and avoids 'predict-then-act' approaches. Instead, 'bottom-up' assessments should be made of the robustness of decisions across a range of conditions, whose likelihood can be interrogated using climate projections and scenarios, including 'surprise scenarios'. They also need to incorporate possible changes outside the range of the projections.
6. **Interventions should be commissioned** by individuals who are familiar with the relevant literature and with approaches based on decision scaling and robust decision-making, or after consultation with those with relevant expertise.

1. Introduction

Climate and weather information is widely viewed as critical for building resilience to evolving climate hazards and enabling adaptation to climate change. Weather forecasts on timescales of days can improve short-term agricultural decision-making (e.g. around planting and harvesting activities) and enable early warning of hazards such as storms and floods (Mwangi et al. 2019). Seasonal forecasts can inform decisions about what crops to plant where and inform activities such as drought preparedness. Longer-term climate projections should inform strategic decision-making and infrastructure planning and can be used to visualise potential future conditions for scenario planning at all levels of society. Observational data is important for identifying climate trends, understanding return periods of extreme events, placing current and future extremes in their historical context, and for understanding how climate extremes and variability are evolving because of climate change. For example, observational data can be used to determine whether climatic trends, variations and extremes are within the range of historical/natural variability. Real-time observational data is important for disaster monitoring, agricultural management, and risk-spreading mechanisms, such as weather-based insurance.

As the promotion and use of climate information to inform resilience and adaptation expands, it is critical that those funding, producing, disseminating, and using climate information follow good practice. However, as discussed in a recent report commissioned by FCDO (LTS, 2020), there is relatively little published evidence relating to how (and how effectively) climate science informs resilience and adaptation in practice.

Nonetheless, there is some emerging consensus regarding what constitutes good practice in the use of climate information, including for resilience and adaptation programming. This guidance note summarises the key issues that need to be considered, and presents a set of recommendations for the provision and use of climate information to inform resilience and adaptation planning, programming and implementation. The focus is on climate change information to inform longer-term resilience and adaptation, rather than short-term weather and seasonal forecast information. However, many of the principles of good practice are the same, regardless of the nature of the information and the timescales it represents. For example, information needs to be relevant to users' contexts and needs, understandable, credible and actionable (Buontempo et al. 2014; Carr et al. 2019; Vaughan et al. 2016, 2019; Vincent et al. 2020).

The guidance note was prepared in the context of a review of the FCDO Climate Resilient Infrastructure Development Facility (CRIDF) for southern Africa and incorporates some learning from this review of the CRIDF programme.

2. Challenges in the use of climate science in resilience and adaptation practice

The LTS (2020) report mentioned above identifies a number of shortcomings in the way climate science is currently provided and used in resilience and adaptation practice, based on a review of relevant literature and interviews with key informants. These reflect a broader lack of capacity of users to interpret, and providers to communicate, climate information, and include:

1. Approaches that are highly supply-driven, based on a 'science-first' or 'impacts-led' approach, and a lack of co-design or consultation with intended users, which often results in information that is not useful or actionable by users;
2. Inadequate attention to the filtering and synthesis of information to ensure it is appropriate for intended audiences, and a lack of context-specific guidance on its use;
3. Information not being presented in appropriate or accessible formats;
4. Information being insufficiently contextualised and thus not sufficiently relevant to users' needs;
5. A lack of intermediaries or knowledge brokers who can translate scientific outputs into usable information;
6. Failure to engage with existing local knowledge systems;
7. Lack of business models to ensure continuity of services;
8. The direction of funding at the production of information at the expense of investment in the knowledge value chain and ensuring relevance, utility and accessibility of information
9. A mismatch of the timescales represented by climate model projections and the timescales of interest to potential users, with a distinct lack of information useful for decadal-scale planning;
10. The misuse of long-term projections for decadal-scale planning as a result of insufficient information at the latter scale, sometimes encouraged by certain climate service providers;
11. The design of adaptation and resilience programmes without clear links to climate science providers;
12. Lack of training on stakeholder engagement in meteorological or climate science training, and a lack of incentives for such training;
13. Poor understanding of the probabilistic nature of climate information by decision-makers, coupled with poor communication of risk and uncertainty by scientists;
14. Lack of international standards on the application of climate data, and lack of application of

existing good practice;

15. Lack of attention to the need for resources, skills and expertise in knowledge management;
16. Lack of external evaluation of how climate science and related information is used in projects, programmes and investments.

The above issues result in a low uptake of information that is already available. While knowledge and information gaps do exist, an emphasis on bridging the gap between producers and users of climate information, on translating scientific information into practice, and on the co-production of useable knowledge, is at least as important as the production of new information.

3. Climate science for resilience and adaptation

Climate science has a critical role to play in building resilience to climate change and in supporting people to adapt to specific climate change impacts. However, the interpretation of climate information can be challenging, and care needs to be taken to ensure that such information is relevant to, useful for, and actionable by its intended users. In order for climate science to effectively inform longer-term planning, it is critical that providers and users of climate information understand both the utility and limitations of climate projects and the scenarios they are used to generate, and the nature of uncertainty in relation to these projections and scenarios. There is an urgent need to bridge the gap in understanding between providers and users in this regard.

3.1. Climate projections and uncertainty

Information on future climate change and its impacts is typically derived from climate projections generated by global and regional climate models. Climate projections need to be interrogated in an appropriate manner that acknowledges uncertainty and the limits of their utility. It is critical to ensure that climate projections are not misused because limits and caveats relating to their ability to model future climatic conditions are not explicit, or because user-driven demands for unrealistic levels of precision and accuracy remain unchallenged (Nissan et al. 2019). **Climate projections should be used principally for identifying climate trends and assessing potential changes in the general behaviour and state of the climate system, not as predictions of likely future conditions.**

Today, modellers typically produce ensembles of climate projections, generated by a suite of different climate models, run using different emissions scenarios. For the IPCC (2013) Fifth Assessment Report (AR5), models were driven by 'representative concentration pathways' or RCPs. Each RCP represented an emissions trajectory culminating in a specified radiative forcing, associated with a specific greenhouse gas concentration, by 2100. Under the fifth iteration of the Coupled Model Intercomparison Project (CMIP5), multiple models were run using multiple RCPs (Eyring et al. 2016). For a given RCP, an individual model is run multiple times, using different sets of initial conditions, to generate an ensemble of projections associated with the RCP (Figure 1).

