PRESIDENTIAL CLIMATE COMMISSION
TOWARDS A JUST TRANSITION

Putting Climate-Resilient Development Pathways Into Practice

Climate Information and Services

REPORT 2 OF 4

November 2022

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SUPPORTED BY

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety of the Federal Republic of Germany

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About the Presidential Climate Commission

The Presidential Climate Commission (PCC) is a multi-stakeholder body established by the President of South Africa to advise on the country's climate change response and support a just transition to a low-carbon climate-resilient economy and society. The PCC facilitates dialogue between social partners on these issues—defining the type of economy and society we want to achieve, and detailed pathways for how to get there.

Suggested citation

Jack, C., Steynor, A,. Taylor, A., Methner, N., New, M., McClure, A., Price, P., Barkai, K., Madhi, Y., Ziervogel G. and Hewitson, B. (2022) Putting Climate-Resilient Development Pathways Into Practice: Climate Information and Services. PCC Technical Paper. Pretoria, South Africa: Presidential Climate Commission.

1. INTRODUCTION

Climate Resilience Development (CRD) pathways and associated pathways thinking provide a useful framework for bringing together adaptation, mitigation, and development decision-making (Denton et al. 2015). Key to deliberations around and development of CRD pathways is information around the climate implications of different pathways and associated options and decisions. In particular, mitigation, hazard, and systemic and compound risk implications should be considered.

Mitigation implications relate to the changes in emissions associated with different development pathway options (Jakob and Steckel, 2016). For example, reducing transport emissions through expansion of public transport services. Options that support mitigation objectives can also have consequences for socio-economic development e.g. the prioritisation of renewable energy without diversifying labourer skills, which can affect unemployment across a region, but these implications do not directly involve climate information or services.

Hazard implications relate to the implications of risks associated with climate-related hazards on different pathway choices (e.g. poorly planned housing development that increases exposure of homes to flooding). **Systemic and compound risk** implications are related to the more complex feedbacks and interactions across sectors and across spatial scales (e.g. drought in India causes wheat prices to increase and oil price increases raising processing and transport costs). We separate direct hazard/impact implications from systemic and compound risk implications because they typically require different approaches to climate information integration. While top-down hazard and risk mapping approaches can provide value in relatively simple contexts, more deliberative bottom-up approaches to risk management and climate information integration are important in complex contexts such as urban flooding.

The need to address these different implications of CRD pathways implies the need for a comprehensive suite of climate information services and, perhaps more importantly, strong integration of physical climate science expertise, together with mitigation, climate impacts and adaptation expertise, in the pathways process. Below we unpack the different facets of climate information and climate science integration required, before mapping out the current availability of climate information as well as the implications for climate science and services capacity in South Africa.

Note: While we frame this discussion around climate science and information, in practice we include broader natural sciences and multi-disciplinary science. For example, hydrological sciences are key to understanding the interaction between climate and water resources and agriculture. Agricultural science is key to understanding the implications of different development pathways and climate scenarios on crop yields, agricultural productivity, etc.

2. CLIMATE SCIENCE AND CLIMATE SERVICES NEEDED FOR CRD PATHWAYS

2.1. Concepts and terminology

We use the term *climate information* to cover the spectrum of climate-related hazards, impacts and risk information. As such, climate information spans the range from historical rainfall trends (e.g. Kruger and Nxumalo, 2017) through to approaches such as collaboratively constructed climate change narratives (Jack et al. 2019).

The term *climate services* encompasses a wide range of activities and processes ranging from the provision of numerical climate data through to in-depth collaborative and co-production processes (Visscher et al. 2020). Given the national government's positioning of this activity we align our assessment of the climate services landscape with framing of the World Meteorological Organisation (WMO) Global Framework for Climate Services (GFCS) (Hewitt et al. 2012) and in particular the User Interface Platform (UIP) component of the GFCS (Hewitt, 2022).

It is useful to distinguish between the concepts of thresholds and hazards because, even though they are often closely related, they are evaluated and managed differently (Adger 1996, Connelly et al. 2017).

> *Thresholds are when biophysical, social, political, or economic conditions change to an extent that existing measures (actions, interventions or technologies) no longer produce an acceptable or tenable risk profile.*

While crossing a threshold is sometimes associated with system failure, a more useful concept is that of regime change. Reductions in rainfall beyond a particular threshold can drive shifts in water access with wealthy households investing in private water sources and services (e.g. boreholes and onsite water treatment) while poorer households experience acute water resource challenges. The system has shifted into a regime that translates into resilience for some, increased vulnerability and impact for others.

Crossing thresholds can also cascade through regime changes. In the above example, increasing abstraction of groundwater under the new regime can move the system towards a new threshold related to groundwater levels.

Finally, thresholds can be climate- and environment-related but also socio-economic. Increasing urban populations increase water demand which can, and has already in some places in South Africa, reached a threshold resulting in some forms and degrees of regime change.

Hazards conceptually sit within the classic climate risk framing where hazards intersect with vulnerability (the degree to which people or systems are vulnerable to a hazard, or would be impacted by a hazard), exposure (the degree to which they experience a hazard), to produce risk (the degree to which people or systems are at risk of negative consequences). While there is much deliberation over how risk is best evaluated (Conway et al. 2019), the concept of a climate hazard remains central.

2.2. Aspects of climate science and services for CRD pathways

Based on the background literature review and the in-depth case studies (eThekwini and Saldanha Bay), the following key climate science information needs have been identified as particularly key to CRD pathways processes.

Identifying current thresholds

The pathways approach requires first understanding the antecedent and current pathways and related thresholds. The contexts in which CRD pathways are deliberated are, to some extent, a consequence of historical and current socio-ecological system thresholds. The nature and scale of economic activities (e.g. agriculture, manufacturing) in an area are often strongly related to resources and the distance from particular thresholds. In the Saldhana test case, the current scale of economic activity has partly been limited by existing water supply thresholds and the costs associated with alternative water sources (e.g. water to suppress dust in the port).

Identifying thresholds is challenging because of the complexity of many contexts in which planning takes place (e.g. urban contexts). Thresholds can be quantified, with associated uncertainties, using systems models. For example, water resource modeling can help identify water resource thresholds. We should be wary of quantitative estimates of thresholds where large assumptions and particular understandings of the system have to be made. Qualitative/descriptive approaches to thresholds can capture diverse perspectives and uncertainties. Looking back at past events provides useful insights into relevant thresholds. Droughts frequently reveal water-related thresholds that may not have been anticipated. The Cape Town drought revealed thresholds that were crossed by poor households before more wealthy households. The installation of water management devices to limit water consumption predominantly impacted poorer areas with larger numbers of people on a single property (Millington and Scheba, 2021). Thresholds are also subjective, affecting some population groups or ecosystems more than others. While a moderate drought may not significantly impact a region on average, it may cause unique stress to particular marginalized groups that result in negative coping strategies with far-reaching consequences.

Some thresholds are associated with ecological viability which have implications for pathways that prioritise Ecosystem-based Adaptation (EbA) options. For example, EbA is prioritised as a response to climate change in eThekwini while a recent Strategic Environmental Assessment (SEA) has indicated that the state of the natural environment is below sustainability thresholds, and that changes in the climate are likely to further undermine these natural ecosystems. This, in turn, will likely influence the ability of these ecosystems to provide services associated with adaptation. Understanding and monitoring these thresholds will be an important part of ongoing CRD pathways deliberations in eThekwini.

Current and historical climate hazards

Notable impacts from climate-related hazards can result in decisions that shift pathways towards climate resilience objectives. The 2019 floods in eThekwini were a key driver of the new Climate Adaptation Strategy (2019). The 2017–2019 drought in the Western Cape was a key driver of the City of Cape Town's Resilience Strategy (2019), Climate Change Strategy and Action Plan (2020) and the new water programme. We need to advance our understanding of the diverse impacts that hazards have on different groups of the population, particularly marginalized groups. While risk and vulnerability mapping is extremely useful, it is important to continue challenging the underlying assumptions that are made while choosing indicators and/or proxies for components of climate risk and vulnerability, or representing these characteristics spatially (e.g. deciding on spatial boundaries for representations, or quantifying water access in ways that ignore the lived experience of accessing water in marginalized communities). More rigorous community level engagement and learning should form the foundation for risk and vulnerability assessments.

Future thresholds

Pathways deliberations should focus strongly on the decisions and options that improve quality of life for all population groups. Shifting environmental thresholds, and how they may threaten or create opportunities for different pathways, should be an important consideration in these deliberations. An example of such a threshold in South Africa is urban water supply security. Urban water supply systems and management in South Africa have been developed and revised over decades to provide high levels of supply surety even through periodic low rainfall periods by way of storage in dams, inter-basin transfer schemes, and utilization of groundwater. However, there are environmental thresholds imposed by the long-term average rainfall beyond which water supply systems simply cannot provide more water without access to alternative sources. As average rainfall begins to decline in some regions (e.g. Western Cape, Southern Cape) this threshold is shifting downwards (less water availability) and intersecting with increasing demand resulting in urban water supply crises.

Another example of this type of threshold relates to temperature increases and the suitability of different agricultural crops. For example, gradually increasing temperatures in the Western Cape are beginning to threaten the viability of certain high value fruit crops (Tharaga, Steyn & Coetzer, 2021).

As with all deliberations around the future, uncertainty is a key factor and managing uncertainty is central to pathways approaches. In the section below, we suggest approaches to integrating and managing uncertainty (see Projections and Scenarios modeling).

Future hazards

We consider short hazards as distinct from thresholds because hazards produce shocks to the system that may be coped with and/or recovered from, whereas thresholds are quasi-permanent system changes that cannot be recovered from. We do of course note that hazards can permanently alter a system or shift it into a new regime, as described above. The interplay between hazards and thresholds is detailed at the start of this section.

Anticipating future climate risks requires integrating our understanding of plausible future climates and associated shifts in hazard frequency and intensity, and our understanding of shifting vulnerability and exposure. For example, anticipating future urban flood risks requires integrating plausible long-term climate change with scenarios of urban development. CRD pathways provide a key opportunity to ensure that urban development pathways do not increase climate risk but rather decrease climate risk or shift the risk profile away from the marginalized.

3. CLIMATE SCIENCE, SERVICES AND INFORMATION INTEGRATION

Based on the literature review and case studies, a number of important climate/environmental science activities need to be prioritized in order to enable the integration of climate science and related evidence into ongoing CRD pathway deliberations and decision-making. It is important to note that these are ongoing activities that need to be sustainable over the long term rather than once off activities at the start of a CRD pathways process. **Sustainability of science and science services is a key strategic priority moving forward**.

These activities are: observations and monitoring, systems modeling, projections and scenarios modeling.

3.1. Observations and monitoring

Understanding the historical and current pathways, whether planned or unplanned, rests strongly on ongoing monitoring of relevant environmental conditions. Environmental monitoring is critically important for three reasons. The first is that monitoring forms the basis for improved understanding of system dynamics and how systems respond to changing drivers and shocks. This improved understanding enables thresholds to be identified and informs pathways options. Secondly, monitoring provides the signals and informs the triggering of decisions within pathways. Finally, monitoring enables the consequences of pathway choices on the environment to be observed, whether planned or unplanned.

For example, monitoring of groundwater is critical to understanding how groundwater levels and quality respond to changes in rainfall under natural variability or extremes (e.g. a drought). This understanding enables us to build conceptual or dynamical/statistical models of components of the system which enables us to explore the implications of different interventions and predict plausible future changes under changing climate or other drivers (e.g. implications of shifting land use on water resources). A stronger focus on equity and justice in pathways planning also guides monitoring as it informs what variables are measured and where they are measured. For example, urban poverty is a key challenge within South Africa and yet monitoring of environmental factors (e.g. water quality) in which the urban poor live is often very limited with the focus historically being on natural/rural ecosystems.

South Africa has a strong foundation of environmental monitoring including climate, hydrology, ecology and land use. Institutions such as the South African Weather Service (SAWS), South African Earth Observing Network (SAEON), and the Agricultural Research Council (ARC) are central to observation and monitoring of natural environments and oceans across the country. However this foundation is in many cases being eroded by a lack of funding and a lack of strategic focus on monitoring infrastructure, human capacity and resources required to maintain and extract real value from datasets. In addition, observational data is currently utilised as a source of revenue for the SAWS and SAEON, hampering the equity of access to critical data to inform environmental monitoring. Models for financially sustainable environmental monitoring are currently being explored but significant work is still required to halt and reverse the trend towards degraded monitoring capability.

Key to effective monitoring is data access and integration. Unrestricted access to monitoring data has been shown to significantly leverage the initial investment through enabling innovative research and services development. This requires a broader value for money perspective that integrates the value of research, innovation, and services development to the national knowledge economy.