Under CMIP6, which is generating projections for use in the IPCC Sixth Assessment Report (AR6), a set of 'Shared Socioeconomic Pathways' (SSPs) has been developed for use with an updated set of RCPs. An RCP is combined with a compatible SSP in an integrated assessment models (IAM), to produce an 'SSP scenario' that delivers the greenhouse gas concentration specified by the RCP in 2100. By repeating this process across the SSPs and RCPs, a set of standardised SSP 'marker' scenarios is produced with which to drive climate models.

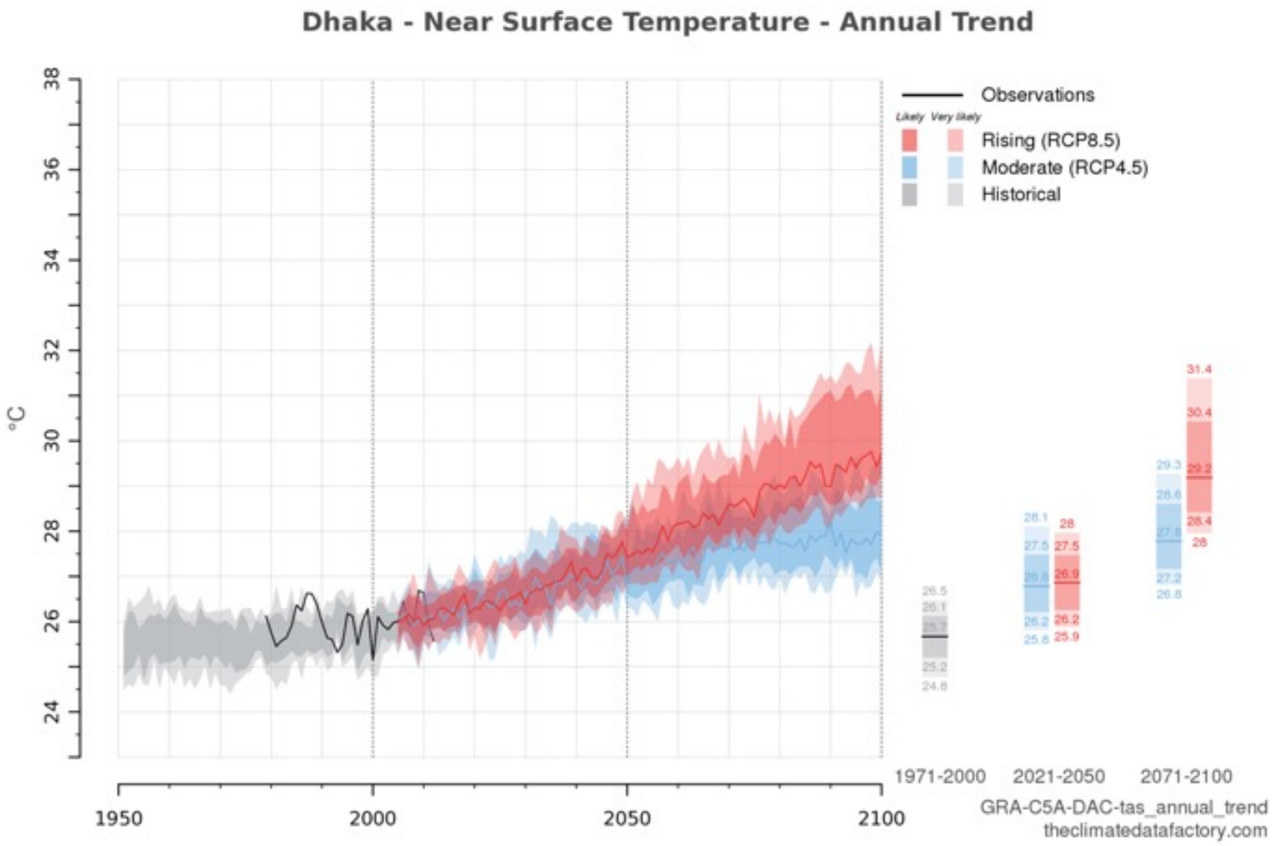


Figure 1: Illustration of ensemble projections from 20 CMIP5 models for surface temperature at Dhaka, Bangladesh, for RCP4.5 (blue) and RCP8.5 (red), with observations and modelled historical temperature. Darker shading indicates the range spanned by 66% of projections (likely); lighter shading by 90% of projections (very likely). Bars to right of graphic indicate median temperatures and temperatures at limits of 66% and 90% probability ranges. Graphic from Wikimedia Commons (https://commons.wikimedia.org/wiki/File:GRA-C5A-DAC-tas_annual_trend.png).

Ensembles of climate projections lend themselves to the probabilistic characterisation of uncertainty. The probability that the simulated value of a specific climate variable will fall within a given range at a given time can be estimated based on the distribution of values of that variable across the whole ensemble. For example, the probability that annual mean temperature averaged over a particular region will fall within a particular range at a given time in the future can be estimated by examining the frequency with which the simulated values fall within that range across the projections. However, the question remains as to how well the ensemble of projections represents the range of actual possible future conditions.

Individual climate models are developed to simulate the climate as closely as possible, based on climate scientists' understanding of the physical processes operating in the climate system. These models are then tested against historical observations. However, models are imperfect representations of reality, and multiple types of uncertainty exist in model projections of future climate.

First, models are simplifications of the climate system. They are refined by changing their parameters in ways that improve their representation of reality. However, this process of refinement does not involve an exploration of all the possible changes in model parameters that would result in the desired improvement. Instead, a limited number of parameters are adjusted based on modellers' evolving understanding. As a result, models do not 'span the full range of behaviour or uncertainty that is known to exist,' (Tebaldi & Knutti 2007). In other words, models may represent aspects of the climate in a way that is 'good enough' to match with historical observations, but which is not optimal or 'right'. Consequently, as the climate changes, a model's ability to reproduce its behaviour may decline.