CRD pathways processes should also inform investment in monitoring. In fact, pathways provide a potentially powerful tool for prioritizing monitoring investment and ensuring maximum value. Where monitoring is strongly aligned to key pathway signals, thresholds and decisions, the value of the monitoring will be readily realized as those decisions are considered. For example, pathways development may identify key decisions around groundwater exploitation. This should inform key investments in groundwater monitoring, including which aquifers or catchments should be monitored. The return on investment of public funding in strategic pathways-focused monitoring will be significant.

3.2. Complex systems understanding

Complex systems thinking provides a useful framework for understanding complex elements and interactions between *inter alia* social, natural, political, technological and economic drivers of development and/or risk. A wide variety of qualitative, quantitative and mixed methods help to understand these elements and/or interactions (Head, 2014). A valuable approach to engaging complexity is integrated systems modelling of key subcomponents of the system. While always conditional on the level of understanding of the systems in question, and the fidelity of the observations of the system (refer to observations and monitoring above), integrated systems modelling can provide key insights into the implications of different pathway choices, insights into system thresholds and sensitivities, and inspire alternative pathways and interventions.

Complex contexts often reflect characteristics of the socio-ecological systems and the historical evolution of these systems. Where people live, their livelihoods, their exposure to hazards, transport routes, etc. are all partly an adaptation to historical socio-ecological system thresholds and hazard landscapes. Socio-economic inequalities compounded by historical injustices also often manifest as an unequal burden of risk. The Group Areas Acts of 1950 and 1966 mean that settlement areas for non-white residents were often more exposed to risks of flooding, high temperatures, and high wind than areas occupied by white households. These inequalities persist today as high risk areas are often the only areas available and/or affordable for marginalized households. We must ensure that our approach to climate and environmental science prioritizes the perspectives and challenges experienced by the marginalized. This means focusing attention on aspects of the system that may seem less obvious to the greater context. For example, water resource research and planning often focuses on bulk water resources under the assumption that water access is uniform across the population. However, if one focuses on the marginalized for whom water access is the primary challenge, even if this is only 10% of the population, then the research may be framed very differently and focus on questions of access and affordability and needs to engage with diverse perspectives around the lived experience of water access.

Quantitative systems modeling is often valuable, (e.g. water resource modeling). However, complex systems require the integration of quantitative and qualitative (mixed method) approaches and focus on integrating diverse perspectives from multiple disciplines and stakeholders. The proposed Transformative River Management Programme (TRMP) in eThekwini provides an example of this integrative qualitative and quantitative approach to understanding complex systems and diverse perspectives. The design of the TRMP Implementation Plan included a cost-benefit analysis to inform the business case and a Theory of Change process involving various stakeholders.

The integration of climate science and uncertain climate projections and understanding of complex systems and contexts is an area of significant challenges and divergent approaches. Top-down approaches often start by identifying hazards (e.g. decreasing rainfall), driving impact models, and then inferring the implications of these hazards and impacts for a particular complex context (e.g. river ecosystems and associated populations). Bottom-up approaches start by understanding the complex context and identifying sensitivities and thresholds (e.g. minimum river flow to sustain key ecosystems) and then develop approaches to avoiding those thresholds in the future. Bottom-up approaches are often more engaged with communities and enable collaborative approaches to decision-making. Top-down approaches are more focused on climate hazards and projections. Increasingly these approaches are being combined to ensure that responses are both locally relevant and "owned" as well as robust to a range of projected changes in climate hazards (Bhave, 2014).

3.3. Projections and scenarios modeling

Climate change projections and emissions scenarios are central to CRD pathways deliberations, identification of pathways, signals, and decision nodes. Climate change projections are grounded on the Coupled Model Intercomparison Project (CMIP)-coordinated climate simulations which are closely aligned to the regular UNFCCC Assessment reporting cycle.

The most recent, CMIP6 (Eyring et al. 2016) provided key evidence for the IPCC AR6 reporting cycle. CMIP experiments are based on different emissions scenarios or pathways with CMIP6 experiments based on Shared Socio-economic Pathways (SSPs). SSPs qualitatively and quantitatively describe possible future patterns of global socio-economic development under different challenges to climate change mitigation and adaptation (O'Neil et al., 2014). SSPs range from SSP 1 to SSP 5, as shown in figure 1. SSP 1 describes a future with limited challenges to mitigation goals. SSP 5, on the other hand, is dominated with challenges to mitigation. Each SSP has associated emissions of GreenHouse Gases (GHG) scenarios, and land use change (LUC) scenarios. Select SSP emissions and LUC scenarios were used to drive specific CMIP6 experiments (O'Neill 2016). For example, the CMIP6 SSP-2.45 experiment involves coupled climate models simulating changes in the couple earth system under SSP2 with an equivalent radiative forcing of 45 W/m².

FIGURE 1: Map of Shared Socio-economic Pathways across the range of socio-economic challenges for adaptation and socio-economic challenges for mitigation.

The reason this is of relevance to CRD pathways is that SSPs and the associated CMIP6 experiments represent global development and mitigation pathways (Riahi, 2017) that have implications for national through to local development and mitigation pathways deliberations. For example, SSP1 aligns with very progressive climate and development policies and is described as: Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation):

> *The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.*

Conversely, SSP4 is considered by many to be the path that many countries are on and is described as: Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation):

> *Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor-intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle- and high-income areas.*

While of course these are scenarios, not predictions, they nevertheless are an important context within which to deliberate CRD pathways not only because of the local implications of each pathway, but also because of the associated climate projections.

While nationally and regionally we might pursue a development pathway more aligned to SSP4 by pursuing our competitive advantage in the provision of non-renewable resources. However, if the world follows a pathway more closely aligned with SSP1 then we may gain from reduced climate impacts but become increasingly economically and politically isolated and be left with stranded assets and unrealized investments. We cannot detach our national development pathways from global development pathways and associated policy, economics and trade, and emissions and climate impacts.

3.4. Climate change uncertainty

Climate projections integrate multiple sources of uncertainty. Above we have outlined the uncertainty associated with global emissions scenarios. Climate modeling uncertainty is also a key factor, particular for mid-century time horizons (Hawkins et al. 2016). Climate modeling uncertainty emerges from the divergent projections produced by different climate models run by climate modeling groups around the world. No model is perfect and determining a "best" model is fraught with challenges and the need to make assumptions that are hard to defend. Best practice is to utilize as large an ensemble of climate model projections as possible in order to ensure that pathways planning considers all plausible futures.

Attempting to reduce modeling uncertainty increases the risk of not anticipating a key threshold or hazard shift (Jack et al. 2021).