Second, the scenarios and assumptions used to drive climate models cannot represent all possible combinations of future circumstances. Model projections therefore can only ever represent a subset of possible futures. This fundamental uncertainty arguably can be reduced through the use of a wider diversity of input scenarios, but it cannot be removed.

Third, a model can only be run a finite number of times, so the resulting projections will represent only a subset of the futures that it could in principle simulate. This uncertainty can be reduced by increasing the number of runs, but it cannot be eliminated entirely without an infinite number of runs.

These first three forms of uncertainty are inherent in the nature of climate models, and cannot be quantified through statistical means.

The fourth type of uncertainty is related to the range of climate outcomes simulated across models for a given scenario or set of scenarios relating to future social, economic, technological and environmental pathways. This uncertainty can be quantified by examining the proportion of projections simulating changes in key climatic variables (e.g. temperature and precipitation) within a particular range. For example, for a given location and period, if more than 66% of temperature projections fall within a particular range, it can be said that temperature change is likely to be in that range (Figure 1) for a given scenario.

It is common for uncertainty to be characterised in probabilistic terms based on ranges of climate projections as described above. However, the first three types of uncertainty discussed above mean that climate projections represent only a subset of possible futures, and do not describe the full range of uncertainty in future conditions. Consequently, decisions that are robust or resilient within the full range of uncertainty represented by climate projections are not necessarily so within the full range of possible future climates. Whereas the range defined by an ensemble of climate projections defines a quantifiable envelope of uncertainty, the full range of possible future conditions is represented by a wider envelope whose boundaries are unknown (Tebaldi & Knutti 2007). Managing uncertainty is important; for more on this see the Topic Guide produced for FCDO staff (Ranger, 2013) and delivering value for money adaptation (Watkiss et al. 2014).

This does not mean that projections are not useful. However, they should not be used deterministically, and their limits need to be appreciated.

3.2. Understanding the utility of climate projections

The quality and utility of models used to generate shorter term (e.g. seasonal) forecasts can be assessed in terms of forecast 'skill' – the correlation between forecast and observed values of specific parameters or indexes (Stern & Easterling, 1999). Information on the forecast skill associated with different models is invaluable in informing users which forecasts to use and how.

Assessing the quality of longer-term climate projections is more challenging, owing to the timescales involved. However, some climate models are sufficiently established for their forecasts to be assessed against observations up to the present day (Hargreaves, 2010). Climate models can also be evaluated against other criteria; for example, their ability to simulate mean climate, historical climate change, and regional modes of variability, as well as key processes and teleconnections in the climate system such as the El Niño Southern Oscillation (ENSO) (Randall et al. 2007; Tebaldi & Knutti, 2007; Flato et al. 2013). Projections from some models might be more useful than those from others in specific regions, based on the relative performance of those models in simulating aspects of regional climate (McSweeney et al. 2015). Where climate information is used to inform resilience and adaptation activities, those commissioning climate services and interpreting climate information should be aware of the potential for variation in the regional performance (and thus relevance) of different models.

The rejection of certain models and the privileging of others for use in specific contexts should be undertaken by a specialist in model evaluation. Such expertise should be included in the knowledge chain, and in models of knowledge co-production.* This can help to highlight the limitations of models and the projections they generate, and help users in a specific geographic region or planning context use projections in an appropriate fashion.

The provision of information relating to the performance and limitations of climate models and projections should be a minimum requirement for providers of information based on climate projections. This information should detail:

- which models have been used to generate these projections;
- which socio-economic scenarios and emissions pathways (e.g. RCPs) have been used to drive the models;
- how many projections have been used to produce the information provided;
- what range (e.g. of an ensemble of projections) is represented in the information provided (e.g. the full range of projections or a subset);
- what is appropriate in terms of the spatial and temporal resolution at which projection-based information is applied;

* Working in a North American context, Briley et al. (2020: 1709) highlight the 'relative inaccessibility or unavailability of information about a given model's quality, trade-offs and suitability for a particular geographic region or decision-making application.' They recommend addressing this through documentation based on consumer reports, developed by knowledge brokers working with experts and real-world consumers, that incorporate otherwise unavailable information from model developers.

- what is known about systematic biases in the projections and underlying models;
- any known strengths and weaknesses in specific models or sets of projections that make them more or less appropriate for a particular (e.g. geographic) context, e.g. their ability to represent specific aspects of the climate that are particularly relevant to users (for example, relationships of local rainfall with ENSO, ability to represent convective rainfall in areas such as the Sahel);
- whether (and which) projections are consistent with observed data over historical periods for which projections and observations overlap.

The above information will help analysts make an informed decision as to whether a provider is delivering useful information and, if so, how this information should be used. For example, a model might consistently overestimate or underestimate rainfall in a particular region. Over some regions, there may be strong disagreement between models regarding the sign of future changes in rainfall. In such contexts, a precautionary approach should be taken when it comes to decisions that are sensitive to model representations of rainfall. The inclusion of climate analysts in co-production processes can ensure that climate information is of sufficient quality and is used appropriately. However, advisories relating to the use of information might also be included by providers of information.

In addition to the provision of information relating to the performance and limitations of climate models and projections, a number of other indicators of good practice may be identified.

Where climate projections are used, **multiple projections from multiple models should be employed**. If a subset of projections or models is selected, this should be based on a sound rationale. For example, projections might be excluded if they or the models used to generate them are known to perform poorly over a particular geographic region that is of relevance to intended users.

Systematic model biases should be addressed, either by calibrating model output against observational data or, where this is not possible, using changes in modelled variables between a future period of interest and a historical period or the present day rather than absolute values of these modelled variables.

As indicated above, **projections should be used principally for identifying trends and assessing potential changes in the general behaviour and state of the climate system**. Even where models can represent natural variability relatively well, this is rarely in sync with the actual variability in the climate system. This means that projections cannot be used reliably as 'forecasts' of specific decadal-scale future time windows, particularly for variables such as rainfall, that exhibit cyclical or quasi-cyclical behaviour in many regions (Nissan et al. 2019).