While national climate modeling capacity is important and should continue to be supported, the outputs of national climate modeling experiments should be considered within the broader spectrum of global projections.

Given the needs from climate information outlined in this section, the following section provides a baseline review of the climate information supply landscape in South Africa.

4. CURRENT AVAILABILITY OF CLIMATE INFORMATION AND SERVICES TO SUPPORT CRD PATHWAYS

The climate science landscape in South Africa is limited in scale but high in quality. Many academic institutions in South Africa have a long history of high-quality, in some cases world-leading, climate science research. South African academics have and continue to play key roles in international climate science activities ranging from the World Climate Research Programme (WCRP) through the IPCC, and many other international science bodies. While constrained by increasingly limited funding and other challenges, South African climate science stands as a key national resource that warrants increased strategic investment.

The climate services landscape in South Africa is currently in a state of flux as the implementation plan for the National Framework for Climate Services (NFCS) is in the process of being developed. This development process provides fertile ground for input on how the NFCS can better enable the provision of climate information to support CRD pathways.

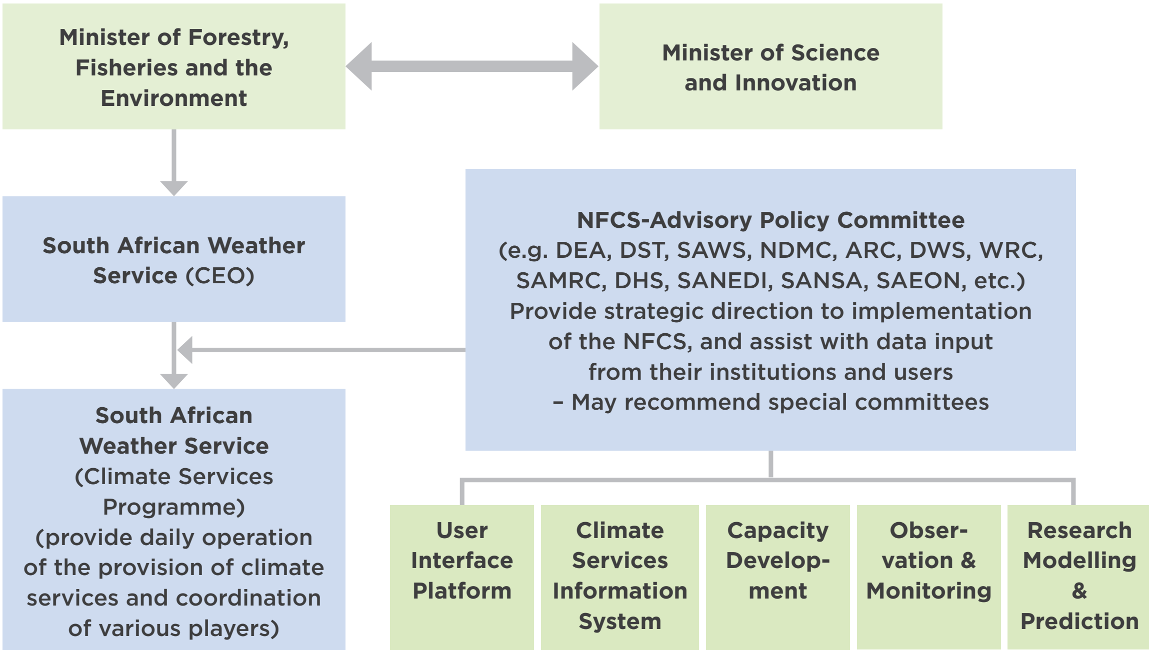
To structure the provision of climate information, the NFCS is designed around five core components, as defined by the Global Framework for Climate Services (Hewitt et al., 2012). These five components are:

1. Observations and monitoring (O&M) – the collection of historical climate data
2. Research, modelling and prediction (RMP) – research into operational weather and seasonal forecasting and climate change modelling
3. Climate services information system (CSIS) – the mechanism through which climate information is archived, analysed, processed and exchanged
4. User Interface Platform (UIP) – the structured means through which users and scientists interact
5. Capacity development (CD) – the development of user capacity to access, interpret and use climate information.

These components each form part of the approved operational structure of the NFCS as shown in figure 2.

As we are most interested in climate information that can support the identification of past thresholds and hazards as well as future thresholds and hazards, we focus the remainder of this section on the current South African landscape with respect to the pillars of 1) observation and monitoring and 2) research, modelling and prediction. However, in recognition of the importance of user engagement and co-production in providing information that is fit for purpose and decision relevant, we also interrogate the current landscape with respect to the User Interface Platform component of the NFCS.

FIGURE 2: Approved operational structure of the NFCS where UIP, CSIS, CD, RMP, O&M refer to each of the components of the NFCS (extracted from the NFCS SAWS/DFFE/DSI implementation plan).



5. CURRENT OBSERVATION AND MONITORING LANDSCAPE IN SOUTH AFRICA

Climate-related observations and monitoring encompasses a diverse array of infrastructure, methods, and institutions. Primary climate and related observations are enabled by both in-situ infrastructure such as weather stations, river flow gauge measures, groundwater monitoring points, water quality measurements, etc. and remote sensing infrastructure, including satellites and satellite receiving and processing infrastructure. Of course many other parameters need to be monitored including land use change, ecosystem health (e.g. biodiversity, species populations, etc.), air quality and emissions. A full assessment of environmental monitoring in South Africa is beyond the scope of this project and we will rather focus on the primary climate observations.

TABLE 1: Quantity of weather stations in South Africa by supplier

	Automatic weather station	Automatic rainfall station	Manual rainfall station
SAWS	226	176	1049
ARC	600	0	0
iLeaf	735	0	0

The current climate observation and monitoring capacity in South Africa is maintained by three primary entities, namely: the South African Weather Service (SAWS), the Agricultural Research Council (ARC) and iLeaf (a division of Hortec). Table 1 indicates the number of active stations monitored by each organisation.

While the number of weather stations indicates a good representation of observing stations across the country, this information is not freely available, except under specific circumstances (such as for use in student research). Even government departments are required to pay for observational data at a daily (or higher frequency) time step. This lack of access to freely available observational data represents a significant hindrance to the equitable access to climate information required to support CRD pathways.

While daily observational data are not freely available, SAWS and other purveyors of climate information in South Africa do provide free observational data at coarser temporal resolutions. A selection of the currently available free observational/historical data is outlined in Table 2 below.

TABLE 2: Currently available observational/historical data in South Africa

Supplier	Products available	Product type
SAWS	**Historical rainfall maps:** 10-day periods, monthly and seasonal	Maps
	Recent weather reports for: • daily records • monthly rainfall • daily extremes • daily rainfall bulletin • daily rainfall • 10-day rainfall	Downloadable data
	Historical synoptic charts Monthly drought bulletin: drought monitoring over a 1-month to 24-month period	Image
	Storm tracker, marine observations, synoptic charts, satellite images and surface observations	Written report with maps and graphs
	Trend data: • Climate Extremes trend report: The South African Weather Service (SAWS) provides updates of the WMO Extreme Climate Indices on an annual basis. • Annual State of the Climate report: historical records analysis.	Maps and satellite imagery
	• Regional weather and climate report for Gauteng (with national maps as well)	Written reports with maps
ARC	Umlindi/Watchman newsletter: provides information on recent rainfall and vegetation conditions	Written report
CSAG	Climate information platform: provides station-scale historical monthly averages for a range of indices.	Graphs and data

Supplier	Products available	Product type
DSI	Square Kilometer Array (SKA) provides satellite data as a proxy for observational data	Satellite imagery
SA Geo	South African Earth Observation System of Systems: Pulls data from CSAG, SARVA, AMSI, WAMIS for Climate information. SAWS and HMO-SW for weather data	Unknown (at time of review, the website was not functioning)
NCCIS (with SAEON)	• Past temperature extremes • Historical climatologies • Observed trends in historical climate	Maps
Greenbook	Current climatologies at the municipal scale	Maps and written output

6. CURRENT RESEARCH, MODELLING AND PREDICTION LANDSCAPE IN SOUTH AFRICA

The research, modelling and prediction landscape incorporates a range of timescales from nowcasting through to climate change projections of 50–100 years into the future. Unlike the observation and monitoring pillar, the research, modelling and prediction landscape in South Africa is broader, including a variety of institutional sources of information (both public and private).

In addition to these separate institutional sources of information, there is a recent initiative to consolidate available climate information into a National Climate Change Information System (NCCIS) (https://ccis.environment.gov.za/#/). This portal provides ready access to data from national to municipal level and links to various suppliers of climate information within the South African supply landscape. The NCCIS is an evolving resource that is still undergoing improvements and refinements. The key challenge with the NCCIS is that, while the scope of the data it provides is extensive, the use of these data requires an in-depth understanding of the underlying assumptions, limitations, and uncertainties. Making data available is an increasingly small part of the challenge of providing climate information. Globally there is a proliferation of easily accessed data platforms and portals (Hewitson et al. 2017). The greater challenge lies in the appropriate and defensible use of the data.

In general, the climate information supply landscape in South Africa is strong with various role players providing climate information at the national to local level as well as sector-specific information. Table 3 provides an indication of the public sources of weather forecasting and climate projections information in South Africa.

TABLE 3: A selection of weather forecast and climate projection suppliers in South Africa. This is not an exhaustive list.

Supplier	Products available	Product type
SAWS	• Impact-based Severe Weather Warning System • Short-term forecasts: Weather, marine, travellers forecast, regional forecast and fire danger • Global seasonal forecast maps. Seasonal climate watch bulletin • Climate change reference atlas: a report that provides projections over South Africa for 10, 50 and 90 percentiles of RCP4.5 and 8.5	Risk matrix table Maps Maps and written report Written report with maps
NDMC	Early warning advisory	Written report with maps
National OCIMS	Coastal flood hazard flood lines, sea state and water quality	Maps
CSAG	Climate information platform: provides station-scale future projections of change for CMIP3 and CMIP5 ensembles	Graphs and data
CSIR	Future projections of climate change	Written report and maps
DFFE	• Third National Climate Change Communication: provides broad temperature and rainfall projections and sectoral impacts • National climate change adaptation strategy: provides broad temperature and rainfall projections and sectoral impacts • South Africa's 3rd Climate Change report 2017: provides broad temperature and rainfall projections and sectoral impacts	Written report and maps Written report Written report
SAEON	In partnership with the Department of Environment, Forestry and Fisheries (DEFF), SAEON is developing a series of decision support tools for climate change adaptation, monitoring and reporting, including the National Climate Change Information System (NCCIS).	Maps, written output and data
SARVA	South African Risk and Vulnerability Atlas: climate risk profiler providing current climate, future climate scenarios, vulnerability to climate change, regional adaptation projects and climate change impacts	Maps, written output and data
Greenbook	Climate projections for 2050 for average temperature, average rainfall, extreme rainfall and very hot days at the municipal scale	Maps and written output

In addition to the local sources of weather forecasting and climate projection information, the South African landscape is complemented by international sources of information. An indication of some of these international sources are outlined in Table 4. Although it should be noted that this table just provides a snapshot of the information available through international sources.

TABLE 4: Climate services/information supply from international institutions

Supplier	Products available
EC Copernicus Climate Change Service	Climate data store and online platform with sectoral and application specific "apps"
World Bank Climate Change Portal	Provides country and watershed-based visualizations and reports detailing current climate, vulnerability, future projections
EU H2020 FOCUS Africa	A research project with the objective of prototyping several climate services across Africa. Strongly climate research oriented but includes stakeholder engagement workshops and some users are part of the consortium (e.g. EDF hydropower)
EU H2020 CONFER	Co-producing climate services informed by stakeholder mapping and needs assessment, strongly research focused
GERICS Climate Services Centre Germany	Bespoke climate services for clients, but also online access to country level "fact sheets" detailing observed and projected climate, impacts, vulnerability etc.
ClimSystems	A number of software systems SimClim and tools tailored to client needs, but also to bespoke user engagement