The LTS (2020) study highlights the lack of projections for the relatively near future to inform decadal-scale planning, and the danger that long-term projections are used inappropriately for such nearer-term planning. **However, while long-term projections should not be used for planning in the near term, they might be useful for awareness raising and the development of narratives and scenarios, which can be used to frame wider discussions about resilience and adaptation**. Long-term projections may have a role to play in planning associated with long-lived infrastructure. However, any such planning needs to consider not only the uncertainty defined by ranges of projections, but also the wider uncertainties that are not captured by climate models. Both these kinds of uncertainty need to be addressed to avoid commitments to costly infrastructural interventions that might be redundant or maladaptive if climate change trajectories deviate significantly from expectations. Addressing uncertainty through scenarios and other methods is discussed below.

Based on the above discussion, we can identify a set of criteria for assessing the quality of climate projection-based information (e.g. scenarios) from third-party providers (Table 1).

Table 1: Desirable criteria and red flags for the selection of third-party climate information.

Desirable 'good practice' criteria	'Red flags' – avoid
Multiple projections from multiple models	Single model, few projections
Multiple scenarios (SSPs, RCPs) represented and discussed	Scenarios not specified or described
Detailed description of model and data	Little or no background information
Ranges of projections provided	Mean, median or 'best guess' only
Probability ranges provides	No probability ranges
Projected changes presented as anomalies	Projected changes presented in absolute terms
Metrics relevant to user context	General metrics (e.g. annual temp., precip. only)
Rational for model/projection selection given	No rationale for model/projection selection given
Appropriateness to region discussed/addressed	Regional relevance not discussed
Information on model biases and performance	No discussion of biases or model performance
Data accompanied by guidance on usage	Data provided with little or no guidance
Limitations of data and their usage highlighted	No 'health warnings' on appropriate usage

3.3. Addressing uncertainty through scenarios

Climate projections can be used to develop scenarios of future climate change that can inform decision-making in specific contexts. An ensemble of climate projections can be used to develop multiple scenarios representing different possible futures that span the range of uncertainty defined by the projections. A scenario may describe possible/plausible conditions at a particular time in the future, or a trajectory of change through time. Given the range of possible futures represented by climate projections, multiple scenarios should be developed to represent this range.

Scenarios may be developed to reflect a more 'likely' future around which there is strong agreement across projections, and less likely futures reflecting projections towards the edges of this range (see Box 1). However, limiting scenarios to those consistent with model projections ignores the larger set of uncertainties that are not captured by climate models. Scenarios may also be developed to explore the implications of plausible changes that might not be represented in climate projections, such as particular types of extreme events or non-linear changes that are not captured by climate models. These scenarios will be based on self-consistent narratives and storylines focused on particular events and can be used to 'stress-test' systems and assumptions under hypothetical but plausible future conditions (Shepherd 2019; Silmann et al. 2020).

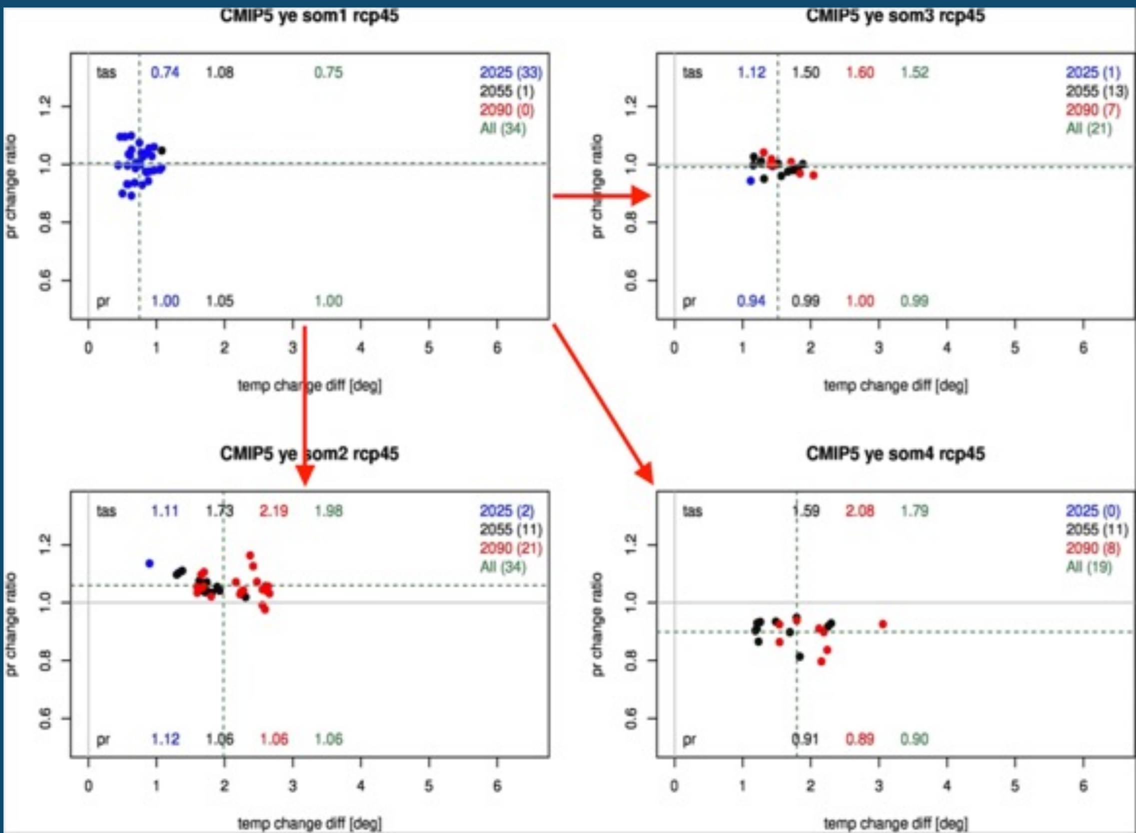
BOX 1: Scenario development in the CRIDF programme

The approach of the CRIDF programme is to identify clusters of projections that exhibit similarities for specified time periods, using a technique known as self-organising maps (SOMs), in which clusters of projections are identified using a neural network. These clusters are then displayed on maps that plot one climate variable against another, for a given representative concentration pathway. Typically, four maps are presented for each RCP. Each point on a map then represents a simulated change in (for example) annual or seasonal mean temperature and rainfall, averaged over a number of years representing one of three time periods. Each map represents a broadly similar set of futures; for example, high warming and little change in rainfall, high warming with large increases in rainfall, high warming with large declines in rainfall, and moderate warming with moderate increases in rainfall.