7. ADEQUACY OF THE CURRENT CLIMATE INFORMATION AVAILABILITY LANDSCAPE IN SOUTH AFRICA

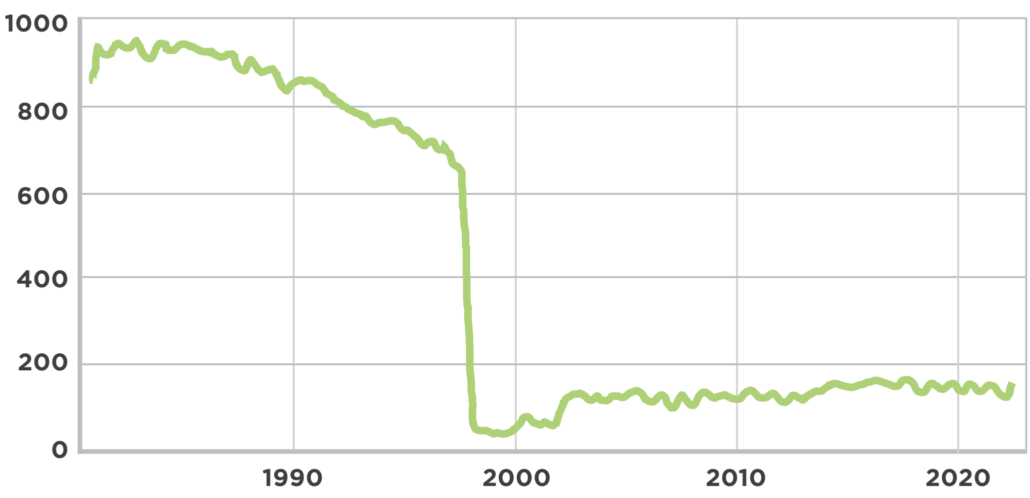
7.1. Observation and monitoring

South Africa has an adequate coverage of observations and monitoring infrastructure, particularly when compared to other African countries. However, the lack of freely available observational data (particularly from the South African Weather Service) is a significant hindrance to the CRD pathways deliberation processes. The cost of access to observational data, significantly restricts the equity of access to data and also affects the development of derivative data products. For instance, international data producers are not able to verify new forecast products for South Africa without access to publicly available observation data. International blended data products that are defacto global standard datasets (e.g. University of East Anglia's Climate Research Unit – CRU rainfall dataset) have access to decreasing numbers of local weather stations (see Figure 3 below). South Africa would be better able to benefit from international collaborations if the free exchange of observational data was made possible.

The free access and exchange of observational data is a model widely used around the world, including developed countries (such as the United Kingdom and Australia) as well as developing countries (such as India and Brazil). In these countries, access to observational data is largely centrally funded through the fiscus, where the government funds both the observational infrastructure and the processing and dissemination of the data. In some cases, the free access to observational data is enabled through a model of part state and part private funding.

In comparison, the South African Weather Service operates with a mixture of state and "user-pays" funding. The core functioning of the South African Weather Service is from the government budget, but the sale of daily to higher frequency observational data is intended to supplement income. However, recent budget figures suggest that the sale of data offers a negligible benefit to the overall SAWS budget. Therefore, the opportunity cost of maintaining the user-pays model needs to be strongly reconsidered when implementing the National Framework for Climate Services.

FIGURE 3: Monthly count of South African weather stations included in the global Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) dataset from the University of California, Santa Barbara



7.2. Research, modelling and prediction

In line with the international community, there are several role players in South Africa involved in the development and delivery of climate information on the nowcasting to climate change timescales. The model of distributed roles, beyond the National Meteorological Service, is a common model employed internationally. For instance, there is a well developed "secondary" meteorological service industry in Japan and, in Brazil, a range of private actors provide climate services to various sectors. Australia has decentralised the provision of climate services through distinct roles played by three agencies. The Bureau of Meteorology is responsible for weather and seasonal climate forecasts and warnings. The Australian Climate Services programme is responsible for integrating climate data and other data and information into the management and recovery from extreme events. Finally the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Climate Resilience Enterprise is focused on the co-development of climate services on the climate change scale.

While the climate information supply landscape in South Africa is strong, coordination across the community is currently weak. There is an opportunity to better support CRD pathways processes under the National Framework for Climate Services by better strengthening partnerships and collaborations across the community of climate service providers (as well as users) in South Africa. Actively enhancing collaborations across this community would allow for:

- definition of roles and responsibilities of each of the actors across the South African climate services field;
- identification of research needs across the community;
- discussion of the requirements for information in different sectors, as well as how such information might be used;
- identification of sectoral experts to develop ideas and co-produce information and products that support complex systems understanding;
- identification of potential partnerships based on complementary expertise and willingness to work together;
- discussion of suitable contractual modalities and the basis for partnerships;
- identification of further research that might be needed to support the development of specific climate-related information and services.

8. CURRENT USER INTERFACE PLATFORM LANDSCAPE IN SOUTH AFRICA

Of particular interest to the integration of climate information into CRD pathways is the User Interface Platform (UIP) component of the NFCS which provides a structured means for users, climate researchers and climate data and information providers to interact at all levels. The objective of a UIP is to promote effective decision-making with respect to climate considerations by making sure that the right information, at the right time and in the right amount, is delivered, understood and used (Hewitt, 2022).

Core to the UIP pillar are processes of transdisciplinary co-production. Transdisciplinary co-production "involves the combining of two or more different types of knowledge, skills and working practices by bringing together people who think and act in often very different ways in order to create new knowledge for addressing societal problems of shared concern and interest" (Taylor et al. 2016; p 8). This approach provides a mutual learning environment, in which decision makers can explore how climate variability and change might influence lives and livelihoods, and researchers can better understand the complex decisions that are being made (Taylor et al., 2021).

Approaches to transdisciplinary co-production fall along a spectrum from very immersive, co-exploratory approaches to more consultative approaches (Carter et al., 2019). The immersive approach is based on the principle that the collaborative learning process is of central importance. Emphasis is placed on the value of people from different disciplines and backgrounds working together in a knowledge exchange process, developing relationships and creating networks (Daniels et al., 2020). This mutual learning process is central to ensuring that climate information is robustly and sustainably incorporated into climate-related decision-making processes. In immersive processes, development of climate services products/outputs is a secondary activity that is not necessarily a central motivation for the engagement process. The central focus is rather on building common understanding and knowledge (Steynor et al, 2020).

At the other end of the spectrum are the more consultative approaches. These approaches assume a need for climate information in decision-making and utilise user engagement techniques as a way of better understanding where and how climate information can be inserted into the decision-making process (Carter et al., 2019).

For the purposes of understanding the landscape of user engagement in South Africa, the entire spectrum of engagement approaches has been included. The following sections outline a selection of activities that have taken place in South Africa.

8.1. User engagement activities in South Africa

More active user engagement takes place primarily at the higher government level through occasional workshops (for example, with DFFE), taking part in the National Disaster Management Advisory Forum and engaging with the joint operation centres set up during disasters, as well as District Disaster Management Centres (to develop disaster impact tables). The Department of Science and Innovation holds a National Conference on Global Change, approximately every two years, which brings together the research community. There is also a burgeoning initiative by DFFE and SAWS, to develop a collaborative engagement platform where climate services practitioners and users can interact, share lessons and develop collaborative relationships. In support of this collaborative engagement platform, SAWS held bilateral meetings with various stakeholders in 2020, and set up cooperation agreements in priority sectors. However, the majority of SAWS' user engagement/co-production work takes place through dedicated research projects (such as the Umgeni Resilience Project) or via the development of bespoke products for commercial clients.

At the sub-national level, many user engagement activities have taken place in urban centres (eThekwini Municipality, Bergrivier Municipality, Cape Town and Johannesburg). In eThekwini, the Durban Climate Change Partnership was established to bring together stakeholders to address adaptation and mitigation issues (Roberts, 2010), however, there were notable challenges due to regulatory limitations, limited commitment of participants, distrust and lack of leadership. eThekwini also supported three pilot sectors (water, health, and disaster risk reduction) in developing their own municipal adaptation plans and piloted community-based adaptation projects in two poor, high risk, low-income communities with a focus on community-based adaptation planning (Roberts, 2010). A novel engagement technique in the form of community theatre was used in community adaptation planning as a way of communicating the threats of climate change and developing possible locally relevant adaptation strategies.

In the Western Cape, an engagement process was piloted in the Bergrivier Municipality where policy makers, local community, researchers, and government staff were brought together to strengthen the knowledge-policy interface through co-production of a climate adaptation plan (Ziervogel et al., 2016). This was achieved through a series of workshops held in 2012/2013 to explore current and future vulnerabilities and develop an adaptation plan.

In the City of Cape Town, The Future Resilience of African Cities and Lands project (FRACTAL) enabled transdisciplinary processes through the embedded researcher approach and through a series of engagements that brought together policy makers and climate researchers to explore differential understandings of climate-related terminology (Steynor et al., 2020). The process resulted in the co-development of three climate-learning tools that could be used by the city to enhance collaboration between city officials when engaging on climate risk decision-making.

In Johannesburg, city officials and climate researchers embarked on a process of co-learning to adapt to climate change (Vogel et al., 2021). The process reviewed previous climate change adaptation planning in the city and then co-reframed and co-designed further adaptation action with the city.

While the above examples outline a burgeoning base of user engagement in South Africa, they represent (almost solely) project-based examples of user engagement and do not demonstrate sustainable relationships that have been established and maintained to support climate-resilient development in South Africa. There is still ample scope for improvement and learning from innovative processes occurring at the international level. The CRD pathways process will require significant enhancement in user engagement processes in order to bring together diverse sets of stakeholders and experts. To inform these enhanced processes, the following section outlines a selection of user engagement practices from the international literature.

8.2. User engagement initiatives from the international literature

At the international level, there are several innovative approaches to user engagement and transdisciplinary co-production. A selection of these approaches that may offer lessons for the South African context are outlined below.

The first category of user engagement approaches falls into the immersive and co-exploratory end of the co-production spectrum. These are exemplified by two processes: the tandem framework (Daniels et al., 2020) and the Future Resilience of African Cities and Lands (FRACTAL) learning labs (Arrighi, 2016). Both approaches are based on the principle that the collaborative learning process is of central importance.

The tandem framework explicitly focuses on the process, as opposed to the end point. It sets out to achieve three aims: 1) to improve the way participants come together to offer different knowledge types and experiences, 2) to actively co-explore decision-relevant needs and 3) to increase capacity to translate climate information into action. The iterative steps of the tandem framework cover the whole process of user engagement, from scoping the challenge and the identification of relevant users through to monitoring its success and the continual reiteration of the process.

In much the same manner, the FRACTAL learning labs also focused on the process of co-production. The learning labs created co-production spaces in which researchers, city officials and other stakeholders gathered to better understand one another and share and develop knowledge relevant to a complex, city-specific issue. While new climate services knowledge products were generated that fill gaps in knowledge for climate-resilient decisio-making, these were of secondary importance to the learning generated through the process. The emergent process changed mindsets and led to a recognition of the value of other disciplines, other industries and other people and to an awareness of the importance of collaboration. Relationship building was a key benefit of the process.

The second category includes co-production approaches that fall more towards the consultative end of the spectrum. These case studies include: Participatory Integrated Climate Services for Agriculture (PICSA) (Dorward et al., 2015) and Participatory Scenario Planning (PSP) (Care, 2018). These approaches assume a need for climate information in decision-making and utilise user engagement techniques as a way of better understanding where and how climate information can be inserted into the decision-making process. Both of these particular examples are focused on the agricultural sector but their approaches are applicable more broadly to other sectors. PICSA is a process of using participatory methods to support farmers to make more informed decisions. The process involves relationships with farmers to combine scientific knowledge with the farmers' knowledge of what works in their particular context. PSP involves multi-stakeholder forums to access, understand and combine meteorological and local seasonal forecasts. This process allows for interpretation of the forecasts, transforming them into locally relevant and actionable information in order to develop advisories for use in seasonal decision-making and planning.

Finally, but perhaps the most promising approach for application in CRD pathways is that of Participatory Impact Pathway Analysis (PIPA) (Alvarez et al., 2010). This approach enables stakeholders to jointly describe a project's theories of action and then develop their impact pathways. The term 'impact pathways' is synonymous with 'theories of action' and 'program theory'. PIPA begins with a participatory workshop where stakeholders clarify their assumptions about the impact of their project and produce an 'outcomes logic model' and an 'impact logic model'. These two logic models provide an ex-ante framework of predictions of impact that can also be used in priority setting and ex-post impact assessment. PIPA engages stakeholders in a structured participatory process, promoting learning and providing a framework for 'action research' on processes of change.

9. ADEQUACY OF CURRENT USER INTERFACE PLATFORM ACTIVITIES IN SOUTH AFRICA

While there have been significant strides towards enhancing UIP activities internationally, it is clear that user engagement (feedback and co-production) processes could be strengthened in South Africa. Currently lacking in the South African landscape is a mechanism for sustaining producer-user engagement beyond the boundaries of discrete projects. The project-based nature of the current user engagement landscape has meant that the majority of innovative user engagement processes are transient in nature which runs counter to the long-term engagement ambitions of CRD pathways processes.

The implementation of the National Framework for Climate Services offers an opportunity to create a mechanism for sustained producer-user engagement to support CRD pathways processes. At the heart of the UIP pillar of the NFCS is the ability to facilitate interactions that bring together researchers, users and climate service providers to develop, deliver and use climate information for climate-sensitive decision-making. The international literature is rich with innovative approaches to this user engagement that span a range of engagement approaches. The appropriate mode of engagement will always be context and needs dependent, however, the structures need to be in place to facilitate this engagement.