Expert judgment is then used to select three points to define a climate scenario. Each point may represent a different model or simulation. The goal is to define a plausible scenario that reflects the clustering of projections around particular sets of future conditions across the range of the ensemble, without tying these scenarios to any one particular model or projection. Three of four such scenarios are developed, one of which is a 'scenario of most agreement' that represents the most populous clusters of projections. The remainder are scenarios of less or least agreement, that represent less populous clusters, some of which are likely to lie near the extremities of the ensemble.

These scenarios can then be used to define a range of possible futures within which decisions and investments need to be robust. Values of climate variables from these scenarios can be used as input to hydrological and other models to examine the potential impacts of climate change on systems of interest across a range of possible futures, to inform decision-making.

The CRIDF approach reflects the conventional approach of developing multiple scenarios for planning, but seeks to ground it in a more robust and inclusive representation of the range of possible futures represented across the ensemble of projections; in this case, the ensemble of projections developed under CMIP3 and CMIP5, as well as a subset of outputs from the CORDEX regional models (CRIDF, 2016).



Self-organising maps showing clusters of projections of precipitation and temperature change for Swaziland from CMIP5 models for RCP4.5, over three time periods (CRIDF 2017).

As indicated above, while projections can be used to develop scenarios spanning a range of plausible climate futures, this approach limits itself to the range of futures simulated by climate models, and does not address the possibility of changes outside this range (Stainforth et al. 2007; Brown 2012). Climate models can address uncertainties around socio-economic development pathways and emissions pathways, reflecting uncertainty in future economic, development and energy choices. The different representation of physical processes in climate models can go some way towards addressing uncertainties in the climate system. However, scenarios based on model projections cannot address deeper uncertainties associated with the possibility of unanticipated societal changes or the omission or misrepresentation of physical processes within the climate system. Consequently, approaches based on a 'predict-then-act' approach, even where this involves the use of multiple scenarios and a range of possible futures, are giving way to approaches where climate projections and scenarios are used to inform, but not necessarily drive, resilience and adaptation actions. These include the use of scenarios that incorporate surprises or 'wild cards' (Bhave et al. 2016).

3.4. Impacts-led versus vulnerability-led approaches and deep uncertainty

While probabilistic characterisations of uncertainty based on ensembles of climate projections are still widely used, approaches and frameworks are emerging for addressing more fundamental uncertainties associated with model limitations and the potential for changes outside the ranges represented by ensembles. Many of these approaches have been developed for the water sector (Brown, 2012; Ray & Brown, 2015; Mendoza et al. 2019), but their principles are more widely applicable (Daron, 2015; Bhave et al. 2016). Typically, these approaches seek to avoid the predict-then-act model, starting instead with assessments of vulnerability and identification of the conditions under which specific decisions or courses of action are viable and robust. Climate projections and scenarios are then used to examine the likelihood that these conditions will be met.

The Decision Scaling (DS) approach, developed for use in the water sector, identifies the range of climate states that favour a decision over others, then uses climate projections and stochastically generated conditions based on historical data to examine how likely these conditions are (Brown et al. 2012). This approach starts not by asking what future conditions will be, but by asking whether a climate favouring one action or decision is more or less likely than that favouring another. Ensembles of climate projections are viewed as representing a lower limit on the range of climate uncertainty: Risks represented in projections need to be addressed, but risks that are not represented by the projections cannot necessarily be discounted. However, within the range of projections, the relative likelihood of different risks can be assessed. CRIDF uses a version of DS to identify the conditions under which water infrastructure is likely to fail, and then to assess the likelihood of these conditions based on climate scenarios.

DS is one of a suite of approaches that fall under the umbrella of Robust Decision Making (RDM). RDM seeks to address large uncertainties by combining top-down modelling approaches with bottom-up stakeholder driven processes, to identify 'robust strategies [that] satisfy performance criteria against most sets of future conditions' (Bhave et al. 2016: 2), or 'adaptation solutions which are insensitive to uncertainty' (Daron, 2015: 459).

The World Bank has developed a Decision Tree Framework (DTF),* which draws on DS to identify system vulnerabilities, and then uses 'simple, direct techniques for the iterative reduction of system vulnerabilities through targeted design modifications' (Ray & Brown, 2015: xvi). Developed for the water sector, the DTF includes elements of screening for climate sensitivity, comparison of climate and other impacts based on simple modelling, and detailed risk assessment combing elements of observed and modelled climate data and system modelling.

Also developed for water resources management, and building on the DTF, the UNESCO Climate Risk Informed Decision Analysis (CRIDA)† seeks to provide 'a coherent and consistent approach for dealing with anticipated but unquantified changes due to "unknown unknowns"' (Mendoza et al. 2019). CRIDA starts by identifying planning objectives and problems, and follows a five-step planning process based on bottom-up vulnerability assessment and incremental planning based on the likelihood of 'unacceptable performance scenarios' (Mendoza et al. 2019: 24). It seeks to enhance flexibility 'by examining a variety of adaptation pathways and formulating and evaluating the sequencing of combinations of measures designed to address future climate uncertainties'. The use of adaptation pathways 'avoids 'locking in' a single strategy by including alternatives that can be implemented when pre-defined "trigger points" are reached' (Mendoza et al. 2019: 25).