In other countries this "structure" has been created by either establishing a dedicated unit for producer-user interaction within the National Meteorological Services (such as at the United Kingdom Met Office) or by establishing a dedicated entity responsible for the co-production and co-development of climate services, such as the CSIRO Climate Resilience Enterprise in Australia. In South Africa, the approved structure for the implementation of the National Framework for Climate Services provides scope for a co-production and user engagement hub to be established as a joint initiative (potentially between DFFE and SAWS). This hub would act as a coordinating entity for 1) bringing together the climate services and providers communities in South Africa and 2) strengthen user engagement and feedback into climate services products in South Africa, whether that be through dynamic feedback processes on websites or through more immersive ongoing face-to-face engagements. The South African Weather Service already has a dedicated climate services team so this hub would be a natural extension to this team in order to better support the producer-user interaction required to support CRD pathways processes.

10. CONCLUSIONS AND RECOMMENDATIONS

It is clear that CRD pathways processes require significant and diverse capacity, both human, technical, and institutional. A core component of this capacity lies within the realm of climate science and services, as well as broader environmental science and information services.

10.1. Observations and monitoring

Observations and monitoring are foundational to climate science and services as they provide the data and evidence to support research that advances understanding of socio-ecological systems, allows monitoring of the impact of interventions, and allows identification of signals and triggers for action to avoid the impacts of hazards and the implications of crossing resilience thresholds. However, daily to higher frequency observational climate data is not currently freely available in South Africa so this "gap" needs to be filled through other sources.

Advances in remote sensing based observations have created unique opportunities (e.g. rapid assessment of damage from extreme events, high resolution land use change and ecosystem mapping, etc.). Utilization of remote sensing should be strongly supported through research, capacity building, and the necessary infrastructure. However, ground-based observations such as weather stations, flow gauges, and ecosystems monitoring systems will remain critical and should not be neglected as they provide ground truth for calibration of remote sensing as well as continuing to monitor variables that cannot be measured through remote sensing.

10.2. Complex systems understanding

As noted above, South Africa has a strong history of climate and environmental science, in many cases contributing to world leading science within particular disciplines. Maintaining this science excellence requires ongoing strategic funding in universities and the creation of sustained and formalised collaborations. Further effort is needed to build the capacity for engaging with complex systems and mixed method multidisciplinary and transdisciplinary engagement. Science research often still occurs within disciplinary silos with limited engagement across disciplines especially across natural science and humanities. The result is that decisions are often informed by evidence produced by fairly narrow disciplinary studies that can fail to incorporate diverse perspectives and divergent perspectives. While international research funding is demonstrating a strong shift towards impactful research and demanding multidisciplinary and transdisciplinary approaches, research funding in South Africa remains dominated by narrow disciplinary perspectives. This includes climate-related research.

10.3. Projections and Scenarios modeling

Access to climate modeling outputs and projections is a key need for decision-making in South Africa and foundational to CRD pathways processes. Indeed, there are many roleplayers in this landscape in South Africa so this diversity of expertise should be better brought together through partnerships and collaborations. The diversity of available climate projections can also create a confusing landscape. In some cases preference is given to projections produced by locally developed climate models even if it is not clear that these span a defensible range of plausible climate futures across the country and across multiple climate parameters and hazards.

The draw towards singular nationally mandated projections should likely be avoided as this approach risks restricting the local climate research landscape and tends towards conservative generalized projections. Rather a combination of strong science capacity and strong governance capacity should be pursued to ensure that science innovation is encouraged while integration and interrogation of science into decision-making is robust and relevant to that particular context. This can be enabled through stronger partnerships and collaborations across the various roleplayers in the climate services sector, potentially facilitated through a co-production and user engagement hub within the NFCS.

10.4. Recommendations

Key recommendations regarding observations and monitoring that emerge from the literature and case studies are:

Development of comprehensive and integrated observations and monitoring systems. Comprehensive relates to both the spectrum of variables and parameters monitored as well as the geographical coverage, noting in particular the need to focus on parameters of relevance to marginalized populations (e.g. urban monitoring). Integrated does not imply that observations should be managed by a single institution. There are several institutions identified above that have existing or nascent capacity for monitoring and the associated data management roles. This should include monitoring of non-environmental parameters such survey and census data that is currently the mandate of Stats SA but augmented in some cases by other institutions (e.g. Gauteng City Region Observatory).

Integration refers to the coordinated strategic planning of observations and monitoring; ensuring that sparse resources across multiple institutions are not wasted on duplicate efforts, and that there is a national scale dialogue across relevant stakeholders around monitoring and observation needs and how these can best be met. Integration also refers to the ability to access data from across multiple institutions. Here the Climate Services Information System (CSIS) could play a key role if guided by broad-based stakeholder engagement to ensure that it meets actual needs.

Sustainability of existing infrastructure and institutions. As noted above, there are a number of existing institutions that have clear mandates and capacity to implement comprehensive monitoring and observation roles. However, many of these institutions are financially strained and are resorting to applying costs for data access in order to remain financially viable. A national dialogue and engagement around the value of observations and monitoring and the financial sustainability of the associated institutions needs to be initiated if we are to avoid ever more degraded capacity dominated by cost recovery and limited open access to data.

A clear National Framework for Climate Services implementation plan that encourages innovation, partnerships and high quality climate services by a diversity of local and international actors. Given the constrained resources available for climate services in South Africa it does not make sense to close down the climate services landscape through tight restrictions on who can provide what services and who has access to what data. Concerns around quality of services and commercialization of climate services can be managed through broad-based capacity building rather than restrictive frameworks and legislations.

Broad-based capacity building is critical. By broad-based we mean that a range of capacities is required across various institutions and those playing different roles within institutions. Key capacities include:

- Science research capacity that includes strong components of multidisciplinary and transdisciplinary approaches and practice in order to encourage systemic and societally engaged research. Science graduates need to be aware and engaged with the broader development context within which they operate. This needs to be supported by universities through cross-departmental and cross-faculty undergraduate and graduate courses and degrees.
- Climate change capacity within different levels of government and related institutions (e.g. key NGOs, parastatals, industry groups). The focus of this capacity should be on strengthening learning cultures, leveraging technical expertise to manage climate risks, improving the capacities to design, act on and maintain interventions (including how to deal with trade-offs and find synergies), and improving ability to manage uncertainty.

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Financial support has been provided by the European Union's Partnership Instrument and the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) in the context of the International Climate Initiative (IKI). The contents of this publication are the sole responsibility of the researchers and do not necessarily reflect the views of the funders.

SUPPORTED BY

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