These approaches and frameworks are potentially data and resource intensive, and are predicated on convening a wide range of stakeholders and expertise that may be impractical in resource constrained contexts. Much of the associated guidance is lengthy, detailed and complex. However, these approaches and frameworks highlight some important principles around the use of climate information (including model-generated projections and associated scenarios). While the full implementation of the DTF or CRIDA framework may be impractical in many developing country contexts, DS and RDM have potential for application in these contexts with some modifications, or at least to inform the use of climate information in decision-making (Daron 2015; Bhave et al. 2016).

It is recommended that those responsible for commissioning initiatives involving the use of climate projections and scenarios familiarise themselves with the above approaches and frameworks, in order to ensure that such data is used appropriately and effectively, and that deterministic, technocratic 'predict-then-act' approaches are avoided. Principles, techniques and learning from these approaches can then be used to inform the use of climate information, even where the approaches cannot be fully implemented.

* https://agwaguide.org/about/decisiontree/

† https://en.unesco.org/crida

3.5. Downscaling

Downscaling refers to a variety of techniques used to model conditions at the local scale, based on known relationships between local conditions and large-scale climatic and meteorological phenomena (Benestad, 2016). These relationships depend on factors including geography, topography, variations in the land surface, and smaller-scale atmospheric processes and atmosphere-ocean-land interactions that are not well represented in global climate models (GCMs) (Lennard et al. 2018). Downscaling therefore provides a means of deriving high-resolution information about local changes from lower-resolution data produced by GCMs.

Downscaling encompasses empirical/statistical and dynamical approaches, with regional climate models (RCMs) representing the latter approach (Giorgi et al. 2009; Hewitson et al. 2014; Lennard et al. 2018). GCMs provide input for downscaling techniques, so any errors or biases in GCM output/projections will influence the downscaled data. Critically, the higher resolution and greater precision of downscaled data therefore does not necessarily result in greater accuracy. For example, Buontempo and Hewitt (2018) report a lack of evidence that the skill of large-scale models can be significantly improved through downscaling. More fundamentally, RCMs inherit the errors and biases of the GCMs whose outputs are used to run them, and add additional errors and biases based on the assumptions and approximations inherent in their own construction, creating a further cascade of uncertainty (Nissan et al. 2019). Statistical downscaling is dependent on long timeseries of observational data, and based on historical relationships between local climates and larger-scale phenomena that may not pertain under climate change (Nissan et al. 2019). The generation of downscaled data in response to user demand for 'more detailed climate projections' therefore creates a risk that decisions will be made on the basis of unreliable information, as a result of poorly informed users mistaking precision for accuracy. There is the potential for downscaled data to be misused by providers of climate data in this way.

Downscaling is a resource-intensive process that requires specialist expertise, so it is important to determine the extent to which it is likely to add value in the use of climate information.

The use of downscaled data should be justified on the basis of both utility and plausibility. Utility demands that there is evidence that downscaled data will add value to an activity that is informed by climate information. **Plausibility** requires that downscaled data is demonstrated to be reliable for a particular geographic context, based on assessments of the ability of the GCMs from whose data they are produced, to reflect aspects of the climate system that are important for that region. This criterion also applies to the RCMs themselves: An RCM may be applied to different regions, and its performance may vary across regions (e.g. Jacob et al. 2012). Providers of downscaled climate projections need to be able to demonstrate their utility and plausibility, offering guidance on the regional performance of the relevant GCMs, and on any shortcomings and limits of the downscaled data.

BOX 2: Assessing the utility of downscaling

The CRIDF programme has used RCM data from the Coordinated Regional Downscaling Experiment (CORDEX) datasets. The CORDEX models are regional models that use data from GCMs as input, which produce higher-resolution temporal and spatial data at the regional scale through a process of dynamical downscaling (Giorgi & Gutowski 2015). However, it was reported that this downscaled data added little of value over and above the GCM data in the case of temperature, and that there were questions about the reliability of the downscaled rainfall data.* In addition, the computational resources required to produce ensembles of regional climate projections that reflect the range of GCM models and projections is prohibitive.

Nonetheless, some studies have developed methodologies for selecting subsets of GCMs for use in regional climate change assessments, based on the elimination of the least realistic GCMs for a particular region. For example, McSweeney et al. (2015) assess GCMs' abilities to simulate large-scale processes that are important for particular regions, and classify model performance as implausible, significantly biased, biased, or satisfactory on this basis. Hewiston et al. (2013) present related criteria for the selection of empirically downscaled data, emphasising the need for downscaled data to be plausible (consistent with the known dynamics of a physical system), defensible (explainable in terms of known mechanisms) and actionable (constituting strong enough evidence for guiding real-world decisions). They also emphasise that the reliability of downscaled data will depend on the intended application, and the level of detail required.

* Interview with Mike Harrison, CRIDF climate science expert, on 14 October 2020.

4. Factors influencing the uptake of climate information

Vincent et al. (2020) present a framework for climate resilient planning, informed by examples from Sub-Saharan Africa, that is consistent with the significant body of literature addressing challenges around the effective use of climate information. This framework emphasises that climate information must be **useful**, based on a proper understanding of the context(s) in which it is to be used and the needs of the users, and based on appropriate metrics that are relevant to users and their needs. It must also be **useable**, which means it must be seen as legitimate and credible, and communicated in appropriate formats that are understandable to users. Even where information is both useful and useable, in order for it to be actually used, it needs to exist in an **enabling environment** of supportive institutions and appropriate policy frameworks, in which users have the capacity to understand and use information and the agency to make decisions.

Vincent et al. (2020) highlight the importance of co-production in the generation of new knowledge and information, involving sustained interaction between producers and users of climate information to ensure that this information is both useful and actionable (see also Buontempo et al. 2018). Such interaction involves users guiding, informing and participating in the generation, processing and dissemination of climate information through collaborative, iterative processes (Mwangi et al. 2019). Co-production can be facilitated by specialist knowledge brokers who understand the processes through which climate information is generated, as well as the needs of users and the contexts in which the information will be used. The role of knowledge brokers is to address the 'multiple boundaries between producers and users of climate information' and bridge the so-called 'valley of death' that has separated climate science and decision-makers (Buontempo et al. 2014: 1).

4.1. Usefulness

To be useful, climate information needs to be 'credible scientifically but also salient and legitimate' (Buontempo et al. 2014: 1). In other words, users need to accept it as relevant to their needs, trustworthy and understandable. This can be supported though assessments of the performance of climate models to identify those that perform best in a given context (Buontempo & Hewitt, 2018).

Climate information also needs to be relevant and tailored to the diverse contexts and users for which it is intended (Buontempo & Hewitt, 2018; Carr & Onzere, 2018; Carr et al. 2019). Weather and seasonal forecasts may be competing with traditional methods of forecasting, meaning that scientific information may be more likely to be used if it is combined with local information and trusted traditional forecasting techniques (Nkiaka et al. 2019)

The use of appropriate metrics is critical if climate information is to be useful. For example, climate scientists and modellers typically work with metrics such as mean annual and seasonal temperatures, and total annual and seasonal rainfall. However, such metrics are often of limited utility to users, who are more likely to be concerned with the seasonal distribution of rainfall, the time of onset and duration of rainfall seasons, changes in the duration of dry periods within the growing season, and the likelihood of multiple drought years (Buontempo et al. 2014). The IPCC has identified a number of climate extreme indices for investigation via climate models, and considerable progress has been made in improving the representation of smaller-scale processes such as convective rainfall. However, the characterisation of climate hazards operating at scales relevant to users from climate model data remains challenging and outside the scope of many studies. Nonetheless, progress is being made in representing some aspects of climate variability. For example, the CRIDF programme is providing information to planners on changes in the likelihood of multiple consecutive drought years for specific future periods.*

A key aspect of knowledge brokering will be the identification of appropriate metrics relating to variability and extremes that are of concerns to users, and the communication of these to climate scientists and modellers. The limitations of climate models in the generation of such metrics may also need to be communicated to users. Through this process, users and producers of climate information might identify a set of metrics that are both useful from a user perspective and legitimate from a scientific perspective. Information relating to these metrics can then be communicated in a format that can be understood and acted upon by the users, based on a pragmatic approach to uncertainty and the limitations of climate projections.

4.2. Useability

While it is important for climate data to be represented using appropriate metrics that address user contexts and needs, it is just as important to convert 'useful data' into 'usable information' (Lorenz et al. 2017). Critical to this process will be an understanding of the contextual factors that influence where and how information is acted upon (Lorenz et al. 2017).

To be useable, climate information needs to be available in appropriate formats that can be readily understood by users. This means presenting information in tailored formats that are relevant to different users and user groups, in local languages and using terminology that users understand. Users have reported that the content and format of forecasts is too technical in some contexts, leading to poor understanding and low uptake (Nkiaka et al. 2019). Attention also needs to be paid to how users prefer to receive information. For example, Nkiaka et al. (2019) report a strong preference among many farmers in Sub-Saharan Africa for receiving short-term weather forecasts via radio, while Mwangi et al. (2019) report a range of different communication preferences among farmers. While a different approach is likely to be required for longer-term climate information, these findings highlight the importance of presentation and media. They also highlight the need for transdisciplinary approaches in the co-production of information, including social scientists and other specialists who can ensure that information is tailored to local social, cultural and livelihood contexts.

* Based on key informant interviews with CRIDF staff in November 2020.

4.3. Actionability and enabling environments

Even where climate information and services are useful and useable, there may be barriers to their being taken up and acted upon. These include the ability to respond to early warnings on the timescales required (Carr et al. 2020). In the case of short-term weather forecasts, uptake may be limited by a lack of access to communication devices through which forecasts are received, and this may be more pronounced among certain groups such as female farmers (Nkiaka et al. 2019).

Even where such information is received at the right time, potential users may not be able to act on it if they cannot access the required resources. For example, at the community and household level, action based on short-term forecasts may be constrained by an inability to access appropriate agricultural inputs owing to financial or other constraints. At the national scale, action may be constrained by a lack of historical information, relevant technology, infrastructure, human and economic resources, and low institutional capacity (Nkiaka et al. 2019). Institutional and legal constraints, transactional costs, political leadership, short-term planning horizons driven by electoral cycles, and behavioural norms may pose additional obstacles to resilience and adaptation actions (Bhave et al. 2016; Lorenz et al. 2017).

Co-production processes need to identify and address such barriers to action on climate information that is otherwise useful and useable. Knowledge brokers and boundary organisations have a key role to play here in identifying these barriers, based on an understanding of the contexts in which users operate, including contexts of political economy and power relations (Vogel et al. 2019; Briley et al. 2020). Figure 2 summarises the 'building blocks' of co-production (Carter et al. 2019).

These actors might then engage with other organisations and institutions, for example local and national governments, research organisations, the private sector, international organisations and community-based organisations, to develop enabling environments and build capacity for action on climate information.

Knowledge brokers can also play a role in convening dialogue forums between producers and users of climate information to facilitate the co-production process (Lugen, 2020). Mwangi et al. (2019) describe how such forums between climate information providers and agricultural extension officers in Mali were formalised in institutional frameworks, enhancing institutional capacity. Similar experiences have been reported by the CRIDF programme, with stakeholder forums evolving into de facto or formal committees for the management of climate risks.

More generally, knowledge brokers can play a role in the curation of climate information and associated decision support tools, to enable decision-makers at different scales to access and use climate information (Briley et al. 2020). For programmes such as CRIDF, which has developed a range of tools, guidance and climate scenarios to inform resilience and adaptation decision-making, such curation will be critical in ensuring the sustainability of programme impacts.

Figure 2: The building blocks of co-production (Carter et al. 2019).

Vogel et al. (2019) caution against a simplistic 'bridging' approach that seeks to translate scientific information for use in policy and wider society in a rather linear way. Instead, they advocate a 'messier' co-production approach that recognises the complexity of real-world interactions between relevant actors in specific contexts. Co-production should be iterative in nature, with the users of climate information and services involved in their production in a sustained manner from the outset. This process may be facilitated by individuals or organisations acting as knowledge brokers. However, ultimately, the goal should be to create a context in which users and producers of climate information can engage in their own co-production and act as their own knowledge brokers, without the need for external intervention.

5. Principles of good practice in the use of climate information for resilience and adaptation: Some recommendations

Based on the above discussion, a number of principles of good practice for the use and commissioning of climate information from third party providers can be identified. These are set out below.

5.1. Co-design

Ensure new climate science, information and services intended for specific users are developed in collaboration with those users through processes of co-design, with user needs and contexts driving the design process. Interaction between producers and users should be sustained rather than sporadic.

5.1.1. Integration

Use transdisciplinary approaches that bring together researchers, scientists, decision-makers, practitioners and users, to reach a common understanding of needs, paying attention to cultural, economic, political, livelihood and environmental contexts in which climate science/services will be used. Embedding researchers in user organisations can support integration. Dialogue forums can evolve into more formal institutional entities to address climate risks where they are given sufficient support.

5.1.2. Knowledge brokering

Ensure co-design processes are facilitated by knowledge brokers with an understanding of the processes involved in the creation of climate information on the supply side; the nature, utility and limits of that information; the needs and goals of users; the contexts in which information is to be used; and constraints on the uptake and effective use of information.

5.2. Usefulness/Relevance

Ensure climate information is relevant to users and their needs through co-production processes that enable user-driven development of information and related services.

5.2.1. Appropriate scales

Climate information and services should represent the spatial and temporal scales that are most relevant to users.

5.2.2. Tailored to context

Climate information and services should to be tailored to the specific sectors or activities that are relevant to users.

5.2.3. Appropriate metrics

Climate information should take the form of the variables and metrics that are most useful to users, based on the climate hazards or aspects of climate variability and change that are of most concern to them. Relevance should be verified either by users or a credible knowledge broker.

5.3. Useability

Ensure climate information is seen as salient and legitimate by users, and that it is accessible, understandable and visible. Involvement of users in the production of information through co-production processes will enhance relevance, ownership, legitimacy and useability.

5.3.1. Local information

Integrate scientific information with local information and knowledge where this is practical, to enhance legitimacy, fill data gaps, provide a 'sense check' (e.g. do near-term projections reflect observed trends?). Enhance capacities for the generation and curation of local observational information where possible, based on low-cost phenological approaches as well as more conventional technical measurement.

5.3.2. Presentation

Ensure climate information and associated knowledge is communicated in appropriate formats whose effectiveness is verified by users. Use narrative methods and alternative visualisations instead of or alongside conventional scientific formats such as graphs and maps.

5.3.3. Communication

Identify and strengthen the most effective communication channels to ensure that useful and useable information reaches those who can benefit from it. For example, users may prefer to receive information via radio broadcasts than via other mechanisms.

5.3.4. Guidance/advisories

Ensure that climate information is accompanied by guidance/advisories that indicate how it should and should not be used, including guidance on limits to the utility of the information.

5.4. Enabling environments

Understand and address factors that influence the uptake of information and the way it is used, including institutional, political economy, resource-related and other barriers to uptake.

5.4.1. Capacity

Support the capacity of users to participate in the development of services, providers to work with users and other relevant actors, and relevant institutions that influence contexts in which information is accessed and used.

5.4.2. Barriers

Understand user contexts, including institutional contexts and the political economy that influences uptake of climate information, and identify and address barriers to uptake.

5.4.3. Sustainability

Ensure that models for the provision of climate information are sustainable and that this provision will not cease once external funding (e.g. from aid donors) stops.

5.4.4. Open access

Ensure that climate information and related guidance is publicly and freely available.

5.5. Use of projections

Information regarding future climate change should be based on multiple projections from multiple models, with guidance on where there is most agreement across models and projections, and the ranges spanned by projections. The aim should be to represent a range of plausible future conditions and to avoid using a single 'most likely' scenario. As far as possible, climate information should be combined from different sources and calibrated to avoid systematic bias. Information should be provided on the relative skill of different models, with reference to the relevant variable(s) and geographic region(s). Projections are best used as heuristic devices to explore uncertainty, not as reliable forecasts of future conditions, particularly for highly variable parameters such as rainfall.

5.5.1. Transparency

Ensure users of climate forecasts and projections understand their limits, and their skill across relevant temporal and geographic scales. Climate information should be accompanied by clear guidance on what constitutes appropriate and inappropriate use of the information, including guidance on uncertainty and limitations of the information.

5.5.2. Downscaling

Where downscaled climate data is used, the utility and reliability of this data needs to be demonstrated, to ensure that data is not assumed to be more accurate or reliable simply because it is available at a higher spatial and/or temporal resolution. Uncertainties and limits of downscaling must be emphasised to avoid precision being confused with accuracy, and climate information must be provided at an appropriate level of precision and no more, to avoid its misuse.

5.5.3. Timescales

Avoid using long-term projections as substitutes for decadal-scale projections where the latter are not available. Reserve long-term projections for more general explorations of future risks, associated awareness raising, and scenario planning around long-lived infrastructure where appropriate.

5.5.4. Uncertainty

Be explicit about the limits of methods for characterising uncertainty based on ensembles of projections. Highlight uncertainties in models and the possibility that future conditions will lie outside the range represented by projections. Ensure that these issues are communicated clearly.

5.5.5. Avoid 'predict-then-act'

Encourage approaches that start by considering the conditions under which decisions or systems are viable and robust, and the conditions under which they are not, rather than starting by trying to describe what conditions may be like in the future. Use projections to examine whether modelled conditions include those under which decisions or systems fail, but recognise that projections represent a lower bound on the range of uncertainty. Use approaches compatible with Decision Scaling (DT), Robust Decision Making (RDM), Decision Tree Analysis (DTA) and Climate Risk Informed Decision Analysis (CRIDA) to take a more bottom-up, vulnerability led approach.

5.5.6. Scenario planning

Using the above approaches and principles of co-design, encourage decision-making based on scenario planning that is informed, but not driven by, climate projections, and that considers the implications of 'unknown unknowns' outside the range of available projections.

5.6. Commissioning

Those responsible for commissioning initiatives that involve the use of climate information from third party providers should be familiar with the issues discussed in this guidance note and with frameworks such as the DTF and the CRIDA framework, and have a reasonable level of familiarity with the literature cited above.

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